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Samanta Chandra Sekhar : The great naked eye astronomer *

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Abstract. Samanta Chandra Sekhar (1835-1904), popularly known as Pathani Samanta in Orissa, worked in astronomy following traditional methods, completely unaware of the telescope and other aids developed in the west. He took observations with ingenious and handy instruments, all fabricated by himself. His study and observations are recorded in an invaluable classic, the Siddhanta Darpana, composed in beautiful metrical sanskrit verse. It contains many original contributions of Samanta in observation, calculation, instrumentation, theory and model. Hence it shows appreciable improvements over the earlier classics like Surya Siddhanta and Siddhanta Siromani. The results of Chandra Sekhar's observations are often comparable with modern data and his predictions in positional astronomy are in fair agreement with actual occurrence of astronomical events, even today. In view of all these, Samanta Chandra Sekhar stands out as a great naked eye astronomer who had reached the limit of accuracy in observation. The aim of this paper is to bring out the merits of Siddhanta Darpana and the genius of its author to the notice of a large scientific community.

Key words : Traditonal Indian Astronomy - Siddhanta Darpana - history

1. Introduction

Astronomy began with the very dawn of civilisation by the observation of celestial objects and phenomena through the naked eye. It continued to remain so till the mid seventeenth century when Galileo invented the optical telescope that ushered a new era in observation. Galileo's discovery brought about rapid progress in astronomy in the West. On the other hand, it is well known that India has a great heritage in this field, beginning with the period of Vedas upto the present century. The genius of astronomers like Aryabhata, Varahamihira, Brahmagupta, Bhaskara, Satananda, Sripati and others blazed from various corners of the country at different periods of history. All of them were naked eye observers.

* The author's dedicate this atricle to late Professor N. C. Rana

Mahamahopadhyaya Chandra Sekhar Simha Harichandan Mahapatra Samanta, referred to here after as Samanta Chandra Sekhar seems to be the last link of this long order of great Hindu astronomers. The Surya Siddhanta, Aryabhatiya, Pancha Siddhantika, Brahmasphuta Siddhanta, Siddhanta Siromani are prominent among the numerous important astronomical works of our illustrious ancestors. The Siddhanta Darpana, composed by Samanta Chandra Sekhar (Singh Samanta 1899) looks to be the latest valuable classic of high order. It is a systematic record of Samanta's life-long research in the field, with substantial original contributions. The treatise has been written in beautiful, metrical sanskrit verse, after the time honoured Hindu tradition and is a fine piece of literary work apart from being of appreciable scientific value. Further, the work enjoys practical importance even today, for the most widely accepted almanac in Orissa is prepared as per its prescriptions. Therefore, it has deep rooted social relevance as well. It is needless to say that the calculations and predictions of Siddhanta Darpana continue to agree with the observations keeping its almanac in vogue for more than hundred years.

Before attempting to give an humble account of Samanta's contribution to astronomy we would like to give a sketch of his early life. Chandra Sekhar was born in the royal family of Khandapara, one of the princely states of Orissa, in 1835. Nick-named as Pathani by his parents, he is fondly called Pathani Samanta in the state. Chandra Sekhar was initiated to identify stars by his father when he was a child. He received primary education in mother tongue Oriya and Sanskrit from a brahmin teacher. His formal education ended there. Then young Chandra Shekar started teaching himself Lilavati, Bijaganita, Jyotisha, Siddhanta, Vyakarana and Kavya, using the family library. During these studies, he was attracted more by mathematics and astronomy.

At the age of fifteen, Chandra Sekhar learnt the meaning of lagna (the ascendant) and the method to calculate the ephermerides of planets. He found that the stars and planets did not rise and appear at positions predicted by the Siddhantas. Traditional texts on astronomy generally do not give details of the instruments to be used for such observations and the methods of measurements explicitly, excepting occasional hints here and there. Therefore, he had to devise instruments by himself.

Now he set out for observation, night and day, checking the figures occurring in the earlier works. He found that, even Surya Siddhanta and Siddhanta Siromani were not always correct. Besides, all these classics authorise one to add corrections as and when necessary. Therefore, Chandra Sekhar took the task of correction onto himself. He began recording his observations and making formulations of the ideas at the age of twenty three and started putting them in the form of a treatise some three years later. The complete script of Siddhanta Darpana was ready by 1869, when he was thirty four. But it took another thirty years for the work originally written on the palm leaves in Oriya character to appear in Devnagari script, printed on paper in 1899. Chandra Sekhar had the Surya Siddhanta for his prime reference and Siddhanta Siromani for his guide.

This remarkable scholar and scientist, confined to a small hilly state in the remote corner of Orissa, far away from the sphere of English education, was virtually doomed to obscurity, but for his chance acquaintance with Sri Mahesh Chandra Nyayaratna, Principal of Sanskrit college of Calcutta, who probably later on introduced him to Prof. Joges Chandra Ray of Cuttack College (today's Ravenshaw College). Sri. Nyayaratna's efforts (Mishra 1932) brought him the title of Mahamahopadhyaya conferred by the British Government in 1893. Of course, earlier the Gajapati Raja of Puri bestowed upon him the title of Harichandan Mahapatra.

