The Emergence of "cyclic" tables in Indian Astronomy in the seventeenth century: Haridatta's *Jagadbhūṣaṇa* and its Islamic inspiration

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Abstract:
Indian planetary tables can be classified into several distinct types with respect to their underlying mathematicbal structure. One of these, the so-called "cyclic" scheme was inspired by goal-year periods introduced via Islamic channels no later than the early seventeenth century. The first set of such cyclic planetary tables is the *Jagadbhūṣaṇa* of Haridatta, composed in Mewar, Rājasthan with an epoch of 31 March 1638. This substantial work, spreading over more than 100 folia in some manuscripts, computes the true longitudes of the planets in a manner similar to those in the Babylonian goal-year texts, Ptolemy, and al-Zarqālī. We will consider the inspiration from these earlier sources and how they are incorporated into a distinctly Indian context, with respect to mathematical structure, astronomical foundation, and layout and arrangement of the data in the tabular format.

Keywords: Numerical tables, Haridatta, *zīj*, goal-year, al-Zarqālī, Indian astronomy

1. Introduction

It has been argued that the emergence of the tabular format in India, that is the spatial presentation of data aligned in rows and columns, is linked to Islamic influences[1] particularly through the popularity of the *Zīj* compositions. In addition to inspiration in format and layout, tabular content and structure also travelled from Islam to India. An instance of this are the so-called cyclic tables, a scheme in which true longitudes of the planets are computed via large period

[1] See Pingree, D. E. (1981). *Jyotihsāstra*, Otto Harrassowitz, Wiesbaden, 41-6 and Plofker, Kim. (2009). *Mathematics in India*, Princeton: Princeton University Press, 274-7.

relations: a set number of revolutions over a known time interval for each planet, such as the schemes used in Babylonian Goal-Years, Ptolemy, and al-Zarqālī. Cyclic tables were eventually transmitted to India. The first set of such cyclic planetary tables is the *Jagadbhūṣaṇa* of Haridatta, composed in Mewar, Rājasthan with an epoch of Saturday 31 March 1638. This substantial work, spreading over more than 100 folia in some manuscripts, tabulates the true longitudes of the planets, as well as some lunar and solar phenomena. The extent to which they rely on earlier inspiration, notably from Islamic sources, is an outstanding question. In order to begin to answer this question, the tables themselves must be better understood so that comparisons can be made.

2. Analysis

Haridatta composed the *Jagadbhūṣaṇa* during the region of Jagatsiṃha I (1628—1652). The title of this work is no doubt a double-entendre; *bhūṣaṇa* means 'ornament' and *jagat* means 'world' but also here refers to Jagat-siṃha, so the title means "ornament of the world' and also 'ornament [offered to the ruling prince] Jagat[siṃha]'. The work has been preserved in at least two dozen manuscripts, many of which are incomplete.[2] The numerical entries in various tables reveal that the terrestrial latitude for which these tables were computed is approximately φ = 24ºN, which corresponds to the latitude of Ujjain. The primary manuscripts available for this study are:

- **P**: Poleman 4869 (Smith Indic 146) 100ff
- $\mathbf{J_1}$: Jaipur 10192 66ff
- $\mathbf{J_2}$: Jaipur 20253 88ff

Apart from the title, none of these manuscripts contains any more information about the work. None of them have a colophon, so we can not be sure of their provenance, their date of copying nor the details of their production.

There is a text which accompanies the tables.[3] Material in the colophon tells us that Haridatta's father was Harajī. The text is divided into 5 chapters which cover topics on the true longitudes of the sun, the moon, and the planets, and gives key dates, parameters, and algorithms on how to use the tables. The text is around 130 verses long, with variations in chapter composition between different copies.

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[2] For a detailed list see Pingree, D. E. (1968). "Sanskrit Astronomical Tables in the United States" *Transactions of the American Philosophical Society* New Series, vol. 58, no. 3, 55—59.

[3] The two copies available for consultation were 5420 City Palace Jaipur 7ff and BORI 399/1899-1915 4ff.

