Bhāskara I on the Construction of the Armillary Sphere

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MLA style citation form: Peng Lu, “Bhāskara I on the Construction of the Armillary Sphere,” History of Science in South Asia 3 (2015): 1–19.

Online version available at: http://hssa.sayahna.org/.
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1. INTRODUCTION

The armillary sphere is said to have been invented by the Greek astronomer Eratosthenes (276–194 BC). Ptolemy’s Almagest (second century AD) contains a detailed description of the armillary sphere. However the armillary sphere described in Sanskrit texts on astronomy, from the seventh century onwards, is substantially different from the Greek armillary sphere.

In Sanskrit, the armillary sphere is known as gola or gola-yantra. The word gola denotes primarily the “sphere.” Āryabhaṭa and other astronomers use this term in the sense of “spherics” as opposed to gaṇita “mathematical in general.” Thus Āryabhaṭa’s Āryabhaṭīya (early sixth century CE, henceforth abh) has four chapters named Daśagitikā (Ten Gīti Stanzas Giving Parameters), Gaṇita (Mathematics), Kālakriyā (Time-reckoning), and Gola (Spherics). Here the chapter on Gola,

expounds Āryabhaṭa’s cosmology and geography, explains the apparent motions of the heavenly bodies, and gives solutions for problems in spherical trigonometry and rules for computing eclipses.

In addition, the term gola also denotes the armillary sphere consisting of several rings to represent the orbits of the celestial bodies in the heavens.

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I wish to offer my special thanks to Professor S. R. Sarma for encouraging me to write this paper and for his constructive comments on the earlier version of this paper. I would also like to express my gratitude to my teacher Professor Michio Yano for his constant support. Finally my thanks are due to Wei Liu of Shanghai Conservatory of Music, China, for producing the 3d cg figures for my paper.

1Bryant 1907: 18.
2Ôhashi 1994: 272.
3Pingree 1981: 18.
4Āryabhaṭa uses the word gola once (abh 4.22) in the sense of the celestial globe also, but such usage is rare. All the other uses of the word gola in abh (1.1, 2.7, 4.5–7, 4.15, 4.16, 4.23, 4.39) refer to spherics.
Brahmagupta discusses the armillary sphere in his *Brāhmasphuṭasiddhānta* (628 AD, henceforth ss), but there he deals more with spherics than with the actual instrument. About the same time (629 AD), Bhāskara I also describes the armillary sphere in his commentary on the *Āryabhaṭīya* (henceforth BAB).

Subsequently Lalla (eighth century) in his *Śisyadhīvṛddhidatantra*, Śrīpati in his *Siddhāntaśekhara* (1039), Bhāskara II in his *Siddhāntaśiromaṇi* (1150) described the construction of the armillary sphere. Interestingly enough Lalla and others do not discuss the armillary sphere in the chapter *Yantrādhyāya* along with other astronomical instruments, but in a separate chapter called “tying or assembling the [various rings of the armillary] sphere” (*gola-bandha*).

Among the descriptions of the armillary sphere to be found in Sanskrit texts on astronomy, Bhāskara I’s description is unique because it explains in detail how to construct the armillary sphere step by step: how to prepare a wooden ring by joining two or three strips of wood after making cuts or indents in the thickness at the ends, how to assemble two or more rings with appropriate indents at the points of intersection and so on. In this connection, he mentions three varieties of cuts (*cheda*) to be made for assembling the rings. Such practical details are not given in other Sanskrit texts. At the end of the passage, Bhāskara mentions that the armillary sphere he envisages is a free-standing one, but some others prefer to place the lower half of the armillary sphere in a pit dug in the level ground so that the horizon ring is level with the surface of the ground (see paragraph 20 of Bhāskara I’s text and Figure 20 below).

