REVIEW OF *SURYA SIDDHANTA*, FOCUSING ON SOME ASTRONOMICAL ASPECTS

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Abstract: *The present study investigates the mathematical and astronomical principles embedded in Surya Siddhanta, an ancient Indian text. Using translated versions in Hindi and English to overcome the Sanskrit language barrier, we decode its celestial mechanics, including elliptical orbits, radial and angular velocity dynamics, and gravitational analogs. Remarkably, the text's calculated planetary diameters show a correlation coefficient of 0.9995 compared to modern values.*

Furthermore, Surya Siddhanta employs iterative numerical techniques to estimate planetary velocities and cosmic timescales, demonstrating its sophisticated approach. By translating Sanskrit slokas into mathematical and graphical forms, this research bridges ancient and modern scientific traditions and highlights the continuing relevance of traditional knowledge.

Keywords: ancient astronomy, cosmic timescales, iterative numerical techniques, *Surya Siddhanta*

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Introduction

Early societies relied on celestial observations for survival (Neugebauer: 1957). Ancient cultures saw celestial events as manifestations of the divine (Vahia and Halkare: 2013). Constellations served as celestial storytellers, blending observation with mythology to preserve cultural knowledge (Parker: 1974:51-65). This integration made astronomy central to cultural and religious life (Neugebauer: 1957). Civilizations developed sophisticated astronomical practices, constructing observatories like Jantar Mantar and Caracol, aligning monuments like the pyramids with celestial events (Kulkarni: 1983), and creating intricate calendars (Aveni: 2001; Needham: 1959). This involved meticulous observations, mathematical modeling, and the development of astronomical instruments like the gnomons, sundials, water clocks, Yasti Yantra, Chakra Yantra, etc. (Pingree: 1978b; De: 2022; Kumar: 2022). Centres of learning like Takshashila and Nalanda in India furthered these advancements (Kumar: 2022).

The *Surya Siddhanta* is a 4th-5th century CE Sanskrit text (Burgess and Gangooly: 1989); Bowman: 2000). The *Surya Siddhanta* is a cornerstone of ancient astronomical knowledge, providing mathematical methods for determining solstices and equinoxes with remarkable accuracy, showcasing the advanced observational skills of ancient Indian astronomers (Sarma: 2008; Wijk:1938:1-25). It describes a geocentric universe divided into concentric spheres, a model that, despite being replaced by the heliocentric system, proved highly effective for practical astronomy (Pingree: 1978a). The *Surya Siddhanta* provides advanced methods for calculating planetary positions, day-night duration, eclipses, and celestial mechanics (Barbour: 1989; Sarma: 1990). Its precise calculations, including the sidereal year (365.2564 days), angular diameters, and planetary distances, demonstrate remarkable accuracy and advanced observational techniques (Sharma: 2009; Thibaut: 1899; Thompson: 1997: 193-200). It has trigonometric innovations, such as sine and cosine (*jya* and *kojya*), and its trigonometric tables facilitated accurate astronomical modeling (Sharma: 2009; Datta: 2001). Its influence extended globally, shaping Islamic and later European astronomy through translations by Al-Biruni and others (Kaye: 1915; PingreeL 1970). It served as a foundation for works like the *Aryabhatiya* and the *Brahmasphutasiddhanta*, underscoring its enduring legacy (Pingree: 1978a). The text remains significant for its historical, scientific, and mathematical contributions to global astronomy.

This study holds both historical and astronomical significance. From an astronomical perspective, this study aims to bridge the gap between ancient and modern astronomy, highlighting the advanced understanding of celestial mechanics presented in the *Surya Siddhanta*. The primary objective of this study is to explore the astronomical insights of the *Surya Siddhanta*. Specifically, it focuses on analysing radial and angular velocities in planetary motion, examining ancient methods for time measurement and universe age estimation, and validating planetary diameter calculations using modern astronomical data. These objectives aim to bridge ancient knowledge with contemporary scientific understanding, highlighting the precision and sophistication of the text. The study utilises key translations of the *Surya Siddhanta* by Ebenezer Burgess, Bapu Deva Sastri, and others as primary sources. Different tools are used for visualisation and mathematical modelling. Analytical methods involve comparing the text's calculations with modern data to evaluate its accuracy. By leveraging these resources and techniques, the research systematically examines the mathematical and astronomical principles presented in the *Surya Siddhanta*.

