

Aryabhata Pioneer of a New Era in Indian Astronomy

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Abstract—Aryabhata was one of the most influential mathematicians and astronomers of ancient India. This paper examines his major contributions to astronomy, including his ideas on the spherical shape and rotation of the Earth, the scientific explanation of solar and lunar eclipses, relative motion of stars, planetary distances, and the heliocentric tendency in his thought. It also reviews his astronomical calculations, instruments, and the intellectual significance of works such as *Aryabhatiya* and *Arya Siddhanta*. The study highlights how Aryabhata's observations and mathematical methods laid the foundation for later developments in Indian and global astronomy.

Index Terms—Aryabhata, Ancient India, Astronomy, *Aryabhatiya*, Eclipses, Earth's Rotation, Gupta Period.

I. INTRODUCTION

India has always been a leader in science and technology since ancient times. Our prominent scholars and sages made significant contributions to this. These contributions are well-documented in the Vedas and other ancient scriptures. Among the illustrious scholars of ancient India, Aryabhata, a renowned figure from the Gupta period (3rd to 6th CE), holds a place of honour. He was born in 476 CE, either in Kusumpura or Pataliputra, present-day Patna.¹ Some sources also suggest Kerala as his birthplace. Aryabhata received his education at Nalanda University and later became its head. He spent his life in Pataliputra and also died here in 550 CE. During this period Gupta dynasty was ruled by Buddha Gupta. During his life in Pataliputra, where he authored significant works in mathematics and astronomy, including *Aryabhatiya* and *Arya Siddhanta*.² In these texts, he presented crucial mathematical formulas and scientific theories using concise Sanskrit verses. His contributions to astronomy were groundbreaking and remain accurate to this day.

In this article we will discuss about the astronomical discoveries of Aryabhata, like he said that the earth is round and rotate on its axis, he shed light on how lunar & solar eclipse occur. What is the distance of Earth and other planets from the Sun etc. which were quite revolutionary idea at that time.

Although Aryabhata was well versed in both mathematics and astronomy, he is mostly discussed for his contribution to mathematics, however his contribution to astronomy was also remarkable. In astronomy he used mathematics to express his views in very scientific way, with accuracy.

This demonstrated how progressive Indian science was during ancient times. Aryabhata's works, during his lifetime (476 CE–550 CE), included several remarkable texts that unveiled groundbreaking discoveries about the Earth and space.

While Aryabhata's ideas were revolutionary, they were not without criticism. Contemporary scholars such as Varahamihira, Brahmagupta, and Bhaskara I reviewed, critiqued, and sometimes praised his work. However, his contributions laid a solid foundation for future advancements in both mathematics and astronomy.

II. SOURCES OF ARYABHATA'S ASTRONOMICAL KNOWLEDGE

a) *Aryabhatiya*

One of the most significant sources of information about Aryabhata is his own work, *Aryabhatiya*, which he wrote at the young age of 23. This book is divided into four chapters and contains critical insights into mathematical formulas and astronomical theories. Through this text, Aryabhata revealed his profound understanding of the cosmos and brought revolutionary ideas to light.

Aryabhata's work not only highlights his individual brilliance but also exemplifies the progressive and scientific nature of ancient Indian scholarship.

Key Chapters of Aryabhata's

Aryabhata's seminal work, *Aryabhata's*, is divided into four chapters, each addressing a specific aspect of astronomy:

i. Gitika Pada (13 verses):

This chapter focuses on cosmology and describes the motions of celestial bodies over a "Maha Yuga," which Aryabhata calculated to be 4.32 million years.

ii. Ganitapada (Mathematical Section):

In this section, Aryabhata presents formulas and theories related to mathematics, including trigonometry, arithmetic, and algebra.

iii. Kalakriyapada (25 verses):

This chapter deals with the measurement of time, detailing the calculations of days, weeks, and months using various units of time.

iv. Golapada (50 verses):

In this comprehensive chapter, Aryabhata explains the causes of day and night, the rising of constellations, the phenomenon of eclipses, celestial equators, nodes, and the shape of the Earth. His work here provides significant insights into his contributions to astronomy.

