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THEMATIC DOSSIER
TOWARDS A GLOBAL HISTORY OF ECLIPSES.
ENTANGLEMENTS OF DISCIPLINES, ACTORS, AND PRACTICES

Visualising Eclipses: Graphical Constructions of Eclipse Phenomena in the Sanskrit Astral Sciences

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Abstract: Eclipse reckoning constituted a significant component of the Indian astronomical tradition and was underpinned by a sophisticated interplay between mathematical theory, observational data, and visual practices. This paper focuses specifically on the diagrammatic dimensions of eclipse computations as articulated in classical Sanskrit treatises. By closely examining two distinctive passages drawn from the astronomical texts *Siddhāntaśekhara* and *Uparāgakriyākrama*, composed over the course of the second millennium CE, we investigate how Indian astronomers employed graphical methods to visually represent eclipse phenomena. These diagrammatic constructions reveal a nuanced understanding of eclipse occurrences. Our analysis highlights key features of these procedures, including the geometric frameworks, instruments, and terminologies employed. We also consider how these visual methods evolved across different texts, noting both similarities and differences in their presentation and underlying rationale. In doing so, we demonstrate how theoretical formulations and empirical observations were integrated within these visual methods, shedding light on how theory and observation informed practice and how these complex astronomical events were made accessible to broader audiences.

Keywords: eclipses; astronomical diagrams; *parilekha*; construction; Indian astral sciences

Introduction

Buried in the substantial collection of Indic manuscripts in the University of Cambridge's manuscript repository is a manuscript itemised as MS Add.1039 "Nepalese Astrological paper." Its description elaborates: "A single-folio Nepalese Astrological paper, relating to the solar eclipse of 10th October 1874."[1] This account is notably modest, for when one opens the roughly 18cm by 16cm folio which is folded in half between a protective sheath, the contents are immediately visually arresting (see Figure 1). On this single sheet is a short Sanskrit text, a note in English, and a distinctive technical diagram of an eclipse which dominates the page.

The text (transcribed and translated in the appendix of this contribution) is largely numerical data pertaining to the details and circumstances of the solar eclipse, including date and other key time instants, duration, magnitude, solar and lunar longitudes and latitudes, parallax, as well as an astrological table linking zodiacal signs to certain outcomes.[2] But what is most striking about this single folio is the eclipse diagram. A technical construction that contains marks of construction along with lettered points and words and a distinctive black eclipsing shadow. A careful inspection reveals the following details. Perpendicular lines denoting the cardinal directions, labelled with the initial letters of the words North—*u* for *uttara*—at nine o'clock, East—*pū* for *pūrva*—at 12 o'clock, South—*da* for *dakṣina*—at 3 o'clock, and West—*pa* for *paścima*—at 6 o'clock. Similarly appropriately offset perpendicular lines denoting the intercardinal directions with labels are inscribed: North-East, *ai* for *aiśānī*, South-East, *ā* for *āgneyī*, South-West, *nai* for *nairṛta*, North-West, *vā* for *vāyavya*, respectively. Three technical terms for the beginning (*sparśa*), middle (*madhya*) and end (*mokṣa*) of the eclipse are located at the appropriate points (namely: beginning in the North-West quadrant, mid-eclipse along a separate line in the North-East quadrant, and release in the South-East quadrant). The magnitude of the eclipse, presumably at the instant of greatest obscuration, is represented by a solid blacked out circular shadow with a crescent-shaped non-eclipsed portion of the sun remaining. Given that modern recomputations state that this eclipse covered around 90% of the sun's disk, this graphic representation is a good depiction of reality.

[1] The digital record of this manuscript can be found on the University of Cambridge's library website at https://cudl.lib.cam.ac.uk/view/MS-ADD-01039/1.

[2] A detailed study examining the numerical data via recomputations and their precision will be presented in another study.

Figure 1: The manuscript MS Add.1039 (University of Cambridge Library) containing computed astronomical and astrological data in Sanskrit and a large diagram pertaining to the 10 October, 1874 solar eclipse which was visible in India. The manuscript also contains a note in English in the bottom right-hand corner noting the date and provenance of the solar eclipse, signed with initials "W. W.". Reproduced by kind permission of the Syndics of Cambridge University Library.

Questions immediately arise from this intriguing eclipse document. Who was the author? Whom was it prepared for? How accurate are the computations and on what set of algorithms and parameters were they computed from? Was this done before or after the eclipse, and what was the role of observation in the preparation and dissemination of this document? What is the scope and use of the diagram? This last question and related themes pertaining to the visual impression of eclipse phenomena forms the basis of what we will investigate more fully in this contribution. Specifically, what was the tradition of visual rendering of eclipse phenomena in the Indian astral sciences? What sets of instructions exist concerning the execution and features to be included? How does the numerical data inform the graphical details on the diagram? In fact, a broad survey of manuscripts concerning eclipse reckoning reveals that such graphical representations of eclipses are relatively rare, despite being a key component in eclipse reckoning. We will investigate this more fully in what follows.

The Visual Aspect in Indian Eclipse Reckoning

Canonical astronomical texts arose in India in the middle of the first millennium CE in the form of *siddhāntas* and related texts. Eclipses formed an important part of these voluminous treatises. At least two chapters, one on lunar eclipses and another on solar eclipses, and sometimes an additional one dedicated exclusively to the graphical representation of eclipses, were included in the early parts of these works. A number of topics were typically covered in these eclipse chapters: instants of opposition and conjunction, apparent diameters, geocentric distances, eclipse limits, longitudinal and latitudinal parallax, duration, magnitude, angle of inclination, colours, and direction of impact.[3]

A last topic, graphical representation, or *parilekha* in Sanskrit, was an integral part of the astro-nomical coverage of eclipses. The rationale given for this section was either as an explanation for the "slow-witted" or as a pre-emptive rendering so that the patron or king knew what the eclipse was going to look like. When surveying the tradition of the graphical representation of eclipses, one fascinating theme emerges. From the very first account in the middle of the first millennium to the latest traditional *siddhāntas* in the eighteenth century, the instructions and intended output remains largely unchanged. Indeed, this tradition of graphical representation remained largely unchanged for over a millennium.[4]

[3] For further details about the history of eclipse reckoning in general on the Indian subcontinent, see Clemency Montelle, *Chasing Shadows: Mathematics, Astronomy, and the Early History of Eclipse Reckoning* (Baltimore: The Johns Hopkins University Press, 2011), 156–284.

[4] Several recent contributions have focused on various aspects of the graphical representation of eclipses in Sanskrit sources. See, for instance, Kim Plofker, "Mathematical Presentation of Eclipse Diagrams in Sanskrit Astronomy," in *Body and Cosmos Studies in Early Indian Medical and Astral Sciences in*

In what follows we consider two seminal excerpts from the *parilekha* sections of distinctive Sanskrit astronomical works that epitomise this tradition. In doing so, we wish to draw attention to the similarities in the accounts across authors and time, as well as highlight some of the more subtle differences. We first consider astronomer-mathematician Śrīpati who flourished in the eleventh century CE and exemplifies the tradition begun by Brahmagupta in the seventh century CE. We then contrast this with accounts given in the Kerala School of Astronomy, through the sixteenth century scholar Acyuta Piṣāraṭi. However, despite these passages being about visual impressions and graphical constructions, what is notable in all these accounts is the scarcity of actual drawn diagrams in available manuscripts.

Our parallel investigations will shed light on this distinct practice of visual representation and the broader themes of connecting computational algorithms with empirical encounters, and the theoretical with observation. These themes are of considerable interest to historians of science, but often more challenging to gain insight into particularly with respect to the Indian subcontinent. These case studies also provide a different perspective from a distinct culture of inquiry on the ways in which humans have reacted to the phenomena of lunar and solar eclipses and the visual artifacts these astronomical alignments have prompted in practitioners.

Instructions for Drawing Eclipses in Śrīpati's *Siddhāntaśekhara* (eleventh century CE)

Śrīpati (eleventh century CE), a prominent astronomer-mathematician in the medieval era and a prolific writer on astronomy, astrology, and mathematics, discusses lunar and solar eclipses extensively in his treatises.[5] He composed a short treatise, the *Dhīkoṭidakaraṇa*

Honor of Kenneth G. Zysk, ed. Toke Lindegaard Knudsen, Jacob Schmidt-Madsen, and Sara Speyer, , 304–314 (Leiden: Brill, 2021), and Clemency Montelle, "Visual Representations and Intertextualities in Second Millennium Sanskrit Eclipse Reckoning," in *Studies in Premodern Sciences in Memory of Noel M. Swerdlow: Antiquity to the Renaissance*, ed. Francesca Rochberg (Berlin: Springer, forthcoming). Like this paper, these studies provide a brief contextual overview and examine specific case studies. Collectively, they underscore the need for a more comprehensive and systematic investigation into the chronological development and detailed accounts of visual practices across Indian astronomy from the mid-first to the second millennium CE.