2. BHĀSKARA’S DESCRIPTION OF THE GOLA

Before commenting on the Gola chapter of the *Āryabhaṭīya*, Bhāskara describes the armillary sphere (*gola*) first, because this instrument will be useful in explaining the statements on the spherics (*gola*) in the *Āryabhaṭīya*. In this paper, we follow the text of Bhāskara’s commentary as given in the critical edition of 1976 by K. S. Shukla (pp. 240–243) and translate the passage on the armillary sphere and add explanatory notes. Bhāskara’s description is so detailed that it is possible for us to reconstruct a *gola-yantra* with wooden rings. The successive stages of the construction are shown by different figures. We have added serial numbers to the paragraphs, and corrected the irregular sandhis that occur in Shukla’s text.

[¶ 1] कालिबयानः गोलं, “ऋण गदति गणित गलक्रिक्यां गोलम्” इत्युक्तवात् गम्यते झापेतःसमाविर्दित गोलम्। किं प्रसंस्माहतेत्? यहांभ्रमणपरिवर्तीसंस्थानानांसकम्। (ll. 6–8, p. 240)

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5 *ss*. 21.49–69.
6 Ohashi 1994: 262.
“Immediately after the [chapter on] reckoning the time (kālakriyā) [comes] the [chapter on] spherics (gola), for it was said [by Āryabhaṭa] that “he discusses three [topics], namely] mathematics (ganita), reckoning of time (kālakriyā), [and] spherics.”7 The word “gola” is derived from [the verb] “gamyate” [which means by it everything is to be understood (jñāyate). What then can be understood from this [spherics]? The revolutions of the planets, the position of the earth, and all such matters.”

7ABH 1.1cd: आर्यभटकीणो गवाति स्तर्यं सत्यम् प्रायिकं गोलम्॥

“Thus those who wish to understand the highest truth (paramārtha) will understand the reality (satya) through the fictitious [assumption] (asatya). For example, physicians understand piercing (vedhana) the vessels of the body (sirā) or other [treatments] by [practicing] on the lotus stalk (utpalanāla) or some other things; those who know the science of sacrifice [understand] sacrifice and other [issues] through mock (śuṣka) rite (iṣṭī) (i.e., play-acting); grammarians understand the correct [usage of] the words (sādhu-śabda) through basic form (prakṛti), affix (pratyaya), elision (lopa), augment (āgana), phonemes (varṇa), modification (vikāra), and so on. In the same manner, here also, astronomers (sāṃvatsara) comprehend the real celestial sphere (gola) through certain [concepts] of geometry (kṣetragaṇita-viśeṣa) like the ring (vyṛtta), the rod (śalākā), the thread (sūtra), the plumb line (avalambaka), and so on.8 Therefore, [here] the demonstration of only the part will be undertaken, for it is impossible to demonstrate everything. While painting, who can paint the closing and opening in the flutter of the eyes?”

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7 In his commentary on the sgs, Ṛthūdaka uses the same argument with almost the same wording. See Ikeyama 2002: 20: पण वेयाकरणः ब्रह्मसम्बन्धार्थकीणकालक्रियाधिदिकवाक्यां यथा वाक्यां तु ब्रह्मसम्बन्धीवाक्यार्थकालक्रियाधिदिकवाक्यां यथा: विषयतःशरमुक्तिकालक्रियाधिवाक्यां कालक्रियाधिदिकवाक्यां यथा: विषयतःशरमुक्तिकालक्रियाधिवाक्यां कालक्रियाधिदिकवाक्यां।

8The contents in the square brackets [] in the Sanskrit text are by Shukla 1976.
“Therefore, he should make the carpenters (krākacika) prepare a half circle (ardha-vṛtta) made out of the timber of either Śrīparṇī (Gmelina arborea, Roxb.) or Vañcula (Dalbergia ougeinensis, Roxb., or Calamus rotang, L., or Saraca indica, L.), [and then] one [full] circle or ring which has the shape of a wheel. Then he should make [the carpenters] produce a ring made either with two well-crafted (sughaṭita) half circles or three well-crafted segments of the circle.”

“In this process, there are three [kinds] of cuts (cheda) for joining the segments of the circle, called arrow-shaft (śarapuṅkha), cutting the side (pārśvaccheda), and cutting half of the component (avayavārdaccheda). With one of these [cuts] the segments of the circle should be joined with each other.”

