Five hundred years of *Tantrasangraha*: A landmark in the history of astronomy*

The year 2000 AD happens to be the five hundredth anniversary of the composition of the celebrated astronomical text *Tantrasangraha* by the renowned Kerala astronomer Nilakantha Somayaji (c. 1444–1550 AD) of Trikkantiyur. *Tantrasangraha* is not only the most important treatise on astronomy composed by the Kerala school of astronomers, it also ranks along with *Aryabhatiya* (c. 499 AD) of Aryabhata and *Siddhantasiromani* (c. 1150 AD) of Bhaskaracharya as one of the major works which significantly influenced all further work on astronomy in India.

Delivering the inaugural address during the conference organized to celebrate the 500th anniversary of *Tantrasangraha*, B. Ramamurthi, neurosurgeon and Sanskritist, drew attention to the fact that the great achievements of Indian tradition in science, such as those of the Kerala astronomers, were hardly known outside the circle of specialists in History of Science; they need to be taught in our school curriculum and also widely popularized otherwise. He also highlighted the need to edit and publish the large corpus of scientific works in Sanskrit and other Indian languages, as a task of national priority. Delivering the Presidential address, Pon Kothandaraman, Vice-Chancellor, University of Madras, urged the science faculties in universities and other national institutions to take up serious and intensive study of traditional sciences so that we can work towards an integrated scientific tradition.

The conference honoured K. V. Sarma, Sri Sarada Education and Research Centre, Chennai, for his valuable contributions to the study of Indian mathematics and astronomy. Responding to the felicitation, Sarma called upon young scholars to take up the task of editing and analysing the texts of our rich scientific heritage. He also delivered the first lecture of the conference on Nilakantha and his works wherein he outlined the contents and some of the highlights of his works, *Tantrasangraha, Golasara, Siddhantadarpana* and its *vyakhya, Chandracchayaganita* and its *vyakhya, Grahaparikshakrama, Sundararajaprasnottara, Aryabhatiyabhashya* and *Jyotirmeemamsa.*

One of the important themes of the conference was the contributions of the Kerala school to the development of mathematical analysis. Trivikraman (Cochin University) presented a survey of the work of the Kerala school in mathematics. M. S. Rangachari (Chennai) compared the root extraction methods given in *Sadratnamala* of Sankaravarman (c. 1830 AD) with the bisection method of numerical analysis. Madhukar Mallaya (Thiruvananthapuram) described the geometrical demonstrations given in Nilakantha's *Aryabhatiyabhashya* for the well-known results of Aryabhata concerning the sums of natural numbers, sums of their squares and sums of their cubes. The pedagogical value of this elegant demonstration involving rectangular strips was appreciated by all.

Johny John (Thiruvananthapuram) discussed the proof of the infinite series for π given in the celebrated Malayalam text *Yuktibhasha* of Jyeshthadeva (c. 16th century) and in the commentary *Kriyakramakari* by Sankara Variar (c. 1550 AD) on Bhaskaracharya's *Lilavati*. Jolly John (Nehru Memorial Library, New Delhi) discussed the rationale given in *Yuktibhasha* for obtaining the correction or the remainder terms, which enable us to easily compute values of π correct to any level of accuracy from this inordinately slowly converging series. He explained how the rationale given in *Yuktibhasha* could be used to derive higher-order correction terms, which essentially lead to a well-known continued fraction.

The central theme of the conference was the significant advances made in planetary theory and other aspects of astronomy by the Kerala school and later astronomers. M. S. Sriram (Madras University) gave an overview of the traditional Indian planetary model. The traditional model worked quite well for the exterior planets but incorrectly applied the equation of centre for the interior planets to the mean Sun. Still it gave a fairly accurate procedure for computing the latitudes of planets. This was in contrast with the Greek planetary model of Ptolemy, where the planes of all planetary orbits intersected at the earth and it became impossible to capture even the basics of latitudinal motion of planets. The problems concerning the planetary latitudes and the equation of centre persisted with the celebrated reformulations of Copernicus and Tycho Brahe (as they followed Ptolemy uncritically in most respects) and were resolved in the Graeco-European tradition only with the work of Kepler in early 17th century.

K. Ramasubramanian (Madras University) discussed Nilakantha's revision of the traditional Indian planetary model as presented in *Tantrasangraha*. Nilakantha unified the two seemingly different procedures of computing planetary latitudes in the traditional planetary theory. He proposed that what was taken as the *sighrocca* of the interior planet in the traditional model should be identified with the planet itself – as what was observed as the latitude was the deflection of the planet from the ecliptic and not of some *sighrocca*. Nilakantha proposed that the equation of centre for the interior planet should be applied to the mean planet (referred to as *sighrocca* by the ancients) and not to the mean Sun. In this way Nilakantha arrived at the correct formulation of the equation of centre for the interior planets; he was perhaps the first astronomer to do so in the history of astronomy. Nilakantha also gave a unified theory of planetary latitudes. This revision of the traditional planetary model as given in *Tantrasangraha* seems to have been accepted by most of the later astronomers of Kerala such as Chitrabhanu, Sankara Variar, Jyeshthadeva, Achyuta Pisarati and Putumana Somayaji.