5 Though biographical data of Śrīpati has not yet been well established, some information can be found in Jambugahapitiye Dhammaloka, "Śrīpati's arithmetic in the *Siddhāntaśekhara* and *Gaṇitatilaka*: Edition, Translation, and Mathematical and Historical Analysis" (PhD thesis, Christchurch: University of Canterbury, 2020), 11-15; Kripa Shankar Shukla, *Dhīkoṭidakaraṇa* of Śrīpati, (Lucknow: Akhila Rajasthan Sanskrit Parishad, 1969); Vihari Lalasarma Vasistha, *Jyotiṣaratnamālā*, (Jammu: Sri Ranavira Kendriya, Sanskrta Vidyapitham, 1978); N.K. Majumdar, "*Dhīkoṭidakaraṇa* of Śrīpati," *Calcutt Oriental Journal* I (1934): 287-299; M.G. Panse, "*Jyotiṣaratnamālā* of Śrīpatibhaṭṭa," *Bulletin of the Deccan College Research Institute* Vol.XVII, no. 4 (Poona: Deccan College Research Institute, 1956); D. Pingree, "Śrīpati", in *Complete Dictionary of Scientific Biography* Vol.12, ed. Charles Coulston Gillispie,

dedicated entirely to lunar and solar eclipse phenomena. He also devotes some verses of his work, the *Dhruvamānasa* to eclipse reckoning.[6] But his most comprehensive treatment of eclipse phenomena appears in his multi-chapter *siddhānta*, the *Siddhāntaśekhara*, his magnum opus. Both lunar and solar eclipses are discussed in the fifth and sixth chapters of the *Siddhāntaśekhara* respectively. As is the case with many other Sanskrit astronomical treatises, Śrīpati begins these chapters on eclipses by providing the measurements of the diameters of the sun and moon (vv. 3, 9), diameters of their orbits (v. 7), and rules of astronomical calculations. Among those astronomical rules are the rules of calculation of the longitudes of the sun, moon and node (vv. 2, 13), the moon's latitude (v. 10), the distance between the sun and moon, and the moon and shadow (vv. 5, 8), the deflection—the so-called *valana* or angle on impact (vv. 18-20), conversion of angular measures into linear measures and vice versa (v.21-23), the measures of obscuration (vv. 11, 14, 15, 17), and the timings of the different phases of eclipses (vv. 12, 17). Afterwards, some sets of instructions are given to draw diagrams of specific lunar and solar eclipses in the last few verses of the fifth chapter by Śrīpati (Śrīpati notes that these instructions given to produce a graphical representation of the lunar eclipse can also be used in the case of solar eclipses as well, but with some features inverted.)

Instructions on Drawing Diagrams

Śrīpati was greatly influenced by the pioneering seventh century astronomer-mathematician Brahmagupta, as seen by the many parallels between his work and Brahmagupta's substantial *siddhānta*, the *Brāhmasphuṭasiddhānta* (628 CE) and also by the eighth century astronomer Lalla (720-790 CE). Brahmagupta's influence on Śrīpati is mainly seen in the content, language, and the terms he used whereas Lalla's influence seems to be mainly on the content and writing style. Śrīpati follows many teachings: theories, procedures, and arguments of Brahmagupta and Lalla in his treatises especially in the *Siddhāntaśekhara*.[7] With respect to eclipse reckoning, there are many similarities between the two accounts; Śrīpati has obviously followed many of the procedures set out in the fourth and sixteenth chapters of the *Brāhmasphuṭasiddhānta*. However, Śrīpati's contribution to the discourse of eclipses in India can be seen in the explanation of eclipse diagrams. As the content of the chapter implies, the astronomer/artist should first find the relevant measurements and properties

Frederic Lawrence Holmes and Noretta Koertge, 598-599 (Detroit, Mich.: Charles Scribner's Sons, 2008); Kripanath Sinha, "Śrīpati: An Eleventh-Century Indian Mathematician," *Historia Mathematica* 12 (1985): 25-44.

[6] Pingree, "Śrīpati,", 598.

[7] For more details on the influence of Brahmagupta and Lall on Śrīpati, see Dhammaloka, "Śrīpati's Arithmetic in the *Siddhāntaśekhara* and *Gaṇitatilaka*," 277-288.

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using the rules given in the previous verses, and then using these parameters, one follows the instructions, also given in verse, to draw the diagrams.

What is particularly striking about this topic is the absence of any actual diagrams, despite the text describing specific and detailed graphical procedures. In all the manuscripts available to us, no scribe has attempted to draw any diagrams. Furthermore, neither has the modern editor and commentator of the *Siddhāntaśekhara*, Babuaji Misra, in his edition with his own commentary.

The first three diagrams to be drawn on the basis of Śrīpati's instructions given in the end of the chapter on the lunar eclipse of the *Siddhāntaśekhara* are:

1. Diagram of the first contact, mid-eclipse, and last contact,
2. Diagram of the beginning of totality and end of totality, and
3. Diagram of the path of the eclipsed body.

What follows these three diagrams are alternative ways to draw those same diagrams, and diagrams representing any desired instant of eclipses. In the following section, we will explain three sets of instructions given by Śrīpati with the schematic representations that we have constructed following those instructions.

Diagram 1

त्रिज्यावृत्तं प्रथममपरं मानयोगार्धवृत्तं
ग्राह्यं वृत्तं तदनु च लिखेन्मध्यतः साधिताशाम् ।
पूर्वाद्भागात् कुमुदसुहृदः पश्चिमात्तिग्मरश्मेः
ज्यावद्दद्यात् स्ववलनभवान्यङ्गुलानि क्रमेण ॥ 25[8] ॥
प्रग्रहः शशधरस्य पूर्वतः
पश्चिमे भवति तस्य मोचनम् ।
स्पृश्यते दिनकरश्च पश्चिमे
मुच्यते स खलु पूर्वभागतः ॥ 26 ॥
व्यस्तं प्रत्यग्वलनमुडुपस्यान्त्यमाद्यं च भानोः
क्षेपाः सर्वे शिशिरमहसो व्यत्ययेन प्रदेयाः ।

[8] Note that this is the 25th verse of the fifth chapter of the *Siddhāntaśekhara* and that the other numbers are also the numbers of the verses in the same chapter.

ते तिग्मांशोः पुनरिह यथैवागतास्तद्वदेवं
दद्यान्मध्यग्रहणवलनं याम्यतः सौम्यतो वा ॥ 27 ॥
विक्षेपविज्ञातककुब्विभागे
प्राक्पश्चिमं तद्वलनं तु मध्यम् ।
भिन्नैकदिक्कं स्वशरेण देयं
सूत्रं तदग्रादपि केन्द्रगामि ॥ 28 ॥
मानार्धयोगवलये वलनाग्रतस्तत्
प्रग्रासमोक्षणशरावपि सारयित्वा ।
मध्यग्रहोद्भवशरं ककुभश्च मध्यात्
तत्संस्थितिं विरचयेद्भ्रमणाद्ग्रहीतुः ॥ 29 ॥

[One] should first draw the circle [with the radius] of R, then, the circle [with the radius] of the half of the sum of diameters [of the eclipser and eclipsed], afterwards, the circle [with the radius] of the eclipsed concentrically. [Then], directions are to be marked. [One] should draw the *aṅgulas* produced from their own *valanas* in the form of chord from the eastern region in the case of lunar eclipse [and] from the western region in the case of solar eclipse.

The first contact of the moon [with the shadow] occurs from [its i.e., moon's] east [and] the release of it in [its] west. Also, the sun contacts [the moon] in [its i.e., moon's] west. It gets released from [its] east.

The opposite (i.e., *valana* at the instant of release) *valana* of the moon and the first and the last *valanas* of the sun are [to be taken] contrarily [in the form of chords]. All the latitudes pertaining to the moon should be drawn contrarily. Further, those pertaining to the sun [should be taken] as they are. Thus, [one] should draw the *valanas* pertaining to the mid-eclipse from the south or the north.

In case of determining the direction of the *valana* based on the knowledge of the latitude, that *valana* of the mid-eclipse should be marked eastward or westward [appropriately] depending on [the *valana* of the mid-eclipse] having the same or opposite directions of the latitude (i.e., if the latitude and *valana* are in the south, the *valana* should be marked eastward from the south; if the latitude is in the south and *valana* is in the north, it should be marked westward from the south; if the latitude and *valana* are in the north, it should be marked eastward from the north; if the latitude is in the north and *valana* is in the south, it should be marked westward from the north). Also, the line [running] from the tip of that (i.e., *valana*[-chord]) to the center [should also be drawn].

Having stretched those latitudes [of the moon] at the first contact and the last contact from the tip of the [relevant] *valana*[-chord] to the circle with the radius of the half of the sum of the diameters [of the eclipser and eclipsed]

> and the latitude produced from the mid-eclipse from the middle direction (i.e., the center) [one] should mark the union/behaviour of them in terms of the motion of the eclipsed.

As evident from the translation, what Śrīpati discusses here is the diagram of the first contact, mid-eclipse, and last contact.

