

# SANSKRIT ASTRONOMICAL TABLES: THE STATE OF THE FIELD

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## Abstract

Tabulated data in various forms were recorded within Sanskrit astronomical texts in a bewildering variety of ways for over two thousand years, from the star-lists of ancient hymns, through the mathematical function values in early medieval verse treatises, to the full-blown numeric-array table texts used in the second millennium to generate calendars and horoscopes. Several of these tables have been studied in the context of the individual works containing them, and some preliminary surveys of the more elaborate table-text genres have been published, but many aspects of these texts' development remain mysterious. This article summarizes what is presently known about the genesis and evolution of such tables in India, and outlines the chief issues urgently requiring further exploration.

**Key words:** Arrays, Astronomy, Bhāskara, Brahmagupta, Handbooks, India, Sanskrit, Tables, Treatises, Zījes

## 1. METROLOGICAL AND ASTRONOMICAL LISTS IN ANCIENT TEXTS

The oldest known Sanskrit works, the Vedic hymn and ritual texts originating at least as far back as the late second millennium BC, were for many centuries composed and preserved exclusively in oral tradition. Created exclusively to be spoken and heard, they could not directly represent two-dimensional visual layouts like the ones that ancient Mesopotamian cultures incised on slabs of clay (Robson 2003). Instead, they recorded sets of data in the form of verbal lists within the verses of hymns or in short prose statements (*sūtras*) in texts on ritual practice.

For instance, in *Taittirīya-saṃhitā* 4.4.10 of the *Kṛṣṇa-Yajurveda* (probably about 1000 BC, give or take a few centuries) the invocation incorporates a canonical list of twenty-seven constellations forming the circle of the moon's path in the sky, each with its own corresponding deity or deities:<sup>1</sup>

*kṛttika nakṣatraṃ agnir devatā.. . rohiṇī  
nakṣatraṃ prajāpatir devatā mṛgaśirṣaṃ  
nakṣatraṃ somo devatā...*

[You are] the constellation Kṛttika, the deity Agni... the constellation Rohiṇī, the deity Prajāpati; the constellation Mṛgaśirṣa, the deity Soma...

Dating from perhaps a few centuries later, a sacral-geometry ritual text begins its technical exposition (*Baudhāyana-Śulbasūtra* 1.3) with several *sūtras* or aphorisms making up a “ready reckoner” of various measures of length (Sen and Bag 1983, p. 17):

*athāṅgulapramānaṃ caturdaśāṅgavaḥ  
catuṣtriṃ śattilāḥ pṛthusamśliṣṭā  
ityaparam | daśāṅgulaṃ kṣudrapadam  
| dvādaśa prādeśaḥ | pṛthottarayuge  
trayodaśike | padaṃ pañcadaśa |*

Now the measure of a digit is fourteen millet-grains; another [measure of a digit] is thirty-four sesame seeds side by side lengthwise. Ten digits is a small foot; twelve is a span; a palm and an *uttarayuga*

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are both thirteen [digits]; a [standard] foot fifteen...

These ancient lists were an important early step in organizing and preserving crucial data for ceremonial observances based on the astronomical calendar, among other purposes. Does that justify including them in the category of astronomical tables? Such a question illustrates some of the difficulties in defining the concept of a mathematical or scientific “table”. If a data set must consist of ordered pairs (or triples or other multiples) of object names and/or quantity values laid out in a two-dimensional array to be considered a table, then the above examples clearly do not qualify. But if a table is understood more generally to include any two or more sequential lists of items with a clearly defined and consistent relation between their respective entries (such as constellation names and associated deities, measuring-unit names and lengths, etc.), then almost any such enumeration could be called a table. In that case, it becomes difficult to differentiate between putatively distinct but vaguely demarcated categories of data structures, such as “table” versus “list”.<sup>2</sup>

