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Clemency Montelle and Kim Plofker

1. INTRODUCTION

The *Karaṇakesarī* of Bhāskara (fl. 1681) is a set of astronomical tables along with a short accompanying versified text for computing the circumstances and details of lunar and solar eclipses. This text is divided into two chapters (*adhikāras*): the *candraparvan* or lunar eclipse which contains thirteen verses, and the *sūryaparvan* or solar eclipse which contains seven verses (although the manuscripts we have seen are not unanimous on this point). The text is both a supplement to the tables and a guide for using them. Its last verse tells us that this work was composed in Saudāmikā (a locality probably in Gujarāt) and the second verse indicates that its epoch is year 1603 of the Śaka era (1681 CE). The tables are computed for the terrestrial latitude $\phi = 22;35,39°$, as discussed in the analysis of verse 1.5 in section 4 below.

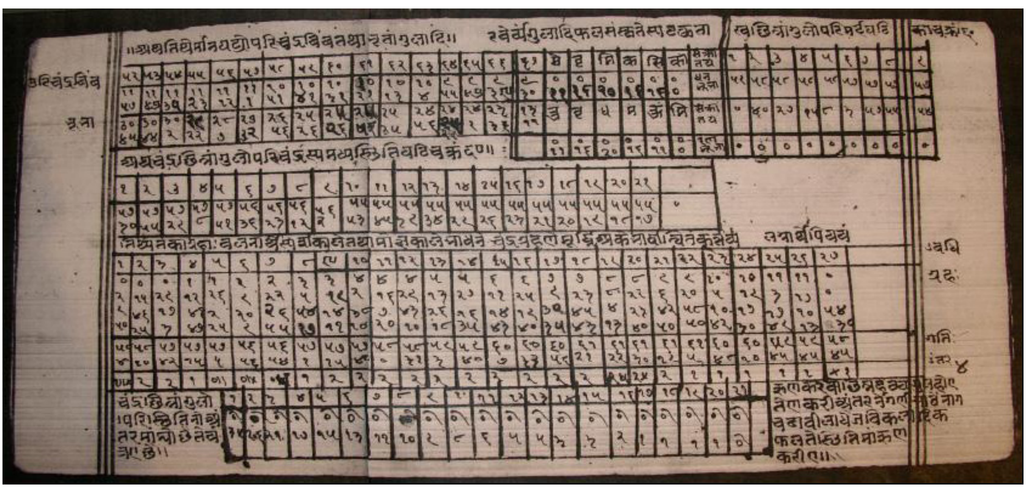

Figure 1: Excerpt from *Karaṇakesarī* tables, Poleman 4946 (Smith Indic MB) XIV f. 4v (MS. P_1)

We know of at least a dozen extant manuscripts of the *Karaṇakesarī*.[1] The ones we have consulted for our present study are the following:

- For the tables:
  - Poleman 4946 (Smith Indic MB) XIV ff. 3–11 (denoted MS. P_1)
  - Poleman 4946 (Smith Indic MB) XXVII ff. 2-3 (MS. P_2)
  - Poleman 4946 (Smith Indic MB) XXVIII 1f (MS. P_3)
  - Rajasthan Oriental Research Institute (RORI) Jodhpur 12792 (MS. R_2)
- For the text:
  - Baroda 11268 (MS. B), whose colophon asserts that it was copied in the 14th day of the bright half of Aśvina in year 1819 (of the Saṃvat era), which the scribe calls a Saturday; indeed it corresponds to Saturday 2 October, 1762 CE.[2]
  - RORI Jodhpur 12814 ff. 1v–2v (MS. R_1), allegedly copied for his own use by Bhāī Īcchārāma on the 15th day of the bright half of Phalguna Saṃvat 1925, a Friday; this converts to 28 March 1869 CE, which however was a Sunday.

An additional manuscript (RORI Jaipur 9757 (MS. J), copied on day 8 of the dark half of Jyeṣṭha in Saṃvat 1818, a Thursday: i.e., Thursday 25 June 1761 CE) contains worked examples of the *Karaṇakesarī* procedures for two eclipses before 1750 CE (see section 3). Unless otherwise noted, all manuscript readings in the tables part refer to MS. P_1 (of which figure 1 shows a sample leaf).

While most tables pertaining to eclipses form part of comprehensive table texts on astronomical prediction in general, the *Karaṇakesarī* is a less common instance of a work devoted exclusively to this topic (Pingree 1981, 46). Its tables describe characteristics of the celestial bodies implicated in eclipses: elongations between them, their apparent diameters, 'deflection', and parallax, as well as other relevant phenomena such as eclipse duration and magnitude. Appended to the eclipse computation tables but not discussed in the text are a set of additional tables concerning astrological phenomena.

Our critical edition of the verse text portion attested in MSS. B and R_1 is included as Appendix B, at the end of which we supply transcriptions and identifications of the titles of all the tables. Preceding it is Appendix A, a brief glossary of the Sanskrit technical terms used in our exposition. Section 4 contains a

1 See Pingree (1970–1994, 328) and Pingree (1968, 70), in which Pingree notes four other works entitled *Karaṇakesarī*; it is unclear whether these works are related to the tables under consideration here.

2 For the relation of Indian calendars to Common Era dates, see Knudsen and Plofker (2011, 57–65) and the discussion of verse 1.2 in section 4 below.

complete transliteration and translation of the *Karaṇakesarī*'s edited text, accompanied by a 'Verse Analysis' and 'Technical Analysis' for each verse or group of verses. The former specifies the metre(s) used as well as any notable features of the composition or the manuscript readings, while the latter explains to the best of our understanding the technical procedures described therein. While we briefly summarise each of the associated tables and draw on their content to explain the verses, we have not attempted to critically edit or thoroughly analyze the tables or their titles and notes; we hope to undertake this task in a future publication. In the present discussion, wherever we have quoted these prose titles or notes we have transcribed them as they appear in the manuscript, without correcting their orthography.

In the edited text as well as in the transliteration, translation and commentary we employ the following editorial conventions:

- Square brackets [ ] indicate an editorial addition or proposed reconstruction of missing text.

- Angle brackets ⟨ ⟩ indicate manuscript readings that we discard as incorrect.

- We use the word *kesarī* 'mane-bearer, lion' with a dental sibilant in our standard form of the work's title *Karaṇakesarī*, but we do not emend the lexically accepted variant *keśarī* with a palatal sibilant where it appears in the manuscripts.

- Scribal variants of *nāgarī* orthography which are emended silently and not noted in the critical apparatus (except where the meaning of the original reading may be ambiguous) include the following: *anusvāra* for a conjoined nasal, omitted *visarga*, *virāma* or *avagraha*, misplaced *daṇḍas*, reversed conjunct consonants (e.g., *adba* for *abda*), conjunct consonants that we cannot reproduce in our *nāgarī* typesetting, doubled consonants after *r* or across a *pāda* break, routinely confused consonant pairs (e.g., *ba* for *va*, *ṣa* for *kha*), and all forms of *koṣṭa* for *koṣṭha* 'table entry'.

- Fragments of Sanskrit words or compounds in *nāgarī* are indicated with a small circle ◦ at the breakpoint.

- Folio breaks are indicated by a single vertical stroke |.

- In the critical apparatus, text followed by a single square close-bracket] indicates the edited version of the manuscript reading that follows it.

- The symbol *x* within *nāgarī* text indicates an *akṣara* (syllable) that is illegible in the manuscript.

- Numerals in sexagesimal or base-60 notation are shown with a semicolon separating their integer and fractional parts, and commas separating their successive sexagesimal digits. The superscripts ^{s} and $^\circ$ and $'$ indicate zodiacal signs (i.e., 30-degree arcs of longitude), degrees and minutes of arc, respectively.

2. BASIC ECLIPSE RECKONING IN THE INDIAN TRADITION

GEOCENTRIC GEOMETRY OF ECLIPSES

Eclipse reckoning is one of the most important functions of Indian astronomy. Indian calendars are fundamentally keyed to the ritually significant instants of luni-solar opposition and conjunction or full and new moon, the so-called *parvans* (syzygies) at which lunar and solar eclipses respectively occur (the term may also be used for the eclipse phenomenon itself). The Indian 'lunar day' or *tithi*, of which there are exactly thirty in a synodic lunar month between two successive conjunctions or oppositions, is defined so that the *parvans* occur at the ends of the fifteenth and the thirtieth *tithi*. The regular solar day, on the other hand, is the time between two successive sunrises (or midnights), conventionally divided into 60 equal time-units called *ghaṭikās* or *nāḍīs*.

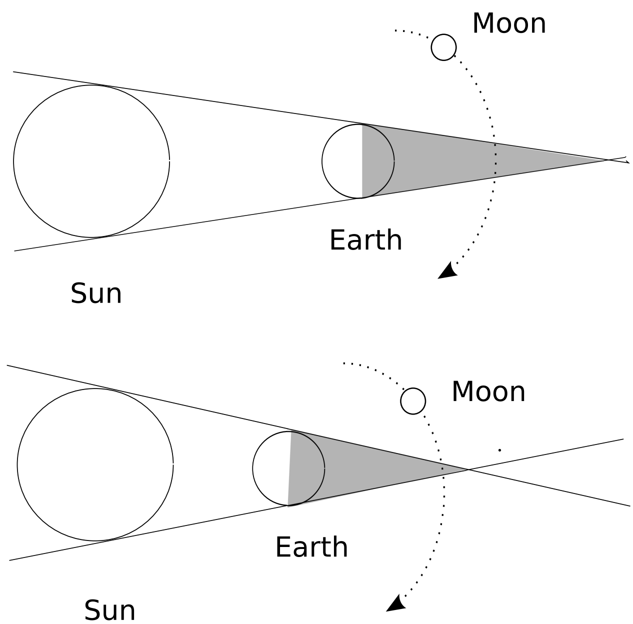

Figure 2: Lunar eclipse configurations showing qualitative effects of variations in the distances of the moon and sun from the earth

A lunar eclipse takes place at a full moon or opposition when the earth interposing between the moon and the sun darkens the moon with its shadow. It is visible everywhere on earth where the moon is above the horizon. As shown (greatly exaggerated) in figure 2, the apparent sizes of the disks of the moon and the shadow are affected by small periodic changes in the geocentric distances of the moon and the sun. When the moon is farther from the earth, its disk looks smaller and so does the cross-section of the shadow cone where it intersects the moon's orbit. When the sun is closer to the earth, the earth's shadow cone is shorter, which also decreases the size of the shadow disk that the moon passes through.

A solar eclipse occurs at new moon (conjunction) when the moon interposes between the earth and the sun, preventing the sun's rays from reaching some points on the earth. It is visible only from a narrow strip of terrestrial localities because the much smaller moon cannot block sunlight from an entire hemisphere of the earth. Observers outside that strip, whose placement varies according to the relative positions of the earth, moon and sun, will not notice any obscuration of the sun's disk. Both lunar and solar eclipses may be either total, implying that the disk of the eclipsed body is at some point completely obscured, or partial if some fraction of it always remains clear.

Observers who can see a solar eclipse will perceive its position in the sky differently depending on the amount of lunar parallax at their locality: i.e., the apparent displacement of the geocentric position of the moon against its background of stars due to the fact that the observer is not on the straight line between the moon and the earth's center. This phenomenon is illustrated on the left side of figure 3, which shows the 'depressing' effect of the parallax angle p appearing to shift the moon downwards, i.e., closer to the local horizon of the observer at P. The parallactic shift is zero for the moon at the observer's zenith and increases to its maximum as the moon gets closer to the observer's horizon. (Parallax shift for the sun is much smaller because of the sun's greater distance, and is generally ignored in eclipse computation.)

COMPUTING ECLIPSE DATA IN INDIAN ASTRONOMY

Indian astronomy texts typically place the bulk of their eclipse computation algorithms in their discussion of lunar eclipses, which precedes a shorter treatment of solar ones. They enumerate around a dozen separate eclipse elements to be determined by computation; the seventh-century astronomer Brahmagupta cites fourteen in the lunar eclipse chapter of his *Brāhmasphuṭasiddhānta* (4.1–3) (Dvivedī 1901–1902, 72). These include time of apparent syzygy (*velā*), duration of eclipse (*sthiti*), instant of first contact (*sparśa*), instant of release (*mokṣa*), duration of totality (*vimarda*), beginning of totality (*sanmīlana*, *nimīlana*), end of totality (*unmīlana*), magnitude of obscuration (*grāsa*), obscuration at a given time

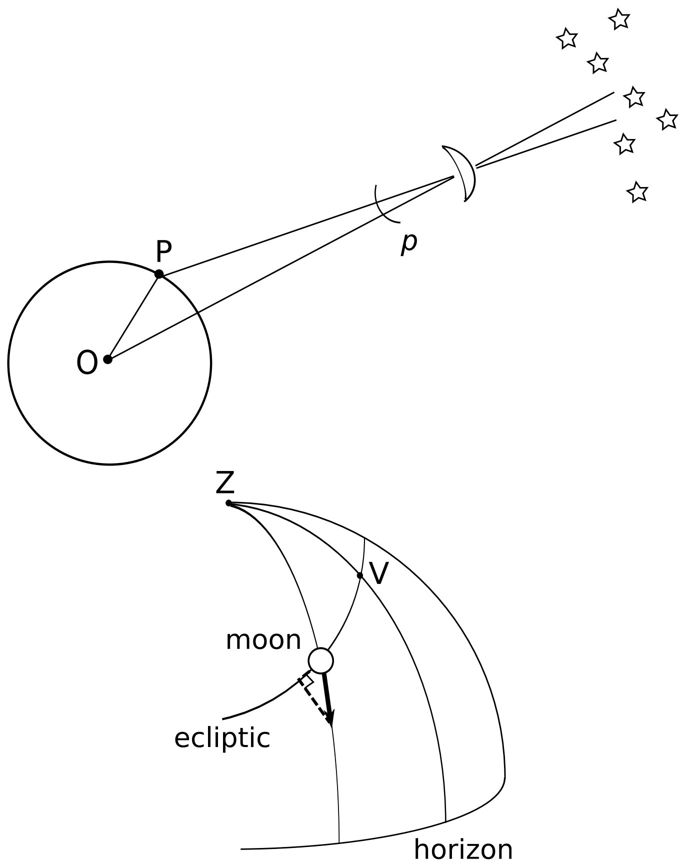

Figure 3: Effect of parallax angle *p* on perceived position of the moon viewed from earth's surface

(*iṣṭagrāsa*), 'shadow' or apparent diameter of earth's shadow (*chāyā*), direction of impact (*diś*), colour of eclipsed body (*varṇa*), inclination to cardinal directions (*valana*), and graphical projection or diagram (*parilekha*). Of course, this list also implies knowledge of other necessary quantities, such as apparent diameters and velocities of the luminaries at a desired time.

Occurrence. The astronomer is chiefly concerned to determine whether, when and how an eclipse at a particular syzygy will appear in the sky at his own locality. Eclipses are more rare than syzygies because the moon's orbit and the apparent orbital path of the sun (the so-called ecliptic) are slightly inclined to each other: as long as the moon is sufficiently displaced in celestial latitude north or south of the plane of the ecliptic, it passes through opposition or conjunction without ever intercepting the earth's shadow or sun's disk, respectively. The elongation of the moon's position from an orbital node, i.e., one of the two diametrically opposed points at which its orbit intersects the ecliptic, determines its latitude. The latitude in turn determines the so-called eclipse limits within which an eclipse is possible (see verse 1.2 in section 4 below) and whether the eclipse will be partial or total.

Phases. There are five phases of a total eclipse considered significant by Indian astronomers: the moments of *sparśa*, *sanmīlana*, mid-eclipse or *madhya*, *unmīlana* and *mokṣa*. The first, third and fourth of these phases are illustrated in the diagram of a total lunar eclipse in figure 4. In a partial eclipse, by definition, there is no period of totality so *sanmīlana* and *unmīlana* do not occur.

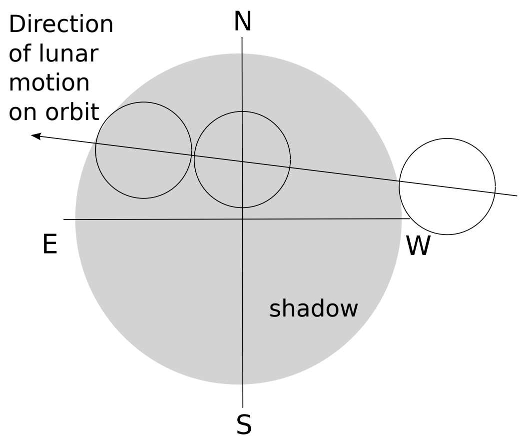

Figure 4: The moon at first contact, mid-eclipse, and end of totality in a total lunar eclipse, as seen in the sky by a south-facing observer

Magnitude. The amount of obscuration of the eclipsed body, or eclipse magnitude, is a linear quantity measured along the diameter of the eclipsing disk. It depends on the apparent diameters of the eclipsed and eclipsing disks (which are inversely proportional to their angular velocities) as well as on the lunar latitude (see verses 1.3–4).

Deflection. In figure 4 the moon's passage through the shadow is tilted with respect to the cardinal directions: this is the so-called *valana* 'inclination, deflection', which is deemed especially significant for astrological purposes. This feature has antecedents in ancient West Asian astronomy and its Greek successors, where it is known as *prosneusis* 'inclination, pointing'. In the Indian tradition, the *valana* is divided into two components (see verses 1.5–7):

- *akṣavalana* accounting for the southward sag of the body's projection onto the celestial equator from the east-west prime vertical circle, proportional to the local terrestrial latitude and the so-called *nata* or depression of the luminaries from the meridian or the zenith;
- *ayanavalana* representing the skew between the celestial equator and the ecliptic at that position, computed based on the ecliptic declination of a point determined by the sun's position with respect to the equinoxes and solstices. (Consequently, its celestial longitude has to be adjusted for precession or the slow motion of the equinoxes and solstices over time.)

The total *valana* is the algebraic sum of these two components.

Parallax. In most early astronomy, the moon's parallax was computed as a single function of its zenith distance (Montelle 2011, 123–125). In the Indian tradition, however, two components of lunar parallax are computed independently; indeed, there is no general term in Sanskrit for 'parallax' *per se*, or the angle here termed p. The two orthogonal parallax components are based on the coordinates of celestial longitude and latitude with respect to the ecliptic or apparent orbital path of the sun (see verses 2.3–6). The right side of figure 3 illustrates them for the moon positioned approximately on the ecliptic. Longitudinal parallax (*lambana*) along the ecliptic is determined chiefly by the distance of the body from the nonagesimal V, a point on the ecliptic 90° west of the ascendant or intersection point of the ecliptic with the eastern horizon. Latitudinal parallax (*nati*) perpendicular to the ecliptic is based on the zenith distance of the nonagesimal, hence dependent on the situation of the ecliptic with respect to the local zenith Z. Each of these components is considered to have a theoretical maximum more or less equivalent to the angular distance the moon moves in 4 *ghaṭikās* of time, i.e., about 53 arcminutes (a little under 18 digits). This arc is in fact approximately the maximum lunar parallax attested in other ancient astronomy traditions (Montelle 2011, 125, 241–244).

