Critical evidence to fix the native place of Āryabhaṭa-I

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An attempt has been made to know the native place of the great Indian astronomer Āryabhaṭa. Opinion is divided between Kusumapura and Kerala, and with the identity of Aśmaka in dispute, the scope of the inquiry is limited to the pursuance of legends in Kerala and some efforts to understand the place of the astronomer from his work Āryabhaṭīyam. Here the study is focused on Āryabhaṭīyam and relying on Āryabhaṭa's two distinctive signatures that we see, viz. (1) Latitude of Ujjayinī being given as at 1/16 of the Earth's circumference north of Laňka. (2) Earth's diameter being 1050 yojanas or circumference 3299 yojanas using his accurate value of $\pi = 3.1416$. It is demonstrated here that the place Āryabhaṭa had been at 10°51'N, 75°45'E. It is further explained that the latitude derived based on the equatorial circumference given by Āryabhaṭa marks the spot where the coastline of Kerala cuts the Hindu prime meridian, i.e. Ponnāni, a major Arab trade centre since ancient times.

Āryabhaṭa, the author of *Daśagītikā* and *Āryāṣṭaśata* (both together is known as *Āryabhaṭīya*), is undoubtedly the greatest Indian Astronomer. In respect of his times there is certainty, even though there is a controversy on the precise date of his treatise *Āryabhaṭīya*, Kali 3600 elapsed (AD 499) or Kali 3623 elapsed (AD 522)? Looking back by about 1500 years, the 23 years difference is negligible and we can be sure that Āryabhaṭa lived in the first half of the 6th century AD. However, with regard to his native place. Opinion is divided between Kerala and Kusumapura (near modern Patna), and scholarly opinion[1] lately is in favour of Kusumapura. Gaṇita, the latter half of verse 1 reads as follows:

> Āryabhaṭstviha nigadati kusumapure-bhyarcitam jnānam,

meaning 'Āryabhaṭa sets forth here the knowledge honoured at Kusumapura'. A little emendation to the verse as:

> Āryabhaṭstviha nigadati kusumapure*f* bhyasitam jnānam,

gives the meaning, Āryabhaṭa sets forth here the knowledge acquired at Kusumapura, and when the same is placed against the Kerala tradition of astronomy founded on *Āryabhatīyam* and *Bhāskarīyams* leaves no doubt that the great astronomer was a native of Kerala. As Kusumapura had a great university in those days, it is likely that the rich natives of Kerala had taken up higher studies at Kusumapura and Āryabhaṭa may have been one such native who returned to Kerala and wrote *Āryabhaṭīyam. A Concise History of Science in India*[2] gives a contradictory account:

> '... scholars have thought for a long time that Āryabhaṭa was either born in Kusumapura or lived and taught in that great city of ancient India. Such a view now appears untenable in the light of recent studies on the works of Bhaskara-I and his commentators and also of the medieval commentators of Āryabhaṭa. In these works, Āryabhaṭa is frequently referred to as an *aśmaka*, that is one belonging to the Aśmaka country which is the name of a country in the south, possibly Kerala ... the fact that commentaries of and works based on Āryabhaṭīya have come largely from South India, from Kerala in particular, certainly constitute a strong argument in favour of Kerala being the main place of his life and activity.'

But the scholarly opinion is strongly in favour of a Kusumapura origin of Āryabhaṭa and his works, as may be noted from the account of Georges[3] as well:

> 'A veritable pioneer of Indian astronomy, Āryabhaṭa is without doubt one of the most original, significant and prolific scholars in the history of Indian science. He was long known by Arabic Muslim scholars as Arjabhad and later in Europe in the middle Ages by the Latinized name of Ardubarius. He lived at the end of the 5th century and the beginning of the 6th century CE, in the town of Kusumapura... .'

Kuppanna Sastry, one of the doyens of the last generation in the field of Indian astronomy and history of astronomy, has discussed the issue on the following lines:

> 'As far as astronomical works are concerned, it seems that the Kerala country was the seat of its development in the South. It is all based on the *Āryabhaṭīya*, with or without corrections called the bījas ... How Āryabhaṭa came to be connected with the Kerala country is yet to be explained. He is called Aśmaka (i.e. one born in the Āśmaka region) and some say that an early name of the erstwhile princely state of Travancore was Āśmaka (*Apte's Dictionary*). But many say that the region near the Vindhyās was called the Āśmaka country ....'

Sarma[4] describes Āryabhaṭa as having flourished at Kusumapura (modern Patna) and explains that the system of Āryabhaṭa in North India owing to the criticisms from later authorities like Brahmagupta, Varāhamihira and Śrīpati. He also observes that with the popularity gained by the great works of Bhaskara-II, the Āryabhaṭan system was practically effaced from North India and not even a manuscript or a North Indian commentator of Āryabhaṭa appeared in the scene after Bhaskara-II. Sarma has also spoken of the legends prevailing in Kerala related to Sanskritization of the vernacular name of Kotuňňallūr, which was the place of an observatory in ancient times. Kotuňňallūr or either of the Kallūr names may be equivalent to aśmaka (hard black stone), and legends which describe Āryabhaṭa as a native of Kerala are present since ancient times. He is believed to have propagated his teachings at Kusumapura in North India.

Shukla's discussion on the issue supported by Sarma who had been the greatest authority on Kerala's astronomical tradition and treatises almost nails the conclusion[5] that Āryabhaṭa was a native of Kusumapura. When discussed the issue with Sarma, he pointed out that the following popular speculations early researchers held notions like Aśmaka referred to by Bhaskara-I as the sanskritized vernacular name of Koṭuññallūr. Subsequently references to ancient Tamil literature suggested that the original name of Koṭuññallūr was Koṭumkolūr and not Koṭumkallūr, the vernacular equivalent of Aśmaka, viz. *koṭum-kal*[6]. Given the background of the sanskritization of vernacular names of places as we find illustrated with Aśvattha-grāma (Ālattūr) of Parameśvara in 1450 AD, Saṅgama-grama (Irinjalakkuda also known as Kūṭalmāṇikyam after a legend of the local temple) 1400 AD, and numerous such innovative names like Śukabhāvukam for Tattamaṅgalam, Śilavipinam for Pārakkatu, etc. Speculation still exists that Aśmaka is the sanskritization of Kallūr, a name with which different places exist in Kerala, since ancient times. Kotakal or Kotakallūr[7] which had a prehistoric stone memorial that gave it the name, became Tirunāvāya in later times. 'Mahamagham' was held for 12-yearly deliberations on Śāstras and has been associated with the Kerala astronomical tradition as early as AD 683, the times of Haridatta, popular in vernacular language as Nārāṇathu Bhrānthan[8] through legends. Kerala has several Siva temples and Śaiva signature that we see in Bhāskara-I can be explained irrespective of which Kallūr we consider as the equivalent of Aśmaka. Koṭakal is said to have a place nearby called Kallūr, associated with a Śiva temple; presently it falls in the Kuttippuram taluk. Based on these speculations Āryabhaṭa is considered to be a native of Kerala, despite the scholarly assessment referred to earlier and with many websites portraying him as a Kerala astronomer[9]. A concise account about the life and works of Aryabhaṭa is available in *Encyclopedia Brittanica*[10]:

> 'Aryabhata I or Aryabhata the Elder to distinguish him from a 10th-century Indian mathematician of the same name, he flourished in Kusumapura – near Patalipurta (Patna), then the capital of the Gupta dynasty – where he composed at least two works, *Aryabhatiya* (c. 499) and the now lost *Aryabhatasiddhanta*. *Aryabhatasiddhanta* circulated mainly in the northwest of India and, through the Sasanian dynasty (224–651) of Iran, had a profound influence on the development of Islamic astronomy. Its contents are preserved to some extent in the works of Varahamihira (flourished c. 550), Bhaskara I (flourished c. 629), Brahmagupta (598–c. 665), and others. It is one of the earliest astronomical works to assign the start of each day to midnight. *Aryabhatiya* was particularly popular in South India, where numerous mathematicians over the ensuing millennium wrote commentaries' (sic).

