

EARLY THEORIES ON THE DISTANCE TO THE SUN

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The Pañcaviṃśa Brāhmaṇa states that the heavens are 1000 earth diameters, d_e , away from the earth. The sun was also taken to be halfway to the heavens, so this suggests a distance of the sun, R_s , about 500 earth diameters from the earth. The confirmation for this supposition comes from the later theories (c. 500 AD) from the same region and from Greek ideas that speak of roughly the same distance. We suggest that the original conception was $R_s \approx 500d_e$ from which the later Indian and Greek theories diverged in different ways to deal with contradictory data related to outer planet periods.

Key words : Distance to the sun, Solar system, Vedic astronomy

INTRODUCTION

In astronomy the story of the gradual development of the knowledge of the size of the solar system is a fascinating chapter. The standard view, as presented in the well-known history of ancient mathematical astronomy by Neugebauer,¹ is that Ptolemy in second century AD, using a method developed by Hipparchus, came to the conclusion that the sun is about 600 earth diameters distant from the earth. This is the estimate which held sway during the whole of the Middle Ages until the time of Copernicus and Brahe. Kepler argued for a distance three times this value but it was not before the end of the seventeenth century that it was found that Ptolemy's estimate was wrong by a factor of about seventeen.

In this paper we sketch the early history of the knowledge of the distance of the sun from the Indian sources, sources that Neugebauer was not familiar with. We now know that the knowledge of the constellations and the planet periods can be traced at least to the third millennium BC and the motions of the sun and the moon to the second millennium BC.^{2,3} Such knowledge must have been placed in the context of a theory about the size of the universe. This suggests that theories on the relative dimensions of the solar system must be very ancient. How did the understanding of the relative distances of the sun and the moon emerge? And how did it evolve?

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The earliest Indian evidence comes from the *Rgveda* where there was recognition that the universe was infinite in extent (e.g. *RV* 1.52.13). Numbers as large as 10^{12} are described in other Vedic texts. *Rgveda* 1.35.7-9 suggests that the sun is at the centre of the universe as the rays of the sun are supposed to range from the earth to the heavens. More practical evidence is to be found in texts called the *Brāhmaṇas* that came to be written as the earliest commentaries on the Vedic texts. For example, *Śatapatha Brāhmaṇa* (*ŚB*) 6.1.10 to 6.2.4 gives us a brief account of the creation of the universe where several elements related to the physical and the psychological worlds are intertwined. Within this account the description of the physical world is quite clear. It begins with the image of a cosmic egg, whose shell is the earth (6.1.11). From another cosmic egg arises the sun and the shell of this second egg is the sky (6.2.3). The point of this story is to suggest that the universe was perceived at this point in the shape of an egg with the earth as the centre and the sun going around it below the heavens.

The stars were seen to lie at varying distances with the polestar as the furthest.

Atharvaveda 10.7 presents an image of the frame of the universe as a cosmic pillar (*stambha*). In this the earth is taken to correspond to the base (10.7.32), the space to the middle parts, and the heavens to the head. The sun, in particular, is compared to the eye (10.7.33). But there is no evidence that this analogy is to be taken in a literal fashion. One can be certain that in the Vedic period, the sun was taken to be less distant than the heavens.

It was also a common supposition in the ancient world to take the motions of all the heavenly bodies to be uniform. For example, such a system of circular motions is considered in *Vedāṅga Jyotiṣa* of 1350 BC.⁴

The relative distance of a body from the earth was, therefore, determined by its period. This set up the following arrangement for the luminaries:

Moon, Mercury, Venus, Sun, Mars, Jupiter, Saturn

Since the sun was halfway in this arrangement, it is reasonable to assume that the distance to the sun was taken to be half of the distance to the heavens. The notion of the halfway distance must date from a period when the actual periods were not precisely known or when all the implications of the period values for the size of the universe were not understood. It is not clear that a purely geocentric model was visualized. It appears that the planets were taken to go around the sun which, in turn, went around the earth. One evidence is the order of the planets in the days of the week where one sees an interleaving of the planets based on the distance from the sun and the earth, respectively; this suggests that two points of focus, the earth and the sun, were used in the scheme. Further evidence comes from the fact that the planet periods are given with respect to the sun in later texts such as the one by Āryabhaṭa. It appears that the purely geocentric model may have been a later innovation.