Diagram. The *valana* and magnitude for any eclipse are to be depicted in a graphical representation: namely, a diagram or set of diagrams portraying its characteristics and key phases (see verses 1.10–13). Careful instructions are usually given for geometrically constructing the disks of the obscuring and obscured bodies, the directions of the ecliptic and lunar orbit, and the trajectory of the eclipsed body in the diagram. Most works also enumerate the varying colours of the eclipsed body. Various shades of reds, blacks, and browns are mentioned (e.g., *dhūmra*, *kṛṣṇa*, *kapila*, *rakta*) and are often correlated to the phases of the eclipse, or sometimes to its position in the sky. These are presumably intended to help determine the astrological significance of the event.

3. RELATIONSHIPS BETWEEN TABLES AND TEXTS

The verses of the *Karaṇakesarī* text have a different emphasis than those found in the Sanskrit astronomical genres of treatises and handbooks (*siddhāntas* and *karaṇas*), whose versified algorithms and parameters constitute a standalone system of computation for astronomical prediction. The primary role of the *Karaṇakesarī*'s verses, on the other hand, is to support a set of tables; to this end, much of their content concerns the selection and manipulation of table entries to produce a desired result. These verses, along with the titles and marginal notes found in the tables themselves, offer insight into the complex interplay between numerical data and text.

However, the *Karaṇakesarī*'s approach remains closely connected to those of earlier works in the *siddhānta* and *karaṇa* genres, in both direct and subtler ways. We consider some of these connections below.

DEPENDENCE OF THE *KARAṆAKESARĪ* ON EARLIER TEXTS

Bhāskara's parameters for mean lunar and nodal motion are typical of the 'school' in Indian astronomy known as the Brāhmapakṣa, dating from at least the 7th century CE. Moreover, his assumption that the precession correction was zero in year 444 of the Śaka era (see verse 1.9 below) was shared by such earlier authors as Parāśara, Pṛthūdakasvāmin, and Āmarāja.[3]

In addition to this common scientific heritage, the *Karaṇakesarī* relies directly on previous compositions for much of its textual content. Two of its sources that can be confidently identified, due to the author's own acknowledgement or to obvious borrowing, are both *karaṇa* texts consisting solely of verses with no accompanying sets of tables: namely, the *Karaṇakutūhala* of Bhāskara II (Mishra 1991, Balacandra Rao and Uma 2008, epoch 1183 CE) and the *Grahalāghava* of Gaṇeśa (Jośī 2006, Balacandra Rao and Uma 2006, epoch 1520 CE). The *Karaṇakesarī*'s indebtedness to these works manifests itself in a number of different ways: Bhāskara may excerpt phrases or entire *pādas* and integrate them into his text, paraphrase an existing algorithm or technique, or use data extracted from another text as a basis from which to compute one of his tables.

For instance, one of his table titles explicitly states that its numerical data is based on a work called the *Siddhāntarahasya*, a well-known alternative name for the *Grahalāghava* (Pingree 1970–1994, 2, 94):

> *atha karaṇakesarigraṃthokte siddhāṃtarahasye sūryeṃdvoḥ parvanayanārthe caṃdrasya koṣṭakā* ...
> Now, tables of the moon for the sake of computation of eclipses of the sun and the moon in the *Siddhāntarahasya* as expounded in the book *Karaṇakesarī*. (MS. P_1, f. 4r)

Similarities in parts of the accompanying text as well as the procedures described confirm this dependence. For instance, Bhāskara's description of parallax and his application of parallax to produce true half-durations (see verses 2.5–6) parallel the procedures set out in the *Grahalāghava*.

The inspiration that our author derived from the *Karaṇakutūhala* is particularly evident in his description of the graphical projection of an eclipse, as well as his determination of parallax. *Karaṇakesarī* 1.10–13 contains several *pādas* identical to ones in Bhāskara II's section on graphical projection. The *Karaṇakesarī*'s table for determining longitudinal parallax (see verse 2.3) is based on a much briefer versified table in *Karaṇakutūhala* 5.4–5: the *Karaṇakesarī* linearly

3 See Pingree (1981, 13–16) for parameter values and Pingree (1972) for a discussion of precession in Indian astronomy.

interpolates between the *Karaṇakutūhala*'s nine specified values to produce a corresponding value for each of its 90 degrees of argument.

In addition, Bhāskara has drawn from non-astronomical sources in constructing his verses: for example, verse 2.1 imparts aphoristic wisdom lightly paraphrased from literary classics or traditional *Subhāṣita* works (proverbs and epigrams; see footnote 27).

INTERDEPENDENCE OF THE *KARAṆAKESARĪ*'S TABLES AND TEXT

Bhāskara's verses are intended both to supplement and to explain the tables: most of the text makes no sense without the information contained in the layout and headings of the tables, and the tables would be useless without crucial parameters and computational steps supplied by the text (or, in many cases, lacking in the text and presumably supplied by the user's own knowledge). The focus of the prescribed procedures shifts back and forth between computational algorithms in the verses and the numerical entries in the tables: while many verses directly refer to operations with tabular values, others merely clarify the concepts being discussed or specify procedures that are unconnected with the table data. Conciseness of expression is also balanced against practical convenience in the user's computations.[4]

Thus the *Karaṇakesarī* is in some sense not so much a self-contained set of tables as an abbreviated handbook or *karaṇa* with some computational procedures and parameters replaced by table entries.

MS. J'S WORKED EXAMPLES FOR USING THE *KARAṆAKESARĪ*

RORI Jaipur 9757 (MS. J), a 1761 manuscript of 6 folia, is written in a mixture of regular technical Sanskrit and an early modern Indo-Aryan vernacular.[5] It consists of two detailed *udāharaṇas* or worked examples of calculations with the *Karaṇakesarī* tables according to the procedures described in its text. The first of these is for a lunar eclipse whose date is given (f. 1r) as Wednesday, the fifteenth *tithi* of the bright half of Āśvina in Saṃvat 1801, Śaka 1666. If the Śaka year is taken as expired rather than current, this appears to correspond to Wednesday 21 October 1744 CE, to which a (partial) lunar eclipse is also assigned by modern

4 For example, the construction of the graphical projection of an eclipse in 1.10–13 is distinct from the table manipulations, while the algorithm for correcting longitudinal parallax in verse 2.3 requires the user to divide by 40 the values in the corresponding table on f. 10r. It would seem more convenient from the user's point of view to have constructed the table with its entries pre-divided by 40 in the first place. Likewise, limiting an angular table argument to the first quadrant reduces the table's size, but imposes on the user the additional task of reducing arbitrary arcs to first-quadrant equivalents (which Bhāskara explains how to do in verse 1.7).

5 A characteristic blend of the two forms is seen in these sentences from f. 1r, line 10:
atha sūryasādhanaṃ ||
prathamaje avadhīmāhegrahegrahaṇathā-yetenosūryamadhyama

calculations.[6] The second eclipse, a solar one, is said (f. 3v) to have taken place on Sunday, the new-moon *tithi* of the dark half of Māgha in Saṃvat 1748 or Śaka 1613: i.e. (again taking the calendar year as expired), Sunday 17 February 1692, when an annular solar eclipse would have been visible as a partial eclipse in most of the South Asian subcontinent.

We have occasionally used these examples to elucidate some point about the *Karaṇakesarī* text or tables in our discussion of them in section 4, but we are deferring a detailed study of MS. J to a more thorough investigation of the tables themselves, as proposed in section 1.

4. *KARAṆAKESARĪ*: TRANSLATION AND COMMENTARY

śrīgaṇeśāya namaḥ || śrīgurubhyo namaḥ || śrīsāradāyai namaḥ || atha karaṇakeśarī likhyate ||

Homage to Gaṇeśa. Homage to the Gurus. Homage to Śāradā.[7] Now the *Karaṇakesarī* is written.

1.1 SALUTATION

śrīkṛṣṇacandracaraṇaṃ praṇipatya bhaktyā
jyotirvidāṃ bahuvidām abhivandanaṃ ca ||
kṛtvā kavīndrakulabhūṣaṇabhāskarākhyo
rāmātmajaḥ karaṇakeśarim ātanoti || 1 ||

Having bowed to the feet of Śrī Kṛṣṇa with devotion, and making respectful salutation to the very learned knowers of *jyotiṣa*, the one called Bhāskara, the ornament of the Kavīndra family (*kula*), the son of Rāma, illuminates the *Karaṇakesarī*.

VERSE ANALYSIS

Metre: *vasantatilakā*.

This invocatory verse introduces the author of the *Karaṇakesarī*, Bhāskara, and makes reference to his lineage. Bhāskara is the son of Rāma, a descendant of a family (*kula*) called Kavīndra.[8] As well as being a proper name, *bhāskara* 'light-

6 Both historical eclipse events mentioned here were established via the USNO Eclipse Portal, astro.ukho.gov.uk/eclbin/query_usno.cgi.

7 Śāradā is another name for Sarasvatī. The manuscript gives the variant form Sāradā.

8 We do not know who is meant by the term 'Kavīndra family'. The name is reminiscent of the famous Kavīndrācārya (see Sastry (1921)), but he is said to hail from one Puṇyabhūmi identified with Paithan near Aurangabad in the Deccan, while our author appears to identify himself as a member of the Moḍha Brahmanas associated with the Gujarat area (see verse 2.7).

maker' is a noun that means 'the sun'. Thus Bhāskara has invoked a pun on his own name; he will naturally be the one to 'illuminate' (*ātanoti*, from the Sanskrit verb *ā-tan*, to illuminate, to spread light) astronomical techniques and principles in the *Karaṇakesarī*.

In the last *pāda* or quarter-verse, the accusative form of the name *Karaṇakesarī* ('the mane-bearer/lion among *karaṇas*', i.e., pre-eminent) is rendered *-kesarim* rather than *-kesariṇam* to conform to the requirements of the metre.

1.2 LUNAR NODE ELONGATION

śako rāmaviṣṇupadāṅgendu 1603 hīno
viyadrāmacandrair hṛto 130 labdhaśeṣau ||
yutau copakarṇaṃ hy avadhyanvitaṃ tat-
sapātendutātkāliko bāhubhāgaiḥ || 2 ||

The [current] Śaka year is decreased by 1603 [and] divided by 130, and [the tabular entries corresponding to the amounts given by] the quotient and remainder are added [together]. The 'result' (*upakarṇa*) is increased by [the tabular amount corresponding to the number of elapsed] *avadhis*. That [resulting sum] is the [lunar node's elongation from the sun corresponding to the] 'lunar elongation' (*sapātendu*) at that time.

VERSE ANALYSIS

Metre: *bhujāṅgaprayāta*;[9] the first *pāda* is hypometric.

The term *upakarṇa* is puzzling. In a mathematical context, *karṇa* (literally 'ear') means 'diameter' or 'hypotenuse'. Context suggests it refers to a different quantity, discussed below.

The last word in the fourth *pāda*, namely *bāhubhāgaiḥ*, belongs to the next verse.

TECHNICAL ANALYSIS

This verse gives a rule for determining the longitudinal elongation between the sun and the lunar node on the ecliptic (in zodiacal signs, degrees, minutes, and seconds) for a specified date. This elongation determines whether or not an eclipse will be possible.

In principle, the eclipse limit is determined rather by the elongation of the *moon* from its node, as suggested by the term *sapātendu*, literally '(the longitude

9 This metre, a form of *jagatī* (12 syllables in a *pāda*), is comprised of the four-*gaṇa* sequence *ya ya ya ya*. For details, see for instance, Apte (1970, vol. 3, Appendix A, p. 5).

of) the moon increased by (the longitude of) its node' (see section 2).[10] However, as noted above and confirmed by the headings of the associated tables discussed below, the quantity tabulated is instead the elongation of the *sun* (*sūryasya*) from the moon's node. We reconcile this seeming contradiction by noting that the sun and moon at an instant of true syzygy are by definition either 0° or 180° apart, so the absolute value of their nodal elongations at that instant will be the same.

The verse explains how to extract and combine the relevant tabular data, whose behavior we reconstruct as follows. The node-sun elongation for the total time since epoch is dependent on the fundamental period relation between time and the revolutions of the node. The parameters appear to be derived from the Brāhmapakṣa tradition in which the moon's node makes −232,311,168 revolutions (the negative sign indicates retrograde motion) in 4,320,000,000 years. This produces the following mean yearly motion for the node:

$$\frac{-232,311,168 \times 360}{4,320,000,000} = -19;21,33,21,...^{\circ}/\text{year}$$

Since the sun returns to the same zero-point of longitude at the start of every (sidereal) year, the mean yearly increment in the node's elongation from the sun is identical to its mean yearly (negative) increment in longitude.

If Y is taken to be the current Śaka year, then the prescribed algorithm divides the difference between Y and 1603 (which we infer to be the epoch year of the tables in the Śaka era) by the constant term 130. The quotient, which we will call E, consists of an integer result (the number of completed 130-year periods) plus a remainder (the number of single years subsequently completed):

$$E = \frac{Y - 1603}{130}.$$

The total time since epoch is broken into three parts:

- the number of completed 130-year intervals elapsed since the epoch (the integer part of E, called *labdha* or 'quotient' in the table heading);
- the number of completed single years elapsed in the current 130-year period (the fractional part of E, called *śeṣa* or 'remainder');
- and the number of completed 14-day intervals elapsed in the current year (*avadhis*, described in the table heading as *candrasya koṣṭhakā* or 'table entries of the moon' despite the fact that we are computing nodal-*solar* rather than nodal-lunar elongation).

10 The reason that this 'increase' or sum actually signifies longitudinal *elongation* of the moon from its node is that the node revolves in the 'backwards' or westward direction, making the nodal longitude negative. Adding the positive lunar longitude to the negative nodal longitude gives the elongation between them.

These three quantities are the arguments in the three associated tables: the elongation (modulo integer revolutions) computed for successive numbers of 130-year intervals from 1 to 130 (f. 3r), the elongation computed for numbers of 1-year intervals from 0 to 130 (f. 3v), and the elongation computed for successive numbers of 14-day *avadhis* from 1 to 27 (f. 4r). (So in principle, the tables would be valid for more than $130 \times 130 = 16,900$ years after the epoch date!)

The sum of the tabular entries in the first two tables corresponding to the quotient and remainder parts of E gives the total amount of elongation corresponding to the beginning of the chosen year, called in the verse *upakarṇa*. Then, considering the number of 14-day periods that have elapsed since the start of the year, the appropriate tabular entry from the third table can be added to produce the elongation for the chosen date within that year.

The first two tables are based on the assumption that the elongation changes linearly, with a constant difference from one entry to the next. In the table of 1-year increments this constant difference is $-19°;21$, derived from the period relation shown above (apparently truncated rather than rounded). In the table of 130-year increments the constant difference is $-3°;16,20$, evidently derived as follows:

$$\begin{aligned}
\text{In one year, the absolute value of the elongation} &= 19;21,34 \\
\text{In 130 years the elongation} &= 19;21,34 \times 130 \\
&= 2516;43,40 \\
\\
\text{Elongation modulo integer revolutions} &= 7 \times 360 - 2516;43,40 \\
&= 2520 - 2516;43,40 \\
&= 3;16,20
\end{aligned}$$

This table of one-year increments also incorporates an epoch correction in its first entry—that is, it begins with the value $6^s,29°;24,36$, which is presumably the amount of elongation at the beginning of 1681 CE or Śaka 1603. Although Bhāskara does not specify exactly what calendar moment he associates with this value, we assume that he equates the year-beginning with *caitraśuklapratipad* (the first new moon after the vernal equinox) which according to modern retrodiction corresponds to noon 20 March 1681.[11]

11 This converted date was computed using Michio Yano's online Pañcāṅga program for the date *śuklapakṣa* 1 of (*amānta*) month Caitra, Śaka 1603. See http://www.cc.kyoto-su.ac.jp/~yanom/pancanga/. In fact, a solar eclipse took place at this conjunction, but it was not visible anywhere on land. Reconstructing the epoch correction from the Brāhmapakṣa *kalpa* parameters with the total number of elapsed years equal to 1972948782 (i.e., the accumulated years up to the start of the Śaka era plus 1603 within the Śaka era) gives the proportional amount of nodal longitude in degrees accumulated at the epoch:

The third table tabulates the change in elongation for each of the 26 14-day periods (*avadhis*) during the solar year, plus a 27th entry to account for the leftover day after the first 26 × 14 = 364. The division of the year into these 14-day intervals is particularly useful for eclipses as conjunction and opposition occur roughly two weeks apart.

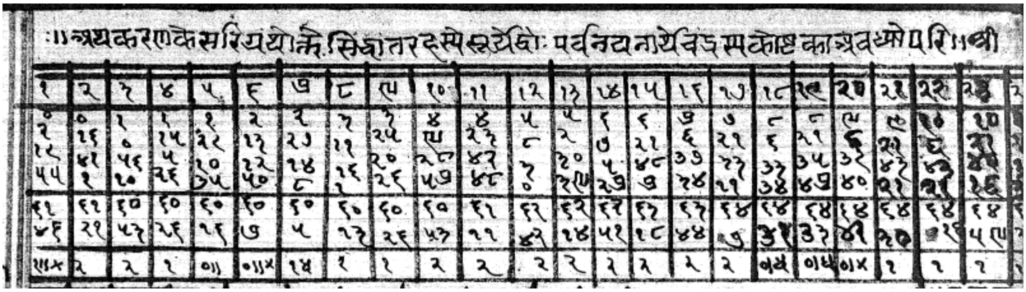

Figure 5: An excerpt from the table of the change in elongation for each *avadhi*, f. 4r

Table 1: The changes in elongation for the 14-day *avadhis* during the year

Argument	Row 1	Row 2	Row 3
1	0 2 19 55	61 46	1 ‖ *ṛ*
2	0 16 41 1	61 21	2
3	1 0 56 10	60 53	2
4	1 15 5 26	60 26	1
5	1 29 10 35	60 16	0 ‖
6	2 13 12 50	60 7	0 ‖ *ṛ*
7	2 27 14 8	60 5	1 *dha*
8	3 11 16 1	60 13	1
9	3 25 20 26	60 26	1
10	4 9 28 57	60 53	2
11	4 23 42 48	61 11	2
12	5 8 3 0	61 42	2

Table contd…

```
divmod((−232311168) ∗ (1972948782),
  4320000000) = (−106096768, 1809402624)
N(1809402624 ∗ 360/4320000000) =
  150.783552000000
```

Recall that this nodal longitudinal increment of approximately 150 degrees or 5 signs is negative; when added to 0° of solar longitude it comes out to a little less than 7 signs of nodal-solar elongation, which more or less corresponds to Bhāskara's epoch value 6^s,29°;24,36. The sun is not usually exactly at 0° longitude at the *caitraśuklapratipad* conjunction, but in this case it appears to have been very close to it.