Even though all these five verses come under the first set of drawing instructions, only the first and last verses of this set give direct instructions on drawing diagrams. The other verses are on the determination of the directions of the first contact, last contact, deflection, and latitude of the moon in lunar and solar eclipses. They are in fact, important information for the diagram, but not instructions on drawing *per se*. Although these instructions are mentioned in the chapter on lunar eclipses, as mentioned before, they apply to both lunar and solar eclipses. Since what applies to the lunar eclipse applies to solar eclipses but in the opposite direction, Śrīpati might have decided to explain them together following Brahmagupta and Lalla.[9]

According to verse 25, one should begin the drawing by inscribing the largest circle, the circle with radius R,[10] followed by the medium-sized circle whose radius is equal to the sum of the radii of the eclipsed and eclipser. Lastly, the smallest circle should be drawn with the radius that of the eclipsed body i.e., the moon in case of lunar eclipse and sun in case of solar eclipse. In fact, the exact measurements of the diameters of these celestial bodies cannot be used in drawing since they amount to large-scale and are given in *yojanas*.[11] Therefore, these circles are drawn with proportional measures by converting *yojanas* into degrees following the rule given in verse 6 of Chapter 5. The other relevant instructions are given in the last verse to draw the latitude of the moon at the first contact, the last contact, and the mid-eclipse, and then the circles with radius of the eclipsing body (i.e., the shadow of the earth in case of lunar eclipse and sun in case of solar eclipse) at those instants. It should be noted that what is represented in the diagram is different from what we experience. In case of lunar eclipse, it appears that the moon is seen moving through the earth's shadow, but Śrīpati instructs us to draw the circle of eclipser, which is the moon in

[9] See Ramswarup Sarma, *Brāhmasphuṭasiddhānta* Vol.III (New Delhi: Indian Institute of Astronomical and Sanskrit Research, 1966), XVI.14-18; Bina Chaterjee, *Śiṣyadhīvṛddhidatantra* Part I (New Delhi: Indian National Science Academy, 1981), V.29-33.

[10] This R represents the scaled non-unity trigonometric radius in Indian astronomy. See for more details on this in Kim Plofker, *Mathematics in India* (Princeton: Princeton University Press, 2009), 79; Clemency Montelle and Kim Plofker, *Sanskrit Astronomical Tables* (Cham: Springer International Publishing, 2018), 57.

[11] *Yojana* is one of the higher units of linear measures used in ancient India. The exact length of this unit, in terms of modern units, is not well established, but it is certainly equivalent to a few miles. For more details see Saradha Sirinivasan, *Mensuration in India* (Delhi: Ajantha Publications, 1979), 25-29.

this case, at these three instances while the shadow moves the moon is always immobile at the center. However, technically they are not different since they represent the first contact, last contact, and mid-eclipse correctly.

The second verse of the above set mentions the directions of the first contact and last contact of the lunar and solar eclipses, and they occur in mutually opposite directions. The third and fourth verses help us determine the direction of the deflection and the direction of latitude of the moon at different instances. The *valana* at the last contact of the lunar eclipse should be marked in the west which is opposite (*vyasta*) of the direction of the *valana* at the first contact. In case of solar eclipse, the *valanas* at the first contact and last contact should be marked in opposite directions (*vyasta*) of their own directions. Hence, the word *vyasta* is here used to mean both opposite of the direction of the first contact, in case of lunar eclipse, and opposite of *valana*'s own direction, in case of solar eclipse. Further, in case of lunar eclipse, the latitudes of the moon at first and last contacts should always be marked towards opposite directions of their own directions. But in case of a solar eclipse, those latitudes are marked towards their own directions. The *valanas* of the mid-eclipse are marked from the south or north as appropriate.

When it comes to determining the directions towards which the *valana* of the mid-eclipse is drawn, Śrīpati simply says that it should be drawn eastward or westward depending on the directions of the latitude and *valanas*. Although Śrīpati's claim does not clarify much, Babuāji Miśra's commentary on this is very helpful in understanding this procedure[12] which is summarized in the following chart (see Figure 2). For instance, at the instant of the mid-eclipse, if the direction of latitude is north and the direction of *valana* is south, the *valana* should be drawn from the north point westward.

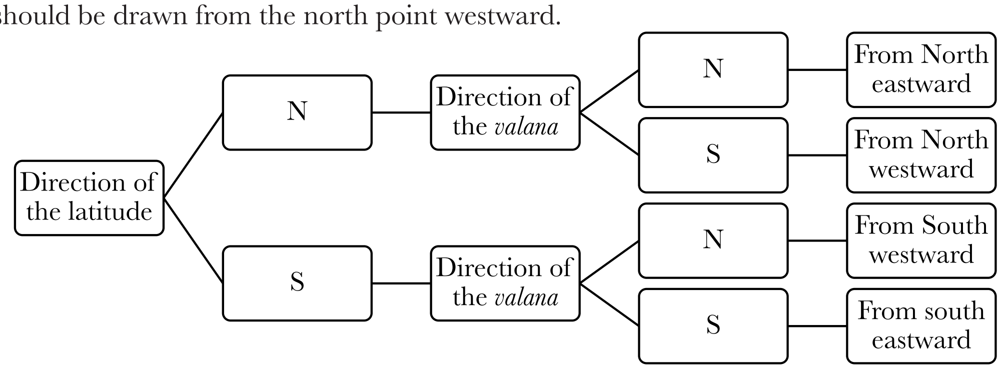
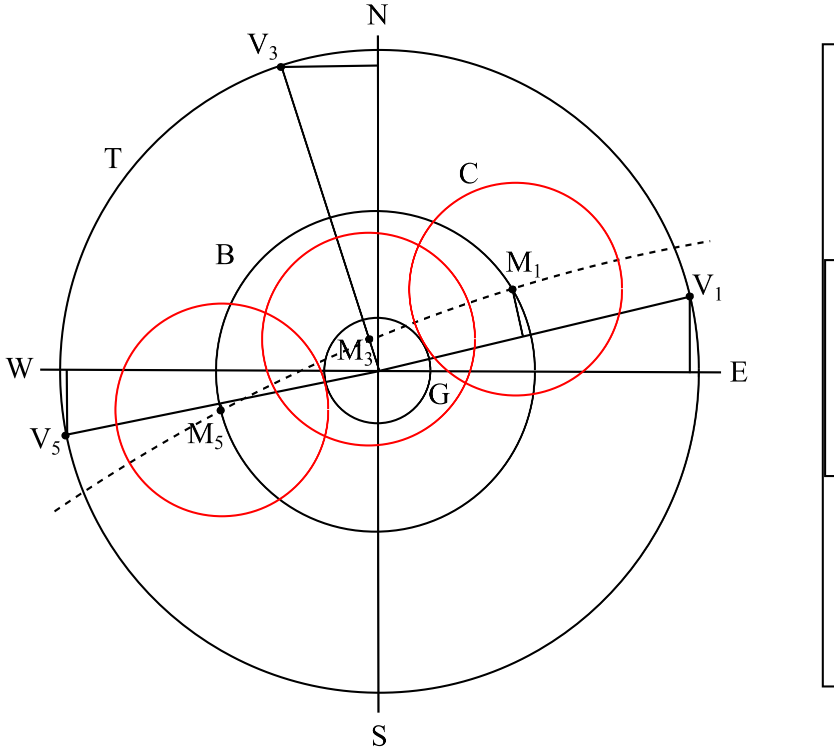


Figure 2: Determination of the direction towards which the *valana* of mid-eclipse to be drawn.

As per the instructions, once the deflections are marked as chords, lines should be drawn from the tip of the deflection-chord to the centre. These lines are known as *valanasūtras*

[12] Babuāji Miśra, *Siddhāntaśekhara* (Calcutta: Calcutta University Press, 1932) 368.

(line of *valana* or deflection line). As mentioned in verse 29, the latitudes related to the first and last contacts should be marked from the *valanasūtra* on the second circle, which implies that the deflections of both instances are marked from the east and west on the R circle appropriately. The latitude of the mid-eclipse should be marked along the deflection line from the centre. Once these points are marked, taking those points as centres, the eclipsing body should be drawn at each point to show the progress of the eclipse. Śrīpati's instructions for drawing this first diagram are not very different from what is found in the *Brāhmasphuṭasiddhānta* and *Śiṣyadhīvṛddhidatantra* under the same topic.[13]



T - Circle with R radius
B - Circle with the radius of sum of two radii of the eclipsor and eclipse
G - Circle representing the moon
C - Circle representing the shadow of the earth
V - Valana (deflection)
M - An instant of eclipse

Figure 3: First contact, mid-eclipse, and last contact of lunar eclipse.

If all the instructions given above are followed, the diagram Figure 3 will be drawn where the first contact, mid-eclipse, and the last contact are depicted. The procedure begins with drawing the circle T which is the circle with R radius, then the circle B, the circle with the

[13] *Brāhmasphuṭasiddhānta*, 1966, xvi.14-18; *Śiṣyadhīvṛddhidatantra*, 1981, v.29-35

radius of the sum of two radii of the eclipser and eclipsed, and lastly the circle G which is the circle with the radius of the moon. Then, the *valana* of the first contact V_1, that of the last contact V_5 and mid-eclipse V_3 are marked from the east, west, and north points respectively on the R circle in the form of chords. Afterwards, the latitudes are also marked in the form of chords. In case of the first and last contacts, these chords are measured from the respective *valana*-chords and marked on circle B, but the latitude of the moon at the mid-eclipse is measured along its *valana*-chord and marked on it. Now, taking these three points marked on circle B and the *valana*-chord of the mid-eclipse, as the centres three circles are drawn with the radius of the eclipsed body which is, in this case, the shadow of the earth.

