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SAWAI JAI SINGH'S HINDU ASTRONOMERS

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Jai Singh (1688-1743), the astronomer prince of India, assembled a large group of scholars trained in different traditions of astronomy, such as the Hindu, Muslim and the European. He learned astronomy from Hindu *pundits* and later the pundits became the mainstay of his program, translating and copying astronomical texts, erecting observatories, and carrying out the day-to-day operations of his observatories. His prominent Hindu astronomers were Jagannātha Samrāṭ, Kevalarāma and Nayansukha Upādhyāya. The paper describes Jai Singh's Hindu astronomers, and their contributions to Jai Singh's astronomical program.

For his ambitious program in astronomy, Jai Singh (1688-1743), the astronomer prince of India, assembled a large group of scholars with backgrounds in different traditions of astronomy. At his observatories, Hindu *pundits*, Muslim *munajjimūn* (astronomers) and European Jesuits worked side by side. Jai Singh's early education, similar to other Rajput princes' education, had been solely under Hindu *pundits*, and it is from them he first learned his astronomy. Later, the *pundits* became the mainstay of his program, translating and copying astronomical texts, erecting observatories, and carrying out the day-to-day operations of his observatories. The object of this paper is to describe Jai Singh's Hindu astronomers.

1. JAGANNĀTHA SAMRĀṬ

Jai Singh's most favoured Hindu astronomer was his religious guru, Jagannātha Samrāṭ. Jagannātha's father's name was Gaṇeśa and his great-grandfather was Viṭhṭhala[1,2]. Jagannātha came in contact with the Raja at an early date, long before his observatories were planned, and remained with him until the very end. Tradition has it that he was born in a Brahmin family of a village in Maharashtra and was discovered by Sawai Jai Singh as he was returning from a campaign against the Marathas sometime during 1702-1703 AD[3,4]. Recognizing the talents of young Jagannātha, the Raja persuaded him to move up north and study Persian and Arabic, the two languages prominent at the imperial court, but neglected by the tradition-bound Brahmin scholars of Sanskrit. Jagannātha soon became well-versed in the languages, and later on, when the Raja initiated a vigorous program in astronomy, he put his knowledge to good use by translating astronomical and mathematical works from Arabic into Sanskrit. Jagannātha outlived his patron by about a year and died in 1744 AD[5]

Jagannātha was an eyewitness as well as an active participant in Jai Singh's astronomical adventures. Writing in his *Samrāṭ Siddhānta,* he points out how Jai Singh's early experiments with metallic instruments, constructed according to the Islamic school of astronomy[6], failed and how Jai Singh opted for instruments of masonry and stone. From Jagannātha we learn that the Raja sent several astronomers overseas to collect data[7]. Jagannātha might have had a role in designing Jai Singh's observatories. Decades later, the local Brahmins of Varanasi told John Lloyd Williams that it was Jagannātha who had designed the observatory of Varanasi[8].

Jagannātha's Works

Samrāṭ Siddhānta

Jagannātha's major work is the *Samrāṭ Siddhānta Sārakaustubha.* Twenty-five to thirty copies of this work survive in the libraries and archives of the country[9]. Because the *Samrāṭ Siddhānta* mentions Jai Singh sending observers to distant islands, the text could have been completed only after 1730 AD[10]. The *Samrāṭ Siddhānta* is based on Nasīr al-Dīn Ṭusī's version of the *Mathematiké Syntaxis (mathematical composition)* or the *Almagest* of Ptolemy, and its first thirteen chapters run parallel to the thirteen books of the *Almagest*[11]. In its introduction, Jagannātha explains that the text is a Sanskrit rendition of the Arabic work *al-Majesti* and that he has written it in a style so that even a novice can comprehend its contents (easily)[12]. Jagannātha goes on to add that his text has 13 chapters, 141 sections, and 196 illustrations[13].

As a supplement to the *Samrāṭ Siddhānta,* Jagannātha has added four chapters of traditional Hindu astronomy, written in the *siddhānta* style. Because these chapters are independent of the translated text, that is, they are not based on the *Almagest,* scholars sometimes argue that Jagannātha had written two separate books, which, because of the carelessness of some scribe, were merged into one book. Scholars further argue that only the last four chapters of the so-called *Samrāṭ Siddhānta* are the real *Samrāṭ Siddhānta,* whereas the translated text preceding them is the *Siddhāntasāra Kaustubha*[14]. However, the issue becomes rather meaningless, once one acknowledges the originality of the four supplementary chapters, and gives credit for these chapters to Jagannātha. It is noteworthy that the inventory of Jai Singh's personal library conducted sometime during 1741-1743 AD does not list any *Samrāṭ Siddhānta* at all[15]. It does list, however, a *Siddhāntakaustubha-majasatī,* which can be certainly identified with Jagannatha's translation of *al-Majestī*[16].

The Supplementary Text

The supplementary text of the *Samrat Siddhānta* starts out with *Yantrādhyāya,* followed by *Jyotpatti, Tripraśnādhyāya, Madhyamādhikāra,* and *spaṣṭādhikāra,* the topics normally included in a traditional text of Hindu astronomy[17]. In *Yantrādhyāya,* Jagannātha describes the instruments at Jai

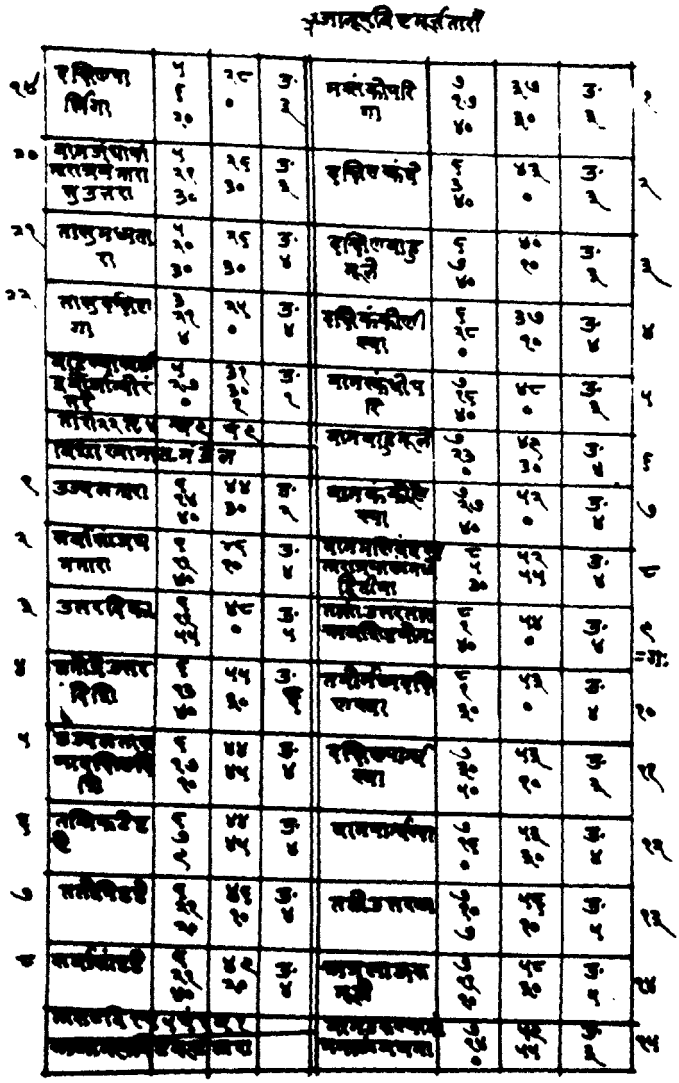

Fig. 1. A page from the *Samrāṭ Siddhānta* of Jagannātha Samrāṭ

Singh's observatories[18]. However, he leaves out the *Rāma Yantra*. Subsequently, in a later chapter, he again discusses briefly a number of instruments[19], and there he includes the *Rāma Yantra* and the *Sarvadeśīya Jarkālī Yantra* (Zarqālī universal astrolabe). The instruments discussed by him at the two places are as follows:

1. *Nāḍivalaya*
2. *Gola Yantra* (armillary sphere)
3. *Digaṁśa*
4. *Samrāṭ Yantra*
5. *Dakṣinottara Bhitti Yantra*
6. *Ṣaṣṭhāṁśa Yantra*
7. *Jaya Prakāśa*
8. *Krāntivṛtta*
9. *Rāma Yantra*
10. *Sarvadeśīya Jarkālī Yantra* (Zarqālī astrolabe)

The Rajasthan Oriental Research Institute, Jodhpur, preserves a manuscript entitled *Yantraśāstra* with Jagannātha quoted as its author. However, the work is identical with the *Yantrādhyāya* and the *Jyotpatti* chapters of the *Samrāṭ Siddhānta*, and, therefore, is not an independent composition[20].