Findings

Explanation of Velocity

Surya Siddhanta explains two typesof velocities. It states that the movement of every planet is fundamentally the same (Sastri: 1864). However, due to differences in the descriptions of their orbits, there appears to be a variation in velocity. There is no difference in the radial velocity around the orbit. This highlights that the apparent differences in planetary speed are a result of observational perspectives influenced by orbital geometry, while the actual motion remains consistent. This explanation of velocity is one type of velocity explained in *Surya Siddhanta*. The explanation of this verse is explained geometrically by following Fig. 3.2.

At the endpoint of the *Mina*, denoted as point A of Fig. 3.3, lies the endpoint of the *Nakshatra Revati*. According to the *Surya Siddhanta,* when a stellar object starts from this point and returns to the same *Rashi Mandala*, it completes one *Bhagana*, highlighting the cyclic nature of celestial motion (Burgess 1860).

From Fig. 3.2, if we consider one *Bhagana* for objects at *H* and *J*, with lengths of orbits l_1 and l_2 respectively, the *Bhagana* is directly proportional to the length of the orbit:

$$B_1 \propto l_1, B_2 \propto l_2$$

$$\text{So,} \quad B_2 = \frac{l_2}{l_1} B_1$$

As $l_2 > l_1$, the ratio $\frac{l_2}{l_1}$ is greater than 1. Thus, the *Bhagana* for the object *J* (B_2) is longer than that for the object *H*(B_1), despite having the same velocity. In the same *Slokha*, the angular velocity is defined as *Konatmak Gati*, with a high *Konatmak Gati* resulting in a faster revolution. *Surya Siddhanta*'s translation means that the Earth will rotate around the Sun in 24 hours, but for better modeling, this should assume that the meaning is for the *Nakshatra Mandala*. Every object has a *Nakshatra Mandala*, as shown in Fig. 3.3, revolving in an elliptical plane. The concept of elliptic orbits is defined through the terms *sighrochha*, *sighra* meaning fast, and *uchha,* meaning highest (highest point for velocity) and *mandochha* (lowest point for velocity) in the orbit plane, with the object positioned at the foci of the ellipse (Chaturvedi: 1917). The equation of an ellipse and the general equation of a plane containing the ellipse are:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$

$$Ax + By + Cz = 0$$

The expression is defined as the ellipsoid and plane intersection equation (Wu: 2012:1-7). Consider two points, *sighrochha* (x_1, y_1, z_1) and *mandochha* (x_2, y_2, z_2), in this plane, as in Fig. 3.1. The normal vector defined by these points from the origin explains the ellipse in the above second equation. The term *sighrochha* refers to the highest point for fast motion, while *mandochha* refers to the highest point for slow motion. These points define the regions of maximum and minimum velocities along the elliptical orbit, highlighting the elliptical nature of the stellar object's path. When considering the interaction between two rotating spaces of different celestial objects, the force $F_{\text{interaction}}$ at a distance *r* can be described by the gradient of their angular velocities:

$$F_{\text{interaction}} \propto \nabla(\Omega_1 \cdot \Omega_2)$$

Since the angular velocity Ω is constant for each object at the surface; this interaction simplifies the angular rotation of the *mandala.* The force responsible for moving objects is attributed to the movement of space, known as *Prawaha* in Sanskrit. *Surya Siddhanta* also explains the instantaneous velocity of the true planet. In *Surya Siddhanta*planet is true if it has a shadow, and a shadow is a false planet. The instantaneous velocity of a planet at any given time can be understood by examining its motion in terms of true and mean positions. As θ_m is known as the mean position of that planet and $\Delta\theta$ is the term for correction. The true position (θ) and the instantaneous velocity (*v*) of a planet in the celestial sphere having a certain mass can be explained and given by:

$$\theta = \theta_m + \Delta\theta, v = \frac{d\theta_m}{dt} + \frac{d(\Delta\theta)}{dt}$$