In Figure 3 the circle whose centre is M_1 contacts the eastern part of circle G, which is the moon, and this contact represents the first contact of lunar eclipse. The circle whose centre is M_5 touches the western part of circle G and this contact represents the last contact. Similarly, the circle with M_3 as its centre along with the circle G represents the mid-eclipse. If this figure is of the solar eclipse, the representation is completely converse i.e., the circles corresponding to M_5, M_3, and M_1 represent the first contact, mid-eclipse, and last contact in order. Note that in case of solar eclipse, the smallest circle of the three consecutive circles represents the sun, which is the eclipsed body, and the circle C represents the moon, which is the eclipsing body. Therefore, in the schematic representation of the solar eclipse, the smallest circle of the three consecutive circles is larger than the circle of the eclipsing body.

Diagram 2

Śrīpati includes only three instances, namely the instance of first contact, mid-eclipse, and the last contact in the above diagram which was discussed in verses 25-29. He then instructs us to draw another diagram representing the other two instances; the instance of beginning of totality and instance of end of totality in verses 30 and 31 as follows.

स्ववलनदिशि बाहुः प्राङ्मुखः शीतरश्मेः
भवति खलु निमीले प्रत्यगुन्मीलने तु ।
सवितुरपरथा तु स्वस्वकोट्यौ तदग्राच्
छ्रुतिरपि भुजकोट्योरग्रसक्ताथ तिर्यक् ॥ 30 ॥
कोटिकर्णयुतिचिह्नतस्ततो
ग्राहकार्धवपुषः परिभ्रमात् ।
दृश्यते शशिदिवाकरग्रहो-
न्मीलनोन्मिषणसंस्थितिः स्फुटम् ॥ 31 ॥

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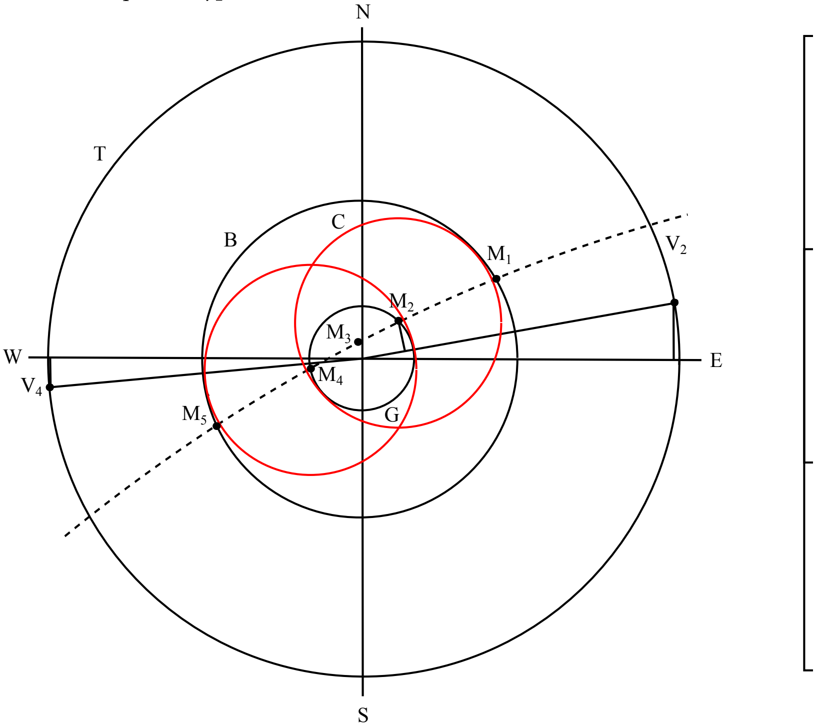
> The base pertaining to the moon running towards the east at the instant of totality (*nimīlana*) and [the base pertaining to the moon running towards] the west at the instant of end of the totality (*unmīlana*) are in the direction of its own *valana*. Those [bases] of the sun are in reverse order (i.e., in case of *nimīlana*, the base is in the west and in case of *unmīlana*, it is in the east). From the tip of the base their own two uprights [should be drawn]. Then, the hypotenuse lying on the tips of both the base and upright [should be drawn] obliquely.
>
> Then, the behaviour of the beginning of the totality of the lunar and solar eclipses are clearly seen from the circle with the radius of the eclipser [drawn with] the connecting point (i.e., vertex) of the upright and the hypotenuse [as its centre respectively].



T - Circle with R radius
B - Circle with the radius of sum of two radii of the eclipsor and eclipse
G - Circle representing the moon
C - Circle representing the shadow of the earth
V - Valana (deflection)
M - An instant of eclipse

Figure 4: Beginning and end of totality of lunar and solar eclipse.

Śrīpati states in verse 30 that the totality of the lunar eclipse occurs in the eastern part of the moon and the end of it occurs in the western part of the moon and that in case of solar eclipse it is completely opposite. This clearly proves that these two verses are about schematic representation of the beginning and end of the totality of lunar and solar eclipses.

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However, Śrīpati employs two terms *unmīlana* and *unmiṣaṇa*, which mean the same, the end of totality (literally "opening of eye") in the last half of the next verse, instead of *nimīlana* (beginning of totality, literally "closing of eye") and *unmīlana* or their synonyms as did in the previous verse. Seemingly, neither is this an author's mistake nor a scribal or editorial error. These two terms should be read with the phrase "*śaśidivākaragraha*. . ." (the solar and lunar eclipses) in the previous line to mean the "end of the totality of solar eclipse and that of lunar eclipse" which, in turn, means that this diagram represents the totality of both solar and lunar eclipses as was the case with the previous diagram (Figure 3).

The drawing of the diagram given in the above two verses is different from that of the previous diagram, Figure 3. Since one is instructed to draw the base, upright, and hypotenuse in the above verses, seemingly the astronomer/artist should have already calculated those measures. In fact, Śrīpati has separate rules for finding them (vv. 12, 14). First, one should draw the *valana*-chords relevant to the instances of totality and end of totality, and then the *valanasūtras*. Afterwards, the base is drawn along the *valanasūtra*, and from its tip the upright. Now, the hypotenuse can be easily drawn by connecting the tips of the base and upright. Once the triangle is drawn, the circle of the eclipser (i.e., the shadow of the earth in case of lunar eclipse, and sun in case of solar eclipse) should be drawn as before, i.e., taking the vertex of the upright and hypotenuse as the centre. Śrīpati says that the diagram thus drawn represents the exact behaviour of the eclipse at the beginning and end of totality.

As before, first the *valana* measures corresponding to the beginning of totality and end of totality are marked on the R circle which are V2 and V4 respectively, in the diagram (see Figure 4). Then the *valanasūtras* are drawn. Since the base has already been measured it is marked on the *valanasūtra* from the centre and from that point the upright is marked on the smallest circle which are M2, and M4 in this case. Then, by connecting the tips of the bases and uprights severally, the hypotenuses can easily be drawn. Finally, taking M2, and M4 as centres, circles with the radius of the eclipsing body are also drawn. The former circle represents the beginning of totality and the latter the end of totality of lunar eclipse. If this is taken to be of a solar eclipse, then the representation is the reverse of this, i.e., the circle with M4 centre along with the smallest circle, which is the moon, represents the beginning of totality and the circle with M2 centre represents the end of it. But in that case, the smallest circle of the three consecutive circles of the diagram represents the sun, and the circles of the eclipsing body represents the moon, hence the middlemost circle is larger than the circles of the eclipsing body.

