A Descriptive Catalogue of Indian Astronomical Instruments

Sreeramula Rajeswara Sarma

Abridged Version

A Descriptive Catalogue of Indian Astronomical Instruments – Abridged Version

Following a suggestion that a shorter version of the Catalogue, consisting of all the introductory essays and appendices, but excluding the catalogue proper, would be easier for the general reader to handle, this abridged version has been prepared. The pagination here remains the same as in the Catalogue. Those who wish to read about individual instruments can always consult the Catalogue which is available online at www.srsarma.in.

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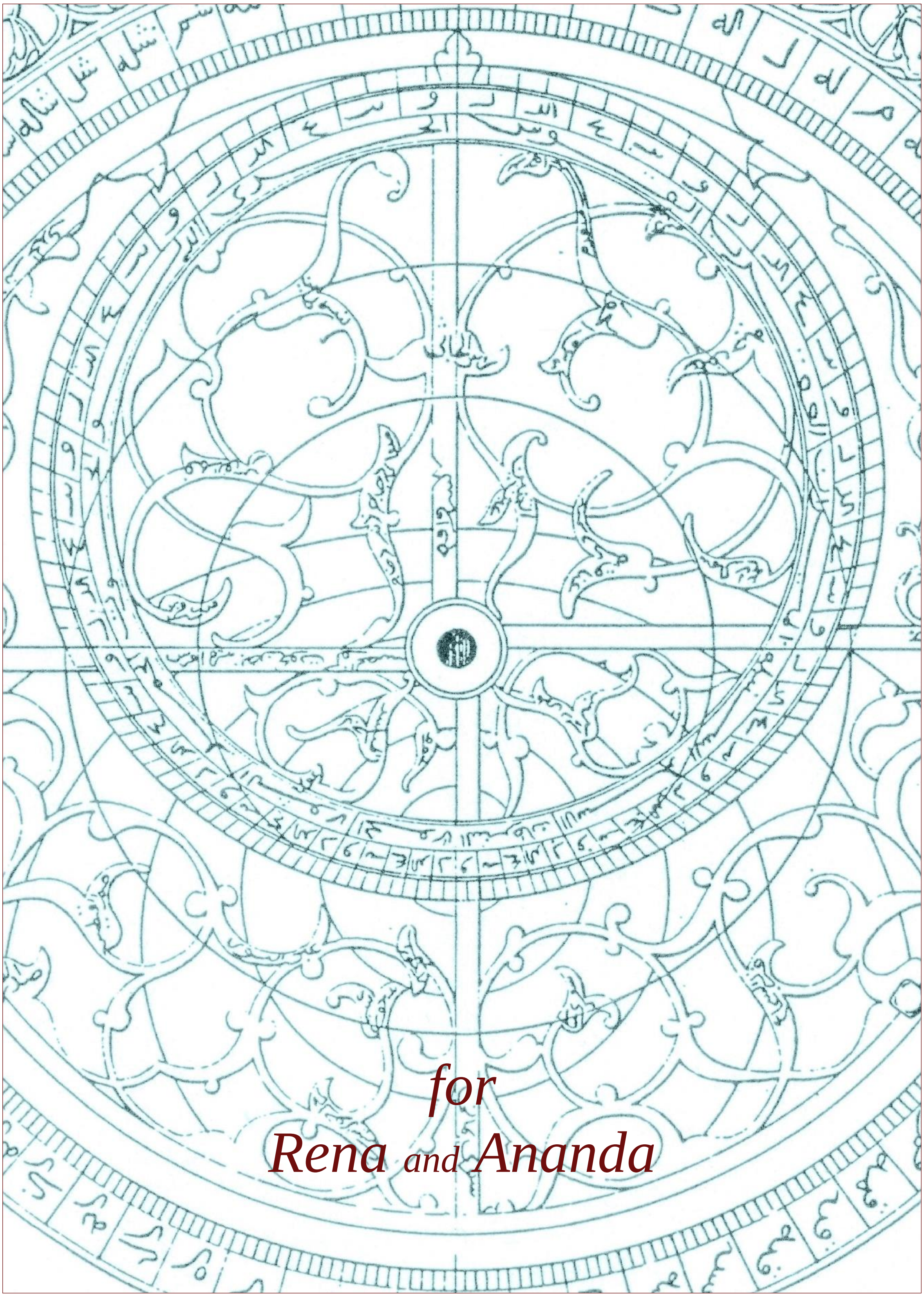

for

Rena and Ananda

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PREFACE

In AD 628, Brahmagupta completed his monumental *Brāhmasphuṭa-siddhānta* which, as David Pingree observes, 'was enormously influential on later Indian astronomy as well as on Islamic and Western European' astronomies.[i] The twenty-second chapter of this work describes the construction and use of several astronomical instruments, from the simple quadrant to mercury-driven perpetual motion machines. While studying this chapter,[ii] I wondered whether any specimens of these instruments are preserved today in museums. Such specimens, I thought, would help in understanding better the rather brief descriptions in Sanskrit texts. Therefore, a survey of Sanskrit astronomical instruments in various museums in India would be a worthwhile task, I reflected. But gradually I came to realise that many Sanskrit instruments are closely related to Islamic astronomical instruments, that several Islamic astronomical instruments were also produced in India as well and that large numbers of specimens of Sanskrit as well as Islamic astronomical instruments are preserved in museums abroad, especially in UK.

It was about this time that I came across a catalogue of the exhibition on 'Science in India' which was mounted by the Science Museum of London in connection with the Festival of India in 1982. The exhibition gave an admirable account of scientific activity in India from the earliest times up to the present day, by means of manuscripts and artefacts. The catalogue, compiled by Dr R. G. W. Anderson, who later became the Director of the British Museum, made me aware of the actual specimens of Indian astronomical instruments which are still extant in various museums in India and abroad. Encouraged by this catalogue and later by personal conversations with Dr Anderson and other scholars, I began studying Indian astronomical instruments in museums and private collections within India and outside.

Thus began my exploration of pre-modern Indian astronomical instruments in 1991 which lasted a quarter century and spanned three continents.[iii] A descriptive catalogue of the extant instruments which I identified during the course of my explorations in about a hundred museums and private collections is presented in the following pages. The majority of the surviving instruments are astrolabes. These are not simple measuring tools. Their fabrication from sheets of brass demands sophisticated workmanship. Engraving the various kinds of lines and circles on the plates and on the back requires high precision. Fashioning the *kursī* and the rete involves fine artistic sense. Furthermore, large quantities of astronomical, astrological and geographical data

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i Pingree 1981, p. 21.

ii Sarma 1986-87a

iii I tried to cover all the known collections in India, Europe and USA; in India, the Asiatic Society, Kolkata, Indian Museum, Kolkata, and L. D. Institute, Ahmedabad, are known to own astronomical instruments, but they did not respond to my repeated requests for permission to study the instruments in their collections. New museums are coming up in Kuwait and in the United Arab Emirates, some of which are reported to possess Indo-Persian astrolabes and celestial globes, but I have not been able to contact these museums.

are engraved on them. Therefore, astrolabes have been carefully preserved by owners and eagerly collected by cognoscenti throughout the centuries in all the regions.

In this catalogue, astrolabes are described in five sections A, B, C, D and E. Then follow celestial globes in three sections F, G and H. These are also products of excellent metal craft and artistic beauty. Thereafter are treated diverse kinds of instruments which exist in smaller numbers.

I have personally examined and photographed many of the instruments described in this catalogue. In some cases, where I could not personally study the instruments, detailed information and photos were kindly sent to me by museums, auction houses and private collectors. The third source is archival. At the Museum of the History of Science, Oxford, Francis Maddison collected a large number of photos of astrolabes and of other instruments which were sent to him for evaluation by auction houses. Likewise, Anthony J. Turner, Le Mesnil-le-Roi, has a large collection of photos. Both very generously lent me photos of Indian instruments in their collections. These photos fill important gaps and help in a drawing a more comprehensive picture of instrument production in India.

Astronomical instruments produced in India in the pre-modern period can be classified into two broad groups. In the first group are those with inscriptions and legends in Arabic and Persian. More specifically, the astronomical technical terms are in Arabic, and the inscriptions regarding the manufacture or ownership are often in Persian. These are classified as Indo-Persian instruments, because they were produced in a milieu where Persian was the official or scholarly language. The second group consists of instruments on which the legends are in Sanskrit language and in Devanagari script. These are called Sanskrit instruments. The original prototypes for the Indo-Persian instruments were derived from the Islamic world. Some of the Sanskrit instruments are indigenous to the Indian subcontinent and some others are adapted from Islamic models. There is also a small number of Sanskrit instruments derived from European models.

Excluded from this survey are the modern or post-telescopic astronomical instruments which were directly imported from the west and did not undergo any substantial variation in India, even when they were manufactured here. A further distinction between these two groups of pre-modern and modern instruments lies in the manner and scale of production: the former were produced by traditional artisans and each item was a unique product, whereas the latter were industrial products on a mass scale with identical copies. This difference is somewhat akin to the difference between manuscripts and printed books.

This does not mean that modern instruments like telescopes, sextants, transit circles have no historical value. Just as the copies of the first edition of a book are valuable as collectibles, so are also nineteenth century European instruments of historical interest. Universities and other academic institutions in India still possess many such historically interesting European instruments. These also deserve to be catalogued; in fact, even other kinds of scientific instruments and obsolete measuring devices like steel-yards which are scattered in museum stores need to be studied; but it is beyond the scope of the present catalogue.[iv]

Had I known the enormity of the project, I probably would not have ventured in the first place. But the interest and encouragement shown by scholars and the enthusiastic cooperation of museum directors gave me the necessary confidence to continue with the project. Therefore, the list of persons to whom I owe deep debt of gratitude is rather long.

I am quite conscious of the many shortcomings in this catalogue, caused by my linguistic and technical limitations. But I do hope that this first ever attempt at compiling the information about pre-modern Indian astronomical instruments which are dispersed in many parts of the world will be of some use to the historians of science and to the curators of museums.

Safavid astrolabe makers like Muḥammad Mahdī al-Khādim al-Yazdī (Y008), ᶜAbd al-A'imma (Y009), Muḥammad Amīn (Y010), ᶜAbd al-ᶜAlī (Y011) and others usually engrave on their richly decorated astrolabes a line from the *Gulistān* of the Persian poet Shaykh Saᶜdī, which reads *gharaḍ nakshīst kaz mā bāz mānad* (the intention of this drawing is that it should remain after us), as can be seen in this cartouche engraved on the back of the astrolabe by Muḥammad Mahdī al-Khādim al-Yazdī (Figure Y008.6).

This is indeed the hope nurtured by every astrolabe maker and every author, including the compiler of this catalogue.

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iv National inventories of scientific instruments, both pre-modern and modern, are being compiled elsewhere. In the 1950s, the History of Science Division of the International Union for History and Philosophy of Science set up a commission to promote the compilation of an 'inventaire mondiale des appareils scientifiques historiques'. The first step in this direction was to compile national inventories. Accordingly, several European countries brought out national inventories of scientific instruments: Belgium (1959-1960), Italy (1963), France (1964), USSR (1968), Czechoslovakia (1970; unpublished), Ireland (1990). The last and the most comprehensive in this series is *Science Preserved: A Directory of Scientific Instruments in Collections in the United Kingdom and Eire*, compiled by Mary Holbrook, R. G. W. Anderson & D. J. Bryden, London 1992.

ABBREVIATIONS AND OTHER CONVENTIONS

1. Abbreviations

anon	=	anonymous
attr	=	attributable
ca	=	circa
d	=	diameter
ed	=	edited
h	=	height
L	=	terrestrial longitude
mm	=	millimeters
nd	=	not dated
PC	=	private collection
PLU	=	present location unknown
r	=	reign
s.v.	=	sub voce
t	=	thickness
tr	=	translated
φ	=	terrestrial latitude
◎	=	instruments which I have personally examined
;	=	(semi-colon) mark of separation in sexagesimal system between degrees and minutes of arc and between hours and minutes of time

All linear measurements are in millimeters

Material of almost all instruments is brass; in a few cases, it is wood or wood and ivory. Only such cases will be mentioned in the catalogue. Where no material is mentioned, it should be understood as brass.

2. Other Abbreviations and Expressions

CCA	=	Sharon L. Gibbs, Janice A. Henderson & Derek de Sola Price, *A Computerized Checklist of Astrolabes*, Yale University, New Haven 1973. Astrolabes are identified with the serial numbers given here.
CESS	=	David Pingree, *Census of Exact Sciences in Sanskrit,* Series A, vols. 1-5, Philadelphia 1970-1994.
DSB	=	Charles Couston Gillipse (ed), *Dictionary of Scientific Biography,* 16 vols, 1970-1980.

ESS = Emilie Savage-Smith, *Islamicate Celestial Globes: Their History, Construction and Use,* Washington, D.C., 1985. ESS followed by a serial number refers to the globe under this serial number in the catalogue part of the book.

Khalili = Nasser D. Khalili Collection of Islamic Art, London

MHS = Museum of the History of Science, Oxford

NMM = National Maritime Museum, Greenwich

Répertoire = Alain Brieux, Francis Maddison, avec la collaboration de Ludwik Kulus et Yusuf Ragheb, *Répertoire des Facteurs d'Astrolabes, et leurs oeuvres. Islam, plus Byzance, Arménie, Géorgie et Inde Hindoue* (in press). I use the 1993 version. Here the instrument makers are listed alphabetically and under each name the instruments by this maker are listed chronologically with serial numbers. Répertoire, followed by a serial number, refers to an instrument made by the instrument maker concerned.

India, Indian = refer to the Indian subcontinent

Indo-Persian = refers to artefacts produced in India where Persian was the official and/or academic language

Islam, Islamic= refer to the culture of the Islamic world and not to the religion.

3. Chronology

AD = Anno Domini, Christian era

AH/H = Hijrī era (lunar)

Śaka = Śaka era (luni-solar)

VS = Vikrama Saṃvat (luni-solar)

Dates in Hijrī era are converted by the CALH (Calendar conversion program) developed by Benno van Dalen.
http://www.bennovandalen.de/Programs/programs.html
[also http://goo.gl/gFvLXO, last accessed in April 2017]

Dates in Śaka and Vikrama Saṃvat eras are converted by the 'Pancanga' program developed by Michio Yano and Makoto Fushimi
http://www.cc.kyoto-su.ac.jp/~yanom/pancanga/index.html
[also http://goo.gl/MN37FC, last accessed in April 2017]

4. Languages

The language of the engravings on the Indo-Persian instruments is mainly Persian with Arabic technical terms. The transcription of these Arabic terms is somewhat peculiar. Because of the limited space available for engraving, or even otherwise, the Arabic definite article *al-* is often omitted. Epithets in masculine gender are added to nouns even when the latter are feminine. The term *ra's* (head) is generally transcribed as *rās.* In order to retain the peculiarity of the language, the engravings are transliterated exactly, without making any attempt at assimilation or vocalization according to the usage either in Arabic or in Persian.

As will be explained in the introduction to Sanskrit astrolabes, unlike in the Islamic and in Indo-Persian milieu in India, no professional class of Sanskrit instrument makers developed. Hindu or Jaina astronomers or astrologers, who used Sanskrit as the language of learning, when they wished to have instrument, themselves prepared the technical designs and the text of engravings and asked the willing brass worker, who may be barely literate, to prepare the instrument. Consequently, the Sanskrit engravings of star names and even place names are often incorrect. Therefore, I have added the correct version in most of the cases, for the sake of intelligibility.

5. Transliteration

Arabic/ Persian

ص	ش	س	ز	ر	ذ	د	خ	ح	ج	ث	ت	ب	آ	ا
ṣ	*sh*	*s*	*z*	*r*	*dh*	*d*	*kh*	*ḥ*	*j*	*th*	*t*	*b*	*ā*	*a*
ء	ی	ه	و	ن	م	ل	ک	ق	ف	غ	ع	ظ	ط	ض
ʻ	*y/ī*	*h*	*w/au*	*n*	*m*	*l*	*k*	*q*	*f*	*gh*	c	*ẓ*	*ṭ*	*ḍ*

Transliteration Sanskrit

अ	आ	इ	ई	उ	ऊ	ऋ	ए	ऐ	ओ	औ	◌ं	◌ः		
a	*ā*	*i*	*ī*	*u*	*ū*	*ṛ*	*e*	*ai*	*o*	*au*	*ṃ*	*ḥ*		
क	ख	ग	घ	ङ	च	छ	ज	झ	ञ	ट	ठ	ड	ढ	ण
k	*kh*	*g*	*gh*	*ṅ*	*c*	*ch*	*j*	*jh*	*ñ*	*ṭ*	*ṭh*	*ḍ*	*ḍh*	*ṇ*
प	फ	ब	भ	म	य	र	ल	व	श	ष	स	ह		
p	*ph*	*b*	*bh*	*m*	*y*	*r*	*l*	*v*	*ś*	*ṣ*	*s*	*h*		

6. Numerical Notations

Abjad | On Indo-Persian instruments, the numerical quantities are transcribed mostly in the *Abjad* alpha-numeric notation and occasionally with the common Arabic/Persian numerals. Khareghat published a very convenient table of the *Abjad* notation which is reproduced below. [v]

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v From Khareghat 1950, pp. x-xii. In the argument astrolabe is misspelt.

Number	Value in Letters	How engraved on the Astralobe	Number	Value in Letters	How engraved on the Astralobe	Number	Value in Letters	How engraved on the Astralobe
1	ا	ا	21	کا	کا	41	ما	ما
2	ب	ٮ	22	کب	کٮ	42	مب	مٮ
3	ج	ح	23	کج	کح	43	مج	مح
4	د	د	24	کد	کد	44	مد	مد
5	ه	ه	25	که	که	45	مه	مه
6	و	و	26	کو	کو	46	مو	مو
7	ز	ر	27	کز	کر	47	مز	مر
8	ح	ح	28	کح	کح	48	مح	مح
9	ط	ط	29	کط	کط	49	مط	مط
10	ى	ى	30	ل	ل	50	ن	ں
11	يا	ىا	31	لا	لا	51	نا	ںا
12	يب	ىٮ	32	لب	لٮ	52	نب	ٮٮ
13	يج	ىح	33	لج	لح	53	نج	ٮح
14	يد	ىد	34	لد	لد	54	ند	ٮد
15	يه	ىه	35	له	له	55	نه	ٮه
16	يو	ىو	36	لو	لو	56	نو	ٮو
17	يز	ىر	37	لز	لر	57	نز	ٮر
18	يح	ىح	38	لح	لح	58	نح	ٮح
19	يط	ىط	39	لط	لط	59	نط	ٮط
20	ک	ک	40	م	م مه	60	س	سه

Number	Value in Letters	How engraved on the Astralobe	Nnmber	Value in Letters	How engraved on the Astralobe	Number	Value in Letters	How engraved on the Astralobe
61	سا	سا	82	فب	فب	155	قنه	قنه
62	سب	سب	83	فج	فح	160	قس	قس
63	سج	سح	84	فد	فد	165	قسه	قسه
64	سد	سد	85	فه	فه	170	قع	قع
65	سه	سه	86	فو	فو	175	قعه	قعه
66	سو	سو	87	فز	فر	180	قف	قف
67	سز	سر	88	فح	فح	185	قفه	قفه
68	سح	سح	89	فط	فط	190	قص	قص
69	سط	سط	90	ص	ص	195	قصه	قصه
70	ع	ع	95	صه	صه	200	ر	ر
71	عا	عا	100	ق	ق	205	ره	ره
72	عب	عب	105	قه	قه	210	ری	ری
73	عج	عج	110	قے قی	قی	215	ریه	ریه
74	عد	عد	115	قیه	قیه	220	رک	رک
75	عه	عه	120	قک	قک	225	رکه	رکه
76	عو	عو	125	قکه	قکه	230	رل	رل
77	عز	عر	130	قل	قل	235	رله	رله
78	عح	عح	135	قله	قله	240	رم	رم
79	عط	عط	140	قم	قم	245	رمه	رمه
80	ف	ف	145	قمه	قمه	250	رن	رن
81	فا	فا	150	قن	قن	255	رنه	رنه

Number	Value in Letters	How engraved on the Astralobe	Number	Value in Letters	How engraved on the Astralobe	Number	Value in Letters
260	رس	رسم	310	شي	شيم	360	شس
265	رسه	رسه	315	شبه	شيه	400	ت
270	رع	رعم	320	شک	شک	500	ث
275	رعه	رعه	325	شکه	شکه	600	خ
280	رف	رف	330	شل	شلم	700	ذ
285	رفه	رفه	335	شله	شله	800	ض
290	رص	رصم	340	شم	شمم	900	ظ
295	رصه	رصه	345	شمه	شمم	1000	غ
300	ش	شم	350	شن	شنم	0	ها
305	شه	شه	355	شنه	شنه		

Common Arabic/ Persian Numerals | used occasionally on Indo-Persian instruments
۱ (1), ۲ (2), ۳ (3), ۴ (4), ۵ (5), ۶(6), ۷ (7), ۸ (8), ۹ (9), ۰ (0).

Devanagari Numerals | used generally on Sanskrit instruments
१ (1), २ (2), ३ (3), ४ (4), ५ (5), ६ (6), ७ (7), ८ (8), ९ (9), ० (0).

The Sanskrit alpha-numeric system called ***Kaṭapayādi*** is employed in two Sanskrit instruments (C015 and H003), in imitation of the *Abjad* notation on Indo-Persian instruments.[vi]

1	2	3	4	5	6	7	8	9	0
क *ka*	ख *kha*	ग *ga*	घ *gha*	ङ *ṅa*	च *ca*	छ *cha*	ज *ja*	झ *jha*	ञ *ña*
ट *ṭa*	ठ *ṭha*	ड *ḍa*	ढ *ḍha*	ण *ṇa*	त *ta*	थ *tha*	द *da*	ध *dha*	न *na*
प *pa*	फ *pha*	ब *ba*	भ *bha*	म *ma*					
य *ya*	र *ra*	ल *la*	व *va*	श *śa*	ष *ṣa*	स *sa*	ह *ha*		unattached vowels

Bhūtasaṃkhyā | A more widely employed notation, in Sanskrit texts on astronomy and mathematics, and also in inscriptions, is generally known as the *Bhūtasaṃkhyā* system, or ‘word numerals’, where Sanskrit words denoting the sky stand for zero, words denoting the moon etc., represent one, words denoting objects that occur in pairs, like eyes, ears, hands etc., express ‘two’ and so on.[vii] This notation is used in the inscription on H003.

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vi Sarma 1999b; Sarma 2012d.

vii Bīrūnī 1910; SarmaKV 2003; Sarma 2009b.

ACKNOWLEDGEMENTS

In Indian Academic tradition, it is customary to commence with a homage to one's gurus. From Professor David A. King (University of Frankfurt) I received my first lessons in how to study an astrolabe when I accompanied him to the Salar Jung Museum at Hyderabad and to the Jaipur Observatory in 1991. In his monumental *In Synchrony with the Heavens*, he dedicated a section to me and mentioned there my work with approval. I cannot think of any honour higher than this.

The little knowledge I acquired in these years on the medieval astronomical instruments is due to the writings of the late Professor Willy Hartner (University of Frankfurt), Professor David A. King (University of Frankfurt), the late Francis Maddison (Museum of the History of Science, Oxford), James Morrison (Rehoboth Beach, Delaware, USA), the late Professor David Pingree (Brown University, Providence), Professor Emilie Savage-Smith (University of Oxford) and Anthony J. Turner (Le Mesnil-le-Roi, France). Not only their books, but they themselves helped me in myriad ways through all these years. To these gurus, I address my first acknowledgement of gratitude.

I owe a deep debt of gratitude to the late Professor Fuat Sezgin, the founder and director of the Institut für die Geschichte der Arabisch-Islamischen Wissenschaften at Frankfurt. I had the privilege of using the rich library and the guest apartment of the Institute several times. Professor Sezgin established a unique museum of history of science and technology in Islam with replicas of instruments and artefacts which were carefully reconstructed from descriptions and diagrams in Arabic manuscripts, and prepared a large comprehensive catalogue of this museum in five volumes. He entrusted my wife and me the task of translating this catalogue from German into English. Through this translation I could widen my knowledge of the Islamic astronomical instruments.

At Aligarh Muslim University, where I spent most of my professional career, my stay was considerably enriched by the occasional conversations with Professor Irfan Habib who always found time to answer my queries on medieval Indian history and has translated several Persian passages for me, for which I am highly obliged.

Special thanks are due to Professor Owen Gingerich (Harvard University), the only university professor I know who owns an Indo-Persian astrolabe, for his encouragement and help at the initial stages of my work.

It is my pleasant duty to thank two friends and colleagues of long standing for their encouragement and constant support. Professor S. M. Razaullah Ansari (formerly Professor of Physics at Aligarh Muslim University and formerly President of the Commission for the History of Ancient and Medieval Astronomy) aroused my interest in astronomical instruments by suggesting that I prepare an edition and translation of the *Yantraprakāra* which the astronomer prince Sawai Jai Singh got compiled before he

designed the huge instruments in masonry.[viii] He also has published some of my early studies on instruments in the *Studies in History of Medicine and Science* of which he was the editor. Dr A. K. Bag (History of Science Division, Indian National Science Academy, New Delhi) has been very supportive of my project from the beginning. He published several of my papers in the *Indian Journal of History of Science* and thus gave me the opportunity to present my work to a wider academic community.

Three other friends whose expertise in Sanskrit and Arabic sources on astronomy and mathematics I could always draw on are Professors Michio Yano (Kyoto Sangyo University), Takao Hayashi (Doshisha University, Kyoto) and Takanori Kusuba (Osaka University of Economics). Professor Hayashi read parts of this catalogue and made valuable suggestions for improvement. It is a pleasure to express my thanks to them.

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For this project, I received funding from the following sources, which is gratefully acknowledged. The Scientific Instrument Commission (Dr R. G. W. Anderson, President; Professor G L' E. Turner, Secretary) awarded me a grant for studying Indian astronomical instruments in the museums in UK in summer 1993.

Through the initiative of Professor Nalini Balbir (Sorbonne Nouvelle, University of Paris 3), I was offered Visiting Professorship at her department to study Indian instruments in Paris from mid-September to mid-October 1994.

On the recommendation of Professor David A. King (Institut für Geschichte der Naturwissenschaften, Goethe University, Frankfurt), the Deutsche Akademische Austauschdienst awarded me a scholarship to study the Indian instruments in Germany in the winter 1995-96.

Through the initiative of Dr A. K. Bag, the Indian National Science Academy, New Delhi, awarded me a project to study the instruments in the various museums in India from October 1998- September 2001.

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Now I must record my deep appreciation and grateful thanks to the authorities of all the museums for opening the treasures of their collections for my study.

MUSEUMS IN INDIA

I began my exploration of museums in May 1991 at the **Salar Jung Museum, Hyderabad**, where I had my first glimpse of the astrolabes and globes of the Lahore Family, with the warm-hearted cooperation of the director Dr M. L. Nigam and the keeper of the manuscripts Dr Rahmat Ali Khan. The next director Dr I. K. Sarma invited me to deliver the Salar Jung Memorial Lecture in 1995 and published the lecture under

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[viii] Sarma 1986-87a.

the title *Astronomical Instruments in the Salar Jung Museum*.[ix] During my third visit in 2004, the director Dr A. K. V. S. Reddy treated me as a special guest of the museum.

There are two other places in India which I visited frequently for the project. Sawai Jai Singh, aside from erecting huge astronomical instruments in masonry, collected some splendid masterpieces of Lahore astrolabes. His son Sawai Madho Singh designed some interesting instruments. A veritable treasury of these and several other instruments are preserved at the **Jaipur Observatory**. I went several times to Jaipur to study these instruments. I would like to thank the authorities of the Rajasthan State Department of Archaeology and Museums and, in particular, the Superintendent of the Observatory, Pandit Om Prakash Sharma. Pandit Om Prakash Sharma constructed a special gallery to display these portable instruments.

The **Rampur Raza Library** owns important instruments which I studied with the warm support of the late Dr W. H. Siddiqi, officer on special duty. Akbar Ali Khan Arshizada and Abu Sad Ilahi deciphered and translated Arabic and Persian inscriptions on some of these instruments. Dr Siddiqi desired that I prepare a catalogue of the astronomical instruments in their collection with the photographs by Mirza Jamshed Agha; the catalogue was published quite elegantly by Tanzim Raza Qureshi, Islamic Wonders Bureau, Delhi.

The other museums I visited, or collected information from, in India are listed in alphabetical order of the cities, with the names of the authorities in parentheses.

Aligarh, Aligarh Muslim University, **Ajmal Khan Tibbia College** (principal).

Hyderabad: **Saidiya Library** (Ahmad Athaullah); **State Museum of Archaeology** (S. S. Rangacharylu, assistant director).

Jaipur: **Government Maharaja's Sanskrit College** (Professor Vijay Kumar Sharma); **Maharaja Sawai Man Singh II Museum, City Palace** (Dr Giles H. R. Tillotson, director of research); **Museum of Indology** (Ramachandra Vyakul); **Shri Sanjay Sharma Museum & Research Institute** (Ram Kripalu Sharma and Tilak Raj Sharma).

Lucknow: **Nadwatul Ulama** (M. Haroon Nadwi, librarian of the Shibli Nomani Library),

Mumbai, **Chatrapati Shivaji Sangrahalay** (Dr Kalpana Desai, director; Arvind Fondekar, assistant curator); **K. R. Cama Oriental Institute** (Homai N. Modi, trustee).

New Delhi: **Mumtaj Mahal Museum (Archaeological Museum)**, Red Fort (Director-General of the Archaeological Survey of India); **National Museum** (U. Das, keeper; Anamika Pathak, C.A.).

Patna: **Khuda Bakhsh Oriental Public Library** (Dr A. R. Bedar, director; Md. Atiqur Rehman, assistant librarian; Ata Khurshid, library assistant; Dr Mohammad Zakir Hussain, research scholar).

[ix] Sarma 1996a.

Srinagar: **Sri Pratap Singh Museum:** Munir Ul Islam, Director, Archives, Archaeology and Museums, Jammu & Kashmir; Rabia Qureshi, Curator, SPS Museum; Dr Seemin Rubab and Nazir Ahmad Doshab.

Srinagar: University of Kashmir**, Central Asian Museum** (Nazir Ahmad Doshab, photographer).

Vadodara: MS University of Baroda, **Oriental Institute** (Professor M. L. Wadekar, director; Dr Sweta Prajapati); **Sanskrit Mahavidylaya** (Professor Yogesh B. Oza, principal).

Varanasi: Banaras Hindu University, **Bharat Kala Bhavan** (Dr R. C. Sharma, director; Yashodhara Agarwal, curator); Sampurnanand Sanskrit University, **Sarasvati Bhavan Library** (Professor Mandan Mishra, vice-chancellor; D. S. Mishra, assistant librarian).

MUSEUMS IN UK

In 1989, I attended the International Congress of History of Science at Hamburg and made a presentation on the 'Astronomical Instruments in Mughal Miniatures.'[x] In the course of my presentation, I spoke about the need of an inventory of the extant astronomical instruments produced in India. The audience included Dr R. G. W. Anderson and Professor G. L' E. Turner, who were then the president and secretary of the Scientific Instrument Commission. They approved of my idea and suggested that I should begin the work in UK where there are large collections. But I could not make it to UK until the summer of 1993.

A large part of my stay was spent at the **Museum of the History of Science at Oxford**, where the director Francis Maddison showed keen interest in my work. He allowed me access to a large collection of photographs of astronomical instruments which various auction houses sent him for his evaluation. He also allowed me to copy the relevant parts of the *Repertoire* he was then compiling. This work was never published, but the 1993 version I have has been very valuable for my work. I am highly indebted to him and also to Dr W. D. Hackmann, assistant director; A. V. Simcock, librarian and L. Norman, photographer. I was again in this museum in 2005 and the new director Dr Jim Bennett very kindly provided me all facilities to study the instruments. The present director, Dr Silke Ackermann, graciously permitted me to include several museum photos in this catalogue.

The other museums I visited in UK are listed in alphabetical order of the cities.

Cambridge: **Whipple Museum of the History of Science** (Dr J. A. Bennett, curator).

Cardiff: **Welsh Industrial and Maritime Museum** (Alex Dawson, documentation officer).

Edinburgh: **Royal Museum of Scotland** (Dr Alison Morrison-Low provided me excellent photos of instruments in the museum).

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[x] Sarma 1992a.

Lancashire: **Stonyhurst College** (Elizabeth Robinson, Persons Fellow).

London: **British Museum** (Dr R. G. W. Anderson, director; Dr Richard Blurton, Beatriz Waters); **The Clockmakers' Company Collection,** Guildhall (Sir George White, curator); **Horniman Museum** (Ken Teague, assistant keeper); **Nasser D. Khalili Collection of Islamic Art** (Professor Nasser D. Khalili and Nahla Nassar, registrar); **National Maritime Museum,** Greenwich (Dr Kristin Lippincott, Dr Gloria Clifton, Dr Louise Devoy); **Science Museum** (Kevin Johnson, Alison Boyle, Jeremiah Solak); **Victoria and Albert Museum** (Anthony North, Susan Strange).

Oxford: **Pitt Rivers Museum of Ethnology** (Linda Mowat, assistant curator).

MUSEUMS IN USA

Professor David Pingree offered me visiting associate professorship at his Department of History of Mathematics at Brown University Providence for the year 1992-93. This gave me the opportunity to visit the various museums in the USA with collections of Indian astronomical instruments. More important, I read Mahendra Sūri's *Yantrarāja,* the first Sanskrit manual on the astrolabe, with David Pingree and his students. I also had the opportunity to read the catalogue of Sanskrit and Indo-Persian astrolabes in the Adler Planetarium at Chicago, which Pingree was then preparing and which appeared posthumously in 2009 under the title *Eastern Astrolabes.*

Chicago: **The Adler Planetarium and Astronomy Museum** (Roderick Webster and Marjorie Webster, honorary curators). I am highly thankful to Dr Pedro Raposo, the curator, and Lauren Boegen, digital collections manager, for their kindness in generously sending me more than a hundred digital images of the Indian instruments in their collection.

New Haven: Yale University, **Cushing/Whitney Medical Library** (Dr Melisa Graffe, librarian).

New York: Columbia University, **Butler Library, Rare Book and Manuscript Library** (Rudolph Ellenbogen, assistant librarian).

Rockford: **Time Museum** (Patricia H. Atwood, executive director).

Washington, D. C.: **National Museum of American History** (Dr Peggy Kidwell, (late) Silvio Bedini, Deborah J. Warner, Drew Robarge).

I must offer special thanks to Dr David Coffeen (**Tesseract**, Hastings-on-Hudson, NY) for many photos of instruments in his collection anf for valuable suggestions.

MUSEUMS IN FRANCE

Paris: **Institute du Monde Arabe** (Jeanne Mouliérac); **Observatory of Paris** (Dr Jean-Pierre Verdet, Dr Suzanne Débarbat).

Anthony Turner and Dominique Brieux helped me in studying the instruments in private collections.

MUSEUMS IN GERMANY

With a scholarship from the Deutsche Akademische Austauschdienst, I spent the winter 1995-96 at Professor David King's Institut für die Geschichte der Naturwissenschaften, where I could make use of the rich library and benefit from the expertise of Professor King's students, Dr Francoise Charette, Dr Benno van Dalen, Dr Petra Schmidl and Dr Burkhard Stautz.

At Frankfurt, I could also use the rich library of the Institut für Geschichte der Arabisch-islamische Wissenschaft where Farid Benfeghoul, Dr Carl Ehrig-Eggert, Lutz Kotthof and Dr Gesine Yildiz rendered me various kinds of help.

Berlin: **Museum für Indische Kunst** (Regina Hickemann, Deputy Director).

Bielefeld: **Kunstgewerbesammlung der Stadt Bielefeld.**

Hannover: **Kestner Museum** (Prof. Dr Rosemarie Drenkhahn, Director).

Stuttgart: **Linden Museum** (Beate Siewart-Meyer, Wissenschaftliche Mitarbeiterin).

BELGIUM

In Belgium, there are several Indian instruments in private collections and it is to the credit of Jan de Graeve that I could study and photograph these instruments.

NETHERLANDS

Leiden: **Museum Boerhaave** (Dr Robert van Gent; Tiemen Cocquyt).

PAKISTAN

I did not have the opportunity to visit the museums in Pakistan. Dr Nasim Naqvi (London) obtained for me some photographs of instruments through his contacts. Now Mubashir Ul-Haq Abbasi (Institute of Space Technology, Islamabad, Pakistan) kindly sent me detailed photos and information of instruments in the **Islamabad Museum**, **Lahore Museum** and **National Museum of Pakistan** at Karachi. He is also preparing a comprehensive catalogue of the astronomical instruments preserved in the museums of Pakistan.

QATAR

Doha: **Museum of Islamic Art** (Marc Pelletreau, Head of Multimedia)

RUSSIA

St. Petersburg: **The State Hermitage Museum** (Dr Olga P. Deshpande, Senior Curator, Oriental Department; Zhanna Etsina, Manager, Rights and Reproductions Office).

SWITZERLAND

Geneva: **Musée d'Histoire des Sciences** (Laurence-Isaline Stahl Gretsch; Stéphane Fischer).

TURKEY

I did not have the chance to visit Istanbul. At **Kandilli Observatory and Earthquake Research Institute**, Professor Mustafa Aktar, professor of geophysics and in-charge of the collection of historical instruments, very kindly sent me photos and the exact measurements of the Indian instruments in the collection.

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Besides the museums mentioned above, many private collectors allowed me to study the Indian instruments in their collections; some have provided me with good photos. I am much obliged to them, but it is not appropriate to identify them with their names.

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Outside the museums, I am highly obliged to many scholars for arranging my lectures on instruments, for publishing my papers, for introducing me to the museums and private collectors and for various other favours.

India: Professor Ishrat Alam (Aligarh Muslim University), Dr Vijay V. Bedekar (Chairman, Vidyaprasarak Mandal, Thane, India); Professor Ramkrishna Bhattacharya (Kolkata); Dr Divyabhanusinh Chawda (Jaipur); Professor Ratna Prabha Chivukula (M. S. University of Baroda); Professor Ashok Das (formerly Director, Sawai Mansingh Library and Museum, Jaipur); Dr Devangana Desai (Editor, *Journal of the Asiatic Society of Mumbai*); Dr Sanjay Garg (National Archives of India, New Delhi); (late) S. A. K. Ghori (Aligarh); Dr Sudha Gopalakrishnan (formerly Director, National Manuscript Mission, New Delhi); Professor S. Irfan Habib (National University for Educational Planning and Administration, New Delhi); Professor Amina Kishore (Aligarh Muslim University); Professor M. A. Kishore (Aligarh Muslim University); Professor Rani Majumdar (Aligarh Muslim University); Dr Syed Liyaqat Hussain Moini (Aligarh Muslim University); Professor Shirin Moosvi (Aligarh Muslim University); Ghulam Mujtaba, Aligarh; Professor Jayant Narliker (Inter-University Centre for Astronomy and Astrophysics, Pune); (late) Professor Ahsan Jan Qaisar (Aligarh Muslim University); Professor Zillur Rahman (President, Ibn Sina Academy of Medieval Medicine and Sciences, Aligarh); Professor K. Ramasubramanian (IIT-B, Mumbai); Professor S. Balachandra Rao (Formerly Professor of Mathematics and Principal, National College, Bangalore); Abdul Rashid (Indira Gandhi National Centre for the Arts, New Delhi); Dr Mira Roy (Kolkata); (late) Yaduendra Sahai (Sawai Mansingh Library and Museum, Jaipur); (late) S. N. Sen (Indian Association for the Cultivation of Science, Kolkata); Subhash Sharma (Jaipur); Professor B. V. Subbarayappa (former President, International Union of History and Philosophy of Science, Bangalore); Dr Vijay Shankar Shukla (India Gandhi National Centre for Arts); Dr B. G. Sidharth (Director, B. M. Birla Science Centre, Hyderabad); Professor Romila Thaper (Jawaharlal Nehru University, New Delhi); Professor Radha Vallabh Tripathi (formerly Vice Chancellor, Rashtriya Sanskrit Sansthan, New Delhi); late Dr Lotika Varadarajan (New Delhi); Dr Kapila Vatsyayan (Founder-Director, Indira Gandhi National Centre for the Arts, New Delhi).

Belgium: Ernesto Canobbio and Dr Jean-Michel Delire.

Canada: Professor Ashok Aklujkar (University of British Columbia, Vancouver); Professor Dominik Wujastyk (University of Alberta, Edmonton).

Egypt: Dr Flora Vafea (Cairo); Ayman Aly (Cairo).

France: Eric and Dominique Delalande (Galerie Delalande, Paris); Professor Jan Houben (École Pratique des Hautes Études, Paris); Dr Jérôme Petit (Bibliothèque Nationale de France); (late) Dr Arion Roşu (Versailles); Professor Fabrizio Speziale (Université Paris 3 Sorbonne Nouvelle).

Germany: Professor Willem Bollée (Bamberg), Professor Rahul Peter Das (Martin Luther University Halle-Wittenburg), (late) Professor Michael Hahn (Philipps University, Marburg), Professor Jürgen Hanneder (Philipps University, Marburg), Professor Oskar von Hinüber (Albert-Ludwigs University, Freiburg), (late) Dr Anthony R. Michaelis (Heidelberg); Professor Eva Orthmann (University of Bonn); (late) Professor Wilhelm Rau (Philipps University, Marburg); Dr Alexander Walland (Ingelheim); Karl Pohl (Cologne); Dr Jayandra Soni (Philipps University, Marburg); (late) Professor Claus Vogel (University of Bonn); Professor Albrecht Wezler (University of Hamburg).

Iran: Professor Mohammad Bagheri (Institute for the History of Science, University of Tehran).

Italy: Dr Paulo Brenni (President, Scientific Instruments Society); Dr Ileana Chinnici (Palermo Observatory, Palermo, Italy); Professor Mara Miniati (Curator Emeritus, Museo Galileo, Florence).

Japan: Dr Yukio Ohashi (Tokyo); Satoshi Ogura (Kyoto University).

Netherlands: Wilfred de Graaf and Professor Jan P. Hogendijk (University of Utrecht); Dr Saraju Rath (International Institute of Asian Studies, Leiden).

Russia: Sergei Maslikov (Director, Large Novosibirsk Planetarium, Novosibirsk).

Spain: Professor Emilia Calvo, Dr Roser Puig and Professor Julio Samso (University of Barcelona).

Sweden: Dr Martin Gansten (Lund, Sweden).

Switzerland: Dr Johannes Thomann (University of Zurich).

Thailand: Professor Ampha Otrakul (Chulalongkorn University, Bangkok).

UK: Dr Josefina Rodriguez Arribas (Warburg Institute, University of London); Professor Charles Burnett (Warburg Institute, University of London); Jeremy Collins (Christie’s, London); Dr Roy Fischel (School of Oriental and African Studies, University of London); Dr Edward Gibbs (Sotheby’s, London); Dr Willem Hackmann (Editor, *Bulletin of the Scientific Instruments Society*).

USA: Professor Muzaffar Alam (University of Chicago); Dr Owen T. Cornwall (Columbia University, New York); Dr Sharon Gibbs-Thibodeau (US National Archives, College Park, Maryland); Dr Toke Lindegaard Knudsen (State University of New York, Oneonta); Professor Phyllis Granoff (Yale University, New Haven); Dr James McHugh (University of Southern California, Los Angeles); Dr Clemency Montelle (Brown University, Providence; now: University of Canterbury, Christchurch, New Zealand); Angur Patel (San Diego, California); Professor Sumathi Ramaswamy (Duke University, Durham, North Carolina); Professor Virendra Nath Sharma (University of Wisconsin); Profesor Michael Witzel (Harvard University).

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I must record my sincere thanks to the following friends whose help I sought frequently during the past two years while drafting this catalogue and who have readily and warm-heartedly responded:

Dr Vijay Bedekar (Thane) and Jan de Graeve (Brussels) sent me, at short notices, rare published material; Dr Jean-Michel Delire (Brussels) very generously provided me detailed photos of instruments in Jaipur; Dr Martin Gansten (Lund) helped me with astrological matters. Mubashir Ul-Haq Abbasi (Islamabad) has been an enthusiastic collaborator during the past three years; the detailed descriptions and photos of the instruments preserved in the various museums of Pakistan are due to him; he also deciphered and translated some Persian inscriptions for me. When I asked Debasish Das (Gurgaon) for a photo of the sundial at the Jama Masjid in Delhi, he promptly sent me detailed photos of that sundial; not only that, he also made explorations throughout India and within a short time located several thitherto unknown sundials and became an expert in this process (see his very comprehensive and eminently readable report on the sundials in mosques in India at Das 2018).

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For their abiding friendship and many acts of help, I owe a special debt of gratitude to Ursula and Oskar Kober (Homberg/Efze, Germany).

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Without the loving support of my wife Renate Sarma and our son Ananda Sarma, I could not have worked for so many years and completed this catalogue. Renate proofread much of the catalogue with great patience. Ananda gave shape to my raw text, with his efficient formatting and nice layout; he is, in fact, the manager, editor and publisher of this catalogue.

PREAMBLE

तनुर्नेत्रैर्न्यूना नृपतिरहिता राजनगरी
सरस्यो निष्पद्मा युवतिरपि कान्तेन रहिता ।
निशा निःशीतांशुः सरिदपि यथा चक्ररहिता
तथा ज्योतिर्विद्या भवति विफला यन्त्ररहिता ॥

tanur netrair nyūnā nṛpatirahitā rājanagarī
sarasyo niṣpadmā yuvatir api kāntena rahitā |
niśā niḥśītāṃśuḥ sarid api yathā cakrarahitā
tathā jyotirvidyā bhavati viphalā yantrarahitā ||

Like body without eyes, royal capital minus the king,
lakes devoid of lotus flowers, a young woman without a lover,
the night without the moon, a river bereft of *Cakravāka* birds,
even so astronomical science is fruitless without instruments.

— Rāmacandra Vājapeyin, 1428, *Yantra-prakāśa*

In reconstructing the history of science and technology of any civilization, scientific instruments play as valuable a role as literary documents do. This is particularly true of astronomical instruments. As Francis Maddison, long-time curator of the famous Museum of the History of Science at Oxford, remarks:

> It was in astronomy that accurate measurement was first used systematically to obtain quantitative evaluations of observed phenomena. The instruments which were invented and which developed in response to this approach to scientific enquiry are (…) worthy of study as primary sources of the history of scientific thought and of technological achievement.[11]

In the Indian subcontinent, scientific instruments were used throughout history. The large number of weights, the remains of some metal scales and the fragment of a linear scale incised on a shell, which were recovered at the Indus Valley sites of Mahenjo-daro and Harappa, are some of the earliest specimens of Indian scientific instruments.[12] Unfortunately, neither a systematic inventory of these instruments was made, nor were they studied in the context of their historical development. On the other extremity of the chronological scale, even Sawai Jai Singh's observatories, which must be ranked as unique astronomical monuments of the world, are in a sad state of neglect. The large masonry instruments which Jai Singh designed and erected in his observatories are indeed the culmination of a long process of development in astronomical instrumentation. But what sort of instruments were used until the eighteenth century, before the time of Jai Singh?

SANSKRIT TEXTS ON ASTRONOMICAL INSTRUMENTS

Sanskrit astronomical texts describe many instruments (*yantra*) for measuring time, for taking the altitudes of heavenly bodies, for measuring the angular distance between two celestial objects, for visually demonstrating the apparent motion of the heavens, and so on. Kauṭilya's *Artha-śāstra,* which was composed and expanded between the second century BC and the third century AD, speaks of measuring time by

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[11] Maddison 1963, p. 17.

[12] Bose, Sen & Subbarayappa 1971, pp. 137-138.

means of a water clock or with a gnomon.[13] At the beginning of the sixth century, Āryabhaṭa described several interesting astronomical instruments in his *Āryabhaṭa-siddhānta*. This work is now lost but the descriptions of the instruments survive in Rāmakṛṣṇa Ārādhya's commentary on the *Sūrya-siddhānta*.[14] About the middle of the sixth century, Varāhamihira discussed a few instruments in the fourteenth chapter of his *Pañca-siddhāntikā*.

The first systematic and comprehensive account of astronomical instruments (*kāla-yantras*) is provided by Brahmagupta in his *Brāhmasphuṭa-siddhānta,* which he completed in 628 in western India. Here the twenty-first chapter is devoted to the armillary sphere (*Gola-yantra*) and the twenty-second chapter to the other instruments. The armillary sphere is treated separately because it is primarily a didactic device and not a measuring tool. Moreover, it appears that students of astronomy were encouraged to assemble their own armillary spheres, because by arranging the various imaginary circles in the heavens such as the celestial equator, the ecliptic and others as physical entities in the armillary sphere, they can grasp the purpose and function of these imaginary circles. Therefore, *gola-bandha,* i.e., tying together the different rings to constitute the armillary sphere, seems to be part of the traditional curriculum.

In the twenty-second chapter called *Yantrādhyāya* (chapter on instruments), Brahmagupta describes the construction and use of nine varieties of instruments, *Dhanus, Turyagola, Cakra, Yaṣṭi, Śaṅku, Ghaṭikā, Kapāla, Kartarī* and *Pīṭha*. In addition, he describes eight types of accessories which are required when observations are made with instruments. He also describes some varieties of automata and perpetual motion machines (*Svayaṃvaha-yantra*).[15]

This procedure was adopted nearly in all the major astronomical texts in Sanskrit. In his *Śiṣyadhīvṛddhida-tantra,* Lalla (eighth or ninth century) devotes the fifteenth chapter *Golabandhādhikāra* for the construction of the armillary sphere and the twenty-

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13 Kauṭilya, *Arthaśāstra,* 1.19.6: *nālikābhir ahar aṣṭadhā rātriṃ ca vibhajet, chāyāpramāṇena vā.* '[The king] shall divide the day, and also the night, into eight parts, by means of the water clock or by means of the shadow-lengths [of the gnomon]'. This passage will be discussed in detail in sections N (Palabhā-yantras & Equinoctial Sundials in Sanskrit) and R (Water Clocks).

14 These are retrieved and interpreted by Shukla 1967.

15 Sarma 1986-87a.

first chapter *Yantrādhyāya* for the following instruments: automata, *Gola, Cakra, Dhanus, Kartarī, Kapāla, Pīṭha, Bhagaṇa, Śaṅku, Ghaṭī, Śalākā, Śakaṭa* and *Yaṣṭi.* Of these *Bhagaṇa, Śalākā* and *Śakaṭa* are new; these have not been described by Brahmagupta.

In his *Siddhānta-śekhara* of 1039, Śrīpati discusses the instruments somewhat briefly as compared to Lalla. The construction of the armillary sphere is treated in the fifteenth chapter entitled *Golādhyāya*. The nineteenth chapter entitled *Yantrādhyāya* deals with the following nine instruments: *Svayaṃvaha-gola-yantra, Cakra, Dhanus, Kartarī, Kapāla, Pīṭha, Śaṅku, Ghaṭī* and *Yaṣṭi.*

Closely following these predecessors, Bhāskarācārya devotes, in the *Golādhyāya* of his *Siddhānta-śiromaṇi* (1150), an exclusive chapter entitled *Golabandhādhikāra* to the armillary sphere and a subsequent chapter called *Yantrādhyāya* to ten different types of measuring instruments and three varieties of perpetual motion machines. The instruments discussed by him are *Gola, Nāḍīvalaya, Ghaṭikā, Śaṅku, Cakra, Cāpa, Turya, Phalaka, Yaṣṭi* and *Dhī.* In addition, he discusses *Nalaka-yantra* in the *Tripraśnādhikāra* of the *Grahagaṇita.*

In his *Siddhānta-sundara* (1503), Jñānarāja also follows the same pattern of separate chapters for the armillary sphere and for other instruments; in the latter he describes *Turya, Chakra, Ghaṭī-yantra* and *Kāca-yantra,* and several automata.

CONTACT WITH ISLAMIC ASTRONOMY

Contact with Islamic astronomy led, from about the fourteenth century onwards, to the composition of texts exclusively devoted to instruments. The earliest work of this nature is the *Yantrarāja* composed by the Jaina monk Mahendra Sūri at the court of Fīrūz Shāh Tughluq in Delhi in 1370. In this first Sanskrit manual on the astrolabe, this instrument was called *yantrarāja,* ‘king of instruments’. Astronomers also began to emphasise that astronomical studies remain incomplete without proper observational instruments. Thus Mahendra Sūri declares in his *Yantrarāja*:

Though hardened in fierce battles,
The soldier is defeated when deprived of weapons,
Though profound in the whole range of astral science,
The astronomer is disgraced without his instruments.'[16]

Writing about half a century later, in 1428, Rāmacandra Vājapeyin echoes the same idea in his *Yantra-prakāśa,* which is cited at the beginning of this Introduction.[17] In the subsequent centuries also, several Sanskrit works were composed on instruments. The astrolabe was discussed in more than a dozen Sanskrit texts, some of which were exclusively devoted to this instrument. These texts will be discussed in the introduction to section C on Sanskrit astrolabes.

Besides, there are also other texts which dealt with several instruments. Notable among these is Rāmacandra Vajapeyin's voluminous *Yantra-prakāśa* of 1428 in six chapters. Here the first four chapters are devoted to the astrolabe, the fifth chapter deals with the gnomon and staff, while the sixth chapter describes the construction and use of as many as 36 different types of instruments.[18] Viśrāma's *Yantra-śiromaṇi* of 1615 is a modest work which deals with six instruments, viz. *Nara-yantra* (gnomon), *Jala-yantra* (water clock), *Yantrarāja* (astrolabe), *Cāpa-yantra* (semi-circular instrument), *Turya-yantra* (quadrant) and *Nalaka-yantra* (sighting tube). Nandalāla Miśra's *Yantra-sāra* of 1772 discusses eleven instruments with special emphasis on the astrolabe and the quadrant.

There are also exclusive works on other instruments. About 1423 Padmanābha composed an exclusive text on the *Dhruvabhrama-yantra* which he had invented. Probably in the first half of sixteenth century, Cakradhara composed the *Yantra-cintāmaṇi* on the sine quadrant. The work must have been very popular; there exist several manuscript copies. Not so popular, but more comprehensive is Bhūdhara's

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16 Mahendra Sūri, 1.4. Extracts from this text, together with translation, are available in Apx.D1.

17 Rāmacandra Vājapeyin, 1.10.

18 Sarma 2008b.

Turya-yantra-prakāśa of 1572 on the sine quadrant, which text is available just in a single complete manuscript.[19]

This overview of Sanskrit texts on astronomical instruments raises the following questions. Were any of these instruments ever constructed and used in observation? Are there any specimens extant in museums in India or outside? If yes, are these extant instruments mentioned or described in literature? [20]

The study of scientific instruments in other culture areas is well developed. In the West, there are excellent museums of history of science and technology, such as the Museum of History of Science at Oxford, the Adler Planetarium at Chicago, and the Deutsches Museum at Munich. Also the literature on medieval European instruments and instrument-makers is truly impressive, beginning with Ernst Zinner's classic study *Deutsche und Niederländische Astronomische Instrumente*.[21] Islamic astronomical instruments like the astrolabe and the celestial globe have been catalogued and studied in several publications, notably in *A Computerized Checklist of Astrolabes* by Derek Price and his associates[22] and in the *Islamicate Celestial Globes, their History, Construction, and Use* by Emilie Savage-Smith.[23] Professor David King embarked on a path-breaking work of cataloguing medieval European and Islamic astronomical instruments,[24] and published a vast corpus of highly valuable work.[25]

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19 SaKHYa 2014. It is beyond the scope of this catalogue to discuss these Sanskrit texts and the instruments mentioned there in greater detail. Some of these texts will be referred to while describing the extant instruments. Extracts from a few texts will also be reproduced with translation in the Appendices. For more information on the instruments described in these Sanskrit texts, see Das 1928, Rai 1985, SarmaKV 1990, and all the papers by Yukio Ôhashi listed in the bibliography.

20 Rai 1985, after giving a lucid account of the instruments described in Sanskrit texts, concludes on p. 336: 'None of the instruments described by Indian astronomers before the time of Maharaja Jai Singh survive today. Perhaps they were made of perishable materials like wood and bamboo. Admittedly they were not very sophisticated. But it must be remembered that mechanical clocks had not been devised up to that time and it was not possible to measure time accurately.' Luckily, several specimens of the instruments described in the Sanskrit texts survive.

21 Zinner 1979.

22 CCA.

23 Savage-Smith 1985.

24 King 1991.

25 See, in particular, his recent publications like King 1999b, King 2004, King 2005.

In India, no comparable work has been done on the existing instruments. While studying Jai Singh's masonry instruments in the early part of the last century, Garrett and Kaye severally paid some attention to the portable instruments at Jaipur.[26] In 1921 Kaye also studied the four instruments acquired by the Archaeological Museum at Delhi.[27] In 1935 Sulaiman Nadvi brought to light a hitherto unknown family of instrument makers of Lahore by listing 8 astrolabes and 4 celestial globes manufactured by the various members of this family.[28] In the 1970s, S. N. Sen undertook a survey of 'Astronomical Instruments of Historical Importance,' and published an interesting study on the astrolabe.[29] Beyond this, nothing more came out of the project.[30]

However, the first steps towards a descriptive catalogue were taken by R. T. Gunther in his pioneering work, *The Astrolabes of the World,* where he published the descriptions of 25 Indo-Persian astrolabes and 9 Sanskrit Astrolabes, together with excellent photos.[31] Likewise, Emilie Savage-Smith's catalogue of *Islamicate Celestial Globes* of 1985 contains descriptions of several Indo-Persian celestial globes.

Following this lead, I began the survey of extant astronomical instruments produced in pre-modern India and now preserved in museums and in private collections in India, Europe and USA, and identified some 555 instruments of diverse types, belonging to the two broad categories of Sanskrit instruments and Indo-Persian instruments.

INDO-PERSIAN ASTRONOMICAL INSTRUMENTS

Muslim astronomers in India cultivated the Middle Eastern tradition of astronomical instrumentation. They avidly studied and copied the Arabic and Persian

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26 Garrett & Guleri 1902, pp. 60-65; Kaye, pp. 16-36.

27 Kaye 1921.

28 Nadvi 1935.

29 Sen 1990.

30 Vijai Govind, Sen's assistant in this project, published two more papers: Govind 1979; Behari & Govind 1980. But there are serious flaws in these two papers in the identification of instruments. For the sake of comprehensiveness, three other papers may be mentioned here: Dvivedi 1923; Dube 1928; Stone 1958.

31 Gunther 1932: Indian astrolabes, nos. 67-91, 74a, pp. 179-220; Hindu astrolabes, nos. 92-98, pp. 221-228.

texts on astronomy, astrology and astronomical instruments composed in the various parts of the Islamic world; this is attested by the rich collections of manuscripts in various libraries in India.[32] They may also have composed original works on astronomical instruments either in Arabic or Persian, but such texts are yet to be surveyed. Immediately relevant for us is the fact that the Muslim astronomers in India produced a substantial number of Islamic, or more precisely Indo-Persian, astronomical instruments, mainly astrolabes and celestial globes, and a small number of other instruments like sine quadrants.

The production of Indo-Persian astrolabes in India may have begun at the court of Fīrūz Shāh Tughluq at Delhi in the second half of the fourteenth century, but the earliest extant dated astrolabe is of 1567. It was made by Allāhdād of Lahore. He and his six descendants dominated the production of astrolabes and celestial globes in the sixteenth and seventeenth centuries. Compared to the instruments made by this family, very few instruments by others outside this family are extant today. The instrument production in the Allāhdād family ceased after 1691. Hardly any Indo-Persian instruments bearing dates in the eighteenth century came to light. But this does not mean that the production of astrolabes or celestial globes ceased completely in the eighteenth century, because there exist quite many instruments fabricated in the nineteenth century. It is possible that some of the extant unsigned and undated astrolabes and celestial globes may have been produced in the eighteenth century. But what seems to be certain is that with gradual decline of the Mughal empire, patronage also declined for astronomical instruments, as a consequence of which not many large and ornate astrolabes and celestial globes with the names of makers and dates may have been made in the eighteenth century.

Although there is a kind of vigorous revival of the production of Indo-Persian astrolabes and celestial globes towards the middle of the nineteenth century, as will be shown below, the geographical extent of their production was limited only to the Panjab-Delhi region.[33]

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32 Rahman, Alvi, Khan & Murthy 1982; see also a critical review of this by Ansari & Fatima 1984.

33 For a solitary case of commercial production of astronomical instruments with Urdu legends at Madras ca. 1915, see Q003.

SANSKRIT ASTRONOMICAL INSTRUMENTS

On the other hand, one would expect that Sanskrit astronomical instruments, unlike the Indo-Persian instruments, were manufactured throughout India. But surprisingly, their production, with the exception of the armillary spheres and water clocks, was also largely confined to the region comprising Gujarat, Rajasthan and Panjab, where it continued in the eighteenth and nineteenth centuries as well. I am unable to explain this anomaly. After all, there has been no discernable break in the study of Sanskrit astronomy in the southern and eastern parts of India. This is attested by manuscripts of all major Sanskrit texts copied in all parts of India and in all regional scripts. In the fifteenth and sixteenth centuries Kerala made great advances in mathematical astronomy. A central figure of these advances, the great Nīlakaṇṭha Somayājin enjoins that only such astronomical treatises should be followed which agree with actual observations.[34] This statement presupposes the existence of instruments for astronomical observation. Yet no astronomical instruments of any consequence were found there.

The earliest dated Sanskrit instrument is an astrolabe (C001) which was completed on Sunday, 25 December 1605, at Ahmedabad. It was commissioned by the astrologer Caṇḍīdāsa for his son Dāmodara. One may wonder why no Sanskrit astronomical instrument made earlier than this date is available. I have shown elsewhere that the custom of engraving the name of the maker and the date of production on metal instruments and other objects was introduced into India along with the astrolabe.[35] Of course, stone epigraphs in India carried often the date and the name of the king who issued the epigraph, the name of the poet who composed the text and the name of the artisan who incised the inscription. The practice was followed later in copper plate epigraphs and in manuscripts as well. But there was no custom of engraving the name of the maker and date on metal artefacts before the introduction of the astrolabe.[36]

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34 Nīlakaṇṭha Somayājin, *Jyotirmīmāṃsā,* p. 6: *yaḥ siddhāntaḥ darśanāvisaṃvādī bhavati so 'nveṣaṇīyaḥ,* quoted in: Subbarayappa & Sarma 1985, p. 7; for similar statements by other astronomers, see ibid, pp. 5-8.

35 Sarma 2010.

36 Interestingly on a Sanskrit astrolabe of 1605 (C001), the style of the inscription followed that of Sanskrit manuscript colophons, even though the custom of engraving the date and the name of the

Another reason for the absence of Sanskrit instruments made before the seventeenth century is that often brass instruments not in use were recycled to produce other objects.

As mentioned above, the earliest extant Sanskrit astrolabe was made in Ahmedabad in Gujarat. Some other early astrolabes also emanate from Gujarat. From there, the production spread to Rajasthan, where it received an impetus at the court of Sawai Jai Singh in the early eighteenth century. It is well known that Sawai Jai Singh (1688-1743) designed huge masonry instruments for accurate observations and with these he set up five observatories at Delhi, Jaipur, Varanasi, Mathura and Ujjain. But he did not neglect portable instruments. He was a great admirer of the astrolabe. He collected some of the best Mughal astrolabes, to some of which he caused Sanskrit legends to be added. He also appears to have established a workshop at Jaipur to produce Sanskrit astrolabes. Here were produced some ornate astrolabes with multiple plates, designed after the Indo-Persian astrolabes of the Lahore family (C021 and C022). But, the main products of this workshop are astrolabes with single plates calibrated to the latitude of Jaipur at 27°. Jai Singh seems to have got a large number of such astrolabes fabricated and distributed them among the astronomers of his court, so that they became proficient in the science of the astrolabe. In the stores of Jai Singh's Observatory at Jaipur, I discovered a number of unfinished astrolabes belonging to this workshop (D077 – D089).

But production of Sanskrit astronomical instruments was not confined to Jaipur in the eighteenth century. Instruments were made and collected also at several other kingdoms in Rajasthan, and also in Gujarat.

In the nineteenth century, western sciences, including astronomy, began to be taught in universities and colleges throughout India and modern observatories were set up at several places with telescopes and related instruments. But these activities did not completely replace the Sanskrit and Islamic traditions of astronomical learning and the production of traditional astronomical instruments. At some places, the traditional Sanskrit or Islamic learning flourished side by side with western sciences; at others there

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person who caused it to be made was borrowed from Islamic practice. Therefore, Pingree dismissed the astrolabe as late production. For his arguments and for my refutation, see Sarma 2012c.

is an amalgamation of both the streams in varying proportions. This is true also of scientific instrumentation. Sanskrit astronomical instruments continued to be manufactured mainly in Rajasthan. A new centre of production came up at Kuchaman, which is situated some 130 km west of Jaipur, but roughly on the same latitude of 27°. Here were produced Sanskrit astrolabes, the last of which (D037) was completed on Monday, the sixth day of the bright half of Kārtika in the year 1960 of Vikrama Saṃvat (= Monday 26 October 1903).[37]

Indo-Persian astrolabes and celestial globes continued to be made in Panjab, mainly at Lahore, in the nineteenth century. At Aurangabad in Maharashtra (19;53 N, 75;23 E), there flourished an astrolabe maker Muḥammad Mūsa Asṭurlābī in the 18th century. A celestial globe made by his grandson Muḥammad Faḍl Allāh in 1808 (presumably at Aurangabad) survives today. This globe is mounted on a European style stand into which a magnetic compass is incorporated.[38] In the east, at Tikari in Bihar (24;57° N, 85;53° E), Ghulām Ḥussayn Jaunpūrī made a celestial globe in 1816.[39] But these are exceptions and not the rule. The production of Indo-Persian astrolabes and celestial globes was centred primarily at Lahore. Towards the middle of the nineteenth century, there was a sudden upsurge in the manufacture of these traditional astronomical instruments at Lahore under the aegis of a Hindu by name Lālah Bulhomal Lāhorī, who crafted astrolabes and celestial globes with legends either in Arabic-Persian or in Sanskrit. He also crafted Sanskrit instruments like *Dhruvabhrama-yantras* and *Turīya-yantras*, signing his name in pretty Sanskrit verses. He even created some new instruments of his own design. Some forty-five instruments of diverse types at Lahore made by him and by his Hindu and Muslim associates are known. Bulhomal can be regarded as the last representative of both Islamic and Sanskrit traditions of astronomical instrumentation.[40]

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37 In the latter half of the nineteenth century, Sāmanta Candraśekhara designed in Orissa his own astronomical instruments out of bamboo and wood and made systematic observations and composed the *Siddhānta-darpaṇa* in Sanskrit; on his work, see Misra 1996; Naik & Satpathy 1995 Naik & Satpathy 1998; Naik 2000.

38 Preserved at the Salar Jung Museum, Hyderabad; cf. Sarma 1996a, pp. 27-28, pl. 15.

39 Cf. Ansari & Sarma 1999-2000.

40 For a comprehensive study of his oeuvre, see Sarma 2015b.

Although the telescope and the pendulum clock were widely available, it is interesting to note that Indian craftsmen copied European models of naked eye instruments, like ring dials, and engraved on them Persian legends for the sake of Muslim astrologers and Sanskrit legends for the use of Hindu *jyotiṣīs*. A scientific instrument that is still produced today at Muradabad in Uttar Pradesh, quite elegantly and in large numbers, is the perpetual calendar. Two nineteenth-century prototypes are preserved in the Victoria and Albert Museum at London and in the Rampur Raza Library. These will be described in section T.

To sum up, the instruments which are extant today were produced between the mid-sixteenth century and the end of the nineteenth century, mainly in the region of Gujarat, Rajasthan and Panjab.

CATALOGUING ASTRONOMICAL INSTRUMENTS

In his *The Astrolabes of the World* of 1932, Robert T. Gunther described 317 standard astrolabes, 8 mariner's astrolabes and 11 astrolabe clocks. He also included six ancient and medieval texts on the construction and use of the astrolabe, which is indeed laudable.[41] Derek J. de Solla Price of Yale University and his associates, Sharon L. Gibbs and Janice A. Henderson, prepared in 1973 *A Computerized Checklist of Astrolabes* (= CCA). This list provides the date, reference number, diameter, equinox, precession, type and maker for over 1700 extant astrolabes produced in several cultural areas. Alain Brieux and Francis Maddison embarked on the compilation *Répertoire des Facteurs d'Astrolabes, et leurs oeuvres. Islam, plus Byzance, Arménie, Géorgie et Inde Hindoue* (= Répertoire) as an expanded version of L. A. Mayer's *Islamic Astrolabists and Their Works* (Geneva 1956). This compilation is arranged by the names of instrument makers and lists under each name the various instruments made by this maker in a chronological sequence. The value of the compilation lies in the fact that it provides, besides the date, size, components of the instrument and the bibliography on

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41 These texts are: John Philoponus of Alexandria, *ca.* AD 625, English translation of the Greek text (pp. 61-81); Severus Sebokt, *ca.* AD 650, English rendering of the Syriac text (pp. 82-103); Henry Bates, Malines, Belgium, *Magistralis Composito Astrolabii* of 1274 (pp. 368-376); Hermannus Contractus, b. 1013, Reichenau, Germany, *De Mensura Astrolabii* (pp. 404-408); idem, *De Utilitatibus Astrolabii* (pp. 409-422); Robert Tanner, *The Travailer's Joy*, facsimile of the London print of 1587 (pp. 502-508).

it, also the full text of maker's signature in original language together with a translation in French. Unfortunately, this very useful compilation was never published.[42] David King began to extend the CCA list by assigning numbers beyond 4000 in some of his publications under the rubric 'International Instrument Checklist' (= IIC). But this new list has not been published in a consolidated form so far.

The Mariner's astrolabe is a drastically simplified version of the standard astrolabe for taking altitudes at the high seas. As mentioned above, Gunther described 8 extant specimens (nos. 318-325) in his work. A complete inventory of all the extant specimens was published in 1988 by Alan Stimson in his *The Mariner's Astrolabe. A Survey of known, surviving Sea Astrolabes.* Mariner's astrolabes were not made in India, but an undated specimen survives in the Raza Library of Rampur.[43]

Emilie Savage-Smith prepared a descriptive catalogue of 132 Islamic celestial globes, which include several pieces made in India.[44] In a subsequent publication, she mentions that the total number of extant Islamic celestial globes stands at 175.[45]

In his publication mentioned above, Gunther describes 25 Indo-Persian astrolabes under the heading 'Indian astrolabes' and 9 Sanskrit Astrolabes as 'Hindu astrolabes'. Otherwise Sanskrit astrolabes have not been discussed systematically so far, but for the few specimens at the Time Museum described by Anthony Turner[46] and at the Adler Planetarium by David Pingree.[47] Other Sanskrit instruments were not discussed at all in any of the publications. A large group of over 200 Sanskrit astrolabes and other kinds of instruments are described here for the first time. As Derek Price aptly remarked, '[e]ach instrument is a valuable document in itself, yielding historical and scientific data often unobtainable elsewhere. … however … the full significance of any one instrument

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42 Francis Maddison allowed me in 1993 to copy the pages dealing with Indian instrument makers. In early 2013, somebody told me in Paris that the Répertoire was being printed, but I did not hear anything concrete thereafter.

43 See Sarma 2003, pp. 58-59.

44 Savage-Smith 1985.

45 Savage-Smith 1990.

46 Turner 1985.

47 Pingree 2009.

cannot be properly realised except by comparison with the corpus of all such instruments extant.'[48]

PRESENT CATALOGUE

The present descriptive catalogue aims to study each instrument in the context of all the related extant specimens. Therefore, each instrument type is organized in a separate section identified by the letters of the alphabet. These sections begin with introductory essays on the history of the instrument type and its varieties, followed by the catalogue of the extant specimens. There are also introductory essays on instrument makers. Extracts from some Sanskrit texts describing the construction and use of certain instruments will be given in appendices, together with translations. In the descriptions of individual instruments, all engraved data are reproduced and interpreted as far as possible.[49]

The Lahore instrument makers generally engrave their names and the year of production. Such instruments are arranged chronologically. But sometimes they omit the dates. Such pieces are arranged by the size. Several astrolabes and celestial globes carry neither names nor the dates, some of which can be attributed to a particular maker on stylistic grounds. These too are arranged by size.

Sanskrit instruments do not always carry the names of the makers and the dates of manufacture. Where these are available, the instruments are arranged in chronological order. Otherwise, sometimes instruments with similar features are grouped together, some other times according to the place of production and so on.

The listings in the CCA and in the Répertoire are not based on personal examination, but often on the basis of the data provided by the authorities of the collections. The CCA assigns sometimes two separate numbers to the same instrument, other times it wrongly attributes instruments to a specific collection. Such discrepancies are corrected to a certain extent in the Répertoire. Therefore, under each astrolabe, I

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48 Price 1955, p. 243.

49 The working conditions and the time at my disposal varied from place to place. In several museums, I had to study and photograph the instruments in the display rooms in the midst of visitors who paused to stare at me, or in the open sun. Consequently, the extent of my descriptions and the quality of my photos also vary.

give the reference number from both these compilations. Likewise, in the case of Indo-Persian celestial globes, I refer to the serial numbers in Emilie Savage-Smith's work with the prefix ESS. In this catalogue, each instrument is given an identification code, beginning with a letter of the alphabet and followed by a three-digit serial number. Instruments which I have personally examined are marked with the symbol ◎ Thus the first entry in the catalogue is marked A001◎

A. INDO-PERSIAN ASTROLABES BY THE LAHORE FAMILY

عشق اسطرلاب اسرار خدا است

^{c}*ishq usturlāb isrār-i khudā ast*

Love is the astrolabe of the mysteries of God.

— Jalāluddīn Rūmī (13th century)

यस्मिन् करामलकवद् विदिते विदितं भवेद् विश्वम्॥

yasmin karāmalakavad vidite viditaṃ bhaved viśvam

When you know the astrolabe well,
you will know the universe
like a fruit on the palm of your hand.

— Rāmacandra Vājapeyin (1428)

A Mirror for Mathematiques, a Golden Gem for Geometricians,
a Sure Safety for Saylors,
and an auncient Antiquary for Astronomers and Astrologians.

— Robert Tanner (1587)

INTRODUCTION

1. Planispheric Astrolabe

The astrolabe is a highly sophisticated astronomical instrument of the Middle Ages, which held its sway from Geoffery Chaucer's England in the west to Firūz Shāh Tughluq's Delhi in the east.[50] It was widely used for observation and computation. As an observational instrument, it was employed in measuring the altitudes of the heavenly bodies and also for ascertaining the heights and distances in land survey. As a computational device, it can be made to simulate the vault of the heavens at any given locality and time. Then one can read off from the dial the time and also note the times of Islamic prayers. One can also directly read off the ascendant for that moment and the other three points where the ecliptic intersects the horizon and the meridian, without resorting to complicated calculations. The knowledge of the these four points (called 'pivots', *atwad* in Arabic) on the ecliptic is essential for casting horoscopes, or for determining the auspiciousness or otherwise of a given moment. More important, the astrolabe works as an analog computer and can be used to solve a number of trigonometrical problems. Jābir al-Ṣufī is said to have listed one thousand problems that can be solved with the astrolabe.[51]

No wonder, the Jaina monk Mahendra Sūri bestows on the astrolabe the Sanskrit name *yantra-rāja* (the king of instruments). Rāmacandra Vājapeyin declares that if one knows the astrolabe well, one will know the universe like a small fruit on the palm of one's own hand (*yasmin karāmalakavad vidite viditaṃ bhaved viśvam*). For Jalāluddīn Rūmī, the famous mystic poet, astrolabe is the sublime metaphor for measuring the immeasurable and for comprehending the incomprehensible. Thus he says: *ishq usturlāb isrār-i khudā ast,* 'love is the astrolabe of the mysteries of God.' Robert Tanner invested his book on the construction and use of the astrolabe with a double title, heaping

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50 The literature on the astrolabe is voluminous, running into some 2000 titles. For the best technical introduction, see Hartner 1968a; Hartner 1968b; North 1974; Pingree 1985; Turner 1985; Proctor 2005; Morrison 2007; Graaf 2011; an important Indian contribution is Khareghat 1950.

51 Michel 1976, p. 83, quips: 'We should be thanked for not taking up the 25 questions expounded by Severus Sebohkt about the year 650, the 43 of al-Khwārizmī about 840, the 21 of Hermann le Boiteux in 1054, the 64 of Blundeville in 1613, to say nothing of the 103 problems of Clauvious and 1000 of Jabir al-Sufi.'

rhyming epithets on this wonder-instrument. He named the book *The Travailers Joy and Felicitie,* with a subtitle, *A Mirror for Mathematiques, A Golden Gem for Geometricians, A Sure Safety for Saylors, and an auncient Antiquary for Astronomers and Astrologians.*'[52]

The astrolabe, or more correctly the planispheric astrolabe, is the representation of the three-dimensional celestial sphere on a two-dimensional plane by stereographic projection. Stereographic projection is a projection of the sphere from one of its points onto the plane which is parallel to the plane tangent to that point. This projection has two essential properties. First, the circles on the sphere are projected on the plane as circles; or, if the circles on the sphere pass through the centre of projection, they are projected as straight lines. Second, the angles between intersecting circles on the sphere remain unchanged when projected on the plane.[53]

Besides the planispheric astrolabe, there are two other varieties, viz. the spherical astrolabe[54] and the linear astrolabe,[55] where the projection of the heavens is made respectively onto a sphere and onto a straight line. But these are mere theoretical curiosities and do not have much practical relevance. Therefore, generally whenever the word 'astrolabe' is used, it means the planispheric astrolabe.

Again, the planispheric astrolabe itself can be of different types. The most common type is the northern astrolabe (Arabic: *asṭurlāb shamālī*). Here the stereographic projections on the rete and on the plates are so made that the celestial North Pole becomes the centre of the astrolabe and the outermost periphery is formed by the Tropic of Capricorn. Therefore, on the rete of such an astrolabe, the positions of only those stars can be shown that lie to the north of the Tropic of Capricorn.

In the southern astrolabe (*asṭurlāb janūbī*), on the other hand, the centre is formed by the celestial South Pole and the outer periphery by the Tropic of Cancer. On its rete

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52 Printed at London in 1587; reproduced in facsimile in Gunther 1932, pp. 524-534.

53 Morrison 2007, pp. 45-57.

54 On spherical astrolabe, see Hartner 1968b, pp. 317-318; Maddison 1962; Canobbio 1976.

55 Morrison 2007, pp. 287-293.

can be shown those stars lying to the south of the Tropic of Capricorn and visible to an observer in the northern temperate zone of the earth.[56]

On the relative advantages of the two varieties, Henri Michel states as follows:[57]

> The sky north of the Tropic of Capricorn contains almost everything visible in northern temperate latitudes. Clearly, the northern astrolabe is much better suited for representing the stellar vault for the northern hemisphere, at least for us who live here.
>
> In both the northern and southern astrolabes the instrument provides the north face of the plane of projection. Therefore, we see constellations in the same order as on the southern astrolabe with the apparent motion of the heavens always moving clockwise and longitude and right ascension [increasing] in the opposite direction. The sense of declination is reversed in the southern astrolabe with positive declinations outside the equator.
>
> The southern astrolabe offers advantages if we consider only the apparent position of the Sun. The daily motion of the Sun in summer, when it is between the equator and the Tropic of Cancer, is projected along a longer arc than in winter and the Sun appears higher above the horizon. The apparent motion, therefore, approximates what we are accustomed to seeing. When construction of large clocks began in the fourteenth century, the clockmakers tried to reproduce the Sun's apparent motion. To this end, they used stereographic projection and gave preference to the southern astrolabe projection for these reasons. The oldest astronomical clocks were configured in this way. The primary use of southern astrolabe face has been on monumental clocks and few examples exist on hand held instruments.

The features of the northern and southern astrolabes are combined in the composite astrolabe, called the north-south astrolabe (*asṭurlāb shamālī wa janūbī*), so that it can display the stars belonging both to the northern and the southern celestial hemispheres. These last two varieties are again theoretical curiosities. Very few of such

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[56] On southern astrolabes, see Morrison 2007, pp. 155-158.

[57] Michel 1976, pp. 12-14.

southern or north-south astrolabes were actually manufactured. Thus the standard variety is the planispheric northern astrolabe. This is the type which was commonly used and which was produced in great numbers in all the cultures where the astrolabe was cultivated. Therefore, henceforth we use the expression ‘astrolabe’ in the sense of this standard astrolabe, viz. the planispheric northern astrolabe.

1.1. The Astrolabe in Antiquity

The astrolabe was invented in Hellenistic antiquity, but it is not known precisely when or by whom. However, the stereographic projection underlying the construction of the astrolabe is said to have been developed by Hipparchus of Alexandria in the second century BC. Claudius Ptolemy in the second century AD was familiar with the instrument but not with its present name. In the sixth century AD, John Philoponus of Alexandria wrote a treatise in Greek on this instrument; it is the earliest extant text to describe the construction and use of the astrolabe.[58] By this time, the astrolabe was fully developed, for Philoponus mentions all the principal components. In the seventh century, Bishop Severus Sabokt of Nisibis in Syria composed a treatise in the Syriac language, which also survives.[59] Otto Neugebauer is of the view that both these treatises were based on a fourth-century work by Theon of Alexandria which is no more extant.[60] Nor did any actual specimen survive from this period.

1.2. The Astrolabe in the Islamic World

From Hellenistic antiquity, the science of the astrolabe spread, through Syriac stages, to the Islamic world where it attained the highest popularity. Like much of Greek science and philosophy, the science of the astrolabe was also preserved, elaborated upon and disseminated further by the Islamic world.[61] By the ninth century, the astrolabe attained such a pre-eminent position in Islamic civilization that several treatises were

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58 Philoponus, ‘Treatise on the Astrolabe. in: Gunther 1932, pp. 61-81; see also Drecker 1928.

59 Sabokt, ‘Treatise on the Astrolabe’ in: Gunther 1932, pp. 82-103.

60 Neugebauer 1949.

61 On the reception of Greek science in the Islamic world, see, among others, Gingerich 1986; Sabra 1987; Gutas 1998.

composed in this century in Arabic on this instrument.[62] It has been thought for long that Māshā'allāh, a famous astrologer and astronomer at the court of the Caliphs at Baghdad, composed one of the earliest treatises on the astrolabe which survives in Latin translations. But Kunitzsch has shown that 'nothing of the popularized treatise on the composition and the use of the astrolabe generally ascribed to Messahalla can be traced back to this author.'[63] However, there are several other works on the astrolabe that were composed in Arabic in the ninth century. Al-Khwārizmī (ca. 825) wrote two small treatises, one on the construction and the other on the use of the astrolabe. The larger one on the use of the astrolabe is the earliest extant Arabic text on this subject.[64] A literal translation of this treatise on the use of the astrolabe was incorporated in the *Sententie Astrolabii,* a Latin text which was compiled in Spain in the late tenth century. This is the oldest extant medieval western text on the astrolabe.[65] Of the other texts composed in Arabic in the ninth century, there survive a treatise, entitled *al-Kāmil,* by Aḥmad ibn Muḥammad ibn Katir al-Farghānī (ca. 857) on the construction of the astrolabe and another on its use by ᶜAlī ibn ᶜĪsa al-Asṭurlābī al-Ḥarrānī (ca. 880).[66] Al-Farghānī was at the court of the Abbasid Calif al-Ma'mūn in Baghdād; later he moved to Egypt where he composed the *al-Kāmil* in 7 chapters.[67] In the earlier chapters of this work, he discusses the mathematical principles of stereographic projection and provides elaborate tables to help the construction of astrolabes. In chapter 5, he teaches how to construct the northern astrolabe. Interestingly, in the following chapter, he also teaches the construction of the southern astrolabe. Al-Farghānī also compiled a set of tables to facilitate the production of latitude plates; these tables, containing over 13,000 entries,

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62 For an overview of the literature on the astrolabe, see Lorch 2005b.

63 Kunitzsch 1959.

64 It is edited with a translation and commentary by François Charette and Petra Schmidl; see Charette & Schmidl 2004.

65 Kunitzsch 1989d.

66 For an excellent overview of the extant treatises on the astrolabe and of the actual specimens in the Islamic world and in Europe, see Stautz 1999, pp. 1-98.

67 Arabic text, edited with translation by Lorch 2005a.

provide the radii and centre distances of altitude circles and azimuth circles for each degree of altitude and each degree of azimuth, for each degree of terrestrial latitude.[68]

In the production of the astrolabe also, the Islamic world achieved high excellence. Indeed, the production of precision instruments can be said to originate in the manufacture of astrolabes in the Islamic world. Thus the Islamic world did not just receive and preserve the science of the astrolabe, which in itself would have been remarkable. It made significant contributions to the theory and practice of the astrolabe. Moreover, the Islamic world also disseminated the science of the astrolabe, westwards up to England and eastwards up to India. As North observes, '[b]efore the end of the 13th century the planispheric astrolabe was known and used from India in the east to Islamic Spain in the west, and from the Tropics to northern Britain and Scandinavia.'[69] Therefore, the astrolabe can be regarded as the finest gift of the Islamic world to scientific instrumentation. Oliver Hoare has correctly observed that '[t]he ability of Islamic civilization to perfect what it inherited, and to endow what it made with beauty, is nowhere better expressed than in the astrolabe.'[70]

In the Islamic world, the astrolabe (*aṣṭurlāb* or *aṣṭurlāb*) and the celestial globe (*al-kura*) were the most popular astronomical instruments, and the usual mode of describing a good astronomer was to say that he was adept in the use of the astrolabe and the celestial globe. Astrolabe making became an important profession in the ninth century and the sobriquet *al-Asṭurlābī* indicated a high professional status because the construction involved not just skill in metal-craft but also sound knowledge of astronomy and trigonometry.

Of the early astrolabes made in the Islamic world, there survive some Abbasid astrolabes, but these are not dated.[71] The earliest dated astrolabe which is extant is by Muḥammad ibn ᶜAbd-Allāh Nasṭūlus. Four astrolabes by him are known. One of these is dated in 315 AH (AD 926-27). It is preserved in the Islamic Archaeological Museum,

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68 King 1987b, p. 5.

69 North 1974.

70 Oliver Hoare, in: *The Unity of Islamic Art,* Riyadh 1985, p. 81, cited by King 1995, p. 76.

71 One of these is described by King 2005, pp. 402-437: 'The oldest known astrolabe from the late 8th-century Baghdad'

Kuwait. It has a diameter of 173 mm. The rete and alidade are lost, but the mater and one plate are extant. The two sides of the plate are calibrated for latitudes 33° (Baghdad, Damascus) and 36° (Mosul, Rayy, middle of the fourth climate). The rim of the front is marked for 1° and 5°. On the back, there are four altitude scales on the rim and one circular shadow scale. Otherwise, the back is blank.[72]

The second astrolabe by Nasṭūlus is in Cairo; here only the mater survives with a gazetteer on the front and trigonometric quadrants on the back. The third astrolabe is said to be in London; the rete and alidade are missing; there remain two plates for latitudes 31°, 32°, 33° and 34°. The fourth one, now at the Museum of Islamic Art in Doha, Qatar, is engraved with concentric solar and calendar scales on the rim in the front. It is not exactly an astrolabe in the conventional sense; it is made more for trigonometric and calendrical calculations.[73]

The few surviving astrolabes and their fragments from the ninth century are somewhat plain devices without any ornamentation. Real ornamentation and sophisticated design began to develop in the tenth century. In this connection, the astrolabe made in 374 AH (AD 984-85) by Ḥāmid ibn Khiḍr **al-Khujandī** with elegantly designed rete and throne represents an important landmark in astrolabe production.[74] Khujandī was an eminent astronomer, mathematician and instrument maker. He constructed a large sextant, with a radius of over 20 metres at Rayy (near modern Tehran) and named it *Suds Fakhrī* (Fakhrī sextant) after his patron Fakr al-Dawla, the Buyid ruler of Iran (r. 977-997).[75] With this sextant, he determined the obliquity of the ecliptic as 23;32,21°.[76]

In contrast, the astrolabe he made is rather small with a diameter of 151 mm, but he equipped it for the first time with many features which were taken up by the

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72 King 1995, pp. 76-83.

73 Described in King 2008, where references are made to the second and third astrolabes.

74 Described and illustrated in King 1995 and more elaborately in King 2005, pp. 503-517; 940-941; see also Graaf 2011.

75 This sextant does not exist anymore; a similar sextant, of twice this size, was erected in 1420 in the Samarqand observatory, which is now in ruins. The only extant functional specimen of the Fakhrī sextant can be seen in Jai Singh's observatory at Jaipur under the name *Vṛtta-ṣaṣṭāṃśa-yantra*; cf. Sarma 1986-87b.

76 King 1995, p. 83.

subsequent astrolabe makers, in particular, by the Lahore family of astrolabe makers. King considers that this astrolabe 'represents the culmination of known Muslim achievements in astrolabe construction in the early period.'[77] The *kursī* is worked *à jour* with two lion's heads facing each other. In the rete also attempts are made to make it ornate with six star pointers shaped like bird's heads with long beaks. In the vertical axis are incorporated a quatrefoil, an ornament shaped like an inverted heart with little wings on either side, and a crescent. There are 33 star pointers, which is a fairly large number.

While the five plates serve latitudes 21°, 27°, 30°, 33°, 36° and 39°, projections for latitude 42° are engraved on the inner side of the mater. More important, there are four plate faces which occur here for the first time. The first is a plate for multiple horizons with declination scales, which was originally invented by Ḥabash al-Ḥāsib at Baghdad in the ninth century. The second is a plate for the complement of the obliquity. Taking the obliquity as 23;33°, Khujandī designed the plate for latitude 66;27° (i.e., 90° – 23;33°) with a maximum duration of the daylight 24 hours. On the back of this plate is a double projection for 0° and 90°; here the maximum lengths of the daylight are stated to be 12 hours and 6 months respectively. These serve mainly pedagogic purposes and satisfy intellectual curiosity.

Another plate which also occurs for the first time is marked with astrological houses, each divided into decans, for the latitude of 33° (Baghdad). King states that the plate 'serves to facilitate the otherwise laborious computations relating to the astrological doctrine of casting the rays and is so designated in the cartouche (*maṭraḥ al-shuᶜāᶜ wa-huwa 'l-tasyīrāt*).'[78]

On the back, altitude scales are drawn on the upper half of the rim and a cotangent scale for a base of 12 on the lower half. In the upper left is a trigonometric quadrant with 90 horizontal lines. In the upper right is a solar quadrant with declination arcs upon which a horary quadrant for latitude 33° is superimposed. In the lower half there are several astrological tables in 8 semi-circular scales, containing the names of the 28 lunar

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77 King 1995, p. 83.

78 King 2005, p. 514.

mansions; the names of the 12 zodiac signs; the limits of signs and their regents; the regents of the decans; triplicities and the diurnal and nocturnal regents. As will be seen later, many of these features are emulated in the Lahore astrolabes.

In the subsequent centuries, astrolabe production spread to different centres which in course of time developed regional variations in technical details and ornamentation, especially in the Eastern (*Mashriq*) and the Western (*Maghrib*) parts of the Islamic world.[79]

1.3. The Astrolabe in Europe

From the Islamic world, the astrolabe was transmitted to Europe through Catalonia in Spain where a large number of Arabic texts were translated into Latin. Kunitzsch remarks that '[t]he oldest Latin texts on the astrolabe from the late tenth century show that those Christian scholars had at their disposal both Arabic texts and instruments and, as it seems, also the help of native speakers of Arabic.'[80] One of the earliest Latin treatises on the use of the astrolabe is attributed to Gerbert of Aurillac, who later became Pope Sylvester II (930-1003).[81] It has already been mentioned that one of the earliest compilations made in Latin was the *Sententie Astrolabii* and that its third section dealing with the uses of the astrolabe was a literal translation of a treatise by Al-Khwārizmī.

In the subsequent centuries, the science of the astrolabe spread to much of Europe where a large number of treatises were composed. Notable among them is *A Treatise on the Astrolabe,* also known as *The Conclusions of the Astrolabie* or *Bread and Milk for Children,* composed by Geoffrey Chaucer about 1393. Instead of the customary practice of writing scientific texts in Latin, Chaucer was the first to write such a text in English, for the sake of his son Lewis, whom he addresses thus at the beginning of the work:

> Little Lewis my son, I perceive that thou wouldst learn the Conclusions of the Astrolabe; wherefore I have given thee an instrument constructed for the latitude of Oxford, and propose to teach thee *some* of these conclusions. […] This treatise, divided into five parts, I write for thee in English, just as

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79 For a fine analysis of these regional variations, see Gibbs & Saliba 1984, pp. 22-60.

80 Kunitzsch 1998, p. 114.

81 Bianchini & Senatore 2016.

> Greeks, Arabians, Jews, and Romans were accustomed to write such things in their own tongue. I pray all to excuse my shortcomings; and thou, Lewis, shouldst thank me if I teach thee as much in English as most common treatises can do in Latin.[82]

Production of the astrolabe also spread to other European countries, gradually giving rise to regional variations as in the Islamic world. The earliest extant European astrolabe is known as the Carolingian astrolabe. It was produced in the late tenth century in Catalonia, in Spain.[83] Astrolabe production reached its highpoint in Renaissance Europe, where some of the artistically beautiful specimens were produced, notably in Prague by Erasmus Habermel, the instrument maker of Rudolph II, towards the end of the sixteenth century.[84]

The astrolabe was popular in Europe up to the seventeenth century until the invention of the telescope. But it left a permanent imprint in another respect. A large number of Arabic technical terms which reached Europe through the astrolabe still survive in all the European languages. Thus, for example, 'zenith,' 'nadir' and 'azimuth' are derived from the Arabic.[85] Several of the star names used in European languages are likewise directly taken from the Arabic astrolabes, such as 'Altair' (from *al-Nasr al-Ṭā'ir* for α Aquilla), 'Caph' (from *Kaff al-Khaḍīb* for β Cassiopeiae), or 'Algol' (from *Ra's al-Ghūl* for β Persei) and so on.

1.4. The Lahore Family of Astrolabe Makers

The astrolabe may have been introduced into India in the eleventh century by Al-Bīrūnī who wrote extensively on this instrument. In the following centuries, scholars migrating from Central Asia to the court of the Sulṭāns at Delhi brought astrolabes with them and employed them here. The manufacture of the astrolabe appears to have commenced in India in the second half of the fourteenth century under Sulṭān Fīrūz Shāh Tughluq (r. 1351-1388). The *Sīrat-i Fīrūz Shāhī*, an anonymous chronicle of his rule

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82 This is a paraphrase in modern English of Chaucer's Middle English, by Skeat, cf. Chaucer, pp. 175-176.

83 King 1996b.

84 For an overview of European astrolabes, see Gunther 1932; Stautz 1999, pp. 65-98.

85 Kunitzsch 1982; Kunitzsch 1984.

composed in 1370, has a long account on the astrolabes manufactured under instructions from Fīrūz.[86] However, none of these astrolabes survive today. Fīrūz also sponsored the composition of manuals on the astrolabe both in Persian and Sanskrit. The Persian manual does not survive any more save in extracts in the *Sīrat-i Fīruz Shāhī*. The Sanskrit manual entitled *Yantrarāja* , which was composed by a Jaina monk Mahendra Sūri in 1370, is extant and published.[87]

The earliest extant astrolabes in India pertain to the Mughal period. Among the Mughal emperors, Humāyūn (r. 1530-1556) was much interested in astronomy, astrology and astronomical instruments.[88] He is said to have 'extra-ordinary excellence in the astrolabe, globe and other instruments of the observatory.' Abū al-Faḍl, minister and chief chronicler of Humāyūn's son Akbar, speaks in glowing terms of Humāyūn's interest in astronomy. At one place he refers to Humāyūn thus: 'His Majesty, who in astrolabic investigations and studies in astronomical tables and observations was at the head of the enthroned ones of acute knowledge and who was a second Alexander....'[89] Elsewhere, employing an astrolabic metaphor, he calls Humāyūn 'the alidade of the astrolabe of theory and practice.'[90] Under Humāyūn's patronage, manufacture of astrolabes and celestial globes commenced at Lahore.[91]

The master craftsman (*ustād*) Allāhdād of Lahore and his descendants of four generations dominated the production of astronomical instruments in Mughal India in the second half of the sixteenth century and in the seventeenth century. [92] Neither the names of any members of this Lahore family, nor the instruments produced by them are mentioned in the contemporary documents. The history of this family and of their work

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86 Sarma 2000.

87 Mahendra Sūri

88 On his interest in astrology, see Orthmann 2008.

89 Abū al-Faḍl 1, p. 123.

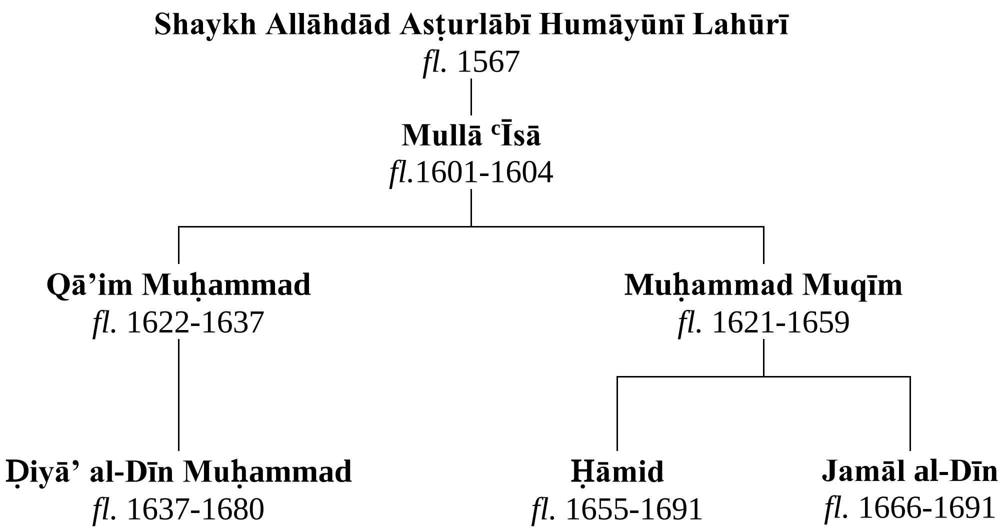
90 Abū al-Faḍl 1, pp. pp. 283-284.

91 Abū al-Faḍl 1, p. 52, states that Mawlānā Maqṣūd of Herat, who was at the court of Humāyūn, made astrolabes and globes which were much admired by people. But none of his instruments survived.

92 Sarma 1994d.

is reconstructed entirely from the signatures of their dated instruments. The credit for discovering the family goes to Sayyid Sulayman Nadvi.[93]

There exist two astrolabes bearing the name of the patriarch Allāhdād (*fl.* 1567). One of these also carries the year of manufacture as 975 Hijrī (AD 1567/58). This is in fact the earliest extant astrolabe produced in India. Allāhdād's son ᶜĪsā (*fl.* 1601-1604) is known through three astrolabes. ᶜĪsā had two sons, Qā'im Muḥammad (*fl.*1622-1637) and Muḥammad Muqīm (*fl.*1621-1659). Four astrolabes and four celestial globes signed by Qā'im Muḥammad survive. Qā'im's younger brother Muqīm and Qā'im's son Ḍiyā' al-Dīn Muḥammad (*fl.*1637-1680) were very prolific instrument makers. While at least thirty-three astrolabes and one celestial globe crafted by Muḥammad Muqīm are extant in different collections throughout the world, his nephew Ḍiyā' al-Dīn's signature adorns thirty-four astrolabes and eighteen celestial globes. In comparison, Muqīm's two sons, Ḥāmid (*fl.* 1655-1691) and Jamal al-Dīn (*fl.* 1666-1691) have a more modest output. Eleven astrolabes and three celestial globes by Ḥāmid are extant, while Jamāl al-Dīn is known through just four surviving astrolabes. Besides these, there are several unsigned specimens which can be attributed to this family for stylistic reasons.



It is also necessary to stress that the instruments made by them are not mass products cast in the same mould. In fact, each instrument is a unique piece as regards the size, decorations, ornaments and configuration of the various technical elements. In

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93 Sarma 1994d.

the medieval period there has been no other family anywhere, comparable to this one in the long continuous family tradition of instrument making, in the large number of instruments produced, in the artistic and technical excellence of production, or in the innovation in design.

The standard northern astrolabes produced by the members of this family distinguish themselves by the high degree of precision in the engraved stereographic projections and by the pleasing floral traceries used to connect the star pointers on the rete, with a matching design on the *kursī.* The members of this family also show a marked predilection for unusual projections invented in Andalusia in the tenth and eleventh centuries, which they incorporated in some of their standard astrolabes. These will be discussed later.

Obviously the Lahore family had a very discerning clientele among the Mughal nobility to appreciate these innovations. For these dignitaries the astrolabists fashioned highly ornate astrolabes of large dimensions, some inlaid with silver, others with gilded plates, yet others with unusual projections.

In their signatures on the astrolabes and celestial globes made by them, the members of the family refer to themselves proudly as the descendants of Allāhdād Lāhūrī Asṭurlābī Humāyūnī, 'Allāhdād of Lahore, astrolabe maker to the Emperor Humāyūn'. The only dated astrolabe by Allāhdād, the patriarch of the family, was produced in 1567, i.e., eleven years after Humāyūn's death, but that does not preclude the possibility of his producing astrolabes in Humāyūn's lifetime for the use of the emperor. The two extant astrolabes by Allāhdād (A001 and A002) are fairly large instruments in which the prime vertical, the oblique horizon, and the curves for equal hours as counted from the western and eastern horizons are inlaid with silver on all the latitude plates. Surely these astrolabes were not meant for common astrologers/astronomers, but for men of rank.

Qā'im Muḥammad is said to have begun the casting of celestial globes in one single hollow piece by *cire perdue* method. He made one such celestial globe in the eighteenth regnal year of Jahāngīr (1622) for Nawāb Iᶜtiqād Khān, brother of Nūr Jahān

Begum, the consort of Jahāngīr.[94] He also fashioned a fabulous astrolabe in 1627 for Nawāb Khwajā Abū al-Ḥasan, a high dignitary at the court of Jahāngīr. Just the rete of this astrolabe survives at Patna: in this unique rete the star pointers are joined not by the usual floral tracery but by a calligraphic design which mentions the year of production in Jahāngīr's regnal years and in Hijrī years and the name of the dedicatee (A011).

Ḍiyā' al-Dīn also fabricated unusual instruments for high nobility. In 1679, he made a celestial globe for Emperor Aurangzeb; here the outlines of the constellations figures are cut out in such way that, when the globe is lit from inside, they would appear as silhouettes. Star positions are marked with tiny holes so that they would sparkle when the globe is lit from inside.[95] In the following year he made a huge *Zarqālī* universal astrolabe for Nawāb Iftikhār Khān, the Fauzdār of Jaunpur (A092).

Such royal patronage clearly promoted the production of very large astrolabes with lavish ornamentation and technical virtuosity. The astrolabes of this Lahore family are masterpieces of Mughal metal-craft and scientific instrumentation. In the astrolabes by Muqīm and Ḍiyā' al-Dīn which are now preserved in the Salar Jung Museum at Hyderabad and in Jai Sigh's Observatory at Jaipur, the latitude plates look as if they were gilded or rubbed with gold dust. At my request, Mr. C. P. Unniyal, the chemist of the Salar Jung Museum, examined the Mughal astrolabes at his museum. He writes: 'The inner parts, which remained unexposed, clearly show remnants of surface gilding effect. This has been produced by smearing gold powder over the bronze or brass surface to enrich the surface looking like golden rather than true gilding.'[96]

It is quite likely that this activity of producing highly ornate astrolabes in Mughal India influenced the revival of astrolabe making in Safavid Persia, in the seventeenth and eighteenth centuries.[97]

Around 2004, Brian Newbury made a metallographic analysis of eight Lahore astrolabes from the Adler Planetarium, Chicago, by applying a new non-destructive

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94 The globe is in the Stonyhurst College Library, Lancashire, UK; see Savage-Smith 1985, catalogue no. 11, p. 224, Figure 12 on p. 37.

95 Savage-Smith 1985, catalogue no. 30, pp. 232-33, Figure 17 on p. 42.

96 Unniyal 1994-95.

97 Maddison 1963, p. 26.

technique of high-energy synchrotron x-ray analysis.[98] Since this technique can be applied only to two-dimensional flat objects, only the maters, retes and plates of the astrolabes were examined.

The analysis revealed that some of these parts have a higher content of zinc than the brass produced by traditional methods.[99] The brass used for these parts (referred to as α + β alloy) must have been produced by co-melting copper and metallic zinc. The high percentage of zinc facilitates the fabrication of thin metal sheets from thicker ones by repeated hammering, but without frequent heating. Metallic zinc was produced in Zawar in Rajasthan from the thirteenth century onwards; these astrolabes provide the first datable evidence for brass production by direct alloying of copper and zinc, a process which was unknown in Europe until the nineteenth century.

2. Components of the Astrolabe

Now we describe the various components of the astrolabe and, while doing so, draw attention to the special characteristics of the Lahore astrolabes. The *Sīrat-i Fīrūz Shāhī,* an anonymous chronicle composed at the court of Fīrūz Shāh Tughluq in 1370 states that the astrolabe consists of twelve components: ring (*ḥalqa*), shackle (*ᶜurwa*), rivet (*mismār*), throne (*kursī*), mater (*umm*), rim *(ḥajra*), plates (*ṣafāʾiḥ*), rete (*ᶜankabūt*), alidade (*al-ᶜiḍāda*), pin (*quṭb*), sighting plates (*libna*) and horse-shaped wedge (*faras*).[100]

2.1. The Suspension Apparatus

The main component of the astrolabe is a heavy circular plate with a raised rim all around on one side. In the recess formed by the rim, the heavy plate carries a series of circular discs, just as the mother carries the child in her womb. Therefore, this heavy plate is called *umm* in Arabic and 'mater' in Latin and in English. For observation, the mater has to be suspended vertically and, to sight the desired heavenly body, it has to

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98 Cf. Newbury 2006. Two of the these are by ᶜĪsā (A005and A006) and the rest by, or attributable to, Ḍiyā' al-Dīn Muḥammad (A060, A062, A078, A087, A097and A105).

99 The results of the analysis are given in Table 2 (Newbury 2006, p. 210). They show that in these 8 astrolabes, 4 maters are made of α +β alloy and 4 are not; 5 retes are made of α +β alloy and 4 are not. In A097 and A105, some plates are made of α +β alloy, whereas in the rest of the six astrolabes, all the plates are made of this alloy.

100 Sarma 2000.

be turned around the vertical axis. For this purpose, the mater requires a suitable suspension apparatus, consisting of a suspension bracket, a shackle and a ring. The suspension bracket, usually of a triangular shape, is attached to the top of the mater. Generally, the mater and the suspension bracket are cast together as one piece. In some early Islamic astrolabes, the throne verse (*āyat al-kursī*) from the *Qur'ān* (Surah 2:255) is engraved on the suspension bracket, which reads: 'His throne extends over the heavens and the earth'. Therefore, the suspension bracket is called *kursī,* or throne. To the top of the *kursī* is attached a shackle (*ᶜurwa*) which has a shape like the upturned Roman character U, with a circular upper part and two straight legs. The ends of the legs or bases are firmly affixed to the top of the *kursī* by means of a rivet (*mismār*). A ring (*ḥalqa*) passes through the shackle. The astronomer pushes his thumb through the ring and lets the astrolabe hang freely. Sometimes, a silken cord (*ᶜilaqa*) is also attached to the ring.

This suspensory apparatus allows the instrument to be suspended so that it remains perfectly vertical and can be swung in a circle about its axis, which is perpendicular to the local horizon. This ensures that the east-west line drawn on the back of the astrolabe and also on the plates remains parallel to the local horizon. In Lahore astrolabes, the shackle has invariably a trifoliate shape; this ensures that the ring remains always in the upper loop of the shackle.

Figure A1 – Trifoliate shackle, openwork *kursī,* lobed profiles
in an undated astrolabe by Allāhdād (A002) (photo by S. R. Sarma)

The *kursī* is relatively high and its two profiles are formed by a series of ogees and lobes with a trifoliate finial.

Figure A2 – Trifoliate finial, solid *kursī* with decorative engravings on the surface in an undated astrolabe by Muqīm (A037) (photo courtesy Dr Naseem Naqvi)

The body of the *kursī* is generally cut *à jour* in an artistic floral pattern. Muqīm likes to fashion his *kursīs* with a series of bell-shaped flowers, or tulips, with two flared petals, one petal long and another short, in such a way that the edges of the petals form the profiles of the *kursī.* Sometimes, the surface on both sides is engraved with decorative lines. Occasionally, cartouches are incorporated in the middle of the *kursīs,* for writing the names of the owners. No other inscriptions are engraved on the *kursīs.*

2.2. Limb

The upraised rim on the mater is called *ḥajra* or limb. The surface of the rim is graduated for 360 degrees of the circle and numbered in a clockwise direction in *Abjad* notation, starting from the south point. The south point is situated at the top of the rim just below the throne. With regard to the points of the compass, it must be noted that the Arabs followed a convention that is quite opposite to that in modern maps. In Arabic maps, and also in astrolabes, the point at the top represents south and the point to the proper right is the east.

In Lahore astrolabes, the degree scale consists of two concentric rings. The narrow inner ring is divided in single degrees of arc. In the wider outer ring, groups of 5° or 6° are marked and numbered in *Abjad* notation. Numbering in 5s or 6s begins at the south point and proceeds clockwise. The numbering can be continuous from 5 or 6 up to 360; in some astrolabes, the numbering is done separately in each quadrant, starting from 5 or 6 and reaching clockwise up to 90.

2.3. Rete

Of the plates stacked in the hollow space inside the rim, the uppermost one is called rete or spider (*ᶜankabūt*). It is a perforated or openwork plate containing the ecliptic, the equator and the tropics of Capricorn and Cancer. Against the projection of these circles, there is a star map with pointers (*shaẓiya,* plural *shaẓāyā*) indicating the positions of some bright stars situated close to the ecliptic on the north and the south.

The rete consists primarily of two rings, a peripheral ring which contains the circle of the Tropic of Capricorn and the zodiac or ecliptic ring placed inside off centre. The ecliptic ring is represented completely, but the upper portion of the outer ring is cut off, leaving open the two ends to the east and west of the ecliptic ring. These two rings are held together by an east-west bar and south-north bar, which carry the lines of the equinoctial colure and the solstial colure respectively. For the sake of balance, so that the rete remains steady at any given position, the two bars are designed with counter changes. Other circles like the celestial equator and the Tropic of Cancer may be represented partially on segments of rings or not at all. To the north and south of the ecliptic ring, the positions of certain bright stars are marked and these points are joined to the mainframe by different forms of supports. Leaving out these rings and straight bars, the rest of the plate is cut off so that the markings on the plate lying beneath the rete can be read.

In the ecliptic ring, the outer rim constitutes the circle of the ecliptic which is the apparent path of the sun through the year. The ring is divided into the twelve signs of the zodiac, and the names of the twelve signs (*al-Ḥamal, al-Thawr, al-Jawzā', al-Saraṭān, al-Asad, al-Sunbula, al-Mīzān, al-ᶜAqrab, al-Qaws, al-Jadī, al-Dalw* and *al-Ḥūt*) are engraved on each division, starting from the vernal equinox (situated at the intersection of the equinoctial colure and the ecliptic circle in the east) and proceeding in an anticlockwise direction. Again each sign is divided into groups of 6 or 5 degrees. The outer rim is divided into single degrees. To the first point of Capricorn is attached a small pointer which aligns the ecliptic ring to the degree scale on the limb. This pointer is called *al-mūrī r'as al-Jadī* or simply *al-mūrī.* This may be called Capricorn index in English.[101]

A knob (*mudīr*) is affixed at some point on the outer ring to rotate the rete to the desired position. By rotating the rete, one can see the stars rising above the eastern horizon, culminating on the meridian or setting below the western horizon.

The manner in which the star pointers are shaped and joined to the main frame is determined by the artistic inclinations of the astrolabe maker, who exhibits his artistic skills in fashioning the throne and the rete. In the Mughal astrolabes the star pointers are joined by floral traceries. A common motif is a bell-shaped flower with two flared petals, the tip of the longer petal representing the star position. This motif occurs already in the undated astrolabe by Allāhdād (A002) and is copied by his descendants in innumerable variations. These flower- or leaf-shaped star pointers and their tendrils are arranged in multiple varieties of traceries, but care is always taken to see that the tracery is almost symmetric on both sides of the meridian, so that the rete is evenly balanced in weight. The names of the stars are engraved on the leaves or flowers containing the star pointers. Since the Lahore astrolabists enjoy complex constructions, they fill the retes with dozens of stars, although few would have sufficed for actual observation.

The **star names** are in Arabic. While engraving these names, the Lahore astrolabe makers do not quite adhere to the proper usage. Because of the limited space available for engraving, or even otherwise, the Arabic definite article *al-* is often omitted. The term *ra's* (head) is usually transcribed as *rās*; thus the prominent star Algol (β Persei) which occurs in almost every astrolabe is labelled as *rās al-ghūl* instead of *ra's al-ghūl.* Epithets in masculine gender are added to feminine nouns; thus the stars α and β in the constellation Libra are labelled respectively as *Kiffa Janūbī* and *Kiffa Shamālī* and not as *Kiffa Janūbiya* and *Kiffa Shamaᶜāliya* with feminine epithets; likewise ε Cancri is named *Nathra Saḥābī.* Finally, Procyon carries the label *Shiᶜrā al-Shāmī* and not *Shiᶜrā al-Shaᶜāmiya.* However, in order to retain the peculiarity of the usage, the engravings are transliterated exactly, without making any attempt at assimilation or vocalization.

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101 Turner 2015.

2.4. Plates

Beneath the rete are housed a series of plates, also called tympans, discs or tablets (singular *ṣafīḥa;* plural *ṣafāᶜiḥ*), which are specific to certain terrestrial latitudes.[102] While the rete represents the stellar heavens, the plates represent the earth at different latitudes. Together, they simulate the stars above a particular terrestrial latitude at a given time.

While the rete in the front and the alidade at the back must be free to rotate around the centre, the plates must stay firmly in position inside the rim of the mater. For this purpose, each plate is provided with a projecting tab, which fits into a slot cut into the thickness of the rim. This system is reversed in the astrolabes produced in India. In Indian astrolabes, the rim has the projecting tab at the north point which fits into the slot cut in the plates at the corresponding place.

2.4.1. Latitude Plates

The projection on the plates varies according to the terrestrial latitude of the place where the astrolabe is used. Therefore, several plates are made with projections suitable to different latitudes, so that the astrolabes can be used at different places, usually from Mecca to Samarqand. On these plates are drawn, as on the rete, concentric circles to represent the Tropic of Capricorn (*madār al-jadī*), the tropical equator (*madār al-ḥamal wa al-mīzān*) and the Tropic of Cancer (*madār al-saraṭān*), and the vertical and horizontal diameters. The horizontal diameter represents the horizon at the equator. These circles and the lines are common to all the latitude plates.

Then on each plate are traced, relative to its latitude, stereographic projections of the local or oblique horizon (*ufq,* or *ufq al-mashriq wa al-maghrib*), equal altitude circles, azimuth arcs, lines for seasonal hours, lines for equal hours, and so on. The point where the horizontal diameter, the oblique horizon and the equator intersect in the east is designated as the east point (*nuqṭat al-mashriq*) and the corresponding point on the west the west point (*nuqṭat al-maghrib*). On astrolabes, these two points are labelled respectively as *al-mashriq* and *al-maghrib.*

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[102] On the plates, see Hartner 1968, 293-299; Morrison 2007, pp. 58-63; 67-94.

The **equal altitude circles** or almucantars (*al-dā'ira al-muqanṭara*) are circles parallel to the local horizon drawn from the horizon up to the zenith (from Arabic *samt al-ra's,* 'the direction of the head'). The intervals at which these circles are drawn depends on the size of the astrolabe. On very large astrolabes, they are drawn for every degree; on smaller ones at intervals of 2°, 3°, 5° or 6°. Astrolabes are classified according to the number of altitude circles. Astrolabes with 90 circles drawn for every degree are called complete, perfect or solipartite (*tāmm*), those with 45 circles at intervals of 2° are called bipartite (*niṣfī*), with 30 circles at intervals 3° tripartite (*thulthī*), with 18 circles at intervals of 5° quinquepartite (*khumsī*), and with 15 circles at intervals of 6° sexpartite (*sudsī*).[103] The altitude circles are numbered on both sides of the meridian, so that it becomes easy to read them when the sun or the star is on the eastern or in the western horizon.

In a few astrolabe plates twilight or crepuscular arcs are drawn at 18° below the oblique horizon to help in determining Islamic prayer times.

Equal **azimuth circles** (from *al-sumūt,* plural of *samt,* 'direction') are the great circles passing through the zenith and the nadir; when projected on the astrolabe plate, they radiate from the zenith at appropriate intervals depending on the size of the astrolabe. On some plates, these are drawn above the local horizon, on some below the local horizon, and on others both above and below the horizon. These are also drawn at appropriate intervals depending on the size of the astrolabe. These are numbered from the east and west points up to the north and south points. From the observer's point of view, the altitude circles and the azimuth arcs are mutually perpendicular and the grid formed by them can be used to define the position of a star.

Lines for the seasonal and equal hours are drawn below the local horizon, in the space between the two tropics. **Seasonal or unequal hours** (*al-sā*ᶜ*āt al-zamāniya*) are the twelfth parts of day or of the night and vary from season to season. In the Middle Ages time was reckoned, in the daily life and in religious rituals, in these seasonal hours both in the Islamic world and in Christian Europe. These are counted from the sunset at night and from the sunrise in the day; in the Islamic world the day (i.e. the combined

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103 Hartner 1968, p. 296.

unit of day and night) is counted from the sunset. The lines for the seasonal hours are drawn by dividing the arcs of the two tropics and the arc of the equator lying below the oblique horizon into 12 equal parts and by joining the corresponding points in the three arcs. These are numbered from the western horizon to the eastern horizon from 1 to 12 and serve for counting the hours both at night and in the day.

Equal hours (*al-sā^{c}āt al-i^{c}tidāl*) are the twenty-fourth parts of the day and night and were used for astronomical purposes. These are constructed by dividing the complete circles of the two tropics and of the equator into 24 equal parts, starting from the point of intersection with the western horizon, and by joining the corresponding points in the three circles. Occasionally the equal hour lines are drawn from the western as well as from the eastern horizon. The lines of the unequal hours and the lines of the equal hours intersect at the equator. Generally the lines of the equal hours are drawn as dotted lines to distinguish them from the lines of unequal hours.

In the space between the oblique horizon and the lower part of the Tropic of Cancer are engraved, on either side of the vertical diameter, the latitude (*al-^{c}arḍ*) for which the plate is calibrated and the maximum duration of the daylight hours (*al-sā'āt*) at that latitude. These values are also recorded in *Abjad* notation. However, on several Lahore astrolabes, care is not taken in recording the correct values of the daylight hours.[104]

In about a dozen astrolabes by Qā'im Muḥammad, Muqīm and Ḍiyā' al-Dīn, **lines for *ghaṭīs*** of 24 minutes are also drawn in addition to the lines for equal and unequal hours. *Ghaṭīs* are the traditional units of time in India and the Muslim rulers and common citizens of India adopted them for their secular activities. These are equal units; two and a half *ghaṭīs* make one equal hour. Therefore on some large astrolabes, the lower half of certain plates is cluttered with lines for unequal hours, equal hours and *ghaṭīs*. Usually these lines are drawn on the plates for the latitudes of the three Mughal

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104 Sometimes just the hours are engraved without the minutes; many times the recorded values of hours and minutes are not correct. Such cases occur often in astrolabes made by Muqīm, e.g., A023, A024, A026, A029, A032 and so on. Ḍiyā' al-Dīn's astrolabes are generally free of this defect; the only cases noticed are in A096, A100, A101 and A102 which are not signed by Ḍiyā' al-Dīn, but are attributed to him. Ḥāmid's astrolabes are also free of this defect; in fact, he mentions the maximum duration in hours, minutes and seconds. Of astrolabes by Jamāl al-Dīn, information is available only of A122; here the maximum duration is mentioned only in hours.

Imperial cities, namely Agra at 27°, Delhi at 29° and Lahore at 32°, but sometimes, other plates are also engraved with such lines (for example, in A052 and A097). Moreover, in the middle of some plates, the duration of the longest day is also expressed in *ghaṭīs* (spelt there as *karīhā*).[105] Strangely in almost all cases, the *ghaṭī* values do not match with the values in hours. This is inexplicable because hours and *ghaṭīs* are in a simple ratio of 60 : 24 or 5 :2.[106]

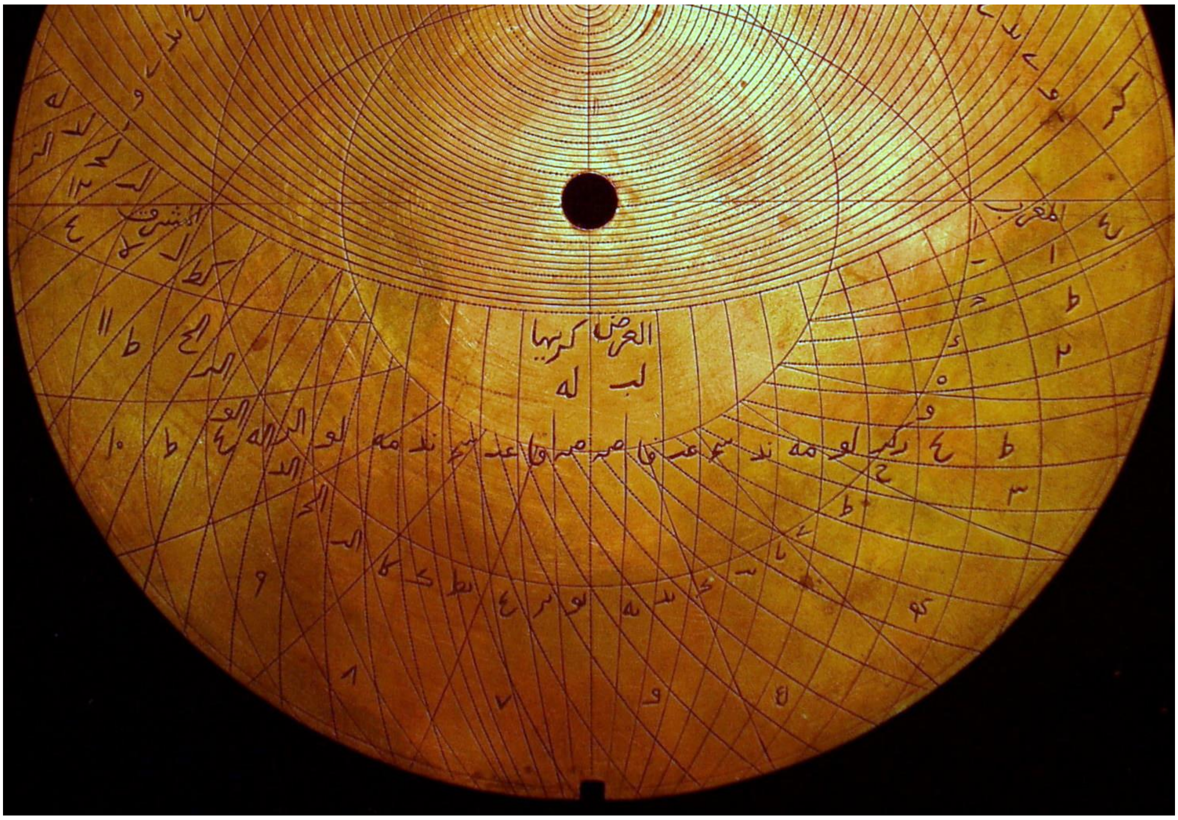

Figure A3 – Plate for 32° in astrolabe A014 by Qā'im Muḥammad (photo S. R. Sarma).

In Figure A3 above, the *ghaṭī* lines are dotted;and numbered in *Abjad* from the western horizon, from 1 to 35, below the circle of equator. Plain lines are for seasonal hours; these are numbered in common Arabic/Persian numerals, from 1 to 12, close to the periphery. In the middle of the plate is written *al-ᶜarḍ 32* and *karīhā 35* (latitude 32, *ghaṭīs* 35). In other astrolabes, the duration of the longest day at latitude 32° is given consistently as 14;8 hours; this is equivalent to 35;20 *ghaṭīs* and not just 35 *ghaṭīs.*

105 These astrolabes are A014, A015, A052, A065, A068, A073, A097, A105 and A113.

106 Equally inexplicable is that in Sanskrit astrolabes also, as will be shown in section C, the *ghaṭī* values and the values in hours for the maximum duration of the daylight rarely match.

2.4.2. Plate of ecliptic coordinates

Besides the plates designed for specific terrestrial latitudes, the Lahore astrolabes invariably contain a plate the two sides of which are designated respectively as *ṣafīḥat mīzān al-ᶜankabūt* (tablet of the ecliptic coordinates) and *ṣafīḥa al-āfāqiya* (plate of horizons). Both occur for the first time in al-Khujandī's astrolabe of 984.

The plate of ecliptic coordinates is basically a plate made for the arctic circle at the latitude of 90° diminished by the obliquity of ecliptic. Al-Khujandī determined the obliquity as 23;33°. Accordingly, he calibrated the plate for the latitude of 66;27°. The Lahore astrolabe makers use the approximate value of 23;30° for the obliquity and design the plates for latitude 66;30°. At this latitude, the ecliptic coincides with the horizon and the ecliptic pole with the zenith. The altitude circles run parallel to the ecliptic and azimuth arcs radiate from the zenith, dividing the ecliptic circle perpendicularly at regular intervals.

Thus, the astrolabic markings on this plate correspond to an ecliptic coordinate system. When the rete is placed on this plate, the ecliptic latitudes and longitudes of the stars represented on the rete can be read directly from the altitude circles and azimuth arcs respectively. Therefore, this plate is called *ṣafīḥat mīzān al-ᶜankabūt*, 'the plate of the balance or measure of the rete'. This plate can be used for converting the coordinates from the ecliptic system to the equatorial system and vice versa.

2.4.3. Plate of horizons

The reverse side of the plate of ecliptic coordinates is designed as the plate of horizons (*ṣafīḥa al-āfāqiya*). It was originally invented by Ḥabash al-Ḥāsib at Baghdad in the ninth century. On this plate are engraved horizons (*ufq,* plural *āfāq*) for several latitudes, many more than those which are available on the other plates. These horizons are useful in solving problems relating to sunrise and sunset, the length of the day and the rising times of stars without requiring a separate plate for each latitude. If complete horizons for all degrees are engraved, the plate would be cluttered. Therefore, half horizons for latitudes up to 66°, at convenient intervals, are arranged in four sets in the four quadrants of the plate. The latitude for each horizon is marked where it begins near the circumference and where it ends near one of the diameters. Along the four radii are drawn graduated declination scales, between the equator and the tropics, and the last cells of these scales are marked with the value of the maximum declination or the obliquity of the ecliptic. The scales to the south of the ecliptic carry the label *mayl kullī janūbī* (maximum declination south) and those to the north the label *mayl kullī shamālī* (maximum declination north).

For making use of any of the horizons drawn in one of the four quadrants, the plate should be so placed inside the astrolabe that the east point of the horizon coincides with the east point of the astrolabes. Therefore, notches have to be cut at the four points of the compass on the plate, so that the plug affixed inside the rim at the north point fits into each of the four notches on the plate. But these plates in the Lahore astrolabes rarely have four notches; they have just one notch at the north point. Thus these plates merely serve didactic purposes.

In the astrolabes produced in the Maghreb, the half-horizons are arranged on the plate, not in four sets, but in eight sets. The horizon plate in the undated astrolabe by Allāhdād (A002) is designed in this manner (see Figure A002.4). The horizon plates in all other Lahore astrolabes carry half-horizons in four sets.

2.4.4. Plates with astrological houses

A very small number of astrolabes, in particular those with *zawraqī* horizons on the rete, are equipped with plates on which the astrological houses are marked. The lines that divide the houses pass through the point of intersection of the oblique horizon and the meridian.[107] On some of these plates the houses are numbered with ordinals (starting at the eastern horizon and proceeding counterclockwise): *ṭāli^c, thānī, thālith, rābi^c, khāmis, sādis, sābi^c, thāmin, tāsi^c, ^{c}āshir, ḥādī ^{c}ashar* and *thānī ^{c}ashar.*

2.4.5. Double Projection for latitudes 0° and 90°

On one of the plates in his astrolabe, al-Khujandī draws, for the first time, projections for latitudes 0° (equator) and 90° (north pole). The horizon at the equator is represented by the horizontal diameter of the plate. The zenith and nadir lie on the circle of equator. The altitude circles parallel the horizon are drawn as arcs of the circle. As they go higher, they become full circles around the zenith. Azimuth circles are drawn

[107] Kaye, p. 19, n. 4.

as arcs radiating from the zenith. This plate is useful for solving problems related to rising times.

The lower half of the plate carries the projections for latitude 90° (North Pole). Here the horizon coincides with the equator; the altitude circles merge with the declination circles and the azimuth circles with the hour lines.[108]

Because of its didactic value, this double projection of latitudes 0° and 90° is emulated in many Lahore astrolabes, starting from the astrolabe of 1604 by ᶜĪsā (A006). This plate should actually have notches at the north and south points so that both halves can be made use of, but the plates in the Lahore astrolabes have just one notch at the north point like the rest of the plates.

The Lahore astrolabes exhibit double projections of other pairs of latitudes also such as latitudes 18° and 72° and so on. In such double projections, the altitude circles of one latitude are ingeniously extended as the latitude circles of the second latitude, creating an interesting pattern like the Roman letter S.

There are also plates with triple projections. A frequently represented combination is for latitude 0° in the upper half and for latitudes 72° and 90° in the lower half. This projection also appears for the first time in the astrolabe attributed to ᶜĪsā (A008). These plates display the virtuosity of the engraver.

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108 Morrison 2007, Fig. 4-10, p. 65: ‘The plate for equator is useful for solving problems common in the study of the history of astronomy involving rising times (i.e., elapsed time for a specific number of ecliptic degrees to rise). The horizon at the equator is called “sphaera recta”. The horizon at other latitudes is called “ascensio recta” or “right ascension”. The astrolabe was commonly used to solve these problems before the development of spherical trigonometry.
‘The plate for the North Pole shows declination directly. At the North Pole the horizon is the equator and declinations of anything on the rete can be read directly from this plate. Negative declinations cannot actually be seen from the North Pole but [on] the plate divisions extend up to the Tropic of Capricorn. The azimuth arcs correspond to hour angles of the sun or a star. If the rete is set to 0 hr sidereal time, the azimuth arcs correspond to the right ascension of any point on the rete. Another use of the plate for the North Pole is to locate planets or other objects not included on the rete.’

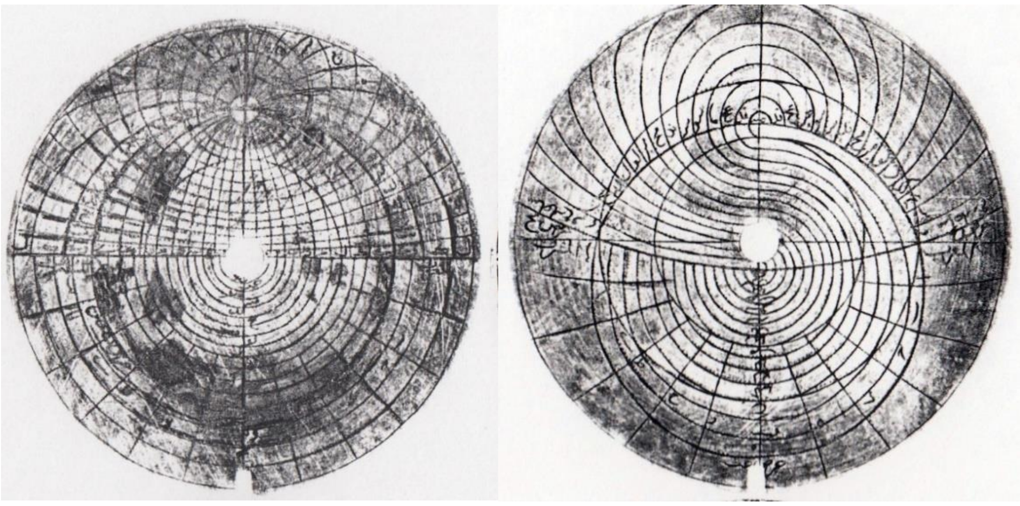

Figure A4 – Double projection of latitudes 0° and 90° on the left;
triple projection of latitudes 0°, 72° and 90° on the right; astrolabe attributable to ᶜĪsā (A008).

2.5. Geographical Gazetteer

The inner side of the astrolabe may contain, like the two sides of the latitude plates, projections for one more latitude or a geographical gazetteer with terrestrial coordinates for certain localities. The geographical gazetteer is not really essential for using the astrolabe; it is added just as a memorandum. One can also consult a manuscript for the information provided by the gazetteer on the astrolabe. But presumably, the astronomers and astrologers desired that the astrolabes contain all the necessary astronomical, astrological and geographical information at one place, as in the smart phones today.

The earliest astrolabe to have a gazetteer is one made by Nasṭūlus around 927; of this astrolabe only the mater survives with a small gazetteer engraved on the front and trigonometric quadrants on the back.[109]

2.5.1. Parameters in the Gazetteers

The gazetteers in Islamic astrolabes usually provide five parameters: (i) longitude (*ṭūl*), (ii) latitude (*ᶜarḍ*), (iii) *inḥirāf,* (iv) *jihat* and (v) *masāfat*. The longitudes are measured from the Fortunate Islands (*al-Jazā'ir al-Khālidāt*) in the Atlantic, roughly 35° west of Greenwich. The latitudes are well known, they are measured from the equator up to the north pole or up to the south pole. In his path-breaking *Description of*

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109 King 2008, p. 97.

the Persian Astrolabe constructed for Shah Husain Safavi, William Morley explains the last three parameters thus:

> The Inhiráf is an arc of the horizon, intercepted between the meridian of any place and a vertical circle passing through the zenith of such place and that of Makkah, such circle being called the Azimuth of Kiblah; and it is equal to the angle at the zenith of such place, formed by the said meridian and vertical circle, which is measured by the forementioned arc. This angle is the Angulus positionis of our older geographers. The Masáfat is the distance in a straight line, as the crow flies, between any place and Makkah, i.e., it is the arc of the great circle intercepted between the zenith of such place and that of Makkah in the nearest direction; the distance is computed in Fasangs, Miles, or Barids, بريد *posts* (Veredus). The Jihat is the direction of the Azimuth of the Kiblah with reference to any place and the four cardinal points; and it denotes the quarter of the horizon of such place in which Makkah is situated. It is obvious if the Inḥiráf, the Masáfat, and the Jihat, are known at any place, the position of Makkah, with regard to such place, is completely defined. If the place be of the same latitude as Makkah, there is no Inḥiráf; of the same longitude, the Inḥiráf is 90°: in either case, the Masáfat and Jihat are sufficient to determine the position of Makkah.[110]

Indo-Persian astrolabes carry a geographical gazetteer on the inner side of the mater and not projections for a latitude. Allāhdād, in the very first extant astrolabe of 1567 (A001), set out to provide the longitude, latitude and *inḥirāf,* and drew five columns on the inner side of the mater for the names of the localities (*al-bilād*), longitude (*al-ṭūl*), latitude (*al-ᶜarḍ*), orientation towards Mecca (*inḥirāf*) and the duration of the longest day (*al-sāᶜāt*), but left, for no discernable reason, the last two columns blank. Surely he must have had at his disposal some *zīj* with all these

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110 Morley 1856, p. 23.

parameters from which he had copied the names, longitudes and latitudes, but not the other two items.

He drew the same five columns in his undated astrolabe (A002), but the cell for the *inḥirāf* is often blank; sometimes it is filled by the maker, other times by a later hand in a smaller and scratchy script. Many cells of the longest days are also not filled, especially for places in the Indian subcontinent. In A003, which can be attributed to Allāhdād, the gazetteer provides the latitude (*al-ᶜarḍ*), co-latitude (*tamām al-ᶜarḍ*), and longitude (*al-ṭūl*) in this order. This is perhaps the only astrolabe to list co-latitudes (90-φ), which can easily be calculated from the latitudes. In A004, which too can be attributed to Allāhdād, the following data is planned to be provided: name of the locality (*al-bilād*), longitude (*al-ṭūl*), latitude (*al-ᶜard*), *inḥirāf* (*al-inḥirāf*) and the duration of the longest day (*al-sāᶜāt*), but the cells corresponding to the last two items are left blank as in the astrolabe of 1567. This is one of the reasons for attributing this astrolabe to Allāhdād.

His descendants ᶜĪsā, Qā'im Muḥammad, Muqīm and Ḍiyā' al-Dīn give only the longitudes and latitudes. In A093 which is attributable to Ḍiyā' al-Dīn, the longest day appears once again along with the longitude and latitude.

Ḥāmid tries to make up for the omission of his ancestors and provides longitudes, latitudes, *inḥirāf* (which he calls *qibla samt*) and *jihat* in four (A114, A115, A116, A117) of his eleven signed astrolabes and also in A120 which is attributable to him.

2.5.2. Sources of the Gazetteers

Obviously these gazetteers were derived from some Arabic or Persian astronomical tables (*zīj*) and similar texts. One of the important records of such geographical information in the Mughal period is the *Ā'īn-i Akbarī,* compiled by Abū al-Faḍl at the court of Akbar. It contains the longitudes and latitudes of some 656 localities arranged according to the climates.[111] I compared the gazetteer on the astrolabe of 1074/1663-64 by Ḍiyā' al-Dīn (A085) with the data in the *Ā'īn-i Akbarī,* but did not

[111] Abū al-Faḍl 3, pp. 50-116. This gazetteer is rearranged alphabetically in Kennedy 1987a, pp. 569-580.

find much correspondence between the two gazetteers.[112] Ḍiyā’ al-Dīn arranges three of his gazetteers according to the regions, starting from Maghreb in the west and reaching up to India in the east (A063, A073, A094; see especially A073). These are derived from Ulugh Beg’s geographical tables.[113] Otherwise, we do not know of any other sources used in these gazetteers. However, whichever sources they may have used, the astrolabe makers do not seem to have gathered the data with some consistency from their sources, so much so the geometrical coordinates given for a city by the same astrolabe maker differ from one astrolabe to another.

For example, in Ḍiyā’ al-Dīn’s astrolabes, Ajmer in Rajasthan, an important centre of Muslim pilgrimage in the Mughal period (and even now) is placed consistently at longitude 111;5° in all the astrolabes, but latitude varies from 24;0° to 25;0° to 26;0°. In the case of Ahmedabad, again an important city in Mughal India, the longitude has the values of 103;40°, 108;0° and 108;40° and the latitude 23;15°, 23;55° and 28;55°. These variations can be explained away by the fact that the forms of *Abjad* numbers look almost alike without the diacritical points. But no such explanation justifies the variation in the case of Iṣfahān; here the longitudes recorded are 82;40°, 85;0°, 86;40° and 87;40. The latitudes are more consistent: often 32;25°, but a few times 34;25°. This is so in the case of the astrolabes by the other members of the family as well. The only cities to have consistently uniform values are Mecca (long. 77;10° and lat. 21;40°), Medina (long. 75;20° and lat. 25;0°), and Lahore (long. 109;20° and lat. 31;50°).

2.5.3. Localities listed in the Gazetteers

While these astrolabe gazetteers seek to cover the entire area of the Islamic world, with the majority of localities enumerated being from the Greater Iran, the geographical information on the eastern and southern parts of the Indian subcontinent is very meagre. The localities usually mentioned in the east are Benares, Jaunpur and Dhākā Bangālah, i.e., Dhaka in modern Bangladesh. The southern localities mentioned are Daulatabad, Golconda (i.e., modern Hyderabad) and Bijapur. This scanty information is particularly surprising in view of the fact that the Mughal Empire extended quite far into the east

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112 Sarma 2003, pp. 43-47.

113 Sédillot 1853, pp. 257-271.

and into the south. Geographical parameters of a large number of Indian localities are compiled in Sanskrit geographical tables, [114] but the Lahore astrolabe makers do not seem to have consulted these sources.

Naturally Agra, Delhi and Lahore, the three Mughal Imperial cities, receive prominence in the Lahore astrolabes. As mentioned already, in many astrolabes there is one plate, one side of which is designed for Lahore at latitude 32° and the other side either for Agra at 27° or for Delhi at 29°. Likewise, as will be shown below, on the back of the Lahore astrolabes, there are often curves for the meridian altitude of the sun at the latitudes 27°, 29° and 32°. In the astrolabe gazetteers, the three cities are invariably mentioned. Agra is referred to as Akrah, Akbarābād, Akbarābād Dār al-Khilāfat, or Akbarābād Dār al-Mulk Hind; Delhi as *Haḍrat Dihlī,* Shāhjahānābād, Haḍrat Shāhjahānābad, or Shāhjahānābād Dār al-Mulk Hind; and Lāhūr as Lahāwar, or Lāhūr Dār al-Salṭanat.[115]

One locality deserves special mention. Most of the astrolabe gazetteers mention 'Sarandīb' (also spelt 'Sarāndīb'), which is the Arabic name for Sri Lanka,[116] with the longitude 130° and latitude 10°. While the latitude of 10° is a reasonable approximation for the northern tip of the island, the longitude of 130° places the island far in the East on the same meridian as Dhaka.[117] This is inexplicable because the exact location of the island must have been well known to the Arab sailors.

2.5.4. Arrangement of the Gazetteers

Now some remarks are in order about how the geographical material is organized in the astrolabe gazetteers. Many gazetteers commence from the holy city of Mecca, or from Qairawān (Kairouan in modern Tunisia) and proceed in the order of increasing

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114 Pingree 1996.