The above references amply illustrate the debate going on in respect to the native place and the place of astronomical observations of Āryabhaṭa, and the prevailing conclusions are speculative in nature. It also becomes apparent that the 1500-year-old tradition consisting of a galaxy of great astronomers as well as the modern ones (at least since the publication of Parameśvara's commentary on *Āryabhaṭīya* by H. Kern[11] in 1874), studying the works of Āryabhaṭa could not find any astronomical data that enable identification of his native place or the place of observations.

It is against the above background that an attempt is made here to present astronomical evidence that supports the origin of the Āryabhaṭan School of Astronomy in Kerala. A simple rationale underlying the measure of the earth's circumference given by different astronomers when considered against the background of the conflict of the latitude of Ujjayinī and earth's circumference leads us to a precise method in finding the native place of the astronomer who originally gave the dimension of the earth's circumference.

The two traditions of Ujjayinī's latitude and earth's circumference

Just as Āryabhaṭa himself gave two siddhāntas which became popular as Audāyika and the Ārdharātrika siddhāntas, we meet in the history of Indian astronomy two specific conflicts in which Āryabhaṭa is involved: (i) Conflict of the latitude of Ujjayinī and (ii) Conflict of the earth's circumference.

A closer look at these conflicts throws light on the native place of Āryabhaṭa, as is explained below.

Conflict of the latitude of Ujjayinī

Āryabhaṭīya Gola – verse 14 specifies the Indian or Hindu prime meridian in the words:

स्थलजलमध्याल्लंका भूकक्ष्याया भवेच्चतुर्भागे।
उज्जयिनी लंकायाः तच्चतुरंशे समोत्तरतः।१४।

'From the centre of the land and water, at a distance of one-quarter of the earth's circumference lies Laňkā; and from Laňkā at a distance of one-fourth thereof, exactly northwards, lies Ujjayinī'.

The verse spells out that on the prime meridian, Ujjayinī is located at one-sixteenth of the earth's circumference north of Laňkā and thus the latitude of Ujjayinī turns out to be $360°/16 = 22°30'$N. Shukla[12] and Sarma have given a discussion on this aspect in their critical edition of *Aryabhatiyam*. To quote:

> '...This makes the latitude of Ujjayinī equal to 22°30′N'. This is in agreement with the teachings of the earlier followers of Āryabhaṭa, such as Bhāskara-I (AD 629), Deva (AD 689) and Lalla and the interpretations of the commentators Someśvara, Sūryadeva (b. AD 1191) and Parameśvara (AD 1431). Even the celebrated Bhāskara-II (AD 1150) has chosen to adopt it.

However, Brahmagupta (AD 628) differed from this view. He had taken Ujjayinī at a distance of one-fifteenth of the earth's circumference from Laňkā and likewise the latitude of Ujjayinī as equal to 24°N. Some of the commentators of *Āryabhaṭīya* who favoured Brahmagupta's view changed the reading 'taccaturaṃśe' into 'pancadaśaṃśe'. The commentator Sūryadeva, who first interpreted the original reading 'taccaturaṃśe', later remarked:

> Ujjayinī laňkāyāḥ pancadaśāṃśe samottarataḥ,

i.e. Ujjayinī is at a distance of one-fifteenth of the earth's circumference to the exact north of Laňkā is the proper reading because Brahmagupta wrote:

> Laňkottarato*ſ*vanti bhūparidheḥ pancadaśabhāge ...'.

This quotation brings out the salient features of the conflict which may be enumerated as follows:

- Āryabhaṭa gave the latitude of Ujjayinī as 360°/16 North of Laňka and it had acceptance among only his followers.
- Brahmagupta and others like Varāhamihira[13] did not agree with Āryabhaṭa and established an alternate school of thought and tradition.
- Bhāskara-II apparently agreed with Āryabhaṭa but some followers of Āry-

abhaṭa like Sūryadeva could not find any rationale underlying the Āryabhaṭa's notion and they did tacitly accept Brahmagupta as correct.

- Apart from what Shukla and Sarma[1] have discussed, we can see that the Sūryasiddhānta also did not agree with Āryabhaṭa in the matter.
- Shukla has quoted Nīlkaṇṭha who has tried to explain the conflict by crediting Āryabhaṭa's reference of 22°30′N to a different Janapada at that latitude. But this is not correct as any reference to Ujjayinī in ancient texts obviously hinted at the location of the Mahākāleśvar temple, whose latitude according to modern determination is 23°13′N.

Cause of the conflict and Āryabhaṭa's place

The Āryabhaṭa notion of Ujjayinī's latitude is based on the idea of equinoctial shadow (known as Palabhā or Palaprabhā) of 5 aňgulas for a gnomon of 12 aňgulas[14]. Just as Laňkā is a hypothetical place on the equator on the meridian of Ujjayinī, Āryabhaṭa fixed the location of Ujjayini on the prime meridian hypothetically as where the gnomon gave a ratio of 5 : 12, i.e. $12 \times \tan \phi = 5$, where ϕ is the latitude of the place equal to 22.5°. It was the practice of ancient astronomers to identify important places in terms of gnomon ratio[15], so that the cara and rāśi-māna could be easily computed for such places and checked by observation. Had Brahmagupta taken $\phi = 24°$N for Ujjayinī, then the equinoctial shadow for the place should have been 05;21 in sexagesimal notation, meaning 5 aňgulas 21 vyaňgulas (5.34) and not 5.0 as is known in the tradition and recorded in Sanskrit geographical tables, which may have come down through repeated copying. For example, the tables published by Pingree[16] accurately mention of the shadows in units of vyaňgulas and as such a mistake of 21 vyaňgulas for Ujjayinī by Āryabhaṭa seems unreasonable. In the four tables that Pingree had published, Ujjayinī is shown to be Palabhā = 5, while differences can be seen in respect of other places across the tables. Values have been given precisely for such measures for Indore 5;20, Jambusar 4;58, Māṇḍu 4;57, Kāñcīpuram 2;30, Kurukṣetra 6;55, Yoginīpura 6;24, Hastinapura 6;30, Junagadh 5;0, Somanāth 5;06, Lahore 7;30, Jalālabad 5;10, Jalandhara 7;0, Jagannāthapuri 5;30 and 5;44, Deogarh 5;04, Brahmapuri 5;20, Nadiad 5;02, Naimiṣāraṇya 5;47, Prayāga 5;45, Baroda 4;52, Broach 4;08, Mathura 6;0, Mālwa 5;30, Mithila 6;0, Ayodhyā 6;07, Agra 6;30, Delhi 6;03, Cambay 4;59, Nagapura 5;0, Goa 3;0 and Kāsi 5;45. It may be noted in this context that during the time of Āryabhaṭa, the gnomon had a history of nearly 1000 years in India and thus the astronomers may have been quite familiar with its use in astronomy.