Through these chapters, Aryabhata made groundbreaking advancements in understanding the cosmos.

b) Arya Siddhanta

Although this text is now lost, references to it in the works of contemporaries like Varahamihira, Bhaskara I, and Brahmagupta indicate that it contained profound insights into astronomy and mathematics.

c) Al-Naf

It is a work in Arabic Language attributed to Aryabhata, though less widely recognized.

d) Dus Getika

Another text written by Aryabhata.

Apart from his own book other contemporary scholars of his time like Brahmagupta, Varahamihira, and Bhaskara I gave their comments on his book and reviewed his work from which we get detailed information about his work. Additionally, foreign travellers and scholars like Al-Biruni and Al-Abu

Rayhan discussed Aryabhata's contributions in their works, demonstrating his influence beyond India.

Based on above references we can learn about notable discoveries of Aryabhata:

➤ Earth's Rotation and Revolution

Aryabhata was the first to propose that the Earth is spherical and rotates on its axis, which was a revolutionary idea at the time.³ This has been mentioned in his contemporary's scholar Brahmagupta's *Khandkhadya*. Aryabhata challenged the then-prevalent belief that the Earth was stationary and supported by a physical base. Later on, during 16th CE Copernicus Scientifically proved the same i.e. Earth is spherical and rotates on its axis.

Aryabhata based on movements of stars, calculated Earth's rotation period as 23 hours, 56 minutes, and 4.1 seconds, remarkably close to the modern value of 23 hours, 56 minutes, and 4.091 seconds, with only a fractional difference.

He estimated the length of the sidereal year as 365 days, 6 hours, 12 minutes, and 30 seconds (365.25858 days), which is only 3 minutes and 20 seconds off from the modern value of 365.25636 days.

➤ Circumference of the Earth

Aryabhata calculated the Earth's circumference to be 39,968.05 km, which is only about 2% smaller than the modern measurement of 40,075.01 km.

➤ Height of the Atmosphere

He estimated the height of the Earth's atmosphere to be 80 km, showcasing his observational precision. As we know that earth's atmosphere ranges up to 10,000 KM but the maximum density of air is only up to 80 km.

Aryabhata's ability to make these near-accurate calculations without modern instruments highlights the advanced state of ancient Indian science and his extraordinary genius.

➤ Explanation of Solar and Lunar Eclipses

In ancient Indian scriptures, solar and lunar eclipses were often attributed to mythical demons like Rahu and Ketu, who were believed to "swallow" the Sun or the Moon, causing darkness. Aryabhata, however, rejected these explanations and provided a scientific understanding of eclipses:⁴

- Lunar Eclipse: Aryabhata explained that a lunar eclipse occurs when the Earth's shadow falls on the Moon.
- Solar Eclipse: He stated that a solar eclipse happens when the Moon comes between the Earth and the Sun, blocking the Sun's light.

Aryabhata accurately calculated the angular sizes of the Earth's shadow and the Moon's orbit. He also devised methods to determine which part of the Moon would be covered during an eclipse and how to calculate the duration of partial and total eclipses.

➤ Theory of Relative Motion of Stars

Aryabhata proposed a groundbreaking theory of relative motion to explain the apparent motion of stars.

- He stated that the Earth rotates on its axis daily, and this rotation creates the illusion of stars moving in the opposite direction.
- In the Golapada section of Aryabhatiya, he illustrated this idea by comparing the motion of stars to how a stationary object appears to move backward when observed from a moving vehicle.⁵

According to Aryabhata:

- A person standing at the equator would perceive fixed stars moving uniformly westward.⁶
- The apparent rising and setting of stars are caused by the Earth's rotation. This concept of relative motion was one of the most revolutionary ideas in Indian astronomy and demonstrated a profound understanding of celestial mechanics.

➤ Sun-Centric Theory

Aryabhata also presented an early form of the heliocentric model:

- He proposed that the Sun is stationary and at the center, with planets, including the Moon, revolving around it.
- He asserted that celestial bodies, including the Moon, do not emit their own light but reflect sunlight.

Aryabhata further explained that the portion of the sky illuminated by the Sun's rays forms the boundary of the celestial sphere, which he called the "periphery of the heavens."

While some aspects of Aryabhata's Sun-centric theory were later refined or disproven by modern science—such as the Sun's rotation on its axis and stars having their own light—his insights were remarkably

advanced for his time. Given the limited resources and observational tools available, Aryabhata's contributions laid a crucial foundation for future astronomical research.