Where, $\frac{d\theta_m}{dt}$ is the mean velocity of the planet and $\frac{d(\Delta\theta)}{dt}$ is the rate of change of the correction term. Thus, the instantaneous velocity of the true planet is the sum of the mean velocity and the correction terms rate of change. The mean position is computed based on the sidereal Period:

the time for one full revolution relative to the fixed stars. And Daily Motion: $\theta_m = \theta_0 + n$, where θ_0 is the initial position, n is daily angular motion, and t is the elapsed time (Emch, Sridharan, and Srinivas 2005). The correction term accounts for deviations using two trigonometric corrections: Manda Correction Adjusts for orbital eccentricity. $\Delta\theta_{manda} = e \cdot \sin(M)$, where e is the eccentricity and M is the mean anomaly. Sighra Correction Accounts for angular deviation due to epicycles. $\Delta\theta_{sighra} = k \cdot \sin(S)$. Where k is a coefficient related to the epicycle, and S is the *sighra* anomaly. The total correction is:

$$\Delta\theta = \Delta\theta_{manda} + \Delta\theta_{sighra}$$

Time Representation

Surya Siddhanta describes time as *Murta* (perceivable) and *Amurta* (unperceivable) (Pandey: 2013) can be expressed as:

$$T = t + it'$$

Murta time units include: One prana equals 4 seconds, and 1 second equals 11.25 *nimesh*. The solar day *(ahoratra)* is slightly longer than a sidereal day *(nachhatra din)*. Time units expand up *to dibyawarsha* (divine year) with 360 *dibya din* (Srivastava: 1941). To understand the age of the universe, we must grasp the concept of *Chaturyuga*, a cycle of four yugas*: Satya Yuga, Treta Yuga, Dvapara Yuga, and Kali Yuga*, including their transitional phases *(Sandhya)*. According to the *Surya Siddhanta,* the durations of *Yugas* and their *Sandhyas* are given in Table 2. In the pie charts in Fig. 3.4 and Fig. 3.5, Table 2 is expressed for *yugas* with and without *sandya.* The figure shows that the duration of *yugas* does not change the ratio, rather longer the time when we consider their *Sandhyas*.

The time measurement in *Surya Siddhanta* has a different dimensional approach for small and cosmic time, where the dimension changes for cosmic time with 1 *sauryawarsha* equals 1 *dibya din*. The different time units in Table 1 and Table 2, in both small and cosmic ways, are given in the graph in Fig.3.6.

Each *yuga* has transitional periods *(Adi Sandhya and Sandhyansha)* equal to 1/12th of its total duration, symbolizing gradual cosmic changes. To calculate the total time for a *Mahayuga*, we must account for both the core duration of the four *yugas* and their *Adi Sandhya and Sandhyansha* phases. Thus, the corrected *Mahayuga* and a *Manvantara*are is defined as: *1 Manvantar = 71 Mahayuga + Sandhya* in a billion years: 469.746 billion years. This is the age of the universe. In the *Surya Siddhanta,* various units of time are systematically defined, forming a hierarchical structure from smaller to larger periods. Due to inherent imperfections in calculations or approximations, small errors accumulate with larger units. To address this, each unit includes a correction term, ensuring system accuracy. For instance, let τ_{A2} represent a time unit derived from τ_{A1}, with a multiplicative factor λ. An additional correction term, τ_{A0}, compensates for errors resulting in:

$$\tau_{A2} = \lambda \cdot \tau_{A1} + \tau_{A0}$$

This method ensures precision across all levels of time measurement in the *Surya Siddhanta*. According to modern science, the age of the universe is explained using the Hubble constant. The age of the universe, according to modern science, is approximately 13.8 billion years. The comparison between *Surya Siddhanta* and current time measurement is given in the graph in Fig.3.7.

Explanation of Planetary Diameters

In Chapter 7, Verse 13 of the *Surya Siddhanta,* the apparent diameters of Mars, Saturn, Mercury, Jupiter, and Venus are described in *yojana* units. The conversion factor from *yojana* to kilometres is given in a range of 3-15 km in various works. For best fit, and some work has shown 8 km for a *yojana*, we will use 8.047 km/*yojana* Diameters for Mars, Saturn, Mercury, and Jupiter increase successively by half of the half: 30, 37.5, 45, 52.5 *yojana*, respectively. Venus has a diameter of 60 *yojana*, which corresponds to its radius. In the *Surya Siddanta*, angular diameters are calculated based on these values at the Moon's orbit distance. This leads to the expression:

$$D(\text{planet}) = \theta \cdot d_{\text{planet}} = \frac{D_M(\text{planet})}{d_{\text{moon}}} \cdot d_{\text{planet}}$$