Given the above precision of gnomon shadow available in the Indian tradition, how could Āryabhaṭa miss the latitude of Ujjayinī by 1.5°, if we accept that the tradition initiated by Brahmagupta is correct?

In other words, had Ujjayinī been known to be at 24°N, how could astronomers without exception give it the equinoctial shadow of 5;0?

We can therefore be certain that Āryabhaṭa stated the longitude on the basis of the 5 : 12 gnomon ratio and he was precisely correct in placing Ujjayinī at 1/16 of earth's circumference from Laňkā. Does this mean that Āryabhaṭa was unfamiliar with Ujjayinī proper and the famous Mahākāla temple?

'With Kusumapura being at 25°35′N, 85°15′E, how is it possible that an astronomer living there was not familiar with the intersection of the Hindu prime meridian and the tropic of Cancer?'

We shall revert to this important question after having a look at the implications of gnomon in finding an answer to the above question.

History of the use of gnomon and sensitivity of the shadow measurement

Use of gnomon is traceable in India to the antiquity of 300 BC, as may be understood from reference to gnomonic shadow measurements in *Ardhaśāstra* of Cānakya[17]. Surviving records of ancient Greek astronomers like Hipparchus[18] (150 BC) also suggest the familiarity with gnomonic computations much before the time of Aryabhata (AD 500). Studies on Hipparchus and Ptolemy have shown that the latitude of Alexandria could be fixed to a precision of quarter of a degree as early as AD 150 and places falling on the tropic of Cancer had been well known in astronomical circles centuries before the times of Aryabhata[19]. We may in this respect also refer to the famous legend of Eratosthenes measuring the earth's circumference with the help of observations between Alexandria and Syene in 200 BC, the latter well known to be on the tropic of Cancer at 24°N. How could then a conflict of the latitude of Ujjayinī have its genesis in *Āryabhaṭīyam* and continue to prevail in India for 1500 years?

Palabhā well known in those days could have been known to Āryabhaṭa for Kusumapura (25°30′N) as 5 : 40 precisely and with the prevalence of smaller units like vyaňgulas, he had no reason to uphold an approximate measurement like 5 aňgulas = 300 vyaňgulas for 'Ujjayinī proper' marked by the Mahākāleśvar temple. The temple and Ujjayinī had been famous during the time as is evident from the *Meghadūt* of Kālidāsa and thus Āryabhaṭa living at Kusumapura (25°30′N) had no reason to remain vague in respect of the equinoctial shadow at a place close to it, where the tropic of Cancer intercepted the prime meridian.

Evidence of the Carakhaṇḍas of Palabhā = 1, 4.775° latitude

Support to the above contentions can be drawn from the Carakhaṇḍas or ascensional differences given in astronomical texts of the Āryabhaṭa tradition for Palabhā = 1, which means the latitude of 4.775°. Places where the equinoctial shadow had been integers were well known to the astronomers, so that the rasimanas in asus could be worked out for those places using the Carakhaṇḍas. Accuracy depended upon the sensitivity of Palabhā if they were to derive the rāśimānams[20] reasonably accurately by the thumb rule given in *Mahābhāskarīya III.8*, where the ascensional differences of high latitudes have been derived using multiplying carakhaṇḍas of Palabhā 1 with the equinoctial shadow of locations. Mallikārjjuna[21] in his commentary on *Śiṣyadhīvṛdhidatantra* mentions the equinoctial shadow north of the Vindhyas as $5\frac{1}{20}$ and is illustrative of the accuracy sought by ancient astronomers. Given such practices, it is for Palabhā = 5, the latitude given as 22°30′ by Āryabhaṭa is correct.

Could Āryabhaṭa have been at Kusumapura (25°30′N)?

Given the above background of the use of gnomon, is it possible that an astronomer observing the sky at Kusumapura (25°30′N) could have differed in fixing the latitude of Ujjayinī at 24°N by 1.5°? Is it possible that Āryabhaṭa had observational experience at higher latitudes given the approximated 5 : 12 notion of the equinoctial shadow for Ujjayinī proper at 24°N? Further, we find no mention in *Āryabhaṭīya* regarding Ujjayinī as situated south of his place of observation. As the shadows fell differently towards south of Ujjayinī, an astronomer working north of the tropic of Cancer in all probability would have made a mention of it as we see in the case of Greek astronomers. In the works of Greek astronomers who were living north of the tropic of Cancer, a clear trend of mentioning the difference in the direction of shadows north and south of the tropic of Cancer is available. It is also reported that the Arab astronomers visiting Alexandria had recorded this observation of the difference in the direction of shadows in Alexandria compared to their places south of the obliquity of the axis.

Also, we must note that the Sun is overhead twice a year in places south of Ujjayinī, while no such phenomenon was possible at a place north of Ujjayinī or north of 24°N, where the shadow fell always south of the east-west line of the gnomon. With obliquity as 24°N, Āryabhaṭa's Ujjayinī at 22°30′N had shadows falling north. Āryabhaṭa could not have invited the criticism of Varāhamihira who lived in Ujjayinī, had he been familiar with the north latitude of Ujjayinī and beyond like Kusumapura.

Further, we may look for a parallel with the history of Alexandria where in 200 BC, Eratosthenes knew that at Seyene the sun could be seen at the bottom of a well on the day of the solstice, while in Alexandria the sun transited 7.2° lower the zenith. With an approximation of the distance between the places, Eratosthenes is said to have computed the circumference of the earth. Kusumapura and Ujjayinī present us a similar picture, but no explanation has been ever put forth to explain the circumference data available in the work of Āryabhaṭa and others.

Evidence of the gnomon therefore suggests that at the time of writing the *Āryabhaṭīyam*, the astronomer had been living in the south and it is quite unlikely that he may have moved north of Ujjayinī or that he may have belonged to Kusumapura. Adherence to the Āryabhaṭa notion of Ujjayinī at 22°30′N in later times was not the real Ujjayinī as we see in the mention of Varāhamihira, Brahmagupta, etc. It only meant a place like Lanka 0°N on the equator, known by coordinates as at 22°30′N having an equinoctial shadow of 5 aṅgulas. This is astronomically more correct than the notion of placing the true Ujjayinī at 24°N, which may have been in error by 20 min as the obliquity amounted to 23°40′ only in AD 500 and Ujjain was 30° South of same with latitude 23°10′N.

Āryabhaṭa placed Ujjayinī at 22°30′N corresponding to the gnomon ratio of 5 : 12 as a consequence of his non-familiarity with the historical Ujjayinī, where the shadow was in excess by 20 vyaṅgulas. Nīlakaṇṭha's (AD 1500) comments which justify 24°N for Ujjayinī on the basis of equinoctial shadow (Shukla quotes[22]) and justification adduced for the hypothetical Ujjayinī of Āryabhaṭa at 22°30′N, offers ample demonstration to the fact that at the time of writing *Āryabhaṭīyam*, Āryabhaṭa was not familiar with Ujjayinī as was Nīlakaṇṭha in later times. It is likely that he wrote *Āryabhaṭīyam* in Kerala at the age of 23 and in later times when he migrated to Kusumapura, the verse having reference to Kusumapura and those praising Lord Brahmā got added.

Further, he had been at Kusumapura within 3° of the tropic of Cancer, Āryabhaṭa could have derived a better estimate of obliquity as Hipparchus or Ptolemy has done.