For the purposes of this discussion henceforth, the term “table” without qualification will be restricted (with some explicitly identified exceptions) to a numeric array of data laid out in rows and columns, especially such arrays in which the table entries substitute for the results of a computational algorithm. Most of the Sanskrit astronomical tables conforming to this description are highly complex, containing several extensive sets of function values to be used in astronomical calculations based on sophisticated geometric models. The defining criterion, however, also applies to simpler tables: for example, a typical elementary multiplication table where each cell contains the product of the numbers in its row heading and column heading, and every cell entry can be reconstructed by applying a deterministic algorithm such as “multiply by 9” or “multiply

by 12”, would qualify as a table, whereas a verbal sequence of paired names of, e.g., constellations and deities would not. However, this distinction is ultimately arbitrary and should not be taken to deny the links between such tables and other forms of data enumeration that might also be described as tables, some of which are discussed in the following section.

## 2. VERSIFIED “TABLES” IN EARLY MEDIEVAL ASTRONOMY TREATISES

The spread of literacy and numeracy in Indic languages in the second urbanization period, shortly before the start of the common era, made it possible for astronomers to compute a variety of new data sets more complicated than the lists in the Vedic texts. Few complete sources survive from the start of this period; the textual record becomes more abundant with Classical Sanskrit works from near the middle of the first millennium AD, by which time the genre had evolved into the canonical discipline of medieval *ganīta-jyotiṣa* or Indian mathematical astronomy. This science emerged as a hybrid of ancient Sanskrit astronomy/calendrics from the late Vedic period and the Hellenistic spherical astronomy known to Indo-Greeks and their partly Hellenized successors in the northern and western regions of South Asia. Consequently, the earliest of the extant medieval texts already reflect a highly developed fusion of Indian and Greek mathematical and astronomical traditions, couched in the metrical verse formats that were standard for Classical Sanskrit didactic literature. Most of them are classified in the genres of *siddhānta* or theoretical treatise, a comprehensive exposition of astronomy frequently containing descriptions of its underlying geometric models, and *karāṇa* or handbook, usually a short collection of necessary data and rules for standard astronomical calculations.

All these *jyotiṣa* works include verses listing various sequences of numerical values

produced by some computational algorithm or other mathematical technique, which are conventionally interpreted and described as tables by researchers. Of course, as in the ancient hymns and *sūtras* described in the previous section, such values are incorporated in the form of verbal lists rather than graphical arrays. The authors adapted them to the metrical requirements of verse structure by employing some form of verbal or alphanumeric encoding for decimal digits (see, e.g., Plofker 2009, pp. 528–532). There appears to be no technical term in the verse texts or commentaries for the structure of such verbally integrated “tables”. They are identified not by their format but by their content: namely, by nouns that directly specify the tabulated quantity in question, such as “the star positions”, “the sines”, “the additive constants”.

Since Classical Sanskrit versified works were still ideally held to be part of a tradition of orally transmitted learning (although in practice they and their prose commentaries were dependent on written manuscripts for their preservation and circulation), astronomical authors generally attempted to keep their verse “tables” brief and memorable. For example, the star-table in the *Brāhmasphuṭasiddhānta* of Brahmagupta composed in the early seventh century uses only eight verses (*Brāhmasphuṭasiddhānta* 7.1–3, 7.5–9) to state polar longitudes and latitudes (most of them precise only to the nearest degree) of the primary star in each of the twenty-eight lunar asterisms (Dvivedi 1902, pp. 123–125). The following excerpts from these verses, stating the coordinates for the first few of the given stars, illustrate the level of compression that versified table data could be subjected to.<sup>3</sup>

*aṣṭanakhair meṣe gavi radaliptonair  
guṇasvarair mithune |...  
pṛthag aśvinyādinam dhruvāṃśair  
yogatārāṣṭhaiḥ |...*

*saumyā daśārkaviṣaya yāmyāḥ śara...  
prājeśayogatārā vikṣepāṃśaiḥ kalā  
trighanahīnaiḥ |*

*āgneyasya kalānāmekonatrīṃśatā hīnaiḥ |...*

Eight [degrees of longitude] and twenty [degrees] in Aries; in Taurus [each of those values] diminished by thirty-two arcminutes... [A conjunction of heavenly bodies is determined] with primary stars of the [asterisms called] Aśvini and so forth with these degrees of longitudinal position, respectively...