[¶ 3] तत्माण्ड्रीपीणिवङ्कुङ्कात्योन्यतत्तमय्वृत्तं चक्तर्थ्यं कारकिकेऽवृत्तमुक्तं निम्नद्व्यतिः।
तत्: सुपृष्टितार्णंदेर्यम् विरिभिः सुपृष्टिनिरुत्तकः: वृत्तमुक्तं निम्नद्व्यतिः। (ll. 14–16, p. 240)

“Therefore, he should make the carpenters (krākacika) prepare a half circle (ardha-vṛtta) made out of the timber of either Śrīparṇī (Gmelina arborea, Roxb.) or Vañcula (Dalbergia ougeinensis, Roxb., or Calamus rotang, L., or Saraca indica, L.), [and then] one [full] circle or ring which has the shape of a wheel. Then he should make [the carpenters] produce a ring made either with two well-crafted (sughaṭita) half circles or three well-crafted segments of the circle.”

[¶ 4] तत्र वृत्तशक्तस्निधिष्ठेष्ट्यायः शारपुण्क्हेष्वर्णवार्णवह्तेष्वर्णवतीले।
ततेशांमयमतमेन वृत्तशक्तन्योऽग्नितेन। (ll. 16–18, p. 240)

“In this process, there are three [kinds] of cuts (cheda) for joining the segments of the circle, called arrow-shaft (śarapuṅkha), cutting the side (pārśvaccheda), and cutting half of the component (avayavārdaccheda). With one of these [cuts] the segments of the circle should be joined with each other.”

[¶ 5] तामाण्ड्रीपीणिवङ्कुङ्कात्योन्यतत्तमय्वृत्तं चक्तर्थ्यं कारकिकेऽवृत्तमुक्तं निम्नद्व्यतिः।
तत्तमय्वृत्तमुक्तं निम्नद्व्यतिः: मण्डलमुक्तम्भर्णेष्वर्णवतीले। (ll. 16–18, p. 240)

“This sentence seems to be redundant since a ring has already been produced by the preceding sentence.

“We do not know the real meaning of the three different types of cuts mentioned by Bhāskara, because these terms do not appear in any other astronomical text. According to the literal meaning of the names, we draw the imaginary pictures in the Figure for ¶ 4.
“Set one ring prepared in this manner [by joining the segments firmly] with copper nails (tāmrakīlaka) in the east-west [direction] and another [ring] in the south-north so that there are intersections (svastika) [of the two rings] above and below. Then, at the [two] points of intersections [above and below], join the two rings after cutting with half cut (ardhacheda) [in the thickness] so that it looks like one circle (i.e., the thickness at the two joints should be the same as the thickness of each ring). The two [rings which are joined] by the half cut prescribed above (vihitārdhacheda) should be made firm with copper nails.”

“Then one should [set up] another [ring] like a girdle (parikara) outside [and around] these two rings so that it has four intersections at the four cardinal directions; one should insert it by the half cuts [in the thickness of the ring] as before at the four intersections and make it firm.”

“He should mark the east-west ring with 60 marks (aṅka) so that in each quarter [of the ring] there are 15 marks. These [marks] are the ghāṭikās of the day and night. In the same way, each of the two remaining rings is also [marked] with 360 marks. These [three are called] the equator ring (viṣuvat), [the meridian or the north-south ring (yāmyottara), and the horizon ring (kṣitija)].”

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12The words which are put in brackets () are redundant here and not translated, because up to here we only have got two intersections above and below, not four. These are repeat part of the next sentence.
Figure for ¶ 5: Two intersections of two rings.

Figure for ¶ 7: Rings of the equator (vīṣuca), meridian (yāmyottaka), and horizon (kṣitija).
Figure for ¶ 8 & 9: Half cut (ardhacheda) and one-third cut (tribhāgacheda).