115 I must not forget to add that the city of Aligarh, where my wife and I spent most of our professional careers and where our son was born and grew up, is mentioned in almost all the gazetteers as 'Kūl [wa] Jalālī'. Kūl (pronounced Kol) was an old name of Aligarh, often listed with Jalālī which lies some 20 km to the east.

116 The Arabic name *Sarandīb*, which gave rise to the felicitous term 'serendipity' in English, has a close phonetic affinity to the Sanskrit *Śaraṇa-dvīpa,* 'the island of shelter', for Sri Lanka offered shelter to the ships tossed about by the fierce monsoon winds. However, the expression is not attested in any Sanskrit source.

117 Even Abū al-Faḍl 3, p. 57, has the same longitude of 130°, but the latitude there is 12°.

longitudes. Several astrolabes by Qā'im Muḥammad, Muḥammad Muqīm and Ḍiyā' al-Dīn have gazetteers organized according to climates. Classical geography divides the inhabited portion of the northern hemisphere into seven stripes called climes or climates (Arabic *iqlīm,* plural *aqālīm*) parallel to the equator so that the maximum daylight at the middle of each climate is half an hour longer than that in the preceding climate. But these gazetteers start from the equator (i.e., below the first climate) and go beyond the seventh climate. In the astrolabe of 1045/1635-36 by Qā'im (A013), the gazetteer is arranged according to climates, but commences with the second climate so that Mecca is at the beginning of the enumeration; thereafter come the first, third, fourth, fifth, sixth and seventh climates. The same is done in the astrolabe of 1031/1621-22 which is attributable to Qā'im Muḥammad (A014).

A third variety of arrangement is by regions, from the Maghreb in the west up to Hind (India south of Indus) in the east. Such arrangement occurs only in three astrolabes by Ḍiyā' al-Dīn (A063, A073 and A094).

Incidentally these arrangements by climates or regions appears to be peculiar to the Lahore astrolabes only.[118]

2.5.5. Style of Presentation

Aside from the variation in the arrangement of the localities, the gazetteers exhibit also varying styles of presentation, because the large area of the inner surface of the mater allows all kinds of stylistic experimentation. While the rows remain circular, the columns are sometimes curved, all slanting in a single direction and sometimes zigzag. The orientation of the letters also varies; in some gazetteers the upper part of the letters is oriented towards the centre and sometimes towards the outer circumference, and sometimes both in different annuli. In some gazetteers, each piece of data is enclosed in cartouches, the designs of which vary from each circle. Thus the Lahore astrolabe makers invested much technical and artistic efforts to make the gazetteers real objects of art.

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118 I checked the catalogues Pingree 2009, Gibbs & Saliba 1984, and King 1999b, but do not find such arrangements in any non-Indian astrolabe.

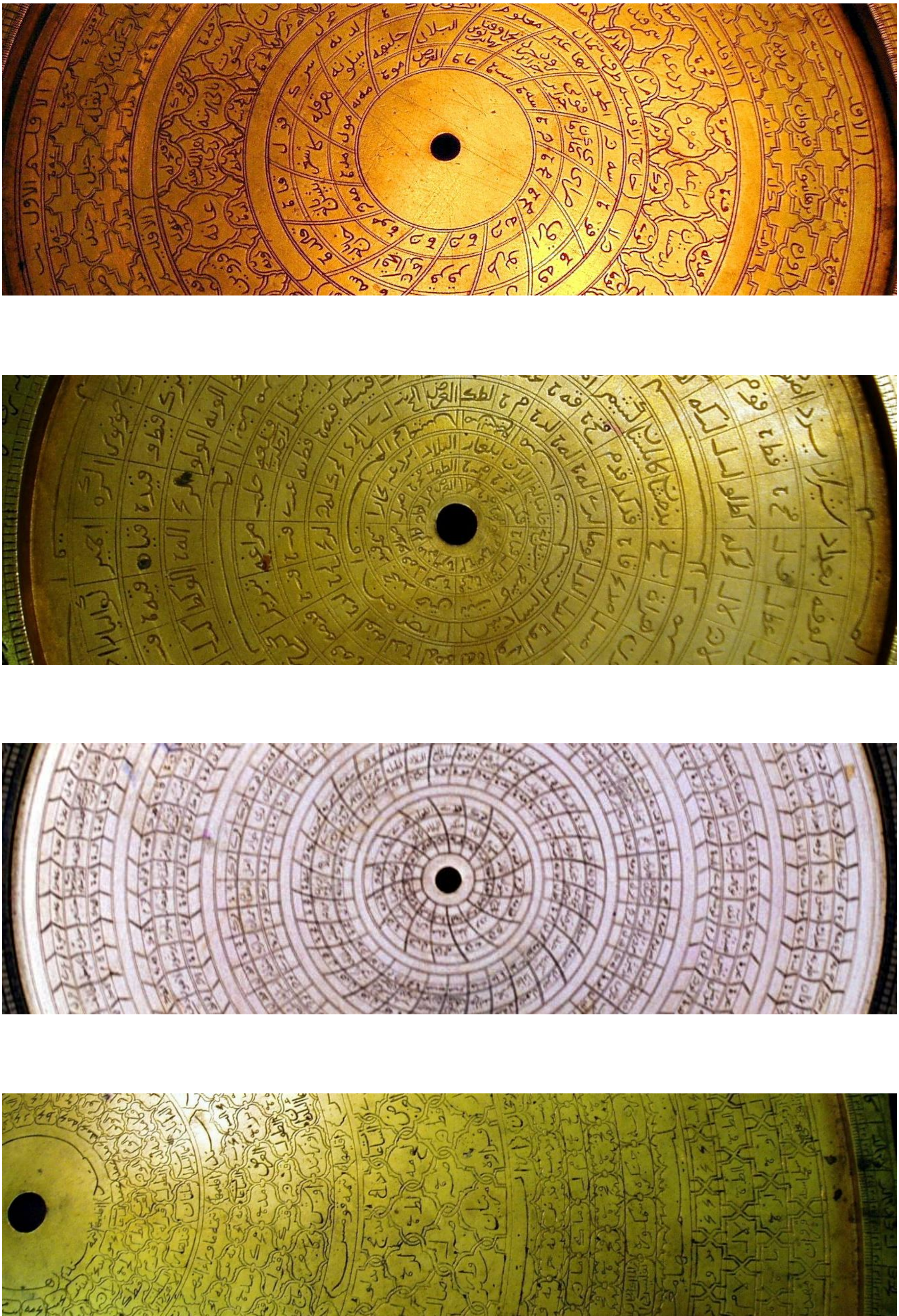

Figure A5 – Different styles of gazetteers (details of gazetteers from A014, A016, A052 and, A094)
(all photos by S. R. Sarma)

2.6. Back of the Astrolabe[119]

The back of the astrolabe (*ẓahr al-asṭurlāb*) is divided by the vertical and horizontal diameters into four quadrants which contain much trigonometric, geometric and astrological data. The rim of the two upper quadrants carries two altitude scales on which the altitudes of the heavenly bodies are measured by means of the alidade. Like the limb in the front, the altitude scales on the back also consist of two bands. The narrow inner band is graduated in single degrees. The broader outer band is divided in groups of 5° or 6°, exactly as in the front. But here these groups are numbered from 5 or 6 up to 90, starting at the east and west points and reaching the south point.

2.6.1. Trigonometric Quadrant on the Upper Left[120]

The upper left quadrant carries a sexagesimal trigonometric graph with equally spaced horizontal lines and vertical lines. In some astrolabes the vertical radius is divided into 60 equal parts, and from each point of division are drawn lines parallel to the horizontal radius up to the circumference. In others, both radii are divided in this manner and horizontal and vertical lines are drawn from each point of division. For the sake of clarity, every third or fifth line is highlighted with dots. The angle of the altitude is measured by the alidade on the altitude scale. The portion of the vertical radius intercepted by the horizontal line from the angle is the sine of the angle. Likewise, the portion of the horizontal radius intercepted by the vertical line from the angle is the cosine of the angle. Smaller astrolabes have 30 horizontal lines and 30 vertical lines.

2.6.2. Solar Quadrant on the Upper Right[121]

The upper right quadrant is designed as a solar quadrant which is a kind of yearly calendar. Here the horizontal and vertical radii are divided into six equal divisions. On these divisions are written the names of the signs or their serial numbers in the following manner. Along the vertical radius, from the centre up to the circumference, are written the names of Cancer (3), Leo (4), Virgo (5), Libra (6), Scorpio (7) and Sagittarius (8),

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[119] See especially Morrison 2007, pp. 109-142 with a wealth of diagrams explaining how to draw the various projections.

[120] Morrison 2007, pp. 126-132.

[121] Morrison 2007, pp. 134-143.

i.e., from summer solstice to winter solstice. Along the horizontal radius are written, from the circumference up to the centre, the names of Capricorn (9), Aquarius (10), Pisces (11), Aries (0), Taurus (1) and Gemini (2), i.e. from winter solstice to summer solstice. From the points of division of the two radii, quarter circles are drawn, i.e., for every 30° of solar longitude. These are the arcs of declination. Solar quadrant shows the sun's declination for each sign of the zodiac. In larger astrolabes, arcs are drawn at smaller intervals, usually for every 10° of solar longitude, occasionally also for 6°.[122] On this solar quadrant, curves showing the sun's midday altitude (*khaṭṭ nisf al-nahār*) for each day of the year at selected latitudes are traced.[123] These curves show the relation between the sun's right ascension and the meridian altitude. ᶜĪsā introduced these curves in the Lahore astrolabes by drawing a curve for the latitude of Lahore (32°). which is the seat of his family. His son Muḥammad Muqīm usually draws two curves for 29° and 32° which are the latitudes of the two Mughal imperial cities Agra and Lahore; his nephew Ḍiyā' al-Dīn Muḥammad followed this practice on some of his astrolabes. But after Shāh Jahān shifted the Mughal capital from Agra to Delhi, Ḍiyā' al-Dīn began to add a third graph for the latitude of Delhi at 29°. Sometimes, he also drew more curves. In A097, which is attributable to Ḍiyā' al-Dīn, there are curves for as many as nine cities.

In a few astrolabes, lines showing the beginning and the end of the afternoon prayer *ᶜasr* are drawn in this quadrant. In a few other astrolabes, lines for a universal horary quadrant are drawn.

2.6.3. Shadow Squares and Cotangent Scales[124]

In the lower half, immediately below the horizontal diameter are engraved two shadow squares.[125] In Islamic astrolabes, the square to the left of the meridian is drawn for the shadows thrown by a gnomon of 7 feet (Arabic *qadam,* plural *aqdām*) and the horizontal and vertical scales are divided into 7 parts each. The vertical scale is labelled

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122 These arcs are equidistant, while in Safavid astrolabes these are drawn stereographically.

123 Cf. Kaye, p. 22; Frank & Meyerhof 1925, pp. 14-15; Gunther 1932, vol. I, p. 184; Morrison 2007, pp. 136-137.

124 Morrison 2007, pp. 114-116, 132-133.

125 Morrison 2007, pp. 114-116.

as *ẓill aqdām maᶜkūs* (umbra versa, or reverse shadow, in feet), i.e. shadow thrown by a horizontal gnomon on a vertical plane. The horizontal scale is labelled as *ẓill aqdām mustawī* (umbra recta, or direct shadow, in feet), i.e. shadow thrown by a vertical gnomon on a horizontal plane.

The square to the right of the meridian is drawn for the shadows thrown by a gnomon of 12 digits or fingers (Arabic (*aṣbaᶜ,* plural *aṣābiᶜ*) and the horizontal and vertical scales are divided into 12 parts each. The vertical scale is labelled as *ẓill aṣābiᶜ* (umbra versa, or reverse shadow, in digits), i.e. shadow thrown by a horizontal gnomon on a vertical plane. The horizontal scale is labelled as *ẓill aṣābiᶜ mustawī* (umbra recta, or direct shadow, in digits), i.e. shadow thrown by a vertical gnomon on a horizontal plane. In some astrolabes, each division in the scales for 12 digits is further divided into 5 parts, so that the scale contains 60 parts. These scales are labelled as *ẓill sittaynī mustawī* and *ẓill sittaynī maᶜkūs.*[126]

The divisions on the horizontal scales are numbered from the centre onwards and those on the vertical scales are numbered from the top downwards. The relation of a division on the horizontal scale to the whole length of the gnomon corresponds to the cotangent and the relation of a division on the vertical scale to the whole length of the gnomon corresponds to the tangent. These shadow squares are useful in land survey for determining the heights or depths of objects and for calculating distances.

The horizontal scales on the two shadow squares are projected on the rim of the lower half to create there two cotangent scales for the bases 7 and 12 respectively.[127] The divisions are subdivided on an inner band. Muqīm labels them usually as *ẓill aqdām* and *ẓill aṣābiᶜ* respectively. Ḍiyā’ al-Dīn labels them in some of his astrolabes as *ẓill aqdām mabsūṭ* and *ẓill aṣābiᶜ mabsūṭ* (e.g., A063, A067 etc).

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[126] See A030, A068, A073 and A093. Dr François Charette informs me that this sexagesimal scale occurs in several middle eastern astrolabes, e.g. an astrolabe dated 790 AH by Jaᶜfar b Umar b Dawlatshāh (Adler Planetarium, Chicago), cf. Pingree 2009, p. 43; an astrolabe dated 830 AH and most probably dedicated to Ulugh Beg (Copenhagen, Davids Samling), cf. King 2005, pp. 761-763; an astrolabe dated 929 AH by al-Jilānī (National Maritime Museum, Greenwich). But in these astrolabes the sexagesimal scale does not carry a label.

[127] Hartner 1968a, p. 302, figure 850.

The Lahore astrolabes do not strictly adhere to the arrangement of scales divided in 7 feet on the left and the scales divided in 12 digits on the right; they often reverse the order.

2.6.4. Astrological Tables

In the space inside the shadow squares and in the space between the shadow squares and the cotangent tables, several astrological tables are engraved on the Lahore astrolabes.[128] The tables engraved on the Lahore astrolabes are broadly of six types.

2.6.4.1. Correspondence between the Zodiac Signs and the Lunar Mansions

In two adjacent semi-circular rows the names of the 12 zodiac signs and those of 28 lunar mansions are written so that one can see which lunar mansions correspond to which zodiac sign. This table occurs on all Lahore astrolabes. Small astrolabes carry just this one and no other astrological table.

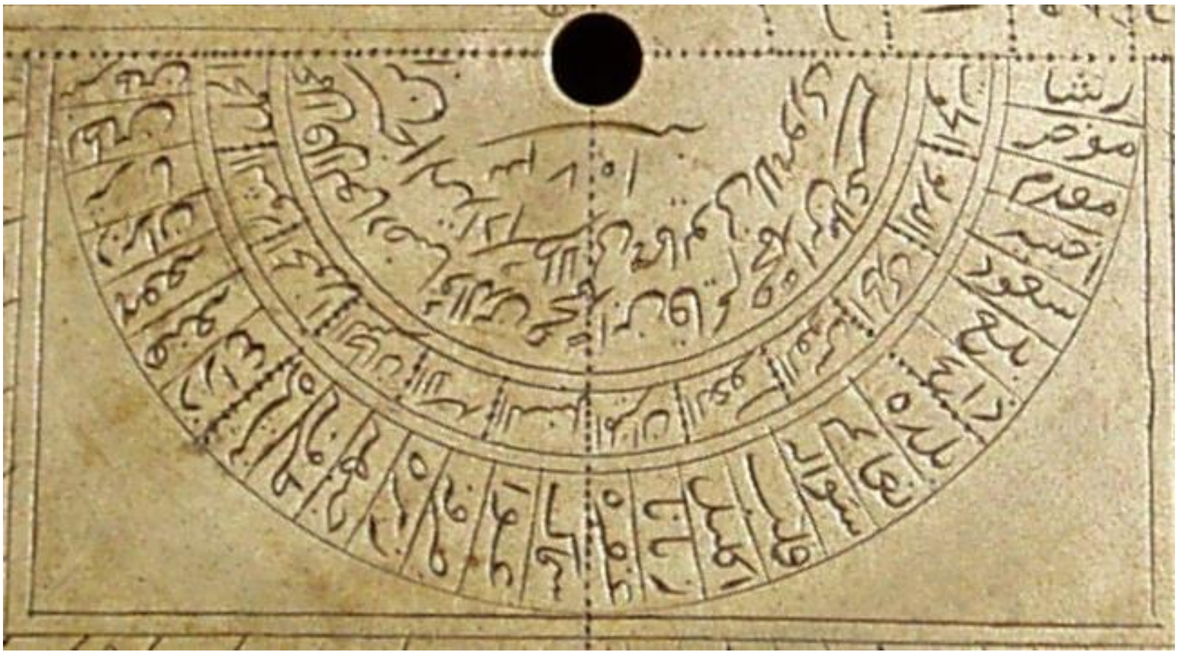

Figure A6 – Zodiac signs and lunar mansions on the back of the astrolabe A081 by Ḍiyā’ al-Dīn Muḥammad (photo by S. R. Sarma)

[128] On astrological tables on the back of astrolabes, see Kaye, pp. 119-126: Appendix B, Astrological Tables; Khareghat 1950, pp. 10-23; Ackermann 2005.

2.6.4.2. Limits or Terms of the Signs

In this system, each zodiac sign has five intervals called *ḥudūd* ('limit' or 'term') of varying lengths which are assigned to the five planets other than the sun and the moon. However, the sequence of the planets and intervals assigned to them vary for each sign.[129] There are said to be several systems, but the one used frequently is derived from Egypt, hence designated as *jadwal ḥudūd misriyan.*

The intervals assigned to each planet are shown in two ways. In one the exact amount of each interval are shown in degrees of arc as in the following table on the back of an astrolabe dated 1045/1635-36 by Qā'im Muḥammad (A013).

Table A1 Limits of the Signs

Aries	Jupiter	6	Venus	6	Mercury	8	Mars	5	Saturn	5
Taurus	Venus	8	Mercury	6	Jupiter	8	Saturn	5	Mars	3
Gemini	Mercury	6	Jupiter	6	Venus	5	Mercury	7	Saturn	6
Cancer	Mars	7	Venus	6	Mercury	6	Jupiter	7	Saturn	4
Leo	Jupiter	6	Venus	5	Saturn	7	Mercury	6	Mars	6
Virgo	Mercury	7	Venus	10	Jupiter	4	Mars	7	Saturn	2
Libra	Saturn	6	Mercury	8	Jupiter	7	Venus	7	Mars	2
Scorpio	Mars	7	Venus	4	Mercury	8	Jupiter	5	Saturn	6
Sagittarius	Jupiter	12	Venus	5	Mercury	5	Saturn	4	Mars	4
Capricorn	Mercury	7	Jupiter	7	Venus	8	Saturn	4	Mars	4
Aquarius	Mercury	6	Venus	6	Jupiter	7	Mars	5	Saturn	5
Pisces	Venus	12	Jupiter	4	Mercury	3	Mars	9	Saturn	2

This shows that, of the five limits of Aries, the first is presided by Jupiter whose quantity of influence is 6, the second is presided by Venus whose influence is 6 and so on. The total influence of all the five planets is 30 degrees in each sign.

The other method is cumulative; it shows the interval assigned to a planet plus the sum of the intervals assigned to all the preceding planets. In this method, the limits of the sign Aries are displayed as follows:

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[129] Cf. Kaye, pp. 122-123; Khareghat 1950, p. 17;

Aries	Jupiter	6	Venus	12	Mercury	20	Mars	25	Saturn	30

In the tables prepared according to these two methods, as well as in all other astrological tables, the signs of the zodiac are denoted by their serial numbers and the planets by the final consonant of their Arabic names. The symbols used for the planets are shown below.

Planet	**Sun**	**Moon**	**Mars**	**Mercury**	**Jupiter**	**Venus**	**Saturn**
Arabic Name	*shams*	*qamar*	*mirrikh*	*ᶜauṭārad*	*mushtarī*	*zuhrah*	*zuḥal*
Symbol	س	ر	ح	د	ى	ه	ل

2.6.4.3. Decans or Faces (*al-wujūh*) and their Regents

Decan (sing. *wujūh*; plural *wajah*) is one-third of a sign, or 10 degrees. The decans are numbered for each sign as 10, 20, 30 in *Abjad* and the presiding planets are indicated by alphabetical symbols.[130]

Table A2 Decans and their Regents

Signs	***10º***	***20º***	***30º***
Aries	Mars	Sun	Venus
Taurus	Mercury	Moon	Saturn
Gemini	Jupiter	Mars	Sun
Cancer	Venus	Mercury	Moon
Leo	Saturn	Jupiter	Mars
Virgo	Sun	Venus	Mercury
Libra	Moon	Saturn	Jupiter
Scorpio	Mars	Sun	Venus
Sagittarius	Mercury	Moon	Saturn
Capricorn	Jupiter	Mars	Sun
Aquarius	Venus	Mercury	Moon
Pisces	Saturn	Jupiter	Mars

It may be noted that the sequence of planets in each column is that of weekdays.

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[130] Cf. Kaye, p. 123; Khareghat 1950, p. 13.

2.6.4.4. Trigons or Triplicities and their diurnal and nocturnal Regents

Trigons or Triplicities are four sets of three signs which are 120 degrees apart. These four sets are characterized as fiery (Arabic *nārī,* Persian *ātishī*), earthy (Arabic *tarābī,* Persian *khākī*), airy (Arabic *hawā'ī,* Persian *bādī*) and watery (Arabic *māhī,* Persian *ābī*) and are assigned different regents in the daytime and at night.[131] The table is entitled *arbāb muthallathāth yawmī wa laylī* , 'the regents (*rabb,* 'lord', plural *arbāb*) of the triplicities (*muthallath,* 'triangle', plural *muthallathāth*).[132]

Table A3 Triplicities and their Regents

Regents of the Trigons, diurnal					Regents of the Trigons, nocturnal			
Fiery	*Earthy*	*Airy*	*Watery*		*Fiery*	*Earthy*	*Airy*	*Watery*
Aries	Taurus	Gemini	Cancer		Aries	Taurus	Gemini	Cancer
Leo	Virgo	Libra	Scorpio		Leo	Virgo	Libra	Scorpio
Sagittarius	Capricorn	Aquarius	Pisces		Sagittarius	Capricorn	Aquarius	Pisces
Sun	Venus	Saturn	Venus		Jupiter	Moon	Mercury	Mars
Jupiter	Moon	Mercury	Mars		Sun	Venus	Saturn	Venus
Saturn	Mars	Jupiter	Moon		Saturn	Mars	Jupiter	Moon

2.6.4.5. Excess of Revolution

This table is entitled *jadwal faḍl al-dawr* (table of excess of revolution). Excess of revolution is the difference between the approximately correct length of the tropical year and 365 days which is taken to be 87;33°. The table displays the multiples of this value from 1 to 9 and then by 10s up to 90. It occurs for the first time in the astrolabes of Muqīm (A018 and others). The multipliers in the first and third columns (counted from the right) are expressed by the standard Arabic / Persian numerals, and the products in the second and fourth column in *Abjad* notation.[133]

131 Persian terms are also used sometimes in these tables.

132 Khareghat 1950, pp. 19-23.

133 Cf. Kaye, p. 24. A shorter version showing the multiples of 1, 2, 3, 4, 5, 10, 20, 40 occurs already on the back of Allāhdād's astrolabe A002, in table III.

Figure A7 – Table of excess of revolution on the astrolabe of 1059/1649-50 by Ḍiyā’ al-Dīn (A063)

2.6.4.6. Climates

In Ptolemaic geography, the inhabited portion of the northern hemisphere is divided into seven climates in such a manner that the maximum duration of daylight at the middle of each climate is half an hour longer than in the previous one, and this notion was adopted by the Islamic world.[134] Abū al-Faḍl explains the system of the climates in the third volume of his *Āī’in-i Akbarī* and also mentions the latitudes at the beginning and middle of each climate and the duration of the longest days at these climates.[135] Such data in tabular form is engraved on the back of three astrolabes by Muḥammad Muqīm with slight differences. In A024, the table is entitled *mubādī aqālīm sab^{c}a* (beginnings of the seven climates) and gives the latitudes and the hours of the duration of the daylight at the beginning of the seven climates and at the end of the seventh climate. The other two astrolabes (A042 and A052) display the latitudes (*arūḍ*) and the hours (*sā^{c}āt*) of the maximum daylight at the beginning (*mabdā’*) and the middle (*wasaṭ*) of the seven climates (*aqālīm*).

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[134] For a table of climates with corresponding latitudes for different values of obliquity, see King 2005, p. 927.

[135] Abū al-Faḍl 3, pp. 51-54.

Figure A8 – Table of climates on the back of A052

2.6.4.7. Table of the Rising Times of Signs at Different Latitudes in India

(zadwal sā^{c}*āt ṭulū*^{c} *burūj bi-*^{c}*arḍ ba*^{c}*ḍī az bilād mulk al-hind)*

This table occurs in three astrolabes by Ḍiyā' al-Dīn with slight variations. The table on A073 provides the rising times of the signs at each degree of latitude from 20° to 39°[136], A093 has a table from 20° to 40° and A094 from 21° to 40°.

2.6.4.8. Zodiac and Calendar Scales

Many European and some Islamic astrolabes contain a calendar scale together with the zodiac scale, both drawn all around inside the rim. The zodiac scale is divided into the 12 signs of the zodiac and labelled with the names of the signs. Each sign is divided into 30 degrees and numbered in 6s. The calendar scale is drawn in an eccentric circle, offset from the centre of the instrument on the line of apsides by Ptolemaic eccentricity. The circle is then divided into 365 equal divisions, which are distributed in 12 months. These two scales are necessary for determining the solar longitude of the given date, expressed in terms of the zodiac. The alidade is placed on the given date in the calendar scale and the corresponding longitude is read off from the zodiac scale. This value is used for positioning the rete on the front.[137]

Two Indo-Persian astrolabes are engraved with these scales on the back. In the astrolabe made by Qā'im Muḥammad in 1045/1635 (A013), there is an eccentric calendar scale, labelled with the names of *Rūmī* (Syro-Macedonian or Byzantine) solar months, together with the number of civil days in each month. In Ḍiyā' al-Dīn Muḥammad's *Zarqālī* universal astrolabe (A092) there is a similar calendar scale, but it

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[136] This table is reproduced in Kaye, p. 23.

[137] Morrison 2007, pp. 111-114.

is concentric. All other Indo-Persian and Sanskrit astrolabes anticipate that the solar longitude is obtained from astronomical tables, either an Arabic or a Persian *zīj,* or a Sanskrit *pañcāṅga.*

2.6.5. Signature of the Astrolabe Maker

The astrolabe maker engraves his name, together with the names of his ancestors up to Allāhdād and the year of manufacture in the lower half of the back. In some astrolabes, the space inside the shadow squares is filled by one or two rectangular tables. The signature is then engraved above these tables and below the horizontal diameter. In some other astrolabes, the space inside the shadow squares is filled by two semi-circular rows with the names of the signs and lunar mansions. The signature is placed above the two semi-circulars rows. There are also other slight variations which will be mentioned in the descriptions of the corresponding astrolabes. The signature begins either with *ᶜamal* (work), or with *ṣanᶜat* (work), or *ṣanaᶜahu* (he made). The astrolabe maker usually adds a phrase of humility before his name: *aqall al-ᶜibād,* 'the least of the servants [of God], *aḍaᶜf al-ᶜibād,* 'the weakest of the servants [of God]', or *aḥqar al-ᶜibād,* 'the most contemptible of the servants [of God]'.

Then follows the year in the Hijrī era. Sometimes the year is mentioned also in the *Rūmī* (Syro-Macedonian era) which commences from 1 October 312 BC. In a few cases the Old Persian Yazdegerd era is employed which begins on 19 June 632 AD. Occasionally the regnal years of the ruling Mughal emperor are also mentioned. While most of the astrolabes carry just the year in which the astrolabe was completed, Ḥāmid likes to mention the exact date on which a particular astrolabe was completed. Thus the very last dated astrolabe made by him was completed on 24 Ramaḍān 1102 which translates to 21 June 1691.

2.7. Alidade, Pin and Wedge[138]

On the back of the astrolabe a diopter is pivoted to the centre. This diopter, called 'alidade' from the Arabic *al-ᶜiḍāda*, is the observational part of the instrument, with

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138 Some science museums offer excellent astrolabe assembling kits, together with descriptions of the components, e.g., National Maritime Museum 1976; Webster & MacAlister 1984.

which the heights or altitudes of the heavenly bodies are measured. It is a flat rectangular strip, roughly of the same length as the diameter of the astrolabe. Its two ends are tapered to sharp points. Near each end is attached a rectangular sighting plate (*libna*) at right angles to the surface of the main bar. Generally two apertures are bored in the sighting plates, one larger and the other smaller. Since the sun should not be viewed directly, the alidade is pointed towards the sun, so that the sun's ray enters the aperture in the upper sighting plate and passes through the aperture in the lower sighting plate and then falls on the observer's palm or on a paper. The stars can of course be viewed by placing one's eye below the lower sighting plate. Then the angle of the altitude can be read on the altitude scales in the upper left, if the sun is in the eastern hemisphere, or in the altitude scale on the upper right if the sun is in the western hemisphere. The angle then can be converted to the corresponding sine or cosine on the trigonometric quadrant.

Figure A9 – Alidade from an astrolabe by Jamāl al-Dīn (= Figure A122.7)

To facilitate this process, the two arms or halves of the alidade are engraved with appropriate scales.[139] The upper register of the right half is engraved with a sexagesimal scale numbered in 6s from the centre to the tip as 6, 12, 18 … 60 and the sloping edge is graduated in single units, so that this scale matches with the divisions of the vertical radius of the upper left quadrant. The left half of the alidade is marked with declination arcs as in the upper right quadrant on the back and labelled with the names or the serial numbers of the zodiac signs and their subdivisions.

The alidade can also be employed as a sundial by placing it in a horizontal position with the sighting plate towards the sun. Then the sighting plate on the right functions as the gnomon and throws its shadow on the surface of the alidade. A scale to measure the unequal hours from this shadow is marked on the lower register on the right hand side,

[139] Cf. Gibbs & Saliba 1984, pp. 57-59.

numbered from 1 to 6 from the sighting plate towards the centre and from 7 to 12 in the reverse direction.

The alidades in the Lahore astrolabes have ornate ends and a matching centre piece. However, these are all straight bar alidades without any counter-change at the centre.

A large hole is bored at the centre of the rete, the plates, the mater and the alidade, through which passes a broad-headed pin to hold these parts together. The exact centre of the rete and of the plates is the celestial pole, called *quṭb* in Arabic. Since the pin passes through the pole, it too is designated as *quṭb.* The pin is inserted through the holes of the components with the broad head on the back above the alidade. The other end of the pin which projects out of the assemblage in the front is pierced with a longitudinal hole through which a wedge is pushed to secure the entire ensemble.

One end of the wedge is traditionally shaped like the head of a horse from at least the time of the celebrated astrolabe made by al-Khujandī in 984. Therefore, the wedge is usually called *faras,* Arabic for 'horse'. Sometimes, washers are added in the front to make the wedge tighter.

Figure A10 – Horse from astrolabe A106

To protect the astrolabe from the vagaries of weather, it is carried in a leather pouch; or it is placed in a cloth bag and then preserved in a specially made wooden case which imitates the outlines of the astrolabe. A few such cases exist, but they may or may not be contemporary with the astrolabes they now house.

Figure A11 – Astrolabe A081 in a leather pouch (photo by S. R. Sarma)

Figure A12 – Astrolabe case, Saidiya Library, Hyderabad
(photo courtesy Ahmad Athaullah)

2.8. How to use the Astrolabe

When one wishes to use the astrolabe, the first task is to place the latitude plate designed for the place of observation beneath the rete. The other plates are stacked below this plate. Then by means of the alidade at the back, the altitude of the sun is measured; or that of a bright star, if it is night. Since the Lahore astrolabes do not have a calendar scale at the back, the exact position of the sun or of the star for that moment has to be found from an almanac or from other astronomical tables. Then turning the astrolabe to the front, the rete should be rotated so that the point on the ecliptic representing the position of the sun or of the star coincides with the circle of the altitude previously measured. When the rete is thus set up on the latitude plate, these two together simulate the position of the heavens upon the observer's latitude.

Then time can be measured either in seasonal hours or in equal hours, horoscopes can be cast for that time, the auspiciousness or otherwise of the moment for any undertaking can be determined and the myriad problems in spherical astronomy listed by various writers can be solved.[140]

3. Non-Standard Astrolabes and Astrolabic Elements

Anthony Turner aptly remarked that 'the multiplication of complexity and a delight in the unusual seem to be typical of the astrolabe-makers of Lahore'.[141] Indeed, they show a marked predilection for unusual projections invented in Andalusia in the tenth and eleventh centuries, such as the universal plates invented by al-Zarqālluh, Ibn Bāṣo and 'Alī ibn Khalaf al-Ṣaidalānī; they were also attracted to the *zawraqī* or ship astrolabes invented by Abū Saʿīd Sijzī, to the north-south astrolabes, to the *qibla*-indicators, and to the 'circle of visibility of Canopus' of unknown origin.

With the exception of the north-south astrolabes and *qibla*-indicators, there had been no tradition of making the other types of instruments in the immediately preceding centuries either in India or in the adjacent countries. The astrolabe makers of Lahore could not have any actual models to follow and their knowledge must have been derived entirely from Arabic treatises on these instruments.[142]

These non-standard features will be discussed here briefly; the full descriptions will be given under the relevant instruments. It may be noted that many of these non-standard features occur mainly in the astrolabes produced by Ḍiyā' al-Dīn Muḥammad.

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140 On the use of the astrolabe, see especially Morrison 2007; Graaf 2011.

141 Turner 1985, p. 83.

142 It should be worthwhile to explore the manuscript collections in Pakistan and India, especially in Lahore, to see whether these contain any manuscript resources which may have been used by the Lahore family.

3.1. ᶜAlī ibn Khalaf's Universal Plate

One of the major contributions of the Islamic world to the construction of the astrolabe is the universal plate that could be used at all latitudes.[143] Perhaps the first attempt in this regard was made by Ḥabash al-Ḥāsib of Baghdad when he invented the plate of horizons in the early ninth century, to which reference has been made earlier in 2.4.3. But this plate is not completely universal because it cannot be used at all latitudes.

A single plate that could be used at all latitudes was developed in Toledo in the eleventh century by ᶜAlī ibn Khalaf al-Ṣaidalanī, also known as al-Shakkāz. The plate contains a vertical projection of the celestial sphere instead of the polar stereographic projection as in the common astrolabes. The equator is represented by the vertical diameter of the plate and the ecliptic by another diameter which intersects the equator at an angle which is tantamount to the obliquity of the ecliptic. On either side of the equator and the ecliptic parallels are drawn up to their respective poles on the periphery of the plate.

This plate is accompanied by a specially designed rete. One half of this rete contains the star map as in common astrolabes, but its periphery represents the equator and not the Tropic of Capricorn. The other half is filled with a net of parallels of the equator and of the meridian.[144] This plate is known as the *Ṣafīḥa Shakkāziyya* after the name of the inventor.

In 729/ 1328-29 ibn al-Sarrāj produced a specimen in Syria by substantially modifying the original design of al-Shakkāz. David King considers this specimen to be 'the most sophisticated astronomical instrument from the entire medieval and renaissance periods.'[145] This fourteenth century specimen is relevant for India in so far as it was imitated in the seventeenth century. The rete and the mater of this astrolabe (A125) which are extant do not carry any signature or date, but David King attributes these parts to Jamāl al-Dīn.[146]

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143 Turner 1985, pp. 151-166; King 2005, pp. 57-73.

144 Turner 1985, p. 152-153.

145 King 2005, pp. 694-700.

146 King 2005, pp. 821-829.

3.2. Zarqālī Universal Astrolabe

Abū Isḥāq Ibrahīm ibn Yaḥyā al-Naqqāsh (d. 15 September 1100), known as al-Zarqālluh (in Latin writings, Azarquiel, Arzachel) was a contemporary of ᶜAlī ibn Khalaf. [147] He simplified the latter's universal plate by dispensing with the rete. Instead he added a diametral rule with a sliding cursor. On the plate, he drew celestial coordinates for both the ecliptic and equatorial axes and marked the positions of several stars.

Al-Zaqālluh designed another universal plate where he superimposed two *shakkāzīya* markings at an angle equal to the obliquity of the ecliptic. On the back are the usual degree scales, zodiacal calendar, sine diagram, shadow squares and such elements as in the common astrolabes. This plate was equipped with an alidade at the back; in the front there is a diametral rule and a sliding cursor attached at right angles to the rule; both the rule and the cursor are graduated. Al-Zarqālluh named this universal plate *al-ᶜabbādiyya* in honour of the King of Sevilla, al-Muᶜtamid b. ᶜAbbād, but it became popular under the name *Safīḥa Zarqāliyya* (in Latin Saphaea Arzachelis).[148]

Anthony Turner lists nine extant specimens.[149] The most spectacular specimen of the *zarqālī* astrolabe was constructed by Ḍiyā' al-Dīn Muḥammad for a high Mughal dignitary Nawāb Iftikhār Khān in 1680 (A092).

Turner adds that 'the plate was difficult to use because of the profusion of markings.' For example, consider the complex procedure for measuring time as explained by Turner:[150]

> First the observer measured the altitude of the sun (or at night one of the stars marked on the astrolabe) by means of the alidade and the degree scale engraved on the back of instrument. Turning the astrolabe over, he set the rule to the latitude of the place of observation against the degree scale on the edge. When thus set, the position of the rule represented the place of

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147 On his biography, see Vernet.

148 Cf. Kaye, pp. 27-30, plate VII; Hartner 1968b, pp. 316-317; Turner 1985, pp. 151 –179; Puig 1985; Puig 1989.

149 Turner 1985, pp. 177-178.

150 Turner 1985, p. 155.

observation. Having found, from the zodiacal calendar on the back, the sun's position in the ecliptic for the day of observation, the cursor was slid along the rule until the graduation on the cursor corresponding to the observed altitude of the sun met the parallel representing the sun's position in the ecliptic. The meridian of the equatorial pole that passed through this point (and which is equivalent to an hour arc) then indicated the time. If a star had been observed, the cursor was moved until the graduation corresponding to the star's observed altitude met one parallel of the star as marked on the instrument, the time being read off from the meridian passing through this point.

3.3. Ibn Bāṣo's Universal Plate

In the thirteenth century Ibn Bāṣo of Toledo developed yet another universal plate by combining the elements from the universal astrolabes designed by ᶜAlī ibn Khalaf and ibn al- Zarqalluh. [151] According to Emilia Calvo, this plate is difficult to use in practice, it serves more theoretical or pedagogical purposes. This plate was apparently very popular; Calvo enumerates some 27 specimens, most of them produced in the Maghreb. Allāhdād is the only astrolabe maker in India who incorporated this universal plate in his undated astrolabe (A002) and in an unsigned and undated astrolabe that can be attributed to him (A003). His descendants did not emulate him in this respect, although they were interested in other types of universal plates.

[151] Calvo 2000, p. 266.

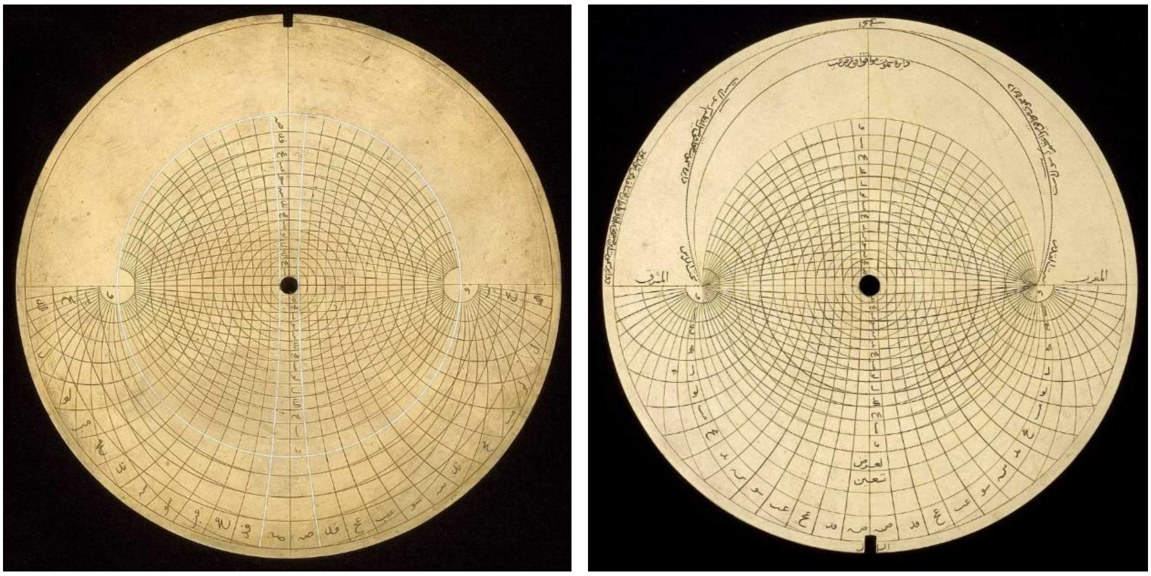

Figure A13 – Ibn's Bāṣo's universal projection; left: Allāhdād's undated astrolabe (A002); right: astrolabe attributable to Allāhdād (A003) (© Museum of the History of Science, Oxford)

3.4. North-South Astrolabes

While the standard astrolabes are northern astrolabes (*asṭurlāb shamālī*), there was a certain fascination in India for north-south astrolabes (*asṭurlāb shamālī wa janūbī*). Sulṭān Fīrūz Shāh Tughluq is reported to have commissioned three north-south astrolabes, one in brass, another in silver and the third in brass, but with large dimensions, which was designated as *Asṭurlāb-i Fīrūz Shāhī*.[152] The first Sanskrit manual on the astrolabe composed at his court by Mahendra Sūri also devotes the third chapter to the construction of northern astrolabes (*saumya-yantra*), southern astrolabes (*yāmya-yantra*) and the composite north-south astrolabes (*saumya-yāmya-yantra*). The north-south astrolabe to which these sources refer is the one in which the combined northern and southern projection is drawn on the rete and on the plates with five concentric circles representing the Tropic of Capricorn, Equator and the Tropic of Cancer, Equator and the Tropic of Cancer, in this order.[153] In the middle of the nineteenth century, Buhlomal constructed two north-south astrolabes which probably are of this type.[154]

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152 Sarma 2000.

153 See Ôhashi 1997, p. 215, Fig. 9.

154 Sarma 2015b, pp. 270-271, Fig. 7. These will be described in section B.

The Lahore astrolabes exhibit three other variants. One of these astrolabes is made by Ḍiyā’ al-Dīn Muḥammad in 1674 (A091) and the other two are attributable to him on stylistic grounds. In the first variant, the obverse side of the single plate is engraved as a latitude plate for 33° N and on it is superimposed a northern projection of the ecliptic circle together with the positions of 46 stars,[155] while the reverse side is designed for latitude 35° N on which a southern projection of the ecliptic circle is drawn and the positions of the same 46 stars, but with southern orientation, are marked. On both sides the positions of many stars are indicated by dots enclosed in small circles. There is a minimal rete consisting of just the zodiac ring. There is an alidade on which a slender sighting tube is mounted.

In the second variant (A104), the obverse side carries a double projection for latitudes 36° and 32°. On this is superimposed the ecliptic circle in its northern projection. The reverse side carries a quadruple projection for 22°, 25°, 27° and 29°. Upon these is superimposed the ecliptic circle in its southern projection. On both sides, many star positions are marked by dots inside small circles. Presumably it had the same type of rete and alidade but these are now missing.

The third variant (A105) is constructed much more elaborately. There are two nicely reticulated retes with northern and southern orientation respectively. There are seven plates. Some sides carry northern projections and some others southern projections.

Yet another variant can be seen in an unsigned and undated Sanskrit astrolabe with a single plate (D025) which will be described in section D below. The obverse side carries the northern projections for latitude 27°; on the reverse side, an attempt was made to trace the altitude circles with the southern orientation and these were not completed. There are two openwork retes with northern and southern orientations respectively.

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155 This plate shows close resemblance to the back of an astrolabe by ʿUmar ibn Dawlatshāh ibn Muḥammad al-Kirmānī in 726 AH (AD 1325-26); see Linton 1980; no. 163, pp. 90-91; see also King 2005, p. 57, Fig. 5.1.3.

3.5. *Zawraqī* Horizons and the associated Plates

An Andalusian feature incorporated in several astrolabes is the so-called 'ship' horizon or *zawraqī* horizon. It is represented on the rete as an arc straddling the equinoctial bar. It looks like the lower outlines of a boat (*zawraq*), the corresponding segment of the vertical meridian looking like the upright mast of the boat. Therefore, this arc is designated as *zawraqī* or ship horizon.

The *zawraqī* astrolabe was invented by al-Bīrūnī's contemporary Abu Saᶜīd Sijzī.[156] The main source of our knowledge of this variety of astrolabe is Josef Frank's *Zur Geschichte des Astrolabs*, [157] which deals with several non-standard astrolabes described by al-Bīrūnī in his *Kitāb fī istiᶜāb al-wujūh fī ṣan'at al-asṭurlāb.* Frank describes the astrolabe as follows:

> Of very special interest is the boat-shaped (*al-zauraqī*) astrolabe of Abū Saᶜīd al-Sijzī, which, in its construction, abandons the geocentric model that was generally accepted at his time, in so far as the horizon he designed is movable. The astrolabe consists of a fixed and a movable part. The former is the plate of the northern astrolabe without the azimuth lines. On the plate are drawn, furthermore, the projections of the zodiac and of the fixed stars, as they are shown in the rete of the northern astrolabe. … The movable part is an arc cut out from a metal plate which can be rotated … at the point through which the axis of the astrolabe passes. The convex edge of the arc is the projection of the horizon of the locality for which the plate is calibrated; … Firmly attached to the arc is a ruler with a pointed end—attached in such a way that when the arc coincides with the horizon line drawn on the plate, the ruler rests on the meridian line. … The main advantage of this astrolabe

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156 Wilfred de Graaf informs me (personal communication dated 4.6.14): 'A treatise by Sijzi on the Zawraqi astrolabe is found in a unique manuscript in Istanbul, Topkapi Palace Library, Ahmet III, 3342. There are no figures in this treatise. As you mentioned, the Zawraqi astrolabe is described in great detail by Biruni. The text by Biruni has recently been edited by Sayyid Muhammad Akbar Jawad Husayni and published in Mashhad in 1422 H (lunar). In this publication, however, partly incorrect figures appear. Slightly better figures can be found in an original manuscript, which is now in Leiden (ms. Leiden, Or. 591).'

157 Frank 1920, pp. 18-21.

> against the common astrolabe is the simple shape of the movable part; the use is, however, much more complicated.'[158]

Frank dwells on the various uses of this astrolabe and concludes with the remark:

> 'From the foregoing, one can see that for solving even simple problems two or more operations are necessary, whereas just one operation would often suffice with the common astrolabe.'

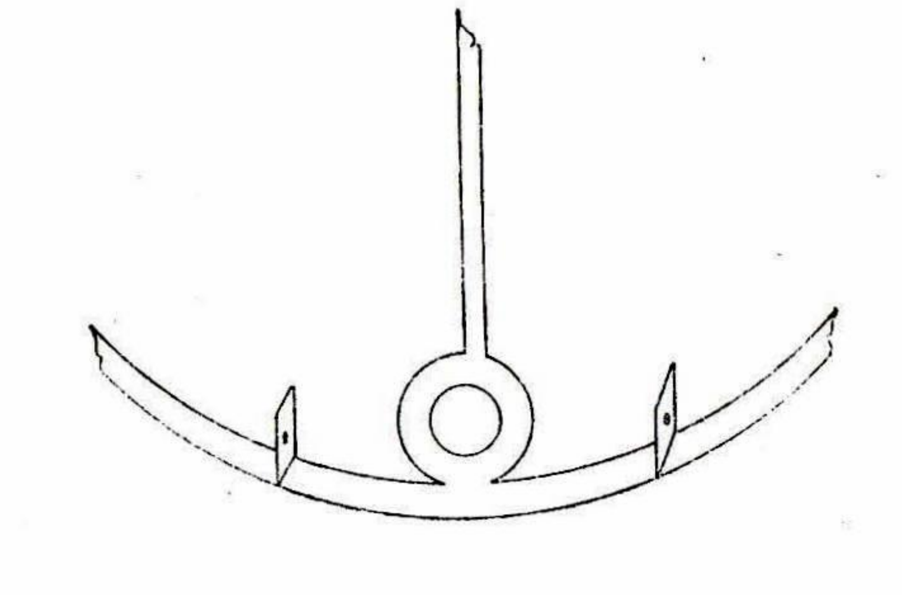

Figure A14 – The rete of a *zawraqī* astrolabe (from Frank 1920)

Astrolabes with this design may have been made and used at the time of its invention in the eleventh century and later, but no such astrolabes are extant today. All that exists now are the ten Lahore astrolabes in which one or two *zawraqī* horizons are incorporated in the otherwise standard retes and which contain a special plate to be used along with the *zawraqī* horizons.

The first step in this direction seems to have been taken by Qā'im Muḥammad who incorporated two arcs in the rete of an astrolabe he made in 1635 (A013).[159] Here both the arcs are curved towards the north; on the upper arc are engraved the names of six zodiac signs from Aries to Virgo; the function of this arc is not known. The lower arc carries the legends 'The Horizon of the Western Solid' and 'The Horizon of the

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158 My translation from Frank's German with slight modifications.

159 Oxford, Museum of the History of Science, accession no. 42730. See also Gunther 1932, no. 71, pp. 191-197, Plates XLV-XLVI, figs. 94-97.

Eastern Solid.'[160] Obviously this arc is the proper *zawraqī* horizon. This has to be used with a special type of projection engraved on one of the plates, which Gunther describes thus: 'a complicated plate in the centre of which is a miniature tablet for lat. 42°, hours 15. Across the bottom is written "A table of the projection of rays", which according to Albiruni is also called "equalization of houses".'[161]

Two short mutually intersecting horizons for latitudes 30° and 33° are added to the rete in an unsigned astrolabe that can be attributed to Qā'im Muḥammad (A016). Some plates are missing in this astrolabe; it is not known whether there was a plate to be used with the *zawraqī* horizons. Seven astrolabes by Ḍiyā' al-Dīn (two are signed by him: A073 and A082; others are attributable to him: A094, A100, A101, A102 and A104) carry these *zawraqī* horizons. Finally, a horizon for 40° occurs in an astrolabe by Jamāl al-Dīn (A122).

There is some variation in the horizons and in the plates that accompany them. In some astrolabes, the horizons are rather short, drawn inside the ecliptic ring. In others they are long, passing through the two equinoxes and reaching up to the Capricorn ring on both sides. The latitudes for which the horizons are drawn also vary.

In four astrolabes by Ḍiyā' al-Dīn, the horizons are for latitudes 29° (Delhi) and 32° (Lahore). In one astrolabe, he has just one horizon for latitude for 32° (Lahore) and in another for latitude 24° (Tropic of Cancer?). Finally, in one astrolabe (A103), there is a special rete consisting of just two horizons for latitudes 37° and 38°. On the other hand, in one of his astrolabes, Qā'im Muḥammad has just one horizon probably for 42° (A013) and in the other for latitudes 30° and 32°. Finally, Jamāl al-Dīn has a horizon for 42°.

The plates which are designed for use are highly complex. These are broadly of two types, those to be used with the short horizons and those to be used with the longer horizons. On the plates to be used with short horizons, first the oblique horizons at the desired latitudes are drawn and then the astrological houses or rather the markings for determining the astrological 'projections of the rays', divided for every 6° at these

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160 Rendered thus by Gunther 1932, p. 192.

161 Gunther 1932, p. 194.

desired latitudes. Then inside the circle of Cancer a miniature plate is engraved with oblique horizons and markings for determining the ‘astrological rays’. In addition, there are engraved a graduated ecliptic ring and the positions of some stars indicated by dots enclosed in small circles. The whole plate is designated as *ṣafīhat maṭraḥ al-shu*ᶜ*ā*ᶜ *kahtrd* (?) *abī rayhān taswīyat al-buyūt khwānand,* ‘plate for finding the projection of the astrological rays according to (?) Abū Rayhān [al-Bīrūnī] [and] equalization of the astrological houses’ (see A013, A083 and A093).

Figure A15 – Short horizons at latitudes 29° and 32° on the rete of the astrolabe made by Ḍiyā’ al-Dīn in 1663 (= Figure A083.3)

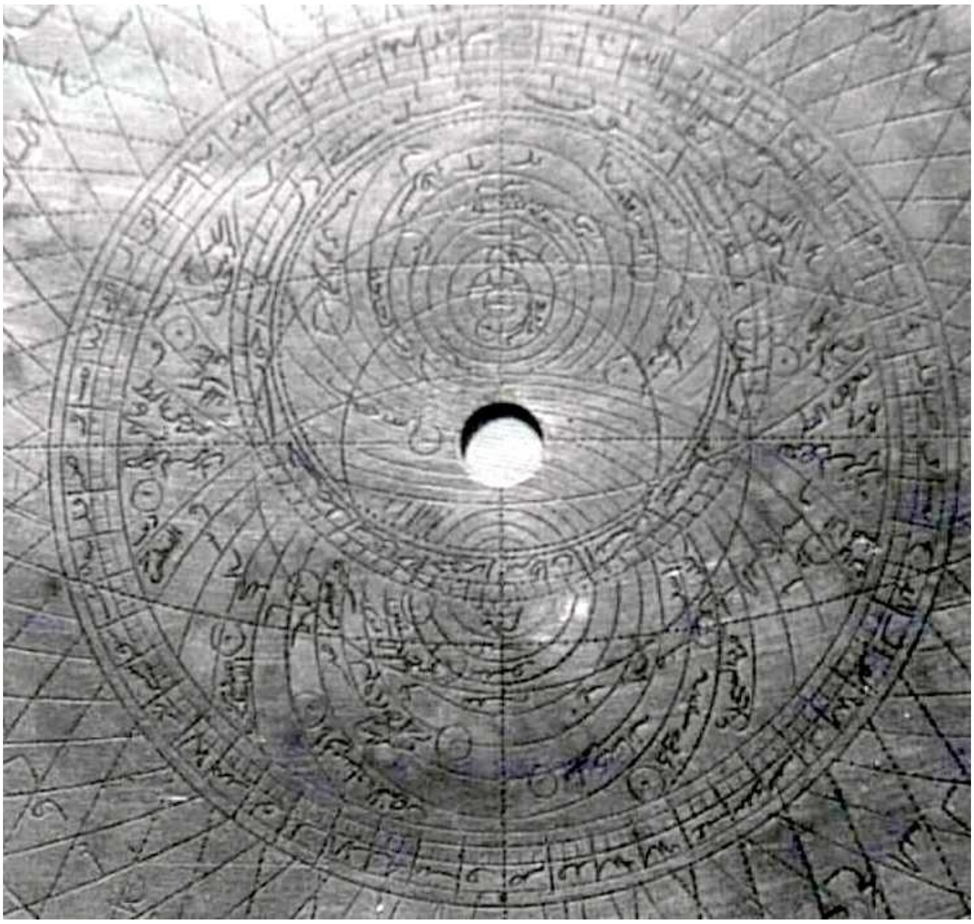

Figure A16 – Miniature plate for use along with the short horizons in the astrolabe made by Ḍiyā’ al-Dīn in 1663 (= detail of Figure A083.4)

The plates to be used with the long horizons are engraved with the oblique horizons and astrological houses at the desired latitudes. The positions of the stars which are on the rete are marked here by dots inside small circles. For example, two long horizons at latitudes 29° and 32° are incorporated in the rete of the astrolabe A100 which is attributable to Ḍiyā’ al-Dīn. Two separate plates are designed for using with these horizons. First there is a plate on which astrological houses are marked for the latitudes 29° and 32°. The second plate carries projections of the altitude circles, azimuth arcs and hours lines for latitude 29° as in a normal plate. Superimposed upon these is the ecliptic circle, divided into signs and groups of 6°, and also the positions of the same 46 stars which are on the rete.[162]

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162 Like the obverse side of the North-South astrolabe by Ḍiyā’ al-Dīn (A091), described previously, this plate also shows close resemblance to the back of an astrolabe by ᶜUmar ibn Dawlatshāh ibn Muḥammad al-Kirmānī in 726 AH (AD 1325-26); see Linton 1980; no. 163, pp. 90-91; see also King 2005, p. 57, Fig. 5.1.3.

Figure A17 – Long horizons at latitudes 29° and 32° in the rete of an astrolabe attributable to Ḍiyā’ al-Dīn (= Figure A100.2)

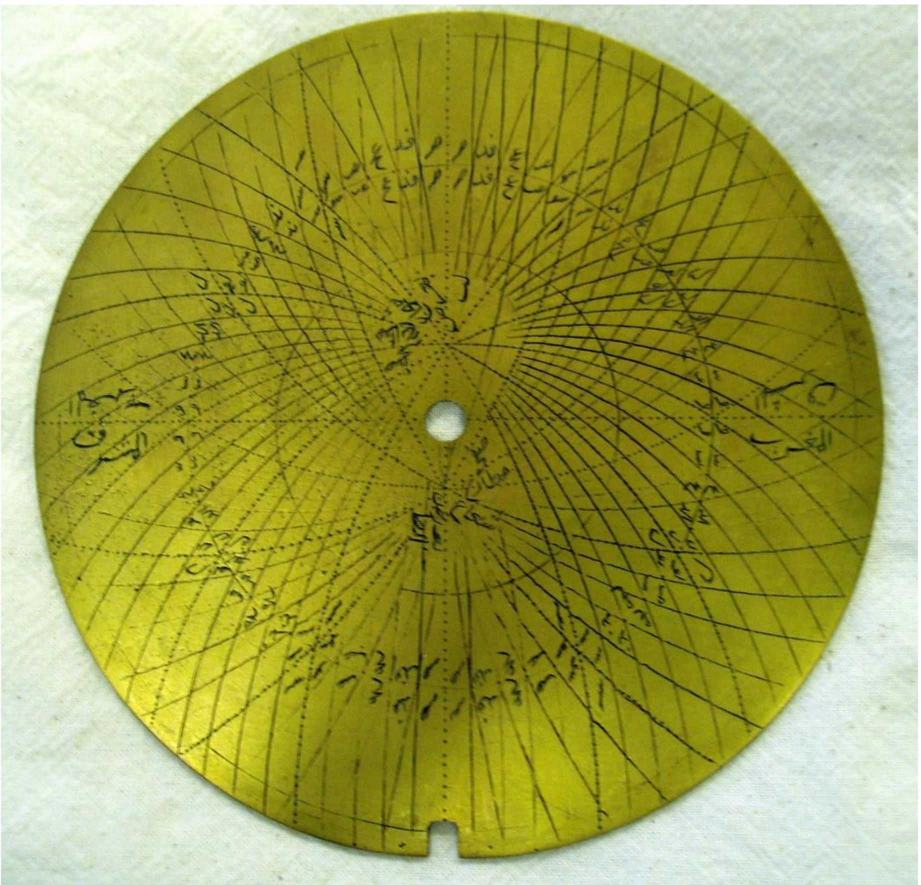

Figure A18 – Astrological houses at latitudes of 29° and 32° in an astrolabe attributable to Ḍiyā’ al-Dīn (= Figure A100.3)

Figure A19 – Plate for latitude 29° with the ecliptic and the positions of 46 stars marked with their names in an astrolabe attributable to Ḍiyā’ al-Dīn (= Figure A100.4)

The following table gives a consolidated overview of the *zawraqī* horizons and the plates with special markings in the ten Lahore astrolabes.

Table A4 ***Zawraqī*** **Horizons and Plates**

	Astrolabe number	*Maker and Date*	*Horizons*	*Special plate*
1	A013	Qā’im 1635	1 short arc for 42°	Plate with a miniature plate inside in the circle of Cancer
2	A016	Qā’im attributable	2 short Arcs for 30° + 33°	Not available

	Astrolabe number	*Maker and Date*	*Horizons*	*Special plate*
3	A074	Ḍiyā’ al-Dīn 1657	1 short arc for 32°	Plate with a miniature plate
4	A083	Ḍiyā’ al-Dīn 1663	2 short arcs for 29°+32°	Plate with a miniature plate
5	A094	Ḍiyā’ al-Dīn attributable	2 short arcs for 29°+32°	Plate with a miniature plate
6	A100	Ḍiyā’ al-Dīn attributable	2 long arcs for 29°+32°	Plate for 29° with several star positions; another plate with markings for astrological ‘projections of the rays’ at 32° and 36°
7	A101	Ḍiyā’ al-Dīn attributable	2 long arcs for 27°+36°	Plate for 27° with a graduated ecliptic ring and some 24 star positions; another plate for 36° with a graduated ecliptic and about 23 positions of stars, some of which are not identical with those marked on the plate for 27°
8	A102	Ḍiyā’ al-Dīn attributable	Long arc for 24°	Plate for 24° with several star positions marked, but no markings for astrological ‘projections of the rays’
9	A103	Ḍiyā’ al-Dīn attributable	Separate rete for oblique horizons of 37° and 38°	There is no plate designed for use with these *zawraqī* horizons
10	A122	Jamal 1666	Long arc 40°	Plate for 40° with star positions; another plate with markings for astrological ‘projections of the rays’ at latitudes 32° and 36°

What advantages these 'ship' horizons and the associated plates bestow is not clear. We may recall Joseph Frank's remark that 'for solving even simple problems [with the *zawraqī* astrolabe] two or more operations are necessary, whereas just one operation would often suffice with the common astrolabe.' Is this merely a case of piling up complexities for displaying virtuosity?[163]

3.6. *Qibla* Maps

By the thirteenth century, the Islamic astrolabes are generally equipped with geographical tables with the longitudes, latitudes, *inḥirāf* (azimuth of *qibla,* i.e., the direction of Mecca), *jahat* (compass direction of Mecca in relation to the observer's locality) and *masāfat* (the linear distance to Mecca). The next step in this development are the maps on which the *qibla* direction is graphically displayed.

In his astrolabe of 1666 (A122), Jamāl al-Dīn engraved a *qibla* map on the inner surface of the mater. There the left hand side carries a geographical gazetteer arranged according to climates. On the right half is the *qibla* map where some 17 localities are marked by means of small circles in the appropriate positions with respect to Mecca.

Twenty years later, in 1686, Jamāl al-Dīn's brother Ḥāmid produced a massive instrument which contains a standard astrolabe and a *qibla* indicator (A113). On several plates, Mecca is placed at the centre and radial lines all around are connected to different localities mainly in India and Greater Iran.

3.7. Circle of the Visibility of Canopus (*Suhayl*)

The last non-standard feature in the Lahore astrolabes is a circle indicating the visibility of the star *Suhayl* (α Carinae, Canopus) which Qā'im Muḥammad engraved on most of the plate faces of his astrolabe of 1635 (A013). On plates for 32°, 35° and 38°, it is seen as a full circle, but on the plates for lower latitudes the circle is not complete. On the western side of this circle is the label *l'mᶜarifat al-ṭalūᶜ al-suhayl,* 'for the knowledge of the rising of Canopus' and the eastern side *l'mᶜarifat al-gharūb al-suhayl,* 'for the knowledge of the setting of Canopus'.

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163 King 2005, p. 806, emphasises the necessity of studying '*zawraqī* markings which have still not been properly explained in the modern literature, in order to document their origin in earlier (that is 9th- and 10th-century) textual sources.' It is still a desideratum.

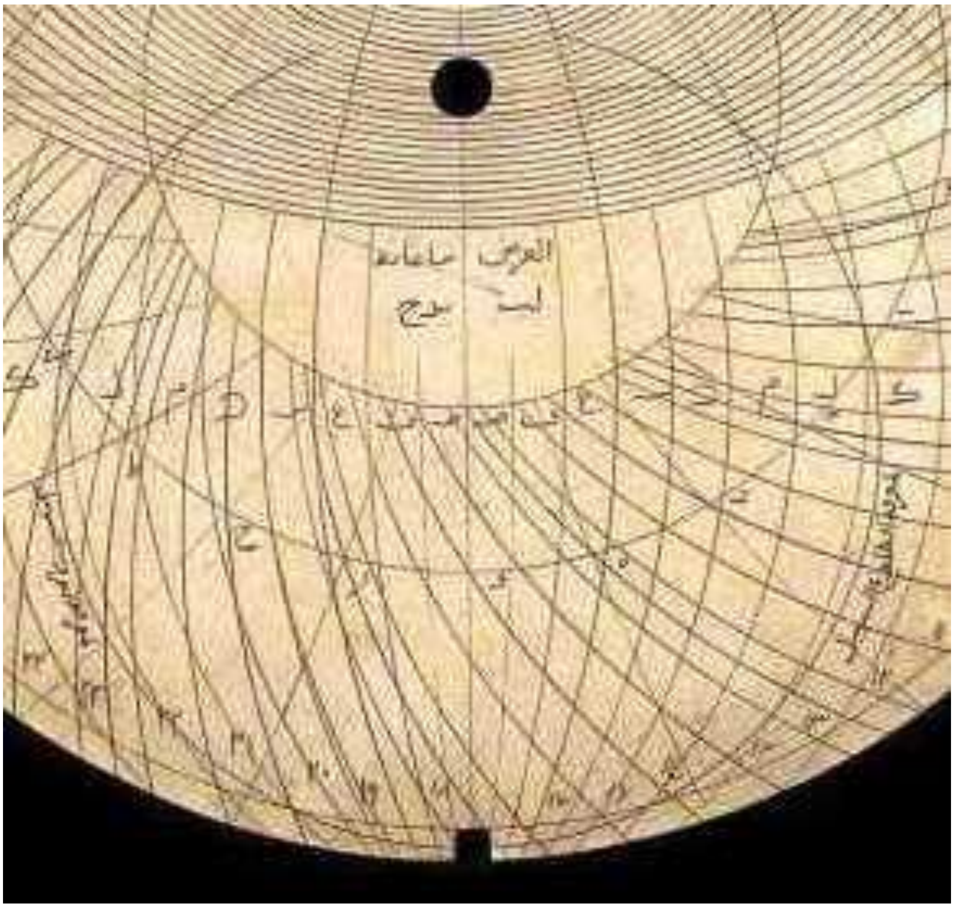

Figure A20 – Canopus circle on the plate for latitude 32° (detail of Figure A013.3)
(© Museum of the History of Science, Oxford)

Canopus is the second brightest star in the heavens. Because of its extreme southern location, it is not represented on astrolabe retes, but on celestial globes it is shown in the lower rudder of the ship Argo Navis.[164] It has a declination of about 52;30° south and therefore it is not visible above the horizon at latitudes lower than 37;30° N.[165]

In Sanskrit, the star is called *Agastya* and Hindus celebrate the first visibility of Canopus after the rainy season with a certain ritual called *Agastya-pūjā* (worship of Canopus). On this, Michio Yano writes as follows:

> The heliacal rising (the first appearance before dawn) of the star *Agastya* (Canopus) is an important astronomical phenomenon concerned with

164 Savage-Smith 1985, pp. 200-201, Fig. 81; see also Kunitzsch 1959, pp. 208-210.

165 In a personal communication of 28 May 2015, Professor Michio Yano informs me as follows: ‘Since Canopus (Agastya)’s declination is about 52.5 degrees south, it can be seen at the place whose geographical latitude is lower than 37.5 degrees north. The lower the latitude the longer is the period of its visibility. At the latitude of Delhi, the star can be seen after mid-August and for quite a long time.’

> weather prognostics. With this phenomenon the rainy season comes to an end and the sky clears. *Pūjā* was performed in the dawn of the first appearance of *Agastya,* and the fortunes of the kings, individuals, and states were foretold. … The date of *Agastya's* first appearance depends on the geographical latitude.[166]

It is highly doubtful that Qā'im Muḥammad was aware of this Hindu custom. No other Lahore astrolabe carries this circle; in fact, no other astrolabe anywhere seems to have this circle as it is not mentioned in any published literature on the astrolabes. It is, therefore, difficult to determine Qā'im Muḥammad's source. That the star does not rise very high above the horizon is indicated by the placement of the circle mostly below the horizon. But it is strange that Qā'im draws the circle of visibility also on the plate for latitude 38° where the possibility of Canopus rising above the horizon is minimal.

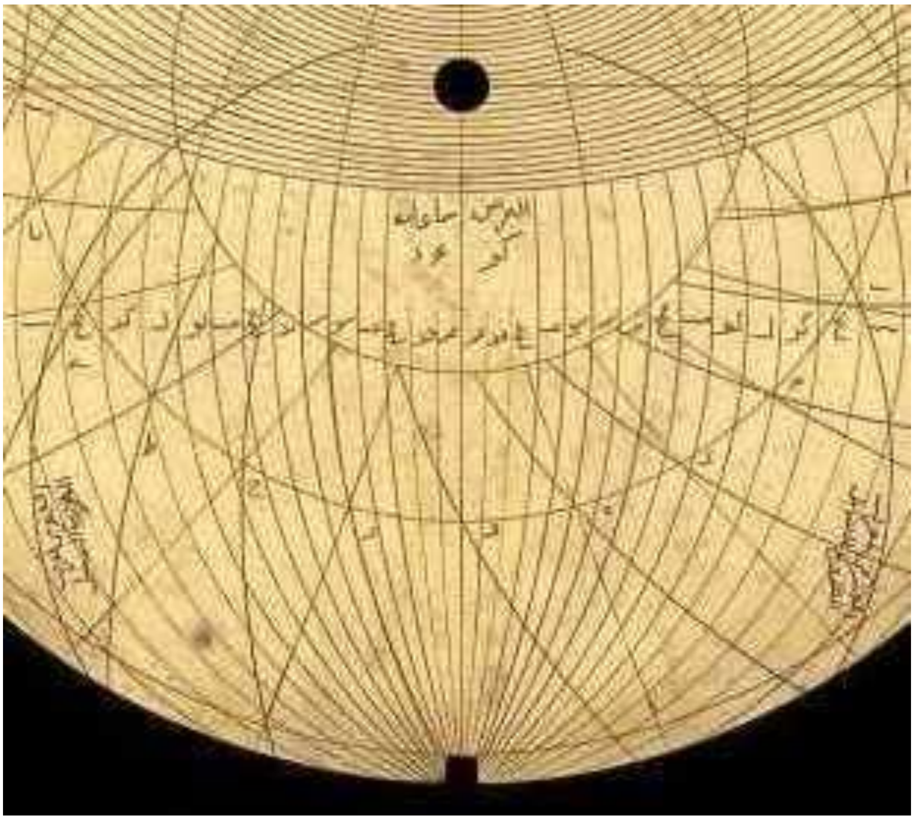

Figure A21 – Canopus circle on the plate for latitude 27° in astrolabe A013
(© Museum of the History of Science, Oxford)

166 Yano 1994, pp. 233. In the following pages, he cites the statements of several Sanskrit texts on the time of the first visibility of Canopus in terms of the sun's position in the zodiac and then a table showing the heliacal risings for each degree from 20° to 37°. See also Rao et al 2016.

I append here the remarks on the plate for latitude 32° verbatim, which James Morrison kindly sent me on 26 and 27 May 2015.

> I took a quick look at the visibility of Canopus at a latitude of 32 deg N. It culminates at only about 5.3 deg above the horizon. This altitude can never be reached on a normal astrolabe plate, which is limited to declinations greater than -23.5 deg. Based on a very quick look, it appears that Canopus would be visible for at least part of a day from about April to early November. That is, Canopus is above the horizon when the Sun is below the horizon. …
>
> I've been looking at the visibility of Canopus at latitude 32 deg. I have been using my program, 'The Electric Astrolabe' to visualize it. It looks to me like it goes something like this: (all dates and positions are for 1635). On about 21 Feb (Pisces 4) Canopus rises just as the Sun sets. Canopus is then visible above the horizon until it sets 4:48 hrs later.
>
> It will continue to be visible at night until it rises just before the Sun on about 28 August (Virgo 4). So, Canopus is visible at night for about 6 mos. of the year. The rising time changes daily by the length of a sidereal day. Canopus' rising time will be about 4 min. earlier each day. This time difference is reflected by the Sun's daily change in longitude on the ecliptic.
>
> When Canopus is visible it is above the horizon for the same amount of time each day; 4:43 (approx.) The question the maker may have been trying to resolve is which 4:43 it can be seen. That is, the rising time of Canopus. His problem was how to represent Canopus when Canopus cannot be shown on the astrolabe. The circles must be his solution.
>
> I notice the Canopus arcs intersect the horizon at the azimuth angle equal to the plate latitude. Could this be a clue? Also, the star Alkaid rises very close to the rising of Canopus and could be used. That is, if Alkaid is visible, so is Canopus. I have not found another star with the same setting time. What mystifies me is why the arcs are circular.

ALLĀHDĀD

The patriarch of the Lahore family of astrolabe makers is Allāhdād (*fl.* 1567).[167] Two astrolabes signed by him are extant. The first is dated AH 975 (AD 1567-68) and is now with the Salar Jung Museum at Hyderabad (A001). The second one, which is not dated, is preserved in the Museum of History of Science at Oxford (A002). On both these astrolabes, he signed his name as Ustād Allāhdād Asṭurlābī Lāhūrī, thus proclaiming himself to be a master craftsman (*ustād*) and a resident of Lahore (*lāhūrī*). Allāhdād's son ᶜĪsā refers to himself, on his own astrolabes, as the son of 'Allāhdād Asṭurlābī Lāhūrī Humāyūnī.' Thereafter, this practice is followed by all members of the family; on the astrolabes and celestial globes crafted by them,[168] they mention their full ancestry beginning with Allāhdād Asṭurlābī Lāhūrī Humāyūnī.

There has been some controversy about the meaning of the epithet *humāyūnī* which, in conjunction with *asṭurlābī,* can only mean the 'astrolabe maker to Humāyūn.' Gunther renders the epithet *humāyūnī asṭurlābī* as the 'royal astrolabe maker'[169] and Nabia Abbott supports this view.[170] Sulaiman Nadvi refutes this saying that the term *humāyūnī* does not have the connotation 'royal'.[171] On the other hand, he speculates that Humāyūn must have invented a special kind of astrolabe which was called *humāyūnī asṭurlāb* and that the members of the Lahore family who manufactured such astrolabes received therefore the sobriquet *asṭurlābī humāyūnī*.[172] But there is no basis for this hypothesis; the astrolabes made by the members of the Lahore family are largely of the conventional type and some of the innovations they made there, as will be shown in this Catalogue, were originally invented in Andalusia in the tenth and eleventh centuries and not by Humāyūn in the second half of the sixteenth century.

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167 His name is variously transliterated in modern literature: Ilāhādād, Allāh Dād, al-Haddād and so on; cf. Abbott 1937, p. 146; Savage-Smith 1985, p. 301, n. 138 and Dar 1994, 174.

168 Except when the instruments are too small for the long signature.

169 Gunther 1932, pp. 187, 197, 208.

170 Abbott 1937, p. 146.

171 Nadvi 1937a.

172 Nadvi 1935, p. 626.

Savage-Smith argues 'that the name Humāyūnī was used to indicate contemporaneity of Allāhdād with Humāyūn and that even if the founder of the workshop [at Lahore] had enjoyed royal favour, his descendants probably did not.'[173] In fact, the descendants also did enjoy royal patronage as will be shown in the following pages. Savage-Smith herself describes a special kind of celestial globe made by Ḍiyā' al-Dīn Muḥammad for Aurangzeb in 1679 and states that on this globe Ḍiyā' al-Dīn refers to himself as the descendant of Allāhdād Humāyūnī.[174] Surely, on this globe made for the Emperor Aurangzeb, Ḍiyā' al-Dīn would not be using the attribute *humāyūnī* with the name of his ancestor merely to express Allāhdād's contemporaneity with Humāyūn, but to stress the fact that Allāhdād made astrolabes for Humāyūn and that his family enjoyed the patronage of Mughal royalty from Humāyūn onwards.

It is, however, true that Allāhdād's only dated astrolabe was made in 1567, i.e. eleven years after Humāyūn's death. But this does not preclude Allāhdād's manufacturing other astrolabes in Humāyūn's lifetime for the use of the emperor who is said to have been interested in astrolabes and celestial globes. Humāyūn's sister Gulbadan Begam reports that when he became impatient of waiting for Hamīdā-bānū Begam's consent to marry him, 'his Majesty took the astrolabe into his own blessed hands, and having chosen a propitious hour, summoned Mīr Abū'l-baqā and ordered him to make fast the marriage bond.'[175] It would be nice to imagine that the astrolabe which Humāyūn took into his blessed hand was crafted by Allāhdād. It is also perfectly legitimate that Allāhdād's descendants should commemorate the royal patronage extended to their ancestor by calling themselves the descendants of the Asṭurlābī Humāyūnī.

Allāhdād's grandson Muḥammad Muqīm adds sometimes 'Shaykh' to Allāhdād's name (A021 etc) and once 'Mullā Shaykh' (A033).[176] Allāhdād's great-grandson Ḍiyā' al-Dīn Muḥammad adds often 'Mullā' to Allāhdād's name (A060 etc) and once to the

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173 Savage-Smith 1985, p. 37.

174 Savage-Smith 1985, pp. 42-43, 232, Figure 17.

175 Gulbadan Begam, p. 151.

176 According to Steingass 1892, the epithet *Shaykh* has the following meanings: venerable old man, man of authority, chief, learned in religion and law, etc.; the term *Mullā* connotes a learned man, judge, priest and so on.

names of all the ancestors, i.e. father Qā'im Muḥammad, grandfather ᶜĪsā and great-grandfather Allāhdād (A062) and once even to his own name (A065).

The two astrolabes which carry Allāhdād's signature are unusually large and heavy. The dated piece at Hyderabad measures 199 mm in diameter. The other one at Oxford is still larger with a diameter of 256 mm. On the various plates in both these astrolabes, some of the circles are inlaid with silver, a feature not met with in any other astrolabe. Obviously these astrolabes were not made for the daily use of common astronomers but were meant for the high nobility as ostentatious show-pieces. The two astrolabes differ from one another not only in size but in respect of ornamentation as well. In the Hyderabad astrolabe, the crown-like projection at the top (*kursī*) is solid and the various star-pointers in the rete (*ᶜankabūt*) are joined by archaic patterns. In the astrolabe at Oxford, on the other hand, the *kursī* is pierced with a finely cut design and the star-pointers are joined by a delicate floral tracery. These two features became the hallmark of the Lahore astrolabes.

The Hyderabad astrolabe has five plates to serve the latitudes 21;40° (Mecca), 28;20° (Delhi?), 30°, 33;15° (Baghdad), 34°, 37°, 38°, 39;37° (Samarqand), 45°, and a plate of horizons of the eastern type. The astrolabe at Oxford has six plates calibrated for latitudes 21;40° (Mecca), 27° (Agra?), 30°; 33;25° (Baghdad), 34;30°, 37°, 38°; 39;37° (Samarqand), 45°, a plate of ecliptic coordinates, a plate of horizons of the western type, and a universal plate for all latitudes. Thus, the plates are not latitude-specific, but locality-specific. Although Allāhdād calls himself *lāhūrī,* it is surprising that in either astrolabe there is no plate for Lahore which lies on 31;50°. Interestingly, the Oxford astrolabe shows two uncommon features: the plate of horizons of a type which is common in the astrolabes made in the Maghreb and the universal plate for all latitudes which was originally invented by Ibn Bāṣo in Andalusia in the eleventh century.

On the inner side of the mater, Allāhdād engraves a geographical gazetteer with five separate columns for the names of cities, their latitudes, longitudes, *inḥirāf* and the duration of the longest day. The majority of these cities are from the Middle East, starting from Mecca at 21;40° and reaching up to Samarqand at 39;37°. But there are also a few Indian cities, and this number increases with each successive descendant. The Hyderabad astrolabe has a gazetteer of 96 cities, but the cells meant for the *inḥirāf* and the longest day are not filled in at all. The Oxford astrolabe contains a gazetteer of 157 localities. Here the cells meant for *inḥirāf* and the longest day are filled partially, some by the astrolabe maker himself and some by a later hand in a much smaller script; but there are many cells in these two columns which are blank.

On the back, in both astrolabes, the upper half of the rim carries the altitude scales and the lower half cotangent scales. There is a sexagesimal trigonometric quadrant in the upper left with 60 horizontal lines and a solar quadrant in the upper right with equidistant arcs of the signs of the zodiac. In the lower half are engraved two shadow squares and inside these an elaborate table which combines several astrological tables.

Besides these two astrolabes, there are two other astrolabes which share some of the features of these two astrolabes and are therefore attributable to Allāhdād. One of these is in the Museum of the History of Science at Oxford (A003) and the other in the National Maritime Museum at Greenwich (A004). There is a great similarity in the workmanship of A002 and A003; their retes are almost alike in their design and have exactly the same 36 star pointers. Both contain Ibn Bāṣo's universal plate for all latitudes.

Likewise, there is much in common between A001 and A004. Both have solid *kursīs* of identical design and the retes in both are similar. As in A001, the geographical gazetteer in A004 has provisions for longitudes, latitudes, *inḥirāf* and the duration of the longest day, but the last two columns are not filled in. There are five plates in A004; some of the sides were engraved by Allāhdād and some by another person. The limb on the front of the mater was engraved by Allāhdād, but the back by another person who drew a graph for the midday solar altitude at latitude 32°. Therefore, this second person must be contemporary and worked on the astrolabe together with Allāhdād; it is quite likely that this second person was Allāhdād's son ᶜĪsā whose astrolabes contain graphs for the midday solar altitude at latitude 32°.

A001 and A004 are stylistically alike and must have been produced about the same time ca. 1567. The other two A002 and A003 show greater refinement in design and must have been produced some time later.

Since his descendants invariably trace their genealogy back to Allāhdād, it may be assumed that he migrated to Lahore and set up his workshop there at the behest of Humāyūn. He may have come from Samarqand. The diversity of styles in astrolabes, the absence of a latitude plate designed for the latitude of Lahore and the incomplete gazetteers indicate that he was experimenting with various features. However, in the two astrolabes at Oxford (A002 and A003) can be seen the beginning of the stylistic peculiarities which characterize the Lahore school.

Index of Astrolabes by Allāhdād (*fl.* 1567)

A001 ◎Astrolabe by Allāhdād, 975 AH (AD 1567-68) 89

Diameter 199 mm, Hyderabad, Salar Jung Museum (#113/1/xxxv)

A002 ◎Astrolabe by Allāhdād, not dated 105

Late 16th century, Lahore, Diameter 255 mm, Oxford, Museum of the History of Science (# 47376)

A003 ◎Astrolabe attributable to Allāhdād, not dated 136

Late 16th century, Lahore, Diameter 208 mm, Oxford, Museum of the History of Science (#34611)

A004 ◎Astrolabe attributable to Allāhdād and ᶜĪsā, not dated 160

Late 16th century, Lahore, Diameter 160 mm, London, National Maritime Museum, Greenwich (# AST0560)

ᶜĪSĀ

Allāhdād's son ᶜĪsa (*fl.* 1601-1604)[206] is known through three astrolabes; a fourth can be attributed to him on stylistic grounds. He may also have engraved parts of an unsigned astrolabe which is attributable to his father (A004). Though of varying sizes, the four astrolabes listed above present a uniform appearance with a solid and multi-lobed *kursī.* More important, in these astrolabes ᶜĪsā introduces for the first time several features which were emulated by his descendants and which become the characteristic features of the Lahore astrolabes.

(i) The sigmoid graph on the back for the meridian altitude of the sun throughout the year. ᶜĪsā draws it for the latitude of Lahore which is the seat of his family. It occurs in A005 (*khaṭṭ zawal*), A006 (*khaṭṭ nisf al-nahār*) and also in A004 (*khaṭṭ niṣf al-nahār*). His son Muḥammad Muqīm usually draws two curves for 29° and 32° which are the latitudes of the two Mughal imperial cities Agra and Lahore, while the nephew Ḍiyā' al-Dīn Muḥammad adds a third graph for 29°, the latitude of Delhi.

(ii) ᶜĪsā engraves the projections for 27° and 32° on the two faces of the same plate.

(iii) Likewise he employs the two sides of the same plate for the ecliptic coordinates and horizons. In the plate of horizons, he introduces the scales of declinations along the two diameters.

(iv) He introduces a combined projection for the latitudes 90°and 0° on one of the plates and a similar composite projection of the latitudes 72° and 18° on another plate.

(v) His gazetteers provide only the longitudes and latitudes and ignore the other parameters.

(vi) He reduces the astrological data on the back to the minimum and shows just the correspondences between the twelve signs of the zodiac and the twenty-eight lunar mansions in two concentric semicircles.

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206 He is usually referred to as Mullā (learned man) by his descendants, but occasionally also as Ḥāfiẓ, i.e., one who has memorized the entire *Qurᶜān* (e.g. A065).

Thus ᶜĪsā lays the real foundation for what are typically the Lahore astrolabes. The *kursī* is not yet standardized in his oeuvre, nor the design of the rete. Just as Allāhdād was experimenting with two styles of rete, ᶜĪsā too appears to be trying different styles. The unusual style of rete seen in A006 and in A008 was one such experiment which was not continued later on. The same is the case with the decorative arches in the degree scales and in the gazetteer in A008. This too was not continued in the subsequent astrolabes.

Index of Astrolabes by ᶜĪsa (*fl.* 1601-1604)

A005 ◎Astrolabe by ᶜĪsā, 1009 AH (AD 1601) 177
Diameter 170 mm, Chicago, Adler Planetarium & Astronomy Museum (# N-69)
A006 ◎Astrolabe by ᶜĪsā, 1013 AH (AD 1604-5) 190
Diameter 120 mm , Chicago, Adler Planetarium & Astronomy Museum (#A-79)
A007 ◎Astrolabe by ᶜĪsā, not dated 207
Ca. 1600, Lahore, Diameter 262 mm, UK, Ely, Cambs, PC
A008 Astrolabe attributable to ᶜĪsā, not dated 212
17th century, Diameter 119 mm, PLU

QĀ'IM MUḤAMMAD

Qā'im Muḥammad (*fl.* 1622-1637), the elder son of ᶜĪsā, is known through four astrolabes; three others can be attributed to him. He also produced one astrolabe jointly with his younger brother Muḥammad Muqīm. There is yet another astrolabe in Hannover (A009) which is said to have been produced by the sons of ᶜĪsā (*ibnī ᶜīsā ibn allāhdād*), but it is uncertain whether the inscription is authentic. Qā'im is the first member of the family to produce celestial globes as well, four of which survive today[221] Until this time, celestial globes were produced first as two hollow spheres and then joined together. Qā'im Muḥammad produced them as single hollow spheres by applying the *cire perdue* or lost wax method which had been employed in India for long time in casting bronze statues.

Qā'im's astrolabes and celestial globes carry dates between 1622 and 1637. Thus the period of his activity falls in the reigns of the Mughal emperors Jahāngīr (r. 1605-1627) and Shāh Jahān (r. 1628-1658). On some of his instruments, Qā'im mentions the time of production in the regnal years of Jahāngīr or of Shāh Jahān, in addition to or in lieu of the Hijrī years.

Qā'im enjoyed the patronage of high dignitaries of the Mughal court. In 1622, he made a celestial globe for Nawāb I'tiqād Khān, who was a brother of Nūr Jahān Begum, the queen of Jahāngīr. Five years later, in 1627 he created a fabulous astrolabe for Nawāb Khwājah Abū al-Ḥasan who held many important positions under Jahāngīr, such as the Subahdār of Deccan and the General Paymaster of the Household; only the rete of this astrolabe survives in Patna (A011).

The Lahore astrolabes became more or less standardized in the work of ᶜĪsā. Qā'im made further refinement in the design of the *kursī* and rete, and also introduced certain innovations.

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221 These four globes are
F001 Celestial Globe by Qā'im 1032/1622-23, d. 188 UK, Blackburn
F002 Celestial Globe by Qā'im 1035/1625-26, d. ? Paris, PC
F003 Celestial Globe by Qā'im J 22/1626-27, d. 156 London, V&A
F004 Celestial Globe by Qā'im 1046/1637-38, d. 173 Patna.
Full descriptions of these globes will appear in section F.

Although four of his astrolabes are known to exist, no details are available about A010 and A012, and in A011 only the rete is extant. Therefore, his work has to be evaluated on the basis of the single complete astrolabe A013. Here the rete contains as many as 58 named star pointers. On the latitude plates, in addition to the lines for seasonal and equal hours, there are also, for the first time, lines for the traditional Indian time units of *ghaṭīs* of 24 minutes. In the 7 plates, 5 plate faces carry double projections of two latitudes. The gazetteer is arranged according to the Ptolemaic climates, but commences with the second climate so that the holy cities Mecca and Medina occupy the first places. The rete carries, for the first time, *zawraqī* or ship horizons and there is a special plate to be used with these *zawraqī* horizons.

There are two innovations in this astrolabe which are unique and are not found in any other astrolabe produced in India. The first is the circle for the visibility of the star *Suhayl* (Canopus) traced on many plates. Second, the back contains a series of completely circular scales including an eccentrically placed *Rūmī* or Syro-Macedonian calendar.

Except these two, the other features mentioned above occur in three unsigned astrolabes A014, A015 and A016, and for this reason these astrolabes can be attributed to Qā'im Muḥammad. In A014, lines for *ghaṭīs* are drawn on many plates; what is new here is that on many plates the maximum duration of daylight is expressed in *ghaṭīs.* Also in common with A013 is the gazetteer commencing with the second climate. A015 is much larger and displays superior workmanship; yet in technical aspects it is exactly like A014 with the same gazetteer and with the plates serving the same latitudes. The third unsigned astrolabe A016 displays splendid workmanship like Qā'im's A011. In its rete, the names of the zodiac signs are cut in silhouette along the rim of the ecliptic almost in the same manner as in A011. It also carries *zawraqī* horizons as in A013.

Index of Astrolabes by Qā’im Muḥammad (*fl.* 1622-1637)

A009 ◎Astrolabe by the two sons of ʿĪsā, 1018 AH (AD 1609-10)............................. 227
Diameter 84, Hannover, Kestner-Museum (#1914, 61)

A010 Astrolabe by Qā’im Muḥammad, 1034 AH (AD 1624-25)................................ 240
Diameter ?, PLU

A011 ◎Astrolabe by Qā’im Muḥammad made for Nawāb Khwāja Abū al-Ḥasan, 1037 AH (AD 1627).. 241
Diameter of the rete 326 mm, Patna, Khuda Bakhsh Oriental Public Library

A012 Astrolabe by Qā’im Muḥammad, 1041 AH (AD 1631-32)................................ 248
Diameter 120 mm, Baghdad, Museum of Arab Antiquities (# 9721)

A013 ◎Astrolabe by Qā’im Muḥammad, 1045 AH (AD 1635-36).............................. 249
Diameter 190.5 mm, Oxford, Museum of the History of Science (#42730)

A014 ◎Astrolabe attributable to Qā’im Muḥammad, 1031 AH (AD 1621-22)............ 279
Diameter 169 mm, London, Nasser D. Khalili Collection of Islamic Art (#SCI 12)

A015 ◎Astrolabe attributable to Qā’im Muḥammad, not dated 293
Diameter 330 mm, London, Nasser D. Khalili Collection of Islamic Art (#SCI 10)

A016 ◎Astrolabe attributable to Qā’im Muḥammad, not dated 304
Diameter 194 mm, London, Nasser D. Khalili Collection of Islamic Art (#SCI 36)

A017 Astrolabe by Qāim Muḥammad & Muḥammad Muqīm, not dated..................... 322
Diameter 120 mm , Baghdad, Museum of Arab Antiquities (#9720) = National Museum of Iraq

MUḤAMMAD MUQĪM

Muḥammad Muqīm (*fl.* 1621-1659) is the second son of Mullā ᶜĪsa and a grandson of the patriarch Allāhdād. He is a prolific astrolabe maker. There are extant 33 astrolabes and 2 celestial globes which bear his signature.[267] There are also eight unsigned astrolabes which can be attributed to him. He also produced an astrolabe jointly with his elder brother Qā'im Muḥammad (A017). There is yet another astrolabe in Hannover (A009) which is said to have been produced by the sons of ᶜĪsā (*ibnī ᶜīsā ibn allāhdād*), but it is uncertain whether these sons are indeed Qā'im and Muqīm and whether the inscription itself is authentic.

Muqīm's brother Qā'im made a name for himself in casting celestial globes by the *cire perdue* process. Muqīm seems to have produced just two globes.[268] Muqīm's main forte is the astrolabe. Although he made a large number of astrolabes, he rarely repeats the design or even the size. The sizes of his astrolabes range from 344 to 45 mm in diameter. While the one with the diameter of 45 mm is the world's smallest astrolabe (A051), there are about a dozen small pieces with diameters measuring less than 100 mm. Neither the large ones nor the very small pieces are really convenient for actual use, but must have been highly prized collector's items at the Mughal court.

Unlike the other members of his family, he does not add non-standard features in his astrolabes. The only exception are two astrolabes with zoomorphic retes (A026) and (A052). While Allāhdād gives bird shapes to two star pointers, α Lyrae and α Aquilae,

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267 No images are available for 8 of the 33 astrolabes. It is possible that the same astrolabe was listed twice in the CCA or in the Répertoire. The Peabody Essex Museum, Salem, MA, holds an astrolabe (# M2560) which the Museum thinks is 'possibly by Muhammad Maqim (sic!) at Lahore'. But it carries certain features characteristic of the astrolabes by Muḥammad Ṣāliḥ. Therefore it is attributed to him and will be described under B014. CCA 3565 records an astrolabe by Muqīm at the National Maritime Museum, Haifa. The museum sent me some images of the astrolabes in their holdings, but none of these can be by Muqīm. Anon 1989, p. 4, states that in the collection at Arriyadh 'Mughal astrolabist Muhammad Muqim [is] represented by three instruments.' It cannot be determined which the three are.

268 Répertoire records, by mistake, two celestial globes: no. 12, dated 1049/1639-40, Kuwait, PC, and no. 17, dated 1067/1656-57, London, Victoria and Albert Museum (#2324-1883). The second globe is actually by Ḍiyā' al-Dīn as the inscription cited in the Répertoire clearly indicates.

in his undated astrolabe (A002), the grandson Muqīm fills the retes with dozens of zoomorphic and anthropomorphic shapes.[269]

Muqīm's elegantly crafted *kursīs* are generally reticulated, but display much variety. Some have highly complex patterns; some others are pierced by just a few large incisions so that what remains looks like an arrangement of tulips, their flared petals forming the profiles of the *kursī* (A020, A021, A050, A059). Some *kursīs* are solid without any reticulation. In two cases floral patterns are engraved in low relief (A033 and A037); two others have extravagant profiles (A043 and A057).

Likewise, the floral traceries connecting the various star pointers in the rete also display much variety. A recurring motif in these retes are bell-shaped flowers or tulips with two flared petals, one long and another short, the longer petal usually forming the star-pointer.

The back contains a trigonometric quadrant in the upper left and a solar quadrant in the upper right with two sigmoid graphs for the latitudes of the two imperial cities of Agra (27°) and Lahore (32°). In three astrolabes (A041, A055, A058), lines for *ᶜasr* prayers are drawn in the solar quadrants. In A057 there is a universal horary quadrant in the upper right. In the lower half are engraved double shadow squares and an assortment of astrological tables. The latter vary according to the size of the astrolabe. In smaller astrolabes, just two semicircular rows display the names of the 12 zodiac signs and the names of the 28 corresponding lunar mansions. In larger astrolabes, there are usually tables of the limits, faces or decans, triplicities, multiples of excess of revolution; sometimes also tables of climates.

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269 On zoomorphic astrolabes, see Gingerich 1987a.

Index of Astrolabes by Muḥammad Muqīm (*fl.* 1621-1659)

A018 Astrolabe by Muḥammad Muqīm, 1030 AH (AD 1621-22)................................ 331

Diameter ca. 130 mm, PLU, Ex-Kazan, Russia

A019 ◎Astrolabe by Muḥammad Muqīm, 1032 AH (AD 1622-23)............................ 344

Diameter 67.5 mm, Paris, PC

A020 Astrolabe by Muḥammad Muqīm, 1034 AH (AD 1624-25)................................ 349

Diameter 86 mm, Istanbul, Kandilli Observatory (No. 6)

A021 ◎Astrolabe by Muḥammad Muqīm, 1034 AH (AD 1624-25)............................ 363

Diameter 114 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (Registration No. 40,420; Acc. No. 66)

A022 Astrolabe by Muḥammad Muqīm, 1034 AH (AD 1624-25)................................ 372

Diameter 84 mm, Samarkand, The Samarkand Museum of History and Art of Uzbek People (#131, A.172.2)

A023 ◎Astrolabe by Muḥammad Muqīm, 1047 AH (AD 1637-38)............................ 373

Diameter 94.5 mm, PLU, ex. PC, Brussels

A024 Astrolabe by Muḥammad Muqīm, 1047 AH (AD 1637-38)................................ 379

Diameter 256 mm, Islamabad, Islamabad Museum (# ID 186)

A025 ◎Astrolabe by Muḥammad Muqīm, 1047 AH (AD 1637-38)............................ 397

Diameter 205 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (Reg. No. 40.421, Acc. No. 65.)

A026 ◎Zoomorphic Astrolabe by Muḥammad Muqīm, 1047 AH (AD 1637)............. 405

Diameter 258 mm, Hyderabad, Salar Jung Museum (#114/1/xxxv)

A027 Astrolabe by Muḥammad Muqīm, 1038 AH (AD 1638-39)................................ 426

Diameter 102 mm, Kolkata, Indian Museum (# 24430)

A028 ◎Astrolabe by Muḥammad Muqīm, 1051 AH (AD 1641-42)............................ 427

Diameter 128 mm, Oxford, Museum of the History of Science (#46935)

A029 ◎Astrolabe by Muḥammad Muqīm, 1051 AH (AD 1641-42)............................ 439

Diameter 134 mm, London, National Maritime Museum, Greenwich (# AST0579)

A030 Astrolabe by Muḥammad Muqīm, 1051 AH (AD 1641-42)................................ 449

Diameter 77 mm, PLU: ex-London, Sotheby's (Catalogue 25 October 2017, lot 149)

A031 ◎Astrolabe by Muḥammad Muqīm, 1053 AH (AD 1643-44)............................ 453

Diameter 167 mm, Oxford, Museum of the History of Science (#43704)

A032 Astrolabe by Muḥammad Muqīm, 1053 AH (AD 1643-44) 470
Diameter 144 mm, Washington, National Museum of American History

A033 ◎Astrolabe by Muḥammad Muqīm, 1070 AH (AD 1659-60) 480
Diameter 142 mm, London, British Museum (#1893,0616.4)

A034 Astrolabe by Muḥammad Muqīm, not dated 496
Diameter 270 mm, Paris, PC (Georges Charliat)

A035 Astrolabe by Muḥammad Muqīm, not dated 499
Diameter 206 mm, Paris, PC

A036 Astrolabe by Muḥammad Muqīm, not dated 500
Diameter 204 mm, Paris, PC

A037 Astrolabe by Muḥammad Muqīm, not dated 504
Diameter 160 mm, Lahore, Lahore Museum (#M.44-1)

A038 Astrolabe by Muḥammad Muqīm, not dated 516
Diameter 146, PLU: ex-Canada, Don Mills, Ontario Science Centre (#68.165.1)

A039 Astrolabe by Muḥammad Muqīm, not dated 528
Diameter 140 mm, PLU, ex. Sotheby's

A040 ◎Astrolabe by Muḥammad Muqīm, not dated 529
Diameter 134 mm, New Haven, Yale University, Harvey Cushing/John Hay Whitney Medical Library, Edward Clark Streeter Collection of Weights & Measures

A041 ◎Astrolabe by Muḥammad Muqīm, not dated 536
Diameter 129 mm, Oxford, Museum of the History of Science (#37530)

A042 ◎Astrolabe by Muḥammad Muqīm, not dated 552
Diameter 107 mm, PLU, ex-Antwerp, PC

A043 ◎Astrolabe by Muḥammad Muqīm, not dated 563
Diameter 105 mm, Paris, Institut du Monde Arabe (#AI 86-25)

A044 Astrolabe by Muḥammad Muqīm, not dated 574
Diameter 96 mm, Cannes, PC

A045 Astrolabe by Muḥammad Muqīm, not dated 575
Diameter 92 mm, PLU

A046 Astrolabe by Muḥammad Muqīm, not dated 579
Diameter 92 mm, Fontenay-le-Comte, PC

A047 Astrolabe by Muḥammad Muqīm, not dated 580
Diameter 90 mm, PLU

A048 Astrolabe by Muḥammad Muqīm, not dated 581

Diameter 90 mm, PLU, Ex-Paris, Sottas

A049 Astrolabe by Muḥammad Muqīm, not dated 596

Diameter 80 mm, Hyderabad, Saidiya Library

A050 Astrolabe by Muḥammad Muqīm, not dated 607

Diameter 90 mm, Qatar, Doha, Museum of Islamic Art (# MW.391.2007); Ex-Skinner, Bolton, USA

A051 Smallest Astrolabe by Muḥammad Muqīm, not dated 615

Diameter 45 mm, PLU, ex-Sotheby's, New York

A052 ◎Zoomorphic Astrolabe attributable to Muḥammad Muqīm, not dated 620

Diameter 344 mm, Jaipur, Jai Singh's Observatory

A053 Astrolabe attributable to Muḥammad Muqīm, not dated.................................... 647

Diameter 263 mm, Qatar, Doha, Museum of Islamic Art (# MW.396.2007); ex-Alain Brieux, Paris; ex-Nachet, Paris

A054 Astrolabe attributable to Muḥammad Muqīm, not dated.................................... 650

Diameter 204 mm, PLU: ex-Alain Brieux, Paris

A055 Astrolabe attributable to Muḥammad Muqīm, not dated.................................... 652

Diameter 160, PLU; ex-London, Christie's

A056 ◎Astrolabe attributable to Muḥammad Muqīm, not dated.................................. 659

Diameter 107 mm, Oxford, Museum of the History of Science (#54063)

A057 Astrolabe attributable to Muḥammad Muqīm, not dated.................................... 667

Diameter 105 mm, Qatar, Doha, Museum of Islamic Art (# MW.396.2007); ex-London, Christie's (auction catalogue of 7 Match 1991, lot 86)

A058 Astrolabe attributable to Muḥammad Muqīm, not dated.................................... 671

Diameter 100 mm, Hyderabad, Saidiya Library

A059 ◎Astrolabe by Muḥammad Muqīm, not dated 685

Diameter 92 mm, Leiden, Museum Boerhaave (A 277)

ḌIYĀ’ AL-DĪN MUḤAMMAD

The instrument production in the Lahore family reached its culmination, both in quantity and quality, in the oeuvre of Ḍiyā’ al-Dīn Muḥammad (*fl.* 1637-1680) of the fourth generation. He is the most prolific and versatile member of the family. He inherited his father Qā'im Muḥammad’s skill in casting celestial globes and his uncle Muqīm’s virtuosity in crafting astrolabes. He also attempted a number of unusual varieties of astrolabes and globes. There are extant 34 astrolabes which bear his signature; another 12 astrolabes can be attributed to him on stylistic grounds.[359] Moreover, he also produced some 18 celestial globes.

On a majority of his instruments, he signs his name as ضياؤالدين , but in a few cases he writes without *wāw* (و) ضياءالدين , as shown in the table below. The name ‘Ḍiyā’ al-Dīn’ means ‘the light of the faith’ in Arabic and this name is fairly common among Muslims. But it is never written with a *wāw* in between. Scholars of Arabic and Persian whom I consulted are unanimous in saying that the letter *wāw* (و) here is not in accordance with the Indo-Persian or Persian usage and that it should not have been added in this name. From his vast and varied oeuvre, it is evident that Ḍiyā’ al-Dīn was not a mere artisan, but a scholar well-versed in mathematical astronomy and well-acquainted with Arabic works on astronomical instruments by the Andalusian astronomers. Why then did he spell his name in this manner in most of his creations remains a mystery.[360]

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[359] CCA attributes the following four astrolabes to Ḍiyā’ al-Dīn, but these are not mentioned in the Répertoire; therefore, they are not included in our catalogue:

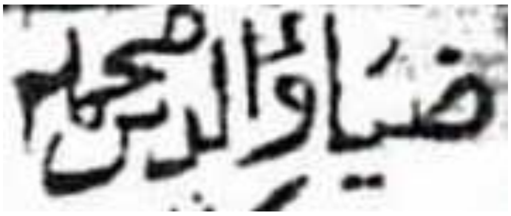
CCA 3524	nd	d. ?	Paris Landau Collection
CCA 3525	nd	d. ?	Paris Landau Collection
CCA 3517	nd	d. ?	Paris Alain Brieux
CCA 2829	1068/1657	d. ?	‘Cairo, Hariri Collection (Instruments now thought to be in Cairo, Museum of Islamic Art)’; but I was informed that the Cairo museum does not have such an astrolabe.

[360] It is also a mystery why the knowledgeable Répertoire refers to him as ‘Muḥammad b. Qā’im Muḥammad’ in the heading to the section dealing with his instruments and dismisses ‘Ḍiyā’ ud-Dīn’ as the surname!

Astrolabe A062 of 1057/1647-48
Chicago

Astrolabe A063 of 1059/1649-50
Lucknow

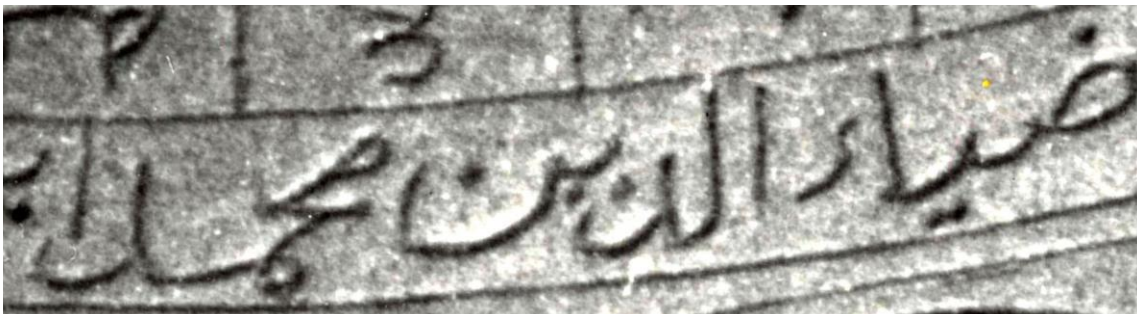
Celestial Globe of 1064/1653-54
Aligarh



Astrolabe A077 of 1070/1659-60
Washington

Celestial Globe of 1074/1663-64
Hyderabad

Astrolabe A073 of 1067/1656-57
Jaipur, without wāw



Zarqālī astrolabe A092 of 1091/1680-81, Jaipur, without wāw

Ḍiyā’ al-Dīn’s astrolabes range from 52 to 555 mm in diameter. Like Muqīm, he also made several miniature astrolabes with diameters measuring less than 100 mm. Muqīm’s astrolabe with a diameter of 45 mm is the world’s smallest (A051), but many of its original components are missing, whereas Ḍiyā’ al-Dīn’s astrolabe of 1064/1653-54 (A072) with its diameter of 65.5 mm is fully intact. The delicately crafted miniature astrolabe has a jewel-like quality.

The *kursīs* in Ḍiyā’ al-Dīn’s astrolabes are mostly reticulated and their surface is engraved with decorative patterns. He incorporates large flowers in the *kursīs* as well as in the traceries of the retes. Some of the floral compositions with large flowers and leaves in the retes (e.g. A071, A073, A075, A076, A092 and A095) recall similar floral arrangements in *pietra dura* style in Mughal monuments.

Ḍiyā’ al-Dīn’s geographical gazetteers generally commence with Mecca or Medina and reach up to India. But in 8 astrolabes, the gazetteers are arranged according to climates of antiquity (*iqlīm*) (e.g. A074, A075, A089 and others). In three astrolabes, the gazetteers are arranged according to regions (also called *iqlīm*) from the Maghreb in the west up to Hind in the east (A063, A073 and A094). Apparently Ḍiyā’ al-Dīn is the only one to arrange the gazetteers in this fashion.

Like Muqīm, Ḍiyā’ also draws two graphs for the midday altitude of the sun throughout the year for the latitudes of Agra (27°) and Lahore (32°) on the back of several astrolabes. After Shāh Jahān shifted the Mughal capital from Agra to Delhi in 1639, Ḍiyā’ began to add a third graph for the latitude of Delhi (29°). In A098, there is a fourth graph for 36° (middle of the fourth climate, i.e., the middle of the inhabited world). A096 and A102 have 2 more graphs for latitudes 21° (Mecca) and 24° (Tropic of Cancer). A068 of 1062/1651-52 displays 8 graphs for latitudes 15°, 19°, 21°, 27°, 29°, 32°, 35° and 40°. The highest number of curves to be found in the Lahore astrolabes are in A097 for 9 latitudes, viz., 19°, 27°, 32°, 36°, 40°, 44°, 49°, 56° and 60°.

As in Muqīm’s astrolabes, in Ḍiyā’ al-Dīn’s astrolabes also, the number of astrological tables engraved on the back vary according to the size of the astrolabe. Smaller astrolabes carry just two semi-circular rows engraved with the names of the 12 signs and the names of 28 lunar mansions. On larger astrolabes, there are also tables of the limits, faces, triplicities and excess of revolution.

Three astrolabes contain a table which is not found in other Lahore astrolabes. This table is called *zadwal sāᶜāt ṭulūᶜ burūj bi-ᶜarḍ baᶜḍī az bilād mulk al-Hind* (table of the times of rising of signs in the latitudes of some of the localities belonging to the country of India). While A073 provides the rising times of the signs at each degree of latitude from 20° to 39°,[361] A093 has a table from 20° to 40° and A094 from 21° to 40°.

In astrolabe A102, the upper right quadrant is designed as a solar quadrant as well as a universal horary quadrant. As a solar quadrant, it carries declination arcs for every 10° of solar longitude and 6 sigmoid curves to show the midday altitude of the sun throughout the year at 6 different latitudes. As a universal horary quadrant, it bears dotted arcs of unequal hours, numbered from 1 to 6 in the anticlockwise direction and from 7 to 12 in the reverse direction.

The lower half on back of the astrolabe A099 is designed in an extraordinary manner. The shadow squares, usually engraved in the lower half, are superimposed on the trigonometric and solar quadrants in the upper half. The lower half is engraved as the left half of a plate for latitude 27° with the altitude circles for each 6° and with lines for equal hours before sunrise. Moreover, the ecliptic circle is drawn along with the names of the 6 signs from *al-Saraṭān* to *al-Qaws.* These projections are framed by a degree scale, divided in 2° and 10° and labelled in 10s, from 90 to 10 (from the south point to the east point) and again from 10 to 90 (from the east point to the north point). With this configuration, the standard operations can be performed by means of the alidade as is done on an astrolabe quadrant.

Zawraqī Horizons

We have seen that Qā’im Muḥammad incorporates *zawraqī* or ‘ship’ horizons for the first time in two of his astrolabes. Ḍiyā’ al-Dīn adds them in 7 astrolabes in two different styles. In astrolabes A083 and A094, two small horizons for latitudes 29° and 32° are inserted in the rete in such a manner that they form a fish-like figure inside the ecliptic ring. A special plate is designed to be used with these horizons, on which astrological houses, divided into 5 units of 6°, are drawn for the two latitudes and a

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[361] This table is reproduced in Kaye, p. 23.

miniature plate is created inside the circle of Cancer where the two small horizons on the rete fit. The positions of several stars are marked on this miniature plate with dots enclosed in small circles. A074 also follows the same style, but with just a single horizon for latitude 32°.

In the second style, the horizons are large and stretch over the whole width of the rete up the Capricorn ring on both sides. The plates to be used with the horizons do not carry miniature plates inside the circle of Cancer, but the entire plates are filled with star positions and astrological houses. Thus in A101, there are two *zawraqī* horizons for latitudes 29° and 32° and the two plates calibrated for 29° and for 32° are engraved with astrological houses as well as star positions. There are slight variations in this style. In A100, two *zawraqī* horizons for 29° and 32° are added to the rete; on the plate face calibrated for 29°, the positions of all those stars are marked which are in the rete; on another plate face, astrological houses are marked for both these latitudes 29° and 32°. In astrolabe A102, there is just one *zawraqī* horizon on the rete for latitude 24° and the plate face for 24° is marked with star positions and astrological houses. In another variation, in A103, there is an extra rete carrying just two *zawraqī* horizons for latitudes 37° and 38°, but without any corresponding plates for these latitudes.

North-South Astrolabes

Three astrolabes are designed as north-south astrolabes (*asṭurlāb shamālī wa janūbī*). In A091, the obverse side of the single plate is engraved as a latitude plate for 33° and on it is superimposed a northern projection of the ecliptic circle together with the positions of 46 stars, while the reverse side is designed for latitude 35° on which a southern projection of the ecliptic circle is drawn and the positions of the same 46 stars, but with southern orientation, are marked. The choice of these latitudes is rather intriguing. There is a minimal rete consisting of just the ecliptic ring and an alidade with a sighting tube.

Astrolabe A104 also consists of a single plate on which the two sides carry respectively the northern and southern projections of the ecliptic and of some star positions. However, the obverse side is engraved with a double projection for two latitudes 32° and 36° and the reverse with a quadruple projection for latitudes 22°, 25°, 27° and 29°.

Astrolabe A105 is much more complex with two separate retes, one with a northern projection and another with a southern projection, and with plates carrying either northern projections, or southern projections, or both.

Zarqālī Universal astrolabe

The crowing glory of Ḍiyā’ al-Dīn’s work is the monumental *Zarqālī* astrolabe he made in 1681 with a diameter of 555 mm. It consists of a single plate which can be used at all latitudes. It was originally designed by Ibn al-Zarqalluh at Toledo in the eleventh century. There are not many Zarqālī astrolabes extant today and none of these is comparable to the magnificent creation of Ḍiyā’ al-Dīn Muḥammad.

Index of Astrolabes by Ḍiyā’ al-Dīn Muḥammad (fl. 1637-1680)

A060 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1047 AH (AD 1637-38) 711
Diameter 117 mm, Chicago, Adler Planetarium & Astronomy Museum (# A-86)

A061 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1056 AH (AD 1646-47) 723
Diameter 193 mm, PLU, ex-Paris, Collection Nicolas Landau

A062 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad 1057 AH (AD 1647-48) 724
Diameter 121 mm, Chicago, Adler Planetarium & Astronomy Museum (#A-70)

A063 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1059 AH (AD 1649-50) 735
Diameter 185 mm, Lucknow, Darul Uloom Nadwatul Ulama

A064 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1059 AH (AD 1649-50) 754
Diameter 190 mm, PLU: ex-London, Sotheby’s (Catalogue 14 April 2010, lot 119)

A065 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1060 AH (AD 1650-51) 759
Diameter 314 mm, PLU; ex-New York, The Brooklyn Museum (# X638.2)

A066 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1061 AH (AD 1650-51) 766
Diameter 210 mm, PLU, ex-London, Christie’s (catalogue 24 September 1992, lot 113)

A067 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1062 AH (AD 1651-52) 769
Diameter 149 mm, Cardiff, National Museum of Wales (# 39.573/2)

A068 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1062 AH (AD 1651-52) 775
Diameter 266 mm, Hyderabad, Salar Jung Museum (#112/2/xxxv)

A069 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1064 AH (AD1653-54) 791
Diameter 108 mm, Oxford, Museum of the History of Science (# 38862)

A070 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1064 AH (AD 1653-54) 801
Diameter ?, PLU, ex. Habibganj Collection

A071 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1064 AH (AD 1653-54) 802
Diameter 103 mm, PLU: ex-London, Sotheby’s (Catalogue 1 April 2009, lot 102)

A072 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1064 AH (AD 1653-54) 808
Diameter 63.5 mm, Cologne, PC

A073 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1067 AH (AD 1656-57) 821
Diameter 308 mm, Jaipur, Jai Singh’s Observatory

A074 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1068 AH (AD 1657-58) 851
Diameter 171 mm, Paris, PC.

A075 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1069 AH (AD 1658-59).................... 858
Diameter 175 mm, Oxford, Museum of the History of Science (#53637)

A076 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1069 AH (AD 1658-59)....................... 873
Diameter 145 mm, PLU: ex-London, Sotheby’s (auction 27 April 2005, lot 46; auction 9 April 2008, lot 212)

A077 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1070 AH (AD 1659-60)....................... 876
Diameter 88 mm, Washington DC, National Museum of American History

A078 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1071 AH (AD 1660-61).................... 883
Diameter 83 mm, Chicago, Adler Planetarium & Astronomy Museum (#A-81)

A079 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1071 AH (AD 1660-61).................... 893
Diameter 114 mm, London, Nasser D. Khalili Collection of Islamic Art (#SC111)

A080 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1072 AH (AD 1661-62).................... 899
Diameter 182 mm, Paris, PC

A081 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1073 AH (AD 1662-63).................... 901
Diameter 106 mm, Cambridge, Mass., PC of Professor Owen Gingerich

A082 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad,1073 AH (AD 1662-63)..................... 912
Diameter 95 mm, Chicago, Adler Planetarium & Astronomy Museum (#A-78)

A083 ◎Ship Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64)............ 922
Diameter 223 mm, Patna, Khuda Bakhsh Oriental Public Library

A084 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64)....................... 939
Diameter 52 mm, PLU, ex-London, Sotheby’s (catalogue 27 April 2005, lot 47, pp. 68-69).

A085 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64).................... 943
Diameter 130 mm, Rampur, Rampur Raza Library (#1345 D)

A086 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64).................... 958
Diameter 113 mm, London, Victoria and Albert Museum (#419-1876)

A087 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64)....................... 961
Diameter 101mm, Mosul, al-Basha Mosque

A088 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64)....................... 962
Diameter ?, PLU, ex. Aligarh, Maulana Abu Bakar

A089 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1077 AH (AD 1666-67)....................... 963
Diameter 190 mm, Srinagar, Sri Pratap Singh Museum (# 2750/A)

A090 Astrolabe by Ḍiyā’ al-Dīn Muḥammad, 1077 AH (AD 1666-67)....................... 983
Diameter ?, PLU

A091 ◎North-South Astrolabe by Diyā’ al-Dīn Muḥammad 1085 AH (AD 1674-75) 984
Diameter 163 mm, Jaipur, Jai Singh’s Observatory

A092 ◎Zarqālī Universal Astrolabe by Ḍiyā’ al-Dīn Muḥammad, made for Nawāb Iftikhār Khān, 1091 AH (AD 1680-1681) 995

Diameter 555 mm, Jaipur, Jai Singh’s Observatory

A093 ◎Astrolabe by Ḍiyā’ al-Dīn Muḥammad, not dated 1014

Diameter 282, London, Nasser D. Khalili Collection of Islamic Art of Islamic Art (#SC 283)

A094 ◎Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1029

Between 1648 and 1658, Diameter 526 mm, London, Nasser D. Khalili Collection of Islamic Art (#SCI 53)

A095 Astrolabe attributable To Ḍiyā’ al-Dīn Muḥammad, not dated 1067

Diameter ?, PLU

A096 Astrolabe attributable to Ḍiyā’ al- Dīn Muḥammad, not dated 1073

Diameter 174 mm, Oxford, Museum of the History of Science (#33411)

A097 ◎Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1092

Diameter 140 mm, Chicago, Adler Planetarium (#N 68)

A098 Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1107

Diameter 202 mm, PLU, ex-Paris, Brieux

A099 Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1112

Diameter 80 mm, PLU, ex-London, Sotheby’s (auction 24 October 2007, lot 196)

A100 ◎Ship Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1119

Diameter 150 mm, Oxford, Museum of the History of Science (#33796)

A101 ◎Ship Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1136

Diameter 241 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (#40.416)

A102 Ship Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1142

Diameter ?, PLU

A103 ◎Ship Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad, not dated 1160

Diameter 100 mm, Chicago, Adler Planetarium (#M39)

A104 ◎North-South astrolabe attributable to Ḍiyā’ al-Dīn, not dated 1175

Diameter 194 mm, London, Victoria & Albert Museum (#809-1889)

A105 ◎North-South astrolabe attributable to Ḍiyā’ al-Dīn, not dated 1180

Diameter 128 mm, Chicago, Adler Planetarium (# L-100)

ḤĀMID

Ḥāmid ibn Muḥammad Muqīm (*fl.* 1655-1691) belongs to the fourth generation of the Lahore family of instrument makers. He is known though 11 astrolabes and 3 celestial globes produced between August 1655 and June 1691.[505] In an astrolabe preserved in the Houghton Library of the Harvard University, the year of production is engraved as 1038 (= AD 1628-29). But this year is too early for Ḥāmid's work since his own father's Muḥammad Muqīm's instruments begin to appear only from AH 1031/ AD 1021-22. Therefore, the year on the astrolabe at the Houghton Library must have been wrongly inscribed as 1038 instead of 1068.

Apart from producing astrolabes and celestial globes, Ḥāmid also copied a manuscript of Naṣīr al-Dīn al-Ṭūsī's highly popular manual on the astrolabe entitled *Bist Bāb* on 10 Sha'bān 1087 (=17 September 1678).[506]

Ḥāmid's astrolabes are relatively small, with diameters ranging between 77 and 142 mm, and they lack the elegance of the astrolabes crafted by his father Muḥammad Muqīm and by his elder cousin Ḍiyā' al-Dīn. Ḥāmid attempts to make his mark in other respects. The most remarkable of these is that, in 10 out of the 14 instruments which bear his signature, he mentions the precise date (*tārīkh*) and month (*shahr*), besides the year of production.

We have seen that in his gazetteers, Allāhdād wished to provide *inḥirāf* along with longitudes and latitudes, but failed to do so, and that thereafter Allāhdād's descendants limited their gazetteers to just longitudes and latitudes. Ḥāmid tries to revive this older tradition and gives *inḥirāf* and *jihat,* in addition to longitudes and latitudes in some of his astrolabes (A113 - A117, A120).

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505 His three globes are dated 1655 (Cambridge, Whipple Museum), 1682 (Hyderabad, Salar Jung Museum) and 1690 (Pune, Kelkar Museum). Their full descriptions will appear in section F.

506 Cf. *Catalogue of the Persian Manuscripts in the Salar Jung Museum and Library, Hyderabad*, Vol. IX, Hyderabad 1988, Ms. no. 3877: *Bist Bāb*, with an anonymous commentary, copied by Ḥāmid Aṣṭurlābī ibn Muḥammad Muqīm on 10 Sha'bān 1087/17 September 1678. While showing me the manuscript, Dr Rahmat Ali Khan, the then Keeper of Manuscripts, Salar Jung Museum, remarked about the particularly poor calligraphy of Ḥāmid.

In the Lahore astrolabes, the arcs of declination are drawn at equal spaces in the solar quadrants at the back. Ḥāmid follows this family tradition in some of his astrolabes, but in others, he projects them stereographically as is done in Safavid astrolabes. In drawing the graphs of the midday altitude of the sun in all seasons (*khaṭṭ niṣf al-nahār*), he gives greater importance to the latitude of Mecca (at 20° or 21°) than to the latitudes of Lahore, Agra and Delhi.

The most remarkable piece of his work is the highly complex and massive astrolabe and qibla-indicator which he completed on 6 December 1686. It is constructed like a round casket in which are stacked the rete and seven plates. Five of these plates are calibrated for different latitudes, but inside the circle of Cancer on each plate are drawn lines radiating from the centre, indicating the azimuths of *qibla* of certain places with their names. The remaining two plates are exclusively devoted to *qibla*-lines from various localities. A very elaborate set of astrological tables is engraved on the back . The geographical gazetteer is engraved on the inner side of the lid, providing the longitude, latitude, the *inḥiraf* or the azimuth of qibla, and *jihat* for 142 localities. This and other gazetteers of Ḥāmid contain names of several Indian cities for the first time, such as Rajmahal and Gaur in Bengal, Bandar Sūrat (the seaport of Sūrat) in Gujarat and Gulbarga in Karnataka.

Apparently, this instrument was meant as presentation piece for some high noble at the Mughal court whose name must have been engraved on the front side of the *kursī.* About a hundred years later, a new owner got the original erased and had his name engraved at the apex of the upper right quadrant on the back as Mālik Qadirdād Khān Muhandis 1186 sanah (owner Qadirdād Khān, engineer/technician, AD 1772-73).

Index of Astrolabes by Ḥāmid ibn Muḥammad Muqīm (*fl.* 1655-1691)

A106 ◎Astrolabe by Ḥāmid, 1068 AH (AD 1657) 1203

2 Muharram 1068 = 9 October 1657, Diameter 131 mm, London, Nasser D. Khalili Collection of Islamic Art (SCI 13)

A107 ◎Astrolabe by Ḥāmid, 1038 AH (AD 1628-1629) (sic!) 1215

Diameter 125 mm, Cambridge, Mass., Harvard University, Houghton Library (552-1)

A108 ◎Astrolabe by Ḥāmid, 1069 AH (AD 1658) 1228

21 Rabī' l-awwal 1069 (17 December 1658), Diameter 112 mm, Hyderabad, Salar Jung Museum (#114/2/xxxv)

A109 ◎Astrolabe by Ḥāmid, 1071 AH (AD 1661) 1239

9 Jumādā al-Awwal 1071 (9 January 1661), Diameter 112 mm, Paris, Institut du Monde Arabe (AI 86-27)

A110 Astrolabe by Ḥāmid, 1071 AH (AD 1660-61).. 1246

Diameter 103 mm , Cologne, PC

A111 Astrolabe by Ḥāmid, 1086 AH (AD 1676) 1255

6 Dhū-l-qaʿda 1086 (22 January 1676), Diameter 141 mm, Qatar, Doha, Museum of Islamic Art (# MW.349.2007), ex-London, Sotheby's

A112 Astrolabe by Ḥāmid, 1087 AH (AD 1677) 1268

4 Dhu'l Ḥijja 1087 (6 Feb 1677), Diameter 140 mm, Kolkata, Asiatic Society

A113 ◎Astrolabe and Qibla Indicator by Ḥāmid, 1098 AH (AD 1686).................... 1269

21 Muharram 1098 (7 December 1686), Diameter 300 mm, London, Nasser D. Khalili Collection of Islamic Art (# SCI 5)

A114 ◎Astrolabe by Ḥāmid, 1099 AH (AD 1688) 1290

12 Rabīᶜ al-Awwal 1099 (17 January 1688) , Diameter 89 mm, London, Guildhall, the Hon'ble Clockmaker's Company Museum

A115 Astrolabe by Ḥāmid, 1102 AH (AD 1691) 1297

24 Jumādā al-Awwal 1102 (22 Feb 1691) , Diameter 116 mm, PLU, ex-Paris, Brieux

A116 Astrolabe by Ḥāmid, 1102 AH (AD 1691) 1303

24 Ramadan 1102 (20 June 1691) , Diameter 126 mm, London, PC? ; ex-Milan

A117 ◎Astrolabe attributable to Ḥāmid, not dated 1308

Diameter 132 mm, Hyderabad, Salar Jung Museum (#112/1/xxxv)

A118 ◎Astrolabe attributable to Ḥāmid, not dated 1318

Diameter 117 mm, Edinburgh, National Museum of Scotland (#1962.13)

A119 ◎Astrolabe attributable to Ḥāmid, not dated 1327

Diameter 77 mm, London, Science Museum (1938-437)

A120 Astrolabe attributable to Ḥāmid, not dated 1336
Diameter 132 mm, PLU: ex-Sir John Findlay Collection
A121 Astrolabe attributable to Ḥāmid, not dated 1340
Diameter 96 mm, PLU

JAMĀL AL-DĪN

Jamāl al-Dīn ibn Muḥammad Muqīm (*fl.* 1666-1691), the last member of the Lahore family, is known from four astrolabes which he produced between 1077/1666-67 and 1103/1691-92. He may have produced more than four astrolabes during this quarter century, but these have not come to light. Even among the four extant astrolabes, the last two are not accessible. Of the remaining two, A123 is an ordinary astrolabe, while A122 is an impressive production with a zoomorphic rete and *qibla*-indicating lines engraved along with the regular gazetteer. Two other astrolabes are attributed to him: a common astrolabe (A127) and a universal astrolabe (A126). The latter is a rare *shakkāziyya* type of universal astrolabe and resembles closely the unique astrolabe made by Ibn al-Sarrāj in Aleppo in 729/1328-29, which David King considers to be 'the most sophisticated [instrument] ever made between Antiquity and 1600'.[527]

[527] King 2005, p. 694.

Index of Astrolabes by Jamāl al-Dīn ibn Muḥammad Muqīm (*fl.* 1666-1691)

A122 ◎Zoomorphic Astrolabe and Qibla Indicator by Jamāl al-Dīn 1077 AH (AD 1666-67) 1347

Diameter 251 mm, London, Science Museum (#1985-2077)

A123 ◎Astrolabe by Jamāl al-Dīn, 1092 AH (AD 1681-82) 1368

Diameter 166 mm, London, Victoria & Albert Museum (30-1882 (I.S)

A124 Astrolabe by Jamāl al-Dīn, 1094 AH (AD 1682-83) 1373

Diameter 160 mm, Kuwait, PC; ex-collection Alain Brieux

A125 Astrolabe by Jamāl al-Dīn, 1103 AH (AD 1691-92) 1375

Diameter 254 mm, Istanbul, Türk ve Islam Eserlieri Müzesi (T 3478)

A126 Universal Astrolabe attributable to Jamāl al-Dīn, not dated 1376

Diameter 187 mm, Qatar, Doha, Museum of Islamic Art (# MW.352.2007)

A127 Astrolabe attributable to Jamāl al-Dīn, not dated 1382

Diameter 96 mm, PLU; ex-London, Sotheby's

ASTROLABES ATTRIBUTABLE TO THE LAHORE WORKSHOP

There are a few Indo-Persian astrolabes which display certain characteristic features of the Lahore astrolabes, but are difficult to be assigned to any individual member of the Lahore family. Some of these may have been commenced by Muqīm or Ḍiyā’ al-Dīn, but completed by the apprentices in the Lahore workshop.

Index of Astrolabes attributable to the Lahore Workshop

A128 ◎Astrolabe attributable to the Lahore Workshop, not dated 1397
Diameter 183 mm, Hyderabad, State Museum of Archaeology (# P720)

A129 Astrolabe attributable to the Lahore Workshop, not dated 1408
Diameter 153 mm, Washington, D.C., National Museum of American History (#2569)

A130 ◎Astrolabe attributable to the Lahore Workshop, not dated 1425
Diameter 240 mm, Paris, PC

A131 ◎Astrolabe attributable to the Lahore Workshop, not dated 1437
Diameter 204 mm, Patna, Khuda Bakhsh Oriental Public Library

A132 ◎Astrolabe attributable to the Lahore Workshop, not dated 1448
Diameter 124 mm, Jaipur, Jai Singh's Observatory

A133 ◎Astrolabe attributable to the Lahore Workshop, not dated 1460
Diameter 130 mm, London, Science Museum (#1953-264)

A134 Astrolabe attributable to the Lahore Workshop, not dated 1464
Diameter 95 mm, PLU; ex-collection of Henri Michel

A135 Astrolabe by Muḥammad Sharīf ibn Muḥammad, not dated 1468
Diameter 102 mm, Chicago, Adler Planetarium (# DPW 52)

A136 Two Astrolabe Plates, not signed, not dated 1481
17th century, Diameter 90 mm, Srinagar, Sri Pratap Singh Museum

B. INDO-PERSIAN ASTROLABES PRODUCED BY OTHERS

INTRODUCTION

Compared to the output of the various members of the Lahore family, the astrolabes produced by instrument makers outside this family are not many. As against the 130 and odd surviving astrolabes of the Lahore family, those produced by others in the sixteenth and seventeenth centuries do not even come up to a score. Likewise, the names of the instrument makers who are not members of this family can be counted on one's fingers.

In the seventeenth century, Pandit who produced the bilingual astrolabe B002 and possibly his teacher were active at the court of Jahāngīr at Agra; ᶜAbd al-Qādir Muḥibb and his son Ibn Muḥibb Ḥaqīqa, and Muḥammad Ṣāliḥ of Thatta were engaged in instrument production in Panjab. While ᶜAbd al-Qādir Muḥibb does not show any familiarity with the Lahore astrolabes, his son Ḥaqīqa and Ṣāliḥ emulate in their astrolabes certain features of the Lahore astrolabes. Two outstanding astrolabes of the seventeenth century are the bilingual astrolabe of 1616 by Pandit (B002) and the Frankfurt astrolabe by ᶜAbd al-Qādir Muḥibb of about the same period (B006).

Of the eighteenth century, just one astrolabe bearing a date at the beginning of the century (B017) and another produced towards the end of century (B018) are extant. A third astrolabe (B019) may also have been made by the same person who produced B018. It is inexplicable why there was such a shortfall in the production of astrolabes in this century. Lack of patronage could not have been the reason; even in the nineteenth century, several princely states patronised instrument makers. Moreover, the theory and practice of the astrolabe continued to be taught in madrasas in the Indian subcontinent. Even if the teachers and pupils used simple astrolabes, some of these should have survived.

However, towards the middle of the nineteenth century, there was an upsurge in the production of astrolabes. This happened not through any external causes, but due to a remarkable man, Lālah Bulhomal Lāhorī, who was at home both in the Islamic and the Sanskrit traditions of astronomical instrumentation and was also exposed to the new developments taking place in Europe. He was attached to the court of Kapurthala.

Bulhomal, a Hindu of Khatri caste, together with his associates — two Muslims named Pīr Bakhsh Lāhorī and Ghulām Qādir Kapūrthalī, and a Hindu Brahmin Joshī Dharm Chand— made Lahore once again a vibrant centre of production of astronomical instruments. I have counted 45 instruments of diverse types, with legends either in Arabic/Persian, or in Sanskrit, or in English, produced by Bulhomal and his associates in and around Lahore towards the middle of the nineteenth century.[561]

Aside from this group around Bulhomal of Lahore, two other names are known. Muḥammad Faḍl Allāh was associated with the court of the Nizam of Hyderabad. A celestial globe made by him in 1808 is extant.[562] His grandfather Muḥammad Mūsā, a resident of Aurangabad, sported the sobriquet *asṭurlābī.* He must have produced astrolabes in the eighteenth century, but none came to light. The second is Ghulām Ḥussayn Jawnpūrī who was the court astronomer of the Raja of Tikari in Bihar. He composed a large encyclopaedia of astronomy and mathematics entitled *Jāmi^{c} Bahādur Khānī* in Persian in 1833; a lithograph edition was published from Calcutta in 1835.[563] In the second chapter of the fifth book of this work, he describes the construction and use of 12 different astronomical instruments together with their illustrations. These are the celestial globe, astrolabe, sine quadrant, *dhāt al-ḥalqatayn* (double ring), *labna* (meridian wall or mural quadrant), *suds-i fakhrī* (Fakhrī sextant), *dhāt al-ḥalaq* (armillary sphere), *dhāt al-shu^{c}batayn* (triquetrum), *dhāt al-thuqbatayn* (dioptre), *ḥalqā-i i^{c}tidālī* (horizontal ring), *shāmlah ufaqī* and *suds-i in^{c}ikās*. Ten of these are traditional Islamic instruments and the last two are of European origin. *Shāmlah ufaqī* consists of a mounting system for the telescope which can be rotated in horizontal as well as in vertical planes. *Suds-i in^{c}ikās* is Hardley's Reflecting Sextant.[564]

What is of immediate interest for us is that a celestial globe made by him in 1816 is extant and will be described below (G006).[565] It is possible that he may have also

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561 Sarma 2015b; see also the short introduction to his work in the following pages.

562 Sarma 1996a, pp. 27-28.

563 Jawnpūrī 1835.

564 Ansari & Sarma 1999-2000.

565 Ansari & Sarma 1999-2000, pp. 84-87, Figs. 1-4.

produced astrolabes and other instruments, but these have not come to light so far. His illustration of the astrolabe is reproduced below.

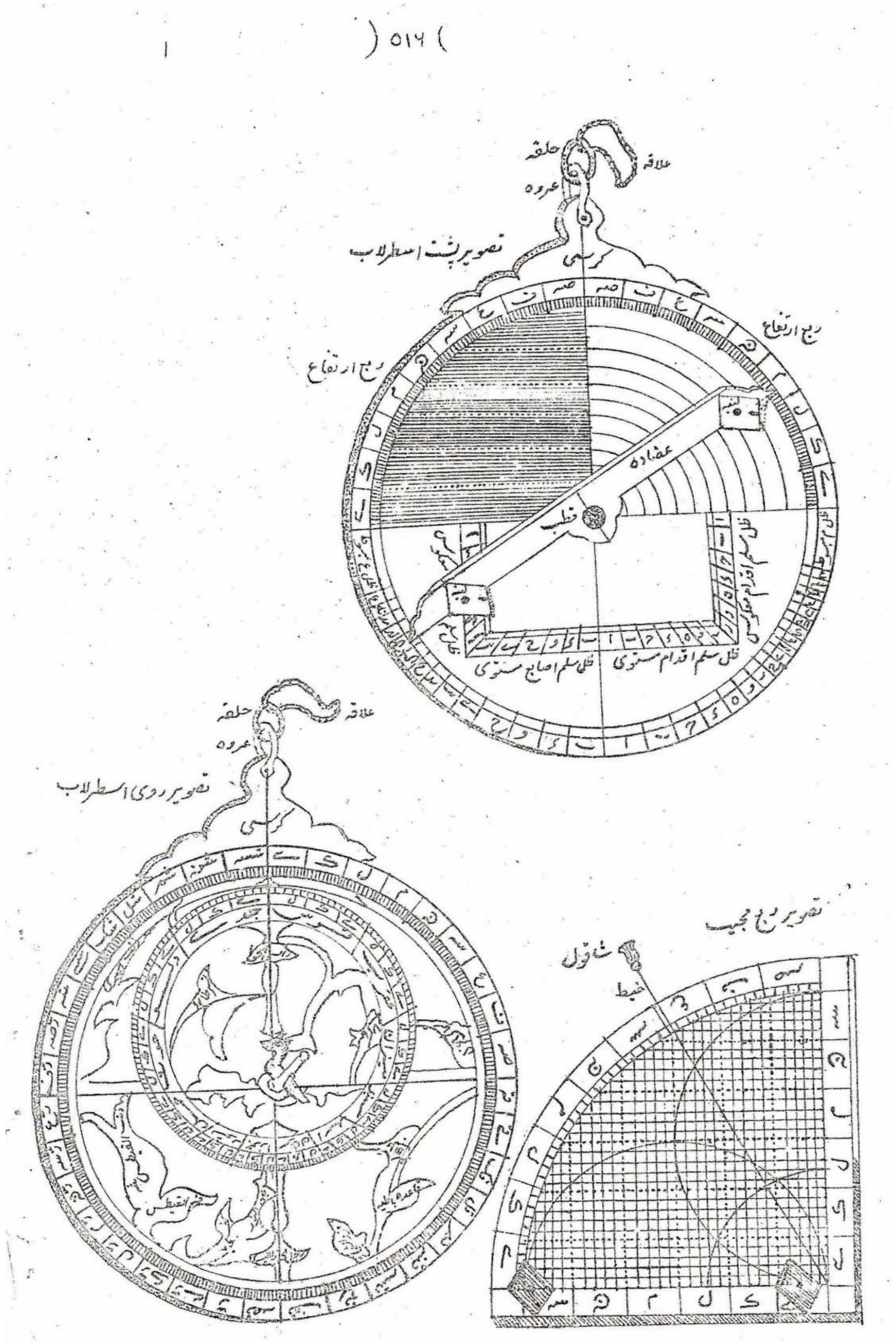

Figure B1 – Illustrations of the astrolabe (front and back) and sine quadrant
(from the *Jami*ᶜ*-i Bahādur Khānī,* p. 516)

Index of Indo-Persian Astrolabes produced by Others

B001 Copy of an Astrolabe of Mīrzā Bāysunghur 1489

1587, Lahore, Diameter 151 mm, Moscow, The State Museum of Oriental Art

B002 ◎Bilingual Astrolabe made by Pandit at the Court of Jahāngīr 1494

11th regnal year of Jahāngīr (AD 1616-17), Diameter 402 mm, Varanasi, Sampurnanand Sanskrit University, Saraswati Bhavan Library

ᶜABD AL-QĀDIR AL-MUḤIBB AL-ASṬURLĀBĪ

ᶜAbd al-Qādir al-Muḥibb al-Asṭurlābī is known through four astrolabes, only one of which is dated 1034 AH (AD 1621-22).[593] An undated celestial globe made by his son Luṭf Allāh ibn ᶜAbd al-Qādir al-Muḥibb al-Asṭurlābī is with the Institut du Monde Arabe, Paris.[594] The Museum of the History of Science, Oxford, holds an astrolabe made in 1647 by Ibn Muḥibb Ḥaqīqa, who may be the son of ᶜAbd al-Qādir Muḥibb.[595]

Nothing is known about Muḥibb's place of origin or the place of work. But from the fact that three plate faces in his undated astrolabe at Frankfurt (B006) are designed for latitudes 27°, 29° and 32° which pertain to the three Mughal imperial cities Agra, Delhi and Lahore and from the fact that his son Haqīqa's astrolabe carries sigmoid curves for the sun's midday altitude at latitudes 27° and 32°, it can be safely concluded that the father Muḥibb and the sons Luṭf Allāh and Ḥaqīqa lived somewhere in Panjab.

Of the four astrolabes made by Muḥibb, details are available only of two astrolabes B005 and B006 which display excellent workmanship with their elegantly designed *kursīs* and retes. Again of these two, B006 is the most ambitious astrolabe with the largest number of star pointers on the rete, largest geographical gazetteer and several other features which are not found in any other Indian astrolabe.[596]

The son Ibn Muḥibb Ḥaqīqā's astrolabe is more modest in comparison; he is familiar with the astrolabes of the Lahore family; the back of his astrolabe closely resembles several small astrolabes made by his contemporary Ḍiyā' al-Dīn Muḥammad of the Lahore family.