It is noteworthy that while discussing the instruments for an observatory, Jagannātha makes no mention of the telescope, although the instrument had been available to the astronomers of Jai Singh[21]. Perhaps to Jagannātha, the *yantras* of an observatory meant the instruments that directly led to some numerical data. He also leaves out the astrolabe, even though the instrument had been popular with Indian astronomers, and Jai Singh had a large specimen of it made[22]. Jagannātha praises *Jaya Prakāśa* and the *Rāma Yantra*, and leads us to believe that the two were the most accurate instruments at Jai Singh's observatories. However, a close examination of Jai Singh's instruments reveals that this is not the case[23]. Besides, the two are cumbersome to use at night. The most precise instruments of Jai Singh's observatories were the large *Samrāṭs* and the *Ṣaṣṭhāṁśas* constructed at Delhi and Jaipur[24].

Rekhāgaṇita

Jagannātha's other work, also done for his patron, is ***Rekhāgaṇita*** – a text on geometry – translated from Naṣir al-Dīn Ṭūsī's *Tahrīr al Ukaledas*, the Arabic version of Euclid's *Stoicheia* or *Elements*[25]. Jagannātha must have completed his *Rekhāgaṇita* by 1727 AD or earlier, because the earliest manuscript of this work has a copying date of 1727 AD (1784 VS)[26]. The copy

was prepared for Jai Singh himself and is preserved at Varanasi[27]. At the Sawai Man Singh II Museum of Jaipur, where most of Jai Singh's library is preserved, there are two copies of *Rekhāgaṇita*[28]. The *Rekhāgaṇita* has 15 chapters or "books" dealing with subjects related to plane geometry, theory of numbers, and solid geometry. Because Jagannātha had very few equivalent terms available to him in the existing literature for his translation, he found it necessary to prepare a glossary of more than 100 terms for his task[29]. These terms were later adopted by virtually every other author in India writing on mathematical topics.

Yantraprakāra

Yantraprakāra is a text on instrumentation. Only two copies of this work are in existence. One is preserved at the Sawai Man Singh II Museum, Jaipur, and the other copy is at the Rajasthan Oriental Research Institute, Udaipur branch[30]. Evidently, Jagannātha or one of the students under his guidance, wrote the *Yantraprakāra,* as it is identical in parts with the *Yantrādhyāya* of the *Samrāṭ Siddhānta.* Its title says: "The instruments constructed by Śri Mahārājādhirāja are being written". A close scrutiny of *Yantraprakāra* reveals that some of its sections could have been written only after 1729 AD, because its author quotes a set of observations conducted on the night of 16-17 May 1729 AD[31]. The *Yantraprakāra* and the supplementary sections of the *Samrāṭ Siddhānta* are of the same general period.

On the very first page, the *Yantraprakāra* gives the following list of instruments constructed by Jai Singh at his observatories:

1.	*Jaya Prakāś*	4
2.	*Nāḍīvalaya*	7
3.	*Krāntivṛatta*	1
4.	*Palabhā yantra*	1
5.	*Digaṁśa yantra*	1
6.	*Śara yantra* (Celestial-latitude dial)	1
7.	*Agrā yantra* (Amplitude dial)	1
8.	*Yāmyottarabhitti (Dakṣinottara Bhitti)*	2
9.	*Jātulhalaka* (Dhāt al-Ḥalaq or Armillary sphere)	1
10.	*Yantrarāja* (Astrolabe, for time reckoning)	2
11.	*Jātuḥśukavataina* (Dhāt al-Thuqbatayn or Dioptra)	1
12.	*Jātuśuvataina* (Dhāt al-shu'batayn or Triquetum)	1
13.	*Sudasphakarī Ṣaṣṭhāṁśa*	1
14.	*Śaṅku yantra* (Upright rod)	(unknown)
15.	*Pratirāśinām Krāntivṛttāni (Rāśivalayas)*	12

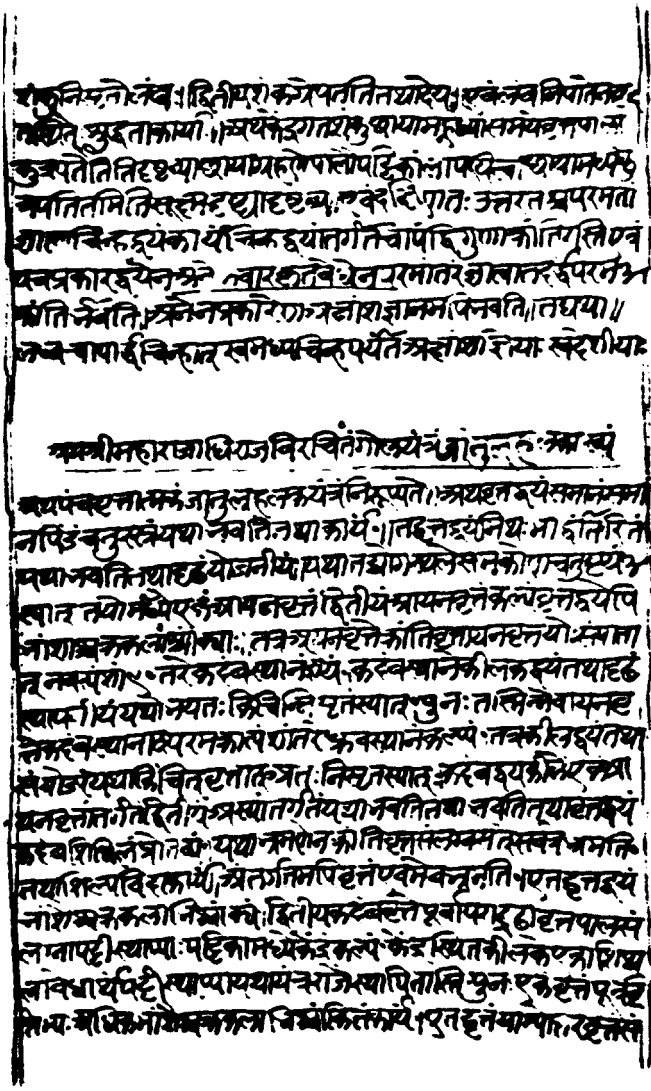

Fig. 2. A page from the *Yantraprakāra*

It is interesting to note that the list does not include the *Samrāṭ yantra* by name. A reason for this omission could be that the *Samrāṭ* was also known as *Naḍīvalaya* in those days, and most likely it is included in that category. But more puzzling than the omission is that the instrument is not discussed in the text[32]. Moreover, the *Śaṇku*, although included in the list, is not described. Instead, two other instruments, namely, the *Sarvadeśīyakapāla Yantra* and *Cūḍā Yantra* have been described in the text that follows the list. The *Pratirāśinām Krāntivṛttāni*, as described in the text, is a portable instrument and not built out of masonry and stone.

A comparison with the *Yantrādhyāya* of the *Samrāṭ Siddhānta*, the *Yantraprakāra*, is rather elaborate and includes computations, some incidental data, a number of tables, and descriptions of instruments such as *Dhāt al-Shucbatayn* of the Islamic School. The instruments of the Islamic School might have been based on some text of Arabic or Persian which had been translated for the Raja when the observatories were being planned[33]. But this conjecture needs to be further investigated. The *Yantraprakāra* is important for the reason that it is the only text in which Jai Singh's early instruments built according to the Islamic school of astronomy are discussed in any detail.