Table 1 contd…

Argument	Row 1	Row 2	Row 3
13	5 2[2] 30 39	62 14	2
14	6 7 5 27	62 51	2
15	6 21 48 7	63 18	2
16	7 6 37 34	63 44	2
17	7 21 33 11	64 7	2
18	8 6 33 34	64 31	0 | *dha*
19	8 21 35 47	64 33	0 | *dha*
20	9 6 39 40	64 41	0 | *ṛ*
21	9 21 43 21	64 30	1
22	10 6 43 21	64 16	1
23	10 21 46 16	6⟨4⟩[3] 59	1
24	11 6 39 35	63 21	1 |
25	11 21 16 25	62 56	2
26	0 5 53 20	62 26	2
27	0 20 22 9	61 56	1 *ṛ*

Unlike the previous two tables, the *avadhi* table contains a non-linear sequence of values: that is, the differences between successive entries are not constant, but vary sinusoidally. It also differs from them markedly in structure, with three rows of data below each of its 27 argument values. (See figure 5 for an example of its format in the manuscript, and table 1 for a complete reproduction of its content. In this reproduction, which displays the original rows vertically rather than horizontally for convenience in layout, an unmistakable scribal error is marked off by angle brackets and missing correct values are supplied within square brackets.)

The first row contains the increment in elongation while the second, labeled *gatayaḥ* '(daily) motions', gives the true velocity of the elongation between sun and lunar node, presumably for the beginning of each *avadhi*. The minimum value of this velocity is 60′;5 at *avadhi* 7 and the maximum 64′;41 at *avadhi* 20. These extrema evidently fall respectively at the solar apogee, where the sun's motion is slowest, and the perigee where it moves fastest; see verse 1.3 below. The third row, which is unlabeled, contains entries of 0, 1 and 2 in a distribution whose rationale is unclear, occasionally accompanied by symbols for the *nāgarī* characters *dha* and *ṛ*, standing for *dhana* and *ṛna* or 'positive' and 'negative' respectively. The positive and negative symbols appear to be applied consistently with the transitions from increasing to decreasing values of the velocity in the second row. The entries in the third row may thus form part of some second-difference interpolation rule that Bhāskara's text does not explain.

It may be that the reason for the non-constant differences between the entries in the first row is that the variation in solar velocity has been taken into account. That is, the elongation per *avadhi* could have been computed via the following relation:

$$\text{Elongation per } avadhi = 14v_{\text{sun}}^{(\circ/\text{day})} + 14\bar{v}_{\text{node}}^{(\circ/\text{day})}$$

where v_{sun} is the true velocity of the sun and $\bar{v}_{\text{node}}$ is the mean velocity of the node. The average difference between entries is about $14'; 30$, which more or less agrees with the fact that the mean sun is moving approximately $0^\circ; 59$ per day and the lunar node roughly $0^\circ; 44, 20$ in the opposite direction over 14 days:

$$\begin{aligned} \text{`Average' value of increments} &= 0;59 \times 14 + 0;44,20 \\ &= 13;46 + 0;44,20 \\ &= 14;30,20 \end{aligned}$$

This reconstruction approximately describes but does not exactly reproduce the entries in the table.

1.3 LUNAR LATITUDE AND SIZES OF DISKS

mitaiḥ koṣṭhakair aṅgulādiḥ śaraḥ syāt
sapātasya bhuktyupari helibimbam ||
tither mānaghaṭyoparī candrabhūbhe
tulājādiṣaḍbhonayuk spaṣṭakubhā || 3 ||

The latitude in digits and so on should be [determined] by the table entries commensurate with the degrees of the *bāhu* [arc of elongation; see the end of the previous verse]. [The diameter of] the disk of the sun [has as its] superscribed [argument] the daily velocity of the [moon increased by its] node. [The diameter of] the moon and the shadow of the earth [have as their] argument the measure of *ghaṭikās* in a *tithi*. [That, i.e., the diameter of the shadow of the earth] is decreased or increased by [the appropriate tabular entry according as the sun is in] the six signs beginning with Libra or with Aries [respectively]. [This is] the corrected shadow of the earth.

VERSE ANALYSIS

Metre: *bhujāṅgaprayāta*.

The metre and/or the grammar in this verse are defective in several instances, and we have tried to compromise between respecting their requirements and accepting the manuscript readings. In the second *pāda*, the last syllable in *upari* should be heavy for the sake of the metre, but we leave it light as the correct ending for a neuter nominative singular *i*-stem *bahuvrīhi* compound agreeing with the neuter noun *bimba* that it modifies. Likewise, the third *pāda* contains a *dvandva* compound ending in *bhā* (f. 'shadow') in the manuscript; we have corrected it to the feminine nominative dual ending *-bhē* and made the final vowel of *upari* long in the preceding *bahuvrīhi* compound to agree with it. In the fourth *pāda*, the syllable *ku* (f. 'earth') should be long for metrical purposes.

The above compound forms with *upari*, an indeclinable adverb meaning 'above, upon, on', are peculiar to this type of technical terminology. Like other adverbs, *upari* can be used as a modifying element in a compound, as in *uparikuṭī* meaning 'upper room'. But in this verse and in many of the table titles, it is used instead as the *primary* member of a *bahuvrīhi* compound: e.g., *bhuktyupari* 'having the velocity [as its] superscribed [argument]'.[12] The numbers indicating the values of that argument are written above or at the tops of the respective columns.

Interestingly, the first part of the compound word *heli-bimba* meaning 'disk of the sun' is a loan-word derived from the Greek *helios*.

TECHNICAL ANALYSIS

The apparent sizes of the disks of the eclipsed and eclipsing bodies and the distance in latitude between their centers are necessary for determining the amount of obscuration. Qualitatively, the latitude of the moon on its orbit is proportional to its elongation or distance from its node, with the maximum latitude (conventionally $4^\circ;30$ or $270'$ (Pingree 1981, 16), equivalent to 90 *aṅgulas* or digits of linear measure) occurring when the moon is 90° from the node. And the apparent size of the disk of sun or moon depends on its distance from the earth, which is proportional to its apparent angular velocity. The size of the earth's shadow also depends on the distances of the moon and sun from the earth (as the moon gets closer it passes through a wider circular cross-section of the shadow cone, while the sun getting closer makes the shadow cone shorter; see figure 2 in section 2). The mean apparent size of the disk of the moon or the sun is realistically assumed in Indian astronomy to be about 32 arcminutes or 10–11 digits, while that of the shadow disk is about $1;21^\circ$ or 27 digits (Montelle 2011, 223). This verse explains how to adjust these values to find their true sizes at a given time, which will determine the appearance of the eclipse.

The first part of the verse refers to the table of lunar latitude on f. 4r, which has three rows. The first is labeled *bhujāṃśa* ('degrees of the *bhuja*' or *bāhu*, both meaning 'arc' or 'angular argument'), ranging from 0 to 16. A note in the margin asserts that this argument refers to the moon's elongation from its node (*atha sapātacandrabhujāṃśopari...*). Evidently, any nodal elongation greater than 16° is

12 The use of *upari* as a technical term meaning the argument of a table is attested in other table texts as well, including Nāgadatta's *Brahmatulyasāraṇī*; e.g., in MS. Poleman 4735 (Smith Indic 45) f. 7v.

considered to negate the possibility of an eclipse and thus is not tabulated.

The second row, labeled *śarāṃgulāḥ* 'digits of latitude', runs from 0; 10 (evidently a scribal error for 0; 0, since the accompanying value of the difference between the first and second entries is equal to the second entry itself) to 24; 45 digits. These latitude values appear to have been computed more or less in accordance with a rule from the *Karaṇakutūhala* of Bhāskara II (verse 4.5, Balacandra Rao and Uma 2008, S67) equivalent to setting the moon's latitude in digits equal to 90 times the (modern) sine of its nodal elongation in degrees. For instance, by this formula the maximum elongation of 16° corresponds to a maximum latitude of 24; 48 digits, nearly identical to the *Karaṇakesarī*'s 24; 45.

The third row gives the differences between successive entries in row 2, and it is noted in the row header that this difference is always positive (*'ṃtara sadā dhanaṃ*). The differences for entries 0 to 8 are 1; 34 and from 9 to 16, 1; 30.

The second *pāda* of the verse refers to the final table on f. 4r, which tabulates the diameter of the disk of the sun (*ravibimba*) using as argument the daily elongation of (presumably) the sun from the lunar node (*sapātasya gatiḥ*), which ranges from 0°; 59, 56 to 0°; 64, 42 over twenty entries. This diameter of the sun (also in digits, evidently) ranges from 10; 19 to 11; 11. Qualitatively, this relation makes sense because the variation in the nodal-solar elongation depends on the change in the sun's apparent angular velocity (that of the node, which has no anomaly of its own, is constant). That is, when the sun is moving faster, the daily nodal-solar elongation is bigger and also the sun is closer to the earth, meaning that the solar disk appears larger. (However, this adjustment may not have been indispensable in a lunar eclipse computation: the compiler of the lunar-eclipse example in MS. J, for instance, neglects it.)

The third *pāda* refers to a table on f. 4v, which has three rows. The first quantifies the length of the Indian time-unit called the *tithi*, running from 52 to 67 *ghaṭikās*. (As remarked above in section 2, a *tithi* on average is one-thirtieth of a synodic month or a little less than one civil day of 60 *ghaṭikās*. The so-called 'true' *tithi*, on the other hand, i.e., the time required for a 12° increment in the elongation between the true longitudes of sun and moon, is of variable length because it depends on their true velocities: the faster they move apart in longitude, the shorter the current *tithi* will be.)

The table's second row enumerates values of the diameter of the moon's disk from 11; 57 to 9; 30, and the third row the diameter of the earth's shadow disk, ranging from 30; 45 to 23; 11. Both these diameters, like that of the sun, are specified in digits. Their values seem to be based on the dependence of the apparent diameters of moon and shadow upon the geocentric distance of the moon, which is inversely proportional to its velocity. As previously noted, fewer *ghaṭikās* in a *tithi* implies higher lunar velocity, and consequently a smaller lunar distance and a larger apparent disk for both the moon and the shadow.

Me[ṣa]	Vṛ[ṣabha]	Mi[thuna]	Ka[rkaṭa]	Si[ṃha]	K⟨ā⟩[anyā]	Sign-entries
0;11	0;16	0;20	0;16	0;1⟨6⟩[1]	0;0	Positive earth-shadow
Tu[lā]	Vṛ[ścika]	Dha[nus]	Ma[kara]	Kuṃ[bha]	M⟨i⟩[īna]	Sign-entries
0;11	0;16	0;20	0;16	0;11	0;0	Negative earth-shadow

Table 2: Transcription of the table in figure 6

The last *pāda* of this verse proposes a positive or negative incremental correction to the size of the disk of the shadow, depending on what zodiacal sign the sun is in (positive when the sun is in the six signs beginning with Aries, negative otherwise; see figure 6 and table 2). The correction amount ranges from 0; 0 digits in signs ending at an equinox to 0; 20 digits in signs ending at a solstice.

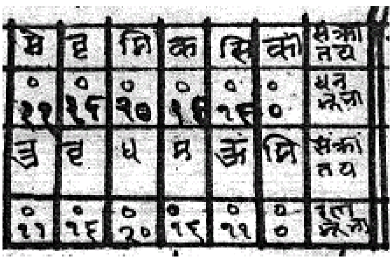

Figure 6: The table of correction to the size of the disk of the shadow, f. 4v

How these values were determined is not entirely clear. But we can reconstruct at least a qualitative justification for them by appealing to Bhāskara II's treatment in the *Karaṇakutūhala* of the position and effect of the solar apogee and the sun's anomaly (that is, its mean position minus the solar apogee position, which in *Karaṇakutūhala* 2.1 he puts at about 78° of sidereal longitude (Balacandra Rao and Uma 2008, S15)). We recall that when the sun is closer to the earth and consequently more distant in anomaly from the apogee, it is perceived as moving faster and shows a larger apparent disk, as well as shortening the earth's shadow cone. The formula for correcting the diameter of the shadow in *Karaṇakutūhala* 4.7–8 (Balacandra Rao and Uma 2008, S69–70) takes this effect into account by equating the correction to 3/67 of the true lunar daily motion minus 1/7 of the solar daily motion, implying that a larger true solar daily velocity means a smaller shadow diameter.

The *Karaṇakesarī* likewise appears to locate the solar apogee somewhere shortly before the beginning of Cancer, as the *avadhi* elongation table discussed in verse 1.2 suggests: that is, it takes the sun 6 *avadhis* or about 84 days from the start of the year at or near the beginning of Aries to attain its slowest velocity. Consequently, a solar anomaly between 90° and 270° would mean more or less that the sun is somewhere between the beginning of Libra and the beginning of Aries, i.e., it seems faster and larger.

We are told in the present verse of the *Karaṇakesarī* to decrease the diameter of the shadow by the tabulated correction when the sun is between Libra and Aries, and to increase it otherwise, which qualitatively agrees with the rationale above. Moreover, the table entries are also qualitatively consistent with it, since the largest corrections (both positive and negative) occur near a solstice (when the sun is roughly at perigee or apogee, respectively), and the zero corrections near the equinoxes where the true and mean solar velocity are about equal. However, it remains unclear whether or to what extent this rationale accounts quantitatively for the *Karaṇakesarī*'s actual correction values.

1.4 ECLIPSE MAGNITUDE

chādyachādakamaṇḍalānvitadalaṃ kāṇḍonachannaṃ punaḥ
channaṃ grāhyavivarjitaṃ tu nikhile grāse 'pi khachannakam ||
channāṅkair mitakoṣṭhake sthitir bhaven mardasya khachannataḥ
śrībhānor udayāt tathāstasamayāt parvāntamadhyagrahaḥ || 4 ||

Half the sum of [the diameters of] the disks of the obscured and the obscurer [is] the obscured amount [when it is] diminished by the [lunar] latitude. Again, the obscuration is decreased by [the disk of] the eclipsed; and in a total eclipse there is obscuration of the sky. In the table commensurate with the numbers [of the digits] of obscuration is the half-duration. [There is also a table] of the half-duration of totality [resulting] from sky-obscuration [i.e., in the case of a total eclipse]. [A solar eclipse is visible] from the rising of the Lord Sun just as [a lunar eclipse] from [its] setting. Mid-eclipse [is] the end of the *parvan*.

VERSE ANALYSIS

Metre: *śārdūlavikrīḍita*. The second syllable ought to be heavy, as should the sixteenth syllable in each of *pādas* 2 and 3, suggesting that the author thought of the following consonant *cha* in each case as doubled.

This verse illustrates Bhāskara's tendency to prescribe the steps of an algorithm before identifying the quantity it produces. It also exemplifies his penchant for technically ungrammatical ways of forming and modifying compounds. For instance, he expresses ◦*dalaṃ kāṇḍonaṃ channaṃ* 'the . . . half-sum diminished by the latitude [is] the obscured amount' as ◦*dalaṃ kāṇḍonachannaṃ*, literally 'the . . . half-sum [is] the obscured amount diminished by the latitude'.[13]

TECHNICAL ANALYSIS

The amount of the *channa* or obscuration (C) is stated to be

$$C = \frac{1}{2}(R + r) - \beta,$$

where R and r are the radii of the obscurer and the obscured respectively and β is the lunar latitude, all of which the user will have found from the procedures

13 This theoretically incorrect mixed construction is by no means unique to Bhāskara, however; see, e.g., Tubb and Boose (2007, 189).

mentioned in the previous verse. As illustrated in figure 4 in section 2, C represents not the extent of the eclipsed body's own diameter which is obscured, but rather the depth to which the leading edge of the eclipsed body penetrates within the disc of the eclipser. The second *pāda* defines 'obscuration of the sky', i.e., excess of the obscuration C over the diameter $2r$ of the obscured disk, which of course implies a period of totality in the eclipse. (The author of the example in MS. J, for reasons unknown, instead (f. 1v, line 8) multiplies C by 20 and divides it by the lunar disk's diameter.) In principle, the greater the obscuration, the longer the eclipse will last, and the greater the amount of 'sky-obscuration', the longer the period of totality will be.

It follows that the second half of the verse invokes two tables, on f. 4v, that tabulate the half-duration of the eclipse from the beginning of obscuration to mid-eclipse, and the half-duration of totality (if any) from the beginning of total immersion to mid-eclipse. It also adds the fairly trivial observation that solar eclipses are visible when the sun is above the horizon and lunar ones when it is not. The 'end of the *parvan*', as noted in section 2, refers to the syzygy moment at the end of a *tithi* when the luni-solar elongation is either exactly 180° or exactly 0°.

The argument of the half-duration table is the digits of 'obscuration of the moon' (*caṃdrachinnāṃgula*, for *caṃdrachannāṃgula*?). Its maximum value of 21 digits evidently means that the maximum possible 'obscuration', with the center of the moon coinciding with the center of the shadow, is taken to be equal to the maximum value of the moon's radius plus that of the shadow's radius or approximately $6 + 15 = 21$ digits. Its corresponding table entries for the mean half-duration (*caṃdrasya madhyasthitighaṭi*) are in *ghaṭikās* and run from 57;30 to 55;17. In fact, as the worked lunar eclipse example in MS. J (f. 1v, lines 9–10) makes clear, these tabulated values must be subtracted from 60 to give the actual extent of the mean half-duration, anywhere from 2;30 to 4;43 *ghaṭikās*. A separate table at the bottom of this folio gives the differences of the successive tabulated entries.

The table of the half-duration of totality has three rows, the last of which seems to be only an extension of the third row of a different table immediately to the left of it, and contains only a (meaningless) zero in each cell. The first row contains the table argument, the digits of 'sky-obscuration' (*khachinnāṃgulopari*), running from 1 to 9. Again, the maximum value suggests that if the moon's and shadow's centers coincide there will be $15 - 6 = 9$ digits of shadow beyond the edge of the moon. The second row contains the corresponding *ghaṭikās* running from 59;0 to 57;54, apparently indicating a range of 1;0 to 2;6 *ghaṭikās* for the actual half-duration of totality (*mardaghaṭikā*).

The last table on f. 4v, which is not alluded to in the text, lists the mean solar longitude (with corresponding solar velocities and their interpolation differences) for each *avadhi* from 1 to 27. The compiler of the MS. J example uses this table to get the mean solar position for his lunar eclipse date (f. 1v, line 10), which he then adjusts to the true position (f. 2r, line 2).

1.5 BEGINNING AND ENDING OF ECLIPSES; ZENITH DISTANCE AND *AKṢAVALANA*

sthityā mardena hīnaḥ sparśasanmīlane syuḥ
mardasthityānvite ’sminn unmilaṃ mokṣasaṃjñam ||
khāṅkair nighnaṃ 90 nanāptaṃ ghasramāne natāṃśās
tānaiḥ 45 śodhyāṃśakoṣṭhe prākpare saumyayāmye || 5 ||

[The moment of mid-eclipse is] decreased by the half-duration [or] by the half-duration of totality. These are the instants of first contact [or] beginning of total immersion [respectively]. When that [i.e., mid-eclipse] is increased by the half-duration of totality or the half-duration, it is called the beginning of emersion, [or] release. Multiplying [the ‘time-arc’, time from noon or hour-angle] by 90 [and] dividing by its own in [the sense of] the day-measure, [the result is] the degrees of [half] the zenith distance (*nata*). In the tabular entry for diminished degrees by 45 [one finds the *akṣavalana*]. [When the body is] East or West [of the meridian, respectively, the (*akṣa*)-deflection is laid off] in the North or South [respectively].