➤ Additional Insights

In Golapada, Aryabhata also described time zones and the relationship between geographical locations and celestial events:

- He noted that when the Sun rises in Lanka (present-day Sri Lanka), it is still night in Siddhpur which is situated in the north direction where the sun sets. It is midday in Yavankoti and midnight in the Roman province (west).

This demonstrated his understanding of the Earth's spherical shape and rotation, which causes differences in sunrise and sunset times across regions.

Aryabhata's work, despite limitations in experimental tools, remains a testament to the intellectual achievements of ancient Indian science. His theories on eclipses, motion, and celestial mechanics were revolutionary and showcased a scientific mindset far ahead of his era.

➤ Other Facts Related to Earth

Aryabhata made significant contributions to understanding Earth's nature and position in Cosmos. He said that the earth is not situated on any base, this is baseless. This concept was later supported by scholars like Varahamihira and Bhaskaracharya.

According to him, the earth which is completely spherical and is surrounded by orbits of planets in the centre of the space and in the middle of the circle of the stars, is made up of four elements such as earth, water, fire and air. He didn't include the fifth element sky in it, due to which he was criticised a lot. Later, the contemporary scholar explained the five great elements by including sky, in the Panchamahabhuta (five elements) theory.⁷

Aryabhata used the analogy of a Kadamba flower, describing Earth as spherical and surrounded by terrestrial and aquatic entities.

Eternal Nature of Time

Aryabhata dismissed the idea of creation and destruction of the universe. For him, time was an eternal, continuous process without a definitive beginning or end. He believed that cycles of time like

yuga and kalpa were based on astronomical phenomena and not linked to earthly events.

➤ Distance Between Sun and Planets

Aryabhata remarkably estimated the distances of planets from the Sun. His calculations were astonishingly close to modern measurements, despite the lack of advanced instruments or telescopes. Below is a comparison of Aryabhata's estimates and modern values (in Astronomical Units, AU):

Planet	Aryabhata's Value (AU)	Modern Value (AU)
Mercury	0.375	0.387
Venus	0.725	0.723
Mars	1.538	1.523
Jupiter	4.16	4.20
Saturn	9.41	9.54

The minimal error in his calculations is remarkable, showcasing his profound understanding of planetary distances using mathematical and astronomical principles.

➤ Moon and its Orbit

Aryabhata made several insightful observations about the Moon:

- Angular Distance from the Sun: He stated that the Moon is visible 12 degrees away from the Sun.
- Apogee of the Moon: He identified the apogee as the farthest point in the Moon's orbit from Earth.
- Ascending Node: He defined the Moon's ascending node as the point where it crosses the ecliptic (Earth's orbital plane) moving northward.⁸

➤ Basis for Measuring Planetary Distances

Aryabhata used proportional calculations based on observations to estimate the relative distances of planets from the Sun. His methods, though lacking the precision of modern tools, were innovative and relied on a deep understanding of geometry, trigonometry, and astronomical cycles.

Aryabhata's work demonstrated a scientific approach that was centuries ahead of his time. His calculations, rooted in observation and mathematical reasoning, continue to be celebrated as a landmark in the history of Indian science and astronomy.

➤ Aryabhata's Astronomical Calculations

Aryabhata used various physical principles and geometric techniques for his astronomical computations. Some key methods of his calculations include:

1. Calculation Based on the Distance Between the Earth and the Sun:
 - By multiplying the distance between the Earth and the Sun with the Earth's diameter and dividing it by the difference between the diameters of the Earth and the Sun, one can derive the length of the Earth's shadow relative to its diameter.
 - Using the shadow's length and the difference between the Earth-Moon distance, multiplying by the Earth's diameter and dividing by the shadow's length, the diameter of the Earth's shadow at the Moon's orbit can be determined.
2. Calculation of Sthityardha (The square root of the remainder is known as Sthityardha)⁹
 - The square of the sum of half the diameters of the Sun and Moon, or the Moon and the shadow, is taken. From this, the square of the Moon's celestial latitude is subtracted.
 - The square root of the remainder is termed as Sthityardha.
 - Sthityardha is used to calculate the time from the first contact to the last contact during an eclipse.
3. Determination of Lunar Eclipse:
 - By subtracting the Moon's radius from the Earth's shadow radius and further subtracting the celestial latitude, the portion of the Moon unaffected by the eclipse is determined.
 - The duration of the eclipse is calculated by adding the given time to the celestial latitude.¹⁰

➤ Instruments Used by Aryabhata

Aryabhata employed various instruments for astronomical experiments. These instruments are mentioned in his now-lost work, Arya Siddhanta. Insights into this book are derived from other texts, which describe the significant tools he used for geographical and astronomical experiments. These include:

1. Shadow Instrument: A tool used for measurements based on the shadow cast by the Sun.
2. Angle-Measuring Instrument:

Used to measure the angular positions of celestial bodies.

