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THE ASTRONOMICAL TABLES OF RAJAH JAI SINGH SAWĀ'I

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The *Zīj-i-Muḥammed Shāhi* is a set of astronomical tables in Persian associated with Jai Singh Sawā'i (died 1743). They are usually represented as embodying the observational work done at the observatories of Delhi and Jaipur, under the direction of Jai Singh and Jagannātha. In this paper these Persian tables are analysed thoroughly, and their various components are identified with earlier sources. In fact no new observational results are to be found, apart from a new determination of the obliquity. Instead, the tables of the Sun, Moon, and Planets are all identical with those of La Hire (1727), apart from a mere change of meridian from Paris to Delhi. There are worked examples for the time of a solar eclipse of A.D. 1734 May 3, which was total in central India. The tables and text of Book II on basic spherical astronomy are taken without alteration from the *Zīj* of Ulugh Beg, except that those functions which depend on the obliquity have been recalculated. The star table is taken from Ulugh Beg. The long geographical table includes those of Ulugh Beg and La Hire, as well as some 240 sites (many in India) from unidentified sources.

The *vṛttaṣaṣṭāṃśa* of Delhi and Jaipur is a sextant totally enclosed by walls in which the Sun's image is formed as in a camera obscura. It is certainly the only instrument in those observatories susceptible of real accuracy, and it was used in determining the obliquity and the latitude. A number of accounts of its design and use are given, including those of Jagannātha and the Jesuits.

INTRODUCTION

The large masonry instruments of Delhi and Jaipur, constructed under the aegis of Rajah Jai Singh Sawā'i (Rajah of Amber from 1693, died 1743), and similar constructions elsewhere at Ujjain, Benares and Mathura, are surely among the most familiar astronomical artifacts anywhere in the world. Apart from valuable contemporary accounts by the Jesuits, especially Father Tieffentaller[1], there are accurate descriptions by William Hunter[2] at the end of the eighteenth century, and more recently by Lieut. A. ff. Garrett[3] and G. R. Kaye[4].

Jai Singh was also responsible for a complete set of tables, entitled *Zīj-i-Jadīd-i-Muḥammad Shāhī* (New Tables of Muhammed Shah), dedicated to the Emperor of the time. These tables have not been printed, but are found in a number of MSS[5]. The studies to be reported here have been based on the MS in the British Library, Additional 14373[6], a clear and correct eighteenth century copy.

The principal object of this paper is to present a long overdue analysis of the contents and sources of these tables. In addition, some extracts from the Jesuit accounts are given, with particular emphasis on the 'aperture gnomon'.

Hunter translated most of the Preface to the *Zīj*, corresponding to f.2v-5r of our MS. He thus revealed that Jai Singh, after he had for some seven years employed himself in the construction and operation of his observatories, and with plans to compile an almanac, learned then of European observatories and tables. He sent one Padre Manuel, with others, to Europe where they obtained the new tables of La Hire (la'ir)[7]. The preface continues, according to Hunter's translation,

> On examining and comparing the calculations of these tables, with actual observation, it appeared there was an error in the former, in assigning the Moon's place, of half a degree; although the error in the other planets was not so great, yet the times of solar and lunar eclipses he found to come out later or earlier than the truth, by the fourthpart of a minute of a day which is 15 seconds of a day <0; 0; 15 day>. Hence he concluded that, since in Europe, astronomical instruments have not been constructed of such a size, and so large diameters, the motions which have been observed with them may have deviated a little from the truth; since, in this place, by the aid of the unerring Artificer, astronomical instruments have been constructed with all the exactness that the heart can desire; and the motions of the stars have, for a long period, been constantly observed with them; agreeably to observation the mean motions and equations were established. He found the calculations to agree perfectly with the observation; and although even to this day the business of the observatory is carried on, a table under the name of his Majesty, the shadow of God, comprehending the most accurate rules, and most perfect methods of computation was constructed; hat so, when the places of the stars, and the appearance of the new Moon, and the eclipses of the Sun and Moon, and the conjunctions of the heavenly bodies, are computed by it, they may arrive as near as possible to the truth, which, in fact, is every day seen and confirmed in the observatory. (Ref. 2, pp. 187-9)

Jai Singh makes it plain therefore that he claimed to find La Hire's tables to be in error, the Moon by up to half a degree, and the times of solar and lunar eclipses by up to 6 minutes of time. Strangely unaware of the instrumental advances that had been made in Europe, he concluded that with his 'larger' instruments he must therefore have established more accurate mean motions and equations.

In spite of this claim, Hunter wisely regarded it as a possibility that the *Zīj* was simply taken from the work of La Hire. Writing in Calcutta, he says,

> But here I should regret that, not having access to the *Tabulae Ludovicia* of La Hire, I am unable to determine, whether those of Jayasinha are merely taken from the former, adapting them to the Arabian lunar year; or, whether,

> as he asserts, they are corrected by his own observations; did not the zeal for promoting enquiries of this nature, manifested in the queries proposed to the Asiatick Society by Professor Playfair (to whom I intend to transmit a copy of the Zeej Mahommedshahy) convince me, that he will ascertain, better than I could have done, the point in question. (Ref. 2 p. 205)

To my knowledge John Playfair (1748-1819) Professor of Mathematics at Edinburgh in the years 1785-1805, never took up the question put to him, nor apparently has anyone else before me.

It will be demonstrated presently that all of the tables of the *Zīj* concerning the Sun, Moon and Planets are taken directly from La Hire's work, as Hunter suspected. They in no way depend on observations made in India, except in so far as the meridian of reference has been shifted from Paris to Delhi. There are of course other components, and their complicated derivation from various sources will also be discussed as far as possible. The only parameter which seems to have been taken from measurements made, or ordered by Jai Singh, is the obliquity, which was determined to be 23; 28.

Although Kaye saw the British Library MS, and had the opportunity of comparing it with La Hire's work, he dismissed Jai Singh's Book 3 (Tables of Sun, Moon and Planets) as 'Ulugh Beg brought up to date' (Ref. 4, p. 10). In order to 'explain' why the Jesuits had not told Jai Singh about European heliocentric astronomy, he tried to make out that they would have been prevented by their Catholic allegiance from doing so, since Copernicanism had been condemned by the Church (Ref. 4, p. 89)

The Parameters of Mean Motion

In order to display clearly the relation between the *Zīj* and La Hire's tables, we begin by giving in a table all the parameters of all the mean motions for both systems, together with the values of the mean longitudes which have been calculated for the epoch date of the *Zīj* on the basis of La Hire's parameters. Refer to Table I. The notation used is defined as follows.

t_L = epoch date of La Hire's tables, Noon Paris A.D. 1 Jan 1=J.D. 1721424
t_J = epoch date of the *Zīj*, Noon Delhi A.D. 1719 Feb 20=J.D. 2348962
λ = mean tropical longitude
Γ = longitude of aphelion
Ω = longitude of ascending node
$♈_0$ = sidereal longitude of equinoctial point
J.D. = Julian Date, according to the usual convention.

The numerical notation is systematically sexagesimal, with a semi-colon used to separate the fractional part; the superscript '*r*' indicates whole revolutions. The precise epoch dates t_L and t_J can be fixed quite confidently by a comparison with the modern fundamental ephemerides; this is a routine matter and the details need not be given.

Muhammed Shah came to the throne in September 1719, but his reign was deemed to have begun at the death of Farrukhsiyar in February 1719[8]. The latter date, taken precisely as 1719 Feb. 20 (Greg.) or 1st *Rabī*ʿ II A.H. 1131, is the epoch date of the *Zīj*.

The rates of motion are given in periods appropriate to the two tables, multiples of Julian centuries and multiples of 30 Arabic years (10631 days) respectively. The motions quoted, such as 12; 13, 20, and 38; 24, 52, 49, 54, 51, can be read essentially directly from the tables. This form of listing is preferable to a standardized reduction to a daily rate since one can then see the degree of precision intended by the calculator.

In the column headed 'position at t_J', the quantities such as the mean Sun are calculated for the epoch date of the *Zīj* from La Hire's parameters. Thus we have

$$278;43,\ 48+(t_J-t_L)\ \frac{1600^r\ 12;13,20}{1600\times 365;\ 15}=329;\ 48,\ 3.7$$

ignoring whole revolutions.

