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THE EUROPEAN ASTRONOMICAL TRADITION: ITS TRANSMISSION INTO INDIA, AND ITS RECEPTION BY SAWAI JAI SINGH II

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When I previously visited India to participate in the Āryabhaṭa Symposium in November 1976, I presented a paper which attempted to trace the nature and extent of Mesopotamian and Greek influences on ancient Indian astronomy.[1] The routes by which these were subsequently transmitted to the Islamic and European nations are complex and varied. Ancient Hindu and Arab astronomers, like their European counterparts, have been indebted to the Greeks for much of their knowledge. However, as a result of the selective transmission of Greek texts in the Hellenistic and Graeco-Roman eras, they took longer to appreciate the fact that Ptolemy of Alexandria's astronomical system[2] was the end product of determined attempts by Greek mathematicians and astronomers from the time of Plato (4th century B.C.) onwards to relate the principle of the uniform circular motion of the heavenly bodies to the concept of a geocentric universe. Even when they did become aware of this, they felt under no obligation to accept or re-examine these assumptions; their prime concern being merely the ability of the Greek planetary model as they knew it, to predict the future motions of the Sun, Moon, planets and stars. After comparisons between the positions derived from Ptolemy's *Almagest* and those from their own observations had revealed the inadequacy of excentric circles, epicyclic motions, and the equant construction for this purpose, Hindu astronomers tried to improve the situation by adopting the earlier Babylonian numerical procedures for computing eclipses and celestial positions.[3] Arab and Muslim astronomers, on the other hand, sought to do so by following the alternative policy of improving their instrumentation and making fresh observations from which to compute more reliable tables.[4] Yet Europeans continued to use the traditional astrolabe, armillary sphere, and triquetrum (or parallactic rulers) as their chief observing tools as late as the sixteenth century A.D. when Nicholas Copernicus's Sun-centred universe posed the first serious challenge to the fundamental philosophical assumptions of the Christianised Aristotelian-Ptolemaic world-view.[5]

Undoubtedly the most impressive Muslim observatory was that at Samarkand, founded by the Tartar Prince Ulugh Beg in 1419.[6] Its principal instrument, with which astronomical observations were carried out without serious interruption during a period of over thirty years, was a huge meridian arc made of masonry. A catalogue of 1,018 stars completed in 1437 A.D. is based mainly upon the new observations collected by Beg and his assistants, and to a lesser extent upon the celestial co-ordinates in Ptolemy's star catelogue updated to compensate for the increase in longitude resulting from the precession of the equinoxes throughout the intervening thirteen centuries.[7] The first Astronomer Royal at Greenwich, John Flamsteed, writing in the early 18th century, ranks Beg with his European counterparts Regiomontanus, Bernard Walther, and Copernicus as a major innovator in this field.[8] Yet none of their observations made with armillary spheres or parallactic rulers could match the accuracy of those made by the Danish astronomer Tycho Brahe with a 7½-foot radius brass quadrant in a rectangular iron frame at his observatory at Uraniborg on the island of Hveen. The same applied, in Flamsteed's view, to Tycho's famous mural quadrant, which had the same radius and a graduated limb from which altitudes could easily be read off to within $\pm 5''$.

A recent discussion of Tycho's instrumentation[9] and an independent analysis of the data in his and other star catalogues[10] have, however, confirmed that Plamsteed was wrong in ascribing errors in Tycho's star positions primarily to his use of plain (i.e. naked eye) sights. This factor accounted for no more than $\pm 1'$, whereas significantly larger errors were incurred through Tycho's incorrect allowances for the effects of astronomical refraction, erroneous value for the solar parallax and errors in his reductions from altitude observations to celestial longitudes and latitudes. Thus the English Astronomer Royal's prejudiced view that the Danzig astronomer Johannes Hevelius's lifelong labours on the rectification of errors in Tycho's star catalogue were in vain because he was also observing with instruments not equipped with a telescopic sighting-tube and an eyepiece micrometer was unjustified, and Hevelius had every right to be offended by Flamsteed's criticisms[11] and by Robert Hooke's vindictive *Animadversions* against the quality of his instrumentation and reliability of his observing technique.[12] In a letter of 23 December 1676 to Flamsteed concerning this matter, published in his *Annus Climactericus* of 1685,[13] Hevelius stresses that discrepancies of $\pm 2'$ between their respective observations of certain stars in the Pleiades constellation ought not to have been ascribed entirely to errors in his data. Flamsteed's own method of reduction presupposed that both Johannes Hecker's *Ephemerides* and Tycho's star-positions were entirely free from error, despite the fact that Flamsteed himself had claimed that both could err by over $\pm 5'$. Moreover as a very recent and still-unpublished analysis would appear to have confirmed, there were several good reasons for systematic errors arising in Flamsteed's own sextant measurements[14] irrespective of whether or not a high internal consistency were achieved with telescopic sights and micrometer eyepieces.