Jagannātha as an Observer

In addition to translating from Arabic texts, Jagannātha was probably involved in collecting data at Jai Singh's observatories. In the *spaṣṭādhikāra* chapter of *Samrāṭ Siddhānta*, while explaining the procedure of finding solar parameters, Jagannātha selects a set of readings taken at the Delhi observatory[34]. "On *Caitra kṛṣṇa* 6, 1786 V S (20 March 1729), the zenith angle of the sun, measured with the *Ṣaṣṭhāṁśa Yantra* was 28°; 44:30′′, he reports[35]. We checked Jagannātha's readings and found them to differ by less than a minute of arc from our computer-generated results. The vernal equinox for the year 1729 AD (1786 VS), according to Jagannātha, arrived on the same day at 18 *ghaṭī* and 57 *palas* (7 h, 34 m, 48 sec) after midday[36]. A computer check reveals that his time is 41 minutes, 34 seconds too early for the Delhi longitude[37]. This error in time measurements could result from an error of 40″ in declination measurements. The results are excellent and represent nearly the limit of unaided eye measurements. By observing the sun around two consecutive vernal equinoxes, he reports the length of the tropical year as 365 d, 14 *ghaṭikā* and 31 *vighaṭikās (palas)*, or 365.24194 d, a calculation that is off by about 25 seconds from its modern value of 365.2421 9878 d.

Jagannātha describes a set of computations based on the observations of three separate lunar eclipses that took place one after the other on 19 April 1728, 13 February 1729 and 29 July 1730 AD respectively[38]. From these two observations, he computes the mean motion of the sun as 0:0;59, 8, 19, 18, 21, 4, 42, 32 per day, or 0°.985 644 935/day which may be compared with the

modern value of 0;59, 8, 19, 49.47[39]. The daily motion of the sun as calculated from the *Zīj-i Muḥammad Shāhī* is 0;59, 8, 19, 46, 51, and it differs somewhat from Jagannātha's[40]. The mean motion of the moon Jagannātha reports as 0, 13; 10, 35, 2, 9, 51, 0, 38, which, according to *Zīj-i Muḥammad Shāhī* is 13; 10, 35, 1, 38.4 and whose modern value is 13; 10, 34, 53, 26.

Jagannātha's Scientific Beliefs

From the supplementary chapters of the *Samrāṭ Siddhānta*, one gets a fairly good glimpse of Jagannātha's astronomical beliefs. They are medieval at best, like those of his predecessors and contemporaries in India. Jagannātha is unaware of theoretical advances in astronomy, such as the discoveries of Kepler and Newton, which had become common in Europe decades earlier. He believes in the astrological effects of planets[41]. He seems to appreciate Ulugh Beg and the astronomical and mathematical advances of the Islamic world. Jagannātha displays a strong belief in the importance of observing. In fact, to him "observation" is the *pramāṇa* or deciding factor when doubts (discrepancies) arise between theory and observation[42].

Strangely, he appears to suggest that there could not be a theory which could be reconciled totally with observation, and he displays an undue faith in the canons of Hindu astronomy. He comments: "The observed motion of the planets in the sky is different than obtained with the canons *(siddhāntas)*. (What is more), even from the texts written by the *ṛṣis* (sages), such as the *Brahma Siddhānta* and the *Surya Siddhānta*, the results for the planets differ from one another". Searching for a reason for this disagreement, he goes on to propose: "In the sky there is no uniformity (consistency). That is, with time and place, because of the inconsistency, disagreements develop between theory and observation. If there were consistency in the sky (as regards planetary motion), then (predictions of) the *Siddhāntas* would always agree"[43]. Jagannātha's statement clearly indicates that he does not suspect anything wrong in the planetary theories of the *siddhāntas*, and, consequently, he makes no suggestion to improve them. Jagannātha has an unjustified faith in the knowledge of the ancient authors, whom he calls "the divinely inspired" or *ṛṣis*![44].

2. Kevalarāma

Kevalarāma was a native of Modesa, a village in Gujarat, and had already become famous as an astronomer in his native state when Jai Singh brought him to Amber in 1725 AD[45,46]. His father, Baija Nātha, was an astronomer-astrologer[47], and it is from him, Kevalarāma studied astronomy. At Amber, Kevalarāma soon earned the favour of his patron, Jai Singh, and received the title of "*Jyotiṣarāya*," or "the astronomer royal". Kevalarāma's year of birth is not known, but from the *Dastūr Kaumvār* records of the Rajasthan State Archives, it is certain that he died in 1782 AD (1839 VS)[48].

Kevalarāma was a prolific writer and is credited to have written the following books: (1) *Jayavinodī Pañcāṅga Sāraṇī*, (2) *Pañcāṅga Sāraṇī*, (3) *Tithi Sāraṇī*, (4) *Jivāchāyā Sāraṇi*, (5) *Vibhāga Saraṇī*, (6) *Dṛkpakṣa Sāraṇī*, (7) *Brahmapakṣanirāsa*, (8) *Rekhāgaṇita*, (9) *Dṛkpakṣaspaṣṭagrahānayana*, (10) *Bhāgavata-jyotiḥ-śāstrayorbhugolakhagola Parihāra*, (11) *Abhilāṣā-śataka*, and (12) *Gaṅgāstuti*.

Jayavinodī Pañcāṅga Sāraṇī[49]

Kevalarāma apparently completed *Jayavinodī Pañcāṅga Sāraṇi* around 1657 SE (1735 AD), as the earliest entry in the *Sāraṇī* begins with that year. The Smith Indic manuscript of this *Sāraṇī* at Harvard University contains tables of *yogas* for 1 to 30 years. The manuscript also has yearly motions for *yogadhruvas*, *yogavāras*, *yogeravikendras* and *yogecandrakendras*. The Rajasthan Oriental Research Institute manuscript No. 28484 of this *Sāraṇī*, on the other hand, is more elaborate and has, in addition, tables for *tithiśeṣāṅkas*, *tithikṣayas*, and *nakṣatras*[50].

Pañcāṅga Sāraṇī[51]

In *Pañcāṅga Sāraṇī*, Kevalarāma includes tables for the longitude of apparent sun, the daily motion of the sun, and the moon's apparent motion and its equation of centre. In the book's introduction, Kevalarāma emphasizes that his *Sāraṇī* is not against the *Sūrya Siddhānta*, probably to ward off criticism that he was going against the established tradition. In the *Sāraṇī*, he quotes the daily motion of the sun as 0:0;59:8:10/day[52]. The daily motion according to *Zij-i Muḥammad Shāhī* is 0:59:8:19:46,51 per day, as pointed out earlier. The weekly mean motions of the sun and the moon according to him are as follows: The Sun:0;6:53:57:11:10 or 6°.899 218 364 (sidereal), the Moon: 3;2:14:4:4:26 or 93°.234 464 97 (sidereal)[53], and the *Candrakendra:* 3;1:37:17:13:37 or 91°.621 451 93.

The yearly motion of the ascending node of the moon, the *Rāhu*, is given as -0:19:21:13:30. The modern value of this constant for the sidereal year is -0;19:20:30:19.5. The length of the sidereal year calculated on the basis of Kevalarāma's constants turns out to be 365 d, 6 h, 12 m, 37.5 sec, which is almost identical with the value given in the *Sūrya Siddhānta*[54]. This value is 3m 28 sec longer than modern measurements.

Because Kevalarāma based his computations on the tradition of *Sūrya Siddhanta*, it is easy to understand why his constants differ from those of Jagannātha in *Samrāṭ siddhānta* and also from the *Zīj-i Muḥammad Shāhī*[55]. Considering the fact that both astronomers worked at the same location, and that they must have had access to the data collected there, one would expect them to have used the data in their work, but they did not. Kevalarāma chooses not to use the data because he was following a tradition, and was not necessarily concerned with the new parameters worked out at the observatories.

Tithi Sāraṇī[56]

Kevalarāma's *Tithi Sāraṇī*, preserved at the Rajasthan Oriental Research Institute, with three folios to it, is probably an incomplete copy of his *Pañcāṅga Sāraṇī*[57].

Jīvāchāyā Sāraṇī[58]

His *Jīvāchāyā Sāraṇī* consists of tables of the logarithms of sines (*Jīvā*) and tangents (*Chāyā*) of angles in 8 digits, in increments of a minute of arc[59]. The tables were copied from a European work brought by the Jesuits. A fairly good copy of this work is preserved at the Rajasthan Oriental Research Institute, Jodhpur.

