Āryabhaṭa and Axial Rotation of Earth

3. A Brief History

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In this part of the series, we shall give a brief historical account of some of Āryabhaṭa's views on axial rotation of Earth, so that we can see his discoveries in perspective

In the previous parts of the article, we mentioned the following statements on axial rotation of Earth which occur in Āryabhaṭīya ([1]).

1. *In a yuga of 4320000 sidereal years, the Earth rotates eastward 1582237500 times and the Moon 57753336 times.* [Gītikā 3]
2. *The Earth rotates by an angle of one minute of an arc in a prāṇa (4 sidereal seconds).* [Gītikā 6]
3. *The rotation of Earth causes the nakṣatra dina (sidereal days).* [Kālakriyā 5]
4. *Just as a person in a boat moving forward sees the stationary objects as moving backward, just so does an observer at Laṅkā see the fixed stars as moving westward.* [Gola 9]

Part 1. Aryabhata and Axial Rotation of Earth – Khagola (The Celestial Sphere), *Resonance*, Vol.11, No.3, pp.51-68, 2006.
Part 2. Aryabhata and Axial Rotation of Earth – Naksatra Dina (The Sidereal Day), *Resonance*, Vol.11, No.4, pp.56-74, 2006.

The choice of Laṅkā ensured that the observer sees the orbit of a star as a vertical circle from the eastern to the western horizon. We also saw that statement 1 implies that the period of rotation of Earth around its axis is 23 hours 56 minutes 4.1 seconds which is remarkably close to the modern estimate (23h 56m 4.09s). Further it gives an extremely accurate value for the number of rotations of Earth per lunar orbit (27.3964693572) which matches the correct value in 500 CE up to seven decimal digits

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and the correct value in 1604 BCE up to ten decimal digits.

We first briefly discuss the time-scale of 4320000 years in Statement 1. (For more details, see [2] and [3].)

Yuga in Āryabhaṭīya

The 4320000-Year Cycle

The cycle of 4320 thousand years is mentioned in the Mahābhārata and the Manusmṛti. The epic defines a Daiva varṣa ("Year of the Gods") as 360 human (i.e., usual) years; and then introduces four *yugas* – Kṛta (or Satya), Tretā, Dvāpara, Kali – totalling 12,000 Daiva varṣa, i.e., $(360 \times 12000 =)$ 4,320,000 years divided in the ratio 4 : 3 : 2 : 1. Thus, the current Kaliyuga is of duration 432,000 years. The terms Kṛta, Tretā, Dvāpara, Kali are very ancient – they appear even in Vedic literature (like Aitareya and Taittirīya Brāhmaṇa); mention is also made in the Bhāgavata Purāṇa. The 4320000-year cycle was called *mahāyuga* or *caturyuga* and sometimes abbreviated as *yuga*. There were even larger cycles. For instance, 1000 mahāyugas (i.e., 4320 million years) constituted a *kalpa* (also called "A Day of Brahmā").

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Various factors of the enigmatic integer (4320000) too have significances in Indian traditions. For instance, in the Vedic era, the ecliptic was divided into 27 nakṣatras and the Śatapatha Brāhmaṇa mentions the use of 10,800 bricks for the construction of the sacrificial fire-altars. Note that $27 \times 4 = 108$ and $108 \times 4 = 432$.

The attempt to understand the genesis and significance of the figure 4,320,000 has generated several speculations among historians; but the origin of the concept of yuga remains a mysterious riddle. We mention here that in the Purāṇas, terms pertaining to the physical universe are used as symbols for narrating inner psycho-spiritual principles. The psychological and spiritual significances

Aryabhata's estimate "The Earth rotates 1582237500 times in a yuga".

of Purāṇic geography and cosmogony are beyond the scope of this article.

An interesting feature of a certain phase of Indian astronomy, that possibly began with Āryabhaṭa, was the adoption of the Purāṇic cycle of 4,320,000 years. Some of the later astronomers like Brahmagupta (628 CE) and Bhāskara II (1150 CE) used the larger cycle *kalpa* of 4,320,000,000 years! Such large periods – with their mythological nuances – have created misleading impressions about ancient Indian astronomy. As Roger Billard admitted in an article ([4], p.207):

To tell the truth, with such common multiples of revolutions, ⋯ and so huge periods and numbers, the Indian astronomy did look like a pure speculation, a wordy literature displaying astronomical elements of pure fancy.