The first person to provide details of the procedures for rectifying the instrumental errors in astronomical quadrants and sextants and for applying telescopic sights to these instruments was the French astronomer Jean Picard in *La mésure de la Terre* (Paris, 1671)—a book rather difficult to obtain in England[15] that Flamsteed himself experienced difficulty in reading on account of his poor knowledge of the French language. Picard's verbal and written instructions were followed by his Danish protégé Olaus Roemer and fellow-countrymen Philippe De La Hire when, in 1683, they began observations with a new 5-foot radius quadrant at the newly-constructed Paris Observatory which the Abbé Nicholas De La Caille was later to describe in 1765 as :—

> "the oldest that have been made with a precision most closely approaching those being employed at present"[16]

The other instrument which helped guarantee a high degree of accuracy was a pendulum clock with which the times of the meridian transits were obtained. After twenty years of observation, principally (though not exclusively) with these instruments, La Hire became convinced that the only remaining cause of error in predicting the planets' positions had to be the lack of accuracy with which their respective orbits can actually be represented by an ellipse.[17] Thus, instead of using Kepler's theory of planetary motion as a framework into which to fit his data, he preferred to use these data to make empirical corrections to the equations developed from that theory. Unfortunately, his adoption of this empirical procedure, coupled with the fact that his observations actually contained errors greater than those arising from the use of different theories, meant that his astronomical tables of 1727[18] were ultimately to be of little value for establishing the actual shape of the planetary orbits.

Amongst the first to apply these tables were the Italian Jesuit astronomers Johannis Baptista Carbone and Dominico Capasso who, between 1723 and 1730, made regular telescopic observations of solar and lunar eclipses and the immersions and emersions of Jupiter's satellites both from the Jesuit College of Saint-Antoine and the Royal Palace of King Joao V of Portugal in Lisbon.[19] One purpose of these astronomical observations was to determine the latitudes of the two places (which happened to be situated on the same meridian). La Hire's tables supplied data for Paris, with the aid of which the longitude difference from that capital city and hence the longitudes of other towns and cities throughout the world could also be obtained. The principal instruments employed were a modest refractor constructed by Joseph Campani and subsequently, for the satellite observations, 8-, 10- and 22-foot long telescopes. A 2½-foot quadrant, 3-foot sextant, and 5-foot mural quadrant were employed at different times for observations of the Sun's altitudes both on and outside the meridian. A reliable pendulum clock, reputedly regulated to the nearest second of mean solar time, was used to determine: the instants of immersion and emersion of Jupiter's satellites; the transits of lunar markings; and the beginnings, ends, and intermediate phases of solar eclipses. Various reports of the results of all those activities appeared in the *Philosophical Transactions* during the period in question.[20] Most of them were communicated to the Royal Society of London by one of its Fellows Dr. Isaac de Seguera Samuda.

The first mention of a micrometer being used in conjunction with the 8-foot telescope to estimate the magnitude of the partial solar eclipse of 25 September 1726 and a lunar eclipse of 10 October 1726, occurs in issue No. 400 of that periodical for October-December 1727.[21] Its design was probably similar to that used by Picard, based on principles similar to those described in La Hire's Astronomical Tables[22]. In the absence of any information to the contrary, it seems reasonable to assume that the quadrant used by the two Jesuit astronomers, like that illustrated in La Hire's book, would have been equipped with a nonius scale and telescopic sights. Certainly, when carrying out lunar eclipse observations, Carbone and Capasso followed La Hire in using the names of the lunar markings and lunar map in Giovanni Battista Riccioli's *Almagestum novum* (Bononiae 1651) as a basis for their identifications of the Moon's topographical features[23]. However, they preferred to take their corrections for astronomical refraction from Edmond Halley's "accurate Table of Refractions" in one of the 1721 issues of the *Philosophical Transactions*[24].