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593 The CCA lists under 1123 a Sanskrit astrolabe with a diameter of 181. This is clearly based on a misunderstanding, for no Muslim is known to have produced a Sanskrit astrolabe. Probably the lost rete in this astrolabe may have been replaced by a Sanskrit rete. No other details are available.

594 Savage-Smith 1985 No. 67, p. 251; Mouliérac 1989, pp. 84-85.

595 Gunther 1932, no. 73, pp. 200-201, Figs. 100, 101; CCA 73.

596 Schmidl 1994.

Index of Astrolabes by ᶜAbd al-Qādir al-Muḥibb al-Asṭurlābī

B003 Astrolabe by ᶜAbd al-Qādir Muḥibb, 1031 AH (AD 1621-22).......................... 1519
Diameter 178 mm, London, PC

B004 Astrolabe by ᶜAbd al-Qādir Muḥibb, not dated 1520
Diameter 317, PLU, ex-London, Sotheby's

B005 Astrolabe by ᶜAbd al-Qādir Muḥibb, not dated 1523
Diameter 146 mm, PLU

B006 Astrolabe by ᶜAbd al-Qādir Muḥibb, not dated 1530
Diameter 306 mm, Frankfurt, Museum für Angewandte Kunst

B007 ◎Astrolabe by Ibn Muḥibb Ḥaqīqa, 1057 AH (AD 1647-48)........................... 1560
Diameter 77 mm, Oxford, Museum of the History of Science (# 52066)

MUḤAMMAD ṢĀLIḤ TATAWĪ [609]

Muḥammad Ṣāliḥ Tatawī (*fl.* 1659-1666) is known from four astrolabes and three celestial globes; besides, three unsigned astrolabes and one unsigned celestial globe can be attributed to him on stylistic grounds. He is the only instrument maker outside the Lahore family who produced so many instruments in the seventeenth century. He signs his creations with a short inscription *ᶜamal muḥammad tatawī,* followed by the year. In the globe of 1659, he writes *tatahwī* in stead of *tatawī.* On this Emilie Savage-Smith remarks as follows: 'It is unlikely that the maker was from Tatta in the Sind (the delta of the Indus river) since the name of the town is written with slightly different letters and should more accurately be transliterated as T'hat't'hā.'[610] Actually the name is written today in English as Thatta, in the local language Sindhi as ٺٽو and in Urdu as ٹھٹہ. At the time of Muḥammad Ṣāliḥ, Urdu was still in the stage of formation and Ṣāliḥ may have spelt his name according to the Sindhi usage. In the geographical gazetteer of his astrolabe of 1666 (B011), he lists the town as Tatah (تته) with a longitude of 102;30° and latitude of 25;10° (the modern values are 67;55,28 E and 24;44,46° N).

It is not known where his workshop lay, at his native place Thatta itself, or elsewhere. On the celestial globe he produced in 1659, he writes that it was made by the order of (*bi-farmāyish*) Shaykh ᶜAbd al-Khāliq. A unique manuscript of the *Tashil-i Zīj-i Ulugh Begī* of Mullā Chānd Bahā' al-Dīn in the Sawai Mansingh Palace Library at Jaipur bears the seal of ᶜAbd al-Khāliq, 'a slave of Shāh Jahān', dated 1030 AH (AD 1628-29).[611] Therefore, Muḥammad Ṣāliḥ's patron ᶜAbd al-Khāliq must be a high dignitary at the court of Shāh Jahān at Agra.

No other information is available about Ṣāliḥ's personal life, save the astrolabes and celestial globes produced by him.[612] His astrolabes can be divided into two broad categories. In the first category are the small astrolabes B009 (Mumbai), B010 (V&A),

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609 Savage-Smith 1985, nos. 25 and 29, pp. 229-232, 304, Fig. 18; Sarma, Ansari & Kulkarni 1993; Maddison & Savage-Smith 1997, I, pp. 235 and 237.

610 Savage-Smith 1985, p. 44; the same wording again on p. 229.

611 Pingree 1999, p. 76, n. 18.

612 His celestial globes will be discussed in section G.

B012 (Patna) and B013 (Karachi); these have diameters of 147 mm and 148 mm. The second category comprises the two large astrolabes B011 (Oxford) and B014 (Salem).

B009, B012 and B013 of the first category contain almost identical *kursīs* and retes. The *kursīs* are solid with profiles made up of two ogees. The shackle is trifoliate like the shackles in the Lahore astrolabes, but has a knob at the top which seems to be a characteristic feature of Ṣāliḥ. In the retes, the three rings of the Tropic of Capricorn, ecliptic and the partially represented equator ring are held together by the complete equinoctial and solstitial bars, both with a counter change at the centre. There is no floral tracery joining the star pointers. These arise from the circular rings and straight bars which have been just mentioned. The star pointers have the simple shape of lobed daggers. Unlike the retes in the Lahore astrolabe makers, Ṣāliḥ's retes are not cluttered with too many star pointers; there are less than 30 named star pointers.

The backs of the astrolabes in this first category also differ from Lahore astrolabes. The solar quadrant on the upper right quadrant carries a universal horary quadrant with two faintly drawn curves of the midday altitude of the sun at latitudes 27° and 32°. The accompanying labels read *niṣf al-nahār bi-ᶜarḍ 27* or 32, while in the Lahore astrolabes the labels read *khaṭṭ niṣf al-nahār bi-ᶜarḍ x.* In the lower half, besides the shadow squares and the cotangent scales, there is just one astrological table with the names of the zodiac signs and the names of corresponding lunar mansions.

The astrolabe B010 broadly shares these features, but has an ornate *kursī* and an indifferent tracery in the rete.

The astrolabe of 1666 (B011) is much larger with a diameter of 194 mm and is very flamboyant with a reticulated *kursī* and a floral tracery in the rete. The astrolabe B014 is still larger with a diameter of 218 mm, its reticulated *kursī* is more ornate than the same in B011, but the rete is closer to the retes in the first category. The backs of these astrolabes are quite similar to the backs of the astrolabes in the first category, but do not have any graphs of solar meridian altitude.

Index of Astrolabes by Muḥammad Ṣāliḥ Tatawī (*fl.* 1659-1666) and others

B008 Astrolabe by Muḥammad Ṣāliḥ, 1072 AH (AD 1661-62) 1573

Diameter ?, PLU, ex-Edgerton (Mass), private collection of Eugen Hoffmann

B009 ◎Astrolabe by Muḥammad Ṣāliḥ, 1074 AH (AD 1663-64) 1574

Diameter 131 mm, Mumbai, Chhatrapati Shivaji Maharaj Vastu Sangahalaya (# F 209)

B010 ◎Astrolabe by Muḥammad Ṣāliḥ, 1076 AH (AD 1665-66) 1582

Diameter 111 mm, London, Victoria and Albert Museum (# IM 408-1924; IPN 2467)

B011 ◎Astrolabe by Muḥammad Ṣāliḥ, 1077 AH (AD 1666-67) 1590

Diameter 194 mm, Oxford, Museum of the History of Science (# 33474)

B012 ◎Astrolabe attributable to Muḥammad Ṣāliḥ, not dated 1607

Diameter 147 mm, Patna, Khuda Bakhsh Oriental Public Library

B013 Astrolabe attributable to Muḥammad Ṣāliḥ, not dated 1615

Diameter 148 mm, Karachi, National Museum of Pakistan

B014 ◎Astrolabe attributable to Muḥammad Ṣāliḥ, not dated 1627

Diameter 218 mm, Salem, MA, Peabody Essex Museum (# M2560)

B015 Unsigned Indo-Persian Astrolabe, not dated... 1640

Diameter 260 mm, PLU, ex-Milan

B016 Rete of an Indo-Persian Astrolabe, not dated 1647

Diameter 150 mm, Hastings-on-Hudson, NY, Tesseract

B017 ◎Astrolabe, not signed, 1129 AH (AD 1716-17) 1650

Diameter 151 mm, Delhi, National Museum (# 58.98/9)

B018 ◎Astrolabe by Sayyid cAbd al-Bāqī ibn Sayyid Ḥusain, 1204 AH (AD 1789-90) 1655

Diameter 125 mm, Oxford, Museum of the History of Science (# 50059)

B019 ◎Astrolate attributable to Sayyid cAbd al-Bāqī ibn Sayyid Ḥusain, not dated . 1673

Diameter 162 mm, Oxford, Museum of the History of Science (# 47063)

B020 Astrolabe by Aḥmad, 1228 AH (AD 1813) 1686

Diameter 63 mm, PLU, ex-PC of W. S. W. Vaux in 1856

LĀLAH BULHOMAL LĀHORĪ

While there had been a hiatus in the production of astronomical instruments at Lahore in the eighteenth century, it was Lālah Bulhomal Lāhorī (*fl.* 1839-1851) who revived it in the nineteenth century. He can be regarded as the true and the last representative of both the Indo-Persian and the Sanskrit traditions of astronomical instrumentation. He produced well-crafted astrolabes and celestial globes with inscriptions and legends either in Arabic-Persian or in Sanskrit. He fashioned *Dhruvabhrama-yantras* and *Turīya-yantras* of Sanskrit tradition. He also created some new Sanskrit instruments of his own. His oeuvre consists of about twenty-eight instruments of excellent workmanship belonging to eleven different varieties. Nine of these instruments bear his signature and were produced between the years 1839 and 1851. Nineteen other instruments do not carry his signature, but because of their close similarity to the signed pieces, they too can be attributed to Bulhomal. In 1839 itself he produced at least four instruments of three different types. At this rate of production, he may have produced many more instruments than the 28 which are extant. No instrument maker in India is known to have produced as many varieties of instruments as Bulhomal did, that too with labels in three different languages.[632]

His name is rather problematic. On the Indo-Persian instruments, he signs his name as *b.l.h.w.m.l* (بلهومل) without any diacritics. Luckily, the vowels can be gleaned from the Sanskrit instruments. In a *Dhruvabhrama-yantra* made in 1839-40, his name appears, in its Sanskritized form, as *bulhomalla* (बुल्होमल्ल) and in an undated horary quadrant as *vulhomalla* (वुल्होमल्ल). In a celestial globe made in 1839, there is a different suffix *vuhlovarmmā* (वुह्लोवर्म्मा). Since in many parts of north India, one writes *va* (व) but pronounces it as *ba* (ब), the first syllable in the name should be definitely *bu* (बु), the second *lho* (ल्हो) and the suffix without Sanskritization *mal* (मल). Thus he must have pronounced his name as 'Bulhomal' (बुल्होमल). I am informed that such names are not prevalent today either in Amritsar or in Lahore. Even so it would be proper to spell his

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632 For a detailed discussion of his entire oeuvre, see Sarma 2015b.

name in a manner that corresponds both to the Persian and Devanagari forms he used on his instruments.

Bulhomal was attached to the court of Nihal Singh Ahluwalia, the Raja of Kapurthala from 1837 to 1852, for whom he fashioned some astrolabes and globes. It is probably at this court that he came in contact with Sir Henry Miers Elliot (1808-1853) for whom he made a very elegant Indo-Persian astrolabe in 1849 (B021). As the Foreign Secretary to the colonial Government, Elliot was negotiating at that time the treaty of annexation of Panjab with the Sikh princes.[633]

Bulhomal was not a mere metal worker specialising in astronomical instruments, but also a scholar well-versed in Persian as well as in Sanskrit. On some Indo-Persian astrolabes and globes he engraved very long florid inscriptions in Persian referring to himself as *Lālah Bulhomal Lāhorī Munajjim wa Muhandis* ('astronomer/astrologer and geometrician/engineer'). On five Sanskrit instruments he signs his name in pretty verses, laying emphasis on his devotion to and Śiva and Pārvatī.[634]

Instead of the conventional *Abjad* notation, he employs the common Arabic/Persian numerals. The degree scale on the limb is invariably divided in 1° and 6° and the groups of 6° are numbered serially from 1 to 60. This is the general practice in Sanskrit astrolabes, because 60 parts of the limb corresponds to the 60 *ghaṭīs,* the time units in which the day-and-night is divided in traditional India. He mentions the years of completion generally in Vikrama Saṃvat and in Christian era, sometimes also in the Hijrī era.

Bulhomal developed his own individual style in the design of astrolabes and other instruments. The stylistic peculiarities of the astrolabes are described here; those of the other instruments will be discussed under the respective instruments.

The *kursī* in Bulhomal's astrolabes is small and low, but is elegantly pierced with three perforations. This design of the *kursī* can be treated as his signature, for it occurs frequently and helps to identify the maker even when there is no actual signature.

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633 He is better known for the *History of India, as Told by its Own Historians,* which he conceived and initiated and which was completed after his death by another servant of the Company, John Dawson, in eight volumes. On his life and a critique of his work, see Wahi 1990.

634 The Sanskrit inscriptions are reproduced and translated in Sarma 2010, pp. 91-92.

In the rete, he incorporates a very small number of star pointers, generally 12, in some astrolabe even less. These are shaped like leaves and the delicate tracery of tendrils which connects these star points is nearly the same in all his astrolabes. Like the *kursī,* the rete can also be treated as his signature.

While the members of the Lahore family tried to decorate every part of the astrolabe, they left the sighting plates mounted on the alidade as mere rectangular blocks. But Bulhomal gives them the shape of tulip flowers (see Figure B022.7 and Figure C028.4).

The other features of his astrolabes are as follows. On the latitude plates, he writes the latitudes, but does not mention the hours or *ghaṭīs* of the longest day. The Lahore astrolabes generally contain a plate with one side engraved as the table of ecliptic coordinates and the other side as the plate of horizons. Bulhomal fills both sides with different sets of half-horizons.

Some of his Indo-Persian and Sanskrit astrolabes are without a geographical gazetteer and the inner surface of the mater is left blank. However, in B022 a gazetteer of 57 localities is engraved with the longitudes and latitudes. The same gazetteer is repeated in B024; Bulhomal's pupil Ghulām Qādir of Kapurthala copies the same gazetteer in his B027 and B028. In this gazetteer, the latitude values are more or less accurate, but the longitudes (counted from the Fortunate Isles) are quite erratic; they differ widely from those in Mughal astrolabes. Particularly intriguing is the longitude of London at 70° which would place London on the same longitude as Damascus. One would expect that, with his contacts with the colonial government, he would have a more accurate knowledge of London's coordinates.

On the back, Bulhomal generally engraves just the sine quadrant, that too on the upper right (as against the upper left in the Lahore astrolabes) and leaves all the other three quadrants empty. The sine quadrant is also engraved on the back of the *Dhruvabhrama-yantras.* In both instruments, it has an almost identical design; the vertical and horizontal lines are numbered along the two radii as well as along the 13th vertical line and the 13th horizontal line.[635]

According to the Répertoire, B023, B025 and B026 contain astrological tables on the back. But the exact details of these astrological tables are not available. However, on the back of the two Sanskrit astrolabes C028 and C029, there are several astrological tables. These will be discussed in the entry on C028.

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635 Astrolabe B024 does not share all these peculiarities; the patron who commissioned it must have desired a more conventional specimen with *Abjad* notation, astrological tables and so on. However, Bulhomal's pupil, Ghulām Qādir follows his teacher's style in many respects.

Index of Astrolabes by Lālah Bulhomal Lāhorī (*fl.* 1839-1851)

B021 ◎Astrolabe made by Lālah Bulhomal Lāhorī for Sir Henry Elliot, 1849 1697
Diameter 154 mm, London, Science Museum (# 1982-777)

B022 ◎Astrolabe attributable to Lālah Bulhomal Lāhorī, not dated 1704
Diameter 153 mm, Cologne, PC

B023 Astrolabe attributable to Lālah Bulhomal Lāhorī, not dated 1716
Diameter 157 mm, PLU, ex-Alain Brieux

B024 Astrolabe designed by Lālah Bulhomal Lāhorī and fabricated by Pīr Bakhsh Lāhorī, 1841 1717
Diameter 235 mm, Lahore, Lahore Museum (# MM 1649)

B025 North-South Astrolabe by Lālah Bulhomal Lāhorī, 1 January 1851 1734
Diameter 406.4 mm, PLU

B026 North-South Astrolabe by Lālah Bulhomal Lāhorī, not dated........................... 1737
Diameter ?, PLU

GHULĀM QĀDIR KAPŪRTHALĪ

In the lone astrolabe of 1861 (B027) which carries his signature, Ghulām Qādir Kapūrthalī calls himself the pupil (*shāgird*) of Bulhomal, the astronomer (*munajjim*) of Lahore. Like his master, he avoids the *Abjad* notation and employs the common Arabic/Persian numerals. The rete is similar to the rete in the astrolabe B024 designed by Bulhomal.

Besides the astrolabe B027, there are two others (B028 and B029) which can be attributed to Ghulām Qādir on stylistic reasons. While a strong influence of his master's work can be seen in these three astrolabes, the workmanship is uneven; B027 and B029 are well crafted, but B028 lacks proper finishing and the *kursī* is joined to the mater in a strange manner.

The Répertoire lists him under Qādir Kapūrthalī and treats the first name Ghulām as an attribute denoting 'aprenti'!

Index of Astrolabes by Ghulām Qādir Kapūrthalī and others

B027 ◎Astrolabe by Ghulām Qādir Kapūrthalī, 1278 AH, 1918 VS (AD 1861-62) . 1741

Diameter 337 mm, New Delhi, National Museum (# 56.155/2 (c))

B028 ◎Astrolabe attributable to Ghulām Qādir Kapūrthalī, not dated....................... 1750

Diameter 153 mm, New Delhi, National Museum (# 56;155/2 (a))

B029 ◎Astrolabe attributable to Ghulām Qādir Kapūrthalī with a single plate for latitude 32°, not dated 1758

19th century, Diameter 921 mm, PLU, ex-Milan

B030 Bilingual Zarqālī Universal Astrolabe, engraved in Arabic/Persian and Gurmukhi, not dated 1763

19th century, Diameter 921 mm, PLU, ex-Milan

B031 Wooden Mater of an Astrolabe, not signed, not dated 1770

19th century, Diameter 220 mm, height 260 mm, thickness 20 mm, weight 410 g, Srinagar, Sri Pratap Singh Museum (# 5159)

C. SANSKRIT ASTROLABES WITH MULTIPLE PLATES

INTRODUCTION

1. SANSKRIT TEXTS ON THE ASTROLABE

Abū Rayḥān al-Bīrūnī states that he composed a book on the astrolabe in Sanskrit verses during his sojourn in India in the first quarter of the eleventh century:

> 'Most of their books are composed in *Śloka* [a particular verse meter in Sanskrit], in which I am now exercising myself, being occupied in composing for the Hindus a translation of the books of Euclid and of the Almagest, and dictating to them a treatise on the construction of the astrolabe, being simply guided herein by the desire of spreading science.'[656]

However, not a single manuscript of any of these three works mentioned above came to light. Moreover, scholars are of the view that Al-Bīrūnī's command of Sanskrit was not adequate enough for translating either the books of Euclid or the *Almagest* of Ptolemy into Sanskrit, not to speak of composing an independent work on the astrolabe in Sanskrit verse.[657] But it cannot be denied that he discussed the astrolabe and its variants in several of his works; therefore it is entirely probable that he may have brought an astrolabe with him and taught its working principles to his Hindu interlocutors. However, the response of his Hindu interlocutors, if any, is not recorded.

The first extant Sanskrit manual on the astrolabe was composed in 1370 at the court of Sulṭān Firūz Shāh Tughluq (r. 1351-1388) in Delhi by the Jaina monk Mahendra Sūri of Bharuch (Bhṛgupura). Impressed by the versatile functions of the astrolabe, Mahendra Sūri called it *Yantra-rāja,* 'the king of instruments,' and since then the astrolabe was known by this name in Sanskrit.[658]

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656 Bīrūnī 1910, I, p. 137.

657 Pingree 1975.

658 In 1428, Rāmacandra Vājapeyin, 1.11, attempted to give it another name *Sulabha* (the easy one), but this name did not gain currency.
sulabhākhya-yantrarājaṃ pūrvam eva pravadāmi |
yasmin karāmalakavad vidite viditaṃ bhaved viśvam ||
'I teach, at the outset, the king of instruments named *Sulabha.* When it is understood well, like the [small] myrobalan fruit on [one's own] palm, the entire universe becomes known.'

Mahendra Sūri's manual on the astrolabe, entitled *Yantrarāja*[659] consists of five chapters. The first chapter *Gaṇitādhyāya* provides various trigonometric and other tables necessary for the construction of the astrolabe. The second chapter (*Yantra-ghaṭanādhyāya*) discusses the components of the astrolabe. The construction of the common northern astrolabe (*saumya-yantra*) and the two other variants, viz. the southern astrolabe (*yāmya-yantra*) and the combination of the two (*miśra-yantra*) is described in the third chapter (*Yantra-racanādhyāya*), while the next one (*Yantra-śodhanādhyāya*) deals with the method of verifying whether an astrolabe is properly balanced or not. The final chapter (*Yantra-vicāraṇādhyāya*) discusses the use of the astrolabe as an observational and computational device and dwells on several problems in astronomy and spherical trigonometry which can be solved by it. Mahendra Sūri's pupil Malayendu Sūri wrote a detailed commentary on the *Yantrarāja* in about 1378. There survive today at least one hundred manuscript copies of the *Yantrarāja*, attesting to its great popularity.

Mahendra Sūri's manual was followed by a succession of other Sanskrit manuals. Thus between 1370 and the middle of the nineteenth century at least sixteen manuals were composed in Sanskrit on the astrolabe.[660] In 1423, Padmanābha, who is otherwise known as the inventor of the *Dhruvabhrama-yantra,*[661] composed a manual on the southern astrolabe which is a theoretical curiosity rather than of practical utility.[662] Five years later, in 1428, the polymath Rāmacandra Vājapeyin devoted the major part of his *Yantraprakāśa* to the astrolabe.[663]

The study of the astrolabe received a great impetus from Sawai Jai Singh in the early eighteenth century. Although he preferred huge masonry instruments for astronomical observations, he had great esteem for the astrolabe on which he composed a manual in Sanskrit prose under the title *Yantrarāja-racanā.* In particular, he seems to

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659 On Mahendra Sūri, see CESS, s.v., Pingree 1978b, Sarma 1999a, Sarma 2000, Plofker 2000. Some extracts from this work are reproduced with English translation in Apx.D1.

660 These texts are discussed in Sarma 1999a.

661 Sarma 2012a; see section L.

662 Cf. Ôhashi 1997, for the text, translation and commentary.

663 Cf. Sarma 2008b.

have popularized Sanskrit astrolabes with just one plate calibrated for the latitude of Jaipur at 27°.

Even after Jai Singh's time, the astrolabe continued to be discussed in some Sanskrit works, notably in the *Yantrarāja-kalpa* or °*ghaṭanā* of 1782 by Mathurānātha Śukla, who knew also Persian well, and was the librarian of the Sarasvati Bhavan Library of the Sanskrit College at Varanasi from 1813 up to his death in 1818. At the outset, he declares that his work is composed in a novel manner in prose and is accompanied by diagrams (*vicitra-racanā-citrācita*). Indeed his work is unique in that it is the only Sanskrit text of this genre which contains detailed diagrams. His autograph copy, therefore, would have been very valuable, but it is not available, even in the Sarasvati Bhavan Library where he was the librarian. The only manuscript extant of this remarkable work was copied after his death in on Friday, 30 June 1820 (Manuscript 35245 of the Sarasvati Bhavan Library, Varanasi Sanskrit University). Unfortunately, some of the diagrams and tables in this manuscript are incomplete.

2. Sanskrit Astrolabes

These Sanskrit manuals on the astrolabe must naturally have been accompanied by the production of Sanskrit astrolabes. But the earliest surviving Sanskrit astrolabe was the one which was produced in 1605 at Ahmadabad in Gujarat (C001). This large and elaborate astrolabe suggests that it is not the first or earliest attempt at the production of Sanskrit astrolabes. There must have been a long line of Sanskrit astrolabes before this. There survive today some 130 Sanskrit astrolabes which were made in the seventeenth, eighteenth and nineteenth centuries in Gujarat and Rajasthan. Chronologically the last traditional astrolabe (as distinct from modern copies or fakes) bears a date corresponding to 1903.

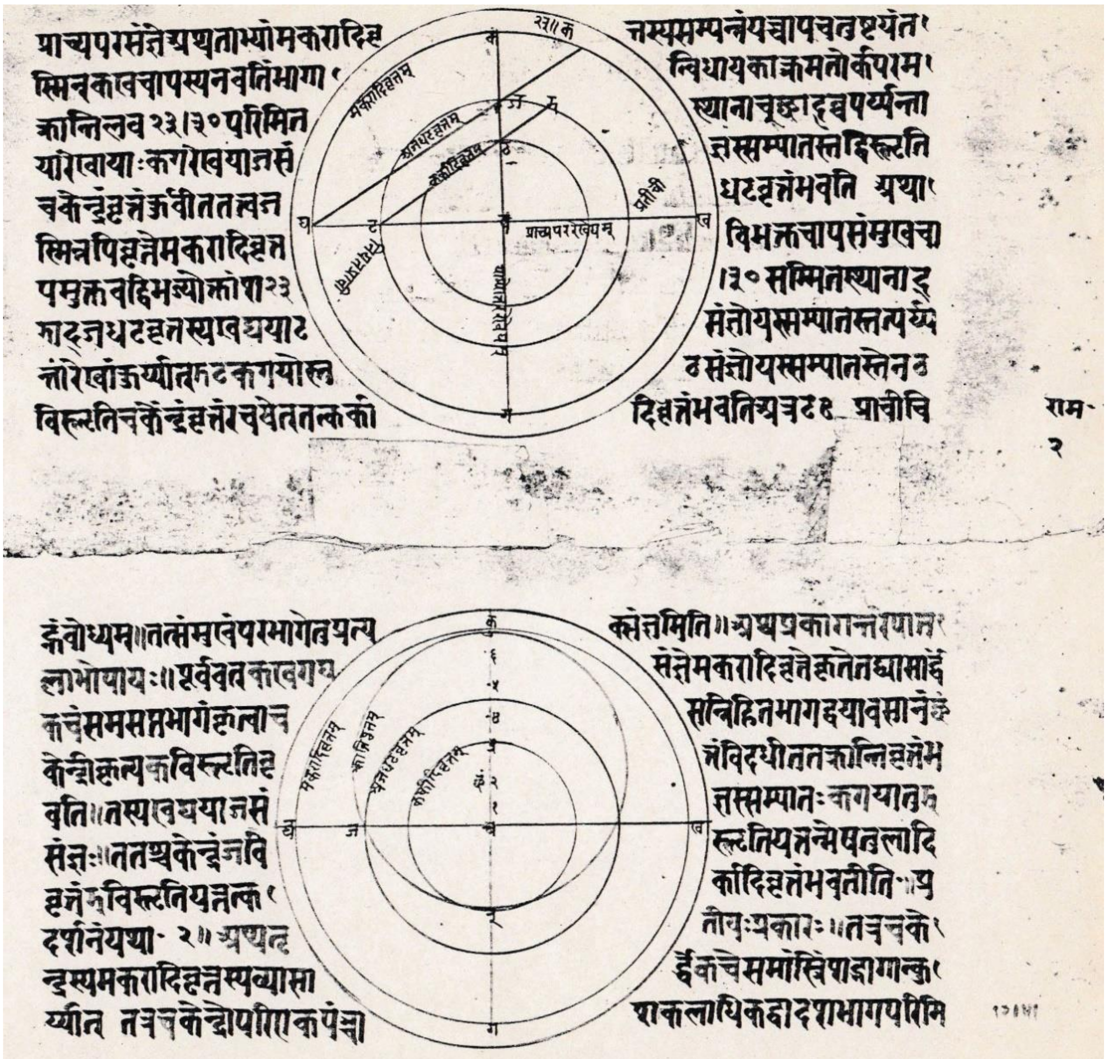

Figure C1 – Two diagrams from *Yantrarāja-kalpa* showing how to draw the circle of the ecliptic (*f*2*v* and *f*3*r* from MS 35245 of Varanasi Sanskrit University)

Until now scholars did not have the opportunity to examine sufficiently large number of Sanskrit astrolabes together. They saw just a few specimens and noticed that these Sanskrit astrolabes did not display any influence of the Lahore astrolabes and therefore concluded that these were produced on the basis of illustrations in Arabic/Persian manuscripts. Thus, writing in 1957, Francis Maddison observes:[664]

> 'Although there are Hindu treatises on astrolabes (derived from Islamic sources) from as early as the fourteenth century, there do not appear to be any surviving instruments engraved in Sanskrit earlier than the astronomical activity under Jai Singh (see Kaye pp. 3, 69 et passim). Many Indian

664 Maddison 1957, p. 30.

> astrolabes resemble in design the Indo-Persian instruments, inscribed in Arabic and Persian, of the Mogul period. This astrolabe [D019 MHS], like that formerly in Plimpton Collection (Gunther, op. cit., no. 98, fig. 115) [D007] which it closely resembles in many respects, probably dates from the eighteenth century (cf. also the astrolabe, belonging to the Royal Asiatic Society, described by Morley …) [C012]. Nevertheless it differs from the Mogul-inspired instruments and its maker may have been guided by an early Islamic treatise on the astrolabe, a tradition deriving from such source, or have copied partially an early Islamic instrument. The design of the *rete* and its star-pointers, the drawing of the azimuth lines *below* the horizon, and the simplicity of the engraving on the back, are all features variously associated with early Syro-Egyptian astrolabes and the somewhat later early Persian instruments.'

Anthony Turner elaborates on this hypothesis and goes on to declare:

> 'Among the [Indian] instruments that survive, we may discern two traditions. The first of these stemmed from the manufactory established at Lahore already described. The second is quite different, being exemplified by a group of instruments inscribed in the *devanagari* script of northern India and characterized by a marked resemblance in their design, both on the *rete* and on the back, to the earliest astrolabes known from Syro-Egypt and Persia … This circumstance suggests that their design was influenced by illustrations in the copies of the early treatises on the astrolabe such as those by as-Sijzī, al-Bīrūnī … or aṣ-Ṣūfī.'

He even reproduces an illustration from a manuscript of the Bodleian Library, Oxford, as an example of manuscript illustration which must have been the basis of the design of the Sanskrit astrolabes.[665]

These two eminent experts on the astrolabe admit the possibility of illustrated manuscripts of Arabic or Persian texts on the astrolabe being available in India, but do not consider the possibility that some specimens of Syrian-Egyptian astrolabes

[665] Turner 1984, p. 28.

themselves could have been available in India. After all it is easier to copy an actual astrolabe rather than to make an astrolabe on the basis of illustrations in Arabic manuscripts unless one knew Arabic very well. In fact, scores of Arabic and Persian manuscripts on the astrolabe exist even today in India and Pakistan, but also several Syrian and Persian astrolabes are extant in Indian collections.[666] After the establishment of the Delhi Sultanate, Muslim scholars began to migrate in large numbers from Central Asia to the court of Delhi and some of them brought with them manuscripts as well as astrolabes. Some of these early Kufic astrolabes are still extant in India, e.g. two astrolabes made by al-Sirāj of Damascus in the years 623 AH (AD 1226) and 626 AH (AD 1228-29) are at Hyderabad[667] and Rampur[668] respectively. Such early astrolabes must have served as models for Sanskrit astrolabes and not Arabic manuscripts. Outside the limited circle of Muslim scholars, Arabic or Persian manuscripts would not be easily accessible (both physically and linguistically) to Hindu astronomers and certainly not to Hindu metal workers.

2.1. Social Milieu of Sanskrit Astrolabe Production

Moreover, there is a basic difference between the Sanskrit astrolabes and the Islamic astrolabes. In Islamic culture, astrolabe making was not just a craft but a learned profession; the astrolabists were not mere metal workers, but also scholars well read in the literature on the instruments, well versed in astronomy, spherical trigonometry and other sciences. Here the same person prepared the technical design and then executed it from brass sheets. In the Hindu context, the technical design was drawn by the upper caste astronomer, who was usually a Brahmin, and the actual manufacture was done by the lowly brass worker who may not even be literate. He managed to draw the lines and curves reasonably well, but often made mistakes in orthography.

In many cases, these must have been one-time exercises, that is to say, a brass worker prepares an astrolabe because the local astronomers had requested, but does not cultivate the art or science of the astrolabe any further. On the other hand, when an

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666 Cf. Y001 and Y002.

667 Sarma 1996a, pp. 23-24, pl. 12.

668 Sarma 2003, pp. 25-33.

artisan specializes in a particular trade, he passes on his skills to his descendants and thus families begin to specialize in a particular product and give it their characteristic imprint, just as the members of the Lahore family did. But instrument making did not develop into a specialized profession among the Hindus.

Consequently, the Sanskrit astrolabes produced by these artisans did not turn out to be precision instruments of observation and measurement or objects of beauty like the Indo-Persian astrolabes; they served the limited didactic purpose of demonstration. Therefore, it is not appropriate to compare Sanskrit astrolabes with the astrolabes of the Lahore family.

2.2. Centres of Production

The earliest Sanskrit astrolabes were produced in Gujarat on the west coast of India. Because of the maritime contacts with Arab countries, it was in Gujarat that the first exchanges took place between the Islamic and Sanskrit intellectual traditions; thus the earliest Sanskrit manuals for learning the Persian language and first Sanskrit texts on Islamic astrology were composed in Gujarat.[669] Moreover, Mahendra Sūri who composed the *Yantrarāja,* the earliest Sanskrit manual on the astrolabe in 1370, hailed from Bharuch (Bhṛgupura) in Gujarat.

As mentioned above, the earliest extant Sanskrit astrolabe (C001) was made at Ahmedabad in 1605, i.e. much before the time when the Lahore astrolabes became fully developed in the work of Qā'im Muḥammad (*fl.* 1622-1637), Muḥammad Muqīm (*fl.* 1621-1659) and Ḍiyā' al-Dīn Muḥammad (*fl.* 1637-1680). Two other specimens C008 and C009 were made at Surat, also in Gujarat. Indeed, all the Sanskrit astrolabes of the seventeenth century appear to have been produced in Gujarat, although we do not know the exact locations in each case.

In the eighteenth century astrolabe production gradually shifted to the neighbouring Rajasthan; it is partly due to the interest Sawai Jai Singh of Jaipur took in the astrolabe, but other princely courts also patronized astrolabe production. While Jaipur and Kuchaman were the major centres of production, astrolabes were produced also at other places like Jodhpur, Bundi and Tonk, all in Rajasthan.

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[669] Sarma 2002; Sarma 2009c.

Very few extant Sanskrit astrolabes emanate from places outside Gujarat and Rajasthan. An interesting case is C004. It was made in 1638 at Varanasi, but the name of the man who made it, Ṭhākura Murārajī Kuarajī, looks like a Gujarati name.

Sakhārāma Jośī is said to have made in 1790 astrolabes for the latitude of Kadoli at 17;21° (D056) and for the latitude of Kaḍegaḍḍi at 17;42° (0), both in Maharashtra, and several other types of instruments, but none of these are extant now.

Four astrolabes with single plates (D052 to D055) are designed for latitude 30°. There is no major town on this latitude in Rajasthan. Possibly these astrolabes were made either in Kurukshetra or in Thanesar, both situated roughly at 29;58° N, 76;50° E.

In the middle of the nineteenth century Lālah Bulhomal Lāhorī produced several kinds of instruments, some with Arabic/Persian and others with Sanskrit legends.[670] Three astrolabes with multiple plates (C028, C029, C030) and two with single plates (D069 and D070) can be attributed to him on stylistic grounds. Finally, a unique astrolabe with Gurmukhi script was made at Patiala in Panjab (C031).

Thus the production of Sanskrit astrolabes was mainly concentrated in Gujarat and Rajasthan. Even so, compared to the Indo-Persian astrolabes, Sanskrit astrolabes were produced at more centres and more people were associated with their design, manufacture and patronage.[671] Consequently, they also display great variety of styles.

2.3. Varieties of Sanskrit Astrolabes

Sanskrit astrolabes can be classified into two broad categories: those with plates designed for several different latitudes and those with a single plate calibrated for a single latitude. The second category will be discussed in section D. There is a small group of astrolabes, which can be treated as a third category, viz., Islamic astrolabes to which Sanskrit labels were added so that these could be used by people who cannot read Arabic or Persian. These will be taken up in section E.

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670 Cf. Sarma 2015b.

671 For an alphabetical directory of the makers, designers and patrons of Sanskrit astronomical instruments, see Sarma 2010.

3. Main Features of Sanskrit Astrolabes with Multiple Plates

Since the production of the Sanskrit astrolabes did not become a specialized profession, there did not develop distinct styles in design and ornamentation and the Sanskrit astrolabes remained by and large utilitarian devices with plain suspension brackets and retes. Alidades are usually equipped with sighting tubes. On the plates, not only the latitude and the duration of the longest day are mentioned, but also other functions of the latitude like the length of the equinoctial shadow. However, plates of ecliptic coordinates occur very rarely and plates of multiple horizons occur occasionally. More striking and very intriguing is the fact that in nearly half of the Sanskrit astrolabes with multiple plates, there are empty or unfinished areas; on some, a circular grid is drawn but not filled with the geographical gazetteer or rectangular grids are made and then left empty and so on. If it is so in one or two cases, one can say that the engraver left the job midway; but this does not explain the large number of cases in astrolabes produced in three centuries and at several different centres of production.

3.1. Suspension Bracket

In some early Islamic astrolabes, the Throne Verse from the Qur'ān was engraved on the suspension bracket and therefore the suspension bracket came to be called kursī (throne) in Islamic parlance. The Sanskrit writers merely called it the 'crown' (kirīṭa).[672] In Sanskrit astrolabes, the crown is generally high and often solid with lobed profiles, occasionally with the two decorative holes as in the early mid-eastern astrolabes. In some cases, the front side of the solid crown is decorated by floral design in bas relief (C008, C010, C011, C012, C013). Towards the end of the nineteenth century, Lakṣmīnārāyaṇa of Kuchaman introduced a pleasing inverted lotus motif into the crown (C034, C035, D034, D035, D036 etc.) and this motif became the distinguishing feature of the astrolabes produced at Kuchaman. A few astrolabes have simple fretwork, but the most outstanding fretwork can be seen on the crown of the Gurmukhi astrolabe made by Rahīm Bakhsh for the Maharaja of Patiala in 1850 (C031) and in the single plate astrolabe commissioned by Mannālāla at Jaipur (D005).

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672 Since the astrolabe was called *Yantra-rāja,* 'king of instruments,' it is but appropriate to call the upper part the 'crown'.

3.2. Degree Scales on the Limb and Back

Mahendra Sūri lays down that the limb of the astrolabe (*pālī, pāli-vṛtta*) should be numbered in 6s, from 1 to 60, to measure the 60 *ghaṭīs* in the day-and-night.[673] Several astrolabes follow this system of having the *ghaṭī* scale on the limb. But other methods of numbering are also followed in Sanskrit astrolabes, such as counting by 6s from 6 to 360, or from 6 to 90 in each quadrant, or from 1 to 15 in each quadrant. In some astrolabes, the limb is numbered in 5s as well.

On the back, the altitude scales on the upper half of the rim are generally marked in 6s from 6 to 90, but other patterns are also employed.

3.3. Rete

Unlike in the Lahore astrolabes, in the retes (*bha-patra*) in most of Sanskrit astrolabes, the equator ring is generally represented, either in full or just as the lower segment, for the simple reason that it can be made to support a number of star pointers as in C001, C007, C015 etc. The influence of the Lahore astrolabe can be perceived in a small number of astrolabes; here the equator ring is not represented at all, but the solstitial bar is fully represented. In the lower half, i.e., between the rings of Cancer and Capricorn, the star pointers are joined by an arabesque tracery (C008 - C013). Two of these astrolabes (C008 and C009) carry also the graph of the solar meridian altitude on the back.

3.3.1. The 'bird in the cage' pattern

While the retes in the Sanskrit astrolabes are generally very austere, some astrolabe retes display an agreeable pattern that can be called the 'bird in the cage' pattern. Here the position of the star *Abhijit* (α Lyrae) is indicated by the tip of the beak of a bird perched on the small ring around the central hole. The figure of the bird is framed by two creepers that arise from the central ring, encircle the bird, and then entwine together for a short while along the south-north solsticial bar, then branch off and, after touching the inner periphery of the ecliptic ring, bend downwards and

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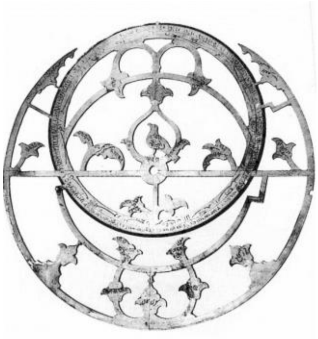
673 Mahendra Sūri, 3.4: 'Having drawn three [concentric] circles on the limb (*pālī*), in the first circle mark the *ghaṭīs,* starting from the middle of the crown. [In the middle circle] mark 360 degrees at desired intervals. Below that, draw the lines of their subdivision.'

terminate in three-petalled flowers just as they reach the upper part of the equator ring. The bird then looks as if it is sitting inside a cage formed by the two creepers.

Besides the 'bird in a cage' pattern in the upper part of the rete, the configuration of the stars directly below has also a distinct pattern. On the left, just above the equator ring is a flower the three petals of which indicate the stars *Pretaśira* (β Persei), *Brahmahṛdaya* (α Aurigae) and *Manuṣya-pārśva* (α Persei). This flower is counterbalanced on the right hand side by a similar flower, but with no stars marked on it. Below the ring of the equator, the three groups of (1) *Rohiṇī* (α Tauri), *Mithuna-vāma-hasta* (γ Orionis) and *Mithuna-dakṣiṇa-pāda* (κ Orionis), (2) *Lubdhaka* (α Canis Majoris), (3) *Lubdhaka-bandhu* (α Canis Minoris) and *Agasti* (α Carinae) are arranged in three creepers rising from the ring of Capricorn symmetrically on both sides of the meridian. Likewise the flower containing the pointer for *Mahāpuruṣa* (α Hydrae) on the right is counter-balanced by a flower on the left which however does not contain any star pointer.

This pattern is significant because it occurs at least in nine Sanskrit astrolabes, albeit with slight variations, produced in western India between 1618 and 1884, namely C002, C006, C014, C017, C024, D009, D058, D071 and E002.

Interestingly, this pattern occurs for the first time in India in the bilingual astrolabe made by Pandit in 1616 (B002). Both Pandit as well as the makers of these Sanskrit astrolabes derive inspiration from a common source which is yet to be identified.[674]



B002

C002

C006

[674] Cf. Sarma 2011a.

C014 C020 C024

Figure C2 – Retes with the ‘bird in the cage’ pattern

3.3.2. Stars on the Rete

In his *Yantrarāja,* Mahendra Sūri gives a list of 32 astrolabe stars with their celestial longitudes (*dhruvaka*) and latitudes (*vikṣepa*) for the year 1370.[675] Many of the names are literal translations of the Arabic names (e.g. *Matsyodara* from *Baṭn al-Ḥūt,* ‘the belly of the fish’, β Andromedae), some are Sanskrit names of the lunar mansions (e.g. *Rohiṇī,* α Tauri) and a few others are star names occurring in earlier Sanskrit texts (e.g. *Brahma-hṛdaya,* α Aurigae).

Most problematic, however, is Mahendra Sūri’s designation of α Canis Majoris by the double name *Ārdrā-Lubdhaka.*[676] *Ārdrā* and *Lubdhaka* are generally treated as two distinctly separate stars in Sanskrit astronomy, the former denoting α Orionis (Betelgeuse) and the latter for α Canis Majoris (Sirius). A large majority of Sanskrit astrolabes follow this nomenclature.

However, a small number follow Mahendra’s nomenclature. On the rete of the astrolabe made for Maṇirāma in 1644 (C006), the star names are engraved in an abbreviated form, but always followed by the serial number from Mahendra’s list. Here the star pointer for Sirius carries the label *ā 14* for *Ārdrā-Lubdhaka.* The name is shortened as *Ārdrālu* in C001, as *Ālu* in C002, C008 and C010; and as *Ārdrā* in C012, C014, C015 and D071. The full name *Ārdrā-Lubdhaka* occurs in C017 and C020.

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675 Mahendra Sūri, pp. 1.22-43; cf. Pingree 1978b, p. 628. See also Apx.D1.

676 The 14th star in the list (p. 26, verse 28) is *ārdrā*. In the tables appended to the commentary, this star is mentioned as *ārdrā-lubdhaka* (pp. 37, 41) and the corresponding Arabic name is given as *sorāmānī* or *serāimānī.* This is clearly an incorrect transcription of *shiʿrā yamānī*, i.e. α Canis Majoris (Sirius).

While Mahendra Sūri changes the traditional name given to Sirius from *Lubdhaka* to *Ārdrā-Lubdhaka,* he retains the original name *Lubdhaka* in the designation he gives to Procyon which he calls *Lubdhaka-bandhu,* 'friend', 'kinsman' or 'companion of *Lubdhaka*', i.e., Sirius. Strictly speaking, Mahendra should have called the star *Ārdrā-Lubdhaka-bandhu.* Be that as it may, in the hands of the incompetent engravers this star name assumes bizarre forms, sometimes as *Lubdhaka-vadhu* (Lubdhaka's bride) and other times as *Lubdhaka-vadha* (murder of Lubdhaka). Even the conjunct consonant in *Lubdhaka* gives difficulties to the engravers who often transcribe it as *ludhvaka.*

Occasionally star names are engraved on wrong pointers, but two anomalies deserve attention. The star name *Siṃha-hṛdaya* means the 'heart of the lion', being a literal rendering of the Arabic *Qalb al-Asad* (α Leonis). Generally, *Siṃha-hṛdaya* and *Maghā* are treated as alternative designations of α Leonis. However, on some astrolabes (C032, D008, D011, D014, D015 and D020), both names occur; while *Maghā* is engraved on the pointer of α Leonis, *Siṃha-hṛdaya* is engraved on a star pointer to the right of ζ Ursae Majoris (Arabic *ᶜAnāq,* Sanskrit *Vaśiṣṭha*); it is not clear which star is denoted by *Siṃha-hṛdaya* in these cases.

Second, the name *Śatabhiṣā* (λ Aquarii) is wrongly inscribed on the pointer for the star *Kukkuṭa-puccha* (Arabic *Dhanab al-Dajājah,* α Cygni) on eight astrolabes (A065, C002, C004, C024, D051, D062, D063 and D071).

3.4. Plates

On the plates (*akṣa-patra, akṣāṃśa-patra*) altitude circles (*unnatāṃśa-valaya*) are drawn at intervals which vary according to the size of the astrolabe; but azimuth arcs (*digaṃśa-vṛtta*) are often omitted. The situation of the hour lines (*horā-vṛtta*) is more complex.

Unlike in the Islamic world and Europe where time was measured in Middle Ages in unequal hours which vary according to seasons, in India time is always measured in *ghaṭīs* of 24 minutes' duration. Mahendra Sūri teaches the method for measuring time in equal *ghaṭīs* as follows. First measure the sun's altitude with the alidade on the back of the astrolabe. Note the sun's longitude (*ravy-aṃśaka*) for the day from some almanac and locate that point (S) on the ecliptic in the rete. Rotate the rete so that the point S touches the eastern horizon. Note where the index at the first point of Capricorn (*mṛgāsya*) touches the degree scale on the limb. Then rotate the rete once again so that

S rests on the altitude circle corresponding to the sun's altitude just measured. Note again where the Capricorn index touches the degree scale on the limb. The interval between the two positions is the altitude in degrees of arc. Divide it by 6. The result in *ghaṭīs* is the time elapsed since sunrise.[677] In order to simplify this procedure, Mahendra Sūri recommends that the degree scale on the limb should be divided into groups of 6° and numbered from 1 to 60.

Therefore, for the purpose of measuring time, it is not necessary to have the lines of unequal hours and those of equal hours on the lower half of the plates. Even so, Mahendra Sūri mentions that curves for unequal hours (*viṣama-horās*) as counted from the western horizon should be drawn on plates.[678] More than half of the Sanskrit astrolabes carry just lines for unequal hours (*viṣama-horā*); less than half of such astrolabes have also lines for equal hours (*sama-horā*) drawn from the western horizon. A few astrolabes have lines for equal hours drawn from both western and eastern horizons. Lines for equal *ghaṭīs* could easily be drawn; in fact, about a dozen Indo-Persian astrolabes have such lines,[679] but no Sanskrit astrolabe does so.

Then why did the makers of Sanskrit astrolabe draw hour lines at all? The simple answer is because such lines are engraved on Islamic astrolabes. Of course, one can measure time in equal hours of 60 minutes and convert them easily into *ghaṭīs* of 24 minutes by multiplying the hours by 2.5.[680] As for the lines of unequal hours on the Sanskrit astrolabes, in theory these can be used for measuring unequal time units of *prahara* or *yāma.* In popular time keeping in India, the variable duration of the day time is divided into four parts called *prahara-s* and the variable duration of the night into

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677 Mahendra Sūri, 5.3-4ab.

678 Mahendra Sūri, 3.9.

679 See A. Introduction, 2.4.1; Figure A3.

680 Although conversion of hours into *ghaṭīs* and vice versa is very easy, it is highly intriguing that many astrolabe makers could not convert correctly. As pointed out in A. Introduction 2.4.1, on some Indo-Persian astrolabes the duration of the longest day is given in both these units, often incorrectly. These astrolabes are A014, A015, A052, A065, A068, A073, A097, A105 and A113. In some Sanskrit astrolabes, the duration of the longest day is given in *horā-s* (hours) and not in *ghaṭī-s.* In C007, the values are given in both the units, but they do not match; cf. Figure C007.2.

four parts called *yāma-s* or also *prahara-s.*[681] Thus with the astrolabe, time can be first measured in unequal hours and then by dividing the hours by 3, *prahara-s* or *yāma-s* can be obtained. But these units are not mentioned in any Sanskrit text on astronomy or mathematics and there is no record of an astrolabe being used to measure these units.

3.4.1. Geographical Data engraved on the Plates

On the plates of the Indo-Persian astrolabes, the latitude (*al-ᶜarḍ*) and the hours of the longest day (*al-sāᶜāt*) are engraved in the middle, to the left and right of the meridian line. On Sanskrit astrolabes are engraved, besides the latitude (*akṣāṃśa*) and the length of the longest day in *ghaṭīs* (*parama-dina*), also the length of the midday equinoctial shadow (*chāyā*) and the name of the locality. Indeed, Mahendra Sūri recommends that these four items be inscribed on the astrolabe plates.[682] The length of the midday equinoctial shadow and the duration of the longest day are dependent on the latitude and are its functions. Sanskrit astronomical texts provide formulas for converting any one of the three values into another parameter.[683] Several astrolabes follow this recommendation.

In addition to these four parameters, the rising times of the signs at these latitudes (*svodaya-s*) are given on the plates of C016 and the length of the hypotenuse (*karṇa*) of the right-angled triangle formed by the gnomon and its shadow at the equinox is mentioned on the plates of C024. The only surviving plate of C019 carries still more information, namely the accessional differences (*cara-khaṇḍa*) and the names of localities whose latitudes are close to the latitude of the plate. In C031, the latitude, the longitude, the names of the localities with proximate latitudes, the climate and the planetary regent of the climate are mentioned. On the other hand, in some astrolabes, only the latitude is mentioned, but not the longest day or the length of the shadow.

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681 Kauṭilya, *Arthaśāstra,* 1.19.6-8, lays down that at the royal court the variable day time should be divided into 8 parts and the night into another 8 parts, by means of a water clock or a gnomon; see also Bīrūnī 1910, pp. 337-338.

682 Mahendra Sūri, 3. 8: ‘On both sides, i.e., in the eastern and the western sides of the meridian or midday line (*madhyāhna-rekhā*) situated inside the tropic of Cancer, one should write successively the equinoctial shadow (*bhā*), maximum daylight (*paramadina*), the name of the locality (*deśābhidhāna*) and the degrees of latitude (*akṣa-bhāga*).’

683 Mahendra Sūri, 3.25-27, gives formulas for converting local latitude into the duration of the longest day and the longest day into the equinoctial shadow.

3.4.2. Plates of Ecliptic Coordinates and of Horizons

The Islamic astrolabes generally contain, besides the plates calibrated to specific latitudes, one more plate, one face of which is designated as *ṣafīḥa mīzān al-ᶜankabūt* (plate for the measures on the rete) and the other as *ṣafīḥa al-afāqiyah* (plate of horizons). The former is a projection for the latitude which is the complement of the obliquity of the ecliptic, i.e. 90-23;30 = 66;30° or roughly 66°. This plate enables us to measure the longitudes and latitudes of all the stars marked on the rete. Mahendra does not mention it or the plate of horizons. A few astrolabes contain this plate (e.g. D008, D009, D010 etc.), but no special designation was coined for this plate.

The plate of horizons contains the projections of families of horizons at several latitudes and is used for determining the times of sunrise and sunset at latitudes other than one's own, or to determine the latitude from the time of sunrise or sunset. This plate is included in some Sanskrit astrolabes, where it is called *sarvadeśī* or *sarvadeśī-patra*.

3.5. Geographical Gazetteer

About half of the astrolabes carry geographical gazetteers on the inner side of the mater, but of these just seven have longitudes (*deśāntara* or *tūlāṃśa,* from the Arabic *al-ṭūl*) marked on them (C008 - C013 and C015). Other gazetteers carry only the latitudes (*akṣāṃśa*). In some like C006, C023, C024 and C029) a grid is drawn but not filled in.

These gazetteers are mainly derived from Indo-Persian and other Islamic astrolabes and copied most carelessly with the result that non-Indian names are barely recognizable. In Sanskrit there are extensive geographical tables generally providing the latitudes (*akṣāṃśa*) and the length of the noon equinoctial shadow at these latitudes (*akṣabhā* or *palabhā*).[684] These have not been used in compiling the gazetteers on Sanskrit astrolabes.

Moreover, Malayendu Sūri's commentary (ca. 1378) on the *Yantrarāja* of Mahendra Sūri contains a list of 77 places with their latitudes.[685] Kamalākara's

684 Pingree 1996.

685 Malayendu Sūri, pp. 18-19; see also Pingree 1978b, pp. 626-627.

Siddhānta-tattva-viveka (1658) has a list of 20 localities with their latitudes and longitudes.[686] The *Yantraprakāra,* which was compiled at the court of Sawai Jai Singh of Jaipur, has a list of 65 towns with their latitudes and longitudes.[687]

3.6. Back

Mahendra Sūri enjoins that the four quadrants (*pakṣa*) on the back of the astrolabe should be filled with the sine graph (*jyā*), the declination arcs (*apakramajā- vibhāgāḥ*) and shadow squares (*śaṅku-prabhā*).[688]

Accordingly, on most of the astrolabes, the upper left quadrant is engraved with a sexagesimal sine graph and the upper right quadrant with declination arcs with the names of the corresponding signs inscribed along the two radii. In two astrolabes (C007 and C014) the declination arcs are without labels and in two others (C017 and C029) radial lines are drawn for each 5° of arc. In four astrolabes (C001, C010, C023 and C024) there are universal horary quadrants. On seven astrolabes there are graphs of the meridian altitude of the sun for different latitudes, a feature borrowed from the Lahore astrolabes: C008 (for lat. 22°), C009 (22°), C015 (32°), C020 (27° and 32° ?), C021 (27°, 29°, 32°), C023 (27°, 29°, 32°) and C024 (two graphs without labels).

Double shadow squares are engraved on most of the astrolabes; just single squares on C010, C011 and C012. There are no shadow squares on C028 and C029 which are attributable to Bulhomal of Lahore. There are no shadow squares either on the Indo-Persian astrolabes made by him (B021) or attributable to him (B022 and B023).

3.6.1. Trigonometric Tables

Unlike the Indo-Persian astrolabes, some of the early Sanskrit astrolabes carry on the back sine tables (C004), tables of gnomon shadows (C003 and C006) and tables of declinations (C004, C006, C010 - C012).

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686 Kamalākara, *Siddhānta-tattva-viveka,* p. 57; see also Pingree 1978b, p. 616.

687 Sarma 1986-87b, pp. 115-116.

688 Mahendra Sūri, 3.3.

3.6.2. Astrological Tables

On the other hand, astrological tables occur rarely on Sanskrit astrolabes. In a few astrolabes, the names of zodiac signs (*rāśi*) and those of the lunar mansions (*nakṣatra*) are engraved in two concentric semi-circles as in the Indo-Persian astrolabes.

Interestingly, in C031 only 27 names of the lunar mansions are engraved, omitting *Abhijit.* In this astrolabe, there are also other astrological tables based on Sanskrit astrology: regents of the 7 planets, regents of the 12 zodiac signs, regents of the various kinds of subdivisions of the zodiac signs, such as when zodiac signs are divided in two parts of 15° (*horā*), three parts of 10° (*dreṣkāṇa*), 5 parts of 6° (*pañcāṃśa*), 7 parts of 4 2/7° (*saptāṃśa*), 9 parts of 3 1/3° (*navāṃśa*) and 12 parts of 2 ½° (*dvādaśāṃśa*).

Astrological tables derived from the Islamic tradition like the limits of the signs (*hudūd,* Sanskitized as *haddā*) and regents of the decans (*wujūh*) are engraved on the astrolabes attributable to Lālah Buhlomal of Lahore (D028, D029, probably also D030).

Moreover, there is one more table in these astrolabes, where zodiac signs are arranged in a zigzag fashion in groups of three as shown below:

Aries	Taurus	Gemini
Virgo	Leo	Cancer
Libra	Scorpio	Sagittarius
Pisces	Aquarius	Capricorn
278 *palas*	299 *palas*	323 *palas*

When arranged in this manner, each column represents zodiac signs having the same right ascension, i.e. the same rising time at the equator (*laṅkodaya*). Thus the four signs Aries, Virgo, Libra and Pisces rise at the equator in 278 *palas* or *vināḍis* (= 1;51,36 hours); the four signs Taurus, Leo, Scorpio and Aquarius rise in 299 *palas* (= 1;59,40 hours) and the four signs in the third column Gemini, Cancer, Sagittarius and Capricorn rise in 323 *palas* (= 2;08,44 hours).[689]

[689] Cf. Varāhamihira, 4.30:
vasu-muni-pakṣā vyekaṃ śatatrayaṃ tridvikāgnayāś cāṅkāḥ |
paratas ta eva vāmāḥ ṣaḍ utkramāt te tulādy-ardhe ||
'The *vināḍīs* of right ascensional difference for the three signs from Meṣa are 278, 299 and 323. In the next quadrant they are the same in the reversed order, *viz.* 323, 299, 278. In the half of ecliptic

This table occurs also on sine quadrants; sometimes the names of the signs are written in full, sometimes they are indicated by the serial number as on C001. Sometimes, the second and the fourth rows are written upside-down to indicate the reverse order of the first and third lines.

3.6.3. Shadow Squares

Although Sanskrit texts on mathematics treat the geometry of shadows, shadow squares do not receive proper attention in Sanskrit astrolabes. Double shadow squares are drawn often on the back, but the four scales are rarely labelled or seldom labelled correctly.

In Islamic astrolabes, two types of shadows are clearly distinguished: the shadows cast by a gnomon of 12 digits (*ẓill aṣābi*ᶜ) and the shadows cast by a gnomon of 7 feet (*ẓill aqdām*). This distinction is not maintained in Sanskrit astrolabes: both units are treated as *aṅgula-s* and the two types of shadows are named as *dvādaśāṅgula-chāyā* and *saptāṅgula-chāyā.* Just two astrolabes C031 and E004 maintain this distinction. In the former, the shadow of the 12-digit gnomon is called *narabhā* and the shadow of 7-feet gnomon *pada-chāyā* or *pāda-chāyā*; in the latter, the shadow of the 12-digit gnomon is called *dvādaśāṅgula-chāyā* and that of the 7-foot gnomon *pāda-chāyā.*

Moreover, the astronomers who design the Sanskrit astrolabes have difficulty in rendering umbra recta or direct shadow (*ẓill mustawī*) into Sanskrit. While umbra versa is correctly translated as *viloma-chāyā,* umbra versa is often translated as *loma-chāyā* or *solama-chāyā,* which is absolutely incorrect. The correct expression *sama-chāyā* occurs rarely.

3.7. Alidade

Islamic astrolabes, whether in India or outside, do not have sighting tubes attached to their alidades. The same is the case with European astrolabes. In the Sanskrit astrolabes, however, the alidade (*bhujā, vedha-paṭṭī*) is fitted with a sighting tube in most of the cases. In India, the sighting tube was used as an independent device to view

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beginning from Libra, the differences are those of the first half, taken in the reverse order.'
See also Malayendu Sūri, p. 46.

celestial bodies.[690] It was called *Nalaka*- or *Nālikā-yantra* and was described in several Sanskrit texts.[691] Apparently Hindu astronomers decided, at quite an early period, to combine the already known sighting tube with the newly imported astrolabe. This, no doubt, facilitates the sighting, but prevents the calibration of the upper surface of the alidade and thus robs off the trigonometric functions envisaged for the alidade in Islamic tradition. No Sanskrit text appears to mention this innovation.

3.8. Inscriptions

Most of the Sanskrit astrolabes do not contain inscriptions mentioning the name of the astrolabe maker and the date of production. In the few cases where such inscriptions occur, prominence is given to the astronomer who commissioned the astrolabe (by providing the technical drawings) and the name of the artisan who made the astrolabe takes a secondary place. The astronomer who designed the astrolabe bears the title *jyotirvid*[692] (knower of the [science of the] luminaries) or *daivajña*[693] (knower of the fate) or *jośī*[694]/ *joṣī* (derived from Sanskrit *jyotiṣin,* one who possesses the astral science); the astrolabe maker is given the title *śilpin*[695] (artisan) or *sūtradhāra*[696] (lit. one who holds the [measuring] rope, denoting primarily the architect, but applied *honoris causa* to the artisan), or *ustād*[697] (from Persian *ustād,* 'master craftsman). The language of the inscriptions is Sanskrit mixed with Old Gujarati, which is a common practice in the seventeenth century Gujarat.

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690 It was also known to the Greeks and Arabs; cf. Schmalzl 1929, pp. 218-219.

691 Cf. Rai 1985, pp. 333-336.

692 C006.

693 C008.

694 C010.

695 D090.

696 C026; C027; D062 – D065.

697 D035 – D038.

Index of Sanskrit Astrolabes with Multiple Plates

C001 ◎Sanskrit Astrolabe made for Dāmodara 1799

1605, Ahmedabad, Gujarat, Diameter 276 mm, Brussels, PC

C002 ◎Sanskrit Astrolabe, not signed 1812

1618, Gujarat, Diameter 148.5 mm, Pune, Raja Dinkar Kelkar Museum (# 106 PMC)

C003 Sanskrit Astrolabe [designed] by Cakrapāṇi 1821

1625, Jodhpur, Rajasthan, Diameter 110 mm, Hastings-on-Hudson, NY, Tesseract

C004 ◎Sanskrit Astrolabe made by Ṭhākura Murārajī Kuarajī for Josī Haranātha ... 1826

1638, Varanasi, Diameter 158 mm, Pune, Bhandarkar Oriental Research Institute (# 1502 of 1887-91)

C005 Sanskrit Astrolabe made by Kalyāṇa for Puruṣottama 1837

1642, Gujarat, Diameter ?, PLU

C006 ◎Sanskrit Astrolabe made for Maṇirāma 1839

1644, Gujarat, Diameter 128 mm, Edinburgh, National Museums of Scotland (# 1986.20)

C007 ◎Sanskrit Astrolabe of Jīvatāpa, son of Jānī Harajī 1851

1651, Gujarat, Diameter 135 mm, Vadodara, M. S. University of Baroda, Oriental Institute (# 20735)

C008 Sanskrit Astrolabe of Rāghavajit 1862

1669, Surat, Diameter ?, PLU

C009 Sanskrit Astrolabe, not signed, not dated 1876

Ca. 1670, Surat, Gujarat, Diameter 119 mm, PLU

C010 ◎Sanskrit Astrolabe of Jośī Indrajī 1881

1673, Gujarat, Diameter 115 mm, Oxford, Pitt Rivers Museum of Ethnology (# 1893.4514)

C011 Sanskrit Astrolabe, not signed 1892

1678, Gujarat, Diameter ?, PLU

C012 ◎Sanskrit Astrolabe, not signed, not dated 1897

17th Century, Gujarat, Diameter 87 mm, London, Victoria & Albert Museum (# I.M. 407; the four plates are marked IPN 2467)

C013 Sanskrit Astrolabe, not signed, not dated 1905

Ca. 1670, Gujarat, Diameter 87 mm, Qatar, Doha, Museum of Islamic Art (# MW.345.2007)

C014 ◎Sanskrit Astrolabe, not signed, not dated 1910

17th century, Gujarat, Diameter 162 mm, Hyderabad, State Museum of Archaeology (# 3122)

C015 ◎Sanskrit Astrolabe with the Kaṭapayādi Notation, not signed, not dated 1919

17th century, Gujarat ?, Diameter 202 mm, Varanasi, Sampurnanand Sanskrit University, Sarasvati Bhavan Library

C016 ◎Sanskrit Astrolabe, unsigned, undated 1930

17th Century, Gujarat, Diameter of the plates 122 mm, New Delhi, National Museum, Ajit Mookerjee Collection (# 82.298/1-6)

C017 ◎Sanskrit Astrolabe, not signed, not dated 1934

17th century, Gujarat, Diameter 177 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (# 40.417)

C018 Sanskrit Astrolabe, not signed, not dated 1939

17th century, Gujarat, Diameter 165 mm, Ahmedabad, PC

C019 Sanskrit Ornithomorphic Astrolabe, not signed, not dated 1947

17th Century, Gujarat, Diameter ca 300 mm, Jodhpur, PC

C020 Sanskrit Astrolabe, not signed, not dated, with a wooden case 1953

17th century, Gujarat, Diameter 148 mm, Jodhpur, PC

C021 ◎Sanskrit Astrolabe (Large Wheel Astrolabe) made for Sawai Jai Singh 1961

Ca. 1720 Amber, Rajasthan, Diameter 351 mm, Jaipur, Jai Singh's Observatory

C022 ◎Sanskrit Astrolabe (Small Wheel Astrolabe) made for Sawai Jai Singh 1971

Ca. 1720 Amber, Rajasthan, Diameter 351 mm, Jaipur, Jai Singh's Observatory

C023 Sanskrit Astrolabe, not signed, not dated 1982

Late 18th or early 19th century, Uttar Pradesh (?), Diameter 167 mm, PLU; ex-London, Sotheby's

C024 Sanskrit Astrolabe made by Vīrabha[dra] 1993

1805, Jodhpur, Diameter 141 mm, Washington DC, National Museum of American History

C025 Sanskrit Astrolabe attributable to Vīrabhadra 2000

1809, Jodhpur, Rajasthan, Diameter 153 mm, PLU, Ex-Rockford, Time Museum

C026 Sanskrit Astrolabe by Sūtradhāra Māyārāma 2006

1810, Jodhpur, Rajasthan, Diameter ca 180 mm, PLU; ex-Paris, Alain Brieux

C027 Sanskrit Astrolabe by Sūtradhāra Māyārāma 2012

1810, Jodhpur, Rajasthan, Diameter 179 mm, PLU; ex-Paris, Alain Brieux

C028 ◎Sanskrit Astrolabe attributable to Bulhomal 2015

Ca. 1849, Lahore, Diameter 133 mm, Rampur, Rampur Raza Library

C029 Sanskrit Astrolabe attributable to Bulhomal 2026

Ca. 1849, Lahore, Diameter 135 mm, Srinagar, Sri Pratap Singh Museum (# 2750/E)

C030 Sanskrit Astrolabe attributable to Bulhomal 2028

Ca. 1849, Lahore, Diameter ?, PLU

C031 ◎Gurmukhi Astrolabe of the Maharaja of Patiala designed by Rishīkes and made by Rahīm Bakhsh 2030

1850 Patiala, Panjab, Diameter 195 mm, Germany, PC

C032 ◎Sanskrit Astrolabe, not signed, not dated 2057

19th century, Rajasthan, Diameter 140 mm, Jaipur, Government Maharaja's Sanskrit College

C033 Sanskrit Astrolabe, not signed, not dated 2064

19th century, Rajasthan, Diameter 153 mm, Qatar, Doha, Museum of Islamic Art (# MW.389.2009), Ex-Leonard Linton

C034 Sanskrit astrolabe designed by Haridatta and made by Lakṣmīnārāyaṇa 2069

1883 Kuchaman, Rajasthan, Diameter 333 mm, Qatar, Doha, Museum of Islamic Art (# MW.395.2007)

C035 ◎Sanskrit Astrolabe, not signed, not dated 2074

Late 19th century, probably Kuchaman, Rajasthan, Diameter 304 mm, Paris, PC

C036 Sanskrit Astrolabe, not signed, not dated 2082

Late 19th century, Diameter 154 mm, PLU, ex-London, Christie's, ex-Frankfurt, PC

C037 ◎Sanskrit Astrolabe, not signed, not dated 2097

Late 19th century, Diameter 148 mm, Mumbai, PC

C038 Sanskrit Astrolabe with a rectangular crown, not signed, not dated 2099

19th century, place of manufacture unknown, Diameter ?, PLU

D. SANSKRIT ASTROLABES WITH SINGLE PLATES

INTRODUCTION

An astrolabe with a single plate designed for a particular locality is a simplified but very pragmatic or utilitarian version of the conventional astrolabe. Except for the limitation that it can be used only at a single latitude and not in all the seven climates, it can perform nearly all the functions envisaged for the astrolabe. The major advantage is that its construction is much easier and therefore the time and cost of production are considerably less. Such versions are not known elsewhere;[821] they seem to have been developed mainly in the Sanskrit milieu, in particular in Rajasthan, quite likely by the astronomer-prince Sawai Jai Singh (1688-1743) who is otherwise well-known for the huge masonry instruments with which he set up observatories at Jaipur, Delhi, Benares, Ujjain and Mathura.[822]

Jai Singh experimented at first with larger versions of some portable instruments of Islamic tradition. One of these was a very large brass astrolabe plate which he got constructed with a diameter of 2115 mm and had it calibrated for the latitude of his capital city at 27° (D001). Since the pin would not have been able to bear the weight of the full rete which needs to be rotated around the pin, he reduced the rete to the minimum, and had the ecliptic and the star pointers engraved on the latitude plate itself. Even then the difficulty of mounting and manipulating this large astrolabe remained. Therefore, he abandoned these large portable metal instruments and designed masonry

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[821] A single plate astrolabe calibrated for the latitude of 34° and inscribed in Kufic characters is described by Morley 1856, pp. 34-36, Figs. xviii-3 (suspensory apparatus), xx-24 (rete), xxi-42 (alidade) and xxi-49 (wedge). It had a diameter of 225 mm and was 'evidently of modern date'. It may have been produced in Damascus, but did they still use Kufic script in 'modern' times? Morley saw it in the museum of the East-India House. Many artefacts from there were transferred to the Victoria and Albert Museum, London. Probably, it is still in this museum.

[822] The fifth observatory at Mathura exists no longer. Today these historic observatories are called by the vulgar name 'Jantar Mantar' which literally means 'magical diagram and magical incantation'. This name was originally given to Jai Singh's Observatory at Delhi by people on the street who did not understand the purpose of these huge structures. In recent times this name was thoughtlessly extended to all the observatories by the authorities; it is employed also in Government of India's application to the UNESCO for grating heritage status to the Jaipur Observatory! It is ironic to call these unique scientific monuments by an unscientific name derived from the realm of the occult. It is better to call them Jai Singh's Observatories.

instruments of very large dimensions in order to achieve very minute readings on the scales.

Although he did not consider the astrolabe suitable for minute observations, Jai Singh had a great respect for the astrolabe as an excellent tool for demonstration and teaching. He collected some of the best Mughal astrolabes fashioned by Ḍiyā' al-Dīn Muḥammad of the Lahore family (A073, A091 and A092), composed a manual on the astrolabe in Sanskrit prose entitled *Yantrarāja-racanā,*[823] commissioned the translation of Naṣīr al-Dīn al-Ṭūsī's *Risālat al-Usṭurlāb,* which is popularly known as *Bist Bāb* (twenty chapters) from the Persian into Sanskrit,[824] and sponsored the composition of a Sanskrit manual *Sarvadeśīya-jarakālī-yantra* on the universal astrolabe designed by al-Zarqālluh, on the basis of the *Zarqālī* astrolabe made by Ḍiyā' al-Dīn Muḥammad which he had with him (A092).[825]

He also realized that the best way to popularize the astrolabe is to keep it to the essentials and remove the peripherals. That is to say, to make it with a single plate calibrated to one particular latitude. He seems to have commissioned several astrolabes with single plates calibrated for the latitude of his capital city Amber (and later Jaipur) at 27° and distributed these among the astronomers at his court.

There is evidence to show that Jai Singh established a manufactory for the production of Sanskrit astrolabes where some astrolabes with multiple plates where made (C020 and C021), but its main production was the single plate astrolabes for the latitude of Jaipur at 27°. At his Observatory at Jaipur today, there are preserved several single plate astrolabes in various stages of completion (D077 - D089), indicating that this manufactory was abruptly closed, probably because of his death.

But the production of single plate astrolabes continued in Jaipur and elsewhere in Rajasthan. Writing in 1902, Lieut. A. ff. Garrett who was responsible for the restoration of the Jaipur Observatory, states: 'The Yantra Raj seems to have been a favourite instrument, and it is still used by the pandits of the present day. It is made in all sizes,

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823 *Yantrarāja-racanā,* ed. Kedāranātha Jyotirvid, Jaipur 1953.

824 Bhattacharya 1979.

825 Cf. Sarma 1996b.

from the huge brass dial 7 ft. in diameter now hanging from masonry supports in the Observatory, down to pocket instruments a few inches across.'[826]

Today there exist some ninety and odd Sanskrit astrolabes with single plates in museums and private collections all over the world. Almost all of these were produced in Rajasthan, except two (D058 and D071) which were made in Gujarat.[827] In Rajasthan, these were produced not only in Jaipur (latitude 27°), but in several other places like Kuchaman (27°), Jodhpur (26°), Bikaner (28° or 28:16°), Bundi (25;30°) and Tonk (26°). Interestingly astrolabe D059 was made in Kuchaman, but with a plate calibrated for latitude 24° for use at Calcutta, the capital of the British Colonial Government in the nineteenth century. Very few of these astrolabes carry the names of the designer or maker or date. The earliest dated one was made in 1742 (D002) and the last one in 1903 (D037).

Being utilitarian devices, these are without any ornamentation. The crown and the plate are cut out in one piece from the same sheet of brass. The crown is solid and profiles are made up of ogees at the base followed by tiered lobes. The only exception are some astrolabes produced at Kuchaman. In an astrolabe made before 1828 (D034), the crown is fashioned in the form of a stylized lotus. This is emulated in several astrolabes made at this place, in some successfully (D038) and in others in a very rudimentary form (especially D035, D036 and D037). No other decorations were attempted on the crown.

In the majority of astrolabes, the scale on the rim is divided in 1° and 6° and numbered in 6s from 1 to 60. Thus the degree scale functions as the *ghaṭī* scale where 6° equal 1 *ghaṭī*. On the plate are drawn the two diameters and the three concentric circles of the Tropic of Capricorn, the equator and the Tropic of Cancer. Upon these are traced altitude circles at intervals appropriate to the size of the plate. Azimuth arcs are

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826 Garrett & Guleri 1902, p. 57.

827 These are constructed in a peculiar manner. The front with the crown and the circular scale was cut of a thicker sheet and the back with the crown was made separately out of another sheet. Then these parts were joined with a series of rivets along the entire circumference, leaving space to accommodate just one latitude plate and the rete. Interestingly, the earliest dated astrolabe in the world, namely the one made by Nasṭūlus in 926-7, was constructed in a similar fashion; cf. King 2005, pp. 470-484: 'Nasṭūlus and his two surviving astrolabes,' esp. p. 473: 'The throne and rim are cast as one, and to this the back is riveted in several places.'

generally drawn, sometimes above the horizon, sometimes below the horizon and some other times both above and below the horizon. In the lower half are traced lines for seasonal hours, but lines for equal hours are rare.

In the rete, the rings of Capricorn, equator and ecliptic are completely represented. In most cases, the equator ring has counter changes at the two equinoxes. Here also, the astrolabes made in Kuchaman form an exception. In these astrolabes, ornate bridges connect the equator ring to the ecliptic ring in the south and to the Capricorn ring in the north. The star pointers are usually of the dagger type.

On the back, the upper half of the rim is engraved with altitude scales; sometimes, the lower half is engraved with degree scales, sometimes it is blank. Generally, a trigonometric quadrant is drawn in the upper left, occasionally in the upper right. Declinations arcs are drawn very rarely. In the lower half, there are usually shadow squares. Astrological tables are added in just four astrolabes (D017, D032, D050 and D069). As in the C-series, here also there are often empty spaces on the back. In the majority of cases, the alidade is fitted with a sighting tube.

There are some unusual astrolabes which deserve a special mention. Three astrolabes (D002, D003 and D004) are made in the style of the Great Astrolabe with minimal rete and with the latitude plate engraved with the ecliptic circle and star positions.

Three other astrolabes (D005, D006 and D007) are equipped in the front with a ruler in which a cursor moves along a graduated longitudinal slit. Besides the three complete rings of Capricorn, equator and ecliptic in the rete, there is also a fourth ring representing the Tropic of Cancer. On the back are drawn two pairs of shadow squares one inside the other, but numbered differently in each astrolabe, suggesting that the astrolabe designer was experimenting with this innovation.

Moreover, D005 is very unique: it is equipped with a northern rete and a southern rete and the two sides of the plate carry respectively the northern and the southern projections for latitude 27°.

Since very few of these single plate astrolabes are dated, chronological arrangement is not possible in this section. Hence, astrolabes are arranged according to the latitudes for which they are made. Towards the end of the section are added some 20 astrolabes and astrolabes parts which are unfinished.

Lest this section does not conclude with these unfinished parts, two extraordinary astrolabes are placed at the end; these were designed by Gaṅgāsahāya with long and scholarly inscriptions which were faultlessly engraved by talented artisans.

This section closes with a modern card-board astrolabe made in ‘Sanskrit style’ by James E. Morrison. In certain respects, it is an improvement on the existing Sanskrit astrolabes and Sawai Jai Singh would have been pleased about it.

ASTROLABES FOR LATITUDE 27° WITH STARS MARKED ON THE PLATE

Among the Islamic astrolabes there are a few specimens where the ecliptic and star positions are marked on the latitude plate. The earliest probably is an astrolabe made by ᶜUmar b. Dawlatshāh b. Muḥammad al-Kirmānī in 726/1325, only the mater of which survives. A geographical gazetteer is engraved on the inner surface and the back is designed as the latitude plate for 36° with the attitude circles, azimuth arcs and hour lines. On this plate are also marked a graduated ecliptic and 30 named star positions by dots enclosed in circles. The rete of this unusual astrolabe has not survived and we do not know how it was designed.[828]

Figure D1 – Astrolabe by ᶜUmar b. Dawlatshāh al-Kirmānī (from Linton 1980)

[828] Linton 1980, no. 163, pp. 90-91. King 2005, pp. 55-57, states that an 'early variety of astrolabe in which astrolabic markings for a specific latitude and the projection of the ecliptic and stars are all on a single plate is known from textual souces and two examples,' but does not mention the second astrolabe or the textual sources.

Ḍiyā’ al-Dīn Muḥammad of Lahore followed this style in the small north-south astrolabe which he made in 1085/1674 (A091). This astrolabe consists of a single plate one side of which is engraved as a latitude plate for 33° N; on this plate is superimposed a northern projection of the ecliptic circle together with the positions of 46 stars. The reverse side of the plate is made for latitude 35° N on which a southern projection of the ecliptic circle is drawn and the positions of the same 46 stars, but with southern orientation, are marked. The rete consists of just the ecliptic ring and the alidade is fitted with a sighting tube.

This astrolabe was collected by Sawai Jai Singh together with some other Lahore astrolabes. He appears to have followed its style when he commissioned a large astrolabe with a minimal rete and the star positions marked on the plate (D001). The same style was followed in three small astrolabes which were made at Jaipur for its latitude of 27° (D002 – D004). Making observations with such an astrolabe is somewhat more complicated than with the common astrolabe.[829]

Another specimen of this nature is the unfinished astrolabe D078 with a minimal rete. On the two sides of the plate, projections are drawn for latitudes 27° and 30° respectively, but no star positions are marked on either side, nor are there any numbers or labels. A minimal rete is to be found also with astrolabe D075 which is likewise incomplete.

While the astrolabes mentioned above are equipped with minimal retes, D033 has a normal rete with 22 star pointers, but the positions of 9 stars are also marked on the plate.

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829 For a detailed procedure of using this astrolabe, see Sharma 2016, pp. 182-183.

Index of Astrolabes for Latitude 27° with Stars marked on the Plate

D001 ◎The Great Astrolabe for Latitude 27° commissioned by Sawai Jai Singh 2115
Ca. 1720, Jaipur, Diameter 2115 mm, Jaipur, Jai Singh's Observatory

D002 Astrolabe for Latitude 27° with star positions marked on the plate, not signed 2125
1742, Jaipur, Diameter ?, PLU

D003 Astrolabe for Latitude 27° with star positions marked on the plate, not signed 2130
Ca. 1742, Jaipur, Diameter 192 mm, PLU

D004 Astrolabe for Latitude 27° with star positions marked on the plate, not signed 2135
18th century, Jaipur, Diameter 162 mm, Hastings-on-Hudson, NY, Tesseract

THREE UNUSUAL ASTROLABES FROM JAIPUR

The following three astrolabes (D005, D006 and D007), which carry no signature or date, display close similarity in design and share several unusual features. The crowns with their lobed profiles have roughly the same design. All are equipped with a ruler in front with a graduated longitudinal slit in which there is a movable cursor. The most striking feature is the rete consisting of four almost complete rings, representing not only the Tropic of Capricorn, the equator and the ecliptic, but also the Tropic of Cancer, which is not generally represented as a ring in astrolabe retes. The star pointers are shaped like daggers with very sharp ends. Some star pointers are situated inside small heart-shaped incisions made in the main frame. The latitude plates are calibrated for 27°. But this fact is not recorded on any of the three astrolabes, nor are the altitude circles, azimuth arcs and hour lines numbered on any of these.

Another unusual feature common to all the three astrolabes is that on the back there are two pairs of shadow squares, one engraved inside the other.

But the three astrolabes are not exact copies of one another. The sizes are different, so also the workmanship and quality of engraving of the star names. The method of numbering the degree scale on the rim and the tangent and cotangent scales in the shadow squares on the back is different in each astrolabe; likewise the number of star pointers is different.

The workmanship of D006 is far superior to that of the other two. The star names on the rete are engraved very carefully and almost correctly. The two loose ends of the Capricorn ring are nicely shaped like peacocks with their crests erect. These crests are missing in D007, but the beak, the curved neck and the body are delineated very well. In the northern rete of D005, one can just discern the beak and head of a bird. In the southern rete, however, no attempt was made to give any shape to the ends. In D005, the quality of engraving of the star names is very indifferent. There are also differences in the various elements on the back, as will be shown in the individual description of these astrolabes.

But it is certain that these three astrolabes were designed by the same enterprising astronomer who attempted to introduce some unusual variations and it is also certain that they were fabricated by the same artisan. The engraving of the star names on the rete, however, was done by different assistants. It is quite likely that these astrolabes were made in Jaipur.

The present owner of D006 acquired it from the Libraire Alain Brieux in Paris. In a letter dated 22 December 1976, Alain Brieux informed him that the astrolabe was bought from a scholar of Jaipur who possessed a large library of manuscripts emanating from the collection of Maharaja Jai Singh. Therefore, Brieux assumed, 'avec la plus grand certitude,' that the astrolabe was from the private collection of the Maharaja. Whether it is from the private collection of the Maharaja or not, it is quite likely that the three astrolabes were produced in the early part of the eighteenth century

But an intriguing feature is that all the three astrolabes are equipped in the front with a ruler in which a cursor moves along a graduated longitudinal slit. Rulers are generally attached to the front of European astrolabes, but not in Islamic or Indo-Persian astrolabes. [840] Even in European astrolabes, such rulers as in these three astrolabes with cusors moving along longitudinal slits are not known.

However, a Sanskrit astrolabe dated 1742 (D002) and another produced about the same time (D003) are equipped with graduated rulers. These astrolabes are also designed for the latitude of 27° at Jaipur. This would show that already in the first half of the eighteenth century astrolabes were produced at Jaipur with graduated rulers attached to the front. Then rulers with cursors may be regaded as a variation developed at Jaipur itself.

840 Allāhdād's undated astrolabe (A002) has a ruler in front. This must have been added later and was not an original component of the astrolabe which was produced in the second half of the seventeenth century.

Index of Three unusual Astrolabes from Jaipur

D005 Astrolabe for latitude 27°, with Northern & Southern Retes, not signed, not dated 2143

18th century, Jaipur, Diameter 241 mm, Hastings-on-Hudson, Tesseract

D006 Astrolabe for latitude 27°, not signed, not dated 2157

18th century, Jaipur, Diameter 363 mm, Brussels, PC

D007 ◎Astrolabe for Latitude 27°, not signed, not dated 2166

18th century, Jaipur, Diameter 304.5 mm, Jaipur, PC

STANDARD ASTROLABES FOR LATITUDE 27° MADE AT JAIPUR

Leaving aside the seven unusual specimens described above, there are extant several standard astrolabes made for latitude 27°. In most cases, these are unostentatious pieces having simple retes with dagger-shaped star pointers. All these must have been produced at Jaipur, either in Jai Singh's palace workshop or outside for individual astronomers. Just one astrolabe (D008) is dated, but it is difficult to extract the precise date from the symbolic notation. Nevertheless, it is an extraordinary piece with the intricately carved crown and with silver inlay in the inscriptions. Worthy of note are also the ornithomorphic motifs on the rete of D018 and in the crown of D026.

The last traditional astrolabe to be made at Jaipur is D027. It was made ca. 1951 at the behest of Madanamohana Śarmā as a companion piece to his Hindi rendering of Mahendra Sūri's *Yantrarāja.*

Index of Standard Astrolabes for Latitude 27° made at Jaipur

D008 ◎Astrolabe for Latitude 27°, commissioned by Mannālāla, made by Śivadatta2177

Mid 19th century, Jaipur, Diameter 344.5 mm, London, Science Museum (# 1986-1190)

D009 ◎Astrolabe for Latitude 27°, not signed, not dated 2188

18th century, Jaipur, Diameter 185 mm, Jaipur, Jai Singh's Observatory

D010 ◎Astrolabe for Latitude 27°, not signed, not dated 2193

19th century, Jaipur, Diameter 180 mm, New York, Columbia University, Butler Library, D. E. Smith Collection (# 27-257A)

D011 ◎Astrolabe for Latitude 27°, not signed, not dated 2198

19th century, Jaipur, Diameter 257 mm, London, Science Museum (#1980-1191)

D012 ◎Astrolabe for Latitude 26;56°, not signed, not dated 2205

19th century, Jaipur, Diameter 509 mm, London, Ahuan Art Gallery

D013 ◎Astrolabe for Latitude 27°, not signed, not dated 2210

19th century, Jaipur, Diameter 552 mm, Oxford, Museum of the History of Science (# 30402)

D014 Astrolabe for Latitude 27°, not signed, not dated 2217

19th century, Jaipur, Diameter ?, PLU

D015 Astrolabe for Latitude 27°, not signed, not dated 2223

19th century, Jaipur, Diameter 269 mm, PLU, ex-Paris, Alain Brieux

D016 Astrolabe for Latitude 27°, not signed, not dated 2229

19th century, Jaipur, Diameter ?, PLU

D017 ◎Astrolabe for Latitude 27°, not signed, not dated 2235

19th century, Jaipur, Diameter 217 mm, Jaipur, PC

D018 ◎Astrolabe for Latitude 27° with an Ornithomorphic Rete, not signed, not dated 2240

19th century, Jaipur, Diameter 251 mm, Jaipur, PC

D019 ◎Astrolabe for Latitude 27°, not signed, not dated 2246

19th century, Jaipur, Diameter 284, PLU; ex-Brussels, PC

D020 Astrolabe for Latitude 27°, not signed, not dated 2251

19th century, Jaipur, Diameter 172 mm, PLU, ex-Tesseract, Hastings-on-Hudson, NY

D021 ◎Astrolabe for Latitude 27°, not signed, not dated 2257

19th century, Jaipur, Diameter 177 mm, Brussels, PC

D022 ◎Astrolabe for Latitude 27°, not signed, not dated 2261

19th century, Jaipur, Diameter 214 mm, Oxford, Museum of the History of Science (# 52478)

D023 Astrolabe for Latitude 27°, not signed, not dated 2267

19th century, Jaipur, Diameter ?, Ahmedabad, Museum of the L. D. Institute of Indology

D024 Astrolabe for latitude 27°, not signed, not dated 2270

19th century, Jaipur, Diameter 175 mm, PLU

D025 Astrolabe for latitude 27°, not signed, not dated 2272

19th century, Jaipur, Diameter 427 mm, Vicenza, PC of Mr Giancarlo Beltrame (# 412)

D026 ◎Astrolabe For Latitude 27°, with a family of horizons on the back, not signed, not dated 2276

19th Century, Diameter 302 mm, Bielefeld, Kunstgewerbesammlung der Stadt Bielefeld, Stiftung Huelsman (# H-W 93)

D027 ◎Astrolabe for Latitude 27°, made for Madanamohana Śarmā 2283

Mid 20th century, Jaipur, Diameter 230 mm, copper, Jaipur, Museum of Indology

SILVER ASTROLABES MADE IN JAIPUR IN THE 20TH CENTURY

In the twentieth century some enterprising jewellers produced silver astrolabes for foreign buyers. Five specimens are known in different collections. These are not original creations, but are copied from earlier brass astrolabes. The first three specimens, D028, D029 and D030, are copied from D007 which is still in Jaipur or another similar specimen. The exact models for D031 and D032 have not come to light so far; they may be in some private collections in Jaipur.

Besides these silver astrolabes, there is a double ring dial preserved in the National Museum at New Delhi; this too appears to have been produced in the twentieth century at Jaipur, in imitation of some brass model. It will be described in section Y.

Different from these is a special type of sine quadrant made in silver; it is not a twentieth century copy of an existing brass model, but an original device which Raja Ram Singh of Kota got designed by a certain Vaijanātha's son and presented to the Government of India ca. 1839.[873] Its present location is not known. It will described in section K.

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[873] Cf. Middleton 1839.

Index of Silver Astrolabes made in Jaipur in the 20th century

D028 ◎Silver Astrolabe for Latitude 27°, not signed, not dated 2291

20th century, Jaipur, Diameter 212 mm, New Delhi, National Museum (# 86.193/1)

D029 ◎Silver Astrolabe for Latitude 27°, not signed, not dated 2298

20th century, Jaipur, Diameter 213 mm, London, Science Museum (# 1990-605)

D030 Silver Atrolabe for latitude 27°, not signed, not dated 2302

20th century, Jaipur, Diameter ?, PLU

D031 Silver Astrolabe for Latitude 26°, not signed, not dated 2306

20th century, Jaipur, Diameter 317 mm, PLU; ex-Time Museum, Rockford

D032 Silver Astrolabe for Latitude 27°, not signed, not dated 2313

20th century, Jaipur, Diameter 360 mm, PLU

ASTROLABES FOR LATITUDE 27° MADE AT KUCHAMAN

Kuchaman (27;10° N, 74;52° E) has been a small princely estate (ṭhikānā) in Rajasthan and its ruler bore the title Ṭhākur. It is some 120 km north-west of Jaipur (26;54° E, 75;48° N) and situated roughly on the same latitude 27° as Jaipur. It became a major centre of production of Sanskrit astrolabes and other instruments in the nineteenth century, either through the patronage of the rulers or through the initiative of certain astronomers.

The earliest dated instrument produced here (D033) is dated 1813. About the same time was produced also D034. The last dated astrolabe (D037) was made in 1903. Between these two dates were produced several astrolabes and other instruments at Kuchaman.

Astrolabe D034 is the most ornate specimen of the Sanskrit astrolabes with single plates. The unknown astrolabe maker of Kuchaman designed the crown very elegantly in form of a stylized lotus. In the rete, he connected the equator ring by means of ornate bridges with the ecliptic ring in the south and with the Capricorn ring in the north.

These decorative features were copied in several astrolabes and thus distinguish the astrolabes produced at Kuchaman from others. Among these, the four astrolabes (D036, D037, D038 and D039) produced around the close of the nineteenth century deserve special mention. Three of these were designed by the astronomer Jayakṛṣṇadāsa and one by his son Haridatta, but all the four were fabricated by the artisan Lakṣīnārāyaṇa. The obverse sides of these four astrolabes are designed for the latitude of 27°; for some unknown reason, the reverse side is also engraved with altitude circles, not for 27°, but for 18°. Besides this strange and inexplicable anomaly, they share the same characteristics in the design of the crown and rete with the other astrolabes of Kuchaman.

Index of Astrolabes for Latitude 27° made at Kuchaman

D033 Astrolabe for latitude 27°, not signed, not dated, with star positions marked on the plate 2327

1813, Kuchaman, Rajasthan, Diameter 203 mm, Washington DC, PC

D034 ◎Astrolabe for Latitude 27°, not signed, not dated 2334

Early 19th century, before 1828, Kuchaman, Rajasthan, Diameter 173 mm, London, Victoria & Albert Museum (# IM 409 1924)

D035 ◎Astrolabe for Latitude 27°/18°, designed by Jayakṛṣṇadāsa, made by Lakṣmīnārāyaṇa 2338

1887, Kuchaman, Rajasthan, Diameter 220 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

D036 ◎Astrolabe for Latitude 27°/18° designed by Jayakṛṣṇadāsa, made by Lakṃīṇārāyaṇa 2343

1902, Kuchaman, Rajasthan, Diameter 219 mm, Paris, PC

D037 Astrolabe for Latitude 27°/ 18°, designed by Haridatta, made by Lakṣmīnarayaṇa 2349

1903, Kuchaman, Rajasthan, Diameter 244 mm, Hastings-on-Hudson, Tesseract

D038 ◎Astrolabe for Latitude 27°/18°, designed by Jayakṛṣṇadāsa, made by Lakṣmīnārāyaṇa, not dated 2356

Late 19th century, Kuchaman, Rajasthan, Diameter 309 mm, Hamburg, PC

D039 Astrolabe for Latitude 27°/18°, not signed, not dated 2366

19th century, Kuchaman, Rajasthan, Diameter 280 mm, PLU

D040 Astrolabe for Latitude 27°, not signed, not dated 2372

19th century, Kuchaman, Rajasthan, Diameter 370 mm, PLU

D041 Astrolabe for latitude 27°, not signed, not dated 2376

19th century, Kuchaman, Rajasthan, Diameter 291 mm, Qatar, Doha, Museum of Islamic Art (# MW.380.2007), ex-Point Lookout, ex-Alain Brieux

D042 Astrolabe for latitude 27°, not signed, not dated 2380

19th century, Kuchaman, Rajasthan, Diameter 211 mm, Vicenza, Italy, PC of Mr Giancarlo Beltrame (# 224)

D043 Astrolabe for latitude 27°, not signed, not dated 2384

19th century, Kuchaman, Rajasthan, Diameter ?, PLU

D044 Astrolabe for Latitude 27°, not signed, not dated 2387

19th century, Kuchaman, Rajasthan, Diameter 290 mm, PLU

D045 Astrolabe for Latitude 27°, not signed, not dated 2388

19th century, Kuchaman, Rajasthan, Diameter, PLU; ex-Saul Moskowitz, Marblehead

D046 Astrolabe for latitude ca. 27°, not signed, not dated 2391

19th century, Kuchaman, Rajasthan, Diameter ?, PLU

D047 Astrolabe for latitude 27°, not signed, not dated 2394

19th century, Kuchaman, Rajasthan, Diameter 295 mm, PLU; ex-Tesseract

D048 ◎Astrolabe for latitude 27°, not signed, not dated 2398

19th century, Kuchaman, Rajasthan?, Diameter 216 mm, Varanasi, Banaras Hindu University, Bharat Kala Bhavan (# 2/5133)

ASTROLABES FOR LATITUDE 26° MADE AT JODHPUR

Three astrolabes are designed for the latitude of Jodhpur at 26°. Stylistically the first two belong together with similar crowns and must have been made by the same person around 1867. The third one displays a different workmanship.

Index of Astrolabes for Latitude 26° made at Jodhpur

D049 ◎Astrolabe for Latitude 26°, not signed 2407
1867, Jodhpur, Rajasthan, Diameter 213 mm, Heidelberg, PC

D050 ◎Astrolabe for Latititude 26°, made for Raṇakuṃjalāla, not signed, not dated 2413
Ca. 1867, Jodhpur, Rajasthan, Diameter 207 mm, Heidelberg, PC

D051 ◎Astrolabe for Latitude 26°, not signed, not dated 2419
19th century, Jodhpur, Rajasthan, Diameter 276 mm, Paris, PC

ASTROLABES FOR LATITUDE 30° MADE AT KURUKSHETRA OR THANESAR

As mentioned in the introduction to the section C, the production of Sanskrit astrolabes was largely confined to Gujarat and Rajasthan.[908] But there are four astrolabes whose plates are designed for latitude 30° (D052 to D055). There is no major town on this latitude in Gujarat or Rajasthan. Possibly these astrolabes were made either in Kurukshetra or in Thanesar, both situated roughly at 29;58° N, 76;50° E.

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908 C. Introduction 2.2.

Index of Astrolabes for Latitude 30° made at Kurukshetra or Thanesar

D052 Astrolabe for Latitude 30°, not signed, not dated.. 2429

19th century, Kurukshetra / Thanesar , Diameter 174 mm, Chicago, Adler Planetarium & Astronomy Museum (# W-102)

D053 ◎Astrolabe for Latitude 30°, not signed, not dated.. 2433

19th century, Kurukshetra / Thanesar , Diameter 174.5 mm, New Delhi, National Museum (#85406/A/B)

D054 ◎Astrolabe for Latitude 30°, not signed, not dated.. 2438

19th century, © / Thanesar, Diameter 236 mm, Vadodara, MS University of Baroda, Oriental Institute

D055 ◎Astrolabe for Latitude 30°, not signed, not dated.. 2443

19th century, Kurukshetra / Thanesar, Diamter 218 mm, Varanasi, Sampurnanand Sanskrit University, Sarasvati Bhavan Library

ASTROLABES FOR OTHER LATITUDES

In the nineteenth century, the production of Sanskrit astrolabes with single plates spread to many other places in Rajasthan like Kota (latitude 25°), Bikaner (28°) and so on. Sūtradhara Sūryamalla produced, under the guidance of Kastūrīcandra, at least 4 identical astrolabes with a peacock perched on the central ring in the rete for the latitude of Bikaner at 28;16°. Sanskrit astrolabes continued to be made in Gujarat, although sporadically, e.g. D058 made for Karvan near Vadodara at the latitude of 22;35.30°.

Sakhārāma Jośī is said have produced astrolabes for places in Maharashtra, but these have not come to light so far.

Two outstanding astrolabes were designed by the astronomer Gaṅgāsahāya for the latitude of Bundi at 25;30° (D090) and for that of Tonk at 26° (D091). These will be described at the end of this section.

Index of Astrolabes for other Latitudes

D056 Astrolabe for Latitude 17;42° made / commissioned by Sakhārāma Jośī 2451

1790, Diameter ?, PLU

D057 Astrolabe for Latitude 17;21° made / commissioned by Sakhārāma Jośī 2452

1796, Diameter ?, PLU

D058 Astrolabe for Latitude 22;35,30°, not signed 2453

1884, Gujarat, Diameter 314 mm, PLU

D059 ◎ Astrolabe made for Kolkata at Latitude 24°/24°, not signed, not dated 2460

19th century, Kuchaman, Rajasthan, Diameter 250 mm, Jaipur, PC

D060 Astrolabe for Latitude 25°, not signed, not dated 2464

19th century, Kota, Rajasthan, Diameter 177 mm, Chicago, Adler Planetarium & Astronomy Museum (#A-68)

D061 Astrolabe for Latitude 28°, not signed, not dated, owned by Kheūjī Ācārya ... 2470

19th century, Bikaner, Rajasthan, Diameter 206, PLU, ex-Paris, Libraire Alain Brieux

D062 ◎ Astrolabe for Latitude 28;16°, designed by Kastūrīcandra, made by Sūtradhāra Sūryamalla, not dated 2474

19th century, Bikaner, Rajasthan, Diameter 273 mm, Cologne, PC

D063 ◎ Astrolabe for Latitude 28;16°, designed by Kastūrīcandra, made by Sūtradhāra Sūryamalla, not dated 2482

19th century, Bikaner, Rajasthan, Diameter 274 mm, Hastings-on-Hudson, NY, Tesseract

D064 Astrolabe for Latitude 28;16°, designed by Kastūrīcandra, made by Sūtradhāra Sūryamalla, not dated 2488

D065 Astrolabe for Latitude 28;16°, designed by Kastūrīcandra, made by Sūtradhāra Sūryamalla, not dated 2496

19th century, Bikaner, Diameter?, PLU

D066 Astrolabe for Latitude 29°, not signed, not dated 2499

19th century, Diameter 197 mm, PLU; ex-Paris, Libraire Alain Brieux

D067 ◎ Copy of an Astrolabe made for Jyotiṣācārya in 1834 2503

19th century, probably Jodhpur, Rajasthan, Diameter 259 mm, Brussels, PC

D068 Copy of an Astrolabe made for Jyotiṣācārya in 1834 2513

19th century, probably Jodhpur, Rajasthan, Diameter 321 mm, Dallas, PC

ASTROLABES WITH SOLID RETE ·

Sri Pratap Singh Museum in Srinagar owns two rather large Sanskrit astrolabes in which there are no perforated retes containing star pointers but solid discs made to the size of the ecliptic circles and pivoted to the central pin eccentrically. The star pointers in the perforated rete allow the use of the astrolabe at night. In the absence of the star pointers, these astrolabes cannot be used at night. It is difficult to see what advantage was sought to be achieved by these unusual solid retes.

These two specimens are not signed or dated. On the back of both the astrolabes, the upper right quadrant contains a sine-cosine graph, which is identical in style to the sine-cosine grids on the astrolabes and *Dhruvabhrama-yantras* made by Bulhomal of Lahore. However, the Devanagari script in these astrolabes is different from the script in Bulhomal's other productions. These astrolabes must have been designed by Bulhomal, but engraved by different assistants in his workshop.

Several astrological tables are engraved on the back of first specimen (D069), but they do not occur in the second specimen (D070).

Index of Astrolabes with Solid Retes

D069 Astrolabe with solid Rete for Latitude 30°, attributable to the workshop of Bulhomal of Lahore........ 2523

Mid-19th century, Lahore, Diameter 260 mm, Srinagar, Sri Pratap Singh Museum (# 2750/C)

D070 Astrolabe with solid Rete for Latitude 30°, attributable to the workshop of Bulhomal of Lahore........ 2532

Mid-19th century, Lahore, Diameter 245 mm, Srinagar, Sri Pratap Singh Museum (# 2750/D)

ASTROLABES FOR UNKNOWN LATITUDES

In some extant specimens, it is difficult to determine the latitude for which they were made, either because the specimen is not completely extant, or because of faulty construction, or for other reasons.

Index of Astrolabes for unknown Latitudes

D071 ◎Astrolabe for unknown Latitude, not signed, not dated 2539

18th century? Gujarat, Diameter 169 mm, New York, Columbia University, Butler Library, D. E. Smith Collection (#27-252)

D072 ◎Astrolabe for unknown Latitude, not signed, not dated 2543

19th century, Rajasthan, Extant only the rete (d. 194, t. 1.5) for 17 stars, Brussels, PC

D073 Astrolabe for unknown Latitude, not signed, not dated 2546

19th century?, Diameter 293 mm, PLU; ex-Skinner, Bolton, MA

D074 Astrolabe for unknown Latitude, not signed, not dated 2548

19th century ?, Diameter 127 mm, Hastings-on-Hudson, NY, Tesseract (Catalog 55, no. 5)

D075 Astrolabe with two Retes 2554

18th century, Lahore, Diameter 86 mm, PLU; ex-London, Christie's

D076 ◎Astrolabe for Latitudes 36° and 27°, not signed, not dated, incomplete 2560

19th century, Rajasthan, Diameter 394 mm, Cologne, PC

UNFINISHED ASTROLABES AND ASTROLABE PARTS AT JAI SINGH'S OBSERVATORY AT JAIPUR

In the stores of the Jaipur observatory, there are several astrolabes and astrolabe parts in different stages of completion. They give the impression as if their production came to a stop all of a sudden in the palace workshop. This could only have been due to the sudden death of Sawai Jai Singh in 1743.

In the first specimen of this group (D077), the rete has a beautiful floral tracery, but the ecliptic ring is not correctly positioned. Probably for this reason it was abandoned. In the second specimen (D078), the rete is minimal and the two sides of the plate are engraved with projections for latitudes 27° and 30° respectively. Then the work stopped; no numbers or labels were added on either side, nor any star positions.

Then follows a set of five unfished astrolabe plates of slightly different diameters, all with the crown in the shape of a bell with a handle. These were obviously meant for single plate astrolabes, but never fully completed. On some the projections of altitude circles etc. are drawn but not labelled or numbered. In four of these, no hole is drilled at the centre for the pin to pass through, nor at the apex of the crown for suspension. But the small decorative circles on either side at the base of the crown are pierced.

Figure D1 – Five unfinshed astrolabes (photo by S. R. Sarma)

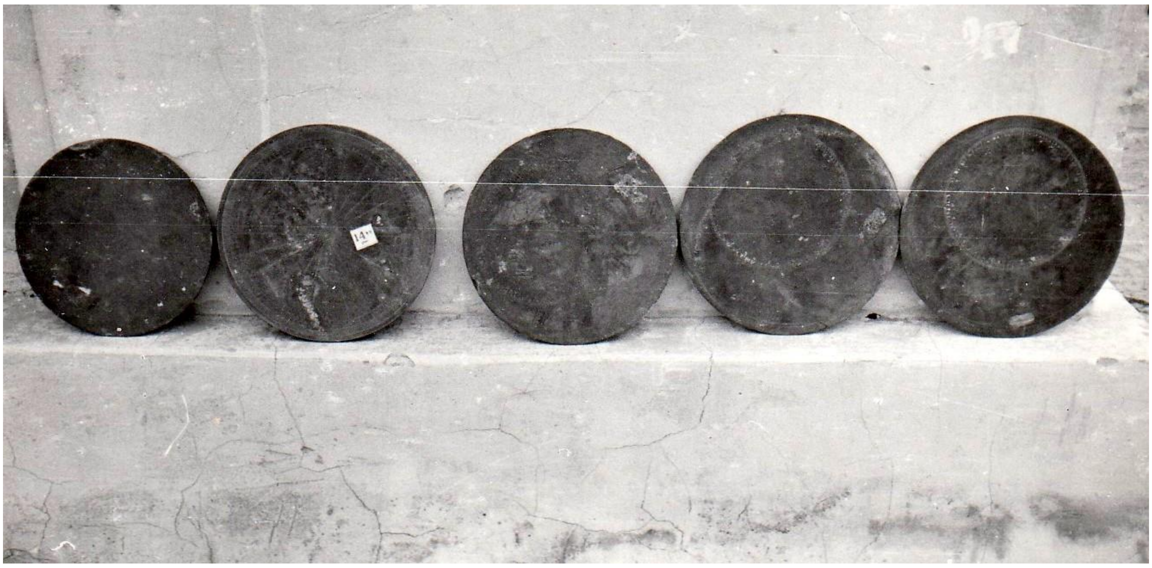

Figure D2 – Five unfinshed circular plates (photo by S. R. Sarma)

There is another set of 5 thick circular discs. One of these was meant to be made into the limb of a mupliple plate astrolabe, three were intended to be made into astrolabe retes, and the last one was probably to be designed as an astrolabe plate.

Unfinished Astrolabes and Astrolabe Parts at Jai Singh's Observatory at Jaipur

D077 ◎Unfinished Astrolabe with a floral Rete ... 2571

18th century, Jaipur, Diameter 280 mm, Jaipur, Jai Singh's Observatory

D078 ◎Unfinished Astrolabe for Latitudes 27° and 30° with a Minimal Rete, not signed, not dated ... 2573

18th century, Jaipur, Diameter 109 mm, Jaipur, Jai Singh's Observatory

D079 ◎Unfinished Astrolabe Plate for Latitude 27°, not signed, not dated ... 2577

18th century, Jaipur, Diameter 212 mm, Jaipur, Jai Singh's Observatory

D080 ◎Unfinished Astrolabe Plate for Latitude 27° ... 2578

18th century, Jaipur, Diameter 261 mm, height 344 mm, Jaipur, Jai Singh's Observatory

D081 ◎Unfinished Astrolabe Plate for Latitude 27° ... 2580

18th century, Jaipur, Diameter 272 mm, height 352 mm, Jaipur, Jai Singh's Observatory

D082 ◎Unfinished Astrolabe Plate for Latitude 27° ... 2582

18th century, Jaipur, Diameter 270 mm, height 350 mm, Jaipur, Jai Singh's Observatory

D083 ◎Unfinished Astrolabe Plate for Latitude 27° ... 2584

18th century, Jaipur, Diameter 269 mm, height 354 mm, Jaipur, Jai Singh's Observatory

D084 ◎Unfinished Astrolabe Plate for Latitude 27° ... 2585

18th century, Jaipur, Diameter 268 mm, height 354 mm, Jaipur, Jai Singh's Observatory

D085 ◎Limb of an unfinished Astrolabe ... 2587

18th century, Jaipur, Diameter 260 mm, thickness 8 mm, Jaipur, Jai Singh's Observatory

D086 ◎Unfinished Rete of an Astrolabe ... 2588

18th century, Jaipur, Diameter 268 mm, thickness 12 mm, Jaipur, Jai Singh's Observatory

D087 ◎Unfinished Rete of an Astrolabe ... 2589

18th century, Jaipur, Diameter 268 mm, thickness 12 mm, Jaipur, Jai Singh's Observatory

D088 ◎Uncut Rete of an Astrolabe ... 2590

18th century, Jaipur, Diameter 258 mm, thickness ?, Jaipur, Jai Singh's Observatory

D089 ◎Unfinished Astrolabe Plate ... 2593

18th century, Jaipur, Diameter ca. 280 mm, Jaipur, Jai Singh's Observatory

THREE SPECIAL ASTROLABES

This section concludes with three extraordinary astrolabes; the first two were designed by the astronomer Gaṅgāsahāya in 1870 and 1895 respectively and the third by the computer specialist James E. Morrison in 2011.

Gaṅgāsahāya

D090 is a very large astrolabe with a diameter of 664 mm. On the back of this astrolabe is engraved the fifth chapter of Mahendra Sūri's *Yantrarāja,* a chapter which describes the use of the astrolabe for solving diverse kinds of problems. If astrolabe can be called the computer of the Middle Ages, this one can be regarded as a computer with a built-in manual. Besides the large extract from the *Yantrarāja,* there are also engraved on the back a sine table for each degree of arc and a table of shadow lengths of the 12-digit gnomon. The rete is also engraved with much astronomical information and several erudite remarks.

The crown carries a long versified inscription which states that the astrolabe was fabricated by the artisan Śivalāla according to the design by Gaṅgāsahāya-śiśuka. The second part of this name means 'small-child' or 'infant'. It is intriguing why he qualifies the name as *śiśuka.* It cannot be an addition made for the sake of metre because the name occurs once again in this manner in another verse with a different metre. Can this mean the 'son of Gaṅgāsahāya'? There is an astrolabe (D091) designed by a certain Gaṅgāsahāya in 1895 for the latitude of Tonk at 26°. While Gaṅgāsahāya-śiśuka states that he designed the astrolabe at the behest of Rāmasiṃha, the ruler of Bundi, and completed it on 25 December 1875 which is the birthday of the said ruler, the Gaṅgāsahāya who designed the astrolabe of 1895 says that he was honoured by the ruler of Bundi who must be the same Rāmasiṃha. The astrolabe of 1895 is much smaller with a diameter of 334 mm, but it too displays certain amount of 'erudition,' in the design of the reverse side of the plate as a combination of three instruments. It also contains legends naming and explaining certain components of the astrolabe. More important, the retes of both instruments have pointers only to the stars known to the Sanskrit astronomical tradition (*siddhānta*) and not to the stars of Islamic tradition (*yavana-mata*) such as *Samudrapakṣī* (sea bird, β Ceti), *Kukkuṭapuccha* (tail of chicken, α Cygni). Therefore, it is certain that the Gaṅgāsahāya-śiśuka who designed the astrolabe of 1870 and the Gaṅgāsahāya who designed the astrolabe of 1895 are one and the same. Probably Tonk was the place of his residence while Bundi was that of his patron Rāmasiṃha. Still the attribute *śiśuka* remains an enigma. We do not know whether it was an expression of humility, or whether Gaṅgāsahāya was very young in 1870.

Be that as it may, Gaṅgāsahāya's two extant astrolabes are the most outstanding specimens of Sanskrit astrolabes, more so because Gaṅgāsahāya was fortunate in obtaining the services of two literate and capable artisans (which was indeed rare) Śivalāla and Rāmapratāpa, who engraved the long and difficult Sanskrit inscriptions on the two astrolabes with very correct, even pedantically correct, Sanskrit orthography, even employing *avagraha* symbols.

James E. Morrison

He revolutionized the astrolabe construction by creating a computer program called 'The Electronic Astrolabe' where he married the ancient design of the astrolabe with the modern technique of computer animation. At the beginning of his paper bearing the same name, he says:

> 'Some ideas are so good that they never changed very much. The astrolabe is such an idea, having been a widely used astronomical instrument for over 1000 years without significant changes in its basic form. Despite embellishments to improve its utility in different cultures and epochs, a tenth century astrolabe would have been instantly recognized by a nineteenth century user. This spectacular success is a result of the uniquely concise, complete and useful view of the heavens that the astrolabe provides. This advantage is retained when the ancient science of the astrolabe is combined with modern computer graphics and new possibilities emerge that were not possible on classical instruments. The combination of old and new technologies is synergetic, enhancing both.'[954]

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[954] Morrison 1994a, p. 55.

He also designed a card-board version about which he wrote as follows:

> ‘I have considered The Personal Astrolabe to be a community service by offering an accurate and usable astrolabe very inexpensively. I've shipped nearly 8,000 of them to individuals and schools since 1994. My objective of generating what interest I can in astrolabes to the general public has never changed.’[955]

In 2007 came out his *The Astrolabe,* the most comprehensive book treating the history, construction and use of the astrolabe with a wealth of diagrams. After reading my *The Archaic and the Exotic,* he became interested in Sanskrit astrolabes. Since 2010, we have had regular correspondence and he was very prompt with his helpful replies. He was also much interested in the progress of my Descriptive Catalogue. I regret very much that I cannot show him now the online Catalogue, as he passed away in April 2016.

In 2010 he made for me a Personal Astrolabe ‘in Sanskrit style’. As a personal tribute to this remarkable promotor of the astrolabe, I close the section with this astrolabe ‘in Sanskrit style’.

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955 Personal communication of 27 January 2016. See also www.astrolabes.org [last accessed in September 2016]

Index of Three Special Astrolabes

D090 ◎Astrolabe for Latitude 25;30°, Magnum Opus designed by Gaṅgāsahāya, made by Śivalāla 2599

1870, Bundi, Rajasthan, Diameter 664 mm, London, Science Museum (# 1897-541)

D091 Astrolabe for Latitude 26°, designed by Gaṅgāsahāya, made by Rāmapratāpa 2615

1895, Tonk, Rajasthan, Diameter 334 mm, PLU

D092 ◎Personal Astrolabe made by James E. Morrison 'in Sanskrit Style' 2621

April 2010, Rehoboth Beach, DE, USA, Diameter 178 mm, Düsseldorf, S. R. Sarma

E. ASTROLABES REWORKED IN SANSKRIT

INTRODUCTION

When the Hindu and Jaina astronomers encountered the astrolabe, they adopted three strategies to incorporate it into their knowledge systems. As we have shown in the earlier sections, they composed manuals on the construction and use of the astrolabe and produced some 130 Sanskrit astrolabes. A third strategy was to rework the Islamic astrolabes with additional legends and numerals in Sanskrit so that these could be used by astronomers who did not read the Arabic script.[981]

As early as 1856, William H. Morley drew attention to one such reworked astrolabe, which came to be known as 'Professor Wilson's astrolabe'.[982] In 1983, Margarida Archinard devoted a full-length monograph to another specimen, now preserved at the Musée d'Histoire des Sciences de Genève.[983] I came across a few more reworked Arabic astrolabes and also celestial globes.

These instruments constitute an interesting chapter in the dissemination of Islamic instruments in India. The reworking required a close cooperation between the Muslim astronomer who explained to the Hindu astronomer the meaning and significance and the original Arabic legends on the astrolabe and between the Hindu astronomer who commissioned the reworking and provided the text of the Sanskrit additions to the artisan who engraved the additions in Devanagari script.

The additions in Sanskrit are not all uniform. While some astronomers were content with marking with Sanskrit labels just those latitude plates which were useful to them, others attempted to render every single Arabic legend into Sanskrit.

Sawai Jai Singh collected some of the finest astrolabes produced by the Lahore family of astrolabists and also other portable instruments engraved with Arabic/Persian or Sanskrit legends. In some Mughal astrolabes, he caused minor additions to be in Devanagari script for the convenience of his Hindu astronomers who could not read the Arabic script.

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981 In Europe also, additions in Hebrew, Latin or Spanish were engraved on Arabic astrolabes; cf. King 2002-03.

982 Morley 1856, pp. 32-34.

983 Archinard 1983.

Thus on the zoomorphic astrolabe A052, the latitude degrees are duplicated in Devanagari script on certain plates. There is one plate calibrated for the latitude of 28;39,20 which is the latitude of Delhi. On this plate was engraved *dilī 28/39.* Dillī is spelt incorrectly and seconds are omitted in the value of the latitude. Also on the plates projected for the latitudes of 23;30°, 27° and 32°, the latitude degrees are duplicated in Devanagari, for these plates are of immediate interest as they represent the latitudes of Ujjain, Agra /Jaipur and Lahore.

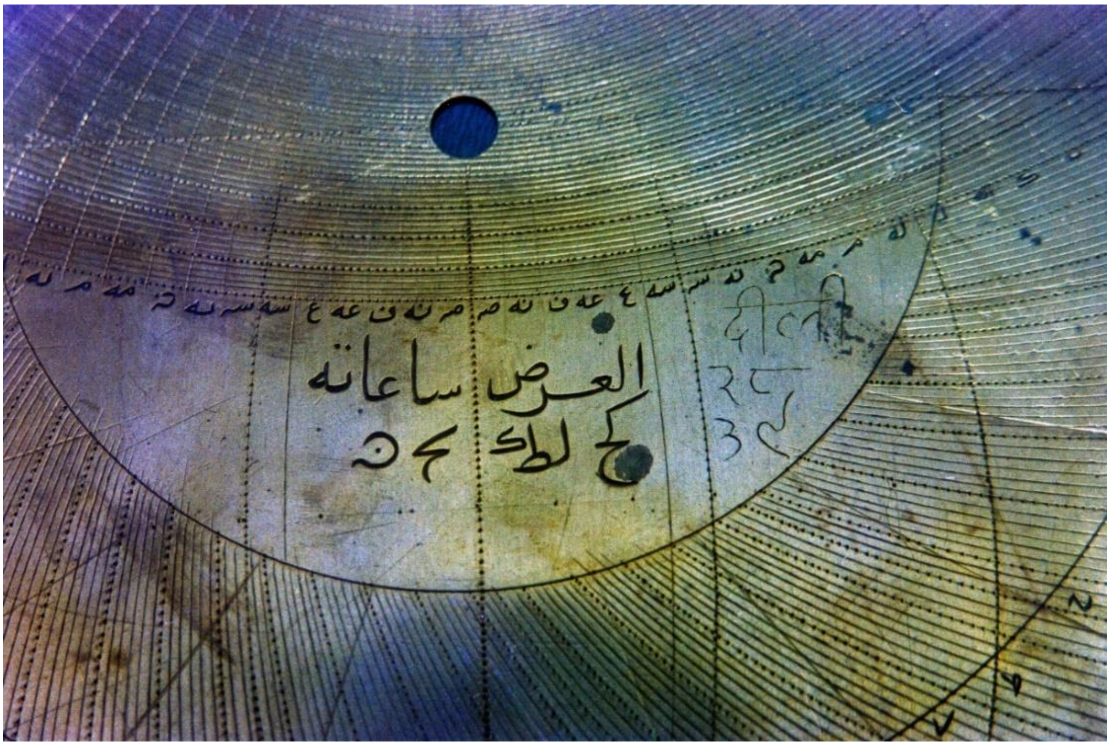

Figure E1 – Plate designed for Delhi in A052 (photo by S. R. Sarma)

Jai Singh’s collection also includes the *Zarqālī* universal astrolabe fashioned by Ḍiyā’ al-Dīn Muḥammad of Lahore in 1680-81 (A092). At Jai Singh’s orders, a Sanskrit name was engraved in Devanagari script at the back of the crown of this astrolabe: *yaṃtra jarakālī sarvadeśī*. The first syllables of the Sanskrit names of the zodiac signs were engraved at appropriate places on both sides of the ecliptic. Several star positions were marked with simple dots and their Sanskrit names were inscribed. Moreover, a copper plaque was attached to the astrolabe on which all the functions of this universal instrument were enumerated in Rajasthani.

Likewise, Sanskrit labels were engraved on two Indo-Persian celestial globes. On a celestial globe made in 1663 by Muḥammad Ṣāliḥ of Thatta, the astronomer Nandarāma caused the additions of several Sanskrit names in 1767. The original globe will be described in section G and the Sanskrit additions in section H. On a celestial globe made in 1690 by Ḥāmid of the Lahore family, the 28 lunar mansions are serially numbered in Devanagari at some later point by an unknown person; this globe will be discussed in section G.

In the present section are treated 5 Islamic astrolabes which are thoroughly reworked in Sanskrit. The first three were originally produced outside and reached India where they were given a Sanskrit coating. The last two were fabricated at Lahore by Ḍiyā’ al-Dīn Muḥammad, sometime after 1648, and were reworked in Sanskrit in about half a century thereafter.

Index of Astrolabes reworked in Sanskrit

E001 ‘Professor Wilson’s Astrolabe’, Kufic astrolabe by Maḥmūd bin [c]Alī bin Yūsha[c] al--rī, 669 AH (AD 1271) 2633

Diameter 95 mm, PLU

E002 Kufic Astrolabe by [c]Alī ibn Ibrahīm, 724 AH (AD 1324) 2639

Diameter 130 mm, Geneva, Musée d'Histoire des Sciences (# 1051)

E003 Astrolabe made by Wafā’ bin Munajjim, 1017 AH (AD 1608-09) 2648

Diameter 123 mm , Qatar, Doha, Museum of Islamic Art (# MW.381.2007), ex-Linton 179

E004 Astrolabe attributable to Ḍiyā’ al-Dīn Mhuammad 2657

Date not available, 17th century, Diameter ?, PLU; photos in the archives of the Museum of the History of Science, Oxford

E005 ◎Astrolabe attributable to Ḍiyā’ al-Dīn Muḥammad 2663

Between 1648 and 1658 , Diameter 526 mm , London, Nasser D. Khalili Collection of Islamic Art (#SCI 53)

F. INDO-PERSIAN CELESTIAL GLOBES PRODUCED BY THE LAHORE FAMILY

INTRODUCTION

1. THE CELESTIAL GLOBE IN GREEK ANTIQUITY

Next to the astrolabe, the celestial globe is the most important astronomical instrument in pre-modern times. While the vault of the fixed stars is represented in two dimensions on the rete of the astrolabe, it is shown in three dimensions on the celestial globe. This makes the representation of the stars in their relative positions visually more appealing on the celestial globe. Therefore, it is a more convenient tool for teaching and demonstration.

The celestial globe and its companion piece, the terrestrial globe, were also invented in Greek antiquity, much earlier than the astrolabe. Their invention is attributed respectively to Thales and Anaximander in the sixth century BC. It was, however, Claudius Ptolemy (ca. 150 AD) who provided in his works comprehensive and systematic data for both the globes. On the terrestrial globe, the location of a place is indicated by its geographical latitude and longitude. Similarly, on the celestial globe, the stars are plotted by their ecliptic latitude and longitude, or by their declination and right ascension. In his *Geographia,* Ptolemy enumerated the geographical latitudes and longitudes for about 8000 localities and thus provided the essential data for the construction of the terrestrial globe. Likewise, in his other major work, the *Almagest,* he described quite elaborately how to construct a celestial globe.[1010] He also gave the ecliptic latitudes and longitudes of some 1020 stars, arranging these stars in 48 constellations which include the twelve signs of the zodiac.[1011]

Since then it has been customary to show the positions of these 1020 stars on celestial globes. The globes also contain outlines of the pictorial representations of the 48 constellations in their zoomorphic, anthropomorphic and other forms as conceived in Hellenistic mythology, or as modified later in the Islamic world.

1010 Ptolemy, VIII.3, pp. 404-407.

1011 Ptolemy, VII.5-VIII.1, pp. 341-399.

In order to determine the positions of these stars, several reference circles are drawn on the globes, such as the celestial equator, the ecliptic, the ecliptic latitude circles, tropics and polar circles. The globe is set up on a stand with a graduated horizon ring and a graduated meridian ring. An axis passing through the two poles of the globe is affixed to the meridian ring. The globe can be so adjusted that it shows the stellar position for a given locality and for any given time. By turning the globe, the risings and settings of the stars can also be demonstrated.[1012]

Figure F1 – Farnese Atlas. Front view of the celestial globe with the constellation figures of (from left to right) Canis Major, Argo Navis, Hydra, Crater, Corvus, Centaurus, Lupus and Ara. (photo by Gabriel Seah, licensed under the Creative Commons Attribution-ShareAlike 3.0 License (CC BY-SA 3.0)).

1012 On the use of the celestial globe for observation and measurement, see Kennedy 1989; Savage-Smith in: Maddison & Savage-Smith 1997, I, pp. 180-185.

Figure F2 – Farnese Atlas, side view of the celestial globe.
Upper row, left to right: Corona Borealis, Hercules, Lyra, Cygnus; middle row: Ophiuchus, Aquila, Delphinus; lower row on the ecliptic: Sagittarius, Capricorn, Aquarius. (photo by Sailko, licensed under the Creative Commons Attribution-ShareAlike 3.0 License (CC BY-SA 3.0)).

The earliest representation of the celestial globe can be seen in the marble statue of the Farnese Atlas, now in the National Museum of Naples in Italy. This statue depicts the Greek mythological figure Atlas carrying the celestial sphere on his shoulders. The sphere shows the equator, the ecliptic, the tropics, the polar circles, the colures and the figures of zodiac signs and several other constellation figures in the northern and southern hemispheres, but star positions are not marked on it. The ecliptic is represented by three parallel lines. The representation of the vernal equinox is similar to that in Ptolemy's *Almagest.* Therefore, it is assumed that the globe was made after 150 AD.[1013]

[1013] Dekker & Krogt 1993, pp. 12-13.

2. THE CELESTIAL GLOBE IN EUROPE

Like the astrolabe, the celestial globe also reached Europe through the Arabic rendering of Greek texts. In the late tenth century, Gerbert of Aurillac, who is said to have written the first Latin treatise on the astrolabe, is also supposed to have been the first to write on the celestial globe in Latin; he is reported to have constructed a celestial globe which was covered with leather. Moreover, the *Libros del saber de astronomia* of about the thirteenth century includes the descriptions of celestial globes among other instruments. A notable work on the celestial globe of the early fourteenth century is by Accursius of Parma. By the fifteenth century Ptolemaic astronomy became well established in Europe; several tracts were composed on the celestial globe and its production became a specialized profession. Some of the earliest globes were those made by Hans Dorn in 1480 and those belonging to Cardinal Nicholas Cusa which were made in Nuremberg.[1014] During the Renaissance, automatically rotating globes with clockwork mechanism were made in large numbers and these represented the highpoint of technology as well as that of the goldsmith's craft. Some of the notable pieces were crafted by Eberhard Baldewein and Jost Bürgi under the patronage of the astronomer-prince Wilhelm IV (1532-1592), the Landgrave of Hesse-Kassel, who established the first European Observatory at Cassel and sponsored the compilation of the star catalogue of Cassel.[1015] Subsequently, with the spread of printing, sections of the globes are printed on paper and then pasted on wooden or papier-mâché spheres.

In Europe, the celestial globe came to be treated as the emblem par excellence of the astronomer just as the astrolabe was considered his chief symbol in the Islamic world. European portraits of the astronomer, like those of Copernicus or Kepler, usually show him plotting the star positions on the globe with a pair of compasses.

3. THE CELESTIAL GLOBE IN THE ISLAMIC WORLD

The celestial globe, along with the astrolabe, was transmitted to the Islamic world through Greek texts. In Arabic, the celestial globe is called *al-kurah,* 'the sphere', *al-bayḍah,* 'the egg' or *dhāt al-kursī,* 'that which is mounted on a stand'; its celestial

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1014 Zinner 1979, pp. 168-176; Dekker & Krogt 1993, p. 16.

1015 Drach 1894; Zinner 1979, pp. 173; Mackensen 1982, pp. 70-88; Gaulke 2007, pp. 177-197.

character is emphasized in terms like *kurah falakī, kurah raṣadī* or *kurah samāwī,* all denoting celestial globe as against *kurah arḍwī* which designates the terrestrial globe. As in the case of the astrolabe, so also on the celestial globe, several treatises were written in the Islamic world and innovations were made in its construction.

Though derived from the Greek or Ptolemaic tradition, the celestial globe in the Islamic world displays a fundamental difference as far as the constellation figures are concerned. In the Greek tradition, the constellation figures are conceived as facing the earth from the concave vault of the starry sky. When depicted on the convex surface of the globe, these figures seem to be looking into the globe, that is to say, the form shown on the surface of the globe is the back view of the human figures, as can be seen in the figures of Hercules, Ophiuchus, Sagittarius and Aquarius on the Farnese Atlas in Figure F2 above. In this manner, the relative position of the right and left is maintained. Thus, for example, Perseus holds the sword in his right hand. Also a star said to be on the right leg of a figure in the Ptolemaic catalogue can be found on the right leg of the figure on the globe.

For some unknown reason, this convention was reversed on the Islamic globes. Here the human figures are drawn on the globe as seen by an observer from outside the sphere and thus as the mirror images of the figures as seen from the earth. This has resulted in the strange situation that all the human figures on Islamic globes appear left-handed; Perseus holds the sword in his left hand, Hercules the sickle in his left hand and so on.[1016]

[1016] Dekker & Krogt 1993, p. 15.

Figure F3 – Constellation figure Orion on globe F013 (photo by Ghulam Mujtaba)

This peculiarity can best be seen in the figure of Orion (*al-Jabbār,* 'the Giant') as depicted on the Islamic globes. In this figure the star named *Yad al-Jawzā' al-Yumnā* (the right hand of *al-Jawzā',* α Orionis) is actually situated on what appears to us as the left hand and the star *Yad al-Jawzā' al-Yusrā* (the left hand of *al-Jawzā',* γ Orionis) on the right hand. Likewise the star with the name *Rijl al-Jawzā' al-Yumnā* (the right foot of *al-Jawzā',* κ Orionis) is situated on the left foot and the star *Rijl al-Jawzā' al-Yusrā* (the left foot of *al-Jawzā',* β Orionis) on the right foot.

Moreover, while the constellation of Orion is called *al-Jabbār* in Arabic, the star names mentioned above contain the term *al-Jawzā'* and this is also the name of the constellation and the house Gemini. Savage-Smith explains that this confusion arose because the traditional Bedouin term for this region was *al-Jawzā',* of uncertain meaning, which encompassed also the house of Gemini. In this region of heavens, the Bedouin tradition conceived of a larger feminine figure, whose hands and feet are referred to in these star names. [1017]

Incidentally, Orion is regarded as a hunter, accompanied by his two dogs Canis Minor and Canis Major, chasing the hare Lupus. He is conceived as holding a staff in his right hand, a short dagger at his waist and a lion's skin draped over his left arm, and kneeling in the same manner as Hercules.[1018] In Islamic globes, the lion's skin is depicted as a long sleeve which accommodates nine stars. On Indo-Persian globes, the dagger at the waist is not always shown and the staff in his right hand is drawn in diverse shapes, often of unidentifiable weapons. Likewise, his hair is also depicted in various bizarre forms.

It is not known how this lateral reversion in the Islamic celestial globes came about and when. In the early ninth century, the city of Ḥarrān was said to be an important centre for the production of Islamic astronomical instruments. ᶜAbd al-Raḥmān al-Ṣūfī (AD 903-986), the court astronomer of ᶜAḍud al-Dawla at Isfahan, mentions in his treatise *Kitāb Ṣuwar al-Kawākib al-Thābitah* (Book of the Constellations of the Fixed Stars) that he saw many celestial globes made at Ḥarrān. It is probably on these globes that the lateral reversal took place for the first time which became established by the time of al-Ṣūfī. In the above-mentioned book which he composed in 974, Ṣūfī describes and illustrates the constellations as they are seen in the sky by an observer on the earth (*fī al-samā'*) and again as seen on the celestial globe (*fī al-kurah*) which is reversed right to left. There are extant some exquisitely illustrated manuscripts of this work, showing the constellation figures in the two styles as seen from the earth and as seen on the

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1017 Savage-Smith 1985, pp. 168, 189-191; .

1018 Savage-Smith 1985, p. 189.

globe.[1019] Al-Ṣūfī also composed a book on the astrolabe of which there exist three different versions.[1020]

In his treatise on the celestial globes, al-Ṣūfī updated Ptolemy's star catalogue. The coordinates of the stars were again updated in 1437 by Ulugh Beg in his astronomical tables. Accordingly, Islamic celestial globes contain the positions of about 1020 stars marked according to the coordinates given by al-Ṣūfī or by Ulugh Beg and updated to their own times.

Other important works on the celestial globe are those composed at the end of the ninth century AD by al-Battānī of Ḥarrān and Qustā ibn Lūqā al-Baᶜlabakkī. In the early twelfth century, al-Khāzinī designed a globe that rotated automatically by means of a falling weight in a leaking reservoir of sand.[1021]

In 1985, Emilie Savage-Smith published a study and a catalogue of the extant Islamic celestial globes under the title *Islamicate Celestial Globes: Their History, Construction, and Use.*[1022] This work contains a comprehensive history of the celestial globe from Greek, Roman and Islamic sources, a masterly account of the various methods of production of the celestial globe, erudite explanations of the Greek myths and the Bedouin beliefs that led to the formation of the constellation figures on the globes, detailed analyses of the nomenclature of the stars, fine descriptions of the individual globes, besides a wealth of linguistic, art-historical and mythological information. This is the model every cataloguer of medieval scientific instruments would aspire to emulate. This catalogue contains information on 132 celestial globes. In subsequent publications, Savage-Smith has described some more globes.[1023]

1019 The oldest manuscript copy prepared by al-Ṣūfī's son in 400 AH (AD 1009-10) is extant in the Bodleian Library at Oxford (Marsh 144); cf. Wellesz 1965. A fifteenth century copy autographed by Ulugh Beg is with the Bibliothèque Nationale in Paris and was printed in Ṣūfī 1954. The treatise was rendered into Persian by Naṣīr al-Dīn al-Ṭūsī in 1260 and by Luṭfullah Muhandis in 1640 in India.

1020 Vafea 2006.

1021 Lorch 1980.

1022 Savage-Smith 1985.

1023 Savage-Smith 1990; Savage-Smith in: Maddison & Savage-Smith 1997, *Science,* I, Nos. 112-114, 134, 138, 140-141; II, Nos. 382-389.

3.1. Early Islamic Celestial Globes

In the ninth and tenth centuries, celestial globes were produced both in the Western and the Eastern parts of the Islamic world.[1024] The earliest extant globe in the Islamic world was manufactured by Ibrāhīm ibn Saᶜīd al-Sahlī al-Wazzān together with his son Muḥammad in Moorish Spain in 473 AH/ AD 1080 (or in 478 AH / AD 1085). It is now preserved in the Museum of History of Science at Florence, Italy.[1025] Elly Dekker and Paul Kunitzsch read the date as 1 Ṣafar 478 AH (29 May 1085). Furthermore, they attribute an unsigned and undated globe in the Bibliothèque Nationale de France, Paris, to this father-son duo and add that it is the earlier of the two globes. The former measures 220 mm in diameter and the latter 190 mm.[1026]

On these globes can be seen already many of the conventions which became the norm in subsequent times. The equator and the ecliptic are represented by double bands, one of which is graduated in 1°. In the second band groups of 5° are marked and numbered in *Abjad* notation, on the equator continuously from the vernal equinox from 5 to 360, but separately for each sign on the ecliptic from 5 to 30. Ecliptic latitude circles are drawn. Names of the zodiac signs are engraved along the ecliptic. The southern equatorial polar circle is drawn around which the signature is engraved. Equatorial poles, constellations and many stars are labelled. Stars are indicated by dots in circles.

The constellation figures are drawn in outlines. Human figures are represented in anatomically correct outlines. The faces are mostly in profile, marked by hair, nose, lips and chin. Eyebrows and eyes are drawn but without pupils. The five fingers in the hands are clearly shown. In the case of Cassiopeia and Virgo, however, the faces are not in profile, but looking to the front. The clothing is not generally indicated, but Andromeda is depicted with some sort of skirt.

1024 Savage-Smith 1985, pp. 23-34.

1025 Savage-Smith 1985, no. 1, p. 217; see also p. 24.

1026 Dekker & Krogt 1993, p. 155.

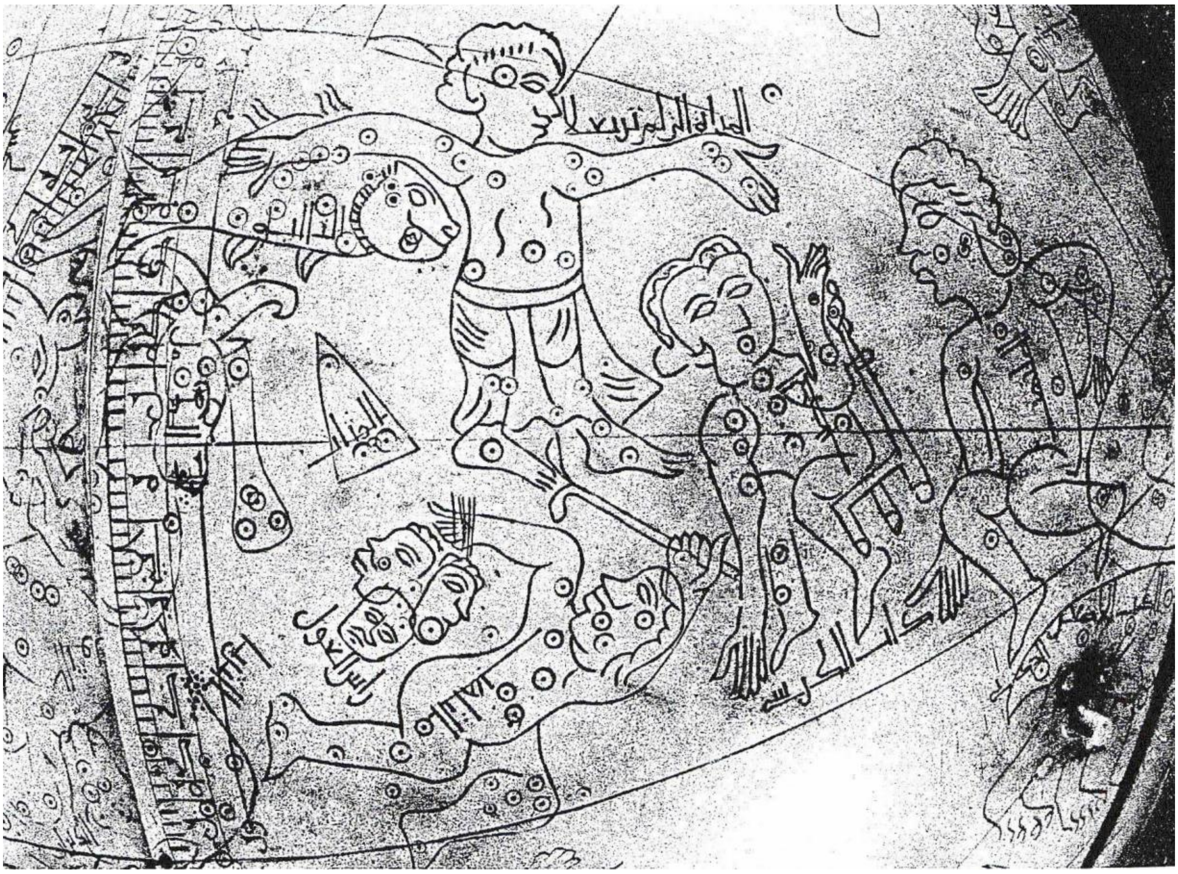

Figure F4 – Andromeda, Cassiopeia, Cepheus and Perseus on the Paris globe (from Dekker & Kunitzsch 2008)

An unusual feature is that Libra is depicted as a woman holding the scales on both the globes at Paris and Naples. Such a depiction does not occur in any other globe.