Thus, at first glance, Āryabhaṭa's estimate "*The Earth rotates 1582237500 times in a yuga*" may appear as a figment of metaphysical imagination. But, as we have seen (in Part 2), it is equivalent to the surprisingly accurate statement: "*The period of rotation of Earth is 23 hours 56 minutes 4.1 seconds*".

Significance of Yuga in Indian Astronomy

It appears that the mahāyuga was conceived by Indian astronomers as a period at the beginning (and end) of

Box 1. Kalpa

In Āryabhaṭa's system (Gītikā 5), 1 Kalpa = 14 Manu and 1 Manu = 72 Mahāyuga.

Thus, Āryabhaṭa defined a kalpa to be $(14 \times 72 =)1008$ mahāyugas.

But the subdivision, followed by most astronomers, is more complicated. Here, 1 Manu = 71 Mahāyuga; and, between two successive manus, there is a *sandhyā* (twilight) period whose duration is same as that of a Kṛtayuga (i.e., $\frac{4}{10}$th of a mahāyuga). 1 kalpa is formed by 14 manus together with the 15 sandhyās (including one before the first manu and one after the last). Thus 1 kalpa $= (14 \times 71 + 15 \times \frac{4}{10} =)1000$ mahāyuga. At present, we are in the Kaliyuga of the 28th Mahāyuga of the 7th Manu (called Vaivasvata Manu) of the Śvetavarāha Kalpa.

Box 2. Time on a Microcosmic Scale

The kalpa of 432×10^7 years shows the ancient Indian penchant for large time periods. The Purānic and astronomy traditions also considered microcosmic time units. In Bhāskara II (1150 CE), a sidereal day is further subdivided (with suggestive terminology) as follows:

1 nakṣatra dina = 30 kṣaṇa (or muhūrta); 1 kṣaṇa = 60 kāla; 1 kāla = 30 kāṣṭhā;

1 kāṣṭhā = 18 nimeṣa; 1 nimeṣa = 30 tatpara; 1 tatpara = 100 truṭi.

Thus, 1 truṭi = $\frac{1}{2916\times10^6}$ of a (sidereal) day, i.e., $\frac{1}{33750}$ of a (sidereal) second.

which all the five visible planets (Mercury, Venus, Mars, Jupiter, Saturn) along with the Sun and the Moon, have zero celestial longitude; that is, all of them are simultaneously on the great circle through the vernal equinox and the pole of the ecliptic. In Gītikā 4, one comes across the hypothesis that, at the beginning of the yuga, all these planets, together with the Sun and the Moon's apogee, were in conjunction at the vernal equinox during sunrise at Laṅkā. Thus the commencement of the yuga (or kalpa) was based on astronomical phenomena pertaining to the positions of the planetary bodies in the sky.

It is likely that the mahāyuga, or the kalpa, was adopted by Indian astronomers as a time-period – necessarily long – in which all known planets (together with the Sun and the Moon) were estimated to execute *integral* numbers of revolutions.

In this context, we recall two features of ancient Indian arithmetic. First, Indians have been comfortable with large numbers right from early Vedic age.[1] As a result, Indian astronomers could effortlessly handle and represent large integers using the ideas of decimal place value and zero.

[1] See, for instance, R C Gupta, World's Longest Lists of Decuple Terms, *Ganita Bharati*, Vol.23, pp.83-90, 2001.

Second, although ancient Indians were proficient in the use of fractions and decimal representation of integers, they do not seem to have conceived of *decimal fractions*

The adoption of a cycle of 4320000 (or its multiples) enabled Indian astronomers to avoid inconvenient fractions; they could express their findings in plain integers (even if large). For instance, instead of saying that a (sidereal solar) year consists of $366\frac{11175}{43200}$ sidereal days, they would rather say that a yuga consists of 1582237500 sidereal days.

– notations like 365.25868. To clarify: they used composite fractions like $\frac{3}{4}$ from the Ṛg-Vedic era, they knew decimal representation of an integer like 75; but they did not think of representing the fraction $\frac{3}{4}$ as 0.75.