Dṛkpakṣa Sāraṇī[60]

Kevalarāma translated the *Tabulae Astronomicae* of de La Hire under the name *Dṛkpakṣa Sāraṇī*. Fragments of this work are preserved at various places. One fragment of the translation is preserved at the Sawai Man Singh II Museum under the title *Firaṅgī Grahavedhopayogī Sāraṇī*[61]. The Oriental Research Institute of Baroda also preserves a copy of the translation listed under the title *Dṛkpakṣa Sāraṇī*[62]. This manuscript includes tables and explanatory text. A table for the parameters of the moon from this manuscript is reproduced in Fig. 1. Another section of the translation, in 103 verses, entitled *Dṛkpakṣasāraṇyām Sūryagrahaṇam*, is stored at Bhandarkar Oriental Research Institute of Pune[63]. The Pune manuscript is a short tract on solar eclipses, and it is based on the *Firaṅgī* (European) treatment of the subject, according to Kevalarāma himself. It has no diagrams, tables or *Sāraṇīs* and also no date of compilation. However, it is reasonable to assume that Kevalarāma completed the work after 1731 AD, the year Jai Singh's delegation returned from Europe, and that it was done with the assistance of some Jesuit, such as Du Bois in the service of the Raja[64].

Dṛkpakṣaspaṣṭagrahānayana[65]

Kevalarāma's *Dṛkpakṣaspaṣṭagrahānayana* is preserved at Rajasthan Oriental Research Institute, but it is not certain if the manuscript is another copy of his *Dṛkpakṣa Sāraṇī*. The manuscript has only four folios to it, and it has a date of 1824 VS (1767 AD).

Brahmapakṣanirāsa

Kevalarāma's *Brahmapakṣanirāsa* is a short essay on the *Brahmapakṣa* of astronomy. Its Rajasthan Oriental Research Institute copy has only six folios to it and is in the pen of the scribe Govinda Rāma, son of Gaṇeśa[66]. Although the manuscript is undated, it is certain from the script that the copy belongs to the post-Jai Singh era.

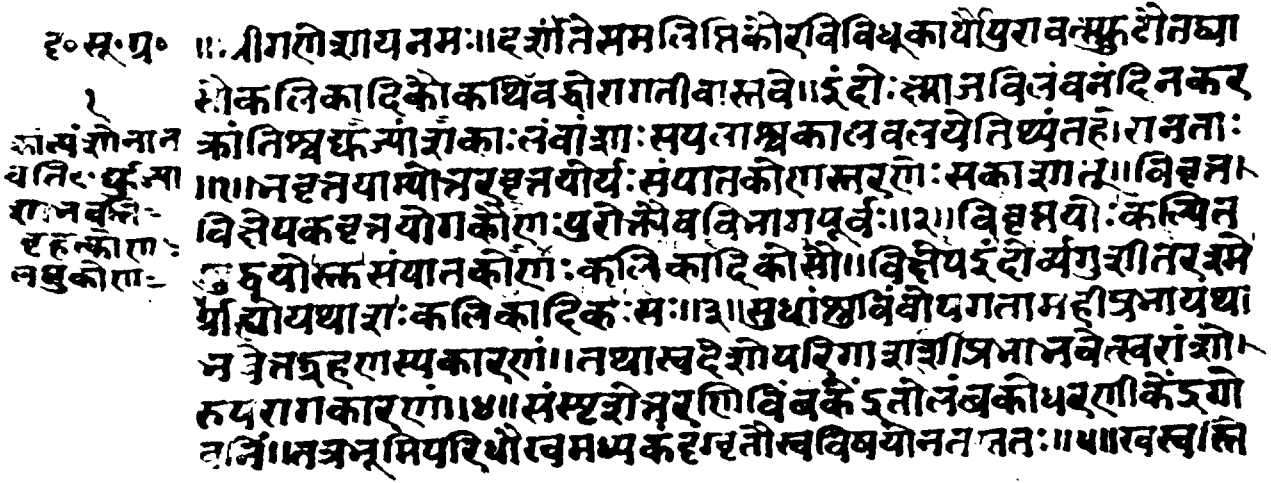

Fig. 3 A page from *Drkpaksa Sārani*. The *Sārani* is a translation of de La Hire's *Tabulae Astronomicae*

Jayavinodī Pañcāṅga

Kevalarāma undertook the responsibility of publishing the yearly calendar of Jaipur, the *Jayavinodī Pañcāṅga*, named after his patron Jai Singh. According to Bahura, these *Pañcāṅgas* received wide acceptance in India[67], and many of them are still preserved at the Sawai Man Singh II Museum of Jaipur[68]. After the death of Kevalarāma, his descendants continued publishing the *Pañcāṅga* under the original name – *Jayavinodī Pañcāṅga*[69].

Vibhāga Sāraṇī

Kevalarāma is said to have prepared *Vibhāga Sāraṇī* consisting of the tables of logarithm[70]. However, no copy of this *Sāraṇī* has been located thus far[71]. Hunter saw a copy of this work at Ujjain around 1786 AD in the possession of Kevalarāma's grandson. Hunter identified the *Sāraṇī* as the "Annex to Cunn's or Commadine's Edition" of some mathematical text[72]. He also noted that in the *Sāraṇī*, the "inventor" of the logarithm was called Don Juan Napier, which led him to conclude correctly that the translation must have been done with the assistance of some Portuguese astronomer[73]. The Portuguese source on which the Sanskrit translation is based was most likely brought by Fr. Figueredo from Portugal[74].

Bhāgavata-Jyotiḥ-śāstrayoḥ-bhūgolakhagola Parihāra

Kevalarāma's *Bhūgolakhagola Parihāra* is an essay, in which he explains the discrepancy between the geography or astronomy given in *Bhāgavata Purāṇa* and the well-known astronomical facts of his times[75]. He concludes his essay by saying that he wrote the work at the order of Sawai Jai Singh.

Tārā Sāraṇī

A number of authors have indicated that Kevalarāma translated *Zīj-i Ulughbegī* under the title *Tārā Sāraṇī*[76]. However, there is no such *Sāraṇī* listed in the published catalogs of the Rajasthan Oriental Research Institute, or, for that matter, in the collection of the Sawai Man Singh II Museum of Jaipur. Possibly the Sanskrit version of *Zīj-i Ulughbegī*, brought by Nanda Rāma from Surat, has been mistakenly identified with *Tārā Sāraṇī*[77]. The Sawai Man Singh II Museum, in its Puṇḍarīka collection, does have a star table – *Krāntivṛtta dhruvāṅka* – with coordinates for 256 selected stars. The stellar coordinates in this manuscript refer to the year 1726 AD (1783 VS or 1648 SE) and are identical with those given in the *Zīj-i Muḥammad Shāhī*[78]. This work, therefore, may not be identified with Kevalarāma's *Tārā Sāraṇī*[79].

Finally, Bühler reports Kevalarāma having written *Rekhāpradīpa*[80]. The manuscript of this text is yet to be traced. Similarly, the *Rāmavinoda Sāraṇī* supposedly written by him is yet to be located[81]. At any rate, the Sawai Man

Singh II Museum, where most of Jai Singh's library is preserved, does not have any copy of this *sāraṇī*.

Abhilāṣaśataka and Gaṅgāstuti[82]

In addition, Kevalarāma is said to have written two non-astronomical religious works, namely, *Abhilāṣaśataka* and *Gaṅgāstuti*[83].

3. NAYANASUKHA UPĀDHYĀYA

Nayanasukha Upādhyāya, or Nayanasukhopādhyāya, hailed from the town of Mālāvatī, where his father Narahari was an astronomer-astrologer. Nayanasukha could very well have been one of the scholars attracted to Jai Singh's court because of the generosity extended by the king towards men of letters. Nayanasukha's brother, Hirānanda, also an astronomer, in his *Thākuradāsavilāsa* completed in 1783 AD (1705 SE), tells us that Nayanasukha was awarded the title of *Paṇḍitarāja* by the emperor at Delhi[84]. According to Hirānanda, Nayanasukha was involved in observing the planets under the patronage of Jai Singh[85].

Nayanasukha Upādhyāya made a valuable contribution to the program of the Raja by translating a number of texts of the Persian-Arabic school of astronomy. In this task he was assisted by one or more astronomers of the Islamic school. The Muslim scholars read and explained a text to Nayanasukha, which he then rendered into Sanskrit[86].