In the last column is to be found the change in the meridian which is required to account for the remaining small difference between 'epoch at t_J', taken from the *Zīj*, and the 'position at t_J' calculated from the tables of La Hire. In the case of the mean quantities which increase only very slowly, namely the solar and planetary apogees and the planetary nodes, it is clear that the change induced by the change of meridian has been ignored.

The rates of motion calculated for the *Zīj* are not strikingly accurate, and do not justify the large number of terms in the sexagesimal fractions. For example, accurate calculations for the Sun, Moon and Saturn give

Sun	29^r 38; 24, 55, 17, 2, 35....
Moon	389^r 38; 15, 25, 24, 58, 38....
Saturn	356; 3, 41, 48, 3, 50,....

Meridian of Reference

The change of longitude assumed in the construction of the *Zīj* from La Hire's Tables is apparently 73; 30. The difference of longitude between Paris and Jaipur is 73; 29 according to modern values. This, together with the fact that Jai Singh was intimately associated with Jaipur, the city indeed which he founded, would appear to point unambiguously to the conclusion that Jaipur was the assumed meridian. It comes therefore as a surprise to learn that Shāhjahānābād (the modern Delhi) was actually assumed as the meridian. This emerges as follows.

Jai Singh gives very detailed worked examples in order to illustrate the computation of the true positions of Sun, Moon and Planets, in every case for the mean time

TABLE I *Mean Motions*

		Tables of La Hire, second edition of 1702			*Zīj-i-Muḥammed Shāhī*		change in meridian
		epoch at t_L	motion in $1600 \times 365;15$ days	position at t_J	epoch at t_J	motion in $30 \times 354;22$ days	
Sun	λ	278;43,48	1600^{r}12;13,20	329;48, 3.7	329;36, 1	29^r 38;24,52,49,54,51	73;19
	Γ	69; 5, 2	27;20	98;26, 5.5	98;26, 4	0;29,51,15,12,20	0
Moon	λ	135;18, 9	21389^{r}245;20,16	343;58,30.5	341;17, 6	389^r 38;15,27,42,56	73;30
	Γ	281; 4,38	180^{r}307;48,18	354;52,17.5	354;50,57	3^{r}104;23,47, 6,41	72;13
	Ω	268;36, 6	−85^{r}346;57,52	157;15,35.3	157;16,14	2^r−157; 2, 3,38,11	72;58
Mercury	λ	316;35,38	6643^{r}110:16,28	204;12,28.5	203;22,21	120^{r}306; 9,14, 5,46	73;29
	Γ	206;24,23	43;54,40	253;33,31.8	253;33,32	0;47,57,39, 5	0
	Ω	4;38, 1	37;53,11	44;56, 6.4	45;19, 1	0;41,22,30,30	0
Venus	λ	41;52,10	2600^{r}310;17,10	346;43,22.2	346;23,34	47^{r}112;42,33,38,35	74;10
	Γ	266;13,34	38;18,57	307;22,12.9	307;22,10	0;41,50,39,49	0
	Ω	52; 9, 1	20;28,30	74; 8,12.0	74; 8,14	0;29,21,15,13	0
Mars	λ	40;34,26	850^{r}266;43,51	234;39,10.2	234;32,42	15^{r}171;23,37,24,37	74; 4
	Γ	119;12,22	29;32,19	150;55,30.5	150;55,32	0;32,21,44, 7	0
	Ω	30; 0,21	16;23,31	47;36, 5.4	47;36,29	0;17,57,39,46	0
Jupiter	λ	179;59,20	134^{r}340;53,20	146;55, 7.8	146;54, 6	2^{r}163;45, 3,56, 0	74;17
	Γ	145;42, 1	41;57,52	190;45,44.5	190;45,43	0;45,47,35,30	0
	Ω	90;31,43	6;16,29	97;15,59.4	97;15,59	0; 6,50,40,59	0
Saturn	λ	75; 8,21	54^{r}133;10,24	213; 7,24.6	213; 6,57	356; 3,37, 2,54	82;27
	Γ	230;40,27	36;18, 8	269;39,21.9	269;39,23	0;39,48,20, 3	0
	Ω	78;12, 0	31;45,26	112;18, 5.1	112;18, 5	0;34,42,30,39	0
Equinox	♈	5; 3, 6	22;23,20		not given in the *Zīj*		

First edition of 1687

This gave parameters for Sun, Moon and ♈

The differences from the above are,

Moon	λ	135;36,49	21389^{r}245; 1,36	344;10,26.8	78;56
	Ω	268;13, 1	as above	156;52,30.4	very large

TABLE II

A selection of places from La Hire's Table

La Hire			*Zij*	Greenwich meridian		
name of site	long. (hours)	lat.	long.	La Hire long.	modern long.	modern lat.
Abbatisvilla (Abbeville)	0; 2,12W	50; 5,30	12;20,30	1;47	1;50	50; 6
Alenconium (Alencon)	0; 9,30W	48;29	12;38,45	0; 2,30W	0; 5E	48;26
Alexandria	1;52, 0	31;12, 0	7;35, 0	30;20	29;54	31;12
Ambianum (Amiens)	0; 0,12W	49;53,46	12;15,30	2;17	2;18	49;54
Ancona	0;47,40	43;54	10;15,50	14;15	13;30	43;38
Andegavium (Angers)	0;12,15W	47;27	12;45,37	0;43,45W	0;33W	47;28
Antuerpia	0; 8,30	51;10	11;53,45	4;27,30	4;25	51;13
Aquae Sextae (Aix en Provence)	0;12,25	43;31	11;43,47	5;26,15	5;26	43;32
Aractae Syriae (ar-Raqqa)	2;50, 0	36; 0	5;10, 0	44;50	39; 1	35;56
Aralatum (Arles)	0; 8,20	43;34	11;54,10	4;25	4;38	43;40
Argentina (Strassbourg)	0;22, 0	48;35,30	11;20, 0	7;50	7;45	48;35
Antisiodorum (Auxerre)	0; 4,20	47;35, 0	12; 4,10	3;25	3;34	47;48
Athenae	1;33, 0	37;40, 0	8;22,30	25;35	23;43	37;58
Atrebatum (Arras)	0; 1,40	50;18,25	12;10,50	2;45	2;47	50;17
Avenio (Avignon)	0; 9,45	43;51	11;50,38	4;46,15	4;48	43;57
Aurelianum (Orleans)	0; 1,45W	47;53,56	12;19,22	1;53,45	1;54	47;55
Goa Indiae (Panjim)	4;46	15;30	0;20	73;50	73;50	15;29
Lutetia in obser. (Paris)	0; 0	48;50	12;15, 0	2;20	2;20	48;52
Ponticheri	5;10	11;55	0;40, 0E	79;50	79;53	11;56
Surat	4;42	21;53	0;30	72;50	72;50	21;10
Chandernagor	5;43	22;54	2; 2,30E	88; 5	88;21	22;51

TABLE III

A selection of places from Ulugh Beg's Table

Ulugh Beg			Jai Singh	modern	
name of site	long.	lat.	long.	long.	lat.
Alexandria	61;54	32;58	8;36,50	29;55	31;13
al-Raqqa	73;15	36; 0	6;43,20	39; 3	35;57
Maraghah	82; 0	37;20	5;15,50	54;19	26;51
Samarkand	99;16	39;37	2;23,10	66;57	39;40
Balkh	101; 0	36;40	2; 5,50	66;54	36;46
Thana	102; 0	19;20	1;55,50	73; 2	19;14
Bamiyan	102; 0	34;35	1;55,50	67;45	34;52
Ghazna	104;20	33;35	1;32,30	68;28	33;33
Kabul	104;40	34;30	1;29,10	69;10	34;30
Mansurah	105; 0	27;40	1;25,50	68;53	25;58
Multan	107;35	29;40	1; 0, 0	71;36	30;10
Kandahar	107;40	33; 0	0;59,10	65;30	31;32
Lahore	109;20	31;50	0;42,30	74;22	31;34
Benares	117;20	24;55	0;37,30E	83; 0	25;20
Kannauj	115;50	26;35	0;22,30E	79;56	27; 2