The adoption of a cycle of 4320000 (or its multiples) enabled Indian astronomers to avoid inconvenient fractions as well as long expressions involving years, months, days and further subdivisions; they could express their findings in plain integers (even if large). For instance, instead of saying that a (sidereal solar) year consists of $366\frac{11175}{43200}$ sidereal days, or $365\frac{11175}{43200}$ (mean solar) days, or 365 days 6 hours 12 minutes 30 seconds, they would rather say that a yuga consists of 1582237500 sidereal days. Thus, the single integer 1582237500 would represent the cumbrous fraction $365\frac{11175}{43200}$ or the long expression "365 days 6 hours 12 minutes 30 seconds". Recall (Part 2) that in Āryabhaṭa's system of notation, the integer 1582237500 becomes (in Devanāgari script) a five-lettered word "ṅiśibuṇḷṣkhṛ"; the integer 4320000 a two-lettered word "khyughṛ"!

Also recall that time was divided sexagesimally: 1 nakṣatra dina (sidereal day) was divided into 60 nāḍikā (or ghaṭikā); 1 nāḍikā into 60 vināḍikā; 1 vināḍikā into 60 gurvakṣara. The number 4320000, being a multiple of 60^3, was suitable for expressing various estimates in integers. In fact, the number $4320000 = 2^8 \times 3^3 \times 5^4$, being divisible by several of the small numbers (like 2, 3, 4, 5, 6, 8, 9, 10, 12, 15, 16, 18, 20, 24, 25, 27, 30, 60) occurring frequently in astronomy, was particularly convenient.

Thus, while representation of large numbers did not pose any problem, the use of large cycles imparted a flexibility to Indian astronomers. They used such cycles to express (in whole numbers) the rate of motion of the planets and other significant astronomical parameters. (See [5] for details.) Just as one now reduces rounding-off errors by increasing the number of fractional decimal places (i.e., the places to the right of the unit's place – after the dot mark), just so did the ancient Indians increase accuracy of a statement by increasing the reference time interval. For, larger the time-interval, lower the rounding-off error. For instance, from the modern estimate of the duration of a sidereal solar year ([5], p.172), "the number of civil days in a kalpa (1000 mahāyuga)", expressed as *an integer*, turns out to be 1577907487027 which is a more accurate statement than "the number of civil days in a mahāyuga is 1577907487" (the latter obtained by "rounding off" three places from the former).

In Aryabhata's system of notation, the integer 1582237500 becomes (in Devanagari script) a five-lettered word "ṅiśibuṇḷṣkhṛ"; the integer 4320000 a two-lettered word "khyughṛ"!

Some of the later astronomers categorically mentioned that the yuga cycles were introduced in astronomy for convenience. The Kerala astronomer Putumana Somayāji (between 15th and 17th century) clarified in Karaṇa Paddhati (5.15): "The measures of *kalpa* etc. have been conceived by the (ancient) authorities differently, for, it is only the result that counts, not the means." ([2], p.79). The astronomers also emphasised that, irrespective of the concepts adopted, the computed results should agree with observations. In a future article, we plan to highlight the Indian astronomers' concern for accuracy and stress on periodic observations and updating of the parameters.

Billard believed that it was Āryabhaṭa who introduced the 4320000-year cycle in Indian astronomy ([4], p.222):

Not only did Āryabhaṭa construct yuga upon such beautiful reductions of observations, but I must add that almost certainly the great astronomer is also responsible for the very introduction of the yuga speculation into mathematical astronomy.

In an earlier article (*Resonance*, Vol.7, No.10, pp.10–22, 2002), we had discussed Āryabhaṭa's ingenious technique (Gaṇita 32, 33) for finding *integer* solutions of

Aryabhata's ingenious technique (Ganita 32, 33) for finding *integer* solutions of simultaneous linear indeterminate equations of first degree (called kuttaka) was applied by Indian astronomers to various planetary problems (graha-kuttakara).

simultaneous linear indeterminate equations of first degree. This algorithm (called kuṭṭaka) was applied by Indian astronomers to various planetary problems (graha-kuṭṭākāra). It is possible that this theory of linear indeterminate equations (along with data from planetary observations) was used by Āryabhaṭa (or his predecessors) to determine the epoch when all planets were in conjunction.