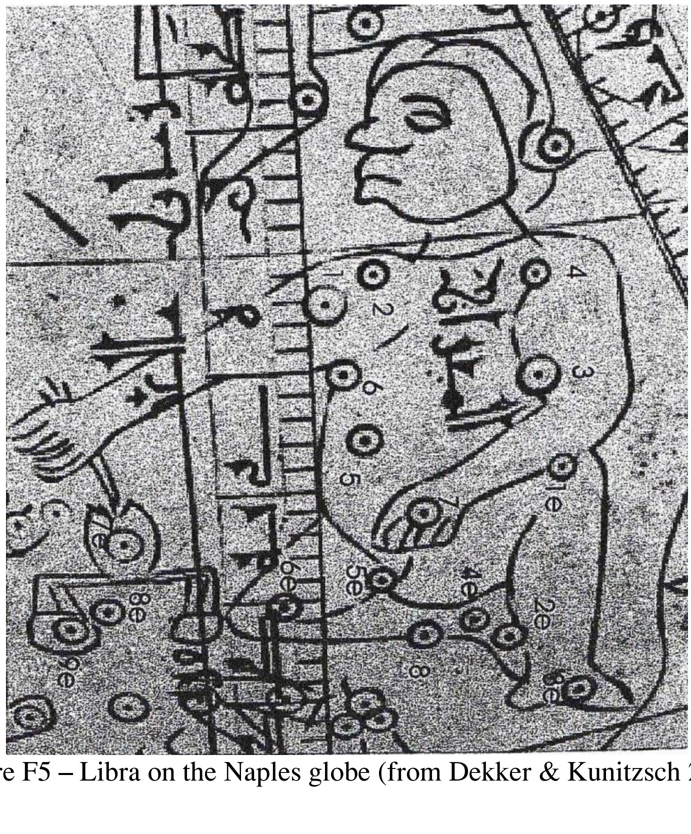

Figure F5 – Libra on the Naples globe (from Dekker & Kunitzsch 2008)

Chronologically the next extant celestial globe was made by Yūnus ibn al-Ḥusayn al-Asṭurlābī in 539 AH / AD 1144. The globe has a diameter of 175 mm. Here the equator and the ecliptic are drawn as in the globes at Paris and Naples. There are also ecliptic latitude circles. The names of the zodiac signs are engraved along the ecliptic, and the equatorial and ecliptic poles, the 48 constellations, 28 lunar mansions and 72 major stars are named. The globe-maker's signature is near the south equatorial pole.

Here for the first time, the star positions are indicated by inlaid silver points of different sizes. There is considerable improvement in the constellation figures, especially the human figures: the outlines are better, the faces are shown facing the front, fingers on the hands and toes on the feet is clearly marked, and clothing is indicated in simple but elegant strokes.

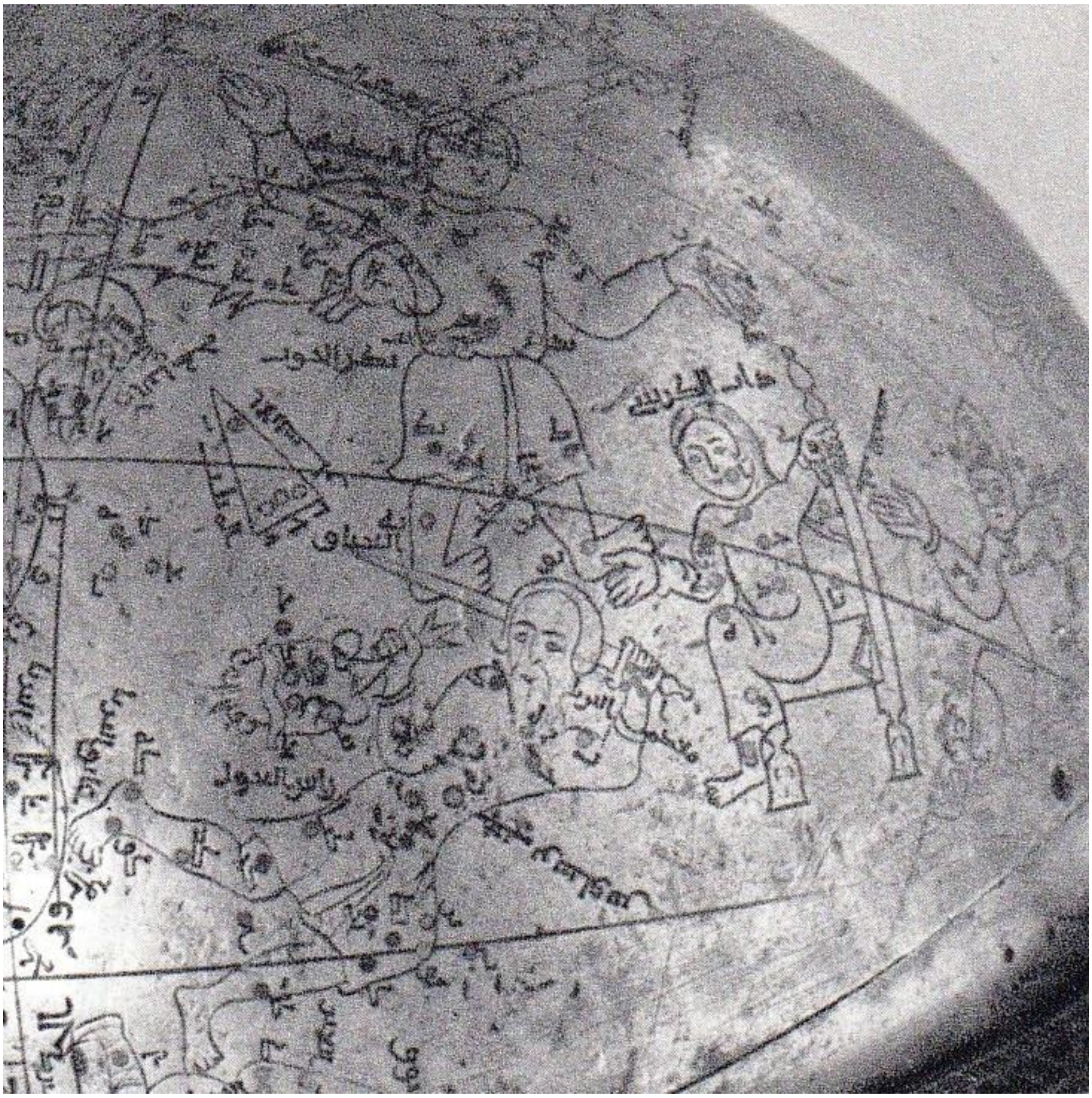

Figure F6 – Celestial globe by Yūnus ibn al-Ḥusayn al-Asṭurlābī, detail showing Andromeda, Cassiopeia, Cepheus and Perseus (detail from Guye & Michel 1971, no. 198)

4. Main Elements of the Celestial Globe

4.1. Reference Circles

For determining the positions of the stars, several reference circles are drawn on the globes, such as the celestial equator, the ecliptic, the ecliptic latitude circles, the tropics, polar circles, the equatorial and ecliptic poles. The equator and ecliptic are generally drawn as double bands, one band graduated in 1° and the other in 5°. The intervals of 5° are numbered continuously on the equator, but separately for each zodiac sign on the ecliptic. In a few cases, the numbering is done in 6s. The double bands of the equator and ecliptic intersect at the two equinoxes at an angle which is equal to the obliquity of the ecliptic, roughly 23;30°. These intersections of the two bands are drawn ingeniously so that there is no overlap of the degree scales. The ecliptic latitude circles are the six great circles drawn perpendicularly to the ecliptic at 30° intervals so that they divide the entire surface of the globe into twelve zones, each being the house of a zodiac sign. The points of their convergence in the northern and southern hemispheres are the ecliptic poles.

The Tropic of Cancer and the Tropic of Capricorn are drawn to the north and south of the equator and parallel to it at a distance of 23;30°. Again at a distance of 66;30 parallels are drawn to the equator in the north and south; these are equatorial polar circles; the northern one is called the Arctic circle and the southern one the Antarctic. At the centres of these circles are situated the celestial poles or equatorial poles. In a few cases, polar circles are drawn around the ecliptic poles as well.

The names of the zodiac signs are engraved along the ecliptic; in some cases, the names of the 28 lunar mansions are written on the other side of the ecliptic. Likewise, the names of the celestial poles are also engraved as *al-quṭb shamālī* (the North Pole) and *al-quṭb janūbī* (the South Pole).

4.2. Constellation figures

Ptolemy enjoins that the pictorial forms of the constellations as shown on the celestial globes should be as simple as possible so that these figures do not overshadow the arrangement of the stars which constitute the constellations.[1027] But globe makers paid no heed to this suggestion and tried to display their artistic talents in fully delineating the figures in all the details; in animal figures, great attention is paid in drawing their fur; in human figures still greater attention in drawing their physical features, facial expressions, all the folds of the clothing and ornaments, including the patterns on their knee-length boots.

Some of the constellation figures are anthropomorphic, some are zoomorphic and the others represent inanimate objects. All these are forms as conceived in Greek antiquity and often connected to Greek mythology. The Arabs took over the forms of the figures wholesale, in some cases even the nomenclature (Cepheus = *Qīqā'ūs,* Perseus = *Barsā'ūs,* Delphinus = *Dālfīn,* Cetus = *Qayṭus* and Centaurus = *Qanṭūrus*), but more often they gave their own designations to these constellations.

On Islamic globes, the names of the constellation figures are inscribed next to the figures; these names are preceded by the prefix *ṣūra* (صورة) meaning 'figure' or 'form'. But on Indo-Persian celestial globes the tendency is to employ the Persianized or proto-Urdu form *ṣūrat* (صورت). Ḍiyā's al-Dīn employs consistently *ṣūrat* while his cousin Ḥāmid prefers *ṣūra.* Qā'im Muḥammad uses both forms rather indiscriminately.

Following are the names of the constellations in the order as listed by Ptolemy.

Table F1 Ptolemaic Constellations on Islamic Globes

	Arabic Name	Translation	Modern Name	Abbreviation
	NORTHERN CONSTELLATIONS			
1	*al-Dubb al-Aṣghar*	the Lesser Bear	Ursa Minor	UMi
2	*al-Dubb al-Akbar*	the Greater Bear	Ursa Major	UMa
3	*al-Tinnīn*	the Dragon	Draco	Dra
4	*al-Qīqā'ūs*	Cepheus	Cepheus	Cep

[1027] Cf. Ptolemy, VIII.3, p. 406.

	Arabic Name	Translation	Modern Name	Abbreviation
5	*al-ᶜAwwā'/ al-Baqqār*	the Howler / the Ploughman	Bootes	Boo
6	*al-Fakkah*	the Crown	Corona Borealis	CBr
7	*al-Jāthī*	the Kneeling Man	Hercules	Her
8	*al-Shulyāq*	the Tortoise	Lyra	Lyr
9	*al-Dajājah*	the Fowl	Cygnus	Cyg
10	*al-Dhāt al-Kursī*	the One with a Chair	Cassiopeia	Cas
11	*al-Barsā'ūs wa Huma Ḥāmil Ra's al-Ghūl*	Barsā'ūs, that is, Bearer of the Ogre's Head	Perseus	Per
12	*al-Mumsik al Aᶜinnah*	He who holds the Reins	Auriga	Aur
13	*al-Ḥawwā*	the Serpent Charmer	Ophiuchus	Oph
14	*al-Ḥayyat al-Ḥawwā*	the Sepent Charmer's Serpent	Serpens	Ser
15	*al-Sahm*	the Arrow	Sagitta	Sge
16	*al-ᶜUqāb*	the Eagle	Aquila	Aql
17	*al-Dālfīn*	the Dolphin	Delphinus	Del
18	*al-Qiṭᶜat al-Faras*	the Part of a Horse	Equuleus	Equ
19	*al-Faras Aᶜẓam*	the Larger Horse	Pegasus	Peg
20	*al-Mar'ah al-Musalsalah*	the Chained Woman	Andromeda	And
21	*al-Muthallath*	the Triangle	Triangulum	Tri

	Arabic Name	Translation	Modern Name	Abbreviation
	ZODIAC SIGNS			
22	*al-Ḥamal*	the Ram	Aries	Ari
23	*al-Thawr*	the Bull	Taurus	Tau
24	*al-Jawjzā’*	the Twins	Gemini	Gem
25	*al-Saraṭān*	the Crab	Cancer	Cnc
26	*al-Asad*	the Lion	Leo	Leo
27	*al-Sunbulah*	the Ear of Wheat	Virgo	Vir
28	*al-Mīzān*	the Balance	Libra	Lib
29	*al-ᶜAqrab*	the Scorpion	Scorpio	Sco
30	*al-Qaws*	the Archer	Sagittarius	Sgr
31	*al-Jadī*	the Goat	Capricorn	Cap
32	*al-Sākib al-Mā’*	the Water-Pourer	Aquarius	Aqr
33	*al-Ḥūt*	the Fishes	Pisces	Psc
	SOUTHERN CONSTELLATIONS			
34	*al-Qayṭus*	Cetus	Cetus	Cet
35	*al-Jabbār*	the Giant	Orion	Ori
36	*al-Nahr*	the River	Eridanus	Eri
37	*al-Arnab*	the Hare	Lepus	Lep
38	*al-Kalb al-Akbar*	the Greater Dog	Canis Major	CMa
39	*al-Kalb al-Aṣghar*	the Lesser Dog	Canis Minor	CMi

	Arabic Name	Translation	Modern Name	Abbreviation
40	*al-Safīnah*	the Ship	Argo Navis[1028]	Pup, Vel, Car
41	*al-Shujā^c*	the Serpent	Hydra	Hya
42	*al-Bāṭiyah*	the Jar	Crater	Crt
43	*al-Ghurāb*	the Raven	Corvus	Crv
44	*al-Qanṭūrus*	the Centaur	Centaurus	Cen
45	*al-Sab^c*	the Wild Beast	Lupus	Lup
46	*al-Mijmarah*	the Incense Burner	Ara	Ara
47	*al-Iklīl al-Janūbī*	the Southern Crown	Corona Australis	CrA
48	*al-Ḥūt al-Janūbī*	the Southern Fish	Piscis Austrinus	PsA

In this list, nos. 1 to 21 are the constellations of the northern hemisphere; nos. 34 to 48 are those in the southern hemisphere, and the remaining twelve from 22 to 33 are the zodiac signs situated along the ecliptic. On some globes these three groups are numbered separately.

The 48 figures can be classified as follows. Fourteen figures are anthropomorphic: 11 of these are male and 3 female. Twenty-four figures are zoomorphic: 12 animals, 4 birds, 8 reptiles. Ten represent various inanimate objects and the river Eridanus.

Human Male figures: 4 Cepheus, 5 Bootes, 7 Hercules, 11 Perseus, 12 Auriga, 13 Ophiuchus, 24 Gemini, 30 Sagittarius, 32 Aquarius, 35 Orion and 44 Centaurus.

Human Female figures: 10 Cassiopeia, 20 Andromeda and 27 Virgo.

Animal figures: 1 Ursa Minor, 2 Ursa Major, 18 Equules, 19 Pegasus, 22 Aries, 23 Taurus, 26 Leo, 31 Capricorn, 37 Lepus, 38 Canis Major, 39 Canis Minor, and 45 Lupus

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[1028] In modern times, this constellation has been divided into Puppis (Pup), Vela (Vel) and Carina (Car).

Bird figures: 9 Cygnus, 16 Aquila, 34 Cetus, and 43 Corvus.

Reptile figures: 3 Draco, 14 Serpens, 41 Hydra, 25 Cancer and 29 Scorpio.

Fish figures: 17 Delphinus, 33 Pisces and 48 Piscis Austrinus.

Inanimate Objects: 6 Corona Borealis, 8 Lyra, 15 Sagitta, 21 Triangulum, 28 Libra, 36 Eridanus, 40 Argo Navis, 42 Crater, 46 Ara and 47 Corona Australis.

The relative positions of the constellation figures can be seen in Figures F6 and F7. Besides the astronomical significance of the constellations, their figurative depiction is of interest for comparative mythology and for art history. On the basis of the iconography of the figures it is possible to situate the globe in a particular craft tradition.

Savage-Smith has given a very valuable and detailed description of the constellation figures, their forms as conceived in Greek Antiquity and in Bedouin traditions, and how these traditions coalesced in the Islamic globes and influenced the nomenclature of the constellations and the stars that constituted the constellations.[1029]

This may be illustrated with the following example. In the Greek tradition, the constellation Ursa Major is conceived as bear, and also as a cart. But the Bedouin tradition saw the four stars on the body of the bear (αβγδ) as a bier or the plank to carry the corpses on (*al-na*ᶜ*sh*), and the three stars on the tail (ε ζ η) as the three mourning daughters (*al-banāt*) of the deceased who follow the bier. Again, the twin stars in each of the four paws are imagined to be the tracks made by the cloven hoof of a deer when it is running away from the lion. Although, the constellation is represented as a bear on Islamic globes, the names of the different stars reflect these Bedouin images.[1030]

Of the three stars on the tail, the middle one ζ is accompanied by a very small star next to it (*g*, Alcor). It was not listed by Ptolemy, therefore al-Ṣūfī called it *al-Suhā* (the overlooked one) and added that this is the star by which men tested their vision.[1031]

The Sanskrit tradition sees these seven stars as the seven patriarchal sages, the most venerable of them being Vasiṣṭha, represented by ζ. The faint star next to it is imagined to be his wife Arundhatī. At marriage ceremonies, this star is shown to the

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1029 Savage-Smith 1985, ch. 5, pp. 114-212.

1030 Cf. Savage-Smith 1985, pp. 134-136, Fig. 50; see also Figure F004.2 and the related description.

1031 See Figure F027.3.

bride with the advice that she should follow the example of Arundhatī and follow the husband in all his endeavours. [1032]

Another notable example is the Bedouin tradition of a huge female form of *al-Thurayyā*: her head is situated in the region of the cluster of stars Pleiades (also called *al-Thurayyā*); her right arm passes through the constellations of Perseus and Cassiopeia, and the left hand through the head of Cetus. Therefore certain stars in these three constellations have names associated with this *al-Thurayyā*: the star on the elbow of Cassiopeia is associated with the hand of *al-Thurayyā* which is stained with henna and is therefore named *al-Kaff al-Khaḍīb,* 'the dyed hand'. The other hand is visualised on the head of Cetus and a star situated there is given the name *al-Kaff al-Jadhmā,* 'the cut-off hand', apparently because no star group connects the hand with *al-Thurayyā.* In the constellation of Perseus, several stars are associated in a like manner with *al-Thurayyā.*[1033]

A third case worth mentioning is the Bedouin conception of another giant female named *al-Jawzā'* which occupies the region of Gemini (also called *al-Jawzā'*) and of Orion. Consequently many stars in the constellation Orion carry names associated with this giant *al-Jawzā'*.[1034]

4.3. Stand

The stand consists of a horizon ring supported by three or four legs. In order to adjust the globe for the latitude of a place where it is used, a meridian ring is attached at right angles to the horizon ring. Both the rings are graduated in 1° and in 5° or 6°. In many cases, the four cardinal points are marked on the horizon ring. For adjusting the globe at the right latitude, the axis of the globe is affixed to the meridian ring and holes are bored on the meridian ring at degrees frequently used.

1032 There are also other popular conceptions regarding these seven stars: in the US, these are known as the 'big dipper', in UK as the 'plough' and in Europe as the 'great cart'. But these conceptions did not generate any special names for the individual stars.

1033 Cf. Savage-Smith 1985, pp. 122-124.

1034 Cf. Savage-Smith 1985, pp. 124-125; 190-191.

Since the stands are made separately from the globes, they get detached in course of time and are lost. Therefore, often the surviving celestial globes are without stands; even if the stands survive, they are often without the meridian rings.

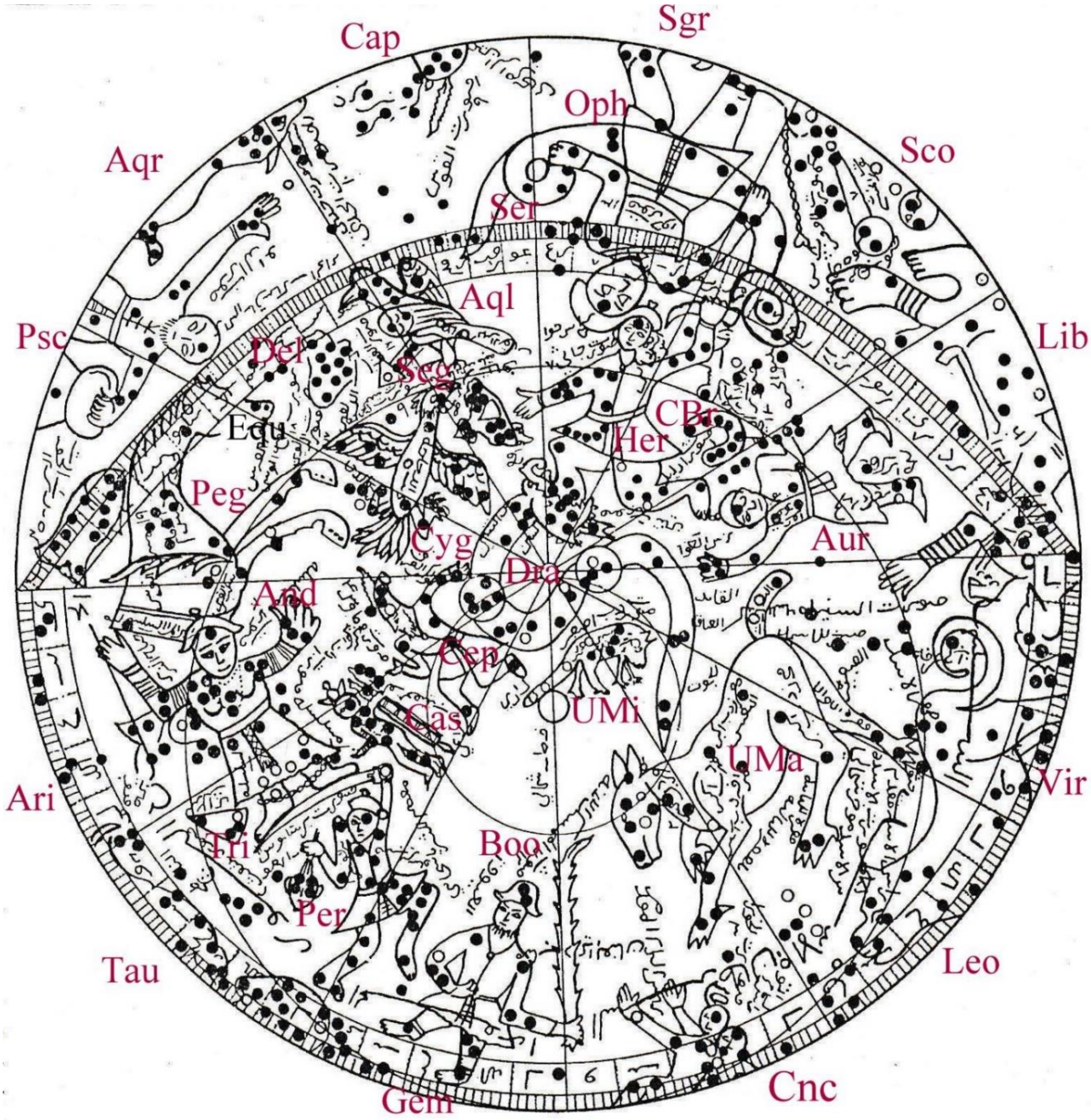

Figure F7 – Schematic Drawing of the Northern Hemisphere on globe F018.
The ecliptic forms the outer periphery and centre is the northern ecliptic pole. The northern celestial pole is at the centre of the smaller circle below the ecliptic pole. The vertical diameter joining these two centres is the solstitial colure and the horizontal diameter the equinoctial colure. The figures of the zodiac signs are partly obscured by the ecliptic scale. (From Klüber 1935, the names of the constellations have been added by us).

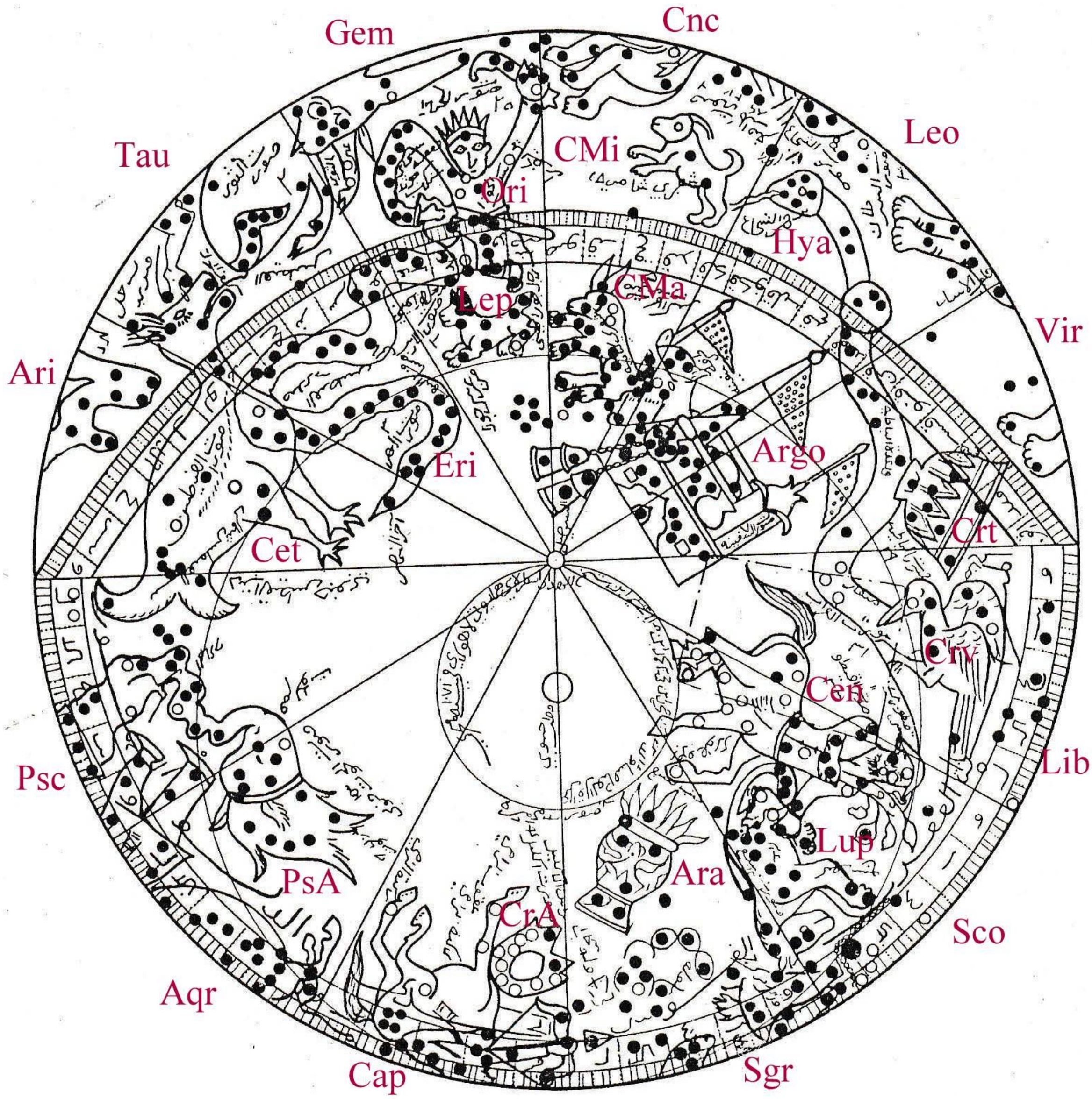

Figure F8 – Schematic Drawing of the Southern Hemisphere on globe F018.
The ecliptic forms the outer periphery and the southern ecliptic pole the centre. The southern celestial pole is at the centre of the smaller circle below the ecliptic pole. The vertical diameter joining these two centres is the solstitial colure and the horizontal diameter the equinoctial colure. The figures of the zodiac signs are partly obscured by the ecliptic scale. (From Klüber 1935, the names of the constellations have been added by us).

5. The Celestial Globe in India

It is difficult to say precisely when the celestial globe reached India. The earliest mention of the celestial globe occurs rather late in connection with the Mughal ruler Humāyūn in the middle of the sixteenth century.[1035] Humāyūn's interest in the celestial globe is revealed in an anecdote narrated in the *Akbarnāma*:

1035 Sarma 1994c.

> ‘When Humāyūn reached Tabrīz during his journey in Persia, he ordered his slave Pik Muhammad Akhta Begi to search for a celestial globe – *kura* -- in that city, as he was very keen about astrolabes, globes and other observatory instruments. In Persian *kura* means a colt, so his simple slave obeyed the orders by bringing a number of colts to the royal presence. The king laughed when he saw the multitude of colts and mares before him, and bought them all the same as a good omen.’[1036]

But this does not mean that the celestial globe was completely unknown in India until the middle of the sixteenth century. Manuscript copies of al-Ṣūfī’s very popular book must have reached India along with other Arabic texts on astrolabes and must have been copied.

Moreover, the Jaina monk Mahendra Sūri, who produced the first Sanskrit manual on the astrolabe in 1370 at the court of Sulṭān Fīrūz Shāh Tughluq at Delhi, gives a list of 32 astrolabe stars with their Sanskrit names. Many of the names are translated or adopted from the Arabic. But *Samudrapakṣī* (literally ‘sea-bird’), the name given by Mahendra to the star ι Ceti is not a translation of the Arabic name *Dhanab al-Qayṭus Shamālī* which means ‘the northern tail of Qayṭus’. Here Qayṭus is a mere transliteration of the Greek name, but it does not say anything about the nature of the figure. That it is a weird bird-like creature related to the sea could be known only from the illustrations in al-Ṣūfī’s treatise or from an actual globe. Likewise, α Geminorum is known in the Arabic as *Ra’s al-Taw’am al-Muqaddam* (the head of the foremost twin). Mahendra Sūri’s Sanskrit name *Prathama-bāla-śīrṣa* (head of the first boy) implies the visual knowledge of the figure of Gemini as a pair of male infants on an Islamic celestial globe; in Sanskrit tradition, on the other hand, Gemini (Skt. *Mithuna*) is conceived of as an adult pair of man and woman.

Be that as it may, like the astrolabes, the first extant celestial globes in India belong to the sixteenth century.

1036 Akbarnāma, 1, p. 445. Steingass, s.v. كره *kura,* a globe, a thing spherical, …; *kurra,* The colt of a horse, camel or ass (one or two years old).

5.1. The Lost-Wax Casting

Through her survey of all extant Islamic celestial globes, Emilie Savage-Smith made the important discovery of a significant difference between the celestial globes made in India and those made outside. Outside India, the celestial globe was made first as two hollow hemispheres and then these two were joined at the celestial equator. But in India, the globe is cast as a single hollow sphere by the *cire perdue,* or the lost wax, method.[1037]

The lost wax process of metal casting has a long history in India. The 110 mm high bronze figure, popularly known as the 'dancing girl' is considered to have been cast by the lost wax process in the Indus Valley culture at Mohenjo Daro around 3500 BC; other examples from this culture include buffalo, bull and dog, and some copper figurines. In classical period, countless metal hollow statues were produced throughout India, Nepal and Tibet for worship in temples. Several Sanskrit texts on sacral art describe the method of casting icons by the lost-wax process which is termed *madhūcchiṣṭa-vidhāna* in Sanskrit.[1038] Even today, this method is practiced in many places including Tamil Nadu in the south and Nepal in the north.[1039] Many tribal communities in central India also produce small decorative or cult objects by this method.[1040]

It is, therefore, not surprising that in India celestial globes began to be cast as single hollow spheres by this method. In this process, some holes are left in the sphere for removing the core after the casting is done. These holes are subsequently covered by plugs. Often such plugs have a higher copper content and look darker than the surrounding area. After the globe is cast, its outer surface is smoothened and on this

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1037 On the technique of casting the celestial globes by the *cire perdue* method, see Savage-Smith 1985, pp. 90-95.

1038 Michaels 1986 translated the relevant passages from three Sanskrit texts: the *Mānasollāsa* composed by Western Chalukyan monarch Someśvara ca. 1129, the *Mānasāra* of unknown authorship and the *Śilparatna* of Kumāra (16th century) and discussed these on the basis of his practical observations of the craft as practised in Nepal.

1039 Michaels 1988.

1040 There are several anthropological and technical studies on this aspect such as Ruth Reeves, *Cire Perdue Casting in India,* New Delhi 1962.

surface are engraved the circles, scales, constellation figures and the legends. Silver nails of different sizes are inlaid to indicate the positions of stars.

It is not known who began this method of producing celestial globes in India. Like the astrolabes, the first extant celestial globes belong to the sixteenth century. The earliest extant celestial globe (G001) was signed by a certain ᶜAlī Kashmīrī ibn Lūqmān in 998 AH in the thirty-fourth regnal year of Akbar (AD 1589-90).[1041] The globe is a seamless hollow sphere with four plugs. The equator and the ecliptic are indicated by single lines on which dots are made at intervals of 2°, but without any numbers. Names of zodiac signs are engraved along the ecliptic in small letters and these names do not extend to the entire length of the zodiac sign. However, we do not know where this ᶜAlī Kashmīrī worked. His *nisbāh* of 'Kashmīrī' need not necessarily mean that his workshop lay in Kashmir. No other astrolabe or celestial globe manufactured in Kashmir came to light so far.[1042]

5.2. The Lahore Family

Even though the technique of casting celestial globes as single hollow spheres by the lost-wax process may have begun earlier in India, it is to the credit of Qā'im Muḥammad of the Lahore family to have perfected this technique and to have firmly established it as the standard method for India. There are extant today some 33 celestial globes made by him, his brother Muqīm, and their respective sons Ḍiyā' al-Dīn and Ḥāmid between the years 1623 and 1691.

Only one instrument maker outside the Lahore family is known to have produced Indo-Persian celestial globes in the seventeenth century. It is Muḥammad Ṣāliḥ of Thatta, whose seven astrolabes have been discussed earlier (B008 - B014); five celestial globes by him are extant. But the tradition of producing celestial globes by the *cire*

1041 Savage-Smith 1985, no. 10, pp. 223-224, Figs. 11 (inscription) and 69 (autumnal equinox with figures Leo, Virgo, Bootes and Centaurus).

1042 Savage-Smith 1985, lists three seamless globes (no. 6, p. 220, signed by Muḥammad ibn Maḥmūd al-Ṭabarī, dated 684 AH; no. 60, pp. 247-248, made by ᶜAbd al-Raḥmān ibn Burhān al-Mawṣilī dated 718 AH; and no. 9, p. 223, by Jamāl al-Dīn Muḥammad [ibn] … al-Dīn Muḥammad al-Hāshimī al-Makkī of 981 AH) which carry dates earlier than the date of ᶜAlī Kashmīrī's globe, but concludes (p. 34) that these are very inaccurate and of poor quality and are possibly copies made at a later date.

perdue process continued up to the middle of the nineteenth century, when Lālah Buhlomal Lāhorī[1043] produced ten rather large-sized celestial globes, with inscriptions either in Persian, or in Sanskrit, or in English.[1044]

There are also extant several unsigned and undated globes; these are of three kinds: globes with the full set of 48 constellation figures and 1020 stars; globes with the reference circles and a limited number of stars; globes with just reference circles.[1045]

On the quality of globes produced by this process in India, Savage-Smith remarks as follows:

> 'The precision and the uniformity in the sphericity of a seamless globe cast by *cire perdue* is impressive. The workshops in the Punjāb and western Himālayas seem to have specialized in this extraordinary technique of producing celestial globes from the sixteenth through the nineteenth centuries. Only pride of craftsmanship could have justified the enormous expenditure of time and effort that went into such a technique, when simpler methods using hemispheres had long been available. The products of these Indian workshops display admirable skills on the part of the artisan in forming a nearly perfect sphere and inscribing it accurately and precisely.'[1046]

Indian celestial globes are not only accurate, they also seem to be more durable than those made in two hemispheres. Of the 58 extant celestial globes which carry constellation figures and star positions listed by Savage-Smith, as many as 35 are single hollow spheres produced in India.[1047]

1043 For his astrolabes, see B021 - B026; C029 - C030.

1044 Sarma 2015b, pp. 271-278.

1045 Indo-Persian astrolabes produced outside the Lahore family will be discussed in the next section G.

1046 Savage-Smith 1985, p. 95.

1047 Savage-Smith 1985, p. 43: 'In terms of the number of extant Islamicate celestial globes, this family is also important. Their workshop claims 21 signed globes — the largest number from a single shop. Moreover, it is very likely that not only the anonymous globe now at the Smithsonian Institution (No. 38) but also a considerable number of other Indo-Persian seamless metal globes could be attributed to this workshop, including Nos. 39-44.'

5.2.1. Qā’im Muḥammad

Besides the nine astrolabes signed by or attributable to Qā’im Muḥammad which have been described earlier (A009 - A017), there are extant today five celestial globes made by him between the years 1623 and 1637. Only two of these are with the original stand; interestingly these two stands are made in two different styles, one with straight legs resting on a lobed ring (F003) and the other with curved legs without any base (F005).[1048]

On these globes, the equator and ecliptic are drawn as two parallel bands, one band divided in 1° and the other in 5°. The equator is numbered from 5 to 360, but the ecliptic from 5 to 30, separately in each sign. There are ecliptic latitude circles, but no tropics or polar circles. Holes are bored at the celestial poles. The maker’s signature and the dedication are engraved in the form of an arc around the ecliptic pole.

All the 48 constellation figures are drawn along with their names and the positions of about 1020 stars are marked with inlaid silver points. In an inscription on the globe of 1637 (F005), Qā’im Muḥammad states that he had added 3° to the star longitudes given by Mirzā Ulugh Beg so that the positions on the globe correspond to the year of manufacture. Perhaps the star positions on the other globes of his also were adjusted in this manner.

Celestial poles and some major stars are named. The names of the constellations are preceded by the term *ṣūrat* (spelt Arabic style as صورة, but in a few cases spelt in Persian or proto-Urdu style as صورت). In F005, the names of the figures of the zodiac signs are preceded by *ṣūrat burj* (figure of the zodiac sign).

However, Qā’im’s celestial globes, though impeccable in construction, are highly disappointing as far as the technical and aesthetic quality of the constellation figures are concerned, especially in view of his innovations in astrolabe design and his extraordinary talent in producing them, in particular, the magnificent calligraphic rete of A013. The animal figures like the bear in Ursa Major and Ursa Minor or the lion in

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1048 These two styles are emulated by Qā’im’s son Ḍiyā’ al-Dīn in his globes.

Leo, the reptiles Draco, Hydra and Serpens (sometimes with scales sometimes without), and the figure of the boat with an oversized figurehead in Argo Navis are passable.[1049]

But in drawing human figures, Qā'im Muḥammad shows absolutely no talent. These figures are drawn in careless outlines and are often anatomically inexact. The faces are drawn in full front, but neither the eyes, nor the nose, nor the mouth have any resemblance to human features. Particularly unattractive is the depiction of the nose, with three irregular holes. The mouth is indicated by a curved line which is too large for the face with a small dot below to indicate the extent of the lower lip.

Generally the human figures, whether male or female (e.g. Hercules, Sagittarius, Perseus, also Andromeda) are clothed in a stereotyped tunic with flared skirt which is held at the waist by a stereotyped belt and buckle. Sometimes the sleeves are indicated by two parallel lines on the wrists. Sometimes these are omitted with the result that the figures appear naked in the upper half.

Furthermore, when one compares the three globes F001, F004 and F005, a gradual deterioration in the quality of the constellation figures can be discerned; the figures become more rudimentary with less detail.

5.2.2. Muḥammad Muqīm

Qā'im's brother, Muḥammad Muqīm is well known for his large number of astrolabes (A018 - A059), but only two celestial globes by him are known. One is said to be in a private collection at Kuwait (F006), but no details are available about the circles or the constellation figures drawn on this globe. The other is now with the Museum of Islamic Art at Doha; it is richly engraved with very elegant constellation figures (F007).

5.2.3. Ḍiyā' al-Dīn Muḥammad

As in the case of astrolabes, so also in the production of celestial globes, Ḍiyā' al-Dīn Muḥammad is the most prolific member of this family. Besides the forty-six astrolabes described above (A060 - A105), he produced the largest number of celestial

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[1049] In fact, his highly talented son Ḍiyā' al-Dīn imitated the father's basic designs of these figures, occasionally embellishing them.

globes attributable to a single instrument maker. There are extant nineteen globes signed by him and six that can be attributed to him on stylistic grounds. Like his astrolabes, his celestial globes are also of different sizes with diameters ranging from 60 mm to 217 mm.

Chronologically the last globe made by him in 1090/1679 (F026) for the Mughal Emperor Aurangzeb is not a conventional celestial globe cast by the lost wax method, but an openwork globe made in two hemispheres and then joined together. Leaving this aside, all his other globes carry the equator and ecliptic in two bands, generally divided in 1° and 5°; the equator is numbered continuously from 5 to 360 starting from the vernal equinox onwards, while the ecliptic is numbered from 5 to 30 separately in each sign. On three small globes (F017, F023, F024), divisions are marked at 2° and 6°. There are ecliptic latitude circles, equatorial tropics and equatorial polar circles. Signature is engraved almost in a full circle inside the Antarctic circle.

In all the globes save four (F011, F017, F023 and F024), the full set of 48 constellation figures is drawn and the positions of about 1020 stars are indicated by inlaid silver points. The labels of the figures are prefixed with *ṣūrat* spelt in proto-Urdu style (صورت). The labels also contain the serial numbers of the constellations. Ḍiyā’ numbers the northern constellations from 1 to 21, the zodiac signs from 1 to 12 and then the southern signs from 1 to 15. On some globes, he also numbers the stars within each constellation.

In the case of animal figures and others like Argo Navis, he follows Qā’im’s basic design with some embellishments or variations. For example, in the figure of Argo Navis, variations can be seen in the design and in the number of the pennants, in the design of the pavilion at the back, in the design of the two oars, and in the figureheads. The figureheads are generally shaped like lion’s heads, but on globe F009 it is formed like a parrot’s head, looking backwards.

Ḍiyā’ al-Dīn makes a radical departure from his father’s rendition of human figures: here he is largely influenced by his uncle Muḥammad Muqīm. There is a great stylistic affinity between Muqīm’s constellation figures on globe F007 and Ḍiyā’ al-Dīn’s figures on several globes, in particular F009 and F029. His outlines are bold and anatomically correct; the clothing and jewellery are drawn with great detail, the faces are often in three-quarters profile, with clear depiction of the eyebrows, eyes, nose and mouth. The eyes are almond shaped with hatched circles for pupils. In many cases, the womanhood of Virgo and Andromeda is indicated by the outlines of their breasts. Even though he is unaware of the mythological context of the figures, he infuses their postures and faces with the correct expression. Technically and aesthetically his constellation figures are comparable to the human figures in contemporary Mughal miniature paintings.

But sometimes unfamiliarity with the mythological background leads to embarrassing depictions. Following the Greek convention, the two figures of Ophiuchus and Hercules are drawn on Islamic globes with short skirt-like kilts. Sometimes, the outlines of Hercules's arms end in half-circles on his chest (e.g. on F028[1050]). Later, either Ḍiyā' al-Dīn himself or one of his assistants developed these half circles into feminine breasts on three globes (F019 at Hyderabad, F020 at Edinburgh and F027 at Rampur[1051]). It is probably such depictions which led to the designation of the figure of Hercules *Nṛtya-kālī-mūti* (figure of the dancing goddess Kālī) on the Sanskrit globe H001 and the star α Herculi as *Nṛtya-kālī-śira* (head of the dancing goddess Kālī) on the Sanskrit astrolabe D013.

But in general, Ḍiyā' al-Dīn's iconography of constellation figures is emulated in the few Sanskrit globes.

Ḍiyā' al-Dīn made an interesting innovation in the design of the meridian ring. In F008, the thickness in one half of the meridian ring is reduced so that there is recess between the ring and the globe. At the mid-point of the thinner half on the inner side is attached an arc of 90° which is graduated in single degrees. This arc can be rotated along the surface of the globe and can be used in measuring the altitudes. In the mid-nineteenth century, Lālah Bulhomal of Lahore introduced this feature, with slight variations, in five globes (G010, G011, G016, G017 and H004).

1050 See Savage-Smith 1985, Fig. 54.

1051 This is the main reason why I attributed this globe to an unknown globe-maker in my Rampur catalogue (Sarma 2003, pp. 65-72). At that time, I did not yet study the images on the globes at Hyderabad and Edinburgh.

5.2.4. Ḥāmid

Just three celestial globes by Ḥāmid are extant (F033 - F035), but none with the original stand. Again, of these three only one carries constellation figures.

On all the three globes the equator and the ecliptic are represented by double bands, but there are variations in the graduations. On F033, the two circles are divided in 1° and 5°, while on the other two globes, they are divided in 1° and 6°. The equator is not numbered continuously, but in two batches from equinox to equinox, as 5 … 180, or 6 … 180. On the ecliptic the numbering is done separately in each zodiac sign. There are ecliptic altitude circles, but no tropics or polar circles. Like Qā'im, Ḥāmid also engraves his signature in an arc around the southern ecliptic pole on F033 and F034, but around the southern celestial pole on F035.

Globes F033 and F035 are without any constellation figures. On F034, all the 48 constellation figures are drawn and the positions of about 1020 stars indicated. The human figures are depicted as contemporary men and women of distinction and not as figures of mythology. Thus Hercules and Ophiuchus, placed head to head, are draped in contemporary Mughal clothing; elaborate turbans, knee-length flared tunics with long sleeves, tight trousers and pointed boots. Most unusually, Leo is depicted as a tiger with stripes.

Star positions are indicated on all the three globes, but in a different manner on each globe. On F033 about 67 stars are marked by inlaid silver points on which are engraved dots within circles; on F034 all 1020 stars are shown in two different styles and on F035 a smaller number of stars in three different styles.

6. THE SMITHSONIAN GLOBE AND ITS ATTRIBUTION

The National Museum of Natural History at Washington DC, a Smithsonian institution, acquired in 1972 an unsigned and undated celestial globe engraved in Arabic. In order to understand the milieu and the context in which this globe was produced, Emilie Savage-Smith studied a vast range of Arabic texts on the celestial globe and astrolabe and surveyed all the Islamic celestial globes extant all over the world. Her study resulted in the path-breaking work *Islamicate Celestial Globes: Their History, Construction, and Use* in 1985. On the basis of her exhaustive study of the historical antecedents of the globe and on the basis of the linguistic and technical features of the globe, she came to the conclusion that the globe is attributable to Qā'im

Muḥammad of the Lahore family. The art-historian Andrea P. A. Belloli of the Los Angeles County Art Museum studied the iconography of constellation figures on the globe, compared them with the constellation figures in the two globes signed by Qā'im Muḥammad which are now with the Stonyhurst College (F001) and the Victoria and Albert Museum of London (F003), and also contemporary Mughal miniature paintings and came to the same conclusion. Her art-historical analysis is included as Chapter 4 of the above-mentioned book. But surprisingly neither scholar made an attempt to closely compare the Smithsonian globe with the globes produced by Qā'im Muḥammad's son Ḍiyā' al-Dīn. Had they done so, they would have seen that the Smithsonian globe shows greater similarity with the globes produced by Ḍiyā' al-Dīn rather than with the globes of his father Qā'im Muḥammad.

While discussing the evidence presented by these two scholars for the attribution of the Smithsonian globe to Qā'im Muḥammad, it should be borne in mind that the Lahore family produced a large body of instruments of which some 134 astrolabes and 33 celestial globes are extant today. Some of these were made for high dignitaries at the Mughal court, including the Emperors Shāh Jahān and his successor Aurangzeb. The family must have maintained a large workshop at Lahore as Savage-Smith rightly assumes.[1052] But we do not have any idea how many people were employed there and what their individual task were. The finished products bore the names of the family members but not the names of any of the assistants. In the case of the astrolabes, it was shown that occasionally there are discrepancies in the astrolabes signed by the same person, with regard to the latitudes of localities, the maximum number of the daylight hours, or even in the symbols used for zero.

Secondly, Mughal miniatures, unlike any other group of art work in India, provide much visual information about the material culture of the Mughal court, like the architecture, furniture, clothing and so on. At the same time, not every depiction can be

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1052 Cf. Savage-Smith 1985, p. 34: 'This particular family of metalworkers from Lahore excelled in certain metallurgical techniques, in particular the production of hollow cast globes. The variety in the techniques and designs of the engraved images on the globes suggest that the family maintained a workshop of metalworkers and apprentices, in which several people would perhaps be involved in the production of an instrument which nevertheless bore only the name of the family members supervising the production.'

taken as a photographic record of the real life. In 1992, I made a study of the astronomical instruments shown in Mughal miniature paintings.[1053] My study brought to light, for the first time, the only two cases of the pictorial representation of the ubiquitous sinking bowl water clock, but rarely any image of the astrolabe which was held in high esteem in the learned circles of Muslims. There are several paintings depicting the assemblage of astronomers measuring time and preparing the horoscope of the new born royal prince; the astronomers in these paintings are depicted more often with an obscure ring dial which is hardly mentioned in literature than with the astrolabe. With this caveat, we shall now discuss the evidence for the attribution of the celestial globe to Qā'im Muḥammad.

6.1. Technical and Linguistic Evidence

Savage-Smith lists six technical and linguistic features which occur on the Smithsonian globe and on Qā'im Muḥammad's two signed globes at the Stonyhurst College and at the Victoria and Albert Museum of London, in support of the attribution of the Smithsonian globe to Qā'im Muḥammad:

> '[i] In Ursa Major the stars on the lower front paw are labelled *tatimmat qafzah al-thālithah* (the complement of the third lap), while [ii] Pegasus the star in the northernmost hoof bears undeciphered label, *mrhlt al-faras.* Furthermore, [iii] in the constellation Perseus the star name written on the sword held overhead is written as *muᶜtaṣam al-thurayyā* (the refuge of the Pleiades), which must be a misspelling of *miᶜṣam al-thurayyā* (the wrist of Pleiades). These terms are not known to occur in any star catalog nor on any globes or astrolabes except the globes No. 11 and No. 13 made by Qā'im Muḥammad ibn ᶜĪsā ibn Allāhdād Asṭurlābī Lāhūrī Humāyūnī made in 1032 H/AD 1622-1623 and AD 1626-1627 … [F001 and F003]. On both of these globes the identical terms are clearly inscribed. Two other globes by Qā'im Muḥammad (Nos. 12 and 14 [i.e., F004 and F005]) were not available for detailed study, and it is not known if these terms occur on them as well. […]

[1053] Sarma 1992a.

> '[iv] The positioning of the sequence of the lunar mansions along the ecliptic as done on the Smithsonian globe is known to occur on only one other globe, that being the earliest globe made by Qā'im Muḥammad (No.11). On these two globes, the first lunar mansion is placed at 13° House of Aries with the twenty-eighth lunar mansion at the vernal equinox, in contrast to the usual arrangement, in which the first mansion is at the vernal equinox and the second about 13° House of Aries. […]
>
> '[v] Moreover, the maker of the Smithsonian globe has numbered the ecliptic continuously from the vernal equinox. On all other globes but one the graduations of the ecliptic are numbered in 30° intervals. This one exception is again the earliest globe by Qā'im Muḥammad (No. 11) where he labels the ecliptic continuously from the vernal equinox as well as giving it a second set of numbers which divide it into 30° intervals.
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> '[vi] Finally, the star positions on the Smithsonian globe are identical to those on the globes of Qā'im Muḥammad that have been examined.'[1054]

These are undoubtedly very carefully made observations, but they cannot be treated as unique characteristics of Qā'im's globes. That they occurred in the Smithsonian globe as well as in one or two globes signed by Qā'im is a mere coincidence and does not establish conclusively that the Smithsonian globe was made by Qā'im Muḥammad and not by his son Ḍiyā' al-Dīn who continued the family profession obviously in the same workshop and possibly with some of the assistants who worked also with his father. Moreover, some of the features like [iv] and [v] are clearly engraving errors; these do not occur on F004 and F005 which carry the signature of Qā'im Muḥammad.

Finally, Savage-Smith offers a possible reason why this one particular globe is without signature while all other globes of this family which she had examined carry signatures and dates:[1055]

1054 Savage-Smith 1985, p. 97.

1055 Savage-Smith 1985, p. 98.

> ‘It is quite probable that the maker, after completing the tedious construction of the sphere and the precise placement of the stars, the drawing and graduation of the great circles, delineation of the constellation figures and labeling of the stars, began to draw the equatorial tropic circles. In the northern hemisphere of this globe a lesser circle parallel to the equator but not in the position of the Tropic of Cancer was partially drawn (see Figures 73 and 76). It would seem that having started to draw the tropics, the maker discovered that he had placed the northern circle too far from the equator. For this reason the maker may have stopped incising the circle and ceased work altogether on the globe, for such an error in engraving would be impossible to correct. This may well be the reason the globe bears no maker's signature and date, which were no doubt the last items to be added to a globe.’

There is indeed an unfinished small circle in the northern hemisphere but, if it was the northern tropic drawn at a wrong place, was that drawn as the last item of engraving?

One would have thought that the globe-maker would first draw the reference circles including the tropics and mark the star positions with silver points and only then would proceed to draw the constellation figures around the star pointers and finally engrave the labels. In any case, this is not the only instance when an instrument produced at the Lahore workshop was left unsigned. Savage-Smith has not surveyed the astrolabes produced by the family, which is done in the present catalogue. Of the 134 astrolabes produced by this family, there are several astrolabes which are signed, but not dated, and a still larger number which are neither signed nor dated. These show no defects or short-comings. Therefore, it is futile to speculate why certain astrolabes were not dated or why certain astrolabes or celestial globes carry no inscription at all.[1056]

6.2. Art-Historical Evidence

The art-historian Belloli sets out to study the ‘iconographic peculiarities of the figures [on the Smithsonian globe] and their relation to counterparts on earlier and

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1056 This is true not only of the products of the Lahore family, but of several other instrument-makers as well, such as Bulhomal and Ṣāliḥ who also left some instruments without signatures.

contemporary globes; and the significance of contemporary factors relevant to the globe's manufacture,' the contemporary factors being Mughal miniature paintings. She describes the various constellation figures on the Smithsonian globe in great detail; she notes how the human figures are delineated and their garments are represented and how the animal figures are represented. Of the other figures, she pays special attention to the figure of the ship in Argo Navis.

Finally, she comes to the astonishing conclusion that: 'A stylistic comparison between the Smithsonian globe figures and those on the other celestial globes listed in the catalog indicates an extremely close affinity between the Smithsonian figures and those on the globes (Nos. 11 and 13) signed by Qā'im Muḥammad.'

It is difficult to see where this 'extremely close affinity' lay. As we have mentioned above, the human figures in the globes signed by Qā'im Muḥammad in 1623 and 1627 (which Belloli has seen) and also in the globes of 1629 and 1637 (which Belloli has not seen), are anatomically very inexact, which is not the case with the human figures of the Smithsonian globe. Belloli concedes that 'the faces on Qā'im Muḥammad's figures differ somewhat in their idiosyncratic rendition from those on the Smithsonian globe' but insists that 'in all other ways the figures on the three globes are almost identical'.

It is again difficult to see what these 'other ways' are. On the Smithsonian globe, the garments worn by the human figures are very carefully represented. On the four globes signed by Qā'im Muḥammad, no great effort was made in this regard. In this connection, Belloli asserts that a sash tied at the waist with one loop is the most decisive factor not only in identifying the maker of the Smithsonian globe but also in fixing the precise time of its manufacture:

> 'A survey of paintings done under Akbar and Jahāngīr shows single-looped sashes occurring in works dated or attributed to the years between AD 1583 and 1610 [fn. 53]. This suggests that such sashes were popular during Akbar's reign and that fashion died out completely shortly after Jahāngīr gained the throne.

> 'A preference for the single-looped sash worn by itself on Qā'īm Muḥammad's globes[1057] suggests that he must have begun work as a maker of celestial globes during the reign of Akbar, continuing under Jahāngīr without adjusting his mode of dressing the constellation figures to mirror changes in the contemporary male fashions. Such a theory fits quite well with the generally conservative picture we have constructed of Qā'im style, especially in comparison to that of his son. In any event, Qā'im's particular modification of outfit standards for male constellation figures on earlier globes to reflect contemporary garb justifies a dating of the Smithsonian globe to the first quarter of the seventeenth century or slightly earlier.'[1058]

Assuming that the fashion of the single-looped sashes really died out after Jahāngīr ascended the throne, and assuming further that Qā'im Muḥammad's globes reflect the sartorial fashions of the Mughal court precisely by the year, how does one then explain the fact that Ḍiyā' al-Dīn depicts Andromeda with a single-looped sash in his globes of 1663 at Hyderabad (F019) and Edinburgh (F020); also in the unsigned globe at Rampur (F027)? But the whole issue becomes irrelevant when we consider that in Mughal miniatures women are never shown with such single-looped sashes and that it is only the men, that too manual labourers, who wear single-looped sash, as for example, in the miniature showing Babur's garden at Kabul.[1059]

1057 It is not clear on which of his globes Qā'im Muḥammad shows this preference for single-looped sashes. As it happens, just two globes signed by Qā'im Muḥammad were available to Savage-Smith and Belloli, namely the one at Stonyhurst College (no. 11 in Savage-Smith Catalogue) and the one at the Victoria and Albert Museum (no. 13). But of these two globes, no figures are published of singled-looped sashes in Savage-Smith's book. Fresh images I have obtained from the Stonyhurst College show Andromeda and Perseus with two loops, and Virgo and Bootes without any loops. The only figure with a single loop is Cassiopeia (see Figure F001.2). On Qā'im's globe at New Delhi (F004), just the figure of Perseus is shown with a single loop and no other figure; I do not find any figure with a single loop on Qā'im's globe at Patna (F005). Even on the Smithsonian globe, there are just two figures with a single loop, viz. Cassiopeia (Savage-Smith 1985, Fig. 56) and Virgo (Savage-Smith 1985, Fig. 68). All others have either two loops or no loops. Thus there is no basis for Belloli's theory of 'preference for single-looped sash worn by itself on Qā'im Muḥammad's globes.'

1058 Savage-Smith 1985, p. 113.

1059 Titley & Wood 1999, front cover illustration and pl. 31.

In a like manner, Belloli assumes that the design of the boat in Argo Navis on the various Lahore globes reflects the contemporary Mughal naval architecture, in particular the different renderings reflect contemporary styles:

> 'The representations of the Argo constellation vary from globe to globe perhaps more than any of the other diagrams; <u>this may have been due to local or temporal differences in ship design of a kind more radical than, for example, variations in basic fashion of dresses</u>. Not all of the boats have sails, pennants, or even masts. Thus it is all the more significant that the Argo Navis diagram on Qā'im's globe (no. 11, see Figure 46) is practically the twin of that on the Smithsonian globe.'[1060]

As stated above, Ḍiyā' al-Dīn followed his father Qā'im Muḥammad in the design of the ship; he did not make any substantial changes in the basic design, but only added embellishments. Therefore, there are many ship figures on Ḍiyā's globes which appear to be close to Qā'im's ship figures. Moreover, it is not correct to say that the differences in the rendition of the ship on the various globes reflect 'local or temporal' differences in ship design. In the vast territory of Mughal empire, there were prevalent several styles of ships. That the thirty and odd celestial globes made at Lahore carry a photographic record of the ship construction in the Mughal empire is an unwarranted assumption. The fact is that the ship designs on the Lahore globes do not even correspond to the ships depicted on Mughal miniature paintings, which themselves may not entirely reflect the contemporary reality.[1061]

The diverse renderings of the boat on the globes are not a factual record of technological changes or variations in naval architecture in the Mughal territories in the seventeenth century, but fanciful creations of the artist who wished to add variety. In real life, no boat existed with such oversized figureheads.

In sum, it is futile to look for one-to-one correlation between the clothing engraved on the globes and the clothing in real life or to attempt to correlate the artefacts or dresses to contemporary styles in the Mughal realm of the seventeenth century. Of

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[1060] Savage-Smith 1985, pp. 109-111.

[1061] On the ships shown on Mughal miniatures, see Verma 1978, Pl. LXXI.

course, the instrument makers are not immune to contemporary surroundings, but imagination also plays a significant role in the design of the constellation figures. Lahore instruments makers may not know the Greek mythological background of the human figures; but they would also not try to depict male figures with unusual names like *Qīqā'ūs, Barsā'ūs,* or *al-ᶜAwwā',* or the female figures named *al-Dhāt al-Kursī* or *al-Mar'ah al-Musalsalah* precisely like contemporary men and women, but try to distance them somewhat from contemporary styles. It is only Ḥāmid, a rebel in many respects, who clothes them like contemporary men and women.

Therefore, it is not these minutiae which are decisive in the attribution of the Smithsonian globe. More decisive is how confident the outlines of the human figures are, how accurate the anatomical details are and how well-formed the faces are. These can be best discussed by juxtaposing the images of the three main figures of Andromeda, Virgo and Centaurus in the two globes signed by Qā'im Muḥammad at Delhi and Patna on the one hand with the same figures on the Smithsonian globe on the other; this will immediately show the great gulf between the globes signed by Qā'im Muḥammad and the Smithsonian globe.

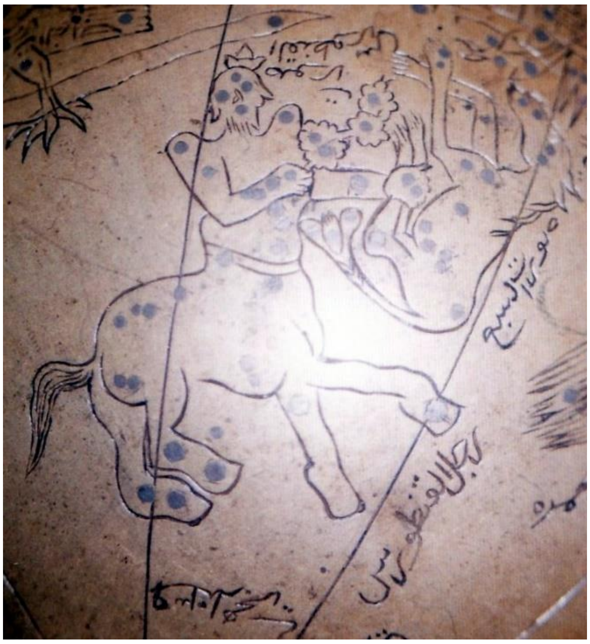
Andromeda 1629 Delhi | Andromeda1637 Patna | Andromeda at Smithsonian

(photo by S. R. Sarma) | (photo by S. R. Sarma) | (From Savage-Smith 1985, Fig. 62)

Figure F9 – The figure Andromeda on three globes

In these three renderings of Andromeda, although the physical posture is the same, the general design of the tunic, the sash and the necklace are the same, the refinement and elegance of the Smithsonian version is unmatched in the other two.

Centarus 1629 New Delhi



(photo by S. R. Sarma)

Centaurus 1637 Patna

(photo by S. R. Sarma)

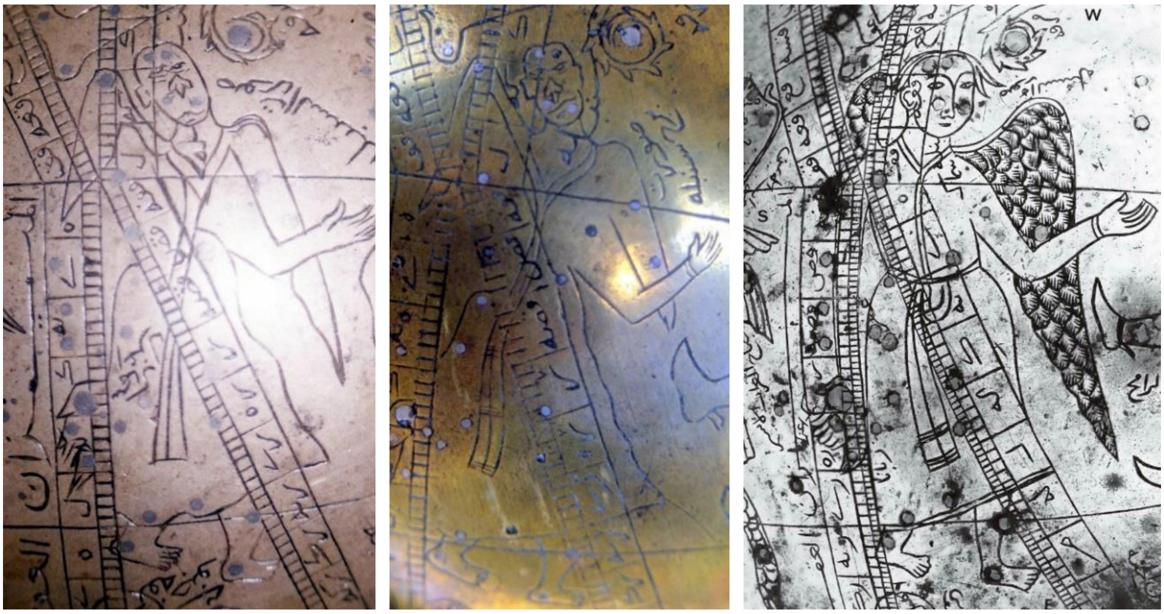
Centaurus at Smithsonian

(from Savage-Smith 1985, Fig. 84)

Figure F10 – The figure of Centaurus on three globes.

In the first two figures, the shoulders of Centaurus are highly exaggerated in order to include the star points, and the faces are undefined. The legs of the horse are drawn in very crude manner. No effort is made to give a proper shape to vine leaves held by Centaurus. As against these two, the horse on the Smithsonian globe is very accurately delineated, so also the upper human half, and the vine twig.

Virgo 1629 Delhi | Virgo 1637 Patna | Virgo at Smithsonian



(photo by S. R. Sarma) | (photo by S. R. Sarma) | (from Savage-Smith 1985, Fig. 84)

Figure F11 – The figure of Virgo on three globes.

The only common feature in these three depictions of Virgo is the outstretched hand on the right. The outlines of the first two figures are extremely clumsy; the arms and the wings are undifferentiated; the faces can hardly be regarded as human faces. It is inconceivable that the person who drew these two repulsive faces could be the same as the one who created the highly elegant figure of Virgo on the Smithsonian globe.

In sum, the physiognomy of the human figures, their facial features and garments on the first two globes are very primitive in comparison to the very fine rendition on the Smithsonian globe; the same is the case with the anatomy of the horse in the figure of Centaurus. The Smithsonian globe does not display any affinity with the globes made by Qā’im Muḥammad and cannot be attributed to Qā’im Muḥammad.

On the other hand, in all the human figures engraved on the Smithsonian globe can be seen the refined hand of Qā’im’s son Ḍiyā’ al-Dīn; and it is to him the globe is attributed in this catalogue under F028.

7. Conclusion

Despite this disagreement on the attribution of the Smithsonian globe, I am heavily indebted to Savage-Smith's splendid work, as the frequent references to it show. I have used her catalogue numbers for the identification of Indo-Persian globes (e.g. 'ESS 11'). In her *Islamicate Celestial Globes,* she classifies the celestial globes into three classes: (A) those carrying the figures of all the 48 constellations and some 1020 star positions, (B) those without any constellation figures, but with the positions and names of some prominent stars, and (C) those without constellation figures or star names, but with only the major circles. I have followed this classification only in the case of anonymous globes; in the case of signed globes, I put together all the globes signed by a globe maker, whether the globes carried constellation figures or not.

She also introduced a new class of 'astrologer's globes'.[1062] Whether they can be of any use to an astrologer or not, these are imperfectly made celestial globes, combining various disperate elements. More and more such globes are turning up in tourist markets in India. These are not included in this catalogue.

Two globes occupy a special place in this catalogue and in the historiography of the instruments produced by the Lahore family. It is while studying the globe F018 at Berlin that von Klüber became interested in the work of its maker Ḍiyā' al-Dīn and wrote to Sulaiman Nadvi, asking for relevant information. This query from von Klüber resulted in Nadvi's pioneering publication of 1935 where he surveyed, for the first time, eight astrolabes and four celestial globes made by various members of the Lahore family.

Globe F013 made by Ḍiyā' al-Dīn in 1653 is with the Aligarh Muslim University where I spent my entire academic career. This is the first instrument by the Lahore family which I had the opportunity to study and which, in a way, set me off on my exploration of other extant Indian astronomical instruments. It is also one of the most beautiful instruments produced by Ḍiyā' al-Dīn. In my description of this globe, I shall provide a very comprehensive photographic documentation, illustrating all the constellation figures - as my personal tribute to Aligarh Muslim University.

[1062] Maddison & Savage-Smith 1997, nos. 112, 113 and 114, pp. 160-165.

Index of Indo-Persian Celestial Globes produced by the Lahore Family

F001 Celestial Globe by Qā’im Muḥammad, 18 J (AD 1623-24) 2729

18th regnal year of Jahāngīr (AD 1623-24), Diameter 188 mm, UK, Lancashire, Clitheroe, Stonyhurst College Library

F002 Celestial Globe by Qā’im Muḥammad, 1035 AH (AD 1626) 2744

21st regnal year of Jahāngīr, Diameter 125 mm, Paris, Galerie Delalande

F003 ◎Celestial Globe by Qā’im Muḥammad, 22 J (AD 1627)................................. 2757

22nd regnal year of Jahāngīr (AD 1627), Diameter 134 mm, London, Victoria and Albert Museum (# M. 828-1928)

F004 ◎Celestial Globe by Qā’im Muḥammad, 1039 AH (AD 1629-30)................... 2759

Diameter 136 mm, New Delhi, National Museum (#80.705)

F005 ◎Celestial Globe by Qā’im Muḥammad, 1047 AH (AD 1637-38)................... 2767

Diameter 173 mm, Patna, Khuda Bakhsh Oriental Public Library

F006 Celestial Globe by Muḥammad Muqīm, 1049 AH (AD 1639-40) 2777

Diameter ?, Kuwait, PC

F007 Celestial Globe by Muḥammad Muqīm, 1039 AH (AD 1639-40) 2778

Diameter 135 mm, Qatar, Doha, The Museum of Islamic Art (# MW.146)

F008 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1055 AH (AD 1645-46)............ 2788

Diameter 170 mm, New York, Columbia University, Butler Library, David Eugene Smith Collection (#27-198)

F009 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1057 AH (AD 1647-48)............ 2791

Diameter 137 mm, St. Petersburg, The State Hermitage Museum (LS-1473)

F010 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1057 AH (AD 1647-48)............ 2811

Diameter ?, PLU

F011 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1058 AH (AD 1648-49)............ 2812

Diameter ?, PLU; ex-Patna, PC

F012 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1060 AH (AD 1650) 2815

Diameter 113 mm, London, Victoria and Albert Museum (#507-1888)

F013 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1064 AH (AD 1653-54)......... 2817

Diameter 120 mm, Aligarh, Aligarh Muslim University, Ajmal Khan Tibbiya College

F014 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1067 AH (AD 1653-54)............ 2873

Diameter 127 mm, London, Victoria and Albert Museum (# 2324-1883 (I.S.))

F015 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1068 AH (AD 1657-58)......... 2875

Diameter 113 mm, Cardiff, National Museum of Wales (# 39.573.1)

F016 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1068 AH (AD 1657-58)............ 2880

Diameter 100 mm, Cairo, Museum of Islamic Art (# 15226)

F017 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1070 AH (AD 1659-60)............ 2882

Diameter 60 mm, Cairo, Museum of Islamic Art (# 3800)

F018 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1071 AH (AD 1660-61)............ 2886

Diameter 94 mm, Berlin, Staatliche Museen zu Berlin, Preussischer Kulturbesitz, Museum für Asiatische Kunst (I 1266)

F019 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad 1074 AH (AD 1663-64).......... 2892

Diameter 167 mm, Hyderabad, Salar Jung Museum (# 113/xxxv)

F020 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1074 AH (AD 1663-64)......... 2904

Diameter 146 mm, Edinburgh, Royal Scottish Museum (# 1890-331)

F021 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1064 AH (AD 1653-54)......... 2911

Diameter 175 mm, Oxford, Museum of the History of Science (# 45247)

F022 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1078 AH (AD 1667-68)............ 2913

Diameter ?, PLU

F023 ◎Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1087 AH (AD 1676-77)......... 2914

Diameter 65 mm, NewDelhi, Red Fort, Mumtaj Mahal Museum (# 40-414)

F024 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, 1087 AH (AD 1676-77)............ 2918

Diameter 60 mm, height 110 mm, PLU, ex-London, Sotheby’s 2005

F025 Celestial Globe by Ḍiyā’ al-Dīn Muḥammad, [1]087 AH (AD 1676-77)......... 2921

Diameter 120 mm, Qatar, Doha, Museum of Islamic Art (# MW.279.2006), ex-London, Sotheby’s 2006

F026 Openwork Celestial Globe by Ḍiyā’ al-Dīn Muḥammad 2923

Diameter 163 mm, Chicago, Adler Planetarium (# A-398)

F027 ◎Celestial Globe attributable to Ḍiyā’ al-Dīn Muḥammad.............................. 2933

Not dated, 17th Century, Diameter 141 mm, Rampur, Rampur Raza Library (# 717 D)

F028 Celestial Globe attributable to Ḍiyā’ al-Dīn Muḥammad................................. 2956

Not dated, 17th Century, Diameter 217 mm, Washington DC, National Museum of American History (# 330781)

F029 Celestial Globe attributable to Ḍiyā’ al-Dīn Muḥammad................................. 2966

Not dated; 17th century, Diameter 115 mm, Chicago, Adler Planetarium (# A-115)

F030 ◎Celestial Globe attributable to Ḍiyā’ al-Dīn Muḥammad.............................. 2974

Not dated, 17th Century, Diameter 110 mm, London, National Maritime Museum, Greenwich (# GLB0175)

F031 Celestial Globe attributable to Ḍiyā’ al-Dīn Muḥammad................................. 2978

Not dated, 17th century, Diameter 116 mm, Lahore, Lahore Museum (# M.m. 44. G)

F032 Celestial Globe attributable to Ḍiyā’ al-Dīn Muḥammad 2988

Not dated, 17th Century, Diameter 115 mm, PLU; ex-London, Spink & Son

F033 ◎Celestial Globe by Ḥāmid, 1065 AH (AD 1655) 2990

Diameter 99.3 mm, Cambridge, University of Cambridge, Whipple Museum of History of Science (# 1255)

F034 ◎Celestial Globe by Ḥāmid ibn Muqīm 1094 AH (AD 1683) 2992

Diameter 203 mm, Hyderabad, Salar Jung Museum (# 114/xxxv)

F035 ◎Celestial globe by Ḥāmid, 1102 AH (AD 1690-91) 3003

Diameter 110 mm, Pune, Raja Dinkar Kelkar Museum (# PMC 106)

F036 Celestial Globe attributable to the Lahore Workshop 3009

Not dated, 17th Century, Diameter 169 mm; weight 1835.7 grams, Chicago, Adler Planetarium (# M-14)

G. INDO-PERSIAN CELESTIAL GLOBES PRODUCED BY OTHERS

INTRODUCTION

MUḤAMMAD ṢĀLIḤ OF THATTA

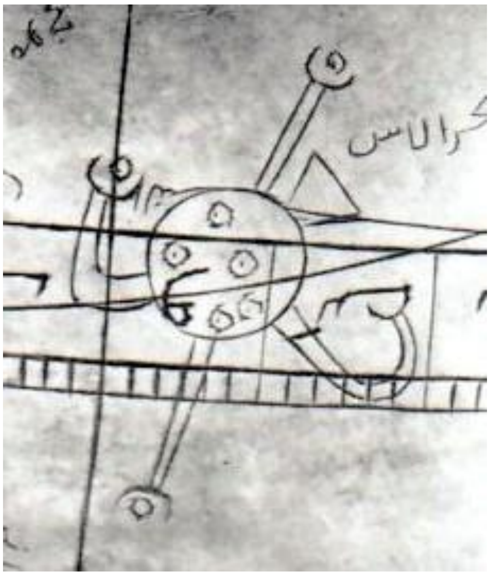
It has already been mentioned that ᶜAlī Kashmīrī who produced the earlier celestial globe in India (G001) was not a member of the Lahore family. Another instrument-maker from outside the Lahore family was Muḥammad Ṣāliḥ of Thatta who made both astrolabes and celestial globes. Four astrolabes signed by him and three others which are attributable to him on stylistic grounds have been described in section B (B008 – B014). But the celestial globes bearing his signature are rather problematic. In early 1992, S. M. Razaullah Ansari and I went for a seminar to Bangalore, where A. M. Kulkarni told us about two celestial globes he had seen in a shop there. The shop readily agreed to our examining and photographing the globes. One of the globes carried the signature of Muḥammad Ṣāliḥ and the year 1072 Hijrī; the other was unsigned and undated, but displayed similar iconography of the constellation figures. We assumed that both these globes were made by Ṣāliḥ. With the enthusiasm of novices, we published our 'discoveries' in 1993.[1174]

Emilie Savage-Smith has, however, shown convincingly that these two globes (and about two dozen more) were not made in the seventeenth century, but are the products of the nineteenth century. The iconography of certain human figures on these globes deviates from the standard iconography of Islamic and, in particular, of the Indo-Persian globes:

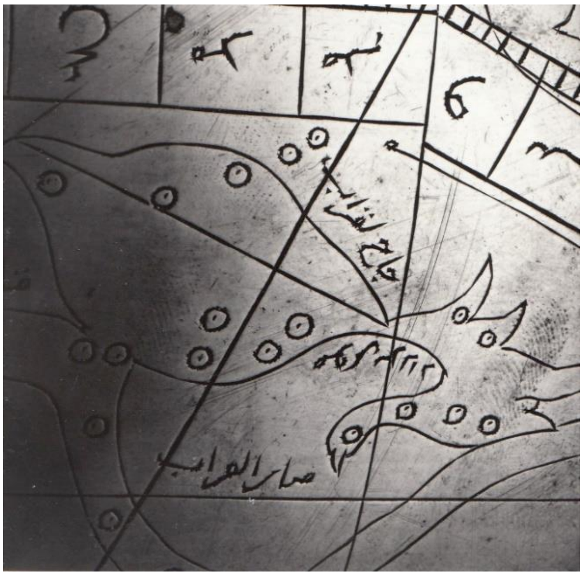
> Cassiopeia is depicted as a woman sitting with her legs drawn up and her ankles crossed, holding an umbrella or parasol over her head. Argo is a square-hulled ship whose masthead is not in the form of an animal head, as is customary, but a man's face, bearded, and turbaned. Also in the southern hemisphere, on the back of the long serpent Hydra, there is a curious version of the constellation Crater, which in this case, resembles a large, wide rimmed cooking-pot covered with a rounded lid.

1174 Sarma, Ansari & Kulkarni 1993.

Most distinctive of all, however, is the constellation of Auriga, which is given a radically new interpretation. He is shown as a bearded man sitting almost cross-legged, with two small animals held in his arms.[1175]

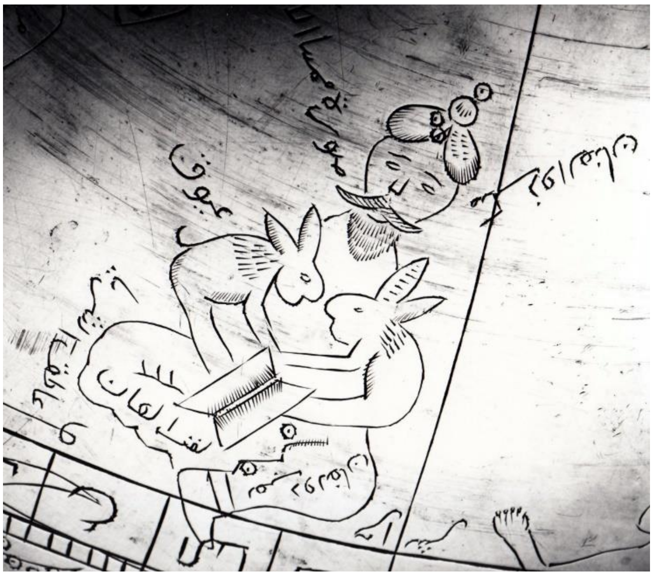


Cancer



Crater

Cassiopeia



Auriga

Figure G1 – Examples of deviant iconography

While the iconography of Cassiopeia and others can be due to misinterpretation or overinterpretation of the mythology of these figures, the new iconography of Auriga displays the impact of early modern European celestial cartography and of the new

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1175 Maddison & Savage-Smith 1997, part 2, pp. 406-408 (Appendix 1: Modern Indian Globes) iconographic models. In Savage-Smith's view, the main source for this deviant iconography is an illustrated manuscript of a Sanskrit work with the title *Sarva-siddhānta-tattva-cūḍāmaṇi* (the crest-jewel of the essence of all astronomical systems/treatises) which is now preserved in the British Library (Or.5259) and which was composed between 1833 and 1839 and contains the horoscope of Maharaja Ranjit Singh's grandson prince Nau Nihal Singh.

In a forthcoming paper, I propose to show that the horoscope is actually of Lehna Singh Majithia[1176] who was one of the generals of Ranjit Singh and that it was written and illustrated a little before 1854. For the present, it suffices to say that this illustrated manuscript is not the earliest source and not the only source of dissemination in India of the new iconographic models of Europe. A celestial globe made by Muḥammad Faḍl Allāh in 1223/1808 (G005) shows already several features that are found in European globes and in European planispheric maps: here Bootes is depicted with two dogs; some of the human figures are drawn in European style, i.e., with their backs towards the viewer.

Coming back to Muḥammad Ṣāliḥ, I accept Savage-Smith's view that the two globes we saw in Bangalore in 1992 were not made by Ṣāliḥ. These are not included in this catalogue.[1177] What are included are just two globes dated 1070 and 1074 respectively which appear to be genuine products of Ṣāliḥ.

Another globe maker of the seventeenth century is Luṭf Allāh ibn ᶜAbd al-Qādir al-Muḥibb al-Asṭurlābī who made a seamless globe which does not contain constellation figures but has 62 stars marked through inlaid silver points (G004).

[1176] He was an expert gun maker; he also produced some astronomical instruments; a horizontal sundial (N003) and a column dial (P023) will be described in the relevant sections.

[1177] Likewise, several other globes which carry this deviant iconography will be not be included in this catalogue. The unsigned globe we saw at Bangalore came up for auction at Christie's, South Kensington, London on 25 June 1997 (catalogue, lot 19). It is not known what happened to the other globe which carries the signature.

LĀLAH BULHOMAL LĀHORĪ

The tradition of producing celestial globes by the *cire perdue* process continued up to the middle of the nineteenth century and culminated in the globes manufactured by Lālah Bulhomal Lāhorī around the middle of the century at Lahore.[1178] Of all the instruments, the production of celestial globes as single hollow spheres by the lost wax process is a very demanding process, requiring a very high order of technical skill. Bulhomal mastered this technique very well and cast several globes of large dimensions. Mention has already been made of the diverse kinds of instruments produced by Bulhomal, in the introduction to the astrolabes by him in sections B and C. In fact, of all the varieties of instruments he had produced, the celestial globes constitute the largest group with eleven extant specimens. Seven of these carry legends in Persian, two in Sanskrit and one in English. Only three of these carry Bulhomal's signature, but the others can easily be attributed to him because they all carry the same characteristic features. With this impressive list of large celestial globes cast in the lost wax process, Bulhomal is a major producer of the celestial globes in India, next only to Ḍiyā' al-Dīn Muḥammad of the Lahore family.

While the Indo-Persian and Sanskrit astrolabes he produced are rather small in size and with less than 10 star pointers on the rete, the celestial globes he cast by the *cire perdue* process are very large— much larger than those of the Allāhdad family whose diameters range between 65 and 188 mm —with diameters measuring between 177.8 and 370 mm; one is said to measure almost half a meter (495.3 mm).

These large-sized globes are mounted on highly distinctive three-legged stands which are once again a characteristic feature of Bulhomal's work. Besides a graduated horizon ring and a graduated meridian ring, these stands consist of a zenith ring and three *S*-shaped legs. The zenith ring comes in two semi-circular parts. The upper part is attached to the upper surface of the horizon ring at right angles to the meridian ring; it then corresponds to the prime vertical and includes the zenith point. The second part is attached below the horizon ring also at right angles to the meridian ring; it contains the

1178 Savage-Smith 1985, pp. 52-56, 235-236, 244, 275-276; Maddison & Savage-Smith 1997, pp. 242-245; Sarma 2015b, pp. 271-278.

nadir point. The two halves of the zenith ring and the three legs are attached to the horizon ring and made fast with winged bolts.

At the apex of the upper half of the zenith ring, there is an ornate crown-like projection; there is also a projection in the lower half at the nadir point which is not so flamboyant, but nevertheless decorative. Just as the *kursī* with three perforations is the hallmark of Bulhomal's astrolabes, the crown-like projection in the zenith ring is the hallmark of Bulhomal's celestial globes; and also the three legs which are curved like *S* and rest on round bases with multiple tiers. Often the zenith rings and the legs are embellished with engravings or mouldings.

In the zenith ring, there are rectangular slits at the zenith and nadir points to accommodate the meridian ring. In one half of the meridian ring, i.e., from one pole to the other, the thickness is reduced on the inner side to create a recess, so that a sleeve carrying a graduated arc can slide along the meridian ring. However, this sleeve with the arc survives just in G011; the sleeve without the arc can be seen in G008 and G010.

Now coming to the globes themselves, they are engraved with the usual great circles of equator, ecliptic and the six latitude circles which run perpendicular to the ecliptic. Aside from these, there are six other great circles about which Savage-Smith remarks as follows:

> Balhumal also added to all his globes six meridian circles at right-angles to the equator, along with the ecliptic latitude-measuring circles. Meridian circles are unusual in Islamic globe design, but Bahlumal made them highly idiosyncratic by shifting them six degrees westward so that no meridian represents the equinoctial colure.[1179]

He also draws equatorial tropics and two other pairs of lesser circles at 12° and 20° on either side of the equator. The circles were lightly traced first (obviously by Bulhomal himself) and then engraved over more deeply (probably by assistants).

On the globes he draws the 48 classical constellation figures and marks the positions of 1022 stars with inlaid silver nails. The names of the constellation figures

1179 Maddison & Savage-Smith 1997, p. 242.

are incised with deeply cut letters, sometimes followed by the serial numbers and sometimes without.

On some globes, the stars within each constellation figure are numbered serially, but not on all the globes. On some globes, some prominent stars are named, on some other globes, only the constellations are named.

Two constellations receive different names. The figure of Hercules is designated as *Jāthī ᶜAlā Rukbat,* 'the one resting on his knees' instead of the usual name *Jāthī,* 'kneeling man' and Corona Borealis is named *Iklīl,* 'crown' instead of the usual *al-Fakkah* of uncertain meaning.

Bulhomal also makes innovations in the iconography of certain figures. He introduces a charming variation in the figure of Andromeda by placing a flower in her outstretched left hand (Figure G010.5). He adds a wing to the equine half of Sagittarius (Figure G010.7). On one globe, the equine half of Centaurus is decorated with a saddle cloth with an ornate border (Figure G012.3). Cetus is depicted with a bird's head, instead of the usual dog's head (Figure G010.4). These changes are seen only in some of the globes.

Bulhomal fills the constellation figures with very fine engravings. In the constellation figures of Ursa Major, Leo (Figure G010.2), Aries, Taurus (Figure G010.4), Canis Major (Figure G010.10), the outlines of the animals are not drawn with simple lines, but with a series of very small oblique strokes to create the impression of the hairy surface (Figure G010.2 and Figure G010.7).

Even inanimate objects are embellished with ornate outlines, e.g. Lyra, Corona Borealis (Figure G010.3), and Triangulum (Figure G010.4).

The human figures are shown with minimum clothing; generally a short skirt, sometimes with pleats and sometimes without. Women like Andromeda and Virgo are bare-breasted. Men generally have one or two straps running from the waist and going across the shoulders. The most distinguishing feature of men are the mustaches with the ends turned upwards, which reflects the contemporary fashion in the mid-nineteenth century Panjab. The engraver takes great pains to draw the hair of men and women, hair of the head, beards, and even eye-brows. They are all drawn with large eyes whether in profile or in front view.

But the iconography is not uniform on all the globes and there is substantial variation. For example, in G012, the bodies of the animals and snakes, and also the clothing of human figures are shown with innumerable tiny squiggles. On G010, the body of the bear in Ursa Major is filled with myriads of oblique strokes. On another globe, the entire body of the bear in Ursa Major is depicted with similar tiny strokes (Figure G010.2).

OTHER GLOBE-MAKERS OF THE 19TH CENTURY

Globes made by a few others in the nineteenth century have come to light. Ghulām Ḥussayn Jawnpūrī, the author of the encyclopaedia *Jāmi*ᶜ *Bahādur Khānī,* produced a celestial globe in 1231 / 1816 (G006). It is in a private collection at Aligarh. Engraved on it are the full set of 48 constellation figures and about 1020 stars, the co-ordinates of which he claims to have measured afresh.[1180]

The nineteenth century also saw the production of a number of globes with great circles, but without constellations or stars. Two such globes were made by Mahdi Ḥussain Khān Bahādur in 1279 / 1862 (G019 and G020).

COPIES OF GLOBES

It appears that there was a custom of making copies of certain important instruments. In section B, we have included an astrolabe which is purported to be a copy made at Lahore in 1587 of an astrolabe belonging to Mīrzā Bāysunghur. Similarly, there are two cases of copies being made of celestial globes. Emilie Savage-Smith drew attention to a Kufic celestial globe fabricated by Muḥammad ibn Maḥmūd ibn ᶜAlī al-Tabarī al-Asṭurlābī in Iran in 684/1285-86 and its copy made in India by *cire perdue* process by an unknown instrument maker in the nineteenth century.[1181] The Indian copy is included in this catalogue (G032).

There is yet another case. In 1357/1938-39 a certain Muḥammad Naᶜīm al-Dīn Murādābādī fabricated two numbered copies of a globe which was originally made in 1260/1844-45 by Akbar Shāh Muhandis Jahānābādī for the Nawāb of Awadh

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1180 Ansari & Sarma 1999-2000.

1181 Maddison & Savage-Smith 1997, I, no. 123, pp. 212-213 and Savage-Smith 1985, no. 6, pp. 220-221, Fig. 6.

Muḥammad ᶜAlī Shāh. Naᶜīm al-Dīn claims that in his copies he made certain improvements on the original. The original has not survived; therefore, it is not possible to see what improvements he made in these two copies. The first copy (G033) is with the Nasser D. Khalili Collection of Islamic Art in London[1182] and the second is in the Lahore Museum (G034).

UNSIGNED GLOBES

There are extant several globes which carry no signature or date. These can be grouped into three categories: those with all the constellation figures and about 1020 stars (G021 - G029), those without these figures, but with a limited number of stars marked and labelled (G030 - G034), and those with only the circles and the names of zodiac signs (G035 - G053). In each category, the specimens will be arranged alphabetically by the places where they are preserved. In the last category, there are four globes which were made in two hemispheres (G047, G048, G049, G051) and two made of wood (G052 and G053).

1182 Maddison & Savage-Smith 1997, I, no. 138, pp. 172, 239-240.

Index of Indo-Persian Celestial Globes produced by others

G001 Celestial Globe by ᶜAlī Kashmīrī ibn Lūqmān, 998 AH (AD 1589-90)............ 3045

Diameter ?, London, PC

G002 ◎Celestial Globe made by Muḥammad Ṣāliḥ for Shaykh ᶜAbd al-Khāliq, 1070 AH (AD 1659-60) 3047

Diameter 120 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (Reg. no. 40.415, Acc. No. 64)

G003 ◎Celestial Globe by Muḥammad Ṣāliḥ, 1074 AH (AD 1663-64) reworked with Sanskrit legends by Nandarāma, 1824 VS (AD 1767).................................... 3050

Diameter ca. 250 mm; weight of the globe 4.95 kg, London, Nasser D. Khalili Collection of Islamic Art (# SCI 45)

G004 ◎Celestial Globe by Luṭf Allāh ibn ᶜAbd al-Qādir al-Muḥibb al-Asṭurlābī...... 3068

Not dated, 17th Century, second half, Diameter 67 mm, height 137 mm, Paris, Institut du Monde Arabe (# AI 86-26)

G005 ◎Celestial Globe by Muḥammad Faḍl Allāh, 1223 AH (AD 1808).................. 3071

Diameter 170 mm, Hyderabad, Salar Jung Museum (# 114/xxxv)

G006 ◎Celestial Globe by Ghulām Ḥussayn Jawnpūrī, 1231 AH (AD 1816) 3079

Diameter 178 mm, Aligarh, PC

G007 Celestial Globe by Muḥammad Karīm, 1241 AH (AD 1825-26)...................... 3088

Diameter 126 mm, London, Victoria and Albert Museum (# M24-1882)

G008 ◎Celestial Globe by Lālah Bulhomal Lāhorī, VS 1899, AH 1258, AD 1842... 3090

Diameter 330 mm, London, Science Museum (# 1985-1257)

G009 Celestial Globe by Lālah Bulhomal Lāhorī, VS 1899, AH 1258, AD 1842...... 3095

Diameter 177.8 mm, Karachi, National Museum of Pakistan (# N.M.1957.1049)

G010 Celestial Globe attributable to Lālah Bulhomal Lāhorī.................................... 3102

Not dated, mid-19th century, Diameter 370 mm, London, Nasser D. Khalili Collection of Islamic Art (# SCI 285)

G011 Celestial Globe with legends in English attributable to Lālah Bulhomal Lāhorī 3116

Not dated, mid-19th Century, Diameter 360 mm, London, Nasser D. Khalili Collection of Islamic Art (# SCI 44)

G012 ◎Celestial Globe attributable to Lālah Bulhomal Lāhorī................................. 3123

Not dated, mid-19th Century, Diameter 214 mm, New Delhi, National Museum (# 56.155/1)

G013 Celestial Globe attributable to Lālah Bulhomal Lāhorī.................................... 3129

Not dated, mid-19th Century, Diameter ca. 190 mm, Srinagar, Sri Pratap Singh Museum (# 2750/B)

G014 Celestial Globe attributable to Lālah Bulhomal Lāhorī 3133

Not dated, mid-19th century, Diameter 184 mm, PLU; ex-Rockford, Time Museum

G015 Celestial Globe attributable to Lālah Bulhomal Lāhorī 3135

Not dated, mid-19th Century, Diameter 495.3 mm, PLU

G016 ◎Celestial Globe attributable to Lālah Bulhomal Lāhorī 3138

Not dated, mid-19th Century, Diameter 103 mm, Oxford, Museum of the History of Science (# 36638)

G017 Celestial Globe, not signed, not dated 3141

19th century , Diameter 140 mm, London, Science Museum (# 1914-597)

G018 Celestial Globe, not signed, 1255 AH (AD 1839-40) 3143

Diameter 165 mm, height with stand 233 mm, PLU

G019 ◎Celestial Globe by Mīr Bahādur Mahdī Ḥussayn Khān, 1279 AH (AD 1862-63) 3152

Diameter 161 mm, Lucknow, Darul Uloom Nadwatul Ulama

G020 ◎Celestial Globe by Mīr Bahādur Mahdī Ḥussayn Khān, 1279 AH (AD 1862-63) 3156

Diameter 104 mm, New Delhi, National Museum (# 56.98/b)

G021 Celestial Globe, not signed, not dated 3159

19th century, Diameter 200 mm, Switzerland, Bern, Bernisches Historisches Museum (# Inv. 1914.610.0174)

G022 Celestial Globe, not signed, not dated 3168

Probably 17th Century, Diameter 166 mm, Chicago, Adler Planetarium (# A-140)

G023 Celestial Globe, not signed, not dated 3172

19th Century, Diameter 127 mm, London, National Maritime Museum, Greenwich (# GLB0004)

G024 Celestial Globe, not signed, not dated 3174

19th century, Diameter 170 mm, height of the globe with stand 295 mm, Jaipur, City Palace, Maharaja Sawai Man Singh II Museum

G025 ◎Celestial Globe, not signed, not dated 3185

Probably 18th century, Diameter 197 mm; height of the stand 265 mm, Mumbai, K. R. Cama Oriental Institute

G026 ◎Celestial Globe, not signed, not dated 3191

Probably 18th Century, Diameter 152 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (# 40.413)

G027 Indian Copy, unsigned, undated, of a Celestial Globe by Muḥammad Ibn Maḥmūd Ibn ᶜAlī Al-Ṭabarī Al-Asṭurlābī, 684 AH (AD 1285-86) 3194

19th century, Diameter 130 mm, Paris, Musée du Louvre, Islamic Arts section (# 6013)

G028 Copy No. 1 by Naᶜīm al-Dīn Murādābādī, 1357 AH (AD 1938-39) of a Celestial Globe made originally by Akbar Shāh Muhandis Jahānābādī, 1260 AH (AD 1844-45) 3197

Diameter 133.6 mm, London, Nasser D. Khalili Collection of Islamic Art (# SC 14)

G029 Copy No. 2 by Naᶜīm al-Dīn Murādābādī, 1357 AH (AD 1938-39) of a Celestial Globe made originally by Akbar Shāh Muhandis Jahānābādī, 1260 AH (AD 1844-45) 3209

Diameter 160 mm, Lahore, Lahore Museum (# A 8/1)

G030 ◎Celestial Globe, not signed, not dated 3218

17th Century, Diameter 80 mm, London, National Maritime Museum, Greenwich (# GLB0005)

G031 Celestial Globe, not signed, not dated 3220

17th Century, Diameter 60 mm, London, National Maritime Museum, Greenwich (# GLB0026)

G032 Celestial Globe, not signed, not dated 3222

17th century, Diameter 76 mm, Oxford, Museum of the History of Science (# 33466)

G033 Celestial Globe, not signed, not dated 3224

19th Century, Diameter 75.2 mm, weight 610 grams, PLU; ex-Sotheby's, London

G034 ◎Celestial Globe, not signed, not dated 3228

19th Century, Diameter 155 mm, Hyderabad, Salar Jung Museum (# 112/3/xxxv)

G035 Celestial Globe, not signed, not dated 3231

19th Century, Diameter 82 mm, Karachi, National Museum of Pakistan (# 1958-210)

G036 ◎Celestial Globe, not signed, not dated 3233

19th Century, Diameter 103 mm; height of the stand 107 mm, Oxford, Museum of the History of Science (# 37195)

G037 ◎Celestial Globe, not signed, not dated 3235

19th Century, Diameter 172 mm, Rampur, Rampur Raza Library (# 27/5070 D)

G038 Celestial Globe, not signed, not dated 3238

19th Century, Diameter 112 mm; height 190 mm, PLU; ex-Paris, Libraire Alain Brieux 1990.

G039 Celestial Globe, not signed, not dated 3240

19th Century, Diameter 111 mm, PLU

G040 Celestial Globe, not signed, not dated 3243

19th century, Diameter 70 mm, Chicago, Adler Planetarium (# A-38)

G041 Celestial Globe, not signed, not dated 3247

19th century, Diameter 69 mm, Chicago, Adler Planetarium (# A-39)

G042 Celestial Globe, not signed, not dated 3249

19th Century, Diameter 88 mm, Oxford, Museum of the History of Science (# 46262)

G043 Celestial Globe, not signed, not dated 3251

19th Century, Diameter 69 mm, Paris, PC

G044 Celestial Globe, not signed, not dated 3253

19th Century, Diameter 150 mm, PLU; ex-Paris, Drouot 1987

G045 Celestial Globe, not signed, not dated 3255

19th Century, Diameter 90 mm, PLU; ex-Sotheby’s, London

G046 Celestial Globe, not signed, not dated 3257

19th Century, Diameter 69 mm; overall height 169 mm, London, National Maritime Museum, Greenwich (# GLB0176)

G047 Celestial Globe, not signed, not dated 3259

19th Century, Diameter 86 mm, New York, Brooklyn Museum, Department of Asian Art (# X659.1)

G048 Celestial Globe, not signed, not dated 3260

19th Century, Diameter 91 mm; height of the stand 122 mm, Ann Arbor, University of Michigan, Hatcher Graduate Library, Department of Rare Books and Special Collections (# GL-1)

G049 Celestial Globe, not signed, not dated 3261

19th Century, Diameter 68 mm, Oxford, Museum of the History of Science (# 40716)

G050 Celestial Globe, not signed, not dated 3263

19th Century, Diameter 84 mm, PLU; ex-Sotheby’s, London

G051 Celestial Globe, not signed, not dated 3265

19th Century, Diameter 120 mm, Srinagar, Sri Pratap Singh Museum (#5157)

G052 ◎Wooden Celestial Globe, not signed, not dated 3268

19th Century, Diameter 115 mm; height of the stand 240 mm, Lucknow, Darul Uloom Nadwatul Ulama

G053 Wooden Celestial Globe, not signed, not dated 3270

19th Century , Diameter 117 mm; weight 500 g, Srinagar, Shri Pratap Singh Museum (# 5156)

H. SANSKRIT CELESTIAL GLOBES

INTRODUCTION

It has been mentioned above that the Sanskrit name *Samudra-pakṣī* (sea-bird), given by Mahendra Sūri to the astrolabe star β Ceti - in his Sanskrit manual on the astrolabe which he composed in 1370 at the Delhi court of Firūz Shāh Tughluq - indicates his familiarity with the iconography of the constellation figure Cetus on Islamic celestial globes. Therefore the celestial globe must have reached India at least in the fourteenth century, if not earlier. But it is only in the seventeenth century that celestial globes began to be produced actively with Arabic/Persian inscriptions by Muslim instrument makers, notably by Ḍiyā’ al-Dīn Muḥammad of Lahore.

But even before Diyā’ al-Dīn’s time, the celestial globe was mentioned in 1621 by Nṛsiṃha Daivajña in his commentary on Bhāskara's *Siddhāntaśiromaṇi*, where he describes it under the name *bhagola* and adds that Muslims call the sphere *kura* and the stand on which it is mounted *kursī*.[1272]

However, there exist very few Sanskrit celestial globes, the main reason being that a higher degree of technical expertise is needed in its production than in the production of astrolabes. As against 130 Sanskrit astrolabes, there exist today just six Sanskrit celestial globes, four of these with constellation figures and two with just the reference circles and a small number of stars. The earliest of these (H001) is preserved in Sawai Jai Singh’s observatory at Jaipur and must have been commissioned by him in the 1720s. The next specimen (H002) is not actually a Sanskrit celestial globe as such; it is the Indo-Persian celestial globe made by Muḥammad Ṣāliḥ in 1074/1663-64 (G003) which was reworked with Sanskrit names and numbers about a hundred years later at the instance of Nadarāma who was a resident of Kāmyakavana on the banks of the river Yamunā, near Mathura. Nandarāma composed several works on astrology and astronomy. One of these is *Yantrasāra* on the construction and use of various instruments including the astrolabe and the celestial globe. The third (H003) and fourth (H004) Sanskrit celestial globes were made by the versatile Lālah Bulhomal of Lahore,

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[1272] Cf. Nṛsiṃha, p. 438.

who produced several kinds of instruments with inscriptions in Arabic/Persian or in Sanskrit. The last two (H005 and H006) carry just the basic circles and the positions and names of a small number of stars and no constellation figures. They are not signed or dated; they must have been produced in the nineteenth century somewhere in Rajasthan.

The iconography of the constellation figures of these Sanskrit celestial globes broadly follows the iconography on the globes by Ḍiyā’ al-Dīn Muḥammad, but the Sanskrit names given to some of these figures require an explanation. The original Greek names of the 48 constellations, as recorded in the *Almagest* by Ptolemy, are partly derived from Greek mythology; these names underwent several changes in their transmission to India through Arab-Islamic mediation. Besides these six extant celestial globes, there are two other sources where some of the Sanskrit names occur. At the court of Sawai Jai Singh, Jagannātha translated Ptolemy’s *Almagest* into Sanskrit from the Arabic version of Naṣīr al-Dīn al-Ṭūsī in the 1730s under the title *Samrāṭ-siddhānta*.[1273] The star catalogue in book 7 of this work contains the names of the 48 constellations. These were rendered by Jagannātha sometimes into Sanskrit and sometimes into contemporary Rajasthani; for example, he renders Ursa Major as *Baḍā Bhālū* (big bear) while it ought to be *Bṛhad-bhallūka* in pure Sanskrit. One of the manuscript copies of Nandarāma’s *Yantrasāra* contains a star catalogue, along with Sanskrit names of the constellations.[1274] These names agree, more or less, with the Sanskrit names engraved on Muḥammad Ṣāliḥ’s globe. Since these Sanskrit names did not become standardized, they occasionally vary from one source to another.[1275]

The main problem in the Sanskrit names lay in rendering the names of the human figures, a problem which is carried over from the Islamic globes. We consider first the names of Andromeda, Cassiopeia, Cepheus and Perseus, who are all connected by a Greek myth. On Islamic globes, as we have seen, **Andromeda**’s name is rendered as *al-Mar’ah al-Musalsalah* (the chained woman); quite often also in a shorter form as *al-*

1273 Jagannātha, *Samrāṭ-siddhānta,* ed. Ram Swarup Sharma, New Delhi 1967, vol. 2, pp. 643-764.

1274 Manuscript No. 851 of 1884-87 of the Bhandarkar Oriental Research Institute, Pune, folios 19-36.

1275 Kaye, pp. 95-115, reproduces an extract from what he calls ‘Jai Singh’s version of Ulugh Beg’s catalogue’; all that Kaye informs about this source is that it is a manuscript in Devanagari characters copied in VS 1964 (AD 1907-08). Here the Sanskrit names of constellations and stars are mostly transliterations (cf. Kaye, p. 97). These will not be considered in the present discussion.

Musalsalah (the chained one). This is translated correctly into Sanskrit as *Śṛṃkhalā-baddha* (more correctly *śṛṅkhalā-baddha*) (bound in chains), or *Śṛṃkhalā-dhara* (bearing chains); but the Sanskrit writers were not sure about the gender. Thus we have *Śṛṃkhalābaddha-strī-mūrtiḥ* (figure of a woman bound in chains) in H001; *Śṛṃkhalā-bandha-mū[rtiḥ], strī mū[rtiḥ]* (figure of imprisonment in chains, figure of a female) in H002; *Śṛṃkhalādhara* (bearing chains) in H003; but *Śṛṃkhalādhara-puruṣa-mūrtiḥ* (figure of a man bearing chains) in the *Yantrasāra* and in H004. On the other hand, the *Samrāṭ-siddhānta* calls the figure *āyasī* (made of iron or metal, in feminine) which is intriguing.

Similar is the case with Andromeda's mother **Cassiopeia,** who is referred to on the Islamic globes merely as *Dhāt al-Kursī* (one with a chair); accordingly, she is called in Sanskrit *Pīṭhāsana-stha* (situated or seated on the chair) on H003 and in the *Yantrasāra;* H004 calls her *Pīṭhāhā-manuṣya-mūrtiḥ* (sic! read *Pīṭhāsanastha-manuṣya-mūrtiḥ* (human being seated on the chair) without specifying the gender. But H001 and H002 see here a man *Pīṭhāsanastha-puruṣa-mūrtiḥ* (figure of a man seated on a chair) and *Pīṭhāsanastha-pu[ruṣa]* (a man seated on a chair) respectively. In Sanskrit, there is no exact equivalent for the Arabic *kursī,* and the term *pīṭhāsana* is a tautology, both *pīṭha* and *āsana* having the same connotation of a seat. Interestingly, the *Samrāt-siddhānta* uses another word in this context and calls the figure *mañci-lalanā* (sic! read *mañca-lalanā*), which means 'a woman on a raised seat or throne'.

The name of Andromeda's rescuer **Perseus** is often transliterated on the Islamic globes as *Barsā'ūs* (also *Parsā'ūs* or *Parshā'ūsh*). Following this, he is named *Varasyāuṣ* on H001. But in Arabic he is occasionally referred to as *Ḥāmil Rās al-Ghūl* (the bearer of Ogre's head'); accordingly, in Sanskrit also he is called *Preta-śiro-grāhaka* (one who carries the head of a corpse) on H004 and in the *Yantrasāra* and *Pretaśirograhī* on H003. H002 has a variation: *Pretakayug-gaṇaḥ*; here *gaṇa* refers to a class of demi-gods who attend on Śiva or Rudra. Therefore *Pretakayug-gaṇaḥ* means 'an attendant of Śiva with [the head of] a corpse'. The *Samrāṭ-siddhānta* calls him not quite correctly *Kāpālika* (an ascetic who carries a human skull and uses it as the receptacle for food).

The name of **Cepheus** is also merely transliterated in Arabic as *Qīqā'ūs;* likewise in Sanskrit as *Kīkāvus* on H001 or *Kaikāvusa-nṛpaḥ* in the *Samrāṭ-siddhānta.* But other sources have an entirely different name: *Jvālā-kṣepaka-naṭa-gaṇaḥ* (H002:), *Jvālā-kṣepaka-rudra-gaṇaḥ* (*Yantrasāra*), *Jvālā-kṣepa-rudra-gaṇa* (H003:) or *Jvālā-kṣepa-gaṇā-murtiḥ* (H004). The word *gaṇa,* as explained above, refers to an attendant of Śiva. Accordingly, the whole expression then means 'a demi-god attached to Śiva, who throws flames'. Apparently this notion is derived from the attribute *al-multahab* (inflamed, blazing, aflame etc.) applied to *Qīqā'ūs* in certain Arabic sources.[1276]

Hercules is referred to by Ptolemy as one who is resting on his knees; therefore in Arabic he is called *al-Jāthī.* All Sanskrit sources call him *Jānūpaviṣṭa.* However on H001, his figure is labelled *Nṛtya-kālī-mūrtiḥ* (figure of the dancing [goddess] *Kālī*). We have seen that the short skirt worn by Hercules according to the Greek fashion confused already Indo-Persian globe makers and that on three globes (F019, F020 and F027) the figure is depicted with large breasts. Assuming that a figure depicted on celestial globes must be a celestial or divine figure, some Sanskrit astronomers saw it as the dancing goddess Kālī.

Muslim astronomers did not quite understand the names and functions of **Bootes** and Auriga. They called the former *al-ᶜAwwā' wa al-Baqqār,* 'the howler, that is, the ploughman'. Accordingly, he is named *Avvā-puruṣa* (the man called *Avvā*) in Sanskrit on H001. But others reasoned thus; *ᶜAwwā'* means 'howler', but a Muslim who howls regularly is the Muezzin who calls the people for the prayers. Accordingly they gave him the Sanskrit name *Dharmi-jana-āhvāyaka* (one who invites or calls the pious people [for prayer].) This expression, with slight variations occurs on H002, H003, H004 and in the *Yantrasāra.*

Auriga is called in Arabic *al-Mumsik al-Aᶜinnah* (he who holds the reins). H001 has just the transliteration *Muṃsekula ānaiṃ mūrtiḥ.* The labels on H003 (*Vallāhaka*) and H004 (*Bala-hasta-pra-ma-mūrtiḥ*) and in the *Yantrasāra* (*Valāha-hasta-puruṣaḥ grāhakah*) are highly corrupt and do not yield any coherent meaning. The *Samrāṭ-siddhānta* has *Yajña-paśu-grāhaka* (one who takes the animals to the sacrifice).

Orion, *al-Jabbār,* is rendered mostly as *Gadādhārī puruṣa* (a man holding a club) in the *Yantrasāra,* and on H002 and H004. The *Samrāṭ-siddhānta* merely calls him *Vīraḥ*

1276 Cf. Ideler 1809, p. 45.

(brave man, hero). H001 carries a different name: *Mithuna-saṃjña-mūrtiḥ* (figure of the one who carries the 'name' *Mithuna*) in order to clearly distinguish this figure from the actual *Mithuna*, which is the zodiac sign Gemini.

The name of **Centarus** is merely transliterated in Arabic as *Qanṭūrus*; so also in Sanskrit. On H001 it is engraved as *Kantūrasa-murtiḥ*; the *Samrāṭ-siddhānta* renders the name as *Ketūrasa*. The *Yantrasāra* offers *kinnara* as an equivalent; this Sanskrit term denotes semi-divine musicians with human bodies and the heads of horses (also equine bodies and human heads). In the *Yantrasāra,* both words *kantūrasa* and *kinnara* occur together. H002 and H004 have just *kinnara*.

Besides the names of the human figures, the pictorial representations of certain inanimate objects also created problems in translation. **Corona Borealis** (Arabic *al-Fakkah*) is generally represented with two concentric circles. Sanskrit sources see here *Mātṛ-maṇḍala* or *Mātṛ-cakra* (circle of the mothers), a mystic circle formed by mother goddesses, which is said to be situated at α Coronae Borealis. Accordingly this star is named *Viśākhā-mātṛ-maṇḍala;* here the first term *Viśākhā* is the name of the sixteenth lunar mansion.[1277] The *Samrāt-siddhānta,* however, sees a mere *Caṣaka* (cup or wine-glass) in the circular figure of Corona Borealis.

Lyra is rendered in Arabic as *Shulyāq* (tortoise) because the musical instrument lyre was made out of the upper shell of tortoises. The *Samrāṭ-siddhānta,* therefore, renders it with the Rajasthani word *kachuvā* (tortoise); a transliteration of *Shulyāq* is attempted on H001 as *Trilīyaka.* For others (H003, H004 and *Yantrasāra*), the pictorial representation suggested a *Pāna-pātra* (drinking vessel). Since gods in the celestial regions drink only the nectar of immortality (*sudhā*), H002 called it *Sudhā-pātram* (vessel for nectar).

Likewise the pictorial representation of **Crator**, Arabic *Bāṭiyaḥ,* suggests a vessel, and so it was called in the *Yantrasāra* and on H004 *sudhā-pātra* (vessel for drinking nectar). H001 and H002 call it *Bahuguṇa-pātra* (vessel with many good qualities). The *Samrāṭ-siddhānta* has some word which is unintelligible.

[1277] The star α Coronae Borealis is often represented on the retes of Indo-Persian as well as Sanskrit astrolabes.

Ara, Arabic *mijmarah,* is an incense-burner. In the pictorial depictions, the fumes of incense rising out of the vessel are drawn like the tongues of flame. Therefore it was thought that it was a brazier or a portable stove. The *Samrāṭ-siddhānta* and H002 call it *Hasantī* (portable stove) and in H001 and in the *Yantrasāra* it is named *Agni-śakaṭī* (fire-cart).

Index of Sanskrit Celestial Globes

H001 ◎Sanskrit Celestial Globe, not signed, not dated 3281

Early 18th century, Diameter 293 mm, Jaipur, Jai Singh's Observatory

H002 ◎Celestial Globe by Muḥammad Ṣāliḥ, 1074 AH (AD 1663-64) 3306

Diameter ca 250 mm, weight of the globe 4.95 kg, London, Nasser D. Khalili Collection of Islamic Art (# SCI 45)

H003 Sanskrit Celestial Globe by Lālah Bulhomal Lāhorī, 1895 VS (AD 1839)....... 3320

Diameter 140 mm, PLU; ex-Milan, PC

H004 Sanskrit Celestial Globe, attributable to Lālah Bulhomal Lāhorī 3338

Not dated; mid-19th Century, Diameter 205 mm, New York, Columbia University, Butler Library, D. E. Smith Collection (# 27-244)

H005 Sanskrit Celestial Globe, not signed, not dated 3345

19th century , Diameter 210 mm, PLU; ex-Skinner, Bolton, MA

H006 Sanskrit Celestial Globe, not signed, not dated 3351

19th century , Diameter ?, PLU

I. SANSKRIT ARMILLARY SPHERES (GOLA-YANTRA)

INTRODUCTION

1. THE ARMILLARY SPHERE IN GREEK ANTIQUITY

The armillary sphere is an assemblage of rings (armilla) representing some great circles with the Earth as the centre and smaller circles with other centres, for graphically demonstrating the orbits and positions of celestial bodies. When the rings are graduated and equipped with sighting plates, planetary positions can also be measured. The instrument was known to the Greek antiquity. Ptolemy calls it *astrolabon* and describes its construction in his *Almagest.* His armillary sphere consists of six rings. There is a fixed meridian ring inside which the ecliptic ring and the solstitial colure are pivoted. Two latitude rings are attached, one outside the solstitial colure and the other inside it. Inside the inner ring is added another ring which is equipped with two sighting plates at diametrically opposite points.[1295]

2. THE ARMILLARY SPHERE IN EUROPE

Armillary spheres made according to Ptolemy's basic model with minor additions can be seen in nearly every museum in Europe. There exist also some large and highly ornate armillary spheres,[1296] and specimens representing the Copernican heliocentric model with the sun at the centre.

3. THE ARMILLARY SPHERE IN THE ISLAMIC WORLD

The armillary sphere was known in the Islamic world as *Dhat al-Ḥalaq* (that which has rings) and followed Ptolemy's basic design, with certain changes for improving the observation. Mu'ayyad al-Dīn al-ᶜUrḍī replaced Ptolemy's sixth ring (i.e., inner latitude ring) with an alidade, arguing that the alidade is more suitable for observation, and constructed an armillary sphere with five rings at the Marāgha Observatory in 1259.[1297]

1295 Ptolemy, Book V, ch. 1, pp. 217-219, Fig. F on p. 218; see also Seemann 1929, Fig. 8 on p. 34.

1296 The largest armillary sphere in the world is the one made by Antonio Santucci between 1588 and 1593 with a diameter of *ca.* 2000 mm, height of *ca.* 3700 mm and width of *ca.* 2450 mm; this magnificent armillary sphere is on display in the Museo Galileo in Florence.

1297 Cf. Seemann 1929, pp. 33-53, esp. 46-47.

Otherwise the armillary sphere did not attract much interest in the Islamic world. The *Yantraprakāra,* attributed to Sawai Jai Singh, describes an armillary sphere with five rings and another of six rings, both under the Arabic name *Dhāt al-Ḥalaq*.[1298] In Jai Singh's Observatory at Jaipur, there exists a loose copper plaque on which is engraved *jātula halaka yaṃtra vṛtta sāt kī* (instrument named *Dhāt al-Ḥalaq,* with 7 rings) (see Figure T2). It indicates that Jai Singh's collection of portable instruments included an Indo-Persian or Arabic armillary sphere with 7 rings. But there is no trace of it now in Jai Singh's observatory. It was mentioned neither by Garrett & Guleri 1902, nor by Kaye. Otherwise, no other armillary sphere with either Arabic or Persian inscriptions is known to be extant anywhere in the world.[1299] It appears in some Mughal miniatures, but these were clearly inspired by European models.[1300]

4. The Armillary Sphere in Sanskrit Astronomy[1301]

The armillary sphere is called *Gola-yantra* in Sanskrit and is quite different from Ptolemy's model. As Ôhashi remarks, the main purpose of the *Gola-yantra* is to ascertain the equatorial coordinates, while Ptolemy's armillary seeks to determine ecliptic coordinates.[1302] It is also much more elaborate than Ptolemy's armillary sphere. For example, in the *Gola-yantra* envisaged by Brahmagupta there are as many as 51 movable rings, besides several fixed rings.[1303]

Moreover, in Sanskrit texts, the *Gola-yantra* is treated in exclusive chapters, separate from those where other instruments are discussed. Thus Brahmagupta

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1298 Sarma 1986-87b, pp. 16-18 (text); pp. 54-58 (translation and commentary).

1299 The auction catalogue of Christie's, London, lot 18, p. 12, speaks of an Indo-Persian armillary sphere thus: 'An Indo-Persian brass armillary sphere, 13-inches (33 cm.) diameter, with six engraved circles, one fixed, five pivoting on the central axis, each engraved with characters, scales and divided in degrees, with central sun ball, the earth ball mounted on the outer circle on two columns, raised on a tapering pillar support and stepped base – *21in. (53.4) high.*' The fact that there is a sun ball at the centre and that the earth ball is placed on the outer circles shows that this specimen follows Copernican model and must be of recent manufacture.

1300 Ramaswamy 2014, pp. 33-34.

1301 Cf. Subbarayappa & Sarma 1985, Ch. 8. Golabandhaḥ: Armillary Sphere, pp. 74-80 (several extracts from Sanskrit texts with translation); Rai 1986, pp. 308-312; see also Das 1928, pp. 265-269; Dikshit 1981, pp. 224-225.

1302 Cf. Ôhashi 1994, p. 272.

1303 Brahmagupta, 21.69: *calavṛttāny ekapañcāśat* (of movable rings [there are] one-and-fifty).

discusses the *Gola-yantra* exclusively in the twenty-first chapter of his *Brāhmasphuṭa-siddhānta* (628) and the other instruments in the twenty-second chapter. Lalla (8th-9th centuries) devotes the fifteenth chapter of his *Śiṣyadhīvṛddhida* to the armillary sphere and the twenty-first chapter to the other instruments. Śrīpati, in his *Siddhānta-śekhara* (1139), discusses the armillary sphere in the sixteenth chapter and the other instruments in the nineteenth. Likewise, Bhāskara II, in the *Golādhyāya* of his *Siddhānta-śiromaṇi* (1150) has separate chapters for the armillary sphere and for other instruments.

The reason for this exclusive and separate treatment of the *Gola-yantra* is that this instrument is considered an essential part of the *Gola* (Spherics) which deals with a host of imaginary circles in the heavens such as the celestial equator, the ecliptic and so on, and teaches methods to determine the linear and angular distances between them. By arranging these imaginary circles as physical entities in the armillary sphere, the student can clearly grasp the purpose and function of these imaginary circles. Therefore, *gola-bandha,* i.e., putting together different rings to constitute the armillary sphere, is a primary task in understanding the *Gola.* Nṛsiṃha Daivajña, in his commentary on Bhāskara II's *Siddhānta-śiromaṇi,* observes that because the armillary sphere forms the basis of all astronomical instruments, it was mentioned first by Bhāskara.[1304]

It is for this reason that Bhāskara I, who is Brahmagupta's contemporary, discusses the construction of the armillary sphere in great detail at the beginning of his commentary on the *Gola-pāda* of the *Āryabhaṭīya.*[1305] Brahmagupta, on the other hand, defines the various circles and their mutual relationships, but does not dwell on the practical aspects of the construction, which is done by Lalla (8th-9th centuries) in his *Śiṣyadhīvṛddhida*.

Lalla arranges the various rings in three groups called *kha-gola* (sphere of the sky), *bha-gola* (sphere of the fixed stars) and *graha-gola* (sphere of the planets). Each group or assemblage of rings constitutes a separate shell or sphere and these are arranged one

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1304 Nṛsiṃha, p. 438; *sarveṣāṃ yantrāṇāṃ gola-mūlakatvāt pūrvaṃ goloddeśaḥ kṛtaḥ [bhāskareṇa].*

1305 Here Bhāskara I also describes minutely how to prepare the various rings out of wood and even mentions three types of joining the wooden rings; such detailed description of constructional methods is common in Arabic texts (e.g. al-ᶜUrḍī's description of the armillary sphere), but most unusual in Sanskrit texts. Bhāskara I's treatment is analysed and illustrated very competently by Peng Lu 2015.

inside the other at three slightly different levels on the polar axis (*dhruva-yaṣṭi*). The *kha-gola* represents the horizontal system of coordinates. It consists of six rings which stand for the prime vertical (*sama-maṇdala*), the prime meridian (*yāmyottara-maṇḍala*), the horizon (*kṣitija-maṇḍala*), two *koṇa*-circles (two great circles, one passing through the zenith, the north-east and the south-west points, and the other through the zenith, the north-west and the south-east points), and the six o'clock circle (*un-maṇḍala*). All these rings are marked with 360 degrees.

The *bha-gola* (sphere of the fixed stars) represents the equatorial and ecliptic coordinates. It consists of the equator (*viṣuvad-vṛtta,* also called *nāḍī-vṛtta*) which is divided into 60 *ghaṭikās*, the solstitial colure, ecliptic (*apa-maṇḍala*) and six *dyu-maṇḍalas* (diurnal circles), three each on either side of the equator, corresponding to the six pairs of signs. The *graha-gola* is the sphere of the planets where diverse rings are fixed for each planet.[1306]

Bhāskara II, popularly known as Bhāskarācārya, in his *Siddhānta-śiromaṇi* of 1150, introduced a *dṛg-gola,* in addition to *bha-gola* and *kha-gola* of Lalla. Instead of having a separate *bha-gola* for each planet, Bhāskarācārya prescribes for all planets only one *bha-gola*, which consists of the ecliptic, equinoctial, diurnal circles, etc., all of which are movable. It is fixed to the polar axis so that it may move freely by moving the axis. Beyond this sphere is fixed the *kha-gola* or the celestial sphere; it consists of the prime vertical, meridian, horizon etc., which remain fixed in a given latitude. Beyond these two is the *dṛg-gola* in which the circles forming both the spheres *kha-gola* and *bha-gola* are combined.[1307] Having discussed the construction and use of the *Gola-yantra* in the *Golabandhādhikāra,* Bhāskara teaches how to determine the ascendant (*lagna*) with the help of the *Gola-yantra* at the beginning of the *Yantrādhyāya.*[1308]

1306 Lalla, I, pp. 200-205; II, pp. 232-237; cf. Ôhashi 1994, pp. 268-269; Sarma 2019.

1307 Bhāskarācārya, *Golādhyāya, Golabandhādhikāra*; cf. Sarma 2019.

1308 Bhāskarācārya, *Golādhyāya*, *Yantrādhyāya,* 3-5*ab.*

Extant Specimens of Sanskrit Armillary Spheres

Since the time of Brahmagupta, if not earlier, teachers of astronomy must have taught their pupils how to prepare a *Gola-yantra* with strips of bamboo. None of these have survived, probably because they were made of perishable material.

Śaṅkaranārāyaṇa, in his commentary of 869 on Bhāskara I's *Laghubhāskarīya,* mentions[1309] that a large *Gola-yantra* was erected at Mahodayapura[1310] on the Kerala coast at the instance of King Ravivarman Kulaśekhara. But it is no more extant.

In his *Zīj-i Muḥammad Shāhī,* Sawai Jai Singh states that he got constructed at Delhi a '*Zatul-huluck,* in brass, in diameter three *guz* of the measure now in use.'[1311] It is not extant any more, but a small specimen with 8 rings constructed by Jai Singh's son Madho Singh is extant at Jaipur (I001).

In an article of 1834, Lancelot Wilkinson reports as follows:

> 'I take this opportunity of informing the public of the existence of a native observatory at Kotah, or rather of a valuable collection of astronomical apparatus, made by the late Maháráo UHMAID SINGH ; and posited on the bastions of the citadel, fitted up for their reception. The apparatus consists of a very splendid and large armillary sphere ; of the celestial and terrestrial globes, dials, gnomons, and also the Ráj Yantra [sic! *Yantra-rāja*], or astrolabe, borrowed from the Musalmáns about 250 or 300 years ago. […]
>
> 'The Maháráo's collection contains also a Turíya Yantrá, or quadrant, with a radius on one side of 30 digits, and linear rectangular intersections, rising from each digit, representing their canon of sines, cosines, and versed sines adapted to this radius.'[1312]

Wilkinson must have been told that these instruments were commissioned by Maharao Umaid Singh. This prince ruled Kota from 1771 to 1819. Some of these instruments are described by Virendra Nath Sharma; he mentions that the place where

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1309 Cf. Subbarayappa & Sarma 1985, p. 81; SarmaKV 1990, pp. 41-42.

1310 This ancient Mahodayapura is said to be identical with the modern locality Makotai, near Kodangallur (10;25° N; 76;15° E).

1311 Hunter 1799, p. 183.

1312 Wilkinson 1834, p. 515.

the instruments were originally set up for observational purposes is known as *Jantar Burj* (instruments tower).[1313] The instruments are now removed from this tower and displayed in the Rao Madho Singh Museum which was set up in the fort in 1974. In this museum, Sharma found an armillary sphere (I003), an ensemble of water clock and gong (R011) and two sundials of the type *Palabhā-yantra* (N011, N012). It is not known what happened to the celestial and terrestrial globes, to the gnomons and to the sine quadrant (*Turīya-yantra*) which were seen by Wilkinson shortly before 1834.

Besides the two armillary spheres at Jaipur and Kota, just five other specimens are known. There is one each at the Royal Scottish Museum, Edinburgh, Scotland (I002); at the Linden Museum, Stuttgart, Germany (I004); at the Maharaja's Sanskrit College, Mysore (now renamed Mysuru) (I006) and at the Sanskrit Mahavidyalaya of M.S. University of Baroda (now renamed Vadodara). At the last mentioned place, it was said that a huge armillary sphere made of bamboo was set up at the top of the building. But it was not found there during my visit in October 2008. What I found was a small armillary sphere made of iron and consisting of just one sphere of rings (I007). Moreover, one armillary sphere was presented by the Maharaja of Benares to the Prince of Wales in 1876 (I005). These seven extant specimens will be described separately in the following pages.

[1313] Sharma 2000.

Index of Sanskrit Armillary Spheres (Gola-Yantra)

I001 ◎Sanskrit Armillary Sphere, not signed, not dated 3363

Second half the 18th century, Diameter 525, height 585, Jaipur, Jai Singh's Observatory

I002 Sanskrit Armillary Sphere, not signed, not dated 3367

Early 19th century, Diameter 1200 mm, Kota, Rajasthan, Rao Madho Singh Museum

I003 ◎Sanskrit Armillary Sphere, not signed, not dated 3369

19th century, Diameter 998 mm, Edinburgh, Royal Scottish Museum

I004 ◎Sanskrit Armillary Sphere, not signed, not dated 3374

19th century, Diameter 570 mm, Stuttgart, Linden Museum

I005 Sanskrit Armillary Sphere presented by Maharaja of Benares to the Prince of Wales, 1876 3375

Dimensions ?, PLU

I006 Sanskrit Armillary Sphere designed by Karur Seshachariar 3377

20th Century, Diameter ?, Mysuru, Maharaja's Sanskrit College

I007 ◎Sanskrit Armillary Sphere, not signed, not dated 3379

Early 20th Century, Diameter ca. 334 mm, Vadodara, M. S. University of Baroda, Sanskrit Mahavidyalaya

J. INDO-PERSIAN QUADRANTS

INTRODUCTION

The quadrant is made in the form of a quarter circle. Its arc is graduated in degrees and marked from 1 to 90. One of the radial edges is equipped with two sights. An index or plumb line is suspended from the apex of the right angle and functions as the vertical reference for the measurements. When the sun or a star is viewed through the sights, the index shows on the arc the angle of elevation or the altitude of the heavenly body. The quadrant is known since the time of Ptolemy in the second century AD.[1319]

From this plain quadrant, also known as the geometrical quadrant, two important varieties were developed in the Islamic world in the ninth century; these are the sine quadrant (Arabic *rub^c al-mujayyab*) for solving trigonometric problems and the horary quadrant (Arabic *rub^c al-sā^cāt*) for determining the time from the sun's altitude . The earliest Arabic text dealing with these two varieties was published recently by François Charette and Petra G. Schmidl who attribute it to the famous Muḥammad ibn Mūsā al-Khwārizmī (ca. 825). [1320]

In the sine quadrant, radial sides are divided sexagesimally, and from the points of these divisions, half chords are drawn up to the arc, thus producing a grid or graph of sines and cosines of the angles marked on the arc. With such a grid, the angles measured on the arc can be directly converted into the corresponding sines and cosines. Aside from measuring the altitude of heavenly bodies, many trigonometric problems can be graphically solved with this sine quadrant.

There are two varieties of horary quadrants; those which measure time in seasonal hours and those which measure in equal hours. While the former can be used at any latitude and is often incorporated on the back of astrolabes, the latter can be used only at the latitude for which it is designed. The former is the universal horary quadrant (*rub^c*

1319 Ptolemy, Book I, ch. 12, p. 61, Fig. D. Ptolemy's quadrant was drawn on a wall erected in the north-south direction and could be used to observe the heavenly bodies only when they are transiting the meridian. From this mural quadrant developed the portable quadrants engraved on wood or metal. Jai Singh erected mural quadrants in his observatories. See also King 1994.

1320 Charette & Schmidl 2004, pp. 154-155; 179-181.

āfāqī); it consists of hour curves radiating from the centre and touching the arc at intervals of 15° and a semi-circle representing midday.

There are two other varieties of the quadrant, viz., the universal *Shakkāzīya* quadrant used for solving problems in spherical astronomy and the astrolabe quadrant or almucantar quadrant derived from the astrolabe.[1321] But these varieties are not relevant for India as they were not produced in India.

The sine quadrant was transmitted to India along with the astrolabe from the Middle East some time in the early medieval period. In India, the sine quadrant is often incorporated on the backs of Indo-Persian as well as Sanskrit astrolabes. The universal horary quadrant, on the other hand, is occasionally included on the back of the Indo-Persian astrolabes[1322], but rarely on the Sanskrit astrolabes.[1323]

Because the quadrants are invariably included on the back of astrolabes, independent quadrants are rather rare. Just four independent specimens of Indo-Persian quadrants are known to be extant; two of these (J002 and J003) are particularly valuable as they carry the names of the various elements on the sine quadrant.

[1321] Cf. King 1987b, pp. 8-10.

[1322] The astrolabes of the Lahore family carry occasionally the universal horary quadrants on the back, e.g. A043, A057, A102 and A126. Muḥammad Ṣāliḥ of Thatta, on the other hand, included the universal horary quadrant on nearly all his astrolabes (B009 - B014).

[1323] Just two Sanskrit astrolabes carry universal horary quadrants on the back, C001 of 1605 and C009 of ca. 1670, both produced in Gujarat.

Index of Indo-Persian Quadrants

J001 ◎Sine Quadrant, attributable to Ḍiyā' al-Dīn Muḥammad................................ 3385

Not dated, second half of the 17th century, Radii 205 and 206 mm, London, Nasser D. Khalili Collection of Islamic Art (# SCI 31)

J002 ◎Sine Quadrant by Jamāl al-Dīn Muḥammad ᶜAlī al-Ḥussaynī, 1273 AH (AD 1856-57) 3391

186 x 173 mm, Rampur, Rampur Raza Library

J003 Sine Quadrant, not signed, not dated 3394

19th century, 223 x 223 mm, Karachi, National Museum of Pakistan

J004 ◎Sine Quadrant, not signed, not dated 3397

19th century, Radius 179 mm; length of the index 170 mm, Mumbai, Chhatrapati Shivaji Maharaj Vastu Sangrahalay

J005 Sine Quadrant, not signed, not dated 3398

Dimensions ?, Hyderabad, Saidiya Library

K. SANSKRIT QUADRANTS (TURĪYA-YANTRA)

INTRODUCTION

In Sanskrit the quadrant is called *Turīya-yantra, Turya-yantra* or *Turya-gola(ka)-yantra*. It is mentioned for the first time by Brahmagupta in his *Brāhmasphuṭa-siddhānta* of 628 under the name *Turya-golaka-yantra.* Brahmagupta discusses the three instruments *Cakra* (circle), *Cāpa* or *Dhanus* (lit. 'bow', semi-circle) and *Turyagolaka* or (quadrant) which are closely related in shape and function. *Cakra* is a circular wooden plate with its circumference graduated into 360 degrees, *Dhanus* is its half, and *Turyagolaka* the quarter. In all the three, a perforation is made at the centre into which a thin rod is inserted as the axis and a plumb-line is suspended from the centre. These instruments are so held towards the sun that the axis throws a shadow on the circumference. Then the arc intercepted between the nadir (indicated by the plumb-line) and the shadow is the zenith-distance. Brahmagupta prefers the semi-circular variety and explains the various functions in connection with it and adds that the same can be done with the *Turya-golaka* and *Cakra*.[1327]

Following him, Bhāskarācārya also describes first the *Cakra-yantra* and then adds laconically that the *Cāpa* and *Turya-gola* are a half and a quarter respectively of the *Cakra* and that all the tasks of the *Cakra* can be performed with *Cāpa* and *Turya-gola* as well.[1328] However, the *Turya-gola* or the quadrant is a handier device and played an important role in India in the medieval period.

1327 Brahmagupta, 22.17:
aṅkitam aṃśanavatyā dhanuṣo 'rdhaṃ turyagolakaṃ yantram |
ghaṭikā-natonnatāṃśa-grahāntarādyaṃ dhanurvad iha ||
'The *Turya-golaka-yantra* is [constituted by] a half of the *Dhanur [-yantra]*. It is marked with ninety degrees; as in the *Dhanur [-yantra]*, here also [can be determined the time in] *ghaṭikās*, the degrees of the zenith-distance (*natāṃśa*), the distance between two planets (*grahāntara*) and other [parameters].'

1328 Bhāskarācārya, *Golādhyāya, Yantrādhyāya*, 15cd: *dalīkṛtaṃ cakram uśanti cāpaṃ kodaṇḍa-khaṇḍaṃ khalu turyagolam*, 'The *Cakra [-yantra]*, when halved, is called *Cāpa [-yantra]*; its [half] part is indeed the quadrant *(turya-gola)*.'
Sūryasiddhānta 13.20 enumerates the names of several instruments without actually describing them; these include *Cakra* and *Dhanus* but not *Turya*. Lalla mentions *Cakra-yantra* and the *Dhanur-yantra*, but not the quadrant in his *Śiṣyadhīvṛddhida*. Likewise, Śrīpati, in his *Siddhātaśekhara*, describes the *Cakra-yantra* and the *Cāpa-yantra*, but not the quadrant.

Sine Quadrant

Padmanābha

It has been mentioned above that the sine quadrant was developed at Baghdad in the ninth century and was transmitted to India along with the astrolabe. Because of its usefulness in solving trigonometric problems graphically, it was easily absorbed into the repertoire of Indian astronomical instruments. In India Padmanābha is the first one to describe the sine quadrant in his *Dhruvabhramaṇādhikāra* of 1423.[1329] In this work, he describes a new instrument for use in the night called *Dhruvabhrama-yantra* consisting of a rectangular plate and adds that the reverse side of this plate should be fashioned as a sine quadrant for use in the daytime.

To the existing design of the plain quadrant, equipped with two sights and the arc graduated in 90 degrees, Padmanābha added 30 parallels (*jyā-rekhās*) with uniform intervals perpendicular to the horizontal radius so that an angle measured on the arc can be directly converted to the corresponding Rsine (*jyā*). A plumb line is suspended from the apex of the quadrant. Also an index arm is pivoted to the centre. This index arm is graduated in the same divisions as the intervals between the vertical parallels or lines of sines.

Padmanābha envisages three kinds of uses for this sine quadrant. First, in the daytime, one measures the sun's altitude and from it determines the true solar time. Second, at night one measures the altitude of a lunar mansion (*nakṣatra*) and from it determines the sidereal time. For this purpose, he provides the meridian altitudes of the 28 lunar mansions at 24° latitude north, and teaches the method of converting these for one's own latitude. Third, he teaches the procedure how to obtain the time at one's own latitude from the time measured with an instrument calibrated for another latitude.

Cakradhara

After Padmanābha, the sine quadrant was discussed by several writers. Notable among these are Cakradhara and Bhūdhara who composed exclusive manuals on the sine quadrant. Cakradhara authored a manual entitled *Yantra-cintāmaṇi* together with a

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[1329] On Padmanābha and the *Dhruvabhrama-yantra* invented by him, see the next section L. For the text and translation of the *Dhruvabhramaṇādhikāra,* see Apx.D2.

commentary called *Vivaraṇa* sometime before 1621. This work enjoyed great popularity. Besides the author's own *Vivaraṇa,* two other commentaries are extant: *Yantra-dīpikā* by Rāma Daivajña (ca. 1625) and *Turyayantropapatti* or *Yantracintāmaṇi-sūtrāṇām Upapatti* by Dādābhāī (ca. 1719). Moreover, some 90 manuscript copies of this work are known to exist.

The *Yantra-cintāmaṇi* is a slender work of just 26 verses. Cakradhara asserts that his work, though small, carries much substance (*alpam analpakārtham*). He goes on to say that the instrument described by him can solve several astronomical problems directly (*pratyakṣataḥ*) without the necessity of mathematical computation (*gaṇitānapekṣya*) and that it makes use of principles and rationales that have never been employed before (*apūrvayukti*).[1330] He coined a special name for the sine quadrant, *Yantra-cintāmaṇi* (wishing gem of an instrument). Two extant specimens (K013 and K014) carry this name, otherwise it did not become popular like Mahendra Sūri's name *Yantrarāja* for the astrolabe. Like the ordinary quadrant, the sine quadrant also continued to be referred to as *Turīya* or *Turya-yantra.*

Cakradhara's design for the sine quadrant is more refined than that of Padmanābha. He defines the various elements with greater clarity and precision, providing them with specific designations. The centre or the apex (A) is named *kendra* (centre), the point diagonally across (H) is named *kuja* (horizon), and the point straight below (Z) is *gagana* (zenith). The line joining the apex and horizon (AH) is called *kṣiti* (earth, base line). Above this line are situated two sighting vanes (*kīlaka*) with holes for observing the heavenly bodies. This line (AH) is divided into 30 equal parts and from each point of division lines perpendicular to the horizontal line are drawn. Along the arc are drawn two circular scales. One is divided into 90 degrees of arc, and the degrees are numbered, from the horizon up to the zenith, to measure the altitude (*unnatāṃśa*) or zenith-distance (*natāṃśa*). The second scale is divided into 15 *ghaṭīs* for measuring time.[1331] In his commentary *Vivaraṇa* he explains how to find out directly the *Kramajīvā* (Rsine) and the *Utkramajīvā* (Rversed sine or Rversine):

1330 Cakradhara, 1-2.

1331 Cakradhara, 3.

If you want the Rsine of, say 30°, measure 30° from the zenith (i.e. 60˚ on the scale) and the corresponding sine-line, namely 15 *aṅgulas*, is the Rsine of 30˚. If you want the Rversine of 30˚, count 30˚ from the horizon, the distance on the *bhūmi* (AH) between the base of the corresponding sine-line and the horizon, namely 4 *aṅgulas*, is the Rversine of 30˚.