An overview of the contents of the tables is given in table 1 below. The majority of the *Jagadbhūṣaṇa* is devoted to tables which provide the true longitudes of the planets and related phenomena according to the cyclic scheme (around 95 folia out of the 100). Each planet is assigned a great cycle, or number of years, in which the various planetary phases and circumstances repeat. These cyclic periods and the order of presentation of the planets as they appear in **P** are presented in Table 2.

Mars	True longitudes and true velocities for 27 14-day periods over 79 years (79 rows)
Mercury	True longitudes and true velocities for 27 14-day periods over 46 years (46 rows)
Jupiter	True longitudes and true velocities for 27 14-day periods over 83 years (83 rows)
Venus	True longitudes and true velocities for 27 14-day periods over 227 years (227 rows)
Saturn	True longitudes and true velocities for 27 14-day periods over 59 years (59 rows)
Lord of the Year	For 0 to 88 years
Epact	0 to 121 years
Moon	Mean annual motion for 0 to 121 years
Anomaly	Mean annual motion for 0 to 42 years
Moon	Mean motion for 27 14-day periods
Anomaly	Mean motion for 27 14-day periods
Moon	Mean motion for 1 to 13 days
Anomaly	Mean motion for 1 to 13 days
Moon	Mean motion for 1 to 60 *ghaṭikā*s
Moon	Table of lunar equations for arguments 0 to 90 degrees (5 columns of entries)
Avadhi (14-day period) Conversion	Table to transform 14-day periods from 24 hour days to sunrise days
Sun	True longitudes for 1 to 27 14-day periods
Length of daylight	Length of daylight at the beginning of each of the 27 14-day periods
Lunar Node	Mean motion for 0 to 92 years.
Lunar Node	Mean motion for 1 to 27 14-day periods
Solar transits	Day and fraction thereof on which the sun enters each of the 12 signs of the zodiac.

Table 1: An outline of the contents of the tables

Planet	Location	Cyclic Period
Mars	ff. 1v–21	42 revs in 79 years
Mercury	ff. 22–33 ff.	46 revs in 46 years
Jupiter	34–47v ff.	7 revs in 83 years
Venus	48–85v ff.	227 revs in 227 years
Saturn	86–95v	2 revs in 59 years

Table 2: The lengths of Haridatta's cyclic periods

Some cyclic periods are relatively short (for instance, Mercury's cyclic period is 46 years) and others are much longer (for instance, Venus is notably long at 227 years). What is also notable about this ordering of the planets is that they appear in the following order: Mars—Mercury—Jupiter—Venus—Saturn, following the "week-day" order.[4]

Unlike other tabular formats that existed in India at the time, such as the mean linear and the true linear tables which required the consultation of multiple tables to establish the true position of a given planet, cyclic tables provided their users with the true longitude of the planet for a *single* look-up. All one needed to enter the tables with was the number of years and 2—week periods since the epoch to retrieve the true longitude for that date.

Great cycles for planetary phenomena had been used in many other cultures of inquiry. In fact some of the earliest planetary schemes were based on such a system, such as the Babylonian "Goal-Year" periods which emerged some time in the first millennium BCE (see table 7).[5] Later authors in different traditions who used similar schemes often introduced small corrections to the Goal Years for increasing their accuracy over time.

As well as the true longitudes, Haridatta's tables give the true daily velocity for that position. The true longitudes are given in zodiacal signs, degrees, minutes and seconds. The true velocities are given in minutes and seconds. In addition, the date and times of the synodic phases for the planets are given as

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[4] For the significance of the ordering of the astronomical day names, see, for instance, Falk, M. (1999) "Astronomical Names for the Days of the Week" in *Journal of the Royal Astronomical Society of Canada*, (93), 122-3.