Evidence of Prime Meridian and Kusumapura

Invariably astronomers have to specify the distance in yojanas of their local meridian with the Hindu Prime Meridian of Laṅkā–Ujjayinī so that 'Deśantaram' can be applied in planetary computations, especially moon. This is not the case with Āryabhaṭa and this is possible only by the fact that he lived at a place located on the prime meridian. Kusumapura being at 25°35′N, 85°15′E, i.e. 9.5° east of the prime meridian of Laṅkā, Āryabhaṭa must have given the accurate distance of his meridian. *Defining his meridian may have been one of the basic exercises that Āryabhaṭa would have undertaken had he been making his observations at significant distances east or west of the Ujjayinī meridian.* We may for example note that Parameśvara had defined his place Aśvatha (sanskritization of Ālattūr in the same way as Kallūr became Aśmaka) as at 18 yojanas east of the meridian of Ujjayinī. Ujjayinī being at 75°45′E, the west coast of Kerala offered astronomers the ideal sea horizon required for making observations. Also Deśāntharam or longitudinal correction for Laṅkā could have been ignored as places were in a narrow band of longitude to the Laṅkā meridian.

Even in his lunar eclipse computations, Āryabhaṭa has failed to mention that Kusumapura was 87 yojanas east of the prime meridian of Ujjayinī/Laṅkā. Such omission is possible only when the astronomer had been observing the sky at the prime meridian.

Conflict of the earth's circumference

Just as in the case of the Ujjayinī latitude that Āryabhaṭa gave as 22°30′N, we meet a conflict of *Āryabhaṭīya* other treatises in the matter of diameter and circumference of the earth. Āryabhaṭa in Gītikā-7 gives 1050 yojanas as the diameter, which translates to 3299 or 3300 as circumference, accepted in commentaries of *Āryabhaṭīyam* using $\pi = 3.1416$ and *Śiṣyadhīvṛdhida*. If the π value is taken as $\sqrt{10}$ as we see in ancient texts; then the circumference will be 3320 yojanas. As against the above, in *Sūryasiddhānta*[23] and according to Brahmagupta, etc. we find 1600 yojanas as the diameter and 5000 or 5026 or 5059.64/ 5060 yojanas as the circumference. The Indian astronomical tradition is almost divided into two groups in the choice of either of the above two values.

(a) Lalla gave the circumference as 3300.
(b) Bhāskara-I gave the same as Āryabhaṭīya = 3299 (Sastry[24]).
(c) Vateśvara[25] gave 1054 yojanas as diameter and 3311.24 as circumference.
(d) Bhāskara-II gave 4967 yojanas[26] as equatorial circumference.

Modern researchers have failed to take note of the cryptic content of the basic data and the underlying rationale of the two traditions of the earth's circumference as given by *Sūryasiddhānta* and *Āryabhaṭīya*, or as is seen between Āryabhaṭa and Brahmagupta.

Circumference according to Sūryasiddhānta and its cryptic content

The *Sūryasiddhānta* value is 5060 yojanas at the equator and at Ujjayinī it was 4622 yojanas for 24°N. Yojanas per degree of longitude is 12.84 at Ujjayinī by the rule 'Equatorial circumference × cos ϕ' where ϕ is the latitude of the place. If we think of the rationale underlying such choice of 5060 or 3299 yojanas for circumference, the only logic that we can find is that *at the place of the observer the circumference shall be an integer multiple of 360, so that the distance in yojanas for 1/6th of the nazhika (1/360) or per degree longitude could be represented by an integer.* An integer value for the place of observation facilitated easy application of Deśānthara_yojana. Little arithmetic suggests that the *Sūryasiddhānta* value had its origin at the latitude of Alexandria: $5060 \times \cos 31.5° = 4314$. Adjusting for 4320 yojanas, $\cos \phi = 4320/5060 = 31°23'$. With circumference as 5026 yojanas using the correct value of $\pi = 3.1416$, we get $\phi = 30°45'$ and 1/6 of a nādikā or 4 min of time per 12 yojanas at the latitude of Alexandria. Precise latitude of Alexandria according to modern findings is 31°13′N, and this gives equatorial circumference as $(360 \times 12)/\cos 31°13' = 5051.37$.

Supporting evidence of Greek astronomy

Eratosthenes (276–194 BCE) is known to have computed the earth's diameter using the following data[27].

The Alexandria–Syene distance = 5000 stadia. Depression of sun on solstice at Alexandria = 7.2° = 360/50. Therefore the earth's circumference = 5000 × 50 = 250,000 stadia and the diameter is $250,000/\pi = 79,580$ stadia. Also, it is believed that later some correction was made and the final value of 252,000 was given by Eratosthenes. It is easy to realize that the correction was meant to achieve the equivalence of 700 stadia and 1° at the equator so that at Alexandria the equivalence is $700 \times \cos 31° = 600$ stadia and the circumference is 216,000 stadia.

Scholars have mistaken the Eratosthenes' determination as the circumference of Alexandria and possibly created explanations to suit the same. Thus controversies have come up which point out that Syene and Alexandria are separated by less than 5000 stadia, etc. In fact, Eratosthenes took the separation as only 4320 stadia and that multiplied by 50 gave him the value 216,000 and the same transferred to the equator gave the value $216,000/\cos \phi = 250,000$.

The Indian value for the circumference as we see in *Sūryasiddhānta* was adopted from the Greek with the unit conversion of 50 stadia as 1 yojana. Thus we get the circumference of the earth at the equator as 252,000/50 = 5040 yojanas or 14 yojanas per degree of terrestrial longitude at the equator. Alternately, as shown earlier, the circumference at Alexandria was taken as 216,000/50 = 4320 yojanas at 31°N and the same transferred to the equator gave the value 5040, thus resulting in integer values of yojanas per degree of longitude at both the equator and at Alexandria.

Circumference according to Āryabhaṭīya and its cryptic content

With above ideas in mind, when we look at Āryabhaṭa's value of circumference at the equator, it can be gleaned that the odd value of 3299 chosen points towards the choice of an integer value of yojanas per degree of terrestrial longitude at his place. Applying little trigonometry with which Āryabhaṭa was familiar, we may create an algorithm (Table 1) to find the latitude of the astronomer's location from the circumference value.

The algorithm can be worked out easily on an Excel worksheet and the possible latitudes of the original astronomer who gave the value of the circumference may be found out and verified using information from other sources. Also, the truth of the method and underlying rationale may be verified from known information about Brahmagupta, Bhaskara-II, etc. Tables 2–6 show the values of circumference given by various Indian astronomers.

Āryabhaṭa (Table 2)

It becomes evident that the Āryabhaṭa's value could have evolved only at the latitude of 10°51′N. This in turn provides evidence for the fact that in Kerala, the latitude 10°51′N is the place where the coastline cuts the prime meridian of Ujjayinī and is coincident with the confluence of the Bhāratappuzha with the sea. It is the first point of land between Shornur and Calicut that is on the Ujjayini meri-

Table 1. Equatorial circumference of Sūryasiddhānta

Circumference at 0°N (C) yojanas	Integer yojanas per degree (Y)	$\cos \phi = Y \times 360/C$	Latitude (ϕ) (degrees)
5040	8	0.57	55.15
5040	9	0.64	49.99
5040	10	0.71	44.42
5040	11	0.79	38.21
5040	**12**	**0.86**	**31.00**
5040	13	0.93	21.79
5040	**14**	**1.00**	**0.00**
5040	15	1.07	–

Note: 4230 yojanas at the latitude of Alexandria became 5040 yojanas at the equator. Greeks had been smaller units like stadia 4320 yojanas = 4320 × 50 = 216,000 stadia and 5040 yojanas = 5040 × 50 = 252,000 stadia.