The fact that it is this particular tradition of European astronomy which first came into contact with the Hindu and Moslem traditions through the person of Jai Singh II is no accident, but a direct consequence of Portugal's possession of a colony at Goa, and the contacts that resulted from this east-west connection. It was the Jesuit Superior of the Mogor mission at Goa, the Portuguese Father Emmanuel de Figuereido, during a visit in 1728 to Jai Singh's Court at Jaipur, who first acquainted the Maharaja with the progress in this science then being made in Europe and particularly in Lisbon[25]. So well did he succeed in exciting his host's interest that the latter persuaded him to lead an embassy to the Portuguese monarch, consisting of several experts in astronomy from Jaipur whose task it would be to acquaint themselves at first-hand with both the general and local state of that science[26]. They were presumably also instructed to return with copies of important books on this subject, which were to form the nucleus of the library in the Maharaja's Palace at Amber[27]. Through this Jesuit emissary, Jai Singh further requested King Joao V to send him someone well-versed in astronomy to instruct him in the European astronomical techniques.

The King doubtlessly recognised the political advantage of co-operating with an Indian ruler whose influence could well serve to prevent the ineffectual Moghul Emperor Muhammad Shah from allowing his vassals to interfere with the Portuguese colonies at Goa and Surat; and he would also have been fully conscious of the opportunity that this scientific mission could provide, for propagating the Christian religion in India. Thus he enlisted the help of his Privy Councillors in instigating a diligent enquiry, and duly selected a recognised astronomer and physician of robust physique called Xavièr (or Jouvier) da Silva, as the person most likely to withstand the rigours of the long and perilous journey[28]. This scholar, who was not a Jesuit, finally reached Jaipur with the embassy about the end of 1730[29]. By this time, Jai Singh's astronomers had completed a Sanskrit translation of Ptolemy's *Almagest* and compiled much of the data for an up-dated version of Ulugh Beg's tables called the *Zij Muhammed Shahi*[30], utilising new observations of celestial altitudes and azimuths collected with the large masonry instruments of the Jantar Mantar at Delhi[31]. The purpose of this work was to provide the basis for a reliable calendar, and for the prediction of future celestial events.

On comparing the solar, lunar and planetary positions in the *Zij* with those calculated from La Hire's tables,[32] Jai Singh quickly found discrepancies of up to half a degree in the positions of the Moon, and six minutes in the times of occurrence of solar and lunar eclipses.[33] Having grown up in the belief that the accuracy of astronomical tables is a direct measure of the reliability of the observational data from which they were derived, he naturally attributed these not to La Hire's lack of skill as an observer, but to his reliance upon measurements made using a brass quadrant of limited size and doubtful stability. Hence he must have felt, as Hevelius had done over fifty years earlier, that little was to be gained by fitting telescopic sights to such an instrument, even if this did significantly increase the internal consistency among the values of observed meridian altitudes. Another fact to be borne in mind is that many such observations were of the Sun, for which a telescope's action as a burning-glass can be a distinct disadvantage. On the other hand, he was well aware of the benefits of this instrument for obtaining geographical longitudes from observations of Jupiter's satellites, the phases of Mercury and Venus, lunar and solar eclipses, following the practice of Fathers Carbone and Capasso in Lisbon; and, as Dr. Ansari has already pointed out,[34] he subsequently made use of telescopes for these very purposes, as well as for sunspot observations.