Prof. Ray was the person under whose involvement and supervision, Siddhanta Darpana was published in 1899 from the Indian Depository in Calcutta, with the financial support of the King of Athmallik and partly by the King of Mayurbhanj. It must be noted that the scholarly introduction of fifty six pages in English, therein, by Prof. Ray (Ray 1899) formed the window through which the English knowing world could get a glimpse of the valuable treasures contained in Siddhanta Darpana, otherwise couched in almost inaccessible Sanskrit. The international journals, Nature(1) and Knowledge(2) have acclaimed this work (Siddhanta Darpana) in glowing terms. Lately, Siddhanta Darpana has gone through two Oriya translations (Singh Samanta 1975, 1976). We present in the following a brief review of this work, citing only a few important original contributions of the author.

2. Siddhanta

यत्रत्रुट्यादिकाल : प्रलयचरमक : खेचराणां प्रचार :
प्रश्नाश्चैवोत्तराणि द्विबिध - गणितमप्युद्भबो भूतराशे : ।
स्थानंभू-भग्रहादेर्ग्रहण - खगयुति - ज्या - धनुष्कर्मयन्त्र -
क्षेत्राद्यं गद्यते सद्गणकगणबरैरेष सिद्धान्तउक्त : ।

Chandra Sekhar enumerates the requisite characteristics of a Siddhanta, in the 17th sloka of the first chapter of Siddhanta Darpana given above. The work that deals with time, beginning from the smallest unit of, "truti" (0.274348×10^{-6} sec.) to "pralaya" (10^{13} solar years) alongwith the motion of celestial objects, their revolution, orbits, alignments, occultation and eclipses etc., with the relevant mathematics like arithmetic, algebra, geometry and trigonometry, and also concerns with the question of the origin of the universe, is called a Siddhanta.

There are quite a number of Siddhantas in India, which fall mainly into two classes; (i) Siddhantas like Pancha Siddhantika, Siddhanta Siromani etc. with definite authors and (ii) Siddhantas like Surya Siddhanta, Vyasa Siddhanta etc., ascribed to various divine sources, in the traditon of the Vedas and the Upanishads. The number of the latter category of works is eighteen which is the same as the number of Hindu puranas. It is needless to say that, all these works fulfill the scriptural norms cited above.

One will notice that, Siddhanta Darpana with 24 chapters comprising 2500 slokas out of which 2284 are Samanta's own compositions and 216 citations from the earlier authors, falls short of none of these qualifications. Chandra Sekhar has original contributions in most of the aforesaid topics dealt in his treatise. The whole contents of Siddhanta Darpana is divided into five sections, namely, Madhyadhikara, Sphutadhikara, Triprasnadhikara, Goladhikara and Kaladhikara. The

(1) Nature, 1899, 52, 436
(2) Knowledge, 1899, XXII, 257

first two sections deal with the mean motion and true position of the planets respectively. The third section deals with the motion described in terms of space, time and direction. The fourth section gives an account of the relevant mathematics like spherical trigonometry and the fifth describes different ways of reckoning time. The distribution of chapters (a chapter in Siddhanta Darpana is called a Prakasha) and slokas into sections in the treatise is as in Table1.

Table 1. Section wise distribution of chapters and slokas in Siddhanta Darpana.

Serial No.	Section	Chapters included	Number of slokas
1	Madhyadhikara	1-4	204
2	Sphutadhikara	5-6	372
3	Triprasnadhikara	7-15	736
4	Goladhikara	16-21	901
5	Kaladhikara	22-24	287
	Total	24	2500

It will not be out of place to mention here that the sections and sequences given above are followed more or less in most Siddhantas.

The material content of Siddhanta Darpana looks amazing as the achievement of a single mind. Chandra Sekhar has observed, verified and corrected wherever necessary, all that was known to the Hindu astronomers for thousands of years. Very often he has gone beyond his predecessors to discover new phenomena, advance better formulations and come out with results in the form of stupendous tables, as corrections to be applied to keep calculations agree with observation for ten thousand years to come. We out-line below Samanta's contributions to four important aspects of astronomy, namely (i) observation (ii) calculation (iii) method of measurement and (iv) theory and model. We briefly deal with these aspects of the work in the following sections.

3. Observation

Samanta Chandra Sekhar was an ardent observer throughout his life. He has made it clear that, barring purely theoretical questions, he has not recorded a single fact in Siddhanta Darpana, without observation. Samanta spent sleepless nights for making observations and ultimately this told upon his health causing dyspepsia with colic that remained his life companion. But this frail figure of a man, has given incredible accurate data that fairly tally even with modern observations. We cite in the following (Tables 2 and 3), the sidereal periods and inclination of orbits of the planets. It may be remembered that the Sun, Moon and two nodes of Moon (Rahu and Ketu) alongwith the five naked eye planets constitute the system of navagraha (nine planets) in Hindu system of astronomy.