¶ 8
तत्तुल्यभेदापरे मण्डले वृत्तस्वर्णाणि तृतीयाभिन्नति: च तीनस्वर्णस्ति: च। कुत्वा हे विभागः मण्डलप्रदृश्यस्ति: व्यवस्थितं घटयेत्। यथा वा मण्डलरत्रमस्य भागभिरमेव तद्यथते तथावङ्गः कब्जोपः। (ll. 5–8, p. 241)

“One should [make] another ring of the same size marked by 360 [marks] and possessed of an oblique one-third cut at the eastern and western intersections; he should join the two one-thirds with the intersection of a point of the ring. Or the cut (avacheda) [in the thickness of the rings] should be made in such way that [the thickness at] the intersection of the three rings should look like [the thickness of] one single [ring].”

¶ 9
पूवापरदि: भवमोयोक्ताः स्वर्णस्ति: तस्मादुत्तरं उत्तरश्लाकायां चतुर्विश्वाति-भागो तथावर्णश्वेलो व्यवस्थितं कारयेत्। (ll. 8–11, p. 241)

“Towards the north from the lower intersection of the east-west ring and the south-north ring, at the distance of 24 degrees on the northern rib [of the south-north ring], he should make an intersection (svastika) [with the fourth ring] by the half cut [in the thickness] (ardhaccheda) as before. On the upper part also, he should make, in the same manner, an intersection on the [southern] rib [of the south-north ring] at the 24th degree from the upper intersection towards the south.”

This can be achieved by cutting the thickness of the three rings at the point of intersection in such a way that only one-third of the thickness remains in each ring. When these three rings are carefully joined, the combined thickness at the intersection is equal to the thickness of a single ring.
“Everywhere the [joints must be] made firm with copper nails. Thus [the circle of] the zodiac signs (rāśi-pada) is placed obliquely. It is called the ecliptic ring (apamaṇḍala).”

“He should tie another ring of the same size, which is movable (sañcārin) at the point where the moon’s node (sampāta) is situated and arrange it in such way that to the north of that [node] at its ninetieth degree there is an interval of four and half degrees between it and the ecliptic ring (apakrama-maṇḍala); he should join [it] at the degree of the node (pāta-bhāga) at an interval of half a circle.

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14The word “sañcārin” (movable) means that this ring representing the moon’s orbit should not be fixed firmly in the structure like the ecliptic ring, because the intersection of this ring and the ecliptic ring, which is called “pāta” (the moon’s node), is moving constantly along the ecliptic ring. According to आहि 1.3c, the moon’s node performs 232226 revolutions in a yuga, that is to say, one revolution in 18.6 years. But Bhāskara does not explain how to make this ring “movable.”
Figure for ¶ 12: Orbit of the moon (vimandala).

In the same manner, he should arrange [the ring] to the south of that [node] at its ninetieth degree so that there is an interval of four and half degrees between it and the ecliptic ring.”

[¶ 12] एवं तद्विमण्डलम, तदेव विक्षेपमण्डलमितुच्यते। व्यवन्यामिप स्वेभ्यः स्वेभ्यः पात-भागेयापि मण्डलाम्। वृषशुबयोः शीयोऽत्मा। (ll. 17–20, p. 241)

“Thus it is the orbit [of the moon] (vimandala); it is also called the circle of deflection (viksepa-mandala).” Likewise, rings should be inserted for other [planets] at their own degrees of nodes. In the case of Mercury and Venus, [the orbit circles are made] according to their śīghroccas.”

[¶ 13] व्यवन्यामिप स्वेभ्याम् --- विक्षेप उत्तरेण मेषापकाकाकुल्तानात्त्वां पूर्वप्रायान्त मण्डलं मेषवाहोरात्रामण्डलं, वृशचाफकाकाकुल्तानात्त्वां वृष्टाय, मित्रानाफकाकाकुल्तानात्त्वां मित्राय, तान्त्रिकक्तमेण कृतेकसिंहक्षानाम्; एवं [विक्षेपो] दृष्टिनेन तुवावृहिंस्कदुर्गुणा स्वाहोरात्रामण्डलाम्, तान्त्रिकक्तमेण मकरकुमनीनानाम। (ll. 20–24, p. 241)