Table 2. Equatorial circumference of Āryabhaṭīyam

Circumference at 0°N (C) yojanas	Integer yojanas per degree (Y)	$\cos \phi = Y \times 360/C$	Latitude (ϕ) (degrees)
3299	5	0.55	56.93
3299	6	0.65	49.10
3299	7	0.76	40.19
3299	8	0.87	29.19
3299	**9**	**0.98**	**10.85**
3299	10	1.09	–

Note: Odd value of 3299 yojanas that Āryabhaṭīyam gives could have given an integer value per degree of longitude only at 10°51′N. In the history of astronomy it may be noted that Āryabhaṭa gave the minimum value of 3299 yojanas at 0°N, as he himself lived closed to the equator at 10°51′N and the cosine formula allowed low value. On the other hand for astronomers at high latitudes the cosine formula gave a high value of equatorial circumference.

dian. At all other latitudes the Ujjayinī meridian intercepts the latitudes of Kerala (<10°51′N) in the sea. It is therefore evident that a specific place falling on the meridian of Ujjayinī and also on land was probably the seat of an ancient observatory and hence Āryabhaṭa had made a distinct choice of 3240 yojanas as the circumference at that precise location.

We obtain a clinching evidence to support the above fixing of latitudes based on *Āryabhaṭīyam* in the works of Parameśvara and Nīlkaṇṭha[28] as they give the place of observation of the eclipse as Aśvatthagrāma, where the equinoctial shadow is 2 aṅgulas and 18 vyaṅgulas, i.e. 2.3 and the corresponding latitude is 10°51′N. As stated by Parameśvara, his native village Aśvatthagrāma, i.e. Ālattūr is 18 yojanas east of the prime meridian of Ujjayinī and so his longitude was 77°45′E, towards east in the hills, but he had been observing the sky at the confluence of Niḷā and the sea.

Truth of the above interpretation can be further illustrated using the value of Brahmagupta, viz. 5000 yojanas, Bhāskara-II, viz. 4967 yojanas and Vaṭeśvara, viz. 3311.24 yojanas.

Brahmagupta (Table 3)

Brahmagupta too followed the same rationale and his latitude can be fixed by noting that 5000 yojanas of equatorial circumference becomes 4680 yojanas @ 13 yojanas per 1/60 nāḍikā or per degree of longitude. $\cos^{-1}(4680/5000) = 20°37'$, which is same as the latitude of modern Bulsar (20°36′N, 72°59′E), Bilimora (Bhilmora or Bhilmala 20°46′N, 72°58′E), which form the southern boundary of Gurjara (modern Gujarat). Identification of Bhinamala as in north Gujarat is open to doubt in view of the above identification[29]. Vyāghramukha from the Cāpa dynasty ruled over the Gurjara kingdom that extended from Śrīmal to the banks of Narmada and Bhilmora or Bhilmala 20°N46′ stood on the south side. Identification of Bhilmala with Śrīmal may be a later development, when Śrīmal got the name Bhinamala as known[30] from the Jaina sources.

Further, Śrīmal north of Mount Abu falls on the tropic of Cancer with $\phi = 24°$N and thus on the latitude of Ujjayinī. But we find no mention of this astronomically important fact in the work of Brahmagupta. An astronomer working on the tropic of Cancer and not mentioning the day when the gnomon casts no shadow, is quite unlikely. Even though Brahmagupta criticized Āryabhaṭa for crediting Ujjayinī at 1/16th of the earth's circumference north of Laṅka and correct it to be 1/15th, Brahmagupta did not point out that his own place fell on the 24°N latitude. It is therefore evident that the Bhilmala of Brahmagupta's time was south of Bhṛgukaccam and its latitude was near about 20°30′N.

Bhāskara-II (Table 4)

Bhāskara-II belonged to a place near modern Bir (Bid) with coordinates 19°00′N, 75°50′E, and as above it can be shown that the place he chose was at latitude 19°34′N on the meridian of Ujjayini (75°45′E), so that the circumference there was 4680 yojanas, i.e. 13 yojanas per 1/6 of the nāḍikā or per degree of longitude. 4680/cos 19°34′ gave him 4967 yojanas as the equatorial circumference and dividing it by π gave him the diameter as 1581 yojanas.

It must be noted that 4967 yojanas is an odd number and the choice was guided by the place of observation of Bhāskara-II, which is near the modern Auraṅgabad.

Bhāskara-II in *Līlavati*[31] gave the different value of 3927 yojanas as the equatorial circumference. This change in value was most likely made when he shifted to Ujjayinī in the later stages of his life. Ujjayinī was roughly 4° north of Bhāskara's earlier station at 19°34′ and this gave 23°34′ as the latitude of Ujjayinī's location. $3927 \times \cos 23°34' = 3600$ yojanas and thus Bhaskara chose 10 yojanas per 1/6 nāḍikas or degree of longitude at Ujjayinī (Table 5).

The choice of two odd values like 4967 and 3927 yojanas by Bhāskara-II during his lifetime, having no rationale, now finds an explanation in the latitude of his places of observation and the fact that he had shifted to Ujjayinī to be the head of the observatory at Ujjayinī.

Vaṭeśvara (Table 6)

Vaṭeśvara's choice of 3311.24 yojanas provides irrefutable evidence for the Yojana criterion as may be understood from the discussion given below.

Shukla has shown that Vaṭeśvara belonged to Vaḍnagar in Gujarat, which was on the same latitude as Dasapura on tropic of Cancer (24°N). Vateśvara belonged to the Āryabhaṭa School and accordingly, Ujjayinī was at 22°30′N. Vaṭeśvara, instead of fixing integer yojanas for his place of observation, fixed the equatorial circumference for Ujjayinī 22°30′N as $3311.24 \times \cos 22.5 = 3060$ yojanas, i.e. @ 8.5 yojanas per 1/6 nāḍikās. Based on this yojana value of 8.5 at 22°30′N, Vateśvara fixed equatorial circumference as $360 \times 8.5/\cos 22.5 = 3311.24$ yojanas.

Varāhamihira

In Pancasiddhāntikā[32], Varāhamihira[33] gives the circumference as 3200 yojanas.

Table 3. Brahmagupta latitude 26°61′N

Circumference at 0°N (C) yojanas	Integer yojanas per degree (Y)	$\cos\phi = Y \times 360/C$	Latitude (ϕ) (degrees)
5000	9	0.65	49.61
5000	10	0.72	43.95
5000	11	0.79	37.63
5000	12	0.86	30.23
5000	**13**	**0.94**	**20.61**
5000	14	1.01	–

Table 4. Bhaskara II, $\phi = 19.57°$

Circumference at 0°N (C) yojanas	Integer yojanas per degree (Y)	$\cos\phi = Y \times 360/C$	Latitude (ϕ) (degrees)
4967	9	0.65	49.28
4967	10	0.72	43.55
4967	11	0.80	37.13
4967	12	0.87	29.57
4967	**13**	**0.94**	**19.57**
4967	14	1.01	–

Table 5. Second value of Bhaskara-II at $\phi = 23°55'$

Circumference at 0°N (*C*) yojanas	Integer yojanas per degree (*Y*)	$\cos\phi = Y \times 360/C$	Latitude (ϕ) (degrees)
3927	9	0.83	34.41
3927	**10**	**0.92**	**23.55**
3927	11	1.01	–

Table 6. Vaṭeśvara: Ujjayinī as reference

Circumference at 0°N (*C*) yojanas	Integer yojanas per degree (*Y*)	$\cos\phi = Y \times 360/C$	Latitude (ϕ) (degrees)
3311.24	7	0.76	40.44
3311.24	8	0.87	29.57
3311.24	**8.5**	**0.92**	**22.46**
3311.24	9	0.98	11.91
3311.24	10	1.09	–

His rationale is also based on Āryabhaṭa's stipulation of Ujjayini's location at 22°30′N i.e. 1/16 of the paridhi and thus 3200 yojanas was chosen to place Ujjayini of Aryabhata at 200 yojanas and the 24°N ayanarekha of his place of observation, Avanti at 213.333 yojanas north of the equator. Further, Varāhamihira modified the Aryabhata value of 3299 yojanas to suit his later place of observation at Kusumapura. Taking the latitude of Kusumapura as 2°N of Avanti, Kusumapura got configured, as near to 26°N and there the circumference was derived as $3200 \times \cos 25°50' = 2880$ yojanas, i.e. 8 yojanas per degree of longitude in modern terms.