3. Semi-Circular and Circular Gauges:

Instruments for measuring the positions and movements of celestial objects.

4. Umbrella-Shaped Device

Likely used for celestial measurements.

5. Yasti Yantra (Rod Instrument):

A cylindrical rod used for measuring angular distances and astronomical calculations.

6. Water Clocks:

Designed in bow-shaped and cylindrical forms, these were used to measure time.

Using these instruments and calculations, Aryabhata precisely computed astronomical events. He provided profound insights into the Sun, Moon, planets, and eclipses, reflecting his advanced scientific knowledge for that era.

Aryabhata's contributions remain a cornerstone in the history of astronomy, not just in India but worldwide.

III. ARYABHATA'S WORKPLACE (KARMASTHALI)

Aryabhata spent most of his life in Pataliputra, known today as Patna. He established his primary workplace 35 kilometers away in Taregana, located near Masaurhi. At this location, Aryabhata studied the positions of celestial bodies, including stars, planets, and constellations.

The name "Taregana" is derived from the phrase "tara gina," meaning "counting stars," reflecting its historical significance in astronomical studies. Taregana was an ideal place for astronomical research. Unfortunately, Aryabhata's workplace at Taregana has largely been neglected over time. There is a need to recognize its importance and make proper use of this historically significant site.

IV. CONCLUSION

Aryabhata was one of the most prominent mathematicians and astronomers of ancient India, playing a critical role in enriching Indian knowledge. While his contributions to mathematics were paramount, he was also highly proficient in astronomy.

Aryabhata introduced several groundbreaking concepts about Earth, including its spherical shape and rotation on its axis.

He accurately calculated the circumference of the Earth, which was only 2% smaller than the actual measurement.

Based on Earth's rotation, he explained the calculation of years, days, and hours.

Aryabhata also provided detailed explanations of solar and lunar eclipses.

Aryabhata's astronomical methods were so advanced that they were adopted in the Islamic world for calendar calculations, known as the Zij.¹¹

Aryabhata's techniques for astronomical calculations were highly popular among astronomers of his time and beyond. His work not only established fundamental principles of astronomy but also linked them closely to mathematics, making calculations simpler and more accurate.¹²

He writes that "I dived deep into the true and false sea of astronomical theories and through the boat of my intellect I rescued the precious sunken gem of true knowledge"¹³. Clearly his conclusion was based on his own observation and research.

Aryabhata's influence on Hindu astronomy is evident, as there is hardly any work in the field that does not reference him or his methods. Numerous commentaries on his works have been written in Sanskrit and other regional languages, especially in South India. Independent works inspired by Aryabhata's theories have also been created, cementing his legacy as a cornerstone of ancient astronomy.

Aryabhata's innovative ideas and dedication to knowledge remain a source of inspiration, showcasing the depth of ancient Indian scientific thought and its global influence.

Aryabhata stands as the first known historical figure to undertake systematic work in astrology (jyotish) and astronomy. Undoubtedly, he is one of the greatest scientists ever produced by India.¹⁴ His contributions to astronomy and mathematics mark a turning point in ancient Indian scientific thought, reflecting his genius and pioneering spirit. But it is matter of regret that he did not get as much respect as the scientist of the western world got.

In today's context, it is crucial for the nation to comprehend and build upon the work of such great

personalities. Drawing inspiration from Aryabhata's monumental contributions can help us reconnect with our glorious past and use it as a foundation to enrich the modern Indian scientific and cultural landscape. His work remains a testament to India's historical achievements in science and technology.

By understanding and preserving Aryabhata's work, we can better appreciate the brilliance of ancient Indian science and inspire future innovations in the fields of astronomy.

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