Here, D_M(planet) is projected diameters, and d_{moon} is the distance to the Moon (Thompson 1997). The calculations based on the above formula with:

$$D(Jupiter) = \frac{422.47}{384{,}400} \times 588{,}000{,}000 = 133{,}972.78\text{km}$$

$$D(Mars) = \frac{241.41}{384{,}400} \times 78{,}000{,}000 = 6{,}429\text{km}$$

$$D(Venus) = \frac{965.64}{384{,}400} \times 41{,}400{,}000 = 11{,}926\text{km}$$

$$D(Saturn) = \frac{301.76}{384{,}400} \times 1{,}200{,}000{,}000 = 111{,}265\text{km}$$

$$D(Mercury) = \frac{362.12}{384{,}400} \times 91{,}700{,}000 = 4{,}841.98\text{km}$$

The graph in Fig. 3.9 demonstrates the accuracy of the *Surya Siddanta* in estimating planetary diameters. It reflects a sophisticated understanding of planetary dimensions, achieved despite the limited observational tools of its time. From the figure for *x* and *y* for the diameter of different models: Modern and *Surya Siddanta*, as in Table 3 and Fig. 3.8 shows near-perfect correlation with correlation coefficient of 0.9995.

Discussion and Conclusion

The *Surya Siddhanta* demonstrates ancient India's advanced understanding of astronomy and mathematics, standing as a testament of ancient and profound astronomical and mathematical ingenuity. This study deciphers its celestial mechanics, revealing concepts that resonate strikingly with modern principles. The text's explanation of planetary velocities, attributing apparent differences to orbital geometry rather than intrinsic speed, parallels contemporary understandings of radial and angular motion. Concepts like elliptical orbits and terms such as *sighrochha* (fast point) and *mandochha* (slow point) highlight its sophisticated grasp of celestial dynamics, predating formalized Kepler's laws. The text also offers unique interpretations of gravitational-like forces and time. By using units like *prana*, it links perceptible time to cosmic cycles, presenting a precise system still relevant today. In the *Surya Siddhanta,* time is categorized into *murta* (perceivable) and *amurta* (unperceivable) units. For smaller time scales, the conversion between units follows a structured ratio, like modern unit conversions. If a time unit τ_{A2} is derived from a smaller unit τ_{A1} with a proportional factor λ, the relationship is given by: $\tau_{A2} = \lambda.\tau_{A1}$. However, for larger time scales, *amurta* time introduces corrections due to accumulated variations. In such cases, the conversion is influenced by an additional correction term τ_{A0}, leading to: $\tau_{A2} = \lambda \,.\, \tau_{A1} + \tau_{A0}$. This adjustment ensures precision in time measurement across different scales, reflecting the text's deep understanding of cosmic time. The correction term does not change the ratio of time division ratio, but it longer the period.

Notably, the *Surya Siddhanta* demonstrates exceptional precision in quantifying planetary diameters, achieving a near-perfect correlation (0.9995) with modern measurements despite relying on angular projections and observational limitations. While its estimate of the age of the universe (469.7 billion years) deviates from modern cosmology, it reflects a bold and profound effort to grasp the vastness of time.

In conclusion, the *Surya Siddhanta* bridges ancient and modern science, blending precision with philosophical depth. Its insights into planetary motion, time, and cosmic scales continue to inspire scientific exploration. This study reinforces the importance of preserving and revisiting ancient texts, deepening both historical understanding and contemporary scientific exploration.

Tables

Table 1: Shows traditional units of time measurement from ancient Indian astronomy, illustrating the hierarchical relationships from the smallest unit (nimesh) to the divine day (dibya din) through systems like prana, vinadi, nadi, ahoratra (day-night)

Units	*Equivalent*
6*pranas*	1*vinadi*
60*vinadi*	1*nadi*
60*nadi*	1*ahoratra*
30*ahoratra*	1*masa*
18*nimesh*	1*kashtha*
30*kashtha*	1*kala*
30*kala*	1*ghatika*
2*ghatika*	1*muhurta*
30*muhurta*	1*ahoratra*
30*ahoratra*	1*sawanmash*
12*sawanmash*	1*sawanwarsha*
1*sauryawarsha*	1*dibyadin*

Table 2: Shows the durations of the four *Yugas* (cosmic ages) in ancient Indian cosmology and their transitional periods *(Sandhyas).* Each *Yuga - Satya, Treta, Dvapara, and Kali*—is measured in divine years and reflects a progressive decline in *dharma*

Yuga	*Duration*	*Sandhya*
Satya	4,800	400
Treta	3,600	300
Dvapara	2,400	200
Kali	1,200	100