TABLE IV

A selection of places which were not taken from either La Hire or Ulugh Beg

Name of site	*Zīj of* Muḥammed Shāhī		Long. from Jāzā'ir	Modern	
	long.	lat.		long.	lat.
Shahjahanabad	0; 0	28;37	113;35	77;13	28;37
Panipat	0; 2,30	28;52	113;20	76;58	29;23
Gwalior	0; 4,10E	26;29	114; 0	78;10	26;13
Sironj	0; 4,50E	24;10	114; 4	77;42	24; 6
Sawa'i Jaipur	0;12,30	26;54	112;20	75;49	26;55
Akbarabad (Agra)	0;14,10E	26;43	115; 0	78; 1	27;11
Ujjain	0;15,50	22;30	112; 0	75;46	23;11
Ajmere	0;25, 0	26; 3	111; 5	74;38	26;27
Daulatabad (near Aurangabad)	0;25,50	20;30	111; 0	75;18	19;56
Jaunpur	0;55,10E	26;36	119; 6	82;41	25;44

TABLE V

A selection of places from the Āʾīn-i-Akbārī. The edition of Blochmann is followed, except for the figures marked,[a] which follow some MSS

Name of site	*Āʾīn-i-Akbārī*		Delhi meridian
	long.	lat.	longitude
Delhi	114;38	28;15	0;10, 3E
Panipat	113;20[a]	28;52	0; 2,30
Gwalior	115; 0	26;29	0;14,10E
Sironj	114;59	27;22	0;14
Agra	115; 0	26;43	0;14,10E
Ujjain	110;50	22;30[a]	0;27,30
Ajmere	111; 5	26; 0	0;25
Daulatabad	101; 0	25; 0	2; 5,50
Jaunpur	119; 0	26;36	0;54,10E

2; 43 hours after noon (0; 6, 47, 30 days) at Jaipur, 1734 May 3. The significance of this moment is that there then occurred a total solar eclipse during which the path of totality passed across central India, approximately along the line from Bombay to Masulipatam; the details according to modern astronomy are given by Oppolzer[9]. In the course of these computations the longitudes are computed from the tables for this moment at Shājahānābād, and are then converted to the meridian of Jaipur, which is taken to lie 1; 15 degrees to the West. It is perfectly clear therefore that the intended meridian is Shāhjahānābād. In order to explore this difficulty we must turn to the geographical table of the *Zīj*.

THE TABLE OF GEOGRAPHICAL COORDINATES

This table is given on f. 119r-128r in our MS. The meridian of reference according to the sub-title is Shāhjahānābād, whose longitude is given as 113; 35 measured from the Eternal Isles (Jazāʾir-i-khālidāt), which is the reference meridian used in Ptolemy's *Geography*, and frequently in medieval Islamic geographical tables. The latitudes are given in the usual way, expressed in degrees, minutes and seconds north of the equator. The longitudes are expressed in terms of a unit equal to one-sixtieth of the circle, that is six degrees; this is the movement of the heavens in 1 *gharī*. Jaipur, for example, is given the coordinates 0; 12, 30 West and 26; 54 North, so that its longitude in degrees is $6 \times 0; 12, 30 = 1; 15$ West. The list is very comprehensive and includes 650 places, situated all over the globe.

It would be extremely difficult to give a correct reading and identification of all the entries. The *nasta'līq* Persian script is written as usual without any vowels, and this is hardly the medium for a conscientious transcription of foreign words. The list is given in two parts, f. 119r-119va, and 120ra-128rb. The space between is ruled but the 73 places are left blank. The two parts are intended respectively for places lying East and West of the meridian through Delhi. In each the places are listed strictly according to increasing longitude, and without any indication of region or country. In the first part 45 places are listed, the last 7 without any latitude; the second lists 605 places.

One can readily discover that virtually the whole of the lists of La Hire and of Ulugh Beg are collected here, and their entries have been redistributed in order of longitude. La Hire's list gives 135 sites, including four in India. Ulugh Beg gives 282 sites, including a few in Northern India, and many more in the Islamic culture area to the North-West of India. One should remember that Ulugh Beg took his list essentially from that of the *Zīj Ilkhānī* of Nasir al-Dīn al-Ṭūṣī, and therefore one would not expect to find many Indian sites.

In our Tables II—IV small selections are given of the three components indicated above. La Hire orders his place names alphabetically, and for the sake of illustration, the names beginning with 'a' are given, together with Paris, and the four Indian sites. The names are in Latin, in keeping with the rest of his Treatise, but I give the modern name in parentheses where it would be needed by a modern reader. The longitudes are expressed in hours with respect to Paris. These were converted by Jai Singh to distances from his meridian by assuming that the interval from Paris to Delhi was equal to 73; 30. Apart from the occasional copying errors, the latitudes are identical. The Latin place names are transcribed into *nasta'līq*, and in most cases are so deformed that one could never identify the entry correctly except for the coordinates.

La Hire's longitudes, referred to Greenwich, as well as the modern Greenwich coordinates, are given in the last columns of Table II. It is clear that his coordinates are generally very accurate, not only for European sites, but for India also. This reflects the radical improvement in the determination of longitudes which had been achieved in the seventeenth century, and particularly in the last quarter of the century.

The second component of Jai Singh's Geographical Table is the table provided by Ulugh Beg in his *Zīj-i-Sulṭānī-i-Gūrganī*. This work has been consulted in the MSS of the British Library Additional 7629, 11637 and 16742. This geographical table along with that of the *Zīj Ilkhānī* of Nasīr al-Dīn al-Ṭūṣī, was printed and translated by John Greaves in 1648[10]. The longitudes are referred to the Greek meridian, through the Eternal Isles. This table was quoted almost completely, even when it repeated some of La Hire's entries. In this uncritical way Alexandria and al-Raqqa are given twice, as one sees in Tables II and III.

The remaining sites, some 240 perhaps, are drawn from unknown sources. Here, however, the table stands in a certain relation to the long geographical table of the *Institutes of Akbar* (*Ā'īn-i-Akbārī*) composed in A.D. 1579 by Abū'l-Faẓl ibn Mubārak (1551-1602). Ibn Mubārak also copied much from Ulugh Beg, but he had other sources, at least one of which must have been used by Jai Singh, particularly for the many places in India which are not known from the tables of La Hire or Ulugh Beg. A few such places are given in Tables IV and V, where one can see that in spite of corruptions in the texts, many of the coordinates are identical. In the last column of Table V the longitudes of the *Ā'īn* are converted to the meridian of Delhi, and expressed in *gharī*. The printed edition of the *Ā īn-i-Akbārī*[11], does not always give a sensible reading, and can even add to the dreadful confusion found in the MSS. Blochmann thus gave the latitude of Ujjain as 28; 30, even though the MSS give 22; 30.

The longitude of Delhi, 113; 35, used by Jai Singh, is not given by Ibn Mubārak; that is the value which is found however according to Kaye (Ref. 4, p. 128) on some astrolabes which he examined.

With regard to the five Observatories, it will be seen that coordinates for all save Mathura are to be found here, but only Delhi and Jaipur are given accurately in latitude. Hunter (Ref, 2, p. 195) claimed that Jai Singh had found 23;10 for the latitude of Ujjain, but I have nowhere noticed in the *Zīj* this accurate value. Jaipur is given two slightly different latitudes: 26; 54 in the Geographical Table, and 26; 56 in the Table of Ascensions (f. 116r). It will become apparent in the later discussion that the aperture gnomons at Delhi and Jaipur were employed to determine the accurate latitudes at those places.

The Catalogue of Stars

This occupies 55 pages following the brief text of section 7 of the conclusion to Book 3. This catalogue is identical, apart the addition of a precession constant, with that of Ulugh Beg's *Zīj*. This work was consulted in the MSS cited above. The epoch date of Ulugh Beg's table is 1437 July 4 (J.D. 2246107), and the rate of precession is 1° per 70 Persian years. The longitudes which are given in Jai Singh's list exceed those of Ulugh Beg by 4; 8. In section 7, the date of the Catalogue is given as 1138 *Hijra*. If this is understood as 1138 complete years, it fixes the date as 1726 Aug. 27 (J.D. 2351707), and for that date, according to Ulugh Beg's precession, the increment is $(2351707\text{-}2246107)/70 \times 365 = 4;\ 7,\ 59$. It is certain therefore that Jai Singh has calculated his stellar longitudes in this way. He did not follow the rate of precession which was given by La Hire, nor did he give any tables for the computation of precession according to either of his two sources.