With the assistance of Muḥammad Ābid, a Muslim scholar, Nayanasukha Upādhyāya translated *Tadhkira* of Naṣīr al-Dīn al-Ṭusī with al-Birjandī's *Sharḥ* in 1729 AD (1786 VS)[87]. The translation involves the eleventh chapter of the second book of *Tadhkira* only[88]. In this chapter, the lunar and the planetary models of the "School of Maragha" have been described. In the translation, Nayanasukha elaborated the difficult passages of the book. A copy of the translation was admitted to the royal library in 1730 AD. Nayanasukha definitely translated two other works, namely, *Ūkaragrantha* and *Yantrarāja risālā bīsa bāba*[89]. *Ūkaragrantha*, which deals with spherical geometry, is based on an Arabic copy of *Spherics* of Theodosius and was completed, once again, with the assistance of Ābid. *Ūkaragrantha* has been published by R.S. Sharma along with the *Samrāṭ Siddhānta* of Jagannātha[90]. The copy of the *Ūkaragrantha* at the Sawai Man Singh II Museum was scribed in 1730 AD (1787 VS) and its manuscript is profusely illustrated with appropriate geometrical figures[91]. *Yantrarāja risālā bīsa bāba* is a translation of Naṣīr al-Dīn al-Ṭusī's *Risālah bīst bāb*. It has been published by Sampurnanand Sanskrit University, Varanasi, under the title *Yantrarājavicāraviṁśādhyāyī*[92]. The *Risālā* consists of 20 chapters and, despite being a text on the astrolabe, has no illustrations at all. The copy of the *Risālā* at the Sawai Man Singh II Museum is in the pen of Kṛpārāma and mentions no date of its writing. A fourth book – *Jarkālīyantrā*-in

13 folios, may also have been translated by Nayanasukha, although definite proof to this effect is lacking[93,94]. *Jarkālīyantra* is a text dealing with the astrolabe *Saphaea Arzachelis*. The Jantar Mantar observatory of Jaipur preserves a fine specimen of this instrument, which was fabricated in 1680 AD[95].

In his *Thākuradāsavilāsa*, mentioned earlier, Hīrānanda asserts that his brother Nayanasukha revised the *Siddhānta*, called *Jayasiṁhakaustubha*. However, *Jayasiṁhakaustubha* is yet to be located[96]. The inventory list of Jai Singh's personal library does not include any such text.

4. Kṛpārāma

Jai Singh's astronomers usually wrote their texts in Sanskrit, the language of the Brahmin scholars of medieval India. However, Kṛpārāma, a Nāgara Brāhmaṇa, wrote his *Samayabodha* in Hindi in 1715 AD[97,98].

5. Anonymous Translators

Nothing is known about the translator of a European monograph on perspective drawing. This translation, entitled *Pratibimba Siddhānta*, is a small booklet in the *Khaḍī Bolī* dialect of Hindi spoken in the cultured circles of Delhi and Agra at the time. Jai Singh had the text translated for builders, engineers, technicians, artists and draftsmen. Because this group of professionals did not necessarily know Sanskrit, Jai Singh had the translation done in Hindi. A unique copy of *Pratibimba Siddhānta* is preserved at the Khasmohar collection of Sawai Man Singh II Museum of Jaipur[99]. The penmanship of the booklet is excellent, and it has 56 illustrations related to the subject. In the manuscript, the translator does not identify himself. But a remark in Rajasthani on the very first page translates: "The book belonging to Pedro Jī (which has been) translated (in here)". The Pedro Jī mentioned by the writer could have been Pedro de Silva, the physician-astronomer who came from Portugal in 1730 AD and settled in Jaipur[100]. He could also have been the Pedro Jī who went to Portugal as a member of the scientific fact-finding mission of the Raja. Since both of these Pedros were Portuguese, the original text must have been either in Portuguese or in Latin. The author believes that *Pratibimba Siddhānta* is the very first book on any technical subject translated from a European work into the *Khaḍī Bolī* dialect of Hindi.

Laiyara Vedha Patrāṇi are daily tables for some unidentified parameters of the sun and the moon, and, according to the title, they are based on *Tabulae Astronomicae* of de La Hire. The exact nature of the tables in *Laiyara Vedha Patrāṇi* is not clear[101]. The tables are for the years 1727-1738 AD, and there are two copies of them at the Sawai Man Singh II Museum, the second copy being entitled *Navīna Vedha Patrāṇi*[102].

6. Anonymous Authors

A Devanagari version of the *Zīj-i Muḥammad Shāhī*, mentioned in the Pothikhana records of the Rajasthan State Archives, must have also been prepared by one or more Hindu scholars, whose names are not known[103].

7. Procurement of Books

Jai Sigh had inherited only a few books on astronomical subjects when he succeeded to the throne of Amber. As a matter of fact, as late as 1715 there were only 32 books on *Jyotiṣa* in the royal library. However, he left behind an excellent collection at his death. An inventory of his *Pothīkhānā*, or the library, which began in 1741 and was completed after his death in 1743, lists 188 books on different aspects of *Jyotiṣa*. Jai Singh built his excellent library by collecting books from far and wide. He received his Sanskrit books via Brahmins. For example, in 1714, he received from Nīlāmbara Bhaṭa a book on *Jyotiṣa* in 145 folios[104]. He procured an incomplete Sanskrit version of Ulugh Beg's famous *Zīj* via Nandarāma[105].

8. Astrologers

In Jai Singh's India there was little difference between an astrologer and an astronomer. The Sanskrit term *Jyotiṣī* applied to both astronomers and astrologers. In fact, the Hindu *pundits* who wrote on their favourite topics in astronomy were mostly astrologers by trade in the first place.

Hari Lāla Miśra

Hari Lāla Miśra was more an astrologer than an astronomer[106]. He hailed from a family of *Jyotiṣīs* who were natives of Rajasthan[107]. Hari Lāla himself had apparently lived for a while in the Shekhavati region of Jaipur state. His astrologer father, Vaṁśīdhara, however, had moved to Vrindavan, and it is from him that Hari Lāla learned his trade. Apparently, Hari Lāla came in contact with Jai Singh while Jai Singh was the administrator of Mathura and the governor of the province of Agra (1723 - ?)[108]. Evidently, Hari Lāla must have also studied under Jagannātha, because he calls him his *guru* or teacher.

Hari Lāla composed *Muhūrtaśiromaṇi*[109], a work on astrology related to astrologically auspicious moments for various observances, at the time when the city of Jaipur was founded[110]. The work was completed on *Phālguna Śukla* 3, 1793 VS, or Monday, 4 March 1737 AD. "This was the day when the new city of Jaipur attained its full bloom after its completion", he writes[111]. Hari Lāla's other composition, similar in content to the *Muhūrtaśiromaṇi*, according to Bahura, is *Muhūrtakalpadruma*[112].

The other work of Hari Lāla, according to Führer, had been *Tithyuktiratnāvali*. It concerns religious observances for various *tithis*. The manuscript of this work was seen by Führer in 1885 with the descendants of Madhusūdana, a a Brahmin, much honoured at the court of the Sikh ruler Ranjit Singh. However, the manuscript along with the others was badly taken care of at the time, and its whereabouts are unknown now[113]. Perhaps, the same Hari Lāla also copied the first eight chapters of *Mantrabhāṣyam* of *Vājasenīyasaṁhitā*, a religious text by Uvvaṭa, the son of Vajraṭa[114].

Yaśasāgara

Another astrological work written during Jai Singh's rule is by Yaśasāgara. Yaśasāgara wrote *Jātakasārapaddhati*, a text on nativity-horoscope in 1705 AD (1762 VS)[115]. Further, some anonymous author wrote *Svarasiddhahaṁsa*, apparently a work on astrology. This text has a date of its composition as 1709 AD (1766 VS)[116].

9. Astronomers on Daily Wages at Jaipur Observatory

Jai Singh employed a large number of astronomers at his observatories. In 1735 AD, the Jaipur observatory alone had 22 Hindu astronomers employed on daily wages[117]. The names of the astronomers, as they appear in the Rajasthani dialect of Hindi, are: Udayanī, Gaṇapatī, Rāma Kisana, Govyanda Bhaṭa, Muljī Bhaṭa, Gangāvīsana, Govyanda Bhaṭa (II), Āṇada Rāma, Nanda Rāma, Sundarjī, Devakīsana, Devasura, Jetakāra (?), Ratna Sīṁgha, Fateha Canda, Jivana Jo. (Jyotiṣī), Āsādhara, Gaja Siṁgha (?), Māyā Rāma, Maujīī Rāma, Tulā Rāma, and Harī Rāma. These daily-wage earners helped erect masonry instruments and took observations of the sun, moon and the planets. They were paid up to Rs 31 per month, depending on the amount of time they put in[118]. Claude Boudier, an eyewitness in 1734 AD to the observatory operations, writes that Brahmins were busy day and night observing at Jaipur[119]. The observatory's financial accounts for the year 1734-35 AD confirm Boudier's remarks. At Delhi, Mathura, Ujjain and Varanasi, where Jai Singh had his other observatories, there must also have been similar teams of astronomers employed. However, the names of these daily-wage earners are not known.