Mihira's modification of Āryabhaṭa's value based on 10°51′N to suit the latitude of Kusumapura taken as 15° further north of the place of observation, i.e. 10°51′N + 15 = 25°51′N, is yet another evidence for the Kerala origin of Āryabhaṭa and his subsequent migration to Kusumapura. It may be noted that the 9 yojanas per degree at 10°51′N (= 3240) got transformed as 8 yojanas per degree at 25°51′N (= 2880) and this made Varāhamihira to adopt the circumference as 3200 yojanas.

Striking evidence can be seen in *Laghumānasam*[34] of Manjuḷa, where two values have been suggested, viz. 3600 and 4800 yojanas as equatorial circumferences by different interpretations of the related verse. Both these lead us to a place at the latitude of Kusumapura 25°50′N, close to which the place Prakāśa is located as well, which is shown to be of latitude 25°36′N based on the Palabhā of 5 : 45.

Even though Āryabhaṭa in his brief treatise is silent about the spaṣṭa-bhūparidhi, the idea is well attested in the tradition of *Āryabhaṭīya*, as may be noted from *Śiṣyadhīvṛdhidatantra* of Laḷḷācārya[35]:

खखामरा योजनवेष्टनं भुवो नभः
शराभ्रक्षितयो*f*स्य विस्तृतिः
दिवाकरघ्नं पलकर्णभाजितं स्फुटं
महीगोलकवेष्टनं भवेत् ।१.४३ ।

The equatorial circumference of the earth is 3300 yojanas. Its diameter is 1050 yojanas. Equatorial value multiplied by 12 and divided by the hypotenus of the equinoctial shadow (Palakarṇa) of a place gives the true circumference of earth at that place.

As 12/Palakarṇa = cos ϕ, where ϕ is the latitude of the place, the rule is

Spaṣṭa-bhūparidhi = Bhūmadhyaparidhi × cos ϕ.

This for the equatorial value of Āryabhaṭa, viz. 3299 yojanas gave spaṣṭa-bhūparidhi as 3240 yojanas at $\phi = 10°51'$N. Though Āryabhaṭa has not given the rule explicitly in his brief treatise, it is apparent in the verse 11 of Goḷapāda, where Meru the abode of Gods at the pole 90°N is described as follows:

मेरुर्योजनमात्रं प्रभाकरो हिमवता परिक्षिप्तः
नन्दनवनस्य मध्ये रत्नमयः सर्वतो वृत्तः ।११ ।

Commentators have taken the verse to mean the height of the Meru, whereas Āryabhaṭa has meant the circumference and so the interpretations have been confusing. Taking the verse as referring to circumference at 1′ short of the pole at 90°N, i.e. 89°59′, we get the right meaning of the verse as $3299 \times \cos 89°59' = 0.96 \approx 1$ yojana. It is just about 1 and so he expressed *Meruryojana mātram* which is the correct reading rather than *Meruryojana matraḥ* which is translated as *Meru is exactly one yojana in height*[36]. It is unlikely that Āryabhaṭa meant 1 yojana height as that of a mountain when the earth's circumference is 3299 yojanas and 1 yojana is just 6′ of arc, not even quarter of the diameter of the solar or lunar disc.

It is therefore evident that Āryabhaṭa's choice of an odd number like 3299 was to have the spaṣṭa-bhūparidhi at 10°51′N as 3240 = 360 × 9, giving 9 yojanas for each degree of terrestrial longitude at his place of observation, where the Ujjayini meridian had intercepted the west coast of Kerala.

Further, *Āryabhaṭīyam* offers no clue in terms of the yojanas east or west of his place of observation[35,37] from the meridian of Ujjayinī. This is possible only when the astronomer had been living at a place where he could use the Ujjayinī meridian as the prime meridian. Data discussed above can be summed up as in Table 7.

An examination of the earth's circumference as given by prominent astronomers of the Indian astronomical tradition leads one to the conclusion that Āryabhaṭa was a native of Kerala and his native place had the coordinates 10°51′N, 75°45′E corresponding to Ponnāni. This place has astronomical significance as it is here that the coastline of Kerala intercepts the Hindu prime meridian. Ponnāni was the most famous centre of Arab trade in Kerala, which placed it clearly in contact with Alexandria and Babylon, and thus it was ideally situated to become the birthplace of refinement and revolution in Indian astronomy.

Confusion on the length of the yojanas

In the preceding section we gave a scientific explanation for the varying lengths that we see for yojana as a unit of distance. With such bewildering difference of 3299 and 5000 yojanas that is seen between Āryabhaṭa and Brahmagupta for the circumference of earth, defining the yojana as a unit of distance is quite impossible. Just as the 12 aṅgulas of a gnomon could vary in dimensions depending on the choice of length by the astronomer, the yojana too was defined by the astronomer and its magnitude depended on

Table 7. Data summary of the places of astronomers

Astronomer	$2\pi r$ at 0°N (C) yojanas	Yojanas per degree Y at ϕ	$\cos\phi = Y \times 360/C$	Latitude (ϕ°)	Place of choice/native
Eratosthenes	4320	12	0.86	31.00	Alexandria
	5040	14	1.00	0.00	Equator
Āryabhaṭa	3299	9	0.98	10.85	Ponnāni
	4948	13.5	0.98	10.82	Ponnāni
Brahmagupta	5000	13	0.94	20.61	Bhilmala
Bhāskara-II	4967	13	0.94	19.57	Bid.
	3927	10	0.92	23.55	Ujjayinī
Vateśvara	3311.24	8.5	0.92	22.50	Ujjayinī
Varāhamihira	3200	8	0.90	25.84	Kusumapura
Manjuḷa	3600	8 (3240)	0.9	25.84	Prakāśa
	4800	12 (4320)	0.9	25.84	25°36′N

Note: (i) Eratosthenes gave the value of 5040 for equator and used 4320 at his place so that 12 yojanas or 12 × 50 = 600 stadia separated a degree of longitude at his place Alexandria 31°00′N. (ii) Āryabhaṭa gave equatorial circumference as 3299 yojanas so that at his place 10°51′N, 75°45′E (camravattam), the circumference had a value 9 yojanas per degree of longitude or the total of 3240 yojanas. Similar explanations stand for other case discussed in the table.

the choice of latitude or Palabhā in ancient times. Ancient works in fact gave provisions for converting yojanas north or south of Ujjayinī into the local noon equinoctial shadow (Palabhā)[38]. Also the different treatises give different yojana measures between important locations like Laṅkā and Ujjayinī and between other important cities due to the above confusion[38]. Yojana as applied in Indian astronomy derived its magnitude from the local latitude and the purpose was to enable the Deśānthara correction as done in modern times with terrestrial longitudes. Odd numbers chosen by astronomers like Āryabhaṭa (3299), Bhāskara-II (4967) and Vaṭeśvara (3311.24) have the underlying rationale of a specific latitude. It has also been explained above that the legendary measurement of Eratosthenes itself was based on the unit stadium defined in terms of the equivalence of 700 stadia = 1 degree of terrestrial longitude at the equator and 600 stadia = 1 degree of terrestrial longitude at Alexandria (31°N).