Index to the Chapters and Tables of the Zīj of Muhammad Shāh

The MS Additional 14373 of the British Library contains 222 folios of fine quality paper, 20×29 cm., gilt edged and finely bound. On the end fly-leaf there is written 'Purchased of Major J. B. Jervis July 1843. Formerly in Dr. Adam Marshe's Collection, Oriental MSS No. 13'. On f. 1r–2r, there is written a list of titles of the solar and lunar tables, copied, in fact, from Hunter's study (Ref. 2, p. 205-8), and signed 'J.B.J.'

In the following index all the titles of the Books, Chapters, Sections, and Tables are given. A Roman number at the left is the number of the original table in the edition of 1702 of La Hire's work. The numbering of the Books (*maqālat*), Chapters (*bāb*) and Sections (*faṣl*) is that found in the work; the tables are not numbered in the original, but are numbered here according to an obvious decimal system, beginning with *T* 1.1.1.

Zīj-i-Muhammed Shāhī

Ch 4	To find the distance of a star from the equator	14r
Ch 5	To find the upper and lower culminations of a star	15v
Ch 6	To find the ascension on the terrestrial equator	16r
Ch 7	To find the equation of the day, the diurnal arc and nocturnal arc, and the hours of the day and night	16r
Ch 8	To find the ascension as a function of latitude	17v
Ch 9	To find the ascendent from the ascension	18r
Ch 10	To know the ascension of a transit	19r
Ch 11	To find the ascension of the rising and setting of stars for the terrestrial equator	19v
Ch 12	To find the azimuth from the upper and lower culmination	20r
Ch 13	To find the upper culmination from the azimuth	21r
Ch 14	To find the meridian	21v
Ch 15	To find the longitude and latitude of a place	22r
Ch 16	To find the latitude of the climate by observation	23r
Ch 17	To find the distance between two stars	23v
Ch 18	To find the ascendent	24v
Ch 19	To find the upper or lower culmination from the ascension	25v
	Conclusion to Book 2 On the effect of changing the meridian of the observer	28r
T 2.1	Sine	28v
T 2.2	First tangent	58v
T 2.3	Second tangent	88v
T 2.4	First declination with obliquity 23; 28	89r
T 2.5	Second declination with the same obliquity	89v
T 2.6	Ascensions of the right sphere beginning with Capricorn	90r
T 2.7	Ascensions of the signs at the latitude 0(1)50	90v
T 2.8	Ascensions of the signs at Jaipūr Sawā'i, latitude 26; 56	116r
T 2.9	Ascensions of the signs at Shāhjahānābād, latitude 28; 37	116v
T 2.10	Equation of days at the position of Sawā'i Jaipūr, latitude 26; 56	117r
T 2.11	Equation of days at the position of Shāhjahānābād, latitude 28; 37	117v
T 2.12	Semidiurnal arc at Sawā'i Jaipūr	118r
T 2.13	Semidiurnal arc at Shāhjahānābād	118v
IV T 2.14	Longitude and latitude of places, the longitude taken from the position of the observatory, the latitude from the terrestrial equator. The position, namely, Shāhjahānābād, is distant 113; 35 from the Eternal Isles	119r

Some Detailed Comments

Book 2 Essentially the whole text of chapters 1-19 is copied from the *Zīj i Sulṭānī i Gurgānī* of Ulugh Beg (Ref. 5, p. 67 seq.); the tables of sine and tangent are taken from that work. The relation between the two series of chapters is as follows.

Ulugh Beg	Jai Singh	
1	omitted	On interpolation between two rows of a table
2-18	1-17	
19	omitted	To find the azimuth of the qibla for any latitude
20-21	18-19	
22	omitted	To find the ascendent from the time

The trigonometrical tables may be summarised as follows.

T 2.3 'second tangent' is cot x; also tabulated are 12 cot x ('digits', *aṣābiʿ*) and 7 cot x ('feet', *iqdām*).

2.4 This table differs from that of La Hire (Table VI), who assumed that the obliquity equals 23; 29, and from Ulugh Beg, who assumed 23; 30, 17.

2.5 The 'second declination' corresponding to the longitude λ is arc tan (sin λ tan ϵ).

2.6 The quantity tabulated is the longitude $\lambda(\alpha)$ intercepted by the eastern horizon, as a function of the right ascension, α, both being measured from the head of Capricorn, and for an observer with zero latitude. La Hire's tabulation of the ascension, Table VII, measures the arcs from the head of Aries, and assumes the obliquity 23; 29.

2.7 The quantity tabulated is the right ascension $\alpha(\lambda,\phi)$ intercepted by the eastern horizon, as a function of the longitude λ, both being measured from the head of

Aries, and for an observer with latitude ϕ. Ulugh Beg's tables of this quantity differ only in the obliquity assumed.

2.8 and 2.9 These are tables of $\alpha(\lambda, \phi)$ for the two latitudes named.

2.10 and 2.11 I have not understood these two tables.

2.12 and 2.13 The semidiurnal arc, expressed in *gharī* (0;1 day) is equal to $15\ (1+\text{arc sin}\ (\tan\delta\ \tan\phi)/90)$, when the Sun's declinaiion is δ.

Book 3 Certain tables have been formed from those of La Hire by making various conventional changes, such as a change of units of measurement.

T 3.0.1 This is the usual equation of time of modern astronomy, taken as additive or subtractive. La Hire's values are converted into *gharī*. He indicated changes of sign at Aries 7, Cancer 15, Libra 22, and Capricorn 10; the first of these indications is omitted in the *Zīj* which might cause confusion in some applications.

T 3.1.1, etc., All the tables of mean motion have been converted to the lunar calendar, as explained above.

T 3.1.3, 3.2.1, etc. In all of these tables of the distance from the Sun La Hire gives the logarithm. In the *Zīj* these have been converted, none too accurately, into ordinary numbers. For example, the first entry in T 3.1.3 is 4.00724 relative to a mean distance 10^4. This is converted to the sexagesimal

$$61;0,32,24=60\ (10^{4.00724}/10^4).$$

A more accurate conversion would be 61; 0, 31, 3, 24, ...

All the remaining tables of La Hire are taken over unaltered. Wherever the titles differ appreciably, La Hire's title is put in parentheses.

Certain tables of La Hire were omitted, namely,

I, II	Conversion between degrees on the equator and mean time
IX	Right ascension and declination of selected stars
X	Longitude and latitude of selected stars
XII	Radius of the Sun's disc and duration of passage of the disc past the meridian
XXVIII	Epacts of new and full Moon
LV	Acceleration of the fixed stars relative to the mean Sun

JESUIT TESTIMONY

Although the Jesuits went to India and elsewhere as Christian Missionaries, they became noted for their scientific and historical research in the countries which they visited. Their geographical observations[12,13] in particular were fundamental in effecting the revolution in the accuracy of longitudes, which was referred to above. The determinations of geographical longitudes were made by means of the timing of lunar eclipses and later, and much more accurately, by the timing of the eclipses of Jupiter's satellites by that planet. The latter method was brought to maturity by Cassini's researches.[14] Certainly La Hire's four Indian sites, and many others from South East Asia, China, and North and South America, were the accurate products of Jesuit observations.

At the time of Jai Singh a number of Jesuits wrote accounts of their work in India, some of which were included in the *Lettres Edifiantes et Curieuses*.[15] These give a fascinating view of the earliest encounter by Europeans with the wealth of Indian science and literature. Some extracts are given here, in the Appendix, relating how Jai Singh a little before 1733 had attempted to draw Missionaries from their station in Bengal, to Jaipur. His committment to Astronomy has greatly impressed all these writers. Already by 1733 Jai Singh is shown to be working with a translation of La Hire's Tables, eager to question their accuracy and to understand their theoretical derivation. Apparently he had become acquainted with La Hire's Tables through the good offices of Father Emmanuel Figueiredo, a Portuguese Jesuit, around 1729. This is the person to whom he refers as 'Padre Manuel' in the Preface to the *Zīj*. Little is known about him, and Sommervogel[16] only notes that he was in India in 1735, and was dead by 1753. La Hiie's Tables were certainly used by Father Boudier around this time.