[5] A good overview of the goal-year texts can be found in Evans, James. (1998). *The History and Practice of Ancient Astronomy*, New York Oxford: Oxford University Press, pp. 312—321. More detailed descriptions can be found in Asger Aaboe, *Episodes from the Early History of Astronomy*, New York: Springer, 2001 and Steele, John. (2011). "Goal-Year Periods and their Use in Predicting Planetary Phenomena" in Selz, Gebhard J. and Klaus Wagensonner, (eds.) *The Empirical Dimension of Ancient Near Eastern Studies*, Wiener Offene Orientalistik, band 6, pp. 101—110.

well. The very first entries of the tables contain a sidereal epoch correction. For each of the planets these are as follows:

Planet	Epoch value
Saturn	4,43;58,13°
Jupiter	6,14;10,15°
Mars	4,2;48,17°
Venus	22;7,34°
Mercury	5,40;37,15°

Table 3: Epoch corrections

Marginal labelling suggests that the epoch of the tables is 31 March 1638, which was a Saturday. This is confirmed by modern retrodictions.[6]

More broadly, establishing the methods of computation to generate the tabular entries and the base tables on which these cyclic tables depended on is a hugely complex enterprise. Scant literature exists even in well documented traditions such as those of medieval Europe.[7] In this case, the accompanying text to Haridatta's tables may provide some clues, however in general reconstructing the precise numbers that are found in the tables can be extremely difficult, even when the method of computation is made explicit by the author. Intermediary roundings, interpolation, unexpressed assumptions, and tacit mathematical shortcuts used by the original calculator can be near impossible to reproduce.[8]

3. Case Study: Jupiter

Haridatta's planetary tables address the following three questions: Where is the planet? How fast is it going? Where and when are the key synodic phases going to occur? The tables tabulate the data necessary to answer these questions using time since the epoch as their argument. Given the extent and complexity of the tables, we select a single planet, Jupiter, to describe some salient features of the data and its arrangement. Jupiter is a superior planet whose synodic arc is about 30 degrees. Here, as mentioned, its cyclic period is 83 years within which time it

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[6] Pingree, D. E. (1968). "Sanskrit Astronomical Tables in the United States" *Transactions of the American Philosophical Society* New Series, (58-3), 1–77.

[7] See for instance, Chabás, José and Bernard R. Goldstein (2012). *A survey of European Astronomical Tables in the Late Middle Ages*, Leiden: Brill.

[8] Some of these issues are outlined in Van Dalen, Benno. (1993). *Ancient and Mediaeval Astronomical Tables: Mathematical Structure and Parameter Values*, Netherlands.

makes 7 revolutions. The very first value in the table for the true longitude is 6s, 14°;10′,5″ and the very last, eighty-three "cyclic-years" later, is 6s, 13°;31′,24″. Given that the previous (penultimate) tabulated value is 6s, 14°;43',0'' (i.e., Jupiter is undergoing a period of retrogradation), one can infer that Jupiter made 7 complete revolutions in just under 83 years.

The argument of the planetary tables is time, which is divided into years and *avadhis*. An *avadhi* is a 14-day interval and this division of time is specific to the Indian tradition.[9] One year thus includes 27 *avadhis*. The first *avadhi* begins on the first day of the year, the second, 14 days later, and so on, so that the 26th *avadhi* begins on the 350th day of the year, and thus the 27th *avadhi* begins on the 364th day of the year. Each one of the 83 years of Jupiter's scheme has 27 *avadhis* as its argument and the true positions and true velocities for these dates are tabulated underneath in a horizontal band.

The way the data is laid out can be seen in figure 1. This page from the tables contains three distinct horizontal bands of numerical data. Here the first band is for the 39th year of the cycle of Jupiter, the second the 40th, and the third the 41st. These cycle numbers are indicated on the far left. Each band is divided into three rows. The first contains the argument, here *avadhis,* which goes from 1 to 27. The next row of numbers gives the true longitudes in zodiacal signs and so on to a precision of seconds. The final row of numbers gives the planet's daily velocity at that longitude in minutes and seconds. The numerical entries themselves hang vertically; that is zodiacal signs are above the degrees, which are above the minutes which are above the seconds. This vertical format is typical of most tables in Sanskrit mathematical astronomy.

[9] See, for instance, Pingree, D. E.(1981). *Jyotihsāstra*, Otto Harrassowitz, Wiesbaden, p. 41 or Montelle, C., & Plofker, K. (2014). "The Karaṇakesari of Bhāskara: a 17th-century Table Text for Computing Eclipses". *History Of Science In South Asia, 2*(1), 1-62. Retrieved from http://hssa.sayahna.org/ojs/index.php/hssa/article/view/6, p. 13-14, 52.