Axial Rotation in History

Vedic and Purāṇic Literature

Indeed I believe that when in time to come the contributions of Indian and Buddhist thought are really taken in hand from the point of view of natural science, it will be found over and over again that the philosophers of these culture areas have shot their arrows correctly to the spots that the mountaineers of science would reach definitely much later on. [J Needham in 'Within Four Seas' (p.179).]

The Ṛg-Veda contains verses suggesting that the Earth was considered spherical; the Śatapatha Brāhmaṇa describes the Earth as *parimaṇḍala*, i.e., a globe or a sphere.

Box 3. Precession in Ancient Literature

There are indications of the knowledge of precession of equinox in the Vedic Saṁhitā and Brāhmaṇa literatures ([7], p.21; [6], p.12). According to K D Abhyankar ([3], pp.125–127), the phenomenon was described by the revered ancient astronomer Vṛdhha Garga around 500 BCE but his terminology was not understood by later astronomers. Some historians feel that the great Chaldean astronomer Kidinnu (c. 400–330 BCE) was aware of precession.

Precession was discovered in ancient Greece by the great astronomer Hipparchus (190–120 BCE). The phenomenon is mentioned by Indian astronomers Viṣṇucandra and Śrīṣeṇa around 6th century CE and Pṛthūdaka Svāmi around 860 CE. Mañjulācārya (also called Muñjāla) of Ujjayinī was famous in Indian astronomy for his detailed exposition of the topic, with accurate estimate of the rate of precession, in his treatise *Laghumānasa* (932 CE).

Several scholars have pointed out indications in the Ṛg-Veda of axial rotation and heliocentric revolution of Earth. There are passages in the Aitareya Brāhmaṇa, Chāndogya Upaniṣad and the Vishnu Purāṇa mentioning that, in reality, the Sun never rises nor sets.[2] Referring to the passage in Aitaryea Brāhmaṇa, M Monier Williams remarked:

[2] See [6], pp.13–14; [7], pp.5–6, 19–20; [8], p.28; [9], p.178.

We may close the subject of Brāhmaṇas by paying a tribute of respect to the acuteness of the Hindu mind, which seems to have made some shrewd astronomical guesses more than 2000 years before the birth of Copernicus ['Indian Wisdom', p.35].

In the Skanda Purāṇa (I.1.31-71), the Earth is described revolving like a *bhramarikā* or spinning top ([1], p.8). The simile is particularly interesting in view of the phenomenon of precession mentioned in Part 2 (see [3], pp.21-22).

Ancient Greece

In ancient Greece, the heliocentric model had been suggested by Aristarchus (310-230 BCE) of Samos. A less-known fact is that axial rotation of Earth had been suggested by Herakleides (around 350 BCE) of Pontus, a contemporary of Aristotle, and by Ecphantus of the Pythagorean school. But the theory of axial rotation was ignored in Greece and soon forgotten. It was the stationary geocentric model of Aristotle which prevailed in Europe. It was adopted in Ptolemy's Almagest (150 CE) which soon came to be regarded as infallible astronomy for several centuries.

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Post-Vedic Indian Astronomy

Notwithstanding certain incidental, and often cryptic, remarks in the vast mass of the allegorical Vedic and Purāṇic literatures alluding to Earth's motion, the Earth was traditionally regarded as stationary both in astronomy as well as ritualistic treatises. Āryabhaṭīya is the first known *astronomy* text in India which clearly mentions the axial rotation of Earth. It was a revolutionary principle (pun intended!) which was in shocking contrast to the impression one would acquire both from conventional knowledge as well as daily observations. One is reminded of the tribute on Copernicus by Bruno: "*Copernicus not only moved the Earth but also set in motion the minds of men.*" Fortunately, Āryabhaṭa lived in a society where such revolutionary views did not risk the kind of persecution which befell Socrates, Bruno or Galileo.