Father Jean Calmette was in India from 1725 until his death in 1740. At the time of his letter, January 1733, Jai Singh has already obtained a translation, and has begun to raise various points which concern him. His remark in the first question, that the lunar calculation differs by one degree from the observation, may be compared with a similar remark in his Preface, where he mentions half a degree. As to his fifth question, La Hire in his Tables gives no geometrical model of any of the equations of Sun, Moon, or Planets, and indeed I do not know where they might be found. Calmette is aware of Boudier's extensive work in Bengal. Evidently he had determined a value of the obliquity different from that of La Hire, although it is probably wrong to suppose that this is the source of Jai Singh's value 23; 28. The latter could well have been fixed by means of the 'aperture gnomon' at Delhi or Jaipur (see below). Calmette himself pursued geographical observations, and published a map of Southern India (Ref. 15, first edition, Vol. 23).

Father Claude Stanislaus Boudier (1686-1757) came to India in 1718, became head of the Bengal Missions, and died in Chandernagore. His geographical and astronomical observations were very extensive indeed. Some of his results were published by Bernoulli (Ref. 1). Other records are preserved in MSS in Paris (Ref. 16, s.v. Boudier). With a companion, he travelled from Chandernagore to Jaipur in the period January to June 1734. The second extract which is given here is the preface to his account of his observations on the journey, an account which is too long unfortunately to be given here in full. This account was not included in the *Lettres* published at that time, but the MS of the account was used to good effect by d'Anville.[17] He records the coordinates of many sites and, besides, descriptions of numerous geographical features. At Delhi and Jaipur they carried out observations at Jai Singh's Observatories where, as will presently be demonstrated, they made use of one of his instruments, the 'aperture gnomon' (*gnomon à trou*) having a radius of 26 feet. While en route for Delhi they made use of two portable instruments of their own, a two foot quadrant used for taking the zenith distance of the lower limb of the Sun, and a seven foot telescope used for observing the satellites of Jupiter. The aperture gnomon will be discussed in the next section.

Father Jean François Pons (1698-1752 or 1753) came to India in 1726. He appears to have spent most of his time in Pondichery but, as our extract shows, he made visits to Delhi and Jaipur, where he met Jai Singh. It is not perfectly clear whether he was Boudier's companion, although this has been asserted. The extract given here is from a long letter in which he reviews numerous aspects of Sanskrit science and philosophy. His discovery of the Greeks terms in Sanskrit Astrology is striking, and an adequate illustration of his penetrating studies. He is known to have written tracts on Sanskrit grammar and metre, but these were never published. His final remark in this extract is expecially to be noted, for he shows clearly that he knew the origin of Jai Singh's tables.

Father Joseph Tieffentaller (1710-1785) came to India in 1743, and after a very long and fruitful career, died in Lucknow. He visited Jai Singh's observatories from his first arrival, and it may be that he was sent for the purpose of assisting in the observations. His arrival coincided however with Jai Singh's death, and we know that the next Rajah had no interest whatever in maintaining astronomical research. During his years in India Tieffentaller showed a profound capacity for research on a wide front, but principally in geography. His main work, the lengthy *Descriptio Indiae*, is sadly no longer extant in the original Latin, but we have German and French versions as published by Johann Bernoulli, the younger (Ref. 1). It was published simultaneously with treatises of Anquetil du Perron and James Rennell. Since Boudier gave no general account of Jai Singh's instruments, we are especially fortunate to have Tieffentaller's descriptions of what he found at Delhi, Jaipur, Ujjain and Mathura; the last three descriptions were quoted by Kaye (Ref 4, pp. 53, 58, 67).

At Jaipur he described the *Samrāṭ Yantra*, where he found that the quadrant was finished in plaster, or plaster of Paris; this has now been replaced by marble, after earlier efforts to restore the fabric. In 1901 Garrett supervised the renewal of the plaster (Ref. 3, p. 42). At Delhi Tieffentaller also seems not to have found any marble in use on the gnomon or the quadrant, altho (ugh HunterRef. 2, p. 190) says that marble was used for the edge of the quadrant, a few portions remaining. During my own visit there I saw only the remains of the old plastered surface of the quadrant. A small copy of the *Samrāṭ Yantra* had been installed also at Jaipur around 1875[18] (Ref. 3, p. 42; Ref. 18, p. 71). Tieffentaller's account of the aperture gnomon at Jaipur is of crucial importance if we are to form a just estimate of Jai Singh's work; this will be treated in the next section.

The Aperture Gnomon ·

Father Boudier and his companion made observations at Delhi of the zenith distance of the lower limb of the Sun, and also of the diameter of the disc, by means of an instrument which he called a *gnomon à trou*, a term which one may translate as 'aperture gnomon'. The evidence for its use by Jai Singh at Jaipur also is provided by Tieffentaller and Garrett. The passages from Boudier and Garrett are given in the Appendix (C and E). Tieffentaller's account is given immediately following his description of the *Samrāṭ Yantra*,

> A double gnomon is seen next to these quadrants, made likewise from plaster. It is placed within a kind of room, in which it rises up on both sides. When the Sun crosses the meridian, its ray passes through two holes in a sheet of copper, and falling low in Summer and high in Winter, indicates the meridian altitude of the Sun.
>
> (Ref. 1; French version, p. 317; German version, p. 224-5)

Garrett completely confirms this account. However when he came to describe it the copper sheet had been lost, and instead only two large holes were found in the masonry. He had enough insight to cover these with a sheet of copper in which he had made pin holes, and so unwittingly restored the instrument to the condition in which Tieffentaller had found it. He also understood very well the importance which this instrument had as the scientific heart of the whole observatory. His account is given in Appendix E.

The instrument which was used by Boudier at Delhi was presumably identical, or nearly so. He gives the radius as about 26 Paris feet, that is 27 feet 8 inches in English units. From his measurements one can determine the accuracy of the calibration. The declination of the noon Sun at Delhi may be calculated accurately enough for our purpose from the longitudes calculated from La Hire's tables, provided that due allowance is made for nutation and refraction, as explained in Appendix C. From each of the measurements, therefore, one obtains a value for the latitude of the gnomon. From the nine values, the average is 28; 37, 17$\pm$0; 0, 8. On the other hand, the latitude of the situation of the gnomon at Delhi is 28; 37, 37, according to my own measurement made from the *Delhi Guide Map*, on a scale of 1: 20,000, drawn up from the Survey of India. This shows that the measurements could be made on the scale of the gnomon with an accuracy of some 8 seconds of arc, while the vertical on the scale deviated from the true vertical by some 20 seconds of arc. From the known radius, one can calculate that the chord subtending 8 seconds is about 0.4 mm,. which is about the limit of precision one would expect. This result amounts to an impressive demonstration of the thoroughly professional character of both Jai Singh's construction and of Boudier's use of it.

The aperture gnomon arose at some point in Islamic astronomy, when people realised the great advantage of replacing the shadow of the tip or edge of the gnomon by the cone of light emerging through the tiny aperture, in the manner of a camera obscura. The advantage lies in the fact that the penumbra around this image is no larger than the diameter of the aperture. In Jai Singh's instrument that diameter is about one-sixth of an inch. Cassini (Ref. 14, p. 126) and La Hire (Ref. 7, p. 100) give corrections to be applied to the image in order to obtain a better estimate of the true angular diameter. It is not clear whether Boudier has already applied any such correction to his figures for the diameter of the disc; taken at face value, they are in fact slightly too large.

The earliest medieval attribution of the use of this instrument refers to al-Khujāndī (fl. A.D. 980).[19] In his own account, al-Khujāndī gives only the calculation of the obliquity from solstitial measurements of the Sun's altitude, but al-Berūnī and later al-Marrakūshī (fl. 1260)[20] claimed to give the details of the apparatus, which had a radius of the order of 20 m. It is believed that Nasīr al-Dīn al-Ṭūṣī, at Marāghah and Ulugh Beg, at Samarkand, also used such an arrangement.