THE PAÑCAVIṂŚĀ BRĀHMAṆĀ (PB)

The *Pañcaviṁśa Brāhmaṇa* (PB) (The Brāhmaṇa of Twenty-five Chapters) 25.10 has an account of a journey to the source of the river Sarasvatī from the point it gets lost in the desert. The drying up of Sarasvatī is believed to have taken place in around 1900 BC so the text is definitely later than that epoch. Internal astronomical evidence of the Brāhmaṇas indicates that these tests date from different times in the second millennium BC. Further evidence for this dating comes from the fact that the Brāhmaṇas describe rites where the interval from the winter solstice to the summer solstice is exactly 180 days.⁵ This makes it impossible for the rites described in these texts to be later than the second millennium BC.

PB is essentially a book that deals with various rites of different durations and so the astronomy given in it is very incidental. The rites themselves appear to have an astronomical intent as given by their durations: 1 through 40 days (excepting 12), 49, 61, 100, and 1000 days; 1, 3, 12, 36, 100, and 1000 years. The rites provide a plan for marking different portions of the year and also suggests longer periods of unknown meaning.

In PB 16.8.6 we have a statement about the distance of the sun from the earth:

*yāvad vai sahasraṃ gāva uttarādhara ity āhus tāvad asmāt lokāt
svaruyo lokāḥ*

The world of heaven is as far removed from this world, they say, as a thousand earths stacked one above the other.

It should be pointed out the Caland⁶ translates this as “.....as a thousand cows standing one above the other”. Presumably, this is because the Sanskrit word *gauḥ* has several meanings including the primary meanings of “earth” and “cow” but considering the context the translation by Caland is definitely wrong. Looking at the earliest Indian book on etymology, Yāska’s *Nirukta* which is prior to 500 BC,⁷ the meaning of *gauḥ*, of which *gāvaḥ* is plural, is given as: “[It] is a synonym of ‘earth’ because it is extended very far, or because people go over it It is also a synonym of an animal (cow) from the same root”. (*Nirukta* 2.5)

Now the question arises where was the sun conceived to be in relation to the heavens. *Śatapatha*, whose astronomy has been described elsewhere,^{8,9} calls the sun the lotus of the heavens in ŚB 4.1.5.17.

Let R_s represent the distance between the earth and the sun, R_m be the distance between the earth and the moon, d_s be the diameter of the sun, d_m be the diameter of the moon, and d_e be the diameter of the earth.

According to *PB*, $R_s < 1000 d_e$, and we take that

$$R_s \approx 500d_e$$

Elsewhere,¹⁰ we have discussed the evidence that the ancients were aware of the relationship:

$$R_s \approx 108d_s$$

and

$$R_m \approx 108d_m$$

This could have been easily determined by taking a pole and removing it to a distance 108 times its height to confirm that its angular size was equal to that of the sun or the moon. This also implies that the heavens were taken to be 216 solar diameters from the earth.

Considering a uniform speed of the sun and the moon and noting that the sun completes a circuit in 365.24 days and the moon 12 circuits in 354.37 days, we find that

$$R_m \approx \frac{354.37 \times 500}{365.24 \times 12} d_e$$

or

$$R_m \approx 40d_e$$

Also we have a relationship on relative sizes because

$$R_s \approx 108d_s \approx 500d_e$$

This means that $d_s \approx 4.63 X d_e$.

A theory on the actual diameters of the sun, the moon, and the earth indicates a knowledge of eclipses. The much older *Rgveda* (5.40) speaks of a prediction of the duration of a solar eclipse, so relative fixing of the diameters of the earth, the moon, and the sun should not come as a surprise.

Also note that the long periods of Jupiter and Saturn require that the sun be much closer to the earth than the midpoint to the heavens, or push the distance of the heavens beyond the $1000d_e$ of *PB* and perhaps also make the distance of the sun somewhat less than $500d_e$. We do see these different modifications in the models from later periods.

PB 25.10.16 also states the duration from the earth to heaven is as long as a journey of 44 days and this is equated, symbolically, to the travel, on horseback, between the point where Sarasvatī is lost in the desert and its source in the mountains. But we are not certain of the astronomical significance of this duration of 44 days.