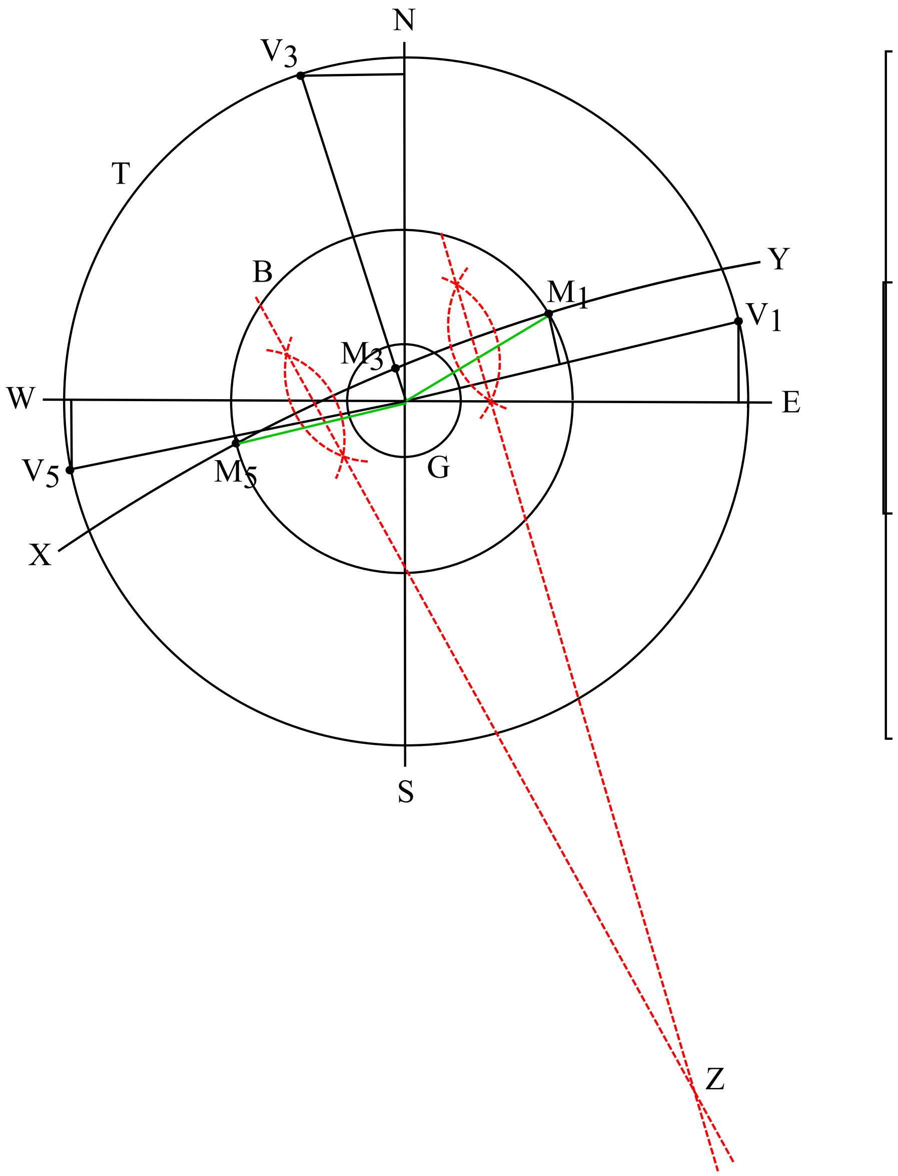
Although these two diagrams could have been amalgamated into one diagram, Śrīpati opted not to, probably on purpose. The totality of an eclipse is not a possible phenomenon if it is a partial eclipse, but first contact, mid-eclipse, and last contact always occur irrespective of eclipse being total or partial. Therefore, the first diagram is applicable to any eclipse, but the second is needed only when a total eclipse occurs. This may be the reason for Śrīpati's decision to explain these two diagrams separately. Further, the fact that Śrīpati recommends using only the three points; points of the first contact, mid-eclipse, and last contact in the process of marking the path of the eclipse, which is seen in verse 33, also supports this hypothesis.

Diagram 3

After drawing these two basic diagrams, or at least the first one, what an astronomer might want to know next is the actual path of the eclipse, i.e., the path of the moon. Therefore, a simple method to find it is given in verse 33.

विक्षेपाग्रत्रयकृततिमिद्वन्द्वमध्यस्थरज्वोः
योगाद्वृत्तं कृतशरशिरो वर्त्म तद्ग्राहकस्य ।
तत्संसक्ता श्रुतिमपि नयेद्युक्तितो मध्यकेन्द्रात्
इष्टग्रासाद्यवगमविधिज्ञप्तये चन्द्रभान्वोः ॥ 31 ॥

[The part of] the circle drawn through the tips of the latitudes [of the eclipsed body] from the converging point of the two lines lying through the middle of two fish figures drawn from the tips of three latitudes [of the eclipsed body] is the path of that eclipser. [One] should also stretch the hypotenuse touching that circle from the centre of [the consecutive circles] appropriately for knowing the method of reckoning desired obscured portion etc. of the sun and moon.



T - Circle with R radius
B - Circle with the radius of sum of two radii of the eclipsor and eclipse
G - Circle representing the moon
C - Circle representing the shadow of the earth
V - Valana (deflection)
M - An instant of eclipse
XY - Path of the eclipsing body

Figure 5: Path of the eclipsed body.

In order to find the path of the eclipse Śrīpati employs two fish figures,[14] a ubiquitous contrivance encountered in Indian astronomy. Taking the points of first contact M1, mid-eclipse M3, and last contact M5 as reference points, one should produce two fish figures as seen in the diagram (Figure 5) and then two lines should be drawn through the intersections of these fish figures so that they meet at a point. Taking this intersection point Z as the centre, the arc XY drawn through all three points of instances M1, M3, and M5 is the path of the eclipse. In fact, Śrīpati says to stretch a rope ("rajvoḥ yogāt") through the fish figures, which means that these diagrams probably have been drawn on the ground using ropes. The purpose of this diagram is to be able to model the course of an eclipse and its features (obscuration, time etc.) at any point in time (... *iṣṭagrāsādyavagamavidhijñaptaye* ...).

Remarks

Śrīpati gives instructions to draw a few diagrams about eclipses in the lunar eclipse chapter of his *Siddhāntaśekhara*, of which three were discussed in the previous sections: 1) the diagram of the first contact, mid-eclipse, and last contact, 2) diagram of the beginning of totality, and end of totality, and 3) diagram of the path of the eclipsing body. Although they are given in the lunar eclipse chapter, they apply to both lunar and solar eclipses. It is clear that Śrīpati also follows the same tradition as Brahmagupta and he parallels some of the descriptions given in the *Śiṣyadhīvṛddhidatantra* of Lalla. This is evident both through the structure and the style of giving instructions to draw diagrams. However, it should be noted that Śrīpati wanted to draw the eclipser as the moving object in both cases, namely a lunar eclipse and a solar eclipse. The sole purpose of these schematic representations, as per Śrīpati, seems to be reckoning different instances of eclipses and having better understanding of the phenomena.

Instructions for Drawing a Lunar Eclipse in Acyuta Piṣāraṭi's *Uparāgakriyākrama* (sixteenth century)

Kerala School of Astronomy

[14] As it is evidenced elsewhere in Makkibhaṭṭa's commentary on the *Siddhāntaśekhara*, diagrams that were used for astronomical calculations were drawn mainly on the ground by using poles, and ropes (For instance, see *Siddh*āntaśekhara, Vol.I, 216-218). Therefore, these fish figures should have also been drawn on the earth using the same equipment. The common method of producing fish figures is as follows. Firstly, a pole is established at M1. Secondly, a rope tied to another pole with a sharp end is tied to the pole at M1. Thirdly, an arc is drawn on the XY arc from M1 using the rope tied to the sharp-ended pole. Then, another arc is also drawn from M2 in the same manner in such a way that it intersects the first arc.

Kerala, a region in south-western India, has a long history of the study of astronomy. Mādhava of Saṅgamagrāma (c. 1340-1425 CE) is perhaps the most renowned of the Kerala astronomers. Mādhava and his disciplic lineage, collectively referred to as the Kerala school, made significant contributions in astronomy and mathematics, mainly from the fourteenth to the sixteenth centuries, and this tradition continued up to the nineteenth century.[15] Figure 6 depicts an abbreviated lineage of the Kerala school.

The Kerala scholars were adept at computing, observing and drawing eclipses. Parameśvara (c. 1360–1455 CE) carried out astronomical observations for fifty-five years and recorded thirteen eclipse observations (eight solar and five lunar) in his *Siddhāntadīpikā*. He proposed corrections to computational algorithms to achieve correspondence with observations and authored three works dealing with eclipses: *Grahaṇa-nyāya-dīpikā, Grahaṇamaṇḍana,* and *Grahaṇāṣṭaka.*[16] In the *Tantrasaṅgraha,* Nīlakaṇṭha (c. 1444–1454 CE) devotes two chapters for the computation of lunar and solar eclipses, respectively, and their associated diagrams.[17] Jyeṣṭhadeva (c. 1500–1610 CE) also discusses eclipse algorithms in his *Gaṇita yukti bhāṣā.*[18] In the next section, we briefly discuss the background and contributions of Acyuta Piṣāraṭi, the illustrious disciple of Jyeṣṭhadeva.

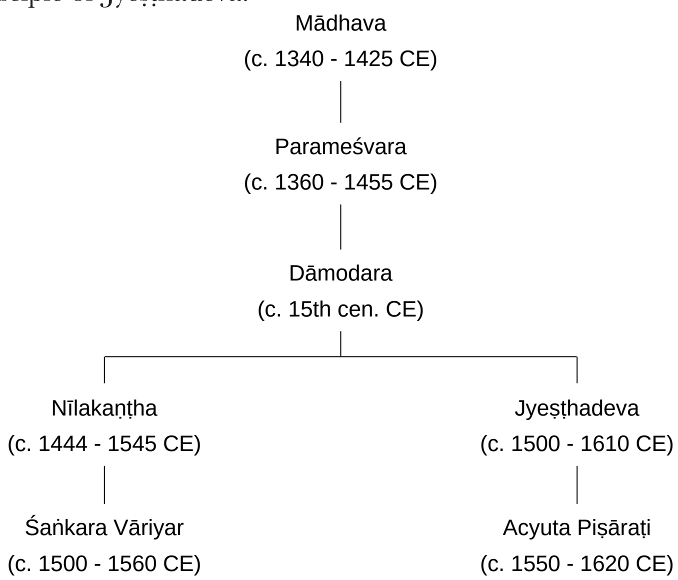


Figure 6: Some scholars of the Kerala school

[15] K. Ramasubramanian and M. S. Sriram, *Tantrasaṅgraha of Nīlakaṇṭha Somayājī* (New Delhi: Hindustan Book Agency, 2011), xxxiii–xxxiv.

