Body and Cosmos

Studies in Early Indian Medical and Astral Sciences in Honor of Kenneth G. Zysk

Edited by

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CHAPTER 14

The Size of the Universe in Indian Astronomy

Michio Yano

1 Āryabhaṭa's Cosmology*

In *Āryabhaṭīya* 3.15–6, Āryabhaṭa says:

> *bhānām adhaḥ śanaiścarasuragurubhaumārkaśukrabudhacandrāḥ* |
> *teṣām adhaś ca bhūmir medhībhūtā khamadhyasthā* || 15
> *saptaite horeśāḥ śanaiścarādyā yathākramaṃ śīghraḥ* |
> *śīghrakramāc caturthā bhavanti sūryodayād dinapāḥ* || 16
>
> Below the asterisms are Saturn, Jupiter, Mars, the sun, Venus, Mercury, and the moon. Below them is the earth that stays in the middle of the sky like a central pillar (of everything).
>
> These seven are the Lords of hours, beginning with Saturn, in the order of [increasing] speed. The [every] fourth from this order of speed are the Lords of the days [which begin] from sunrise.

In order to get the order of planetary weekdays, the seven planets must be arranged in the order prescribed here by Āryabhaṭa. This order presupposed that the concentric orbs of the planets were below the sphere of asterisms. In Greek cosmology, the idea of concentric spheres was first conceived by Eudoxus, then supported by Aristotle, and it continued to be the main cosmography until the time of Copernicus. However, it took a long time before the order of the planets was fixed around the beginning of the first millennium. The order was established shortly before Ptolemy (ca. 150 CE), but he says nothing about the weekday, even in his book on astrology, *Tetrabiblos*. Ārybabhaṭa associated this order with the angular velocity of the planets, Saturn being the slowest and the moon the fastest. The linear speeds of all the planets were considered to be the same (see below). When we count every fourth planet thus

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arranged, we get the order of weekdays beginning with Saturday. This is because the seven planetary gods, beginning with Saturn, are assigned as the Lord of 24 hours (*horeśa*), and the Lord of the first hour of the day is also the Lord of the day (*dinapa*).

The weekday became one of the most important elements in Indian astrology after the introduction of Hellenistic astronomy and astrology. In Sanskrit astronomical texts, planets are always enumerated and described in the order of the weekdays. Thus, when they say "those beginning with Mars" (*bhaumādi*), they mean the five star-planets in the order of the weekdays.

The size of the sky is well defined by Āryabhaṭa. The basic size is that of the moon's orbit. In *Āryabhaṭīya* 1.6 he says:

> *śaśirāśayaṣ ṭha cakraṃ te aṃśakalāyojanāni yavañaguṇāḥ* |
> *prāṇenaiti kalāṃ bhaṃ khayugāṃśe grahajavo bhavāṃśe 'rkaḥ* || 6
>
> A circle multiplied by 12 is the moon's signs. These multiplied by 30, 60, 10 are [respectively,] degrees, minutes, and *yojana*s. The earth[1] moves one minute in one *prāṇa*. The circumference of the sky [in *yojana*s] divided by the rotations of a planet in a *yuga* is the [orbit of the] planet's motion.[2] The [orbit of the] sun is a sixtieth part of the circumference of the asterism.

This verse is better understood with *Āryabhaṭīya* 3.12:

> *śaṣṭyā sūryābdānāṃ prapūrayanti grahā bhapariṇāham* |
> *divyena nabhaḥparidhiṃ samaṃ bhramantas svakakṣyāsu* || 12
>
> By sixty solar years planets fulfill the circumference of the asterism. Revolving equally in their own orbits, they [fulfill] the circumference of the sky by one divine [year].

First of all, the circumference of the lunar orbit (C_m) is $12 \times 30 \times 60 \times 10 = 216{,}000$ *yojana*s. The moon's sidereal rotations in a *yuga* (R_m) are 57,753,336. Therefore, the moon travels $C_m \times R_m = 12{,}474{,}720{,}576{,}000$ *yojana*s in a *yuga* consisting of 4,320,000 human years (called "one divine [year]" in 3.12). This is also the cir-

1 Our text reads *bhaṃ* ("asterism") but in Brahmagupta's quotation (BSS 11.17) of this verse he reads *bhūḥ* ("earth"). This is one piece of evidence supporting Āryabhaṭa's theory of the rotation of the earth.