Fixing the local meridian as meridian of Ujjayinī

Equatorial circumference as convenient integer yojanas at the local place yielded the latitude of Āryabhaṭa as 10°51′N. The question however remains as to how the astronomer may have identified his location as falling on the Laṅkā–Ujjayinī meridian?

Indian astronomy had been using a day count (ahargaṇa) since the beginning of Kaliyuga on 00:00 Ujjayinī Local Time or 06:00 on 18 February 3102 BC. The midnight system of day counting (probably an adaptation of the sunset epoch of Alexandrian astronomers to suit Ujjayinī meridian) as seen in *Sūryasiddhānta* gave the epoch of Siddhāntic astronomy as Kali year 3600 elapsed equal to 1,314,931.5 days, i.e. mean noon at Laṅkā (0°N, 75°45′E) of 21 March 499 AD. Epochal positions as such had to be checked against the Ujjayinī meridian and the day count after the epoch, viz. the Kalikhaṇḍam involved counting since local noon when the gnomon shadow was the shortest. Any difference in the time of stellar conjunctions of the moon observed for the local place while using day count from the local noon, gave the astronomer the east-west distance of the local meridian from the Laṅkā–Ujjayinī meridian.

Another way of assessing the distance from the Laṅkā–Ujjayinī meridian would have been by observing the beginning and end of a lunar eclipse. Kalikhaṇḍam based on the local noon would have given the correct times only if the local noon was coincident with the Ujjayinī noon. It is therefore apparent that the Siddhāntic astronomy had an in-built absolute time by defining the epoch at 1,314,931.5 days. Noon of Ujjayinī was at hand in terms of epochal positions and noon at other places could be found from the shortest gnomon shadow. Thus the difference between meridians was understood by Āryabhaṭa. Subsequent day count as Kalikhaṇḍam from local noon for computing the moon's conjunction with the ecliptic stars like Regulus gave the astronomers an estimate of their place from the Prime Meridian.

According to the Kerala tradition, Kali 3623 or AD 522 is the epoch of *Āryabhaṭīya*. It is possible that the treatise was given shape with solar eclipse observations like 15 February 519 AD (total at 10°51′N) and 11 August 519 (annular total at 2° south of Āryabhaṭa's place) and total lunar eclipse of 23 March 517 AD, 15 September 517 AD, etc. which were observable at his native place with remarkable features. More studies on these observations as forming the basis of Āryabhaṭīya are being undertaken.

Conclusion

Two distinct schools of astronomy are apparent in the history of Indian astronomy since AD 499 in terms of intellectual conflicts that arose due to historical and geographical reasons. The first may be identified as originating out of *Āryabhaṭīyam*, which flourished only in South India in later times and the second having pre-Āryabhaṭa roots nurtured by Varāhamihira, Brahmagupta, etc. and getting identified in terms of *Sūryasiddhānta* in later times. A closer look reveals these as the conflict of the latitude of Ujjayinī and conflict of the circumference of the earth. Except for the improvization of astronomical computations that we see in Brahmagupta, Āryabhaṭa appears more scientific and unorthodox in his precepts as may be exemplified his statements on earth's rotation and also in giving the latitude of Ujjayinī with equinoctial shadow of 5 as 22°30′N. Analysis of these conflicts has led us to the following conclusions.

1. Measures of the earth's circumference were chosen by early astronomers based on integer units of distances corresponding to 1/6 of a nāḍikā or 1° of terrestrial longitude in modern terms. An algorithm was devised to derive the latitudes that gave rise to various measures of the earth's circumference in the history of astronomy.
2. The native places of various Indian astronomers have been identified and supporting discussions have been provided. The fact that the method conceived and explained the circumference values of Eratosthenes and Ptolemy and enabled the derivation of their latitude attests the truth of the ancient practice and the method outlined.

3. The method provides a rationale for the odd numbers chosen by various astronomers as the circumference of earth. In the context of Indian astronomy, the discussion enables us to understand the different magnitudes that have become available for a yojana.
4. Verse 11 of Goḷapāda of *Āryabhaṭīya*, where Meru, the abode of the Gods, at the pole 90°N is described as having a circumference of just about 1 yojana, renders textual evidence for the rationale employed in fixing the place.
5. Āryabhaṭa undoubtedly belonged to Kerala, as may be gleaned from the circumference measure in *Āryabhaṭīyam*, 10°51′N, 75°45′E, which corresponds to Ponnāni, where the coastline of Kerala cuts the Hindu prime meridian defined in terms of the Laňkā–Ujjayinī longitude.
6. Bhāskara-I's reference to the place of Āryabhaṭa as Aśmaka may be explained on the basis of the Aśmaka Jain country that surrounded the stone monoliths of Ṣravaṇabelgoḷa at latitude 12°51′N, just 2° North of Āryabhaṭa's place.
7. This note also identifies the latitude of the native places of Brahmagupta and Bhāskara-II and has explained the use of different values of earth's circumference by Varāhamihira, Vateśvara, Manjula, etc.