VERSE ANALYSIS

Metre: *maratatagaga*.[14]

Lexically speaking, the Sanskrit word *unmīla* in *pāda* 2 (more usually *unmīlana*) should have a long ‘i’. However, it occurs in the verse with a short ‘i’ which is required for the metre.

The word *tāna* in the last *pāda* is associated in the Sanskrit *bhūtasaṃkhyā* or ‘word-numeral’ system with the number 49.[15] But in this context, the number must mean 45 (and indeed in MS. R_1 the numeral ‘45’ is written out). Bhāskara’s nonstandard approach to compounding is again apparent in the use of the instrumental *tānaiḥ* ‘by 45’ to modify only the individual element *śodhya* ‘diminished’ in the following compound.

TECHNICAL ANALYSIS

This verse deals with the determination of the five significant moments in an eclipse (see section 2). The first part of the verse shows how to find the beginning of the eclipse or first contact and the beginning of totality, if any: namely, subtract the length of the half-duration or the half-duration of totality, respectively,

14 This is a form of *sakvarī*, a 14-syllable metre. Each *pāda* in *maratatagaga* is split into two groups of seven. See Apte (1970, vol. 3, App. A, p. 19).

15 See, e.g., Sarma (2003, 64).

from the time of mid-eclipse or end of the *parvan* (which presumably the user is expected to know from a calendar or some other source). Conversely, when these same intervals are added to the mid-eclipse moment, the results specify the instants of release (end of the eclipse) and beginning of emersion, respectively.

The second half of the verse concerns the *akṣavalana* or 'deflection due to latitude'. The 'deflection' or *valana*, as discussed in section 2, is the angle between the directional axes determined by the more-or-less easterly movement of the eclipsed body and the true local cardinal directions aligned with the prime vertical circle and the prime meridian shown in figure 7: it is traditionally considered to have ominous significance.[16] The *valana* is conventionally given in the form of two components, one due to the tilting of the celestial equator off the prime vertical by the amount of terrestrial latitude (*akṣavalana*) and the other to the skew between equatorial east and ecliptic east at the body's current tropical longitude (*ayanavalana*).

Instead of identifying or defining the quantity *akṣavalana*, this half-verse gives a rule to find the zenith distance (*nata* 'depression', ζ)—or rather, half of it—which is manipulated to become the argument in the table of *akṣavalana*. The zenith distance depends on the hour-angle, or amount of time in *ghaṭikās* before or after noon (which, somewhat confusingly, is also conventionally termed *nata*), and the length of the body's 'own day', i.e., the amount of time it is above the horizon:

$$\text{(half)}\, \zeta = \frac{\text{hour-angle} \times 90}{\text{own day measure}}$$

This rule is similar to a standard approximation appearing in, e.g., *Karaṇakutūhala* 4.14 (Balacandra Rao and Uma 2008, S80), which more or less converts hour-angle (time) into zenith distance (arc) by the simple proportion $\zeta : 90^\circ ::$ hour-angle : half-day.[17] By using the whole 'own day' in place of the half-day in the divisor of this proportion, the *Karaṇakesarī* actually computes *half* the arc of zenith distance. (Note also that this procedure does not include the information needed to determine the length of the 'own day', which appears eventually in verse 1.9).

Theoretically, the relation of the zenith distance ζ to the *akṣavalana* is based on the following geometric rationale. In figure 7, showing the celestial hemisphere above the local horizon with zenith at Z, M is the deflected body and P and P' are the poles of the equator and ecliptic respectively (the latter is lifted off the rear surface of the hemisphere for ease of viewing). Qualitatively, as noted above, the local latitude or elevation of the pole P above the northern horizon is responsible for the *akṣavalana* component of deflection, while the splay of the ecliptic away

16 For further details, see Montelle (2011, 229–230). The diagram in figure 7 is based on a similar diagram in Chatterjee (1981, 125).

17 The relevant part of the *Karaṇakutūhala* verse (Mishra 1991, 56) has clearly influenced the phrasing of the *Karaṇakesarī*'s rule: *khāṅkāhataṃ svadyudalena bhaktaṃ sparśe vimuktau ca nataṃ lavāḥ syuḥ*

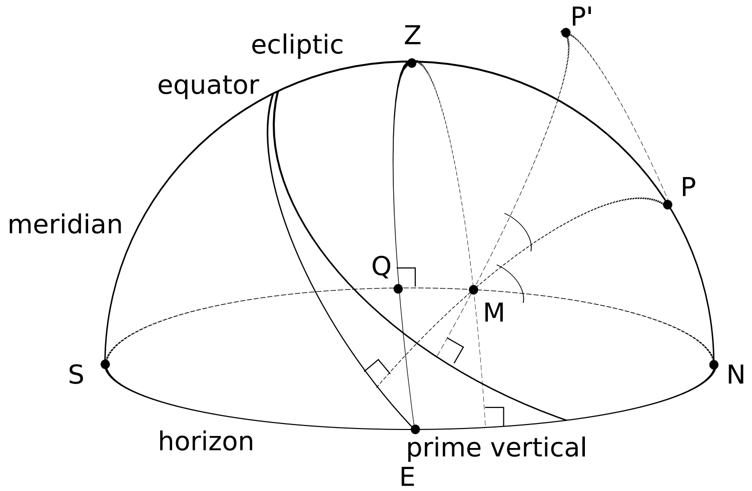

Figure 7: The *akṣavalana* $\angle NMP$ and *ayanavalana* $\angle P'MP$ of a body at M

from the equator produces the *ayanavalana* component. The total *valana* is thus equal to the angle $\angle NMP'$. To compute its *akṣavalana* part $\angle NMP$, we note that angle $\angle MNP$ or arc ZQ is the projection of the body's zenith distance ZM onto the prime vertical, while PM is the complement of its declination δ and NP, the elevation of the north celestial pole above the horizon, is the local latitude ϕ. By the law of sines for spherical triangles, $\angle NMP$ is trigonometrically determined by

$$\sin \angle NMP = \frac{\sin \angle MNP \cdot \sin NP}{\sin PM}$$

Assuming that the hour-angle or *nata* converted to degrees of zenith distance ζ as discussed above is approximately the same as $\angle MNP$, this equation is equivalent to a typical form of the rule for *akṣavalana* in Indian astronomy:[18]

$$\sin akṣavalana = \frac{\sin \zeta \cdot \sin \phi}{\cos \delta}$$

Note that if the body is at the zenith and/or the latitude ϕ is zero, there is no *akṣavalana* angle $\angle NMP$: the *akṣavalana* increases with both zenith distance and latitude. The maximum *akṣavalana* for a given ϕ, when $\delta = 0$ and $\zeta = 90°$, is just ϕ itself.

The *Karaṇakesarī*'s *akṣavalana* table, on the other hand, requires a rather peculiar manipulation of the half-ζ computed in this verse: the user is to subtract it

18 Variant forms of this rule also existed, using slightly different functions or rougher approximations. The differing formulas for *valana* and the disagreements about it between rival authors are discussed in, e.g., Montelle (2011, 246–247).

from 45° and use the result as the argument in the table, which appears on f. 5r and continues onto f. 5v. Its first row, the argument, labeled *natāṃśa* or 'degrees of *nata*', runs from 0 to 45. The second row, labeled *valana*, is given in degrees, minutes and seconds and runs from 22°;35,39 to 0. The third column, labeled *antara* 'difference', gives the differences between successive entries in row 2.

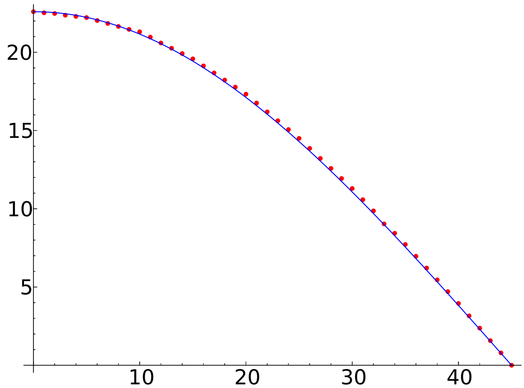

Figure 8: Plot of tabulated values of *akṣavalana* (dots), and the graph of $\arcsin(\sin(90^\circ - \zeta) \cdot \sin\phi)$ versus $\zeta/2 = 0$ to 45° for latitude $\phi = 22^\circ;35,39$ (line)

These *akṣavalana* values progress backwards with respect to the order one would expect from the *akṣavalana* equation shown above: for a given ϕ and δ, the *akṣavalana* ought to *increase* as ζ increases. As we can see in figure 8, the values in the table actually conform to the graph of a 'reversed' *akṣavalana* function, $\arcsin(\sin(90^\circ - \zeta) \cdot \sin(22^\circ;35,39)$, where it is assumed that $\phi = 22^\circ;35,39$ and $\delta = 0$. This and the instruction *tanaiḥ śodhya*∘ 'diminished by 45' inform us that the actual table argument running from 0 to 45 is $45^\circ - \zeta/2$: in other words, the table entries are given for every *two* degrees of zenith distance starting at 90 (when the *akṣavalana* attains its maximum value ϕ if δ is 0) and ending at 0.

Bhāskara's final remark about directions can be justified as follows: When the eclipsed body is east of the meridian, the equator-east direction skews north of the easterly direction parallel to the prime vertical, so the *akṣavalana* is north. When the body is west of the meridian, on the other hand, the *akṣavalana* is south.

The awkwardness of the *Karaṇakesarī*'s presentation as a guide to actually using the tables is indicated by the way the author of the worked example in MS. J handles these calculations. First he corrects for precession (f. 2r, line 4) the true solar longitude that he found at the end of the procedure in the previous verse. This precession-corrected longitude is entered into a table described in verse 1.9 to get the length of the half-day (f. 2r, line 5). Then he follows the directions in verse 1.5 to find the moment of first contact (f. 2r, lines 10–11; there is no period of totality since the example concerns a partial eclipse), and determines the *nata* and its direction in accordance with the rule in verse 1.8 (f. 2v, lines 3–4). He then proceeds to compute the *valana* as specified (f. 2v, line 11–f. 3v, line 4).

1.6 *AYANAVALANA*

yāmyottare diśi grahasya yutāyanāṃśāḥ
koṭyāṃśakeṣu valanāntaraguṇyayuktam ||
yogāntarāṃśapramite valanaṃ sphuṭaṃ syāt
sūryasya grāsavidhumokṣavilomadeyam || 6 ||

In the south [or] north direction, the precession-increased degrees of [the longitude of] the planet [determine the *ayanavalana* in the same direction respectively]. [The difference between the precession-increased degrees and the nearest table argument is] multiplied by the [tabulated] *valana*-difference and applied to the degrees of the complement [of the precession-increased longitude]. The *valana* [determined] in the amount of the degrees of the sum or the difference [of the two components] should [now] be accurate. [In the case of an eclipse] of the sun, [the *valana*] is given in the reverse order of release [and first contact] from [the case of] the eclipsed moon.

VERSE ANALYSIS

Metre: *vasantatilakā*.

In Bhāskara's prosody, a consonant conjoined with a following 'r' appears to be counted as a single consonant that does not make the preceding syllable heavy. This can be seen in the present verse in, e.g., *graha* in the first *pāda* and *pramite* in the third *pāda*, each of which is preceded by a syllable that must still be considered as 'light' to fit the *vasantatilakā* metre.

TECHNICAL ANALYSIS

Like the last verse, this verse does not explicitly specify the quantity it is computing, in this case the *ayanavalana* or 'deflection due to tropical [longitude]'. The *ayanavalana* (angle $\angle P'MP$ in figure 7) is the amount of deflection of the easterly direction along the ecliptic from the easterly direction along the equator due to the position of the body's tropical longitude λ^T in its quadrant of the ecliptic. Qualitatively, when the body is at a solstice there is no deflection from this effect, since east is in the same direction along both great circles. At an equinox, on the other hand, the deflection is equal to the obliquity of the ecliptic (conventionally 24°), since the local directions of the two circles diverge by that amount.

Quantitatively, the value of the *ayanavalana* $\angle P'MP$ between those two extremes, again by the law of sines for spherical triangles, is given by

$$\sin \angle P'MP = \frac{\sin \angle PP'M \cdot \sin PP'}{\sin PM}.$$

The angle $\angle PP'M$ is the complement of the (tropical) longitude of M, while PM again is the complement of its declination δ and the arc PP' between the two poles is the ecliptic obliquity. The verse's algorithm for using the table to find the *ayanavalana* $\angle P'MP$ simply prescribes adding the degrees of precession to the degrees of the known (sidereal) longitude of the body to convert it to tropical longitude, and using the *koṭi* or complement of this result to interpolate linearly in the table. When the tropical longitude is between the winter and summer solstices (called the northern *ayana*), the *ayanavalana* is north because ecliptic-east points northwards of equator-east; conversely, in the southern *ayana*, it is south.

The last part of this verse refers to the inverse symmetry between a lunar and solar eclipse. In a lunar eclipse, the eastern part of the moon's disk is eclipsed first; so at first contact it is the western part of the shadow (the 'eclipser') that is being affected, and the eastern part for release. This is reversed in the case of a solar eclipse where the moon is the 'eclipser' and the sun the 'eclipsed'.

There are three tables related to this verse, on ff. 6r and 6v. The first is a table giving the *ayanavalana* at 'the time of contact [or] the time of release' (which are the chief moments for which the deflection is calculated). Of its three rows, the first contains the argument, running from 0 to 90 degrees, which is evidently the complement of the precession-corrected longitude. The second row contains the corresponding values of the *ayana*-deflection, from $0;0,3$ when the argument is 0 (i.e., when the body is at a solstice) to $24;0,1$ (90° of longitude away, at an equinox). The third row gives the differences between successive entries in the second row; they change only at every tenth entry, indicating that *ayanavalana* values were computed first for every tenth degree of argument and the remaining entries found by linear interpolation.[19]

The other two tables on f. 6v give the 'corrected' *valana* (*spaṣṭavalana*), which is not mentioned in the verse, and which despite its name does not actually introduce any new elements to give a more accurate value of the deflection. Rather, it simply converts the combined deflection into a linear measure scaled appropriately for the disks of the eclipsed and eclipsing bodies. Consequently, there is one table for solar and one for lunar eclipses. The arguments for both tables run from 0 to 47, which evidently represents the degrees of total *valana* as the algebraic sum of *akṣavalana* (whose maximum for the *Karaṇakesarī*'s latitude is between 22 and 23 degrees) and *ayanavalana* (which, as noted above, can be as much as 24°), giving a possible combined maximum of 47°.[20] The table entries run from $0;7$ to $8;2$ digits for the sun and $0;4$ to $13;51$ digits for the moon.

MS. J's procedure confirms this interpretation; he adds his *akṣavalana* and

19 In fact, the non-interpolated table entries seem to conform very closely to Bhāskara II's simple expression for *ayanavalana* in *Karaṇakutūhala* 4.14–15 (Balacandra Rao and Uma 2008, S81–82), which is equivalent to $\sin(90^\circ - \lambda^T) \cdot 24$.

20 See the rule for 'corrected' *valana* in, e.g., *Karaṇakutūhala* 4.16 (Balacandra Rao and Uma 2008, S81–82).

ayanavalana components to get the argument he uses for the lunar corrected-*valana* table, in the case of both contact (f. 3r, lines 1–2) and release (f. 3v, lines 1–3).

1.7 REDUCTION OF ARCS TO THE FIRST QUADRANT

tryūnaṃ bhujaḥ syāt tryadhikaṃ ca ṣaḍbhāt
viśodhya bhārdhād adhikaṃ vibhārdham ||
navādhikaṃ tad ravipātitaṃ ca
koṭir bhavet syāt trigrahaṃ bhujonam || 7 ||

The *bhuja* should be: [an arc] less than three [signs]; moreover, subtracting from six signs one [i.e., an arc] that is greater than three signs; [or, an arc] greater than a half-circle is diminished by a half-circle; [or, an arc] greater than nine [signs is] that taken away from 12 [signs]. The *koṭi* should be three signs diminished by the *bhuja*.

VERSE ANALYSIS

Metre: *upajāti*.

The grammar in this verse is particularly inconsistent in its parallel constructions, as frequently happens when Bhāskara tries to revamp a borrowed *Karaṇakutūhala* verse with some original phrasing (see below). However, the intended meaning seems clear.

TECHNICAL ANALYSIS

This verse gives a rule for producing a *koṭi* or complement from a *bhuja*/*bāhu* or given arc.[21] Most commonly in geometry the *bhuja* and *koṭi* are understood as perpendicular sides of a right triangle, but generally in astronomical texts the *bhuja* is an arc, e.g., of longitude. This arc is conventionally reduced to a trigonometrically equivalent amount less than 90° or three zodiacal signs, and the complement arc of this standard *bhuja* is the *koṭi*.

This verse is not directed specifically toward the use of any particular table. Rather, it is a standard general procedure for reducing arcs to their canonical forms in the first quadrant, for which alone function values are tabulated. Note that Bhāskara in the immediately preceding verses has prescribed procedures assuming the user's ability to reduce arcs, and now belatedly gives explicit directions for it.

21 Compare *Karaṇakutūhala* 2.4 (Mishra 1991, 20):
tryūnaṃ bhujaḥ syāt tryadhikena hīnaṃ bhārdhaṃ ca bhārdhād adhikaṃ vibhārdham |
navādhikenonitam arkabhaṃ ca bhavec ca koṭis trigrahaṃ bhujonam ||

1.8 POSITION OF *NATA* WITH RESPECT TO THE MERIDIAN

sūryagrahe divasam eva dinaṃ svakīyaṃ
rātris tathaiva śaśiparvaṇi vaipari syāt ||
ahno 'rdhato niśidalendunataṃ pratīcyāṃ
rātridalād dyudalato 'rkanatasya pūrve || 8 ||

In an eclipse of the sun, the day is just its own day. The night is likewise. In a lunar eclipse, it should be reversed. The [post-]midnight *nata* of the moon after the middle of [its own] day [i.e., with 'night' and 'day' reversed in meaning as specified] is in the west. From midnight to midday, [the place] of the sun's *nata* is in the east.

VERSE ANALYSIS

Metre: *vasantatilakā*.

The last *pāda* is defective: the second syllable ought to be heavy for the metre's sake.

TECHNICAL ANALYSIS

This verse conveys rather simple astronomical facts about the *nata* or hour-angle/zenith distance of the moon and the sun, with respect to the meridian (here indicated by midday or midnight). 'Its own day' means the period of time when the body in question is above the horizon, which is of course daytime in its usual sense for the sun but nighttime for the full moon. And indeed for both luminaries, from 'midnight' to 'midday' of its own day the body is to the east of the meridian, and from 'midday' to 'midnight' it is west of the meridian, because of the westward daily rotation. Again, it might have been more intuitive from the user's point of view to supply this information earlier: namely, before prescribing the calculation of the *akṣavalana*, whose direction depends precisely on this issue of whether the body's *nata* is in the east or the west.