On the whole, this first contact with European astronomy served merely to strengthen Jai Singh's conviction that large solid immovable structures were capable of yielding a higher degree of accuracy than large brass or iron astrolabes or the astronomical quadrants and sextants of the European astronomers.[35] What he initially failed to recognise was that the major source of error in his comparisons was not inherent in these instruments but rather in La Hire's adoption of a faulty theoretical basis for his lunar and planetary computations. However, after mastering the explanations supplied in La Hire's book (presumably with some assistance from his Portuguese tutor), the intelligent Maharaja did indeed notice that its author gave no indication of which hypothesis of celestial motion or which geometric method had been used in constructing his tables. Then, on discovering five tabulated positions of the Moon differing by almost a degree from new measurements made by his astronomers at Jaipur, he began to wonder whether any better tables existed and, if so, what their underlying theoretical principles were. These were the very matters raised by him in a letter late in 1732 to Claude Boudier, the Superior of the Jesuit Mission at Chandernagore, when seeking his advice on how one might proceed from an axiomatic basis to derive the lunar theory geometrically.[36] This query is in itself an indication that he was by this time already familiar with Euclid's *Elements*, most probably an English edition revised by Samuel Cunn based on the Latin translation of Frederigo Commandino to which were appended treatises on plane and spherical trigonometry and on the construction of logarithms.[37] Boudier was, however, not equipped to answer such queries, even though he was a skilled telescopic observer of the heavens.

Jai Singh's own theories of planetary motion, as might be expected, were just those described in the old Siddhāntas where all planets were supposed to possess the same linear speeds, implying that their mean angular speeds varied inversely in proportion to their respective distances from the Earth. Their actual erratic motions, to which they owe their Greek name, were ascribed to their individual "whims" or free wills. Since Hindu astronomy has itself been partially derived from Sanskrit translations from ancient (mainly pre-Ptolemaic) Greek sources,[38] the task of the theoretical astronomer was simply to "save the phenomena" by accurate predictions and not to explain the planets' motions in terms of physical causes. Consequently, Jai Singh's earlier exposure to the Hindu tradition would have pre-conditioned him to accept the Christianised variant of the Aristotelian-Ptolemaic universe still accepted by loyal Catholics in western Europe, and doubtlessly taught to him by Xavier da Silva.[39]

It must, however, be emphasised that irrespective of whether or not he was introduced by this tutor to Copernicus's arguments for the Earth's diurnal and annual motions, his failure to espouse that Polish astronomer's system of planetary motion[40] had little bearing on his decision to persevere with the construction of further masonry instruments similar to those in Delhi at his capital city of Jaipur and subsequently at Ujjain, Benares and Mathura.[41] Although he was certainly unaware of the fact, the Danish astronomer Philip Lansberg's adoption over a century earlier of the complex geometrical constructions of Copernican astronomy as the basis of solar, lunar, and planetary ephemerides[42] had yielded predictions greatly inferior to those based upon Kepler's *Rudolphine Tables* (Ulm, 1627). On the other hand, as Newton had since convincingly demonstrated, Kepler's three laws of planetary motion were all consequences of the inverse-square distance law of a centrally-attracting gravitational force.[43] Thus, only by adopting this universal principle and Newton's own three laws of motion as the axioms of a new theoretical set of planetary tables, could the accuracy of La Hire's *Tabulae* and Jai Singh's *Zij* be transcended. Yet even in Europe three more decades were destined to elapse before the inheritors of the Newtonian tradition were able to develop methods of analysis and observation that were sophisticated enough to enable the Moon's celestial position to be predicted to within the limits of observational accuracy[44]—a development which Jai Singh could scarcely have been expected to foresee, especially in the light of the very selective introduction to European methods in mathematics and astronomy that he had received.

For the sake of completeness, I feel obliged to add some further remarks concerning Jai Singh's subsequent contacts with Jesuit astronomers, although I consider that they contributed very little that was new to his understanding of European astronomy. In response to his plea in 1733 for assistance with observations of a forthcoming eclipse, Boudier agreed to undertake the arduous 1000-mile journey to Jaipur. In company with Father Pons, Boudier set out for that destination on 6 January 1734.[45] No doubt the idea of establishing a new Christian mission at Jaipur to complete the religious blockade of the Moghul dominions was for them as strong a motivation as their desire to assist Jai Singh in his astronomical observations! At any rate, after making longitude determinations en route from observations of Jupiter's satellites with a 17-foot focal length refracting telescope at Delhi, Benares, and Mathura[46], the two French Jesuits duly arrived at Jai Singh's court some nine months later. However, ill-health forced them to return to their native land after only a brief stay, during which they spent a great deal of time disputing with the local Brahmins the extent of Indian astronomy's indebtedness to ancient Greek culture.