1. Shukla, K. S. and Sharma, K. V., *Āryabhaṭīya*, Indian National Science Academy, New Delhi, 1976, pp. xvii–xix.
2. Bose, D. M., Sen, S. N. and Subbarayappa, B. V., *A Concise History of Science in India*, Indian National Science Academy, New Delhi, 1971, p. 92.
3. Georges, I., *The Universal History of Numbers – II*, Penguin Books India, New Delhi, 2005, p. 182.
4. Sarma, K. V., Doctoral thesis, Panjab University, 1977, vol. I, pp. 6–8.
5. *Ibid*, p. xviii. 'Hence we can conclude without any shadow of doubt that Āryabhaṭa-I flourished at Kusumapura or Pāṭalīputra in ancient Magadha or modern Patna (long. 25°37′N, lat. 85°13′E)' (sic). (Typographical error has exchanged the latitude and longitude correct reading is lat. 25°N37′ and long. 85°E13′.) Title page of the book gives the information that *Āryabhaṭīya* had been critically edited with introduction, English translation, notes, comments and indexes by Kripa Shankar Shukla in collaboration with K. V. Sarma, whose doctoral dissertation was on the Kerala astronomical tradition.
6. *Ibid*, p. 8, footnote. Sarma has also quoted a Malayalam article as reference to the legends prevailing in Kerala.
7. Information shared on 6 April 2007 while discussing the possibility of Kallūr near about Ponnāni–Beypur area where Bhāratappuzha or Niḷa joined the sea, by C. Radhakrishnan, Meteorologist, and ex-Editor of *Bhāṣāpoṣiṇi* and *Science Today*, and well-known scholar and historian from Kerala, whose magnum opus is the research-oriented biographical novel on the life and works of Tunjathezhutachan (AD 1500), the father of modern Malayalam alphabets.
8. Kutti, N., *Melaňňattu*, Sangha Sahitya Caritram, Kerala Bhāṣā Institute, Trivandrum, 2003, pp. 276–277.
9. http://www.spacetoday.org/India/IndianAstronomy.html; 'Aryabhatta was born in 476 AD at Ashmaka in what today is the Indian state of Kerala. He was sent to the University of Nalanda as a boy to study astronomy'. Also the same description may be seen at sites like http://www.crystalinks.com/indiastronomy.html. The website http://www-groups.dcs.st-and.ac.uk/~history/Projects/Pearce/Chapters/Ch8_2.html describes that: 'We can accurately claim that *Aryabhata* was born in 476 AD, as he writes that he was 23 years old when he wrote his most significant mathematical work, the *Aryabhatiya* (or *Arya Bhateeya*) in 499 AD. He was a member of the Kusuma Pura School, but is thought to have been a native of Kerala (in the extreme south of India), although unsurprisingly there is some debate'.
10. Quoted from the website which has the same account as in the *Encyclopedia*; http://concise.britannica.com/ebc/article-9009749/Aryabhata-I.
11. Shukla, K. S. and Sharma, K. V., *Āryabhaṭīya*, p. xi of Introduction, Indian National Science Academy, New Delhi, 1976.
12. *Ibid*, 1976, pp. 123–126.
13. *Ibid*, Varāhamihira's opinion is discussed on p. 125.
14. Shukla, K. S., *The Karaṇratna of Devācārya*, Lucknow University, Lucknow, 1979, p. 26.
15. Pingree, D., Sanskrit Geographical Tables, IJHS 31(2), INSA, New Delhi, 1996, pp. 173–220.
16. *Ibid*, Tables published are illustrative of the precise mention of Palabhā in aňgulas and vyaňgulas and the differentiation of places in terms of the equinoctial shadow.
17. *Ibid*, Pingree mentions *Śārdūlakarṇavādana* and *Ardhaśāstra*, but dates them to first or second century AD. He also quotes Megathenes' record that at Dvāraka the gnomon cast no shadow around solstice. He may have quoted this observation from the natives and so we may not be that wrong if the *Ardhaśāstra* reference to the gnomon points to a traditional use of gnomons at least since 300 BC, pp. 173–174.
18. Jones, A., *Eratosthenes, Hipparchus, and the Obliquity of the Ecliptic*, JHA, 2002, p. 19. This quotes the Hipparchus value of 3:5 for Alexandria, 7:11 for Carthage, 3:4 for Rhodes and also precise measurement such as $41\frac{4}{5}:120$.
19. *Ibid*, Jones quotes O. Neugebauer with the remark that Alexandria's correct latitude is 31°13′. Ptolemy should have been able to detect a discrepancy of a quarter degree, p. 18.
20. Shukla, K. S., *Mahabhaskariya*, Lucknow University, Lucknow, 1960, p. 65.
21. Chatterji, B., *Śiṣyadhīvṛdhidatantra*, Indian National Science Academy, 1981, p. 74.
22. *Ibid*, p. 125.
23. Burgess, R. E., *Suryasiddhānta*, Chaukhamba, Varanasi, 1977, p. 43.
24. Sastry, T. S. K., *Mahābhāskarīya*, Madras Government Oriental Series, 1957, vol. 4, p. 251.
25. Shukla, K. S., *Vaṭeśvara Siddhānta Part-II*, Indian National Science Academy, New Delhi, 1985, p. 135.
26. *Ibid*, In footnote Bhaskara-II is quoted. Also at reference (7) above.
27. Berggren, J. L. and Jones, A., *Ann. Sci.*, 2003, **60**. Also, see the website http://www.yorku.ca/bwall/nats1730/bw-notes/scienceasdiscovery09-ptolemy.pdf
28. Nīlkaṇṭha quoted from Jyotirmīmāmsa in *Indian Astronomy – A Source Book*, Nehru Centre, Mumbai, 1985, p. 15.
29. Details of the place of Brahmagupta, Bhillamala may be found at Sarasvatī, Satyaprakash Swami, *A Critical Study of Brahmagupta and his Works*, Govindram Hasanand, Delhi, 1986, p. 49.
30. *Ibid*, Śrīmal became Bhillamala only during the time of King Bhoja. It is therefore likely that the original Bhilmala was at the south end of the Cāpa kingdom, 1986, p. 50.
31. Burgess, R. E., *Suryasiddhānta*, Chaukhamba, Varanasi, 1977, p. 43, Burgess quotes Bhāskara-II in the discussion.
32. Sastry, T. S. K. and Sarma, K. V., *Pancasiddhāntika*, PPST Foundation, Chennai, 1995, vol. 13, pp. 18–19.
33. Subbarayappa, B. V., Sarma, K. V., *Indian Astronomy – A Source Book*, Nehru Centre, Mumbai, p. 26.
34. Shukla, K. S., *Laghumānasam*, Indian National Science Academy, New Delhi, p. 141, Details of the place has been mentioned on p. 3.
35. Chatterjee, B., *Śiṣyadhīvṛdhida tantra*, Indian National Science Academy, New Delhi, 1981, vol. 2, pp. 28–33, Lalla has also discussed the correction of planets computed for the meridian of Ujjayinī to the local meridians.

36. Shukla, K. S., *Āryabhaṭīya*, Indian National Science Academy, New Delhi, 1976, p. 121. Shukla, K. S. and Sarma have discussed the verse as referring to the height of the Meru Mountain.
37. Bhāskara-I has devoted a chapter to discuss the 'Deśāntara-Yojanas' in *Mahābhāskarīyam*. Shukla, K. S., *Mahābhāskarīyam*, Lucknow University, Lucknow, 1960, pp. 47–55; 94. Āryabhaṭa himself speaks in verse 13 of Goḷa about the four mythical cities marking the four quarters of the earth's circumference from Laṅkā between which obviously 15 nāḍikās becomes the interval of planetary motion that must be adjusted. But Āryabhaṭa gives no rule for practical application to his local place. This is quite unnatural, given the fact that Bhāskara-I repeatedly takes the name of Āryabhaṭa and the tradition of his disciples while enunciating the different aspects of Deśāntara in Chapter 2 of *Mahābhāskarīyam*. Āryabhaṭa himself having introduced two systems of reckoning ahargaṇa from Laṅkā differing by 15 nāḍikās, needed to have related his observations to the local meridian and Ujjayinī meridian for reconciling the two systems without computational conflicts. Āryabhaṭa's adherence to the Ujjayinī meridian is evident from the fact that he reduced the year length in such a way as to avoid any conflict at his epoch of Kali 3623 when the two systems coincided. Even if it was improper for a Siddhānta to make reference to a specific location, any reference given by Āryabhaṭa to his disciples on the local meridian would have come down to us through the works of his disciples. But we meet with no such reference to the meridian of Kusumapura in the history of Indian astronomy. As shown in the discussion on spaṣṭa-bhūparidhi, Āryabhaṭa's choice of two values for the equatorial circumference had as reference, the local latitude 10°51′N and was located on the prime meridian of Ujjayinī.
38. Pingree, D., Sanskrit Geographical Tables, INSA, New Delhi, June 1996, IJHS 31(2), pp. 187 and 195.

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MEETINGS/SYMPOSIA/SEMINARS

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Date: 18–20 December 2007
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Topics include: Sequence analysis; Structure prediction; Homology modeling; Molecular visualization; Phylogenic analysis; Cheminformatics.

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