10. The Scribes

Jai Singh employed a number of competent scribes for copying books for his library, because there were no printing presses in India then. These scribes, because of the technical nature of the subject matter they copied, had to have some training in astronomy and often called themselves *jyotisīs*. They copied the manuscripts in Sanskrit using the Devanagari script. They frequently initialled the manuscripts and wrote down the date of completion of their work. Accordingly, the names of a number of such scribes participating in the astronomical program of the Raja have survived. Kṛpārāma copied *Sharḥ Tadhkira* of al-Bīrjandī. Tulārāma made copies of *Makaranda Jyotiṣa-tippaṇam* in 1706 AD

(1763 VS)[120], *Bhāsvatī* of Śatānanda in 1701 AD (1758 VS)[121], and *Nalikābandhakramapaddhati* of Rāmakṛṣṇa in 1706 AD (1763 VS). He also copied *Kāla Jñānam*[122]. Another scribe, Lakṣmīdhara, was responsible for *Ūkaragrantha* which he copied in 1729 AD (1786 VS). He also copied *Vakramārgavicāra* sometime before 1787 VS[123]. Ṭīkārāma copied *Hayatagrantha*, a Sanskrit translation of some Persian work[124]. The manuscript of *Hayatagrantha* was added to Jai Singh's library in 1730 AD (1787 VS)[125,126]. Lokamaṇi was responsible for making a copy of Jagannātha's *Rekhāgaṇita* in 1728 AD[127]. Of the three copies of *Zīj-i Nityānandī-i Shāhjahānī* at the Sawai Man Singh II Museum, at least one was definitely copied by Gaṅgārāma, a native of Kashmir[128,129]. The work was completed on Thursday, the 11 *Badī* of the month of *Vaisakha*, 1784 VS (1727), at noon, as he notes.

11. Conclusions

The astronomical activities of Jai Singh's Hindu astronomers may be divided into four categories: (1) erecting instruments and taking data at the observatories, (2) writing texts and commentaries, (3) translating from other languages, and (4) collecting or copying books for the royal library.

The Hindu *pundits* helped Jai Singh erect stone and masonry instruments. Their efforts in this regard are praiseworthy. The *Great Samrāṭs* and the *Ṣaṣṭhāṁśa Yantras* of Delhi and Jaipur, that they helped erect, had a very high degree of accuracy. The readings taken with the Delhi *Ṣaṣṭhāṁśa* deviated less than $\pm 1'$ from the true values[130]. One minute of arc is considered to be the limit for non-telescopic observations. Jagannātha, the principal astronomer of Jai Singh, displayed a strong belief in observing, and it is quite likely that his belief was shared by others as well.

The Hindu *pundits*, with encouragement and active support of their patron Jai Singh, wrote a large number of books and commentaries. However, these texts and commentaries were mostly based on the works of their predecessors. In other words, there is little original in their works. A cause for this lack of originality may lie in the scholars' undue faith in the *Siddhāntas*, or canons of Hindu astronomy[131]. It appears as if Jai Singh's *pundits* did not wish to break away from a tradition which for all practical purposes had become stagnant. They also believed in the astrological effect of planets as did the astronomers of Europe in medieval times.

The Hindu scholars translated a great number of texts. However, the credit for these translations, in part at least, should go to Jai Singh. He realized more than any one else that the astronomy of the country needed an infusion of fresh ideas, and that there was much to be learned from other traditions, such as from the Islamic, and the European. Having reached this conclusion, he made arrangement for translating astronomical and mathematical works into Sanskrit and divided the task between his principal assistants: Jagannātha, Kevalarāma,

Nayanasukha Upādhyāya, and others. However, these translations turned out to be of those works which, in retrospect, had become outdated in the astronomical circles of Europe.

The *pundits* came in contact with Europeans – the Jesuit priests mostly – and thus became acquainted with better methods of computations. But this association produced only fragmentary infiltration of European thought. It did not introduce them to the epoch making theories of Kepler and Newton and, consequently, did not initiate the modern age of astronomy in the country[132].

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ABBREVIATIONS

Bahura I	Gopal N. Bahura, *Catalogue of Manuscripts in the Maharaja of Jaipur Museum*, Jaipur, 1971.
Bahura II	Gopal N. Bahura, *Literary Heritage of the Rulers of Amber and Jaipur*, Jaipur, 1976.
Bhatnagar	V.S. Bhatnagar, *Life and Times of Sawai Jai Singh*, Delhi, 1974.
BORI	Bhandarkar Oriental Research Institute, Pune.
CESS	David Pingree, *Census of the Exact Sciences in Sanskrit*, 4 Vols., Philadelphia, 1970-1981. The fifth volume of this series will be published soon.
DK	Dastūr Kaumvār records of the Jaipur state, Rajasthan State Archives, Bikaner.
Hunter	William Hunter, "Some Account of the Astronomical Labours of Jayasinha, Rajah of Ambhere, of Jayanagar," *Asiatic Researches*, No. 5, pp. 177–211, 1799.
Kaye	George R. Kaye, *The Astronomical Observatories of Jai Singh*, Archaeological Survey of India, Calcutta, 1918, reprint, New Delhi, 1982.
The Museum	Sawai Man Singh II Museum, Jaipur.

R.S.A.	Rajasthan State Archives, Bikaner.
RORI	Rajasthan Oriental Research Institute, Jodhpur.
SSMC	*Siddhānta-samrāṭ*, ed., Murlidhar Chaturveda, Sagar Univ., 1976.
SSRS	*Samrāṭ-siddhānta*, ed. Ram Swarup Sharma, New Delhi, 1967.
Yantraprakāra(J)	*Yantraprakāra* of Sawai Jai Singh, Ms. 261/31-MJM or No. 31, Sawai Man Singh II Museum, Jaipur.
Yantraprakāra (S)	*Yantraprakāra of Sawai Jai Singh*, ed. and tr., Sreeramula Rajeswara Sarma, *Supplement to Studies in History of Medicine and Science*, Vols. X and XI, New Delhi, 1986, 1987.

Notes and References

1. Temani, B.N., An Account of Maharaja Sawai Jai Singh's Works in Astronomy, Rajasthan State Archives, Bikaner, File No. 1425, dated Oct. 30,1939. Temani does not give the sources of his information. However, being the superintendent of the office of *Divān-i Huzūrī* of the Jaipur State he had access to the archival records of the State.
2. Bahura II, p. 54. Bahura's information is based on an article of Temani. Bahura, G., private communication. Temani, Ref. 1.
3. Sudhākara Dvivedī confuses between two Jai Singhs,that is, between the Mirzā Raja and his great grandson the builder of the observatories. Further, Dvivedī speculates 1652 AD as the date of birth of Jagannātha. He does not give any evidence in support of the date, however. See Sudhākara Dvivedī, *Gaṇaka Taraṅginī*, p. 109, reprint, Varanasi, 1933.
4. Dvivedī's account of Jagannātha's birth date is disputed by Bhargava who concludes it to be 1680. However, Bhargava's own date is also not based on any solid archival evidence either. See Bhargava, Purshottamlal, *Contribution of Jaipur to Sanskrit Literature*, Ph.D. thesis, (unpublished), Rajasthan University, pp. 237-242.
5. R.S.A., Dastur Kaumvar Records of Jaipur Rajya, as quoted by Bhargava, p. 242, *Op. Cit.*
6. SSRS, pp. 1162-1163, and SSMC, pp. 38-39.
7. SSRS, p. 1064 and SSMC, p. 41
8. John Lloyd Williams was a resident of Varanasi in 1790's. Williams, John Lloyd, Further particulars respecting the Observatory at Benares, of which an Account, with Plates, is given by Sir Robert Barker, in the LXVIIth Vol. of the Philosophical Transactions, *Phil. Trans. R. Soc. Lond.* **88**, Part 1, pp. 45-49, 1793.
9. CESS, Vol. A3, p. 57; also S.N. Sen, *A Bibliography of Sanskrit Works on Astronomy and Mathematics*, Part 1, p. 90, New Delhi, 1966.
10. SSRS, p. 1164 and SSMC, p. 41. Contrary to this internal evidence, Bahura writes that the text was completed in 1728 A.D. See Bahura II, p. 58. The author has not been able to confirm Bahura's assertion.
11. *Ptolemy's Almagest*, tr. and annotated by Toomer, G.J., New York, 1984.