“[All] the day circles (svāhorātra-mandala) are also movable (sañcārin). From the equator (visuvat) towards the north at a distance equal to the arc on the declination circle (apakrama-kāśtha) for Aries (meṣa), a ring [should be added to the ecliptic ring] with stretches in the east-west direction (pūrvāparāyata); it is the day

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15 Or the latitude circle in modern astronomy.
16 In the case of inner planets (i.e., Mercury and Venus), their śīghroccas (i.e., apex of fastest motion) are regarded as the planets’ mean heliocentric positions.
circle of Aries. At a distance equal to the arc on the declination circle that ends in Taurus (वृष), [a ring should be added to the ecliptic ring], it is [the day circle] of Taurus. At a distance equal to the declination arc that ends in Gemini (मिथुन), [a ring should be added to the ecliptic ring], it is [the day circle] of Gemini. The same [rings] belong also to Cancer (कर्कश), Leo (शिव) and Virgo (कृष्ण) in the reverse order (उत्क्रमं). In the same manner, the day circles of Libra (तुला), Scorpio (वृष्क) and Sagittarius (धनु) should be added towards the south [of the equator]. [The same rings belong also to] Capricorn (मकर), Aquarius (कुंभ) and Pisces (मिन) in the reverse order.”

“One should tie (बाद्हनियात) on the day circles threads which stretch in the south-north direction. Their halves are the [half-]chords of the declination (अपक्रमाज्या). He should tie one end of the thread at the intersection of the six o’clock circle (उन्मण्डला) and the day circle of Aries, and another end at the intersection of the six o’clock circle and the day circle of Pisces. He should tie the thread which passes through the middle of the earth (भूमध्यावध्यान) to the equator.
Where it intersects with the first thread, there is the mid-point (*ardha*) of the first thread. In the same manner, the halves of the other threads are determined. They are all the chords of declination of the day circles. Because it is impossible [to tie threads at all the necessary points], they are shown only at certain places (*kvacit tu*). These orbit [of the moon], ecliptic and day circles (*vikṣepāpakrama-svāhorātramaṇḍalāni*), which have been commented upon, are not [all] shown [in this armillary sphere]. Otherwise, it would not be possible to rotate the armillary sphere according to time due to the abundance of the rings.”

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17 The intersection of the six o’clock circle, which is identical with the horizon in Figure 14, and the day circle of Aries is marked $A$, the other intersection of the six o’clock circle and the day circle of Pisces is $B$. The intersection of the red thread $AB$ and the thread which passes through the middle of the earth to the equator (not shown in Figure for ¶ 14) is $C$. Therefore $AC$ is the chord of declination of the day circles of Aries while $BC$ is the chord of Pisces.

18 In the commentary on the *abh 4.3*.

19 Because the orbits of the moon and other planets and the day circles are said to be movable (*sañcārin*), they are not drawn in the figures in where those circles are not necessary.

20 Bhāskara does not mention how the armillary sphere can be made to rotate according to time. We assume that he might have used a self-rotating device same as Āryabhata’s self-rotating globe, for which see Ōhashi 1994: 260.
Figure 15: Axis with the earth at the center.

“Then he should insert a very smooth and straight iron rod (āyāḥśalākā) which is capable of bearing the weight of the shell of rings (pañjara), whose [two ends are] oval like the cow’s tail (gopucchāyatavṛttā)\(^{21}\) and which pierces through the intersections at the south and the north in such a way that its extremities (agra) project out on both sides. In the middle of it (i.e., the rod) make a spherical ball (samavṛttā) of clay or of any other [material to represent] as the earth. Thus, only one shell of rings is [enough] for all the planets. Although the planets are situated in different orbits, they are indeed seen as moving on a single orbit. Therefore only one shell of rings is [enough] here. Or, shells have to be shown separately (prīthak prīthak) for [each of] all the planets according to the size (pramāṇa) of their own different orbits (paricchinna-svakakṣyā).