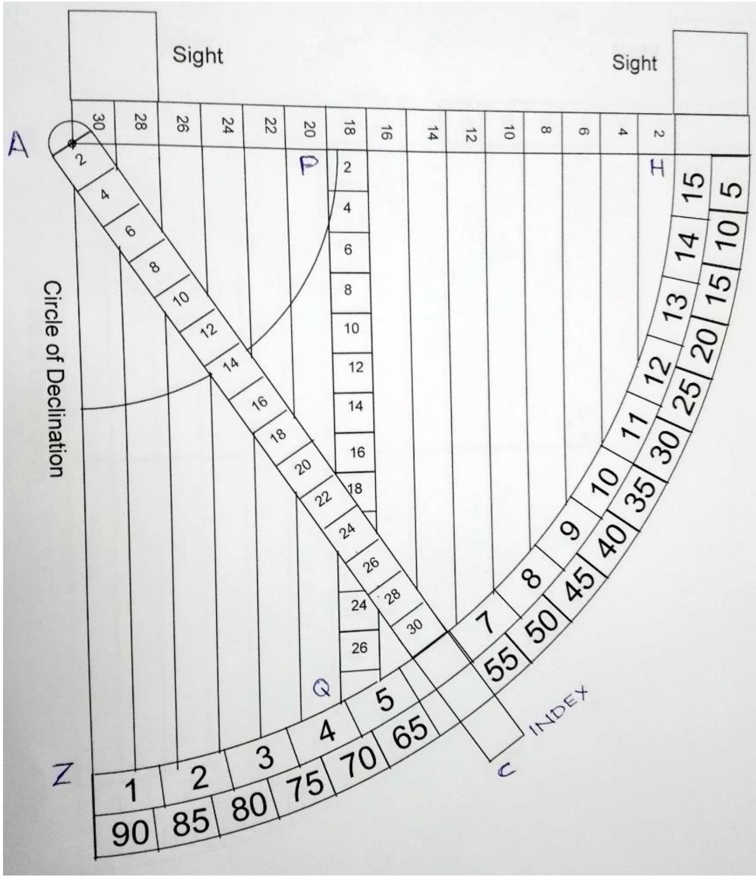

Figure K1 – Sine quadrant designed by Cakradhara
(drawing by Mubashir Ul-Haq Abbasi)

The vertical parallels are numbered from the arc to the apex. The 18th line, or more correctly the 18th column, is divided into parts equal to the intervals between the vertical lines. These intervals are designated as *aṅgulas* (digits). The reason for choosing the 18th column is as follows. When counted from the apex, it is the 12th column, and the distance from the apex to this line represents the gnomon of 12 *aṅgulas.*[1332] On this scale can be determined the shadow lengths of the gnomon at any given time.[1333]

[1332] In all the sine quadrants made by Bulhomal, the twelfth vertical and horizontal columns are numbered in this manner.

[1333] Cf. Rai 1985, pp. 327-328.

Then with the apex as the centre and with a radius of 12 and 1/5 *aṅgulas* a quarter circle is described. In Indian astronomy, the traditional value of the obliquity of the ecliptic (*parama-krānti*) is 24. Therefore, the Rsine of the obliquity (*parama-krānti-jyā*) is roughly 12 and 1/5. Thus this quarter circle represents the circle of declination (*krānti-vṛtta*) (see Figure K015.1 and Figure K016.1).

From the apex, a plumb line with a weight is suspended. An index (*paṭṭikā*), somewhat longer than the radius of the quadrant is pivoted to the apex. It is also divided into *aṅgulas* of the same dimension as before and the *aṅgulas* are numbered from the apex onwards. It can be held firmly at any degree on the arc or at any division on the 18th line for solving different trigonometric problems, such as the conversion of the equinoctial midday shadow (*palabhā*) into the latitude or vice versa.

Cakradhara envisages that the *Yantra-cintāmaṇi* is employed for determining the time at night also from the altitude of some bright stars, such as the junction-stars (*yogatārās*) of *Puṣya* (δ Cancri), *Maghā* (α Leonis), *Śatabhiṣā* (λ Aquarii) and *Revatī* (ζ Piscium). Since the celestial latitude (*śara*) of these stars is low (that is to say, they are not far from the ecliptic), sighting them is tantamount to sighting the ecliptic. Treating the altitude of any of these stars as the altitude of the sun, one should follow the same procedure as with the sun in the daytime.

Bhūdhara

The second exclusive text on the sine quadrant is the *Turyayantra-prakāśa* composed by Bhūdhara sometime after 1572 at Kāṃpilya (modern Kampil, UP, 27;37° N, 79;17° E); it is a larger work, consisting of 265 verses distributed into 21 chapters.[1334] While Cakradhara prescribes a series of 30 vertical lines, Bhūdhara in his *Turyayantra-prakāśa* prescribes 60 horizontal and 60 vertical parallels, so that both sines and cosines can be directly determined of the angles measured on the arc. An interesting feature of Bhūdhara's work is the employment of the sine quadrant in geodesy, which is discussed in the final chapter entitled *Parvatādi-unnati-jñāna* (knowledge of the height of mountains and others). This topic of the determination of the heights of mountains or

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[1334] A critical edition of the first ten chapters with translation and commentary was published by SaKHYa 2014.

the depths of wells was discussed much earlier in mathematical texts, and Bhāskara's *Līlāvatī* offers some charming examples, but Bhūdhara appears to be the only one to suggest the use of the sine quadrant for the solution of such problems.[1335]

Jñānarāja in his *Siddhāntasundara* of 1503[1336] and **Kamalākara** in his *Siddhāntatattvaviveka* composed in 1568[1337] discuss the sine quadrant and its application, basically in the same manner as taught by Cakradhara. Chronologically the last Sanskrit text to discuss the sine quadrant is the *Yantrasāra* [1338] composed in 1771 by **Nandarāma**. It deals with several instruments, but the lion's share, comprising 190 verses, goes to the sine quadrant, for which Nanadarāma also prescribes 60 vertical and 60 horizontal parallels.

EXTANT SPECIMENS

The extant specimens of Sanskrit quadrants belong to the three catagories of plain or geometrical quadrants, sine quadrants and horary quadrants, but among these the sine quadrants predominate.

Sine Quadrants

The sine quadrants are incorporated on the back of Sanskrit astrolabes, on the back of *Dhurvabhrama-yantras* and also on the reverse side of several other kinds of instruments. But there are some specimens exclusively of sine quadrants.

Here two specimens deserve attention. In 1834, a person referring to himself as Vaijanātha's son designed a sine quadrant at the instance of the ruling prince of Kota in Rajasthan. The insription on the instrument states that this instrument is [described] in the *Yantra-cintāmaṇi.* This *Yantra-cintāmaṇi* must be the manual composed by

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1335 Mahendra Sūri, 5.55-57, teaches how to solve problems of this type by means of the astrolabe. The *Koneri-yantra,* consisting of a square board with 16 x 16 cells, functions in a similar manner; cf. Sinha & Hayashi 1983.

1336 On Jñānarāja and his *Siddhāntasundara*, cf. CESS, 3.75-76; 4.100; 5.122-123; Toke Lindegaard Knudsen, 'The *Siddhāntasundara* of Jñānarāja: A Critical Edition of Select Chapters with English Translation and Commentary,' PhD Thesis, Brown University, Providence 2008.

1337 Kamalākara, *Siddhāntatattvaviveka,* edited by Sudhakara Dvivedi, second edition revised by Muralidhara Jha, Benares 1924-1935, *Tripraśnādhikāra* 391-466, pp. 304-314. Here he refers to the sine quadrant by a strange name *aṅghri-yantra.* Of course, *aṅghri,* lit. 'foot', can also denote the foot of a verse and thus 'one-quarter [of a circle].'

1338 CESS, 3.128-130; 5.156-158.

Cakradhara. But Cakradhara’s manual teaches only how to construct the sine quadrant; it does not say what to do with the back of the plate. The specimen designed by Vaijanātha’s son carries a sine quadrant on the obverse side, but on reverse it has a circular instrument along with a four-armed index, for determining the oblique ascensions for any given moment at the latitude of Kota. The consuction of this instrument was not mentioned in Cakradhara’s book; then where did it come from?

Another specimen prepared by Hṛṣīkekeśa, most probably at Patiala, around 1850, carries a sine quadrant on the obverse and on the reverse an instrument somewhat different from that on the back of the instrument by Vaijanātha’s son, but with the same function of determining the oblique ascensions of a place situated on a particular latitude. Where did this design come from? In his account of the astronomical instruments and Sanskrit manuscripts he saw at Kota, Lancelot Wilkinson reports as follows:

> ‘The Maháráo’s collection contains also a Turíya Yantrá, or quadrant, with a radius on one side of 30 digits, and linear rectangular intersections, rising from each digit, representing their whole canon of sines, cosines, and versed sines adapted to this radius. From the Maháráo’s astronomer I procured a copy of the Sanscrit treatise on the quadrant, called Yantracitamani, by CHAKRADHARA, son of SRI WAMANA, containing directions for construction and use of the instrument, with the mathematical proofs and demonstrations of all the many problems which may be worked by it. The reverse side of this quadrant contains the signs and degrees of the ecliptic, and a hour circle, with an index hand by which you are entitled to tell at once the lagna (or horoscope), that is, the exact point or star of the ecliptic, rising in the horizon at any given time.’[1339]

The last sentence referring to ‘the reverse side of this quadrant’ is intriguing. Does it mean the reverse side of the quadrant as described in the book by Cakradhara, or the reverse side of the quadrant which was in the collection of the Maharao? In the former case, somebody must have made the addition to the text of the *Yantra-cintāmaṇi* in the

1339 Wilkinson 1834, p. 515.

manuscript procured by Wilkinson at Kota. In the latter case, Wilkinson saw at Kota sometime before 1834 an actual specimen on which the sine quadrant was engraved on one side and the oblique ascensions on the other side. Then this would be the forerunner of the silver specimen designed by Vaijanātha's son in 1834. However, on the silver instrument of 1834, Vaijanātha's son states that he made the instrument which is in the *Yantra-cintāmaṇi,* meaning that he designed the instrument as it was described in the *Yantra-cintāmaṇi.* This would support the first hypothesis, namely some unknown author made additions to the text of the *Yantra-cintāmaṇi,* describing how to engrave the reverse side of the sine quadrant so that the oblique ascensions can be determined with its help for any given moment of time.

Horary Quadrant

Sometime about the middle of the nineteenth century, Bulhomal of Lahore made an exclusive horary quadrant which is described under K005. He incorporates similar horary quadrants in some of his instruments, but this is the only piece which exclusively carries a horary quadrant on one side. This is obviously derived from a large instrument designed by Sawai Madho Singh with the title *Yantrādhipati.* It will be described in section T on the instruments designed by Madho Singh. It has not been possible to trace the antecedents of such a horary quadrant in the Islamic world. Therefore, it must have been an independent invention by Madho Singh.

Horary quadrants occur also on the back of some *Dhruvabhrama-yantras* which will be described in the next section L.

Index of Sanskrit Quadrants (Turīya-yantra)

K001 ◎Sanskrit Geometrical Quadrant, not signed, not dated.................................... 3411

19th Century, 118 x 118 mm, thickness 4 mm, Jaipur, Museum of Indology

K002 Sanskrit Geometrical Quadrant, not signed, not dated 3414

19th Century, Length of the side 105 mm; height 131 mm, PLU; ex-Drouot

K003 Sanskrit Geometrical Quadrant, not signed, not dated 3415

19th Century, 73 x 73 mm, PLU; ex-Sotheby's, London

K004 Sanskrit Geometrical Quadrant, not signed, not dated 3416

19th Century, Radius 114 mm, PLU; photo in MHS archives

K005 ◎Sanskrit Horary Quadrant by Lālah Bulhomal of Lahore............................... 3417

Not dated, mid-19th Century, Radius 119 mm, Oxford, Museum of the History of Science (# 39884)

K006 Sanskrit Sine and Horary Quadrant, not signed, not dated................................ 3420

19th century, Radius 113 mm, Hastings-on-Hudson, NY, Tesseract

K007 ◎Sanskrit Sine Quadrant, not signed, not dated 3422

Early 20th century, Radius 115 mm, Vadodara, Maharaja Sayajirao University of Baroda, Sanskrit Mahavidyalaya

K008 ◎Sanskrit Sine Quadrant, not signed, not dated 3424

Early 20th century, 151 x 154 x 3 mm, Vadodara, Maharaja Sayajirao University of Baroda, Sanskrit Mahavidyalaya

K009 Sanskrit Sine Quadrant, not signed, not dated 3426

18th century ?, Radius 350 mm, Jaipur, Jai Singh's Observatory

K010 ◎Sanskrit Sine Quadrant, not signed, not dated 3427

19th century, Radius 54 mm, Brussels, PC

K011 ◎Gurmukhi Double Quadrant (Cāpa-yantra), not signed.................................. 3430

Not dated, mid-19th century, Diameter 130 mm, Germany, PC

K012 Cāpa-yantra presented by the Maharaja of Benares to the Prince of Wales, 1876 3436

Probably 19th century, Dimensions ?, PLU; ex-Kota, palace of the Mahārāo.

K013 Turīya-yantra, not signed, not dated 3437

K014 Turīya-yantra presented by the Maharaja of Benares to the Prince of Wales, 1876 3438

Dimensions ?, PLU

K015 Yantra-Cintāmaṇi by Vaijanātha's Son, 1891 VS (AD 1834)........................... 3439

Dimensions?, PLU; Kolkata, The Asiatic Society?

K016 Yantra-cintāmaṇi by Hṛṣīkeśa for the son of Caṇḍīdatta.................................. 3447

Not dated, mid-19th century, Radius 137 mm, Chicago, Adler Planetarium (# W-103)

K017 ◎Yantra-cintāmaṇi, not signed, not dated 3452

19th century, Radius ca. 120 mm, Jaipur, PC

L. DHRUVABHRAMA-YANTRA OF PADMANĀBHA

INTRODUCTION

1. PADMANĀBHA

In pre-modern times, instruments developed gradually in the course of several centuries, through occasional improvements or borrowings from other cultures; therefore, their invention cannot be attributed to any single individual. But there are two exceptions. In 1150, Bhāskarācārya declared that he invented a new instrument by name *Phalaka-yantra.* Around 1423, Padmanābha, son of Nārmada, claimed the invention of a novel instrument *Dhruvabhrama-yantra.* Of these two, the *Dhruvabhrama-yantra* was more popular, attested by the number of extant specimens. Therefore, it will be treated first.

Padmanābha is known from three small tracts on the construction and use of three different instruments, viz. the *Yantrarājādhikāra* on the southern astrolabe,[1357] the *Dhurvabhramādhikāra* (=DBA) on the *Dhruvabharma-yantra* and the *Diksādhana-yantra* on an instrument of the same name. The first two are said to be the first and second chapters of a work variously mentioned as *Yantra-kiraṇāvalī* or *Yantra-ratnāvalī,* but manuscript copies of the full text are not extant. Therefore it is not known whether *Diksādhana-yantra* is also a chapter of the same work or whether it is an independent work. Padmanābha also wrote commentaries on his *Yantrarājādhikāra* and DBA, and on the *Karaṇakutūhala* (AD 1183) of Bhāskara II.[1358] Both Padmanābha's father Nārmada[1359] and Padmanābha's son Dāmodara[1360] were also astronomers.

In his DBA (verses 24-26)*,* Padmanābha gives the meridian altitudes (*madhyonnatāṃśas*) of the lunar mansions (*nakṣatras*) for the terrestrial latitude of 24°.

1357 Ôhashi 1997 provides a critical edition, English translation and mathematical commentary of this work.

1358 On Padmanābha, his works and their manuscript copies, see CESS, A-4, 170-172; A-5, 205; Ôhashi 1997, Sarma 2012a.

1359 Nārmada composed *Nabhogasiddhi* following the Brāhmapakṣa; cf. CESS, A-3, 171b; A-5, 183a.

1360 Dāmodara is known from three works: a *Karaṇa* work called *Bhaṭatulya* based on the *Āryabhaṭīya* of Āryabhaṭa, another *Karaṇa* by name *Sūryatulya* based on the *Sūryasiddhānta,* and a commentary on the *Karaṇaprakāśa* of Brahmadeva; cf. CESS, A-3, 100b-101a; A-4, 108a; A-5, 137a.

He must, therefore, belong to some place close to this latitude in Central India. In his *Yantrarājādhikāra,* he gives the precession (*ayanāṃśa*) for the Śaka year 1345 (= AD 1422-23), which may be the year of composition of this work.[1361] Padmanābha's son Dāmodara composed his *Sūryatulya* in Śaka 1339 (= AD 1416-17). Thus both Padmanābha and his son must have flourished in the first quarter of the fifteenth century somewhere in Central India.

The DBA is a small text of 31 verses in different metres, accompanied by an auto-commentary.[1362] Here Padmanābha gives the most detailed instructions for the construction and the use of the instrument. Such detailed instructions are not to be found in any other Sanskrit text on instruments.

2. Dhruvabhrama-yantra and the Diurnal Rotation of the Stellar Sphere

The *Dhurvabhrama-yantra* is an oblong (*āyata-caturasra*) metal plate one side of which is designed as the *Dhurvabhrama-yantra* and the reverse side as a sine quadrant (*Turya-yanta*). The *Dhurvabhrama-yantra* proper is a kind of nocturnal, i.e. an instrument to be employed at night. Its construction is based on the apparent diurnal rotation of the stellar sphere around the celestial poles. In his commentary, Padmanābha explains the diurnal rotation thus:

> 'At the beginning of the creation, the resplendent Brahmā arranged two stars as the celestial poles at the end of the southern and northern directions so that the stellar sphere (*bhacakra*) can properly revolve in the sky towards the west, without any support but impelled by the *Pravaha* wind. These two stars were designated as the celestial poles (*dhruva*). That which is the southern [Pole] Star is situated below the horizon at a distance of the degrees of the local latitude (*palāṃśa*). The northern Pole Star lies above the horizon at a distance of the degrees of the local latitude. Around the latter is seen a fish-shaped constellation (*maṇḍala*) consisting of twelve stars. This is designated as the Polar Fish (*dhruva-matsya*). Two bright stars are visible at its mouth

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1361 Ôhashi 1997, p. 217.

1362 Extracts from the *Dhruvabhramaṇādhikāra* and the commentary together with a translation will be given in Apx.D2.

> and tail. Of these, the one at the mouth lies at an interval of three degrees (*bhāga*) from the [actual] Pole Star and the one at the tail lies at thirteen degrees. The two are separated from one another by sixteen degrees.'[1363]

The rotation of the *Dhruva-matsya* was known to earlier astronomers as well. Brahmagupta makes a brief reference to it in his *Brāhmasphuṭa-siddhānta.*[1364] Bhāskarācārya, in his *Vāsanā-bhāṣya* commentary on his *Siddhānta-śiromaṇi,* speaks of the daily rotation of the *Dhruva-matsya* in somewhat greater detail:

> 'When the sun is situated in the lunar mansion *Bharaṇī*, then at the time of his setting, the Polar Fish becomes horizontal. The star at its mouth will be in the west and the star at the tail in the east. It means that the sun would be in line with the star at the mouth. At the end of the night, the star at the mouth reverses its position and comes to the east and the star in the tail goes to the west. Then will be seen the rise of the sun who is again in line with the star at the mouth.'[1365]

The *Dhruva-matsya* is a constellation of twelve stars. Of these the stars at the mouth and tail of the fish figure are α and β in the constellation Ursa Minor. The remaining ten stars should include some of the stars in Ursa Minor. But no Sanskrit text seems to have described this constellation in detail.

Padmanābha lays strong emphasis, at the beginning and at the end of his work, on the fact that, while other instruments make use of the sun or of other fixed stars, his is

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1363 Padmanābha, commentary on DBA 11: *pūrvaṃ sr̥ṣṭyādau śrībrahmaṇākāśa ādhārarahitasya pravahānilākṣiptasya bhacakrasya samīcīnapaścimābhimukhaparibhramaṇāya dakṣiṇottarayoḥ prāntasthite dve tārake dhruvatve niyukte | tayor ubhayor dhruva-saṃjñā kr̥tā | yā dakṣiṇā tārā sā tu palāṃśaiḥ kṣitijād adhasthād vartate | yā tūttarā tārā sā palāṃśaiḥ kṣitijād uparito varīvarti | tatparito dvādaśatārakābhir matsyākāramaṇḍalam upalakṣyate | tasya dhruvamatsya-saṃjñā vihitā | tanmukhe pucche sthūle tārake dve dr̥śyete | tayor madhye yā mukhasthā sā dhruvatārāyās tribhir aṃśair antaritā | yā pucchasthā sā tu trayodaśabhir aṃśair antaritā vartate | ubhe parasparaṃ ṣodaśabhāgāntarite staḥ |*

1364 Brahmagupta, 11.3:
bhāni catuṣpañcāśad dvau dvāv arkaindavo jinoktaṃ yat |
dhruvamatsyasyāvarto bhavati yato 'hnā tatas tad asat ||

1365 Bhāskarācārya, *Vāsanābhāṣya*, p. 345: *yadā bharaṇīstho ravir bhavati tadā tasyāstamayakāle dhruvamatsyas tiryakstho bhavati | tasya mukhatārā paścimataḥ | pucchatārā pūrvataḥ | tadā mukhatārāsūtre ravir ity arthaḥ | atha niśāvasāne mukhatārā parivartya pūrvato yāti | pucchatārā paścimato yāti | tato mukhatārāsūtra-gatasyaivārkasyodayo dr̥śyate |*

the only instrument which makes use of the Pole Star and that it is a multi-purpose instrument. Thus he states at the beginning of the work:

> 'All the instruments measure time etc. according to the sun or according to the fixed stars. This one, however, shows time according to the celestial Pole. Therefore it is called the best of the instruments. … Apart from the time of the night, it also indicates the ascendant (*lagna*), other astrological houses (*bhāva*), and the results in time (*kālaphala*) (oblique ascensions) related to these. The time of the night etc. are found by observing the Polar Fish (*dhruva-matsya*). Therefore the name *Dhruvabhrama* is quite appropriate.'[1366]

Again at the end of the work, he repeats that such an instrument based on the Pole star has never been mentioned previously by any astronomer:

> '[Others] taught previously how to measure time from the stars, but none [has taught how to find time] from the Pole Star. Therefore, out of intellectual curiosity (*kautuka*), this has been done [by me].'[1367]

3. DHRUVABHRAMA-YANTRA AND THE EUROPEAN NOCTURNAL

Padmanābha may not be aware that the Pole Star was employed for orientation by sailors also. On the west coast of India sailors measured time and fixed their bearings at night by observing the relative position of the two stars β and γ Ursae Minoris vis-à-vis the Pole Star. Tibbets writes:[1368]

> The Farqadān (sic! *Farqadayn*, β and γ Ursae Minoris) were most important in the Indian Ocean navigation because they were the brightest stars in the vicinity of the Pole, were circumpolar and never at any great distance from the meridian. They were thus the most prominent objects on the northern

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1366 Padmanābha, commentary on DBA 1: *sarvāṇi yantrāṇi sūryavaśān nakṣatravaśād eva kālādy-avayava-bodhakāni | idam pṛthag dhruvavaśāt kālāvabodhakam | tasmād yantravaram ity uktam | … triyāmāsamayādibodhakam …. ādiśabdāl lagnādibhāvās tatsambandhīni kālaphalāny api bodhayati | anena yantreṇa rātreḥ samayādijñānaṃ dhruvamatsyālokanād evotpadyata ity ato dhruvabhramaṃ nāma suyuktam |*

1367 Padmanābha, DBA 31:
nakṣatrāt samayajñānaṃ tamisrāyāḥ puroditam |
dhruvāt kenāpi na proktaṃ tad etat kautukāt kṛtam ||

1368 Cf. Tibbets 1981, p. 337.

> horizon immediately after the Pole Star has disappeared and measurements taken from them in any position were relatively accurate. Like the Mediterranean navigators the Arab navigators recognized eight positions of the Guards, two horizontal, two vertical together with the two culminations and two extreme positions of the Greater Farqad (β Ursae Minoris). There were four other positions being the culmination and extreme positions of the smaller Farqad, but they were not so important.'

The same phenomenon gave rise to another related instrument, viz. the European nocturnal, which is based on the diurnal rotation of the line joining the α and β Ursae Majoris with the Pole Star. It is not known who invented it, but it was first mentioned by Martin Cortes in *Arte de Navegar* in 1551 and the earliest extant specimens belong to the late sixteenth century.[1369] The *Dhruvabhrama-yantra* and the European nocturnal have much in common in the basic principle as well as in the design. But the former is older by about one and half centuries. In the present state of knowledge, it is difficult to decide whether Padmanābha's *Dhruvabhrama-yantra* has inspired the European nocturnal or whether the two are independent inventions.

4. DHRUVABHRAMA-YANTRA ON THE OBVERSE

4.1. Main Plate

The *Dhruvabhrama-yantra* consists of an oblong plate with a narrow horizontal slit close to and parallel to one of the shorter sides, say at the top. Below the slit are drawn eight concentric circles, producing seven annuli (*koṣṭhakas*). These annuli contain different scales and the legends pertaining to them. Padmanābha numbers these scales, counting them from the outside.

The outermost or the first annulus (*prathama-koṣṭhaka*) contains a scale of *ghaṭīs.* The scale is divided into 60 equal parts to represent the 60 *ghaṭīs* in a nychthemeron (*ahorātra*). These *ghaṭīs* are numbered in the following manner. At the uppermost point of the circle, i.e. where it is closest to the horizontal slit, is marked the commencement of the 22nd *ghaṭī.* To put it differently, if the circle is divided into 360 degrees from the

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1369 Wynter & Turner 1975, p. 69; Bud 1998, pp. 414-418.

uppermost point where the 22nd *ghaṭī* commences and the degrees are numbered serially clockwise, then the *ghaṭī* scale and all other scales would commence from 234°. Thus Padmanābha places the vernal equinox at 234°. He does not explain the reason for choosing 234° as the vernal equinox, but he must have empirically arrived at this arrangement of the *ghaṭī* scale by observing the position of the stars α and β Ursae Minoris at his place situated on the latitude of 24°.[1370] The remaining six annuli are calibrated accordingly. The innermost scale is divided into 12 unequal units in accordance with the oblique ascensions, i.e. the times of the risings of the twelve signs of the zodiac at the observer's latitude (*svodaya*). The middle scale is divided into 12 unequal units to represent the right ascensions, i.e. the times of the risings of the twelve zodiac signs at the equator (*nirakṣodaya*). There are also additional scales containing the names of these two sets of the zodiac signs (*rāśis*), their sub-divisions, and the lunar mansions (*nakṣatras*) pertaining to these two sets of the zodiac signs. Thus the specifications of these seven scales, counted from the outside, are as follows:

1. *Ghaṭī* scale.
2. Names of the 28 lunar mansions as related to the zodiac signs in scale 4 and their meridian altitudes, after correcting these for precession (*āyana-dṛkkarman*).
3. Twelve unequal divisions as in scale 4, with further subdivisions. (In the extant specimens, each division is subdivided in five parts and numbered as 6, 12, 18, 24, 30, as is generally done on the retes of astrolabes).
4. Twelve unequal divisions containing the names of the zodiac signs. The lengths of these divisions should be in proportion to their right ascensions.

1370 Garrett & Guleri 1902, pp. 63-64, explain the reason thus: 'Now when Beta Ursae Minoris is due east of the Pole Star, the sidereal time is approximately 8 hours 48 minutes or 22 ghatis. But the Hindus reckon their time from the instant of the rising of the equinox on the eastern horizon, whereas we reckon from the equinox on the meridian. The difference is evidently six hours. Hence subtracting 6 hours or 15 ghatis, we get 2 hours 48 minutes or 7 ghatis as the Hindu sidereal time. If now the Dhruvabhrama Yantra be held in a vertical plane, so that the Pole Star and Beta Ursae Minoris are both seen through the slit, which in this case will be horizontal, then the west indicator must point to 7 ghatis, as in the plate [X], and having fixed the west point in this manner, the whole ring is divided into the usual graduation of 60 ghatis of 6 degrees each. Then the other rings can be graduated as described above.'

5. Names of the 28 lunar mansions as related to the signs in scale 7 and their true polar longitudes (*sphuṭa*), after correcting them for the observer's latitude (*akṣa-dṛkkarman*).
6. Twelve unequal divisions as in scale 7, with further subdivisions. (In the extant specimens, each division is subdivided in five parts and numbered as 6, 12, 18, 24, 30).
7. Twelve unequal divisions containing the names of the zodiac signs. The lengths of these divisions should be in proportion to their oblique ascensions.

4.2. Index

Loosely pivoted at the centre of these concentric circular scales is an index with four pointers which project into the four cardinal directions at right angles to one another. These pointers should be of unequal length so that they reach up to different scales. The eastern pointer, which is the shortest, reaches up to the sixth scale to point the degree of the zodiac sign rising at the observer's latitude. The northern pointer is of middle length and reaches the third scale to point the signs rising at the equator. The western pointer is the longest to reach the outermost scale containing the *ghaṭī* divisions. The southern-most projection is actually not a pointer but the plumb. Either a plumb bob is suspended from this projection, or it is made considerably heavier than the others, so that it always points downwards and gives a vertical line of reference. Therefore, irrespective of the tilt of the plate, the eastern and western pointers will always be horizontal and the northern pointer will always be vertical.

4.3. Observation with the Dhruvabhrama-yantra

At night the instrument is held in a vertical plane and tilted in such a manner that the two stars α and β UMi are visible in a line through the slit in the instrument (DBA 9-10). Then the eastern pointer will indicate that point of a zodiac sign which is rising in the east at that moment; this is the ascendant for that moment (*lagna*). The point at which the western pointer touches the *ghaṭī* circle is called 'point of observation' (*vedha-cihna*). Let us call it *A*. Now find out the solar longitude for that moment from an almanac (*pañcāṅga*). Place the tip of the eastern pointer at the solar longitude with precession plus six signs (*sa-calana-lava-ṣaḍ-bha*). Note where the western pointer is situated now. That point will indicate the time of the previous sunset. Let us call it *C*.

The distance *CA* equals the number of *ghaṭīs* elapsed (*gata-ghaṭikās*) in the night from the previous sunset up to the time of observation. On the other hand, if the tip of the eastern pointer is placed just at the solar longitude with precession (i.e. without adding 6 signs), then the corresponding western point will indicate the time of the next sunrise. Let it be *B*. Then the distance *AB* is tantamount to the number of *ghaṭīs* to come in the night from the time of observation up to the next sunrise (*eṣya-ghaṭikās*) (DBA 11-13). Thus the time of observation is *CA ghaṭīs* after the previous sunset and *AB ghaṭīs* before the next sunrise, the total duration of the night being *CB ghaṭīs*.

While the ascendant and the sidereal time of observation are determined thus with the help of the eastern and western pointers, the point at which the middle pointer touches the scale of the risings at the equator is the upper culmination (*madhyama-lagna*) with precession (*sāyana*). Then from the upper culmination (*viyad-lagna*) and the ascendant (*udaya-lagna*), other astrological houses (*bhāvas*) can be determined easily.

In horoscopy (*horāśāstra*), the zodiac circle is divided into twelve houses (*bhāvas*) which are different from the twelve signs (*rāśis*). The twelve houses are divided on the basis of four key points, or pivots, where the ecliptic intersects the local horizon and the local meridian. These are as follows: 1. 'ascendant' (*lagna, udaya-lagna*), i.e. the point or the degree of the ecliptic which is on the eastern horizon; 2. 'lower culmination' or 'lower midheaven' (*pātāla, caturtha-bhāva*), i.e. the degree of the ecliptic which is on the lower meridian; 3. 'descendant' (*asta-lagna, saptama-bhāva*), i.e. the degree of the ecliptic which is on the western horizon; and 4. 'upper culmination' or 'upper midheaven' (*khamadhya, madhyama-lagna, viyad-lagna, daśama-bhāva*), i.e. the degree of the ecliptic which is on the upper meridian. Of these the ascendant (*lagna*) and the descendant (*saptama-bhāva*) are diametrically opposite, i.e. at 180 degrees from one another; so also the upper culmination (*daśama-bhāva*) and the lower culmination (*caturtha-bhāva*).

Thus the *Dhruvabhrama-yantra* is a multipurpose instrument with which the sidereal time and the four key points on the ecliptic which are important in horoscopy can be read off from the dial without resorting to complicated computations. On the astrolabe also these four points can be directly read off from the dial, when once the rete is correctly set for the moment. What distinguishes the *Dhruvabhrama-yantra* from the astrolabe is the relatively simple design, avoiding the difficult stereographic projections needed for the astrolabe. Padmanābha's design consisting of the horizontal slit for orientation, the series of circular scales and the index with multiple arms to reach up to different scales, though simple, is brilliantly conceived. In this design, the angle of the rotation of the line connecting α and β Ursae Minoris is translated automatically into (i) the time units of *ghaṭīs,* (ii) the zodiac signs and parts thereof which rise on the eastern horizon and (iii) the zodiac signs or parts thereof which are crossing the meridian at the time of observation.

5. SINE QUADRANT ON THE BACK

The *Dhruvabhrama-yantra* which is described here can be used only at night. Padmanābha desires that it is used also in the daytime and prescribes that the reverse side of the oblong plate is fashioned as a sine quadrant (*Turīya-yantra*). As stated in the introduction to section I, the sine quadrant was developed in the Islamic world in the ninth century. In India, Padmanābha was the first to describe it in Sanskrit. He prescribes that from one of the radial edges thirty lines be drawn parallel to the other radial edge. The arc of the quadrant is graduated into 90 degrees. At the apex of the quadrant, an index is pivoted, which is marked with 30 divisions, and also a plumb line. Furthermore, two sighting vanes with holes are attached to one of the sides of the quadrant.

Holding the sine quadrant in a vertical plane, one observes the sun or the stars through the two sights by tilting the quadrant appropriately. Where the plumb line touches the graduated arc is the altitude of the object sighted. With the help of the index and the parallel lines drawn on the quadrant, time can be measured.

Measuring Time at Night with the Sine Quadrant

With the sine quadrant time can be measured at night by sighting a star whose meridian altitude is known. For this purpose, Padmanābha gives the meridian altitudes of the 28 lunar mansions which are valid for the latitude of 24° (DBA 24-26). For those who live at other geographical latitudes, Padmanābha also teaches how to convert the given meridian altitudes for other latitudes (DBA 27).

In the case of the *Dhruvabhrama-yantra,* it may be recalled that some of the circular scales are related to the oblique ascensions which pertain to a specific terrestrial latitude. It cannot, therefore, be used at other latitudes, while the sine quadrant can be used at all latitudes. Padmanābha also teaches how to obtain time at one's own latitude with a *Dhruvabhrama-yantra* made for another latitude (DBA 28). However, he omits to teach how to adjust the *ghaṭī* scale for latitudes other than that of 24°. Nor does he explain how to determine the ascendant and culmination in the daytime with the *Dhruvabhrama-yantra*.

6. Reception of the Dhruvabhrama-yantra

The *Dhruvabhrama-yantra* is not mentioned in any subsequent Sanskrit work on instruments, neither in Rāmacandra Vājapeyin's *Yantraprakāśa* (1428), Viśrāma's *Yantraśiromaṇi* (1615) nor in Nandarāma Miśra's *Yantrasāra* (1772). However, in his voluminous commentary (1621) on Bhāskara II's *Siddhāntaśiromaṇi,* Nṛsiṃha gives a fairly long description of the *Dhruvabhrama-yantra*.[1371]

But, more important are the nearly seventy manuscript copies of the *Dhruvabhramādhikāra*[1372] and the twenty and odd actual specimens which are extant; these show that the *Dhruvabhrama-yantra* was next to the astrolabe in popularity. Most of these surviving specimens belong to the nineteenth century. There is much variation in these specimens, not only in the outer form of the plate—oblong, circle or quarter circle— and the design of the four-armed index, but also in the configuration of the circular scales. The wide variety in the style of execution and in the arrangement of scales indicate the popularity of the instrument in the nineteenth century; this may be true of the earlier centuries as well.

Muslim astronomers of India have also adapted *Dhruvabhrama-yantra* with Arabic/Persian legends.[1373] Two specimens have come to light so far, one at the Khuda Bakhsh Oriental Public Library of Patna (L024)[1374] and the other at the Raza Library of Rampur (L025).[1375] In these versions, the obverse side, calibrated as the nocturnal, is called *Shabnumā*, 'night indicator' and the reverse side with the quadrant is called

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1371 Nṛsiṃha, pp. 446-457.

1372 CESS A-4, 170-172; A-5, 205.

1373 Sarma & Bagheri 2011.

1374 Sarma 1999b.

1375 Sarma 2003, pp. 22-23, 85-88.

Rūznumā, ‘day indicator’. These two specimens are manufactured in the nineteenth century but there must have been forerunners in earlier periods of which we do not yet know. Nor do we know at present whether these are discussed in any Persian or Arabic manual. Though it is clear that this version was inspired by the *Dhruvabhrama-yantra* and that this adaptation took place within India itself, the exact path of transmission still remains to be mapped.

Though clearly based on the *Dhruvabhrama-yantra,* the two extant specimens of the *Shabnumā-wa-Rūznumā* differ from the former in the following respects.

1. There is no horizontal slit in the *Shabnumā-wa-Rūznumā* as in the *Dhruvabhrama-yantra*; instead the upper edge is used as the reference.
2. There is no four-armed index in the *Shabnumā-wa-Rūznumā*; instead there are two indices in the specimen at Patna. If there were any indices in the Rampur specimen, they are missing now.
3. Initial points of the scales. In the *Dhruvabhrama-yantra*, the 21st *ghaṭī* division ends and the 22nd *ghaṭī* division begins just below the slit. Therefore the starting point of this scale is 234°. This is also the starting point in the scales of right ascensions and oblique ascensions. But the *Shabnumā-wa-Rūznumā,* especially the specimen at Rampur has several starting points, the significance of which is not clear.
4. The *Dhruvabhrama-yantra* determines, in addition to time, the ascendant and the culmination. On the other hand, the *Shabnumā-wa-Rūznumā* measures, besides the time in *ghaṭī*s*,* the ascendant and the *taḥwīl* (sun’s passage from one sign to the other).

7. EXTANT SPECIMENS OF THE DHRUVABHRAMA-YANTRA

As stated above, the twenty odd specimens exhibit much variation in the outer form, in the disposition of the circular scales, in the choice of the quadrant for the reverse side and so on. Such wide variations do not occur in other instruments. These variations will be discussed in the descriptions of the respective specimens, but an overview is given below.

7.1. Outer form of the main plate

Although Padmanābha clearly prescribes that the plate should be oblong in shape, some astronomers/instrument makers experimented with other shapes as well. For example, Sonī Morarajī of Bhuj, Gujarat, prepared two identical pieces in 1815 with the shape of a quarter circle (L003 and L004). There is one more such specimen in Jaipur (L017).

In the same city of Jaipur, the Shri Sanjay Sharma Museum & Research Institute owns two *Dhruvabhrama-yantras* which have the form of the full circle (L019 and L020). One of these (L020) resembles an astrolabe in outline. But it has no horizontal slit and it is difficult to sight the two stars α and β UMi in a straight line. The instrument maker engraved on the back a sine quadrant in the middle of the circular surface without providing any edges along the two radii. Consequently no observation can be done with this quadrant either.

The other circular specimen (L019) in the same collection tried to overcome these two difficulties to a certain extent. In the front, above the circle, two triangular holes were created through which the two stars can be observed, but the angle of rotation of the line joining them cannot be measured accurately. The quadrant at the back was more successful. Here the instrument maker filled the circular surface with four quadrants and fixed an alidade for sighting at the centre of the circle. In a compendium at the Victoria and Albert Museum, London (L018), there is one more circular *Dhruvabhrama-yantra*. Here the instrument maker cut a longish slit for observation.

But these variations do not mark any improvement on the oblong form prescribed by Padmanābha. In fact, for a portable instrument to be used also at night, the oblong form provides the optimum of convenience in handling.

7.2. Horizontal slit

Even in oblong plates, some instrument makers dispensed with the horizontal slit (nos. L002, L007, L015, L019 and L020). This does not cause any disadvantage, because the upper edge of the plate can safely be used as the line of reference for observing the stars α and β Ursae Minoris.

7.3. Quadrant on the Back

Padmanābha prescribes a sine quadrant with 30 vertical parallels on the back with which time can be measured in the daytime by observing the sun and at night by observing a star whose meridian altitude is known. Instead of the sine quadrant, several instrument makers engraved a horary quadrant. It is easier to measure time with this in the daytime, because the time can be read off from the point where the plumb line intersects the hour scale of the season, instead of making additional computations as in the case with the sine quadrant. However, unlike the sine quadrant, the horary quadrant cannot be used for measuring time at night. Moreover, the horary quadrant is latitude-specific and cannot be used at all latitudes like the sine quadrant.

7.4. Ghaṭī Scale

Padmanābha prescribes that for the latitude of 24°, the *ghaṭī* scale should be so arranged that the commencement of the 22nd *ghaṭī* should be at the topmost point of the circle, which point is situated under the horizontal slit and closest to it. That is to say, the scales begin at 234° and the 22nd *ghaṭī* commences at 0°.

In three specimens, the *ghaṭī* scale seems to have been adjusted for the latitude. In L001 at the Jaipur Observatory, made presumably for the latitude of 27°, the scale begins at 228° and the 23rd *ghaṭī* commences at the top at 0°. In the two pieces made by Sonī Morarajī (L003 and L004), which he designed for the latitude of 22;30°, the scale begins at 240° and the 21st *ghaṭī* commences at 0°.

In three specimens (L002, L015, L016), the scale begins at 0°, obviously by mistake. In L015, the scale comprises only 48 and not 60 *ghaṭīs*! In L007, there is no distinct *ghaṭī* scale. The remaining specimens follow the arrangement prescribed by Padmanābha.

7.5. Index

Just as the astrolabe-maker shows his artistic skill in the design of the openwork rete of the astrolabe, the maker of the *Dhruvabhrama-yantra* exhibits his artistry in fashioning the multiple-armed index. Several pretty indexes can be seen in the extant specimens. In his two creations (L003 and L004) Sonī Morarjī even reversed the specifications for the pointers: he made the eastern pointer the longest to reach up to the *ghaṭī* scale and the western arm the shortest to reach up to the scale of oblique ascensions. In one specimen (L013) all the arms are made of equal length, which was obviously done by mistake.

7.6. Numerical Tables

Padmanābha enjoins that the names of the 28 lunar mansions and their meridian altitudes should be engraved in scale no. 2 and the names of the lunar mansions and their true polar longitudes in scale no. 5 (DBA 5-6). It is not clear what advantage can be derived from engraving such numerical data (which can be consulted in any book) on the instrument; it would merely make the instrument too cluttered. Nevertheless, several instruments carry such numerical data. In particular Bulhomal of Lahore fills his instrument (L006) with so much data that it becomes, instead of a handy tool, a learned tome of reference which is difficult to consult.

7.6.1. Meridian Altitudes of the Lunar Mansions

Meridian altitudes are engraved on four specimen, viz. L006 (New York, Columbia), L010 (London, Sotheby's), L009 (Pune, Kelkar) and L011 (Varanasi, Banaras Hindu University). L009 carries also the meridian altitudes of the twelve signs.

7.6.2. Polar Longitudes of the Lunar Mansions

These are engraved only on two instruments (L008 and L009). In the latter specimen, there are two sets of polar longitudes, one in scale 2 and the other in scale 5. Strangely there are variations in the two sets. It is also strange that each value in scale 2 ends in 10 minutes. On specimen L001, some other parameters of the lunar mansions are engraved, which are not identifiable.

7.6.3. Tables of Zodiac Signs

Bulhomal's instrument (L006) at Columbia University contains the right and oblique ascensions of the twelve zodiac signs. Sonī Morarjī's two instruments (L003 and L004) carry the oblique ascensions on the back; these values are in *palas.*

7.6.4. Tables of Shadow Lengths

Sonī Morarajī (L003 and L004) incorporates in his two specimens tables of shadows cast by gnomons of 7 and 12 digits at 22;30° N for each 3° of solar altitude.

8. DHRUVABHRAMA-YANTRA FOR USE IN THE DAYTIME

Towards the middle of the nineteenth century, Bulhomal of Lahore made an attempt to modify the *Dhruvabhrama-yantra* for use in the daytime and named his new version *Jyotiḥsattā.* The three extant specimens are described in section U below. Somewhat more successful is the version designed by Joshi Dharm Chand under the name *Āyīnah Falqī* (Mirror of the Heavens) which is discussed in section X.

Index of Dhruvabhrama-yantra of Padmanābha

L001 ◎Dhruvabhrama-yantra & Horary Quadrant, not signed 3473

Not dated, 18th century, 178 x 162 mm, Jaipur, Jai Singh's Observatory

L002 ◎Dhruvabhrama-yantra & Sine Quadrant by Motīrāma for King Kīrticandra, 1707 Śaka (AD 1784-85).. 3479

Wood and ivory, 276 x 240 x 9 mm, Brussels, PC

L003 ◎Dhruvabhrama-yantra & Horary Quadrant by Sonī Moraraјī for Premajī Paṇḍyā at Bhuj, 1872 VS (AD 1815) 3485

Radii: 117, 113 mm; thickness 4 mm, Paris, Observatoire de Paris (# I.A. n°. 1938)

L004 ◎Dhruvabhrama-yantra & Horary Quadrant by Sonī Moraraјī for Premajī Paṇḍyā at Bhuj, 1872 VS (AD 1815) 3494

Radii 118, 114 mm; thickness 4 mm, Oxford, Museum of the History of Science (# 23,600)

L005 ◎Dhruvabhrama-yantra by Rāmanātha Jyotirvid of Kota, 1884 VS (AD 1827) 3496

277 x 232 mm, London, Science Museum (# 1954-703)

L006 ◎Dhruvabhrama-yantra & Sine Quadrant by Bulhomal, 1896 VS (AD 1839-40) 3499

225 x 179 x 2 mm, New York, Columbia University, Butler Library (# 27-254)

L007 ◎Dhruvabhrama-yantra & Sine Quadrant attributable to Bulhomal................. 3508

Not dated, mid-19th century, 116 x 115 mm, London, Victoria and Albert Museum (# IM 11-1915)

L008 Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated......................... 3512

19th century, Silver inlay on a wooden plate, radius 457 mm, Hastings-on-Hudson, NY, Tesseract

L009 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated...................... 3515

Jodhpur, 19th century, 163 x 144 mm, London, Science Museum (# 1990-581)

L010 ◎Dhruvabhrama-yantra & Sine Quadrant made for Yādo Jośī of Ukala-grāma3521

Not signed or dated, 19th century, 112 x 104 mm, Pune, Raja Dinkar Kelkar Museum (# KM 31-13)

L011 Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated......................... 3530

19th century, 222 x 220 mm, PLU; ex-London, Sotheby's 2010

L012 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated...................... 3535

19th century, 155 x 131 mm, Varanasi, Banaras Hindu University, Bharat Kala Bhavan (# 3/9490)

L013 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, 1935 VS (AD 1878-79).. 3539
236 x 226 mm, Jaipur, PC

L014 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated 3542
Copper, 193 x 175 x 3 mm, Jaipur, Museum of Indology

L015 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated 3545
19th century, Copper, 160 x 159 mm, New Delhi, National Museum (# 56.155/4)

L016 Dhruvabhrama-yantra, not signed, not dated 3549
19th century, Dimensions ?, PLU; ex-Marblehead, Mass, USA

L017 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated 3551
19th century, Radius 384 mm, Jaipur, PC

L018 ◎Dhruvabhrama-yantra, not signed, not dated 3554
19th century, Diameter 132 mm, London, Victoria & Albert Museum (# 471.5-1924)

L019 ◎Dhruvabhrama-yantra & Horary Quadrant, not signed, not dated 3555
19th century, Diameter 242 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

L020 ◎Dhruvabhrama-yantra & Sine Quadrant, not signed, not dated 3559
19th century, Inferior metal, diameter 147 mm, height 177 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

L021 ◎Dhruvabhrama-yantra, not signed, not dated 3562
20th century, 141 x 119 x 2.5 mm, Vadodara, M. S. University of Baroda, Sanskrit Mahavidyalaya

L022 Dhruvabhrama-yantra by Sakhārāma Jośī, 1790-96 3564
Dimensions ?, PLU

L023 Dhruvabhrama-yantra exhibited at the Lahore Exhibition 1864 3565
Dimensions ?, PLU

L024 ◎Shabnumā-wa-Rūznumā by Nadhīr al-Dīn Ḥussayn, 1218 AH (AD 1803) at Bareilly 3566
Copper, 178 x 174 mm, Patna, Khuda Bakhsh Oriental Public Library

L025 ◎Shabnumā-wa-Rūznumā by Mīrzā Faḍl ᶜAlī ᶜĀmil 3575
19th Century, Painted wood, 263 x 255 x 9 mm, Rampur, Rampur Raza Library (# 9395)

M. PHALAKA-YANTRA OF BHĀSKARA II

INTRODUCTION

Bhāskara II, who is popularly known as Bhāskarācārya, announces his invention of the *Phalaka-yantra* in the following words in his *Siddhānta-śiromaṇi* of 1150:

> Because others have not attempted to determine the apparent time (*sphuṭa-kāla*) easily from the vertical circle passing through the zenith and the planet (*dṛṅ-maṇḍala*), I have done so. I shall now explain lucidly the instrument named *Phalaka-yantra* which represents the essence of all computations (*gaṇitasya sāra*) pertaining to the true principles of Spherics (*sadgola-yukti*).[1397]

The instrument, according to his description,[1398] consists of a rectangular board measuring 180 x 90 units (*aṅgula*). A chain (*śṛṅkhalā*) is attached at the centre of the long side with which the plate can be suspended in the vertical plane. From the place of the chain a vertical line (*lamba*) is drawn which divides the plate in two equal halves. Perpendicular to this vertical line are drawn 90 equidistant horizontal parallels, called sines (*jīvā*). At the middle of the 30th sine-line is inserted a pin (*śalākā*), which is designated as the axis (*akṣa*). With the pin as the centre, a circle is drawn with a radius of 30 units and the circle is divided in 60 *ghaṭikās* and 360 degrees. To the pin is pivoted an index, 60 units long and divided in 60 parts. The instrument is used first to measure the altitude of the sun by direct observation and then to ascertain graphically the corrections for ascensional difference in order to determine time.[1399]

This *Phalaka-yantra* is a forerunner of the sine quadrant and was eclipsed by the latter when it was introduced into India in the following centuries from the Islamic world. Therefore, very few astronomers seem to have used the *Phalaka-yantra* for actual

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1397 Bhāskarācārya, *Siddhānta-śiromaṇi, Golādhyāya, Yantrādhyāya,* verse 16:
dṛṅmaṇḍale 'tra sphuṭakāla uktaḥ sukhena nānyair yatitaṃ mayātaḥ |
sadgolayukter gaṇitasya sāraṃ spaṣṭaṃ pravakṣye phalakākhyayantram ||
See also Sarma 2019.

1398 Bhāskarācārya, *Siddhānta-śiromaṇi, Golādhyāya, Yantrādhyāya,* verses 16-27.

1399 On the exact procedure and its rationale, see Wilkinson & Sastri 1861, pp. 213-218; Rai 1985, pp. 328-332; Ôhashi 1994, pp. 286-290, Fig. 53.

observation. There exist just four specimens, or rather - reports of three specimens being made between 1790 and 1876 and a photo of an astrolabe of 1895, on the back of which a *Phalaka-yantra* is incorporated.

The *Phalaka-yantra* is also represented, among others, on five compendia; these will be discussed in section V below (Figure V002.6, Figure V004.1, Figure V005.4 and Figure V006.4).

Index of Phalaka-yantra of Bhāskara II

M001 Phalaka-yantra by Sakhārāma Jośī, 1790-96 3585

Dimensions ?, PLU

M002 Phalaka-yantra exhibited at the Lahore Exhibition 1864.................................. 3586

Dimensions ?, PLU

M003 Phalaka-yantra presented by the Maharaja of Benares to the Prince of Wales, 1876.. 3587

Dimensions ?, PLU

M004 Phalaka-yantra engraved on the back of an Astrolabe designed by Gaṅgāsahāya and made by Rāmapratāpa.. 3588

1895, Tonk, Rajasthan, Diameter 334 mm, PLU

N. PALABHĀ-YANTRAS & EQUINOCTIAL SUNDIALS IN SANSKRIT

INTRODUCTION

Every culture must have made use of the shadow cast by the gnomon, i.e. a straight stick erected vertically on a level ground, to measure time. The simplest form of the gnomon is that of a man standing upright and his shadow indicating the time. A reminiscence of this practice can be seen in the Sanskrit terms *nara-bhā* or *nṛ-bhā* employed in the sense of the 'gnomon shadow' but whose literal meaning is the 'shadow of a man (*nara, nṛ*); and also in the terms *pauruṣī* (man's length) and *tripauruṣī* (thrice man's length) employed to describe the shadow in Kauṭilya's *Arthaśāstra* which will be discussed below. Likewise the custom of mentioning the height of the gnomon as seven feet in Islamic astronomy goes back to a period when the human body was used as the gnomon and the ideal height of a man was considered to be seven times the length of his foot.

From such simple sticks erected on the ground, sundials evolved gradually which consist of a gnomon that casts a shadow upon a graduated dial on which the position of the shadow is translated into units of time. This basic form gave rise to diverse varieties in the course of centuries, some with vertical gnomons and horizontal dials, others with horizontal gnomons and vertical dials or curved dials and so on.

SUNDIALS IN ANTIQUITY

The earliest extant sundials are two fragments from Egypt, datable to about 1500 and 1000 BC respectively. Sundials were also cultivated in Greek antiquity, but more actively in the Roman empire, where large decorative sundials were set up at public places and in private palaces.[1400] The Roman engineer Vitruvius describes as many as fifteen different kinds of sundials in his book *Architectura.*[1401] Sharon L. Gibbs, in her pioneering study of 1976, *Greek and Roman Sundials,* described 257 sundials.[1402] Subsequently several more were discovered. About five hundred specimens are said to

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[1400] Turner 1998; see also Turner 1993c.

[1401] Vitruvius, Book IX, chs. 8-9.

[1402] Gibbs 1976.

exist today in various collections. These Greek and Roman sundials display seasonal hours.

A large number of these dials have the shape of a half-cone with the gnomon affixed at the vertex of the cone and the dial engraved on the concave surface, in such a way that the axis of the cone is parallel to the axis of the earth. The hour lines radiating from the vertex are intersected by three concentric semi-circles which are parallel to the equator; the lowermost semicircle represents the summer solstice, the one in the middle the equinoxes and the upper semi-circle the winter solstice.[1403] An example can be seen in Figure N.1 below which shows a Roman sundial excavated at Athens.

Figure N.1 – Roman sundial at the National Archaeological Museum, Athens (photo by S. R. Sarma)

[1403] Catamo et al 2000.

Christian monasteries adopted the sundial for indicating the times of their prayers from the fifth century onwards. The individual prayers offered in the daytime are named after the respective hours: Matins (before dawn); Prime (at sunrise); Terce (third hour after sunrise); Sext (sixth hour after sunrise); None (ninth hour after sunrise); Vespers (sunset) and Nocturnes (after sunset in the night). To facilitate these prayers, vertical sundials with horizontal gnomons were added to the south-facing walls of churches. Since the prayers called Terce, Sext and None were particularly important, crosses were added to the third, sixth and ninth hour-lines. Sometimes, only these three hours lines are marked on the dial and the rest are omitted. Such specimens are called ‘mass dials’ or ‘tide dials’. There are said to be some 3000 specimens surviving in the UK.[1404]

As Islam spread in the seventh century into areas which were formerly under the Greco-Roman domain, and as the Muslim astronomers came into contact with Greco-Roman sundials, they began to modify them by adding lines to indicate the times of Islamic prayers. Thus some highly sophisticated sundials were created in the Islamic world, some of which were transmitted westwards to Europe and eastwards to India. The development of these Islamic sundials will be discussed in the introduction to the section Q on the Indo-Persian sundials.

In Europe, after the development of mechanical clocks, seasonal hours were gradually replaced by the equal hours in the religious and civil life from the fourteenth century onwards, and the sundials also were marked in equal hours.

In the St. Mary’s Church in the small German town of Homberg an der Efze, the walls are adorned both with a tide dial (‘Gebetsuhr’ in German) (Figure N.2) and a dial marked with equal hours (Figure N.3); the former is equipped with an horizontal gnomon and the latter with an inclined gnomon. The church was constructed originally in the fourteenth century, but many additions and modifications were made in the subsequent centuries. Therefore, it is not possible to date either of the dials accurately. However, the hour-lines in the common sundial are numbered with a mixture of the Roman (I, V, VI, VII, VIII, X, XI, XII) and the so-called Arabic (2, 3, 4) numerals; such a combination can be dated to the late sixteenth or seventeenth century.

[1404] Rumley.

Figure N.2 – Tide Dial in the St. Mary's Church, Homberg an der Efze
(photo by Dr Klaus Lambrecht - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/wiki/File:Untere_Gebetsuhr.jpg
[also: https://goo.gl/jrTXy8, last accessed in December 2017]

Figure N.3 – Sundial marked with equal hours in the St. Mary's Church,
Homberg an der Efze (photo by S. R. Sarma)

Even though the production of mechanical clocks gradually gained importance in later centuries in Europe, sundials continued to be produced in great numbers, either as stationary objects for the decoration of urban spaces or tombstones, or as small portable items of diverse designs and in diverse materials.[1405]

SUNDIALS IN INDIA

Gnomon in Kauṭilya's Arthaśāstra

In India, the first mention of measuring time by means of the shadow cast by the sun occurs in the *Arthaśāstra* of Kauṭilya which was composed and redacted between the second century BC and the third century AD. Kauṭilya lays down that a king should divide his day into eight parts and the night into another eight parts, by means of the water clock (*nālikā*) or by the length of the gnomon's shadow (*chāyā-pramāṇa*), and devote each part for a specific administrative or personal task.

> 'He should divide the day into eight parts as also the night by means of *nālikās,* or by the measure of the shadow (of the gnomon). (A shadow measuring three *pauruṣas,* one *pauruṣa,* (and) four *aṅgulas* and the midday when the shadow disappears are the four eighth parts of the day. By them are explained the later (four).'[1406]

The water clock will be discussed in section R below. The simplest form of the gnomon is that of a man standing upright and his shadow indicating the time and this is suggested by the terms *pauruṣī* and *tri-pauruṣī.* But probably Kauṭilya envisages an actual gnomon in the form of a straight wooden stick erected vertically on the level ground with markings on the ground which divide the time between the sunrise and sunset into eight parts.

From the *Brāhma-sphuṭa-siddhānta* of Brahmagupta (AD 628) onwards, Sanskrit texts of the type *Siddhānta,* usually devote the third chapter for the gnomonics; the chapter is entitled *Tri-praśna-adhyāya* (chapter on three questions or topics) and

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1405 On the variety and classification of the European sundials, cf. Higgins 1953; Zinner 1979, pp. 46-135; Turner 1993c.

1406 Kauṭilya, *Arthaśāstra*, 1.19.6-8: *nālikābhir ahar aṣṭadhā rātriṃ ca vibhajet chāyā-pramāṇena vā* | *tripauruṣī pauruṣī caturaṅgulā naṣṭacchāyo madhyāhna iti catvāraḥ pūrve divasasyāṣṭabhāgāḥ* | *taiḥ paścimā vyākhyātāḥ* | translation by Kangle; see also Abraham 1981.

discusses the determination of *diś* (cardinal direction), *deśa* (locality, i.e., terrestrial latitude) and *kāla* (time) by means of the gnomon (*śaṅku*). As in the *Arthaśāstra,* here also a straight staff is set up temporarily on a level ground on which lines are drawn for the determination of the three parameters. The staff, whatever may be its actual length, is divided into 12 *aṅgulas*, and this unit of length is employed in measuring the shadow.

The *Brāhma-sphuṭa-siddhānta* describes several other instruments of permanent nature in the twenty-first and twenty-second chapters and so do several subsequent texts. Although many types of instruments are described in these texts for measuring time by the sunlight, those that are represented by extant specimens are just three:[1407] the horizontal dial with a triangular gnomon (*Palabhā-yantra*), the column dial with a horizontal gnomon (*Kaśā-yantra*) and the graduated ring in which sunlight enters through an aperture (*Cūḍā-yantra*). These are relatively late and are described in Sanskrit texts only from the fifteenth century onwards. Besides these three varieties of Sanskrit sundials, there are extant a few Indo-Persian sundials. The horizontal dials will be described in the present section N, the ring dials in section O, the column dials in section P and the Indo-Persian dials in section Q.[1408]

PALABHĀ-YANTRA

In the *Palabhā-yantra,* the horizontal sundial with a triangular gnomon, the hypotenuse of the gnomon points to the north pole. About its origin Berggren writes as follows:

> 'A surprising feature of Ibn al-Shatir's dial (made in the second half of the fourteenth century for the Umayyad Mosque in Damascus) was that its gnomon was parallel to the polar axis. In fact, it was inclined to the horizon at an angle of 33½°, a common medieval value for latitude of Damascus. This was the first known proof that it was the Muslims, and not the

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[1407] The great diversity noticeable in the innumerable sundials extant in Europe and the much greater complexity of design presented in the Arabic texts such as the one by al-Marrākushī is not reflected either in the Sanskrit texts or in the extant specimens.

[1408] The reason for this arrangement is purely pragmatic (and not chronological) so that the smallest number of specimens receives the code numbers beginning with O (which so closely resembles 0).

> Europeans of the Renaissance, who introduced the sundial with the gnomon aligned to parallel the earth's axis.'[1409]

However, the horizontal dial in Ibn al-Shāṭir's sundial is highly complex and is unlike the simple dials found in India or in Europe. On the other hand, no other Islamic sundial has been discovered which corresponds to the Indian or European horizontal dials. Even so, it is fairly certain that the original prototype was developed in the Islamic world and thence transmitted westwards to Renaissance Europe and eastwards to India. Because of the simplicity of construction, it was produced hundreds of times in Europe and also in North America, where it became a popular garden ornament.

In India it was absorbed in the Sanskrit repertoire of instruments under the title of *Palabhā-yantra.* Here *palabhā* denotes the noon equinoctial shadow, i.e., the length of the shadow thrown at noon by a gnomon of 12 units (*aṅgulas*) on the days of the equinox. The length of the shadow is dependent on the latitude of the place. A *palabhā-kṣetra* then is a right triangle where the length of the shadow forms the base and the height of the gnomon (i.e. 12 digits) the vertical. The hypotenuse of this triangle subtends an angle which is equal to the terrestrial latitude of the place. The *Palabhā-yantra* is a horizontal sundial on which a triangular gnomon is set up in a plane perpendicular to that of the dial. The gnomon has the form of the *palabhā-kṣetra,* where the angle between the base and the hypotenuse is equal to the terrestrial latitude of the locality.

For measuring time, the instrument is so set up that the gnomon rests on the north-south line. Then the hypotenuse will point to the celestial north pole and its surface will become parallel to the earth's axis. The shadow of the gnomon will follow the sun's passage across the sky and show the time on the horizontal dial. For this purpose the dial is divided into time units, either in the traditional units of *ghaṭīs* (= 24 minutes) and *palas* (= 24 seconds), or in modern units of hours and minutes. These units will be unequal when projected on a horizontal dial. Since the gnomon is fashioned according to the terrestrial latitude of a specific locality, it can be used only on that latitude, and not elsewhere.

1409 Berggren 2001, p. 12, where a sketch of Ibn al-Shāṭir's dial is reproduced.

The *Palabhā-yantra* is described probably for the first time in the *Yantraprakāra* which was compiled between 1716 and 1724 at the court of Sawai Jai Singh of Jaipur.[1410] This text teaches how to calculate the angles between the hour-lines on a horizontal dial for the latitude of Delhi at 28;39° and for that of Amber at 27°. In 1771 Nandarāma Miśra of Kāmyakavana (Kamon, near modern Mathura in UP) described the instrument in twelve verses at the beginning of his *Yantrasāra.* While the *Yantraprakāra* offers a trigonometric formula for computing the angles between the hour lines, Nandarāma teaches a geometrical procedure.[1411] Around 1799-1800 Viśveśvara Mahāśabda Puṇḍarīkayājin composed a *Palabhā-yantra*.[1412]

Palabhā-yantra in the Yantraprakāra

The Yantraprakāra describes the Palabhā-yantra thus:[1413]

> 'Now the method of the *Palabhā-yantra.* Multiply the shadow cast by a horizontal gnomon (*viloma-cchāyā*) at any given hour angle (*nata-kāla*) by the Rsine of the local latitude (*akṣa-jyā*) and divide by the Radius (*tri-jyā*). For the result thus obtained, locate the corresponding arc in degrees in the table of shadows cast by the horizontal gnomon (*vilomacchāyā-sāraṇī*). These will be the degrees of horizon (*kṣitijāṃśa*).[1414]
>
> 'Example. In Delhi, the latitude is 28;39°. [Let] the hour angle be 1 *ghaṭī* which is equal to 6°. Its tangent (*vilomacchāyā*) is 1;18,22,30. This is multiplied by the Rsine of the latitude 28;46,2,53,52 and divided by Radius 60. The quotient is 3;1,24,53,31,8. The arc corresponding to this in the table

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1410 Sarma 1986-87b, pp. 26 (text), 76-77 (translation and commentary).

1411 Unpublished. I use MS Nos. 851/1884-87 (copied in 1802) and 504/1892-95 (copied in 1830) of the Bhandarkar Oriental Research Institute, Pune. Independent manuscripts containing just the *Palabhā-yantra* from Nandarāma Miśra's *Yantrasāra* are also in circulation. Thus 9223 of the Oriental Institute, Vadodara, and 2672 of the Rajasthan Oriental Research Institute, Udaipur, contain the extract on the *Palabhā-yantra* from the *Yantrasāra* without identifying it as such. The latter manuscript contains several other texts on instruments. Manuscript no. 3185 of the Oriental Institute, Vadodara, offers the same trigonometric formula as the *Yantraprakāra,* but in six verses.

1412 Cf. Pingree 2003, p. 126, no. 243.

1413 Cf. Sarma 1986-87b, pp. 76-77; slightly modified.

1414 This can be expressed as $\tan \alpha = \sin \varphi \,.\, \tan \beta$, where α is the angle between the hour line and the horizon, and β the time unit expressed as arc degrees.

of tangents is 2;53°. These are degrees of horizon (*kṣitijāṃśa*), i.e., the angle between the horizon and the line for the first *ghaṭī.* Thus calculate the angles for each *ghaṭī,* or half *ghaṭī,* or quarter *ghaṭī,* or any other fraction thereof. Then draw a circle of any radius on an even ground. On it mark the cardinal points. Graduate the circle in degree and minutes. [In the circle], mark off the degrees obtained in the computation from the horizon (i.e., the east-west line) onwards. Draw a line from the centre up to that mark. This is the line of the first *ghaṭī.* Thus draw lines for each *ghaṭī.*

Next set up a [triangular] gnomon on the north point of the circle [in such a way that] from the foot of the gnomon up to the centre of the circle lies the base of the equinoctial triangle (*palabhā-bhuja*), from the top of the gnomon up to the centre is the equinoctial hypotenuse (*chāyā-karṇa*). Or [let] the Rsine of latitude (*akṣa-jyā*) be the base, Rsine of the colatitude (*lamba-jyā*) the perpendicular and Radius (*tri-jyā*) the hypotenuse. Prepare such a triangle and set it up there. The hour angle, expressed in *ghaṭīs,* at any moment is measured from the point where the shadow of the triangle, so set up, falls on the circle, up to the line of midday (*madhyāhna-rekhā*) (i.e., up to the north point).'

'Here is the table of *Palabhā-yantra* for the latitude of Delhi (*Indraprastha*) [at 28;39° and for the latitude of Amber (*Ambāvatī*) at 27°].'

Hour angle in *ghaṭikās*	**Degrees of horizon**	
	Delhi	Amber
1	2;53	2;45
2	5;59	5;34
3	8;51,30	8;29
4	12;3	11;33
5	15;28,30	14;50,30
6	19;12,45	18;27
7	23;21	22;27,30
8	28;2	27;1
9	33;25,30	32;17,30
10	39;25,30	38;29,50

11	47;7	45;53
12	55;52,30	54;43
13	66;5,30	65;9,30
14	77;38	77;7
15	90;0	90;0

Extant Specimens of the Palabhā-yantra

The instrument appears to have been popular in Rajasthan. Since the present study is limited to museum specimens, I did not explore the *Palabhā-yantras* set up in public places, except in a few cases. In Sawai Jai Singh's Observatory at Jaipur, a *Palabhā-yantra* is incorporated at the top of the *Nāḍīvalaya-yantra* (N001). The Observatory also owns a *Palabhā-yantra* made by Gokula Nātha Śarmā in 1882 (N005).

Elsewhere in Jaipur there are other specimens in the Maharaja Man Singh II Museum, in the Sanjay Sharma Memorial Museum and in the Museum of Indology. In Amber Fort near Jaipur, there is a *Palabhā-yantra.* There is also one in the Jaisalmer Fort (N004). The Rao Madho Singh Museum of Kota has two *Palabhā-yantras* in stone, presumably designed for the latitude of Kota (N011 and N012).[1415] There must have been several others erected in public places. In a few cases, these have been removed and preserved in museums. But a large majority must have been irretrievably lost.

The *Palabhā-yantras* made in the eighteenth century were engraved with lines to measure time in *ghaṭīs* (N001). But gradually these yielded place to sundials with hour-lines in the nineteenth century. The *Palabhā-yantra* in Jai Singh's Observatory at Ujjain (N002), like the one at the Observatory at Jaipur (N001), must have been engraved originally with lines to measure *ghaṭīs,* but in course of repairs the original marble dial was replaced by another carrying hour lines.

1415 Cf. Sharma 2000, pp. 233-244, esp. 243-244, figs. 6-7.

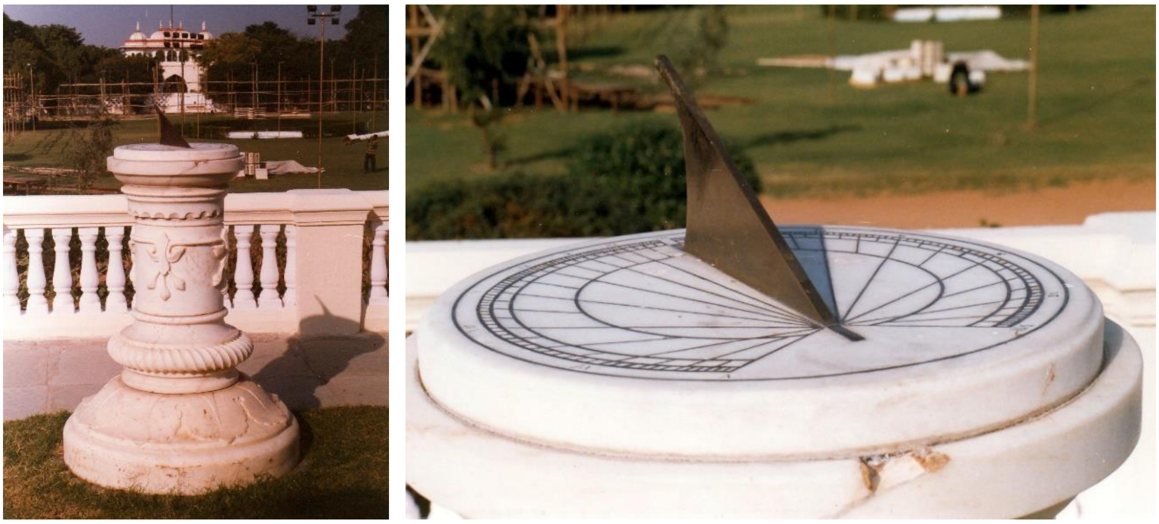

Figure N.4 – English sundial at Sujan Rajmahal Palace Hotel, Jaipur, former Residency of the British Political Agent (photos by S. R. Sarma)

English Colonial Sundials

During the British colonial times, many sundials were set up with horizontal dials and triangular gnomons; these resembled the *Palabhā-yantras* in design, but carried lines to measure hours which are numbered either in Roman numerals or in modern international numerals. One of the earliest such sundial was set up in 1784 at the British garrison in the Chunar Fort near Allahabad. There is one in the residency of the British Political Agent who represented the British Governor-General at the Princely State of Jaipur, which is now converted into a hotel (Figure N.4). Similar English sundials are to be found in the British Viceroy's summer residence at Shimla (now converted into the Indian Institute of Advanced Study), in the Allahabad Fort and many other places. Since these do not belong to the traditional repertoire of Indian astronomical instruments, these are not included in this catalogue.

Palabhā-yantra as Urban Sculpture

Following the European fashion, large sundials are being set up as urban sculptures in public places. In the Inter-University Centre for Astronomy and Astrophysics (IUCAA) at Pune, there are sculptures of 'Isaac Newton under an Apple Tree' and of Bhāskarācārya, besides a clumsy imitation of Sawai Jai Singh's equinoctial sundial *Samrāṭ-yantra.* There are said to be also sundials set up as army memorials. A notable specimen is a sundial in the shape of the *Palabhā-yantra* set up recently near the Barapullah Flyover in New Delhi by the Delhi Development Authority (DDA). In this sundial, the brass gnomon has a height of 12.7 metres and a length of 24.5 metres.

The hour lines are laid out in coloured marble and numbered in large Devanagari numerals.

Figure N.5 – Sundial near Barapullah Flyover, New Delhi (photo by Debasish Das)

Mention may also be made, in this connection, of a sundial set up in Antwerp in Belgium. It was designed by the artist Hubert Minnebo. Its connection to India lies in the fact that the well-travelled artist who spent several years in India and Nepal, numbered the hours in large nicely shaped Devanagari numerals.

Figure N.6 – The sundial with Devanagari numerals (left); the artist Hubert Minnebo, the central figure at the base of the gnomon (right) (photos courtesy Jan de Graeve)

EQUINOCTIAL SUNDIALS

In the *Palabhā-yantra,* the *ghaṭī* lines or the hour lines on the dial are not equally spaced around the gnomon. The angles have to be calculated separately for each line. This problem is overcome in the equinoctial (also called equatorial) sundials where the dial plate is parallel to the plane of the equator and the gnomon, which points to the pole, is perpendicular to it. In Jai Singh's Observatories, two masonry instruments, viz. the *Nāḍī-valaya-yantra*[1416] and the *Samrāṭ-yantra*[1417] are constructed on this principle. Moreover, in the *Samrāṭ-yantra* the gnomon is shaped like a right triangle with its hypotenuse pointing to the north pole. There exist two large portable specimens made in the style of the *Samrāṭ-yantra,* which appear to have been created at the time of Sawai Jai Singh (N015 and N016). The Adler Planetarium at Chicago holds an equinoctial sundial with Devanagari numerals which is clearly modelled after a European specimen (N017).

1416 Sharma 2016, pp. 171-173.

1417 Sharma 2016, pp. 97-101, 133-141.

Index of Palabhā-yantras & Equinoctial Sundials in Sanskrit

N001 ◎Palabhā-yantra set up on top of the Nāḍīvalaya-yantra 3607
Ca. 1734, Diameter 763 mm, Jaipur, Jai Singh's Observatory

N002 Palabhā-yantra set up on top of the Dakṣiṇottara-bhitti-yantra 3608
Ca. 1734, Diameter 460 mm, Ujjain, Jai Singh's Observatory

N003 Palabhā-yantra by Lehna Singh Majithia, 1909 VS (AD 1852) 3610
Dimensions ?, Amritsar, Golden Temple

N004 Palabhā-yantra by Gajadhar Sarūp Khemāṇī, 1916 VS (AD 1859) 3613
Diameter 365 mm, Jaisalmer Fort, Raj Mahal Palace Museum

N005 ◎Palabhā-yantra by Gokulanātha Śarmā, 1939 VS (AD 1882-83) 3615
Diameter 238 mm, Jaipur, Jai Singh's Observatory

N006 ◎Palabhā-yantra, not signed, not dated 3617
19th century, Diameter ca. 400 mm, Jaipur, City Palace, Maharaja Sawai Man Singh II Museum

N007 Palabhā-yantra, not signed, not dated 3618
19th century, Diameter ?, Jaipur, Museum of Indology

N008 ◎Palabhā-yantra, not signed, not dated 3619
19th century, Diameter 213 mm, Jaipur, Museum of Indology

N009 ◎Palabhā-yantra, not signed, not dated 3620
19th century, Diameter 404 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

N010 ◎Palabhā-yantra, not signed, not dated 3621
19th century, Diameter ca. 200 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

N011 Palabhā-yantra, not signed, not dated 3622
19th century, Dimensions?, Kota, Rao Madho Singh Museum

N012 Palabhā-yantra, not signed, not dated 3623
19th century, Dimensions?, Kota, Rao Madho Singh Museum

N013 ◎Palabhā-yantra, not signed, not dated 3624
19th century, 490 x 490 mm, Varanasi, Banaras Hindu University, Bharat Kala Bhavan

N014 ◎Palabhā-yantra, not signed, not dated 3625
Early 20th century, 170 x 112 x 3 mm, Vadodara, M. S. University of Baroda, Sanskrit Mahavidyalaya

N015 ◎Equinoctial Sundial, not signed, not dated... 3626
Early 18th century, Height ca. 1800 mm, Jaipur, Jai Singh's Observatory

N016 ◎Equinoctial Sundial, not signed, not dated 3628

Early 18th century, Diameter of the base ca. 500 mm, PLU; ex-Rockford, Time Museum (# 1174)

N017 ◎Universal Equinoctial Sundial, not signed, not dated 3630

19th century, Inner diameter of the base 530 mm, Chicago, Adler Planetarium (# A-256)

O. CŪḌĀ-YANTRAS

INTRODUCTION

In a ring dial, a small hole in the breadth of the ring allows the sunlight to pass through and fall upon the inner concave surface on the opposite side, which is graduated in degrees to measure the altitude. Local time can also be measured directly if the inner surface is provided with separate scales for each solar month, and each scale is divided into so many *ghaṭīs* as there are in a half day (from the sunrise to the noon) in that month.

In India, the ring dial was first described by Āryabhaṭa about the beginning of the sixth century in his *Āryabhaṭa-siddhānta*. He calls it *Cakrayantra* and recommends that its circumference be divided in 360 degree and that two holes are made in the breadth at diametrically opposite points.[1429] The instrument is described by Varāhamihira also, in the middle of the sixth century, in his *Pañcasiddhāntikā*. He does not give it a name, but provides only a single hole and intends it to be used for measuring the sun's meridian zenith distance:

> Take a circular hoop, on whose circumference the 360 degrees are marked, whose diameter is equal to one *hasta*, and which is half an *aṅguli* broad. In the middle of the breadth of that hoop make a hole. Through this small hole made in the circumference allow a ray of the sun at noon to enter in an oblique direction. The degrees, intervening at the lower half of the circle between (the spot illumined by the ray and) the spot reached by a string hanging perpendicularly from the centre of the circle, represent the degrees of the zenith-distance of the midday sun.[1430]

Of course, a string cannot be suspended from the 'centre' of a ring, but a string let down from the topmost point of the ring will pass through the notional centre and represent the vertical.

[1429] Cf. Shukla 1967, pp. 93, 98; see Ôhashi 1994, pp. 236-238.

[1430] *The Pañcasiddhāntikā of Varāhamihira*, ed. tr. G. Thibaut and Sudhakara Dvivedi, Varanasi 1968, 2nd. ed., 14.21-22, p. 80; see Ôhashi 1994, pp. 238-239.

Rāmacandra Vājapeyin, in his *Yantraprakāśa* of 1427, describes three varieties of the ring dial, viz. *Valaya* (circle), *Cūḍā* (bracelet) and *Mudrikā* (finger- or signet-ring).[1431] All the three work on the same principle, but differ in size as their names suggest. Rāmacandra prescribes that the *Valaya-yantra* should measure a cubit in its diameter, the *Cūḍā-yantra* a span or less, and the *Mudrikā-yantra* much smaller. The inner concave surface is graduated in *ghaṭīs* for measuring time and the rim in 360 degrees for measuring altitudes.

Of the three sizes, the middle one, viz. *Cūḍā-yantra*, appears to have been more popular; it is represented in several Mughal miniatures, where it corresponds to this size.[1432] In these paintings, the astronomers/astrologers are depicted in majority of cases holding a small ring dial to measure the solar altitude, and not the astrolabe as one would have expected. Because of its frequent occurrence in paintings depicting the Mughal court, one is apt to think that it may have been of Islamic origin. But according to competent authorities on Islamic astronomical instruments whom I consulted, the ring dial was not known to the Islamic world.[1433]

In Europe, there is a similar instrument called ring dial or Bauernring in German. It is said to have been invented by George Peuerbach (1423-1461) and improved upon by his pupil Regiomontan (1436-1476). It was very popular until the nineteenth century, especially in Austria, but it is small in size like the signet ring.[1434] Since the ring dial was not known to the Islamic world, there does not seem to be any connection between the European ring dial and the Indian *Cūḍā-yantra*.

The Yantra-prakāra of Sawai Jai Singh

The *Yantraprakāra*, which Sawai Jai Singh caused to be compiled before designing the huge masonry instruments for accurate observation, contains not only a detailed description of the *Cūḍā-yantra*, but also an elaborate set of tables to be used in conjunction with this instrument (*Cūḍāyantrasya Sāraṇī*). There are 19 separate tables,

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1431 Rāmacandra Vājapeyin, *Yantraprakāśa*, 6.9-13, Ms 975/1886-92 of the Bhandarkar Oriental Research Institute, Pune, ff. 61-62.

1432 Sarma 1992a.

1433 Professors E. S. Kennedy (Princeton) and David A. King (Frankfurt).

1434 Zinner 1979, pp. 120-122, Pl. 45.2; Price 1957, p. 598, fig. 351.

one for each decan of the zodiac, prepared for the latitude of Delhi (28; 39°).[1435] Here, the construction is explained thus:

> ‘Now the method of constructing the instrument. Prepare a [cylindrical] ring of any diameter, the height [of the cylinder] being 4 *aṅgulas* or 5 *aṅgulas* or any other amount. With a tool, file the ring so that it becomes circular, even and smooth all around. Then at any point of the upper part, affix a crown (*kirīṭa*) with an aperture in it. Pass a plumb line through the aperture. By dropping the plumb line, draw a vertical line on the rim (*pāli*) of the ring. Also an east-west (horizontal) line. Then each quarter of the rim should be graduated in 90 degrees. Thus there will be 360 degrees on the rim of the instrument.
>
> ‘Then on both sides of the crown, at any distance from it, draw the line of horizon, keeping, however, in mind that the distance from one horizon to the other should be slightly less than four times the maximum altitude [of the sun] at midday at that place. Then one horizon should be marked as southern *gola* and the other northern.
>
> ‘Along the inner [concave] surface of the instrument, draw as many circum-parallel lines as the groups into which one wishes to classify the day-lengths (*abhīṣṭa-dinakhaṇḍa-saṃkhyāka*). Below the northern horizon, mark the southern half-days (*yāmya-dyudala*). Below the southern horizon, mark the half-days belonging to the northern *gola.* Calculate the degrees of altitude corresponding to each *ghaṭikā* after the sunrise (*uannata-ghaṭikā*), take double the degrees and mark these as 1, 2, etc., for each half-day in the corresponding circle. These then will be the marks of the desired *ghaṭikās* in the instrument.
>
> ‘Next make an aperture in the line of horizon. Write down the name ‘northern *gola*’ both inside and outside above the half-days of the southern *gola,* near the aperture. Likewise write down the name ‘southern *gola*’ both inside and outside the northern *gola.*

1435 Sarma 1986-87b, pp. 27-28 (text), 79-82 (translation), 105-114 (tables).

> ‘Hold the thread of the crown in the hand and manipulate it so that, in whichever *gola* the sun is situated, the aperture belonging to that *gola* faces the sun. When this is done, the point where the sunlight, passing through the aperture, falls on the corresponding half-day circle indicates the time in *ghaṭikās* from the sunrise. Thus [ends] the construction of the ring/bracelet (*valaya*) instrument.’

Extant Specimens

Compared to horizontal and vertical sundials, the ring is more difficult to construct and also more difficult to use. It is probably for this reason, very few specimens are extant; in fact there exist just three. Two of these are preserved in Jai Singh’s Observatory at Jaipur. These must have been made for Jai Singh himself in the first quarter of the eighteenth century at Jaipur. The third one, of an inferior make, is with the Museum of Indology at Jaipur.

Index of Cūḍā-yantras

O001 ◎Cūḍā-Yantra, not signed, not dated 3639

Early 18th century, Diameter 129 mm, height 88 mm, Jaipur, Jai Singh's Observatory

O002 ◎Cūḍā-Yantra, not digned, not dated 3642

Early 18th century, Diameter 101 mm, height 49 mm, Jaipur, Jai Singh's Observatory

O003 ◎Cūḍā-Yantra, not signed, not dated 3644

19th century, Diameter 73 mm, height 16 mm, Jaipur, Museum of Indology

P. SANSKRIT COLUMN DIALS

INTRODUCTION

The column dial, also known as cylindrical sundial, consists of a straight wooden staff with a circular or prismatic cross-section; it is divided lengthwise into several columns or facets, each carrying a separate scale of *ghaṭīs* for measuring time in a particular season or solar month. The *ghaṭīs* are numbered serially from the top to the bottom according to the length of the half-day from sunrise to noon or noon-sunset in that particular season. In the upper part, just above the scale, there is a hole in each facet into which a horizontal gnomon is inserted which throws its shadow upon the scale below when the staff is set up vertically, either by suspending it or by pushing the lower end firmly into the ground. Suspension is preferable because then the staff will automatically assume a vertical position; when it is pushed into the ground, a plumb line becomes necessary to see that the staff is really in a vertical position.

For measuring time, the horizontal gnomon is inserted into the hole above the scale meant for the current solar month and the staff turned slowly towards the sun so that the gnomon throws its shadow exactly on the scale below.[1436] Where the end of the shadow touches the numbered scale, the number indicates in the forenoon the *ghaṭīs* that have elapsed since the sunrise, and in the afternoon, the number of *ghaṭīs* that are to elapse up to the sunset. Thus, if the shadow shows 5 on the scale of 13 in the afternoon, it means there are still 5 *ghaṭīs* left till sunset. To know how much time has elapsed since sunrise, 5 should be subtracted from the total length of the day. In a scale of 13 *ghaṭīs,* the total length of the day will be twice 13, i.e., 26 *ghaṭīs*. Therefore, when the shadow indicates that there are still 5 *ghaṭīs* to go until sunrise on a day of 26 *ghaṭīs,* it means that (26 – 5 =) 21 *ghaṭīs* have elapsed since sunrise on that day.

The column dial is represented in India by several specimens, but its history is the most tangled one. In Sanskrit, it is called *Cābuka-yantra, Kaśā-yantra* or *Pratoda-yantra*. Of these names, *Cābuka* is a loan-word from Persian and denotes a horse-whip;

1436 It is important that the horizontal gnomon should be of a fixed length. When the length is changed, the dial is no more valid for the latitude for which it was prepared; cf. Winter 1964, p. 381.

the Sanskrit terms *Kaśā* and *Pratoda* have the same connotation and are clearly Sanskrit renderings of the Persian *Chābuk.* This fact suggests that the instrument was borrowed from the Islamic world, but the specimens in the Islamic world and those in India have hardly anything in common except the horizontal gnomon.

In certain museums in the UK, the specimens are labelled as 'Ashadar stick' or 'Tibetan Priest's Time-stick'; both these designations are based on questionable sources.

In the following pages, an attempt will be made to disentangle these strands by separating facts from uncritical assumptions. We begin with Sanskrit sources; these have been studied most thoroughly by Yukio Ôhashi in his paper entitled 'The Cylindrical Sundial in India,' which contains the relevant Sanskrit texts, critically edited from unpublished manuscripts, translated and commented by him.[1437]

1. Sanskrit Sources on the Column Dial

The column dial is mentioned in the following Sanskrit texts: (i) Rāmacandra Vājapeyin's *Yantra-prakāśa,* 1428, 1 verse; (ii) Hema's *Kaśā-yantra,* second half of the fifteenth century, 52 verses, (iii) Gaṇeśa Daivajña's *Pratoda-yantra,* sixteenth century, 13 verses; (iv) Nityānanda's *Siddhānta-rāja,* 1639, 2 verses; (v) Munīśvara's *Siddhānta-sārvabhauma,* 1646, 8 verses; (v) *Vṛddha-vasiṣṭha-siddhānta* of unknown authorship and unknown period, 2 verses. The treatment of the column dial in Rāmacandra Vājapeyin's *Yantra-prakāśa* and Nityānanda's *Siddhānta-rāja* is too brief to give a coherent idea of the instrument. The *Vṛddha-vasiṣṭha-siddhānta* devouts two verses to this instrument and repeats what is already known from the other texts. [1438]

1437 Ôhashi 1998.

1438 Ôhashi 1998, pp. S 198-200; Ôhashi would like to think that this *Vṛddha-vasiṣṭha-siddhānta* was composed before the contact with the Islamic knowledge systems; but there is no firm evidence for this; the first verse in this text describes the instrument briefly and the second verse provides the formula: 'The R-sine of the [sun's] altitude is multiplied by 12, and divided by the R-sine of the zenith distance. The result is [the length] of the shadow in reverse in terms of *aṅgulas.*' This formula occurs also in Hema (verse 24), Gaṇeśa (verse 8) and Munīśvara (verse 6).

1.1. The *Kaśā-yantra* of Hema

The *Kaśā-yantra* of Hema, composed in the second half of the fifteenth century in 52 verses, is the only complete treatment of the column dial.[1439] Hema lays down that the instrument be made of metal or of the timber of the *Śiṃśapa* tree (commonly known as Shisham, *Dalbergia Latifolia* Roxb.), that the gnomon of the instrument (*śaṅku*) must be 12 *aṅgulas* long and the staff (*yaṣṭhi*) should be twenty-two times the length of the gnomon, and that the staff be endowed with seven columns or facets that run lengthwise (*saptāsraka*). At the top is tied a silk thread for suspending the instrument in a vertical position.

Three of the columns are to be marked with scales for the solar months when the sun is in the northern hemisphere and three for the months when the sun is in the southern hemisphere. On this Ôhashi remarks as follows: 'Since the sun's declination is symmetrical before and after the solstice, one column can be used in two corresponding solar months except for the solstitial month. So, three column are used for five solar months.' But then, there would remain just one column for the month of winter solstice and for the month of summer solstice. Hema does not say how to arrange the scales for two months, nor does Ôhashi make a comment on this. Presumably, these have to be accommodated by dividing the seventh column vertically in two halves. Then why not have eight complete columns, as is done in several of the extant specimens (P008 to P022)?

On these columns *ghaṭī* scales are marked according to the length of the reverse shadows (*utkramacchāyā*). Above the scales, holes are bored for inserting the gnomon. Below the hole are written the length of the day in terms of *ghaṭīs* in that particular month. When the sun is in the east, i.e., in the forenoon, the dial shows the *ghaṭīs* elapsed since sunrise; in the afternoon it shows the *ghaṭīs* to elapse up to sunset.

Hema teaches how to calculate the reverse shadow from the length of the day as taught by Padmanābha in his manual on the southern astrolabe (verses 21-26) and how to calculate the R-sine (*trijyā*) at intervals of 6 (27-34).

1439 Ôhashi 1998, pp. S 149-174: complete text based on a single manuscript, translation and commentary.

Interestingly Hema envisages the use of this sundial for telling time at night also, on the basis of oblique ascensions when one of the 27 *nakṣatras* (lunar mansions) is on the meridian. Thus he states (37-38):

> 'With this instrument of seven columns, the time can easily be known at night from [the star] on the meridian and from the degree of *lagna* that have been told in the verses. A small slit should be made above the cavity, through which the object on the meridian is observed. Then with the top of this instrument, the star on the meridian should be observed following the instruction of the preceptor.'[1440]

For this purpose, Hema provides oblique ascensions of all the 27 *nakṣatras* (34-35). This is followed by the enumeration of the right ascensional differences of *nakṣatras* in terms of *palas* (*antara-palāni*) (39-41) and the calculation of solar longitude from the time measured on the *Kaśā-yantra* (42-47).

The notion of using the column dial for telling time at night is no doubt ingenious, but it does not seem to be quite practical. The position of the hole at the top to view the star is not clearly defined, but wherever the hole is at the top of the staff, suspending the large staff by a silk thread with one hand and viewing the star through a hole would not have been an easy task. No other writer recommends this procedure.

1.2. The *Pratoda-yantra* of Gaṇeśa Daivajña

Gaṇeśa Daivajña's work consists of 13 verses.[1441] He recommends that the shaft should have 16 vertical columns (*paṭṭikā, paṭṭī*), three of which are marked with the degrees of altitude (*unnata-bhāga*) , shadows of the vertical gnomon (*śaṅkucchāyā*) and a man's shadow in feet (*caraṇacchāyā*), but does not elaborate how these are to be marked. No extant specimen carries this feature. The other thirteen columns carry *ghaṭī* scales; Ôhashi is of the view that these are adequate to mark *ghaṭī* scales for each half-solar month from the winter solstice to the summer solstice.

1440 Ôhashi 1998, pp. S 155, 167-168.

1441 Ôhashi 1998, pp. S 174-186, containing a critical edition of the text on the basis of 8 manuscripts, an English translation and commentary.

The work contains rules for calculating the sun's altitude from the time measured on the column dial; for calculating from the solar altitude the length of the shadow on the instrument as well as the length of a man's shadow in terms of feet; for calculating the shadow lengths of the vertical gnomon from the shadow lengths of the horizontal gnomon and so on.

1.3. Pratoda-yantra in the *Siddhānta-sārvabhauma* of Munīśvara[1442]

In the *Yantrādhyāya* chapter of his *Siddhānta-sārvabhauma* of 1646, Munīśvara describes the column dial in eight verses. He begins by saying that he is offering a summary of what Gaṇeśa said about an instrument with which time can be measured without much effort (*gaṇeśoditaṃ yantram etat pratodam anāyāsa-kālāvabodhaṃ pravacmi*).[1443] But his design for the instrument is different from that of Gaṇeśa and is quite pragmatic. He says that the instrument should have as many sides as there are *ghaṭīs* in the difference between the longest day and the shortest day at a given latitude. This addresses quite well the requirements for the north Indian localities. The difference in northern India is generally about eight *ghaṭīs* and therefore the column dials usually have eight *ghaṭī* scales.

In the monthly general meeting of the Asiatic Society of Bengal, held on 7 November 1860 at Calcutta, a *Pratoda-yantra* made by Lehna Singh Majithia (P023) was the main subject of discussion. [1444] In this connection, Pandit Bapu Deva Sastri communicated an 'extract from an old Hindoo work on astronomy'. This communication was in fact a literal translation of the first seven verses of Munīśvara's description. Because this translation has not been noticed in literature and because of its historical importance, it is reproduced below in full:

> '1. I am explaining the instrument called *Pratoda* (a goad) invented by Ganesa, by which the hour of the day can be easily known. Take a straight stick of moderate thickness of the tree called Dalbergia Sisu, of any length.

1442 Ôhashi 1998, pp. S 188-192.

1443 There are some manuscripts containing just these eight verses, sometimes with a commentary. Some modern scholars thought erroneously that this work was composed by Gaṇeśa; thus Sharma 1982.

1444 *Journal of the Asiatic Society of Bengal,* 23 (1860) 424-427.

‘2. Make it in the form of a right prism whose ends should be regular polygons having as many angles as the number of *ghatikas* contained in the excess of the longest day above the shortest (at the given place) ; and for the convenience of holding it join a chain (or a string) at the top ; (and mark the number of *ghatikas* from that of the *ghatikas* of the shortest day to that of those of the longest on the upper parts of the sides of the prism successively.)

‘3. Below its support, in order to place a gnomon, make holes in each side of the prism at the beginning of its length in such a manner that they may not touch each other in the middle (of the prism).

‘4. In order to conceal the gnomon (in this instrument) make *another* hole near the support (of the prism) at its top in the middle. Let the length of the gnomon be such as after placing it in the hole (made in each side) the length of its external part be nearly equal to the sixth part (of the length of the prism).

‘5. A twelfth part of the length of the external portion of the gnomon should be considered an *Angula* (a digit) in this *Pratoda* instrument. And find the sines of the (sun’s) zenith distance and altitude at the end of each of the given *ghatikas* (from the sun-rise of every day, the number of the length of which is marked on the instrument) by the rule mentioned by the former astronomers.

‘6. The sine of the (sun’s) altitude (found at the end of the given *ghatikas* from sun-rise) multiplied by 12 divided by the sine of the zenith distance (of the sun found at the same time) gives the number of digits belonging to the given *ghatikās.*

‘Thus find the digits belonging to the given *ghatikas* one, two, &c., from sun-rise (of every day, the length of which is marked on the instrument) and mark these digits on the respective (sides of the prism) from the hole.

‘7. (When you want to know the time after sun-rise at the given day) place the gnomon in the hole of that side (of the prism) on which the number of the *ghatikas* contained in the length of the given day are marked, and hang the instrument by holding it in the chain in such a manner that the shadow of the gnomon falls on the side. And reckon the *ghatikas* (on the side) from the

> hole to the end of the shadow. These *ghatikas* are after sun-rise (when you observe the shadow) before noon, (but when you observe it) after noon they are the *ghatikas* remaining (to complete the whole day.) (This holds then when the end of the shadow falls exactly on the mark of the *ghatikas*) but when it falls between two marks, there will be required a proportion.'

1.4. King and the Column Dial

Perhaps to justify the allusion to the horse-whip in the name of the instrument, the Sanskrit texts emphasize that this instrument is particularly suitable for the king to know time while riding a horse. Thus Hema declares: [1445] 'The king, […] astride a horse, swift like the wind, can find all on his own, and with much interest, [the time in] *nāḍikās* and their fractions, by holding in his hands this skillfully designed instrument (*catura-racita-yantra*) named *Kaṣā,* made of metal or of wood.'

Gaṇeśa also speaks in the same vein at the beginning and end of his small tract:[1446]

> 'I shall describe the *pratoda-yantra,* which amazes the kings and pleases the best of astronomers. Even if a man is riding a horse, he can obtain the full knowledge of the time, the gnomon-shadow and so on, merely by holding [this instrument in his hands]. Therefore, this cleverly designed [instrument] (*yuktyā yukta*) should always be carried by the members of the king's entourage, by mature astronomers, and even by wise kings, [as if] for controlling [the horse].'

1445 Hema, *Kaśā-yantra,* verse 19; cf. Ôhashi 1998, p. S 152:
pavana-java-turaṅgādhiṣṭhito bhūmipālaḥ
kalayati kutukād vāpy ātmanā nāḍikādyam |
kara-vidhṛta-kaṣākhye dhātuje dāruje vā
catura-racita-yantre mālinī-vṛtta-vettā ||

1446 Gaṇeśa, *Pratoda-yantra,* verses 1 *cd* -2; cf. Ôhashi 1998, p. S 178:
pratoda-yantraṃ gaṇakāgra-tuṣṭyai
vakṣye camatkārakaraṃ nṛpāṇām ||
hayādyārūḍhenāpi ca vidhṛtamātre 'tra sa nare
ghaṭī-śaṅkucchāyādika-sakala-bodhaḥ prabhavti |
ato yuktyā yuktaṃ nṛpa-sahacaraiḥ pauḍha-gaṇakaiḥ
sadā dhāryaṃ bhūpair api sumatibhis tarjanavaśāt ||

Again at the end of the work he repeats that this instrument produces amazement in the kings (*camatkṛti-karaṃ bhūpādikānāṃ*).[1447]

This is indeed very strange and very intriguing. It is not clear why this simple device should produce amazement in kings; such a statement is not made in connection with any other instrument. Moreover, even if the king had a great urge to know the precise time, it would be impossible while riding a swift horse to suspend the staff in a vertical position and to read the time from the shadow length.

1.5. Column Dial in the Islamic world

It has been mentioned that the names *Cābuka, Kaśā and Pratoda* suggest that the instrument was borrowed from the Islamic world.

One of the earliest column dials in the Islamic world is a Syrian sundial made for Sulṭān Nūr al-Dīn who ruled Aleppo from 1146-1173; it was made by Abu'l Farāz ᶜĪsā, in 554 AH (AD 1159-60) for determining the hours at the latitude of 36°, which is the latitude of Aleppo, and also at the latitude 33°, the latitude of Damascus.[1448] It has twelve columns and the hours on these are divided by continuous curves.[1449]

In the thirteenth century, Abu'l Ḥasan ᶜAlī, generally known as al-Marrākusī, composed a treatise *Jamiᶜ al-mabādi' wa-l-ghāyāt fi ᶜilm al-mīqāt* (Comprehensive Collection of the Principles and Objectives in the Science of Timekeeping), where he discusses the column dial among several other types of sundials. He too envisages that the staff be divided into twelve columns, one for each of the zodiac signs, and that the hours in these columns are divided by continuous curves.[1450]

But neither source contains any reference to a horse-whip which is called *sawṭ* in Arabic. A faint trace is found in an Arabic manuscript of unidentified authorship which speaks of the 'construction of the *mukḥula* for the hours (*sc.,* as a sundial), which is suitable for the column, the whip (*sawṭ*) and the stick.' [1451] The passage that follows

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1447 Gaṇeśa, verse 13; cf. Ôhashi 1998, p. S 182.

1448 Cf. Casanova 1923.

1449 See the illustrations in Casanova 1923, Pl. XLV.

1450 Sédillot 1834, vol. 2, book 2, chapter 3, pp. 433-437; plate 71; the plate is reproduced in Ôhashi 1998, p. S 196.

1451 Charette & Schmidl 2004, p. 159.

describes a portable vertical sundial which has the shape of a conical container for collyrium, and makes no other reference to the horsewhip.

But it is possible that there may be other so-far unexplored Arabic sources where the column dial is associated with the horse-whip. Some such source may have reached India and transmitted the notion of the horsewhip.

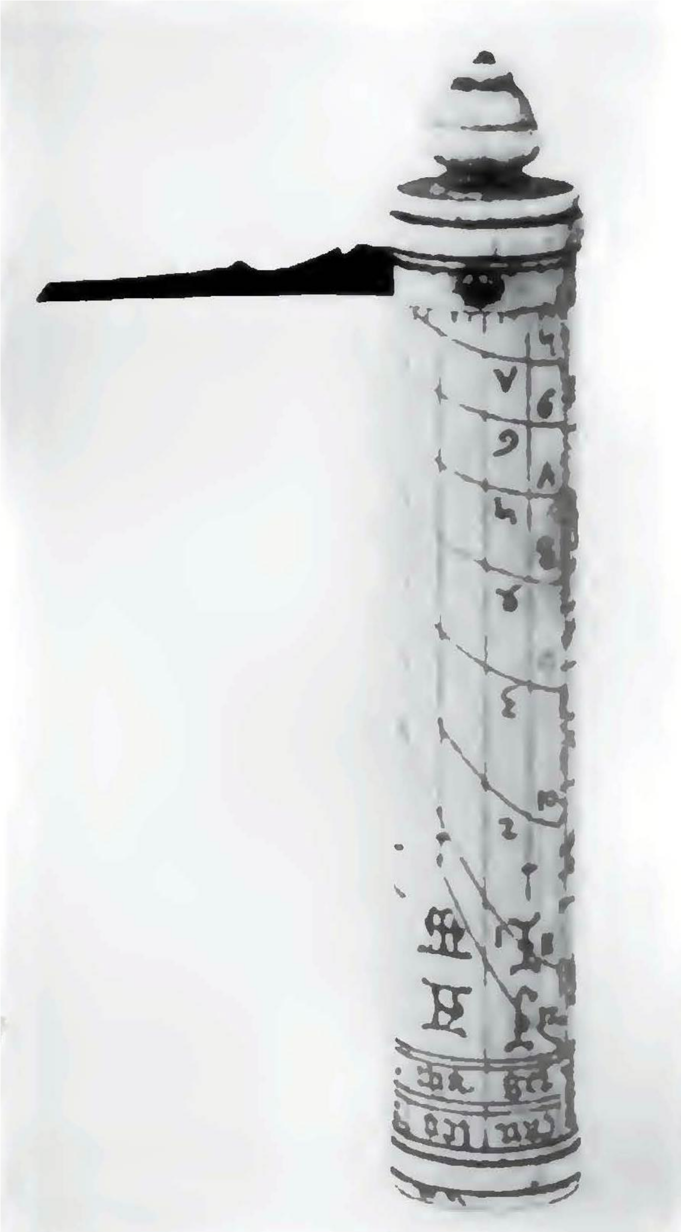

Figure P1 – Ivory Sundial dated 1455.[1452]

[1452] From Bassermann-Jordan 1922, figure 31 on p. 38.

1.6. Column Dial in Europe

The column dial is known in Europe since the eleventh century. Hermann of Reichenau, also known as Hermannus Contractus, (1013-1054) composed a small work on the column dial to be used at latitude 48° (roughly Vienna). In the subsequent centuries, several works appeared on this instrument, generally known as *horologium viatorum*.[1453]

The earliest extant specimen in Europe is made of ivory and dated 1455; it is preserved in the National Museum at Munich.[1454] Here the columns are assigned to the twelve zodiac signs and the hours in the scales are marked by continuous curves. This specimen is interesting also from another point of view. The numerals engraved on this object show close similarity to Devanagari numerals, especially 3, 4 and 5, and thus illustrate an important stage in the development of the modern international numerals (popularly, but erroneously, known as 'Arabic' numerals).

Similar sundials were used till recently by shepherds in the Pyrenees mountains between France and Spain, lying approximately on latitude 42°. Therefore, this type is also called Shepherds' Time Stick. There are several specimens of these in museums in Europe.

Of the specimens produced in the Islamic world, there do not seem to have survived many specimens; a well preserved Ottoman specimen of the eighteenth century is in the Institut du Monde Arabe at Paris.[1455]

However, both the Islamic and the European specimens are somewhat different in construction. They are much smaller, with lengths about 200 mm. The scales on their facets are divided by continuous curves which flow from one facet to another. The top with the gnomon can be rotated so that the gnomon rests on the desired month.

Compared to these, the Indian versions are much longer, ranging between 1100 to 1550 mm. The scales are separate for each month and the gnomon has to be inserted into a separate hole for each month. The scales are not divided by continuous curves;

1453 Zinner 1979, pp. 50-51.

1454 Zinner 1930.

1455 Naffrah 1989. Another column dial made for the latitude of Istanbul at 41;5° is with the Adler Planetarium, Chicago; cf. Pingree 2009, p. 222.

the divisions are marked by straight lines unconnected with those on the adjacent facet. In other words, these are cruder imitations of those produced in the Islamic world and in Europe. Obviously the theory of horizontal gnomon came from the Islamic world (we cannot identify the exact process of transmission), but the Sanskrit authors merely borrowed the name, but not the principle feature, namely the style of marking the hours on the difference scales by continuous curves.

2. Names given to Column Dials

2.1. **'Ashadar Stick'**

In certain museums in the UK, the specimens are labelled as 'Ashadar stick' or 'Tibetan Priest's Time-stick'. These names have their origin in an unusual event. Of the 23 extant specimens, a large majority of 15 are made of carved wood. A carved wooden column dial was exhibited for the first time in 1898 in a horological exhibition at the Urania Palace in Berlin by a certain Professor Reuleaux. The *Deutsche Uhrmacher-zeitung* reported about this exhibition and gave detailed descriptions of some exhibits in several instalments in 1898 and 1899.[1456] The carved wooden column dial was the very first instrument to be described in the issue of October 1898, because Professor Reuleaux claimed that it was about two thousand years old. The *Horological Journal* carried the description of the wooden stick under the title 'Pilgrim's Staff with Sun-dial,' in its issue of 1899, with an exact English rendering of the account from the *Deutsche Uhrmacherzeitung* along with the two illustrations. It is necessary to quote the entire long passage, in order to clear up the various misconceptions that arose from this report. The account in the *Horological Journal* reads as follows:

> 'It was an East Indian[1457] pilgrim's staff, 160 centimeters long, and at the widest places about four centimeters thick, and so arranged that it could by means of the divisions cut into its eight lateral surfaces, perform the services of a sun-dial. In a vertical hole bored into the top end of the staff, a little stick is lodged, fitting in the cross holes closely, above the beginning of the scales.

[1456] Anon 1898.

[1457] The original has 'Indian'; the English version made it 'East Indian' so that the English reader may not mix it up with 'West Indian, or 'Red Indian' !

If this little rod is, as far as a certain mark, introduced into one of the holes, allowing the pilgrim’s staff to hang down perpendicularly and directing the point of the small rod toward the sun, the shadow of the latter will fall on the division (see the dotted line in illustration) and thus denote the time of the day.

‘The explanation given by Prof. Reuleaux, the exhibitor, regarding this highly interesting piece, is as follows:

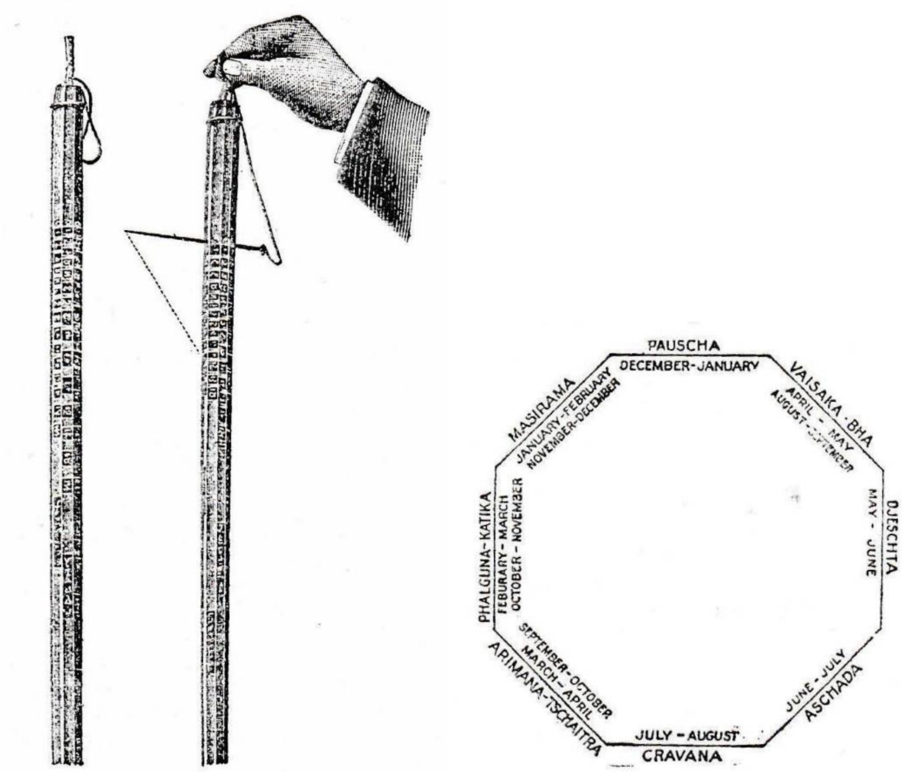

Figure P2 – The staff with the *ghaṭī* scales (left); cross-section with the Sanskrit months and their modern equivalents (right)[1458]

‘The name of such a staff is Ashadah, after the month of the same name - from middle of June to middle of July - during which the pilgrimages to Benares are chiefly commenced. The staffs of the East Indian pilgrims are made from the wood of the Palaca tree; this doubtless holds good for the staff exhibited, which was purchased from a pilgrim on the road leading through the Himalayas to Benares. The shadow of the little stick when inserted in the staff (ordinarily it is carried inside the latter) shows upon the divisions

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[1458] From *The Horological Journal,* January 1899, p. 70.

> carved into the surface of the staff, the number of half-hours which have elapsed since sunrise; if it is in the afternoon, it indicates the number of half-hours counted till sundown.
>
> 'According to the month, or very strictly speaking, to the day on which the observation is made, a certain division must be employed. For points of time in equal distances from the solstices, the division can be the same. This has enabled the maker to have the eight surfaces of the staff suffice for the twelve months.
>
> 'It is very noteworthy that the engraved names of the months are in the language and characters of Sanscrit (with a few orthographic errors). This speaks for the great age of the article; if it were of more recent origin the Hindoostanee characters and Hindoostanee names, greatly different from the Sanscrit names, would have been used.
>
> 'In the following figure will be found, on the outside, the names engraved in the staff-surfaces, including the orthographical errors, with our corresponding English denominations inside the octagon.
>
> 'The deviation of "Arimana" instead of "Aacvinah" (wind month in the fall), wherein the name of the old-Persian evil spirit occurs (Ahriman), indicates that the old Persian-Indian influences have been expressed in the text.
>
> 'The age of this peculiar and exceedingly well preserved sun-dial is estimated about two thousand years.'

Franz Reuleaux (1829-1905) was a distinguished scholar who is said to have raised the profession of engineering to a rigorous academic discipline. He was a lecturer at the Berlin Royal Technical Academy and rose to become the President of the Academy. He was often called the father of kinematics. But a smattering of Sanskrit philology caused him to make several grave errors.

About the source of the column dial, Reuleaux merely says that it 'was purchased from a pilgrim on the road leading through the Himalayas to Benares'; he does not say whether he bought it himself in India or acquired it in Germany from a dealer in antiques. Most probably the latter must have been the case. We do not know whether the dealer told Reuleaux (i) that the time-stick was bought from a pilgrim on his way to Benares, (ii) that the stick is called *Āṣāḍha,* (iii) that *Āṣāḍha* is the month in which pilgrimages to Benares are undertaken and (iv) that the staffs of the Indian pilgrims are made from the timber of the Palāśa tree.

This dealer may have acquired it in Darjeeling (in the Himalayas); but all others are either tales told by the dealer or assumptions made by the German professor. Assumptions iii and iv can easily be dismissed; there is no specific time as such for pilgrimages to Benares; but it is a matter of commonsense that pilgrimages covering long distances were undertaken in autumn, when the rains have ceased and the temperature is rather moderate, and certainly not in the month of *Āṣāḍha* (June-July) when summer is at its severest in the Gangetic plains.

I do not know where Reuleaux got the notion that these time sticks are made of the timber of Palāśa tree; he may have learnt from dictionaries that the Palāśa tree is also called Āṣāḍha in Sanskrit and therefore concluded that the Āṣāḍha time-sticks were made from the timber of Āṣāḍha tree, also called Palāśa. But the timber of Palāśa, commonly known as the 'Flame of the Forest' (*Butea Monosperma* Taub.), is hardly suitable for the time-sticks; Pradip Krishen says that 'the timber is not durable except under water and used for well-curbs and scoops.'[1459] On the other hand, we have seen that Hema and Gaṇeśa recommend the timber of *śiṃśupa* (Shisham, *Dalbergia Latifolia* Roxb.) for making the column dials. G. Watt remarks: 'The timber is one of the most valuable in India, is strong, very hard, close-grained, and of a purple black colour. It takes a beautiful polish, is reckoned the best furniture wood.'[1460]

Reuleaux's conclusion that instead of the month name *Āśvinaḥ* the carving on the stick reads 'Arimana' which goes back to Ahriman of old Persian is patently absurd. Because of the hardness of the wood, the carved letters look slightly different from printed or hand written letters; because of the similarity between *Āśvina* (आश्विन) and *Arimana* (अरिमन), and Reuleaux misread *Āśvina* (आश्विन) as *Arimana* (अरिमन) and jumped to the absurd conclusion that the time-stick emanates from the times of old-

1459 Cf. Pradip Krishen, *Trees of Delhi: A Field Guide,* Dorling Kindersley, Delhi 2006, p. 201.

1460 Cf. G. Watt, *Dictionary of Economic Products of India,* 1890, vol. 3, p. 9, cited in H. Santapau, *Common Trees,* National Book Trust, New Delhi, 3rd impression, 1981, p. 33.

Persian. But even in those days of old-Persian, Ahriman never denoted or symbolized the month of *Āśvina*.

Finally, his view that 'in recent times' in the Gangetic plains 'Hindustani characters and Hindustani names, greatly differing from the Sanskrit names, would have been used' is also wrong. I suppose by Hindustani, he means Urdu written in Persian script; but in the Gangetic plains various dialects of Hindi, with a large vocabulary of words derived from Sanskrit and written in Devanagari script prevailed in the nineteenth century as also at present, side by side with Urdu.

Modern writers do not accept any more Reuleaux's notion that the time-stick is more than 2000 years old, but follow his designation as *Āṣāḍha* stick and apply this not only to the carved wooden varieties, but also to the other kinds of column dials. Aside from Reuleaux's statement, there is no other evidence that this time-stick was ever called *Āṣāḍha*. But modern writers justify the name with the reasoning that it is called *Āṣāḍha* stick because the scale for this month is the longest. In British pronunciation, the name became 'Ashadar' and the instrument is labelled as 'Ashadar Stick' in museums in the UK.

2.2. 'Tibetan Priest's Time-Stick'

It is difficult to say how this carved wooden column dial came to be associated with Tibetan pilgrims. Reuleaux himself does not state this. Somebody in the UK must have thought that the 'pilgrim on the road leading through the Himalayas to Benares' who sold the stick must be a Tibetan pilgrim.[1461] But Tibetans, being Buddhists, do not make pilgrimages to Benares, which is famous for its temple of Śiva. The Tibetan Buddhists could make a pilgrimage to Sarnath, which is close to Benares, where Buddha received enlightenment. But Sarnath was forgotten and lay in ruins for long time until archaeological excavations in the nineteenth century began to unravel its significance for the history of Buddhism; however it did not develop into a centre of Buddhist pilgrimage until the twentieth century. Even if it is assumed that the Tibetan Buddhists

1461 For example, in Ward 1958, II, p. 9, no. 57, a column dial at the Science Museum, London, is designated as 'Tibetan Priest's Time Stick'.

heard of the archaeological excavations and began visiting Sarnath around 1898, why would they from their colder regions travel to Sarnath in the hottest of all seasons?

H. J. J. Winter, the noted historian of science, published a valuable study of the column dial preserved in the Gershom Parkington Collection of time-measuring instruments at Bury St. Edmunds (P009).[1462] In this study, Winter compared the numerals carved on this stick with those inlaid on the damascened steel specimen at the Museum of the History of Science at Oxford (P001) and the Tibetan numerals from J. A. Jäschke's *Tibetan Grammar* and came to the conclusion 'that whilst the Nepali figures are essentially Nāgarī, the ones on our specimen seem to exhibit in addition very slight Tibetan influence.'[1463] However, what he added in a footnote 'Or perhaps the difference could be accounted for by the fact that the carving of the figures is in hard wood,' hits the mark. They are Devanagari numerals alright, but the curves in them became somewhat straight when carved on a hard timber.

3. Extant Specimens

The extant specimens can be classified into three groups. In the first group are those which are not made of wood.

3.1. Metal or Ivory Dials from Rajasthan

There are just two specimens in this category and these two form exceptional cases. One (P001) is an exquisitely crafted steel column dial where all the lines on the scales, the numbers and decorative patterns are inlaid with gold. It is topped with an ornate finial and the other end terminates in a sharply polished blade. This must have been created for some noble man in Rajasthan.

The other one made of ivory (P002) is also of excellent workmanship, with a beautifully carved finial at the top and an ornate end at the bottom.

3.2. Painted wooden Column Dials from Rajasthan

In the second category are wooden column dials on which the scales and numbers are painted. In Jai Singh's Observatory at Jaipur, there is one with twelve columns, one

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1462 Winter 1964.

1463 Winter 1964, pp. 378-379.

for each solar month (P003). The wooden surface is given a coat of white paint on which the scales and numbers are written in black. However, much of this writing is effaced now and cannot be read anymore. But it appears that on this and the other specimens in this category, the length of the daylight in *ghaṭīs* is mentioned at the top of the scales, as is done in P001.

3.3. Carved wooden Column Dials from the Darjeeling Region

A majority of wooden column dials (from P008 to P022) belong to this type, where the numbers and letters are carved in relief. These are said to have been made in the Himalayan foothills in the region of Darjeeling (27;3 N, 88;16 E) and Kalimpong (27;3,36 N, 88;28,12 E).

The Museum of the History of Science, Oxford, has a display sheet for P018 which says: 'A staff-dial of this type is said to have been invented and made by Kalu Jaisi at Chuybu Busti, District of Kalimpong, Darjeeling, in 1898-99.' Probably the second word should read 'Josī' (astrologer / astronomer) and not 'Jaisi'. The place Chuybu Busti, according to Winter, is in the Himalayan Foothills at latitude 27;5° N and altitude 3500 ft. above sea level. [1464] This Kalu Josī could not have been the inventor, nor the person who introduced the style in this region, for there exist sticks made earlier to this date, in 1869 (P019) and 1884 (P013). The second one even carries the name of the maker Jemaṃgala (or Jaya-maṅgala).

These column dials appear to have been made for the latitude of about 27°; their length varies from 1034 mm (P015) to 1541 (P020). All the extant specimens are in museums and private collections outside India. No Indian museum owns a single specimen. Apparently, these were acquired by British colonial officers in the late nineteenth or early twentieth century and brought directly to England and Europe. The column dial P019 at the Pitt Rivers Museum was presented by Lady Westland; she may have acquired it at Darjeeling. Some may even have been made on order; for example, in P010 at Edinburgh, the maker left much space above each scale so that the man who ordered it could write down the names in Roman transliteration.

[1464] Winter 1964, p. 283.

These are all octagonal. On each column, instead of the maximum day-length in *ghaṭīs,* the names of the solar months are engraved; on four columns are engraved the names of two months in which the maximum day-length is the same. Usually, the distribution of the 12 solar months on the 8 facets of the column is as follows: 1. *Āṣāḍha*; 2. *Jyeṣṭha*; 3. *Pauṣa*; 4. *Śrāvaṇa*; 5. *Caitra* & *Āśvina;* 6. *Vaisākha* & *Bhādrapada*; 7. *Phālguna* & *Kārtika*; and 8. *Māgha* & *Mārgaśira*. These Sanskrit names undergo slight phonetic changes in Nepali language; particularly remarkable is Sanskrit *Mārgaśira* becomes *Māṃsir* in Nepali.

On some column dials, the month names are carved at the top of the scales (P008, P010, P012, P014, P016, P019, P020) and in some others (P011, P013, P015, P018, P021, P022) they are below the scales. In P015, the boundaries between the complete *ghaṭīs* are marked by dots enclosed by small circles.

Nearly all the column dials are equipped with an iron spear-head at the bottom. This iron spear-head has to be dug into in the ground so that the column stands upright and the scale for the current month faces the sun. A plumb line is needed to ensure that the staff is in vertical position, which is not necessary when the staff is suspended by means of a rope or chain.

Finally, the last specimen of the column dials (P023) was produced by Lehna Singh Majthia, a general in the army of the Sikh ruler Maharaja Ranjit Singh. Lehna Singh is said to have combined the column dial with a gun, but further details are lacking.

4. Correct Designation of the Column Dial

In the light of the above discussion, the correct designation of this time-measuring device should be 'Indian Column Dial' or 'Indian Cylindrical Sundial'; it can also be called 'Sanskrit Column Dial' or 'Sanskrit Cylindrical Sundial'. Although 'Ashadar' has some justification, the manner in which it is spelt may not immediately suggest the solar month '*Āṣāḍha*' when the days reach the maximum length and consequently that *ghaṭī* scale pertaining to this month is the longest.

This device is latitude-specific and can be used only at the latitude for which it is designed. There is no question of pilgrims using it as a walking stick and time-measurer in their long journeys which cross many latitudes. Therefore, any association with pilgrims, whether Tibetan or otherwise, is unwarranted.

As for the place of manufacture, the carved dials were produced in the Darjeeling region in the Himalayan foothills. The main population in this region are of Nepali origin and speak Nepali language, but the region itself is in India, and not in the Kingdom of Nepal. I have not come across any evidence that such column dials are used either in Nepal proper or in Tibet. Therefore the geographical attribution to either Nepal or to Tibet would not be correct. Other types of columns, made of metals or painted wood, were not produced in the Darjeeling region, but in Rajasthan; therefore, they should not be confused with the carved wooden specimens.

Index of Sanskrit Column Dials

P001 ◎Column Dial of Damascened Steel, not signed, not dated 3667

19th century ?, Length 956 mm, thickness 21 mm, Oxford, Museum of History of Science (# 50041)

P002 ◎Ivory Column Dial, not signed, not dated 3670

18th century, Length 510 mm, thickness 18 mm, PLU, ex-Rockford: Time Museum (#1299)

P003 ◎Painted Wooden Column Dial, not signed, not dated 3674

18th century, Length 870 mm, diameter 50 mm, Jaipur, Jai Singh's Observatory

P004 ◎Painted Wooden Column Dial, not signed, not dated 3675

19th century, Length 620 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

P005 ◎Painted Wooden column Dial, not signed, not dated 3676

19th century, Length, ca. 900 mm, Jaipur, Shri Sanjay Sharma Museum & Research Institute

P006 Painted Wooden Column Dial, not signed, not dated 3677

19th century, Length 577 mm, thickness 40 mm, Hastings-on-Hudson, NY, Tesseract

P007 Wooden Column Dial, not signed, not dated 3678

19th century, Length 610 mm, Jodhpur, PC

P008 ◎Carved Wooden Column Dial, not signed, not dated 3680

19th century, Length 1275 mm, thickness 30 to 31 mm, Brussels, PC

P009 Carved Wooden Column Dial, not signed, not dated 3682

19th century, Length 1499 mm, Bury St. Edmunds, Suffolk, UK, John Gershom Parkington Memorial Collection

P010 ◎Carved Wooden Column Dial, not signed, not dated 3683

19th century, Length 1360 mm, Edinburgh, Royal Scottish Museum (# 1956.97)

P011 ◎Carved Wooden Column Dial, not signed, not dated 3685

19th century, Length ca. 600 mm (the stick is broken just below the longest scale), Edinburgh, Royal Scottish Museum (on permanent loan from the Royal Observatory)

P012 Carved Wooden Column Dial, not signed, not dated 3686

19th century, Length 1360 mm, Hastings-on-Hudson, NY, Tesseract

P013 ◎Carved Wooden Column Dial by Jemaṃgala, 1941 VS (AD 1884) 3689

Length 1166 mm, thickness 28 mm, London, Horniman Museum (# 21.2 52/5)

P014 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3691

19th century, Length 1355 mm, thickness 27 mm, London, Horniman Museum (# 972.810)

P015 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3693

19th century, Length 1034 mm, London, Science Museum (# 1952-442)

P016 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3695

19th century, Length 1330 mm, London, Science Museum, ex-Wellcome Collection

P017 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3696

19th century, Length 1508 mm, London, Science Museum, ex-Wellcome Collection.

P018 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3697

19th century, Length 1277 mm, diameter 30 mm, Oxford, Museum of the History of Science (# 52782)

P019 ◎Carved Wooden Column Dial, not signed, 1926 VS (AD 1869).................... 3699

Length 1318 mm, thickness 28 mm, Oxford, Pitt Rivers Museum of Ethnology (# 1925.49-1)

P020 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3701

19th century, Length 1541 mm, thickness 33 mm, Oxford, Pitt Rivers Museum of Ethnology (# 1892.41.56)

P021 ◎Carved Wooden Column Dial, not signed, not dated.................................... 3703

19th century, Length 1124 mm, length of the iron spearhead 145 mm, Paris, PC

P022 Carved Wooden Column Dial, not signed, not dated 3706

19th century, Length 1500 mm, Prague, Náprstek Museum of Asian, African and American Cultures (# 56 396)

P023 Iron Column Dial by Lehna Singh Majithia for Lord Hardinge....................... 3707

Ca. 1850, Length ?, Kolkata, Asiatic Society ?

Q. INDO-PERSIAN HORIZONTAL SUNDIALS IN MOSQUES AND MUSEUMS

INTRODUCTION[1472]

SUNDIALS IN THE ISLAMIC WORLD

It is obligatory for Muslims to offer five prayers in a day, a day which commences at the sunset. These prayers are *maghrib*, *ᶜishāʼ, fajr, ẓuhr* and *ᶜaṣr*. The times for these prayers were standardized in the eighth century. The prayers are offered within certain intervals or time brackets which are astronomically defined. The interval for the *maghrib* prayer begins when the disc of the sun has set over the horizon; the intervals for the *ᶜishāʼ* and *fajr* prayers commence at daybreak and nightfall respectively. Thus the times of these night prayers are determined in terms of horizon and twilight phenomena.

The times of the daytime prayers, on the other hand, are defined in terms of shadow lengths, usually the lengths of the shadows cast by a gnomon of standard length, of either 7 feet or 12 digits. Accordingly, the interval for the *ẓuhr* begins at midday when the sun has crossed the meridian, i.e., when the length of the gnomon's shadow is at its minimum (say n). The interval for the *ᶜaṣr* begins when the shadow length equals the midday shadow (n) plus the length of the gnomon (g) and ends when it equals the midday shadow plus twice the length of the gnomon ($n + 2g$). These times are variable according to the declination of the sun, and have to be computed for each day and for each latitude.

As Islam spread in areas which were formerly under the Greco-Roman domain and the Muslim astronomers came into contact with Greco-Roman sundials, they realized that these sundials could be effectively used to regulate their prayers and began to modify them by adding lines to indicate the times of the midday (*zuḥr*) and afternoon (*ᶜaṣr*) prayers.

1472 This section owes its existence largely to the invaluable help rendered by Debasish Das and Mubashir Ul-Haq Abbasi. Das took several photos of the sundial in Delhi and arranged through his friends the photography of the sundials at Hyderabad (Subbarao, K.), Jaipur (Sanjay Parmar), Mysore (Ejaz Ahmed) and Pulicat (Premnath, M. S.); he also collected several interesting references to these sundials. Abbasi, who designs sundials himself, deciphered and translated the Persian inscriptions and legends; more important; he analyzed the projected lines and provided detailed technical explanations. It is a pleasure to thank Das, his network of friends, and Abbasi.

To facilitate the construction of such dials, Muslim astronomers, with their well-known penchant for preparing detailed mathematical tables, began compiling special tables from the ninth century onwards. In early ninth century, al-Khwārizmī compiled at Baghdad a set of tables of coordinates for the construction of horizontal dials. About this work, David King notes:

> 'With values of solar altitude and azimuth (*h, a*), computed for the required ranges of solar longitude and time intervals, the radial coordinates of the points of intersection of the hour lines with the shadow traces are simply (*n* cot *h, a*) where *n* is the length of the gnomon. Each of al-Khwārizmī's sub-tables for a specific latitude display for both of the solstices the solar altitude, the shadow of a standard gnomon (12 units) and the solar azimuth, i.e., triplets (*h, s, a*) for each seasonal hour of the day.'[1473]

Ḥabash al-Ḥāsib, who worked at Baghdad during the ninth and tenth centuries, prepared tables for the construction of horizontal dials with vertical gnomons, where he recorded the height of the sun over the horizon and the length and direction of the gnomon's shadow for each of ten latitudes, and for each seasonal hour on both of the solstices.

Towards the end of ninth century, Thābit ibn Qurra, also at Baghdad, wrote a comprehensive work on the theory of the sundial, where he discussed the transformation of coordinates between the planes of horizon, celestial equator and the sundial, with the possibility that the plane of the sundial can be of many kinds.

Most prominent of all is Abu'l Ḥasan ᶜAlī al-Marrākushī, who composed the magnum opus *Jamiᶜ al-mabādi' wa-l-ghāyāt fi ᶜilm al-mīqāt* (Comprehensive Collection of the Principles and Objectives in the Science of Timekeeping) at Cairo at about 1280.[1474] It contains an extensive treatment on a wide variety of sundials, horizontal, vertical, inclined, cylindrical and conical, with tables and diagrams. He also discussed portable dials in plane, cylindrical or conical formats.

1473 King 1996c, pp. 170-171; see also King 2004, Part II: A survey of tables for regulating the times of prayer, pp. 191-456.

1474 For a French translation, see Sédillot 1834.

Thousands of sundials are believed to have been constructed in the Islamic world between the ninth and nineteenth centuries, but those that have survived are very few and no full inventory has been made so far.[1475] Most of these carry markings for *ẓuhr* and *ᶜaṣr* prayers in seasonal or equal hours; some are engraved with the direction of the *Qibla*.

The earliest surviving dial was made by Ibn al-Ṣaffār about 1000 at Cordoba. Only one half of it is extant which displays lines for seasonal hours and for the *ẓuhr* prayer; presumably lines for the *ᶜaṣr* prayer were engraved on the missing half. The vertical gnomon is missing, but its length is indicated by the radius of the circle described around the point where the gnomon was originally affixed.[1476]

The most spectacular sundial was constructed by Ibn al-Shāṭir in 1371/72 for the great Umayyad Mosque in Damascus. It is a horizontal sundial engraved on a rectangular marble plate measuring 2 x 1 m. The gnomon is inclined to the horizon at an angle of 33;30°, which is the medieval value for the latitude of Damascus, and thus points to the celestial north pole. This is indeed the origin of the triangular gnomon associated with the *Palabhā-yantra* in India and with the most common form of the sundials in Europe. But the dial itself is highly complex; in fact, it consists of three separate dials.

> 'The small northern sundial with its gnomon has markings for the seasonal hours and the *ᶜaṣr* prayer. The small southern sundial has markings for equatorial hours before midday and after midday, as well as after sunrise and before sunset. Its gnomon, parallel to the celestial axis, is ingeniously aligned with the larger gnomon of the third and main sundial. The latter bears markings for each twenty minutes before midday and after midday, as well as for each twenty equatorial minutes after sunrise up to midday and for each twenty minutes before sunset starting at midday. There are also curves for each twenty minutes up to the *ᶜaṣr* prayer starting two hours before the prayer, as well as curves for the times three and four hours after daybreak.

1475 On the extant Islamic sundials see King 1987a, XV-XVIII; King 1996c; Berggren 2001; King 2005, ch. 7 (Sundials), pp. 81-91.

1476 Cf. King 1996c, plate 4.11; Berggren 2001, p. 10, Fig. 1.

> Finally, there is a curve for the time 13 ½ hours before daybreak the next day.'
>
> '… It measures time relative to the *ẓuhr* and *maghrib* prayers, and the *ᶜaṣr* curves enable measurement of time relative to the *ᶜaṣr* prayer as well. The curves associated with night fall and daybreak are for measuring time with respect to the *ᶜishā'* and *fajr* prayers.'[1477]

This sundial was set up on a platform on the southern side of the main minaret of the mosque, but was damaged towards the end of the nineteenth century. The fragments are on display in the garden of the National Museum in Damascus. An exact replica of the original sundial made by al-Ṭanṭāwī in 1890 can be seen on the minaret.

SUNDIALS IN INDIA

As in the Middle East, in the Indian subcontinent also very few sundials exist in the mosques with projections to indicate the prayer times.

1. AGRA, MOTI MASJID

J. T. Boileau, of the Bengal Engineers, was the first to describe a sundial set up in a mosque in India. In 1833, he published a short description of a sundial in the Moti Masjid inside the Red Fort at Agra along with a sketch:

> '… a dial-plate of white marble, with lines inlaid on its surface of a black slate … The style, which appears to have been an upright round pin, is gone, and the inlaying has been pulled out; but the configuration of the lines is still perfect, being marked by channels wherein inlaying fitted. The breadth of these channels is about 3/8 of an inch.'
>
> 'The dial-plate is set up in the court of the *Moti Masjid,* a building which was constructed in the latter end of the reign of AURANGZIB, about the year 1673, and it is probable that this dial was put up about the same time; but whether in its present site or position, or elsewhere, I have not been able to ascertain.'

[1477] King 1996c, pp. 166-167, plate 4.13.

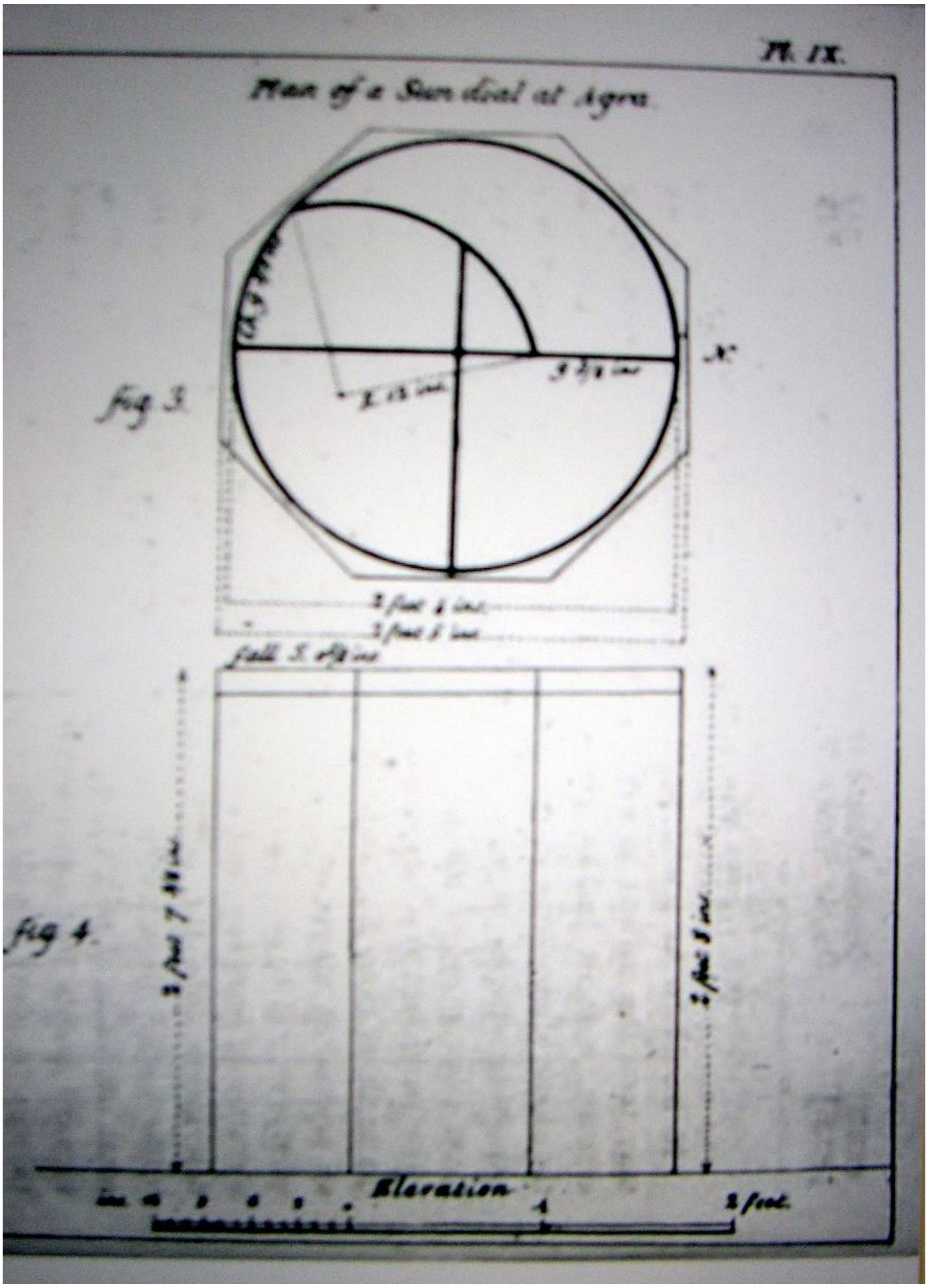

Figure Q1 – Sketch of the sundial and its pedestal (from Boileau 1833)

'The absence of hour lines, excepting XII and VI A. M. and P. M. would lead to the supposition, that the object for which the dial was constructed had reference only to the times of Mussulman prayer ; but the object of the circular arc, which subtends an angle of about 95 degrees, has never been explained, although many celebrated *Moulvis* have visited the *Masjid* and examined the dial as it stands.'

> 'The surface of the dial inclines south about 3/8^{ths} of an inch, which leads me to believe , that it has been removed from the place where it was originally fixed.'
>
> 'It is not possible … that the circular arc, which is inclined about 29° to the present meridian line, could under any circumstances mark the shadow of a style placed as the style of this was, in a vertical position.'[1478]

Boileau is not quite right in stating that the Moti Masjid in the Red Fort at Agra was constructed under Aurangzeb in 1673; it was in fact constructed by Shāh Jahān. The noted historian of Indian architecture, James Fergusson, states that '… the Moti Masjid or Pearl Mosque, which Shāh Jahān erected in the Fort of Agra, 1646-1653, is one of purest and most elegant buildings of its class to be found anywhere.'[1479] But the sundial may not have been set up at the same time.

Already in 1833, when Boileau examined the sundial, he thought that the sundial must been moved from its original position. Moreover, his description gives the impression that the dial may not have been engraved completely. Whether it is still there now or not cannot be ascertained because the Moti Masjid is now closed to the public.

Leaving this one aside, we know at present of six sundials in mosques which carry lines to indicate prayer times.[1480] The earliest of these was set up in 1694 in the Mecca Masjid at Hyderabad. It is the only sundial in India which shows close affinities with the sundials in the Middle East (Q001). Three others (Q002, Q003, Q004) are designed like the *Palabhā-yantra* with a horizontal dial engraved with a semi-circular time-scale and a triangular gnomon; but the curves to display the two time limits of the *ᶜaṣr* prayer are drawn differently in each of them. The last two (Q005 and Q006) carry an identical design of concentric circles.

1478 Boileau 1833.

1479 Fergusson 1910, II, p. 317.

1480 To explore all the mosques in the Indian subcontinent for sundials is far beyond the scope of this project. But it is worthwhile doing so, for there may be some interesting sundials, hitherto unnoticed.

Professor Éric Mercier remarks that the three sundials at Hyderabad (Q001), Pulicat (Q003) and Srirangapatnam (Q005), situated as they are between the tropics, are very rare and valuable specimens, with correct projections for the ᶜ*Asr* prayer times.[1481]

Detailed individual descriptions of these six sundials will follow this introduction. Here will be given brief descriptions of the mosques where these sundials are set up.

2. Hyderabad, Mecca Masjid

The construction of this mosque was commenced by Muḥammad Qulī Quṭb Shāh in 1616, but was completed much later in 1694 under the Mughal emperor Aurangzeb who annexed the kingdom of Hyderabad into the Mughal empire in 1687. Muḥammad Qulī Quṭb Shāh is said to have begun its construction with bricks made of the sacred soil brought from Mecca; therefore, the mosque came to be called Mecca Masjid. It is a very large mosque that can accommodate about ten thousand people. The sundial was set up at the time of completion of the mosque under the orders of Aurangzeb in his 36th regnal year in 1694. The dial is made of a polished black stone with a diameter of 635 mm; it is set up upon a 1219 mm high pillar.