[16] K. V. Sarma, *A History of the Kerala School of Hindu Astronomy* (Hoshiarpur: Vishveshvaranand Institute, 1972), 33.

[17] Ramasubramanian and Sriram, *Tantrasaṅgraha*, 255–356.

[18] K. V. Sarma, K. Ramasubramanian, M. D. Srinivas and M. S. Sriram, *Gaṇita ukti bhāṣā* of Jyeṣṭhadeva (New Delhi: Hindustan Book Agency, 2008).

Acyuta Piṣāraṭi

Acyuta Piṣāraṭi (c. 1550-1620 CE), a polymath from Kerala, is perhaps best introduced through his obituary composed by his eminent disciple Nārāyaṇa Bhaṭṭatiri:[19]

हे शब्दागम निर्दयं विबुधतालुब्धैर्निपीडिष्यसे
धाष्ट्यैकप्रवणासि वैद्यसरणे नष्टोऽस्यलङ्कार भोः ।
हन्त ज्योतिषतन्त्र पर्यवसिता तिथ्यृक्षयोस्ते कथा
विद्यात्मा स्वरसर्पदत्र भवतामाधारभूरच्युतः ॥

O grammar! You are going to be mercilessly squeezed by those greedy for scholarship. O path of physicians! You are completely surrendered to the arrogant. Hey poetics! You are lost. Astronomy! Alas, your tales of *tithi* and *ṛkṣa*[20] have come to an end. For, here, your foundation, the embodiment of knowledge, Acyuta, has slipped away to the heavens!

The above verse, in the *Śārdūlavikrīḍita* metre, attributes scholarship in linguistics, medicine, poetics, and astronomy to Acyuta Piṣāraṭi. The phrase *vidyātmā svarasarpad* at the beginning of the fourth quarter of the above verse also encodes the number 1724514 in the *kaṭapayādi* system,[21] which gives the *kali-ahargaṇa*[22] of the date of Acyuta's demise, and corresponds to August 15, 1620 CE.

Acyuta received patronage from King Ravi Varma of Veṭṭattu-nādu and authored works in astronomy, astrology, and Sanskrit grammar.[23] His major astronomical works include:

1. *Sphuṭanirṇayatantra* (with auto-commentary): A treatise on the computation on true longitudes of planets, consisting of ninety verses and six chapters,

2. *Rāśigolasphuṭānīti:* Rationale for 'reduction to the ecliptic' in fifty verses,

3. *Uparāgakriyākrama:* Procedures for eclipse computations in four chapters and 127 verses,

4. *Uparāgaviṃśati*: twenty verses on eclipse computation,

5. *Karaṇottama* (with auto-commentary): Astronomical procedures in 119 verses and five chapters,

[19] *K. V.* Sarma, *Sphuṭanirṇayatantra of Acyuta* (Hoshiarpur: Vishveshvaranand Institute, 1974), xi.
[20] *Tithi* and *ṛkṣa* (*nakṣatra*) are two of the five major elements of the Indian almanac (*pañcāṅga*).
[21] Sarma, *Sphuṭanirṇayatantra*, xv.
[22] Number of days elapsed in the *kali-yuga*, a commonly employed epoch in Indian astronomy.
[23] Sarma, *Sphuṭanirṇayatantra*, xi–xiii.

6. *Chāyāṣṭaka*: eight verses on shadow computations,
7. Commentary on *Sūryasiddhānta*, and
8. Commentary on *Veṇvāroha* of Mādhava.

Acyuta is credited with the correction known as the 'reduction to the ecliptic', which he introduced in the *Sphuṭanirṇayatantra* and elaborated upon in the *Rāśigolasphuṭānīti.* This correction was introduced in western astronomy by Tycho Brahe around the same time period.[24] Acyuta also computed a complex derivative of a ratio of two functions to determine the instantaneous velocity of a planet in the *Sphuṭanirṇayatantra.*

In the following section, we briefly outline the contents and significance of Acyuta's *Uparāgakriyākrama*, a major work on eclipse computations.

Uparāgakriyākrama: Manuscripts and Contents

Uparāgakriyākrama (Procedures for eclipse computations) is a treatise on the computation of eclipses composed in 127 verses. Its four chapters cover:

1. Computation of syzygy (fourty-two verses),
2. Computation of lunar eclipse (twenty-seven verses),
3. Computation of solar eclipse (fourty-five verses), and
4. Shadow measurements (thirteen verses).

We have based our study on nine manuscripts of *Uparāgakriyākrama,* the details of which are summarized in Table 1. Figure 7 depicts a sample folio from one of the manuscripts. It may be noted that two other texts with the same name are known. One of them is by an anonymous author, while the other is attributed to Nārāyaṇa, another Kerala scholar.[25]

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[24] A. K. Bag, "Indian Literature on Mathematics During 1400–1800 A.D.," *Indian Journal of History of Science* 15, no. 1 (1980): 79–93, on 82.
[25] Sarma, *A History of the Kerala School of Hindu Astronomy*, 33.

Manuscript	**Material**	**Folios**	**Condition**	**Extent**	**Commen-tary**
K-22225	Palm leaf	47	Good	Complete	Yes
K-MC441C	Palm leaf	27	Good	Incomplete	Yes
K-MC628B	Palm leaf	33	Good	Complete	Yes
K-15095A	Palm leaf	34	Torn	Incomplete	Yes
K-14568B	Palm leaf	13	Torn	Incomplete	Yes
K-MC173G	Palm leaf	18	Good	Incomplete	Yes
K-404A	Palm leaf	25	Torn	Complete	No
K-404B	Palm leaf	94	Torn	Complete	Yes
S-358	Paper	71	Good	Complete	Yes

Table 1
K - Kerala Oriental Research Manuscript Library, Thiruvananthapuram
S - K. V. Sarma Library, Chennai (Transcript of K-404A/B)

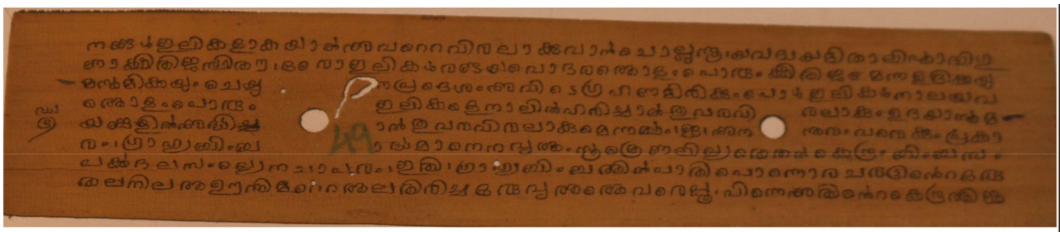

Figure 7: A sample folio from manuscript K-22225.

Indian astronomical texts customarily commence with an invocatory verse venerating the author’s preferred deity and laying out the purpose and motivation of the work. The invocatory verse of *Uparāgakriyākrama,* composed in the *anuṣṭubh* metre, follows this custom:[26]

मार्ताण्डाख्यं परं ज्योतिः नत्वाऽस्माभिर्विलिख्यते ।
हिताय मन्दबुद्धीनाम् उपरागक्रियाक्रमः ॥

Having venerated the supreme light, called *Mārtāṇḍa* (Sun), the *Uparāgakriyākrama* is composed by me for the benefit of the dull-witted.

[26] The *Uparāgakriyākrama* is a Sanskrit text, a language which is usually written in the Devanagari script. However, the manuscripts of the *Uparāgakriyākrama* available to us are written in the script of the Malayalam language, spoken locally in Kerala. In this paper, for consistency, we have opted to transliterate the text into the more widely employed Devanagari script.

The second and third verses of the text, also in the *anuṣṭubh* metre, immediately give the criteria for the occurrence of lunar and solar eclipses:

यदा पातद्वयार्कैक्यम् अभितस्तद्दिनं द्वयोः ।
पर्वणोर्ग्रहणं चिन्त्यं यथायुक्त्यर्कचन्द्रयोः ॥
पूर्णिमान्तो निशायां चेत् भूच्छाया छादयेद्विधुम् ।
दर्शान्तोऽह्नि तथा सूर्यं चन्द्रः संच्छादयेदिह ॥

> The solar and the lunar eclipses, by appropriate reasoning, shall be analysed on the two *parvas* (*amāvāsyā* or new moon and *pūrṇimā* or full moon) lying in the vicinity of the day on which there is an occurrence of the conjunction of [either of] the two nodes with the Sun. Here, if the end of the *pūrṇimā* [*tithi*] (i.e., full moon) occurs during the night, the shadow of the earth shall eclipse the moon. Likewise, if the end of the *darśa* [*tithi*] (i.e., new moon) occurs during the day, the Moon will eclipse the Sun.

The text goes on to give several astronomical parameters and algorithms necessary for the computation of syzygy, lunar, and solar eclipses. In its second and third chapters, the text also discusses procedures for drawing lunar and solar eclipses. In the following section we briefly lay out the instructions given in *Uparāgakriyākrama* for drawing a lunar eclipse.

Uparāgakriyākrama: *Instructions for Drawing a Lunar Eclipse*

Verses 19(b)–27 of the second chapter of the *Uparāgakriyākrama* outline the procedure for drawing a lunar eclipse. Here, we translate these verses on the basis of a Malayalam commentary, of uncertain authorship, available in the manuscripts.