Figure 1: f. 40v from Haridatta's *Jagadbhūṣaṇa* showing years 39, 40 and 41 for Jupiter

In addition to giving the velocity, additional marks around the numbers reveal trends in the data. For instance, small crosses (an abbreviation for the Sanskrit word *ṛṇaṃ*) indicate that the planet is travelling in retrograde motion. This is not always consistently applied in this particular manuscript. Here in figure 1, the crosses can be seen, for instance, in the first band, third row, 6th entry, 10th entry, 12th entry, 13th entry, and 14th entry.

As mentioned, the synodic phases of the planet, often called the Greek Letter Phenomena,[10] are included as part of the tables. The details concerning these phases are either inserted at the various appropriate entries or directly below them. More commonly, they are listed in the far right hand margin. The way in which this has been achieved is notable. The correspondence between the date and time of a specific synodic phenomenon and the appropriated column is captured via an indexing number. The synodic phenomena are recorded via an abbreviation for the particular phase in question, followed by 2 numbers. The first number is an *avadhi* day number (from 1 to 13) and the second a measure of *ghaṭikās* (one day is divided into 60 *ghaṭikās* so that 1 *ghaṭikā* is 24 minutes) from 1 to 60. Above this data, the *avadhi* number to which it is to be applied is given (from 1 to 27). The synodic phenomena for a superior planet and its Sanskrit equivalent and abbreviation can be seen in table 4.

Sanskrit Abbreviation	Sanskrit Term	Phenomenon
va	vakra	first station (φ)
mā	mārga	second station (ψ)
a	asta	disappearance (Ω)
u	udaya	reappearance (Γ)

Table 4: Greek letter phenomena and the Sanskrit equivalents for a superior planet.

On the right hand side of the page, this specific arrangement and indexing can be seen; for instance, on f. 40v (see figure 2 and table 5) the synodic phenomena are recorded as:

[10] For an explanation of these, see for instance Neugebauer, Otto. (1975) *The History and Practice of Ancient Astronomy*, New York, Springer-Verlag, p. 386—7.

5	14	23	25
va 10 0	mā 3 36	a 2 21	u 6 14

Table 5: Table of the presentation of the synodic phenomena on the first band of f. 40v.

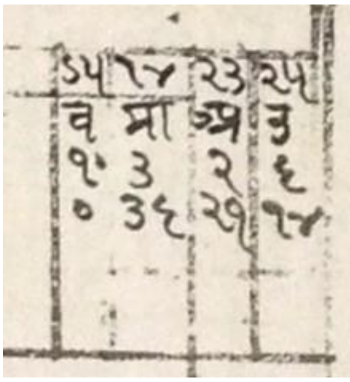

Figure 2: Close up of the synodic phenomena being indexed for cycle 39

The first row gives the column to refer to (in *avadhis*), the second row the synodic phase, the third row the number of days after that particular *avadhi*, and the fourth the time of day (in *ghaṭikās*) in which the synodic phase occurs.

Thus:

- **5 va 10 0** means the first station *vakra* occurred 10 days after the 5th *avadhi* (or (5-1) x14 = 56 days), that is on the 66th day on the zeroth *ghaṭikā*.
- **14 mā 3 36** means the second station *marga* occurred 3 days after the 14th *avadhi* (or (14-1) x 4 = 182 days), that is on the 185th day of the year during the 36th *ghaṭikā*.
- **23 a 2 21** means the disappearance *asta* occurred 2 days after the 23rd *avadhi* (or (23-1) x 14 = 322 days), that is on the 324th day of the year during the 21st *ghaṭikā*.
- **25 u 6 14** means the reappearance *udaya* occurred 6 days after the 25th *avadhi* (or (25-1) x 14 = 336 days), that is on the 342th day of the year during the 14th *ghaṭikā*.

To contrast the layout given in **P**, the same tables are reproduced for $\mathbf{J}_1$ (see figure 3) and $\mathbf{J}_2$ (see figure 4).