The figures quoted as modern data in the table are taken from Lahiri (1994). The data quoted against the traditional works are taken from Ray (1899) and Burgess (1860). The results presented as the European values as on 1899 are taken from Ray (1899). One may notice that Siddhanta Darpana agrees with the modern measurements more closely in most of the cases. Even in some cases like the sidereal periods of Moon's node and the inclination of orbit of Venus the modern values are closer to that of Samanta than the European values of 1899. It is surprising how Samanta Chandra Sekhar could attain such accuracy.

Table 2. Sidereal periods of planets in days.

Planet	Surya Siddhanta	Siddhanta Siromani	Siddhanta Darpana	European value as in 1899	Modern value
Sun	365.25875	365.25843	365.25875	365.25637	365.25636
Moon	27.32167	27.32114	27.32167	27.32166	27.3216615
Mars	686.9975	686.9979	686.9857	686.9794	686.97982
Mercury	87.9585	87.9699	87.9701	87.9692	87.969256
Jupiter	4332.3206	4332.2408	4332.6278	4332.5848	4332.589
Venus	224.6985	224.9679	224.7023	224.7007	224.70080
Saturn	10765.773	10765.8152	10759.7605	10759.2197	10759.23
Moon's Nodes	6794.3948	6792.2535	6792.644	6793.270	6793.470

Table 3. Inclinations of the orbits of planets to the ecliptic.

Planet	Surya Siddhanta	Siddhanta Siromani	Siddhanta Darpana	European value as in 1899	Modern value
	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″
Moon	4 30 –	4 30 –	5 09 –	5 08 48	5 08 33
Mars	1 30 –	1 50 –	1 51 –	1 51 2	1 50 59
Mercury	5 55 –	6 55 –	7 2 –	7 00 08	7 00 18
Jupiter	1 0 –	1 16 –	1 18 –	1 18 41	1 18 18
Venus	2 46 –	3 6 –	3 23 –	3 53 35	3 23 41
Saturn	2 0 –	2 40 –	2 29 –	2 29 40	2 29 10

Table 4. Comparison of r/R ratio (See Text).

Planet	Siddhanta Siromani	Siddhanta Darpana	Modern value
Mars	1.5	1.518	1.52
Mercury	0.37	0.3875	0.387
Jupiter	5.3	5.21	5.2
Venus	0.716	0.725	0.723
Saturn	9	9.47	9.5

Table 5. The greatest equations of Sun and Moon.

Celestial Body	Surya Siddhanta	Siddhanta Darpana	Western astronomy as in 1899
	° ′ ″	° ′ ″	° ′ ″
Sun	2 10 31	1 55 33	1 55 19
Moon	5 2 46	5 1 10	6 3 41

It is well known today that the planets go round their force-centre (the Sun) in ecliptic orbits. But, for traditional Indian astronomers, who depend purely on their observation from the earth, the motion of planets (nava graha) was a great puzzle. It was the same also for the Greeks. The observed deviation of their orbits from circles was explained in India to be due to fictitious centres of attractions "stationed in the zodiac called the conjuction (sighrochcha), apsis (Mandochcha) and node (pata" (Surya Siddhanta, Ch.II verse-1). One draws epicycle circles on the mean circular orbit of planet around the Earth and makes necessary corrections to get the true position of planet. Most of the Siddhantas give the dimension of these circles. A possible test of the correctness of these observational result is the calculation of (r/R) ratios and their comparision with the modern values, where r & R, refer to the radii of the sighra circle and that of the mean planet orbit respectively. Table 4 shows a comparison of these ratios. Siddhanta Darpana again has a closer agreement with the modern values. Related with this fact are the orbital elements like eccentricity of orbits and the greatest equations of anomaly. The greatest equations of Sun and Moon obtained according to Siddhanta Darpana are compared with those of western values and Surya Siddhanta in Table 5.

In connection with the corrections to be applied to the mean positions to get the true planets, Samanta has made an original observation contained in the following slokas.

कुजज्ञशनिमन्दानां प्राक्-पश्चाच्चलनेक्षणात् ।
ज्ञशीघ्रस्यापि कुप्तोहन्य : परोच्चाख्य : सुरोमचा ॥

सषड्भ : सूर्य्यमध्य : स्याद्भूमिपूत्रपरोच्चक : ।
ज्ञपरोच्चो मृदो : शीघ्र : शीघ्रस्यापि मृदूच्चक : ॥

धृत्यं-शोनः शनिर्मध्य : स्वबन्दस्य परोच्चक : ।
मन्दोच्चादिबदेतेहपि न दृशया : केलमूर्त्तय : ॥

(S. D. Ch. V. Slokas 76,77,78)

which means that he observed the motion of apsides and conjuctions of Mars, Mercury and Saturn to be both forward and backward. Therefore, he introduced *Parochha*, a new centre of attraction to explain his observations. He has given the parochcha correction to be applied to the planets Mercury, Mars and Saturn, the maximum of which are 12° 20'. 7° 30' and 5° respectively.