1.9 PRECESSION; LENGTH OF THE HALF-DAY

prabhābdhi 445 śakonāptakhāṅgo 60 'yanāṃśāḥ
yuto 'rkasya rāśyaṃśamāneṣu koṣṭhe ||
dinārdhaviśodhyaṃ kharāmair niśardhaṃ
dinārdheṣṭanāḍyantaraṃ taṃ nataṃ syāt || 9 ||

445 subtracted from the [current] Śaka year [and] divided by 60 are the degrees of precession. [That amount is] added to the amounts in signs and degrees of the sun['s longitude]. The subtracted [complement] of the half-day in the table

[entry] with [respect to] 30 [*ghaṭikās*] is the half-night. [Whatever is] the difference between the desired *nāḍī* [i.e., *ghaṭikā*] and the half-day, that should be the 'hour-angle' (*nata*).

VERSE ANALYSIS

Metre: *bhujāṅgaprayāta* (see verse 1.2) with minor deviations: the third syllable of the first and third *pādas* is light instead of heavy.

This unfamiliar *bhūtasaṃkhyā* numeration takes *prabhā* 'light' or 'shadow' to mean 45. The related compound *prabhāvaka* is elsewhere attested as meaning 8 (Sarma 2003, 66).

A comprehensible translation of this verse requires taking substantial liberties with its phrasing: its literal sense is more like '[The amount] which has 60 as dividing the difference between the [current] Śaka year and 445 are the degrees of precession.' The mathematical meaning, however, is unmistakable.

TECHNICAL ANALYSIS

This verse explains how to correct the solar longitude for precession or the difference between sidereal and tropical longitude (which it would have been helpful to know before calculating the *ayanavalana* requiring that correction). The year Śaka 444 or 522 CE is frequently attested as the assumed date of zero precession, and the canonical rate of precession is taken as 1 degree in 60 years.[22] The difference between 445 and the current Śaka year gives the integer number of years elapsed between the end of 444 and the start of the current year, each of which produces one additional arc-minute of precession.

The resulting precession-corrected solar longitude in signs and degrees is the argument of the table on f. 7r (see 2.2 below) that tabulates the sun's 'half-day' (*dyu-dala*). This means the length in *ghaṭikās* of half the seasonally varying period of daylight (the solar form of the 'own day' previously invoked in 1.5).

1.10–11 GRAPHICAL PROJECTION OF ECLIPSE APPEARANCE

grāhyārdhasūtreṇa vidhāya vṛttaṃ
mānaikyakhaṇḍena ca sādhitāśam ||
bāhye 'tra vṛtte valanaṃ yathāśaṃ
prāk sparśikaṃ paścimataś ca mokṣam || 10 ||
deyaṃ raveḥ paścimapūrvataś ca
jyāvac ca bāṇau valanāgrakābhyām ||
utpādya matsyaṃ valanāgrakābhyāṃ
madhyaḥ śaras tanmukhapucchasūtre || 11 ||

22 See, for instance, Pingree (1972, 30–31).

When one has produced a circle by means of a [radius] string half [the size] of the eclipsed body, and [another circle by a radius string equal in length to] the [half] part of the sum of their measures [i.e, diameters of eclipsed and eclipser: this is the circle of first contact (*sparśa*) and release (*mokṣa*)] with cardinal directions established. Now on the outer circle, the *valana* is to be set according to [its] direction, contact in the east and in the west the release [*valana*, for a lunar eclipse];

[and] in the case of the sun, west and east [respectively]. And having extended two latitude [values] like a chord at the two extremities of the *valana*, a fish [-figure is drawn with arcs centered] at the two extremities of the *valana*. The mid-eclipse latitude is [laid off from the center] on its head-tail-line [i.e., the axis of the fish-figure].

VERSE ANALYSIS

Metre: *indravajrā*.

The first of these two verses is identical to Bhāskara II's *Karaṇakutūhala* 4.18, and the second nearly the same as *Karaṇakutūhala* 4.19, except for the syllable *ca* instead of *te* at the end of its first *pāda*.[23] The word *āśā* can mean 'quarters of the compass'; this adverbial form *āśam* evidently means 'relating to cardinal directions'.

TECHNICAL ANALYSIS

These verses and the two following give directions for producing the graphical projection of the eclipse. The procedure does not refer directly to any of the data given in the tables, as it is a practical description of how to represent the eclipse configuration using the quantities previously computed. The following interpretation of these two verses is illustrated in figure 9.[24] The author of the lunar-eclipse example in MS. J briefly echoes the text's instructions for this diagram (f. 3v, lines 4–8), but alas, the manuscript preserves no drawing in illustration of them.

The central circle represents the disk of the eclipsed body. At the moment of *sparśa* or *mokṣa*, the center of the eclipsing body is on the circumference of a second, larger concentric circle with radius equal to the sum of the radii of

23 *Karaṇakutūhala* 4.18–19 (Mishra 1991, 60):
grāhyārdhasūtreṇa vidhāya vṛttaṃ
mānaikyakhaṇḍena ca sādhitāśam |
bāhye 'tra vṛtte valanaṃ yathāśaṃ
prāk sparśikaṃ paścimataś ca mokṣam || 18 ||
deyaṃ raveḥ paścimapūrvatas te
jyāvac ca bāṇau valanāgrakābhyām |
utpādya matsyaṃ valanāgrakābhyāṃ
madhyaḥ śaras tanmukhapucchasūtre || 19 ||

24 As noted in the Verse Analyses for this and the following group of verses, this procedure is directly copied from that of the *Karaṇakutūhala*, which in turn is a simplified version of its counterpart in the same author's *Siddhāntaśiromaṇi* 5.26–32 (Śāstrī 1989, 121–124).

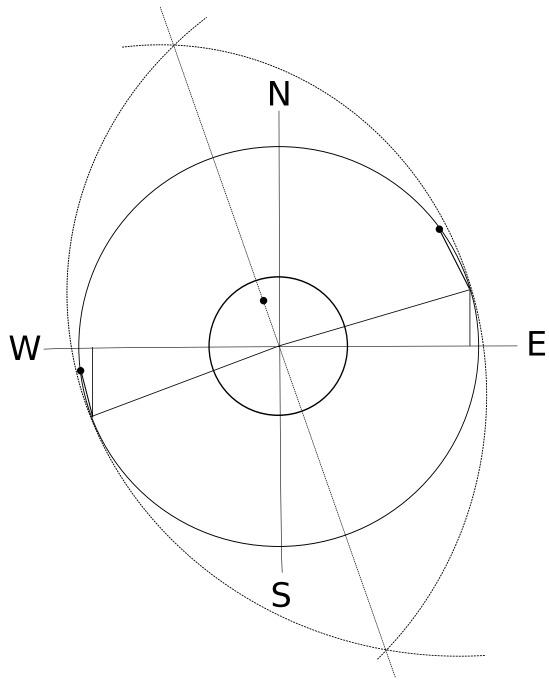

Figure 9: Initial circles and lines for the graphical projection of an eclipse

eclipsed and eclipser, so the two bodies are tangent. The trajectory between *sparśa* and *mokṣa* is determined by the values of the *valana* and lunar latitude.

The local cardinal directions are laid out on this outer circle as shown in figures 9 and 10. Note that this direction grid represents a left-right-reversed image of the eclipsed body as it would appear in the southern part of the sky, where the southward-facing observer would see east on the left hand and west on the right.[25]

The amount of the appropriately scaled linear combined *valana* (see 1.6 above) for *sparśa* or *mokṣa* is marked off north or south of the appropriate extremity on the east-west line. The radii between those two points will not be exactly collinear unless the *sparśa* and *mokṣa* values of *valana* are exactly equal, but they will indicate approximately the direction of the ecliptic with respect to local east-west.

Then the corresponding values of the latitude are marked off from the *valana* points 'like a chord' so that they fall on the circumference of the outer circle, to indicate the positions of the center of the eclipser at *sparśa* and *mokṣa*. (Presumably, since the possible values of latitude are small, the fact that the 'chord-like' line

25 See, e.g., *Sūryasiddhānta* 6.12, *viparyayo diśāṃ kāryaḥ pūrvāparakapālayoḥ* 'a reversal of the directions of the east and west hemispheres is to be made' (Pāṇḍeya 1991, 69). The graphical projection shows how the eclipse would look in a mirror image, e.g., in a tray of water or other reflector set on the ground next to the diagram.

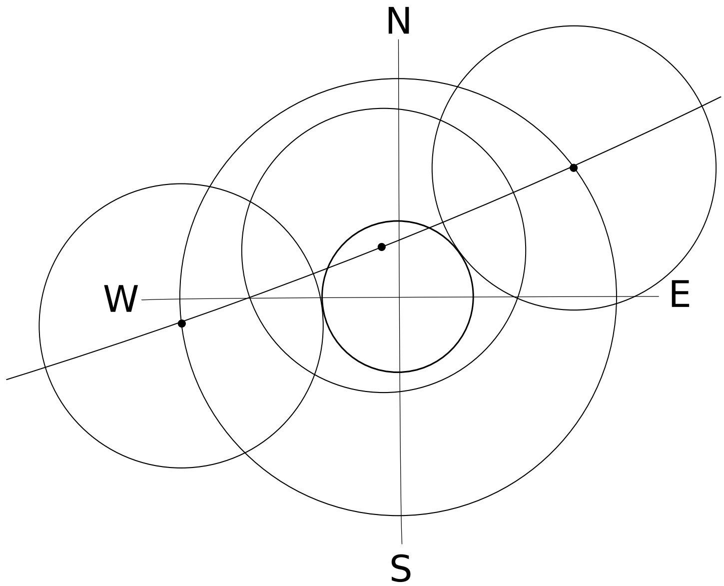

Figure 10: Depicting the three moments of contact, mid-eclipse, and release in the projection

segments representing them are not quite perpendicular to the approximate line of ecliptic direction determined by the *valana* points is considered negligible.) Then a 'fish-figure' or perpendicular bisector to the ecliptic direction is constructed through the center of the circle, and a line segment representing mid-eclipse latitude is laid off along it.

1.12–13 GRAPHICAL PROJECTION, CONTINUED

kendrād yathāśo 'tha śarāgrakebhyo
vṛttaiḥ kṛtair grāhakakhaṇḍakena
syuḥ sparśamadhyagrahamokṣasaṃsthā
athāṅkayen madhyaśarāgracihnāt || 12 ||

mānāntarārdhena vidhāya vṛttaṃ
kendre 'tha tanmārgayutidvaye 'pi ||
tamo 'rdhasūtreṇa vilikhya vṛttaṃ
sanmīlanonmīlanake ca vedye || 13 ||

By means of circles constructed from a centre in the [appropriate] direction at the tips of the latitude [line segments] now [at that time], with [radius equal to] the [half] part [of the diameter] of the eclipser, the forms [of the eclipser] at contact, mid-eclipse and release should be [shown].

Now, producing a circle with [radius equal to] half the difference of the amounts

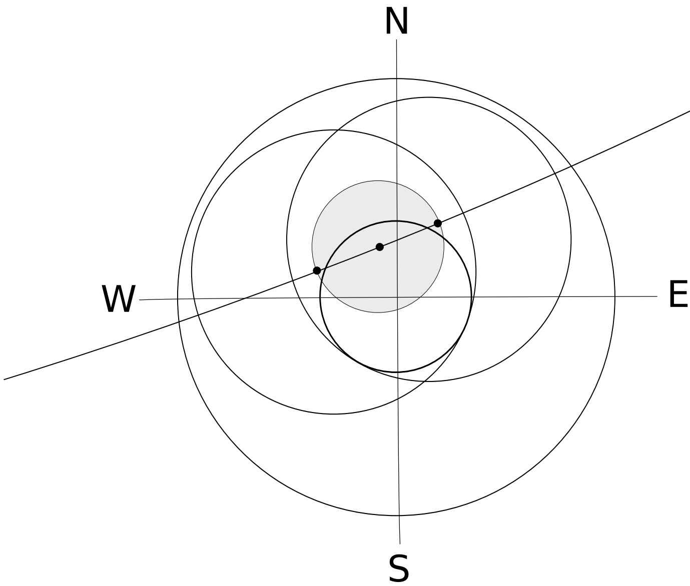

Figure 11: Depicting the beginning and end of totality

[of the diameters of the two bodies], one should draw [it] from the point of the tip of the mid-eclipse latitude. Now [there are] two centres at the two intersections of that [circle] and the path [of the eclipser]. [Upon] drawing a circle [at each centre] with radius [equal to that of] the eclipser, the beginning of totality and end of totality too are to be known.

VERSE ANALYSIS

Metre: *upajāti*.

These verses, like the preceding ones, closely track their counterparts in the *Karaṇakutūhala*.[26] The *Karaṇakesarī* version has introduced a couple of unusual or awkward grammatical constructions, such as the nominative/accusative form of *tamas* 'darkness' that we take to refer to the eclipser in a genitive sense, and what appears to be an instance of the particle *atha* 'now' more or less prepended

26 *Karaṇakutūhala* 4.20–23 (Mishra 1991, 61):
kendrād yathāśaṃ svaśarāgrakebhyo
vṛttaiḥ kṛtair grāhakakhaṇḍakena |
syuḥ sparśamadhyagrahamokṣasaṃsthā
athāṅkayen madhyaśarāgracihnāt || 20 ||
ādyantyabāṇāgragate ca rekhe
jñeyāv imau pragrahamuktimārgau |
mānāntarārdhena vilikhya vṛttaṃ
kendre 'tha tanmārgayutadvaye 'pi || 21 ||
bhūbhārdhasūtreṇa vidhāya vṛtte
sammīlanonmīlanake ca vedye |
mārgapramāṇe vigaṇayya pūrvaṃ
mārgāṅgulaghnaṃ sthitibhaktam iṣṭam || 22 ||
iṣṭāṅgulāni syur atha svamārgo
dadyādamūniṣṭavaśāt tadagre |
vṛtte kṛte grāhakakhaṇḍakena
syād iṣṭakāle grahaṇasya saṃsthā || 23 ||

to *śara* 'latitude', instead of *sva* 'its own', to imply 'the now-latitude' or 'latitude at that time.'

TECHNICAL ANALYSIS

Figure 10 shows an arc drawn through the aforementioned three latitude points to mark the 'path' of the eclipse, and the disk of the eclipsing body centred at each of them. To find where the eclipsing body sits at the remaining two principal moments of the eclipse, i.e., the beginning and end of totality, the user is instructed to draw a circle (shown shaded in figure 11) whose radius equals the difference between the radii of eclipsed and eclipser. The two points where this circle intersects the 'path' mark the positions of the centre of the eclipser at those two moments.

iti candraparvādhikāraḥ ||

Thus, the chapter on lunar eclipses.

2.1 DIDACTIC APHORISM

śāstrāṇy anekāni mahārthasūtrā-
ṇy anantavidyālpamatir jano 'yam ||
kalau na dīrghāyur ato hi [grā]hyaṃ
tattvaṃ yathā kṣīravidhau ca haṃsaḥ || 1 ||

[There are] many treatises (*śāstras*), rules (*sūtras*) with great purpose, [and] endless knowledge; this person [i.e., the speaker, is] of small intelligence. In the Kaliyuga, life is not long; therefore, truth is to be grasped just as the swan [does] in the act of [separating] milk [from water].

VERSE ANALYSIS

Metre: *upajāti*?

We have taken considerable liberties with the arrangement of the *pādas* and especially with the reconstruction and translation of the third *pāda*, in which the penultimate syllable seems to be missing. The final syllable looks in the manuscript more like *hvaṃ* than *hyaṃ*, so the final word in the original might have been something quite different. But the reference is clearly to the well-known analogy between the soul discerning valid knowledge from a mixture of truth and untruth and the proverbial ability of a goose or swan to separate out the components of a mixture of milk and water.[27] The Kaliyuga or Indian 'Iron Age' is traditionally considered a time of degeneration and decay, in which, for example, the standard human lifespan is much shorter than it is said to have been in earlier ages.

2.2 HALF-DAY AND OBLIQUE ASCENSION

sāyanārkabhalavādikoṣṭhakāḥ
yukte ceṣṭhaghaṭiyuktatatsamān ||
koṣṭhakāṅkamitiṃ rāśipūrvakaṃ
labdhalagnam ayanāṃśakonnatam || 2 ||

The table entries [for half-day and oblique ascension have as argument] the precession-increased [longitude of the] sun in zodiacal signs and degrees and so on. And when [the longitude in signs and degrees] is increased [by minutes, use the digits] corresponding to those [minutes] increased by the *ghaṭikās* [corresponding to] the desired [argument: these digits are] commensurate with the number in the table cell headed by [its] zodiacal sign. The obtained oblique ascension [has] the precession-increased [solar longitude] beginning with zodiacal signs [as its] argument (*unnata*).

VERSE ANALYSIS

Metre: *rathoddhatā*.

As usual with the verses that appear to be original to the *Karaṇakesarī*, there are a few metrical irregularities: namely, in *pāda* 2 the second syllable should be light, as should the sixth syllable in *pāda* 3.

TECHNICAL ANALYSIS

This verse apparently applies to two tables, although it explicitly mentions only the second of them. The first, on f. 7r, tabulates half the seasonally varying length of daylight in *ghaṭikās* (see 1.9 above), and is titled *atha sāyanaravirāśyoparidyudalaṃ* 'Now [the length of] the half-day with argument the signs [and degrees] of the precession-corrected [longitude of the] sun'. Its values for each degree of

27 This simile is attested in Sanskrit literature as far back as, e.g., *Mahābhārata* 1.69.10 Smith (1999):
prājñas tu jalpatāṃ puṃsāṃ śrutvā
vācaḥ śubhāśubhāḥ |
guṇavad vākyam ādatte haṃsaḥ kṣīram
ivāmbhasaḥ ||
But the direct inspiration for the *Karaṇakesarī*'s verse was apparently closer to the form found in, e.g., *Garuḍapurāṇa* 16.84 (Wood and Subrahmanyam 1911, 164):
anekāni ca śāstrāṇi svalpāyur vighrakoṭayaḥ |
tasmāt sāraṃ vijñānīyāt kṣīraṃ haṃsa ivāmbhasi ||

the sun's (tropical) longitude are arranged in double entry format, zodiacal signs against degrees: along the vertical axis are the signs numbered 1–11 followed by 0, and along the horizontal, degrees numbered 0–29. The maximum entry 16;48 *ghaṭikās* occurs at Cancer 0° and the minimum is 13;13 *ghaṭikās* in Capricorn 0°; the equinoctial half-day is of course 15 *ghaṭikās*, one-quarter of a full nychthemeron or 60 *ghaṭikās*.[28]

As noted above, this table seems more relevant to computations involving the *nata* in the lunar eclipse chapter. Its placement here may have been intended to allow the user to check whether the sun will be visible above the horizon at the time of the predicted solar eclipse.

The remaining instructions in the verse deal with computing the *lagna*, usually meaning the 'horoscopic point' or ascendant where the ecliptic intersects the eastern horizon, but in this case evidently intended to signify the oblique ascension in *ghaṭikās* of the ecliptic arc between the sun and the vernal equinox. The computation employs a two-part set of tables: the first part, on ff. 7v–8r, is another double entry table for each degree of (tropical) solar longitude, with zodiacal signs 0–11 on the vertical axis and degrees 0–29 on the horizontal. The tabulated values begin with 0 at 0° of argument and increase to 60 *ghaṭikās* at 360°, meaning that these oblique ascensions are cumulative. The differences between tabular entries for successive degrees within a given zodiacal sign are constant and their values are symmetrical about the equinoxes, as shown in table 3.