[The stars’ respective latitudes]: North ten [degrees], twelve [degrees] and five [degrees]; South five [degrees]... The primary star of Prājeśa [i.e., the fourth constellation] is [corrected] with latitude-degrees minus the cube of three minutes, [and] that of Āgneya [i.e., the third constellation] by subtracting thirty-less-one minutes...

That is, while the polar longitudes of the first two primary stars are given straightforwardly as 8° and 20° starting from the beginning of the ecliptic, the longitudes of the next two are more obscurely phrased. They too are denoted by 8° and 20° respectively, but starting from the beginning of the second sign of the zodiac, Taurus: i.e., counting from 30° of longitude. Furthermore, they require a subtractive correction in arcminutes so that, for example, the longitude of the fourth star is Taurus 20°, or 50°, less 32°, or in standard form Taurus 19°28′ or 49°28′. Likewise, the polar latitude of the primary star of the fourth constellation is specified as 5° south of the ecliptic, but once again with a subtractive correction in arcminutes, this time paraphrased as “the cube of three minutes” or 27°. That is, the verse ultimately means that the fourth star’s latitude is 4°33′ South. Not only are the arcminute terms stated in rather periphrastic form separately from their corresponding degree entries, but they do not even consistently follow the same sequence: for instance, the arcminutes of latitude correction for the third star follow after those for the fourth star. Clearly, such a dense and involuted table may be comparatively easy to memorize but is not a very convenient or comprehensive reference tool for quickly retrieving detailed numerical data.<sup>4</sup>

A different type of verbally encoded table data is found in the South Indian *vākya* or “sentence” texts, whose first explicitly dated surviving examples go back to the early second millennium but which are traditionally ascribed to an inventor several centuries earlier (Pingree 1981, pp. 47–48, Koolakkodlu 2011). They record celestial positions of the planets not by means of number words as in the *Brāhmasphuṭasiddhānta* verse table cited above, but rather by assigning each of the consonants of the Sanskrit *nāgari* alphabet to one of the ten decimal digits, and then making up a short Sanskrit sentence for each given data value that contains consonants chosen and ordered to correctly represent its numerals. (See Mahesh 2013 for a detailed discussion of one such *vākya* text).

What we cannot determine from any of these verbal compositions is the point in time when the scribes who copied them out began to display their data sets in the two-dimensional array format familiar from later Sanskrit tables. Most Sanskrit astronomy and mathematics texts have no surviving manuscript exemplars copied earlier than the eighteenth century, and almost none are attested in copies from earlier than about the sixteenth century, so the details of early medieval scribal practices remain somewhat obscure. But in these later documents, it is common practice for scribes to write out number words within the verses in both verbal and numeral form: moreover, some prose commentaries exhibit features such as worked example problems in which some numbers appear exclusively in numeral form.

And in fact, the only major mathematical Sanskrit manuscript that may date as far back as the first-millennium texts themselves confirms that displayed formats for numeric quantities were not unknown to the scribes of that era. This document, the so-called Bakhshālī manuscript, comprises dozens of mathematical rules and examples written on birch-bark; it was buried for safekeeping not far from modern Peshawar

probably sometime between the eighth and twelfth centuries. The Bakhshālī manuscript includes many boxed layouts (somewhat similar to modern displayed equations) illustrating arithmetic operations on numbers in decimal place-value notation (Hayashi 1995). Although more specific direct evidence in favor of this hypothesis may never be found, it seems plausible to infer that versified “table values” also were somehow laid out with numerals in manuscripts for the reader’s convenience from a very early period.