Table 3: Comparing planetary diameters as given in ancient Indian astronomical texts (S) with modern scientifically measured values. The close approximations highlight the advanced observational techniques and astronomical understanding embedded in the classic *Surya Siddhanta*

Planet	*S(km)*	*Modern(km)*
Jupiter	133,972.78	139,820
Mars	6,429	6,779
Venus	11,926	12,104
Saturn	111,265	116,460
Mercury	4,841.98	4,988.95

Illustrations

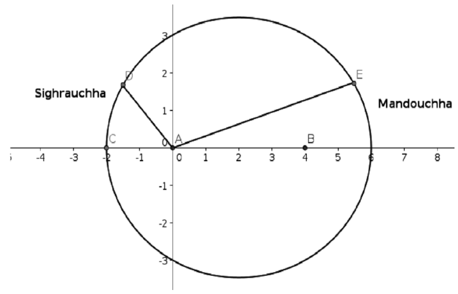

Fig. 3.1: Illustration showing the two critical points*: Sighrauchha and Mandouchha* along the orbital path known as *Bhagana.* These points are significant in ancient Indian astronomical models for describing the non-uniform motion of celestial bodies, reflecting an early understanding of orbital mechanics like the concept of modern astronomy.

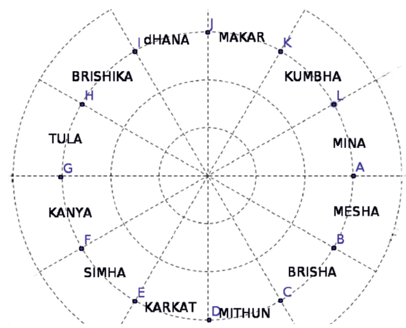

Fig. 3.2: A graphical representation illustrating the motion of a celestial body as described in the *Surya Siddhanta.* The diagram demonstrates how two objects, starting simultaneously from points H and J with equal velocities, reach points G and F, respectively, at the same time but do not complete *Bhagana* at same time.

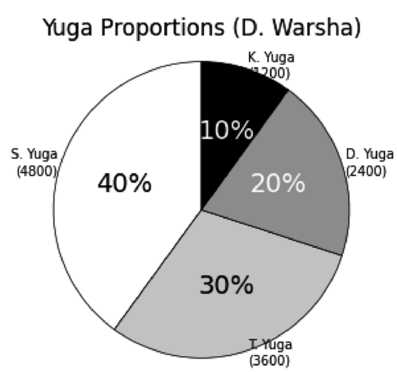

Fig. 3.3: Depiction of the 12 *Rashi Mandala* (zodiacal divisions) arranged uniformly around a central mass, as outlined in *the Surya Siddhanta*. Each *Rashi* occupies an equal area and spans an identical segment of the orbital path *(Bhagana),* reflecting the division of the ecliptic into twelve equal parts, a foundational concept in ancient Indian astronomy and astrology.

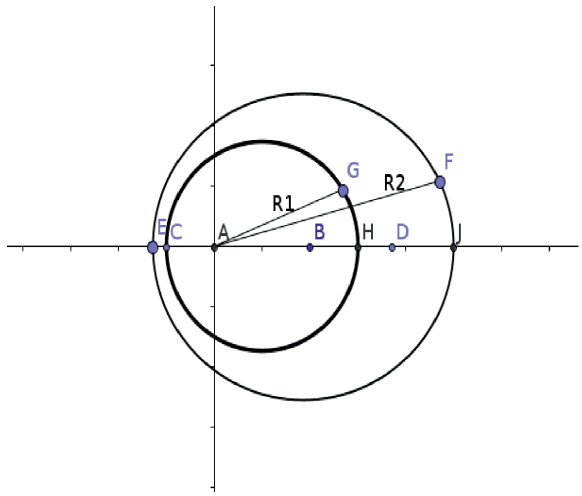

Fig. 3.4: Pie chart illustrating the relative durations of the four *Yugas-Satya, Treta, Dvapara, and Kali*-excluding their transitional periods *(Sandhyas).*