Nothing daunted, Jai Singh quickly enlisted the help of the Portuguese Viceroy Dom Pedro Mascarenhas, Conde de Sandomil, in attracting others in their place; and they were ultimately successful in persuading two German Jesuits Anthony Gabelsberger and Andrew Strobel to embark upon the long and hazardous journey to Jaipur. Here again, it must be assumed that the prospect of establishing the Christian church in India at a time of serious political and social unrest was a strong incentive to them. After a number of delays, which have been well documented elsewhere[47] and need not be repeated here, they arrived on 4 March 1740 to a very warm reception and were most considerately treated in every way until the death of Father Gabelsberger just over a year later[48]. With Jai Singh's own death in 1743, Strôbel left for Agra where, according to the most reliable source, he died in 1758.[49] Meanwhile, the Jaipur observatory was allowed to go to ruin, while the Maharajah's valuable collection of books and manuscripts became scattered and some instruments sold as old copper[50].

Notes and References

[1]Forbes, Eric G., "Mesopotamian and Greek Influences on Ancient Indian Astronomy and on the Work of Aryabhata", *Indian J. Hist. Sci.* xii (1977), 150-60.

[2]This is contained in Claudius Ptolemaeus, *Megale Syntaxis*, the Arabic-Latin text of which has recently been subjected to a critical study by Paul Kunitzsch, in *Der Almagest: Die Syntaxis Mathematica des Claudius Ptolemaus in arabisch-lateinischer Uberlieferung* (Wiesbaden, 1974). The history of the text and its study through the ages has also been well summarised by Olaf Pedersen, *A Survey of the Almagest* (Odense, 1974).

[3]Details regarding this are contained in Forbes, *op. cit.* 1.

[4]An excellent description of these developments is contained in Aydin Sayili, *The Observatory in Islam and its Place in the General History of the Observatory* (Ankara, 1960).

[5]Two general text-books giving balanced historical accounts of European astronomy are Pannekoek, A., *A History of Astronomy* (London, 1961) and Dreyer, J. L. E., *A History of the Planetary Systems from Thales to Kepler* (Cambridge, 1906). A stimulating controversial view of the same line of development is to be found in Arthur Koestler, *The Sleepwalkers: a History of Man's changing vision of the Universe* (London, 1959). A fresh appraisal is presented by Thomas S. Kuhn in *The Copernican Revolution* (Harvard, 1957); and many other books have been written on this subject.

[6]*Op. cit.* 4. See, in particular, the section entitled "The Samarqand Observatory" on pp. 260-89.

[7]Knobel, Edward Ball, *Ulugh Beg's Catalogue of Stars revised from all Persian Manuscripts existing in Great Britain, with a vocabulary of Persian and Arabic words* (The Carnegie Institute of Washington; Washington D.C., 1917).

[8]Flamstedius, Johannes, *Historia Coelestis Britannicae* iii (Londini, 1725), ch. 51.

[9]Victor E. Thoren, "New Light on Tycho's Instruments", *Jour. Hist. Astronomy* iv (1973), 25-45.

[10]Moesgaard, Kristian Peter, "The Bright Stars of the Zodiac, a Catalogue for Historical Use", *Centaurus* xx (1976), 129-58.

[11]A comment to this effect was made by Flamsteed in the *Philosophical Transactions* vii No. 89 (1672), 5119, when reporting the results of his first solar parallax observations: it elicited a reply by Hevelius in his *Machina coelestis pars prior* (Gedani, 1673). Flamsteed, in a subsequent issue of this same periodical (vol. viii, No. 96, 1673) repeated his objection in the form of an open letter to Giovanni Domenico Cassini on the motions of Jupiter's satellites; whereupon Hevelius protested in a private communication of 7 April 1674 (New Style) to the Royal Society's secretary Henry Oldenburg, published in his *Annus Climactericus* (Gedani, 1685), 67-74, that his observational method was much more reliable than Flamsteed seemed to imagine.

[12]Robert Hooke, *Animadversions on the first part of the Machina Coelestis of...Hevelius* (London, 1674), independently attacked Hevelius's published defence of the conventional bare sights and likewise failed to acknowledge the high internal consistency of Hevelius's sextant observations.

[13]*Op. cit.*, pp. 79-89.

[14]Ashworth, William B., "A Probable Flamsteed Observation of the Cassiopeia A Supernova", *Jour. Hist. Astronomy* xi (1980), pp. 1-9.