12. SSRS, p. 5.

13. For a brief summary of the *Samrāṭ Siddhānta* see Sharma, M.L., Jagannātha Samrāṭ's Outstanding Contribution to Indian Astronomy in Eighteenth Century A.D.," *Indian J. History of Science*, **17**, 244-251, 1982.

14. Sharma, M.L., Ref. 13. There is some substance to the arguments raised by M.L. Sharma, because a number of manuscripts of the *Samrāṭ Siddhānta* lack the last four chapters. For instance, the manuscripts obtained by Muralidhara Chaturveda from the Rajasthan Oriental Research Institute, Jodhpur and the one from the Vikram University of Ujjain, did not include the last four chapters. See SSMC, p. 1.

15. R.S.A., Pothikhana records, Jaipur Rajya, for the year 1798 V.S. (1741 A.D.)

16. *Ibid.*

17. The order of the chapters in the supplement edited by Muralidhar Chaturvedi is somewhat different than in the *Samrāṭ Siddhānta* text published by R.S. Sharma. See SSRS, pp. 1031 ff., and SSMC.

18. SSRS, pp. 1031-1048 also SSMC, pp. 2-14. There are two copies of the *Yantrādhyāya*, ms. Nos. 24 (i), 7460-17213; and 24 (i) 2905-36223 preserved at the RORI.

19. For Rāma Yantra, see SSRS p. 1163 and SSMC, p. 39; and for Jarkalī yantra SSRS, pp. 1252-1260, also SSMC, pp. 96-105.

20. *Yantraśāstra* of Jagannātha, RORI, No. 35964, 45ff. The *Jyotpatti* section is incomplete in this ms.

21. There is evidence to believe that Jai Singh's astronomers were familiar with the telescope. In the *Zīj-i Muḥammad Shāhī*, Jai Singh discusses the telescope and what can be observed with it. *Zīj-i Muḥammad Shāhī*, f. 189, Add. ms. 14373, of the British Library, London.

22. Sharma, Virendra Nath, "The Great Astrolabe of Jaipur and Its Sister Unit," *Archaeoastronomy* No. 7, *J. Hist. Ast.*, XV, 126-128, 1984.

23. Jaya Prakāśa has a varying degree of accuracy. The Jaipur instrument, for instance, measures time with an uncertainty of $\pm 1/2$ to $\pm\ 1^1/_2$ min, and the zenith distance and declination both with uncertainty of ± 3 of arc. The uncertainty in the measurement of azimuth and right ascension could be anywhere from $\pm 3'$ to ± 1 deg. With the Rāma Yantra, a precision of $\pm 6'$ of arc is the best one can expect for angles of 40° to 45°.

24. The Samrāṭ of Jaipur, if properly constructed, can measure time with an accuracy of ± 3 second or better, and the right ascension and declination both with accuracy of $\pm 1'$ of arc.

25. *The Rekhāgaṇita or Geometry in Sanskrit Composed by Samrāṭ Jagannātha*, Vol. I. Books I-VI. Undertaken for Publication by the Late Harilāl Harshādarāi Dhruva, ed. by Kamalāśankara Prāṇaśankara Trivedī, Nirṇaya-Sāgara Press, Bombay, 1901. For the manuscript listings of *Rekhāgaṇita*, see CESS, Vol. A3, pp. 56-57, and Sen (1966), pp. 89-90, *Op. Cit.*

26. Dhruva and Trivedī, *Op. Cit.*, p. 7. According to Trivedī, the library of Sanskrit College, Varanasi, has a copy of it.

27. *Ibid.*

28. Bahura II, p. 432, Mss. no. 5372 and 5373. One of these manuscripts was completed in S.E 1650, on *Vaiśākha Śukla pūrṇimā*, or on 23 April 1728 AD.

29. For the compilation of the terms coined by Jagannātha see Upadhyaya, B.L., *Pracīna Bhāratīya Gaṇita*, (in Hindi), pp. 371-374, New Delhi, 1971. For a comparison of the terms coined by Jagannātha with their Greek equivalents see Rocher, J. Ludo, "Euclid's Stoicheia and Jagannātha's Rekhāgaṇita; A Study of Mathematical Terminology." *J. Oriental Inst, Baroda*, **3**, 236-256, 1953-1954.

30. Ms. No. 3156, Rajasthan Oriental Research Institute, Udaipur Branch, City Palace, Udaipur. For a detailed analysis of the *Yantraprakāra*, see *Yantraprakāra* (S).

31. *Yantraprakāra* (J), f. 11; and *Yantraprakāra* (S), p. 85.

32. A possibility exists that the instrument section of the *Yantraprakāra* was written before the Samrāṭ yantra was erected at any of Jai Singh's observatories.

33. Sarma has identified five instruments, namely, Yāmyottara yantra, Yāmyottarabhitti yantra, Dhāt al-Ḥalaq, Dhāt al-Shuᶜbatayn, Dhat al-Thuqbatayn taken from Naṣīr al-Dīn Ṭūsī's version of the *Almagest*. See *Yantraprakāra* (S), p. 4.

34. See SSMC, pp. 81-83. Also SSRS, p. 1216-1221, p. 1240 ff.

35. SSRS, p. 1218. Also SSMC, p. 81.

36. SSRS, p. 1217, also SSMC, p. 80.

37. The vernal equinox for 1729 AD, based on computer generated values arrived at 15 h, 7 m, 30 s. U.T. The program used for the computations was obtained from Bretagnon, Pierre and Simon, Jean-Louis, *Planetary Programs and Tables from – 4000 to + 2800*, publ. William-Bell, Inc., Richmond, VA, USA. The longitude of Delhi for the calculations was taken as 5 h, 8 m, 52 sec, E.

38. SSRS, pp. 1240--1246.

39. SSRS, p. 1246. The modern value is for a tropical year.

40. The reason for the difference might be that Jagannātha is merely illustrating a procedure, whereas the parameters in the *Zīj-i Muḥammad Shāhī* are based on multiple observations. See Sharma, Virendra Nath, "*Zīj-i Muḥammad Shāhī* and the Tables of de La Hire", *Indian J. Hist. Sci.*, **25** (1-4), 34-44, 1990.

41. "A planet which has set is weak in its (astrological) influence", he says. SSRS, p. 1064, and SSMC, p. 40.

42. SSRS, p. 1165, anad SSMC, p. 41.

43. *Ibid.*

44. *Ibid.*

45. Temani, *Op. Cit.*

46. Kevalarāma should be distinguished from Kevalarāma Pañcānana (*fl* 1728-1762 AD), his contemporary from Bengal. Pañcānana resided first at the court of Kṛṣṇacandra of Navadvīpa (1728-1780 AD) and then at the court of Sawai Madho Singh (1750-1767 AD) the third son of Jai Singh. CESS, Vol. A2, p. 63. Kevalarāma who was associated with Jai Singh often carries the title of *Jyotiṣarāya* (astronomer royal) with his name in many of the works attributed to him. The Pañcānana, Kevalarāma also wrote a number of books, see CESS, Vol. A2, it is easy to confuse the works of the two authors particularly when a manuscript does not have its author indicated.

47. Bhargava, p. 258, *Op. Cit.*

48. R.S.A., DK, Vol. 16, p. 595.

49. RORI Nos. 11839, 36ff, and 28484, 39ff. The second manuscript has a copying date of V.S. 1953 or 1896 A.D. The other copies according to Pingree are: Smith Indic Collection, No. 61, 23ff, Harvard Univ., and Calcutta Sanskrit College 17, 19 ff. See David Pingree, "Sanskrit Astronomical Tables in the United States", *Trans. Amer. Phil. Soc. NS* **58**, Part 3, 66-67, 1968.