Āryabhaṭa's theory was lucidly expounded by Caturveda Pṛthūdaka Svāmī (860 CE):

bhapañjaraḥ sthiraḥ bhūrevāvṛtyāvṛtya pratidaivasikau udayāstamayau sampādayati nakṣatragrahāṇām

The sphere of the stars is stationary. It is only the Earth that is regularly rotating once in a day, and thereby causing the daily rising and setting of the stars and the planets.[3]

[3] See [8], p.26, for the original verse and other quotations from ancient Indian astronomers endorsing this theory.

However, the theory of axial rotation of Earth was not

Box 4. "Calā Pṛthvī Sthirā Bhāti"

To say that Indian philosophy has led away from the study of nature is to state a gross unfact and to ignore the magnificent history of Indian civilisation.... Not only was India in the first rank in mathematics, astronomy, chemistry, medicine, surgery, all the branches of physical knowledge which were practised in ancient times, but she was, along with the Greeks, the teacher of the Arabs from whom Europe recovered the lost habit of scientific enquiry and got the basis from which modern science started. In many directions India had the priority of discovery, – to take only two striking examples among a multitude, the decimal notation in mathematics or the perception that the earth is a moving body in astronomy, – *calā pṛthvī sthirā bhāti*, the earth moves and only appears to be still, said the Indian astronomer many centuries before Galileo. This great development would hardly have been possible in a nation whose thinkers and men of learning were led by its metaphysical tendencies to turn away from the study of nature. [Sri Aurobindo in *The Foundations of Indian Culture.* (p.67)] acceptable to most Indian astronomers right from Varāhamihira (505–587 CE). Bhāskara I (6th century), an admirer of Āryabhaṭa, evaded the topic: in his commentary on Āryabhaṭīya, he omitted Āryabhaṭa's phrases (in Gītikā 3 and 6) pertaining to Earth's rotations (though he did not omit the data of Āryabhaṭa for the moon and the planets)! Bhāskara II (1150 CE) was indifferent to the concept of Earth's rotation and perhaps sceptical.

Various difficulties were raised by the astronomers (see [9] for more details): if the Earth were rotating at such a tremendous speed, then all buildings would have crumbled down, people could not have stood still, there would have been constant earthquakes, etc. Lalla (around 8th century), another admirer of Āryabhaṭa, asked:

"If the Earth is rotating eastward at a very rapid speed, how do birds flying in the sky return to their nests (which would be continuously shifting from their original positions)? Moreover, why do not arrows, shot towards the sky, fall westward? Why do not the clouds appear to move only towards the west? If the Earth rotates slowly, then how can it complete one rotation in a day?"[4]

[4] Sisya-dhi-vrddhida-tantra (20.42) of Lalla; quoted in [8], p.44; [9], p.174. The text, edited with translation by Bina Chatterji, has been published by INSA, 1981.

Brahmagupta (628 CE), in particular, was fierce in his criciticism of the theory. One of the arguments of Brahmagupta can be phrased (using familiar units) as follows (vide [9], pp.176-177):

"A heavy body, when falling from even the highest peak of a mountain, invariably falls at the foot of a mountain. The circumference of the Earth is 25000 miles and the Earth takes 24 hours to complete a revolution on its supposed axis; hence the Earth moves at over 1000 miles per hour or $16\frac{2}{3}$ *miles per minute. Now if a heavy body takes 30 seconds to touch the ground, by that time, the Earth has moved 8 miles. Therefore, how can the body fall at the foot of the mountain?"*

Such arguments might amuse the modern reader. But without the clarity brought about by the principles of mechanics developed by Galileo and Newton, it would not have been easy to understand the dynamic equilibrium of terrestrial bodies and address such questions. Even during the 16th century, Copernicus did not have satisfactory answers to all the riddles. The arguments enrich our understanding of the evolution of astronomy and mechanics.

When a stone is dropped from the top of a very high tower, its initial eastward velocity is greater than the eastward velocity of the base – so the stone actually falls to the east of the vertical line through the point of dropping. This eastward deviation is actually a proof of Earth's rotation.