However, in the case of Moon, Chandra Sekhar noticed the three important perturbations, Tungantara (Evection) Pakshika (Variation) and Digamsa (Annual equation) as declared in the following sloka.

तुङ्गान्तर पाक्षिकनाभधेयं फलं दिगंशाख्य मदस्तुरीयम् ।
कमेण बक्ष्यामि निरीक्ष्य यत्नाच्चित्रांगतिं रत्रिपतेश्चिराय ॥

(S.D. Ch. VI Sloka 6)

"Strange is the motion of the Moon. I have observed it for long time. I am giving here three more corrections namely, Tungantara, Pakshika and Digamsa in addition to the Manda correction of the Moon" Chandra Sekhar clearly says that the maximum value of 160' (2° 40') of Tungantara was known to his predecessors in the sloka.

खाङ्गेन्दु लिप्तं चिरकालतोहभू त्तद्बृद्धिहासा बुररी क्रिययेताम् ।
इत्यादि पूर्बोक्तिद्भिरेब सिद्धं बीजैः स्वकालाक्षिसमैः स्फुटत्वम् ॥

(S. D. Ch. VI Sloka 51)

But J. C. Ray in his "Introduction" to Siddhanta Darpana says, "Pandit Sudhakar Dwivedy informs us in his excellent manual called Ganaka-tarangini, that Munjala (A.D. 933) had something like evection in his Karana, named Laghumanasa. He appears to be the oldest Hindu astronomer who detected the irregularity, though curiously enough, his successors, including Bhaskara left it unnoticed". Burgess in Surya Siddhanta (Burgess 1860) mentions, "Ptolemy also adds to the Moon's orbit an epicycle, to account for her second inequality, the evection, the discovery of which does him so much of honour. Of this inequality, the Hindus take no notice." Ray clearly states, "Chandra Sekhar has discovered some original corrections - original in the sense of their having been unknown to the ancient astronomers of our country". However, Sengupta (1934) in his appendix to translation of Khandakhadhyaka concludes that evection and variation were introduced by Munjala and Bhaskara. But it is definite that Samanta Chandra Sekhar is the only Indian astronomer of traditional school to have clearly observed all the three irregularities and measured all of them with utmost accuracy. The maximum of Tungantara according to modern astronomy (Jones 1934, Barlow 1944) is 1° 17' whereas Samanta gives the maximum value of 2° 40'. The maximum value of Pakshika and digamsa, as observed by Chandra Sekhar are 38' 12" and 12' against 39' 31" and 11' 9" of modern values.

It may appear from the figures quoted above that Samanta's maximum value for the evection is nearly twice the modern value. This apparent discrepancy in Samanta's observations has been explained by Ray (1899). He points out, "The amount of greatest equation of moon is 6° 18' and maximum evection 1° 20', making the total of 7° 38'. Chandra Sekhar has 5° 1' as the greatest equation and 2° 40' as the greatest Tungantar, making the total 7° 31'. Therefore result of Chandra Sekhar's observations are in surprisingly close agreement with the modern values. In passing, it may be remarked that Tycho Brahe was the first Western astronomer to have detected and measured all the three irregularities.

The circumferences of the orbits of Moon, Sun and stellar universe are given below, as per the estimate of the main Siddhantas (Table 6) with the earth taken as centre. It is straight forward to reach an estimate of their distances from the common centre. More important is the ratio of the distances of the Sun and Moon, which is given in the last row. It may be noticed that the ancient Indian Astronomers placed the Sun at a distance not more than 14 times that of the Moon from the Earth. However, Chandra Sekhar hiked this ratio by more than 10 times to 156 which is much closer to the modern value of 390.

Chandra Sekhar has given positions of junction stars of 28 nakshatras (including Avijit) which are not always same as in earlier literature. There is a comparative study of the matter in a recent work (Mishra 1995) which concludes that Chandra Sekhar's values for coordinates of the junction stars are significantly closer to the modern data.

Finally, it will not be out of place to mention that conjunction, occultation and transits of celestial objects have been dealt in detail in a number of works in Hindu astronomy. Of them all, the transit of Mercury and Venus are important in the sense that they cause, some sort of solar eclipses. Transit of Mercury cannot be sighted in the naked eye, whereas the Transit of Venus has been recorded by observers in the West. Samanta Chandra Sekhar seems to be the only traditional astronomer to have left a record of having observed the 1874 (December) Venus transit visible from India in the following sloka.