First, verses 19(b)–23(a) state the method to determine the points of first and last contact:

ग्राह्यबिम्बार्धमानेन वृत्तं सूत्रेण लिख्यते ॥
तत्केन्द्रबिम्बसम्पर्कदलसंख्येन चापरम् ।
व्यासरेखां लिखेत् पूर्वापरां याम्योत्तरां तथा ॥
शलाकाऽङ्कितमध्या या वलनद्विगुणाऽथ ताम् ।
न्यसेत् व्यासस्थमध्याङ्कां नेमिस्पृष्टोभयाग्रकाम् ॥
बिन्दुस्तन्नेमियोगे प्राक् स्पर्शिकात् वलनात् स्वदिक् ।
पश्चार्धे मोक्षवलनात् बिन्दुस्तद्विपरीतदिक् ॥
बिन्दोः केन्द्रं नयेत् सूत्रं तत्स्पर्शे स्पर्शमोचने ।

> A circle, by the measure of half [the radius of] the disc of the *grāhya* (obscured), is drawn using a thread. With that centre, another circle is also drawn by the measure of half the sum of the diameters of the discs [of *grāhya* and *grāhaka* (obscurer)]. One must draw the east-west and south-north diameter. Thereafter, one must place that stick, whose length is twice the *valana*,[27] and which is marked at the centre, such that the mark is located on the diameter and both ends touch the circumference [of the outer circle]. In the east, a dot [is marked], in the same direction [as the *valana*], at the intersection of the circumference and [the tip of] that stick [whose measure is obtained] from the *valana* at first contact (*sparśa*). In the west, [another] dot [is marked], in the opposite direction [of the *valana*], at the intersection of the circumference and [the tip of] that stick [whose measure is obtained] from the *valana* at last contact (*mokṣa*). One must extend a thread from the dot[s] towards the centre. The point[s] of intersection [of the thread with the inner circle] represent the [points of] first contact (*sparśa*) and last contact (*mokṣa*).

Subsequently, verses 23(b)–26(a) explain how to draw the diagram at the instant of mid-eclipse:

मध्यजं वलनं व्यासे न्यस्येद्याम्योत्तरे तथा ॥
वलनस्य दिशि प्रत्यक् बिन्दुः प्रागन्यतो दिशः ।
केन्द्रबिन्दुद्वयस्पृष्टरेखां कृत्वाऽथ केन्द्रतः ॥
क्षेपं व्यस्तदिशं नीत्वा बिन्दुं तत्र प्रकल्पयेत् ।
लिखेत्तत्र स्वमानार्धसूत्रेण ग्राहकं सुधीः ॥
ग्राहकान्तर्गतो भागो ग्रस्तो ग्राह्यस्य दृश्यते ।

> Similarly, place [a stick with the measure of twice] the *valana* at mid-eclipse on the south-north diameter. [One must mark a] dot at the [intersection of the tip with the circle in the] west [when the stick is placed] in the direction of the *valana* and at the [intersection in the] east [when the stick is placed] in the other direction. Having drawn the line passing through both the dots and the centre, and thereafter having measured the *kṣepa* from the centre in the opposite direction, conceive of a dot there. The intelligent must draw there the *grāhaka* with a thread of half its measure [of diameter]. The portion of the *grāhya* contained within the *grāhaka* is seen to be obscured.

Finally, verses 26(b)–27 outline the procedure for drawing the eclipse at a desired instant:

स्पर्शमोचनबिन्दुभ्यां यत् सूत्रं मध्यबिन्दुगम् ॥२६॥
तद्ग्राहकस्य वर्त्माऽत्र मध्यान्मत्वा स्फुटान्तरम् ।
तत्रेष्टकालजो ग्रासो ग्राहकार्धेन लिख्यते ॥२७॥

[27] For more on *valana* in the Kerala tradition, see Ramasubramanian and Sriram, *Tantrasaṅgraha*, 298.

> That thread which extends from the points of first (*sparśa*) and last (*mokṣa*) contact towards the *madhya* (middle) dot, represents the path of *grāhaka* here. Having measured the *sphuṭāntara* (longitudinal separation) from the *madhya* dot, the *grāsa* (obscuration) at the desired time is drawn with [a thread of length equal to] half the *grāhaka*.

The Malayalam commentary in the manuscripts elaborates upon the procedure further. The following is a translation of the same:

> Now, to draw: A circle is drawn, using a thread [whose length is] equal to half [the diameter of] the disc of the *grāhya*, by fixing one of its ends on the ground and rotating the other end. Then, at the centre of that [circle], considering that to be the centre, a circle is drawn outside [the previous circle] using a thread [of length] equal to half the sum [of the diameters] of the discs of both *grāhya* and *grāhaka*.
>
> After that, one must draw a diameter-line in the east-west direction, touching both the circles. Similarly, one must draw a diameter in the south-north direction also.
>
> After constructing a stick [with length] equal to twice the *valana*, and by making a mark at its centre, one must place [this stick] such that the mark falls on one of the diameters and both ends touch the circumference [of the circle].
>
> Here, by placing the stick, whose length is twice the *sparśa-valana*, on the eastern side, like this, one must mark a dot at the exact spot where the stick touches the circumference, along the direction of the *valana*. On the western side, by placing the stick whose length is twice the *mokṣa-valana*, one must mark a dot at its intersection point with the circumference, in the opposite direction of the *valana*.
>
> Then, from this [*sparśa*] dot, one must draw [a line] towards the centre by placing a thread. At the point where this thread touches the circumference of the *grāhya* disc, the obscuration commences. At the point where the thread, which extends from the *mokṣa* dot towards the centre, touches [the circumference of the *grāhya* disc], the eclipse concludes.
>
> Then, to draw *madhyagrahaṇa* (mid-eclipse):
>
> One must place the stick whose length is twice the *madhya-valana* on the south-north diameter, such that it (the mark) is at the centre, like this. At the point of intersection of that [stick] with the circumference, along the direction of *valana*, one must mark a dot on the western side. In the other direction, at the point of intersection of [the tip of the stick which measures twice] the [*madhya*-]*valana* and circumference, one must mark a dot on the eastern side.
>
> After drawing a thread which touches both these *madhya* dots and the centre, and by measuring the *vikṣepa* in the opposite direction on this thread, one must mark a dot at its tip. At this point, considering it to be the centre, one must draw

> a circle using a thread whose length is half [the diameter of] the *grāhaka* disc. Inside this circle, the obscured region is seen on the *grāhya* disc.
>
> Then, to draw *iṣṭakālagrahaṇa* (eclipse at desired instant):
>
> That thread which reaches the *madhya* dot from both the *sparśa* and *mokṣa* dots, represents the path of the *grāhaka*. One must draw the circle of the *grāhaka*, on the eastern or western side, by considering that point to be the centre which is removed from the *madhya* dot by a distance equal to the *sphuṭāntara*. The centre of the *grāhaka* will be on the western side if the *sphuṭa* of the Sun is lesser, and on the eastern side if greater.

Remarks

The procedure outlined in *Uparāgakriyākrama* for drawing a lunar eclipse is different from that of *Tantrasaṅgraha*. It may however be noted that the terminology employed in verses 19b–21a of *Uparāgakriyākrama* bears resemblance to verses 46b–48a of the fourth chapter (Lunar eclipse) of *Tantrasaṅgraha*.[28] The procedure given in the *Uparāgakriyākrama* broadly involves using the *valana* to determine the points of first contact, last contact and mid-eclipse. The given procedure can be applied to draw the eclipse diagram at either mid-eclipse or any other desired instant. Remarkably, the entire exercise is carried out using just a thread and a stick.

It is interesting to note that the source text as well as the commentary employ general terms such as *grāhya* (obscured) and *grāhaka* (obscurer) instead of directly referring to the Moon and the Earth's shadow. While the manuscripts available to us do not contain any diagrams, it is notable that two places in the commentary appear to be referring to a diagram with the phrase "like this". This may indicate that the commentary originally contained diagrams which were omitted in later copies.

A deeper study of the *Uparāgakriyākrama* is necessary to understand the rationale of the procedure outlined for drawing eclipses in relation to the eclipse computation algorithms given in the text. Therefore, we have not attempted to reconstruct the diagram as we have for the earlier instances in this paper.

Concluding Remarks

Eclipses are spectacular events and out of all astronomical phenomena prompted the most direct inspiration for graphical representation of a celestial event. Eclipse maps are

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28 Ramasubramanian and Sriram, *Tantrasaṅgraha*, 302.

unique depictions in the history of cartography as they bring together space and time in a distinctive way. In this way they are perhaps the earliest type of spatio-temporal maps. When considering how to represent them graphically, practitioners had to balance a static capture of the principal phases with the fact that the heavenly bodies creating these alignments were always in motion.