### 3. EMERGENCE OF INDIAN ARRAY-FORMAT TABLE GENRES

At some point probably in the early second millennium, the canon of Sanskrit mathematical astronomy expanded to include many texts consisting solely or primarily of two-dimensional arrays of numerical values. These arrays are generally accompanied by instructions on how to use the values to perform simplified versions of astronomical calculations, in place of the more laborious parameter and algorithm procedures in *siddhāntas* and *karāṇas*. Such labor saving works acquired the technical names *koṣṭhaka*, literally “granary, treasury” and *sāraṇi* (with variant forms *sāriṇi*, *sāraṇī*, etc.), literally “stream, path, line”, echoing the etymology of its classical synonym “canon”. Although individual table texts vary in content and format (see section for some typical categories), there seems to be no systematic distinction between those called *koṣṭhaka* and those called *sāraṇi*.

These texts, the first Indian works fully corresponding to our standard notion of an astronomical table, are thought to have been initially inspired by the Persian and Arabic table texts in Greco-Islamic Ptolemaic astronomy known as *zījēs* (Pingree 1981, p. 41). As with the *siddhānta* and *karāṇa* genres nearly a millennium earlier, there is no textual evidence documenting the initial steps of this development: the earliest surviving *koṣṭhaka/sāraṇi* works are already

mature specimens of the Sanskrit table-text format. But similarities between some Indian and Islamic table types, along with the presence of many Islamic *zījes* in second-millennium India, support the inference.

Fig. 1 shows the first couple of pages from a manuscript of one such work, the *Laghu-Mahādevi*.<sup>5</sup> The remaining 88 pages of the manuscript (not shown) contain additional tables, while the text on the first page comprises the complete instructions for using them.

While the colophon indicates that the manuscript was copied in approximately 1708 and the text gives its year of composition as about 1664, the basic content and structure go back to

one of the earliest surviving examples of this genre, the 1316 *Mahādevi* of Mahādeva, of which the *Laghu-Mahādevi* is an abbreviated recension (Neugebauer and Pingree 1967). So the detailed two-dimensional layout on which the work depends was evidently thoroughly integrated into the Sanskrit scientific textual tradition by that time, and indeed by the time of the first known extant *sāraṇi* text nearly two centuries earlier (Pingree 1981, p. 42).

Moreover, the tabular array format made its way into manuscripts of other types of astronomical texts, as illustrated in Fig. 2 and Fig. 3. Both manuscripts show a section on planetary epoch longitude values from the same late