When I saw the sundial and photographed it in 1991, the gnomon was missing and the dial face began to deteriorate. Now in the year 2017 the pedestal is much damaged, plaster is peeling off the pedestal and the dial plate rests precariously on the pedestal. The sundial is in urgent need of conservation and preservation. This is the only sundial which shows some affinity to the sundials of the Middle East, with the solstices represented as hyperbolas and with a line showing the direction of the *qibla* (Q001).

1481 In his email of 7 February 2018. For a technical analysis of these sundials, see Mercier 2018.

Figure Q2 – Sundial in 1991 (photo by S. R. Sarma)

Figure Q3 – Two views of the sundial in 2017 (photos by Subbarao K., courtesy Debasish Das)

3. DELHI, JAMA MASJID

The *Masjid-i Jahān-Numā* (World-reflecting Mosque), commonly known as the **Jama Masjid**, was built by the Mughal emperor Shāh Jahān between 1644 and 1656. It is a large and ornately built mosque; its forecourt can accommodate about five thousand devotees at the time of congregational prayers.

Figure Q4 – Jama Masjid with the world map in the foreground (photo by Debasish Das)

In the centre of the forecourt is a large water tank, lined with marble, for ablutions before the prayers. It is not known whether any sundial was set up at the time of its construction, but there exists now a sundial that was erected much later in 1829-30. In fact, there exist now three small structures. In the south-east corner of the forecourt, there are two pedestals, one circular and the other rectangular. The former may have carried a circular dial on its top, but it is now missing. The rectangular pedestal (470 mm high and the upper surface measures 1190 x 460 mm) was designed to carry two square dial plates side by side, but only one is extant and the other is missing. The surviving dial plate (460 x 450 mm) is engraved with a sundial and another dial for the determination of the times of the beginning and end of the interval for the ᶜ*aṣr* prayer in all seasons. It was made by Ḥāfiẓ Anwar ᶜAlī Siddiqī of Rohtak under the supervision of Saiyid Aḥmad, the Imām of the congregational mosque at Ajmer, in 1245 AH (= AD 1829-30) (Q002).

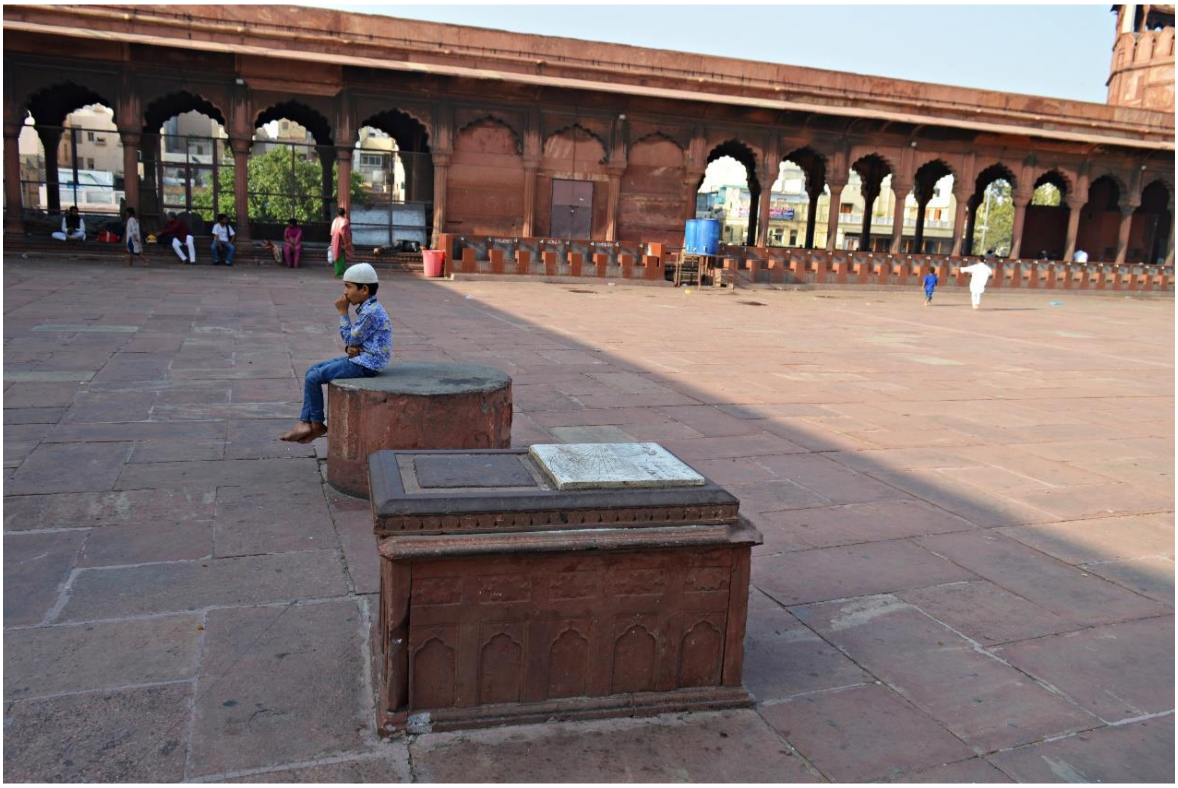

Figure Q5 – Sundial and an empty circular pedestal in the forecourt ;
in the background is the southern arcade (photo by Debasish Das)

The third pedestal is in the north-east corner of the forecourt. It is 1120 mm high and covered on the top by a marble plaque measuring 580 x 550 mm. The plaque is engraved, most unusually, by a world map drawn inside a circle in what is technically known as 'Lambert azimuthal equal-area projection'. On it the circles of latitude and those of longitude are drawn for every 10°, with the prime meridian passing a little to the proper right of the peninsular India. The outline of the Indian peninsula is not well defined. Australia is labelled as *naw wilz janub,* 'New South Wales', which was the original name of the first British colony in Australia. It must obviously have been copied from an English atlas, but why it was set up in a mosque remains an enigma. At the centre, where 0° latitude and longitude intersect, is a large hole. There may have been some kind of a pole erected in it, but for what purpose is not known.

Figure Q6 – World Map in the North-East corner of the forecourt
(photo by Debasish Das)

The inscription engraved at the bottom of the plaque in three lines reads as follows: [1482]

> *ṣūrat arḍ wa aqālīn janūbī wa shamālī khaṭṭ istiwā bā khaṭūṭ darjāt ṭūl wa ᶜarḍ bilād*
>
> *dar ᶜahd ḥaḍrat muḥammad akbar shāh pādshāh ghāzī sanah 1247 hijrī bāmar (?) shāhzādah ᶜalījāh muḥammad salīm bahādur shāh qāḍī shujāᶜ al-dīn*
>
> *ᶜalīkhān ghāzī (?) hū … (?) darsat kardah yādgār guzāsht*
>
> ‘The figure of the earth and the southern and northern climates [with respect to] the equator with the lines of longitude and latitude of the cities
>
> ‘in the reign of His Majesty Muḥammad Akbar Shāh Bādshāh Ghāzī, [in the] year 1247 AH (1831-32), by order of the prince ᶜĀlījāh Muḥammad Salīm Bahādur Shāh, Qāḍī Shujaᶜ al-Dīn
>
> ‘ᶜAlī-Khān Ghāzī ... built and left as a memorial.’

The following labels are engraved on the map (from north to south): *quṭb shamāl* (North Pole); ? (England); *frāns* (France); *āsīyā* (Asia); *īrān* (Iran); *fars* (Persia); *hindūstān* (India); *ᶜarabistān* (Arabia); *afrīqā* (Africa); *bahr ᶜarab* (Arabian Sea); *khalīj bangālah* (Bay of Bengal); *bahr hind* (Indian Ocean); *naw wīlz* (?) *janūb* (New South

1482 I am grateful to Professor Mohammad Baqeri and Mubashir Ul-Haq Abbasi for deciphering and translating the inscription.

Wales, original name of the British Colony in Australia); *bahr janūb* (southern ocean); *bahr quṭb* (polar sea, Antarctic ocean); *quṭb janūb* (South Pole).

Muḥammad Akbar Shāh Bādshāh Ghāzī, generally known as Akbar Shah II, was the penultimate Mughal king (r. 1806-1837) of Delhi. Prince Mīrzā Muḥammad Salīm Bahādur Shāh (1799-1836) was his son. He was younger than Bahādur Shāh Zafar who succeeded Akbar Shah II as the last Mughal ruler (r. 1837-1857). Qāḍī Shuja^c al-Dīn ^cAlī-Khān Ghāzī must be the person who set up the world-map. No other information is available about him. The inscription states that the world map was set as a memorial (*yādgār*). It is not known which event it is supposed to commemorate.

Sir Syed Ahmad Khan, the founder of the Aligarh University, wrote a valuable book on the historical monuments of Delhi, entitled *Asār ul-Sanādīd* in 1854. There he mentions an addition made in the Jama Masjid by prince Mīrzā Salīm:

> ‘Thanks to God’s blessings, the mosque is able to accommodate such a large number of worshippers that they resemble ants and many cannot hear the voice of the *imam.* Hence, Prince Mirza Salim, son of King Mo’inuddin Muhammad Akbar Shah, had a magnificent raised platform of stone constructed in the middle of the central arch in 1245 AH (1829 AD), so that a *mukabbir* could stand upon it and deliver the call to prayer and other sections recited aloud so that they would resound in the ears of all present.’[1483]

The pavilion is still extant. Interestingly it was constructed in the same year when the sundial by Ḥāfiẓ Anwar ^cAlī Siddiqī was set up in the south-eastern corner of the forecourt. Therefore, it is entirely possible that the sundial was also set up at the instance of this prince; the missing plaque next to the sundial may have carried some reference to the prince. It is also possible that he caused the setting up of some other sundial on the round pedestal next to it about the same time. While the sundials in a mosque are appropriate, if not essential, the world map in the mosque deserves an explanation.

Obviously it was influenced, in some way or other, by the British administration of Delhi. For Akbar Shah II was just a nominal king, and the actual administration was

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[1483] Sir Syed Ahmad Khan, *Asār ul-Sanadīd,* edition 1904, Book III, p. 66; translation of the passage by Quraishi 2012, p. 14.

in the hands of the British Resident, who represented the Governor-General of the British East India company. Therefore any repairs which become necessary at the Jama Masjid were done by British engineers on behalf of the Resident. For example, when the northern minaret was struck by lightning and fell down and the flooring of the forecourt suffered damage, the English had rebuilt the minaret and repaired the flooring in 1817.

However, the sundial and world map find hardly any mention in the nineteenth century accounts. Sir Syed merely states that there is a sundial (*dā'ira'-i hindī*) opposite the southern and eastern arcades,[1484] but does not mention the world map. Consequently, Stephen Carr Stephen is the only one to mention both:

> 'In the year 1829, Mirzá Salim, son of Akbar II, put up a sand-stone pulpit under the central entrance of the mosque, the congregation being at times too large to take part in the prayers offered by the Imám inside the mosque.'
>
> 'In the north-eastern corner of the court of the mosque is a plain sphere cut upon marble, giving a map of the world, according to the common projection of the sphere. …
>
> 'In the south-western corner of the court-yard, is a marble sun-dial, corresponding to the plain-sphere on the opposite side.'[1485]

Both Sir Syed and Stephen Carr mention only one sundial; if the circular pedestal also carried a sundial, they would have mentioned the 'sundials' in plural; it means either the dial on the circular pedestal was removed by at least 1854 or the circular pedestal was meant for another purpose which is not known. As regards the rectangular pedestal, from their statement it is not clear whether the two marble plaques were still in tact or not at the time of their writing.

[1484] Sir Syed Ahmad Khan, *Asār ul-Sanadīd,* edition 1904, Book III, p. 67 (as explained by Muabashir Ul-Haq Abbasi).

[1485] Stephen 1876, p. 253.

4. Pulicat, al-Masjid al-Musharraf

The next sundial is found in the far south, at Pulicat (13;25° N; 80;19° E), which lies on the coast of Bay of Bengal on the southern border of Tamilnadu. It was an important port of the Vijayanagara empire in the fourteenth and fifteenth centuries. In 1502 the Portuguese established a trading post and built a fort there. The Dutch occupied the port in 1609 and held it until 1825 when the British East India Company seized it.

There has been a large Muslim population in Pulicat throughout its history. Two of the important mosques today are the Peria Jamia Pallivasal which is the large congregational mosque and the Chinna Pallivasal. The sundial is set up in the Chinna Pallivasal. The mosque was constructed in 1708, but the sundial was added only in 1334 AH (AD 1915-16).[1486] This is the only sundial where the gnomon is intact.

5. Patna, Khanqah Emadia

In Patna, there is a Ṣūfī seminary named Khanqah Emadia. Sometime in the second half of the twentieth century, the head of the Khanqah, Shah Faridul Haque Emadi, designed an elegant sundial and had it set up on the roof of the mosque. The dial was engraved with hour lines and two long curves to indicate the times of the midday prayer *ẓuhr* and the after-noon prayer *aṣr.* I saw it and photographed it in 1991. In course of repairs, subsequently, the sundial was removed and discarded in a store room; I understand that the dial plate is still intact, but the gnomon is lost.

6. Srirangapatna, Tipu Sultan's Sundials

Tipu Sultan (1750-1799) built at Srirangapatna (Lat. 12;26 N; Long. 76;35 E), near Mysore, a mausoleum for his father, which is popularly known as the Gumbaz (dome), and a mosque named Jamia Masjid or Masjid-i A^{c}lā in about 1782 and set up sundials of identical design at both places (Q005 and Q006). The dial faces are badly eroded; all that can be seen are a series of nineteen concentric circles upon which eight diameters are drawn indicating the cardinal and intermediate directions.

[1486] Cf. *Pulicat & Sadras : Confluence of History, Culture & Environment,* Anameka Architects & Designers, Chennai 2010, pp. 70-71.

7. Other Extant Indo-Persian Sundials

Besides these sundials in the mosques, there exist three other specimens which show just the hours of the day (Q008, Q009 and Q010) and resemble the *Palabhā-yantras* in their design. Finally, there are two portable dials which were designed after European models (Q011 and Q012).

Index of Indo-Persian Horizontal Sundials in Mosques and Museums

Q001 ◎Sundial by Mīr Qāsim, 36th regnal year of Muhy al-Dīn Muḥammad ᶜĀlamgīr (AD 1694) 3727

Diameter of the dial 635 mm; height of the pedestal 1219 mm, Hyderabad, Mecca Masjid

Q002 Sundial & ᶜAṣr Indicator by Ḥāfiẓ Anwar ᶜAlī Siddiqī Ruhtakī, 1245 AH (AD 1829-30) 3735

Dimensions 460 x 450 mm, Delhi, Jama Masjid, forecourt

Q003 Sundial by Muḥammad ᶜAbd Allāh Aḥqar, 1334 AH (AD 1915-16) 3744

Dimension 250 x 200 mm, Pulicat, Tamilnadu, Al-Masjid al-Musharraf

Q004 ◎Sundial by Shah Faridul Haque Emadi, not dated 3749

20th century, second half, side of the octagon152 mm, Patna, Managal Talab, Khanqah Emadia

Q005 Sundial set up by Tipu Sultan, 1782 3751

Diameter of the dial 533 mm; height of the pedestal 2.057 m, Srirangapatna, Jamia Masjid or Masjid-i Aᶜlā

Q006 Sundial set up by Tipu Sultan, ca. 1782 3753

Dial 635 x 483 mm; height of the pedestal 940 mm, Srirangapatna, Mausoleum, commonly known as Gumbaz

Q007 Sundial, not signed, not dated 3754

Late 18th or early 19th century, Diameter ?, Jaipur, Khanqah of Hazrat Maulana Ziauddin Sahab

Q008 ◎Sundial, not signed, 1246 AH (AD 1830) 3755

Diameter 285 mm, Hyderabad, State Museum of Archaeology (#P. 2266)

Q009 ◎Sundial, not signed, 1294 AH (AD 1877) 3757

Diameter 610 mm, Patna, Firdaus Manzil

Q010 ◎Sundial, not signed, not dated 3758

20th century, Dimensions ?, Lucknow, in the courtyard of the house of a Ḥakīm

Q011 ◎Sundial, not signed, not dated 3759

19th century, Diameter 138 mm, New Delhi, National Museum (# 56.98/C)

Q012 ◎Universal Equinoctial Sundial, not signed, not dated 3761

19th century, Diameter 172 mm, Patna, Khuda Bakhsh Oriental Public Library

R. WATER CLOCKS

INTRODUCTION

Water clocks have been the main devices for measuring time in India from the earliest times up to the end of the nineteenth century. Even now, they are used for measuring time of certain rituals in all the major faiths in the Indian sub-continent (see below sub-section 10).

In his monumental work *Science and Civilisation in China*, Joseph Needham classifies the ancient water clocks into three types:[1497] (i) outflow water clocks, i.e. vessels from which a certain quantity of water flows out in a specific time interval through a hole at the bottom; (ii) inflow clocks, where water from a reservoir flows into a vessel and fills it in a specific time span; and (iii) sinking bowl type, where water percolates into the bowl through a hole at its bottom and makes the bowl sink in a specific period of time.

In India, the first and the last type were used, not simultaneously but one after the other. These two types were roughly coeval with two major periods in the history of Indian astronomy: while the outflow clock was mentioned in the *Vedāṅga-jyotiṣa* and related texts, the introduction of the sinking bowl coincided with the beginnings of the *Siddhānta* astronomy.

However, both the types were designed to measure the same unit of time, namely, one-sixtieth part of the nychthemeron, and this has been the standard unit of time throughout the centuries. In the texts where the outflow water clock is mentioned, this time unit is mentioned variously as *nālikā, nālī, nāḍikā,* or *nāḍī.* For the sake of convenience, we shall use the form *nāḍī* in this catalogue. But the instrument itself is not mentioned by any name; it will be called here *Nāḍikā-yantra.* The sinking bowl type of water clock is mentioned as *ghaṭikā-yantra, ghaṭī-yantra,* or *jalaghaṭī-yantra,* and the unit of time measured by it as *ghaṭikā* or *ghaṭī.* Here also, for the sake of consistency, the instrument will be referred to as *Ghaṭikā-yantra* and the time unit as *ghaṭī.*

[1497] Needham 1959, p. 315; for a four-fold classification, see Turner 1984, p. 1 et passim.

1. NĀḌIKĀ-YANTRA

The outflow water clock is described in the *Vedāṅga-jyotiṣa*, Kauṭilya's *Arthaśāstra,* the *Śārdūlakarṇāvadāna* of the *Divyāvadāna* and *Jyotiṣkaraṇḍaka.*[1498] The descriptions here are extremely brief and not very coherent. In the absence of actual specimens, it is difficult to interpret these sources properly. Therefore, the relevant information from these sources will be summarized below, after a short introduction.

The *Vedāṅga-jyotiṣa* (also called *Jyotiṣa-vedāṅga*) is one of the ancillary texts of the Vedic corpus.[1499] It is available in two recensions, one attached to the *Ṛgveda* and the other to the *Yajurveda.* The former (the Ṛk-recension), is variously dated from *ca.* 1370 to 400 BC; the Yajus-recension is of a later period. The *Arthaśāstra* of Kauṭilya underwent several redactions. The version that is available today is said to be roughly from second century AD. The *Śārdūlakarṇāvadāna*, which forms the 33rd chapter of the Buddhist work *Divyāvadāna,* supplies some additional information. It was translated into Chinese in the third century AD; therefore, the original must belong to a period before this century.[1500]

The fourth source is the Jaina text *Jyotiṣkaraṇḍaka*; its date is also uncertain. Malayagiri, a contemporary of King Kumārapāla, wrote a commentary on it between 1150-1175 AD.[1501] In this commentary, Malayagiri states that the author of the *Jyotiṣkaraṇḍaka* is an ācārya of Valabhī (*jyotiṣkaraṇḍakasūtrakartā cācāryo vālabhyaḥ*). It would imply that the work was composed or redacted in the first council of Valabhī which took place in the latter half of the fourth century, between 360 and 373 AD. There is another tradition which attributes the composition of the *Jyotiṣkaraṇḍaka* to *Pādalipta.* His date is uncertain; he is assigned variously to the second or the third century AD. Thus, of the two printed editions we have of this book, the first one published from Ratlam in 1928 attributes it to Vallabhīya Ācārya,[1502] while

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1498 The first three sources are discussed in Fleet 1915 and in Pingree 1973.

1499 Lagadha, *Vedāṅga-jyotiṣa.*

1500 Fleet 1915, pp. 217-218.

1501 CESS, 4, pp. 359-363.

1502 *Vallabhīyācāryīyaṃ Śrījyotiṣkaraṇḍakaṃ Prakīrṇakaṃ, Śrīman-Malayagiry-ācāryakṛta-vṛttiyuktaṃ*, Rishabhdevji Kesharimal Shvetambar Samstha, Ratlam 1928.

the second edition of 1989 from Bombay to Pādaliptasūri.[1503] We follow the second edition.

The outflow water clock or the *Nāḍikā-yantra* described in these texts consists of a large vessel with a very small hole at the bottom through which the water in the vessel flows out and indicates time. The shape and size of the vessel is not clearly mentioned in any of these texts. The names of the time unit *nālikā* or *nālī* are diminutive forms of *nala,* which denotes, among others, a reed or a tube, or a hollow cylinder.[1504] Accordingly the water vessel must have been generally of cylindrical shape. On the other hand, the *Jyotiṣkaraṇḍaka* prescribes the shape of a pomegranate flower (*dālimapupphāgārā*); it would suggest a vessel shaped like a bucket or a truncated cone as in Egypt. In the middle of the second millennium BC, the Egyptians chose a bucket-shaped vessel whose upper diameter was about twice the lower diameter, and graduated its sides in equal divisions. But the size of the vessel is not mentioned in any text.

On the amount of water with which the vessel was to be filled, the texts make contradictory statements.[1505]

Vedāṅga-jyotiṣa: 1 droṇa minus 3 kuṭapas (61|64 droṇa)
Arthaśāstra: 1 āḍhaka (¼ droṇa)
Divyāvadāna: 1 droṇa
Jyotiṣkaraṇḍaka: 2 ādhakas (½ droṇa)

Since these amounts vary, the sizes of the vessels must also have been different. Moreover, since the length of the day varies according to seasons, the *Vedāṅga-jyotiṣa* (Ṛk-recension 7 = Yajus-recension 8), prescribes that a *prastha* (= ¼ *āḍhaka* = 1|16 *droṇa*) of water should be added every day when the duration of the daylight or night

1503 Pādaliptasūrī's *Joisakaraṇḍagaṃ*, with Prākṛta Ṭippaṇaka by Vācaka Śivanandī, ed. Muni Shri Puṇyavijayajī, Introduction etc., by Pt. Amritalal Mohanlal Bhojak, Jaina-Āgama-Series No. 17 (Part III), Paṇṇiyasuttāiṃ, part III, Shri Mahāvīra Jaina Vidyālaya, Bombay 1989.

1504 In the late medieval period, astronomical texts speak of a *nalaka-yantra,* which is a tube for viewing planets and stars, used like a telescope without lenses; cf. W002.

1505 The *Jyotiṣkaraṇḍaka* (31-32) mentions the units of volume (*meya-pramāṇa*) as follows: 4 *kulava* = 1 *pattha*; 4 *pattha* =1 *āḍhaka* (16 *kulava*); 4 *āḍhaka* = 1 *doṇa* (64 *kulava*); see also Srinivasan 1979, pp. 72-73.

time increases and the amount of water is removed when the duration of the day or of the night decreases. [1506] Other texts do not mention this, but it is probably implied there.

1.1. Dimension of the Aperture

The most remarkable feature is the prescription regarding the size of the hole at the bottom of the vessel through which the water flows out and by doing so denotes time intervals. It is said that the size of the hole should be such that a gold wire of specific length drawn out of a piece of certain weight should pass through it.

The *Arthaśāstra* and the *Jyotiṣkaraṇḍaka* prescribe that the aperture should be so large that a gold wire, 4 *māṣas* in weight and 4 *aṅgulas* long, should just fit into it. The *Śārdūlakarṇāvadāna* prescribes 1 *suvarṇa* weight but retains the length of 4 *aṇgulas.* Gold naturally means pure gold, i.e. as pure as was possible with the contemporary technology. The *Arthaśāstra* indeed exhibits a wide knowledge of gold metallurgy and is the first text to describe the method of gold assaying.[1507] As pure gold is malleable enough, a gold wire of a uniform diameter can be drawn with a given weight of gold. The aperture in question is a minute one, and there is no better way of defining it than by this method. The Babylonian records on outflow water clocks do not appear to be familiar with this method. Therefore, we will not be much wrong in assuming that this method of micro-measurement developed in India, perhaps in the second century AD, when the relevant portions of the *Arthaśāstra* are believed to have been composed. On the face of it, this sounds like a very scientific method of micro-measurement. Even when the outflow water clock was replaced by the sinking bowl type of water clock, the dimension of the aperture in the sinking bowl was defined in a similar manner (see the next section). Therefore, Harry Falk has taken the trouble of estimating that the gold wire mentioned in the *Arthaśāstra* would have a diameter of 1.448 mm.[1508] Drawing gold wire with the help of a hard plate containing holes of gradually diminishing sizes was an ancient art, but to draw a small lump of gold exactly to the length of four digits, no more and no less, is near to impossible.

[1506] Lagadha, *Vedāṅga-jyotiṣa,* p. 44.

[1507] Cf. Kauṭilya, *Arthaśāstra* 2.13-14; Sarma 1983.

[1508] Falk 2000, p. 118.

The *Jyotiṣkaraṇḍaka* adds two more ways of defining the hole: 'Take ninety-six hairs from the tail of a three years old female elephant calf (*gaya-kumārī*; *gaja-kumārī*); straighten them and bundle them together, and with them make the hole in the *nālikā* vessel. Or take twice [the previous number] of hairs (i.e. 192) from the tail of a two years old female elephant calf, and with them make the hole.' What the text means to say is that the hole must be such that ninety-six hairs from the tail of a three years old female elephant calf, or twice that number from the tail of a two years old female elephant calf, can pass through it.

This prescription should not be considered very unusual. The breadth of a strand of hair is considered to be a micro-unit in linear measurement in many cultures as the English expression 'hair's breadth' shows. Though logical, the micro-measurement with the tail hairs of an elephant is not very practical. These are obviously fictitious prescriptions, probably to emphasize the smallness of the hole, but it is remarkable that every text repeats them.

1.2. Al-Bīrūnī on the Outflow Water Clock

There is one more description of an outflow clock which is somewhat reminiscent of the one in the *Jyotiṣkaraṇḍaka*, and this occurs in al-Bīrūnī's *India,* where al-Bīrūnī cites the following from the *srūdhava* by Utpala of Kashmir: [1509]

> 'If you bore in a piece of wood a cylindrical hole of twelve fingers' diameter and six fingers' height, it contains three *mana* of water. If you bore in the bottom of this hole another hole as large as six plaited hairs of the hair of a young woman, not of an old one nor of a child, the three *mana* of water will flow out through this hole in one *ghaṭi.*'

Unfortunately we do not know any book of Utpala (fl. 966-69), the well-known commentator of Varāhamihira's *Bṛhatsaṃhitā* and other books, which matches the consonant scheme of *srūdhava*. This description is interesting because this is the only

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1509 Bīrūnī 1910, 1, p. 334; he also describes a sinking bowl type of water clock which he had seen in *Purshūr* (modern Peshawar), pp. 337-338.

passage which clearly mentions the cylindrical outflow vessel and gives its dimensions as well.[1510]

2. GHAṬIKĀ-YANTRA

The sinking bowl type of water clock consists of a hemispherical bowl (*ghaṭī, ghaṭikā*), made of a thin sheet of copper, with a fine hole at the exact centre of the bottom. When this bowl is made to float on the surface of the water in a larger basin (*kuṇḍa, kuṇḍī*), water percolates into the bowl through the hole and fills it, and the bowl sinks down. The bowl is then lifted up, emptied and set up once again on the surface of the water. The hole is so made that the bowl sinks sixty times in a day-and-night, that is to say, that the bowl takes 24 minutes to fill and sink. Since the bowl is called by the diminutive word *ghaṭikā* or *ghaṭī* (from *ghaṭa,* 'pot'), the time unit measured by this instrument also came to be called *ghaṭikā* or *ghaṭī.*

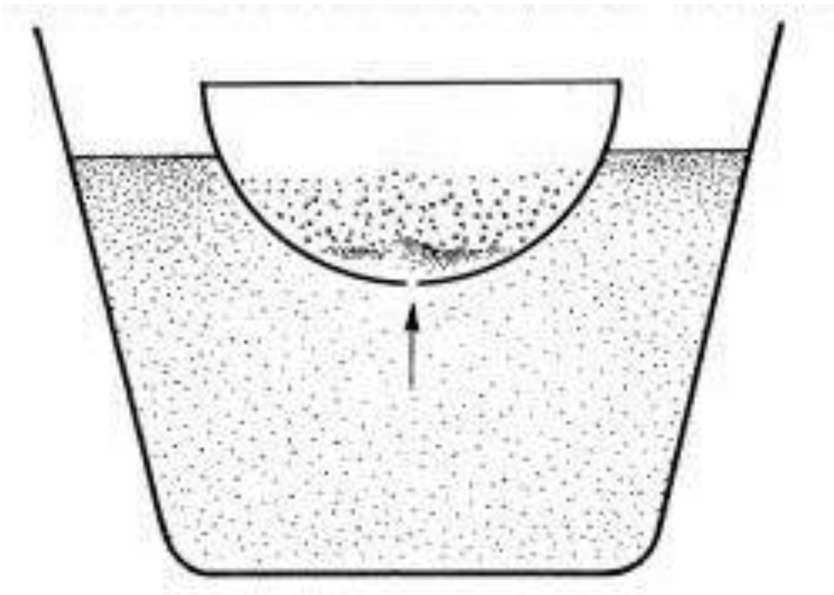

Figure R1 – Working principle of the Ghaṭikā-yantra

[1510] These dimensions agree with those given by Āryabhaṭa for the sinking bowl type, for which see 2.1.1 below.

2.1. Descriptions of the Ghaṭikā-yantra in Sanskrit Texts

2.1.1. Āryabhaṭa I on the Ghaṭikā-yantra

Āryabhaṭa I (b. 476) is the first author to describe the *Ghaṭikā-yantra,* in the *Yantrādhyāya* of his *Āryabhaṭasiddhānta*:[1511]

vṛttaṃ tāmramayaṃ pātraṃ kārayed daśabhiḥ palaiḥ |
ṣaḍaṅgulaṃ tadutsedho vistāro dvādaśānane ||
tasyādhaḥ kārayec chidraṃ palenāṣṭāṅgulena tu |
ity etad ghaṭikāsaṃjñaṃ palaṣaṣṭyāmbupūraṇāt ||
sveṣṭaṃ vānyad ahorātre ṣaṣṭyāmbhasi nimajjati |
tāmrapātram adhaśchidram ambuyantraṃ kapālakam ||

'Get a round (i.e. hemispherical) bowl made with ten *palas* of copper. Let its height be six *aṅgulas* and the diameter at the mouth twelve *aṅgulas.* Get a hole bored at its bottom [so that a gold wire] one *pala* [in weight] and eight *aṅgulas* [in length can pass through it]. This is designated as *Ghaṭikā*[-*yantra*] because it is filled with sixty *palas* of water.

'Alternatively, any other hemispherical (*kapālaka*) copper bowl with a hole at the bottom, which sinks sixty time in a day-and-night, [will serve as] water clock (*ambu-yantra*).'

Āryabhaṭa mentions two ways of making the *Ghaṭikā-yantra*: the first is the standard model with prescribed weight, height, diameter and the size of the hole; alternatively, any vessel with a hole can be used, provided it immerses sixty times in a nychthemeron.

After Āryabhaṭa, the *Ghaṭikā-yantra* is described in several astronomical texts.[1512]

2.1.2. Lalla's Modification

Lalla (8th or 9th century), in his *Śiṣyadhīvṛddhida-tantra,* while retaining the dimensions of the bowl, changed the size of the perforation:

daśabhiḥ śulbasya palaiḥ pātraṃ kalaśārdhasannibhaṃ ghaṭitam |

[1511] This text is no more extant, but the descriptions of certain instruments are cited by Rāmakṛṣṇa Ārādhya in his commentary on the *Sūrya-siddhānta,* cf. Shukla 1967.

[1512] Some of these descriptions are translated and discussed in Sarma 2014b.

hastārdhamukhavyāsaṃ samaghaṭavṛttaṃ dalocchrāyam ‖
satryaṃśamāṣakatrayakṛtanalayā samavṛttayā hemnaḥ |
caturaṅgulayā viddhaṃ majjati vimale jale nāḍyā ‖ [1513]

'The bowl, which resembles half a pot (i.e. hemispherical), which is made of ten *palas* of copper, which is half a cubit (i.e. twelve *aṅgulas*) in diameter at the mouth and half (i.e. six *aṅgulas*) as high, which is evenly circular, and which is bored by a uniformly circular needle, made of three and one-third *māṣas* of gold and of four *aṅgulas* in length, sinks into clear water in one *ghaṭikā* (*nāḍī*).'

It is difficult to say what caused this shift in the size of the perforation—from the gold needle of one *pala* weight and eight *angulas'* length to a gold needle three and one-third *māṣas* in weight and four *aṇgulas* in length.[1514] According to Śrīdhara, who is a near contemporary of Lalla, sixty-four *māṣas* make one *pala*.[1515] Then the perforation prescribed by Lalla would be 5|48th of that prescribed by Āryabhaṭa. While the size and weight of the bowl remained the same, such stark reduction in the size of the perforation would have greatly increased the duration of the time needed for the bowl to become full and then to sink, and consequently the duration of the *ghaṭī* as well. One is therefore led to suspect that these specifications for the size of the perforation in terms of a gold wire of certain weight and length are fictitious and have no connection with actual practice. Yet this latter specification for the size of the perforation is repeated in several subsequent works.

Sanskrit astronomical texts do not prescribe the dimensions in such detailed manner for any other instrument except the water clock; here too the obsession with the size of the hole in this sinking bowl as well as in the outflow variety is indeed very strange. Defining the minute size of the hole in terms of the diameter of a gold wire of a certain weight and length is, no doubt, very ingenious, but it is very doubtful whether

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1513 Lalla, *Śiṣyadhīvṛddhida-tantra*, *Yantrādhikāra*, 34-35, Part I, p. 246.

1514 Of course, Lalla also adds in verse 36 that the vessel and the perforation can be of any dimension, provided the bowl sinks in one *ghaṭī*: *athavā svecchāghaṭitaṃ ghaṭīpramābhiḥ prasādhitaṃ bhūyaḥ* (Or, it is a vessel made according to one's liking which is adjusted for one *ghati* by repeated trials).

1515 Śrīdhara, *Pāṭīgaṇita*, rule 10, text, p. 5; translation, p. 3.

it has any practical relevance. Therefore, Bhāskarācārya in his *Siddhāntaśiromaṇi* of 1150 dismisses these prescriptions as illogical (*yukti-śūnya*) and difficult to implement (*durghaṭa*).'[1516]

In spite of this confusion in the textual prescriptions, countless specimens must have been made throughout the centuries and these must have kept reasonably correct time of one *ghatika* of twenty-four minutes. But it is doubtful whether any artisan has ever produced a bowl according to these textual prescriptions. In the few specimens that survive in modern collections, rarely any bowl has the exact shape of a hemisphere; some are more conical, some are shallower, than a precise hemisphere. The sizes and weights too do not conform to the textual prescriptions and vary considerably. The holes were obviously made by a trial and error method, by comparing the new bowl with one that showed correct time or with a sundial, and by suitably enlarging the hole or by reducing its size, rather than by means of a gold wire of given dimensions.

2.2. Measuring Fractions of a Ghaṭī

2.2.1. Pala-vṛttas

Āryabhaṭa states that the time taken to utter sixty long syllables (*gurv-akṣara*) is one *vināḍikā* of a sidereal day.[1517] *Vināḍikā* is also called *vighaṭikā,* and more commonly *pala*. Therefore, concluded Varāhamihira, a *ghaṭī* is the time taken to recite 60 times a verse made up of 60 long syllables. [1518] Since each recitation of such a verse takes 1 *pala,* these verses came to be known as *pala-vṛttas.* Bhāskara I's commentary on the *Āryabhaṭīya* contains one such *pala-vṛtta* which reads thus: [1519]

mā kānte pakṣasyānte paryākāśe deśe svāpsīḥ
kāntaṃ vaktraṃ vṛttaṃ pūrṇaṃ candraṃ matvā rātrau cet |
kṣutkṣāmaḥ prāṭaṃś cetaś ceto rāhuḥ krūraḥ prādyāt
tasmād dhvānte harmyasyānte śayyaikānte kartavyā ||

[1516] Bhāskarācārya, p. 442; see Sarma 2019.

[1517] Āryabhaṭa, *Āryabhaṭīya*, *Kālakriyāpda* 2.

[1518] Varāhamihira, 14.32; interestingly, this verse itself is made up of 60 long syllables!

[1519] Sarma 2001b.

> ‘Do not, O pretty one, at the end of the [bright] fortnight (that is, on the night of the full moon), sleep in a place open to the sky. Should it turn night, the cruel Rāhu, starving with hunger and roaming hither and thither, may eat you up, taking your pretty round face for the full moon. Therefore, after darkness, make your bed at a secluded place inside the house.’[1520]

2.2.2. Marking on the Bowls

Another possibility is to mark the divisions of the *ghaṭī* on the inner side of the vessel, but it is very difficult to graduate geometrically the inner wall of the bowl into 60 *vighaṭīs*.[1521] However, it should be possible to empirically divide the bowl, if not into 60 parts, at least into 10 parts of 6 *vighaṭīs* (= 2 min 24 sec) each. Gilchrist reports in 1795 that in some specimens he saw in Bengal, the bowl (he uses the Bengali/ Hindi word *kaṭorī*) was marked with divisions:

> These *katorees* are now and then found with their requisite divisions, and subdivisions, very scientifically marked in *Sanscrit* characters, and may have their uses for the more difficult and abstruse operations of mathematicians or astronomers, … .[1522]

Thurston also speaks ‘nicks on the inside of the cup’ (see 9.3 below), but we did not come across any such specimen during our survey.

2.3. Horological Vocabulary

Even after the *Nāḍikā-yantra* was completely replaced by the *Ghaṭikā-yantra,* the terms related to the older device, viz., *nālikā, nāḍikā, nāḍī,* continued to be used along with the new terms *ghaṭikā* and *ghaṭī* to denote the basic unit of time of 24 minutes. From these two sets of terms, two other sets of names are derived to designate the

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1520 For other such verses, see Sarma 2014b.

1521 In his treatise on the astrolabe (*Kitāb al-ᶜamal bi l’asṭurbāb*) of 986, al-Ṣūfī teaches how to graduate the inner surface of a large vessel (*pinkān*) with the help of an astrolabe; cf. Bruin 1968; but here the perforated vessel must be very large, because it is graduated for each hour of the day. This procedure cannot be employed for the much smaller *Ghaṭikā-yantra* to measure *vighaṭīs* of 24 seconds.

1522 Gilchrist 1795, p. 87.

sixtieth part of a *ghaṭī* (i.e. 24 seconds), viz. *vināḍikā, vināḍī* and *vighaṭikā, vighaṭī*. But this unit is more frequently called *pala* in northern India.

The influence of the *Ghaṭikā-yantra* on the horological vocabulary is all pervasive in India. In many modern Indian languages, time-keeping devices, howsoever sophisticated they may be, are still called *ghaḍī* (from Sanskrit *ghaṭī*).[1523] The term *ghaṭikālaya,* originally the designation of the time-keeping establishment, engendered the names of the time-keeping devices in Gujarati (*ghaḍiyāl*), Telugu (*ghaḍiyāramu, gaḍiyāramu*), Malayalam (*gaḍigāram*), and so on. While the Telugu word *gaḍiya* for the traditional unit of 24 minutes is derived from Sanskrit *ghaṭikā*, the Tamil term *nāḷigai* goes back to Sanskrit *nālikā.* Finally, in many Indian languages, when it is, e.g., four o' clock, ones says 'it is sounding four' or something similar; such an expression is not derived from the chimes of the European clocks but from the old practice of striking the *ghatis* and *praharas* on the gong.

2.4. Ghatikā-yantra in Poetry

In the medieval period, the *Ghaṭikā-yantra* became popular enough to be used as a standard of comparison in poetry. In an anonymous Jaina narrative on the life of Kumārapāla, there occurs the following verse:[1524]

> *ghaṭikāpy ekayā ghaṭyā kuṇḍīpayasi majjati* |
> *gotraṃ punar aputrasya kṣaṇān nirnāmatāmbhasi* ‖
> "The *Ghaṭikā* [bowl] takes at least one *ghaṭī* to sink in the water of the basin (*kuṇḍī*); the lineage of a sonless man takes but a moment to drown in the waters of namelessness."

In the *Jaiminibhāratamu,* a fifteenth century Telugu poem by Pillalamarri Pinavīrabhadra, a charming imagery is woven around the *Ghaṭikā-yantra.* Śiva goes to wed Pārvatī in his usual head-gear, wearing Gaṅgā and the moon on his head. To Pārvatī's maids, the half moon looks like the *ghaṭikā* bowl floating on the waters of

[1523] On the other hand, in Thai language, the word for the time-keeping device, whether it is a clock or a wrist-watch, is *nāḷikā*.

[1524] *Kumārapāla-caritra-saṃgraha,* ed. Jinavijaya Muni, Bombay 1956, p. 113.

Gaṅgā. They tease Pārvatī by saying, 'Look, who put the water clock on the head of the poor bridegroom?'[1525]

3. Prahara and Yāma

3.1. Prahara-Yāma

While time was measured in equal *ghaṭīs* for astronomical and astrological purposes, for common people broader segments were sufficient, such as the fourth part of the day and of the night. Thus in the *Kāvyamīmāṃsā*, Rājaśekhara recommends to the poet-aspirant:[1526]

> *aniyatakālāḥ pravṛttayo viplavante tasmād divasaṃ niśāṃ ca yāma-krameṇa caturdhā vibhajet | sa prātar utthāya … anuśīlayed āpraharāntam |*
>
> 'Activities without any fixed time lead to disorder. Therefore, the poet should divide the day and also the night into four [parts] by the sequence of *yāmas*. He should get up in the morning …. and study up to the end of the [first] *prahara*.

These time units were probably announced by strokes on a drum at a central place like the royal palace, temple or monastery, and hence were called *prahara* (lit. 'stroke'). The duration of this *prahara / yāma* is variable according to the geographical latitude and the season.

Astronomical texts do not mention this time unit *prahara / yāma* at all; the only exception is Bhāskara I, who, in his commentary on the *Āryabhaṭīya* of Āryabhaṭa, makes a brief reference to *yāma*: *divasa-rātri-caturbhāgo yāmaḥ* (*yāma* is the fourth part of the day and of the night).[1527] But these terms are frequently mentioned in the *Purāṇas* and literary texts, where both are usually treated as synonyms. But there is a subtle difference between the two: *yāma* is used mainly in connection with the night and

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1525 Pillalamarri Pinavīrabhadra Kavi, *Jaiminibhāratamu,* Madras 1959, *Aśvamedha-parvamu*, verse 2.

1526 *Kāvyamīmāṃsā of Rājaśekhara,* ed. C. D. Dalal and R. A. Sastry; revised and enlarged by K. S. Ramaswami Sastri, Baroda 1934 (GOS 1), p. 52.

1527 *Āryabhaṭīya of Āryabhaṭa,* with the commentary of Bhāskara I and Someśvara, critically edited by Kripa Shankar Shukla, Indian National Science Academy, New Delhi 1976, p. 176.

prahara with daytime, occasional occurrences to the contrary notwithstanding. Hence the night is called *yāminī, yāmikā, yāmavatī,* or *triyāmā,* but never *prahariṇī* etc.

About the term *triyāmā* used in the sense of the night, one may ask: if *yāma* is the fourth part of the night, why is the night called *triyāmā,* 'that which consists of three *yāmas*'? Here practical considerations play a role. In theory, night begins at sunset and ends at sunrise. But for some time after the sunset and again for some time before the sunrise, it is bright enough to see and to do things (*ceṣṭākāla*). Hence, half a *yāma* at the beginning of the night and the same at the end are not counted. The remaining part of the night which is really dark consists then of three *yāmas* and therefore the night is called *triyāmā*.[1528]

3.1.1. Night of three Yāmas

This dark part of the night is divided into three *yāmas* probably for monastic reasons, because the Jaina and Buddhist monks were to perform certain observances in each *yāma.* Thus the Jaina canonical work *Ṭhāṇaṃga* 3.2 enumerates the three *yāmas*:[1529]

> *tao jāma pannattā* | *taṃ jahā paḍhame jāme majjhime jāme pacchime jāme* |

The Buddhist text *Dhammapada* 157 likewise speaks of three *yāmas* of the night:

> *attānaṃ ce ppiyaṃ jañjā rakkheyaṃ naṃ surakkitaṃ* |
> *tiṇṇaṃ añjataraṃ yāmaṃ paṭijaggeyaṃ paṃḍito* ||
>
> 'If one holds oneself dear, one should diligently watch oneself. Let the wise man keep vigil during any of the three watches of the night (*tiṇṇaṃ añjataraṃ yāmaṃ*).'

3.1.2. Buddhaghoṣa

Here it is not necessary to discuss what the monks did in each of the three *yāmas.* Suffice it to say that they needed to know the passage of each *yāma,* and so must have

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[1528] Thus an anonymous line reads: *triyāmāṃ rajanīṃ prāhus tykvādyantacatuṣṭayam* (they call the night *triyāmā*, after discounting the fourth *yāma,* which occurs [in two halves] at the beginning and at the end). In his commentary on *Amarakośa* 1.4.3-5, Bhānujī Dīkṣita explains that only three *yāmas* are taken into account because the first and last [half *yāmas*] are almost like the day, being the periods of activity (*ādyantayoś ceṣṭākālatvena dinaprāyatvāt*).

[1529] Quoted in the *Abhidhānarājendra,* s.v. *jāma.*

made arrangements to announce it with the help of a water clock. Such an arrangement is described by Buddhaghoṣa in his *Papañcasūdanī* commentary on the *Majjhimanikāya*, which was composed in the first half of the fifth century in Sri Lanka:

> *ajagaravihāre pi kāḷadevathero antovasse yāmagaṇḍikaṃ paharati | āciṇṇaṃ etaṃ therassa | na ca yāmayantanālikaṃ payojeti, aññe bhikkhū payojenti | atha nikkhante paṭhame yāme there muggaraṃ gahetvā ṭhitamatte yeva ekaṃ dve vāre paharante yeva vā yāmayantaṃ patati | evaṃ tīsu yāmesu samaṇadhammaṃ katvā …* [1530]
>
> 'In the rainy season, the monk Kāḷadeva used to strike the gong (*gaṇḍika* < *ghaṇṭika,* bell?) at the end of each *yāma* in the Ajagara monastery. He was so well accustomed to do this that he did not [need to] use a water clock with the duration of one *yāma* (*yāma-yanta-nāḷikā*), but other monks did. As the first *yāma* concluded, and as the monk stood there holding the mallet, or as he just struck once or twice, then the water clock for one *yāma* (*yāma-yanta*) used to sink (*patati*). Thus having performed his monastic duties in the three *yāmas* …'

This is the earliest passage to describe the sinking bowl type of water clock, which is clearly indicated here by the word *patati.* It is interesting that here the water clock is called *yāma-yantra,* instrument for measuring one *yāma.* The bowl here is a larger one for measuring one *yāma,* specially made for the needs of the Buddhist order in Sri Lanka. This island stretches roughly from the latitude of 6° to 8° N and here the seasonal variations in the length of the day or of the night are negligible. Therefore, probably no adjustments were made in the duration of *yāma* and it was maintained at the mean rate of seven and a half *ghaṭīs* (= 3 hours). The monk, appropriately called Kāladeva, 'the Lord of Time', became so adept that he did not need to watch the actual sinking of the bowl; his hand automatically lifted the mallet to strike the bell when the bowl was about to sink.

1530 *Papañcasūdanī, the commentary on the Majjhima-Nikāya,* vol. 1, ed. U. Dhammaratana and U. Jagarabhivamsa, Nālandā 1975; for an interpretation of this passage, see Hinüber 1978, pp. 224-225.

3.2. Royal Timetable in the Arthaśāstra

While the day and night are divided into four *praharas* or *yāmas* for common pursuits, the *Arthaśāstra* divides the day and the night into eight parts each for the rigorous timetable of the king and assigns him different tasks in each of these 8+8 periods. However, no name is given to these time units.[1531] These periods are to be measured by means of a water clock or a gnomon. The outflow water clock according to this text has been mentioned above.

The *Arthaśāstra* thus envisages a royal establishment for time-keeping, where time is measured with water clocks and gnomons.[1532] In fact Kauṭilya mentions time-measuring instruments only in connection with the royal timetable of the 8+8 periods.[1533]

3.3. Royal Timetable in the Tamil Country

Similar royal timetable is mentioned also in Tamil Śaṅgam literature, assigned generally to the first three centuries after Christ. The daytime of the king is divided into three periods of 10 *nāḷikais* (= *nālikā*) each. In the first period, the king follows what is traditionally prescribed for a person of high rank; the next ten *nālikās* are meant for public audience, and the third period of ten *nālikās* is devoted to private relaxation and entertainment. The anthology called *Kuruntokai* mentions that a group of officials with the designation *Nāḷikai Kaṇakkar* (Skt. *Nālikā-gaṇaka*) measured time by means of an instrument called *Nāḷikai Vaṭṭil,* a vessel from which water trickled out, i.e. an outflow clock or *Nāḍikā-yantra,* and that these officials kept awake by turns in order to be able to watch the clock day and night. [1534]

This raises the following question: how was the variable *prahara / yāma* or a half of it measured with water clocks, whether outflow type or sinking bowl type, which

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1531 Kauṭilya, *Arthaśāstra,* 1.19.6: *nālikābhir ahar aṣṭadhā rātriṃ ca vibhajec chāyāpramāṇena vā* (the king should divide the day into eight parts, and also the night, by means of *nālikās* or by the shadow-length [of the gnomon]); at 1.19.9-24 his different duties in these 8 + 8 periods are mentioned.

1532 Kauṭilya, *Arthaśāstra,* 1.7.8; 1.19.6 ff.; 2.20. However, no special officer called *Kālamānādhyakṣa* is mentioned at 2.20 where one would expect it.

1533 Pargiter 1915, pp. 702-703, draws attention to the fact that the time table of 8+8 of periods is followed also in the care and training of the royal elephants (cf. Kauṭilya, *Arthaśāstra,* 2.31.5-7).

1534 N. Subrahmanian, *Śaṅgam Polity: The Administration and Social Life of Śaṅgam Tamils,* Bombay 1966, pp. 53, 105, 206-207.

measure only the fixed units of one *ghaṭī* ? In other words, how were the variable units reconciled with the fixed units? On this, no evidence is available from the ancient or early medieval periods, but only in the records from mid-sixteenth century onwards. From these, it appears that, although the *prahara* is one-forth of the daylight, in practice, however, the *praharas* are so arranged that they always consist of an integral number of *ghaṭīs.*

Writing in 1795, John Gilchrist explains how this was done with the help of an elaborate 'Hindoostanee Horal Diagram.' According to him, in a day all the *praharas* were not of equal length but each *prahara* consisted of an integral number of *ghaṭīs.* Thus, on equinoctial days, the first and fourth *prahara* of the day consisted of 8 *ghaṭīs* each, whereas the second and third contained 7 each, making a total 30 *ghaṭīs.*[1535] This would mean that the second *prahara* ends at noon, thus dividing the day into two equal parts. Secondly, the length of the *prahara* cannot be adjusted each day but only when the day or the night becomes longer or shorter by two *ghaṭīs*, i.e. 48 minutes. In other words, the *prahara* length was adjusted infrequently, perhaps once in about two months, and not every day. Neugebauer writes that in Mesopotamia the length was adjusted once in every 15 days.[1536]

Seen in this light the following statements by Abū al-Faḍl and Mrs. Meer Hassan Ali become intelligible. Writing in the second half of the sixteenth century, Abū al-Faḍl reports:

> The Hindu philosophers divide the day and night into four parts, each of which they call *pahr.* Throughout the greater part of the country, the *pahr* never exceeds nine *gharis* nor is less than six.[1537]

Mrs. Meer Hassan Ali, an English woman who was married to an Indian Muslim and lived with him in Lucknow for twelve years from 1816, writes:

1535 Gilchrist 1795, p. 83.

1536 Neugebauer 1947, p. 41: 'In order, e.g., to define the length of a "night watch" at the summer solstice, one had to pour a mana of water into a cylindrical clepsydra; its emptying indicated the end of the watch. One-sixth of a mana had to be added each succeeding half month. At equinox, 3 mana had to be emptied in order to correspond to one watch, and 4 mana were emptied for each watch of the winter solstitial night.'

1537 Abū al-Faḍl 3, p. 17.

> The day is divided into four equal parts, or watches, denominated purrhs (pahar); as, first purrh, second purrh, &c. The night is also divided into four purrhs, each of which is subdivided into ghurries, varying in number with the change of the season : the longest days require eight ghurries to one purrh; the shortest, only six. The same division is observed for the night. [1538]

It is also in this light that we should understand the following account by I-Tsing.

4. Time-keeping Establishment at Nālanda in the Seventh Century

The Chinese traveller I-Tsing (modern spelling Yi Jing) spent some ten years (ca. 675-685) at the famous Buddhist monastery of Nālanda, and gave a detailed account of the time-keeping establishment at this monastery, where time was measured by means of the water clock with the sinking bowl[1539]:

> Besides, clepsydrae are much used in great monasteries in India. These together with some boys are the gifts from kings of many generations, for the purpose of announcing hours[1540] to the monastics. Water is filled in a copper vessel, in which a copper bowl floats. This bowl is thin and delicate, and holds two Shang (prasthas) of water (about two pints). In its bottom a hole is pierced as small as a pin-hole, through which water springs up; this hole is to be made larger or smaller according to the time of the year. This must be well set, measuring (the length of) praharas.[1541]
>
> Commencing from the morning, at the first immersion of the bowl, one stroke of drum is announced, and at the second immersion, two strokes; at the third immersion, three strokes. But, at the fourth immersion, besides four strokes of a drum, two blasts of a conch-shell, and one more beat of a drum are added. This is called first hour, that is when the sun is at the east (between the zenith and the horizon). When the second turn of four immersions of the bowl is done, four strokes (of a drum) are sounded as before, and a conch-

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[1538] Ali 1974, p. 55.

[1539] I-Tsing 1896, pp. 144-146.

[1540] Here 'hour', underlined by us, is used apparently in the sense of *prahara.*

[1541] Here 'prahara' is used not in the technical sense, but in the sense of the duration of immersion of the bowl.

> shell is also blown, which is followed by two more strokes (of a drum). This is called the second hour, that is the exact (beginning of the) horse-hour (i.e. noon). If the last two strokes are already sounded, priests do not eat, and if any one is found eating, he is to be expelled according to the monastic rites. There are also two hours in the afternoon which are announced in the same way as in the forenoon. There are four hours at night which are similar to those of the day. Thus division of one day and one night together makes eight hours. … This is the regulation of the clepsydra in the Nālanda monastery. …
>
> Owing to the use of those clepsydrae, even in thick clouds and in a dark day, there is no mistake whatever about the horse-hour (i.e. noon), and even when rainy nights continue, there is no fear of missing the watches. It is desirable to set such ones (in the monasteries in China) asking for royal help, as it is a very necessary matter among the Brotherhood.
>
> In order to set a clepsydra, one has first to calculate (the lengths of) the day and night, and then to divide them into hours. There may be eight immersions of the bowl from morn to midday. If it happens that the immersions are less than eight (when it is midday), the hole of the bowl is to be opened a little wider. To set it right, however, requires a good mechanician.

It is a highly complex business to regulate the size of the hole every day. Of course, the hole can be enlarged with a tapering needle, or its size can be reduced by plugging it with wax or hammering the area around it with a hammer. But to do it once every day and every night, i.e. 730 times in the year, is no mean business, especially when it is remembered that the hole in question is an extremely fine one. Moreover, there would be an interruption in time measurement while the hole was being readjusted.

A somewhat simpler proposition would be to use a different bowl each day and each night. Then one would need a series of 183 bowls with holes of gradually increasing size. These can be used successively each day for the first six months from the winter solstice to the summer solstice and then in reverse order for the next six months. At night the contrary sequence is followed.

But what exactly is the daily increase or decrease in the day-length at Nālanda which lies on the latitude of 25° N? The maximum duration of the day here is 13;35

hours. That is, between the vernal equinox on 21 March and the summer solstice on 21 June (roughly 92 days), the increase is 1;35 hours or 95 minutes. Thus in 92 days, the daily increase would amount to a little over 1 minute per day. In a bowl that measures normally 45 minutes (16 immersions in 12 hours), the daily increase should be 1|16 minutes = 3.75 seconds. Can any 'mechanician', howsoever ingenious he may be, enlarge the hole so that it shows a difference of 3.75 seconds? If the Buddhist monks at Nālanda needed to know the 1|16th parts of the day or of the night for their ritual performances, they probably changed the perforated bowls of the water clock once every week or once every two weeks and certainly not every day and every night.

Therefore Yi Jing's account has to be treated with great caution. More so, as the passage quoted above is followed by this sentence: 'When the day or night becomes gradually shorter, half a ladle (of water) is to be added, and when the day or night grows gradually longer, half a ladle is to be let off.' In the sinking bowl type of water clock, addition of water into the basin, or letting some of it off, does not make any difference. This stipulation actually should pertain to the outflow clock, at Pulo Condore which Yi Jing describes next, or to the outflow water clocks of ancient India. Even in the outflow water clock, water is added gradually when the days grow longer and not otherwise. There is surely an error in Yi Jing's account.

Stranger still is the following sentence: 'It is desirable to set such ones (in the monasteries in China) asking for royal help, as it is a very necessary matter among the Brotherhood.' This conclusion gives the impression as though China did not have water clocks until the end of the seventh century AD. This is rather intriguing because China had made great strides in the manufacture of highly complex models of inflow water clocks. The inflow clocks with a float and indicator rod is attested as early as the Han period. Yi Jing's elder contemporary, Lü Tshai (d. 666) is credited with the invention of a poly-vascular inflow clock consisting of three compensatory tanks between the reservoir and the receiver. [1542]

[1542] Cf. Needham 1959, pp. pp. 313-329; figures 138-144.

In view of these inconsistencies, not much credence can be given to Yi Jing's account of the time keeping practice at Nālanda in the seventh century.[1543] It is possible that time was measured there in variable quarter *praharas* for unknown monastic reasons. But that was not the general practice in India, which was to measure time in equal *ghaṭīs* of 24 minutes.

The mode of announcing time by drum-beats, conch-blasts and again drum-beats will become clear from the following table.

Table R1 Scheme of announcing the quarter-praharas and full praharas

No. of immersions of the bowl from sunrise	Drum strokes	Conch blasts	Drum strokes to announce the no. of elapsed *praharas*
1	1		
2	2		
3	3		
4	4	2	1 first *prahara*
5	1		
6	2		
7	3		
8	4	2	2 second *prahara* = noon
9	1		
10	2		
11	3		
12	4	2	3 third *prahara*
13	1		

1543 In Indian historiography, Chinese accounts of India, are usually considered to be very useful because they provide much valuable information about material conditions, with reliable chronology, but strangely this is not the case with Yi Jing; elsewhere (pp. 140-142) he attempts to give a correct interpretation of *pradakṣina,* the circumambulation of sacred objects; instead of observing how it was actually practiced in India, with one's right hand towards the object, he tries to analyse the term etymologically, and comes to the wrong conclusion.

14	2		
15	3		
16	4	2	4 fourth *prahara* = sunset

Here the two conch blasts merely serve the purpose of separating two sets of drum strokes, announcing respectively quarter *praharas* and full *praharas.*

5. Ghaṭikā-yantra in Inscriptions and Literary Texts

Institutions for time-keeping are attested, from the seventh century onwards, at Buddhist monasteries, royal palaces, town squares and the like, where time was measured constantly with this water clock and the passage of each *ghaṭī* and completion of each quarter of the day (*prahara*) or of the night (*yāma*) was broadcast regularly by means of drums and conch-shells. In the medieval period, the drum and the conch-shell were replaced by the gong, which was called *ghaḍiyālā* in the Middle Indic. The Chinese traveller Yi Jing's account of the time-keeping establishment at Nālanda in the seventh century has been cited above, where he states that these water clocks, 'together with some boys are the gifts from kings of many generations, for the purpose of announcing hours to monastics.' At the beginning of the eleventh century, Al-Bīrūnī reports about a time-keeping establishment in Peshawar thus:

> The Hindus have a popular kind of division of the nychthemeron into eight *prahara, i.e.* changes of the watch, and in some parts of their country they have clepsydrae regulated according to the *ghaṭī,* by which the times of the eight watches are determined. After a watch which lasts seven and half *ghaṭī* has elapsed, they beat the drum and blow a winding shell called *śaṅkha,* in Persian *sped-muhra.* I have seen this in the town *Purshūr.* Pious people have bequeathed for these clepsydrae, and for their administration, legacies and fixed incomes.[1544]

[1544] Bīrūnī 1910, I, pp. 337-338.

5.1. Documents from Gujarat

References to water clocks and to the buildings where such clocks are regularly maintained are to be met with in inscriptions and literary texts mainly from Gujarat on the west coast and the Telugu-speaking regions on the east coast. The buildings which house the water clocks are called *ghaṭikālaya, ghaṭikāgṛha,* or *ghaṭīgṛha* in inscriptions and other documents from Gujarat belonging to the thirteenth and fourteenth centuries.[1545]

5.1.1. References to Ghaṭikā-gṛha

The *Lekhapaddhati,* a collection of model drafts for official and private documents, compiled in the thirteenth century, lists *Ghaṭikāgṛha-karaṇa* among the names of 32 different administrative departments (*karaṇa*); this would then be the department which maintains and supervises time-keeping establishments in different cities in the kingdom. The *Prabandhacintāmaṇi of Merutuṅga* (1306) speaks of the establishment of the *ghaṭikāgṛha,* along with *vyayakaraṇa* (department of state expenditure) and *hastiśālā* (elephant-stable). [1546]

In an inscription dated 1287, a certain Tripurāntaka is stated to have erected five temples, close to the splendid but decaying water-clock (*jīrṇa-ghaṭikālaya*).[1547] In the *Kumārapālacaritra-saṃgraha,* it is said that in the city of Karṇāvatī, the minister Ambaḍa set up three golden *kalaśas*, in the king's *ghaṭikā-gṛha.*[1548]

1545 Majumdar 1956, pp. 213-215, lists such references, but argues that these were not buildings with water clocks, but educational institutions. Here he confuses between *ghaṭikā-gṛha* and *ghaṭikā-sthāna.* The latter was an institution which flourished in the seventh and eighth centuries in the Pallava kingdom, more particularly in the capital city Kāñcī, but it had nothing to do with time-keeping. In fact, it was an educational institution, wielding at the same time some kind of political authority. But it must be noted that this meaning of the expression *ghaṭikā* is peculiar to Tamilnadu and surrounding areas and that the term itself is said to be a hyper-Sanskrit form of the Tamil *kaṭakai,* 'place for learning'.

1546 Merutuṅga, *Prabandha-cintāmaṇi,* ed. Jina Vijaya Muni, Santiniketan, 1933, p. 20: *vyayakaraṇa-hastiśālā-ghaṭikāgṛha-sahitam kāritam.*

1547 Bühler, 'The Cintra Praśasti of the Reign of Sarangadeva, *Epigraphia Indica*, I (1892) 271-287, verse 40, on p. 284.

1548 *Kumārapālacaritra-saṃgraha*, ed. Jina Vijaya Muni, Bombay 1956, p. 101: *śrī-udayanacaitye karṇāvatyāṃ śrīśakunikāvihāre rājño ghaṭīgṛhe kauṅkaṇanṛpateḥ kanakamayaṃ kalaśatrayaṃ nyāsthād āmbaḍamantrī rājapitāmahaḥ.*

5.1.2. Illustrations of the Ghaṭikā-gṛha

More valuable than these are two illustrations depicting a small building with the caption *ghaṭikā-graha* on a painted wooden manuscript cover, measuring 762 mm in length and 76 mm in breadth.[1549] It was discovered by Jina Vijaya Muni in the Jñāna Bhaṇḍār of Jaisalmer. It is painted on both sides with events related to the historic debate between Vādi Devasūri of the Śvetāmbara Jain sect and the Digambara monk Kumuda Candra, which took place at the court of Siddharāja Jayasiṃha in the year 1124 and in which Devasūri was victorious.

The borders of the front side of the manuscript cover are decorated with rows of geese (*haṃsa-paṅkti*), which is a popular motif of decoration in the miniature paintings of western India, but the reverse side is not so decorated. The front side shows, from left to right, scenes from the city of Āśāpallī:[1550] first the shrine of Neminātha (with the caption *āśāpallyāṃ nemicaityaṃ*), followed by the house of water clock (*ghaṭikā-gṛhaṃ*); thereafter is a picture of Devasūri (*devasūrayaḥ*) seated on a low stool with a high back, giving a discourse to a scholar named *Paṃ[ḍita] Māṇikyaḥ*. The rest of the cover shows Kumuda Candra with his disciples, Devasūri receiving a message from Kumuda Candra, challenging him for a debate, and so on.

The reverse side contains scenes from Pāṭan where the debate was to be held in the court of King Jayasiṃha; the arrival of Devasūri with his entourage on the left half and on the right half the arrival of Kumuda Candra with his followers. The latter, immediately after his arrival, proceeds to the royal harem to meet the queen mother, because her own father was partial towards the Digambaras, but was not allowed to meet her. He is stopped from doing so by the gatekeeper, who is pushing him away unceremoniously.

Interestingly, *ghaṭikā-gṛhas* are depicted on both sides of the wooden cover, indicating their presence at both Āśāpallī as well as Pāṭan; in *Āśāpallī* one sees the front side of the *ghaṭika-gṛha* and in Pāṭan the backside of the *ghaṭikā-gṛha.*

[1549] Chandra 1949, pp. 59-62, Figs. 193-198.

[1550] Also known as Ashaval, modern Ahmedabad, east of the river Sabarmati.

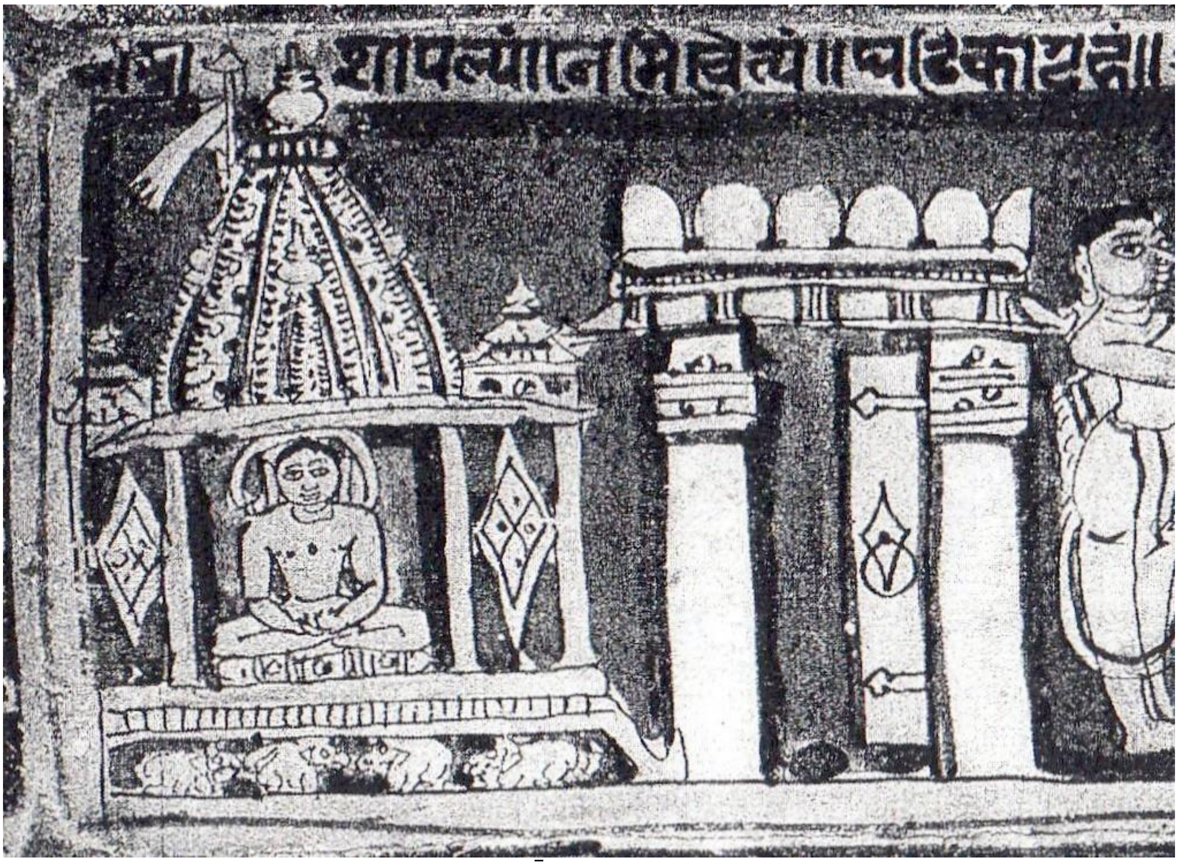

Figure R2 – *Ghaṭikāgṛha* in Āśāpallī next to the Neminātha temple;
caption: *āśāpalyāṃ nemicaityaṃ* ‖ *ghaṭikāgṛhaṃ*‖ (detail from Fig. 193, in Chandra 1949).

On the front of the manuscript cover, on the left is shown the shrine of Neminātha at Āśāpalli. In the shrine can be seen the image of Neminātha. The shrine is surmounted by a tall, tapering tower, with a flag and a finial at the top. To the right of the shrine is the *ghaṭikā-gṛha,* with two thick pillars on either side of the door which is half open; the other half is closed by a door panel, which is joined to the pillar by two long hinges. In the middle of the panel is a rhombus-shaped decoration. To the centre of the rhombus is attached a ring, which is pulled to close the door. Above the two pillars is the roof, upon which there is a parapet consisting of a series of roundish battlements.

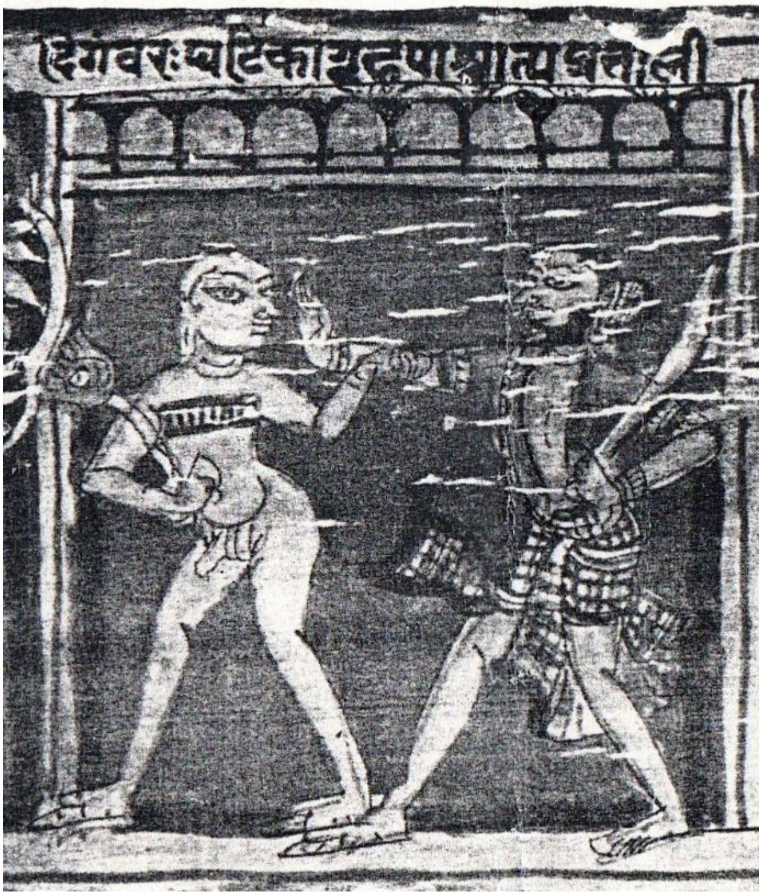

Figure R3 – *Ghaṭikā-gṛha* at Pāṭan;caption: *digaṃvaraḥ ghaṭikā-gṛha-pāścātya-pratolī*,
(detail from Fig. 198, in Chandra 1949)

The reverse side of the manuscript cover shows the Digambara monk Kumuda Candra being turned away from the king's harem by the royal guard in front of the *ghaṭikā-gṛha* of Pāṭan. The monk is clad in nothing, but holds a broom made of peacock feathers; the guard is elaborately dressed. The caption reads: *digaṃvaraḥ ghaṭikā-gṛha-pāścātya-pratolī* (the Digambara monk [at] the thoroughfare (*pratolī*) to the west of the *ghaṭikā-gṛha*). Of the *ghaṭikā-gṛha,* which forms the background, nothing much can be seen except the blank wall at the back of the building, but here the wall, with ten battlements in the parapet, appears to be wider than the one at Āśāpallī depicted on the front side. Probably here this *ghaṭikā-gṛha* is drawn wider in order to accommodate the two figures of the monk and the guard in front of it; but it may also suggest that the *ghaṭikā-gṛha* in the royal capital Pāṭan is larger than the one at Āśāpallī. More important, in both cities, the *ghaṭikā-gṛhas* are located at central places; at Āśāpallī next to the shrine of Neminātha and at Pāṭan next to the royal harem. In the view of the artist who painted this manuscript-cover, the *ghaṭikā-gṛha* must be an important feature in the urban landscape.

About the date of this wooden manuscript cover, Moti Chandra writes: 'According to Jinavijayaji, it is quite possible that this painted wooden cover was prepared within five or six years of the great discussion, when the incidents were still fresh in memory. If this surmise be correct, then the date of the painted cover should fall near about 1130 A. D.' There is not much merit in this reasoning, for this debate was an important event in the Śvetāmbara history and was narrated in several texts of later periods as well. But Moti Chandra also cites stylistic reasons for the early date, which are more convincing; therefore, the wooden book may be assigned to the twelfth century.

5.2. Documents in Telugu

It is very significant that there are available three Telugu inscriptions on the endowment of time-keeping establishments with water clocks (*ghaḍiyāramu*) during the thirteenth and fourteenth centuries, besides several references in literary texts.[1551] An inscription at Warangal dated 1228 states that each household was to pay the tax of a certain measure of rice for the maintenance of the *ghaḍiyāramu*.[1552]

5.2.1. Inscription of 1403

An inscription dated 10 January 1403 found at Tāḷḷūru near Rajamahendravaramu (formerly Rajahmundri, Lat. 16;59° N, Long. 81;47° E), mentions the endowment made by a certain Bhaṃḍāru Seṭṭi of a water clock in the temple of Gopīnātha. [1553]

This inscription is written in Sanskrit and Telugu. It commences with a preamble in Sanskrit which states that Bhaṃḍāru Seṭṭi gifted the water clock (*ghaṭikā-yantra*) for measuring the times of rituals (*arcana-kāla-māna*) and a bell (*ghaṇṭā*) for announcing

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1551 I have not been able to obtain the full text of the first inscription, but the other two will be cited in full and translated.

1552 N. Venkataramanaiah (ed), *Inscriptions of Andhra Pradesh, Warangal District*, Hyderabad 1974, no. 63. p [?]. 197: *maṭhe aśeṣa na(ka)ramunu ghaḍiyārānaku iccina āyamu iṃtanu pāḍika biyyamu* …. The inscriptional passage conveys the meaning that the entire (*aśeṣa*) *nakaram* of Mathe gave one *pāḍika* of rice in every house for the maintenance of the *ghaḍiyāram*, which has the public utility. For this reason only the *nakram* of Mathe has collected the tax (*āyam*) of one *pāḍika* of rice towards the upkeep of *ghaḍiyāram*.'

1553 *Reḍḍi-Saṃcika,* ed. Vaddadi Appa Rao, Andhra Itihāśa Pariśodhaka-Maṃḍali, Rajamahendravaramu 1947, supplement, inscription no. XXIII, p. 35. (https://archive.org/stream/in.ernet.dli.2015.370460/2015.370460.Reddi-Sanchika#page/n0/mode/2up); [also https://goo.gl/Nxnb1p, last accessed in January 2018].

the time-intervals. It goes on to say that for the maintenance of the water clock, two brahmins were given in perpetuity a piece of land measuring 8 *khārikās.* Finally it adds that the text of the inscription was drafted by Śrīvallabha, son of Vallabhārya, of Kaṇva-gotra.

The Telugu part elaborates further; that the endowment was made with the consent of Kāṭamareḍḍi Vemāreḍḍi and that it was made to perpetuate the fame of **Komaragiri-reḍḍi** and his queens. It mentions the names of the four brahmins who were to maintain the water clock.

The three verses in Sanskrit that follow are standard verses appended to the land grants and contain an appeal to the future kings not to usurp the land from the descendants of the brahmins.

ambudhi-netra-viśva-gaṇite 'bde citrabhānau raven …
… mahīsurataku (?) bhaṃḍāru seṭṭi-prabhuḥ |
so 'yaṃ rājamaheṃdra-nāma-nagare vaprāṃtare
gopīnāthāyārcana-kāla-māna-ghaṭikā-yaṃtraṃ ca ghaṇṭām adāt ||
gopīnāthasya tasyaiva grāme krītvāṣṭa-khārikāḥ |
kṣetraṃ divijebhyo ghaṭikā-māyibhyo (?) jīvikām adāt ||
śrīvallabhārya-putreṇa kaṇvagotreṇa dhīmatā |
śrīvallabhena racitaṃ śāsanaṃ jayatāc ciram ||
svasti śrī śaka-varṣaṃbulu 1324 aguneṃṭi citrabhānu saṃvatsara puṣya b|| 2 ṃnāṃḍu makara-saṃkramaṇa-puṇyakālamaṃdunu ***kāṭamareḍḍi vemāreḍḍi****ṃgāri ānatini* ***komaragirireḍḍi****ṃgārikini vāri devulaku śāśvatamayina kīrtini*
sukṛtamulu kalugunaṭṭugānu rājamahendrāvarapu koṭaloni śrī-gopīnātha-devarakunu pūjākāla-jñānārthamai ghaḍiyāropacāramu ***bhaṃḍāru śeṭṭi****naṃgāru samarpiṃciri.*
yī ghaḍiyāraṃ veṭṭī bhāṃhmalu sūrāojjhala māranna bollāojjhala devaramma peddibhoṭla mānadyoru annamojjhalu yī nalugurukunnū śrīgopīnātha-devaraku vūru
anuparutanu kālocitamūyaṃ peṭṭi pe … maṭham …ḍu kṣetram.
[mi]davuṭlu kṣetraṃ vilciyicciri | yī dharmaṃ ācaṃdrārkam |
maṃgalaṃ mahā śrīśrīśrīṃ jeyun |

svadattāṃ paradattāṃ vā yo hareta vasuṃdharāṃ |

ṣaṣṭivarṣasahasrāṇi viṣṭhāyāṃ jāyate kṛmiḥ ||

svadattād dviguṇaṃ puṇyaṃ paradattānupālanaṃ |

paradattāpahāreṇa svadattaṃ niṣphalaṃ bhavet ||

sāmānyo 'yaṃ dharmasetur nṛpāṇāṃ

kāle kāle pālanīyo bhavadbhiḥ |

sarvānn etān bhāvinaḥ pārthivendrān

bhūyo bhūyo yācate rāmacandraḥ ||

[Sanskrit] 'In the year counted by oceans (4), eyes (2) and worlds (13) [i.e., 1324, in the Jovian year] Citrabhānu, of the sun … (broken)…, Bhaṃḍāru Seṭṭi, the lord, endowed a *ghaṭikā-yantra* for measuring the times of worship of Gopīnātha and a bell (*ghaṇṭā*) in the city named Rājamahendra inside ramparts [of the fort].

'In the same village of Gopīnātha, he bought a piece of land measuring eight *khārikās* and gave it to the brahmins, the *ghaṭikā-māyins* (?), for their livelihood.

'May this inscription (*śāsana*), drafted by the learned Śrīvallabha, son of the illustrious Vallabhārya, of Kaṇva-gotra, flourish forever.'

[Telugu] 'May it be auspicious [*svasti*]. In the *Śaka* year 1324 which corresponds to [the Jovian year] *Citrabhānu*, on the second lunar day of the dark fortnight of the month *Puṣya*, on the auspicious occasion of the *Makara-saṅkramaṇa,* with the consent of the respected **Kāṭamareḍḍi Vemāreḍḍi**, in order that eternal fame and religious merit (*sukṛta*) accrue to the respected **Komaragiri-reḍḍi** and to his queens (*devulaku*), the respected Bhaṇḍāru Śeṭṭi made the endowment of a *Ghaḍiyāra* for knowing the times of worship of the Śrī Gopīnātha Devara.

'He purchased a piece of land for a price appropriate to the times in the vicinity of the village of Gopīnātha, and gave it to the four brahmins, namely Sūrā-ojjhala Māranna, Bollā-ojjhala Devaramma, Poddibhoṭla Mānapadryoru [and] Anna-ojjhalu.

'This religious endowment (*dharma*) [should last as long as there are] the moon and the sun. Let it be auspicious.'

> **[Sanskrit]** 'Whosoever usurps the land given [as an endowment] by oneself or by others will be reborn a worm in faeces for six-thousand years.
> Respecting the gifts bestowed by others is twice meritorious as compared to one's own gift. Usurping the others' gifts renders one's own gift fruitless.
> Rāmacandra entreats all the future kings again and again [saying] "this is the common bridge to attain the religious merit; you must protect it all the time."'

The date of the inscription is Śaka 1324, Jovian year *Citrabhānu,* second lunar day in the dark half of the month *Pauṣa,* which translates to Wednesday 10 January 1403. This is said to be the auspicious day of *Makara-saṅkrānti,* the day on which the *Uttarāyaṇa,* sun's northern progress commences. On this day Hindus make religious gifts (*dāna*), such as gifts of land as a religious endowment.

In the name of the donor Bhaṃḍāru Seṭṭi, the second part is derived from Sanskrit term *śreṣṭhin,* originally the designation of the head of the merchant's guild, later applied to every merchant of Vaiśya caste. The first part of the name is related to Sanskrit *bhaṇḍāra* or *bhāṇḍāgāra,* 'the royal treasury'. That this man may indeed be the head of the royal treasury is indicated by two circumstances. He instituted this endowment, not for his own personal merit (*puṇya*), but for perpetuating the fame of Komāragiri Reḍḍi, presumably the ruling monarch, and his queens. Second, in the Sanskrit preamble, he is referred to as *prabhu* (lord), an epithet usually applied to the nobility and not to merchants.

5.2.2. Inscription of 1404

Endowment made on 9 July 1404 for the installation of a water clock (*ghaḍiyāramu*) at the temple of Bhāvanārāyaṇa in Sarpavaram (Lat. 17;1° N – Long. 82:13° E), near Kakinada, East Godavari District, Andhra Pradesh. The inscription is in Telugu; it is engraved on a stone pillar set up behind the shrine:[1554]

> *svasti. śrī śakavarṣaṃbulu 1326 aguneṃṭi tāraṇa śrāvaṇa śu 5 gu*

[1554] K. Krishna Sastri (ed), *South Indian Inscriptions,* vol. V, Madras 1925 (Archaeological Survey of India, New Imperial Series, No. XLIX), reprint: New Delhi 1986; No. 10 (A.R.No. 455-B of 1893), p. 4.

śrīsarpapura-śrībhāvanārāyaṇa perumāllaku golisomāreḍḍiṃgāru ghaḍiyāramu veṭṭi
ā brāhmalu aubhalojhu simgā(o)jhumgāri jītālaku tūrputānu (kha) kha 1 na 10 cenu paḍumaṭi-polāna kha (7) na 10 nnu ve(ra)si kha 5 cenikai ṭaṃ 100 kālu samarppiṃciri.
ī ghaḍiyāramu dharmmamu ācamdrārkasthāyi.
kaiṃkaryamuna evvaru virodhiṃpinānu (ta) ma śe(śi)na sukṛtālu (se)ḍunu.
ghaḍiyāramu brāhmalagotrālaku (vri)tti pannu (pa)rayam evvaru gonaṃ dala-
cina brāhmaṇuṃ jaṃpina doṣānaṃ bovāru.
'Let it be auspicious. Śaka year 1326 which corresponds to [the Jovian year] Tāraṇa, Śrāvaṇa [month] bright half, fifth day, Thursday. The respected **Goli Somāreḍḍi**, having set up a *ghaḍiyāramu* in the temple of Bhāvanārāyaṇa Perumāḷ at Sarpapura, [donated] for the wages of the brahmins **Obhalojhu** and **Simgāojhu** one field (*cenu*) in the east … and one field in the west … total *kha* 5; for [acquiring these] fields, he paid 100 *ṭaṃkas*.
This *ghaḍiyāramu* is a religious endowment (*dharma*) and should last as long as the moon and sun [exist].
Whosoever opposes this temple service (*kaiṃkarya*) would lose the merits he had acquired.
If anyone wishes to impose *vritti* taxes on these families of the brahmins connected with the *ghaḍiyāramu*, he would incur the sin of killing a brahmin.'

The date Śaka 1326, Jovian year Tāraṇa, 5th lunar day of the bright half of the month Śrāvaṇa translates to 9 July 1404. Two brahmins were appointed for the maintenance of the water clock; they were given two pieces of land, one on the east of the village and another on the west, with a total area of 5 *kha*; here *kha* probably stands for the area measure *khāri* or *khārika.* This land was purchased for 100 *taṅkas.*

5.2.3. References to the Water Clock in Telugu Literary Works

In the Telugu literary works also there are many references to water clocks. These have been collected by M. Somasekhara Sarma:[1555]

> The water-clock that was in use in the Andhra country during the period under review [ca. 1325-1448] is a late device that worked by drawing in water. The *ghaṭikā-pātra* or the bowl, which draws in water and sinks in the water in the big receptacle within a *ghaṭikā* of time was called *gaḍiya-kuḍuku* in Telugu. Koravi Goparāja compares very aptly the sun setting in the ocean with a *gaḍiya-kuḍuku* sinking in the sheet of water in the big receptacle. That this appliance operated in this way was further made clear by the passages in the *Bhojarājīyam* and the *Vīrabhara-vijayam,* written by Anatāmātya and Potana respectively. They refer to the sinking of the eagerly watched *tāmra-ghaṭikā-pātra* or the copper-bowl. The passage in the latter work referred to above, suggests that this appliance was also set up temporarily at the time of marriages, and other auspicious occasions, to ascertain and announce the precise auspicious *lagna* or moment. No sooner than the bowl sank in water than the time was announced to the public, by either striking a gong with a rod (called *koḍupu* in Telugu) … Time was calculated and announced in *ghaṭikās* of time beginning from sunrise to the sunset, and probably from the sunset to the sunrise. Vallabhāmātya, the author of the Telugu drama *Krīḍābhirāmam,* refers to the *gaḍiyāram* in the *mosāla* (entrance hall) of the Andhra monarch at Warangal. Hearing the *gaḍiyāramu* strike sixteen (*reṇḍ=enimudul*), indicating thereby that sixteen *ghaṭikās* of time elapsed till then from the sunrise, Govinda Mañcana Śarma … suggests to his friend Tiṭṭibha Setti … that it was a little past midday and time to go for dinner …

1555 SarmaMS 1948, pp. 324-327, esp. 326-327; see also Kumari 1994.

6. ṬĀS-I GHAḌIYĀL AT THE COURT OF FĪRŪZ SHĀH TUGHLUQ

6.1. cAfīf on the Ṭās-i Ghaḍiyāl

In the first half of the eleventh century, Al-Bīrūnī describes, as was shown above, the mode of announcing time by means of the drum and conch-shell. During the next centuries, these sound-producing instruments appear to have been replaced by the brass or bronze gong (*ghaḍiyāl*) on which a series of rapid blows separated the strokes for the *ghaṭikās* and those for the *praharas.*

Shams-i Sirāz cAfīf, a contemporary and chronicler of Fīrūz Shāh Tughluq (r. 1351-88), writes in his *Tarīkh-i Fīrūz Shāhī* that, soon after returning from the campaign at Thatta in Sind (1365-67), Fīrūz installed at the top of his palace at Fīrūzābād, the *ṭās-i ghadiyāl.*[1556] cAfīf does not provide any description, but dwells eloquently on the 'seven merits' of this device: aside from the fact that it can be used also at night and on cloudy days, its chief merit lay, according to him, in that it can tell the times of Muslim prayers every day and times of breaking fast during the month of Ramaḍān.

In their translation of cAfīf's work, Elliot and Dowson did not translate this chapter, but gave a bare summary, leading to much unwarranted speculation on the nature of this *ṭās-i ghadiyāl,* the invention of which cAfīf attributes to the Sulṭān himself, in accordance with the habit of the courtiers of that age.[1557]

First of all, the Persian word *ṭās* here means 'cup' or 'bowl'. From Bābur's memoirs we learn that *ghadiyāl* is the name for the gong on which the intervals of time are announced with the strokes of a mallet. Therefore, this device set up by Fīrūz Shāh consists of a cup and a gong. Second, the Mughal emperor Bābur and Abū al-Faḍl, the chief chronicler of Bābur's grandson Akbar, give a fairly detailed description of measuring time by means of the sinking bowl water clock and of announcing *ghaṭīs* and *praharas* (or *pahars*) by means of the gong known as *ghaḍiyāl / ghariyāl.* Extrapolating this information backwards to the time of Fīrūz Shāh in the second half of the fourteenth century, it can be safely concluded that the device which Fīrūz Shāh installed on the top

1556 *Tārākh-i Fīrūz Shāhī,* Book III, ch. 18.

1557 Elliot & Dowson, III, pp. 338.

of his palace is the same *Ghaṭikā-yantra*, which was being used about the same time in Gujarat and in the Telugu-speaking areas for measuring and announcing time.

On the other hand, ᶜAfīf lays emphasis on the fact that the new device helps in determining the Muslim prayer times and the times for breaking the fast during the month of Ramaḍān. These times are based on the variable seasonal hours which the sinking bowl water clock cannot measure. But one can determine them with the help of the water clock and with a book of tables which show the variable times of prayers for every day of the year. Such books were well known at Fīrūz's times.

6.2. Was the Ṭās-i Ghaḍiyāl an Automatic Device?

However, several scholars wish to see here some kind of automatic device, such as those designed by ibn al-Razzāz al-Jazarī (1136–1206).[1558] But several factors go against this view. First, if the device set up at the palace of Fīrūz Shāh was an automatic machine in the manner of al-Jazarī, then its name would have been different; al-Jazarī calls the water clock incorporated in his automata *ṭarjahār.* It was also known as *bingān* in Iran. Then Fīrūz's Shāh's device would also have been called by such a name and not *ṭās-i ghadiyāl* where the term *ghadiyāl* is an Indian term denoting the gong.

Second, the device which Fīrūz set up on his palace gate was such that when the *ghaṭīs* or *praharas* are struck, the sound was audible for a long distance. This is possible only with a gong, but not with any of the automata of al-Jazarī.

More important, al-Jazarī's automatic devices function on the regular movement of the various components; in principle, these cannot indicate the variable times of Muslim prayers. This can only done by the astrolabe, or with the water clock in combination with a book of appropriate tables where the times of prayers are listed for every day of the year for different latitudes.

[1558] Cf. Hill 1974.

7. GHAṬIKĀ-YANTRA AT THE MUGHAL COURT

7.1. Bābur on the Water Clock

Bābur (r. 1526-30), the first Mughal emperor, was so impressed by this system of time-keeping that he adopted it, while introducing innovations in the mode of announcement. His lucid account deserves to be cited in full:

> So the people of Hind divide the night-and-day into 60 parts, each called a *gharī.* They also divide the night into four and the day into four, calling each part a *pahr* (watch) which in Persian is a *pās.* A watch and a watchman (*pās u pāshān*) had been heard about (by us) in those countries (Transoxania), but without these particulars. Agreeing with the division into watches, a body of *gharīālīs* is chosen and appointed in all considerable towns of Hindūstān. They cast a broad brass (plate)…, perhaps as large as a tray (*tabaq*) and about two hands' thickness; this they call gharīāl and hang up in a high place (*bī buland yīr-da*). Also they have a vessel perforated at the bottom like an hour-cup (?) and filling in one gharī (i.e. 24 minutes).
>
> These gharīālīs put this into water and wait till it fills. For example, they will put the perforated cup into water at day-birth; when it fills for the first time, they strike the gong once with the mallets; when a second time, twice, and so on till the end of the watch. They announce the end of the watch by several rapid blows of their mallets. After these they pause; then strike once more, if the first day watch has ended, twice if the second, three times if the third, and four times if the fourth. After the fourth day-watch, when the night-watches begin, these are gone through in the same way.
>
> It used to be the rule to beat the sign of a watch only when the watch ended; so that the sleepers chancing to wake in the night and hear the sound of third and fourth *gharī,* would not know whether it was of the second or third night-watch. I therefore ordered that at night or on a cloudy day the sign of the watch should be struck after that of the *gharī,* for example, that after striking the third *gharī* of the first watch, the *gharīālīs* were to pause and then strike

> the sign of the watch, in order to make it known that this third *gharī* was of the first night-watch.[1559]

7.2. Abū al-Faḍl on the Water Clock

The same system continued in Akbar's reign also (1556-1605). Abū al-Faḍl describes the practice under the title the 'Institution of Gharyāl,[1560] but there are some errors in his account:

> This is a round gong of mixed metal, shaped like a griddle but thicker, made of different sizes; and suspended by a cord. It may not be sounded except by royal command, and accompanies the royal equipage.
>
> The Hindu philosophers divide the day and night into four parts, each of which they call *pahr.* Throughout the greater part of the country, the *pahr* never exceeds nine *gharis* nor is less than six. The *ghari* is the sixtieth part of a nychthemeron, and is divided into sixty parts, each of which is called a *pal* which is again subdivided into sixty *bipal.*
>
> In order to ascertain and indicate time, a vessel of copper or other metal is made of a hundred *tanks* weight. In Persian it is called *pingān.* … It is in the shape of a bowl narrower at the lower part, twelve fingers in height and breadth. A perforation is made below to admit of a golden tube being passed through, of the weight of one Māshā, and in length the breadth of five fingers.[1561] It is placed in a basin of pure water in a place undisturbed by the wind. When the bowl is full of water, one *ghari* is elapsed, and in order that this should be known to far and near, the gong is struck once, and for the second time twice, and so on. When a *pahr* has elapsed, the number of *gharis* expired therein is first sounded and then more deliberately from one to four (according to the *pahr*), thus announcing the *pahr* struck. Thus when it is two

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1559 Babur, pp. 516-517. Bābur's innovation in the mode of announcing *ghaṭīs* and *praharas* corresponds to the practice at the Nālanda monastery in the seventh century; cf. Table R1.

1560 Abū al-Faḍl 3, pp. 17-18.

1561 It is obvious that a hemispherical bowl with a width (diameter of the mouth) of 12 fingers, cannot have a height also of 12 fingers; the height should be only 6 fingers. The late Professor A. J. Qaisar kindly compared Jarrett's translation with the Persian original of the Nawalkishore Press: the original also mentions 12 fingers as the height.

pahr, (twelve o' clock), the gong is struck twenty-sixth [sic!] times, taking the *pahr* at eight *gharis.*

This description of the bowl is not the description of an actual bowl used at the court of Akbar; it looks more like an inaccurate rendering from a Sanskrit text. When the *pahr* consists of eight *gharis*, at the end of the second *pahr*, there will be 8 strokes for 8 *gharis* and 2 strokes for 2 *pahrs.* This makes 8 + 2 strokes, and not 26.

7.3. Water Clock in Mughal Miniature Paintings

This clumsy account is redeemed, to a large extent, by two miniature paintings executed at Akbar's atelier in which the *Ghaṭikā-yantra* is depicted very accurately.[1562] In fact, these are the only pictorial depictions of this instrument.[1563] The first painting is related to the birth of Akbar. It shows Akbar's father Humāyūn seated on a throne, with astronomers in attendance. The astronomers have measured the time of the birth by means of a water clock and a ring dial and drew up the native's horoscope. The water clock, with the bowl floating in a large basin is drawn very clearly; in contrast, the ring dial is very small; one sees just the ring with suspension bracket; a sheet of paper with a fold in the middle indicates the horoscope.

The second miniature is related to the birth of Salīm, the future Jahāngīr. It shows Hindu and Muslim astronomers seated together, measuring the birth-time with a *Ghaṭikā-yantra*, and the sun's altitude with a ring dial (*Cūḍā-yantra*), and drawing up the horoscope. Here the perforated bowl and the ornate water basin are painted golden.[1564]

Abū al-Faḍl states that time-keeping and announcing was the royal prerogative under Akbar. In the subsequent centuries, minor rulers also began to maintain water clocks at their palace gates and to regularly announce time.

[1562] Sarma 1992a.

[1563] British Library, Ms. Or. 12988, f. 20b; reproduced in Geeti Sen, *Paintings from the Akbarnama: A Visual Chronicle of Mughal India,* Calcutta 1984, Pl. 57, pp. 130-131.

[1564] Museum of Fine Arts, Boston, #17.3112; reproduced in Stuart Cary Welch *Imperial Mughal Painting,* London 1978, Pl. 16, pp. 70-71.

8. GHAṬIKĀ-YANTRA IN MINOR KINGDOMS

After the Mughals, smaller kingdoms also introduced this custom of measuring time with the *Ghaṭikā-yantra* and announcing the intervals by strokes on the gong. According to the *Lekhakamuktāmaṇi* of Vatsarājaputra Haridāsa Kāyastha Śrīgauḍa, one of the 36 royal departments (*śālā,* corresponding to the *kārkhānā* of Akbar's court) was called *Tūryagṛha* and contained water clocks for measuring time and various kinds of drums and trumpets for announcing it.[1565] This work is supposed to have been composed between 1550 and 1600 at the court of Amber in Rajasthan and may reflect the state of affairs there.

A later ruler of Amber, Sawai Jai Singh (1688-1743) made use of the water clock in his astronomical researches. In this connection, Irfan Habib writes as follows:[1566]

> A more refined way [of determining longitudes] had been suggested by Ptolemy; that was by measuring time, not distance, to establish relative longitudes. This was repeated in the *zīj* of Ulugh Beg: Lunar eclipse was to be availed of, and the time elapsing between the noon at each of the two places and the beginning and end of the eclipse was to be measured. Each difference of an hour in the periods elapsing at two places meant a difference of 15 degrees of longitude. Jai Singh copies this passage [in his *Zīj-i Muḥammad Shāhī*], but makes a significant addition: As soon as the sun had reached and passed its highest altitude at noon, he says, the observer was to set up the time-keeping water vessel [*finjān-i āb*] or sand-glass (*shisha-i sā^{c}at*), and record the time until the eclipse began or ended.

In a contemporary map of Jai Singh's observatory at Jaipur, a small square at the northern boundary is marked as the place of the *ghaḍiālīs* (*ghaḍiyālī-khānā*).[1567]

1565 *Lekhakamuktāmaṇi,* Ms. No. 464, Pothikhānā, City Palace Library, Jaipur, 3.88 cd: *tūryagṛhe saghaṭī-yantrāṇi rasāla-bhery-ānaka-tūryāṇi* (in the *tūryagṛha,* [there shall be] water clocks, drums called *rasāla, bherī* and *ānaka,* and trumpets); I owe this information to the kind courtesy of the late Gopal Narayan Bahura of the Palace Library.

1566 Habib 1977, p. 132.

1567 Sharma 2016, map on p. 128, no. 25.

9. Accounts of European Travellers

Between the seventeenth and nineteenth centuries, several European visitors wrote about the sinking bowl and the mode of announcing time with its help in India. In his *Geographical Account of Countries Round the Bay of Bengal, 1669 to 1679,* Thomas Bowrey informs that most wealthy Muslims have set up water clocks in their front porches with two servants attending all the time, one to lift the bowl and set it up again and the other to strike the gong, and that this custom is emulated also by the English and Dutch in their factories.[1568] These accounts, often inaccurate and full of outlandish transcription of Indian names, do not add much to our knowledge, except to show that this archaic time measurement continued without much challenge from the European clocks. The following three accounts deserve our attention.

9.1. John Gilchrist[1569]

> The apparatus with which the hours are measured, and announced, consists of a shallow bell metal pan, named from its office *G,huree,al*, and suspended so as to be easily struck with a wooden mallet by the *g,huree,alee*, who thus strikes the *g,hurees* as they pass, and which he learns from an empty thin brass *cup (kutoree)* perforated at bottom, and placed on the surface of water, in a large vessel, where nothing can disturb it, while the water gradually fills the cup, and sinks it in the space of one *g,huree*, to which this hour cup or *kutoree* has previously been adjusted astronomically by an *astrolabe*, used for such purposes in India. These *kutorees* are now and then found with their requisite divisions, and subdivisions, very scientifically marked in *Sanscrit* characters, and may have their uses for the more difficult and abstruse operations of the mathematician or astrologer, but for the ordinary occurrences of life, I believe the simple horology described above suffices (perhaps divided into the fourths of a *g,huree*) the *Asiaticks* in general, who

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1568 Thomas Bowrey, *Geographical Account of Countries Round the Bay of Bengal, 1669 to 1679,* ed. Lt.-Col. Sir Richard Carnac Temple, Hakluyt Society, Cambridge 1905, pp. 195-197.

1569 Gilchrist 1795, p. 88.

> by the bye, are often wonderfully uniformed, respecting everything of this kind.
>
> Six or eight people are required to attend the establishment of *g,huree,* four through the day, and as many at night, so that none but wealthy men or grandees can afford to support one as a necessary appendage of their consequence and rank.

9.2. Mrs Meer Hasan Ali[1570]

Occasionally, of course, some bowls were made to measure the European hours of sixty minutes or half hours. The best of such European accounts is from Meer Hassan Ali's English wife, who lived in Lucknow with her husband's family for twelve years from 1816. In her *Observations on Mussalmauns* in India, Mrs Meer Hassan Ali shows how the sinking bowl had become an integral part of the upper class Muslim households at the beginning of the nineteenth century:

> They have a simple method of measuring the hour, by means of a brass vessel, with a small aperture at the bottom, which, being floated on a tank or large pan of water, one drop to a second of time forces its way through the aperture into the floating vessel, on which marks are made outside and in, to direct the number of ghurries by the depth of water drawn into it; and in some places, a certain division of time is marked by the sinking of the vessel. Each hour, as it passes, is struck by the man on duty with a hammer on a broad plate of bell-metal, suspended to the branch of a tree, or to a rail: the gong of an English showman at the country fairs is the exact resemblance of the metal plates used in India for striking the hours on, and must, I think, have been introduced into England from the East.
>
> The *durwan* (gate-keeper), or the *chokeedars* (watchmen), keep the time. In most establishments, the watchmen are on guard two at a time, and are relieved at every watch, day and night. On these men devolves the care of observing the advance of time by the floating vessel, and striking the hour,

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[1570] Ali 1974.

> in which duty they are required to be punctual, as many of the Mussalmauns' services of prayer are scrupulously performed at the appointed hours.[1571]

9.3. Edgar Thurston

Edgar Thurston (1855-1935) joined the Ethnographic Survey of India in 1901 and made several valuable contributions such as the *Castes and Tribes of Southern India* (1909); later he became the superintendent of the Madras Museum. His *Ethnographic Notes* (1907) contains the following information on the use of the water clocks in southern India at the end of the nineteenth and beginning of the twentieth centuries: [1572]

> This form of the time-measurer, made of a half cocoanut or copper, is still in use among native physicians, astrologers and others in Malabar. A cup of this nature was employed in the Civil Court at Mangalore in 1852, a peon being posted in charge of it, and beating on a gong the number of gadis [*ghaṭīs*] every time that it sank. At the present day it is used on the occasion of marriage among higher Hindu castes. The Brāhman priest brings the cup, and places the bridegroom in charge of it. It is the duty of the latter to count the gadis until the time fixed for his entrance into the wedding-booth. The apparatus is nowadays often replaced by a clock or watch, but the officiating priest insists on producing the cup, as he receives his fee for doing so.
>
> The method of computing time by means of a water clock, on which the gadiya [*ghaṭikā*] or nazhigai [*nālikā*] (24 minutes) and jām or jāmam [*yāma*] (7 gadiyas) <u>are indicated by nicks on the inside of the cup,</u> is still in vogue in the huzur and temple at Venkatagiri [Lat. 13;58° N, Long. 79;35° E]. The cup is in charge of a sepoy, who keeps time, and makes it known by beating a gong at the end of each gadiya or jām. To compensate for the seasonal variations of day and night, correction is made in the length of the periods. The hole in the cup, after it has been in use for some time, becomes dilated, and to correct the error, it is contracted by beating the cup with a hammer. <u>A standard cup is kept for the purpose of regulating the water-clock.</u> The

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[1571] Ali 1974, pp. 55-56.

[1572] Thurston 1907, pp. 565-566.

computation of time by means of an hour-glass in some Brāhman (especially Mādhva) mutts. Mr. Percy Brown[1573] writes to me that Mr. J. L. Kipling[1574] introduced the water-clock for use by the Police at the Lahore Museum, as the clock was always getting out of order. The bowl is a copper one, floated in an earthen bowl, and takes an hour to sink. It is in charge of the policeman on duty, who strikes a gong each time that it sinks. Water-clocks are in use in many places in the Punjāb, and nearly always in connection with native sentry work.

10. WATER CLOCK AT PLACES OF WORSHIP

Even after the *Ghaṭikā-yantra* was replaced by European clocks, the former continues to be used for ritual purposes in the places of worship of all major faiths in the Indian sub-continent.

On the day of Janmāṣṭamī, the birth of Kṛṣṇa is celebrated at all the temples of Mathura in Uttar Pradesh. The festivities commence at midnight when Kṛṣṇa is supposed to have been born. At the Dwarakadhish temple, the precise time of midnight is said to be determined by means of the traditional water clock.

At Jhalawar (Lat. 24;35° N, Long. 76;10° E) in Rajasthan, at the Jain temple dedicated to Tirthankar Shantinath, *Ghaṭikā-yantra* is still used to determine the time of various rituals.[1575]

At Ajmer, also in Rajasthan, at the mausoleum of Khwaja Moinuddin Chisti, there is no water clock to measure time any more, but there is still a *ghaḍyālī,* the time-keeper, who announces in a certain ritual that six *ghaṭīs* have passed (R013).

In the town of Sehwan in Sindh, Pakistan, there is the mausoleum of Shaikh Usman, popularly known as Qalandar Shahbaz. At this mausoleum, the sinking bowl was in use as late as 1973 for regulating the times of various daily rites. According to N. A. Baloch, the bowl must have been in use during the lifetime of the saint in the thirteenth century for determining the times of prayer and the time of the dance of the

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1573 Percy Brown is a well known art-historian.

1574 J. L. Kipling was the father of Rudyard Kipling.

1575 Reported in *The Hindu,* New Delhi Edition, 24 April 1994; cf. Sarma 1994a.

dervishes (*dhammal*) just after the Maghrib prayer. After the saint's death, the ceremonies which became more elaborate were still performed according to the time measured by the water clock. In Sindhi, the bowl is called *wato*, the water basin in which it is made to float is known as *degrro*, and the gong *gharryal.*[1576]

11. Origin and Diffusion of the Sinking Bowl Water Clock

The sinking bowl type of water clock was not confined to India, it was used in many countries from Iran to Spain in the west and from Myanmar to Indonesia in the east. It was used not only for regular time-keeping, but also to measure certain segments of time for the distribution of irrigation water in the west and to measure certain segments of time in cock-fights in South-East Asia. But where did it originate?

The earliest mention of the sinking bowl, as shown above (3.1.2), occurs in the commentary of the *Majjhimanikāya,* written by Buddhaghoṣa in the first half of the fifth century in Sri Lanka. Here the bowl is not the basic model which measures the *ghaṭī,* but one that was specially prepared to measure one *yāma,* which unit is roughly equal to three *ghaṭīs* at the low geographical latitude of Sri Lanka. Bowls that measured one *ghaṭī* must then be still older. Therefore, it is reasonable to suppose that the sinking bowl type of water clock was developed some time in the fourth century in the Indian Ocean region, either in Sri Lanka, or on the southern coast of India, or in one of the islands of the Malay Archipelago. It is also likely that the original inspiration for the sinking bowl came from the coconut shell, which is naturally endowed with a hole; water clocks made of well-scrubbed halves of the coconut shell survive in museums.

However, there is one problem in this scenario. The use of the sinking bowl in Iran was mainly associated with the distribution of irrigation water from the underground system water channels called *Qanāt.* While this *Qanāt* system is said to be very ancient,[1577] it is not known when the distribution of irrigation water to individual farmers began to be regulated by means of the sinking bowl. Therefore, it is difficult to say whether the sinking bowl used with the *Qanats* reached India and from there spread to

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1576 Baloch 1979.

1577 On *Qanāts,* see Wulff 1966, pp. 249-256; Wulff 1968; English 1968.

South-East Asia, or whether it originated either in Sri Lanka or India, and thence spread westwards and eastwards.

11.1. Sinking Bowl Water Clock in the West

Early records of the use of the sinking bowl in the west are not many; these go back only up to the tenth century. In his treatise of the astrolabe, *Kitāb al-ᶜAmal bi l'Asṭurlāb,* dated 986, al-Ṣūfī laid down a procedure to graduate the inner sides of a very large sinking bowl into twelve hours.[1578] At the beginning of the thirteenth century, al-Jazarī, the author of the *Kitāb fī maᶜrifat al-ḥiyal al-handasiyya,* incorporated the sinking bowl in two of his automatic clocks. On this Donald R. Hill says[1579]

> 'Another mechanism used by al-Jazarī was the submersible bowl (*ṭarjahār*); this had an orifice in its underside which caused it to submerge in pre-determined time. This was used in two water-clocks (category I, Chapters 3 and 4), both of which operated on the closed-loop principle. The *ṭarjahār* was used before this to time the allocation of irrigation water.'

The sinking bowl was also mentioned by Giyāth al-Dīn al-Kāshī who was associated with the Samarqand observatory in the fifteenth century, according to Aydin Sayili:

> 'Giyāth al Dīn speaks of water clocks constructed in the form of bowls with a hole at their bottom. They were placed upon the surface of the water, and they became filled gradually with the passage of time. … It may be conjectured that these bowls were in use in the Samarqand observatory.'[1580]

11.1.1. Sinking Bowl as an Irrigation Clock in Iran

The *Qanāt* system spread from Iran to other areas in the Middle East and then to North Africa and Spain; in some of these places, the distribution of water to individual cultivators was regulated by sinking bowls. About their use in Iran, Hans E. Wulff offers a very detailed account:[1581]

[1578] Bruin 1968a, p. 56.

[1579] Hill 1998, I, pp. 26-27 (drawings), III, p. 205.

[1580] Sayili 1960, p. 288.

[1581] Wulff 1966, pp. 254-256.

> The distribution of irrigation water, especially that of *qanāt* water gained after so much effort, is regulated by custom and law, often going back to pre-Islamic times and early Islamic codification. … The water bailiff (*mīr-āb, āb-māl, āb-bargardān, ābgār, lāvān, pākār, qāsem-āb, bārāndar*), who supervises the distribution from a hut near the distribution basin, has a large bowl (*kūzeh, tašt*) filled with water near him on the floor. When he begins time he places a small dish (*taštak, piyāleh, finjān, finkāl, peing*) on the surface of the water so that it floats. Water gradually enters this dish through a small hole (*sūraḥ, lūbeh*) in its bottom until it eventually sinks down with a noise. This marks one time unit. As most customers are allotted a number of time units, a pebble is transferred from one jar into another each time the dish has gone down. When the last pebble has been transferred and the customer's time is up, the water is directed to another channel.

According to Steingass, the sinking bowl is also called *bingān* in Persian, which he explains as follows:

> a copper bowl or basin with a hole bored in the bottom, which being placed in water is suffered to fill, and thus serves to measure the time that each cultivator is allowed to have water turned upon his land from a canal for the purposes of irrigation.[1582]

11.1.2. Sinking Bowl as an Irrigation Clock in North Africa and Spain

About the use of water clocks for regulating the distribution of irrigation water, Thomas F. Glick published an important study, mentioning the types of water clocks used and their duration: [1583]

> Sinking clocks have been continuously associated with the practice of irrigation in the Near East, particularly Persia and the Yemen … It is still commonly used in many parts of North Africa and was the traditional measuring device of the small irrigation district of the Vall de Segó north of Valencia [in Spain]. In the Vall de Segó there were two such clocks, the *olla,*

1582 F. Steingass, *A Comprehensive Persian-English Dictionary,* London 1892, reprint: Delhi 1996, s.v.

1583 Glick 1969, pp. 425-426.

which sank in about an hour, and a smaller version, the *carapit,* which sank in seven and a half minutes. …

The most typical clock of the North African oases was the *qadus* — that is, the bucket of a *noria* (hydraulic wheel), which when punctured with a hole became an outflow clepsydra.

11.1.3. Sinking Bowl as an Irrigation Clock in India

Although the sinking bowl must have been used, aside from regular measuring of time, also as an irrigation clock in several parts of India, there do not seem to be any published records. The only tangible evidence we have is the copper bowl (R004) from Rampet, Pallar Valley, in Tamilnadu, now preserved in the Pitt Rivers Museum of Ethnology at Oxford. The village officer who superintends the distribution of the irrigation water was said to be designated as *Nerkatti* in Tamil and *Nīrganti* in Kannada.

11.2. Sinking Bowl in South Asia and South-East Asia

About the eastward diffusion of the sinking bowl, there can be no doubt that it spread from India, in some cases along with Indian terminology as well. Aside from its use for the regular measurement of time, the sinking bowl was also employed in timing the duration of cockfight in Bali and Thailand. While cockfights were held in Bali in religious rituals, in Thailand they were held to commemorate a legendary event.[1584] The only mention of this nature in India occurs in the encyclopedia called *Mānasollāsa,* composed in 1129, by King Someśvara of the Western Chālukya dynasty, in connection with the regulation of the duration of quail (*lāvaka)* fights: the quails are to fight for 24 seconds and then rest for another 24 seconds:

mātrāśatena viṃśena pūryate toyadhārayā |
tāvat pātraṃ prakurvīta sā nāḍī kathitā budhaiḥ ||
ekāṃ ca yodhayen nāḍīm ekāṃ viśrāmayet tathā |
viśrāmanāḍīḥ saṃtyajya yodhayet pañcanāḍikāḥ ||[1585]

1584 In both countries, betting in cockfights is now strictly prohibited.

1585 *Mānasollāsa of King Bhūlokamalla Someśvara,* ed. G. K. Shrigondekar, vol. II, Baroda 1939 (GOS 84), p. 257.

> ‘Let a vessel be made which can be filled with a jet of water in 120 *mātrās*. That [duration] is called *nāḍī* by wise men. Let the quail fight for one *nāḍī* and rest for another *nāḍī*. Leaving aside the *nāḍīs* of rest, let it fight for [a total of] five *nāḍīs*.’

Obviously Someśvara is referring to the sinking bowl water clock. But he defines *nāḍī* as consisting of 120 *mātrās*, i.e. time taken to utter 120 short syllables (or 60 long syllables), which constitute just 1 *vighaṭikā* or 24 seconds. Therefore, his *nāḍī* is entirely different from the standard *nāḍī* which is equal to 24 minutes. Probably this shorter *nāḍī* is used only in the fight of quails.

Fred B. Eiseman writes that in Bali, the water clock used in cockfight has a duration of 10 seconds only, which is the time allowed for one round of fight.[1586]

11.2.1. Sri Lanka (formerly Ceylon)

Mention has been made above (3.1.2) of the large sinking bowl that measured one *yāma* in the fifth century. It is not known how time was measured in subsequent centuries in Buddhist monasteries. In the seventeenth century, however, measuring time with the sinking bowl became the exclusive privilege of the king, according to Robert Knox (1681), who reports as follows: [1587]

> Their day, which they call *Dausack*, they divide into Thirty *Pays*, hours or parts, and begin their account from the Sun rising, and their Night also into as many, and begin from Sun-setting: So that the Fifteenth *Pay* is Twelve a Clock at Noon. They have a *Flower* by which they judge of the time, which constantly blows open seven *Pays* before Night.
>
> They have no *Clocks*, *Hour-glasses*, or *Sun-Dials*, but keep their time by guess. The King indeed hath a kind of Instrument to measure time. It is a *Copper Dish* holding about a Pint, with a very small hole in the bottom. This Dish they set a swimming in an Earthen Pot of water, the water leaking in at

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[1586] Fred B. Eiseman, Jr. *Bali: Sekala and Niskala, Essays on Religion, Ritual, and Art,* Berkley-Singapore 1990, p. 248.

[1587] Robert Knox, *An Historical Relation of the Island Ceylon in the East Indies,* [London 1681], with an Introduction and Afterword by Dr H. A. I. Goonetileke, third facsimile reprint, Navrang, New Delhi 1995, p. 111.

> the bottom till the Dish be full, it sinks. And then they take it out, and set it empty on the water again, and that makes one *Pay*. Few or none use this but the King, who keeps a man on purpose to watch it continually. The People will use it upon some occasions, as if they are to sow their Corn at any particular hour, as being the good lucky Season, then they make use of the *Copper Pan*, to know the time exactly.

But in later times, sinking bowl appears to have been used even outside the royal palace. The Pitt Rivers Museum of Ethnology, Oxford, owns a specimen from Sri Lanka which must have been made at the end of the nineteenth or the beginning of the twentieth century (R005).

11.2.2. Nepal

On the use of the sinking bowl in Nepal for regular time-keeping, Thurston reports as follows: [1588]

> In Nepāl the measurement of time is regulated in the same manner [as in India]. Each time the vessel sinks, a gong is struck, in progressive numbers from dawn to noon. After noon, the first ghari struck indicates the number of gharis which remain of the day till sunset. Day is considered to begin when the tiles on a house can be counted, or when the hairs on the back of a man's hand can be discerned against the sky.

At Hanumandhoka Palace, and also at Gorkha Palace, it is said that time was measured with a water clock and announced regularly up to the beginning of the twentieth century. Recently Olivia Aubriot studied the irrigation system in Aslewacaur, a village in central Nepal, and noticed that sinking bowl water clock was used there for distributing the irrigation water to individual farmers. [1589]

1588 Thurston 1907, pp. 563-564.

1589 Cf. Olivia Aubriot, *L'eau, miroir d'une société—Irrigation paysanne au Népal central,* CNRS Éditions, Paris 2004, pp. 175-182: L'horloge à eau : de l'astronomie à l'hydraulique" (water clock, from astronomy to hydraulics). I owe this information to Dr Jérôme Petit, Paris.

11.2.3. Myanmar (formerly Burma)

About Myanmar, fortunately there exists a sinking bowl which was used at the emperor's palace in the nineteenth century (R006) as well as a description of it by John Nisbet of 1901:[1590]

> Each day was under Burmese rule divided into sixty hours (*Nayi*), and subdivided into eight watches, each of about three hours, which varied in length at different seasons of the year according as the days and nights were relatively longer or shorter. The *Nayi* or 'time measurer' was a copper cup having a tiny perforation at the base, which, being inserted in water, sank to a particular mark within a given time. The *Nayi* had various subdivisions from 'ten winks of an eye' (*Kaná*) upwards, but these terms were seldom used except in astrological works. As each *Nayi* was thus measured off a gong was beaten, and at every third hour the great drum-shaped gong was sounded from the *Pahózin* or time-keeper's tower within the inner precincts of the royal palace at the eastern gate. One beat of the drum denoted nine o'clock in the morning or evening, two beats twelve o'clock, three beats three o'clock, and four beats six o'clock. From Pah*ó* the beats were repeated on large bells by all the guards throughout the palace. To ensure the attention to this matter in the olden days, the timekeeper could be carried off and sold in the public market if he were negligent in the discharge of his duties, being then forced to pay a fine in the shape of ransom.
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> Now, under British rule, wherever there are jails, police stations, treasury guards, and so forth, the hours are marked off by beat of a gong. Hence, in towns, the word *Nayi* has now come to mean both the hour, measured by the European method, and the clock or watch by which it is measured.

1590 John Nisbet, *Burma under British Rule - and before,* Archibald Constable & Co, Westminster 1901, vol. II, pp. 288-289.

11.2.4. Indonesia

In Indonesia, there is a considerable influence of Sanskrit language and Hindu religion in the islands of Java and Bali. Consequently, many Indian units of time measurement have been absorbed there, as described by Lewis Pyenson:[1591]

> Indian astronomy was certainly present in Old Javanese texts of Brahman inspiration dating from the ninth and tenth centuries. The Indian time units of day and night — divasa for 24 hours; muhurta, ksana for 48 minutes; ghati, ghatika, nadi, nadika for 24 minutes (30 kala); kala for 48 seconds—all are present in the language. In Old Javanese poetry composed in Indian meter, however, the natural day is divided into equal parts of 8 hours, calculated from sunrise to sunset. The word for 'hour' is also that for 'stroke' or 'fall', suggesting hours being signalled by a striking device.

It is not known whether the sinking bowl was ever used for time-keeping, but in the island of Bali, it was used for timing the cockfight. Here cockfight was not a sport for amusement, but part of the ritual of exorcising evil spirits by spilling the blood of cocks. It was generally held in temples, but sometimes also in private homes as a purification ceremony. Fred B. Eiseman describes the use of the sinking bowl in these cockfights thus: [1592]

> When the birds are pulled apart, the time keeper starts his clock, called *ceeng*. It is a half coconut shell with a hole in the bottom, placed, large side up, in a bucket [*cobek*] of water. It sinks in about 10 seconds, or one *ceeng*. The cocks are allowed three *ceengs* to recoup between rounds.

11.2.5. Thailand (formerly Siam)

In Thailand, on the other hand, cockfights were held to commemorate the victory of the Siamese prince Naresuan over a Burmese prince in their legendary cockfight in

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[1591] Lewis Pyenson, 'Assimilation and Innovation in Indonesian Science' in: Morris F. Low (ed), *Beyond Joseph Needham; Science, Technology, and Medicine in East and Southeast Asia*, [special issue of the] OSIRIS, A Research Journal devoted to the History of Science and its Cultural Influences, Second series, Volume 13, 1998, pp. 34-47.

[1592] Fred B. Eiseman, Jr. *Bali: Sekala and Niskala*: *Essays on Religion, Ritual, and Art,* Berkley-Singapore, 1990, pp. 240-250, p. 244 illustration of the water clock.

the second half of the sixteenth century. In these cockfights time was measured with a sinking bowl water clock (*nāliga nām*), as the illustration below shows.

Figure R4 – Cockfight with a water clock in Thailand
(illustration from a popular book on folklore, courtesy Professor Ampha Otrakhul)

11.2.6. China

In China, the prevailing water clock was the inflow type with a series of water tanks, but the sinking bowl type was also known, according to Needham who states: [1593]

> The Chinese also knew another archaic device, the inverse variant of the outflow clepsydra, a floating bowl with a hole in its bottom so adjusted that it took a specific time to sink. … A Chinese example is afforded by the work of Thank monk Hui-Yuan, who arranged a series of lotus-shaped bowls to sink one after another during the twelve double-hours (*Thang Yü Lin,* ch.5, p. 31b).

[1593] Needham 1959, p. 315 and footnote h.

Figure R5 – Water Clocks in the Pitt Rivers Museum of Ethnology, Oxford (photo by S. R. Sarma)
First row, left to right: Mirzapur, Mandalay (Myanmar), Lord Shand's 1;
second row: Rampet, Lord Shand's 2, Uva, Sri Lanka;
third row: Malabar.

12. EXTANT SPECIMENS

The sinking bowl type of water clock was in use throughout India (and also in South Asia and South-East Asia) until the end of the nineteenth century. Writing in 1872, Baden Powell, reports thus: 'This article is in common use, and by it all police guards, &c, keep the time, striking their gong as each hour comes round.'[1594] One would therefore expect scores of water clocks to be surviving in every part of India. But people usually recycle unused copper or brass vessels and therefore there are few specimens extant.[1595] Of late, some former Maharajas have established museums inside their palaces and began to display artefacts of historical interest. Thus in the palace museums at Bharatpur, Bundi, Kota, Udaipur (all in Rajasthan) and Ramnagar (in Uttar Pradesh) there are displayed ensembles of the perforated bowl, water basin and gong.

The largest collection of water clocks---of different shapes, sizes and materials---is to be found in the Pitt Rivers Museum of Ethnology at Oxford. While some of these

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1594 Powell 1872, p. 200.

1595 It is not known whether any specimens are preserved in any South-Asian or South-East Asian countries; a friend informs me that he saw a specimen in the Ankor Wat Museum in Cambodia.

were made to measure the traditional Indian unit of *ghaṭī* or its fractions, others were made to measure the hour of 60 minutes, introduced by the British Colonial administration, or its fractions. Yet there is one more specimen which was not intended to measure time as such, but to measure the duration of irrigation water supply into different fields.

There are said to be also bowls that measured three *ghaṭīs* (72 minutes). The German Baron Hermann von Schlagintweit-Sakünlünski, who undertook a scientific expedition to northern India between 1855 and 1857, collected two such bowls from Panipat and Varanasi and one metal gong.[1596] Some of the Indian artefacts collected by him are now with different museums in Germany;[1597] but there is no trace of the two water clocks, nor of the gong.

In the following pages, the water clocks of the Pitt Rivers Museum will be described first and then a few other specimens that I have seen.

1596 Schlagintweit-Sakünlünski 1871, pp. 129-130.

1597 Armitage 1989.

Index of Water Clocks

R001 ◎Water Clock from Mirzapur, Uttar Pradesh 3817

Diameter 160 mm, height 66 mm , Oxford, Pitt Rivers Museum of Ethnology (# 1892.49.108)

R002 ◎Water Clock 3818

Diameter 160 to 173 mm, height 100 mm, Oxford, Pitt Rivers Museum of Ethnology (# 1916.40.1)

R003 ◎Water Clock 3819

Diameter 140 to 145 mm, height 75 mm, Oxford, Pitt Rivers Museum of Ethnology (# 1916.40.2)

R004 ◎Irrigation Water Clock from Rampet, Tamil Nadu 3820

Diameter 119 mm, height 68 mm , Oxford, Pitt Rivers Museum of Ethnology (# 1916.32.1)

R005 ◎Water Clock from Uva Province, Sri Lanka 3821

Diameter 100 mm, height 49 mm , Oxford, Pitt Rivers Museum of Ethnology (# 1923.75.1)

R006 ◎Water clock, called *nayi*, from the Emperor’s palace at Mandalay, Myanmar 3822

Diameter at the base 132 mm, at the mouth 149 mm, height 105 mm , Oxford, Pitt Rivers Museum of Ethnology (# 1892.41.37.1)

R007 ◎Water Clock made of Coconut Shell from Malabar 3823

Diameter 112 mm, height 37 mm , Oxford, Pitt Rivers Museum of Ethnology (# 1905.8.3)

R008 ◎Water Clock, not signed, not dated 3824

Diameter 115 mm , height 39 mm, London, The Guildhall Library, The Worshipful Company of Clock-Makers’ Collection (# 646)

R009 ◎Water Clock from Kandy, Sri Lanka 3825

Diameter 116 mm, height 50 mm, thickness 1 mm, London, Horniman Museum (# 19-140)

R010 Water Clock made of Coconut Shell 3826

Diameter ?, Chennai, Government Museum

R011 Water Clock, full Ensemble of Bowl, Basin and Gong 3827

Diameter of the bowl 150 mm; diameter of the larger vessel 310 mm, Kota, Rao Madho Singh Museum

R012 ◎Water Clock: Bowl and Basin (modern reconstruction) 3828

Diameter of the basin 464 mm, diameter of the bowl 317 mm, PLU

R013 Water Clock in the Dargah of Khwaja Moinuddin Chishti at Ajmer 3829

S. METAL INSTRUMENTS DESIGNED BY SAWAI JAI SINGH

INTRODUCTION

The focus of this section will be on the metal instruments used by the astronomer-prince Sawai Jai Singh of Jaipur before he replaced them with large masonry instruments.[1604] But first a brief introduction to his life and work.[1605]

1. Sawai Jai Singh

Jai Singh was born on 3 November 1688. When he was barely 11 years old, he ascended, on 25 January 1700, the throne of Amber in Rajasthan, which was a semi-autonomous kingdom under the Mughal rule. He served several Mughal rulers, taking active role in their struggles for succession. Through his diplomatic skill, he expanded his kingdom several-fold and became the most powerful of the feudatories of the Mughal emperor, who gave him the title *sawāī*, meaning that he is one quarter more brilliant than his illustrious ancestor who bore the same name. After an active life of nearly half a century - active in political intrigue, warfare, city building and learned activities - he died on 2 October 1743.

In spite of the incessant political upheaval, Jai Singh's rule ushered in a golden era of arts and sciences. His lasting contributions are architectural and astronomical. He built the new capital city Jaipur with its broad and straight roads in a rectangular grid pattern, to which he attracted a large number of scholars, artists and craft-persons. In the realm of astronomy, in order to prepare an accurate calendar, he gathered at his court astronomers of various faiths and traditions - at first Hindus and Muslims, and later, also Europeans - and initiated a systematic programme of observations. Initially he experimented with portable instruments of diverse types, but finally designed majestic

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1604 Jai Singh's masonry instruments will not be covered in this catalogue; they are adequately and competently described in Sharma 2016.

1605 Cf. V. S. Bhatnagar, *Life and Times of Sawai Jai Singh,* Delhi 1974; Garrett & Guleri 1902, pp. 9-13; Kaye, pp. 1.7; Sharma 2016, pp. 1-4; see also Pingree 1978b; Pingree 1999; CESS, 3, pp. 63-64; 5. pp. 117-118.

instruments in masonry with which he set up five observatories at Delhi, Jaipur, Varanasi, Ujjain and Mathura.[1606]

1.1. Jai Singh's Astronomical Efforts

Jai Singh appears to have been initiated at an early age into the study of Sanskrit astronomical texts by his religious preceptor Jagannātha Samrāṭ. Aware of the discrepancy between the computed and observed positions of the heavenly bodies, Jai Singh decided to prepare new astronomical tables based on his own observations. Since the Islamic world paid greater attention to observational astronomy and hence possessed more sophisticated instruments, he turned to Muslim astronomers and to their Arabic and Persian manuals on instruments. At first he took observations with small portable brass and wooden instruments that were available at that time, but was not satisfied with the results. In order to obtain as minute readings as possible, he ordered much larger instruments in metal, but mounting and pivoting the heavy metal parts proved to be problematic.

Therefore he abandoned brass instruments altogether and began designing huge instruments in masonry. The inspiration for large masonry instruments came from the Samarqand observatory. But Jai Singh's genius lay in elegantly translating the designs into stone and plaster. These instruments are starkly functional and, unlike his other constructions, have no ornamentation whatsoever. Particularly ingenious is the idea of complementary pairs of the *Jayaprakāśa-yantra* and the *Rāma-yantra*, where the observer could walk into the instruments and note the readings on the scales accurately. While his workmen could not cope with the problems connected with making large metal instruments, his architects and masons could elegantly solve the problems of masonry instruments.

With these masonry instruments, the first observatory was set up at Delhi around 1724. The observatory at Jaipur may have been built between 1727 and 1734; the others at Ujjain, Benares and Mathura thereafter between 1734 and 1738. The one at Mathura does not survive any more. After the completion of the Jaipur Observatory, it became

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1606 The simple elegance of these masonry instruments inspired many imitations in India and abroad. Some of these will be described in Apx.E.

the principal centre of observation. Here are assembled the largest number of instruments.

About 1727, when the Delhi observatory was already erected and the others were in the planning stage, Jai Singh heard that the European nations had made great progress in astronomy. Therefore, he sent a delegation to Portugal in 1727. This delegation returned in 1730, bringing with them, among others, the astronomical tables *Tabulae astronomicae Ludovici* of the French astronomer Philip de la Hire which were published in 1702. These tables were received with great enthusiasm, and a French physician named Josef Du Bois was entrusted with their translation.[1607]

Jai Singh found certain discrepancies between La Hire's tables and the observed values regarding the longitude of the moon. As Du Bois and other Europeans could not explain the discrepancies, Jai Singh addressed a set of five specific questions to a Jesuit by name Claude Boudier who was then at the French colony of Chandernagore, and invited him to Jaipur. Boudier set out for Jaipur in January of 1734. On the way, while observing the solar eclipse on 3 May 1734 at Delhi, he too noticed that the observed time of the eclipse did not agree with La Hire's tables. Boudier spent about two years at Jaipur and returned to his mission in 1736.[1608]

1.2. Zīj-i Muḥammad Shāhī

Jai Singh got prepared a set of new astronomical tables in Persian and named them *Zīj-i Muḥammad Shāhī* after the reigning Mughal emperor Muḥammad Shāh.[1609] There are said to be some fifty manuscripts extant, but the full text has not been published so far. Of this work, the star catalogue is dated 1725-1726 and the preface was written after 1734. However, these tables are not based on the observations carried out at the five observatories with the aid of the masonry instruments designed especially for this purpose. Instead, these were derived in large parts from the tables of Ulugh Beg and

[1607] Sharma 2016, pp. 301-302; see also Mercier 1993.

[1608] Sharma 2016, pp. 302-303.

[1609] On the contents of this work, see Hunter 1799, pp. 205-209; Mercier 1984, pp. 153-157; Sharma 2016, pp. 238-265; 323-341.

Philip de la Hire. Raymond Mercier[1610] and Benno van Dalen[1611] argue convincingly that the star catalogue in the *Zīj-i Muḥammad Shāhī* is substantially the same as that in Ulugh Beg's *zīj*, but updated to Jai Singh's time by the addition of the precession, and that the tables of the sun, moon and planets are all identical with those of La Hire, apart from a mere change of meridian from Paris to Delhi.

It is obvious that Jai Singh's endeavours did not lead to any new discovery in astronomy. But there is no doubt that under his auspices, Hindu and Islamic traditions of mathematical astronomy were cultivated, perhaps for the last time, very intensively, before they were overshadowed by the new astronomical theories and instruments coming from Europe.

1.3. Translation Programme

As the work on the observatories progressed, Jai Singh's interest in Islamic astronomical tradition deepened and he launched also an ambitious programme of translation of the major works of Islamic mathematical astronomy into Sanskrit.[1612] Under this programme, Jagannātha translated Euclid's *Elements*[1613] and Ptolemy's *Almagest,* [1614] both from the Arabic versions prepared by Naṣīr al-Dīn al-Ṭūsī (1201-1274). Nayanasukha Upādhyāya rendered, with the help of Muḥammad ᶜĀbid, the *Spherics* of Theodosius from the Arabic version of Qusṭā ibn Lūqā al-Ba'labakī into

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1610 Mercier 1984.

1611 Dalen 2000.

1612 Cf. Pingree 1978a; Pingree 2000; Sarma 1998; Sarma 2002.

1613 *The Rekhāgaṇita of Jaganntha,* ed. H. Dhruva & K. Trivedin, Bombay Sanskrit Series 61-62, Bombay 1901-1902.

1614 Jagannātha 1967-69; Jagannātha 1976. Some of the available manuscripts contain, besides the translation of the thirteen books of the *Almagest*, five more chapters entitled *Yantrādhyāya, Jyotpatti, Madhyamādhikāra, Spaṣṭādhikāra* and *Tripraśnādhikāra.* These five chapters can be treated as an independent work in the style of the traditional *siddhāntas.* These chapters are edited by Muralīdhara Caturveda under the title *Siddhānta-samrāṭ* (Jagannātha 1976). Under the aegis of Indian Institute of Astronomical and Sanskrit Research, a team of scholars headed by Ram Swarup Sharma, published the thirteen books constituting the translation of the *Almagest* and the additional five chapters in three large volumes; this edition is practically unreadable as it violates all principles of textual criticism and also the basic norms of book production.

Sanskrit. He also translated chapter 11 of the second book of Naṣīr al-Dīn's *Tadhkira* together with the commentary of al-Birjandī.[1615]

1.4. Hindu, Muslim and European Astronomers at Jai Singh's Court

In these tasks of designing instruments and translating Arabic and Persian texts into Sanskrit, Jai Singh was assisted by a large number of astronomers, both Hindu and Muslim. Notable among the Hindus were Jagannātha Samrāṭ, Nayanasukha Upadhyāya and Kevalarāma. The translations by the first two scholars have been mentioned above. Kevalarāma, who was awarded the title of the *Jyotiṣarāya* (Astronomer Royal), helped in rendering La Hire's tables in Sanskrit.[1616]

Among the Muslim Nujūmīs, mention may be made of Muḥammad ᶜĀbid who helped Nayanasukha translate Arabic texts, Shaykh Asad Allāh Nujūmī who was a member of the delegation dispatched to Europe and Muḥammad Sharīf who was sent to take observations in the southern hemisphere. [1617] Abū al-Khayr Khayr Allāh Khān is said to have drafted the *Zīj-i Muḥammad-Shāhī,* but Virendra Nath Sharma contends that there is no evidence for this.

Information about Jai Singh's Muslim astronomers comes primarily from the *Dastūr Kaumvār,* a 32-volume set of books in the Rajasthan State Archives, which records favors, honors and gifts that the rulers of Amber or Jaipur granted over a period of several generations. The *Dastūr Kaumvār* records go back to the time of Man Singh (1550-1617); however, they are more detailed for the Jai Singh period. The records list Muslim astronomers under *Kaum Musalmān* (Muslim caste) and identify them by the title *nujūmī* (astronomers or astrologers).[1618]

Khairu'llah has been called the chief assistant of the Raja and the author of the *Zīj-i Muḥammad-Shāhī.* However, these titles appear doubtful when one does not find any mention of gifts or honors bestowed upon him in the *Dastūr Kaumvār.* It is inconceivable that the Raja, generous as he was in bestowing honors upon his scholars,

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1615 Cf. Takanori Kusuba and David Pingree, *Arabic Astronomy in Sanskrit: Al-Birjandī on Tadhkira II, Chapter 11 and its Sanskrit Translation,* Brill, Leiden, 2002.

1616 Sharma 2016, ch. XII, pp. 261-284.

1617 Sharma 2016, pp. 285-290.

1618 Sharma 2016, p. 285.

would totally ignore his "chief assistant" and the "author" of an important work such as the *Zīj-i Muḥammad-Shāhī*.[1619]

Of the Europeans at Jai Singh's court, the French physician Josef Du Bois and the Jesuit Claude Boudier have been mentioned above.[1620] Unfortunately, there are no records about Boudier's activities at Jaipur, in particular, how he answered Jai Singh's queries. Nor is there any record of the astronomical activities of another Jesuit Andreas Strobl who was with Jai Singh from 1740 until the latter's death in 1743. In spite of these close contacts with European astronomers, Jai Singh remained ignorant of the telescope which heralded a revolution in the observational astronomy, and of the heliocentric theory of Copernicus which likewise drastically changed the traditional view of the solar system.

1.5. Jai Singh and the Astrolabe

Although Jai Singh preferred large masonry instruments for astronomical observation, he had a great esteem for the astrolabe. Besides commissioning a Sanskrit translation of Naṣīr al-Dīn al-Ṭūsī's popular Persian manual *Risālat al-usṭurlāb*,[1621] he himself composed in Sanskrit prose a manual on the astrolabe with the title *Yantrarāja-racanā.*[1622] In the Sarasvati-Bhavan library of the Sanskrit University at Varanasi, there is a unique manuscript (no. 50258) in which al-Ṭūsī's Persian manual on the astrolabe is transliterated in Devanagari script; it is most likely that it was transcribed at Jai Singh's court.

1.5.1. Indo-Persian Astrolabes collected by Jai Singh

Being a connoisseur of instruments, Jai Singh collected some of the best and most ornate Mughal astrolabes. One of these was the universal *Zarqālī* astrolabe crafted by Ḍiyā' al-Dīn Muḥammad in 1681 (A092). After acquiring this unique astrolabe, Jai Singh caused the composition of a Sanskrit manual entitled *Sarvadeśīya-Jarakālī-Yantra* on the construction and use of this instrument. Other important Indo-Persian

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[1619] Sharma 2016, p. 288.

[1620] Cf. Mercier 1984, pp. 159-161; Mercier 1993.

[1621] Bhattacharya 1979.

[1622] *Yantrarāja-racanā,* ed. Kedāranātha Jyotirvid, Rajasthan Oriental Series 5, Jaipur 1953.

astrolabes collected by him are the zoomorphic astrolabe attributable to Muḥammad Muqīm (A052), a standard astrolabe with an exquisitely crafted rete by Ḍiyā' al-Dīn Muḥammad of 1656 (A073), a unique north-south astrolabe by Ḍiyā' al-Dīn of 1674 (A091) and some others (A132).[1623]

1.5.2. Production of Sanskrit Astrolabes

There is evidence to show that Jai Singh established a manufactory to produce astrolabes with Sanskrit numbers, legends and labels. It is quite likely that C021 and C022 were made for him. In order to popularize the astrolabe among his Hindu astronomers, this manufactory produced a great number of Sanskrit astrolabes, with a single plate calibrated to Jaipur's latitude of 27°.[1624]

2. METAL INSTRUMENTS USED BY JAI SINGH

In the introduction to the *Zīj-i Muḥammad Shāhī,* Jai Singh describes how he had first used metal instruments and, finding them not suitable for his purpose, how he designed large masonry instruments. Speaking in third person, he narrates

> He … constructed here (at *Dehly*) several of the instruments of an observatory, such as had been erected at *Samarqand*, agreeably to the *Musalman* books : such as *Zatul-huluk,* of brass, in diameter three *guz* of the measure now in use, … and *Zat-ul-shobetein,* and *Zat-ul-suchein,* and *Suds-Fukheri,*[1625] and *Shamilah.*

[1623] These are now displayed in a new gallery built inside the Jaipur Observatory. Unfortunately, these portable instruments are arranged indiscriminately: historically valuable astrolabes are displayed side by side with unfinished astrolabes, technically unique items along with models of masonry instruments of no particular merit. The labels do not express the specific nature of the instrument, and the descriptions are rudimentary, sometimes even misleading. Nearly every instrument is said to be useful for finding the sun's transit from one zodiac sign to the other, the ascendant, and the actual position of the planets and stars in the zodiac sign. All instruments, whether Sanskrit, Indo-Persian or even French, are described as 'commissioned by Sawai Jai Singh II'. Even the *Zarqālī* universal astrolabe made by Ḍiyā' al-Dīn for a high Mughal dignitary in 1690 is shown as 'commissioned by Sawai Jai Singh II'.