[15]"A Breviate of Monsieur Picarts Account of the Measure of the Earth" was, however, published in the *Phil. Trans.* x No. 112 (1675), 261-72.

[16]La Caille's actual words, in his *Éphemerides* for 1765, p. 50 were: "Ses observations sont les plus anciennes qui aient été faites avec la précision la plus approchante de celles qu'on emploie à présent". Cited by Delambre, J. J. *Histoire de L'Astronomie Moderne* ii (Paris, 1821), p. 662.

[17]Delambre, *ibid.*, p. 663.

[18]Philippus de la Hire, *Tabulae Astronomicae Ludovici Magni* (Parisiis, 1727).

[19]A valuable bibliographic guide to literature about observatories in general, which first directed me to the relevant sources of information on Lisbon cited in ref. 20 is: J. C. Houzeau, *Vade-Mecum de l'Astronomie* (Bruxelles, 1882), Cf. p. 983.

[20]Altogether eight articles were published under Father Carbone's name during the period in question. The precise references are as follows: *Phil. Trans.* xxxiii No. 382 (1724), 51-3; *ibid.* xxxiii No. 385 (1724), 180-9; *ibid.* xxxiv No. 394 (1726), 90-101; *ibid.* xxxv No. 400 (1727), 335-9; *ibid.* xxxv No. 401 (1728), 408-13; *ibid.* xxxv No. 403 (1728), 471-9; *ibid.* xxxvi No. 410 (1729), 170-4; *ibid.* xxxvi No. 414 (1730), 363-5. The second article, which was a joint publication with Father Capasso, drew the attention of the English Astronomer Royal James Bradley who, by making what appears to be a somewhat dubious allowance for the inferior performance of Campani's refracting telescope, increases the value for the London-Lisbon longitude difference obtained from the Portuguese observations by $5\frac{1}{2}'$, to $36\frac{1}{2}'$ (*ibid.* xxxiv No. 394 (1726), 85-90).

[21]All that is stated in this source regarding that instrument is "——quarum 18, integras praecontinebat Diameter solis"; that is, 18 revolutions of its screw contains the solar diameter. From this meagre information, and the fact that each revolution was subdivided into sixty parts, we can deduce that any individual setting could be made with an accuracy of within $\pm 2''$.

[22]"Micrometri Descriptio & usus", *op. cit.* 18, 2nd edition, pp. 65-71.

[23]"De Observatione Eclipsium", *ibid.*, pp. 84-89, lists the names of 48 lunar features.

[24]Edmond Halley, "Some remarks on the allowances to be made in astronomical observations for the refraction of the air.... With an accurate Table of Refractions", *op. cit.* xxxi No. 368 (1721), 169-72.

[25]Sir Edward Maclagan, *The Jesuits and the Great Mogul* (London, 1932), p. 133.

[26]Many interesting details concerning this embassy are contained in J. B. Amâncio Gracias, "Uma embaixada cientifica portuguesa à corte dum rei indiano no século XVIII", *O Oriente Português* xix (1938), 187-202. The negotiations were carried on with Portuguese government officials in Goa, through the intermediary of Pedro da Silva Leitão, a Portuguese physician already in Jai Singh's service at Jaipur (*ibid.*, p. 194).

[27]Although Jai Singh's library was dispersed, a comparatively recent index to the manuscripts still preserved in the Jaipur Palace Museum has been prepared by Bahura, G. N. and published at Jaipur in 1971.

[28]*Op. cit.* 26, pp. 198-9.

[29]A. B. de Braganca Pereira, *Archivo Português Oriental* i (Bastora: Rangel, 1940), p. 181. It is not known for certain whether Xavier Da Silva ever returned to Portugal. Both Maclagan (*op. cit.* 25, p. 134) and Sir Jadunath Sarkar, *Sci. Cult.* ix (1944), p. 478, have sought to identify him with Pedro da Silva Leitão (cf. ref. 26), while Soonawala, M. F. (*ibid.*, p. 414) believes Xavier de Sylva (*sic*) to be Hakim Martin of Jaipur. Hunter, *op. cit.* 31, p. 210 asserts that Pedro was Xavier's son.