It is interesting to note that one astronomer (Pṛthūdaka) who strongly supported Āryabhaṭa's principle was a commentator of Brahmagupta (who was initially a virulent critic of Āryabhaṭa); while many followers of the Āryabhaṭa school of astronomy like Lalla – who always put Āryabhaṭa on a very high pedestal– criticised his theory of axial rotation! The astronomers imbibed the general intellectual robustness of the era. Inspite of the reverence for Āryabhaṭa, his theory was rejected (though wrongly in retrospect) – one cannot fail to notice in this controversy the prevalence of a critical scientific attitude and spirit of open-minded free enquiry.

In the context of Brahmagupta's question, we remind the young readers that there is, in fact, a small eastward deviation of a falling body; but it would not have been possible to detect such minute deviations with the technology of the ancient times. This deviation is caused by the fact that points which are at a greater distance from the Earth's axis of rotation move with a greater velocity than those near the axis. As a result, when a stone is dropped from the top of a very high tower, its initial eastward velocity is greater than the eastward velocity of the base – so the stone actually falls to the east of the vertical line through the point of dropping. This eastward deviation is actually a proof of Earth's rotation.

It would perhaps never be known what prompted Āryabhaṭa to assign an axial rotation to Earth, how exactly he got convinced of such a theory – which he asserted so strongly and confidently – and whether he had ingenious answers to the various counter-questions. After all, the theory of rotation of Earth has not been explicitly used in the text to simplify the methods of calculation or to explain any astronomical phenomenon (other than movement of stars and sidereal day). If we take out his specific statements on rotation of Earth, the rest of Āryabhaṭīya remains the same whether we take rotating or stationary Earth.

There is an impression among several historians that Āryabhaṭa had also conceived of the Earth's annual revolution around the Sun.[5] For instance, A L Basham writes: "For purposes of calculation the planetary system was taken as geocentric; though Āryabhaṭa in the 5th century suggested that the Earth revolved round the Sun and rotated on its axis, this theory was also known to later astronomers, but it never affected astronomical practice."[6]

[5] Strictly speaking, both the Sun and the Earth revolve around their common centre of mass.

[6] *The Wonder That Was India*, p.493.

But there is no phrase in Āryabhaṭīya (analogous to "ku āvartaḥ" – Earth's rotation – in Kālakriyā 5) explicitly mentioning Earth's heliocentric revolution. On the contrary, the solar year had been attributed (Kālakriyā 5) to *ravi bhagaṇā* (Sun's revolution). From Āryabhaṭa's cryptic verses, it is not clear if the author had in mind any motion of the Earth in space in addition to axial rotation. The numerical data in Āryabhaṭīya, explicitly involving Earth's motion, pertain either to the number of rotations in a yuga (Gītikā 3) or the rate of rotation (Gītikā 6). On the other hand, as pointed out in ([9], p.174), Āryabhaṭa's verses Gola 9 (where he gave the picturesque analogy with the motion of a boat) and Gītikā 3 (where he listed the number of revolutions of the Sun, the Moon, the Earth, and other planets, in the same breath!), taken together, could evoke the image of some motion in space (apart from axial rotation) in the mind of a reader. This can be seen, for instance, from the style of Brahmagupta's refutation (of the relevant portion of Gītikā 6): "If the Earth moves through one minute of arc in one prāṇa, from where does it start its motion and where does it go? And, if it rotates (at the same place), then why do not tall lofty objects fall down?"[7]

[7] *Brahma Sphuta Siddhanta* XI.17. The Sanskrit verse also occurs in [1], p.15.

A more technical basis for the speculation that Āryabhaṭa might have tacitly envisaged a heliocentric model comes from "śīghrocca" (Gītikā 3-4) – the period of Mercury and Venus. As H Thurston remarks[8]:

[8] *Early Astronomy*, Springer-Verlag 1996, p.188.

Not only did Āryabhaṭa believe that the earth rotates, but there are glimmerings in his system (and other similar Indian systems) of a possible underlying theory in which the earth (and the planets) orbits the sun, rather than the sun orbiting the earth. The evidence is that the basic planetary periods are relative to the sun. For the outer planets [e.g., Mars, Jupiter, Saturn] this is not significant: both earth and sun are inside their orbits and so the time taken to go round the earth and the time taken to go round the sun are the same. The significant evidence comes from the inner planets [i.e., Mercury and Venus]: the period of the śīghrocca is the time taken by the planet to orbit the sun.