[1624] See Introduction to section D.

[1625] It is surprising that *Suds-Fukheri* is listed among the metal instruments discarded by Jai Singh. On the contrary, it is incorporated in the *Samrāṭ-yantra* at Delhi and Jaipur under the name *Vṛtta-ṣaṣṭhāṃśa-yantra,* which, according to Virendra Nath Sharma, 'is by far the most sensitive and easy-to-use instrument' (Sharma 2016, p. 151).

> But finding that brass instruments did not come to the ideas which he had formed of accuracy, because of the smallness of their size, the want of division into minutes, the shaking and wearing of their axes, the displacement of their centres of the circles, and the shifting of the planes of instruments;[1626] …
>
> He constructed in *Dar-ul-kheláfat Shah-Jehanabad,* which is the seat of empire and prosperity, instruments of his own invention, such as *Jey-pergás* and *Ram-junter* and *Semrát-junter,* the semidiameter of which is of eighteen cubits, and one minute on it is a barley-corn and a half; of stone and lime, of perfect stability, with attention to the rules of geometry, and adjustments to the meridian, and to the latitude of the place, and with care in the measuring and fixing of them; so that the inaccuracies, from the shaking of the circles, and the wearing of their axes, and displacement of their centres, and the inequality of the minutes, might be corrected.

At first Jai Singh collected descriptions of various kinds of astronomical instruments from diverse sources and got these translated into Sanskrit. Thus from Naṣīr al-Dīn al-Ṭūsī's recension of Ptolemy's *Almagest,* the descriptions of the following five instruments were translated: 1. solstitial armillary (*Yāmyottara-yantra*), 2. mural quadrant (*Yāmyottara-bhitti-yantra*); 3. armillary sphere with 6/7 rings (*Dhāt al-Ḥalaq*), 4. triquetrum (*Dhāt al-Shu*ᶜ*batayn*), 5. dioptra (*Dhāt al-Thuqbatayn*). Sanskrit translations were also made of the description of the instruments used at the observatories of Maragha and Samarqand, especially al-ᶜUrdi's improved version of the armillary sphere, consisting of 5 rings, and of the Fakhrī sextant (*Suds Fakhrī).* Some of the descriptions of these instruments which he thus collected, and possibly also some of the instruments which he began designing on his own, were compiled in the *Yantraprakāra*.

According to the designs he thus assiduously collected, Jai Singh got instruments made in wood and brass. It is quite apparent that, in order to obtain as minute divisions as possible, Jai Singh ordered enormously huge enlargements from designs meant for

[1626] Jagannātha also describes the difficulties in the use of large wooden and metal instruments; cf. Pingree 1987, pp. 315-316.

portable instruments. But making large-scale brass instruments and the consequent problems of mounting and pivoting them was beyond the engineering skills of the artisans.[1627]

None of the metal or wooden instruments which Jai Singh caused to be made according to the Islamic sources are extant now. Besides these, he also designed some metal instruments of his own.[1628] Some of these are extant now and will be described in the following pages. The main purpose of these instruments appears to have been to determine the position of the heavenly bodies in terms of the horizontal, equatorial and ecliptic systems. Thus an instrument was designed to measure the horizontal coordinates, namely the altitude and the azimuth. There survives a small specimen (S001), which is now slightly damaged. It is not known whether any attempt was made to prepare a larger version. But there exists a very large ring for measuring the latitude (S002). Both have been superseded by the *Rāma-yantra* built in masonry. But there is a separate instrument in masonry to measure the azimuth, named *Digaṃśa-yantra.* It is not known what advantage this offers over the *Rāma-yantra.* Second, for measuring the equatorial coordinates (declination and hour angle), Jai Singh designed a metal instrument which goes today under the colourless names *Cakra-yantra* (circle instrument), three specimens of which are extant (S003). Third, for determining the ecliptic coordinates (celestial longitude and latitude), an instrument called *Krāntivṛtta-yantra* (ecliptic instrument) was prepared. There are extant two specimens, one small and one very large, both unfinished (S004 and S005). Jagannātha says that he got made a small specimen in which the ecliptic ring had a diameter of an artisan's cubit; probably that was complete, but it is not extant anymore.

However, these three types of instruments were superseded by the masonry instrument *Jayaprakāśa-yantra* where measurements can be done in all the three planes, horizontal, equatorial and ecliptic.

1627 It is said, for example, that he caused to be made an armillary sphere with a diameter of about 2.7 m; this is no more extant. At Jaipur there survives still a huge astrolabe with a diameter of 2.17 m, which is not at all convenient for observation (D001), and also a huge *Unnatāṃa-yantra* with a diameter of over five metres (S002).

1628 Some of these are described in the *Yantraprakāra* and also by Jagannātha in the *Yantrādhyāya* of his *Samrāṭ-siddhānta*.

Even so these metal instruments were not discarded altogether. Some of them were incorporated in the Jaipur Observatory.

3. MASONRY INSTRUMENTS

3.1. Jayaprakāśa-yantra and Samrāṭ-yantra

At the beginning of the *Yantrādhyāya* chapter of his *Samrāṭ-Siddhānta,* Jagannātha enumerates the masonry instruments in the following verses:

nāḍīyantaṃ golayantraṃ digaṃśākhyaṃ tathaiva ca |
dakṣiṇodakbhittisaṃjñaṃ vṛttaṣaṣṭhāṃśakaṃ tathā ||
yantrasamrāḍ-iti khyātaṃ yantrāṇām uttamottamam |
jayaprakāśaṃ tadvac ca sarvayantraśikhāmaṇiḥ ||

These are *Nāḍīvalaya-yantra* (equatorial instrument), *Gola-yantra* (armillary sphere), *Digaṃśa-yantra* (azimuth instrument), *Dakṣiṇottara-bhitti-yantra* (south-north wall instrument, or mural quadrant), *Vṛttaṣaṣṭhāṃśa-yantra* (one-sixth-of-the-circle instrument, i.e., sextant, known as *Suds Fakhrī* in Arabic); *Yantra-samrāṭ* or *Samrāṭ-yantra* and *Jayaprakāśa-yantra.* Surprisingly, the masonry instrument *Rāma-yantra* is excluded and the metal instrument *Gola-yantra* or armillary sphere is included in this enumeration of the masonry instruments with which the observatories were erected. Be that as it may, it is noteworthy that the last two are named after Jagannātha Samrāṭ and Jai Singh respectively as *Samrāṭ-yantra* and *Jayaprakāśa-yantra.* About the former, it is said that it is 'the best among the best of all instruments' (*uttamottama*) and about the latter that it is the crest-jewel of all instruments (*sarva-yantra-śikhāmaṇiḥ*).

The *Jayaprakāśa-yantra* to which Jai Singh lent his name is a versatile instrument, containing the projection of the great circles and small circles of the armillary sphere upon the concave surface of the hemispherical bowl facing upwards. Built in two complementary halves, this instrument allows measurements on all the three planes, horizontal, equatorial and ecliptic. These were built only at Delhi and Jaipur.

Figure S.1 – Jayaprakāśa-yantra at Jaipur (photo by Professor Michio Yano)

The most imposing, however, is the lofty *Samrāṭ-yantra*, rising to a height of 20.72 m at Delhi and to 27.35 m at Jaipur. Of all the instruments designed by Jai Singh, this is unique in being accurate, architecturally pleasing, and perhaps easy to replicate. It exists in all the observatories, and moreover, it is executed in two different media: while at Delhi and Jaipur it is built of bricks and mortar, in Benares the quadrants are made out of carved sandstone blocks. Leaving aside the size, the utter simplicity of the design is truly impressive.

It is an equinoctial sundial with the gnomon in the form of a right-angled triangle situated on the north-south meridian line, its hypotenuse pointing to the north pole. Therefore the angle between the base and the hypotenuse is equal to the local terrestrial latitude. The gnomon throws its shadow on two graduated quadrants which project on either side of the gnomon wall, thus indicating the local solar time.

But the *Samrāṭ-yantra* is not just an instrument for measuring time; it is designed to measure the declination as well. For this purpose, the hypotenuse is graduated to read the tangent of the angle of declination. At night the declination and the hour angle of the stars can also be read.

Figure S.2 – Samrāṭ-yantra at Jaipur (photo by Dr Jean Michel Delire)

Inside the structures supporting the quadrants of the *Samrāt -yantra,* Fakhrī sextants (*al-suds al-fakhrī*; Sanskrit: *vṛttaṣaṣṭhāṃśa-yantra*) are incorporated, both at Jaipur and Delhi. At midday the sun's ray passes through a pinhole in the roof and falls on the graduated arc of 60° built in the plane of the meridian within a dark chamber, thus indicating the sun's meridian altitude. This type of sextant was originally designed by Abū Maḥmūd al-Khujandī who built it with a diameter of 20 m at Rayy near the modern Tehran in 994, but it does not exist any more. A similar sextant with a diameter of 60 m was erected in 1420 in the Samarqand observatory, which is now in ruins. Therefore, of the Fakhrī sextant originally invented in Iran, the only functional specimens are now in Jaipur.

3.2. Modern Studies of the Masonry Instruments

Sawai Jai Singh's masonry instruments attracted the attention of European scholars soon after their construction. Joseph Tieffenthaler, an Austrian Jesuit, who arrived in India a few years after Jai Singh's death, travelled extensively and produced a very valuable historical-geographical description of India in Latin.[1629] He visited the observatories at Jaipur, Mathura, Delhi and Ujjain and gave brief descriptions of the instruments there.[1630]

William Hunter was the first scholar to provide a full report of the instruments at the four observatories at Delhi, Ujjain, Mathura and Varanasi in 1799 in his celebrated publication 'Some Account of the Astronomical Labours of Jayasinha, the Rajah of Ambhere, or Jayanagar', where he reproduced Jai Singh's preface to his *Zīj-i Muḥammad Shāhī,* in original Persian together with an English translation, and added a summary of its contents.[1631] Lieutenant A. ff. Garrett, who restored the instruments at Jaipur in 1901-02, described these instruments.[1632] G. R. Kaye, 'Honorary Correspondent of the Archaeological Department India', published in 1918 a very competent description of the masonry instruments set up by Jai Singh in the four observatories of Delhi, Jaipur, Varanasi and Ujjain, and also of some metal instruments available in Jaipur, together with many useful tables, astronomical, geographical and astrological.[1633]

Subsequently many books, booklets and articles have appeared.[1634] The most valuable of these is the *Sawai Jai Singh and his Astronomy* by Professor Virendra Nath Sharma of the University of Wisconsin. The great merit of this book (first published in 1995 and revised in 2016) is that Sharma spent several months in 1981-82 making observations with the instruments at Jaipur and other observatories and thus estimated the level of accuracy of these instruments. According to him, the *Jayaprakāśa-yantra* and *Rāma-yantra* belong to the medium-precision category, while the *Samrāṭ-yantra* and *Vṛttaṣaṣṭhāṃśa-yantra* are the most sensitive instruments with a high degree of precision. He has also examined the archival records related to Jai Singh's observatories

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[1629] A German translation under the title *Historisch-Geographische Beschreibung von Hindustan* was published by Johann Bernoulli in 1785.

[1630] These descriptions are reproduced in English translation in Sharma 2000, pp. 85 (Delhi), 124-125 (Jaipur), 218 (Ujjain), 237 (Mathura).

[1631] Hunter 1799.

[1632] Garrett & Guleri 1902.

[1633] Kaye.

[1634] Those published up to 1985 are listed in Sarma 1986-87b, pp. 122-131.

in the Rajasthan State Archives at Bikaner and thoroughly studied the relevant Sanskrit sources like the *Yantraprakāra* and Jagannātha's *Yantrādhyāya*. His book *Sawai Jai Singh and his Astronomy,* therefore, offers the most comprehensive description of each instrument in all the observatories, starting with the description of the instrument in the Sanskrit sources, and then providing its physical description and its use in observation, its level of precision and so on.

3.3. Problematique of the Miśra-yantra

The *Miśra-yantra* is the most attractive instrument of the Delhi Observatory, but it raises many problems.[1635] Its gnomon is split into two parts which enclose four semi-circular arcs with the strange name *niyata-cakras.* This and other names are apparently due to Gokul Chandra Bhavan, who, as the court-astrologer of Jaipur, was responsible for the restoration of the Delhi Observatory in 1909-1910 on behalf of the Maharaja of Jaipur. He also seems to be the only source for the interpretation of the various elements in this *Miśra-yantra.*

This instrument is not mentioned in the *Yantraprakāra* or in Jagannātha's *Yantrādhyāya*, nor in any archival record; Joseph Tieffenthaler who visited the Delhi Observatory in 1747, just four years after Jai Singh's death, does not mention it either. Therefore, concludes Virendra Nath Sharma, that it was not built by Jai Singh, but by Madho Singh between 1750 and 1754 when he was in the good graces of the Mughal ruler Aḥmad Shāh.[1636]

But when one looks at Madho Singh's creation of small instruments (in the next section T), it is difficult to accept the view that he could be the author of this large masonry instrument with an unusual design. Moreover, he was supposed to succeed Jai Singh in 1743, but due to palace intrigues, his claim was ignored and his step-brother Isvari Singh succeeded Jai Singh. It is only after Isvari Singh's untimely death in 1750 that Madho Singh could become the ruler of the Jaipur kingdom. His first priority would naturally be to consolidate his authority at home and not build a large instrument at Delhi. He could not have built the *Miśra-yantra* later, because Aḥmad Shāh was deposed

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1635 For the description of all the various elements in the *Miśra-yantra*, see Sharma 2016, pp. 109-118.

1636 Sharma 1994, p. 94.

in 1754 and the political situation in Delhi deteriorated. In 1764, Jats led by Jawahar Singh vandalised the observatory. Therefore, Madho Singh could not have built it during the short span between 1750 and 1754.

But this is not to argue that the *Miśra-yantra* was built by Jai Singh himself before his death in 1743, for it does not quite fit into Jai Singh's instrument design either. The available sources do not permit a resolution of this conundrum, although the attractive design of the *Miśra-yantra* engendered many imitations (Apx.E.4.)

3.4. The Nomenclature of the Instruments

Because of the various changes that took place in these observatories, certain new names came into circulation, which are not quite appropriate.

Jantar Mantar: Jai Singh did not give any name to his observatories; he merely referred to them as *yantras* (in the sense of a collection of instruments), or *jantra* or *jantar* in the vernacular. The archival records examined by V. N. Sharma also refer to the observatories at *jantra.*[1637] In Delhi, people on the street who did not understand the purpose of these strange structures added a rhyming word *mantar* and began to call these structures *Jantar Mantar.* This pair of words denote 'magical diagrams and magical incantations' in the occult realm, which is far removed from observational astronomy. Now this vulgar name came to be applied not only to the Delhi Observatory, but to all the observatories. It is improper to call this unique set of scientific instruments by the unscientific name. It would be better to call them Jai Singh's Observatories.

Nāḍīvalaya-yantra: The *Nāḍīvalaya-yantra* consists of two graduated plates set up parallel to the plane of equator; here the term *nāḍī-valaya* (lit. circle of *nāḍīs,* i.e., *ghaṭīs* of 24 minutes) denotes the equator. In the British colonial tongue, it became *Nārīvalaya-yantra* and this name is still being used by Indians. There is no justification for this; in fact, it is misleading, because *nārī* in Indian languages means woman, and *nārī-valaya* would mean a feminine ring or bracelet. This instrument should be called *Nāḍīvalaya-yantra.*

Dakṣiṇodak-bhitti-yantra: While translating Arabic texts into Sanskrit, Jagannātha unwisely chose the rare term *udaṅ* for north and accordingly called the wall set up on

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[1637] Sharma 2016, pp. 96-97.

the south-north line *Dakṣiṇodak-bitti-yantra*, which became *Dakshino Writti Yantra* in British colonial tongue and continues to be used in this form. It is better to call it *Dakṣiṇottara-bhitti-yantra.*

Cakra-yantra: The name *Cakra-yantra,* lit., wheel or ring, or circle instrument, is a colourless name; it can be applied to nearly every instrument, because there are rings or circles in almost every instrument for measuring angles.

In fact, the instrument in the Varanasi observatory was originally called *Krānti-vṛtta* in the sense of 'ring to measure declination'.[1638] John Lloyd Williams, in his report of 1793, describes it as follows:

> A brass circle in the line of equator, facing north and south. It has a movable index, turning on a pivot in the centre; the circle is divided into 360 degrees, or *unse* [= *aṃśa*], subdivided again in 60′, and again into 60″, and into 1/4ths. This instrument is called *cund-brit,* or *cranti-brit* [= *krānti-vṛtta*], but I could not learn the use of it.[1639]

William Hunter objected to the name *Krānti-vṛtta* with the following argument:

> The literal meaning of the *Sanscrit* term *Kranti-writ,* is a circle of *declination,* which may, with some propriety, have been applied to this instrument, as mentioned by Mr. *Williams.* But this name is, in the *Hindu* astronomical books, peculiarly appropriated to the ecliptic; and as the *Sem'rat Sid-dhanta* contains the description of an instrument called *Kranti-writ-yunter,* wherein a circle is made, by a particular contrivance, to retain a position parallel to the ecliptic, I am inclined to believe that the appellation has been erroneously given by the ring above mentioned.'[1640]

Either because of Hunter's objection, or because people in later times did not know how to call it, it was named *Cakra-yantra.* It would be more appropriate to call it *Krānti-yantra* (declination instrument).

1638 Also, in a map of the Jaipur Observatory, reproduced in Sharma 2016, p. 128, the two rings are named *Krānti-vṛtta.*

1639 John Lloyd Williams, 'Further Particulars respecting the Observatory at Benares,' *Philosophical Transactions of the Royal Society at London,* 83.1 (1793) 45-49, esp. 47-48.

1640 Hunter 1799, p. 204.

3.5. Jai Singh's Observatories Today

The observatory at Mathura was set up on the roof of a building in the fort on the banks of river Yamuna. William Hunter described the instruments in 1799.[1641] This fort, together with Jai Singh's astronomical instruments, was pulled down sometime before 1857 and there are no remains of the instruments. The other four observatories are extant in different states of preservation. Virendra Nath Sharma gives a detailed account of the restorations undertaken at the four observatories at different times. The observatory at Ujjain appears to have been substantially modified since the middle of the last century.

The observatory at Varanasi was set up on the roof of a palace on the banks of Ganga river. The palace was built by Jai Singh's ancestor Man Singh (1550-1614) and therefore came to be known as Man Mandir; accordingly the observatory was called 'Man Mandir Observatory'. It could be reached through a lane from the bank of the Ganga. Since Varanasi is the most important centre of pilgrimage and since the river front is full of temples and other places of interest, rarely anybody used to visit this Observatory. When I went to live in Varanasi 1967, it took me one full month to find a person who knew where the observatory lay. Sometime before 2000, the old entrance through a small lane from the riverfront was closed, and a new entrance was opened on the side of the Dashashvamedh Ghat, and also an entrance fee was introduced. This was not a wise move; the Dashashwamedh Ghat is considered the most holy place for ritual baths, with many important temples in the vicinity. With such preponderance of religious and other places of interest, hardly anybody would visit the observatory, that too with an entrance fee. In the absence of human visitors, monkeys took over Jai Singh's astronomical instruments. When I visited the observatory in 2000, the attendant had to accompany me with a stick to prevent monkeys from attacking me, and I could see that the instruments were full of simian excreta.

The **Delhi Observatory,** the first one set up by Jai Singh, was vandalised 1764; it was completely restored in 1909-1910. Here the lofty *Samrāṭ-yantra* was partly built below the ground-level so that the shadow of the gnomon may fall on the quadrants soon after sunrise. But water began to seep into the base of the *Samrāt-yantra* and to collect

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[1641] Hunter 1799, pp. 200-201; see also Sharma 2016, ch. X, pp. 229-233; on p. 231 is reproduced an old drawing of the Mathura Fort.

there as a muddy pool. To avoid this, the base was filled with concrete at some point, thus burying large parts of the quadrants under the concrete. Even so, water still collects there. The Fakhri sextant incorporated in one of the wings of the *Samrāṭ-yantra* was also sealed up. In recent years, high-rise buildings came up in the vicinity; the sun reflecting from their glass facades burns down the grass and other greenery around the instruments. Moreover, the observatory is situated on a road leading to National Parliament; and 'Jantar Mantar' is the usual venue where all the political protest marches gather.

The **Jaipur Observatory** was originally set up within the palace complex so that Jai Singh could walk from his living quarters straight to the instruments. At the beginning of the twentieth century, however, the observatory was separated from the palace (known as the City Palace) by a public thoroughfare, but the instruments were completely restored by Garrett. Since then, the instruments are well maintained. In 2010, the UNESCO included the Jaipur Observatory on the World Heritage list.

Index of Metal Instruments designed by Sawai Jai Singh

S001 ◎Unnatāṃśa-digaṃśa-yantra 3853

Early 18th century, Diameter of the horizontal ring 390 mm; diameter of the vertical ring 330 mm, Jaipur, Jai Singh’s Observatory

S002 ◎Unnatāṃśa-yantra 3856

Early 18th century, Diameter of the ring 5.334 m, Jaipur, Jai Singh’s Observatory

S003 ◎Cakra-yantra (Krānti-Yantra) 3858

Early 18th century, Diameters of the rings 1.79 m; 1.84 m, Jaipur, Jai Singh’s Observatory

S004 ◎Krāntivṛtta-yantra 1 3864

Early 18th century, Diameter of the plates 820 mm; height of the stand 1.5 m, Jaipur, Jai Singh’s Observatory

S005 ◎Krāntivṛtta-yantra 2 3867

Early 20th century, Diameter of the ecliptic ring 915 mm, Jaipur, Jai Singh’s Observatory

T. INSTRUMENTS DESIGNED BY SAWAI MADHO SINGH

INTRODUCTION

Figure T1 – Sawai Madho Singh
(contemporary pencil sketch, photo courtesy late Yaduendra Sahai)

When Sawai Jai Singh died in 1743, his elder son Isvari Singh became the ruler of Jaipur, but he had a short span of reign and died in 1750. Then his step-brother Madho Singh ascended the throne. He had a relatively peaceful rule from 1750 to 1767, and during this period he could cultivate his interests in literature and astronomy.[1647] He is said to have patronised many poets and artists; the artists painted him in elaborate costumes and in different postures. Several of these paintings can be seen in the internet.

1647 James Tod, the well-known chronicler of Rajasthan, extols Madho Singh in these words: 'He inherited no small portion of his father's love of science, which continued to make Jaipur the resort of learned men, so as to eclipse even the sacred Benares'; cf. Lieut. Col. James Tod, *Annals and Antiquities of Rajasthan, or The Central and Western Rajput States of India,* ed. with an Introduction and Notes by William Crooke, Oxford University Press, London 1920, vol. 3, p. 1361.

Like his father, he too was interested in designing new instruments, but with a difference. While Jai Singh designed huge instruments in masonry, Madho Singh, himself a huge person, liked to make small portable instruments. There are extant five instruments and a diagram painted on cloth that bear his name as the creator.

Madho Singh's instruments are variations of horary quadrants and column dials, calibrated for the latitude of Jaipur at 27°. The first of these, named *Yantrādhipati* (T001), is shaped like an astrolabe with a circular plate surmounted by a suspension bracket; the two sides of the circular plate are filled with eight horary quadrants containing scales, which display the half-durations of daylight in different periods of the year, measured in *ghaṭīs.* There are 61 scales, one for each 3° solar longitude.

The next one is made of wood (T005) in the shape of a column with four equal sides, each of which carries five *ghatī* scales; these scales are extended on flaps which are hinged to each side and which can be folded back when not in use. On the four sides there are 20 scales, one scale for each 10° of solar longitude.

The last three are named *Śoṭā-yantras*; these are hollow columns made of brass, consisting of four sides of equal width. The fist two among these are meant for the daytime (T002 and T003), with *ghaṭī* scales to measure the half-durations of daylight throughout the year. These are constructed on the same principle as column dials, but made more complex with no special advantage. The third *Śoṭā-yantra* is also a hollow square column, but with it time is measured at night by sighting one of the eight junction stars of the lunar mansions.

The one common feature among those designed for use in the daytime (viz. T001, T002, T003 and T005) is that each *ghaṭī* scale on them is drawn for two solar longitudes whose sum is tantamount to 6 signs or 180°. However, none of these creations by Madho Singh represents any real advance in instrument design. The *Yantrādhipati* which is equipped with eight horary quadrants is an interesting innovation, but this cannot be said about the rest of the instruments. The complexities introduced in these column dials can at best be termed 'clever'. These are clearly the attempts of a dilettante trying to emulate his illustrious father, but they fall far short of the majesty and simplicity of Jai Singh's creations in stone.

To the instruments he has designed, Madho Singh added Sanskrit verses proclaiming his authorship of these instruments. Chronologically, he appears to have been the first to sign his instruments in Sanskrit verse.[1648] He is said to be an accomplished poet who compiled an anthology of Sanskrit poems and rendered them into Brajabhāṣā.[1649] But surprisingly the signature verses on the instruments do not betray his poetic talents. They are full of empty rhetoric, poor in syntax, and say very little about instruments themselves. Bulhomal of Lahore appears to have been inspired by Madho Singh's example and added metrical signatures to some of his own Sanskrit instruments (H003, K005, L006, U001 and U002); his verses are more successful than those of the royal predecessor.

Figure T2 – Copper plaques with the names of the instruments
(photo by S. R. Sarma)

[1648] Sarma 2010, p. 80.

[1649] Bahura 1976, pp. 75-77.

Besides designing new instruments, Madho Singh appears to have equipped the various portable instruments collected by his father and the instruments which he himself designed with copper plaques on which the name and function of the instrument is engraved. Some are small which just the name of the instrument (as in Figure T2) and some are very large with an elaborate listing of the functions of the instrument (e.g. Figure A092.9, which is attached to the Zarqālī astrolabe made by Ḍiyā' al-Dīn Muḥammad). The uniformity in their make and in the style of engraved letters suggests that all these plaques must have been made about the same time, most likely at the instance of Madho Singh.

Unfortunately, these plaques are attached to the instruments with a thin wire and not very securely. Every time these instruments are shifted, some of the plaques get detached from the instrument. Figure T2 shows four small plaques. The first three belong to the three *Śoṭā-yantras*; they have now been attached to the respective instruments (see Figure T003.1). The fourth one carries the label *jātula halaka yaṃtra vṛtta sāt kī* (instrument named *Dhāt al-Ḥalaq,* with 7 rings). *Dhāt al-Ḥalaq* is the Arabic name for the armillary sphere. It indicates that Jai Singh's collection of portable instruments included an Indo-Persian or Arabic armillary sphere with 7 rings. There is no trace of it now in Jai Singh's Observatory. It was mentioned neither by Garrett & Guleri 1902, nor by Kaye. At Jai Singh's Observatory, there exists a Sanskrit armillary sphere (I001), but that one is equipped with another and larger plaque (Figure I001.2).

Index of Instruments designed by Sawai Madho Singh

T001 ◎Yantrādhipati by Sawai Madho Singh 3877

18th century, second half , Diameter 348 mm, Jaipur, Jai Singh's Observatory

T002 ◎Ghoṭā-yantra by Sawai Madho Singh 3885

18th century, second half , Central column 206 x 39 mm; flaps 206 x 39 x 11 mm, Jaipur, Jai Singh's Observatory

T003 ◎Śoṭā-yantra (1) by Sawai Madho Singh 3888

18th century, second half , 428 x 43 x 43 mm, Jaipur, Jai Singh's Observatory

T004 ◎Śoṭā-yantra (2) by Sawai Madho Singh 3892

18th century, second half, 430 x 43 x 43 mm, gnomon 167 mm, Jaipur, Jai Singh's Observatory

T005 ◎Śoṭā-yantra for the Night by Sawai Madho Singh 3893

18th century, second half, 426 x 41 x 41 mm; , Jaipur, Jai Singh's Observatory

T006 ◎Star Chart by Sawai Madho Singh 3897

18th century, second half, 765 x 735 mm, Jaipur, City Palace, Maharaja Sawai Man Singh II Museum (# Khasmohor 1257)

U. INSTRUMENTS DESIGNED BY BUHLOMAL AND HIS ASSOCIATES AT LAHORE

INTRODUCTION

LĀLAH BULHOMAL LĀHORĪ (*FL.* 1839-1851)

The various astrolabes, celestial globes, *Dhruvabhrama-yantras,* sine quadrants and horary quadrants made by the versatile instrument maker Bulhomal, with legends in Persian, or Sanskrit, or English, have been described in earlier sections.[1655] Bulhomal was indeed the true and the last representative of both the traditions of Indo-Persian and Sanskrit astronomical instrumentation. Besides producing some 24 well-crafted specimens of the above-mentioned traditional Islamic and Sanskrit instruments, he also tried his hand at designing some new ones. Most prominent of these is the *Jyotiḥsattā* of which three specimens are extant (U001, U002, U003).

Jyotiḥsattā

This new device was intended to measure the local time, the ascendant and the culmination in the daytime in the same manner as Padmanābha's *Dhruvabhrama-yantra* allows simultaneous measurement of these elements at night. These can, of course, be determined more easily both at night and in the daytime with the astrolabe, but it appears Bulhomal was interested in creating an alternative device.

The *Jyotiḥsattā* is shaped like an astrolabe with a suspension bracket at the top. It carries on one side (let us call this the obverse side), a set of four horary quadrants together with an alidade as in the *Yantrādhipati* designed by Sawai Madho Singh of Jaipur in the second half of the eighteenth century (T001). The reverse side is engraved with a modified version of the *Dhruvabhrama-yantra* with scales for *ghaṭīs,* zodiac signs according to their right ascensions and zodiac signs with their oblique ascensions, together with an index pivoted to the centre.

We assume that the intended procedure would be that first one measures the local time with the alidade on the obverse side, by choosing the appropriate horary scale for

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[1655] Sarma 2015b; see also Apx.C, Index of Instrument Makers, s. v. Bulhomal.

the day in question. Then turning the disc to the reverse side, the index is placed on the local time just obtained. Where the ruler intersects the scale of the signs marked according to their oblique ascensions can be seen the ascendant and where the ruler intersects the signs marked according to their right ascensions the culmination.

But there are several problems in this procedure. Bulhomal drew on the obverse side scales of hours to denote the lengths of the half-day in different periods of the year, but equipped the reverse side with scales in *ghaṭīs* in the outer periphery. This would necessitate conversion of hours and minutes into *ghaṭīs* and *palas* or vice versa in every operation.

More problematic are the hour scales themselves which are not properly defined. The obverse side of the *Jyotiḥsattā* is engraved with 19 scales to measure the half days in different periods of the year. These scales are divided into hours by radial lines and numbered from the horizontal diameter onwards. The durations of these 19 scales are as follows: 5;17 hours, 5;21 hours, 5;24 hours, 6;00 hours, 6;02 hours, 6;03 hours, 6;04 hours (twice), 6;06 hours (twice), 6;08 hours (twice), 6;10 hours, 6;12 hours, 7;10 hours, 7;12 hours, 7;17 hours, 7;21 hours and 7;24 hours. There is a large inexplicable gap between 6;12 hours and 7;10 hours. According to this arrangement, the half day-length at latitude 32° ranges between 5;17 hours and 7;24 hours.

But this arrangement does not conform to the generally accepted value of maximum daylight at 32° which is ca. 14;08 hours and according to which the length of the half-day at this latitude should range from 4;56 hours to 7;04 hours. Moreover, it is not known how one can determine which scale to use on which day.

There are problems on the reverse side as well which is fashioned somewhat like a *Dhruvabhrama-yantra,* with concentric scales of *ghaṭīs* and *palas,* zodiac signs according to their right ascensions and according to their oblique ascensions. Since this one is meant for use in the daytime, there is no slit for viewing the stars α and β Ursae Minoris, nor a four-armed index as in the *Dhruvabhrama-yantra.* Instead there is just an index, one end of which is pivoted to the centre of the circle. This has to be manipulated by hand.

While the obverse side in all the three specimens is identical, on the reverse side there are differences in the placement of the two scales of zodiac signs. In U001, the scale of the zodiac signs according to the right ascensions commences 90° ahead of the *ghaṭī* scale, while the scale of the zodiac signs according to their oblique ascensions commences at the same point at the *ghaṭī* scale. In U002 and U003, however, all the three scales commence at the same point. Therefore, none of the three specimens of the *Jyotiḥsattā* can provide the desired results.

Jyotiḥsattā, the name which Bulhomal bestowed on this new device is also problematic, because it is not clear what is intended to be conveyed by this name; *jyotiḥ* means a 'light', 'luminary' or 'celestial body' and the term *sattā* denotes 'existence', 'being', or 'power'. If the term *Jyotiḥsattā* is intended to denote something like the 'power of planets', then it is not known where this power is supposed to reside in this device.

The only successful innovation in this device seems to be the alidade. The alidades in the Lahore astrolabes have straight bars without any counter-change as in the astrolabes produced in the Middle East and Europe. Bulhomal also equipped his Indo-Persian and Sanskrit astrolabes with similar alidades with straight bars. But for the *Jyotiḥsattā* he devised an alidade with counter-change, by joining two narrow strips of metal in an ingenious manner so that the two sides of the alidade are equally balanced. Dharm Chand emulated this style in his horary quadrants X015 - X019.

JOSHI DHARM CHAND (*FL.* 1854-73)

Joshi Dharm Chand (*fl.* 1854-73) is a contemporary and an associate of Bulhomal.[1656] His title 'Jotishi' or 'Joshi' (from Sanskrit *Jyotiṣī)* indicates that he was a traditional Hindu astrologer, trained in Sanskrit astronomy and astrology; his surviving instruments show that he was at home in Persian as well. We do not know whether he was from Lahore, but it is certain that he was a resident of Panjab, for he uses the Panjabi phonetic forms of Sanskrit solar months (e.g. *hāṭ* for *āṣāḍha,* or *maggar* for *mārgaśirā*) on some of his instruments. Brahmin by birth, educated in Persian, trained in metal craft and in making traditional astronomical instruments, he was also open to new ideas from Europe. He seems to have been the first one to adapt European perpetual calendars for use in India, an attempt which he designates as *ikhtara*^{c} *naw* (a new invention). There

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[1656] Sarma 2003, pp. 78-84; Sarma 2010, pp. 88-89; see also Apx.C, Index of Instrument Makers, s. v. Dharm Chand.

survive five specimens made by him; three are engraved in Persian and two in English(X015 - X019). These are the earliest known prototypes of the brass perpetual calendars which are now mass-produced at Muradabad.

Āyīnah Falqī

Like Bulhomal, Dharm Chand was also interested in designing an instrument to determine the time, ascendant and culmination in the daytime. He used the reverse side of his perpetual calendars for this purpose. Unlike Bulhomal, Dharm Chand arranged here the scales of half-duration of daytime and the scales of the zodiac signs according to the right ascensions and the scales of the zodiac signs according to oblique ascensions on the same side of the plate and equipped this side with an alidade. Quite pragmatically, he drew just 7 *ghaṭī* scales for the half-duration of daylight and defined these precisely in terms of the Sanskrit-Panjabi solar months. (In the two English specimens, he has only six scales which he defined in terms of English months). He called this new device *Āyīnah Falqī* (mirror of the heavens). His attempt is more successful than Bulhomal's.

As regards the perpetual calendars on the obverse side, his first two attempts in X015 and X016 were not quite successful, because he did not include the years there. He achieved the objective in a third attempt in X017 which is engraved in Persian. He translated this device into English in X018 and X019. These five attempts will be described in section X under the heading 'Indian Adaptations of European instruments'.

In the present section the focus will be on another attempt by Dharm Chand at designing a new instrument by arranging the sine quadrant on one side of a rectangular plate and the plate of multiple horizons on the other side. Dharm Chand calls this creation a *taṣnīf* (invention). There exist two specimens (U006 and U007), but it is difficult to see any advantage in this juxtaposition.

Index of Instruments designed by Buhlomal and his associates at Lahore

U001 ◎Jyotiḥsattā by Lālah Bulhomal Lāhorī, 1896 VS (AD 1839-40) 3915

Diameter 88 mm; height 115 mm, London, Victoria & Albert Museum (# IM.10.1915)

U002 ◎Jyotiḥsattā by Lālah Bulhomal Lāhorī, 1896 VS (AD 1839-40) 3919

Diameter 92 mm, New Delhi, National Museum (# 56.155/7)

U003 ◎Jyotiḥsattā attributable to Lālah Bulhomal Lāhorī, Ca. 1840 3922

Diameter 96 mm, height 112 mm, New York, Columbia University, Butler Library (# 27-258)

U004 ◎Sine Quadrant & unidentified table attributable to Lālah Bulhomal Lāhorī .. 3926

Mid-19th century , 274 x 250 mm, New York, Columbia University, Butler Library (# 27-253)

U005 ◎Sine Quadrant & unidentified table attributable to Lālah Bulhomal Lāhorī .. 3930

Ca. 1840, Diameter 97 mm; height 121 , New York, Columbia University, Butler Library (# 27-199)

U006 ◎Plate of Horizons & Sine Quadrant by Joshi Dharm Chand, 1911 VS (AD 1854-55) 3935

212 x 165 x 3 mm, Stuttgart, Linden Museum (# A 36.124 L)

U007 Plate of Horizons & Sine Quadrant by Joshi Dharm Chand, 1911 VS (AD 1854-55) 3940

212 x 165 x 3 mm, PLU: ex-Skinner 2002.

V. ASTRONOMICAL COMPENDIA

INTRODUCTION

In the fifteen century, instrument makers in Germany began assembling together a variety of sundials like leaves in a book. Such an assemblage is called in German 'Büchsensonnenuhr', in English 'compendium' (pl. compendia). These were usually in miniature size to fit easily into one's pocket, yet accurate enough for actual observation, and made of gold- or silver-plated brass or copper for wealthy clients.[1662] Exquisitely crafted specimens can be seen in several European Museums.

In India, a few attempts were made in the nineteenth century to prepare compendia in which Sanskrit astronomical instruments were assembled. The first is a metal compendium in the form of a cylindrical casket (V001).

The second is a set of two wooden diptych sundials (V002 and V003) produced at Kuchaman during the reign of Maharaja Kesari Singh, ca. 1884. While the inner surfaces carried vertical and horizontal sundials as in the European diptych dials, the outer surfaces were designed as *Phalaka-yantras, Dhruvabhrama-yantras,* or sine quadrants.

The third example is a set of three rectangular wooden boards (V004, V005, V006) also produced at Kuchaman in 1896, during the reign of Maharaja Sher Singh. On these boards, the two sides were filled with the representations of *Phalaka-yantras* and *Dhruvabhrama-yantras.*

These wooden specimens were not fabricated by professional instrument makers, but by unskilled Brahmin astronomers; the workmanship is rather poor; the lines, circles, and the Devanagari letters and numerals were painted clumsily with thick brushes.

It is interesting that the instruments chosen for these compendia are the *Dhruvabhrama-yantra* and the *Phalaka-yantra*. The former, which was invented by Padmanābha around 1423, was a popular instrument and there are many extant

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[1662] Zinner 1979, pp. 98-102.

specimens of it; the instrument is described and the extant specimens are catalogued in the section L above.

In addition to these extant specimens, the *Dhruvabhrama-yantra* is represented also on the five wooden compendia (Figure V002.4, Figure V003.5, Figure V004.3, Figure V005.1, Figure V006.1). However, these representations do not quite follow Padmanābha's instructions. In all the five cases, the *ghaṭī* scale on the outer periphery commences below the slit. The inner scales of the zodiac signs are divided in 12 equal parts and not according to the right or oblique ascensions. More strangely, while the *ghaṭī* scales run clockwise, the scales of the zodiac signs run anti-clockwise in three cases (Figure V002.4, Figure V003.5, Figure V005.1). The indexes are missing in three cases; there are indexes with just two arms in two examples (Figure V003.5 and Figure V005.1), but these cannot function without a plumb. Slits are made in all examples, but these are too short and too narrow to view the stars α and β Ursae Minoris in one line. In two cases (Figure V002.5 and Figure V005.3, the *Dhruvabhrama-yantra* is accompanied by the same star table, but the connection between the two is not known.

The *Phalaka-yantra* is represented four times (Figure V002.6, Figure V004.1, Figure V005.4 and Figure V006.4). It was invented by Bhāskara II in about 1150, but it was not so popular like the *Dhruvabhrama-yantra.* There are references to three actual specimens; in a fourth case, it was depicted on the back of an astrolabe (see section M above). Therefore, the four representations in these compendia here are of some importance. However, these too were not drawn exactly according to Bhāskara's specifications.

Bhāskara lays down that the 90 horizonal lines should be drawn on a rectangular board at equal distances and a circle with a radius of 30 units be described with the centre of the 30th horizonal line as the centre. But these four examples contain grids of rather haphazardly drawn horizontal and vertical lines with a graduated circle superimposed on them. According to Bhāskara, one end of an index should be pivoted at the centre of the circle. Here the middle of the index is pivoted to the circle in three cases (Figure V002.6, Figure V004.1 and Figure V006.4). Bhāskara envisages that the plate is suspended in a vertical plane; then there is no necessity of a compass; yet three specimens (Figure V002.4, Figure V004.1, Figure V005.4) are equipped with ready-made magnetic compasses.

For what purpose these compendia were fabricated must remain an enigma. If these were meant for demonstration in a class room, then there was no need to write long numerical tables on them. They appear to have been made more for amusement than for any practical use.

Index of Astronomical Compendia

V001 ◎Astronomical Compendium, not signed, not dated 3947

19th century, Diameter 132 mm, London, Victoria & Albert Museum (# IM 471-1924)

V002 Astronomical Compendium in the Form of a Diptych by Jośī Rāmacandra, 1941 VS (AD 1884) 3949

Kuchaman, Rajasthan, 220 x 135 x 20 mm, Hastings-on-Hudson, NY, Tesseract

V003 Astronomical Compendium in the Form of a Diptych, attributable to Jośī Rāmacandra 3957

Ca. 1884, 170 x 110 x 20 mm, Hastings-on-Hudson, NY, Tesseract

V004 ◎Astronomical Compendium, not signed 3964

Saṃvat 1953 Vaiśākha sudi 3 (= 1896 May 15 Friday), 352 x 232 x 20 mm; weight 758 gm, Paris, PC

V005 ◎Astronomical Compendium, not signed, not dated 3970

Ca. 1896, 316 x 234 x 15 mm; weight 607 gm, Paris, PC

V006 ◎Astronomical Compendium, not signed, not dated 3975

Ca. 1896, 358 x 235 x 16 mm; weight 928 gm, Paris, PC

W. MISCELLANEOUS INSTRUMENTS

INTRODUCTION

This section contains a few odd artefacts which cannot be placed in any other category. The first (W001) is an interesting lunar calendar in brass, engraved in Arabic/Persian, but of uncertain provenance. This is followed by a Sanskrit instrument named *Nalaka-yantra* also in brass. In 1915, when the Sanskrit Mahavidyalaya was established at the Maharaja Sarajirao University of Baroda to teach Sanskrit in traditional manner, some instruments were prepared as teaching aids for the classes of astronomy (*jyotiṣa*); this is one of those instruments; here the instrument maker gave a modern interpretation to the simple sighting tube.

Then follow three objects made in the shape of astrolabes. The first of these (W003) is carved in marble with an ornate *kursī* and engraved in Persian letters and *Abjad* numerals, displaying on one side the limb and a geographical gazetteer and on the other the usual configuration of tables to be found on the back of astrolabes. The other two (W004 and W005) are made of slate stone and engraved with circles and lines that are similar, but not identical, to those on astrolabes. These three stone items cannot be used either for observation, or for demonstration. They must have been made by some astrolabe makers or their apprentices to while away time.

Index of Miscellaneous Instruments

W001 ◎Lunar Calendar, not signed, not dated 3983

Diameters of three discs 86 mm, 66 mm, 48 mm, Oxford, Museum of the History of Science (# 25966)

W002 ◎Nalaka-yantra, not signed, not dated... 3986

Early 20th century, Height 430 mm; base of the stand 427 x 290 mm; length of tube 398 mm, Vadodara, M. S. University of Baroda, Sanskrit Mahavidyalaya (# R.S.M.D. 100)

W003 ◎Astrolabe-shaped Marble Artefact, not signed 3988

Late 19th century, Diameter 206 mm, height 294 mm, thickness 24 mm, London, Nasser D. Khalili Collection of Islamic Art (# SCI 44)

W004 Astrolabe-shaped Stone Artefact, not signed.. 3995

19th century, Diameter 218 mm, height 253 mm, thickness 12 mm, Chicago, Adler Planetarium & Astronomy Museum (# W-273)

W005 Astrolabe-shaped stone artefact, not signed... 3998

19th century , Diameter 203 mm, PLU, ex-Tesseract

X. INDIAN ADAPTATIONS OF EUROPEAN INSTRUMENTS

INTRODUCTION

In the nineteenth century, as has been mentioned earlier, instrument makers continued to produce traditional Sanskrit and Islamic instruments. They also began copying, for reasons that are not completely clear, European models of some obsolete naked eye instruments and engraved on them legends in Sanskrit or in Persian.

UNIVERSAL EQUINOCTIAL DOUBLE RING DIALS

This device consists of two rings placed one inside the other; the inner one is pivoted to the outer one in such a manner that the two can be stretched apart until they are at right angles to one another, or folded flat when not in use. The outer ring functions as the meridian ring and the inner one as the equatorial ring. The rim of the two upper quadrants of the meridian ring is graduated in degrees and numbered from 1 to 90, starting from the two points where the two rings are joined. These scales in the two quadrants allow the use of this instrument at the northern as well as the southern latitudes.

The lower part of the equator ring is marked with a symmetrical pair of hour-scales.

A horizontal bridge is attached to the meridian ring at the two points of 90° in such a manner that it can be rotated on its sides. This bridge is a flat rectangular piece of metal with a long slit running through its length. The bridge carries a calendar scale on one side and a declination scale on the other. Inside this slit is a sliding plate containing a small hole through which a ray of sunlight passes and a small knob which assists in moving the plate inside the slit.

The meridian ring carries a groove all around on its rim. The suspension bracket clasps the meridian ring in the groove; the two legs of the clasp can be tightened with a screw. By turning this screw the clasp can be loosened and moved to the desired degree of latitude and then tightened. To the bracket is attached a large ring for suspension.

For measuring time, the suspension bracket is fixed at the latitude of the place of observation and the two rings are stretched apart until they are at right angles. The sliding plate is moved so that the pinhole is at the solar longitude corresponding to the day of observation. Then the dial is suspended by the ring and slowly turned around until a ray of sunlight passes through the pinhole and falls on the time scale on the equatorial ring, and thus indicates time.

The invention of this universal double ring dial is generally attributed to the English mathematician William Oughtred (1574-1660) who published a description of it in 1652. He is credited with the invention of the slide rule and the introduction of the symbol ‘x’ for multiplication and the abbreviations ‘sin’ and ‘cos’ for sine and cosine functions. However, it is not quite certain that he was the real inventor of the universal double ring dial, because it was described or illustrated in European documents which are earlier than the alleged invention by Oughtred.

This universal equinoctial double ring dial can be used at all latitudes without the aid of compass, can be folded flat and carried easily. However, suspending it steadily until a ray of sunlight passes through the tiny pinhole is not an easy job. Even so, it was quite popular in Europe and specimens of various sizes can be found in all the European museums. Even now one can buy small pocket models, such as the one below, which has an outer diameter of just 46 mm.

Obverse side with the latitude scale on the outer meridian ring and time scale on the inner equatorial ring. Note that the mark on the suspension bracket is pointing to 51°, the latitude of Düsseldorf.

Reverse side; on both rings are engraved the names of various cities in Europe with their latitudes.

Figure X1 – Modern pocket double ring dial (photos by S. R. Sarma)

Some specimens brought to India by the British colonial officers must have aroused the interest of local astronomers and metal-smiths and several Sanskrit versions were produced in the nineteenth century. All the extant specimens are reasonably well made and the labels are correctly engraved. In the time scale, instead of hours, the traditional Indian units of *ghaṭīs* (of 24 minutes) are employed, with a range of 17 *ghaṭīs* before and after noon; in X001, however, the range is 20 *ghaṭīs*.

One side of the bridge is engraved with the Sanskrit names of zodiac signs, from solstice to solstice, on the panels above and below the long slit, in the following manner.

On the upper panel above the slit are engraved the names of the six signs from the winter solstice to the summer solstice, which constitute the *Uttarāyaṇa,* the northern course of the sun, namely Capricorn, Aquarius, Pisces, Aries, Taurus and Gemini.

On the lower panel below the slit are engraved the names of the six signs from the summer solstice to the winter solstice, which constitute the *Dakṣiṇāyana* (southern course of the sun), namely Cancer, Leo, Virgo, Libra, Scorpio and Sagittarius; these are written in the reverse order, that is, from right to left. Quite often, instead of the full names of the signs, only the first syllables of the names are engraved.

The reverse side of the bridge is engraved with pairs of declination scales, which are marked in single degrees and numbered in sixes thus: 24, 18, 12, 6, 6, 12, 18, 24.

It is not known when and where these Sanskrit ring dials were produced. Only one of the extant specimens (X005) carries what appears to be a personal name and a date. The name, however, cannot be deciphered, except the last syllable *sya*; it is genitive singular particle used in the sense of 'of' or 'belonging to'. Therefore, the name must be the name of the owner, that is, the person for whom it was made. The date reads *Saṃvat* 1922 which corresponds to 1865-66. It is reasonable to assume that the other specimens were also produced about the same time, roughly in the second half of the nineteenth century. The workmanship and particularly the form of the numerals indicate that all these specimens were produced in Rajasthan, and probably in Jaipur itself. In fact, one of the specimens (X003) was said to have been purchased from the astrologer of the Maharaja of Jaipur.

At present, we know of 10 specimens; six of these must have been produced in Rajasthan in the second half of the nineteenth century. There are two specimens in silver; these must have been produced by the jewellers of Jaipur in the twentieth century for foreign tourists, the same jewellers who produced silver astrolabes (D028 to D032).

There are also two Indo-Persian ring dials. One of these (X009) is a large specimen with scales numbered in *Abjad* system and the bridge engraved with the Arabic names of the zodiac signs. Interestingly, the equatorial ring carries a pair of time scales numbered from 1 to 17; therefore, the units must be *ghaṭīs* and not hours. Thus this scale is similar to the time scales on the Sanskrit ring dials. Therefore, this ring dial must also have been produced in India and in the same milieu as the Sanskrit dials.

In the second Indo-Persian ring dial (X010), the meridian ring is engraved with common Arabic/Persian numerals on one side and with modern 'English' numerals on the other side. The equatorial ring carries an hour scale, numbered in Roman numerals on both sides.

Even though these Sanskrit ring dials are endowed with *ghaṭī* scales, they do not quite conform to the time-measuring practices of the Hindu astronomers or astrologers, because they measure time in *ghaṭīs,* but starting from the local sunrise. Therefore, instruments which measure *ghaṭīs* from the midday backwards or forwards do not serve their purpose. These were produced merely as curiosities.

Universal Equinoctial Sundials made by Mangaran

Mangaran of Patna, who claims to be a worthy pupil (*shāgird-i rashīd*) of Lālā Makhan Lāl, produced several nearly identical copies of the same type of an unusual universal equinoctial sundial between the years 1275 AH (AD 1858-59) and 1303 AH (AD 1885-86). The dial is unusual because it is engraved on a rectangular brass sheet which was bent to form a semi-cylindrical trough. A gnomon set perpendicular to the axis of the dial on one side of the trough throws its shadow on the scales engraved on the inner side of the trough. Time can be measured on these scales both in hours of 60 minutes and *ghaṭīs* of 24 minutes. The trough is mounted on a stand at the back of which there is an arc graduated in single degrees which are numbered from 10° to 50°. By sliding the trough along the arc up to the desired degree, the sundial can be adjusted according to the local latitude. A magnetic compass is attached to the base of the stand so that the sundial can be correctly positioned on the north-south axis.

This was obviously copied or adapted from a European model. The Time Museum, Rockford, owned a French sundial in which the dial was engraved also on a bent rectangular metal sheet. It was sold in an auction by Christie's of London on 14 April 1988; the catalogue of that auction describes the sundial thus:

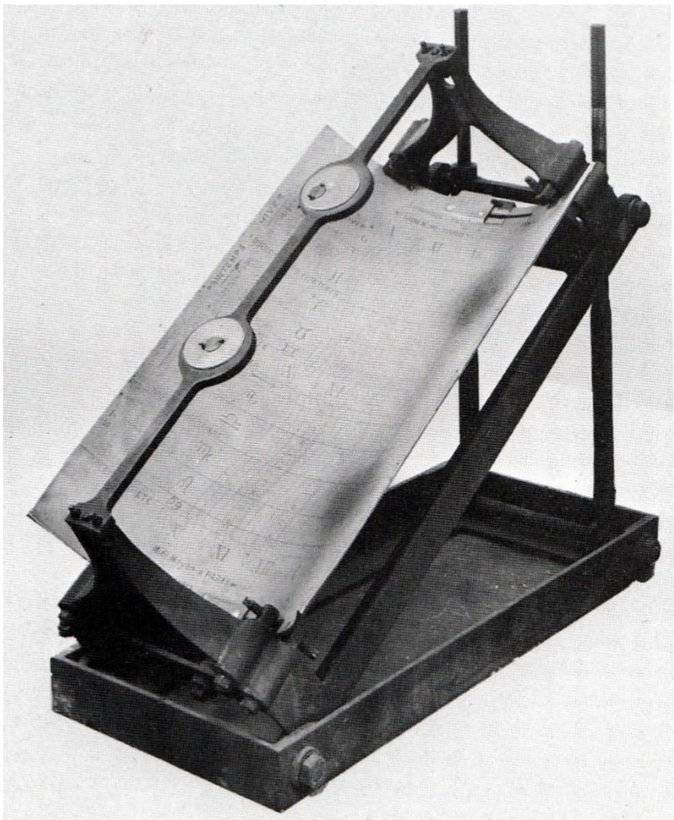

Figure X2 – Sundial by Louis Alphonse Decohorne (from Christie's catalogue)

> 'A French iron and brass meantime sundial, the frame on the base with scroll supports and adjustable for declination via hinged screw thread supports, the crossbar with twin apertures, the concave plate engraved with hours, the meridian of Paris, adjustable vernier for latitude East and West, the season's equinoxes and zodiac calendar scale, and with descriptive plaque for the *Régleur Solaire, Système Decohorne Breveté S. G. D. G.,* the stand — 46 ½ in (118 cm).'[1668]

However, the prototype of this device was designed by Louis Alphonse Decohorne in 1891, i.e., much later than the dates of the known pieces by Mangaran. Therefore, both Mangaran's and Decohorne's sundials must be based on an earlier European model, which is not known.

1668 Christie's, London, *Time-Measuring Instruments from the Time Museum,* auction catalogue of 14 April 1988, lot 116, p. 61.

A dealer in Lucknow told me in 2001 that he had a dozen specimens of this sundial by Mangaran and that he had sold off all but one.

At least, six of these came to light. Khuda Bakhsh Oriental Public Library of Patna owns a specimen dated 1275/1859 (X011); Victoria and Albert Museum, London, has one of 1284/1868 (X012); another dated 1295/ 1878 came up for auction at Sotheby's, London, on 24 October 2007 (X013). Moreover the French catalogues of a dealer named 'Tazan', whom I cannot identify, carry photos and brief descriptions of two more copies dated 1293/1876-77 and 1303/1885-86 respectively. Just now came to light a silver specimen made jointly by Mangaran and his pupil Ram Charan in 1292/1875 (X014); this was commissioned by a zamindar of Patna and was presented on 4 January 1876 to the Prince of Wales during the latter's tour of India.[1669]

Mangaran seems to have specialised only in making copies of the same device, for no other instrument made by him came to light, nor any instrument made by his teacher Lālā Makhan Lāl. All the specimens made by Mangaran display excellent workmanship. It is not known how the European prototype reached him at Patna.

All the specimens carry an almost identical inscription in Persian. The inscription on the specimen at Patna reads: 'The maker of this compass is Mangaran, worthy pupil of Lālā Makhan Lāl, resident of the locality Mainpura in the city of Patna.' Other copies do not mention the residence; they merely state: 'The maker of this compass is Mangaran, worthy pupil of Lālā Makhan Lāl.'

Mangaran's teacher Lālā Makhan Lāl and his pupil Rām Charan have Hindu names; Mangaran must also be a Hindu. In nineteenth century India, it was not unusual that many Hindus used Persian as their professional or academic language. In two specimens, which are in the Khuda Bakhsh Library of Patna and in the Victoria & Albert Museum in London, Sanskrit names of the twelve zodiac signs are engraved on the outer surface of the dial in Devanagari script. The various scales are numbered in what were

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[1669] Some of the gifts received by the Prince of Wales during his tour of India are the subject of a special exhibition entitled 'Splendours of the Subcontinent: A Prince's Tour of India 1875-6' being held at several places in the UK in 2017-18; there is a catalogue of the exhibition with the same title, viz. Meghani 2017.

called in nineteenth century India ‘English numerals’; these are now variously designated as ‘Hindu-Arabic numerals’ or ‘Arabic numerals’.

However, certain features of these sundials are quite intriguing.

(i) Sanskrit names of the zodiac signs are engraved on the outer surface of two copies, the one at Patna and the other at London, for no practical purpose.

(ii) The upper parts of the gnomons are engraved with a numbered scale, the purpose of which remains unknown.

(iii) All the specimens carry an inscription in Persian which begins with the words ‘the maker of this compass is Mangaran’. The specimens are, no doubt, equipped with a magnetic compass, but these universal equinoctial sundials are much more than mere compasses. Why did Mangaran then call them compasses?

(ii) Besides the magnetic compass for the correct placement of the sundial in the north-south axis, the sundials are equipped with a mechanism which enables the use of the sundial at different terrestrial latitudes. At each latitude, the gnomon must point towards the celestial north pole; for this purpose, it must subtend an angle equal to the latitude of the place above the horizontal plane. Therefore, the trough carrying the dial must be tilted so that the angle between it and the horizontal plane is the complement of the terrestrial latitude, i.e., the co-latitude. The curved bar at the back of the stand is engraved with a scale of co-latitude from 0° to 50°. The trough must be tilted along this scale and the screw tightened at the desired degree of co-latitude.

However, since the scale is marked only up to the colatitude of 50°, the sundial can be adjusted only for the terrestrial latitudes of 40° or more. Thus it cannot be used at any latitude in India. For example, if the sundial is to be used at Patna which has a latitude of at 25.6°, then the gnomon should be elevated from the horizontal base by an angle of 25.6°; this can be done only when the trough carrying the dial is raised by an angle equal to the co-latitude of the place, which in this case is (90° – 25.6° =) 64.4°. This is not possible with this curved scale which is marked only up to 50°.

In the silver specimen made for the Prince of Wales, the scale of co-latitude is marked up to 60°; therefore it can be used at places with the latitude of 30° or more. This cannot be used at Patna, but could be used in Lahore, and definitely in London if the Prince of Wales was inclined to do so.

It is highly intriguing why Mangaran produced so many specimens with unsuitable scales of co-latitudes, which cannot be used anywhere in the Indian subcontinent. Did he not understand the simple principle of latitudes and colatitudes? Or did he make these exclusively for the British clients who could use them in England?

PERPETUAL CALENDAR & HORARY QUADRAT BY JOSHI DHARM CHAND

European months of 28/29, 30, or 31 days do not synchronise with the weeks of seven days. Therefore, perpetual calendars are designed to provide the matching weekday for any date in the European calendar. The idea is said to have originated with Samuel Moorland (1625-95) of England, who arranged the dates in cycles of seven with appropriate instructions for locating the weekday for the desired date. Small copper or silver discs, carrying such information, were produced in good numbers and were known as 'coin calendars'.[1670]

In India, perpetual calendars for 3, 30, or 100 years are among the souvenirs offered for sale. Made in the shape of an astrolabe at Muradabad, a north Indian town famous for its production of brassware, these perpetual calendars consist of a circular disc with enamelled decorations in the border. A smaller circular disc with windows cut in it is pivoted at the centre of the main disc, so that the smaller disc rotates above the surface of the main disc, partly blocking and partly revealing the engraved numerical data on the main disc. The design of this perpetual calendar is clearly of European origin, but the path of its transmission from Europe to India has not been mapped so far.

[1670] Turner 1993-94.

Figure X3 – Perpetual Calendar for 2001-2100 made in Muradabad;
here it is set for October 2017 (photo by S. R. Sarma)

Joshi Dharm Chand of Lahore (*fl.* 1854-73) appears to be one of the intermediaries in the transmission of perpendicular calendars to India. In 1860s and 1870s he produced some devices with perpetual calendars on one side and horary quadrants on the other. At present, we know of five specimens made by him; three of these are engraved in Persian letters and numerals and two with English letters and numerals.

The earliest of these (X015) is dated 1918 VS (AD 1861-62); here Dharm Chand calls this device a 'new invention' (*ikhtirā*^{c} *naw*). It consists of a main plate which is shaped like an astrolabe with a *kursī* and two volvelles. It provides the weekday for any date in the European calendar, but in order to use this, one should find out from another source on which weekday the first of the month in question falls or at least the first of January in that year falls. This is the same case with the chronologically second extant specimen (X016) which is dated 1929 VS (AD 1872-73).

The third extant specimen (X017) inscribed in Persian represents an advanced version. It is not dated, but it must have been produced some time after 1873. It is engraved with the years 1 to 100, i.e., 1801 to 1900. Its construction is also simplified in that it contains just a single volvelle, instead of the two in the earlier versions. Here one can easily find out the weekday for any date of any month in any year from 1801 to 1900. The two other extant specimens (X018 and X019) are basically English versions of this X017. Between this specimen and the modern products of Muradabad, there lie some more stages of development . We would not know about these stages until more specimens of the intermediary stages are discovered.

Besides providing the weekday corresponding to the given date in the English calendar, all the five specimens provide a table of equivalence between the first date of each English and the corresponding day in the Hindu solar months. This is necessary for Hindu *Jyotiṣīs* who were freshly exposed to the English calendar. They needed to understand the new English months in terms of the familiar Hindu solar months. Otherwise, this data does not serve any calendrical purpose. This data is absent in the modern perpetual calendars of Muradabad.

Horary Quadrant on the reverse

The reverse side of these five specimens are designed as horary quadrants. Here *ghaṭī* scales for different solar months are engraved in all the four quadrants of the circular disc in the same manner as in the *Yantrādhipati* designed by Sawai Madho Singh of Jaipur (T001). Here also the five specimens represent two stages of development. With X015 and X016, one can measure the ascendant also, in addition to the time of the day. The other three (X017, X018 and X019) contain three additional scales for finding out the culmination. Thus these specimens combine Madho Singh's *Yantrādhipati* and Padmanābha's *Dhruvabhrama-yantra.* Dharm Chand designated this new creation as the 'Mirror of Heavens' (*āyinah-i falqī*) in X017.

In the Persian specimens, Dharm Chand employs common Arabic/Persian numerals and not *Abjad* notation; his dates are in the Vikrama era; for the Hindu solar months, he uses the names current in Panjab.

CIRCUMFERENTOR BY JOSHI DHARM CHAND

Circumferentor is a surveying instrument widely used in Europe, UK and in the British colonies before it was superseded by the theodolite. Dharm Chand prepared two Indian versions (X020 and X021) of which only parts are extant.

MECHANICAL CLOCKS ADAPTED FOR INDIA

I have noticed four cases of mechanical clocks which were adapted to show Indian astronomical parameters.[1671] The first (X022) is set up in the Saraswati Bhavan Library of the Sanskrit University at Banaras. The dial carries scales for hours, *ghatis*, *palas* (with labels to the effect) and three hands for pointing these three time units. On the dial face is written 'Synchronome'.

The second (X023) is a highly elaborate astronomical clock in the Ramnagar Palace of the Maharaja of Banaras. It was made in 1872 by the state clockmaker named Mulchand. 'It shows not only the correct time of the day but also the position of the sun and the phases of the moon together with the signs of the zodiac and the date of the month and year.' A smaller version of this astronomical clock (X024) was presented to the Prince of Wales when he visited the Maharaja on 5 January 1876.

Finally, a private collector in Leeds owns several dials and plaques (X025) which were once part of an astronomical clock which is now dismantled.

[1671] I did not search for these systematically. I noticed these four purely by chance. There may be many others in Indian Royal palaces or in the Salar Jung Museum of Hyderabad which has a large collection of clocks.

Index of Indian Adaptations of European Instruments

X001 Sanskrit Universal Equinoctial Double Ring Dial 4015

Not signed, not dated, 19th century, Diameter 140 mm, PLU, ex-Tesseract

X002 ◎Sanskrit Universal Equinoctial Double Ring Dial 4017

Not signed, not dated, 19th century, Diameter 131 mm, Jaipur, Shree Sanjay Sharma Museum & Research Institute

X003 ◎Sanskrit Universal Equinoctial Double Ring Dial 4019

Not signed, not dated, 19th century, Diameter 101 mm , New York, Columbia University, Butler Library (# 27-262)

X004 ◎Sanskrit Universal Equinoctial Double Ring Dial 4021

Not signed, not dated, 19th century, Diameter 88 mm, Patna, Khuda Bakhsh Oriental Public Library

X005 Sanskrit Universal Equinoctial Double Ring Dial 4023

Not signed, VS 1922 (AD 1865-66) , Diameter 122 mm, Vicenza, PC of Giancarlo Beltrame (# 266)

X006 Sanskrit Universal Equinoctial Double Ring Dial 4025

Not signed, not dated, 19th century, Diameter 145 mm, Washington DC, National Museum of American History (# 323621)

X007 ◎Sanskrit Universal Equinoctial Double Ring Dial in Silver 4026

Not signed, not dated, 20th century, Diameter 124 mm, PLU; ex-London, Christie’s

X008 ◎Sanskrit Universal Equinoctial Double Ring Dial in Silver 4028

Not signed, not dated, 20th century, Diameter 122 mm, New Delhi, National Museum (# 86.193/2)

X009 ◎Indo-Persian Universal Equinoctial Double Ring Dial.................................. 4030

Not signed, not dated, 19th century, Diameter 318 mm, London, Nasser D. Khalili Collection of Islamic Art (# SCI 47)

X010 Indo-Persian Universal Equinoctial Double Ring Dial..................................... 4033

Not signed, not dated, 19th century, Diameter 120 mm, Karachi, National Museum of Pakistan

X011 ◎Universal Equinoctial Sundial by Mangaran, 1275 AH (AD 1858-59).......... 4035

Dimensions ca. 125 x 120 x 100, Patna, Khuda Bakhsh Oriental Public Library

X012 ◎Universal Equinoctial sundial by Mangaran, 1284 AH (AD 1867-68) 4038

Dimensions ca. 125 x 120 x 100, London, Victoria & Albert Museum (# IS 06484)

X013 Universal Equinoctial Sundial by Mangaran, 1295 AH (AD 1878-79)............. 4039

Height 148 mm, length 158 mm, width 112 mm, PLU; ex-London, Sotheby’s

X014 Universal Equinoctial Sundial in Silver by Mangaran & Ram Charan, 1292 AH (AD 1875-76) 4042

Dimension 162 x 150 x 113 mm, London, Royal Collection

X015 ◎Perpetual Calendar & Horary Quadrant by Joshi Dharm Chand, 1918 VS (AD 1861-62) 4044

Diameter 114 mm, height 134 mm, Rampur Raza Library, Rampur

X016 ◎Perpetual Calendar & Horary Quadrant by Joshi Dharm Chand, 1929 VS (AD 1872-73) 4054

Diameter 104 mm; height 134.5 mm, New Delhi, National Museum (# 56.155/5)

X017 Perpetual Calendar & Horary Quadrant by Joshi Dharm Chand 4057

Not dated; second half of the 19th century , Diameter ca. 130 mm, Lahore, Lahore Museum (# M.m.44 H)

X018 ◎English Perpetual Calendar & Horary Quadrant by Joshi Dharm Chand 4063

Not dated; second half of the 19th century , Diameter 102 mm, height 127 mm, London, Victoria & Albert Museum, London (# IM410-1924)

X019 English Perpetual Calendar & Horary Quadrant by Joshi Dharm Chand 4065

Not dated; second half of the 19th century , Diameter ?, PLU

X020 ◎Parts of a Circumferentor attributable to Joshi Dharm Chand 4073

Not dated; second half of the 19th century, Outer ring, diameter 157 mm, width 13 mm, thickness 6 mm; inner plate, diameter 131 mm, New Delhi, National Museum (# 56.155/3 and 56.155/7 (a))

X021 ◎Parts of a Circumferentor by Joshi Dharm Chand 4077

Not dated; second half of the 19th century, Outer ring: diameter 195 mm; width 9 mm, thickness 8 mm, Circular plate with alidade: diameter 157 mm, London, Victoria & Albert Museum (# IM 413-1924; IM 413c-1924)

X022 ◎Synchronome Clock with a Dial for Hours and Ghaṭīs, ca. 1930-40 4078

Varanasi, Sampurnanand Sanskrit University, Saraswati Bhavan Library

X023 ◎Sanskrit Astronomical Clock by Mulchand, 1872 4081

Ca. 1.25 x 1.25 m, Varanasi, Ramnagar, Maharaja Banaras Vidyamandir Trust Museum

X024 Sanskrit Astronomical Clock made for the Prince of Wales, ca. 1875 4086

Dimensions ?, London, Royal Collections

X025 Sanskrit Astronomical Clock (loose parts), 1772 Śaka (AD 1850-51) 4087

Leeds, PC

Y. FOREIGN INSTRUMENTS IN INDIAN COLLECTIONS

INTRODUCTION

There is a small number of foreign instruments in Indian collections, brought by travelling scholars at various points of time. One of these is a Kufic celestial globe (Y013) made in 834/1430 by Muḥammad ibn Jaᶜfar Kirmānī, which is in the Rampur Raza Library. There are also two Kufic astrolabes made respectively in 623/ 1226 and 626/ 1228-29 by al-Sirāj of Damascus. [1688]

Kufic Astrolabes

Al-Sirāj of Damascus is known through three astrolabes which are extant. It is remarkable that two (Y001 and Y002) of the three extant astrolabes by this Syrian astrolabe maker are now in Indian collections.

Besides these, three other Kufic astrolabes are now in Indian collections. The Khuda Bakhsh Oriental Public Library at Patna owns a Kufic astrolabe made in 706/1306 by Maḥmūd ibn Shaukat al-Baghdādī (Y003). An astrolabe made by Jaᶜfar ibn ᶜUmar of Kerman in 790/1388 is in the Indian Museum, Kolkata (= Calcutta). The Archaeological Museum at the Red Fort in Delhi possesses a Kufic astrolabe (Y005), which is unsigned and undated, but assigned to about 1270 by G. R. Kaye.[1689]

The degree scales in these Kufic astrolabes are graduated in 1° and numbered in 5s in a peculiar manner. While the decades are fully marked (10, 20, 30 …), the numbers which end in 5, are shown as mere 5; thus 5, 15, 25 etc. are marked with the *Abjad* symbol for 5; the actual value has to be understood by the decade which precedes or follows.

These astrolabes must have been brought to India in the thirteenth and fourteenth centuries by scholars for their own use when they migrated to the court of the Sultan of

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[1688] He should not be confused with Ibn al-Sarrāj (actually Shihāb al-Dīn Aḥmad ibn Abī Bakr) who flourished at Aleppo about a century later and was renowned for his universal astrolabe, made in 729/1328-29, which now at Benaki Museum, Athens; cf. King 1987a, IX; King 2005, pp. 694-700.

[1689] There is evidence of at least three other astrolabes (E001, E002 and E003) of this period having been present in India.

Delhi. These and similar other astrolabes which may no longer be extant in India had a certain influence in the design of some early Sanskrit astrolabes.[1690]

SAFAVID ASTROLABES

At present there are five Safavid astrolabes in Indian collections. Like Lahore in the latter half of the sixteenth and seventeenth centuries, Iṣfahān was the centre of astrolabe production in the latter half of the seventeenth and the eighteenth centuries. The notable astrolabe makers here were Muḥammad Zamān of Mashhad, Muḥammad Mahdī al-Khādim al-Yazdī, ᶜAbd al-A'imma and ᶜAbd al-ᶜAlī, who produced large number of opulently decorated astrolabes. [1691] All these masters are represented in the astrolabes extant in Indian collections (Y007 - Y011).

Although some of these belonged to different cities like Mashhad and Yazd, they all seem to have worked in Iṣfahān. An interesting feature of these Safavid astrolabe makers is that sometimes two persons worked together on the same astrolabe. ᶜAbd al-A'imma produced about three dozens of astrolabes on his own, but also decorated the astrolabes made by Muḥammad Amīn bin Muḥammad Ṭāhir (Y010), Khalīl Muḥammad and others. Muḥammad Mahdi al-Khādim al-Yazdī created about 24 astrolabes on his own, but also decorated some of the astrolabes made by ᶜAbd al-A'imma, Muḥammad Khalīl and Muḥammad Muqīm al-Yazdī. It would be interesting to know how these astrolabe makers divided their work in a joint production and where the boundary lay between 'making' and 'decorating'.

Another remarkable feature is that, unlike the astrolabe makers of Lahore, the Safavid astrolabists often repeat the same design of retes or employ the same configuration of different elements on the back exactly in the same style.[1692]

MARINER'S ASTROLABE

Mariner's astrolabe is a drastically simplified version of the common astrolabe designed to measure the solar altitude in the high seas. A single specimen is in India, in

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1690 See the Introduction to C. Sanskrit Astrolabes, Section 2.

1691 King 1999b, pp. 170-193; 255-274. .

1692 For example, in Gibbs & Saliba 1984, astrolabe nos. 31, 37, 39, 40, 42, 59, 61 and 62 contains retes of the identical design.

the Rampur Raza Library (Y012). According to Alan Stimson, the leading authority on the mariner's astrolabes, the specimen in India was produced in France or Portugal in about 1575.

CELESTIAL GLOBES

As mentioned above, the oldest foreign instrument in Indian collections is the Kufic celestial globe (Y013) made in 834/1430 by Muḥammad ibn Ja^{c}far of Kerman. This globe is with the Ramapur Raza Library. The same institution owns an English celestial globe, made of papier-mache with a printed surface (Y014).

TURKISH QUADRANTS

The astrolabic quadrant (*rub^{c} al-muqanṭarāt*), also known as 'astrolabe quadrant', represents the reduction to a quarter of a circle of the essential projections of the astrolabe plate (*ṣafīḥah*) made for a particular latitude. A cord with a movable bead is tied to its apex, with which diverse kinds of computations can be made. It was invented sometime before the twelfth century, but became popular in Turkey since the seventeenth century. The Turkish quadrants are made of lacquered wood, on which the lines and legends are drawn in black, red and gilt. As they contain a universal horary quadrant at the apex and also lines for determining the times of Muslim prayers, they become useful devices for the *muwaqqits* of mosques.

Dozens of these quadrants produced in the Ottoman period are extant. However, no complete description of any of these extant specimens has been made so far, and there is no account available on how to use astrolabic quadrant for the different kinds of computations, in particular for determining the times of Muslim prayers.

Partial descriptions of the astrolabic quadrants are available in the following sources. Morley 1860 describes a brass quadrant, 'constructed for the use of the Shaikh Shams ad-Din Ben Sa'id, the chief of Muezzins in the Jami' al-Umawi (the mosque of the descendants of Umayyah), in the year 735 (A.D. 1334) by 'Ali Ben ash-Shihab and engraved by Muhammad Ben al-Ghazuli'; it was made for the latitude of Damascus. It was bought at Damascus for Morley, but the present location is not known.

Würschmidt 1918 writes on a quadrant which he saw with a dealer in Istanbul.

Christie's, London, *Fine Scientific and Philosophical Instruments,* auction catalogue of 27 September 1990, lot 195, p. 46: Ottoman astrolabic quadrant for the latitude of Istanbul at 41° with a radius of 121 mm.

Sotheby's, London, *Arts of the Islamic World,* auction catalogue of 27 April 2005, Lot 41, pp. 58-59: brass quadrant made by Shams al-Dīn, son of Ghars al-Dīn, of Aleppo, 967/1559-60, for the latitude of Aleppo at 35;50° with a radius of 157 mm.

Sotheby's, London, *Arts of the Islamic World, including fine Carpets and Textiles,* auction catalogue of 24 October 2007; Lot 198, p. 189: Ottoman astrolabic quadrant made for the latitude of 39° with radius of 158 mm.

Michel 1976 (pp. 117-120) and Morrison 2007 (pp. 221-238) describe, with detailed diagrams, the construction and use of the Profatius Astrolabe Quadrant, but it is slightly different from the Turkish quadrants.

Two specimens of Ottoman astrolabic quadrants are in Indian collections. One of these (Y015), made in 1136/1723-24, is with the K. R. Cama Oriental Institute, Mumbai; it was described, rather inadequately in Khareghat 1950, pp. 75-82. The second one (Y016), not dated, is in the Saidiya Library at Hyderabad.

GUNTER'S QUADRANT

The Sanskrit University at Varanasi owns a Gunter's Quadrant (Y017), probably made in 1768.

OTHERS

There are two other foreign instruments in Indian collections; one is a French model of the heliocentric system (Y019) and another an English Orrery (Y020).

Index of Foreign Instruments in Indian Collections

Y001 ◎Kufic Astrolabe by al-Sirāj Dimashqī, 623 AH (AD 1226)........................... 4103

Diameter 113 mm, Hyderabad, Salar Jung Museum (# 113/2/xxxv)

Y002 ◎Kufic Astrolabe by al-Sirāj Dimashqī, 626 AH (AD 1228-29) 4110

Diameter 137 mm , Rampur, Rampur Raza Library (# 1832 D)

Y003 Kufic Astrolabe by Maḥmūd ibn Shaukat al-Baghdādī, 706 AH (AD 1306-07)4121

Diameter 190.5 mm, Patna, Khuda Bakhsh Oriental Public Library

Y004 Kufic Astrolabe by Ja[c]far ibn [c]Umar al-Kirmānī, 790 AH (AD 1388-89)......... 4122

Diameter 78 mm, Kolkata, Indian Museum (# A.24432)

Y005 ◎Kufic Astrolabe, not signed, not dated.. 4123

Diameter 143 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (# 40.418)

Y006 ◎Astrolabe, not signed, not dated... 4130

Diameter 95 mm, New Delhi, Red Fort, Mumtaj Mahal Museum (# 40.419)

Y007 ◎Astrolabe by Muḥammad Zamān, 1070 AH (AD 1659-60) 4136

Diameter 128 mm, Mumbai, K. R. Cama Oriental Institute

Y008 ◎Astrolabe by Muḥammad Mahdī al-Khādim al-Yazdī, 1071 AH (AD 1660-61) 4151

Diameter 91 mm, Varanasi, Banaras Hindu University, Bharat Kala Bhavan (# 4/5879)

Y009 Astrolabe by [c]Abd al-A'imma, not dated... 4164

Diameter 135 mm, Hyderabad, Saidiya Library

Y010 Astrolabe made by Muḥammad Amīn ibn Muḥammad Ṭāhir and decorated by [c]Abd al-A'imma, not dated 4179

Diameter 186 mm, Kolkata, Indian Museum (# A 24.431)

Y011 ◎Astrolabe by [c]Abd al-[c]Alī, [1]119 AH (AD 1707-08)................................... 4185

Diameter 132.5 mm, Mumbai, K. R. Cama Oriental Institute

Y012 ◎Mariner's Astrolabe, not signed, not dated.. 4197

French or Portuguese, ca. AD 1575, Diameter 187 mm, Rampur, Rampur Raza Library (# 430)

Y013 ◎Kufic Celestial Globe by Muḥammad ibn Ja[c]far, AH 834 (AD 1430-31)..... 4201

Diameter of the globe ca. 80 mm; height of the stand 117 mm, Rampur, Rampur Raza Library

Y014 ◎Smith's Celestial Globe, English, 19th century 4209

Diameter 477 mm, Rampur, Rampur Raza Library

Y015 ◎Ottoman Astrolabic Quadrant, not signed, 1136 AH (AD 1723-24).............. 4212

Radius 93 mm , Mumbai, K. R. Cama Oriental Institute

Y016 Ottoman Astrolabic Quadrant, not signed, not dated.. 4219

Radius ?, Hyderabad, Saidiya Library

Y017 ◎Gunther's Quadrant, AD 1768 (?)... 4221

Radius 112 mm, Varanasi (= Benares), Sampurnanand Sanskrit University, Sarasvati Bhavan Library

Y018 Qibla-Indicator, not signed, not dated.. 4224

19th century, Iran , Diameter 96.4 mm, height 27.8 mm, Srinagar, Sri Pratap Singh Museum (# 5158)

Y019 ◎Geocentric Model of the Solar System by François le Mariée, Paris............. 4233

Not dated, early eighteenth century, Diameter of the base plate 328 mm, Jaipur, Jai Singh's Observatory

Y020 Portable Orrery made by W. Jones and sold by him at Holborn, London, W & S. Jones 4235

Not dated, early nineteenth century, Dimensions ?, Hyderabad, Saidiya Library

Z. FAKE ASTRONOMICAL INSTRUMENTS

INTRODUCTION

Since scientific instruments fetch fabulous prices in the international antique market, there is now a growing industry that fabricates fake astrolabes, celestial globes and other instruments for the tourist market. This section is concerned with fake instruments with Arabic/Persian engravings. There does not seem to be any demand for Sanskrit items; I am aware of just one fake Sanskrit astrolabe (Z004).

FAKE ASTROLABES

The majority of fake astrolabes with Arabic/Persian engravings found in museums were manufactured in Iran, in particular in Isfahan, and imitate the style of astrolabes produced by ᶜAbd al-A'imma and his contemporaries. The Adler Planetarium in Chicago has as many as twelve such fake astrolabes.[1773]

In India, one of the centres where fake astrolabes and celestial globes are being produced is Moradabad (28;50° N and 78;49° E) in the state of Uttar Pradesh, which is famous for its brass industry. At one time, Bombay was supposed to be such a centre; I have heard that fake instruments are being produced in Jaipur as well. The fake astrolabes that are coming now from Moradabad can be identified by the following features.

Alidade

Generally these fake astrolabes are made without alidades at the back for quite practical reasons. If an astrolabe is equipped on the back with an alidade in which two sighting plates jut out, it is difficult to place the astrolabe on its back and it is even more difficult to stack several astrolabes one upon the other for transport. Therefore, alidades are avoided. But without an alidade, the astrolabe cannot be used for any observation, i.e., for measuring the altitude of the heavenly bodies.

[1773] Described and illustrated in Pingree 2009, nos. 36-47, pp. 172-195.

Degree scales

Quite often the fake astrolabes do not have degree scales on the rim in the front and on the back. Instead, they are occasionally filled with the anthropomorphic figures of the zodiac signs (Z001 and Z003). Sometimes the rims are engraved with scales divided in an arbitrary manner, not in conformity with the sexagesimal division of the circle into 360°.

Abjad Notation

Wherever there are scales, attempts are made to number them in *Abjad* notation without any understanding of this notation; some pseudo Arabic alphabets are added arbitrarily. Even the common Arabic/Persian numerals are not always used correctly.

Rete

The rete is made with perforations as in a genuine astrolabe. In a genuine astrolabe the outer ring of Capricorn is not graduated, but it is often graduated in fake astrolabes, but not in correct sexagesimal division of the circle. In a genuine astrolabe, the ecliptic ring is divided into 12 zodiac signs, labelled with their names, and each sign is subdivided into 30 degrees. Sometimes fakes carry the names of the zodiac signs, written correctly, but their subdivisions are often very irregular. The tracery of the perforated part should contain star pointers with their names engraved upon them. In fake astrolabes, the star pointers are never placed correctly and the names engraved on them often make no sense.

Plates

The plates are invariably engraved only on one side. There is no mechanism to lock them in position so that they do not rotate around the pin. The altitude circles, azimuth arcs and lines of seasonal and equal hours are copied reasonably correctly, but these are not numbered properly. Often the names of Islamic lunar months, names of zodiac signs and other irrelevant material are engraved indiscriminately. In the three fake astrolabes Z001, Z002 and Z003, the main body and rete differ in each case, but the plates are exactly similar and must have been derived from a common source where originally all these insertions must have been made.

Back

The back is generally divided into four quadrants. But the rims of the two upper quadrants either do not carry degree scales, or if they do, the scales are not correctly divided and numbered. In the trigonometric quadrant on the upper left, the radius is divided into 60 divisions, or into sub-multiples of 60, and from the marks of these divisions perpendiculars are drawn up to the arc. But fake astrolabes are engraved with any arbitrary number of horizontal and vertical parallel lines. Likewise, the zodiac quadrant on the upper right is engraved with an arbitrary number of quarter circles and labelled with meaningless scribbles.

In the lower half, the four scales in the shadow squares are divided arbitrarily and not into 7 feet and 12 digits. In the semi-circular scales which enclose the shadow squares, one of the scales is filled correctly with the names of the zodiac signs, but the other scales are engraved with meaningless writing.

Quality of engraving

The legends and numbers are engraved with irregular strokes of the chisel and not in fluid lines as in the medieval astrolabes and celestial globes.

A striking feature of these fake astrolabes is that all empty spaces are filled with decorative motifs of flowers and leaves.

Sometimes fake astrolabes carry the names of well-known instrument makers like ᶜAbd al-A’imma [1774] or even the names of great astronomers like Naṣīr al-Dīn al-Ṭūsī (Z001) , or just fictitious names. Sometimes they carry fictitious dates as well; the year 1142 Hijrī (AD 1729-30) occurs often in the fake astrolabes seen by me.

[1774] Cf. Gingerich, King & Saliba 1972.

FAKE CELESTIAL GLOBES

No fake celestial globes produced in Iran or elsewhere have come to light; they all appear to be fabricated exclusively in India. Many of these are cast as single hollow spheres by the 'lost wax' process, a technique in which India specialized in the seventeenth century.

In 1992, we saw at Bangalore two celestial globes which appeared to have been cast as single hollow spheres. One of these, with a diameter of 150 mm, carried the inscription stating that it was the work of Muḥammad Ṣāliḥ Tatawī with the date 1073 Hijrī (AD 1662-63). On this globe, the celestial equator and the ecliptic are represented by double bands of lines. The narrower band is graduated in single degrees, while on the broader band groups of 6° are marked and numbered correctly in *Abjad* notation. The tropics, polar circles and those around the ecliptic poles are marked by single lines. Likewise, the six ecliptic latitude circles and the solstitial and equinoctial colures are also represented by single lines. The 48 classical constellation figures are engraved and the positions of about 1020 fixed stars are indicated by dots enclosed within small irregular circles. There is a dark finish on the surface of the globe. Against this background, the engraved star points, constellation figures and circles stand out clearly.

The globe is mounted on a stand consisting of a horizontal ring supported by four baluster-like legs which are joined below by two cross-bars. Like the equator and the ecliptic on the globe, the horizon ring also has two bands of lines. The narrower band is graduated in single degrees and the wider band in groups of 6° which are, however, not numbered. The axis of the globe is permanently fixed to the horizontal ring, and there is no provision for a meridian ring.

The second celestial globe is much larger with a diameter of 210 mm and is not engraved with the maker's name and date. Otherwise it was identical with the first globe in all respects.

Therefore we assumed that we discovered an unrecorded celestial globe signed by Muḥammad Ṣāliḥ and another that could easily be attributed to him.[1775] But Emilie Savage-Smith argued convincingly that the iconography of the constellation figures on

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[1775] Sarma, Ansari & Kulkarni 1993.

these globes starkly deviates from the standard iconography of Indo-Persian celestial globes and that these globes are modern fabrications.[1776] Indeed, several globes of this type came into the international market about that time. None of them carried the signature of Muḥammad Ṣāliḥ, but they displayed the same degenerate iconography, and were mounted on the same type of stands, with the axis permanently affixed to the horizontal ring.[1777]

But the globes that are being produced in more recent times (e.g., Z005) not only deviate from the standard iconography of constellation figures, but they are also engraved with far more figures than the conventional 48, all placed at random according to maker's whim. The *Abjad* symbols that are used on these globes have hardly any relation to the standard notation.

COLLAGES

A new phenomenon of recent times are collages or rather monumental medleys of different astronomical instruments, such as globes imbedded inside astrolabes or astrolabe-like objects imbedded upon what look like celestial globes.[1778] Dr Owen Cornwall saw some specimens in New Delhi and sent me the following photos.

1776 Maddison & Savage-Smith 1997, part 2, pp. 406-408 (Appendix 1: Modern Indian Globes); see also the Introduction to the section G above.

1777 See, e.g., Christie's, London, auction catalogue of 25 June 1997, lot 19, p. 12 (d. 253 mm); auction catalogue of 24 June 1998, lot 80, p. 48 (d. 191 mm); lot 81, p. 49 (d. 114 mm); on the same p. 49 are to be found two other fake globes mounted on different types of stands: lot 82 (d. 124 mm); lot 83 (d. 203).

1778 Savage-Smith 2017, pp. 7-8.

Figure Z1 – Collage of astrolabes and globes (photo by Dr Owen Cornwall)

Here the main body has the outline of an astrolabe, in which a globe is incorporated at the top and five openwork discs resembling astrolabe retes are affixed symmetrically on the body. The empty spaces are filled with diagrams of the terrestrial globe, the names and figures of the zodiac signs, the names of the Islamic lunar months and geometrical and floral patterns.

Figure Z2 – Detail of the Figure Z1 (photo by Dr Owen Cornwall)

Two extravagant specimens of this genre are Z006 and Z008 where uncommon talent in metalwork is wasted in creating pseudo-astronomical-astrological artefacts. But, of course, these are not the solitary examples. A piece almost identical with Z006 came up for auction in 1998 (Z007) and one similar to Z008 is said to be with the Osaka Science Museum in Japan. There may be many more of this kind.

Index of Fake Astronomical Instruments

Z001 ◎My *Asṭul Lob* ... 4245

Late 20th century, Diameter 228 mm, height 307 mm, thickness 10 mm,
Düsseldorf, PC

Z002 ◎Fake Astrolabe ... 4258

Late 20th century, Diameter 172 mm, height 221 mm, thickness 8 mm,
New Delhi, PC

Z003 ◎Spectacular Fake Astrolabe ... 4264

Late 20th century, Diameter 858 mm, height 1045 mm, thickness 30 mm,
Lucknow, PC

Z004 ◎Fake Sanskrit Astrolabe ... 4275

Diameter 153 mm, height 189 mm, thickness 13 mm,
Rampur, Rampur Raza Library

Z005 ◎Fake Celestial Globe ... 4277

Diameter of the globe ca. 180 mm; height of the stand 150 mm,
Rampur, Rampur Raza Library

Z006 ◎Armillary Sphere with a Celestial Globe at the centre ... 4278

Late 20th century, Diameter, Lucknow, PC

Z007 Armillary Sphere with a Celestial Globe at the centre ... 4282

Diameter ?, PLU; ex-Christie's

Z008 ◎Collage of spurious Instruments ... 4284

Late 20th century, Height ca. 1.5 m; diameter of the upper part 828 mm,
Lucknow, PC

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[1784] Except in a few cases, auction catalogues are not listed.

[1785] PDF versions of the volumes of the *Indian Journal of History of Science* are available online at http://insa.nic.in/UI/journaldetails.aspx?AID=Mw [also https://goo.gl/XYo7Ym, last accessed in March 2018].

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APX.B INDEX OF MUSEUMS WITH INDIAN ASTRONOMICAL INSTRUMENTS

India

Ahmedabad, L. D. Institute
D023

Aligarh, Aligarh Muslim University, Tibbiya College
F013

Chennai, Government Museum
R010

Hyderabad, Salar Jung Museum
A001, A026, A068, A108, A117, F019, F034, G005, Y001

Hyderabad, Saidiya Library
A049, A058, Y009, Y016, Y020

Hyderabad, State Museum of Archaeology
A128, C014, Q008

Jaipur, Jai Singh’s Observatory
A052, A073, A091, A092, A132, C021, C022, D001, D009, D077, D078, D079, D080, D081, D082, D083, D084, D085, D086, D087, D088, D089, H001, I001, K009, L001, N001, N005, N016, O001, O002, T001, T002, T003, T004, T005, Y019

Jaipur, Government Maharaja’s Sanskrit College
C032

Jaipur, Maharaja Sawai Man Singh II Museum, City Palace
G024, N006, T006

Jaipur, Museum of Indology
D027, K001, L014, N007, N008, O003

Jaipur, Shri Sanjay Sharma Museum & Research Institute
D035, L019, L020, N009, N010, P002, P003, X002

Kolkata, Asiatic Society of Bengal
A112, K015, P023

Kolkata, Indian Museum
A027, Y004, Y010

Kota, Rao Madho Singh Museum
I002, N011, N012, R011

Lucknow, Darul Uloom Nadwatul Ulama
A063, G019, G052

Mumbai, Chhatrapati Shivaji Maharaj Vastu Sangrahalay
(formerly Prince of Wales Museum)
B009, J004

Mumbai, K. R. Cama Oriental Institute
Y007, Y011, Y015

Mysuru, Maharaja's Sanskrit College
I006

New Delhi, Red Fort, Mumtaj Mahal Museum (Archaeological Museum)
A021, A025, A101, C017, F023, G002, G026, Y005, Y006

New Delhi, National Museum
B017, B027, B028, B029, C016, D028, D053, F004, G012, G020, L015, Q011, U002, X008, X016

Patna, Khuda Bakhsh Oriental Public Library
A011, A083, A131, B012, F005, L024, Q012, X004, X011, Y003

Pune, Bhandarkar Oriental Research Institute
C004

Pune, Raja Dinkar Kelkar Museum
C002, F035, L010

Rampur, Rampur Raza Library
A085, C028, F027, J002, L025, X015, Y002, Y012, Y013, Y014

Srinagar, Sri Pratap Singh Museum
A089, A136, B031, C029, D069, D070, G013, G051, G053, Y018

Vadodara, M. S. University of Baroda, Oriental Institute
C007, D054

Vadodara, M. S. University of Baroda, Sanskrit Mahavidyalaya
I007, K007, K008, L021, N014, W002

Varanasi, Banaras Hindu University, Bharat Kala Bhavan
D048, L012, N013, Y008

Varanasi, Ramnagar, Maharaja Banaras Vidyamandir Trust Museum
X023

Varanasi, Sampurnanand Sanskrit University, Saraswati Bhavan Library
B002, C015, D055, X022, Y017

Canada

Don Mills, Ontario Science Centre
A038

Czech Republic

Prague, Náprstek Museum of Asian, African and American Cultures
P022

Egypt

Cairo, Museum of Islamic Art
F016, F017

France

Paris, Institut du Monde Arabe
A043, A109, G004

Paris, Observatoire de Paris
L003

Germany

Berlin, Museum für Asiatische Kunst
F018

Bielefeld, Kunstgewerbesammlung der Stadt Bielefeld, Sammlung Huelsmann
D026

Frankfurt, Museum für Angewandte Kunst
B006

Hannover, Kestner Museum
A009

Stuttgart, Linden Museum
I004, U006

Iraq

Baghdad, Museum of Arab Antiquities = National Museum of Iraq
A012, A017

Mosul, Al Basha Mosque
A087

Netherlands

Leiden, Museum Boerhaave
A059

Pakistan

Islamabad, Islamabad Museum
A024

Karachi, National Museum of Pakistan
B013, G009, J003, X010

Lahore, Lahore Museum
A037, B024, F031, X017

Qatar

Doha, Museum of Islamic Art
A050, A053, A057, A111, A126, C013, C033, C034, D041, E003, F007, F025

Russia

Moscow, State Museum of Oriental Art
B001

St. Petersburg, The State Hermitage Museum
F009

Switzerland

Geneva, Musée d'Histoire des Sciences
E002

Turkey

Istanbul, Kandilli Observatory and Earthquake Research Centre
A020

Istanbul, Türk va Islam Eserlieri Müzesi
A125

UK

Cambridge, Cambridge University, Whipple Museum of History of Science
F033

Cardiff, National Museum of Wales
A067, F015

Clitheroe, Lancashire, Stonyhurst College
F001

Edinburgh, Royal Scottish Museum
A118, C006, F020, I003, P010, P011

London, British Museum
A033

London, Clockmaker’s Company, Guild Hall
A114

London, Guildhall Library
R008

London, Horniman Museum
P013, P014, R009

London, Nasser D. Khalili Collection of Islamic Art
A014, A015, A016, A079, A093, A094/E005, A106, A113, G003/H002, G010, G011, J001, X009, W003

London, National Maritime Museum, Greenwich
A004, A029, F030

London, Science Museum
A018, A021, A133, B021, D008, D011, D029, D090, G008, G017, L005, L009, P015, P016, P017

London, Victoria and Albert Museum
A086, A104, A123, B010, C012, D034, F003, F012, F014, G007, L007, L018, U001, V001, X012, X018

Oxford, Museum of the History of Science
A002, A003, A013, A028, A030, A041, A056, A069, A075, A096, A100, B007, B018, B019, D013, D022, F021, G016, K005, L004, P001, P018, W001

Oxford, Pitt Rivers Museum of Ethnology
C010, P019, P020, R001, R002, R003, R004, R005, R006, R007

USA

Cambridge/Mass, Harvard University, Houghton Library
A107

Chicago, Adler Planetarium and Astronomy Museum
A005, A006, A060, A062, A078, A082, A097, A103, A105, A135, D052, D060, F026, F029, F036, K016, N017, W004

New Haven, Yale University
A040

New York, Brooklyn Museum
A065

New York, Columbia University, Butler Library
D010, D071, F008, H004, L006, U003, U004, U005, X003

Salem, Peabody Museum
B014

Washington DC, National Museum of American History
A032, A077, A129, C024, F028, X006

Uzbekistan

Samarqand, The Samarqand Museum of History and Art of the Uzbek People
A022

APX.C INDEX OF THE INSTRUMENT MAKERS, DESIGNERS AND THEIR PATRONS[1787]

ᶜAbd al-A'immā (*fl.* 1688-1719)
Astrolabes Y009, Y010, Y011.

ᶜAbd al-ᶜAlī (*fl.* 1707)
Astrolabe Y011.

ᶜAbd al-Qādir al-Muḥibb al-Asṭurlābī (*fl.* 1621-22)
Indo-Persian astrolabes B003, B004, B005, B006.

ᶜAbd Allāh Aḥqar (*fl.* 1915)
Sundial Q003.

Abū al-Ḥasan. Nawāb Khwājā Abū al-Ḥasan (*fl.* 1627)
Patron of Indo-Persian astrolabe Y011.

Acaleśvara (*fl.* 1889-1902)
Owner of Sanskrit astrolabes D035, D036.

Aḥmad (*fl.* 1813)
Indo-Persian astrolabe B020.

ᶜAlī ibn Ibrahīm (*fl.* 1324)
Kufic astrolabe E002.

ᶜAlī Kashmīrī ibn Luqmān (*fl.* 1589)
Indo-Persian celestial globe G001.

Allāhdād. Ustād Shaykh Allāhdād Asṭurlābī Humāyūnī Lāhorī (*fl.* 1567)
Indo-Persian astrolabes A001, A002, A003, A004.

Amīn ibn Muḥammad Ṭāhir. Muḥammad Amīn ibn Muḥammad Ṭāhir (late 17th century)
Astrolabe Y010.

Anwar ᶜAlī Siddiqī, Ḥāfiz Anwar ᶜAlī Siddiqī (*fl.* 1829)
Sundial & ᶜAṣr indicator Q002.

Aurangzeb, Mughal emperor (r. 1658-1707)
Patron of Indo-Persian openwork celestial globe F026.

[1787] For a detailed index of Sanskrit names, cf. Sarma 2010.

Bāqī. Sayyid ᶜAbd al-Bāqī ibn Sayyid Ḥusain (*fl.* 1789-900)
Indo-Persian astrolabes B018, B019.

Bulhomal. Lālah Bulhomal Lāhorī (*fl.* 1839-1851):
Indo-Persian astrolabes B021, B022, B023, B024, B025, B026;
Sanskrit astrolabes with multiple plates C028, C029, C030;
Sanskrit astrolabes with single plates D069, D070;
Indo-Persian Celestial globes G008, G009, G010, G011, G012, G013, G014, G015, G016;
Sanskrit Celestial globes H003, H004;
Dhruvabhrama-yantras, L006, L007;
Sanskrit Horary Quadrant K005;
New instruments designed by him U001, U002, U003, U004, U005.

Cakrapāṇi (*fl.* 1625)
Sanskrit astrolabe C003.

Caṇḍīdāsa (*fl.* 1605)
Commissioned Sanskrit astrolabe C001.

Caṇḍīdatta's son (mid-19th century)
Owner of *Yantracintāmaṇi* K016.

Dāmodara (*fl.* 1605)
Owner of Sanskrit astrolabe C001.

Dharm Chand. Joshi Dharm Chand (*fl.* 1854-73)
Perpetual Calendars & Horary Quadrants in Persian X015, X016, X017;
Perpetual Calendars & Horary Quadrants in English X018, X019;
Parts of an unknown instrument X020;
Plate of Horizons & Sine Quadrant U006, U007.

Ḍiyā' al-Dīn Muḥammad ibn Qā'im Muḥammad (*fl.* 1637-1680)
Indo-Persian astrolabes A060, A061, A062, A063, A064, A065, A066, A067, A068, A069, A070, A071, A072, A073, A074, A075, A076, A077, A078, A079, A080, A081, A082, A083, A084, A085, A086, A087, A088, A089, A090, A091, A092, A093, A094, A095, A096, A097, A098, A099, A100, A101, A102, A103, A104, A105;
Indo-Persian celestial globes F008, F009, F010, F011, F012, F013, F014, F015, F016, F017, F018, F019, F020, F021, F022, F023, F024, F025, F026, F027, F028, F029, F030, F031, F032;
Indo-Persian sine quadrant J001.

Elliott, Sir Henry Miers Elliot (1808-1853)
Patron of Indo-Persian astrolabe B021.

Gajadhar Sarūp Khemānī (*fl.* 1859)
Palabhā-yantra N004.

Gaṅgāsahāya (*fl.* 1870-1895)
Designer of Sanskrit astrolabes D090, D091.
Designer of *Phalaka-yantra* M004.

Ghulām Qādir Kapūrthalī (*fl.* 1861)
Indo-Persian astrolabes B027, B028, B029.

Gokulantha Śarmā (*fl.* 1882)
Palabhā-yantra N005.

Ḥāmid ibn Muḥammad Muqīm (*fl.* 1655-1691)
Indo-Persian astrolabes A106, A107, A108, A109, A110, A111, A112, A113, A114, A115, A116, A117, A118, A119, A120, A121;
Indo-Persian celestial globes F033, F034, F035.

Haranātha. Josī Haranātha (*fl* 1638)
Owner of Sanskrit astrolabe C004.

Haridatta (*fl.* 1903)
Designer of Sanskrit astrolabe D037.

Hṛṣīkeśa (mid-19th century)
Yantracintāmaṇi K016.

Ibn Muḥammad Ḥaqīqā (*fl.* 1647-48)
Indo-Persian astrolabe B007.

Iftikhār Khān. Nawāb Iftikhār Khān (*fl.* 1680)
Patron of Indo-Persian astrolabe A092.

Indrajī. Josī Indrajī (*fl.* 1673)
Owner of Sanskrit astrolabe C010.

I^{c}tiqād Khān. Nawāb I^{c}tiqād Khān (*fl.* 1623)
Owner of Indo-Persian celestial globe F001.

^{c}Īsā. Mullā / Ḥāfiz ^{c}Īsā ibn Allāhdād (*fl.* 1601-1604)
Indo-Persian astrolabes A005, A006, A007, A008.

Ja^{c}far ibn ^{c}Umar al-Kirmānī (*fl.* 1388)
Kufic astrolabe Y004.

Jamāl al-Dīn ibn Muḥammad Muqīm (*fl.* 1666-1691)
Indo-Persian astrolabes A122, A123, A124, A125, A126, A127.

Jamāl al-Dīn Muḥammad ^{c}Alī Ḥussaynī (*fl.* 1856)
Indo-Persian sine quadrant J002.

Jayakṛṣṇadāsa (*fl.* 1887-1903)
Designer of Sanskrit astrolabes D035, D036, D037, D038.

Jemaṃgala (*fl.* 1884)
Carved Wooden Column Dial P013.

Jīvatāpa (*fl.* 1651)
Owner of Sanskrit astrolabe C007.

Jyotiṣācārya (19th century)
Owner of Sanskrit astrolabes D067, D068.

Kalyāṇa (*fl.* 1642)
Sanskrit astrolabe C005.

Kastūrīcandra (19th century)
Designer of Sanskrit astrolabes D062, D063, D064, D065.

Keśarīsiṃha, ruler of Kuchaman (r. 1857-1877)
Patron of Sanskrit astrolabe D037;
Astronomical compendia V002, V003.

Khāliq. Shaykh ᶜAbd al-Khāliq (*fl.* 1659-60)
Patron of Indo-Persian celestial globe G002.

Kheūjī Ācārya (19th century)
Owner of Sanskrit astrolabe D061.

Kīrticandra, king of an unidentified kingdom (*fl.* 1784)
Patron of *Dhruvabhrama-yantra* L002.

Kiśorasiṃha, ruler of Kota (r. 1817-1827)
Patron of *Dhruvabhrama-yantra* L005.

Lakṣmīnārāyaṇa (*fl.* 1883-1903)
Sanskrit astrolabe with multiple plates C032;
Sanskrit astrolabes with single plates D035, D036, D037, D038.

Lehna Singh Majithia (ca. 1806-1854)
Palabhā-yantra N003;
Iron column dial P023.

Madho Singh. Sawai Madho Singh (r. 1750-1767)
Yantrādhipati T001;
Ghoṭā-yantra T002;
Śoṭā-yantras T003, T004, T005;
Star-chart T006.

Mahdī al-Khadīm al-Yazdī. Muḥammad Mahdī al-Khadīm al-Yazdī (*fl.* 1660)
Astrolabe Y008.

Maḥmūd bin ᶜAlī bin Yūshāᶜ (*fl.* 1271)
Kufic astrolabe E001.

Maḥmūd ibn Shaukat al-Baghdādī (*fl.* 1306)
Kufic astrolabe Y003.

Muḥammad ibn Ja^{c}far ibn ^{c}Umar ibn Dawlatshah al-Kirmānī (*fl.* 1393-1431)
Kufic celestial globe Y013.

Mangaran (*fl.* 1858)
Universal equinoctial sundials X011, X012, X013, X014.

Maṇirāma (*fl.* 1644)
Owner of Sanskrit astrolabe C006.

Mannālāla (mid-19th century)
Commissioned Sanskrit astrolabe D008.

Māyārāma. Sūtradhāra Māyārāma (*fl.* 1810)
Sanskrit astrolabes C027, C028.

Mīr Qāsim (*fl.* 1694)
Sundial Q001.

Mīrzā Faḍl ^{c}Alī ^{c}Amīl (19th century)
Shabnumā-wa-Rūznumā L025.

Morāraji. Sonī Morarajī (*fl.* 1815)
Dhruvabhrama-yantras L003, L004

Motīrāma (*fl.* 1784)
Dhruvabhrama-yantra L002.

Mulchand (*fl.* 1872)
Sanskrit astronomical clock X024.

Muqīm. Muḥammad Muqīm ibn ^{c}Īsā (*fl.* 1621-1659)
Indo-Persian astrolabes A017, A018, A019, A020, A021, A022, A023, A024, A025, A026, A027, A028, A029, A030, A031, A032, A033, A034, A035, A036, A037, A038, A039, A040, A041, A042, A043, A044, A045, A046, A047, A048, A049, A050, A051, A052, A053, A054, A055, A056, A057, A058, A059;
Indo-Persian celestial globes F006, F007.

Murārajī Kuarajī. Ṭhākura Murārajī Kuarajī (*fl.* 1638)
Sanskrit astrolabe C004.

Nadhīr al-Dīn Ḥussayn (*fl.* 1803)
Shabnumā-wa-Rūznumā L024.

Nandarāma Miśra (*fl.* 1767)
Reworked Indo-Persian celestial globe H002.

Nayanānanda (*fl.* 1701)
Reworked Indo-Persian astrolabe E005.

Nareṃdrasiṃgha Mahīṃdra Bahādrajī, Maharaja of Patiala (r. 1845-1862)
Patron of Gurmukhi astrolabe C031.

Pandit (*fl.* 1616)
Bilingual astrolabe B002.

Pīr Bakhsh Lāhūrī (*fl.* 1841)
Indo-Persian astrolabe B024.

Premajī Pāṇḍyā (*fl.* 1815)
Owner of *Dhruvabhrama-yantras* L003, L004.

Puruṣottama (*fl.* 1642)
Owner of Sanskrit astrolabe C005.

Qā'im Muḥammad ibn ᶜĪsā (*fl.* 1622-1637):
Indo-Persian astrolabes A009, A010, A011, A012, A013, A014, A015, A016, A017;
Indo-Persian celestial globes F001, F002, F003, F004, F005.

Rāghavajit (*fl.* 1669)
Owner of Sanskrit astrolabe C008.

Rahīm Bakhsh (*fl.* 1850)
Gurmukhi astrolabe C031.

Ram Charan (*fl.* 1875)
Universal equinoctial sundial X014.

Rāmacandra, Josī Rāmacandra (*fl.* 1884)
Astronomical compendia V002, V003.

Rāmanātha Jyotirvid (*fl.* 1827)
Dhurvabhrama-yantra L005.

Rāmapratāpa (*fl.* 1895)
Sanskrit astrolabe D091;
Phalaka-yantra M004.

Rāmayatna Ojha (early 20th century ?)
Sometime owner of Sanskrit astrolabe C015.

Raṇakuṃjalāla (*fl.* ca. 1867)
Owner of Sanskrit astrolabe D050.

Rishīkes (*fl.* 1850)
Designer of Gurmukhi astrolabe C031.

Ṣāliḥ. Muḥammad Ṣāliḥ Tatawī (*fl.* 1659-1666):
Indo-Persian astrolabes B008, B009, B010, B011, B012, B013, B014;
Indo-Persian celestial globes G002, G003.

Sakhārām Jośī (*fl.* 1790-1796)
Sanskrit astrolabes D056, 0;
Dhruvabhrama-yantra L022;
Phalaka-yantra M001.

Seshachariar. Karur Seshachariar (20th century)
Sanskrit armillary sphere I006.

Sharīf, Muḥammad Sharīf ibn Muḥammad (17th century)
Indo-Persian astrolabe A135.

Shah Faridul Haque Emadi (20th century)
Sundial Q004.

Shāh Jahān, Mughal emperor (r. 1628-1658)
Patron of Indo-Persian astrolabe A094.

Sirāj. Al-Sirāj Dimashqī (*fl.* 1226-1229)
Kufic astrolabes Y001, Y002.

Śivadatta (mid-19th century)
Sanskrit astrolabe D008.

Śivalāla (*fl.* 1870)
Sanskrit astrolabe D090.

Sūryamalla. Sūtradhra Sūryamalla (*fl.* 19th century)
Sanskrit astrolabes D062, D063, D064, D065.

Tipu Sultan (1750-1799)
Patron of sundials Q005, Q006.

Vaijanātha's son (*fl.* 1834)
Yantra-cintāmaṇi K015.

Vīrabhadra (*fl.* 1805-1809)
Sanskrit astrolabes C024, C025.

Wafa' bin Munajjim (*fl.* 1608)
Kufic astrolabe E003.

Wilson, Professor Horace Hayman Wilson (1786-1860)
Owner of reworked astrolabe E001.

Yādo Josī of Ukala-grāma (mid-19th century)
Owner of *Dhruvabhrama-yantra* L010.

Zamān. Muḥammad Zamān (*fl.* 1659)
Astrolabe Y007.

APX.D1 THE YANTRARĀJA OF MAHENDRA SŪRI WITH MALAYENDU SŪRI'S COMMENTARY: SOME EXTRACTS

INTRODUCTION

MAHENDRA SŪRI'S YANTRARĀJA

Mahendra Sūrī's *Yantrarāja* is the first Sanskrit manual on the construction and use of the astrolabe.[1788] He commences the work with a homage to Sarvajña (Jina) and to his own teacher Madana Sūri. He concludes each of the five chapters with an almost identical verse employed as a refrain, where he pays homage once again to Madana Sūri of Bhṛgupura, who was the crest-jewel of the circle of astronomers and the teacher of Mahendra Sūri. Bhṛgupura, now known as Bharuch (21; 43° N – 72; 59° E), is in Gujarat. In his commentary on his work, Malayendu Sūri emulates this practice; he too commences the commentary with homage to Sarvajña (Jina) and to his own teacher Mahendra Sūri; he too concludes the commentary of each chapter with an almost identical verse which proclaims that Mahendra Sūri was the foremost astronomer (*sarva-gaṇaka-praṣṭa*) at the court of Sultan Fīrūz Shāh Tughluq (r. 1351-1388) of Delhi.

Mahendra Sūri and his pupil Malayendu Sūri were Jaina monks, hailing originally from Bharuch in Gujarat; they spent some time at the court of Fīrūz Shāh at Delhi, where the text *Yantrarāja* and the commentary were composed. Malayendu informs that the text was completed in Śaka 1272.[1789] In fact, the star longitudes mentioned in this text pertain precisely to the 15th day in the bright half of the month Caitra in Śaka 1272 (11 April 1370).[1790] Malayendu Sūri appears to have completed his commentary around 1378.

1788 Cf. Dikshit 1981, pp. 230-231; Pingree 1978b, pp. 626-628; Pingree 1981, pp. 52-53; Ôhashi 1997; Sarma 1999a; Sarma 2000.

1789 Malayendu Sūri, p. 29: *ayam granthaḥ śāke 1292 varṣe niṣpannaḥ* (this text was completed in the year 1292 Śaka = AD 1370-71). In the same year was completed the Persian chronicle *Sīrat-ī Fīrūzshāhī* which contains valuable information on Fīrūz Shāh's interest in the astrolabe and its promotion and manufacture at his court. On a comparison between Mahendra's *Yantrarāja* and the *Sīrat,* see Sarma 2000.

1790 Malayendu Sūri, p. 35.

The *Yantrarāja* is divided into five chapters.[1791] The first chapter *Gaṇitādhyāya* provides various trigonometrical parameters needed for the construction of the astrolabe. Malayendu's commentary supplements these by several detailed tables drawn for each degree of arc from 1° to 90°. There are tables of sines and cosines for the Radius 3000, a table of declinations with the obliquity of 23;35°, shadow tables for the gnomon of 12 digits and the gnomon of 7 feet. There is a list of 76 localities and their latitudes; there are tables that show the eccentricities and radii of altitudes circles at 6° intervals for six localities in India with latitudes ranging from 18° to 31°. More important is the star catalogue providing the Arabic and Sanskrit names of 32 astrolabe stars with their longitudes and latitudes, for 1370 when the *Yantrarāja* was composed and for 1437 when the longitudes increase by 1° due to precession.

The second chapter *Yantraghaṭanādhyāya* mentions the components of the astrolabe.[1792] The third chapter *Yantraracanādhyāya* mentions briefly the different types of the astrolabes and then discusses the construction of three major types, viz. northern astrolabes (*saumya-yantra*), southern astrolabes (*yāmya-yantra*) and a combination of these two (*miśra-yantra*).[1793] The fourth chapter *Yantraśodhanādhyāya* explains how to test whether the astrolabe is properly constructed or not. The final fifth chapter, entitled *Yantravicāraṇādhyāya* discusses the use of the astrolabe as an observational and computational instrument and dwells on the various problems in astronomy and spherical trigonometry that can be solved by means of the astrolabe.

Malayendu Sūri's Commentary

In his commentary, Malayendu explains each mathematical procedure in detail with worked examples. Interestingly, some of these examples are based on actual observations made at Delhi on specific dates. In his commentary on *Yantrarāja* 3.26, he

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1791 Cf. Ôhashi 1997, pp. 211-216.

1792 Actually there is no need of this chapter; it could have been safely combined with the third chapter.

1793 Among the mixed varieties, importance is given to one which is designated as *Phaṇīndra-yantra* (lit. instrument of the 'lord of the serpents') (verses 20-23). The significance of this name eludes us. The Persian chronicle *Sīrat-i Firūz-Shāhī* describes in great detail a very large north-south astrolabes produced for Fīrūz Shāh under the name *Asṭurlāb-i Firūz-Shāhī*. But it is difficult to say whether the Sanskrit name *Phaṇīndra-yantra* contains any allusion to this *Asṭurlāb-i Firūz-Shāhī*; cf. Sarma 2000.

shows how to derive the duration of the longest daylight from the terrestrial latitude with the concrete example of Delhi's latitude of 28;39° and derives from this latitude the maximum duration 34 *ghaṭīs,* 34 *palas* and 34 *vipalas.*[1794] The dates mentioned by him are as follows:

11 April 1370, Thursday (*saṃvat 1427 varṣe caitrasudi 15*) is the gauge year of the star catalogue (commentary on I.57-58, p. 35).

7 April 1377, Tuesday: the true longitudes of the sun and moon were ascertained at midnight by means of the astrolabe (*saṃ. 1433 varṣe caitra sudi 30 bhaume yantreṇa sphuṭau ravicandrau ardharātra-samaye sādhitau,* on 5.46-51, p. 76).

17 September 1377, Thursday: tropical longitudes of the sun and Venus are determined with the help of the astrolabe at midnight (*saṃ. 1434 varṣe āśvina sudi 15 gurau ardharātrasamaye sāyanau ravi-śukrau sādhitau,* on 5.58-60, p. 79).

1 October 1377, Thursday: true longitudes of the sun and Venus were determined with the help of the astrolabe at midnight (*saṃvat 1434 varṣe āśvina vadi 30 gurau ardharātrasamaye sphuṭau raviśukrau yantreṇa sādhitau,* on 5.61-53, p. 80).

13 May 1378, Thursday: the eastern altitude of the sun was 42° (*saṃvat 1435 prathama-jyeṣṭha-śukla-pañcadaśī 15 gurau raveḥ prācyonnatāṃśāḥ 42,* on 5.26-27, p. 70).

EDITIONS OF THE *YANTRARĀJA*

The *Yantrarāja* with Malayendu Sūri's commentary was edited by Sudhākara Dvivedī, Varanasi 1882, and by Kṛṣṇaśaṃkara Keśavarāma Raikva, Mumbai 1936. Neither edition is very satisfactory. While the former does not contain all the 21 tables compiled by Malayendu Sūri, the latter reproduces the last table twice.[1795] There are also many typographic errors in the edition of 1936.

In his *Gaṇaka-taraṅgiṇī,* Sudhākara Dvivedī makes the following remarks on the *Yantrarāja*: 'It appears that this text was not an independent work of Mahendra Sūri, but a Sanskrit rendering of some Persian text. … By looking at this work, it does not appear either Mahendra or his pupil had any mastery in mathematical astronomy … Here the

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1794 Malayendu Sūri, p. 62: dillyām akṣāṃśāḥ … dillyāṃ parama-dinam 34|34|34.

1795 Malayendu Sūri, pp. 49-51 and pp. 52-54.

determination of the *dṛkkarman* was not correctly presented.'[1796] But in his own edition of the *Yantrarāja*, Dvivedi does not make any comment on the passage where Mahendra discusses the *dṛkkarman.*[1797] Almost a century later, Kim Plofker supports Dvivedī's contention with a detailed analysis of verses 41-54 of the first chapter of the *Yantrarāja* and Malayendu's commentary on these and shows that Mahendra and his pupil Malayendu did not fully comprehend the principles of spherical trigonometry and substituted them with various approximation devices.[1798]

Even so, Mahendra's *Yantrarāja* (together with Malayendu's commentary) occupies an important position among the Sanskrit texts on astronomical instruments; it is the first Sanskrit text exclusively devoted to a single astronomical instrument and all other texts composed subsequently on the astrolabe broadly follow it. There exist today nearly a hundred manuscript copies of the text and commentary.[1799] Several actual specimens of Sanskrit astrolabes are also based on this text. Moreover, it is an important document related to the interaction between the Islamic and the Sanskrit scientific traditions.

Therefore, some extracts from Mahendra's text and Malayendu's commentary are presented in the following pages together with an English translation. The Sanskrit text is based on Raikva's edition of 1936; typographical errors are silently corrected. In a few cases, I follow the superior readings of a manuscript dated 23 May 1853.[1800]

1796 *Ganaka-tarangini, or Lives of Hindu Astronomers,* by Mahamahopadhyaya Sudhākara Dvivedī, edited by his son Padmakara Dvivedī, Benares 1933, pp. 48-49:
ayaṃ granthaḥ kasyacit-pāraśīgranthasya saṃskṛte 'nuvādo na svātantryeṇa mahendrasūrikṛto iti pratīyate | … *granthasya vilokanenāsya tadīyaśiṣyasya malayendusūreś ca gaṇite prauḍhir na vibhāti* | … *atra dṛkkarmmānayanaṃ na samīcīnam*

1797 1.48-53 in Dvivedi's edition; 1.49-54 in Raikva's edition.

1798 Plofker 2000.

1799 CESS, s.v. Mahendra Sūri, vol. 4, 393-395; vol. 5, 296-297; s.v. Malayendu Sūri, vol. 4, pp. 363-364; vol. 5, pp. 282-283.

1800 Jyotiṣa Ms no. 37, formerly with the Sanskrit Department of the Aligarh Muslim University, now transferred to the Maulana Azad Library of the same university.

श्रीमहेन्द्रसूरि-प्रणीत-यन्त्रराजः श्रीमलयेन्दुसूरि-कृत-व्याख्या-समेतः

1. GAṆITĀDHYĀYA (CHAPTER ON COMPUTATION)

1.1-4 Preamble

śrīsarvajñapadāmbujaṃ hṛdi parāmṛśya prabhāvapradaṃ
śrīmantaṃ Madanākhyasūrisuguruṃ kalyāṇakalpadrumam |
lokānāṃ hitakāmyayā prakurute sad-Yantrarājāgamaṃ
nānābhedayutaṃ camatkṛtikaraṃ sūrir Mahendrābhidhaḥ ||*1*||
apāre saṃsāre katikati babhūvur na caturāḥ
paraṃ tair durbodhaṃ gaṇitam araci prauḍhamatibhiḥ |
tataḥ svalpaṃ sāraṃ viśadam idam atyantasugamaṃ
vitanve 'haṃ śāstraṃ suhṛdayahṛdānandakṛtaye ||2||
kḷptās tathā bahuvidhā yavanaiḥ svavāṇyā
yantrāgamā nijanijapratibhāviśeṣāt |
tān vāridhīn iva viloḍya mayā sudhāvat
tatsārabhūtam akhilaṃ praṇipadyate 'tra ||*3*||
yathā bhaṭaḥ prauḍharaṇotkaṭo 'pi śastrair vimuktaḥ paribhūtim eti |
tadvan mahājyotiṣanistuṣo 'pi yantreṇa hīno gaṇakas tathaiva ||*4*||

1. Having meditated in his heart upon the lotus-feet of *Sarvajña* [Jina], which bestow [intellectual] power, and upon the illustrious teacher **Madana Sūri**, the wishing tree of good fortune, **Mahendra Sūri** composes, for the welfare of mankind, the excellent treatise called ***Yantrarāja*** which contains many [interesting] details and which is stimulating.

2. There had been born clever persons in this boundless world. Of mature intellect, they wrote highly obscure manuals on astronomy. Therefore, I present this learned work (*śāstra*), which is brief, [contains just] the essence, is lucid and very easy to understand, for the delectation of the good-hearted.

3. Many kinds of manuals on [astronomical] instruments were composed by Muslims in their own language, each book distinguished by the genius of its author. Having churned them like oceans, I present their essence here like nectar.

4. Just as a soldier, though bold and fierce in warfare, is disgraced when he is without weapons, even so an astronomer (*gaṇaka*), though great expert in astral science, [is disgraced] without instruments.

1.5-6 COMPUTATION OF SINES (*KRAMAJYĀ*) AND VERSED SINES (*UTKRAMAJYĀ*)

Table 1: sines and differences (*jīvāṃtara*) for each degree of arc from 1° to 90°.

Table 2: Versed sines (*utkramajīvā*) and differences for each degree of arc from 1° to 90°.

Table 3: Declinations and differences for each degree from 1° to 90°

1.7-12: COMPUTATION OF DECLINATION (*KRĀNTI*)

Table 4: *dyujyāphala* and difference for each degree from 1° to 189°.

1.13-15: CALCULATION OF THE ECCENTRICITIES (*KENDRA*) AND RADII (*VYĀSĀRDHA*) OF ALTITUDE CIRCLES (*UNNATA-VALAYA*) IN THE NORTHERN ASTROLABE

palair vihīnā gaganāṣṭacandrā 180 śeṣās tathākṣāḥ pṛthag eva dhāryāḥ |
śeṣākṣayor vāsarakhaṇḍakebhyo dyujyā-phalaṃ vai parisādhanīyam ‖13‖
tadakṣasaṃjñena phalena hīnaṃ yuktaṃ ca śeṣākṣaphalaṃ vidhāya |
ardhaṃ vidheyaṃ ca tataḥ krameṇa kendraṃ bhaved vyāsayutaṃ kujākhye ‖14‖
śeṣe tathākṣe ca yathepsitāṃśāḥ śodhyās tataḥ pūrvavad uktarītyā |
kāryāṇi kendrāṇi savistarāṇi kujākhya-vṛttāt purataḥ sphuṭāni ‖15‖

13. Subtract the degrees of the given latitude (*pala*) from 180. Keep the remainder and the given latitude degrees separately. From the table of the *dyujyā-khaṇḍas*, determine the *dyujyā-phala* for the remainder (A) and for the latitude degrees (B).

14. Subtract the *dyujyā-phala* of the latitude degrees from, and add to, the *dyujyā-phala* of the remainder (A - B; A + B). Halve these two quantities. These respectively are the eccentricity [(A – B) ÷ 2] and the half diameter [(A + B) ÷ 2] of the circle of horizon (*kuja*).[1801]

[1801] Here *kendra* (eccentricity) means the distance of the centre of the altitude circle from the north pole which is the centre of the astrolabe, measured along the meridian line.

15. Then from the remainder (*śeṣa*) and from the latitude (*akṣa*) subtract the desired degrees [depending on the desired frequency of altitude circles]. Then in the same way as before compute the eccentricities beyond the horizon together with the [half] diameter (*vistāra*).

Commentary:

palaśabdenākṣāṃśā ucyante | palaiḥ sva-sva-deśākṣāṃśair gaganāṣṭarūpā aśītyadhikaśatāṃśā 180 hīnāḥ kartavyāḥ | śeṣāṃśā akṣāṃśāś ca pṛthag dhāryāḥ | tato 'kṣaśeṣāṃśayor dyujyā-khaṇḍebhyaḥ pūrvavad dyujyāphalam ānīyākṣāṃśād āgataphalenākṣaśeṣaphalaṃ dviḥstham ekatra hīnam aparatra yutaṃ ca kṛtvā dvayam apy arthitaṃ sat krameṇa kendra-vyāsau bhujavṛttasya bhavataḥ | tad atrākṣaśeṣe vākṣe ekādiṣaṭparyanteṣu dṛṣṭonnatāṃśeṣu pātiteṣu akṣaśeṣād akṣāc ca pūrvoktarītyaiva tāvatām unnatāṃśānāṃ kendra-vyāsānayanaṃ kāryam |

*atrodāharaṇam | yathā śrīmad**yoginīpure** saumyākṣāṃśāḥ 28|39 ete aśītyadhikaśata 180 madhyāt pātite śeṣāṃśāḥ 151|21 ebhyo dyujyāphalam ānīyate | yathā rāśiṣaṭkasya svāhorātra-pramāṇa-phala-jyā-koṣṭhakeṣu ekapañcāśad-adhika-śatādhaḥ prāptaṃ dyujyā-phalaṃ 75|59 tadatho 'ntaraṃ 2|50 anenāntareṇāṃśādhaḥsthitāḥ kalāḥ 21 guṇyante jātāḥ 42|1050| adhastanāṅkasya ṣaṣṭi 60 bhāge labdhāḥ 17 ete uparitanāṅke 42 yojyante jātāḥ 59 ete dyujyāphalāṅka 75|59 madhye yojyante jātam akṣaśeṣaphalaṃ bhāgādyaṃ 76|58 | anayaiva rītyā akṣāṃśebhyaḥ 28|39 dyujyāphalaṃ prasādhyam | tad idam akṣāṃśaphalaṃ bhāgādyaṃ 5|1 tadanu pūrvānītaṃ śeṣāṃśaphalaṃ sthānadvaye saṃsthāpyākṣāṃśaphalam ekatrapātayitvānyatra yojayitvā cāvaśiṣṭāṃśe 'rdhīkṛte krameṇa bhujavṛttasya kendraṃ 35|58|30 vyāsaś ca 40|52|30 syātām ||*

atha bhujavṛttād agretanānām unnatāṃśānāṃ kendra-vyāsānayanam | pūrvoktād akṣaśeṣāt 151|21 ṣaḍunnatāṃśāḥ pātyante jātāḥ śeṣāṃśāḥ 145|21 tathākṣāṃśebhyo 'pi 28;39 ṣaṭ pātyante jātā akṣāṃśāḥ 22|32 tataḥ pūrvoktarītyā ṣaḍunnatāṃśānāṃ kendraṃ 29|32 vyāsaḥ 33|28| evaṃ kriyamāṇe caturviṃśaty-unnatāṃśānām pātanāc cheṣāṃśāḥ 127|21 akṣāṃśāḥ 4|39 | ebhyaḥ pūrva-sādhitarītyā sādhitaṃ kendraṃ 19|35 vyāsaḥ 20|24||

The word *pala* here denotes the degrees of latitude. Hence, subtract the *palas*, i.e. the degrees of the given latitude, from 180 degrees. Keep the remaining degrees and the latitude degrees separately. Then in the same manner as taught before, determine the *dyujyā-phalas* for the remainder (A) and for the latitude degrees (B). Next subtract the *dyujyā* corresponding to the latitude degrees (B) from the *dyujyā* corresponding to the remainder (A) at one place (A – B) and at another place add these two (A + B). Halve both the quantities. These will be the eccentricity and radius respectively of the circle of horizon (*bhuja-vṛtta*). Next from the remainder (*akṣaśeṣa*) and from the latitude (*akṣa*) subtract the desired altitude degrees (*iṣṭa-unnatāṃśa*) from 1 up to 6 and from the resulting remainder and latitude, determine anew the eccentricity and radius for that many altitude degrees above the horizon.

Example: The latitude of the glorious **Yoginīpura** (= Delhi) is 28/39°. These degrees are subtracted from 180. The remaining degrees are 151/21. For these two values, the *dyujyā* is computed. In the table of the *svāhorātrapramāṇaphalas* (i.e., the *dyujyā* table) under 151 degrees, the value given is day radius 75|59 and below that the difference is 2|50. With this difference, the 21 minutes written below are multiplied. The product is 42|1050. The lower number is divided by 60, the quotient 17 is added to the upper number 42 and we get 59|30. These are added to the value of the day radius found in the table, viz. 75|59. We get 76|58 as the *phala* corresponding to the *akṣaśeṣa* (A). The result in degrees and sub-multiples (*bhāgādya*) is 76 degrees and 58 minutes. In the same manner the day radius should be computed for the latitude 28;39. This value is 5;1. After this, place the value for the remainder at two places and from one subtract the value for the latitude and at another add and halve it at both places. Thus we get the eccentricity 35;58,30 and the radius 40;59,30 of the circle of horizon.

Now the computation of the eccentricities and radii of altitude circles above the horizon. From the remainder of latitude (*akṣa-śeṣa*) mentioned before 151/21 subtract 6 degrees of altitude, remaining are 145/21. Likewise from the latitude also [reduce 6 degrees] 28/39 – 6 = 22/39. Then in the same manner as before, the eccentricity of the circle of altitude 6 ° is obtained as 29/32; diameter 33/28. Thus proceeding further, when 24 altitude degrees are subtracted, the remainder (*śeṣāṅka*) is 127/21 and latitude 4;39. The eccentricity computed from these, in the same manner as before, is 19;35 and the diameter 20;24.

1.16-17: PROCEDURE TO FOLLOW WHEN THE LATITUDE IS LOWER THAN THE ALTITUDE

1.18-21: CALCULATION OF THE ECCENTRICITIES AND RADII (*VYĀSĀRDHA*) OF ALTITUDE CIRCLES (*UNNATA-VALAYA*) IN THE SOUTHERN ASTROLABE

Climates

Commentary:

atha nirakṣāl laṅkā-pradeśāt meruparvata-paryantaṃ pūrvāparadigvyāpinaḥ sapta 7 vibhagāḥ tadantarvartināṃ nagarāṇām akṣāṃśajñānārtham ādyaiḥ kalpitāḥ santi | teṣāṃ yavana-bhāṣayā ikalameti saṃjñā kṛtā | śani-guru-bhauma-ravi-śukra-somāḥ kramāt svāminaś ca | evaṃ nirakṣalaṅkāpradeśāt pratibhāgam akṣāṃśās trayodaśa navaliptābhir nyūnāḥ 12|51 madhyarekhātaḥ pūrvāparabhāgasthā bhavanti | evaṃ yantrāṃśās trayodaśa 13, ṣaḍviṃśatiḥ 26, ekonacatvāriṃśat 39, dvipañcāśad 52, pañcaṣaṣṭiḥ 65, aṣṭasaptataiḥ 78, navati 90 paryantāḥ | anenaiva krameṇa sapta bhāgāḥ syuḥ | paraṃ dvipañcāśad-akṣāṃśān yāvan manuṣyāṇāṃ nivāsaḥ | tadagrataḥ ṣaṭṣaṣṭyaṃśaparyantaṃ śītabāhulyād andhakārāc ca manuṣyāṇām alpa eva saṃcāraḥ | tatparataḥ kiṃnara-gandharva-vidyādhara-siddhānāṃ pracārā devabhūmayaḥ ||
*atha caturvibhāgāntarvartināṃ nagarāṇāṃ sukhāvabodhārtham akṣāṃśāḥ pradarśyante | tad yathā | laṅkāyām akṣāṃśāḥ 0|0, ādane 11, tilaṅge 18, …**śrībhṛgukaccha**-nandabhadrava-vaṭapatra-stambhatīrtha-dhavalake 22, … dillyāṃ **śrīyoginīpure** 28|39 … **śrīperojanṛpavāsita-siṃsāra-perojābāde** 29|45, … samarakanda 40, khurāśāna 42|20, kāsagara 44, bulagāra 49, etvatparyantaṃ nivāsabhūmiḥ |*[1802]

Now, the ancients have conceived of seven divisions stretching from the east to the west from the 0° latitude at Laṅkā up to the north pole (*meru-parvata*) for the knowledge of the latitudes of the towns situated within them. These divisions are

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1802 Three places are honoured with the honorific *śrī*: Bhṛgukaccha (Bharuch) which is the seat of Madana Sūri, the preceptor of Mahendra Sūri; Yoginīpura sacred to Jainas and the place of residence of Mahendra Sūri and Malayendu Sūri, and Hissar-Firozabad where Fīrūz Shāh Tughluq built a fortified palace in 1354.

designated as *iqlīm* in Arabic language.[1803] Saturn, Jupiter, Mars, Sun, Venus, Mercury and Moon are the lords of these divisions successively. Thus starting from the equator, each division spreads up to 13 degrees minus by 9 minutes (*liptā*) = 12;49°. These divisions spread to the east and west from the meridian.

Accordingly, the divisions on the instrument are [in integral degrees] 13, 26, 39, 52, 65, 78, 91. In the same sequence let the seven divisions be. But human habitation is up to 52° . Beyond that up to 66°, few humans live because of excessive cold and darkness. Beyond that are realms of the celestials (*deva-bhūmayaḥ*) where *Kinnaras, Gandharvas, Siddhas* and *Vidyādharas* move about.

Now for the convenience [of readers] we write the latitude degrees of [certain] towns situated within the first four divisions.[1804]

Table Apx.D1-1 Geographical Gazetteer

	Place Name	φ	Modern Name	Modern φ	Modern L
1	Laṅkā	0;0	Equator	0;0	0;0
2	Ādana	11	Aden, Yemen	12;48	45;02
3	Tilaṅga	18	Hyderabad	17;21,58	78;28
4	Anagūndī	18;10	Hampi Vijayanagar Karnataka	15;20,06	76;27
5	Gaṅgāsāgara	18;20	Sagar Island, WB	21;48	88;06
6	Hāvasa	18;30	al-Ḥabasha (= Abyssinia)[1805]		

1803 Malayendu clearly did not understand the concept of the climates of classical antiquity which divides the 'inhabited portion' of the northern hemisphere (and not the entire northern hemisphere from latitude 0° to latitude 90°) into seven strips which reach roughly up to 50;30°; several Lahore astrolabes carry tables of climates on the back (e.g., Figure A042.3, Figure A052.4) and in many the geographical gazetteers are arranged according to climates (e.g. A024, A030).

1804 Here the 'first four divisions' are not the first four climates of antiquity, but the divisions as Malayendu understood them. Thefore the places listed by him belong to all the seven climates. These are arranged in the following table, along with their modern names and modern coordinates. To the Indian place names are added the names of the federal states; for some of these, the following abbreviations are used: in abbreviations. Maha = Maharashtra; MP = Madhya Pradesh; Raj = Rajasthan; UT = Union Territory; WB = West Bengal.

1805 The reference here is to Jarmī, the ancient capital of Abyssinia, called al-Ḥabasha in Arabic. This place is mentioned in the gazetteers of about a dozen Indo-Persian astrolabes (A002, A013, A014

	Place Name	φ	Modern Name	Modern φ	Modern L
7	Devagiri	20;34	Daulatabad, Maha	19;56	75;13
8	Tryambaka	21	Tryambak, Maha	19;55	73;30
9	Saṃjāna	21	Sanjan, Gujarat	20;12	72;48
10	Damana	21	Daman, UT	20;25	72;51
11	Navasārikā	21	Navsari, Gujarat	20;57	72;54
12	Makkā	21;20	Mecca	21;25	39;49
13	Śrī-Bhṛgukaccha	22	Bharuch, Gujarat	21;42	72;58
14	Nandabhadrava	22	?		
15	Vaṭapatra	22	Vadodara?, Gujarat	22;18	73;12
16	Sthambhatīrtha	22	Khambhat, Gujarat	22;18	72;37
17	Dhavalaka	22	Dholka, Gujarat	22;43	72;28
18	Aṃśāvalī[1806]	23?	Ashowal, Gujarat	23;02	72;35
19	Somanāthapattana	22;15	Somnath, Gujarat	20;53	70;24
20	Māṅgalyapura	22;15	?		
21	Raivatakācala	22;31	Girnar, Gujarat	21;29	70;30
22	Dvārakā	22;31	Dwaraka, Gujarat	22;14	68;58
23	Navapattana	22;31	?		
24	Ujjayinī	23;30	Ujjain, MP	23;11	75;46
25	Dhārā	23;30	Dhar, MP	22;36	75;18
26	Aṇahilapurapattana	24	Patan, Gujarat	23;50	72;07

etc.) as ‘Jarmī, Dār al-Mulk Ḥabasha’ and the coordinates in all cases are latitude 9;30 and longitude 65;30. The latitude 18;30 given in the present list is off the mark.