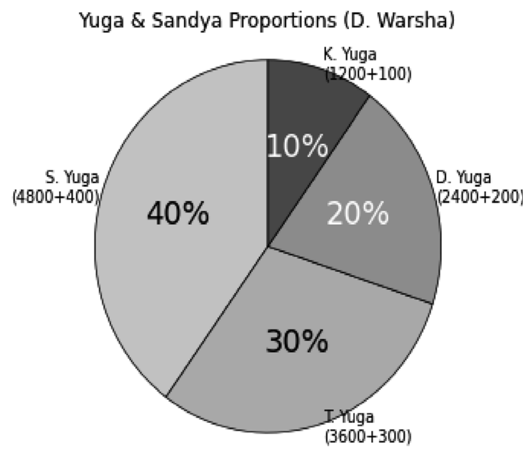

Fig. 3.5: Pie chart illustrating the relative durations of the four *Yugas-Satya, Treta, Dvapara, and Kali*-including their transitional periods *(Sandhyas).*

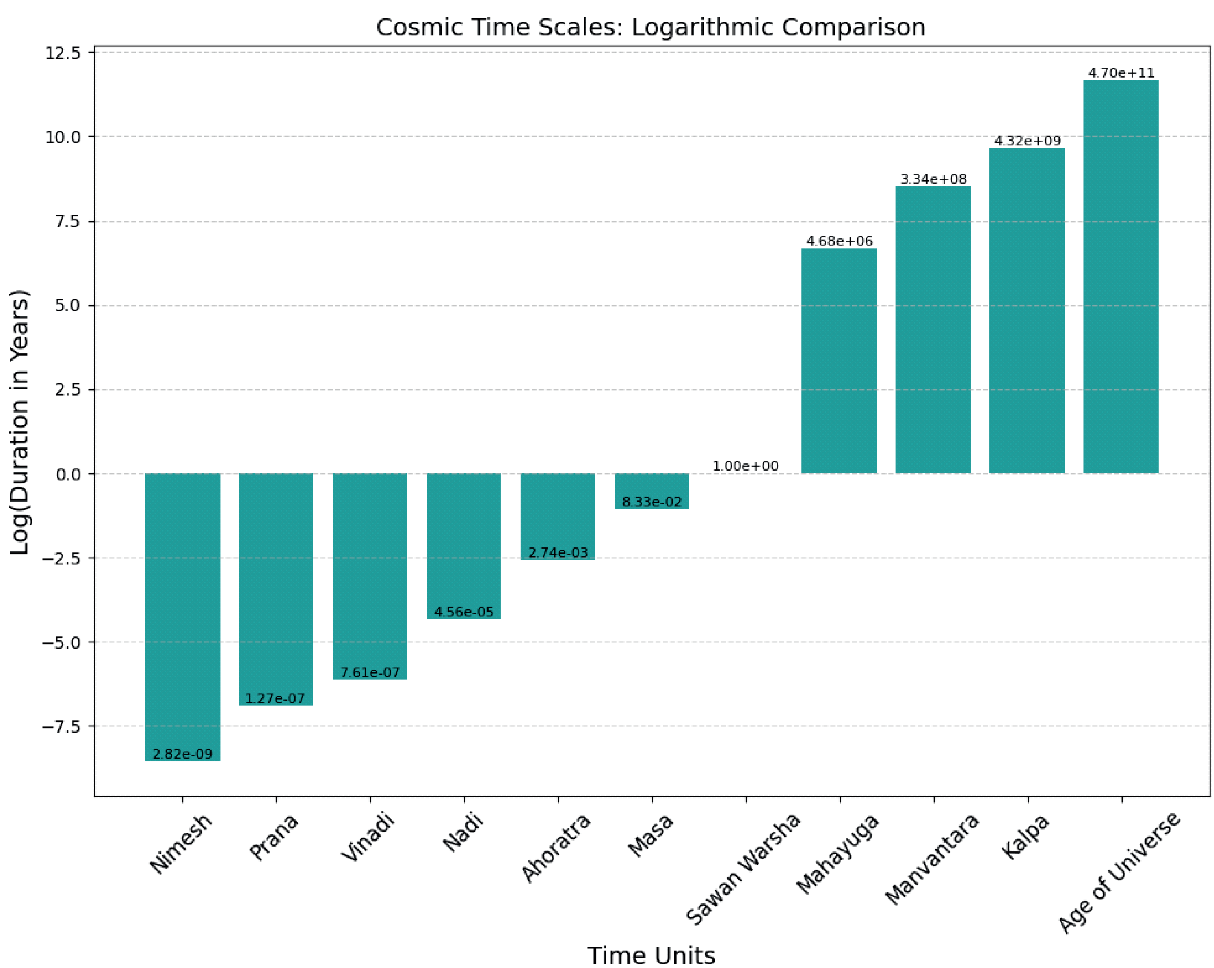

Fig. 3.6: Pictorial representation of small-time scales and the age of the Universe according to the *Surya Siddhanta.* This diagram illustrates the vast chronological framework *of Kalpas, Manvantaras, and Yugas,* reflecting the cyclical and expansive nature of time.