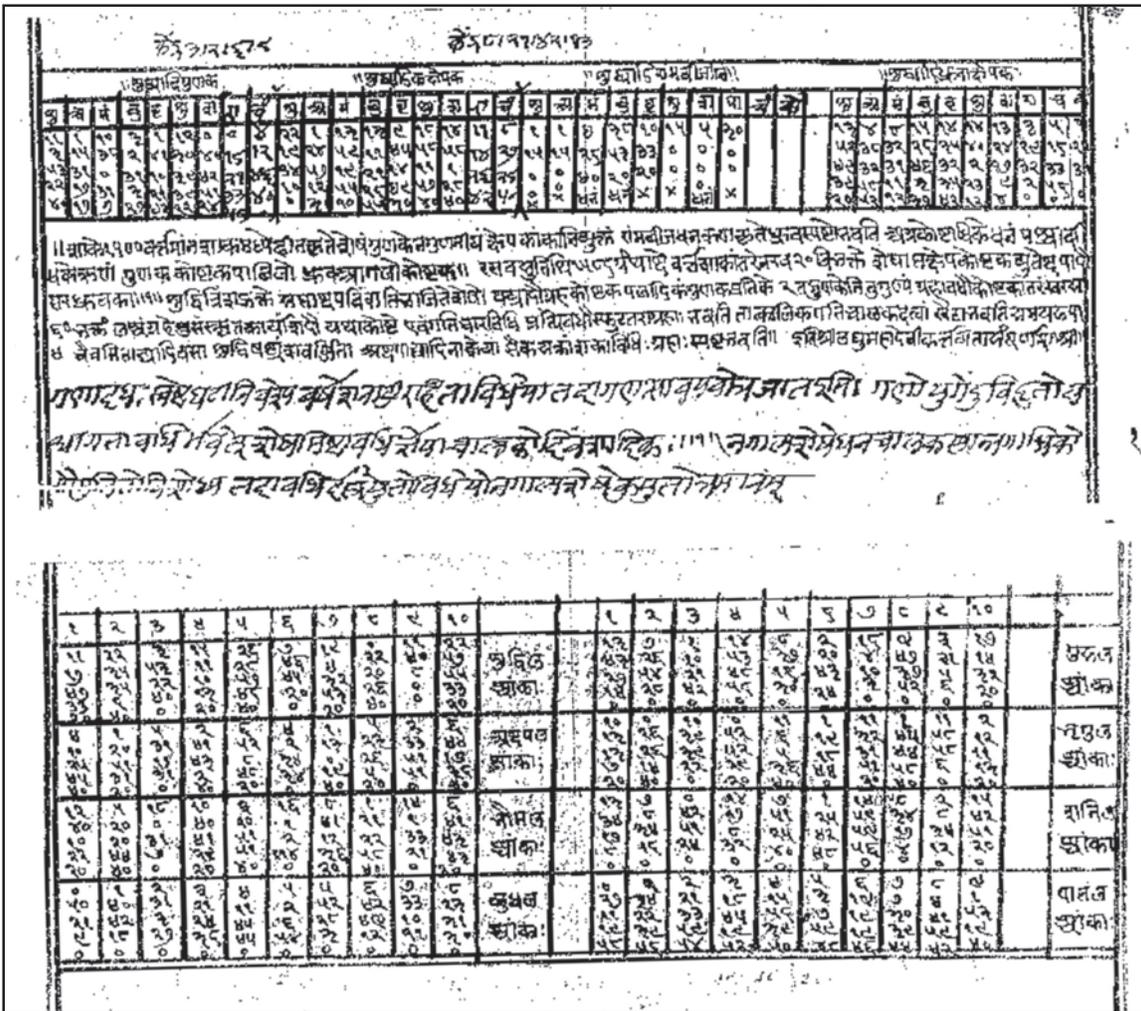


Fig. 1: The first two pages of a manuscript of an astronomical *koṣṭhaka*



table. But this practice evidently never became an ironclad scribal convention, as indicated by the fact that the chronologically later manuscript shown in Fig. 2 uses a linear sequence of numbers to represent the same data that the earlier manuscript of Fig. 3 shows in a tabular array. While texts in the *koṣṭhaka/sāraṇi* genre invariably employed the two-dimensional tabular format, scribes copying astronomical texts in other genres might stick to the traditional linear flow of Sanskrit technical treatises.

#### 4. IDENTIFYING, CLASSIFYING AND ANALYZING TABLE TEXTS

Indian astronomers do not seem to have created any formal taxonomy of different types of table texts beyond the overlapping genres of *koṣṭhaka* and *sāraṇi* described in the previous section: an individual table of values of a specific quantity or function, such as astronomical declination or longitude, was identified merely by the name of that quantity.

Modern scholarship on *jyotiṣa*, however, has defined a few general categories for table texts, based on the type of data they contain. These categories divide the works roughly as follows (Pingree 1981, pp. 41–48):