\(^{21}\)It is not clear why the rod here is described as a oval like a cow’s tail. We imagine that the two ends of the rod are made swollen so that they can prevent the shell from slipping off.
Or one should firmly attach a three or four angula’s long smooth stalk of reed (śara-daṇḍikā) to the iron rod [projecting] out of the two intersections of the shell of rings. Then taking [a ring] of an appropriate dimension representing the orbit of the sky (kha-kakṣyā), a ring in which [two] holes are made at distances equal to half the circumference (cakrārdhāntara) on both sides, one should place it in the south-north direction (dakṣiṇottarāvagāhin, lit., passing through the south and north [points]), and set the shell inside it by inserting the iron rod into the holes on both sides, so that that stalk of reed is embedded (avagāhin) in the boundary (i.e., interstice) of the two shells [along the iron rod]."

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22The stalk of reed (śara, (Saccharum sara, Roxb.)) extends the length of the iron axis beyond the original shell on both sides. This addition is made in order to prevent the inner shell from shifting along the axis. This stalk of reed is hollow and smooth like a tube, so it would not hinder the spin of the axis.
This is a figure illustrating the setup of a gola (armillary sphere) on the terrestrial equator. The diagram shows a view of the sphere with labels for sama-mandala and kṣitija-mandala, indicating the prime vertical or east-west ring and the horizon ring, respectively. A text figure is also present, showing a rotating sphere with labels for different parts of the setup.

**Figure for ¶ 17: Gola set for use on the terrestrial equator.**

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### ¶ 17

Figure for ¶ 17: Gola set for use on the terrestrial equator.

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[¶ 17] तावात्मणंमवाण्यवर्तम पूवापाभाणुपर्वत अधेश जनितवतिक्तव पूवुन्न निद्ध्यात्।
तत्सममण्डलम्। पुनरेषि तावदेववाण्यमण्डलम परिकरवत्त दिक्तुगजम्बितवतिक्तव दक्षिणावस्थ:-
समासप्तवतुःबधाभुमभवत तोहाशालकाँ प्रवेशादयं निद्ध्यात्। नित्यवतिगणमण्डलम्।
एवमयं गोलो विषणस्वति सम एवावतितंत्रे। (ll. 19–23, p. 242)
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One should affix as before another ring having the same size, which is embedded in the east and west directions, and in which intersections are made above and below. This is the prime vertical or east-west ring (sama-mandala, literally “equal[izing] circle”). Again, one should affix another ring of the same size like a girdle [around the two rings] so that four intersections are produced in each cardinal direction, make holes at the points of the intersection in the south and north, insert the iron rod into them and then make [the third ring] firm. This is the horizon ring (ksitija-mandala). In this way, this armillary sphere (gola) is set horizontally [in the case of a locality] on the [terrestrial] equator.

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### ¶ 18

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[¶ 18] विषणतः उससर्षण वाणावतसतवत्सक भागेशु खगोलान्तरस्वरतिकादपि वेष निन्येत।
दक्षिणात्त तावदेववाणात्तर अपित वेष।। पूवापाभाणुपर्वत काणां निकाय रत्नदेवाशामाणणः
परिकर्तितवतज्ञोऽवितावतल। प्रवेशादयं। एव व्यविष्क्रियमणावरित्वातः गोलः। तत्सर्षेव सिद्धिष्यत्त्।
(ll. 23–25, p. 242, and 1. 1, p. 243)
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One should have a hole made above the northern intersection of the sphere of the sky (khagola) by so many degrees as the [local] latitude is to the north of the equator; also one should make a hole in the south at the same interval [from
the southern intersection]. One should remove the iron rod from the two holes made before, and insert it into the two holes which are made according to the degrees of the local latitude (svadesākṣa). In this manner, the armillary sphere is now correctly adjusted to the degrees of the local latitude. On this [armillary sphere] one should demonstrate everything.”