The Jesuit Missionaries in China at this time were similarly engaged. Maspero[21], is certain they were responsible for the introduction of the aperture gnomon there. Earlier, as Maspero demonstrated, the Chinese astronomer Kuo Shou Ching (fl. 1276) had devised a different, but rather ingenious, alteration of the traditional gnomon. This made use of a narrow horizontal bar supported at some height above the ground, and of such a thickness that it subtended an angle much smaller than the Sun. With the aid of a small movable plate, pierced with a pin hole and held only a few inches from the scale, an image of the Sun's disc, with the bar across it, was projected. The plate was moved to and fro until the image of the bar was central in the image of the Sun. Father Antoine Gaubil (1688-1759), who was the principal Jesuit astronomer in China, gave numerous results of his own measurements, but so far as I can discover, never described the aperture gnomon. For references to his work, see Needham.[22]

Jai Singh could have learned of the aperture gnomon from those who informed him of the techniques which had been employed at Samarkand. It is interesting that both the scale of Jai Singh and that of al-Khujāndī were sextants. Jai Singh, we may be sure, determined both his new value of the obliquity (23; 28) and also the accurate latitudes of Delhi and Jaipur (26; 56) with this instrument. Those latitudes are also given by Boudier in his account of the visit to Delhi and Jaipur, and one would expect that he either observed these for himself with Jai Singh's instruments, or accepted

Jai Singh's values. The presence of this instrument at the Observatories makes all the differcnce to one's estimate of their scientific character, and it would be a nice service to the memory of Jai Singh, and also to historians of astronomy, if all the aperture gnomons were intelligently restored to their original condition and opened to the public. According to the most recent account, by Singh, of the two aperture gnomons at Jaipur, only one is accessible, while that at Delhi remains inaccessible[23], this confirms Kaye's report (Ref. 4, p. 39).

DATE OF COMPOSITION OF THE *Zīj*

With so much evidence collected, we can come to some conclusions regarding the period of composition. Clearly the translation of La Hire's tables had been provided after 1729, and yet at a sufficient interval before 1733 so that Calmette would know then of Jai Singh's developing interest. The text of Book 2 could have been copied at any time from Ulugh Beg's *Zīj*. The tables of Book 2 which depend on the new value of the obliquity are modelled on those of Ulugh Beg, and could have been calculated once the new value had been fixed.

In Book 3 Jai Singh gives worked examples, in great detail, of the solar eclipse of 1734 May 3, of the lunar eclipse of 1732 June 8, and of the true positions of the Sun, Moon, Mars and Mercury, for the moment 0; 6,47,30 days (2; 43 hours) after Noon of 1734 May 3. Surely these portions were composed after these dates, and therefore not earlier than the end of 1734.

Since the Star Catalogue is dated 1738, it is reasonable to suppose that this year had passed by the time this section had been composed.

In conclusion then, the principal tables had been prepared by 1733, but the work had not been completed before 1738.

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APPENDIX

A Father Calmette, 1733
B Father Boudier, the Preface to his account; written after 1743
C Father Boudier, observation of the Sun at Delhi, 1734
D Father Pons, 1740
E Lieut. Garrett, on the aperture gnomon of Jaipur, 1902

A

Father Calmette, from Venkatagiri, 1733 Jan 24

We are six Missionaries in the land of the infidels, with two others prepared to come, whereas the Kingdom of Bengal is wide open for the establishment of a new Mission: this is the whole of the North of India. The Prince of Orissa calls us. Another Prince, greater still, in Hindustan, of the Raja caste, and also a skilled astronomer, strongly urges the Missionaries in Bengal to come to his lands, where he would have them settle. He is a skilled astronomer, and one can judge the extent of his understanding by the questions he has already put to them, as follows,

1. What is the reason for the difference in longitude of the Moon as observed, and the calculation made according to the Tables of La Hire, which he has had translated? This difference is nearly one degree; however, the instruments which were employed are large and exact, and the observations were made with the necessary care. Is this difference also found at the meridian of Paris?

2. Are there tables which give the Moon exactly, in agreement with observations? If there are, who is their author, and what hypotheses does he make?

3. What hypotheses did M. de La Hire follow, and according to what geometrical model did he construct his table of lunar movements?

4. In Europe, what method is used to observe the Moon, when it is not on the meridian, and what instruments are used?

5. On what basis did M. de La Hire establish his third equation of the Moon; further, how would one reduce this to a hypothesis so as to calculate it geometrically?

Father Boudier, to whom these questions were addressed, is himself skilled in astronomy. He has made a number of observations in Bengal, and from these, some new astronomical tables, which are believed to more accurate than the earlier ones. They are based on the difference which he found in the obliquity of the ecliptic.

The arrangement proposed is that Father Boudier, with another Missionary whose poor health obliges him to leave the Mission, should seek out the Prince. After they have satisfied the Prince on the subject of Astronomy, they will study what advantage Religion might take from the protection of this Prince, and also what is the attitude of the people. For here, as in China, the sciences may be one of the chief means of which God makes use in the building of his Church,. . . .

(Ref. 15; old ed., vol.21, p. 449-465; new ed., vol.13, p. 390-400)

B

Father Boudier. Preface to his account: written after 1943

The Raja of Amber, Jai Singh Sawā'ī, who was mentioned in the Gazettes of Europe in 1728 or 1729, concerning a voyage to Portugal which the Reverend Father Figueredo, a Portuguese Jesuit, made at his request, died in 1743. He was a rich and powerful Prince, and learned in astronomy, for the sake of which he provided immense funds. He maintained several astronomers who observed day and night without interruption in various observatories which were built magnificently at his expense; particularly at Delhi, in a large suburb which he controlled, and called for that reason Jai Singh Pura; and at Jaipur, a notable town, at least as large as Orleans, which he erected a little more than a league from Amber, and in which he normally resided. All the streets of this town are wide and perfectly straight, and it is, they say, like Delhi but on a smaller scale.

This Prince had asked for Jesuits from Chandernagore. Therefore the hope of making him even better disposed toward the Christians, for whom he had already begun to build a church in his new town, induced their Superior General in the Indies to send him two of them, who left Chandernagore on the sixth of January, 1734, and who made the geographical observations to be related here. This was all that was allowed them by the strains of travelling, which was of necessity overland, and by their poor health, both of them having almost died before returning, on account of exhaustion, and the foul waters which one has to drink en route.

(Ref. 15; new ed., vol. 15, p. 337)

C

Father Boudier. Observations of the Sun at Delhi in 1734

Observations of the apparent distances of the lower limb of the Sun, made at the same place (Delhi) with a gnomon.

date	zenith distance	image of Sun	zenith distance of centre	refraction	equation of time (hours)	longitude of Sun, true Noon Delhi	latitude of gnomon
17 May	9;36,16	558	9;20,14	0;0,9	−0;8,21	56; 1,31	28;37,37
18 May	9;22,30	558	9; 6,28	0;0,8	−0;8,19	56;59,14	28;37,17
19 May	9; 9,29	558	8;53,18	0;0,8	−0;8,17	57;56,54.5	28;37,14
21 May	8;44, 6	558	8;28, 4	0;0,8	−0;8,11	59;52,13	28;37,14
25 May	7;57,50	558	7;41,48	0;0,7	−0;7,53	63;42,37	28;37,15
26 May	7;47, 2	557	7;31, 2	0;0,7	−0;7,47	64;40,11	28;37,11
27 May	7;36,50	557	7;20,50	0;0,7	−0;7,41	65;37,43	28;37,19
28 May	7;26,50	557	7;10,50	0;0,7	−0;7,34	66;35,14	28;37,17
21 Jun	5;24,45	555	5; 8,48	0;0,5	−0;3,10	89;31,36	28;37, 8

The copper sheet in which is located the aperture of the gnomon is placed parallel to the polar axis. The rays of the Sun fall on the concave surface of the quadrant, whose radius is about 26 [Paris] feet. The quadrant is graduated in minutes; the chord of 30 minutes is 522 parts, of which the diameter of the aperture is 32. The image of the Sun was without penumbra, at least as far as one could perceive, so that it was easy to measure it exactly.