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M. D. Srinivas (Centre for Policy Studies, Chennai) outlined the geometrical picture of planetary motion according to Nilakantha. He emphasized the fact that unlike in the Graeco-European tradition which presented exclusively geometrical models for planetary motion (and that too based solely on compositions of uniform circular motions), the Indian astronomers present computational models, and on rare occasions give geometrical pictures merely as aids to understanding. One such discussion of the geometrical picture associated with the traditional planetary model may be found in the commentary *Bhatadipika* on *Aryabhatiya* by Paramesvara, the *Paramaguru* of Nilakantha.

In his *Aryabhatiyabhashya*, Nilakantha notes that the geometrical picture of planetary motion depends on the computational model employed. In the same work Nilakantha clearly explains that the interior planets go around the sun in orbits that do not enclose the earth and that they go around the earth only by virtue of the sun going around the earth. In his works *Golasara* and *Siddhantadarpana*, Nilakantha presents a concise but precise statement of the geometrical picture of planetary motion. According to this picture the five planets, Mercury, Venus, Mars, Jupiter and Saturn, go around the mean Sun in eccentric orbits; the planes of the orbits of the planets are inclined to the ecliptic and pass through the mean Sun.

L. Satpathy (Institute of Physics, Bhubaneswar) discussed the work of the great Astronomer of Orissa, Chandrasekhara Samanta, who flourished in the 19th century. Working under trying circumstances and without any training in modern astronomy, Chandrasekhara arrived at a very similar geometrical picture of planetary motion (as discussed by Nilakantha) and was also able to obtain all the four important corrections for the lunar motion – the *manda* correction (equation of centre), *tungantara* (which incorporates evection), *pakshika* (variation) and *digamsa* (annual equation). It was no wonder that the Council of the Puri temple decided to follow the *Panchanga* as computed by Chandrasekhara, since it was in best accordance with observations. Incidentally the seminal work in observational astronomy of Chintamani Raghunathachari, who was a contemporary of Chandrasekhara but trained in modern astronomy, was discussed by R. Subramanian (M. P. Birla Planetarium, Calcutta).

S. Madhavan (Thiruvananthapuram) explained how the variable epicycle model given in the *Suryasiddhanta* for the *manda* process, leads to the orbit of the planet being made up of two elliptical segments which are asymmetrical. Radhakant Thakur (Kendriya Samskrita Vidyapeetha, Tirupathi) discussed the contents of *Tantrasangraha*.

N. K. Sundareswaran (Sri Sankaracharya University, Kaladi) emphasized the long tradition of meticulous and continuous observation in Kerala astronomy, starting from the observatory in Mahodayapuram in the 9th century. Paramesvara (1460–1455), the *Paramaguru* of Nilakantha, is famous for having carried on precise observations for over half a century. Nilakantha in his *Aryabhatiyabhashya* and *Jyotirmimamsa* emphasizes that the texts of the Aryabhatan schools are not really meant to teach any finished theory of planetary motion; indeed their object is mainly to instruct the student about the need for constant revision of theories in the light of observations.

The flexible theoretical framework of Indian astronomy was highlighted in the presentations of S. Balachandra Rao (National College, Bangalore) and his co-workers Padmaja Venugopal and S. K. Uma. Based on a detailed study of the large corpus of writings of the great scholar T. S. Kuppanna Sastri, who edited many works in 'Jyotisha' and instructed a number of students in the first half of 20th century, they have come up with *bija* corrections for the parameters and procedures employed in Indian astronomy for the computations of longitudes and eclipses, so that the results come out to be fairly accurate.

Another important theme of the conference was the interaction between Indian astronomical tradition and other traditions. S. M. R. Ansari (Aligarh) discussed the development of the Islamic astronomical tradition in India and highlighted how some of the developments such as the preparation of the *Zij i Nasiri* during the reign of Iltutmish (1246–1265) and the construction of an observatory during the reign of Firuz Shah Bahamani, were in fact prior to the corresponding developments in Islamic astronomical traditions in West/Central Asia. He also discussed the impact of Islamic astronomical tradition and the debates that it gave rise to, in the works of Nityananda, Kamalakara and Muniswara in the 16th and 17th centuries and also in the works of astronomers in the court of Raja Sawai Jai Singh in the 18th century. A highlight of the conference was the presentation by the young historians of astronomy from Iran, Negar Naderi and Farid Ghassemlou of the Encyclopaedia Islamica Foundation, Tehran. Outlining their intensive search for Persian astronomical tables in India, they reviewed the contents of 11 astronomical tables and their relation with Indian astronomy.

Apart from the above main themes, the conference also saw some presentations on larger issues in History and Philosophy of Science. Navjyoti Singh (NISTADS, New Delhi) discussed the traditions of applying mathematical reasoning for understanding the functioning of the mind. S. Venkatesan (VJTI, Mumbai) discussed the notion of exact science as developed by the Greeks and leading up to Newtonian physics and contrasted it with the Indian tradition in astronomy. S. M. Bhave (N. W. College, Pune) discussed the methodology of Indian mathematics as can be gleaned from the *upapattis* or proofs given in the Marathi translation of *Siddhantasiromani* by Khanapurkar.

Apart from focusing on many important themes, the highlight of the conference was the lively discussions in which a large number of participants took active part. The presence of a large number of participants from Kerala was indeed noticeable, which led one observer to comment that perhaps the Kerala school is coming to life once again.

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