There is an interesting altar design in the *Śatapatha Brāhmaṇa* (8.5) which represents the orbit of the sun around the earth (Fig. 1). Note that the number of bricks in the four quarters of the year are not identical. This suggests a recognition of the fact that the orbit of the sun was asymmetric.

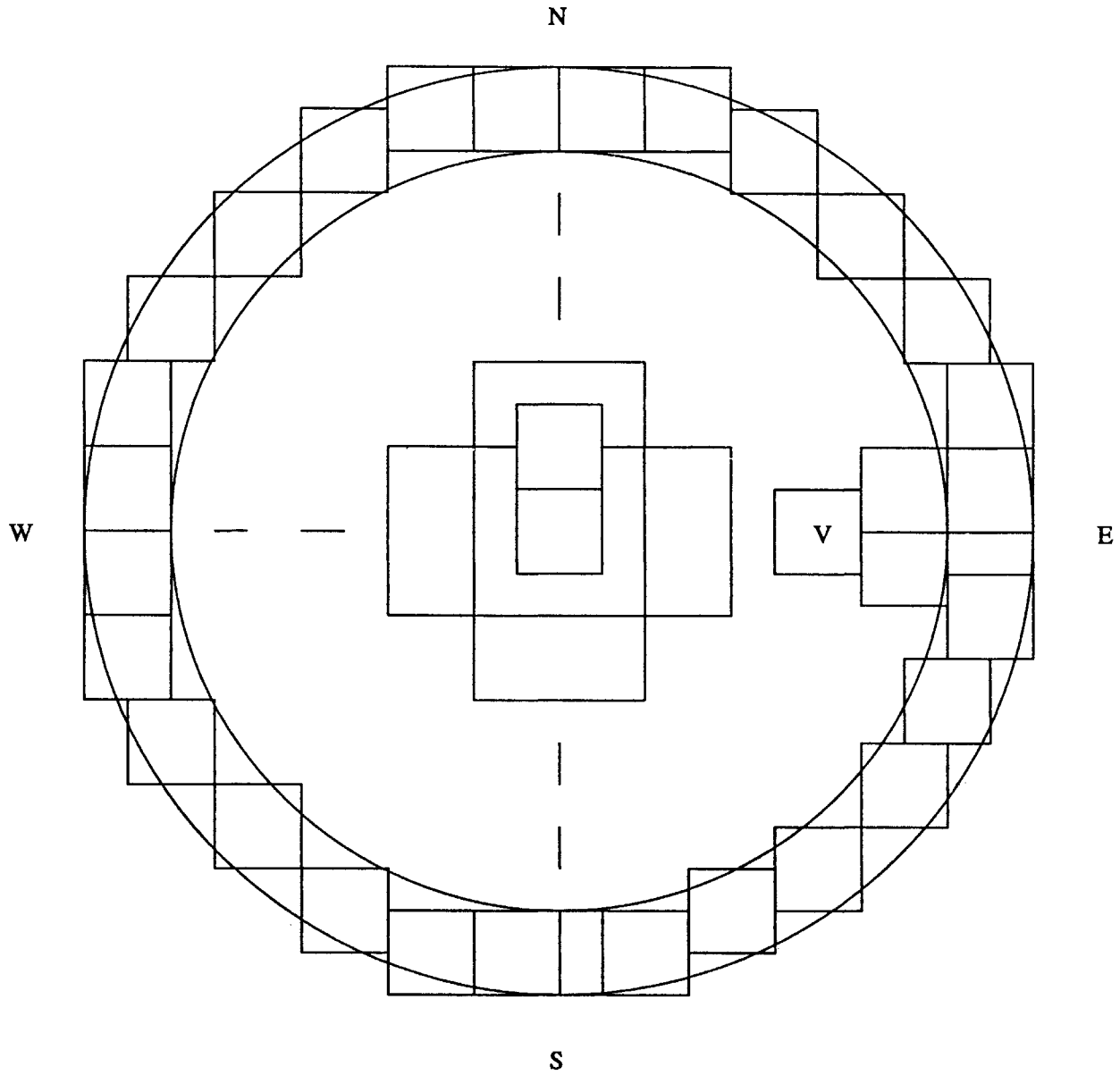


Fig. 1. An altar that represents the asymmetric circuit of the sun.