2 I followed Shukla's 1976 translation when translating *grahajava*.

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TABLE 14.1 Circumference and distance of the planets in *yojana*s according to Āryabhaṭa

	R_i	C_i	Distance
Moon	57,753,336	216,000	34,377
Mercury	17,937,020	695,473	110,688
Venus	7,022,388	1,776,421	282,726
Sun	4,320,000	2,887,667	459,585
Mars	2,296,824	5,431,292	864,415
Jupiter	364,224	34,250,133	5,451,065
Saturn	146,564	85,114,493	13,546,361
Asterism	72,000	173,260,008	27,575,122
Sky (C_k)		12,474,720,576,000	

cumference of the sky (C_k) (*nabhaḥparidhi*) in *yojana*s. It is presupposed that all the planets travel the same linear distance in a *yuga*. In other words, $C_i \times R_i = C_k$ is constant. Since the number of civil days in a *yuga* is 1,577,917,500 according to Āryabhaṭa's school (Āryapakṣa), the constant daily motion in *yojana*s of all the planets is 12,474,720,576,000/1,577,917,500 = 7,905.

Thus, for example, in the case of the sun, whose rotations in a *yuga* are 4,320,000, its circumference (C_s) is C_k/R_s = 2,887,666 4/5 *yojana*s. This means that the distance of the sun from the earth is $C_s/2\pi \approx$ 459,585 *yojana*s (with Āryabhaṭa's value of π = 62832/20000 = 3.1416).

In table 14.1 I have shown the rotations of planets in a *yuga* (R_i) according to Āryabhaṭa, the resulting circumference (C_i, rounded) of their orbits, and their distance ($C_i/2\pi$) from the earth. These are remarkably different from the "distances" of planets in the Purāṇas which are shown in table 14.2.[3]

According to Āryabhaṭa, the radius of the earth is 1,050/2 = 525 *yojana*s (*Āryabhaṭīya* 1.7). Therefore, using the radius of the earth (r_e) as a unit, we can express the distance of the moon as 34,377/525=65.48 r_e and that of the sun as 459,585/525= 875.4 r_e. The circumference of the sphere of the asterisms (*bhapariṇāha*) is 60 times that of the sun (cf. *Āryabhaṭīya* 1.6 and 3.12 above) (i.e., 173,260,008 *yojana*s). This means that the distance of the fixed stars from the earth is 173,260,008/2π = 27,575,122 *yojana*s = 52,524 r_e.

3 See Willibald Kirfel, *Die Kosmographie der Inder nach Quellen dargestellt* (Hildesheim-Zurich-New York: Georg Olms Verlag, 1990): 128.

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TABLE 14.2 Distance of the planets in *yojana*s according to the Purāṇas

Sun	10,000
Moon	20,000
Asterism	30,000
Mercury	50,000
Venus	700,000
Mars	900,000
Jupiter	1,100,000
Saturn	1,300,000
Saptarṣi	1,400,000
Pole Star	1,500,000

TABLE 14.3 Distances from the earth in r_e

	Moon	**Sun**	**Asterism**
Ptolemy	48	1,210	20,000
Āryabhaṭa	65.48	875.4	52,524

Now we can compare the Indian numbers with those given, for example, by Ptolemy (table 14.3). According to his *Planetary Hypothesis*,[4] the mean distance of the moon from the earth in the unit of the earth's radius (r_e) is 48. The mean distance of the sun is 1,210 r_e, and that of the fixed stars of the first magnitude is 20,000 r_e. These are not much different from the Indian values mentioned above. The only difference is that in Greek cosmology nothing seems to be beyond the sphere of the asterism, while in India they wanted to keep the huge size of the sky (*ākāśa* or *kha*) as the dwelling place of Brahman.

Bhāskara I (fl. 629 CE), the earliest commentator of the *Āryabhaṭīya*, thought that the sky (*ākāśa*) is limitless (*aparimita*) but that one can put a boundary on it. Commenting on *Āryabhaṭīya* 1.6, he says:

4 See Bernard R. Goldstein, "The Arabic Version of Ptolemy's Planetary Hypotheses," *Transactions of the American Philosophical Society, New Series* 57, no. 4 (1967): 11, Table I, and Otto Neugebauer, *History of Ancient Mathematical Astronomy* (Springer-Verlag: 1975), 922, Table 26.