दृष्टं शुक्रस्य गाढास्तमयसमयजं मण्डलं चण्डभानौ कीटांशे पञ्चबिंशे गत बर्ति कलितोहर्थाहद्रिगोहब्ध्यब्दबृन्दे ।
भास्वद् बिष्कम्भदन्तां शमितमित इदं खार्थषट् योजनं स्यात् । इत्यन्यजज्ञेयमस्मात्तनब इन - तंनोस्तारका : कोग्रहा : स्युः ।

(S. D. Ch. XI, Sloka 110)

Of course, the next transit of venus occurred in December, 1882, but was not visible from India and so there is no record of it in Siddhanta Darpana.

4. Calculation

Observation and calculation go side by side in astronomy. As indicated in section-1, discrepancy between the prediction of siddhantas and his own observations prompted Chandra Sekhar to write Siddhanta Darpana. Particularly, calculation of positions of planets demands prime attention of a beginner. Predicting their positions is a very complicated process. Usually, the traditional astronomers assume an epoch, at the beginning of which all the planets started their revolutions (bhagans). They take a mean rate of motion for each planet, then multiply the rate with the number of bhagans during the epoch, and get the mean position of the planet on a particular day with respect to a location chosen as the reference point on the Earth.

It is also a fact that, the traditional astronomical works fall into three categories depending upon the choice of the epoch. Tantra and Karans choose beginning of the Kali Yuga and some recent date respectively to mark the epoch where as Siddhantas take the period to be a Maha Yuga (sum of the period of the four yugas). But Samanta Chandra Sekhar takes the epoch from the beginning of the Kalpa (1000 Maha Yuga). He has calculated the number of sidereal revolutions of the planets during the Kalpa.

He gives the mean rates of motion (average angular displacement per day) of the planets upto ten places in the sexagesimal system, whereas the earlier siddhantas give these figures to five places at best. In Table 7 we have presented these data including the modern ones (Lahiri 1994) for comparison.

One may note that Samanta does not give the rate for Mercury and Venus. Instead he gives the rates of their sighrochcha in sexagesimal system to be respectively, 4° / 05' / 32"16 / 07 / 59 / 43 / 42 / 44 and 1° / 36' / 07" / 47 / 57 / 50 / 39 / 32 / 31 / 35. He considers these rates to be more

Table 6. Circumferences of the orbits in Yojanas. One Yojana = 5 miles approximately.

Planet etc.	Surya Siddhanta	Siddhanta Siromani	Siddhanta Darpana
Moon (= p)	324000	324000	306000
Sun (= q)	4331500	4331497.5	47800800
Asterism	259890012	259889850	17208288000
Universae	18712080814×10^6	187120892×10^8	94297796×10^4
q/p	13.96	13.36	156.21

Table 7. Rate of mean motion of planets per day. The quantities in the upper line in each row in the third and fourth columns are in sexagesimal system, and the ones in the corresponding lower line are in decimal system.

Planets	Modern value (Lahiri)	Brahmagupta Sripati Bhaskar	Samanta Chandra Sekhar
	° ' "	° ' "	° ' "
Sun	0 59 08.2	0 59/8/10/21 59 8.1725	59/8/10/24/12/30/4/0/4 59 8.1733912
Moon	13 10 35.0	13/10/34/53/0 13 10 34.8833	13/10/34/52/03/49/ 08/02/16/10/11 13 10 34.8677274
Mars	0 31 26.5	0/31/26/28/7 31 26 . 4686	0/31/26/30/06/47/ 44/32/49/03/04 31 26.5018876
Mercury	4 05 32.4	4/05/32/18/28 4 5 32 . 3077	*
Jupiter	0 04 59.1	0/0459/9/9 04 59 . 1525	0/04/59/05/37/0/ 36/41/17/01/51 0 4 59.0936139
Venus	1 36 07.7	1/36/7/44/35 1 36 7.74305	*
Saturn	0 02 01.9	0/02/0/22/51 2 0.380833	0/02/0/26/55/02/ 53/21/02/04/54 0 2 0.4486244
Moon's	– 0 03 10.6	0/03/10/48/20 03 10.8055	0/03/10/47/40 40/27/11/25/13/30 0 03 10.7946317

* Mean of sighrochcha for Mercury and Venus are given as 4°/05'/32"/16/07/59/43/42/44 and 1°/36'/07"/ 47/57/50/39/32/31/35 respectively.

Table 8. Ayana Chalan rates from various sources.

Sl. No.	Astronomical work	Annual rate
1	Surya Siddhanta	54"
2	Soma Siddhanta	54"
3	Sakalya Siddhanta	54"
4	Laghu Vashistha	54"
5	Parasara Siddhanta	52.35"
6	Aryastha Stika	46.25"
7	Munjala (quoted by Bhaskar)	59.9"
8	Bhasvati	60"
9	Grahalaghava	60"
10	Siddhanta Darpana	57.615"

essential for the calculation of the position of planets which is warranted due to his special model of the solar system to be discussed later. It must be remembered that very accurate rates are necessary for correct calculation of the mean position.