Zodiacal sign	Constant difference (*ghaṭikās*)
Aries/Pisces	0;7,36
Taurus/Aquarius	0;8,38
Gemini/Capricorn	0;10,12
Cancer/Sagittarius	0;11,20
Leo/Scorpio	0;11,18
Virgo/Libra	0;10,56

Table 3: The constant differences between oblique ascension values for successive degrees

The other table in this set, on ff. 8v–9v, allows the user to make the oblique ascension calculation precise for arcminutes of longitude: it is somewhat mislead-

28 We assume that zodiacal sign 1 in the first row is Taurus and zodiacal sign 0 (the last row) is Aries. The half-day extreme values imply that the so-called 'maximum half-equation of daylight' ω_{max}, i.e., the difference between half the equinoctial day and half the solstitial day, is 1;47 *ghaṭikās*. We used this quantity to confirm the value of the terrestrial latitude $\phi = 22;35,39°$ that we inferred from the *akṣavalana* table used in verse 1.5: plugging it into the formula for the terrestrial latitude $\phi = \arctan(\sin \omega_{\text{max}} / \tan \varepsilon)$, where ε is the canonical ecliptic obliquity of 24°, yields a value for ϕ of approximately 22;38°.

ingly titled *atha lagnasya kalākoṣṭakā* 'Now, the tabular entries for the arcminutes of the oblique ascension'. Actually, in each of its six sub-tables (one for each pair of zodiacal signs from Aries/Pisces to Virgo/Libra), it is the *argument* that is measured from 1 to 60 *kalās* or arcminutes within a degree, not the tabulated oblique ascension amounts.

The table entries, in sixtieths of a *ghaṭikā*, are the corresponding increments added by those extra arcminutes to the oblique ascension already computed for the degree of tropical solar longitude specified by the previous table's argument. Again, the differences between entries in each sub-table are constant: the entries for successive arcminutes differ by just one-sixtieth of the previous table's constant difference between entries for successive degrees of the appropriate zodiacal sign. (Thus, for example, every additional arcminute in a solar longitude falling in the sign Aries adds 0;0,7,36 *ghaṭikās* to the corresponding oblique ascension.) By the combination of the table for degrees and the one for arcminutes, the accumulated oblique ascension can be determined for each of the possible 21,600 arcminutes of tropical solar longitude.

The version of this procedure in the solar eclipse example in MS. J starts by finding the usual *lagna* or longitude of the ascendant and computing the longitude difference between that and the tropical solar longitude to give the argument for the algorithm in the following verse.

2.3 LONGITUDINAL PARALLAX

darśāntakāle 'rkatanoviśeṣaṃ
kāryaṃ tadaṃśamitispaṣṭhakoṣṭhe ||
yallambanaṃ sve guṇakena guṇyaṃ
khaveda 40 bhaktaṃ sphuṭalambanaṃ syāt || 3 ||

At the time of the end of the conjunction [*tithi*], the difference [of the longitudes] of the sun and the ascendant (? *tanas*) is to be computed. Whatever longitudinal parallax (*lambana*) [corresponds to that difference], multiplied by the multiplier in its own true-table entry commensurate with the degree of that [ascendant] and divided by 40, should be the corrected longitudinal parallax.

VERSE ANALYSIS

Metre: *upajāti*.

In *pāda* 2, the second syllable of *aṃśa* ought to be heavy and the second syllable of *mitispaṣṭa* ought to be light for the sake of the metre. We know of no other use of the word *tanas* as a synonym for *lagna* or ascendant, but that is the meaning required by the procedure.

TECHNICAL ANALYSIS

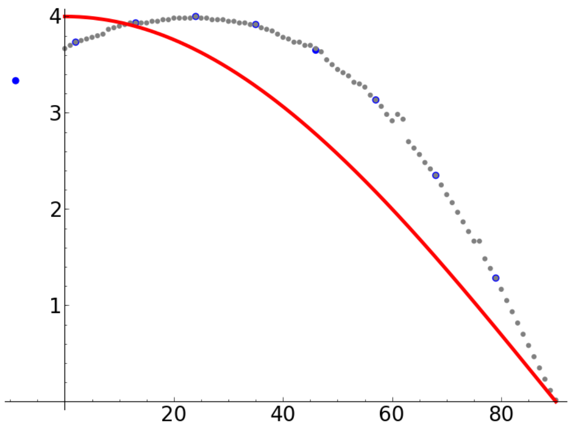

Figure 12: Plots of 'mean' *lambana* in *ghaṭikās* against elongation $\lambda_A - \lambda_S$ in degrees, in three forms: the trigonometric expression $4\sin(\lambda_A - \lambda_S)$ (line), the short list of values in the *Karaṇakutūhala* (large dots), and the tabulated values in the *Karaṇakesarī* (small dots)

The first of the two tables referenced in this verse lists the 'mean' longitudinal parallax or *lambana* in *ghaṭikās* for values of elongation between the sun and the ascendant ranging from 0 to 91°. The table entries start with 3;40 *ghaṭikās* at 0°, maximising to 4;0 at 24°, and decreasing to 0;1 at 91°. The next table, which gives the *laṃbanaspaṣṭaguṇakāḥ* 'multipliers for correcting the longitudinal parallax', has as its argument the longitude of the ascendant (*lagna*) adjusted for precession. This is a double-entry table with 0–11 zodiacal signs along the vertical and 0–29 degrees along the horizontal. The multiplier's maximum is 35,59 (for Virgo 9–12°) and its minimum is 27,21 (for Pisces 29°). According to the instructions in the verse, the multiplier is divided by 40 when applied to the 'mean' longitudinal parallax to correct it.

This application of table data roughly parallels the algorithmic approach to parallax calculation in *Karaṇakutūhala* 5.2–3 (Balacandra Rao and Uma 2008, S92–S94), which also begins with finding a so-called 'mean' *lambana*. This 'mean' or approximate *lambana*, as in the corresponding *Karaṇakesarī* table, depends only on the elongation of the sun's position λ_S (which in a solar eclipse more or less coincides with that of the moon) from a given point on the ecliptic. In the *Karaṇakutūhala*'s formula the reference point for elongation is the so-called nonagesimal with longitude exactly 90° less than the longitude of the ascendant λ_A; a body at the nonagesimal has no longitudinal parallax. The 'mean' *lambana* is just the sine of that sun-nonagesimal elongation linearly scaled from its minimum of 0 when the sun and nonagesimal coincide to a maximum absolute value of 4 *ghaṭikās* when the sun is on the horizon. However, the *Karaṇakutūhala* also provides a

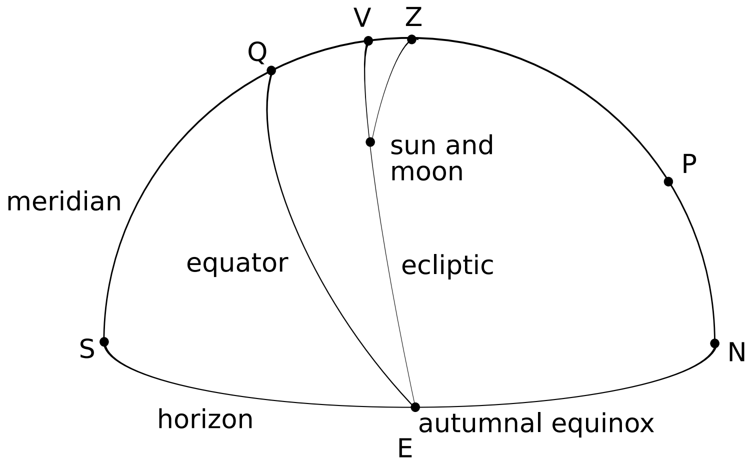

Figure 13: Celestial hemisphere with the autumnal equinox at the ascendant and the nonagesimal on the meridian near the zenith

brief versified table of nine 'mean' *lambana* values that do not exactly correspond to this relation, but which apparently inspired the *Karaṇakesarī*'s tabulated values on f. 9v. Figure 12 shows the two sets of values along with the curve representing the scaled sine of the elongation.

The 'mean' *lambana* is subsequently corrected to its 'true' counterpart by taking into account the contribution from the depression of the nonagesimal from the zenith. Figure 13 illustrates a case where the nonagesimal V is at the summer solstice and consequently high in the sky near the zenith Z: the small nonagesimal zenith distance ZV does not greatly affect the parallax due to the elongation between V and the sun. Bhāskara II's correction represents this by multiplying the 'mean' *lambana* by the cosine of ZV, which will make the *lambana* zero if the nonagesimal V is on the horizon but leave the 'mean' *lambana* unchanged if it is at the zenith. The zenith distance arc ZV is taken as approximately equal to the local latitude ϕ or ZQ diminished by the nonagesimal's ecliptic declination or VQ. (Note that this combination usually only approximates the exact zenith distance, because the declination and latitude are measured along different arcs unless the nonagesimal, the zenith and the celestial pole all fall on the same great circle as shown in figure 13.) So this true *lambana* or longitudinal parallax correction to the time of mid-eclipse is given by the equation

$$\text{(true) } lambana = 4 \cdot \sin|\lambda_S - (\lambda_A - 90^\circ)| \cdot \cos(\phi - \arcsin(\sin 24^\circ \sin(\lambda_A - 90^\circ))).$$

The individual 'multipliers' in the second *Karaṇakesarī* table on f. 10r, which must be divided by 40 and then multiplied by the 'mean' *lambana*, have been computed to imitate this correction. The graphs in figure 14 reproduce the 'mean' *lambana* values from figure 12 and also show their corrected versions for two

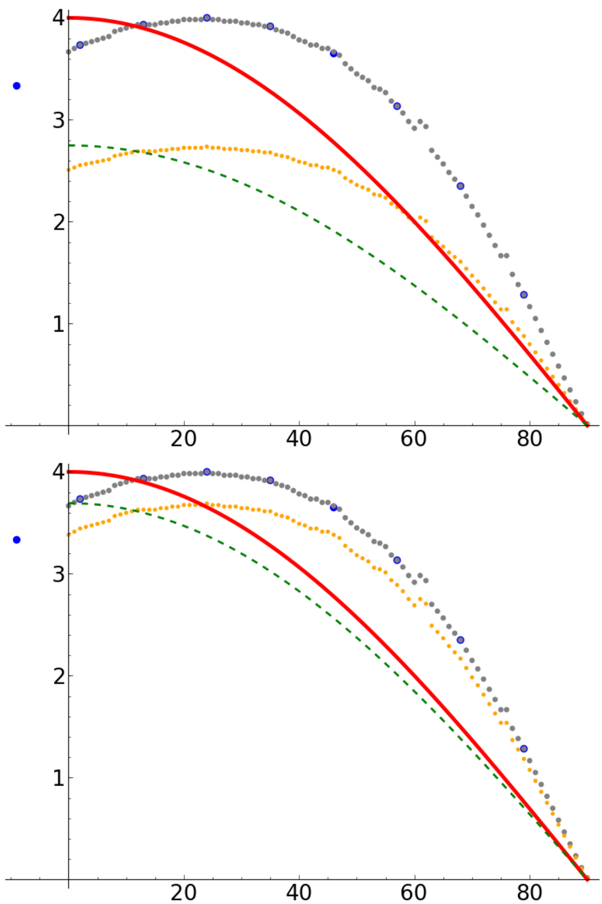

Figure 14: Plots of 'mean' and corrected *lambana* in *ghaṭikās* against elongation $\lambda_A - \lambda_S$ in degrees with $\phi = 22;35,39°$, for $\lambda_A = 0°$ (left) and $\lambda_A = 90°$ (right): the corrected quantity in both trigonometric (dashed line) and tabulated (dots) form is smaller than its uncorrected counterpart

sample values of λ_A at the *Karaṇakesarī*'s terrestrial latitude $\phi = 22;35,39°$. The above trigonometric expression for true *lambana* is graphed as a dashed line, while the *Karaṇakesarī*'s tabulated *lambana* values corrected by their appropriate tabulated multipliers are shown as small dots. As λ_A increases from 0° and V gets closer to the zenith, each corrected version of *lambana* approaches its original 'mean' value, so that by about $\lambda_A = 150°$ the 'mean' and true versions become indistinguishable on the graph.

2.4 LONGITUDINAL AND LATITUDINAL PARALLAX

viśleṣas tribhyo 'bhyadhikonakaś cet
tithyāntadā svarṇam idaṃ kramāt syāt ||
lagnasya rāśyaṃśamiteṣu koṣṭhe
natis tathā lambanako guṇo 'sti ||4||

If the difference [between the longitudes of the sun and the ascendant] is greater or less than three [signs] at the end of the tithi, this [longitudinal parallax] should be [applied] positively or negatively respectively. The latitudinal parallax (*nati*) is in the table [entry] among those [entries] determined by the signs and degrees of the ascendant. Now, the lambana is [to be] multiplied: [see next verse.]

VERSE ANALYSIS

Metre: *upajāti*.

The third syllable in *pāda* 1 ought to be light. The rather odd construction *tithyāntadā* in the second *pāda* appears to be intended as an adverb of time, along the lines of *tadā* 'then'.

TECHNICAL ANALYSIS

Bhāskara's discussion of longitudinal parallax continues with a rule for applying it to the time of conjunction. If the luminaries are westward of the nonagesimal (roughly, post meridian, or more precisely, farther than one quadrant away from the ascendant), it makes the conjunction later than initially calculated, since the parallax depresses the moon toward the (western) horizon. Likewise, parallax applied to a position east of the nonagesimal makes the conjunction earlier. So the longitudinal parallax in *ghaṭikās* calculated in the previous verse is applied to the mid-eclipse time positively or negatively, respectively.

The other parallax component, latitudinal parallax or *nati*, accounts for the fact that the nonagesimal or midpoint of the visible semicircle of the ecliptic usually does not coincide with the local zenith. The parallactic depression of the nonagesimal toward the horizon is treated as a correction to the moon's latitude north or south of the ecliptic.

From the graph in figure 15 it seems almost certain that the *Karaṇakesarī*'s *nati* values in the table on f. 10v, whose argument is the sign and degree of the longitude λ_A of the ascendant, were derived from a formula in *Karaṇakutūhala* 5.3 (Balacandra Rao and Uma 2008, S92–93). In this rule the ecliptic declination of the nonagesimal is again arithmetically combined with the local latitude ϕ to produce the nonagesimal's approximate zenith distance, whose sine is then

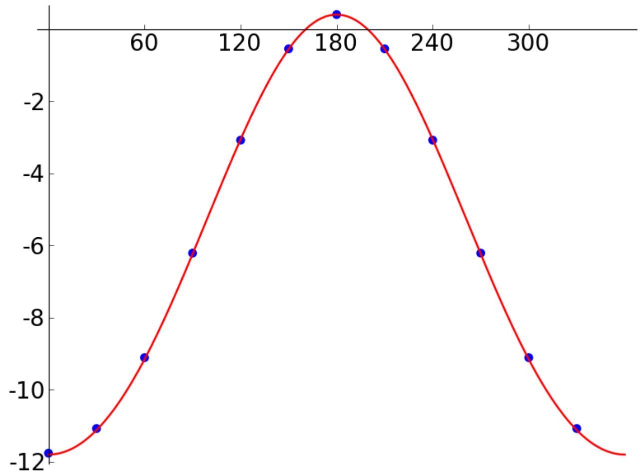

Figure 15: Plot of *nati* in digits (northward positive, southward negative) against λ_A in degrees, showing the *Karaṇakesarī*'s tabulated values of *nati* at the initial degree of each sign (dots), and the *Karaṇakutūhala*'s *nati* function with $\phi = 22;35,39^\circ$ (line)

linearly scaled to give the *nati* in digits:

$$nati = \frac{1}{8} \cdot \frac{13}{12} \cdot 120 \sin(\arcsin(\sin 24^\circ \sin(\lambda_A + 90^\circ)) - \phi)$$

Qualitatively, we can understand the behavior of this function by recollecting that the nonagesimal is the point where longitudinal parallax is zero, so the latitudinal component of parallax or *nati* depends only on how much (and in which direction) the nonagesimal is depressed from the zenith.

Note that in the above expression, subtracting ϕ from the declination means that the zenith distance ZV will be negative if the nonagesimal V falls south of the zenith, and positive if it is north (see figure 13). Consequently, the nonagesimal will approximately occupy the zenith point and the latitudinal parallax will vanish when the northern declination VQ is equal to the local terrestrial latitude $\phi = ZQ$, here about $22;35,39^\circ$. This value is not far from the maximum declination of 24° that the nonagesimal reaches in the southern or northern direction when it falls at the winter or summer solstice respectively, while the ascendant occupies the following equinox. In other words, when the ascendant falls a little before or a little after the autumnal equinox at tropical Libra 0°, we should expect the *nati* for this latitude to be minimised.

Indeed, the values in the *Karaṇakesarī*'s *nati* table reach their minimum of 0;1 digits when the argument λ_A is Virgo 12° or Libra 18°; between these two positions, the *nati* is to be applied in the northern direction (because then the nonagesimal is slightly north of the zenith), although it is a southward correction everywhere else. Conversely, the *nati*'s maximum (absolute) value of 11;46

digits occurs when the ascendant is around the vernal equinox and the nonagesimal around the winter solstice, producing the largest possible depression of the nonagesimal south of the zenith.[29] Most of the other *nati* table entries appear to have been linearly interpolated between trigonometrically computed values at 15-degree intervals.

The final reference to the longitudinal parallax goes with the subsequent verse.

2.5 ADJUSTING ECLIPSE DATA FOR PARALLAX

viśva 13 ghnalambanakalās tithivad yutona-
pātācca kāṇḍamataṣaḍguṇalambanāṃśaiḥ ||
yugyaṃ vilagnatanatiś ca śarau vidadyāt
spaṣṭo bhavec ca viśayāt sthitichannasādhyam || 5 ||

[There are] arcminutes [produced by] the *lambana* multiplied by 13, and [by them the elongation of the sun] from the node [is] increased or decreased, [according] as [the time to the end of] the *tithi* [is increased or decreased by the *lambana* to give the moment of apparent conjunction]. By the degrees [produced by] the *lambana* considered as a [separate] quantity [and] multiplied by 6, [the longitude of the nonagesimal] is to be increased [or decreased, respectively]. One should apply the nonagesimal-[derived] *nati* to the [lunar] latitude, and [it] should be correct. The determination of the half-duration and the obscuration is [derived] from [the corrected time of] the middle [of the eclipse].

VERSE ANALYSIS

Metre: *vasantatilakā*.

Our translation understands *nati* in the accusative in the third *pāda*, which is grammatically incorrect but represents our best guess at the sense. The unusual term *vilagnata*, if we have not misread or misinterpreted it, seems to be intended as a sort of portmanteau word implying the correction of the nonagesimal (*vilagna*) by the *lambana* as well as the recalculation of its *nata* or zenith distance and its resulting new *nati* value.