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> As far the place of the sky that the rays of the sun illuminate entirely, so far is the place of the circumference of the globe of the sky (*khagola*), [namely] the orb of the sky (*khakakṣyā*). Otherwise, since the sky is limitless, telling the size of the sky is not appropriate.[5]

Āryabhaṭa declares at the end of the first chapter of the *Āryabhaṭīya* (1.13):

> *daśagītikasūtram idaṃ bhūgrahacaritaṃ bhapañjare jñātvā |*
> *grahabhagaṇaparibhramaṇaṃ sa yāti bhittvā paraṃ brahma* || 13
>
> One who knows the aphorism of [the chapter called] *Daśagītikā* (consisting of ten Gīti meter verses) on the motion of the earth and the planets in the cage of the asterisms, after breaking through the passage of the planets and asterisms, arrives at the highest Brahman.

As mentioned above, the diameter of the earth is only 1,050 *yojana*s according to Āryabhaṭa. *Yojana* is a unit of length that is most commonly used in astronomical texts as well as in Purāṇas. Āryabhaṭa defines it saying "a *yojana* is 8,000 *puruṣa*s."[6] The *puruṣa* (here *nṛ* means "man") is a unit of length that was used since the time of the Śulbasūtras, manuals for constructing sacrificial altars. Its length is measured from the tip of the extended hands of a standing man, for whom the sacrifice is performed, to the ground. It depends on the person, but let us assume that a *puruṣa* is about 1.8 m. Then, one *yojana* is about 14.4 km. Thus, Āryabhaṭa's diameter of the earth would be about 15,120 (1,050×14.4) km, which is not much different from the modern value (12,756 km). Such a small size for the earth was very much contradictory to the cosmology of the Purāṇas. Thus, when commenting on *Āryabhaṭīya* 1.7, Bhāskara I rejects the Purāṇic point of view.

Since the size of the earth is very close to reality, the mountains on it should also be also close to reality. Thus, Āryabhaṭa says that Mt. Meru is only one *yojana* high[7] on two occasions, namely, *Āryabhaṭīya* 1.7 and 4.11.[8] Stating the

5 *yāvantam ākāśapradeśṃ raver mayūkhāḥ samantād dyotayanti tāvān pradeśḥ khagolasya paridhiḥ, khakakṣyā. anyathā hi aparimitatvād ākāśasya parimānākhyānaṃ na upapadyate.* (translation of Shukla, 26–7).

6 *Āryabhaṭīya* 1.7a: *nṛṣi yojanaṃ*.

7 This is less than two times the height of the highest mountains in the Himalayas.

8 *Āryabhaṭīya* 1.7b: *ka meroḥ*, "(The height of) Meru is one *yojana*." *Āryabhaṭīya* 4.11: *meruḥ yojanamātraḥ*, "Meru is only one *yojana*." Mt. Meru was thought to be spherical in Āryabhaṭa's school.

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same import twice is very exceptional in Sanskrit verse texts, and Āryabhaṭa in particular was greatly concerned with the brevity of expression.[9] He probably wanted to stress the inevitable difference from the traditional view.

In Purāṇic cosmography, the height of the cosmic mountain Meru is 84,000 *yojana*s above and 16,000 *yojana*s below the earth.[10] Followers of Āryabhaṭa should have been seriously concerned with the difference between the cosmography of the Purāṇas and that of mathematical astronomy. Bhāskara I was the first defender of Āryabhaṭa's view. In his commentary on *Āryabhaṭīya* 1.7 he says, "I will explain it (later) in the commentary on (the verse) beginning with 'Meru is only one *yojana*'" (*Āryabhaṭīya* 4.11). Unfortunately, all the manuscripts of Bhāskara I's commentary break off toward the end of *Āryabhaṭīya* 4.6. But we have Someśvara's commentary (eleventh–twelfth century CE), which is a kind of summary of Bhākara I's text. Commenting on *Āryabhaṭīya* 4.11, Someśvara says:

> Meru is said to be of the size of 100,000 *yojana*s by those who believe in Purāṇas. This is devoid of reason. [From Laṅkā to the center of Meru there are not even 1,000 *yojana*s].[11]

Further he adds:

> Further, if Meru is of a big size the stars north of Meru can't be seen because they are blocked by the summit of Meru.[12]

Āryabhaṭa does not say how he calculated the diameter of the earth, but Bhāskara I, commenting on *Āryabhaṭīya* 1.7, gives two methods. One is by "the elevation of the pole" (*akṣonnati*), namely, the geographical latitude. He discusses the actual distance in *yojana*s between Laṅkā, Kanyakumārī, and Ujjayinī. They were regarded as on the same meridian, and the differences in

9 Michio Yano, "Oral and Written Transmission of Exact Sciences in Sanskrit," *Journal of Indian Philosophy* 34, no. 1–2 (2006): 147.