Figure 3 $\mathbf{J}_1$ Haridatta's *Jagadbhūṣaṇa* showing years 36, 37, 38, and 39 for Jupiter

Figure 4 **J**$_2$ Haridatta's *Jagadbhūṣaṇa* showing years 39, 40, and 41 for Jupiter

4. First and Second stations

Reconstructing the methods of computation of the various synodic phases in this case is complex. Selecting one synodic phenomenon, first stations, all the entries were extracted from the tables[11] and their first and second differences were examined. Indeed, there were some obvious (scribal) errors in the data. However, neither the first differences nor the second differences were constant. Therefore, it can be concluded that these stations were *not* computed via a step function to generate the differences from one entry to the next (one would expect the differences to be in blocks of largely the same number) *nor* via a linear zig zag function (as the second differences would be almost all constant). However, when the times of the stations were plotted, the general pattern in the data revealed that qualitatively these differences are nearly linear (see figures 5 and 6).

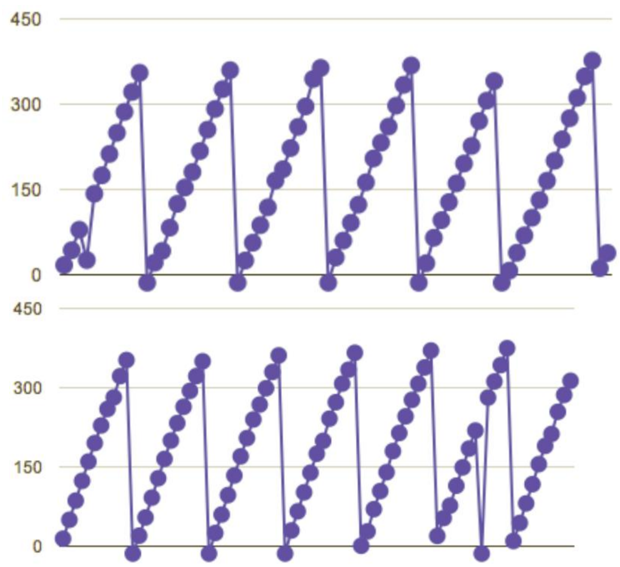

Figure 5 and 6 A graph showing the first (left) and second (right) stations

5. Transmission

In medieval Europe, the Almanac tradition, that is sets of tables giving the true longitudes of the sun, moon, and the planets per small interval of days via period

[11] See table in appendix

relations, became increasingly popular.[12] Such schemes were used by the Babylonians and these goal-year periods (see table 6) reached Greek astronomers and adaptations of them formed the basis of Ptolemy's *Almagest*. Ptolemy's periods are outlined in *Almagest* IX, 3 are as follows (see table 6)

	Ptolemy
Saturn	2 revs +1;40° in 59 y + 1;35d
Jupiter	6 rev + 4;50° in 71y + 4;54d
Mars	42 rev +3;10° in 79 y + 3;13d
Venus	8 rev - 2;1° in 8 y - 2;18d
Mercury	46 revs + 1ª in 46y + 1;2d

Table 6 Ptolemy's cyclic periods

	Babylonian 'Goal Years'	al-Zarqālī
Saturn	2 revs in 59 years	2 revs in 59 years
Jupiter	6 revs in 71 years	7 revs in 83 years
Mars	42 revs in 79 years	42 revs in 79 years
Venus	8 revs in 8 years (5 syn periods)	8 revs in 8 years (5 syn periods)
Mercury	46 revs in 46 years (145 syn periods)	46 revs in 46 years (145 syn periods)

Table 7 Other cyclic periods

One of the earliest known almanacs produced in Muslim Spain which proved to be highly influential is that of al-Zarqālī (d.1100) working in al-Andalus. The epoch of these tables is September 1 1088, and while these tables appear to be based on Ptolemy there are several key differences which are critical for

[12] Chabás, José and Bernard R Goldstein. (2000) "Astronomy in the Iberian Peninsula: Abraham Zacut and the Transition from Manuscript to Print", *Transactions of the American Philosophical Society*, New Series, (90-2), pp. iii—xii + 1–196.

understanding the transmission to Indian sources. Al-Zarqālī's tables are based on the following relations (see table 8):

	al- Zarqālī
Saturn	59y + 1;55°
Jupiter	83y - 2°
Mars	79y + 1°
Venus	8y + 1;30°
Mercury	46y - 2;45°