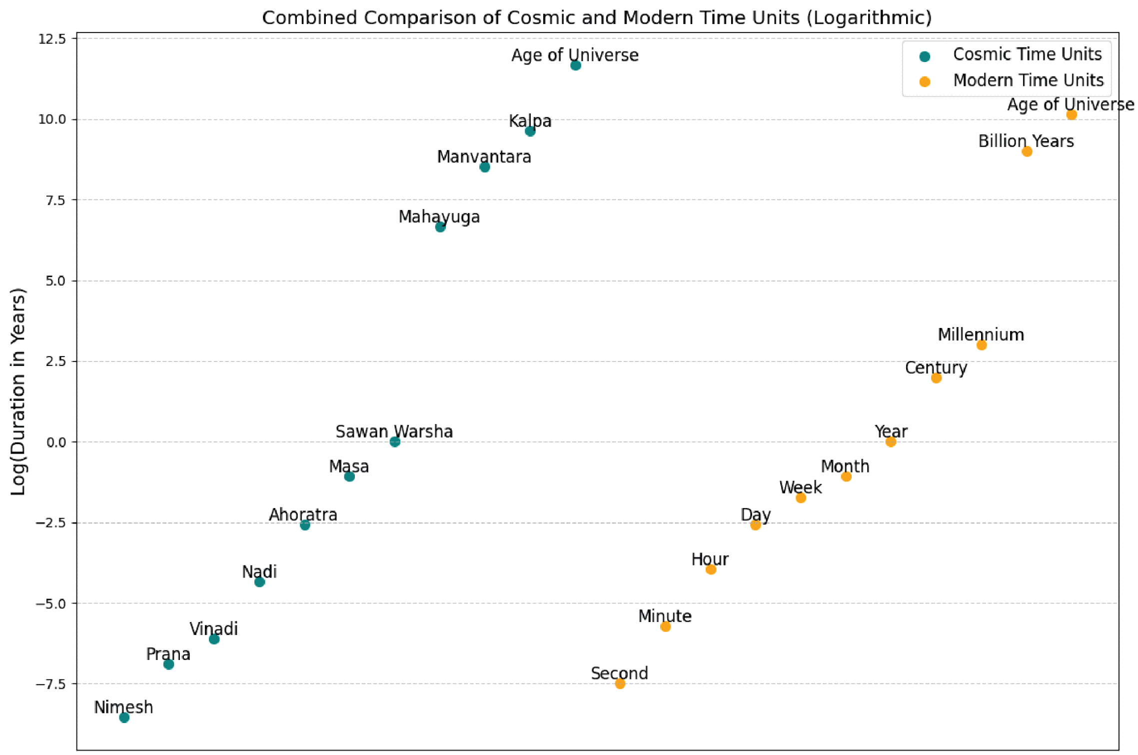

Fig. 3.7: Graphical representation of time scales ranging from the smallest unit (such as *nimesha*) to the age of the Universe, as described in the *Surya Siddhanta*, alongside corresponding time scales from modern science.