10 For example, *Agnipurāṇa* 108.3, *Viṣṇupurāṇa* (202.8 in the e-text; translation of Wilson, 116), and *Varāhapurāṇa* 75.54. See Kirfel, *Die Kosmographie der Inder*, 93.

11 *atha paurāṇikair lakṣayojanapramāṇo meruḥ paṭhyate tad yuktirahitam/* [*laṅkāto yāvad merumadhyaṃ tāvad yojanasahasram api na ast*]. The part in the square brackets is supplied in Shukla's text and translation. A similar argument is given in Bhāskara I's commentary on *Āryabhaṭīya* 1.7.

12 *kiṃ ca yadi mahāpramāṇo meruḥ syād meruśikharāntaritatvād bhāvād uttareṇa tārakā na dṛśyeran* (translation of Shukla, 262).

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their geographical latitudes were known by the altitude of the north pole. This method should have been the same as that of Eratostenes.[13]

The other method is by “mathematical computation” (*gaṇita*).[14] According to Bhāskara I, the maximum longitudinal parallax (π_{max}) of the moon is 52′30″. The mean distance of the moon (ρ_m) from the earth is 34,377 *yojana*s (table 14.1). The radius of the earth (r_e) is obtained by: $r_e = \sin \pi_{max} \times \rho_m = \sin 52'30'' \times 34{,}377 = 525$. Therefore, the diameter of the earth is 1,050 *yojana*s.

In this way, Indian astronomers had to reduce the size of the earth as well as that of Mt. Meru to an extreme degree.

On the other hand, they wanted to keep, or even increase, the huge size of the sky or Brahman's world. Of course, there is no astronomical problem whichever size the sky or heaven may be. Brahman's world is sometimes referred to as the Brahmāṇḍa, or the Egg of Brahman, in the traditional cosmography.[15] Astronomers also use this word.

2 Brahmagupta

In his *Brāhmasphuṭasiddhānta*, composed in 628 CE, Brahmagupta (b. 598 CE) gives the number of rotations of planets in a *kalpa* consisting of 4,320,000,000 years,[16] which is 1,000 times that of a *yuga*. The rotations of the moon in a *kalpa* is R_m=57,753,300,000.[17]

Moreover, he says (*Brāhmasphuṭasiddhānta* 21.11):

> *ambarayojanaparidhiḥ śaśibhagaṇāḥ śūnyakhakhajināgniguṇāḥ* |
> *yasya bhagaṇair vibhaktās tatkakṣā'rko bhaṣaṣṭyaṃśaḥ* || 11
>
> The rotations of the moon (in a *kalpa*) multiplied by 324,000 is the circumference of the sky in *yojana*s. When it is divided by the rotations of a planet, [the result is] the orbit (*kakṣā*) of the planet. The [orbit of the] sun is one sixtieth of [that of] the asterism.

13 Neugebauer, *History of Ancient Mathematical Astronomy*, 652 ff.
14 Bhāskara I and *Āryabhaṭīya* 1.7 (translation of Shukla, 29): *bhūvyāsaḥ gaṇitenāpi ānetuṃ śakyate*, “The diameter of the earth can be obtained by mathematical computation, too.”
15 For example, *Sūryasiddhānta*, 12.29.
16 *Brāhmasphuṭasiddhānta* 1.15–24.
17 *Brāhmasphuṭasiddhānta* 1.16.

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He thought that one minute of the moon's orbit is 15 *yojana*s. Thus, the moon's orbit C_m is $360 \times 60 \times 15 = 324{,}000$ *yojana*s. Accordingly, the circumference of the sky (*ambara*) became $C_k = R_m \times C_m = 18{,}712{,}069{,}200{,}000{,}000$ *yojana*s, which is about 1,500 times that of Āryabhaṭa. This number is found in the *Paitāmahasiddhānta* of the *Viṣṇudharmottarapurāṇa* 3.5.[18] The same number is called the "*yojana*s of the circumference of the orbit of the sky"[19] in Pṛthūdakasvāmin's commentary on the *Brāhmasphuṭasiddhānta*.