Table 8: al-Zarqālī 's cyclic periods

Here, Jupiter's period is 83 years, which is the value that Haridatta uses in contrast to Ptolemy's 71 years. This suggests that the Indian cyclic tables derived from this particular tradition, initiated by al-Zarqālī. There do exist some important contrasts though. For instance, al-Zarqālī tabulates his entries for Jupiter for 10 days periods (on the 1st, 11th, and 21st day of each month) to a precision of degrees. Whatever the passage of tables arranged in this way, they undergo two key modifications by Haridatta. The first is that these 10-day intervals have been reorganized into *avadhis*, or 14 day periods, a time-interval fundamental to much mathematical astronomy in the Indian subcontinent. Secondly their precision is to degrees, minutes, and seconds. These are but a few of the obvious traces of modification of astronomical tables transmitted from another culture of inquiry.

6. Concluding Remarks

Cyclic tables inspired a new way to organize planetary phenomena to Indian practitioners. Although they involved much computation to prepare the tabular data, the tables themselves offered the true longitudes of the planets with a single look up. Furthermore, modifications were made to the scheme, such as the arrangement with respect to *avadhis*, or two week periods, and some minor corrections to the goal years. Further analysis needs to be done to establish the precise details of the transmission from earlier sources, particularly from the Islamic near east.

Firstly, the extent of the transmission needs to be established. Was it simply the ‘goal year periods’ which were incorporated into existing Indian planetary motions or were more detailed parameters imported as well? The tables represent a huge computational effort. The precise assumptions, operations, and parameters need to be determined by a through numerical analysis of the true longitudes and their corresponding velocities to reconstruct the ways in which these tables were computed. A careful translation and technical commentary of the accompanying text will no doubt be crucial to this aim. Other questions arise, such as the reception these tables had. Did they prove to be more popular amongst practitioners than the existing tradition tables to compute planetary phenomena? The efficacy of these tables should also be considered. How close to the phenomena were these data in these tables? Addressing these questions will help to shed light on the variety and scope of planetary phenomena computations in second millennium Sanskrit astral sciences.

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Appendix: Jupiter's Second Stations

Year Number	Avadhi	Day and *ghaṭikā*
0	6	5 – 2
1	8	3 – 27
2	11	11 – 15
3	13	2 – 47
4	15	1 – 15
5	18	6 – 23
6	21	1 – 28
7		
8		
9		
10	2	3 - 2
11	4	1 – 8
12	6	9 – 7
13	2	11 – 51
14	11	2 – 28
15	13	6 – 48
16	16	2 – 27
17	18	11 – 41
18	21	6 – 28
19	23	13– 30
20	26	5 – 12
21		
22	2	7 – 18
23	4	
24	6	12 – 48
25	9	12 – 42
26	11	13 -–25
27	13	12 – 40
28	16	7 – 32
29	19	3 – 7
30	21	11 – 35
31	24	4– 27

32	26	9 – 45
33		
34	2	11 – 4
35	5	0 – 21
36	7	3 – 12
37	9	6 – 36
38	12	11 – 38
39	14	3 – 36
40	16	12 – 45
41	19	8 – 5
42	22	2 – 3
43	25	8 – 17
44	26	13 – 48
45		
46	3	2 – 25
47	5	4 – 8
48	7	7 – 25
49	9	11 – 20
50	12	8 – 34
51	15	8 – 34
52	17	8 – 18
53	19	8 – 38
54	22	3 – 25
55	24	12 – 0
56	27	4 – 12
57		
58	2	6 – 25
59	5	9 – 3
60	7	11 – 59
61	10	1 – 43
62	12	6 – 44
63	14	13 – 38
64	17	2 – 35
65	20	4 – 15
66	22	12 – 7
67	25	4 – 42
68		

69	1	7 – 12
70	3	10 – 40
71	5	13 – 15
72	8	2 – 15
73	10	5 – 18
74	12	11 – 21
75	15	4 – 32
76	18	0 – 6
77	20	9 – 20
78	23	3 – 20
79	25	12 – 49
80	27	12 – 48
81	1	11 – 32
82	3	10 – 15