PLANET SIZES IN ĀRYABHATA'S ASTRONOMY

By way of comparison, we provide the values for various sizes and distances in a later text from India, namely *Āryabhaṭīya* (AA) of Āryabhaṭa¹¹ that dates to c. 500 AD. Āryabhaṭa explains the motion of the stars as a result of the rotation of the earth and the motions of the planets are explained in terms of epicycles that, in contrast to the Greek theory, expand and contract rhythmically. Furthermore, he gives the planetary periods relative to the sun which *appears* to be based on an “underlying theory in which the earth (and the planets) orbits the sun”.¹²

The basic measure in this text is to take 8,000 *nr* to be equal to a *yojana*, where a *nr* is the height of a man; this makes a *yojana* approximately 7.5 miles.¹³ AA 1.7 gives the following measures for the diameters (all of *yojanas*):

Earth (d_e)	1,050.00
Sun (d_s)	4,410.00
Moon (d_m)	315.00
Mars	12.60
Mercury	21.00
Jupiter	31.50
Venus	63.00
Saturn	15.75

Furthermore, AA 1.6 gives the distance of the sun, R_s , to be 459, 585 *yojanas*, and that of the moon, R_m , as 34,377 *yojanas*.

It follows then that in AA,

$$R_s = 437.7d_e$$

and

$$R_m = 32.74d_e$$

Also,

$$R_s \approx 104.21d_s$$

and

$$R_m \approx 109.13d_m$$

Comparing the earlier figures of the *PB* era it is clear that the R_m had to be reduced to account for the extra time spent in the epicyclic motions of AA.

CONCLUDING REMARKS

We first note that the idea that the sun is roughly 500 or so earth diameters away from us is much more ancient than Ptolemy. So Neugebauer was wrong on two counts; first, he did not know of any Indian connections although he admitted¹³ that the “study of Hindu astronomy is still at its beginning”; second, he did not recognize that the tradition regarding the distance of the sun might be much older in Greece itself. This greater

antiquity is in accordance with the ideas of van der Waerden,¹⁴ who ascribes a primitive epicycle theory to the Pythagoreans. But it is more likely that the epicycle theory is itself much older than the Pythagoreans and it is from this earlier source that the later Greek and Indian modifications to this theory emerged which explains why the Greek and Indian models differ in crucial details.¹⁵

Did the idea that $R_s \approx 500d_e$ originate at about the time of *PB*, that is from the second millennium BC, or is it older? Since this notion is in conflict with the data on the periods of the outer planets, it should predate that knowledge. If it is accepted that the planet periods were known by the end of the third millennium BC, then this knowledge must be assigned an even earlier epoch. Its appearance in *PB*, a book dealing primarily with ritual, must be explained as a remembrance of an old idea. We do know that *PB* repeats, almost verbatim, the R̥gvedic account of a total solar eclipse.

Once the conflict between the planet period information and the supposition that the heavens were 1000 earth diameters away became clear, this supposition was dropped. Presumably, the theory that $R_s \approx 500d_e$ was too entrenched by this time and it became the basis from which different Greek and later Indian models emerged. As mentioned before, Ptolemy considers an R_s equal to $600d_e$, whereas Āryabhaṭa assumes it to be about $438d_e$. Thus the Greek and the later Indian modifications to the basic idea proceeded somewhat differently.

The ideas regarding the distance of the sun hardly changed until the modern times. The contradictions in the assumption that the luminaries move with uniform mean speed and the requirements imposed by the assumed size of the solar system led to a gradual enlargement of the models of the universe from about twice that of the distance of the sun in *PB* to one 4.32×10^6 times the distance of the sun by the time of Āryabhaṭa. This inflationary model of the universe in *AA* makes a distinction between the distance of the sky (edge of the universe) and that of the stars which is taken to be a much smaller sixty times the distance of the sun. "Beyond the visible universe illuminated by the sun and limited by the sky is the infinite invisible universe" this is stated in a commentary on *AA* by Bhāskara I writing in 629 AD.¹⁶ The Purāṇic literature from India, part of which is contemporaneous with Āryabhaṭa, reconciles the finite estimate of the visible universe with the old R̥gvedic notion of an infinite universe by postulating the existence of an infinite number of universes.

It is possible that the original notion that the heavens are $1000d_e$ away from the earth arose as a metaphor for the large extent of the universe, given that a thousand represents a very great size in Indo-European languages. But it is more likely that some measurements and a theory were at the basis of this supposition.

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