With the modern value of π,[20] the radius of the cosmic sphere, or the distance from the earth to the end of the sky, according to Brahmagupta, is $C_k/2\pi$ = 2,978,111,344,537,815 *yojana*s = 42,884,803,361,344,536 km.[21]

The *Sūryasiddhānta* (SS 1.30) gives a slightly different number of rotations of the moon in a *kalpa*: R_m = 57,753,336,000. The moon's orbital circumference is 324,000 *yojana*s. Thus, C_k = 18,712,080,864,000,000 *yojana*s.[22]

3 Al-Bīrūnī

Al-Bīrūnī (973–1050 CE),[23] referring to Brahmagupta, says that "the number of the *yojana* of the sphere of zodiac"[24] is 18,712,069,200,000,000. On another

18 Pingree, "The *Paitāmahasiddhānta* of the *Viṣṇudharmottarapurāṇa*," *Adyar Library Bulletin* 31–32 (1967–1968) offers an English translation based on the text published by P.V. Dvivedin. He introduced new numbering of chapters 3–9 which correspond to chapters 168–174 of the second *khaṇḍa* of the *Viṣṇudharmottarapurāṇa*. The relevant part of the latter (printed by Nag publishers) is very corrupt. Pingree argues that the *Paitāmahasiddhānta* is dated at about 450 CE and that it is the oldest text of the Brāhmapakṣa; therefore, it must predate Brahmagupta. But his argument is not very convincing. There is some evidence that the *Viṣṇudharmottarapurāṇa*, or at least some parts of it, is posterior to Āryabhaṭa.

19 *khakakṣāparidhiyojana*. Cf. Setsuro Ikeyama, "*Brāhmasphuṭasiddhānta* (ch. 21) of Brahmagupta with Commentary of Pṛthūdaka, Critically Edited with English Translation and Notes," *Indian Journal of History of Science* 38, nos. 1–4 (2003): S184 and S185. Here *kakṣā* (orbit) is the same as *kakṣyā*.

20 Brahmagupta uses $\sqrt{10}$ as the value of π.

21 For the sake of comparison, I expressed the size of the sky according to the modern understanding. Brahmagupta's distance would be about 4,532 light years, one light year being 460,730,472,580.8 km.

22 This number is given in Kirfel, *Die Kosmographie der Inder*, 173.

23 See Michio Yano, "al-Bīrūnī," in *The Encyclopedia of Islam Three*, eds. Gudrun Krämer, Denis Matringe, John Nawas, and Everett Rowson (Leiden and Boston: Brill, 2013), 50–56.

24 See al-Bīrūnī's *Kitāb fī taḥqīq mā li-l-Hind*: Eduard Sachau's English translation, I.224; Arabic text in Sachau's edition, 110; Hyderabad edition, 183.

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occasion, he says "Brahmagupta calls this number the *yojana*s of the ecliptic."[25] In the next paragraph he refers to the view of a "Pulisa" whose reckoning is based on *yuga*s instead of *kalpa*s. Thus, the product of the lunar orbit and the moon's rotations in a *yuga* is 18,712,080,864,000, exactly one thousandth of the *Sūryasiddhānta*'s number. He calls this "*yojana*s of heaven."[26]

It seems that al-Bīrūnī was impressed by the huge size of the heavens in Indian astronomy, especially since he was extremely familiar with the moderate size of the heavens in Greek astronomy.

In this context, it would be interesting to hear al-Bīrūnī's words:

> Brahmagupta says in the first chapter[27] of the *Brahma-siddhānta*, where he enumerates the heavens, placing the moon in the nearest heaven, the other planets in the following ones, and Saturn in the seventh: "The fixed stars are in the eighth heaven, and this has been created round in order to last for ever, that in it the pious may be rewarded, the wicked be punished, since there is nothing behind it." He indicates in this chapter that the heavens are identical with the spheres, and he gives them in an order which differs from that of the traditional literature of their creed, as we shall show hereafter in the proper place. He indicates, too, that the *round* can only be slowly influenced from without. He evinces his knowledge of the Aristotelic notions regarding the round form and the rotating motion, and that there is no body in existence behind the spheres.[28]

I cannot find any of Brahmagupta's words that correspond to al-Bīrūnī's quotation. What he meant by "heavens" is probably *kakṣā*s. *Kakṣā* also means the "orbit" of the planets and can be used in plural form. We have another word, *kha*, for heaven that is always used in the singular form and designates empty space. The "fixed stars" are *bha*s or *nakṣatra*s. Anyway, it is interesting to hear from him that "the heavens" are identical with "the spheres." More interesting is that al-Bīrūnī thought there was an Aristotelian origin to the Indian concept of a circular sky.