TECHNICAL ANALYSIS

This and the following verse rather sketchily describe a procedure evidently modeled on that of the *Grahalāghava* for correcting the eclipse based on the com-

29 If ϕ were zero, the *nati* would fluctuate symmetrically between zero and equal north and south extremes of about 6.6 digits, corresponding to the maximum nonagesimal depression of 24° north or south (see section 2 for the relation between arcs and digits of parallax).

puted values of the parallax components.[30] The flowchart in figure 16 illustrates the main sequence of steps in such a procedure, starting with the time of true conjunction and the positions of the bodies at that time. These quantities and the corresponding longitudinal parallax are computed in turn until they become fixed at the time of apparent conjunction. The resulting latitudinal parallax corrects the mid-eclipse latitude and magnitude and consequently the half-duration of the eclipse. A similar cycle of correction is then applied to each half to find the positions and times of the apparent contact and release.

The present verse starts the *Karaṇakesarī*'s version of this process by computing a quantity more or less equivalent to the change in arcminutes in the moon's longitude between true and apparent conjunction. Specifically, the *lambana* in *ghaṭikās* multiplied by 13 is taken as arcminutes applied to the elongation of the sun from the node, positively if the *lambana* in *ghaṭikās* is positive (i.e., increasing the time to conjunction) and negatively if it is negative. This scale factor is qualitatively justified by recollecting that the sun's position at the time of a solar eclipse is nearly coincident with the moon's, and if the moon travels approximately 13 degrees per day then it moves approximately 13 arcminutes per *ghaṭikā*. Of course, strictly speaking the *lambana* corresponds to an arc of time-degrees or right ascension along the equator rather than to elongation along the ecliptic, but this distinction is disregarded for the sake of convenience.

Meanwhile, the original *lambana* in *ghaṭikās* is also converted to degrees by mutiplying it by 6. Again, this quantity is applied as though it were an arc of longitude to correct an ecliptic position, in this case the longitude of the nonagesimal. From the new position of the nonagesimal a new value of *nati* is to be computed, which then requires recomputing the times of contact and release and the extent of the obscuration.

30 The key verses are *Grahalāghava* 6.3–5 (Balacandra Rao and Uma 2006, S394):
trikunighnavilambanaṃ kalās tatsahitonas
tithivad vyaguḥ śaro 'taḥ |
atha ṣaḍguṇalambanaṃ lavās tair
yugayugvitribhataḥ punar natāṃśāḥ || 3 ||
daśahṛtanatabhāgonāhatāṣṭendavastad
rahitasadhṛtiliptaiḥ ṣaḍbhir āptāsta eva |
svadigiti natir etatsaṃskṛtaḥ so 'ṅgulādiḥ sphuṭa
iṣuramuto 'tra syāt sthiticchannapūrvam || 4 ||
sthitirasahatiramśā vitribhaṃ taiḥ pṛthaksthaṃ
rahitasahitamābhyāṃ lambane ye tu tābhyām |
sthitivirahitayuktaḥ samskṛto madhyadarśaḥ
kramaśa iti bhavetāṃ sparśamuktyos tu kālau ||5||
Compare the *Karaṇakutūhala* counterpart quoted in the discussion of the following verse, and the worked example in Balacandra Rao and Uma (2008, S99–S108). As noted in Balacandra Rao and Venugopal (2008, 68), the solar eclipse methods in the *Karaṇakutūhala* and *Grahalāghava* give quite similar results.

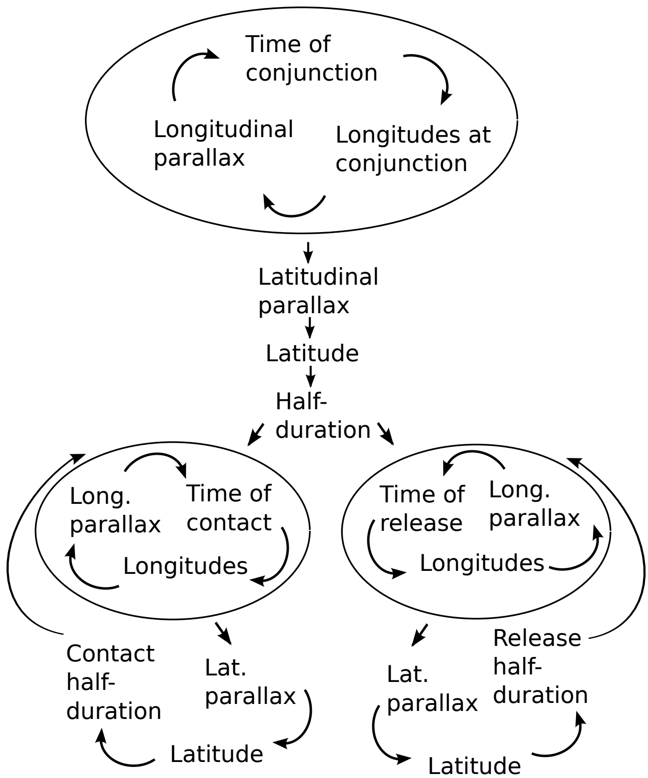

Figure 16: The cycles of parallax correction to get from the time of true conjunction to the moments and positions of apparent conjunction, contact, and release

2.6 ADJUSTING ECLIPSE DATA FOR PARALLAX, CONTINUED

sthitiśūlasūta 6 ghnalavonayuktāḥ
pṛthaksthatanvoḥ kṛtalambanaṃ svam ||
ṛṇaṃ sthitihīnayuter vidarśe
tataḥ sphuṭasaṃspṛśi[mo]kṣikālau || 6 ||

[The degrees of the nonagesimal's longitude] are [separately] diminished and increased by the degrees [produced by] multiplying the half-duration by 6. For [each of] the two separate results [? *tanu*], the *lambana* [is] made [and applied] additively [or] subtractively [to the half-duration, to get the interval between mid-eclipse and release and the interval between contact and mid-eclipse, respectively]. When the mid-eclipse [time] is decreased or increased by the [corresponding] half-duration, then the two times of true contact and release [result].

VERSE ANALYSIS

Metre: *upajāti*?

The metre and sense of this verse as transcribed here are both far from satisfactory, but it seems to borrow some of its phrasing not only from the above-mentioned *Grahalāghava* verses but also from the *Karaṇakutūhala*.[31]

As reconstructed in *upajāti* metre, the first syllable makes the first *pāda* hypermetric and the fourth syllable in each of the last two *pādas* ought to be heavy instead of light, but neither the manuscript nor the sense gives any pretext for enforcing corrections. We are not sure how to interpret *śūlasūta* to supply the required content of a word-numeral meaning six. Perhaps this form is a corruption of the reading *śūlisuta 6* 'son of the spear-bearer' quoted twice (f. 5r, line 11 and f. 5v, line 4) in the worked example of MS. J: we assume this alludes to the six-headed deity Skanda but we know of no other instance of his name invoked as a word-numeral. The word *tanu* in, presumably, the genitive dual must mean the adjusted nonagesimal longitude, although we are not familiar with this meaning (compare *tanas* for 'ascendant' in verse 2.3 above).

TECHNICAL ANALYSIS

Although the verse's grammar is very hard to follow, there seems no doubt that it is attempting to continue describing the above *Grahalāghava*-inspired procedure. Namely, the corrected half-duration in *ghaṭikās* is converted to degrees by multiplying it by 6, and then, as before, that time-degree arc is treated as an arc of the ecliptic, applied negatively or positively to the longitude of the nonagesimal to give approximate positions of the nonagesimal at the moments of contact and release, respectively. A new *lambana* is computed for each of those nonagesimal positions, and the time of half-duration is adjusted separately by each of those *lambana* values to give the actual duration of each 'half' of the eclipse. These two distinct 'half' durations, no longer equal halves of the total eclipse duration, give the moments of contact and release when applied with the appropriate sign to the moment of mid-eclipse.

This completes the *Karaṇakesarī*'s determination of the times of the beginning, middle and end of a solar eclipse. Indefinite cycles of iterative recalculation are discarded in favour of a few specified corrections and re-corrections. Nor are

31 *Karaṇakutūhala* 5.6–8 (Mishra 1991, 68–69):
spaṣṭo 'tra bāṇo natisaṃskṛtaḥ syāc channaṃ
tataḥ prāgvad ataḥ sthitiś ca |
sthityonayuktād gaṇitāgatāc ca tithyantato
lambanakaṃ pṛthakstham || 6 ||
svarṇaṃ ca tasmin pravidhāya sādhyas tātkālikaḥ
spaṣṭaśaraḥ sthitiś ca |
tayonayukte gaṇitāgate tat svarṇaṃ pṛthaksthaṃ
muhur evam etau || 7 ||
syātāṃ sphuṭau pragrahamuktikālau sakṛt kṛte
lambanake sakṛtsnaḥ |
tanmadhyakālāntarage sthitī sphuṭe śeṣaṃ
śaśāṅkagrahaṇoktam atra hi || 8 ||

there specific directions stated for computing the times of beginning and end of totality, if any.

The example in MS. J appears to follow these directions faithfully, finishing with the sum of the disks' radii (presumably for the purpose of an eclipse diagram) and identifying the eclipse 'lord' (*parveśa*) as Brahmā.

2.7 CONCLUSION

asti vaiṣṇavadhāmni sajjanavati saudāmikāhve pure
śrautasmārttavicārasāracaturo moḍho hi rāmāhvayaḥ ||
jyotirvittilakopamanyava iti khyātaḥ kṣitau svair guṇaiḥ
tatsūnuḥ karaṇākhyakeśarim imaṃ cakre kavir bhāskaraḥ || 7 ||

In the city called Saudāmikā, filled with good people, in the Vaiṣṇava clan, there is one called Rāma, a Moḍha, learned in the essence of investigations of *śrūti* and *smṛti*, a [member of the] Aupamanyava [*gotra*, who is] an ornament of the *jyotiḥ*-knowers, renowned on the earth for his own good qualities. His son, Bhāskara, the poet, wrote this [work], the *Karaṇakesarī*.

VERSE ANALYSIS

Metre: *śārdūlavikrīḍita* with minor discrepancies: the second and twelfth syllables of the first *pāda* should be heavy rather than light.

Bhāskara's idiosyncratic method of compounding appears to be at work in the last compound where the name of the text is unpacked as '*Keśari* called *Karaṇa*' instead of the other way around. The term *moḍha* seems to refer to a Brahmana group primarily associated with the Gujarat region (which is consistent with the terrestrial latitude used in the *Karaṇakesarī*), but we have no other information on Bhāskara's location or any identification of the placename Saudāmikā with a modern locality.

iti śrīdaivajñarāmātmajabhāskaraviracite karaṇakeśariye sūryaparvādhikāraḥ || saṃpūrṇo 'yaṃ granthaḥ || śubhaṃ lekhakapāṭhakayoḥ || śubhaṃ bhavet kalyāṇam astu || saṃ. 1819 varṣe śāke 1684 mitī aśvinaśudi 14 śanau dine lipīkṛtaṃ ||

Thus the chapter on solar eclipses in the *Karaṇakesarī* composed by Bhāskara, the son of Rāma Daivajña. This book is complete. Good fortune to the writer and the reader; may there be good fortune, may there be prosperity. [The manuscript was] written in the year Saṃvat 1819, Śaka 1684, on the 14th [*tithi*] of the bright [fortnight] of Āśvina, on Saturday [i.e., Saturday 2 October 1762 CE].

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APPENDIX A. GLOSSARY OF TECHNICAL TERMS

akṣavalana The component of *valana* or directional deflection/inclination that depends on the *akṣa* or local terrestrial latitude.

aṅgula Literally 'digit' (in the sense of finger-breadth), a linear measure applied to quantities like disk diameter and lunar latitude; taken as equivalent to three arc-minutes.

avadhi A period of fourteen mean solar days.

ayanavalana The component of *valana* that depends on the tropical longitude of the bodies.

bāhu, bhuja Arc or angle, usually referring to some table argument measured in units of arc.

ghaṭikā One-sixtieth of a day, equal to twenty-four minutes.

karaṇa Usually a brief astronomical handbook in verse (may also mean one-half of a *tithi*).

kalā One-sixtieth of a degree, or arc-minute.

koṭi The complement of a given arc or angle (*bāhu* or *bhuja*).

koṣṭha, koṣṭhaka A numerical table or an entry in such a table.

lagna Ascendant: the point of intersection of the ecliptic and the local horizon in the east.

lambana Longitudinal component of parallax, usually measured in time-units.

madhya The moment of mid-eclipse.

mokṣa The moment of release or end of eclipse, when the eclipsed body is no longer obscured.

nāḍī A synonym for *ghaṭikā*.

nāgarī The most common North Indic script, in which these manuscripts of the *Karaṇakesarī* are written.

nata Literally 'depression' or angular distance from an apex; used both for zenith distance and for hour-angle separation from the meridian.

nati Latitudinal component of parallax, usually measured in digits.

nimīlana The moment of immersion or beginning of totality.

parvan Either an eclipse itself or the instant of syzygy when mid-eclipse occurs.

pāda One line of a (usually) four-line Sanskrit verse.

sāyana Precession-corrected, referring to tropical longitude.

sanmīlana A synonym for *nimīlana*.

sparśa The moment of first contact between eclipsed and eclipsing bodies.

tana Used idiosyncratically in the *Karaṇakesarī* to mean ascendant.

tithi One-thirtieth of a synodic month.

unmīlana The moment of emersion or end of totality.

upari Literally 'above', but in this case referring to the argument at the top of a table.

valana 'Deflection' or 'inclination', i.e., angle between the local east-west direction and the eastward movement of the moon in an eclipse.

vilagna Nonagesimal: the point of the ecliptic 90° west of the ascendant.

B Critical Edition of the text

।श्रीगणेशाय नमः॥ श्रीगुरुभ्यो नमः॥ श्रीसारदायै नमः॥ अथ करण-केशरी लिख्यते॥ f. [1]v B, f. 1v R_1

श्रीकृष्णचन्द्रचरणं प्रणिपत्य भक्त्या
ज्योतिर्विदां बहुविदामभिवन्दनं च॥
कृत्वा कवीन्द्रकुलभूषणभास्कराख्यो
रामात्मजः करणकेशरिमातनोति॥ १॥

शको रामविष्णुपदाङ्गेन्दु १६०३ हीनो
वियद्रामचन्द्रैर्हृतो १३० लब्धशेषौ॥
युतौ चोपकर्णं ह्यवध्यन्वितं त-
त्सपातेन्दुतात्कालिको बाहुभागैः॥ २॥

मितैः कोष्ठकैरङ्गुलादिः शरः स्यात्
सपातस्य भुक्त्युपरि हेलिबिम्बम्॥
तिथेर्मानघट्योपरी चन्द्रभूभे
तुलाजादिषड्भोनयुक् स्पष्टकुभा॥ ३॥

छाद्यछादकमण्डलान्वितदलं काण्डोनछन्नं पुनः
छन्नं ग्राह्यविवर्जितं तु निखिले ग्रासेऽपि खछन्नकम् ॥
छन्नाङ्कैर्मितकोष्ठके स्थितिर्भवेन्मर्दस्य खछन्नतः
श्रीभानोरुदयात्तथास्तसमयात् पर्वान्तमध्यग्रहः॥ ४॥

1–2 श्रीगुरु०—लिख्यते॥] श्रीगुरुभ्यो नमः॥ श्रीसारदायै नमः॥ B, अथ कर्णकेशरि लिख्यते॥ श्लोक॥ R_1 **3** श्रीक्रष्ण० R_1 ; प्रनीपत्य R_1 **4** ज्योतीर्विदां बहूविदामविभं जनं चः R_1 **5** कवेंद्रकुलभुषण० R_1 **7** ०विष्णुर्पदांगेंदु १६०३ हीनो B, ०विष्णुपदांगेंदुहिनो १६०३ R_1 **8** ०चंद्रै १३० हृतो R_1 **9** युतो चोपकर्णें R_1 ; त om. R_1 **10** त्ससपातेंदु० R_1 **11** ०गुलादिः शरः] ०गुलादिशरः B, ०गूलादिसर R_1 **12** सपातस्वभूक्त्युपरि R_1 **13** ०घट्योपरिश्चंद्रभूभा B, R_1 **14** ०कूंभा R_1 **15** छाद्यः छाद० B, R_1 ; कां ढोनछन्नं B, कांडोनछंनं R_1 **15–16** पुनश्छन्नं R_1 **16** निखिलंग्रा B ; कछंनकं R_1 **17** स्थितिर्भवेन्मर्दस्य] स्थितिभवेन्मर्द्दस्य B, स्थितभवेमर्डस्य R_1 ; खछन्नतः] खछन्नतो B, R_1 **18** ०रुदायात्तथास्तसमयात् B, ०रुदयात्तथास्तसमयाद्रा R_1 ; पर्वांत्तमध्य० B, पूचमध्य० R_1

स्थित्या मर्देन हीनः स्पर्शसन्मीलने स्युः
मर्दस्थित्यान्वितेऽस्मिन्नुन्मिलं मोक्षसंज्ञम्॥
खाङ्कैर्निघ्नं ९० ननाप्तं घस्रमाने नतांशा-
स्तानैः ४५ शोध्यांशकोष्ठे प्राक्परे सौम्ययाम्ये॥ ५॥

याम्योत्तरे दिशि ग्रहस्य युतायनांशाः
कोट्यांशकेषु वलनान्तरगुण्ययुक्तम् ॥
योगान्तरांशप्रमिते वलनं स्फुटं स्यात्
सूर्यस्य ग्रासविधुमोक्षविलोमदे|यम्॥ ६॥ f. [2]r B

त्र्यूनं भुजः स्यात्त्र्यधि|कं च षड्भात् f. 2r R_1
विशोध्य भार्धादधिकं विभार्धम्॥
नवाधिकं तद्रविपातितं च
कोटिर्भवेत्स्यात्त्रिग्रहं भुजोनम्॥ ७॥

सूर्यग्रहे दिवसमेव दिनं स्वकीयं
रात्रिस्तथैव शशिपर्वणि वैपरि स्यात्॥
अह्नोऽर्धतो निशिदलेन्दुनतं प्रतीच्यां
रात्रिदलाद्युदलतोऽर्कनतस्य पूर्वे॥ ८॥