- “Mean linear” planetary longitude tables, modeled on Greco-Islamic *zīj* formats. Increments of each planet’s mean longitude are tabulated for various time intervals, and the total mean longitude for a particular time is then converted to true longitude by means of a separate table of trigonometric corrections. For example, if a certain planet’s longitude is sought at a time three years and five days after some epoch when it had a known mean longitude, then the user looks up the planet’s yearly and daily mean longitude increments in the table, adds three times the former to five times the latter and increments the epoch mean longitude by the result. The tabulated correction terms or “equations” corresponding to this total mean longitude are then applied to produce the desired true longitude.
- “True linear” planetary longitude tables, apparently an Indian modification of the former system. In this format the planet’s true longitudes corresponding to successive values of mean longitude are tabulated directly, so there is no need to compute or look up the correction terms. A true longitude falling between two tabulated values is computed by interpolation.
- “Cyclic” planetary longitude tables, combining the “true linear” concept with ancient “goal year” orbital period parameters transmitted via Islamic astronomy. Somewhat like a modern planetary ephemeris, these tables contain true longitudes for successive equally spaced times, continuing for one orbital cycle: when the planet returns to the same true position at the same time of year, the cycle recommences.
- Tabulated relative positions and parameters of the sun and moon, for computing elements of lunisolar calendars. These are frequently combined with planetary tables.
- Tabulated relative positions and parameters of the sun and moon, for computing lunar and solar eclipse predictions. These are generally combined with planetary tables.
- South Indian *vākya* tables of planetary positions, described in section above; they are somewhat similar to the “cyclic” tables in listing true longitudes at equidistant intervals within an orbital cycle, but are alphanumerically encoded.
- Tables of geographical data, such as terrestrial longitudes and latitudes for various cities (Pingree 1986, Pingree 1972, p. 5).

These are rough classification guidelines rather than a developed taxonomy of table types; many manuscripts combine different sorts of tables or include additional tabulated astronomical quantities, and some contain numerical tables whose purpose and structure remain completely unclear.<sup>6</sup>

Even those Sanskrit *koṣṭhakas* and *sāraṇis* whose nature is fairly well understood generally do not explicitly describe how their tabulated values were computed or specify the underlying parameters on which they depend. Some texts contain rules for using the tables to calculate predicted positions, and some consist of tables alone. Several of them bear the same name as a known *siddhānta* or *karāṇa* work, whether by the compiler of the table text himself or by a different author, which suggests that the tables in question were constructed using algorithms and parameters from the namesake treatise or handbook.

However, even tables firmly linked to other, more expository works by the same author can be difficult to reconstruct satisfactorily. The scribal copying process for *koṣṭhaka* and *sāraṇi* texts is particularly error-prone due to the predominance of numerical data, and the resulting errors are sometimes hard for researchers to spot. Also, as far as is currently known, there are no technical guides in Sanskrit explaining to astronomers how to compile a *sāraṇi* or how the algorithms from a treatise or handbook should be tweaked to simplify computing table entries. Astronomers constructing table texts enjoyed wide latitude in creating and applying their mathematical techniques, and were under no obligation to describe or justify their procedures.<sup>7</sup>

## 5. DIRECTIONS IN CURRENT RESEARCH

Compared to other developments and genres in second-millennium Indian mathematical astronomy, table texts have been somewhat neglected in current scholarship, not only in the history of mathematics in general but even among

its Indological specialists. To the best of my knowledge, the present publication represents the first volume devoted specifically to exploring Indian mathematical and astronomical tables since the appearance of the seminal Pingree 1968 and Pingree 1972 some forty years ago. The incorporation of Indian sources into cross-cultural studies of the history of tables is an almost equally recent development, beginning with the publication of Tobies and Tournès 2011; the groundbreaking 2003 survey of the history of mathematical tables subtitled “from Sumer to Spreadsheets” Campbell-Kelly et al 2003 made no mention of Indian tables.<sup>8</sup>

The long hiatus in addressing these table genres in detail has been partly due to the difficult and sometimes uninviting nature of the sources. Few *koṣṭhaka* and *sāraṇi* texts so far have been published, and few of the published editions that do exist are critical editions, so the relation between the printed data values and the manuscript traditions themselves is unclear. The vast majority of the content of table texts is not intrinsically interesting to read, and understanding the algorithms used to create it often seems either tediously trivial or maddeningly impossible, due to the above mentioned textual disconnect between underlying theoretical models and tabulated function values. Sophisticated data analysis tools are required in the reconstruction process, as is familiarity with a sufficient range of table formats and individual works to recognize adaptations and innovations unacknowledged by the authors.