(Ref. 15; new ed., vol.15, p. 354-5)

Comment

The first three columns of the table given above are taken from Boudier's account. The remaining are calculated as follows. The fourth is obtained by converting the figures in the third column by a factor 0;15/522, and subtracting from those in the third column. Refraction is calculated according to a formula which can be found in any standard textbook. The equation of time is taken from La Hire's table III and, as he explains, has been adjusted so that the mean time of his tables agrees with true solar time on 1701 Jan. 1. In the first row, then, true Noon occurs at 12;0,0 − 0;8,21 = 11;51,38 mean time. The difference of longitudes between Paris and Delhi has been taken as 74;53. The mean obliquity at this time is 23;28,25.8, but when nutation is taken into account, one obtains 23;28,19 for the first eight rows, and 23;28,18 for the last. The final latitude of the gnomon is equal to the sum of the zenith distance of the centre, the declination, and the refraction. The mean of these values is 28;37,17 ± 0;0,8. The effect of parallax would be to reduce the calculated latitudes by about one second, but the approximate nature of the calculation of the Sun's longitude would not justify its inclusion.

D

Father Pons, from Karikal, 1740 Nov. 23

The Brahmins have cultivated almost all the parts of Mathematics. Algebra was not unknown to them, but Astronomy, whose aim is Astrology, was always the main aim of their mathematical studies, because the superstitions of both the upper classes and the people cause it to be more useful to them. They have a number of methods in Astronomy. A learned Greek once travelled to India, like Pythagoras, and having learned the Sciences of the Brahmins, taught them in turn his astronomical method. In order that his disciples might keep it a secret from others, he left them in his works the Greek names for the planets, the signs of the Zodiac, and several terms, such as *hora*, the twenty-fourth part of the day, *kendra*, centre, etc. I learnt this at Delhi, and made use of it to convince the astronomers of Jai Singh, of whom there are a great number in the famous Observatory which he caused to be built in this capital that, in the past, masters had come to them from Europe.

When we had arrived at Jaipur, the Prince, in order to properly convince himself of the truth of my claim, wanted to know the etymology of the Greek words which I gave him. I learned also from the Brahmins of Hindustan, that the most venerated of their authors had put the Sun at the centre of the orbits of Mercury and Venus. Raja Jai Singh will be seen in the centuries to come as the Restorer of Indian Astronomy. The Tables of M. de La Hire, under the name of this Prince, will be in use everywhere in a few years.

(Ref. 15; old ed., vol.26, p. 218-256; new ed. vol.14, p. 65-90)

E

Garrett, on the aperture gnomon at Jaipur

The Shashtamsa Yantra or sextant instrument is so called from the graduated arcs being sextants or 60 degrees in length. This instrument is for exactly the same purpose as the Bhitti Yantra just described. There are two pairs of these instruments, one pair being situated in each of the side walls SS. of the huge sundial known as the Samrat Yantra, vide Fig. 1, Plate VI. A lofty but narrow chamber is contrived in the thickness of the walls, and access is gained from a door opening from the masonry platform on which the Samrat stands. Into this chamber no ray of light can find its way except through two small square openings high up in the south wall. Every day at noon the sun shines through these apertures for the space of about a minute, and the light falls on circular arcs, which are graduated to read zenith distances and declination. There are four of these arcs, two in each chamber; they are made of plaster, each of 28 feet 4 inches radius and graduated to read minutes of arc. Thus every day at noon the sun's meridian altitude, zenith distance, and declination can be found, and as explained above, the latitude and obliquity of the ecliptic easily follow. The Shastamsa Yantra is probably the most accurate of all the instruments in the Jaipur Observatory. The experiment was tried of closing up the square aperture with a metal plate, punctured in the centre with a pin hole, and this arrangement gave a wonderfully sharp image of the sun on the arc, enabling the angular diameter of the sun to be measured to within fifteen seconds of the true value. Thus the difference in the sun's diameter in winter and summer could be measured with the greatest ease, and the sun's image being some three inches in diameter, large sun spots would also be visible, and even obvious. No record, however, can be found of Jai Singh's having employed a pin hole, though there is no doubt that such an arrangement would have greatly increased the accuracy of his observations.

(Ref. 3, p. 36-7)

Notes and References

[1] Translations of Father Tieffentaller's *Descriptio Indiae* appeared in French and German, each of these published in two editions. These consulted were:
Description Historique et Geographique de l'Inde. Vol. 1, *La Geographie de l'Indoustan*, ecrite en Latin, dans le pays meme, par le Pere Joseph Tieffenthaler, ..., Berlin, 1786.

Des Pater Joseph Tieffenthalers der G.J. und apostel. Missionarius in Indien historisch-geographische Beschreibung von Hindustan, ..., Erster Bd., Berlin 1785.
In both cases the translations and general editorial control were due to Johann Bernoulli, the younger.

[2] Hunter, William, 'Some account of the astronomical labours of Jayasinha, Rajah of Ambhere, or Jayanagar', *Asiatick Researches* **5**, Calcutta, 1799, 177-211.

[3] Garrett, A. ff., *The Jaipur Observatory and its Builder*, Allahabad, 1902.

[4] Kaye, G. R., 'The Astronomical Observatories of Jai Singh', *Archaeological Survey of India*, New Imperial Series, **40**, Calcutta, 1918.

[5] Storey, C. A., *Persian Literature. A Bio-bibliographical Survey*. Vol. II, Part 1, London, 1972, pp. 93-4.

[6] Rieu, C., *Catalogue of the Persian manuscripts in the British Museum*, Vol. 2, London, 1881, 460*b*.

[7] La Hire's work appeared in two editions. The first of 1687 contained only solar and lunar tables. The second appeared in 1702, and was reprinted in 1727. Other printings: Ingolstadt, 1722 (Tables only); Nurnberg, 1725 (German version); Paris, 1735 (French version).
Tabularum astronomicarum pars prior de motibus solis et lunae nec non de positione fixarum ex ipsis observationibus deductis: cum usu tabularum, cui adjecta est geometrica methodus computandarum eclipsium per solam triangulorum analysim ad meridianum parisiensem. Auctore Ph. de La Hire, Regio Matheseos Professore, et Regiae Scientiarum Academiae Socio, Paris, 1687.
Tabulae astronomicae Ludovici Magni. Jussu et munificentia exaratae et in lucem editae. Adiecta sunt descriptio constructio et usus instrumentorum astronomiae novae practicae inservientium variaque problemata astronomis geographisque perutilia. Ad meridianum Observatorii Regii parisiensis in quo habitae sunt observationes ab ipso autore Philippo de La Hire, Regio Matheseos Professore, et Regiae Scientiarum Academiae Socio Secunda editio, Paris, 1702.

[8] Elphinstone, Mountstuart, *The History of India*, Ninth edition, 1905, London, p. 674 n. 23.

[9] von Oppolzer, Theodor R., *Canon of Eclipses*, translated from the German by O. Gingerich, New York, 1962.

[10] Greaves, John, *Binae tabulae geographicae, una Nassir Eddini Persae altera Ulug Beigii Tatari*, London, 1648.

[11] Abūl-Faẓl-i-Allāmi, *The Aín i Akbari*. Edited by H. Blochmann. *Bibliotheca Indica*, Vol. 58, Calcutta, 1872, 1877.
The same, translated from the original Persian by H. S. Blochmann (Part 1), and Col. H. S. Jarrett (Parts 2, 3). *Bibliotheca Indica*, Vol. 61, Calcutta, 1873-1894. Revised and further annotated by Sir Jadu Nath Sarkar, *Bibliotheca Indica*, Vol. 272, Calcutta, 1939-1947.

[12] Phillimore, R. H., *Historical Records of the Survey of India*, Vol. 1, Dehra Dun (U.P.), 1945.

[13] *Observations physiques et mathematiques pour servire à l'histoire naturelle, et à la perfection de l'astronomie et de la geographie. Envoyé de Siam a l'Academie Royale des Sciences à Paris, par les Pères Jesuites Francois qui vont à la Chine en qualité de Mathematiciens du Roy, avec les reflexions de messieurs de l'Academie et quelques notes du Père Goüye*, Paris, 1688.
This volume includes a number of tracts by G. D. Cassini and La Hire on the determination of longitudes by means of Jupiter's satellites, as well as original reports of such measurements.

[14] *Diverses ouvrages d'Astronomie par M.* (*Giovanni Domenico*) *Cassini*, Paris, 1693. This volume includes six separate tracts, in particular, 'De l'origine et du progrès de l'Astronomie et de son usage dans la geographie et dans la navigation'.
'Regles de l'Astronomie Indienne pour calculer les mouvemens du soleil et de la lune expliquées et examinées'.
'Les hypotheses et les tables des satellites de Jupiter, reformées sur nouvelles observations'.
The second refers to a Siamese version of a *karaṇa* based on the early *Sūrya Siddhānta*, and may be the earliest European notice of early Indian Astronomy.