“Now, one should insert another ring of the same dimension as the sphere of the sky, which has [two] holes on both sides at intervals of half the circumference, in such a way that the tip of the iron rod goes out of [the hole in] the north. One should insert [the same ring] in such a way that the other tip of the iron rod might go out of the other hole in the south. Having inserted it there firmly, he should make that ring firm at the east and west intersections by the oblique kind [of cutting] (tiryagbheda) at its two intersections of the joints on the east and west, as before. It is called the six o’clock ring (unmaṇḍala). All these rings should be made marked with 360 divisions.”

“Now, one should insert another ring of the same dimension as the sphere of the sky, which has [two] holes on both sides at intervals of half the circumference, in such a way that the tip of the iron rod goes out of [the hole in] the north. One should insert [the same ring] in such a way that the other tip of the iron rod might go out of the other hole in the south. Having inserted it there firmly, he should make that ring firm at the east and west intersections by the oblique kind [of cutting] (tiryagbheda) at its two intersections of the joints on the east and west, as before. It is called the six o’clock ring (unmaṇḍala). All these rings should be made marked with 360 divisions.”

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“On the other hand, some people dig a hole in the level ground according to half the size of the sphere of the sky. Then they place the sphere of the sky there in such a way that its [lower] half is sunk [in the pit] so that the [entire] horizon ring (ksitiya-maṇḍala) might be above [the ground level]; [with this arrangement,] they make demonstrations.”

“Thus this wooden armillary sphere is made. If wood is not available, then the armillary sphere can also be made with the rings of smooth pieces (śalākā) of [split] bamboo (vaṃśa) which has a narrow hollow channel (suṣira) inside and which is completely dry (paripakva). After [explaining how to] construct the armillary sphere in this manner, all the rest will be explained in [the commentary on] the text [of the Āryabhaṭīya].”

3. CONCLUSION

In the preceding section we have followed Bhāskara’s own words. I would like to add a few words on his method of constructing armillary sphere. The armillary sphere consists of two concentric shells with a clay terrestrial globe at the centre; the iron axis passes through the centres of all the three. The later writers call the
inner shell “sphere of stars” (*bhagola* or *nakṣatragola*) and the outer shell “sphere of the sky” (*khagola*).

As mentioned in ¶ 2, Bhāskara regards the armillary sphere as a fictitious construction to understand the real celestial sphere. Already at the beginning of the commentary he states: “the armillary sphere (*gola*) is a means (*upāya*) to demonstrate the revolution of the planets and the situation of the earth.”

23  somewhat later, while commenting on *Āryabhaṭīya* 1.10, he asserts that,

the armillary sphere (*gola*) is a shell of stars (*bhapañjara*), in which the motion of the planets is understood because the armillary sphere (*gola*) is a tool for the perception (*pratipatti-hetu*) of the true motion of the planets.\(^{24}\)

But besides measuring the chords of declination of the day circles by threads, Bhāskara does not mention other uses of the armillary sphere, whereas Lalla

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\(^{23}\)BAB 1.1: गोलं महॅमणधिरऽीसंनोपायम्। Shukla 1976: 6.

\(^{24}\)BAB 1.10: भपरो गोलः, तिोले तहचिरतं अवग, महाणं स्मुटम: प्रतिपतितत्वत्तुत्तमैं गोलः। Shukla 1976: 42.
teaches how to determine time and the lagna (the point of sunrise on the east horizon) with the armillary sphere.\textsuperscript{25}

Moreover, Bhāskara does not explain clearly how to add the “vimaṇḍala” or the orbit rings of Mercury and Venus according to their śīghrocca scales. Since these two are inferior planets which always appear near the sun, the rings of their orbits are not like those of the moon or of the other planets, which are akin to the ecliptic ring. The rings of the orbits of Mercury and Venus ought to be smaller and added to the armillary sphere as shown in the Figure above. But if they are so added, they would hinder the rotation of the rings in the inner shell of the armillary sphere.

\textsuperscript{25}See Ōhashi 1994: 269.
ABBREVIATIONS

**ABH**  Āryabhaṭīya (Shukla, 1976)

**BAB**  Bhāskara’s commentary on the Āryabhaṭīya (ibid.).

**BSS**  Brāhmaspuṭasiddhānta (Ikeyama, 2003).

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