[30]Blanpied, William A., "The Astronomical Program of Raja Sawai Jai Singh II and its Historic Context", *Japanese Stud. Hist. Sci.* xiii (1974), 87-126, tells us (cf. p. 103) that there are at least 13 extant Persian copies of this *Zij* of which the oldest—an incomplete Devanagari Manuscript—is still in Jaipur and the British Museum Add. Ms. 14,373 (fol. 212) contains a copy of it. Five other copies are in the Tashkent Oriental Manuscript Library (Nos. 1/230, 517/440, 519/438, 520/411, 521/439); 2 are in the Aligarh University Mss Library (Fasiyah Ulum No. 30 and Sulaiman No. 527/6); while the remaining four are respectively in the Cambridge University Mss. Collection (742 King 212); Bankipur Library, Patna (No. 11/69); State Central Library, Hyderabad (Riyazi No. 300); and Raza Library, Rampur (No. 1221).

[31]Hunter, William, "Some account of the astronomical labours of Jaha Sinha, Raja of Ambhere, or Jayanagar", *Asiatic Researches* v (1799), 177-210 contains a fairly complete description of the Delhi Observatory and an English translation of the preface to the *Zij*. A summary of the contents of the Jaipur Manuscript of that work is also to be found on pp. 8-15 of Kaye, G. R. *The Astronomical Observatories of Jai Singh* (Calcutta, 1918)—a publication which was soon expanded into *op. cit.* 33. More recently, K. M. Talgeri, "Jai Singh and his Observatory at New Delhi", *Sky and Telescope* xviii (1958), 70-72 and William A. Blanpied, "Raja Sawai Jai Singh II: an 18th Century Medieval Astronomer", *Amer. Jour. Phys.* xliii (1975), 1025-35, have again taken up the same theme.

Yet none of these authors nor other travellers to India who have written on this subject has even hinted at the strong likelihood of the *Miśra Yantra* having been constructed after the return of the Portuguese mission, after La Hire's tables could be used to make the calculations of longitude differences required to draw the scale on one of the four semicircular arcs on this instrument. That scale was surely intended to show Paris time, since Greenwich was not internationally chosen as the prime meridian until 1882. Another possible link with the Portuguese mission on which no one appears to have hitherto speculated, is the timing of the journey of Muhammed Mahdi to "the further islands" and that of Muhammed Sharif to a place (in latitude 4°12′S) where "the southern pole was overhead" (see Kaye, *op. cit.* 33, p. 7). Could Mahdi have made his astronomical observations during the return voyage, either in the Azores or the Cape Verde Islands, and Sharif at the Seychelle Islands or one of the Portuguese colonies (e.g. Malmdi or Mombasa) on the East African coast?

[32]*Op. cit.* 18.

[33]Kaye, G. R., *A Guide to the Old Observatories at Delhi; Jaipur; Ujjain; Benares* (Calcutta, 1920), p. 17.

[34]Ansari, S. M. Razaullah, "The Establishment of Observatories and the Socio-Economic Conditions of Scientific Work in Nineteenth Century India", *Indian J. Hist. Sci.* xiii (1978), 63.

[35]Blanpied, *op. cit.* 30, p. 101 estimates that the level of accuracy actually attainable with Jai Singh's instruments was $\pm 2'$ in measuring solar altitudes and $\pm 15^s$ in estimating solar time. These figures compare not unfavourably with contemporary European measurements, although the latter were about to be rapidly superseded during the next generation.

[36]Noti, Severin, *Joseph Tieffenthaler, S. J.—a forgotten geographer of India* (Bombay, 1906), p. 92.

[37]This may be inferred from Hunter (*op. cit.* 31, p. 209), who tells us that a Sanskrit translation of an edition answering this description was in the possession of the grandson of Jagannath, Jai Singh's

principal assistant in Jaipur, when he met him at Ujjain. Since the treatises in question were surely the third edition of John Keill's *Trigonometriae planae et sphericae elementa* (1726) and Cunn's translation of the tract on the nature and arithmetic of logarithms appended to it, the Sanskrit translation is likely to have been made from Cunn's second (1728) edition of *Euclid's Elements of Geometry* rather than from the first (1723) edition.

[38]See Forbes, *op. cit.* 1 for details of this early transmission from Hellenistic Greece into northern India.