However, the importance of this field of study is commensurate with the challenges it poses. No other genre in second-millennium Indian astronomy potentially has more to tell us (if we can decode its cryptic data) about how its authors approached their subject, how they reshaped theoretical models into practical calculations, and how these developments impacted the professional practice of the many ordinary astronomers and astrologers who relied

on their texts for fundamental routine tasks like calendar-making and horoscope-casting. The groundbreaking preliminary studies of Indian table texts published in past decades make the significance of this field in the historical study of the Indian astronomical tradition very clear:

For the moment I shall only indicate that it seems likely that a very complex tradition lies behind what is here presented (Pingree 1986, p. 174) ...

As far as the theory of planetary motion is concerned there remain two major problems unsolved... [T]he mass of extant material will make it a formidable task to restore reasonably clear lines of development for the history of late Indian astronomy. (Neugebauer and Pingree 1967, pp. 81–82)

### NOTES

1. The Sanskrit is reproduced (omitting the Vedic pitch accents) from the TITUS Project transcription of the edited *Yajur-veda* text in Weber 1871, <http://titus.uni-frankfurt.de/texte/etcs/ind/aind/ved/yvs/ts/ts.htm>. For a table of all its listed asterisms and deities (along with the adjoined twenty-eighth constellation Abhijit included in the star-list of the *Brāhmasphuṭasiddhānta* mentioned below), see Pingree 1978, p. 535.
2. A discussion of the concepts of “list” and “table” and their historiographic evolution is sketched in Campbell-Kelly et al 2003, pp. 12–15.
3. The data quoted are summarized in modern form in the following table. Brahmagupta’s coordinates are discussed in more detail in Pingree and Morrissey 1989, pp. 109–112.

Asterism name	Polar longitude (degrees; minutes)	Polar latitude (degrees; minutes)
Aśvinī	8	10N
Bharaṇī	20	12N
Kṛttika (Āgneya)	37; 28	4; 31 N
Rohiṇī (Prājeśa)	49; 28	4; 33 S

4. Similar compression is seen in other such datasets in *jyotiṣa* texts: for example, Brahmagupta’s “table” of sines, twenty-four sine values for the first quadrant of

arc (scaled to a trigonometric radius value of 3270 and precise to the nearest integer), are packed into a mere four verses (*Brāhmasphuṭasiddhānta* 2.2–5) Dvivedi 1902, 23.

5. MS Jaina Vidya Sansthan Sri Mahavirji (Jaipur) 147.2479.
6. A sense of the wide-ranging variations in these texts can be gathered from the introductory descriptions in, e.g., Pingree 1968, Pingree 1970, and Pingree 1972.
7. Some of the pitfalls of the reconstruction process are illustrated in Ikeyama and Plofker 2001, pp. 276–287. The development of modern computational tools for table analysis is well underway in the context of other astronomical traditions, particularly in the ongoing *zīj* survey project of Dr. Benno van Dalen in Frankfurt, but has yet to be systematically incorporated into scholarship on Indian tables.
8. This omission is rapidly being remedied by several ongoing and emerging studies and surveys relating to the history of tables globally or within the Indian tradition alone. Among these are the five-year research project within France’s Centre national de la recherche scientifique, “Histoire des tables numériques” (Projet ANR 2009-20 13 of REHSEIS/SPHERE, <http://www.rehseis.univ-paris-diderot.fr/spip.php?rubrique148>); the “LOCOMAT” Digital Tables Library, an online census and library of historical tables for the use of historians of mathematics (<http://locomat.loria.fr>); and recently launched projects led by Dr. Clemency Montelle at the University of Canterbury in New Zealand and by Dr. Annette Imhausen at Goethe Universität Frankfurt/Main.

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