25 See al-Bīrūnī's *Kitāb fī taḥqīq mā li-l-Hind*: Eduard Sachau's English translation, II.71; Arabic text in Sachau's edition, 236; Hyderabad edition, 402.

26 See al-Bīrūnī's *Kitāb fī taḥqīq mā li-l-Hind*: Eduard Sachau's English translation, II.72; Arabic text in Sachau's edition, 237; Hyderabad edition, 404.

27 What al-Bīrūnī means by the "first chapter" is chapter 21 (*Golādhyā*) of the modern editions. See Ikeyama, "*Brāhmasphuṭasiddhānta* (ch. 21) of Brahmagupta."

28 See al-Bīrūnī's *Kitāb fī taḥqīq mā li-l-Hind*: Eduard Sachau's English translation, I.223–224; Arabic text in Sachau's edition, 110, line 4ff.

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The “traditional literature” here means the Purāṇas. In fact, al-Bīrūnī refers to the *Viṣṇupurāna* for the distances of the heavenly bodies, which is exactly the same as table 14.2 above.[29]

4 Survival of Purāṇic and Buddhist Cosmology

In an earlier article[30] I argued that there were five stages of the development of the concept of *graha* as heavenly bodies. The Purāṇic texts belong to the fourth stage, namely, a group of seven or nine *graha*s was established, although the order of enumeration was not yet fixed. This stage is evidenced in table 14.2 above. The relative position of the inferior and superior planets was known, but the sun is closer to the earth than the moon, and the asterisms (*nakṣatra*s) are next to the moon because they are the abode of the moon.

The Purāṇas are of an encyclopedic nature and some of them incorporated new elements of astronomy and astrology that had Hellenistic origins. Still, the older elements were not discarded. The *Viṣṇudharmottarapurāṇa* mentioned above is a typical example. Its date was a little later than Āryabhaṭa and almost contemporary with the establishment of the Buddhist cosmology[31] by Vasubandhu (fl. fourth–fifth century CE) in his *Abhidharmakoṣabhāṣya*. Especially popular among Buddhists was the *Lokaprajñaptyabhidharmaśāstra*, which survived in a Chinese translation (立世阿毘曇論, *Lishiapitanlun*) by Paramārtha (眞諦, Zhendi, 499–569 CE)[32] as well as in a Pali translation, *Lokapaññatti*.[33] The Chinese translation was very popular and extensively used by a Japanese Buddhist Entsu (円通, 1754–1834 CE) when he tried to defend Buddhist cosmology in the *Bukkoku Rekishohen* (仏国暦象編) against the newly introduced Western cosmology in the Edo period.

29 See al-Bīrūnī’s *Kitāb fī taḥqīq mā li-l-Hind*: Eduard Sachau’s English translation, 1.238. Similar numbers are found in the *Vāyupuraṇa* 53.95c–97d, but the text is very corrupt.

30 Michio Yano, “Planet Worship in Ancient India,” in *Studies in the History of the Exact Sciences in Honor of David Pingree*, eds. Charles Burnet et al (Leiden and Boston, 2004), 331–348.

31 For Buddhist cosmology, see Akira Sadakata, *Indo Uchuron Taizen* (Tokyo, 2011).

32 Paramārtha was born in Ujjayinī, the center of astronomy, and he knew about Āryabhaṭa’s theory of the rotation of the earth on its axis, which he refutes. Cf. Sadakata, *Indo Uchuron Taizen*, 243.

33 Takao Hayashi, “On the Chapter on the Measurements of the World in the *Lishiapitanlun*,” *The Science and Engineering Review of Doshisha University* 49, no. 4 (2009): 3–8 and “A Study of the Chapter on the Motions of the Sun and Moon in the *Lishiapitanlun*,” *South Asian Classical Studies* 8 (2013): 1–50.

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