[39]In a footnote on p. 414 of the article by Soonawala, M. F., entitled "Maharaja Sawai Jai Singh II, (1686-1743)" in *Sci. & Cult.* ix (1944), 412-18, the editor remarks that Jai Singh was probably not familiar with the works of Copernicus, Kepler, Galileo and Newton since these were under papal interdiction and Jesuits were forbidden either to study or teach them. However, it must be stressed that Da Silva (though a Catholic) was not a Jesuit, Kepler's Rudolphine Tables are explicitly referred to in the preface to La Hire's tables of 1702, and there was no papal ban on Newton's work.

[40]Nicholas Copernicus, *De revolutionibus orbium coelestium* (Norimbergae, 1543).

[41]Blanpied, *op. cit.* 30, pp. 111-17, speculates on Jai Singh's motives for founding these observatories without reaching any firm conclusion. Accounts of the Jaipur observatory are contained in Bernoulli, J. (ed.), *Des Pater Joseph Tieffenthaler's historisch-geographische Beschreibung von Hindustan* i (Basel, 1785), pp. 244 ff. and in vol. xv of the Jesuit *Lettres édifiantes et curieuses. écrites des Missions étrangères* (Paris, 1780). A good description of the instruments, but not of the history, of this observatory is to be found in Lieut. A. F. Garrett, R. E. and Pundit Chandradhar Guleri, *The Jaipur Observatory and its Builder* (Allahabad, 1902). A more recent assessment of its historical role is given by Solla Price, Derek J. de, "Astronomy's Past preserved at Jaipur", *Natural History* lxxiii (1964), 48-53. Bernoulli (ed.), *op. cit.* also contains the earliest accounts of Jai Singh's observatories at Ujjain and Mathura. The Benares Observatory was descibed by Sir Robert Barker in a communication to the Royal Society of London published in *Phil. Trans.* lxvii No. 30 (1777), pp. 598-607.

[42]Philip Lansberg, *Tabulae motuum coelestium perpetuae* (Middelburg, 1632).

[43]Newton, Isaac, *Principia mathematica philosophiae naturalis* (Londini, 1687); Lib. *i*, Prop. xi, pp. 50-51.

[44]The precise nature of this theoretical breakthrough is explained in Eric G. Forbes (ed.), *The Euler-Mayer Correspondence,* 1751-1755: *a new perspective on eighteenth-century advances in the lunar theory* (London, 1971); while the application of the Newtonian-based lunar tables a to the urgent practical problem of finding longitude at sea is discussed in the same author's National Maritime Museum monograph *The Birth of Navigational Science* (London, 1974).

[45]Moraes, George M., "Astronomical Missions to the Court of Jaipur 1730-1743", *Jour. Bombay Br. R. Asiatic Soc. (New Series)* xxvii (1951-52), 65.

[46]The details are to be found in Claude Boudier (ed.), "Observations géographiques faites en 1734 par des Pères Jesuites, pendant leur voyage de Chandernagor à Delhi et à Jaipour". See, D Anville, *Eclaircissement géographiques sur la Carte de l'Inde* (Paris 1753), p. 46. The fact that this official account refers to the observatories at Delhi and Jaipur but not to those in Benares and Mathura is generally interpreted to mean that work at these latter sites was begun at a later date. In fact, the observatory at Mathura was never completed and demolished later in the eighteenth century.

[47]The articles by Gracias, *op. cit.* 26 and Braganca Pereira, *op. cit.* 29 each contain several references to this mission. Moraes, *op. cit.* 45 cites, in addition to these important Portuguese sources, the remarks on this subject by Maclagan, *op. cit.* 25, the Rev. H. Hosten, *op. cit.* 48, and a few less significant writings.

[48]According to the Rev. H. Hosten, S. J., *Jesuit Missionaries in Northern India and Inscriptions on their Tombs, Agra* (1580-1803) (Calcutta, 1906), p. 38, Gabelsberger died at Jaynagar or Sivai Jaypur on 9 March 1741.

[49]This is the year of Strobel's death inferred by Father H. Hosten from an extract of Joseph Tieffenthaler's "Narratio expeditionum bellicarum quas Afganes seu Pattanes in Indiam susceperunt" sent to him by Father S. Noti (cf. *ibid.*, p. 39).

[50]Rousselet, Louis, *India and its Native Princes* (London, 1878), p. 227.