After incorporating the usual corrections in the calculation of planet positions, one may apply further corrections enlisted in tables given by Chandra Sekhar for each planet for hundred million (one arbuda) years. There are as many as fifty-five tables, each on the average having fifty numbers, some times given upto five places in the sexagesimal system. These tables look to be a challenge for one's unaided computational skill.

We confess out inability to enter into the intricate procedure in the text on calculation of the planetary positions, eclipses, alignments, transit and phases. However, we would like to touch upon only Samanta's calculation of the "ayan chalan" (precession of Earth's axis) rate. This is an important parameter for fixation of longitudes of celestial bodies. A detailed account of Samanta's calculation and its comparison with other traditional works is given in the introduction to Siddhanta Darpana (Ray 1899). As a summary, we quote the rates given by various works / authors in Table 8.

The modern value of the precessional rate is, however, 50".3 per year. Therefore, it can be seen from the table that all the Indian data seem to be in disagreement with this value excepting that of the Parasara Siddhanta which looks apparently closer. But Ray gives a solution to this puzzle by pointing out that the Indian astronomers take the sidereal year for calculation of rate of precession in contrast to the tropical year, taken in the West. It is well known that the assumed sidereal year is longer by some minutes during which the Sun advances by 8".4. When this correction is taken into account on Samanta's value, the rate of precession turns out to be 49".179, in near agreement with the modern value. We have checked with a current almanac (Khadiratna 1995) and found that a rate of 57".628 per year is still in vogue in the calculation.

Finally we would like to point out a couple of facts of pure mathematical interest from Siddhanta Darpana. Samanta has stated that Bhaskar and others have taken 22/7 as the ratio of the circumference and diameter of the circle (= Π). But he has taken the values as 3927 / 1250 and 600 / 191 in the text at various places. These values are definitely more accurate. He has given a new method of finding the cube root of numbers, different from that of Bhaskar.

5. Methods of measurements and instruments

Completely unware of the scientific and technological developments in the west, Samanta Chandra Sekhar employed traditional methods for astronomical measurements. Very often, he has constructed new instruments and used them for own observations. It is a remarkable point that, Jai Singh (1688 - 1743) influenced by his western contact, built a number of observatories in the northern parts of the country and erected rather large sized instruments for naked eye observations (Sharma 1995). In contrast, Samanta Chandra Sekhar, who came about 150 years later, fabricated simple and mostly portable devices with which he could make very accurate observation.

Chandra Sekhar gives detailed description of construction and use of various instruments, (yantras) in the 20th chapter of Siddanta Darpana. In this respect he is unlike his predecessors, who hardly mention even, the name of the instruments used. It is worth mentioning here that recently an attempt has been made (Ohashi 1987, 1994) to shed light on instrumentation in classical Indian astronomical works.

Chandra Sekhar's instruments can be broadly classified into three categories i.e. (i) Instruments for measuring time, (ii) armillary sphere and (iii) versatile instruments. There is a description of as many as ten different instruments in Siddhanta Darpana for measuring time. These include the sun-dial like Chakra Yantra (fig.1), Chapa Yantra (fig.2), Golardha Yantra (fig.3) and a water clock (swayambaha yantra) (fig.4). The armillary sphere (fig.5) has been used by the Greek, Arab and Hindu astronomers. But what is interesting with Samanta's device is that he prescribes ways to construct it with wood and bamboo chips. He has described the construction and use of a multi compartment armillary sphere (Bahu Kaksha Gola Yantra) also.

The instruments that were of versatile use are, the Sanku (gnomon) and the Mana Yantra. They could be used to determine the local time, latitude, altitude, zenith distance, declination of sun, its position in the zodiac, angular separation between celestial objects and even height and distance of mountains. In fact, the Mana Yantra, is the most talked of instrument of Chandra Sekhar. Even the students in the primary schools in Orissa know as a legend that Samanta Chandra Sekhar was a number of times put to test by being asked to measure the separation between two celestial objects, their elevation or the height of a distant mountain. Chandra Sekhar came out successful all the times invariably with the use of his Mana Yantra (cross-bar). This instrument is a "T' shaped arrangement of wooden rods of measured length, graduated according to prescription (fig. 6).

A couple of these instruments used by Samanta are preserved in Orissa State Museum. Some of these instruments have recently been fabricated and exhibited at the Regional Science Centre, Bhubaneswar (Sahu 1995). These instruments, in today's standard are undoubtedly crude. But using them, Chandra Sekhar could arrive at results, almost agreeing with modern measurements,

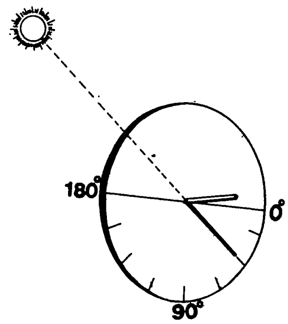

Figure 1. Chakra Yantra for measurement of time.