1806 Misreading for Āśāpallī, an old capital of Gujarat, today a suburb of Ahmedabad

	Place Name	φ	Modern Name	Modern φ	Modern L
27	Nalapura	25	Narwar, MP	25;19	77;58
28	Ajameru	26	Ajmer, Raj	26;27	74;38
29	Nāgapura	26	Nagaur, Raj	27;12	73;44
30	Vārāṇasī	26;15	Varanasi, UP	25;17	82;57
31	Lakṣaṇāvatī	26;20	Lucknow, UP	27;51	80;55
32	Kaḍānagara	26;19	Kara, UP	25;42	81;21
33	Kānyakubja	26;35	Kannauj, UP	27;04	79;55
34	Māṇikapura	26;49	Garhi Manikpur, UP	25;04	81;07
35	Tīrabhukti	27	Tirhut=Muzaffarpur Bihar	26;04	85;27
36	Jājanagara[1807]	27	Jajpur, Orissa	20;51	86;20
37	Uddīsāsthāna	27;5	probably the same as above		
38	Ayodhyā	27;22	Faizabad, UP	26;48	82;12
39	Gopālagiri	27;29	Gwalior, MP?	26;13,17	78;10,41
40	Bundī	27;32	Bundi, Raj	25;26	75;38
41	Gopīmaṇḍala	27;45	Gopamau, MP?	27;32	80;17
42	Kola-Jalālī	28;4	Aligarh, UP	27;53	78;05
			Jalali, UP	27;52	78;16
43	Kaṃpil	28;10	Kampil, UP	27:37	79;17
44	Śivasthāna	28;15	Sistan-e Olya, Iran?	28;31	53;16
45	Uccanagara	28;20	Uch, Punjab, Pakistan	29;14	70;04

1807 Ancient capital of Orissa.

	Place Name	φ	Modern Name	Modern φ	Modern L
46	Vaḍānagara	28;28	Vadnagar, Gujarat	23;47	72;38
47	Ḍhillī Yoginīpura	28;39	Delhi	28;36	77;13
48	Rohītaka	28;45	Rohtak, Haryana	28;53	76;34
49	Meraṭha	29;20	Meerut, UP	28;59	77;42
50	Mūlatāna	29;40	Multan, Pakistan	30;12	71;28
51	Hāṃsī	29;45	Hansi, Haryana	29;06	75;58
52	Hiṃsāra-Phirozabada	29;48	Hissar, Haryana	29;09	75;49
53	Sarasvatīpattana	29;50	?		
54	Sthāneśvara	30;10	Thanesar, Haryana	29;59	76;49
55	Kurukṣetra	30;10	Kurukshetra, Haryana	30;06	76;45
56	Kapisthala	30;30	Kaithal, Haryana	29;48	76;23
57	Jālandhara	30;30	Jalandhar, Panjab	31;20	75;35
58	Sunnāma	30;30	Sunam, Panjab	30;08	75;48
59	Simāṇika	30;30	?		
60	Nepālapura	31	Kathmandu, Nepal	27;42	85;20
61	Lāhora	31;50	Lahore, Pakistan	31;33	74;21
62	Vodhaura	31;50	?		
63	Badaṣa(kha)sāna	36;22	Badakhshan, a region in Afghanistan and Tajikistan		
64	Dāmagām	36;30	Damghan, Iran	36;10	54;21
65	Posaṃja	36;40	?		
66	Balaṣa (Balakha)	36;40	Balkh, Afghanistan	36;45	66;54

	Place Name	φ	Modern Name	Modern φ	Modern L
67	Nayasāpura	37;10	Nishabur, Iran	36;13	58;48
68	Kāśmīra	37;20	Srinagar, JK	34;5	74;47
69	Tirimidi	37;35	Termez, Uzbekistan?	37;13	67;17
70	Vāvarada	37;40	?		
71	Cīgāni	37;50	?		
72	Kaluāra	39	?		
73	Samarakanda	40	Samarkand, Uzbekistan	39;39	66;57
74	Khuāragrāma (Khurāśāna)	42;20	Khurasan, a region in Iran		
75	Kāsagara	44	Kashgar, China	39;28	75;59
76	Bulagāra	49	Bulghar, the land of the Svavs north of the Caspian Sea around the Volga River.		

Tables 5-16: Eccentricities (*kendra*) and Radii (*vyāsārtha*) of altitude circles pertaining to six different latitudes

Commentary:

atha gaṇakānāṃ hitāya kiyatām apy akṣāṃśānāṃ saumya-yāmyāḥ kendravyāsāḥ sāntarāḥ parama-viṣuvacchāyā-tatkarṇa-sahitāḥ pradarśyante | *yathā navīna-yāmya-saumya-miśra-yantra-karaṇatvam āyāti* |

Now for the convenience of astronomers we display for certain latitudes northern and southern eccentricities, radii, with differences, together with the maximum daylight hours (*parama-dina*), equinoctial shadow (*viṣuvac-chāyā*) and equinoctial hypotenuse so that the novel south and north combined astrolabe can be produced.[1808]

Table Apx.D1-2 Maximum Day Length, Equinoctial Shadow & Equinoctial Hypotenuse

Place name	φ	Maximum Day length (in *ghaṭīs*)	Equinoctial Shadow (in digits)	Equinoctial Hypotenuse (in digits)
Tilaṃga	18	32;44	3;6	12;38
Tryaṃbaka	21	33;24	3;6	12;5
Aṇahilla-pattana	24	33;48	5;20	-
Tīrabhukti	27	34;10,54	5;5	13;2
Dillī	28;39	34;34	6;33	13;41
Nepāla-pura	31	35;6	7;12	14;01

1.22-39 ASTROLABE STARS AND THEIR LONGITUDES[1809]

Commentary:

atha yantre bhamaṇḍalārthaṃ grantha-niṣpatti-varṣotpanna-sāyana-dvātriṃśan-nakṣtra-dhruvakāḥ saumya-yāmya-vikṣepa-sahitāḥ procyante ‖

…

śakamate *nakṣatratragole nakṣatrāṇāṃ dvāviṃśaty-adhikaṃ sahasram uktam asti* | *tanmadhyāt granthakāreṇa yāvan nakṣatragolaṃ savistaraṃ samyag avabudhya yantropayogīni dvātriṃśat nakṣatrāṇi gṛhītāni* | *tatra*

1808 These eccentricities and radii are necessary for drawing the altitude circles or almucantars on the latitude plates of the astrolabes. Malayendu gives six tables of eccentricities and radii for six different latitudes, but these will not be reproduced here; just the parameters of these six places will be displayed in the following table.

1809 In verses 1.22-39, Mahendra enumerates the names of 32 fixed stars to be marked on the rete, together with their longitudes, expressing the numerical quantities in the *Bhūta-saṃkhyā* notation (cf. Pingree 1978b, p. 628.). Malayendu supplements this data with two tables, the first with longitudes as given by Mahendra for 1370 and in the second with longitudes corrected for the year 1437.

meṣe 5, vṛṣe 2, mithune 5, karke 4, siṃhe 1, kanyāyāṃ 2, tulāyāṃ 2, vṛścike 1, dhanuṣi 4, mṛge 2, kumbha 2, mīne 2 eṣāṃ granthādi dhruvakāḥ sāyanāḥ savikṣepāḥ spaṣṭārthā eva | yathā meṣe prathamanakṣatrasya rāśyādi-dhruvakaḥ 0|6|43|52 uttaro vikṣepaḥ 27|0 (uttara-śaraḥ)

atha nakṣatrāṇāṃ meṣādirāśyaṃśāḥ krameṇa nakṣatra-dhruvakāḥ | meṣādirāśibhyo yāmya-saumya-vibhāgena nakṣatrāṇām antaraṃ vikṣepaḥ | tathā sarveṣu nakṣatra-dhruvakeṣu dvipañcāśad vikalā vikṣepāḥ | nakṣatranāmādi-nyāso nakṣatrakoṣṭhakebhyo 'vadhāryaḥ | etāni nakṣatrāṇi dṛkkarmaśddhāni kṛtvā gurūpadeśd yantre sthāpyāni | dṛkkarmakaraṇaṃ purastād vakṣye, nakṣatragole punaḥ dṛkkarmarahitāni sthāpyānīti śeṣaḥ | saśarāṇi sthāpyānīti viśeṣaḥ |

Now for the sake of the rete of the astrolabe, the tropical longitudes (*sāyana-dhruvaka*) of thirty-two fixed stars pertaining to the year in which the present manual is completed (i.e., Śaka 1292), together with the latitudes (*vikṣepa*), north or south, are enumerated. …

In Islamic [astronomical] theory (*śaka-mata*), 1022 fixed stars were mentioned in the celestial globe (*nakṣatra-gola*). The [present] author, having understood the celestial globe (*nakṣatra-gola*) with all its details (*sa-vistara*), chose from the [1022] thirty-two fixed stars which are suitable for the astrolabe. Of these 5 are from Aries, 2 from Taurus, 5 from Gemini, 4 from Cancer, 1 from Leo, 2 from Virgo, 2 from Libra, 1 from Scorpio, 4 from Sagittarius, 2 from Capricorn, 2 from Aquarius and 2 from Pisces.

Of these stars, the tropical (*sāyana*) longitudes and latitudes at the time of composition of the present manual are known. For example: the star in Aries has the longitude 0 signs, 6 degrees, 43 minutes, and 52 seconds and the northern latitude is 27 degrees 0 minutes.

The longitudes (*dhruvaka*) of the stars are their positions along the ecliptic in the signs like Aries etc. Latitude (*vikṣepa*) indicates their distance in the north and south from the (ecliptic consisting of) signs like Aries etc. …

The names of the *nakṣatras* and other particulars are set down in the tables. These stars (scil. these coordinates) after correcting for *dṛkkarman*, should be marked in the astrolabe according to the instruction of the teacher. The process of the *dṛkkarman* will be explained later. On the other hand, the coordinates should be marked on the celestial globe (*nakṣatra-gola*) without the correction for *dṛkkarman*.

1.40 ANNUAL RATE OF PRECISION

granthdidhruvakebhyo 'bhīṣṭavarṣe nakṣatradhruvakānayanam āha |
dvinandasūrya 1292 rahitāḥ śakābdā nabho'śviśailair 720 guṇitāḥ khakhāṣṭaiḥ 800 |
āptaṃ kalādyena yutaṃ bham iṣṭe varṣe bhavet sāyananāmakaṃ tat ‖ 40‖

Now he teaches the calculation of the star longitudes in a desired year from the star longitudes at the time of the composition of the present manual.

40. Diminish the Śaka years by 1292, multiply by 720 and divide by 800. Add the quotient in minutes etc. to the longitude as given here (*bhaṃ*); that will be the tropical longitude in the desired year.

Commentary:

iṣṭavarṣasya śakābdān dvinandasūryar 1292 ūnayitvā śeṣaṃ nabho'śviśailair 720 guṇayitvā khakhāṣṭaiḥ 800 bhājyās tebhyo yal labdhaṃ kalādikaṃ phalaṃ tadyuktāḥ sāyana-granthādi-nakṣatra-dhruvakā iṣṭavarṣasya dhruvakā bhavanti |

atrodāharaṇam | ayaṃ granthaḥ śāke 1292 varṣe niṣpanna eṣu pātiteṣu śāke kiñcin na tiṣṭhati | tataḥ kalpanayā śāke 1304 varṣe nakṣatra-dhruvakodāharaṇaṃ pradarśyate | sthāpanā — śāke 1304 varṣe ebhyo dvinandasūryaiḥ 1292 pātite śeṣaṃ 12 nabho'śviśailaiḥ 720 saṃguṇite jātaṃ 8640 khakhāṣṭabhāge 880 labdhaṃ kalādyaṃ 10|48 | ***yavanamate*** *meṣādirāśyaṃśaṃ varṣaiḥ 66 māsaiḥ 8 nakṣatram atrikrāmati | prativarṣaṃ catuḥpañcāśat 54 vikalāḥ | labdhāḥ kalā 10|48 etāḥ pūrvokte sāyane meṣādyanakṣatradhruvake 0|6|43|52 kṣipyante jāto 'bhīṣṭavarṣasya nakṣatradhruvako 'yaṃ 0|6|54|40 evaṃ śeṣā api granthādi-nakṣatradhruvakebhyaḥ svayam ūhyāḥ ‖*

The Śaka years in the desired year are diminished by 1292; the remainder is multiplied by 720 and divided by 800. The quotient in minutes etc. is added to the tropical longitudes of the stars at the time of the composition of the [present] manual; the sum is the longitude of the desired year.

Example: This manual was completed in Śaka 1292. If this [number] is diminished by (1292) there will be no remainder. Therefore, we take the examples of star longitudes for the hypothetical case of Śaka 1304. Write down Śaka 1304. From these years 1292 is subtracted, the remainder 12 is multiplied by 720; it becomes 8640. When divided by 800, the quotient is 10 degrees and 48 minutes.

According to the Islamic [astronomical] theory (*yavana-mata*), a star traverses one degree of ecliptic in 66 years 8 months. Thus it traverses 54 minutes in each year. The obtained minutes are then added to the above mentioned tropical longitude of the first star in Aries, namely 0|6/43/52 (0 signs, 6 degrees, 43 minutes, 52 seconds). It becomes 0/6/54/40 (0 signs, 6 degrees, 54 minutes, 40 seconds), which is the tropical longitude of the same star in the desired year. Thus from the star longitudes at the time of the completion of the present manual, the longitudes for other years can be computed.

Mahendra's Astrolabe Stars

[In verses 1.22-39, Mahendra enumerates the names of 32 fixed stars to be marked on the rete and mentions their longitudes.[1810] Malayendu supplements this with two tables, the first with longitudes as given by Mahendra for Śaka 1292 and in the second with longitudes corrected for Śaka 1359. Mahendra states that according to the Islamic view, the rate of precession is 1 degree of arc in 66 years and 8 months. Therefore Malayendu chooses the second year which is removed from the year of composition of Mahendra's manual by roughly 66 years and 8 months and increases the star longitudes by 1°.]

[Malayendu's tables contain both the Arabic and the Sanskrit star names. The former are called *Pārasīka-nāma* (Persian name) because Mahendra and Malayendu derived these from Persian sources. But strangely, the Sanskrit names are referred to as *Hindu-nāma,* although they themselves are Jainas and not Hindus. Because of the difficulty in transcribing Arabic or Persian words in Devanagari, the 'Persian names' given in these tables are difficult to understand. Besides the names in these languages, Malayendu's star list contains the following additional data.]

[1810] Mahendra derived the longitudes by adding 18;53° for precession to the longitudes of Ptolemy; cf. Pingree 1978b, p. 628 and table XI.3.

[Table 17: Star table for Śaka 1292 (AD 1370-71), providing for 32 fixed stars, star names in Persian (*pārasī-nāma*), star names in Sanskrit (*hindu-nāma*), longitudes at the completion of the manual (*granthādi-dhruvaka*), latitude (*vikṣepa*), direction of the latitudes (*dik*), longitudes corrected for *dṛkkarman* (*dṛkkarma-śuddha-rāśyādikam*), day-radius north (*saumyaṃ svāhorātram*), day-radius south (*yāmyaṃ svāhorātram*), maximum altitude (*paramonnatāṃśāḥ*). On the top of the table is written *dillyāṃ dṛkkarma 7|5|20* (*dṛkkarman* at Delhi 7;5,20°.]

[Table 18: Star table for Śaka 1359 (AD 1437-38), providing for the same 32 fixed stars the same parameters, but with values corrected for Śaka 1359 when the star longitudes increase by 1°. The argument at the top of column 4 is printed incorrectly as *granthādi-dhruvaka* (longitudes at the completion of the manual).]

[The names of the thirty-two star names are arranged in the following table together with the meaning of the Arabic star names and their identification.]

Table Apx.D1-3 Astrolabe Stars

No	Sanskrit Name	*pārasīka-nāma* (Persian) Name	Meaning of the Arabic Name	Identification
1 *	*Aśvanābha*	*Surrat al-Faras*	navel of the horse	δ Pegasi = α Andromeda
2 *	*Nadyantaka*	*Akhir al-Nahr*	end of the river	θ Eridani
3 *	*Matsyodara*	*baṭn al-Ḥūt*	belly of the fish	β Andromedae
4	*Aśvinī*	*Sharatayn*		γ Arietis
5 *	*Kartitakara*	*Kaff al-Khaḍīb*	the dyed hand	β Cassiopeiae
6 *	*Pretaśirāḥ Manuṣyaśirā*	*Ra's al-Ghūl*	head of the ghoul	β Persei
7 *	*Manusyapārśva*	*Mirfāq al-Thurayyā*	elbow of al-*Thurayyā*	α Persei
8	*Rohiṇī*	*ᶜAyn al-Thawr Dabarān*	eye of the bull follower	α Tauri
9 *	*Mithuna-dakṣiṇa-pāda*	*Rizl al-Jawzā' al-Yusrā*	the right foot of *al-Jawzā'*	κ Orionis

No	Sanskrit Name	*pārasīka-nāma* (Persian) Name	Meaning of the Arabic Name	Identification
10 *	*Mithuna-vāma-skandha*	*Yad al-Jawza' al-Yusrā*	The left hand of *al-Jawzā'*	γ Orionis
11	*Ṣaḍāsya Ṣaṇmukha Kārtikeya*	*ᶜAyyūq*	(meaning obscure)	α Aurigae
12 *	*Mithuna-hasta* (*mithuna-skandha*)	*Mankib al-Jawzā'* or *Yad al-Jawzā'*	shoulder of *al-jawzā'* or arm of *al-jawzā'*	α Orionis
13	*Agastya*	*Suhayl*		α Carinae
14	*Ārdrā Lubdhaka*	*Shiᶜra Yamānī*	the southern *Shiᶜra*	α Canis Majoris
15 *	*Prathama-Bāla-śīrṣa Punarvasu*	*Ra's al-Taw'am al-Muqaddam*	head of the foremost twin	α Geminorum
16 *	*Lubdhaka-bandhu*	*Shiᶜra Shāmī*	the northern *Shiᶜra*	α Canis minoris
17	*Maghā*	*Qalb al-Asad*	heart of the lion	α Leonis
18	*Uttara-Phālgunī*	*Ṣarfah*	change of weather	β Leonis
19 *	*Kākaskandhapaksa*	*Janāḥ al-Ghurāb al-Ayman*	the right wing of the raven	γ Corvi
20	*Citrā*	*Simāk Aᶜzal*	the unarmed *Simāk*	α Virginis
21	*Svāti*	*Simāk al-Rāmiḥ*	the armed *Simāk*	α Bootis
22	*Viśākhā Mātṛmaṇḍala*	*Nayyir al-Fakkah*	the brilliant star of *al-Fakkah*	α Coronae Borealis
23	*Jyeṣṭhā*	*Qalb al-ᶜAqrab*	heart of the scorpion	α Scorpii
24	*Dhanuḥkoṭi*	*Ra's al-Ḥawwā*	the head of the serpent charmer	α Ophiuchi
25	*Mūla*			λ Scorpii

No	Sanskrit Name	*pārasīka-nāma* (Persian) Name	Meaning of the Arabic Name	Identification
26	*Dhanuḥśarāgra*			μ $^{1-2}$ Sagittari
27	*Abhijit*	*al-Nasr al-Wāqī‘*	the falling eagle	α Lyrae
28	*Śravaṇa*	*al-Nasr al-Ṭā’ir*	the flying eagle	α Aquilae
29 *	*Matsyamukha*	*Fam al-Ḥūt al-Janūbī*	the mouth of the southern fish	α Piscis Austrini
30 *	*Kakudapuccha*	*Dhanab al-Dajājah*	the tail of the fowl	α Cygni
31	*Pūrva-bhādrapadā*	*Mankib al-faras*	shoulder of the horse	β Pegasi
32 *	*Samudrapaksī*	*Dhanab al-Qayṭus Shamālī*	The northern tail of Cetus	ι Cet

[Here 14 names are literal translation of the Arabic names; these are marked with an asterisk in the table. Eleven are junction stars of the Sanskrit lunar mansions. *Aśvinī* (4), *Rohiṇī* (8), *Maghā* (17), *Uttara-phālgunī* (18), *Citrā* (20), *Svāti* (21), *Jyeṣṭhā* (23), *Mūla* (25), *Abhijit* (27), *Śravaṇa* (28), *Pūrva-bhādrapadā* (31).]

[A few other stars are mentioned in earlier Sanskrit texts. Thus *Agastya* (13) is mentioned in *Sūrya-siddhānta* 8.10. Sirius (α Canis Majoris) is mentioned in the *Sūrya-siddhānta* 8.10 as *Mṛga-vyādha* (hunter of animals); in its place, Mahendra employs a synonym *Lubdhaka* (13). Since Procyon (α Canis Minoris) can be regarded as a companion of Sirius, Mahendra names this star *Lubdhaka-bandhu* (kinsman of *Lubdhaka*).]

[In *Sūrya-siddhānta* 8.11, *Brahma-hṛdaya* is the name given for Capella (α Aurigae); ignoring this name, Mahendra calls this star *Ṣaḍāsya* (six-faced) which is another name of Kārtikeya in Hindu pantheon; in Malayendu’s tables two other synonyms are given: *Ṣaṇmukha* and *Kārtikeya.* In Sanskrit astrolabes the name *Ṣaṇmukha* appears frequently (B002, C003, C008 etc.); in some other astrolabes, in particular in those astrolabes with single plates calibrated for the latitude of Jaipur at 27°, the name *Brahma-hṛdaya* appears often for the same star (D006, D007, D009 and so on).[1811]]

[As mentioned in the introduction to C on Sanskrit astrolabes, Mahendra, or rather Malayandu in his tables, gives double name *Ārdrā-Lubdhaka* to Sirius (α Canis Majoris); however, *Ārdrā* and *Lubdhaka* are generally treated as two distinctly separate stars in Sanskrit astronomy, the former denoting α Orionis (Betelgeuse) and the latter for α Canis Majoris (Sirius). A large majority of Sanskrit astrolabes follow this nomenclature. But a small number follow Mahendra's nomenclature as well.]

[Finally the name *Samudra-pakṣī.* As mentioned in the introduction to section F on celestial globes, Mahendra must have chosen this name after seeing the pictorial representation of Cetus on Islamic celestial globes. However, Mahendra seems to have understood it as ι Ceti, the northern tip of the tail of Cetus, but on all Sanskrit astrolabes I have seen this star is shown below the equinox to represent the southern tip of the tail of Cetus, i.e., β Ceti. In an astrolabe made for Rāghavajit in 1669 (C008) ι Ceti is designated as *sa[mudra]pakṣī u[ttara],* i.e. 'the northern Cetus', while β Ceti was called *samudra[pakṣī].*]

Table 19: Rising times at the Equator (*laṅkodaya-pramāṇa*) of each degree of the ecliptic from 1° to 90°.

Table 20: Shadow lengths of the gnomon of 12 digits (*dvādaśāṅgula-śaṅku-cchāyā*) and the gnomon of 7 feet (*saptāṅgula-śaṅku-cchāyā*) for each degree of solar altitude from 1° to 90°.[1812]

1811 I have not been able to locate Sanskrit sources for the names *Dhanuḥkoṭi* for α Ophiuchi, *Dhanuḥ-śarāgra* for $\mu^{1\text{-}2}$ Sagittari and *Viśākhā-mātṛ-maṇḍala* for α Coronae Borealis, nor the reasons why Mahendra chose these names.

1812 In Raikva's edition, this table is given on pp. 49-51 and repeated once again on pp. 52-54 with minor changes in the wording of the argument.

1.72: AUTHOR'S COLOPHON

abhūd bhṛgupure vare gaṇakacakracūḍāmaṇiḥ
kṛtī nṛpatisaṃstuto madanasūrināmā guruḥ |
tadīyapadaśālinā viracite suyantrāgame
mahendraguruṇā sphuṭaṃ gaṇitakarma pūrtīkṛtam ||71||

In the eminent city of Bhṛgupura, there lived the learned preceptor by name Madana Sūri, the crest-jewel of the circle of astronomers, who was praised by the kings. In this excellent treatise on the instrument (i.e. the astrolabe), composed by the preceptor Mahendra, a devotee of his (Madanasūri's) feet, [the first chapter dealing with] the mathematical operations is completed.

COMMENTATOR'S COLOPHON

śrīperojaśakendra-sarva-gaṇaka-praṣṭo[1813] *mahendra-prabhur*
jātaḥ sūrivaras tadīyacaraṇāmbhojaikabhṛṅgadyutā |
sūriśrī-malayendunā viracite 'smin yantrarājāgama-
vyākhyāne gaṇitābhidhaḥ prathamako 'dhyāyaḥ samāptiṃ gataḥ ||

Master Mahendra Sūri, the eminent scholar, is the foremost one among all the astronomers at the court of the glorious Fīrūz, the sovereign of the Muslims. In this commentary on the treatise *Yantrarāja* composed by the illustrious Malayendu Sūri, who is like the bee at the lotus-feet of the said master, the first chapter entitled *Gaṇitādhyāya* is concluded.

1813 Both the printed editions read *gaṇakaiḥ pṛṣṭaḥ* which makes no sense. I follow the reading in Jyotiṣa Ms. no. 37, copied on 23 May 1853, of the Aligarh Muslim University.

2. YANTRAGHAṬANĀDHYĀYA (CHAPTER ON THE CONSTITUTION OF THE ASTROLABE)

2.1-6: CONSTITUTION OF THE ASTROLABE

ādau yantraṃ mṛṇmayaṃ dhātujaṃ vā vistīrṇaṃ ca svecchayā kārayitvā |
dairghyavyāsau pālivrittasya tasminn āryaiḥ kāryau yantracakrānumānāt ‖1‖
yāmye bhāge 'sya trikoṇaṃ kirīṭam īdṛg yantraṃ koṣṭhakāgāram uktam |
madhye tasya svecchayākṣāṃśakānāṃ patrāṇy anyāny unnatāṃśāśritāni ‖2‖
ekaṃ patraṃ connatāṃśasya patrād dvighnaṃ piṇḍe sādhanīyaṃ tato' nyat |
laṅkotpannā rāśayo meṣamukhyāḥ saṃsthāpyante yatra dhiṣṇyaiḥ sametāḥ ‖3‖
patrāṇy evaṃ koṣṭhakāgāramadhye muktvā sādhyās teṣu pūrvādikāṣṭhāḥ |
pṛṣṭhe yantrasyāyate dve bhujāgre sūkṣme kṛtvā chidram antarbhujaṃ ca ‖4‖
agre paścāt tasya cānte 'bdhikoṇe klṛptvā chidre yantranetre niveśye |
chidre klṛptvā merukīlaṃ dalāliṃ tena kṣiptvā ghoṭikā saṃniveśyā ‖5‖
kṛtvā chidraṃ sūkṣmam asya trikoṇe tatra kṣiptvā kaṇṭakaṃ vṛścikābham |
tasya prānte mudrikāṃ lambikākhyaṃ sūtraṃ deyaṃ yantraniṣpattir evam ‖6‖

1. First get an instrument (i.e. disc) (*yantra*) prepared out of clay or of metal, in the desired size (*vistīrṇa*). Then the noble persons should fix on that [disc an upraised] rim (*pālivṛtta*) with height and breadth appropriate to the size of the astrolabe.

2. On the southern (i.e. the upper) part of the disc, [there should be] a triangular crown (*kirīṭa*). Such a component is called the mater (*koṣṭhakāgāra,* lit. store-house, repository). Inside this [are placed] as many latitude plates (*akṣāṃśakānāṃ patrāṇi*) as one wishes, which are endowed with [circles of equal] altitudes (*unnatāṃśa*).

3. Prepare another plate with double the thickness of the plates bearing the [circles of] altitudes. On this plate will be marked the zodiac signs starting from Aries, according to their rising times at the equator (*laṅkā*) (i.e. right ascensions) together with [some prominent] fixed stars (*dhiṣṇya*).

4. Insert these plates inside the mater (*koṣṭhakāgāra*) and mark on [each face of] them the cardinal directions like east etc. At the back of the instrument, [attach] a long arm (i.e. alidade) with pointed tips and a hole in the middle.

5. At the front and back [of the arm] (i.e. on either end of the arm) set up (*niveśye*) two rectangular sighting vanes (*yantra-netra*), having made holes in them. Into the hole [at the middle of the alidade], insert the pin which represents the north celestial pole (*meru-*

kīla) so that it passes through the series of latitude plates (*dala*). Into [the other end of] this pin, insert a horse-headed wedge (*ghoṭikā*).

6. Make a small hole at [the apex of] the triangular [crown], insert into it the shackle (*kaṇṭika*), which is shaped like the scorpion's sting, into it a ring (*mudrikā*) and then pass through it a string called the suspender (*lambika*). Thus is the astrolabe constituted.

3. YANTRARACANĀDHYĀYA (CHAPTER ON THE CONSTRUCTION OF THE ASTROLABE)

3.1: Varieties of the Astrolabe

yantraṃ proktaṃ ṣaḍvidhaṃ hy ānavatyā
eka-dvi-trīṣv-aṅga-paṅkty-aṃśa-kḷptyā |
dvedhāpy etat saumyayāmyaprabhedāt
tanmiśratve miśrasaṃjñaṃ paraṃ ca ‖1‖

1. The astrolabe is said to be of six kinds [according as the altitude circles] are drawn up to ninety [degrees], [with one circle] for each one (*eka*), two (*dvi*), three (*tri*), five (*iṣu*), six (*aṅga*), [or] ten (*paṅkti*) degrees (*aṃśa*). It is also of two varieties, northern (*saumya*) and southern (*yāmya*). Where these two are combined, there is one more variety called the composite (*miśra*).

3.2-3: Back of the Astrolabe

vṛttadvayaṃ karkaṭakena pṛṣṭhe yantrasya nirmāya catur diśo 'ṅkyāḥ |
prāgyāmyagāḥ koṣṭhagatās tataś ca sthāpyāḥ kha-nanda-pramitonnatāṃśāḥ ‖2‖
vṛtte dvitīye likhitonnatāṃśā rekhā vilekhyā pratibhāgajātāḥ |
pakṣatraye 'pakramajā vibhāgāḥ śaṅkuprabhā prāg gaditā tathā jyā ‖3‖

2. On the back of the astrolabe, draw two annuli (*vṛtta,* lit. circles) with a pair of compasses (*karkaṭa*) and mark the four cardinal directions. Then between the east and west points, mark out ninety (*kha-nanda*) degrees of altitude in separate cells (*koṣṭha*).
3. In the second annulus, mark the lines for each degree corresponding to the degrees of altitude written [in the first annulus]. Then in three quadrants (*pakṣa*) draw respectively the units/arcs of declination (*apakramaja vibhāga*), gnomon shadows (*śaṅkuprabhā*) and the afore-mentioned sines (*jyā*).[1814]

[1814] There is some confusion here in the specifications for the four quadrants. Both the text and the commentary appear to be mentioning only three quadrants. The commentary states that the arcs/units of declination should be drawn in the south-western quadrant (*dakṣiṇapaścimāntarāla*), shadow squares in the north-western quadrant (*pascimasaumyāntarāla*) and the sine graph (*jīvāṅkāḥ*) in the north-eastern quadrant (*uttarapūrvāntarāla*). This makes sense only if it is clearly stated that the shadows squares are drawn in the *two* lower quadrants. Moreover, the sine graph is usually drawn in the south-eastern quadrant, some times also in the south-western quadrant, but never in the north-eastern quadrant, as the commentary recommends.

3.4: FRONT OF THE MATER (*KOṢṬHAKĀGĀRA*)

atha yantre koṣṭhakāgārasya pūrvapakṣasādhanam āha |
vṛttatraye pāligate kṛte prāg vṛtte kirīṭāntarato ghaṭīś ca |
aṃśān abhīṣṭān kha-rasāgni-saṃkhyān rekhās tadīyās tadadho vilekhyāḥ ‖*4*‖

Now he teaches the calibration of the front (*pūrvapakṣa*) of the mater (*koṣṭhāgāra*) of the astrolabe (*yantra*).

4. Having drawn three [concentric] circles on the rim (*pāli*), in the first circle, mark the *ghaṭīs*, starting from the middle of the crown (*kirīṭa*). [In the middle circle] mark 360 degrees at desired intervals. Below that, draw the lines of their subdivisions.

3.5-8: LATITUDE PLATES (*AKṢA-PATRA*)

atha saumyayantre iṣṭākṣāṃśapatreṣūnnatavalayānāṃ sādhanam āha |
yantre ca saumye viracayya kaṃbāṃ patrānumānena vilikhya tatra |
bhāgān kharāmān racayed tadaṃśaiḥ karkādivṛttatritayaṃ daleṣu ‖*5*‖
digaṅkiteṣv eṣu ca madhyakendrād avācyarekhopari kendramānaiḥ |
cihne kṛte tacchirasaḥ pṛthutvamānena vṛttāni likhet sphuṭāni ‖*6*‖
bhūjākhyam ādyaṃ bhavatīha vṛttaṃ tataḥ paraṃ connatamaṇḍalāni |
teṣāṃ likhed ānavater vibhāgān śuddhān inādyunnatatāvagatyai ‖*7*‖
madhyāhnarekhām abhito 'sya karkavṛttasthite prāgapare vibhāge |
kramāl likhed bhāṃ paramaṃ dinaṃ taddeśābhidhānena tathākṣabhāgān ‖*8*‖

Now he teaches how to draw the altitude circles (*unnata-valaya*) in the desired latitude plates (*akṣāṃśa-patra*) in the northern astrolabe (*saumya-yantra*).

5. In the [case of the] northern astrolabe, prepare a ruler (*kambā*) according to the size of the plate (i.e. as long as the radius of the plate) and graduate it into 30 (*kha-rāma*) units (*bhāga*). With these units (*aṃśa*) draw the three circles of Cancer etc. upon the plates (*dala*).

6. On these plates, on which the cardinal directions have been marked [by means of the north-south and east-west lines], make marks on the south line, starting from the centre, at distances measured by the values of eccentricity (*kendra*). Then from each of the marks at the centre draw clear circles with the measure of the radius (*pṛthutva*) [as given in the tables].

7. The first of such circles here is called the horizon (*bhūja*). Above that will be circles of altitude (*unnata-maṇḍala*). These [altitude circles] may be drawn clearly (*śuddha*) up

to ninety degrees for ascertaining the altitude (*unnatatā*) of the sun and other [celestial bodies].

8. On both sides, i.e., in the eastern and the western sides of the meridian or midday line (*madhyāhna-rekhā*) situated inside the tropic of Cancer, one should write successively the equinoctial shadow (*bhā*), maximum daylight (*paramadina*), the name of the locality (*deśābhidhāna*) and the degrees of latitude (*akṣa-bhāga*).

3.9: Unequal Hour Lines

atha saumyayantre horāsthāpanam āha |
kujād adho dvādaśadhā vibhajya mṛgādikarkāhvayamaṇḍaleṣu |
vidhāya vṛttāny abhitaḥ pratīcyā aṅkair niveśyā dvidaśāpi horāḥ ‖*9*‖

Now he teaches the creation of the hour (*horā*) [lines] in the northern astrolabe.

9. Divide [the arcs of] the [three] circles of Capricorn, Aries and Cancer, which are situated below the horizon (*kuja*), into 12 parts each. Draw on both sides [of the meridian line, arcs of] circles (*vṛtta*) [through the respective points of division on these three circles] and number them from the west as the 12 hours (*horā*).

3.10-16: Rete (*bhacakra-patra*)

atha saumyayantre bhacakrapatre karkādivṛttatrayasādhanam | *bhacakra-kendrapramāṇena bhamaṇḍalasādhanaṃ tatra nirakṣameṣādilagnānām iṣṭa-bhāgānāṃ sthāpanam āha* |
bhacakrapatre 'pi puraiva kḷpte vṛttatraye 'bhyantarato 'ṣṭabhāgān |
hitvā kalāś cābdhiguṇān avācye vyāsārdhamānena vidhāya vṛttam ‖*10*‖
nirakṣameṣādivilagnamānān pūrvoditān prāci niveśya caindryāḥ |
vṛtte dvitīye tadadho niveśyās tadaṅkasaṃkhyā gaṇakair nijeṣṭāḥ ‖*11*‖
meṣe bhāgā kalāś cāpi dhiṣṇyāni gaganeṣavaḥ |
vṛṣe nandadṛśo 'bdhyakṣā yugme dantāḥ ṣaḍindavaḥ ‖*12*‖
vyutkramād eta eva syuḥ karkasiṃhakanīṣv api |
kanyādiṣaṭkamānaṃ syāt tulādau vaiparītyataḥ ‖*13*‖
vyāsākhyavṛtte 'jamukhāni santi lagnāni laṅkodayajāni yatra |
rekhā hy uḍūnāṃ pratibhāgajātās tatraiva kendrābhimukhā vilekhyāḥ ‖*14*‖
kendrāt pratīpaṃ viracayya cihnaṃ dyujyāpramāṇena ca karkaṭena |
tatraiva dhiṣṇyasya yathoditasya niveśyam asyāgram atīva sūkṣmam ‖ *15*‖

dhanurmṛgāntar niśitaṃ vidheyaṃ cihnaṃ prasiddhaṃ makarāsyanāmnā |
yadbhrāmyamāṇaṃ gaṇakena viṣvaṅ muhur muhuś cumbati nāḍivṛttam ‖*16*‖

Now he teaches how to draw the three circles of Cancer and others on the rete (*bhacakrapatra*), how to draw the ecliptic circle (*bha-maṇḍala*) by means of the given value of the eccentricity of the ecliptic circle (*bhacakra-kendra*) and how to mark there the divisions of the zodiac signs according to their ascendants at the zero degree latitude (*nirakṣa-lagna*).

10. On the rete (*bhacakra-patra*) also, after having drawn the three circles [of Capricorn, Aries and Cancer] as before, leave out from the centre of the plate 8;34 units [which is the eccentricity of the ecliptic] in the south (*avācya*) (i.e. on the southern radius) [and with this point as the centre] draw a circle with the measure of the radius [of 21;26 units as shown in 1.66].

11. [On this circle], after having marked, from the east point onwards (*aindryāḥ*), the lengths of the right ascensions of the zodiac signs which have been mentioned before, in the second circle below the [previous one] the astronomer may mark their subdivisions according to his liking.

12. For Aries (*meṣa*) the degrees (*bhāga*) and minutes (*kalā*) [of right ascension] are 27;50; for Taurus (*vṛṣa*) 29;54 and for Gemini (*yugma*) 32;16.

13. The same in reverse order pertain to Cancer (*karka*), Leo (*siṃha*) and Virgo (*kanī*). The values of the six signs beginning with Virgo (*kanyā*) will apply in the reverse order to the six starting with Libra (*tulā*).

14. In the ecliptic circle (*vyāsākhya-vṛtta*) where there are the right ascensions (*laṅkodayajāni lagnāni*) of Aries and others, there draw the lines of stars, with the subdivisions, towards the centre.

15. With the measure of the day sine (*dyujyā*) make a mark away from the centre with the pair of compasses on that line. There at that point, create a very fine tip (*sūkṣmam agram*) for [the pointer of] the afore-mentioned star.

16. Between Sagittarius (*dhanus*) and Capricorn (*mṛga*) affix the well-known mark called the 'Capricorn index' (*makarāsya,* lit. face of Capricorn, in the sense of the first

point of Capricorn[1815]) which touches the hour circle (*nāḍivṛtta*) constantly, when the rete is rotated all around by the astronomer.

Thus the preparation of the rete in the northern astrolabe is complete.

3.17-19: LATITUDE PLATES AND RETE IN THE SOUTHERN ASTROLABE

3.20-24: NORTH-SOUTH COMBINED ASTROLABE

3.25-26: COMPUTING THE MAXIMUM DAY-LENGTH (*PARAMA-DINA*) FROM THE LATITUDE

dviṣṭākṣāṃśā jinair bhaktā labdham akṣād viśodhitam |
śeṣam ardhaṃ hataṃ digbhiḥ ṣaṣṭyāptaṃ dviguṇīkṛtam ||25||
tannāḍikā vināḍyādi ūrdhvāṅkaṃ triṃśatā yutam |
nṛyugmānte ravau proktaḥ palebhyaḥ paramaṃ dinam || 26||

25. Write down the degrees of latitude separately at two places. Divide at one place by 24 and subtract the quotient from the latitude. Divide the remainder by 2, multiply by 10, divide by 60 and multiply by 2.

26. The 'higher' number, augmented by 30, denotes the *ghaṭīs* and *palas*. When the sun is at the end of Gemini, this is the maximum day length, [usually expressed] in terms of *palas.*

Commentary:

vyākhyodāharaṇam eva | dillyām akṣāṃśāḥ 28|39 dvisthāḥ 28|39 caturviṃśatyā bhaktā labdhaṃ 1|11|38 akṣāṃśāt pātyate | śeṣaṃ 27|27|22 ardhitaṃ 13|43|41 daśaguṇaṃ 131|17 ṣaṣṭyāptaṃ 2|17|17 dviguṇaṃ 4|34|34 upari triṃśadbhir 30 yutaṃ jātaṃ dillyāṃ paramadinam 34|34|34 evam anayā rītyā triṃśad-akṣāṃśaparyatam āyāti | agre 'ntaraṃ karoti | evaṃ sarvatra ||

The example itself provides the explanation. In Delhi the degrees of latitude are 28;39°. This is written at two places. 28;39 is divided by 24. Quotient is 1;11,38. This is subtracted from the latitude. Remainder (28;39 – 1:11,38) 27;27,22 is halved 13;43,41. Ten times 137;17, divided by 60, 2;17,17. Doubled 4;34,34. The 'higher' number (higher unit) is augmented by 30; it becomes 34;34,34 (34 *ghaṭīs,* 34 *palas,* 34

[1815] Arabic *murī ra's al-Jadī.*

vipalas = 13 hours, 49 minutes, 49 seconds, 36 thirds); this is the maximum day length (*parama-dina*) at Delhi. In the same manner the result is obtained up to 30 degrees latitude. Beyond this one takes the difference.

3.27: COMPUTATION OF THE EQUINOCTIAL SHADOW (VIṢUVACCHĀYĀ) FROM THE MAXIMUM DAY LENGTH

hīnaṃ kharāmaiḥ paramaṃ dinaṃ ca śeṣaṃ nagaghnaṃ guṇitaṃ ca ṣaṣṭyā |
bhaktaṃ trigobāhubhir 293 aṅgulādicchāyā sphuṭā syād viṣuvaddvayasya ||27||

The duration of the maximum day length is diminished by 30. The remainder is multiplied by 7 and again multiplied by 60, and then divided by 293. The quotient is the shadow in *aṅgulas* at the time of both the equinoxes.

Commentary:

atrodāharaṇam eva vyākhyā | athātra paramadinaṃ 34|34|34 viṣuvaddinamānena 30 hīnaṃ 4|34|34 saptaguṇaṃ 32|1|58 kalāpiṇḍaḥ 1921|58 kalpita 293 bhāgahārāptaṃ viṣuvacchāyā 6|33 kalāpiṇḍaśeṣaṃ 166 anayā yuktyā chāyānayanam kāryam ||

Here the example itself provides the explanation. Now here the maximum day length is 34;34,34 (*ghaṭīs*). This is diminished by the length of the equinoctial day, namely 30. Remainder 4;34,34. Seven times of this 32;1,58. This is converted into arc minutes (*kalā*) 1921;58. Divided by 293; quotient 6;33 [*aṅgulas*] is the equinoctial shadow. The remainder of the sum of minutes (*kala-piṇḍa-śeṣam*) is 166.

4. YANTRA-ŚODHANĀDHYĀYA (CHAPTER ON TESTING THE ASTROLABE FOR ACCURACY)

4.1-2: TESTING THE ASTROLABE FOR EQUAL WEIGHT ON BOTH SIDES OF THE MERIDIAN

niṣpannayantram ullambya randhre kīlaṃ praveśayet |
tadagre lambayet sūtraṃ sūkṣmaṃ bhāreṇa saṃyutam ‖1‖
madhyarekhāṃ spṛśet tac cet jñeyaṃ śuddhaṃ tathā hi tat |
anyathādhikam asyāṅgaṃ ghṛṣṭvā śodhayet tataḥ ‖2‖

1. When the astrolabe has been made, suspend it vertically and insert a pin (*kīla*) in the hole [in the crown]. From its tip suspend a thin thread with a weight [attached to the other end].

2. If the thread coincides with the meridian line (*madhyarekhā*), then the instrument must be understood to be accurate (*śuddha*). Otherwise, grind its heavier limb and then test [once again].

4.3: TESTING THE HORIZON (KUJA) AND OTHER CIRCLES [OF ALTITUDE]

meṣadyujīvāprāgrekhāyogasparśāt kuje sphuṭe |
kendravyāsāntaraiḥ śuddhaiḥ śodhayed unnatāṃśakān ‖3‖

3. The two horizon circles (*kuje*) (i.e. the two eastern and the western halves of the horizon circle) are accurate (*sphuṭe*) if they touch the intersections (*yoga*) of the diurnal circle of Aries (*meṣa-dyu-jīvā* = celestial equator) and the east-[west] line (*prāgrekhā*). The other circles of altitude (*unnatāṃśaka*) are to be tested by the differences in eccentricity (*kendra*) and in the radii (*vyāsa,* lit. diameter).

Commentary:

meṣadyujīvā-prāgrekhayor yoge sannipāta ubhayatas tayoḥ sparśād uddhṛtakujākhyavṛtte sphuṭe bhavataḥ | tathā pūrvoktaiḥ kendra-vyāsāntarair unnatāṃśān arthād unnatāṃśavṛttāni śodhayet | śuddhāni kuryād ity arthaḥ | udāharaṇam | tad yathā | madhyāt ṣaḍunnatāṃśānāṃ kendrapramāṇena 29|32 cihnaṃ kṛtvā tadupari vyāsamānena 33|28 vṛtte kṛte ṣaḍunnatāṃśānāṃ valayaṃ niṣpannam | tato yantra-madhyāt madhyāhnarekhopari unnatavalayaṃ yāvat kendravyāsāntaraṃ 3|7 kambābhāgaiḥ pramīyamānaṃ yadi syāt tadā tadvalayaṃ śuddham | evaṃ śeṣāṇy unnatavalayāni śodhyāni ‖

By touching (*sparśa*) the intersections (*yoga*) of the diurnal circle of Aries and the east-[west] line (*prāgrekhā*), that is at the intersections (*sannipāta*) on both sides, the two up-raised circles (i.e. the two eastern and western halves) called horizon become accurate.

In the same manner, by the differences in eccentricity (*kendra*) and in the radii (*vyāsa,* lit. diameter), which have been mentioned before, one should test the degrees of altitude (*unnatāṃśaka*), that is, the circles of altitude (*unnatāṃśavṛttāne*). That is to say, they should be made accurate (*śuddhāni kuryāt*).

Example: From the centre (*madhya*) [of the astrolabe], at a distance of 29;32, which is the value of eccentricity (*kendra-pramāṇa*) for six degrees of altitude, make a mark. On that (i.e. with that point as the centre) draw a circle with a radius (*vyāsa-māna,* should this not be *vyāsārdha* ?) of 33;28.[1816] This is the circle for the altitude 6°. Then the distance between the circle and the centre of the astrolabe as measured on the meridian line with the units of the ruler (*kambā*) equals 3/56[1817] which is the difference between the given *kendra* and *vyāsa* (*kendravyāsāntara*), then that circle is correct. In this manner, test the remaining altitude circles also.

4.4: TESTING THE TWELVE LAGNAS AND THEIR SUBDIVISIONS

udayāstodīcyayāmyarekhāgre sadṛśāṃśatā |
prāksaptaturyadiksaṃkhyalagnānāṃ syād viśuddhatā ||*4*||

If there is symmetry in degrees (*sadṛśāṃśatā*) in the risings and settings, at the tip of the north line and the tip of the south line, between the pivots (*lagnas*) having the numbers one (*prathama,* i.e. ascendant) and seven (*sapta,* i.e. descendant); four (*turya,* i.e., lower mid-heaven) and ten (*dik,* i.e., upper mid-heaven), then there is accuracy.

Commentary:

udaye pūrvakṣitije aste ’pare kṣitije udīcyarekhāgre yāmyarekhāgre ca prathama-saptama-caturtha-daśamānāṃ meṣa-tulā-karka-makarāṇāṃ sadṛśāṃśatā tulyāṃśatā yadi syāt tadā teṣāṃ caturṇāṃ lagnānāṃ śuddhatā

1816 The values 29;32 for eccentricity and 33;28 for the radius pertain to the latitude of Delhi, as given in the table on p. 23 of the printed text.

1817 The printed text reads (p. 63) wrongly 3|7; it should be (33;28 – 29;32 =) 3;56.

jñeyā | tadvaiparītye 'śuddhatā ca | evaṃ śeṣāṇy api lagnāni aṃśaiḥ śodhanīyāni |

In the rising on the eastern horizon, in the setting on the western horizon; at the tip of the north line and at the tip of the south line; in the first and seventh; fourth and tenth [pivots] i.e. between Aries and Libra, between Cancer and Capricorn, if there is symmetry in degrees (*sadṛśāṃśatā*), i.e. equality in degrees (*tulyāṃśatā*), then it should be understood that there is accuracy in the four pivots. Otherwise, there is inaccuracy. In the same manner the remaining risings and settings also should be tested.

4.5: TESTING THE STAR-POINTERS (NAKṢATRA-CAÑCU)

atha dṛkkarmaśuddhasthāpitanakṣatrāṃśān paramonnatāṃśair
nakṣatracañcuśodhanam āha |
madhyarekhāsthite svasvarāśyaṃśe saṃpṛśed yadi |
bhāsyaṃ svān paramān aṃśān tadā taccañcuśuddhatā ||5||

Testing the accuracy of the star-pointers (*nakṣatra-cañcu*) by means of the star's longitude (*nakṣatrāṃśa*) corrected for *dṛkkarman* and its maximum altitude (*paramonnatāṃśa*).

5. When the star's longitude (*sva-sva-rāśyaṃśa*) is placed on the meridian (*madhyarekhā*), if the star-pointer (*bhāsya*) touches the degrees of its maximum altitude (*svān paramān aṃśān*), then the accuracy of that pointer (*cañcu*) [is established].

Commentary:

yad yad nakṣatraṃ yasya yasya rāśer yasmin yasminn aṃśe 'sti tasmin tasmin bhāge madhyarekhopari sthite sati tasya tasya nakṣatrāsyaṃ cañcusthānaṃ svān paramonnatāṃśān yadi spṛśati tadā tasya nakṣatrasyāsyaśuddhiḥ syāt | *tadabhāve cañcor hāni-vṛddhir vā kāryeti śeṣaḥ* | *yathā śuddhaṃ rohiṇī-nakṣatraṃ mithunasya tṛtīyāṃśe pavartate* | *tasminn aṃśe madhyarekhopari sthāpite yadi rohiṇyāsyaṃ svīyān paramonnatāṃśān 76|53*[1818] *spṛśati tadā rohiṇyā āsyaśuddhir bhavati* | *evaṃ śeṣāṇy api nakṣatrāsyāni śodhanīyāni* |

If [the longitude of] a particular star is situated at a particular degree of a particular zodiac sign, when that particular degree is placed on the meridian line [by rotating the

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1818 Printed text (p. reads 70; but the correct value as given in the star table on p. 36 is 76;53.

rete], if that star's pointer touches its maximum altitude, then that star's pointer is accurate. If not, the pointer should be shortened or extended.

For example, the corrected longitude of *Rohiṇī* lies at the third degree of Gemini. When that degree is placed on the meridian [by rotating the rete], if *Rohiṇī*'s pointer (*rohiṇyāsya*) touches the degrees of its maximum altitude 76;53, then the pointer of *Rohiṇī* is accurate. In the same manner, other stars are to be tested.

4.6: TESTING THE ALIDADE (BHUJĀ)

bhujāgrayugmaṃ śuddhaṃ syād rekhāsthaṃ parapūrvayoḥ |
tanmadhyarekhoparigaṃ śuddhaṃ pādadvayaṃ tadā ‖6‖

6. The two tips of the alidade are accurate if they lie on the east-west line. The two sighting plates (*pāda*-*dvaya*) are accurate if they lie on the middle line of the astrolabe.

5. YANTRA-VICĀRAṆĀDHYĀYA (CHAPTER ON THE USE OF THE ASTROLABE)

MEASURING TIME IN *GHAṬĪS* AND HOURS[1819]

5.1-2 MEASURING THE ALTITUDES OF THE PLANETS AND STARS

kare 'pasavye viniveśya yantraṃ jyotirvidā bhāskarasanmukhena |
tathā bujāgraṃ paricālanīyaṃ yathā viśec chidrayuge'rkatejaḥ ||1||
pūrve 'hani prākkubho bhujāgraspṛṣṭā raver unnatabhāgakāḥ syuḥ |
ta eva madhyaṃdinato 'parāṃśā rātrau grahoḍuṣv api caivam eva ||2||

1. The astronomer (*jyotirvid*), facing the sun, holding the astrolabe in his right hand, should so rotate the tip of the alidade (*bhujāgra*) that the sun's ray (*arka-tejas,* sun's light) enters the two holes.

2. In the forenoon the degrees of the eastern direction (*prāk-kakubha*) touched by the tip of the alidade denote the altitude degrees of the sun. The same after the noon become the altitude degrees in the west. The same is the case with planets and stars (*uḍu*) at night.

Commentary:

pūrve 'hani pūrvāhṇe prākkakubhaḥ pūrvasyā diśo bhujāgraṃ spṛṣṭā ekādyā navatiparyantā raver unnatabhāgāḥ syuḥ | evaṃ madhyaṃdinato madhyāhnād ūrdhvaṃ aparonnatāṃśāḥ syuḥ | tatra rātrau gaṇakena dakṣiṇanetraṃ nimīlya vāmanetroparisthena yantreṇa iṣṭasya grahasya dhiṣṇyasya vā vedhe bhujāgraspṛṣṭā aṃśāḥ pūrvāparadiggatatvena pūrvonnatāṃśā aparonnatāṃśāḥ jñeyāḥ ||

In the forenoon the degrees of the east, i.e. from one up to ninety, touched by the tip of the alidade, will be the altitude degrees of the sun. Likewise, from noon onwards, the same become degrees of altitude in the west (*aparonnatāṃśa*). At night, the astronomer (*gaṇaka*) closes the right eye and looks with the left eye at the desired planet

[1819] Sanskrit astrolabes generally contain only lines for the unequal hours counted from the western horizon, which is suitable only for the Islamic method of telling time. The astrolabes do not have lines for equal hours counted from the eastern horizon, which would be appropriate for the Indian method of telling time. Such lines can easily be drawn. In fact, some large Lahore astrolabes have such lines. Then how did Hindus/Jains measure time in *ghaṭīs* with the help of the astrolabe? The method is simple. Mahendra Sūri explains the method in 5.3-4; in 5.5 he also explains how to measure time according to Islamic fashion which he calls *āmnāya*!

or the star (*dhiṣṇya*) through the alidade, then the degrees touched by the tip of the alidade become the altitude degrees in the east or the altitude degrees in the west according as the body is in the east or west.

5.3-4 Ascertaining the time of the day and the ascendant

Atha ravisaṃbaddha-pūrvāparonnatāṃśebhyo dinagata-śeṣa-ghaṭikānayanaṃ lagnānayanaṃ cāha |

ravyaṃśakaṃ prāgapare ca bhūje dhṛtvonnatāṃśoparige kṛte 'smin |

dvisthānasaṃlagnamṛgāsyamadhye kālāṃśakaiḥ paṅkti 10 palapramāṇaiḥ ‖*3*‖

ṣaḍbhir vibhaktair divasasya yātaṃ śeṣaṃ ca ghaṭyādi parisphuṭaṃ syāt |

tathonnataṃśaspṛśi bhāskarāṃśe prāgbhūjagaḥ sāyanalagnabhāgaḥ ‖*4*‖

Now he teaches the method of ascertaining the elapsed *ghaṭīs* and those to come in the day (*dina-gata-śeṣa-ghaṭikā*) and the computation of the ascendant (*lagna*) from the degrees of the sun's altitude in the east or in the west.

3-4. [Rotate the rete in such a way that] the sun's [longitude in] degrees (*ravy-aṃśaka*) [as seen in ecliptic, on the given day] falls on the eastern horizon (*bhūja*) [if it is the forenoon] or on the western horizon [if it is the afternoon, and then rotate it again so that the longitude] falls on the altitude degrees. The time degrees (*kālāṃśa*) between the two positions of the Capricorn index (*mṛgāsya*), each of which equals 10 *palas*, are divided by 6. The quotient in *ghaṭīs* etc. is the time elapsed or the time to come in the day [in the forenoon and in the afternoon respectively]. Likewise, when the sun's degree is touching the altitude degree, [the point on the ecliptic of the rete] which touches the eastern horizon (*prāg-bhūja-ga*) is the degree of the tropical ascendant (*ṣayana-lagna-bhāga*).

Commentary:

iṣṭadine sāyana-meṣādi-rāśi-sthita-sūryāṃśaṃ prāci bhūje aparāhṇam astabhūje ca kṛtvāsminn eva sūryāṃśe kramād viddhe ca pūrvāparonnatāṃśopari kṛte sati kramād dvisthāna-saṃlagna-mṛāgsya-madhyasthitaiḥ kalāṃśakair daśapalapramāṇaiḥ ṣaḍbhir 6 bhakrair dinasyātītaṃ [śeṣaṃ vā] ghaṭyādi parisphuṭaṃ bhavati | *tathā pūrvokta eva bhāskarāṃśe viddha-pūrvāparonnatāṃśaspṛśi pūrvakṣitijagataḥ sāyana-meṣādi-lagnāṃśaḥ spaṣṭaḥ syāt* ‖

On the desired day, the degree of the sun's tropical [longitude] as situated in one of the signs of the zodiac beginning with Aries (*ṣayana-meṣādi-rāśi-sthita-sūryāṃśa*) should be placed [by so rotating the rete] on the eastern horizon in the forenoon or the western horizon in the afternoon. Then place the same sun's longitude degree on the eastern or the western altitude degree that has been measured (*viddha*). When this is done, the units of time lying between the two positions of the Capricorn index (*mṛgāsya*), each of which is equal to 10 *palas*, are divided by 6. Then the elapsed *ghaṭīs* and its submultiples or those to come in the day will be obtained.

Similarly, when the afore-mentioned [longitude] degree of the sun is placed on the observed altitude circle in the east or west, then the degree of the zodiac signs beginning with Aries that touches the eastern horizon will be the ascendant (*lagna*).[1820]

5. 5 MEASURING THE TIME IN HOURS IN THE DAY

evaṃ raveḥ saptamarāśibhāgo yatraiva horāvalaye 'sti saiva |
horā dyunāthāc ca tataḥ svaṣaṣṭhaṣaṣṭasya gaṇyāparabhūjavṛttāt ||5||

5. Likewise [when the sun's degree is placed on the altitude circle corresponding to the observed altitude degree], wherever the degree of the seventh sign [from the sun's position, i.e. the opposite point in the ecliptic] touches the hour circle (*horā-valaya*) that is the hour (*horā*) [at the time of observation]. [Thus] the hour should be counted from the western horizon, by moving six signs from the sun's position [marked on the rete] ?

Commentary:

evem iti ko 'rthaḥ | pūrvavad bhāskarāṃśe iṣṭonnatāṃśopari sthāpite sati tasmāc ca saptamarāśyaṃso yasmin horāvalaye 'sti saiva taddine ādyā dinavārādihorā | tato dinavārahorātaḥ ṣaṣṭhasya dvitīyādyā

1820 On a given day, suppose that the sun is at Libra 15° and the sun's altitude as measured by the alidade is 36°. Turn the rete so that Libra 15° in the ecliptic touches the eastern horizon if it is in the forenoon or western horizon if it is in the afternoon. Note where the Capricorn index touches the degree scale. Then turn the rete so that Libra 15° touches the altitude circle for 36°. Note where the Capricorn index touches the degree scale now. Divide the difference in degrees of arc by 6. The quotient in *ghaṭīs* is the time elapsed since sunrise if it is the forenoon or time remaining up to sunset if it is the afternoon.
Again, when the Libra 15° is on the determined circle of altitude, that point on the ecliptic in the rete which touches the eastern horizon is the ascendant.

dvādaśaparyantā horā jñeyā | ādyā dinavārato vāropalakṣitagrahasya ṣaṣaṣṭhasya dvitīyā | param iyam āmnāyahorāparabhūjavṛttād gaṇyā |

When the sun's (longitude) degree is placed, as before, on the desired altitude degree, the [corresponding degree] of the seventh sign from there falls on whichever hour circle that is the first [hour] on that day of the week (*saiva taddine ādyā dinavārādihorā*) ? From that, i.e. from that hour of the day of the week, of the sixth should be known as the hours starting from the second up to the twelfth ?

Moreover, this conventional hour (*āmnāya-horā*) should be counted from the western horizon circle (*aparabhūjavṛtta*).[1821]

5.6-7 ASCERTAINING THE SUN'S ALTITUDE FROM THE GIVEN TIME

atha dinagataśeṣaghaṭībhyo ravyunnatāṃśānayanam |

ravyaṃśakaṃ prākkṣitije niveśya cihnaṃ mṛgāsye vidadhīta paścāt |
abhīṣṭakāle ghaṭikoparisthaṃ tad eva kṛtvā paricintanīyam ||6||
ravyaṃśako yatra hi tuṅgavṛtte tadaṅkasaṃkhyās tapanonnatāṃśāḥ |
madhyāhnato 'stakṣitijāt tathaiva te bodhanīyāḥ sudhiyāvaśiṣṭāḥ ||7||

Now ascertaining the degrees of the sun's altitude from the elapsed *ghaṭīs* or those to come in the day.

6. Having placed the [longitude] degree of the sun on the eastern horizon (*prākkṣitija*), make a mark then on [the limb where] the Capricorn index [touches]. Then place the same [Capricorn index] on the given time in *ghaṭīs*.

7. Where the degree of the sun's [longitude] lies on the altitude circle (*tuṅgavṛtta*), its serial number denotes the sun's altitude degrees. From midday onwards, one [places the sun's longitude degree] on the western horizon (*asta-kṣtija*) [makes a mark. Then moves the Capricorn index to the given time]. Learned men should understand that these are the *ghaṭīs* remaining [till sunset].

1821 Here Mahendra is obviously explaining the Islamic method of counting unequal hours from the western horizon. He calls the unequal hours *āmnāya-horā,* 'conventional or traditional hours of the Muslims'. But the second half of the text and the commentary on it are not clear. Commentary uses the terms *ādyā* and *dvitīyā;* do they refer to the two sets of 12 unequal hours, one for the day and another for the night? Then what is *dina-vāra-ādihorā* ?

Commentary:

ravyaṃśakaṃ prākṣitije niveśya mṛgāsye cihnaṃ viracya paścād abhīṣṭakāle ghaṭikoparisthaṃ tad eva mṛgāsyaṃ kṛtvā gaṇakena vilokanīyam | yasmin tuṅgavṛtte ravyaṃśaḥ sthito 'sti tāvadaṅka-pramāṇāḥ pūrvataḥ sūryonnatāṃśās tāvatīṣu ghaṭīṣu jātā iti śeṣaḥ | tathā madhyāhnato 'stakṣitijāt tathaiva pūrvoktarītyā sudhiyā viduṣā avaśiṣṭāsv iṣṭaghaṭīṣu avaśiṣṭā unnatāṃśā bodhanīyāḥ ||

Having placed the sun's degree on the eastern horizon and having made a mark where the Capricorn index touches, then having moved the Capricorn index to the given time, the astronomer should look. On which ever altitude circle the sun's degree is situated, the degrees of altitude corresponding to that circle; so many altitude degrees of the sun were reached from the east during so many *ghaṭīs*. In the same manner, the scholar should determine in the afternoon the remaining (*avaśiṣṭa*) altitude degrees from the western horizon from the remaining *ghatīs*.

5.8: MEASURING THE TIME AT NIGHT FROM THE ALTITUDE OF THE STARS

atha rātrau viddhanakṣatronnatāṃśebhyo rātrigataśeṣaghaṭikānayanam āha |
viddhonnatāṃśopagate ca bhāsye ravyāṃśake 'stendrakujasthite ca |
cihnadvayāntargataśeṣanāḍīpalāni pūrvāpararātribhāge ||*8*||

Now he teaches how to find the elapsed and remaining *ghaṭīs* at night from the altitude degrees of the star observed (*viddha*) at night.

8. When the star-pointer (*bhāsya*) is placed on [the altitude circle corresponding to] the measured degrees of altitude (*viddhonnatāṃśa*) and then when the sun's degree is placed on the western horizon (*asta-kuja*) or eastern horizon (*indra-kuja*) [as the case may be] in the first half or second half of the night, [one obtains from the interval] between the two marks [of the Capricorn index] the elapsed or remaining *ghaṭīs* and *palas.*

Commentary:

rātrau bhujāgreṇeṣṭanakṣatre viddhe prācyāḥ pratīcyā vā ye unnatāṃśāḥ prāpyante teṣūnnavalayasthiteṣu viddhonnatāṃśeṣu viddhe nakṣatramukhe dhṛte, sūryāṃśe astakujasthe aindrakujasthe vā pūrvāpararātribhāge kramān makara-mukhacihnadvayāntargataṃ śeṣaṃ nāḍīpalādi-sphuṭaṃ syāt ||

At night, when the desired star is sighted, the degrees of its altitude in the east or west are obtained through the tip of the alidade (*bhujāgra*). When the pointer of the star (*nakṣatra-mukha*) that has been observed is placed on those altitude circles corresponding to the measured degrees of altitude, and the sun's degree is placed on the western horizon or eastern horizon respectively in the first or the second half of the night, then the elapsed time or remaining time in *ghaṭī* (*nāḍī*) and *palas* can be read off from the [interval] between the two positions of the Capricorn index.

5.9 Ascertaining the ascendant and the time at night

tatraiva nakṣatramukhe niviṣṭe prāgbhūjagaṃ sāyanam eti lagnam |
sūryāṃśakādhiṣṭhitavṛttasaṃsthā tadātra horāpi niśi sphuṭā syāt ‖9‖

9. When the star-pointer (*nakṣatra-mukha*) is placed at the same place (i.e. on the altitude circle corresponding to the measured altitude degree), [the point on the ecliptic resting] on the eastern horizon [indicates] the ascendant with precision (*sāyanaṃ lagnaṃ*). Then, at that time, the hour corresponding to the circle on which the sun's degree is situated is clearly the hour of the night.

Commentary:

tatraiva viddhonnatāṃśeṣveva viddhanakṣatramukhe niviṣṭe pūrvarātrau apararātrau prāgbhūjagaṃ sāyanaṃ lagnam eti | *tadā tasmin kāle sūryāṃśakādhiṣṭhita-vṛttasaṃsthā horā niśi rātrau sphuṭā syāt* | *lagnakāle yasmin valaye 'rkaḥ sthito'sti tadvalaye tadgatahorā bhavatīty arthaḥ* |

At the same place, i.e., on the sighted altitude degrees when the pointer of the sighted star is placed, in the first half of the night or in the second half [the point of the ecliptic that] touches the eastern horizon is the ascendant with precision. Then, at that time, the hour corresponding to the circle on which the sun's degree is situated is clearly the hour of the night. That means, at the time of the ascendant, in whichever circle the sun is situated in that circle the hour of that circle occurs.[1822]

[1822] The second half of the verse and the commentary on it are rather obscure; the altitude circle where the sun's longitude is situated will not indicate the hour by itself; from the sun's position on the altitude circle, one should count six signs and find the corresponding hour line in the lower half of the plate.

5. 10: ASCERTAINING THE ALTITUDES OF THE STARS FROM THE GIVEN TIME

atha rātrigateṣṭaghaṭībhyo nakṣatrākrāntonnatāṃśānayanam āha |
sūryāṃśake 'stakṣitijasthite 'ṅkaṃ kṛtvā mṛgāsye gatanāḍikāsu |
niveśite 'tronnatavṛttagāḥ svāḥ prācyapratīcyoḍubhavonnatāṃśāḥ ||*10*||

Now he teaches how to determine the altitude of the star from the given *ghaṭīs* at night.

10. Having made a mark [on the limb touched by the Capricorn index] when the sun's degree is on the western horizon (*astakṣitija*), place the Capricorn index on the elapsed *ghaṭīs*. [Then wherever the star-pointer touches] on the altitude circle there will be the degrees of the star's altitude in the east or west.

Commentary:

sūryāṃśake 'stakṣitijasthite sati mṛgāsye aṅkaṃ kṛtvā paścād gateṣṭanāḍikāsu mṛgāsye niveśite sati unnatāṃśavṛttasthitāḥ svakīyāḥ prācya-pratīcyoḍubhavāḥ pūrvāparakapāla-sthita-nakṣatrākrāntā unnatāṃśā sphuṭā bhavantīti śeṣaḥ ||

When the sun's degree is on the western horizon, make a mark [on the limb] where the Capricorn index [touches]. Then place the Capricorn index on the elapsed *ghaṭīs* (that means, move the Capricorn index on the limb by so many *ghaṭīs*); then the altitude degrees of the star situated on the altitude circle [touched by the star pointer] originating from the star in the east or west are clearly the altitude degrees attained by the star in the eastern or western hemisphere.

5.11 ASCERTAINING THE ASCENDANT FROM THE *GHAṬĪS*

atha dinarātrigataghaṭībhyo lagnānayanam āha |
prāgastabhūjopagate 'rkabhāge 'ṅkite mṛgāsye gatanāḍikāsu |
sthite ca tasmin dyuniśoḥ kramāt syāt prāgbhūjagaḥ sāyanalagnabhāgaḥ ||*11*||

Now he teaches how to determine the ascendant (*lagna*) from the elapsed *ghaṭīs* in the day or at night.

11. When the sun's degree is placed on the eastern or western horizon and a mark is made at the point touched by the Capricorn index, then the Capricorn index is placed at the elapsed *ghaṭīs*; the degree of the ascendant with precision will be situated upon the eastern horizon either for the day or for the night.

Commentary:

dine sūryāṃśe prākkṣitijopage mṛgāsye cihnite tato gatanāḍikāsu tasmin mṛgāsye sthite sati prākkṣitijasthaḥ sāyano lagnabhāgaḥ syāt | evaṃ rātrāv astakṣitijasthe sūryāṃśe mṛgāsyaṃ cihnayitvā tato rātrigata-ghaṭīṣu mṛgāsye āropite prākkṣitijagataḥ sāyano lagnabhāgo bhavati ||

In the daytime, the sun's longitude is placed on the eastern horizon, and a mark is made [on the limb touched by] the Capricorn index. Then this Capricorn index is moved to the elapsed *ghaṭīs*, then the degree of the ascendant with precision (*sāyana-lagna-bhāga*) will be situated upon the eastern horizon. Likewise, at night, place the sun's degree on the western horizon and mark where the Capricorn index touches the limb, then move the Capricorn index to the elapsed *ghaṭīs*, the degree of the ascendant with precision (*sāyana-lagna-bhāga*) will be on the eastern horizon.

OTHER USES OF THE ASTROLABE

The rest of the chapter discusses several other uses to which the astrolabe can be put. These are listed below.

5.12-17: Determination of the twelve zodiac houses.

5.18-19: How to find the degrees of sun's longitude that lie in between the sexpartite almucantar circles.

5.20-21: How to find the altitude degrees that lie in between the sexpartite almucantar circles.

5.22-23: Ascertaining the ascendant and the altitude degrees of the stars in the four watches of the night (*yāma*).

5.24: Ascertaining the sun's true position.

5.25: Ascertaining the longitudes of stars and the remaining planets.

5.26: A different method for finding out the true longitudes of the five planets starting with Mars from the star's altitude degrees.

5.27: Ascertaining the daily motion of a planet (*graha-bhukti*).

5.28-31: Ascertaining the half of the maximum ascensional difference (*parama-caradala*) at the given degree [of latitude].

5.32: Ascertaining the lengths of the day and of the night.

5.33: Ascertaining the degrees of precision (*ayanāṃśa*).

5.34-35: Determination of the conjunction of planets (*grahayut*i).

5.36: Ascertaining the ascendant (*lagna*) of the next year from the ascendant of the current year.
5.37-38: Determination of the accurate ascendant through correction for the longitude difference.
5.39: Determination of the northern/southern declination (*saumya-yāmya-krānti*) of the fixed stars.
5.40-42: From ascendant derived from the terrestrial latitude marked on the astrolabe, ascertaining the ascendant for other latitudes.
5.43: Determination of the latitude of a desired locality from the circumpolar stars (*sadoditarkṣa*).
5.44-45:Ascertaining [the longitudes of] the fixed stars as corrected for *dṛkkarma*n.
5.46-51: Ascertaining the *tithi, nakṣatra* and *yoga*.
5.52: Ascertaining, by the Rule of Three, the shadow of the gnomon of 7 digits from the gnomon of 12 digits.
5.53: Ascertaining the shadow of the gnomon of 12 digits from the gnomon of 7 digits .
5.54: Ascertaining the shadow of the 12 digit gnomon and that of the 7 digit gnomon from any given altitude degrees.
5.55-57: Method of finding the heights of mountains, surrounding walls, temples, arches, pillars, trees etc. by sighting them from a distance.
5.58-60: Finding the times of rising in the east of the five [planets] starting with Mars.
5.61-63: Determination of the times of the setting of the planets Mars etc.
5.67: Author's colophon

abhūd bhṛgupure vare gaṇakacakracūḍāmaṇiḥ
kṛtī nṛpatisaṃstuto madanasūrināmā guruḥ |
tadīyapadaśālinā viracite suyantrāgame
mahendraguruṇoditājani[1823] *vicāraṇā yantrajā ||67||*

In the eminent city of Bhṛgupura, there lived the learned preceptor by name Madana Sūri, the crest-jewel of the circle of astronomers, who was praised by the kings. In this excellent treatise on the instrument (i.e. the astrolabe), composed by the preceptor

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1823 Thus Sudhākara Dvivedī's edition; Raikva's reads °*guruṇoddhṛtā*.

Mahendra, a devotee of his (Madanasūri's) feet, [the chapter dealing with] the use of the instrument is born (i.e., completed).

COMMENTATOR'S COLOPHON

śrīperojaśakendra-sarvagaṇakaiḥ prasṭo mahendraprabhur
jātaḥ sūrivaras tadīyacaraṇāmbhojaikabhṛṅgadyutā |
sūriśrīmalayendunā viracite 'smin yantrarājāgama-
vyākhyāne pravicaraṇādikathanādhyāyo 'gamat pañcamaḥ ||

Master Mahendra Sūri, the eminent scholar, is the foremost one among all the astronomers at the court of the glorious Fīrūz, the sovereign of the Muslims. In this commentary on the treatise *Yantrarāja* composed by the illustrious Malayendu Sūri, who is like the bee at the lotus feet of the [said master], the fifth chapter [that dwells on] the uses and so on [of the astrolabe] is concluded.

APX.D2 THE *DHRUVABHRAMĀDHIKĀRA* OF PADMANĀBHA WITH HIS OWN COMMENTARY: SOME EXTRACTS

Padmanābha (*fl.* 1423) and his works have been discussed in the introduction to section L (Dhruvabhrama-yantra) above. His *Dhruvabhamādhikāra* has not been published so far. There exist some seventy manuscript copies.[1824] I have prepared a working edition of the text and of the commentary on the basis of the following eight manuscripts:

(1) Asiatic Society of Bombay, # 245, dated Monday, 26 January 1660

(2) Bhandarkar Oriental Research Institute, Pune, # 329/1882-83 (text only)

(3) British Museum, London, # 14.3651

(4) Rajasthan Oriental Research Institute, Chittorgarh, of 1878

(5) Varanasi Sanskrit University, # 35606, dated Sunday 3 July 1825

(6) Varanasi Sanskrit University, # 35750 (commentary only)

(7) Vishweshwaranand Vedic Research Institute, Hoshiarpur, # 2481, dated Thursday, 6 September 1663 (commentary only)

(8) Vishweshwaranand Vedic Research Institute, Hoshiarpur, # 469.

Some extracts from the text and from the commentary are reproduced in the following pages, together with English translation, but without the critical apparatus.

[1824] cf. CESS A-4, pp. 170-172; A-5, p. 205.

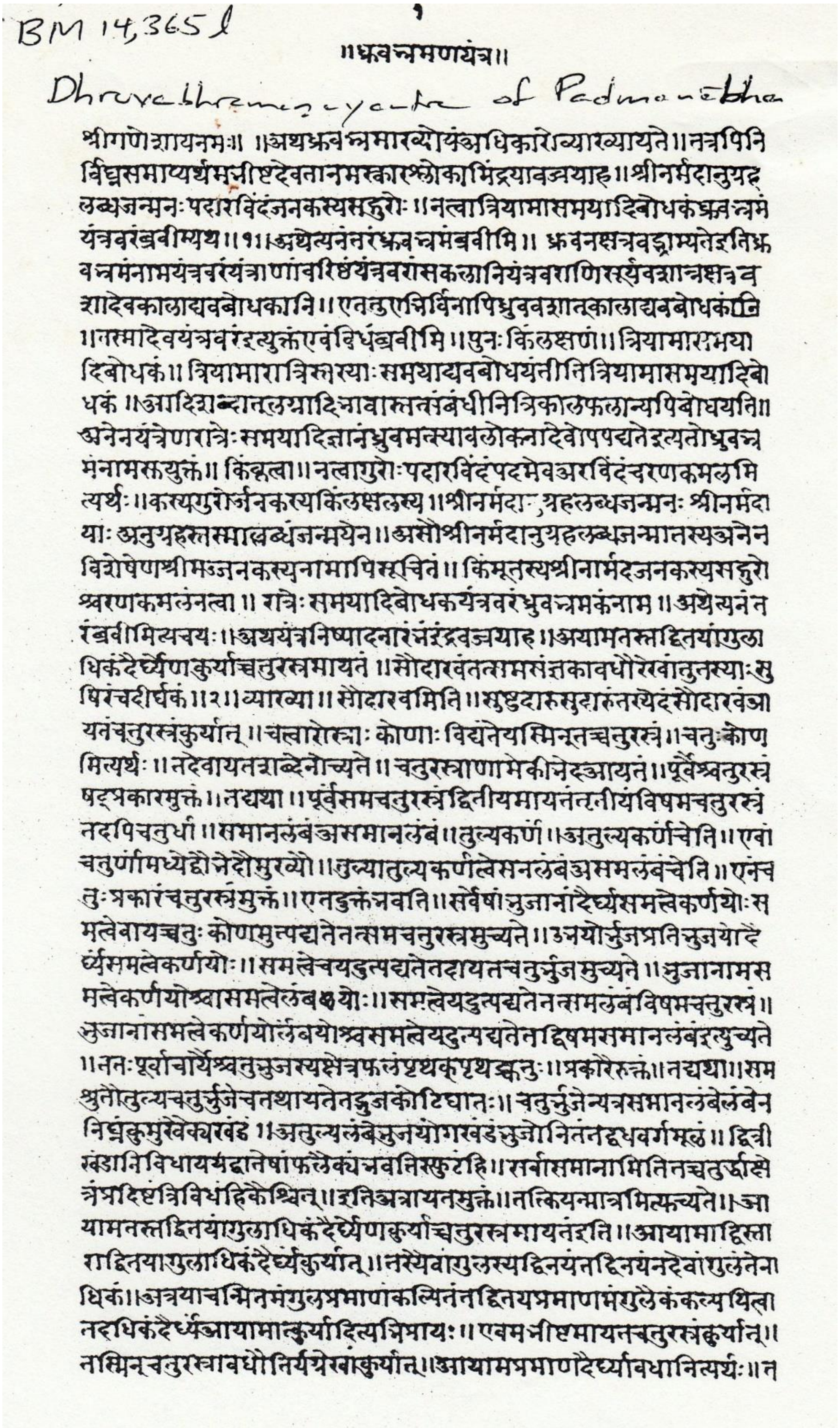

Figure Apx.D2.1 – British Museum Manuscript

श्रीपद्मनाभ-विरचित-ध्रुवभ्रमाधिकारः स्ववृत्ति-सहितः

1. Preamble

śrīnarmadānugrahalabdhajanmanaḥ
padāravindaṃ janakasya sadguroḥ |
natvā triyāmāsamayādibodhakaṃ
dhruvabhramaṃ yantravaraṃ bravīmy atha ‖ *1* ‖

Having bowed to the lotus feet of [my] father, who was [my] best teacher and who was born by the grace of the glorious [River Goddess] Narmadā, I now teach the excellent instrument *Dhruvabhrama,* which shows the time of the night and other [parameters].

2. Construction of the Dhruvabhrama-yantra

āyāmatas taddvitayāṅgulādhikaṃ
dairghyeṇa kuryāc caturasram āyatam |
saudāravaṃ tatsamasaṃjñakāvadhau
rekhāṃ tu tasyāṃ suṣiraṃ ca dīrghakam ‖ *2* ‖
aṣṭāṅgulaṃ sūkṣmataraṃ samākhye
vṛttāṣṭakaṃ sārdhayavāntareṇa |
tadbāhukhaṇḍena vidhāya pūrvaṃ
parāṇi caivaṃ hi pṛthak tadantaḥ ‖ *3* ‖
randhrasthabāhvardhagavṛttanemyāṃ
cihnaṃ tataś cākṛtināḍikātaḥ |
aṅkyāḥ samāḥ ṣaṣṭir athādito 'dho
vṛttāntarāle prathame ca koṣṭhe ‖ *4* ‖
tatas tṛtīye valayāntarāle
vyakṣāḥ kriyādyāḥ svaghaṭībhir aṅkyāḥ |
ṣaṣṭhe svakīyās tadadhaḥ svanāmā-
ny ūrdhve tu dhiṣṇyāni ca sāyanāni ‖ *5* ‖

Commentary: *…tatas tasmāt paraṃ tadadhas tṛtīye valayāntarāle tṛtīyakoṣṭhake prathamaghaṭīm ārabhya svasvaghaṭīpramāṇena nirakṣodayena meṣādyā dvādaśarāśayo vyakṣā aṅkyāḥ* | *tataḥ ṣaṣṭhe koṣṭhe svadeśīyāḥ svasvaghaṭībhir* *aṅkyāḥ | tadadhas tṛtīyaṣaṣṭhakoṣṭhayor adhaś caturthasaptamayo rāśīnāṃ svasvanāmāny aṅkyānīti lekhyāni | tadūrdhve dvitīyapañcamakoṣṭhayor dhiṣṇyāni sāyanānīti | nakṣatradhruvakānām ayanāṃśān dattvā yasmin rāśau yasminn aṃśe yan nakṣatram tadaṃśā aṅkyā iti | sarvāṇy aṅkyāni lekhyāni |*

madhyonnatāṃśā nijarāśibhānāṃ
lekhyā upāṅkeṣu nirakṣajānām |
svīyodaye svākṣajadṛṣṭikarma-
kṛtasphuṭāny eva likhed uḍūni || 6 ||

Make an oblong (*āyata caturasra*) board out of hard timber, two finger-breadths (*aṅgula*) longer than the width. Draw a line at the boundary of the square part and upon this make a long slit. It should be eight finger-breadths long and very narrow.

Inside the square [draw] eight [concentric] circles at intervals of one and half barley corns. Having thus drawn the [circle with a radius] equal to half the side [of the square, draw] the remaining circles inside that one.

Make a mark on the circumference of the [first] circle where it touches the middle of the side situated upon the slit. In the first annulus (*koṣṭha*) between the [first and the second] circles, make sixty equal [divisions] and number them from the [above-mentioned] mark, starting with *ghaṭī*[1825] twenty-two, and [going up to sixty, and thereafter] from one [to twenty-one].

Then in the third annulus (*valayāntarāla*), mark [the signs of the zodiac] at the equator beginning with Aries (i.e., according to their right ascensions) in *ghaṭīs,* and in the sixth annulus [the signs] in one's locality (*svakīya*) (i.e., according to their oblique ascensions). Below that write their names and above [the polar longitudes of] stars (*dhiṣṇya*) with precession (*sāyana*).

Commentary on 5: Then in the third annulus, starting from the first *ghaṭī,* mark the twelve signs of the zodiac, viz. Aries etc., without latitude, i.e. according to their risings in *ghaṭīs* at the equator (*nirakṣa*). Then in the sixth annulus, mark the same according to their risings in *ghaṭīs* in one's own locality. Below that, i.e. below the third

[1825] *Ghaṭī,* the standard unit of time in traditional India which equals 24 minutes, has three other synonyms in Sanskrit, viz. *ghaṭikā, nāḍikā* and *nāḍī.* While the text uses all the four synonyms, these will be rendered as *ghaṭī* in the translation.

and the sixth annuli, viz. in the fourth and the seventh annuli, write down the names of the zodiac signs. Above that, i.e. in the second and fifth annuli, write down the lunar mansions with the degrees of precession. That is to say, in whichever sign at whatever degree, [the polar longitude of] a lunar mansion is situated, those degrees must be written, after adding the degrees of precession (*ayanāṃśa*) to the polar longitudes (*dhruvaka*) of the stars. Thus all [stars] are to be written down.

Near the marks [of division of the signs], computed according to their right ascensions, write the meridian altitudes (*madhyonnatāṃśa*) of the stars belonging to the respective signs. In [the annuli] of the oblique ascensions, write down the true (*sphuṭa*) [polar longitudes of] the stars after correcting these by the latitudinal *dṛkkarma* (*akṣaja-dṛṣṭikarma*).

3. INDEX

tatkendrakīle viniveśya cakraṃ
cañcutrayāḍhyaṃ śithilaṃ salambam |
prākcañcukāgraṃ nijabhodayāptaṃ
madhyaṃ nirakṣe tv aparaṃ ghaṭīṣu ‖ 9 ‖
turyāṃśakeṣv eva niyojiteṣu
lambas tv adhas turyalave yathā syāt |
tathā prakuryāt sudṛḍham ca kīlaṃ
paribhramat tan na pated adhastāt ‖ 10 ‖

9. Attach loosely to the pin situated at its centre a circular disc, equipped with three pointers (*cañcu,* literally, beak) and a plumb (*lamba*) in such a manner that the eastern pointer touches the oblique ascensions (*nijabhodaya*), the middle [pointer] the right ascensions (*nirakṣa*), the western [pointer] the *ghaṭīs,*

10. — [the three pointers] being attached in three different quadrants [of the circular disc]— and the plumb rests in the lower-most quadrant. The pin should be fixed tightly [to the instrument] in such a manner that the circular disc does not slip out while rotating.

4. METHOD OF OBSERVATION

dhruvatimimukhapucchādhiṣṭhite tārake dve
yugapad iti bhavetām vedharandhrasya madhye |
mukura iva karābhyām saṃgṛhīte hy amuṣmin
haridiśi bhavatīṣṭaṃ cañcukāgre vilagnam ‖ 11 ‖
sacalanam iti nāḍyāṃ vedhacihnaṃ ca paścāt
sacalanalavaṣaḍbhe pūrvacañcvagrage 'rke |
tadaparayutanāḍīcihnato vedhacihnā-
vadhi gataghaṭikāḥ syuś ced ravau cañcuyukte ‖ 12‖
tad aparaghaṭicihnaṃ yāvad eṣyā vyadhāṅkād
viyati bhavati madhyaṃ vyakṣabhe yatra cañcuḥ |
viyadudayavilagnābhyāṃ pare veditavyā
abhimataghaṭikā bhāt procyate 'rkāt tathāhnaḥ ‖ 13 ‖

11. When this [instrument] is held in both hands like a mirror in such a manner that the two stars situated at the mouth and the tail of the Polar Fish (*dhruva-timi*) are seen simultaneously through the sighting slit, at the tip of the eastern pointer can be seen the ascendant (*vilagna*) for that moment

12. with precession (*sacalana*). Make a mark of observation (*vedha-cihna*) in the west [at the tip of the western pointer] on the *ghaṭī* circle. Move the tip of the eastern pointer to the solar longitude [for that time] with precession, increased by six signs. Then from the corresponding point on the *ghaṭī* circle at the tip of the western pointer up to the [previously laid out] mark of observation (*vedhacihna*) are the elapsed *ghaṭīs* [in the night]. If [the tip of the eastern] pointer is placed on the sun's longitude [with precession],

13. then from the mark of observation (*vyadhāṅka*) up to the mark on the *ghaṭī* circle at the western pointer are [the *ghaṭīs*] to come. Where the [middle] pointer is situated in the sign rising at the equator, it is the upper culmination (*madhya, madhyma-lagna*). Then the other [astrological houses] can be known from the upper culmination (*viyad-vilagna*) and the ascendant (*udaya-vilagna*). Now will be told [the method of finding] the desired *ghaṭīs* [of the night] from [any] fixed star and [the time] of the day from the sun.

5. THE CONSTELLATION OF THE POLAR FISH (*DHRUVA-MATSYA*): COMMENTARY ON VERSE 11

pūrvaṃ sṛṣṭyādau śrībrahmaṇākāśa ādhārarahitasya pravahānilākṣiptasya bhacakrasya samīcīnapaścimābhimukhaparibhramaṇāya dakṣiṇottarayoḥ prāntasthite dve tārake dhruvatve niyukte | tayor ubhayor dhruva-saṃjñā kṛtā | yā dakṣiṇā tārā sā tu palāṃśaiḥ kṣitijād adhasthād vartate | yā tūttarā tārā sā palāṃśaiḥ kṣitijād uparito varīvarti | tatparito dvādaśatārakābhir matsyākāramaṇḍalam upalakṣyate | tasya dhruvamatsya-saṃjñā vihitā | tanmukhe pucche sthūle tārake dve dṛśyete | tayor madhye yā mukhasthā sā dhruvatārāyās tribhir aṃśair antaritā | yā pucchasthā sā tu trayodaśabhir aṃśair antaritā vartate | ubhe parasparaṃ ṣodaśabhāgāntarite staḥ |

At the beginning of Creation, the glorious [Creator] Brahmā arranged two stars as the celestial poles at the end of the southern and northern directions so that the stellar sphere (*bhacakra*) can properly revolve in the sky towards the west, without any support but impelled by the *Pravaha* wind. These two stars were designated as the celestial poles (*dhruva*). That which is the southern [Pole] Star is situated below the horizon at the degrees of the local latitude (*palāṃśa*). The northern Pole Star lies above the horizon at the degrees of the local latitude. Around the latter is seen a fish-shaped constellation consisting of twelve stars. This is designated as the Polar Fish (*dhruva-matsya*). Two bright stars are visible at its mouth and tail. Of these, the one at the mouth lies at an interval of three degrees (*bhāga*) from the [actual] Pole Star and the one at the tail lies at thirteen degrees. The two are separated from one another by sixteen degrees.

6. SINE QUADRANT ON THE BACK

kadūnadoṣṇā vaṇigūrdhvakoṇato
yantrānyapārśve vṛtituryam ālikhet |
tadrandhrabāhoḥ khaguṇonmitajyakās
tulyāntarālāś ca vilambasūtravat || 14 ||
kendrād adhaḥ koṇapadāc ca nemyāṃ
aṅkyāḥ samāḥ khāṅkalavās tu sāṅkāḥ |
tatturyakendre viniyojya paṭṭīṃ
triṃśatpadāṅkāṃ sahalambasūtrām || 15 ||
randhrordhvabāhūpari kīlayugmaṃ

sarandhrakaṃ prāntagatam vidadhyāt |
iṣṭārkṣamadhyonnatabhāgakeṣu
vinyasya paṭṭīṃ sudṛdhāṃ ca kendrāt ‖ *16* ‖

14. On the reverse side of the instrument, from the corner above Libra [which is marked on the front side] draw a quadrant of the circle (*vṛti-turya*) with an arm (radius) slightly less [than the side of the square]. From the side containing the slit, draw thirty sines at equal intervals like dangling strings.

15. Below the centre, starting from the foot of the corner (*koṇa-pāda*), mark ninety equal degrees on the rim and number them. Having attached an index (*paṭṭī*) marked in thirty units together with a plumb line (*lambasūtra*) at the apex of the quadrant (*turya-kendra*),

16. affix two sighting vanes (*kīla*) with holes at the two ends of the edge [of the instrument] on the side of the slit. [While observing a star, move the index] to the degrees of the meridian altitude of that star and hold it there firmly.

7. Observation with the Sine Quadrant

tatpārśvakīlena ca kendrakīla-
pathena dṛṣṭyā khalu vedhayed bham |
kendrāvalambonmitabhāgajīvā-
spṛkpaṭṭikāṅkapramitajyakāṃśāḥ ‖ *17* ‖
saduddhṛtās te 'bhimatāś ca nāḍyaḥ
pūrve 'gatāḥ paścimatas ca yātāḥ |
vyakṣasvarāśisthitatatpadāntaś
caraṃ ca tadghnās tithihṛd vināḍyaḥ ‖ *18* ‖
tenonayuktā ghaṭikāḥ sphuṭāḥ syur
nyūnādhike vyakṣapade svacihnāt |
bhūjasthacihnordhvaganāḍikāṅkāt[1826]
triṃśadyutāc ca kramaśo yutonāḥ ‖ *19* ‖
tatsanmukhaprāksthitacañcukāgre
lagnaṃ paratra vyadhacihnam asmāt |

[1826] Should one read *deśastha*° instead of *bhūjastha*° ?

prāgvat prasādhyā ghaṭikā niśāyāṃ
sūryasya tā eva parisphuṭāḥ syuḥ ‖ *20* ‖

17. Then sight the star along the path of vision between the sighting vane on the side and the sighting vane above the apex. [Note] the number on the index touched by the sine [of the altitude] degrees indicated [by the plumb line] suspended from the apex. The degrees of the sine with the same value as that number,

18. when divided by six, become the desired *ghaṭīs*, those to come (*agata*) if the star is in the east, elapsed (*yāta*) if the star is in the west. The [difference] between the respective positions [of the star on the circles] of the signs in right and oblique [ascensions] is the ascensional difference (*cara*). The *ghaṭīs* are multiplied by that [*cara*] and divided by fifteen. [The result is called the *caraphala.*]

19. The *ghaṭīs,* when diminished or increased by this [*caraphala* according as the star's] position on the [circle of] right ascensions (*vyaksapada*) are less or greater than the mark on the [circle of] oblique [ascensions] (*svacihna*), will be true [*ghaṭīs*]. These are respectively added to or subtracted from the number, augmented by thirty, on the *ghaṭī* [circle] just above the [star's] mark when it is on the horizon (?).

20. At the tip of the eastern pointer, facing this mark, is the ascendant and in the west the mark of sighting (*vedha*-*cihna*). From this the *ghaṭīs* of the night can be determined as before. In the case of the sun, the same [without the operation detailed above] will be the true [*ghaṭīs*].

8. MERIDIAN ALTITUDES OF THE LUNAR MANSIONS AT THE LATITUDE OF 24°

rasāṣṭau 86 gajāṣṭau 88 navāṣṭau 89 guṇāṣṭau 83
navāśvā 79 gajāśvā 78 śarāṣṭau 85 rasāṣṭau 86 |
navāśvā 79 khanāgā 80 yugāṣṭau 84 yamāṣṭau 82
tribāṇāḥ 53 kubhṛnmārgaṇa 57 nandanāgāḥ 89 ‖ *24* ‖
śaśāṅkeṣavo 51vedavedāḥ 44 kuvedāś 41
catustriṃśad 34 aśvāgnayaḥ 37 śailarāmāḥ 37 |
rasāśvā 76 guṇāśvāh 73 kuśailā 71 rasākṣā 56
yamāṣṭau 82 navāṣṭau 89 dviśailāḥ 72 kramena ‖ *25* ‖
jināṃśāḥ palās tatra madhyonnatāṃśā
upāntyānileśādyayugmasya sārdhāḥ |
vidher bhāt trayādityayāmyānilānāṃ

udaksaṃsthitā dakṣiṇāḥ śeṣabhānām ‖ *26* ‖

24. [The meridian altitudes are] successively [Aśvinī] 86; [Bharaṇī] 88; [Kṛttikā] 89; [Rohiṇī] 83; [Mṛgaśirā] 79; [Ārdrā] 78; [Punarvasu] 85; [Puṣya] 86; [Āśleṣā] 79; [Maghā] 80; [Pūrvaphālguṇī] 84; [Uttaraphālguṇī] 82; [Hasta] 53; [Citrā] 57; [Svāti] 89;

25. [Viśākhā] 51; [Anurādhā] 44; [Jyeṣṭhā] 41; [Mūla] 34; [Pūrvāṣādhā] 37; [Uttarāṣādhā] 37; [Abhijit] 76; [Śravaṇa] 73; [Dhaniṣṭhā] 71; [Śatabhisaj] 56; [Pūrvabhādrapadā] 82; [Uttarabhādrapadā] 89; [Revatī] 72.

26. Here the local latitude is 24 degrees. The [given] meridian altitudes are increased by half a degree in the case of Uttarabhādrapadā (*upāntya*), Svāti (*anila*), Ārdrā (*īśa*), Aśvinī and Bharaṇī (*ādya-yugma*). These are north for Rohiṇī, Mṛgaśirā, Ārdrā (*vidher bhāt traya*), Hasta (*āditya*), Bharaṇī (*yāmyā*) and Svāti (*anila*); and south for the remaining stars.

Table Apx.D2-1 Meridian Altitudes of the Lunar Mansions

	Star Name	Identification	Meridian Altitude
1	*Aśvinī*	β Arietis	86;30° S
2	*Bharaṇī*	41 Arietis	88;30° N
3	*Kṛttikā*	η Tauri	89° S
4	*Rohiṇī*	α Tauri	83° N
5	*Mṛgaśirā*	λ Orionis	79° N
6	*Ārdrā*	α Orionis	78;30° N
7	*Punarvasu*	β Geminorum	85° S
8	*Puṣya*	δ Cancri	86° S
9	*Aśleṣā*	ζ Cancri	79° S
10	*Maghā*	α Leonis	80° S
11	*Pūrvaphālguṇī*	δ Leonis	84° S
12	*Uttaraphālguṇī*	β Leonis	82° S
13	*Hasta*	δ Corvi	53° N
14	*Citrā*	α Virginis	57° S

	Star Name	Identification	Meridian Altitude
15	*Svāti*	α Bootis	89;30° N
16	*Viśākhā*	α Librae	51° S
17	*Anurādhā*	δ Scorpii	44° S
18	*Jyeṣṭhā*	α Scorpii	41° S
19	*Mūla*	λ Scorpii	34° S
20	*Pūrvāṣāḍhā*	δ Sagittarii	37° S
21	*Uttarāṣāḍhā*	σ Sagittarii	37° S
22	*Abhijit*	α Lyrae	76° S
23	*Śravaṇa*	α Aquilae	73° S
24	*Dhaniṣṭhā*	β Delphini	71° S
25	*Śatabhiṣaj*	λ Aquarii	56° S
26	*Pūrvabhādrapadā*	β Pegasi	82° S
27	*Uttarabhādrapadā*	γ Pegasi	89;30° S
28	*Revatī*	ζ Piscium	72° S

9. How to convert the Meridian Altitudes given for the Latitude of 24° into those pertaining to the Observer's Latitude (*svadeśīya*)

akṣabhāgavivareṇa hīnayug
madhyajonnatalavāḥ samānyadik |
te hy udaksvaviṣaye khamadhyajā
yantrataḥ syur iti dakṣiṇe 'nyathā ‖ 27 ‖

27. The degrees of the meridian altitude are respectively diminished or augmented by the difference between the desired latitude and 24° according as the two quantities are in the same direction or not. The result will be the meridian altitude in degrees, if one's own latitude is to the north of the instrument's latitude. If it is to the south, the operation will be the reverse.

10. How to measure Time with an Instrument calibrated for another Latitude

akṣabhāntaracarārdhajaiḥ palaiḥ
saumyadiksthaviṣaye yutonitāḥ |
golayor abhimatās tu nāḍikāḥ
prasphuṭā yamadiśi syur anyathā ‖ 28 ‖

28. In the case of a locality to the north [of the instrument's latitude, the *ghaṭīs* read from the instrument are] increased or diminished by the *palas*[1827] of the half *cara* [arising from] the difference between the equinoctial shadows (*akṣabhā*) [at the instrument's latitude and at the given latitude, respectively in the northern and the southern] hemispheres. Then one gets the true *ghaṭīs* that are desired. If [the locality is] to the south [of the instrument's latitude, then the process is] the reverse.

ghaṭikāparijñānaprakāraṃ kautukāc chārdūlavikrīḍitābhyām āha |
sārdhākṣā 5|30 ghaṭikā bhavāḥ sacaraṇāḥ 11/15 saptendavo 17 dvyaśvinaḥ 22
sāṅghryaṅgāśvina 26|15 khāgnayo 30 vicaraṇā vedāgnayo 33|45 'ṣṭāgnayaḥ 38| sārdhāṃśās trikṛtāś ca 43|30 pādarahitās tānāś ca 48|45 vedeṣavaḥ sārdhāh 54|30 saṣṭṭir 60 itīndradiksthitatulādyante pratīcyāṃ gatāḥ ‖ 29 ‖

… etā nāḍya indradiksthitatulādyante pratīcyāṃ gatā jñeyāḥ | yantroparisthita-cakrasya pūrvacañcukāgraṃ [yadā] tulādirāśīnām ante sthitaṃ bhavati tadā pratīcyāṃ sthitaṃ cañcukāgraṃ kramād āsu nāḍīṣu sthitaṃ bhavatīti jñeyaṃ | …

nemyām aṅgulakonnatān samaśiraskān kīlakān sthāpayed
dīrghādyān pratināḍikāsv ajamukhād dhvānte 'pi tajjñaptaye |
bhāsvatsāyanabhāgaṣaḍbhajaghaṭīhīnāḥ svavedhodbhavā
yātā vyatyayato 'gatās tu ghaṭikā vyabhrāgnayo 'ṅgam vyadhāt ‖ 30 ‖

… nemyāṃ yantraparidhau paridhyūrdhvabhāge tiraścīnānān aṅgulakonnatān samaśiraskān kīlakān pratināḍikāsu sthāpayet | kāryāḥ | anya ekonaṣaṣtikīlakās te samaśiraskāḥ kāryāḥ | kasmād ārabhya kathaṃbhūtān | dīrghādyān iti prathamaghaṭikāsthitakīlakaḥ kiñcid dīrghaḥ

[1827] *Pala* is the one-sixtieth part of a *ghaṭī,* i.e. 24 seconds.

sthāpya ity ucyate | ajamukhān meṣamukhād ity arthaḥ | kasmai | tajjñaptaye prāptaghaṭīnām jñaptir jñānaṃ dhvānte 'pi kīlakagaṇanayā ghaṭīnāṃ saṃkhyā labhyata ity abhiprāyaḥ | tat katham ity ucyate | bhāsvatsāyanabhāgaṣaḍbhajaghaṭīhīnāḥ svavedhodbhavā nāḍyaḥ kāryās tā yātā nāḍyo bhavanti | ayanabhāgāś ca saḍbhaṃ cāyanabhāgaṣaḍbhe tayoḥ saha sāyanabhāgaṣaḍbhaṃ tasmāj jātāś ca | tā ghaṭyaḥ sāyanabhāgaṣaḍbhajaghaṭyaḥ | bhāsvataḥ sūryasya sāyanabhāga-ṣaḍbhajaghaṭyaḥ | tābhir hīnā gatā bhavanti vyatyayato 'gatāś ca | viparītaśodhana eṣyāh syuḥ | param tv eṣyās tās triṃśadbhir ūnitāh kāryās tā eṣyāḥ sphuṭāḥ syuḥ | aṅgaṃ lagnaṃ tu vyadhād vedhāj jñeyam | pūrve cañcukāgra iti pūrvavaj jñeyam | etad uktaṃ bhavati | rātrau dhruvam ityādividhinā dhruvaṃ vidhvā paścimacañcukāgraṃ kasyāṃ ghaṭyām lagnaṃ sā ghaṭī dīrghakīlakād ārabhya katitameti jñātvā tataḥ sāyanasūryaḥ kasmin rāśau kasminn aṃśe vartate tatsaṣaḍbhasya kati ghaṭikā prāg uktāḥ santi sārdhākṣā ghaṭikā ityādividhinā yāvatyas tābhir vedhodbhavā nāḍya ūnāḥ satyo rātrer gatā ghaṭikā bhavanti | yadi sāyanaṣaḍbhasūryaghaṭikā vedhaghaṭikābhir hīnāh kriyante tad ārabhya triṃśat paryantaṃ śeṣā rātrer eṣyaghatikā bhavanti | lagnaṃ tu prāgvad iti |

Now he teaches, as a matter of interest (*kautuka*), how to read the *ghaṭīs* [at night, even when it is dark], in two verses in *Śārdūlavikrīḍita* meter.

29. [Libra] 5;30, [Scorpio] 11;15, [Sagittarius] 17, [Capricorn] 22, [Aquarius] 26;15, [Pisces] 30, [Aries] 33;45, [Taurus] 38, [Gemini] 43;30, [Cancer] 48;45, [Leo] 54;30, [Virgo] 60. When the end points of Libra etc. are in the east, these will be the elapsed *ghaṭīs* in the west.[1828]

Commentary. These many *ghaṭīs* are elapsed when the end-points of Libra and other signs are in the east. That is to say, when the tip of the eastern pointer of the index of the instrument rests at the end of Libra and other signs [successively], then the western pointer touches these *ghaṭīs* successively.

[1828] That is to say, when the tip of the eastern pointer of the index rests on Libra, it can be inferred that the time is 5;30 *ghaṭīs* elapsed since sunrise, and so on, for these points are diametrically opposite each other; cf. %Figure L003.1.

30. On the rim, starting from the first point of Aries, affix pins at each *ghaṭī.* The first pin should be [somewhat] long[er, the rest one] *aṅgula* long with uniform pinheads. In darkness also, these [will help] in recognition. The *ghaṭīs* obtained by one's own sighting (*svavedhodbhava*), when diminished by the *ghaṭīs* corresponding to the sun's longitude with precession and increased by six signs, will become the past *ghaṭīs.* In the reverse operation, these will be the future *ghaṭīs,* when diminished by thirty. The ascendant (*aṅga*), [however, has to be found] by direct observation (*vyadha*).

Commentary. On the upper part of the rim of the instrument, at right angles to its plane, affix pins with uniform heads at each *ghaṭī.* The first one should be a bit longer. The remaining fifty-nine should have uniform heads. The pins should start from the first point of Aries. By counting the pins, the number of *ghaṭīs* can be known in darkness.[1829] The *ghaṭīs* obtained by direct observation should be diminished by the *ghaṭīs* corresponding to the sun's longitude with precession and increased by six signs. The result will be the past *ghaṭīs.* In the reverse operation, these will be future *ghaṭīs.* But these future *ghaṭīs* should be diminished by thirty. Then they will become true future *ghaṭīs.* The ascendant, however, has to be known from direct observation as before, according to the rule *pūrvacañcukāgre* etc.

Here, this must be added. Having sighted the Pole Star at night according to the rule *dhruva* etc. (vs 11ff), note which *ghaṭī* is touched by the tip of the western pointer by counting the pins from the longest pin. Find out in which sign and at what degree the sun's longitude with precession and increased by six signs lies. Find out the corresponding *ghaṭīs* by the rule *sārdhākṣā ghaṭikāḥ* etc. (vs 29) and subtract them from the *ghaṭīs* obtained by observation. The result will be the *ghaṭīs* elapsed in the night [since sunset]. If the *ghaṭīs* corresponding to the sun's longitude with precession and increased by six signs are diminished by the *ghaṭīs* of observation, then the resulting *ghaṭīs* up to thirty are the future *ghaṭīs* of the night [up to the next sunrise]. The ascendant is determined as before.

1829 No extant specimen is equipped with such pins. However, in L003 and L004, both made by Morarji in 1815, there are raised dots around the *ghaṭī* circle, about two for each *ghaṭī.*

11. Importance of the Dhruvabhrama-yantra

nakṣatrāt samayajñānaṃ tamisrāyāḥ puroditam |
dhruvāt kenāpi na proktaṃ tad etat kautukāt kṛtam ‖ 31 ‖

[Others] have taught previously how to measure time from the stars, but none [has taught how to find time] from the Pole Star. Therefore, out of intellectual curiosity, this has been done [by us].

12. Excursus on the Classification of the Quadrilaterals

The auto-commentary on verse 2 contains a long excursus on the types of quadrilaterals which deserves to be cited in full.

catvāro 'srāḥ koṇā vidyante yasmiṃs tac caturasraṃ catuṣkoṇam ity arthaḥ | … pūrvaiś caturasraṃ ṣaṭprakāram uktam | tad yathā | prathamaṃ samacaturasraṃ dvitīyam āyataṃ tṛtīyaṃ viṣamacaturasram | tad api caturdhā | samānalambam asamāmānalambaṃ tulyakarṇam atulyakarṇaṃ ceti | eṣām caturṇām madhye mukhyau dvau bhedau | tulyātulyakarṇatve samalambam asamalambaṃ ceti dvau bhedau | evaṃ catuṣprakāraṃ caturasram uktam | etad uktam bhavati | sarveṣāṃ bhujānāṃ dairghyasamatve karṇayoḥ samatve ca yac catuṣkoṇam utpadyate tat samacaturasram ucyate | ubhayor bhujapratibhujayor dairghyasamatve karṇayoḥ samatve ca yad utpadyate tad āyatacaturasram | bhujānām asamatve karṇayoś cāsamatve lambayoḥ samatve yad utpadyate tat samānalambaviṣamacaturasram | bhujānām asamatve karṇayor lambayor asamatve yad utpadyate tad viṣamacaturasram ity ucyate | tataḥ pūrvācāryaiś caturbhujasya kṣetraphalaṃ pṛthak pṛthak catuṣprakāram uktam | tad yathā |

samaśrutau tulyacaturbhuje ca
tathāyate tadbhujakoṭighātaḥ |
caturbhuje 'nyatra samānalambe
lambena nighnaṃ kumukhaikyakhaṇḍam ‖
atulyalambe bhujayogakhaṇḍaṃ
bhujonitaṃ tadvadhavargamūlam |
dvitrāṇi khaṇḍāni vidhāya yad vā
teṣāṃ phalaikyaṃ bhavati sphuṭaṃ hi ‖
sarvāsamānām iti tac caturdhā

kṣetraṃ pradiṣṭam trividhaṃ hi kaiścit ||

That which has four corners (*asra*) is called a quadrilateral. Six varieties of quadrilaterals were mentioned by the ancients. The first is the square (*sama-caturasra*), the second the oblong (*āyata*) and the third the uneven quadrilateral (*viṣama-caturasra*). The last one is again fourfold: having equal altitudes (*samāna-lamba*) and having uneven altitudes (*asamāna-lamba*); with equal diagonals (*tulya-karṇa*) and with unequal diagonals (*atulya-karṇa*). Of these four, there are two main varieties: those with equal altitudes and those without, the diagonals being equal or unequal. Thus the quadrilateral is said to have four varieties. In this context, the following needs to be stated (*etad uktaṃ bhavati*). The quadrilateral, produced when the length of all [four] sides is equal and that of the [two] diagonals is equal, is called the square (*sama-caturasra*). That which is produced when the lengths of the two pairs of opposite sides are equal and when the two diagonals are also equal is called the oblong rectangle (*āyata-caturasra*). When the sides are unequal and the diagonals are also unequal but the altitudes are equal, the figure is called trapezium (*samānalamba-viṣama-caturasra*). When the sides are unequal, and the diagonals and the altitudes are also unequal, the figure thus produced is called an uneven quadrilateral (*viṣama-caturasra*). Therefore, the area (*kṣetraphala*) of the quadrilateral (*caturbhuja*) was taught in four different ways by the previous teachers thus:

> 'In the case of an oblong in which the diagonals are equal and the four sides are equal, [the area is] is the product of the base (*bhuja*) and the perpendicular (*koṭi*). In other quadrilaterals, where the altitudes (*lamba*) are equal, [the area is] the product of the altitude and half the sum of the base and the face (*ku-mukhaikya-khaṇḍa*).
>
> 'When the altitudes are [also] unequal, [the area is] the square-root of the product of half the sum of [all fours] sides diminished [severally] by [each] side. Alternatively, make two or three [triangular] segments; the sum of their areas will clearly become [the area]
>
> 'of [quadrilaterals in which] all [the elements] are unequal (*sarva-asama*). Thus the area is stated to be fourfold, or threefold according to some [authorities].'

APX.E REPLICAS AND OTHER IMITATIONS OF SAWAI JAI SINGH'S MASONRY INSTRUMENTS

In the nineteenth and twentieth centuries many small-scale replicas were prepared of the masonry instruments in Sawai Jai Singh's observatories at Delhi and Jaipur. In the Jaipur Observatory can be seen several of these, made of plaster of Paris, marble or brass.

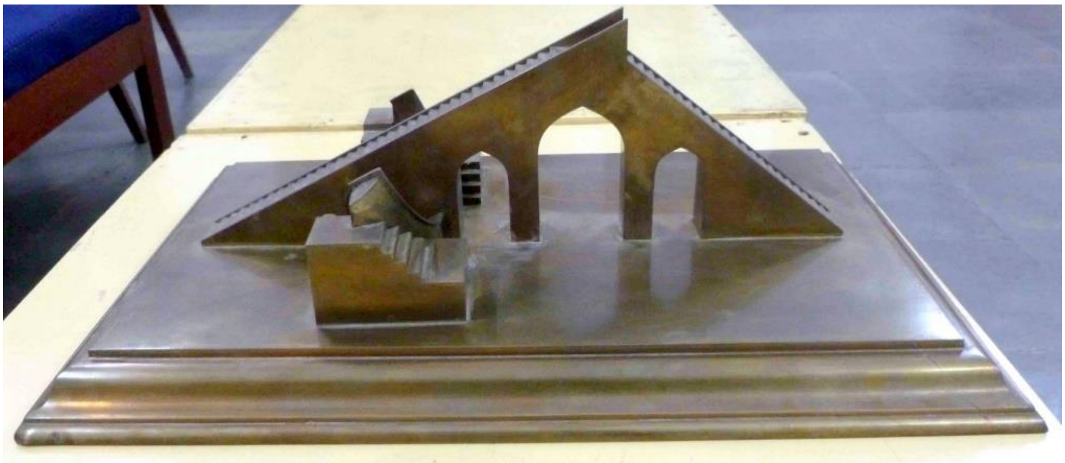

Figure Apx.E.1 – Brass replica of the smaller Samrāṭ-yantra, Jaipur Observatory
(photo by Dr Jean-Michel Delire)

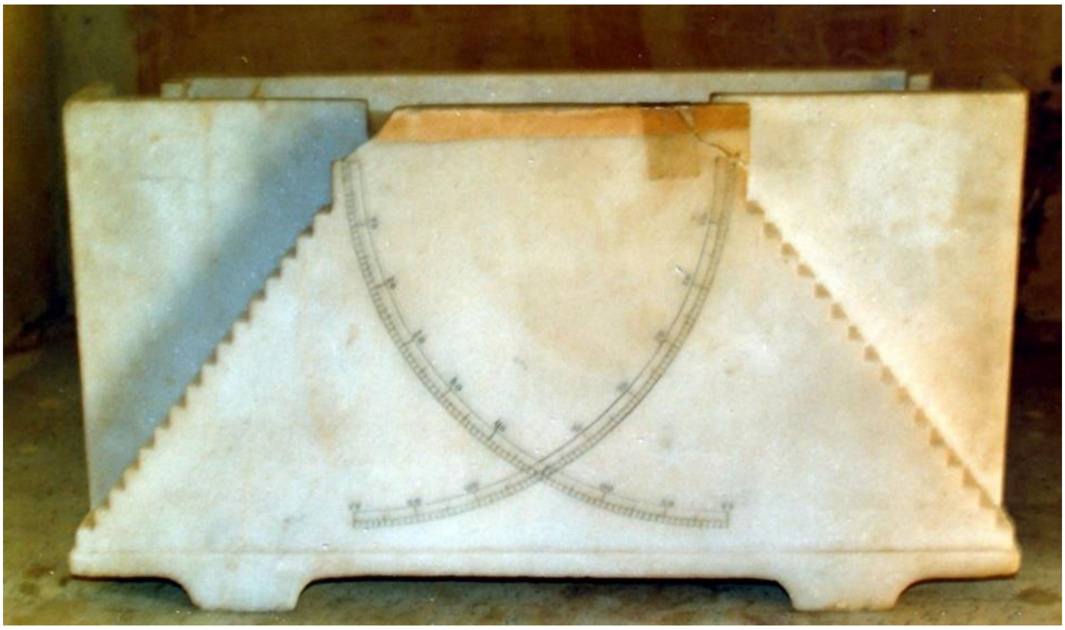

Figure Apx.E.2 – Marble replica of the Bhitti-yantra, Jaipur Observatory
(photo by S. R. Sarma)

The Science Museum in London owns several finely made small replicas. Elsewhere there are also larger replicas and even complete observatories filled with instruments similar to those of Sawai Jai Singh; some of these will be described in the following pages.

1. KALYAN DUTT SHARMA'S STONE OBSERVATORIES

Kalyan Dutt Sharma was in-charge of Jai Singh's Jaipur Observatory for several years. Like the royal predecessor, he also set up observatories at five different places in India, not for actual astronomical observations, but more for didactic purposes, at Varanasi, New Delhi, Haridwar, Ayodhya and Jaipur. He filled these observatories with smaller versions of Jai Singh's masonry instruments, sometimes with minor modifications.

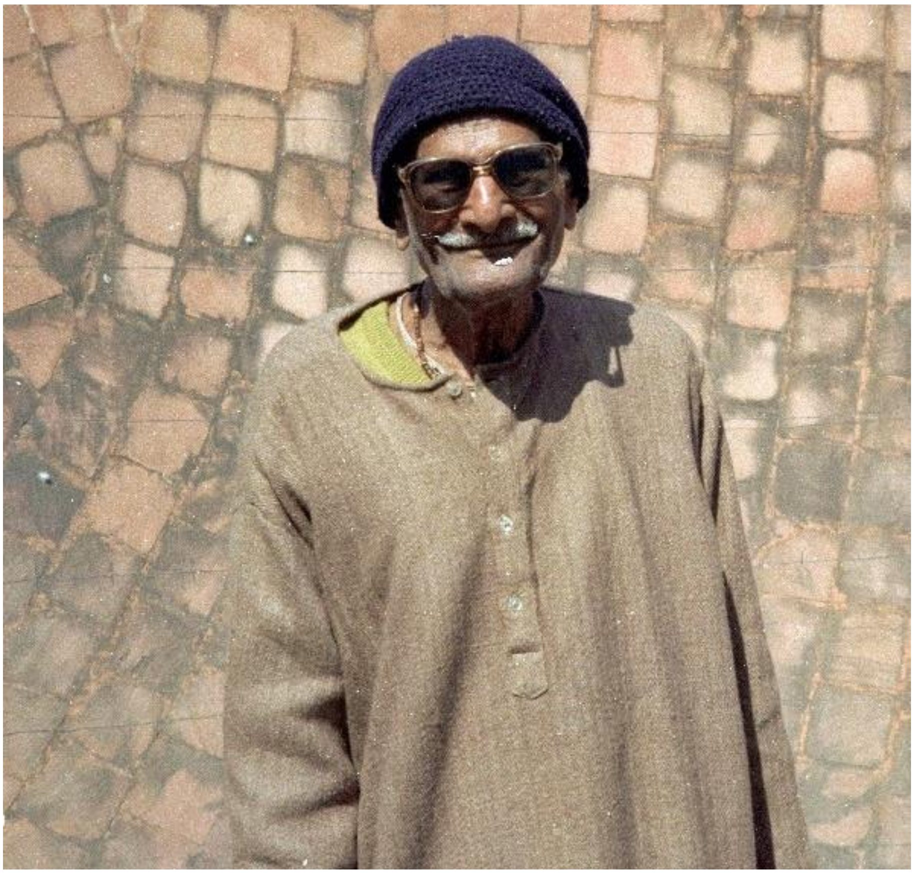

Figure Apx.E.3 – Kalyan Dutt Sharma (photo by S. R. Sarma)

I had the pleasure of meeting him briefly at the Sampurnanand Sanskrit University at Varanasi and he showed me the observatory he had set in the campus there, which was very appropriately named 'Mahāmahopādhyāya Śrī-Sudhākara Dvivedī Vedhaśālā'.[1830]

[1830] Sudhākara Dvivedī was Professor of Jyotiṣa at the Benares College or the Queen's College, the names under which Sampurnanand Sanskrit University was known in colonial times; he made pioneering contributions to the study and interpretation of Sanskrit texts on astronomy and mathematics; cf. Upadhyaya 1994, pp. 300-317; see also R. C. Gupta, 'Sudhākara Dvivedī (1855-1910): Historian of Indian Astronomy and Mathematics,' *Gaṇita Bhāratī,* 12.3-4 (1990) 83-96.

Astrologer's rare gift of observatories

JAIPUR, March. 10.

In a rare gesture which would have made the founder — King of the Pink City Sawai Jai Singh proud, a commoner of Jaipur has contributed five stone observatories to the country for astronomical calculations.

A well-known astrologer of the city, Prof. Kalyan Dutta Sharma, has built four stone observatories — in Haridwar (1981-82), in New Delhi (1982-85), in Varanasi (1992) and in Ayodhya — on behalf of various institutions. He built another one atop the Galta Hills in Jaipur investing his own earnings.

Interestingly, founder King Sawai Jai Singh (Second) had built five observatories at Jaipur, Delhi Mathura, Ujjain and Varanasi in the 18th century.

Prof. Sharma, a former teacher of Maharaja Sanskrit College here, worked as incharge of the ancient observatory — Jantar Mantar, situated in the Walled City here — for several years and had done lot of research work on astronomy.

Later, he joined Vedmata Gayatri Trust of Haridwar in 1981 and remained with the Trust for more than a year to built a stone observatory in Shantikunj thee on request from the Trust management.

In 1982, Prof. Sharma joined the Law Bahadur Shastri Kendriya Sanskrit Vidhaypeeth (Deemed University), New Delhi and worked for three years till 1985 and during the period he built a stone observatory for the use of astronomical scholars as the Jantar Mantar in Delhi built by King Sawai Jai Singh no more remained a centre of research and observations.

Prof. Sharma also built two other stone observatories for the Sampurnanand Sanskrit University in Varanasi and one on the bank of the Sarya river in Ayodhya.

Prof. Sharma said the state of affairs at the Jantar Mantar here was also the same. It has become more of a tourist spot than an astronomical research centre.

He said this situation made him build another stone observatory as an alternative to the Jantar Mantar, atop the Galty Hills. He footed the construction expense using the money received on his footed the construction expense using the money received on his retirement from the services and by other sources. of income.

Prof. Sharma's assistant, Kailash Chaturvedi said it took around Rs. 1.50,000 and a period of five years to build the second stone observatory of the city.

However, this had not provided a relief to Prof. Sharma as there was nobody to look after and utilise the observatory in a systematic manner. He said: "My intention was that some competent agency or institution would take over the observatory which was unused and unprotected since its erection about six years ago. He said although he urged the State Government to take over the observatory, nothing so far has been assured. — UNI

Figure Apx.E.4 – News report in The Hindu, 11 March 1997, New Delhi edition

I had the occasion to visit Shri Lal Bahadur Shastri Rashtriya Sanskrit Vidyapeeth as a member of a committee and we were taken on a brief tour of the grounds where Kalyan Dutt Sharma erected the same set of instruments as in Varanasi. The instruments, made of masonry with marble dials, are the following:

1. *Samrāṭ-Palabhā-yantra.* It is the same as the *Samrāṭ-yantra,* but here the term *palabhā* is added to emphasize the fact that the base of the triangular gnomon is proportionate to the *palabhā* (equinoctial shadow) of the terrestrial latitude of the place.

2. *Yāmyottarīya-cāpa-yantra.* It is the same as the mural quadrant or *Bhitti-yantra* at the Jaipur Observatory, which consists of a wall erected on the north-south line with a single quadrant on one side and a double quadrant on the other; accordingly the replica in

Varanasi is named *Yāmyottara-Turīya-yantra* (quadrant on the south-north line) and that at New Delhi *Yāmyottarīya-cāpa-yantra* (double quadrant on the south-north line).

3. *Nāḍīvalaya-yantra*. It is a simplified version of the instrument bearing the same name in the Jaipur Observatory. On an inclined plane parallel to the plane of the equator, a semi-circular dial is engraved, which is divided in 12 equal segments, each segment is further subdivided in 15 parts, so that each small part corresponds to a degree of arc, or 4 minutes or 10 *palas* in time.

4. *Śaṅku-yantra.* Straight staff set up vertically on an even ground, inside a graduated circle.

5. *Dhī & Miśra-yantra.* It is a hemispherical bowl somewhat like the *Jayaprakāśa-yantra*, but given different names: *Miśra* (mixed) because it can perform the functions of several instruments, *Dhī* (intellect) because the observer's intellect plays an important role in its use and so on.

6. *Cakra-yantra,* the metal ring of the same name in the Jaipur Observatory.

7. *Karkarāśī-valaya-yantra* and 8. *Makararāśī-valaya-yantra* are made in the same manner as the two carrying the same names among the twelve *Rāśīvalaya-yantras* in Jaipur Observatory. In New Delhi a third *Tulārāśi-valaya-yantra* was added to these.

9. *Yāmyottarīya-dharātalīya-turīya-yantra,* some kind of quadrant in the south-north direction.

10. *Krānti-vṛtta-yantra* (ecliptic instrument) and 11. *Ṣaṣṭāṃśa-yantra* (sextant): I did not have the time to see these two at Varanasi and New Delhi; from the very brief descriptions, both appear to be some kind of aperture gnomons, like the *Vṛtta-ṣāṣṭāṃśa-yantra* of the Jaipur Observatory.

For the two institutions, Kalyan Dutt Sharma prepared separate guidebooks in Hindi where the use of the instruments is explained lucidly with detailed examples and tables.[1831]

1831 Kalyāṇadatta Śarmā, *Ma.Ma. Śrīsudhākara Dvivedi Vedhaśālā Paricaya,* Sampurnanand Sanskrit University, Varanasi, 1992; idem, *Vedhaśālā Paricaya Pustikā,* Shri Lal Bahadur Shastri Rashtriya Sanskrit Vidyapeeth, New Delhi, 1994.

Figure Apx.E.5 – Samrāṭ-yantra at Varanasi; on the right can be seen the mural quadrant and behind it the original Neo-Gothic building of the university (photo by S. R. Sarma)

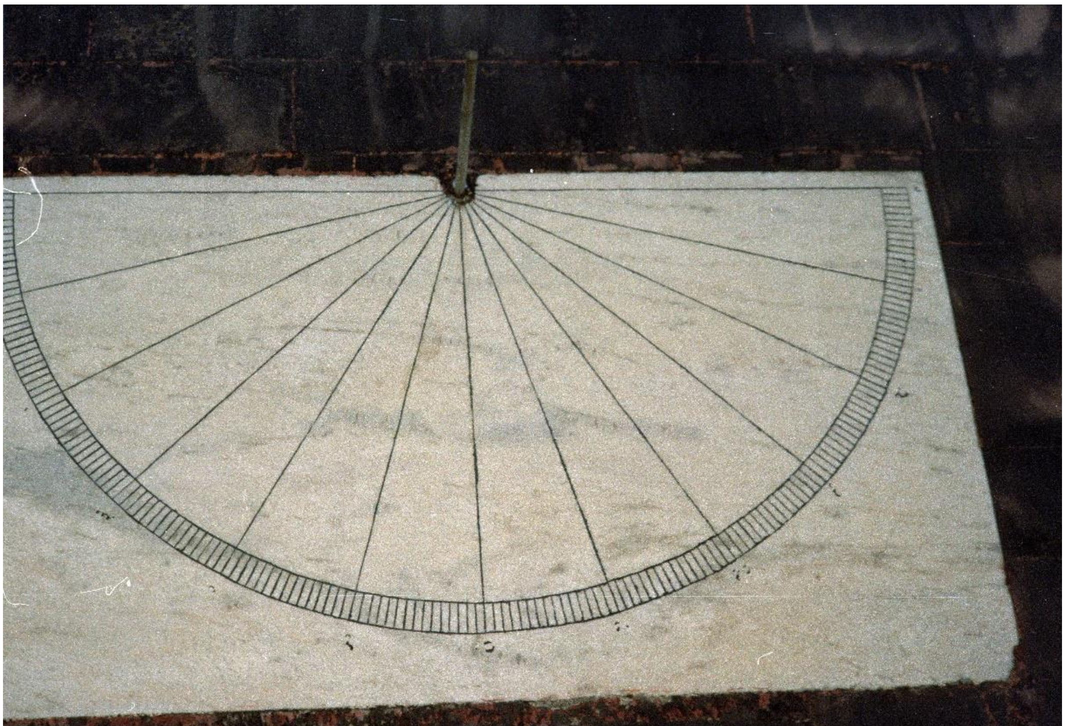

Figure Apx.E.6 – Nāḍivalaya-yantra at Varanasi (photo by S. R. Sarma)

Figure Apx.E.7 – The mural quadrant at Varanasi, front and rear views (photos by S. R. Sarma)

While these two observatories set up in institutions imparting Sanskrit learning in the traditional manner are useful for students studying Sanskrit astronomy (*jyotiṣa*), it is not clear what purpose the remaining were intended to serve. I have not seen the two observatories at Hardwar and Ayodhya, nor could I find any reports or descriptions of the instruments set up there.

The fifth one was set up on the Galta Hills at Jaipur, to the east of Jai Singh's observatory. I walked there on a hot summer day in 2003 and had some difficulty in locating the observatory built in a desolate place. The barbed wire enclosing the instruments was trampled down and cows and pigs were resting amid the marble instruments.

There were five instruments, erected one behind the other on the north-south line. Each instrument carried a small plaque on which the name and the function of that instrument were written in Hindi. The five instruments are *Samrāt-yantra*, *Makararāśī-valaya-yantra, Karkarāśī-valaya-yantra, Bhitti-yantra* and *Ṣaṣṭyaṃśa-yantra.*

The last name literally means 'Sixty-degree-instrument'. It is built like a room, closed on three sides, but open in the north. On the top, where there should be an aperture to let in a ray of sunlight, cow dung cakes were arranged to dry.

Inside the room, a sextant is built in masonry in the north-south direction, the arc is divided in single degrees, and labelled with the names of the zodiac signs in Hindi, starting with *Karka* at the bottom and ending with *Makara* at the top, in the following manner:

0° *Karka, sab se baḍā din* (Cancer, the longest day of all)

Siṃha / Mithuna (Leo, Gemini)

15° *Vṛṣa / va Kanyā* (Taurus and Virgo)

27° *Tulā / Meṣa krāṃti 0 din rāt barābar* (Libra, Aries, declination zero, day and night equal) *Mīna / Vṛścika* (Pisces, Scorpio)

47° *sā[yana] Kuṃbha / Dhana* (tropical Aquarius, Sagittarius)

60° *Sā[yana] Makara, sab se choṭā din* (tropical Capricorn, the shortest day of all)

It was highly distressing that the instruments here were in such a sad state of neglect;[1832] it is not known what their situation is now.

1832 It is perhaps good that I cannot locate my photos of these instruments any more!

2. GUNMA OBSERVATORY, JAPAN

Figure Apx.E.8 – Gunma Observatory, General View (photo courtesy Gunma Observatory)

When the population in the province of Gunma, in central Japan, crossed two million, it was decided to commemorate the event by erecting a lasting monument. Since the first Japanese lady astronaut Chiaki Mukai who made a space flight in 1994 was born in this province, it was further decided to built an astronomical observatory in her honour and also to add replicas of some ancient observatories next to the modern one on the top of a 850 metres high mountain. The noted architect Arata Isozaki was commissioned to design the entire complex.

In the photo above, the observatory is in the foreground; on the right can be seen the replicas of the smaller *Samrāṭ-yantra* and of the twelve *Rāsīvalaya-yantras* at the Jaipur Observatory and behind them the replica of Stonehenge. The replica of the smaller *Samrāṭ-yantra* is about half the size of the original and the *Rāśivalaya-yantras* are of about the same size or slightly larger than the originals. The location is splendid and the replicas are made with the greatest care and accuracy. Opened to the public in 2001, it has now become an important centre of tourism. I visited this place in May 2002.

Figure Apx.E.9 – Replicas of Jaipur instruments, with the replica of Stonehenge in the background (photo courtesy Gunma Observatory)

Figure Apx.E.10 – Replica of the smaller Samrāṭ-yantra (photo courtesy Gunma Observatory)

3. COTTESLOE SUNDIAL, NEAR PERTH, AUSTRALIA[1833]

For commemorating the two hundred years of European settlement in 1988, the Australian Government offered financial support for a suitable bicentennial monument. Cottesloe, a waterfront suburb 11 km west of Perth, capital of the State of Western Australia, took up the offer and erected a high sundial in mid 1990s on the cliff above Mudurup Rocks. The sundial, visible to motorists travelling along Marine Parade, is a blend of the old and the modern; the original design is based on the *Samrāṭ-yantra* of Jaipur, but it also incorporates computer-generated equation curves.

Figure Apx.E.11 – Cottesloe Sundial (photo courtesy Professor John Perdrix)

In the place of the single triangular gnomon of the original *Samrāt-yantra*, two gnomons are set up here, which are separated by a walkway. They are constructed of limestone blocks, each capped by a precast concrete section in order to give a sharper shadow line. The height of the gnomon is 7 metres and the hypotenuse is inclined from

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[1833] I am grateful to Professor John Perdrix, Managing Editor of the *Journal of Astronomical History and Heritage* for the photos; the description is based on a note kindly sent by him on 22 June 2000.

the base at an angle of 31;56°, which is the geographical latitude of the place and thus parallel to the earth's axis.

The quadrants are made of 316 marine grade stainless steel with a thickness of 5.3 mm and a width of 1.2 metres. In order to convert apparent solar time indicated by the gnomon's shadow to mean solar time, equation of time curves are engraved on the surfaces of the quadrants. The curves were engraved with a computer-controller laser, the program for which was written by the astrophysicist Tony Hooley.

Figure Apx.E.12 – Dial on the quadrant engraved with equation of time curves, on the right is the shadow of the gnomon (photo courtesy Professor John Perdrix)

4. MIŚRA-YANTRA IMITATIONS IN AMUSEMENT PARKS IN FRANCE

Figure Apx.E.13 – Miśra-yantra in the Delhi Observatory (photo by S. R. Sarma)

The question when and by whom the *Miśra-yantra* of the Delhi observatory was erected will remain an unsolved enigma, but pictures of this instrument with its elegant curves inspired some structures in the amusement parks in and around Paris in early nineteenth century, not for astronomical observation, but for the diversion of the visitors as the forerunners of roller-coasters.

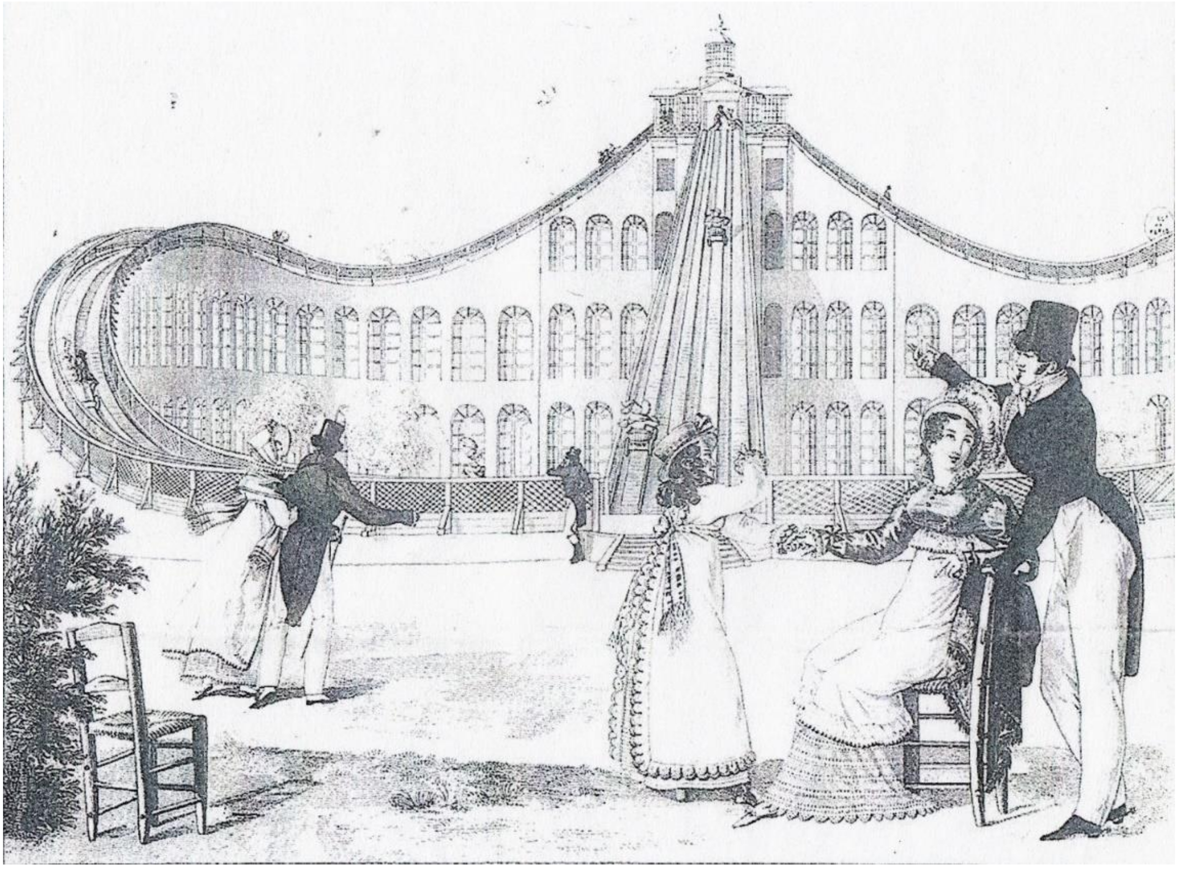

Figure Apx.E.14 – Prominade aérienne, Neuilly (image courtesy Anthony J. Turner)

In the structure called 'prominade aérienne' (aerial promenade) at Neuilly, a suburb of Paris, there was a pavilion at the top of the central aisle. The visitor reached the pavilion by a staircase at the back and sat in a little wheeled carriage which was then pushed down one of the curved wings. In descent the carriage would gain such a speed that it would go up the central aisle up to the pavilion, from where the visitor could go down for one more round.[1834]

1834 Penelope Chetwode, 'Delhi Observatory: the Paradise of an early Cubist,' *The Architectural Review,* 1935, pp. 57-60, esp. 59.

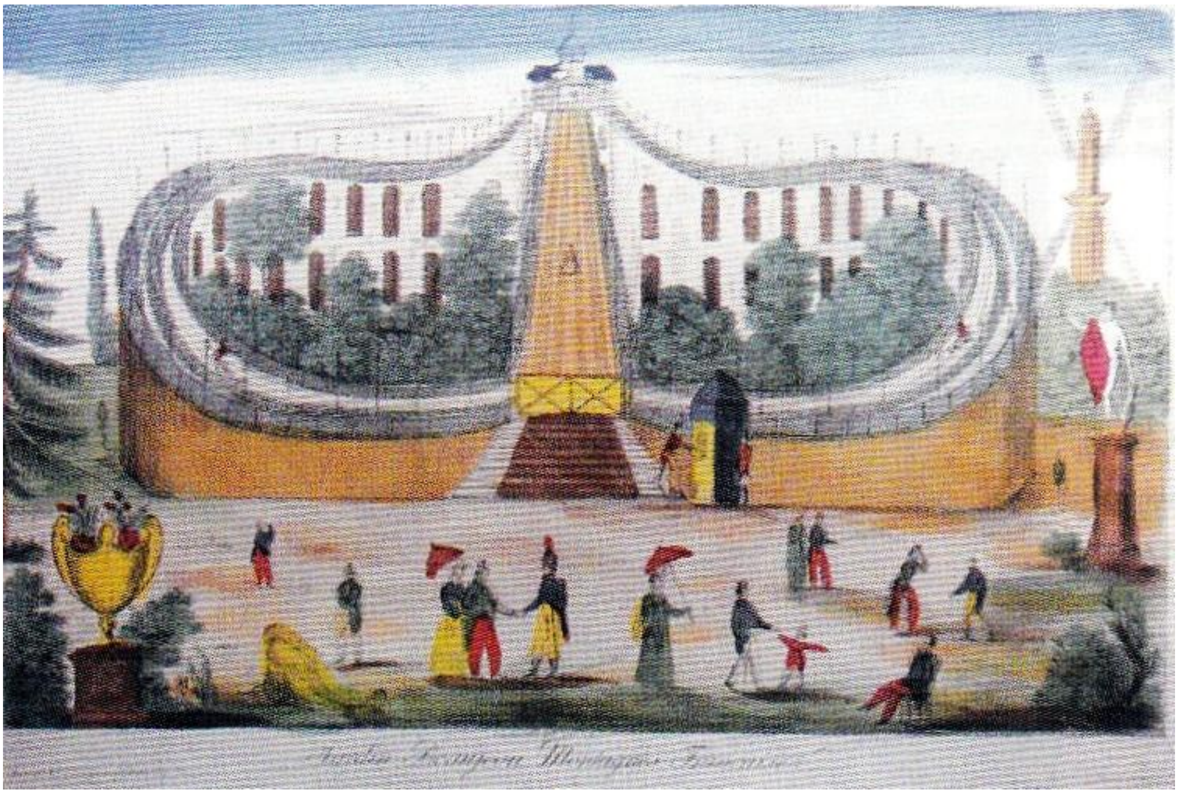

Figure Apx.E.15 – ’Les Montagnes françaises’ (image courtesy Anthony J. Turner)

Another structure was set up in 1817 in an amusement park by name ‘Folies Beaujon’ (Beaujon’s Follies) in the vicinity of the present Champs Élysées and this one carried the name ’Les Montagnes françaises’ (the French Mountains). Here the visitor was driven up one or the other side wings in a horse drawn carriage. At the top, the carriage was detached from the horses and made to slide down the central aisle at a bewildering speed. None of these structures are extant anymore, except for the pictorial records.

5. MAHARISHI VEDIC OBSERVATORY

From amusement, we now go to spiritualty. In 1997 Maharishi Vedic University appropriated Sawai Jai Singh's astronomical instruments and marketed a product: 'The Maharishi Vedic Observatory: An Ancient Vedic Technology to Expand Awareness, Train the Vision and Mind to focus on the Mathematical Precision and Order that Regulate the Universe without Problems'.[1835]

In this product, stylized replicas of Jai Singh's astronomical instruments from the Jaipur and Delhi observatories are arranged in a circle; starting at the top and proceeding clockwise, these are *Samrāṭ-yantra, Nāḍīvalaya-yantra,* the pair of *Rāma-yantras,* the pairs of *Kapāla-yantras* and of *Cakra-yantras, Miśra-yantra, Digaṃśa-yantra,* the pair of *Jayaprakāśa-yantras* and *Dakṣiṇodak-bhitti-yantra.* The large circle surrounded by eight small circles in the centre is said to represent the *Rk-veda.* The website describes the structures and their astronomical functions reasonably correctly, but in each case the emphasis is not on astronomical observation, but on viewing the instrument itself in order to awaken one's consciousness.

In the interpretation of this organization, the instruments designed by Sawai Jai Singh in the first quarter of the eighteenth century have become part of 'ancient Vedic technology'. Sawai Jai Singh's name is mentioned nowhere, nor the names of the Jaipur Observatory and of the Delhi Observatory from where the instruments are copied.

Lest one should question the ahistorical approach in the misattribution of instruments created for the first time in the eighteenth century to the Vedas and the total suppression of the name of Sawai Jai Singh, one is told: 'When viewing the Maharishi Vedic Observatory what is important is the actual perception, not the intellectualization.'

1835 http://vedicobservatory.svr.com/YRkVedaDisplay.html
[also https://goo.gl/dRSvcu, last accessed in January 2018]