[15] *Lettres Edifiantes et Curieuses. Ecrites des Missions Etrangeres, par quelques Missionaires de la Compagnie de Jesus*. Paris, 1702.—Same title, Nouvelle edition, Paris, 1780.

[16] Sommervogel, C., S.J., *Bibliotheque de la Compagnie de Jesus*. 11 Vols., Paris, 1890.

[17] d'Anville, B., *Eclaircissemens géographiques sur la carte de l'Inde*, Paris, 1753.

[18] Noti, Severin, S. J., *Land und Volk des königl. Astronomen Dschaisingh II Maharadscha von Dschaipur*, Berlin, 1911, p. 71.

[19] Sezgin, Fuat, *Geschichte des arabischen Schriftums*. Bd VI (Astronomie), Leiden, 1978, p. 220.

[20] Sédillot, L. Am., *Materiaux pour servir à l'histoire comparée des sciences mathematiques chez les grecs et les orientaux*. 2 Vols., Paris 1845, 1849. (Vol. 1, p. 360).

[21] Maspero, Henri, 'Les Instruments Astronomiques des Chinois au temp des Han', *Mélanges Chinois et Buddhistes*, **6** (Bruxelles, 1939) 183-370; p. 226.

[22] Needham, J., *Science and Civilisation in China*. Vol. 3, Cambridge, 1959.

[23] Singh, Prahlad, *Stone Observatories in India, erected by Maharajah Sawai Jai Singh of Jaipur* (*1686-1743 A.D.*), Varanasi, 1978, pp. 107-110; 187; 191.

SUPPLEMENTARY NOTES

A

Since writing this paper, I have had occasion to consult two other manuscripts of these tables. One of these is MS 212 of King's College Cambridge (kept in the University Library). It is described in the Catalogue as having only 26 folios (Ref. 5, p. 94), and I assumed that it must be merely a fragment. On examination, however, it proved to be another complete copy, perhaps more correctly written than the London MS which I have used, and containing, at least, more of the geometrical diagrams than the latter. Only the first 26 folios are numbered, corresponding to ff. 1-28r of the London MS.

The other manuscript is Or. 5614 of the British Library. This was not noted by Storey (Ref. 5). It is rather small (10×17.5 cm.), with 197 folios, and written in a fine and neat nasta'līq. The geographical table is much abbreviated and the star table lacks the latitudes of most stars; it is unlikely that it would prove very useful to any student of the text.

B

There is brief geographical list in the Sanskrit astronomical work *Siddhāntatattva-viveka* (A.D. 1658) by Kamalākara. I take this from the edition of Sudhākara (Benares, 1885), and also from the quotation in Śaṅkara Bālakṛṣṇa Dīkṣiṭ's *Bhāratīya Jyotiṣ* (Hindi version, Lucknow, 1975). It is appended as a gloss to the verse ii, 174.

	Siddhāntatattvaviveka		identification
1. kābula	104; 0	34;40	Kabul
2. ahamadābāda	108;20	23; 0	Ahmadabad
3. khambāyata	109;20	22;20	Cambay
4. burahānapura	111; 0	21; 0	Burhanpur
5. ujjayinī	112; 0	23;31	Ujjain
6. lāhaura	109;20	31;50	Lahore
7. indraprastha	114;18	28;13	Delhi
8. argalāpura	115; 0	26;35	Agra
9. somanātha	106; 0	22;35	Somnath
10. bījāpura	118; 0	17;20	Bijapur
11. kāśī	117;20	26;55	Benares
12. golakuṇḍā	114;19	18; 4	Golkhonda
13. lakhanaura	114;13	26;30	Lucknow
14. ajamera	111; 5	26; 5	Ajmer
15. devagiri	111; 0	20;30	Daulatabad
16. mulatāna	107;35	29;40	Multan
17. kanauja	115; 0	26;35	Kanauj

18. pāṇḍava	121; 0	27; 0	Pandua
19. kāśmīra	108; 0	35; 0	Kashmir
20. samarkanda	99; 0	39;40	Samarkand

The only textual problem concerns no. 18 which is given in the texts as *māṇḍava.* Although that happens to be a *Paurāṇic* geographical name (without any known reference), it must surely be corrected, bearing in mind the possibility of confusion between 'm' and 'p' in Nagari. Pandua, now a ruin, was the capital of Bengal in the fourteenth and early fifteenth centuries.

Eight of these 20 places (1, 6, 9, 11, 16, 17, 19, 20) are given by al-Ṭuṣī and Ulugh Beg with coordinates much the same as in the Sanskrit text; the only marked difference concerns the latitude of Somnath (22; 35 in place of the earlier 17; 0). Of the remaining, only nos. 3 and 10 are not to be found in Jai Singh's list, where the coordinates are almost all identical.

This text therefore adds something to our evidence of geographical research in India before 1650.

C

The Persian text of Ulugh Beg's work, together with a French translation, were published by L.P.E.A. Sedillot: *Prolegomènes des Tables Astronomiques d'Olugh-Beg*, Paris 1847, 1853. Book Two of the *Zīj-i Muhammed Shāh*, as explained above, is included in Book Two of Ulugh Beg's work.

D

A recent notice of Jai Singh's work appears in an article by D. Pingree, 'Islamic Astronomy in Sanskrit', *J. History of Arabic Science*, **2** (1978) 315-330. He remarks incorrectly that Hunter's description 'makes it clear that the structure of the tables is entirely Islamic'. Fancy La Hire's tables having an Islamic structure!

E

It was only at a late stage, unfortunately, that I came upon the Sanskrit treatise *Siddhāntasamrāṭ* (Prince of *Siddhāntas*) which was written by Jagannātha, the Pandit employed by Jai Singh. The greatest part of this work is no more than a Sanskrit version of Ptolemy's *Almagest*, but it also includes an original tract by Jagannātha in which he describes the various instruments of Delhi and Jaipur, as well as an account of mean and true motions and some other matters of theoretical astronomy. (The revolution numbers of the mean motions are all taken from the later *Sūrya Siddhānta*). The description of the aperture gnomon (*vṛttaṣaṣṭāṃśa*) is as follows, in my translation.

> On ground made level by means of water erect a square wall as before, in the direction determined as North-South. On the southern side of it, at some point, a vertical line is drawn, and at its upper end, a North-South line equal to it is drawn. Around their intersection, as centre, a circle is constructed with a width somewhat greater than four inches (*aṃśa*). Make then a circle of plaster adhering to it, exactly four inches (*aṅgula*) in width. This is to be polished, and the degrees and minutes marked on it and numbered. Make another wall parallel to the first and separated from it by two cubits (*hasta*). Make a circle on this in just the same way. At the north end another wall is placed to cover these two completely, and the south end is also so covered. The upper part is then covered by boards, etc. At the two southern corners of the two walls cut openings at the vertical line, and cover these with plates. Along the North-South line, where each of these corners is cut, make a fine aperture (in the plate) at the vertical line. When this is done the light of the Sun falls at Noon as required. In order to use the instrument, a door giving entry is made. When, at Noon, the light of the Sun enters the aperture, it is visible each day on the circle, and fixes exactly the declination and the latitude. In other respects this is to be understood like the Wall Instrument (*bhittiyantra*). The larger the instrument, the more precise it is. By foreigners (Muslims) this is called Suds al-Fakhrī.

This account conforms with the descriptions quoted above from Boudier, Tieffentaller and Garrett. '*Suds al-Fakhrī*' is the name given to the instrument by al-Khujandī (Ref. 19, p. 221).

The Sanskrit text has been printed by Muralidhar and also by Sharma; the former has given only Jagannātha's original tract, while the latter gave the whole work, including the version of the *Almagest*.

Samrāṭ Siddhānta by Samrāṭ Jagannātha, edited by Ram Swarup Sharma, Indian Institute of Astronomical and Sanskrit Research, Delhi, 2 Vols., 1976; p. 1038.
Siddhāntasamrāṭ by Jagannātha Samrāṭ, edited by Muralidhar Caturveda, Benares Sanskrit University, 1976; p. 7.