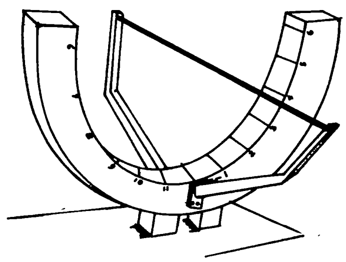

Figure 2. Chapa Yantra for measurement of time.

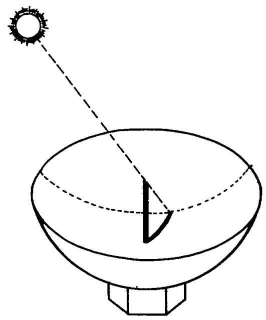

Figure 3. Golardha Yantra for measurement of time.

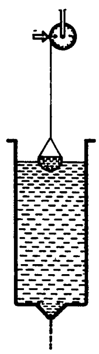

Figure 4. Swayambha Yantra - a water clock for measurement of time.

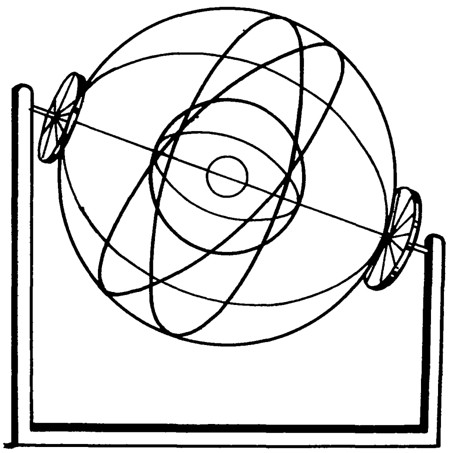

Figure 5. Gola Yantra for measurement of planetary position.

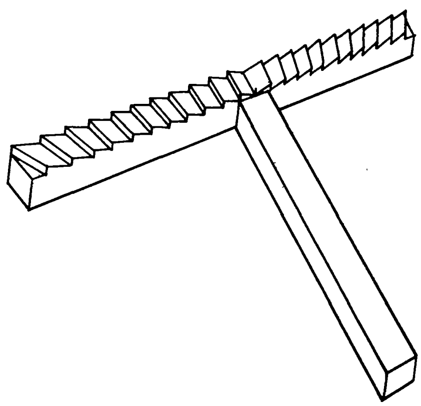

Figure 6. Mana Yantra - a versatile instrument for measurement of various astronomical quantities (See Text).

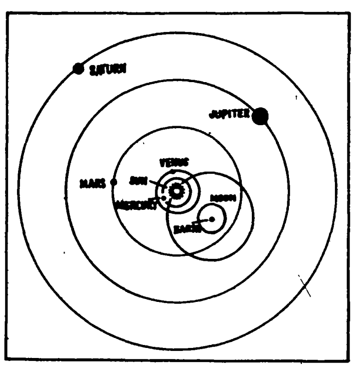

Figure 7. Samanta Chandra Sekhar's model of the solar system.

primarily due to the skill attained through long years of dedication and practise.

Samanta Chandra Sekhar gives methods based on geometry (parilekha for observation of events like eclipses, conjunctions and even phases of the Moon. We do not see description or mention of such methods in any earlier work. The prescriptions look a little complicated. It needs closer investigations.

6. Theory and models

Samanta Chandra Sekhar had his own concepts of the solar system and the universe, based on his own observations and he has given them mathematical formulations, wherever necessary. As indicated earlier, he postulated the concept of parochcha for certain planets.

The most important contribution of Samanta Chandra Sekhar to the planetary models is a picture of the solar system, entirely different from those of his predecessors. Of course, like all other Hindu astronomers he supports a geocentric hypothesis. However, his model has the novel feature that planets - Mars, Mercury, Jupiter, Venus and Saturn go round the Sun and the Sun moves around the Earth together with these companions. Thus, he has assigned heliocentric motion to the planets (fig.7). The central idea of this model is contained in the following slokas of Siddhanta Darpana.

तत्रमध्यम - मार्त्तण्ड : परितोमण्डलंभुव :
भ्रमन् ताराखेचराणां कक्षामधायस्थ उच्यते ।

तं भ्रमन्तो महीजाद्यास्तत्सङ्गेन भुवं पुन :
परिक्रामन्ति यत्तस्मात् स प्रोक्त : सर्वकर्षक : ।

मन्दापकर्षणं हित्वा सदार्कात् समद्रगा :
यान्ति ताराग्राहा : प्राचीं भचक्रमनुनक्षते ।

(S. D. Ch. V Slokas 6, 7 & 17)

Incidentally an identical model of the solar system was proposed by Tycho Brahe in the West. A recent work by Ram Subramanian et al. (1994) suggests that a similar model of the planetary system was given by Nilakantha Somasatvan of the Kerala school in 1500 A.D.