There are a number of notable features in the Sanskrit sources. The first is the instructions are intended to capture a specific eclipse event with all features appropriately quantified, not just a rough generalised eclipse diagram. Abstract astronomical entities, such as the lunar orbit and the cardinal directions are to be clearly drawn, and mathematical scales, such as the circle with radius equal to the Radius of the trigonometric relation and another circle with radius equal to the length of half the sum of the radii of the eclipsed and the eclipser are to be drawn. On one of the circles, eight grid marks on each quadrant are to be inscribed as a scale to capture the angular displacement of the different phases of the eclipse. Half-chords are to be drawn from the radial lines to capture the angle of impact and latitudinal deviations. This may explain the absence of graphical constructions included in astronomical treatise manuscripts; following the instructions requires an actual eclipse occurrence with its various timing and phases to render a visual image, just like we see in the striking image included as part of the Nepal eclipse description.

Secondly, the instructions do contain an element of generalisation in the language they use. That is, that they don't specify the sun or the moon or the shadow in the procedures, but rather invoke the 'eclipsed' and the 'eclipser'. This appears to be deliberate, so that the instructions can be used in either the case of a solar or a lunar eclipse without needing to repeat a separate set of instructions. Where appropriate, the authors elaborate on the inverse nature of the direction of impact for a lunar and a solar eclipse, by specifying the moon or the sun as appropriate.

Furthermore, the instructions call to attention the tools of construction to be used to effect the constructions. A string or a rope and a stick (to aid drawing circles) are all that is required to produce these diagrams. While some aspects are spelled out (such as constructing "fish figures" to bisect arcs) other features, such as dividing each quadrant into eight parts (non-trivial!) are seemingly assumed to be known how to be done by the practitioner. The diagram is overlaid with lettered abbreviations or the full technical terms for the cardinal and intercardinal directions, as well as the significant phases of an eclipse at the appropriate places.

These lines of construction, demarcating grids and angles of inclination produce a figure that is both technically instructive as well as visually appealing. The pre-computed nature of the parameters that are needed to produce the diagram suggest that this graphical construction was to be carried out prior to the eclipse event and used as a template from which to compare to and clarify the actual event in the sky. As such, these sets of instructions are fascinating insights into the ways in which eclipses may be viewed and visually documented in those centuries before the advent of cameras and other recording devices. More broadly, the visual representation of eclipses as described in these astronomical treatises give a glimpse into the links between the practising astronomer and their more general audiences. This is an area which is currently largely unexplored in modern scholarship and in the absence of explicit evidence can only be filled in by more nuanced speculations such as those that can be derived from studies such as this one. As well as an astronomical tool, one can't help but conclude that these representations served in part as an inducement for non-expert observers to be able to engage with these visually stunning astronomical events, inviting them to appreciate not only the spectacle of eclipse phenomena but also the abstract parameters and procedures through which astronomy models celestial motions and reconciles theory with observation.

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Competing Interests

The authors have declared that no competing interests exist.

Appendix

A MS Add. 1039: Solar eclipse on 10th October 1874

This record corresponds to the solar eclipse of Saturday, 10 October 1874; in the date given by the text, namely *śaka* 1796 = *saṃvat* 1931, the solar month *Āśvina* which here must correspond to the 7th solar month, day 26. *Āśvina* as the 7th solar month requires that the year count begins with *Vaiśākha*. This may reveal something about the region, with solar month year counts of this nature being more common in the north of India. In 1874, *Meṣa-saṃkrānti* occurs on April 12th. The 10th of October falls exactly 181 days after this which also fits with the data given in the text.

Regarding the geographical region this eclipse data pertains to, from the length of daylight we can recompute an approximate terrestrial latitude to be around 26°. We note that the terrestrial latitude of Kathmandu in Nepal is 27.7°which broadly fits with the attribution of this text to have come from Nepal. Also from the text we can infer the primary phases of the solar eclipse, using the Indian measure of *ghaṭikās,* that is sixtieths of a day (or 24 minutes). The first contact occurred at 3*gh*; 29 before sunset, mid-eclipse to be 0*gh*; 35 before sunset, and release 2*gh*; 19 after sunset, with the entire duration being 5*gh*; 48.

A.1 Text and translation

A.1.1 Sanskrit text

स्वस्ति श्रीशाके १७९६ श्रीसम्वत् १९३१ सौरात् आश्विनमासे दिनगता २६ सूर्यग्रहणावलोकनार्थं अहर्गन १८१ दिनमान २८।५६ अमावास्यां घटि २४।४२ हस्तघटि १३।३ ऐंद्रघति १०।२३ शनिवासरे याम्यनतं १०।१४ प्रथमलंबनं २।५९ स्थिरलंबनं ३।३९ सौम्यस्फुटशरः ८।१९ स्फुटसूर्यः ९३।३० स्फुटतमः ८४।० मानयो गार्धः ८८।४५ ग्राश ८०।२६ स्थित्यर्ध २।४५ स्फुटतिथ्यंतं २८।२१ दिनशेषघटि ३।२९ स्पर्शः पुनः शेषघटि ०।३५ मध्यः रात्रौगतघटि २।१९ मोक्ष्यः सूर्यमानांगुल ११।४४ तममानांगुल १०।३२ सौम्यशरांगुल १।२ ग्राशांगुल १०।५ याम्यवलनांगुल ५।११ शलाकांगुल ७।५९

मे ६ सुख

वृ ५ चिंता

मि ४ व्यथा

क ३ श्री

सि २ क्षाति

कं १ घात

तु १२ अया?य

वि ११ लाभ

ध १० शुखम्

प ९ माननाश

कुं ८ मृतय

मी ७ स्त्रीपिडा

A.1.2 Sanskrit transliteration

svasti śrīśāke 1796 *śrīsaṃvat* 1931 *saurāt āśvinamāse dinagatā* 26 *sūryagrahaṇāvalokanārthaṃ ahargaṇa* 181 *dinamāna* 28|56 *amāvāsyāṃ ghaṭi* 24|42 *hastaghaṭi* 13|3 *aiṃdraghati* 10|23 *śanivāsare yāmyanataṃ* 10|14 *prathamalaṃbanaṃ* 2|59 *sthiralaṃbanaṃ* 3|39 *saumyasphuṭaśaraḥ* 8|19 *sphuṭasūryaḥ* 93|30 *sphuṭatamaḥ* 84|0 *mānayo gārdhaḥ* 88|45 *grāśa* 80|26 *sthityardha* 2|45 *sphuṭatithyaṃtaṃ* 28|21 *dinaśeṣaghaṭi* 3|29 *sparśaḥ punaḥ śeṣaghaṭi* 0|35 *madhyaḥ rātraugataghaṭi* 2|19 *moksyaḥ sūryamānāṃgula* 11|44 *tamamānāṃgula* 10|32 *saumyaśarāṃgula* 1|2 *grāśāṃgula* 10|5 *yāmyavalanāṃgula* 5|11 *śalākāṃgula* 7|59

me 6 *sukha*

vṛ 5 *ciṃtā*

mi 4 *vyathā*

ka 3 *śrī*

si 2 *kṣāti*

kaṃ 1 *ghāta*

tu 12 *ayā?ya*

vi 11 *lābha*

dha 10 *śukham*

pa 9 *mānanāśa*

kuṃ 8 *mṛtaya*

mī 7 *strīpiḍā*

A.1.3 English translation

Auspiciousness! In the *śaka* year 1796, saṃvat 1931, in the solar month of *Āśvina,* (after) 26 elapsed days, for the purpose of the observation of a solar eclipse. The civil day count (*ahargaṇa*) (since the beginning of the year) is 181. The length of daylight 28;56. The new moon *tithi* (*Amāvāsyā*) (begins on the) 24;42 *ghaṭī*. The (*nakṣatra*) *Hasta* (begins on the) 13;3 *ghaṭī*. The (*yoga*) Indra (begins on the) 10;23 *ghaṭī*. (The eclipse falls) on Saturday. Southerly 'depression' (zenith distance) is 10;14. The 'first' parallax is 2;59. The 'fixed' parallax is 3;39. The corrected latitude, southern, is 8;19. The true longitude of the sun is 93;30. The true longitude of the moon is 84;0. The half (?) of the two measures (of the diameters) is 88;45. The obscuration is 80;26. The half-duration is 2;56. The end of the corrected tithi is 28;21. First contact (occurs when) 3;29 *ghaṭīs* is the remainder of the day (i.e., 3;29 *ghaṭīs* before sunset). Next, mid-eclipse (occurs when) the remainder (of the day) is 0;35 *ghaṭīs* (i.e., 0;35 *ghaṭīs* before sunset). Release (occurs when) 2;19 *ghaṭīs* is (the amount of the night elapsed; i.e., 2;19 *ghaṭīs* after sunset). The digits of the measure (of the diameter) of the sun is 11;44. The digits of the measure (of the diameter) of the moon is 10;32. The digits of the southerly latitude is 1;2. The digits of the obsuration is 10;5. The digits of the southerly inclination (*valana*) is 5;11. The digits of the *śalaka* (rod?) is 7;59.

Ari(es) 6 Happiness

Tau(rus) 5 Worry

Gem(ini) 4 Pain

Can(cer) 3 Wealth

Leo 2 Loss

Vir(go) 1 Harm

Lib(ra) 12 Debt?

Sco(rpio) 11 Gain

Sag(ittarius)10 Pleasure

Cap(ricorn) 9 Loss of Honour

Aqu(arius) 8 Death

Pis(ces) 7 Woman's distress