प्रभाब्धि ४४५ शकोनाप्तखाङ्गो ६०ऽयनांशाः
युतोऽर्कस्य राश्यंशमानेषु कोष्ठे ॥

1–2 हीनस्पर्शसन्मीलनं स्युः मर्दस्थित्यांन्विते B, युक्तः स्पर्शसन्मिलनस्युर्मर्दस्थित्युन R_1 **2** ऽस्मिन्नुन्मिलं] स्मिनुन्मिलं B, तस्मिन्मुमीलन् R_1 **3** खांकेनिघ्नं R_1; ९० om. R_1; नताप्तं R_1 **4** ४५ om. B; सोध्यंसकोष्टे R_1; सौम्य०] सोम्य० R_1 **5** यामोत्तरे दिशी R_1 **6** कोट्यांशकेषु] कोर्द्धंशकेषु R_1; ०गुण्य०] ०गूंण्य० R_1 **7** ०प्रमिते] ०प्रमीते R_1 **8** ग्रासविधु०] ग्रासविधु० B, ग्रासविधू० R_1 **9** त्र्यूनं] त्र्युनं B, R_1; भुजः] भूजः R_1; स्यात्त्र्यधिकं च] स्यात् त्र्यधिकेन R_1; षड्भात्] षड्भा B **10** भार्धादधिकं] भार्द्धादद्धिकं B **11** नवाधीकं R_1 **12** कोटिर्भवेत्स्यात्त्रि०] कोटिर्भवेत्स्यात्त्रि० B, कोटीभवेत्स्यात्त्री० R_1; भुजोनम्] भूजोनं R_1 **13** दिवसमेव] विदिवश एव R_1; स्वकियं R_1 **14** रात्रीस्तथैव शसीपर्वणी R_1 **15** निशि०] निशी० R_1; प्रतीच्यां] च प्राच्यां R_1 **16** रात्रिदलाद्युदलतो B, रात्रीदलाद्यूदलतो R_1 **17** प्रभाब्धि] भप्राब्धि R_1; ०खाङ्गो] ०खांगै R_1; ६० om. B **18** युतोऽर्कस्य] युतार्कस्य R_1; ऽर्कस्य] र्कस्या B; राश्यंश०] रास्यंश० R_1; कोष्ठे] कोटेः R_1

दिनार्धविशोध्यं खरामैर्निशार्धं
दिनार्धेष्टनाड्यन्तरं तं नतं स्यात्॥ ९॥

ग्राह्यार्धसूत्रेण विधाय वृत्तं
मानैक्यखण्डेन च साधिताशाम् ॥
बाह्येऽत्र वृत्ते वलनं यथाशं
प्राक् स्पर्शिकं पश्चिमतश्च मोक्षम्॥ १०॥

देयं रवेः पश्चिमपूर्वतश्च
ज्यावच्च बाणौ वलनाग्रकाभ्याम्॥
उत्पाद्य मत्स्यं वलनाग्रकाभ्यां
मध्यः शरस्तन्मुखपुच्छसूत्रे॥ ११॥

केन्द्राद्यथाशोऽथ शराग्रकेभ्यो
वृत्तैः कृतैर्ग्राहकखण्डकेन
स्युः स्पर्शमध्यग्रहमोक्षसंस्था
अथांकयेन्मध्यशराग्रचिह्नात्॥ १२॥

मानान्तरार्धेन विधाय वृत्तं
केन्द्रेऽथ तन्मार्गयुतिद्वयेऽपि ॥
तमोऽर्धसूत्रेण विलिख्य वृत्तं
सन्मीलनोन्मीलनके च वेद्ये॥ १३॥

इति चन्द्रपर्वाधिकारः॥

1 दिनार्धविशोध्यं] दिनार्द्धं वीसोध्यं R_1 ; खरामैनिशार्द्धं R_1 **2** दिनार्धेष्ट०] दीनार्द्धस्य० R_1 ; नतस्यात् R_1 **3** ग्राह्यार्धसूत्रेण] ग्राह्यप्रमाणसूद्जेन R_1 **4** मानैक्यखण्डेन च साधिताशाम्] मानान्वितस्य च दलेन च साधितांशा R_1 **5** वृत्ते वलनं यथाशं] वृत्तवजनंदियत्तं यथाशां R_1; वलनं] ववलनं B **6** स्पर्शिकं पश्चिमतश्च मोक्षम्] स्पर्शमोक्षमपरं रवीव्यस्तदेयं R_1 verses 11–12.वलनाग्रकाच्च शरज्याबतदेयपूर्वं वलनाग्रकाच जखलेख्यमुखांसरासां बांणाच्च केंद्रकृतग्राहकखंडकेन स्यु स्पर्सग्रह मोक्षशराग्रचिह्नात् ११॥ R_1 **7** ०पूर्वतश्च] ०पूर्वताश्च B **10** मध्यः] मध्य B ; ०पुच्छ०] ०पुछ० B **12** वृत्तैः] वृत्तै B **15** विधाय] विविधाय B ; वृत्तं] वर्त्तं R_1 **16** ऽपि] पीः R_1 **17** र्द्धसुत्रेण विलेख्य वृत्तं R_1 **18** च वेद्ये॥ १३॥] च- - -वेधे॥ १२॥ R_1 **19** इति चन्द्रपर्वाधिकारः] इती चंद्रपर्वसमाप्तं R_1

शास्त्राण्यनेकानि महार्थसूत्रा-
ण्यनन्तविद्याल्पमतिर्जनोऽयम्॥
कलौ न दीर्घायुरतो हि [ग्रा]ह्यं
तत्त्वं यथा क्षीरविधौ च हंसः॥ १॥

|सायनार्कभलवादिकोष्ठकाः f. [2]v B
युक्ते चेष्ठघटियुक्ततत्समान् ॥
कोष्ठकाङ्कमितिं राशिपूर्वकं
लब्धलग्नमयनांशकोन्नतम्॥ २॥

दर्शान्तकालेऽर्कतनोर्विशेषं
कार्यं तदंशमितिस्पष्ठकोष्ठे ॥
यल्ल|म्बनं स्वे गुणकेन गुण्यं f. 2v R_1
खवेद ४० भक्तं स्फुटलम्बनं स्यात्॥ ३॥

विश्लेषस्त्रिभ्योऽभ्यधिकोनकश्चेत्
तिथ्यान्तदास्वर्णमिदं क्रमात्स्यात् ॥
लग्नस्य राश्यंशमितेषु कोष्ठे
नतिस्तथा लम्बनको गुणोऽस्ति॥ ४॥

विश्व १३ घ्नलम्बनकलास्तिथिवद्युतोन-
पाताच्च काण्डमतषड्गुणलम्बनांशैः॥
युग्यं विलग्नतनतिश्च शरौ विदद्यात्

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verse 1. om. R_1 **1** महार्थ०] माहार्थ० B **3** हि ग्राह्यं] हिह्यं B **4** हंसः] हंसं B **5** सायनार्क०] *x x* नार्क०B **6** युक्तचेष्टघटीयुक्ततत्स्मान् R_1 ; ०घटि०] ०घटी०B **7** ०मितिं] ०च्युत R_1 ; रासीपूर्वकं R_1 **8** लब्धलझम० R_1 ०कोनतम् B, ०कोंनितं R_1 ; २] १ R_1 **9** दर्शान्तकाले] *x x* तकाले B, दर्शातकाले R_1 ; ऽर्कतनोविश्लेषं B, र्कतनोर्वशेषं R_1 ; । followed by two *akṣaras* crossed out B **10** कार्यं च तदौंशमितस्यकोष्टेः R_1 **11** यल्ल बनं B, यल्लं|बन R_1 ; गुण्यं] गूंण्यं R_1 **12** ४० om. R_1 ; ३] २ R_1 **13** विश्लेषस्त्रिभ्यो] विश्लेषत्रिभ्यो B, R_1 ; ०नकश्चेत्] ०नकश्च R_1 **14** तिथ्यंतदास्वर्णमीदं क्रमस्यात् R_1 **15** लझस्य राशंश० R_1 **16** गुणो] गुंणो R_1 ; ४] ३ R_1 **17** १३ om. R_1 ; ०वद्युतोन०] ०वद्यूतोन० R_1 **18** कांडकृतखड्गुण० R_1, ०लम्बनंशै B **19** युग्यं] युगयम् with overline on म् Note in margin गं B, युग्युग् R_1 ; विलग्नतनतिश्च] विलझतनतिश्च R_1 ; शरौ] शरो B, शरे R_1

स्पष्टो भवेच्च विशयात् स्थितिछिन्नसाध्यम्॥ ५॥

स्थितिशूलसूत ६ घ्नलवोनयुक्ताः
पृथक्स्थतन्वोः कृतलम्बनं स्व-॥
मृणं स्थितिहीनयुतेर्विदर्शे
ततः स्फुटसंस्पृशि[मो]क्षिकालौ॥ ६॥

अस्ति वैष्णवधाम्नि सज्जनवति सौदामिकाह्वे पुरे
श्रौतस्मार्त्तविचारसारचतुरो मोढो हि रामाह्वयः॥
ज्योतिर्वित्तिलकोपमन्यव इति ख्यातः क्षितौ स्वैर्गुणैः
तत्सूनुः करणाख्यकेशरिमिमं चक्रे कविर्भास्करः॥ ७॥

इति श्रीदैवज्ञरामात्मजभास्करविरचिते करणकेशरिये सूर्यपर्वाधिकारः॥ संपूर्णोऽयं ग्रन्थः॥

MS. B concludes:

शुभं लेखकपाठकयोः॥ शुभं भवेत् कल्याणमस्तु॥ सं १८१९ वर्षे शाके १६८४ मिती अश्विनशुदि १४ शनौ दिने लिपीकृतं॥

MS. R_1 concludes:

सूर्येन्द्वोर्ग्रहणेषु गाङ्गजलवद्व्यासोपमा वाडवाः
स्पर्शः स्नानमथान्तरा हवनकं स्यान्मुच्यमानार्यणं [॥]
रात्रावप्यशितस्य पितृयजनं चन्द्रोपरागे स्मृतं
स्नानं दानमथान्तयो निगदितो सावेथयौ नः सति॥ १॥

1 भवेच्च विशयात्] भवेतु विशिषात् R_1 ; ५] ४ R_1 **2** स्थितीशूलीसुत R_1 ; ६ om. R_1 **3** ०तन्वोः] ०तनो R_1 ; ०लंबंनं R_1 **3–4** स्वमृणं] श्वमृणं B **4** ०हीनयुतेर्वि०] ०हीचयुतेर्वि०B, ०हिनयुतेवि० R_1 **5** ततः] भवतः R_1 ; ०स्पृशिमोक्षि०] ०स्पृशिक्ति० B, स्पर्शमुक्ति R_1 ; ६] ५ R_1 verse 7. om. R_1 **6** सज्जनवति] संज्जनवति B ; सौदामिकाह्वे] सौदमिकाह्व B **8** ०तिर्वित्तिलको०] ०तिर्वित्तलको० B ; ख्यातः] ख्यातो B ; स्वैर्गुणैः] स्वैगुणैः B **10–11** ईती कर्णकेशरिग्रंथे सूर्यपर्वसमाप्तं॥ ॥ R_1 **11** ग्रन्थः] ग्रंथः॥ १॥ B **13** भवेत्] भवत् B ; कल्याणमस्तु] कल्याणमस्तुः B **14** अश्विनशुदि] अश्वनसुदि B **16** सूर्येन्द्वौ R_1 **17** स्नानमथांतराहबनकं R_1 ; स्यान्मुच्यमानार्य्यणंः R_1 **18** स्मृतंः R_1 **19** न सति R_1

सर्वस्वेनापि कर्तव्यं श्राद्धं वैराग्यदर्शने
अकुर्वनस्तु नास्तिक्योन्यके गौरिव सीदतु॥ २॥

दासिदाससुतो वा यदि भवति कुलान्मित्रपुत्रोऽपि भृत्यः कुर्यात्पिण्डप्रदानं ग्रहणमुपगते भास्करे सितगे वा वञ्चितान्क्षीणलोकान् सत्रा पितरः [।] किं पुनः पुत्रपौत्रं तस्मात्कुर्वीत पिण्डाद्गुडसहिततिलैः किं कृतौ कोटिपिण्डौ॥ धे॥

इति संपुर्णं॥ सं १९२५ फाल्गुनशुदि १५ शुक्रे लिखितं भाइः इच्छारामः स्वयमेवार्थं इदं पुस्तकं। श्री॥

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1 सर्वश्वेनपि R_1; वैराद्गदर्शनेः R_1 2 अकुर्वाणस्तु R_1; नास्तिक्योन्यंके R_1; सिदतु R_1 3 कुलान् मित्रपूत्रोपीभृत्यः R_1; कुर्यात्पींडप्रदानं R_1 4 सीतगे वाः R_1; वांछितान् क्षिणलोकान् R_1; सत्र R_1 5 पुनः] पुंनः R_1 ; पुत्रपौत्रंः R_1 ; तस्मात् कुर्वित R_1 ; पिंडात् गुडशहिततिलैः R_1 ; कोटीपिंडौ R_1 7 ईती R_1 ; नाफागुंणशुदि R_1 ; शुक्रेः R_1 ; लीषितं: R_1 ; ईछारांम R_1 8 ईदं R_1

अथ सूर्यस्य लब्धपंक्तिचक्रं ।

Table I, on f. 3r : elongation between the sun and lunar node, argument from 1 to 130 at intervals of 130-year periods

अथ श्रीकरणकेशरिग्रंथे सूर्यस्यशेषपंक्तिचक्रं १२ । ३०

Table II, on f. 3v : elongation between the sun and lunar node, argument from 0 to 130 at intervals of single years

अथ करनकेसरिग्रंथोक्ते सिद्धान्तरहस्ये सूर्येंद्वोः पर्वनयनार्थे चंद्रस्य कोष्टका अवध्योपरि

Table III, on f. 4r : elongation between the sun and lunar node, argument from 1 to 27 at intervals of 14-day *avadhis*

शरांगुलाः

Table IV, on f. 4r : digits of lunar latitude, argument from 0 to 16 degrees of nodal-solar elongation

अथ सपातचंद्रगत्युपरिरविबिंबांगुलादि ॥

Table V, on f. 4r : digits of size of solar disk, argument from 59; 56 to 64; 42 minutes of daily nodal-solar elongation

अथ तिथिर्मानघट्योपरि चंद्रबिंबं तथाभूतांगुलादि ॥

Table VI, on f. 4v : digits of apparent lunar diameter, argument from 52 to 67 *ghaṭikās* in a day

रवेर्व्यंगुलादिफलसंस्कृते स्पष्ट

Table VII, on f. 4v : digits of increments to apparent shadow diameter, argument from Aries to Virgo and from Libra to Pisces

खछिन्नांगुलोपरि मर्दघटिकाचक्रं

Table VIII, on f. 4v : *ghaṭikās* of half-duration of totality, argument from 1 to 9 digits of sky-obscuration

अथ चंद्रछिन्नांगुलोपरि चंद्रस्य मध्यस्थितिघटिचक्रं ६० ॥

Table IX, on f. 4v : *ghaṭikās* of half-duration, argument from 1 to 21 digits of lunar obscuration

तिथ्यंतका ग्रहाः वलनार्थे स्पर्शकाले तथा मोक्षकाले साधनं चंद्रग्रहणे

Table X, on f. 4v : degrees of solar true longitude and true daily motion, argument from 1 to 27 *avadhis*

चंद्रछिन्नांगुलोपरि स्थितिनो अंतरं

Table XI, on f. 4v : differences in entries of table IX, argument from 1 to 21 digits of lunar obscuration

अथ चंद्रछिन्नांगुलोपरि स्थित्यग्निभागः

Table XII, on f. 5r : *agnibhāga* (?) of the half-duration, argument from 1 to 21 digits of lunar obscuration

अथ मध्यबाणांगुलोपरि बाणफलमध्यस्थिति

Table XIII, on f. 5r: latitude-result (?), argument from 1 to 21 digits of lunar obscuration

अथ खांकहृतश्च घश्रमानेन भक्ते लब्धनतांशा तस्य ताने ४५ शोध्यते शोध्यांशा उपरि अक्षख्य-वलनं

Table XIV, on f. 5r–5v: degrees of *valana*, argument from 0 to 45 degrees of zenith distance

अथ सपातचंद्रसूर्यराश्युपरि पर्वेशज्ञानं

Table XV, on f. 5v: lords of *parvans*, argument 9 eclipse-possibility month numbers between 0 and 24

अथ स्पर्शकाले तथा मोक्षकाले सायनग्रहस्य कोट्यंशोपरि अंशाद्यं अयनजं वलनं सायनसह-कर्कादौ दक्षिणे मकरादौ उत्तरे वलनं देयं ।

Table XVI, on f. 6r: degrees of *valana*, argument from 0 to 90 degrees of the complement of tropical solar longitude

अथ सूर्यस्यवलनं स्पष्टं । आक्षाख्यं तथा आयनजं वलनयोर्योगांतरांशोपरि अंगुलाद्यं वलनं स्पष्टं सूर्यस्य । सूर्यस्य ग्राशवलनं पश्चिमे देयं । मोक्षवलनं पूर्वे देयं । सूर्यस्य स्पर्शवलनं विपरीतं देयं । उत्तरे जातं दक्षिणे देयं । दक्षिणे जातं उत्तरे देयं ।

Table XVII, on f. 6v: scale-factor for conversion to digits of solar *valana*, argument from 0 to 47 degrees of combined *valana*

अथ चंद्रस्य वलनं स्पष्टं अक्षाख्यवलनं तथा आयनजं वलनयोर्योगांतरांशोपरि अंगुलाद्यं वलनं स्पष्टचंद्रग्रहणे स्पर्शवलनं पूर्वदेयं मोक्षवलनं पश्चिमे देयं चंद्रस्य मोक्षवलनं विपरीतं देयं उत्तरे जातं दक्षिणे देयं दक्षिणे जातं उत्तरे देयं ॥

Table XVIII, on f. 6v: scale-factor for conversion to digits of lunar *valana*, argument from 0 to 47 degrees of combined *valana*

अथ सायनरविरश्योपरि द्युदलं ॥

Table XIX, on f. 7r: *ghaṭikās* of half-lengths of daylight, argument from 0 to 29 degrees of 1 to 12 signs of tropical solar longitude

सायनरविरश्यंशोपरि लग्न[को]ष्टकाः ।

Table XX, on ff. 7v–8r: *ghaṭikās* of oblique ascension, argument from 0 to 29 degrees of 0 to 11 signs of tropical solar longitude

अथ लग्नस्य कलाकोष्ठका ॥

Table XXI, on ff. 8v–9v: *ghaṭikās* of oblique ascension, argument from 1 to 60 arcminutes of any degree of signs 1 to 6 and equivalently 12 to 7 (decreasing)

अथ दर्शांत लग्नार्कयोर्विवरबाहुभागप्रमिते कोष्टके मध्यमलंबंनं घटिकादि ॥

Table XXII, on f. 9v: *ghaṭikās* of longitudinal parallax, argument from 0 to 90 degrees of elongation between ascendant and sun

अथ शायनलग्नराश्यंशोपरि लंबनस्पष्टगुणकाः ॥

Table XXIII, on f. 10r : scale-factor for longitudinal parallax, argument from 0 to 29 degrees of 0 to 11 signs of tropical longitude of ascendant

अथ सायनं लग्नराश्यंशोपरि नति अंगुलादि

Table XXIV, on f. 10v : digits of latitudinal parallax, argument from 0 to 29 degrees of 0 to 11 signs of tropical longitude of ascendant

अथ रविछन्नंगुलात् मध्यस्थितिघटिकादि

Table XXV, on f. 11r : *ghaṭikās* of half-duration of solar eclipse, argument from 1 to 12 digits of solar obscuration

अथ जातके ग्रहाणां विकलानां कोष्टकादि नादिः

Table XXVI, on f. 11r : the arc-seconds per *ghaṭikā* of the planets in horoscopy, argument from 1 to 60

अथ नक्षत्राणां योनिविचारः

Table XXVII, on f. 11v : type of birth category for each of the *nakṣatras*, argument the 28 *nakṣatras*

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