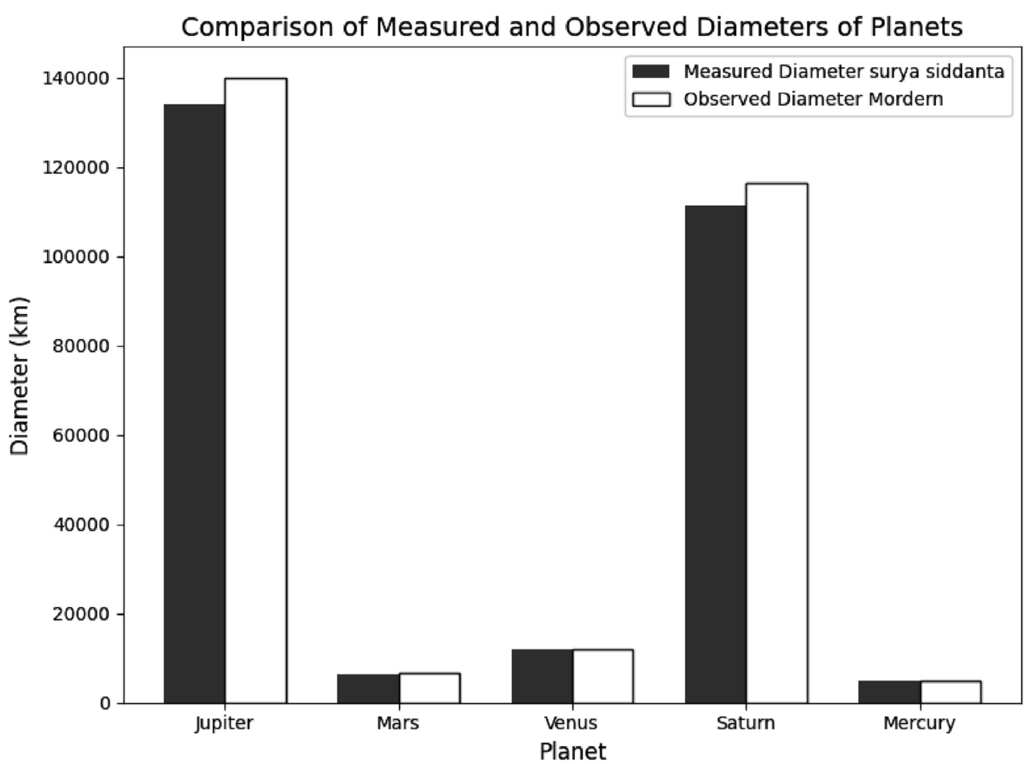

Fig. 3.8: Histogram comparing the diameters of planets as described in the *Surya Siddhanta* and modern scientific measurements. This visualization contrasts the values provided in ancient Indian astronomical texts with the current measurements, highlighting the accuracy.

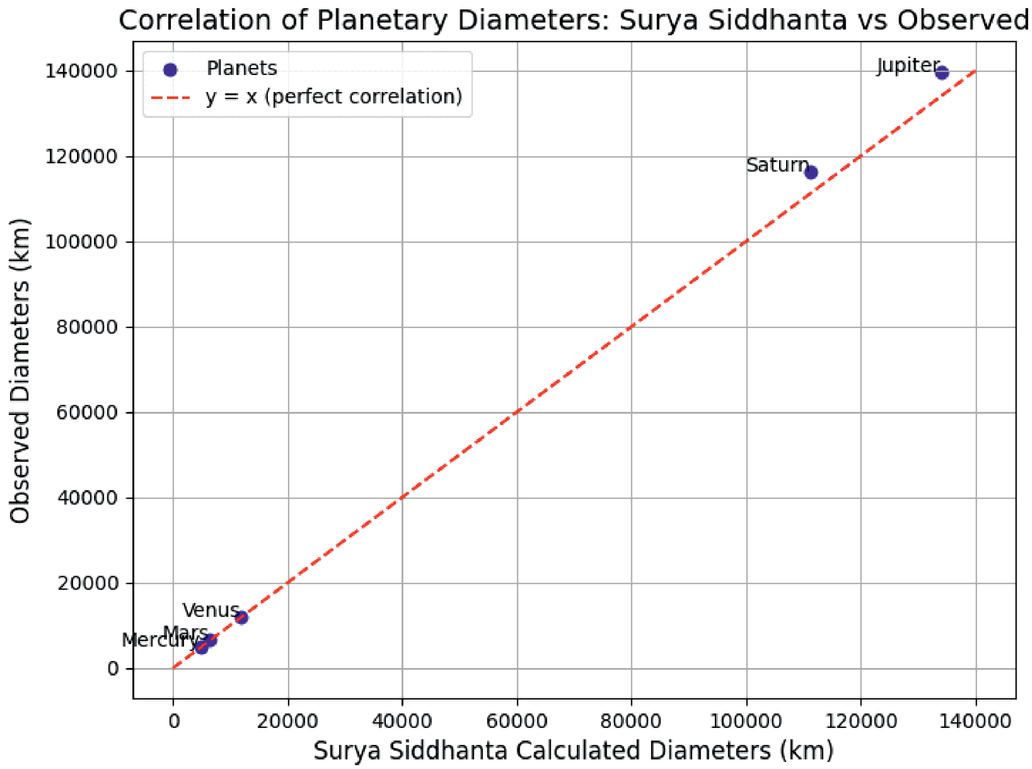

Fig. 3.9: Correlation to show the comparison of Diameters of Planets as explained in *Surya Siddanta* and modern measurement.

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