The two other remarkably different views of Samanta Chandra Sekhar from that of the earlier Hindu astronomers, are : (i) Fixation of the mean line for zero terrestrial longitude and (ii) Fixation of time of calculation of ahargana.

These are important factors in traditional astronomy. It is well known that the longitude of Ujaini was assumed as the mean line and the sunrise at this longitude was taken to be the initial time of the epoch in all the earlier works in India. But Chandra Sekhar has accepted a Lanka (not the present Sri Lanka) as the place of mean longitude, collinear with Junagarh of Gujarat and Jalabadpur (Jalalabad) of Afghanisthan, with modern longitude 70° 30' (E) and 70° 26' (E) respectively. Therefore, modern 70° 31' must have been taken as the mean line which further agrees with local time difference (desantar correction) for specific places (Shastri 1975).

As mentioned above, Samanta Chandra Sekhar like most of our traditional astronomers believed in a static Earth. But probably he was informed of the heliocentric picture prevalent in the West. But he did not accept it. Rather he has devoted a full chapter (Ch.17 with one hundred and sixty one slokas) in support of his view. One may look at the conviction and intellectual courage of the man, who poses, in the concluding stanza of Siddhanta Darpana, a direct challenge to the western astronomers (And it was during the British Raj!)

ब्रह्माण्डाखण्डभाण्डस्थिरतरधरणीमण्डलभ्रान्तिशौण्ड ।
प्रोद्दण्डैंलण्डदन्ताबलबलदलनाकुण्ठकण्ठीरबथी : ॥
सोहयं नीलाद्रिसिंहान्वयबदनदरीनिर्गतः प्राप्तदुर्ग : ।
स्फीत स्वख्यातिरस्तु प्रथमबिगणितस्कन्धसार : प्रबन्ध : ॥

(S. D. Ch. XXIV sloka 158)

7. Conclusion

Enormous is the contributions of Chandra Sekhar to astronomy as recorded in Siddhanta Darpana. In fact, the treatise is a Siddhanta, a Tantra and a Karana, all in one, since Samanta has calculated and tabulated "aharagana" and mean planets in three systems with respective times starting from the beginning of the Kalpa, Kaliyuga and the day of commencement of writing Siddhanta Darpana. Chandra Sekhar has declared, his formulae will remain valid upto ten thousand years. Thereafter, if the formulae fail to agree with observations further corrections given in the tables are to be taken into account to keep the work valid upto ten crore years to come. It needs closer investigation again to test Samanta's predictions for long future with modern calculations.

A century has passed since Samanta passed away in 1904 living through poverty and struggle, muckery and dyspecpia with colic. The only consolation to this dedicated scientist during his life time was the title of Harichandan Mahapatra conferred upon him by the Gajapati king of Puri in 1870 when his prescriptions were adopted for observance of rituals in the Jagannath temple. The practice has been continuing since. Lately in 1893, the British Government conferred the title of Mahamahopadhyaya upon him and granted him a monthly pension of Rs.50/- only.

In the mean time ten decades have passed since the publication of Siddhanta Darpana. But it is a pity that the author and his work had remained almost unknown beyond the boundary of Orissa state. It is a matter of relief that Chandra Sekhar has found mention recently in two works on astronomy (Kochhar and Narlikar 1993; Sriram 1993). It may be noted that Siddhanta Darpana is not a work of historical curiosity only. Even today, it serves as the basis of almanac preparation in Orissa and has practical value for positional astronomy.

Ray has drawn a nice parallelism between Samanta Chandra Sekhar and Tycho Brahe. But he does not give the contrast. Tycho, in recognition of the merits of his work gained the friendship of the king of Denmark. He was given a full island with an observatory, built under the royal patronage. He was succeeded by a student like Kepler who made use of the fabulous data collected by Tycho and formulated the most famous three laws of planetary motion. But Samanta worked single handed and unaided, under most adverse conditions. Nevertheless, Siddhanta Darpana stands as a monumental piece of work in traditional astronomy. Chandra Sekhar's position among great Hindu astronomers is yet to be fixed. Nature[1] (1899) commented. "Prof. Ray compares the author very properly to Tycho. But we should imagine him to be greater than Tycho". It will probably not be an exaggeration to say that Samanta Chandra Sekhar belongs to the class of the four great Hindu astronomers, Aryabhata, Varahamihira, Brahmagupta and Bhaskara.

In view of the quality of data obtained by Samanta Chandra Sekhar through naked eye observations, which are comparable to those of the modern astronomy based on telescope and other optical devices and also the predictive potential of his work expected to remain valid for thousands of years to come, it may be fair to state that he is probably one of the greatest naked eye astronomers of the world. In fact, Knowledge[2] (1899) comments to this effect, "The work is of importance and interest to us, westerners also. It demonstrates the degree of accuracy which was possible in astronomical observation before the invention of the telescope".

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