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H Thurston

We mention here that, inspired by the ideas of Parameśvara (1360-1455), Nīlakaṇṭha (1500 CE) developed a heliocentric model for the planets – a significant achievement decades before Copernicus. Details on evolution of Nīlakaṇṭha's model are described in ([10]).

Āryabhaṭa had explicitly stated (Gola 5 and 6) that the Earth is spherical. His commentators Lalla and Nīlakaṇṭha explained why the spherical Earth appeared as a plane. Said Nīlakaṇṭha: "Due to the large area, one does not feel that it is spherical because we see only a small part of the Earth and also because of the ups and downs on the surface of the Earth."

Till the time of Renaissance, the belief that the Earth was a plane was deep-rooted in Europe. As late as the 15th century, the travellers accompanying Columbus feared that they might fall to the depth when they reach the edge of the (plane) Earth!

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Modern Europe

In his *De Revolutionibus* (1543 CE), N Copernicus enunciated the principles of axial rotation and heliocentric revolution. (He acknowledged Aristarchus, Herakleides and Ecphantus.) G Bruno (1548–1600) was a vociferous exponent of the Copernican theories. Subsequently telescope was invented and Galileo used it to discover (1610) four satellites (moons) of Jupiter which gave an indirect but strong evidence in favour of Copernican doctrines. On the basis of the long series of meticulous observations of Tycho Brahe (during 1576-1597), Kepler postulated his laws of planetary motion (1609). These developments prepared the ground for Newton's laws of gravitation (1687) – the cornerstone of Newtonian celestial mechanics where Copernican theory could finally find a solid theoretical basis. *De Revolutionibus* was banned in 1616, Galileo prosecuted in 1633. It was in 1822 that the Roman Catholic Church first officially announced the acceptance of Copernican theories. Goethe remarked:

Of all the discoveries and the opinions proclaimed, nothing surely has made such a deep impression on the human mind as the science of Copernicus. Perhaps never before had mankind been confronted with a bolder challenge, for, how many things were dispelled like smoke or fog as a result of his statement?

Epilogue

We conclude this article with a quote from Roger Billard's work cited earlier ([4], p.224)

I wish ... everybody will be able to see what was verily *the Indian astronomy, how admirable an astronomer was Āryabhaṭa, why exactly he is the leading figure of such a history. I hope furthermore he will soon be acknowledged as one of the greatest astronomers of the past and, in consideration of his rigour and probity even within error, as a paragon of science.*

Suggested Reading

[1] K S Shukla and K V Sarma: *Āryabhaṭīya of Āryabhaṭa*, INSA, New Delhi, 1976.

[2] G Swarup, A K Bag and K S Shukla (ed): *History of Oriental Astronomy*, IAU Colloquium 91, Cambridge University Press, 1987.

[3] K D Abhyankar, *Pre-Siddhantic Indian Astronomy – A Reappraisal*, INSA Project Report (1998).

[4] R Billard, Āryabhaṭa and Indian Astronomy – An Outline of an Unexpected Insight, *Indian Journal of History of Science*, Vol.12, pp.207-224, 1977.

[5] S Balachandra Rao, *Ancient Indian Astronomy – Planetary Positions and Eclipses*, BPRC Ltd,, New Delhi, 2000.

[6] K V Sarma, *Observational Astronomy in India*, University of Calicut, 1990.

[7] P R Ray and S N Sen (ed), *The Cultural Heritage of India Vol VI: Science and Technology*, The Ramakrishna Mission Institute of Culture, Calcutta, 1986.

[8] B V Subbarayappa and K V Sarma (ed), *Indian Astronomy*, Nehru Centre, Bombay, 1985.

[9] S R Das, Motion of the Earth as conceived by the ancient Indian astronomers, *Bulletin Calcutta Math Society*, Vol.17, pp.173-182, 1926.

[10] M S Sriram, K Ramasubramanian and M D Srinivas, *500 Years of Tantrasangraha – A Landmark in the History of Astronomy*, Indian Institute of Advanced Study, 2002.

Truth does not pay homage to any society, ancient or modern. Society has to pay homage to truth or die.

— Swami Vivekananda
The Complete Works II, p.84.