50. Mehra, having examined the tables of the Harvard copy, concludes that the parameters used in there are from the Sūrya Siddhānta. See Mehra, Anjani Kumar, *Indian J. Hist. Sci.*, 17 (2) 257-259, 1982. According to Pingree, on the other hand, the parameters are from

Pañcāṅgavidyādharī composed by Vidyadhara at Jīrṇagaḍha in Saurāṣṭra in 1643 A.D. See Pingree, David, "Indian and Islamic Astronomy at Jayaasiṁha's Court", *From Deferent to Equant, Ann. N.Y. Acad. Sci. New York*, 313-328, 1987. For the constants of *Pañcāṅgavidyādharī*, see Pingree, David, "Sanskrit Astronomical Tables in the United States," pp. 60-61. *Op. Cit.*

51. *Pañcāṅga Sāraṇi*, RORI No. 12615, 31 ff.

52. The modern value for the daily motion of the sun is 0;59:8:19:49.47. The daily motion of the sun calculated from the 30 Arabic year motion given in the *Zīj-i Muḥammad Shāhī* also differs considerably with Kevalarāma's values. The daily motion of the sun from the *Zīj* is 0:59:8:19:32 per day. See *Zīj-i Muhammad Shāhī*, f. 130. Also see Sharma, V.N., (1990), Ref. 40.

53. The accepted weekly sidereal values of these parameters are: Sun = $6^0.899\ 263\ 797$ per 7 days, Moon = $93^0.234\ 508\ 17$ per 7 days.

54. Somayaji, D.A., *A Critical Study of the Ancient Hindu Astronomy*, p. 72, Karnatak Univ., Dharwar, 1971.

55. SSRS, p. 1246.

56. RORI, No. 3125, 3 ff.

57. According to Bhargava, the *Sāraṇī* is based on the *Sūrya Siddhānta*. See Bhargava, thesis, *Op. Cit.*, p. 271.

58. RORI, No. 23958, 91ff. The manuscript was copied in 1887. There is no colophon to confirm that the work is indeed by Kevalarāma.

59. The *Jīvā* of angle $\theta = 10 + \log \sin \theta$. For example, the *Jīvā* of 31;51 is listed as 97223848 and *Chāyā* as 97932560. The decimal point after 9 is understood.

60. *Dṛkpakṣa Sāraṇī*, BORI 926 of 1886/92. 10ff., Pingree in his CESS, Vol. A2, mistakenly identifies the author of this work as Kevalarāma Pañcānana. The error has been rectified by him in a later paper. See Pingree (1987). *Op. Cit.*

61. Formerly mislabeled as *Firaṅgī Candravedhopayogī Sāraṇī*, See the Museum, no. 5609. Also Bahura II, p. 63.

62. *Dṛkpakṣa Sāraṇī*, cat. no. 3162, 29 ff, Oriental Research Institute, Baroda.

63. *Dṛkpakṣasāraṇyām sūryagrahanam*, Bhandarkar Oriental Research Institute, Pune, no. 926 of 1886-92.

64. Du Bois, Joseph, Introduction to de La Hire's *Tabulae Astronomicae*, ms., the Museum.

65. RORI, No. 11259/1, 4ff.

66. RORI No. 28628, 6ff.

67. Bahura II, p. 59.

68. Bahura II, p. 54-55.

69. *Jayavinodī Pañcāṅga* is currently published from Manihāron kā Rāstā, Jaipur. The publishers claim to be the direct descendents of Kevalarāma.

70. Soonawala, M.F., *Maharaja Sawai Jai Singh II of Jaipur and His Observatories*, p. 10, Jaipur, 1952.

71. An elaborate set of mathematical tables in Devanagari for astronomical computations is preserved at the Jantar Mantar of Jaipur. According to a note on the tables, they were translated by Chaurasia, Govinda Nārāyaṇa, from some tables in English, and should not be identified with the *Vibhāga Sāraṇī* of Kevalarāma. Chaurāsiā completed the work of rendering the tables in Devanagari on 26 June 1926.

72. Hunter, p. 209.

73. *Ibid.* The Portuguese astronomer-physician at the court of the Raja was Pedro de Silva.

74. For Jai Singh's delegation to Europe see Sharma, Virendra Nath, Sawai Jai Singh-The astronomer, *Pathways to Literature, art and Archaeology*, pp. 87-88, Jaipur, 1992.

75. *Bhāgavata-Jyotih-śastroyoh-bhūgolakhagola Parihāra.* 1. Oriental Research Institute, Baroda, No. 11049. 2. The Bhandarkar Oriental Research Institute, Pune, No. 956 of 1886-92. 13 ff. This manuscript does not have the name of the author. 3. PUL II 3731, 20ff. CESS, Vol. A2, p. 63.

76. Soonawala, p. 10, *Op. Cit.;* Bahura II, p. 59; Bhargava, p. 269, *Op. Cit.;* and Bhatnagar, p. 328, all state that Kevalarāma wrote a *Tārā Sāraṇī.* The source of their information appears to be the monograph of Soonawala, published in 1952, *Op. Cit.*

77. *Zīj-i Ulughbegī,* The Museum, No. 45; Bahura I, pp. 58-59.

78. The Museum, No. 21, of Puṇḍarīka collection. 4ff.

79. The manuscript that Kaye reports having seen, and which is reproduced by him in his book, is a Devanagari rendition of the star catalog of the *Zīj-i Muḥammad Shāhī,* and is definitely not a creation of Kevalarāma. See Kaye, pp. 98-118.

80. Bühler, G., A Catalog of Sanskrit Manuscripts in the Private Libraries of Gujarat, Kathiawad, Kachchh, Sindh and Khandes, Bombay, 1871-1873, as quoted by Sen, p. 110, *Op. Cit.,* Also CESS, Vol. A2, p. 63. The ms. has 4 folios to it.

81. Bahura II, p. 59.

82. *Abhilāṣaśataka,* RORI, No. 11204, and *Gaṅgāstuti,* RORI, No. 3300, 7ff.

83. Bhargava, based on an article by Kedar Nath Sharma, states that Kevalarāma wrote *Jaya Siṁha Kalpalatā,* an incomplete work on planetary computations, and that the work is preserved at the Sawai Man Singh II Museum. However, no such work is listed in Bahura I or Bahura II. See Bhargava, *Op. Cit.,* p. 268. The article quoted by Bhargava is: Sharma, Kedar Nath, "Āmera ke Mahārājā Sawā'ı Jaya Siṁha ke Grantha aur Unakī Vedhaśālāyen." (in Hindi), *Nāgarī Pracāraṇī Patrikā,* Navīna Saṁsakaraṇa, Vol. 3, p. 403.

84. *Thākurasāsavilāsa,* Mss. Nos. 5523/3009, *Rajasthan Puratana Granthamala* No. 151, general ed. Pathak, P.D., *Catalog of Sanskrit and Prakrit Manuscripts* (Alwar collection), Part XXI, ed. O.L. Menaria, et al, RORI, Jodhpur, 1985. Most probably it was Muḥammad Shāh, the Mogul emperor between 1719-1748 AD, who awarded the title of *Paṇḍitarāja* to Nayanasukha.

85. *Ibid.*

86. For the contribution of the Muslim astronomers to the astronomical program of the Raja see Sharma, Virendra Nath, "Muslim Astronomers at Jai Singh's Court," *J. Arabic Hist. Sci.,* **9,** 23-30, 1991.

87. *Tadhkira of Naṣīr al-Dīn Ṭūsi in commentary of Alī al-Birjandī* by Nayanasukhopādhyāya, ms. No. 46 AG, 56ff, The Museum. Also Bahura I, pp. 62-63, 101-102; and Bahura II, p. 58.

88. Pingree (1987), *Op. Cit.*

89. *Ūkaragrantha,* (copied 1729, acquired 1730 A.D.), 46ff. No. 44 AG, Bahura I, pp. 58-59. *Yantrarāja risālā bīsa bāba,* No. 42 AG, 28ff., Bahura I, pp. 60-61.

90. SSRS, pp. 1260-1328.

91. Bahura I, 245E, ff. 44, The Museum. The other two copies of this work are preserved at (1). Baroda, No. 8926, entitled *Kaṭara* from Arabic *quṭr.* (2). Calcutta Sanskrit College, *Jyotiṣa,* No. 118. This copy was made in 1730 A.D. and most likely at Jai Singh's own court. For these copies and for others, see CESS, Vol. A3, p. 132 and CESS, Vol. A5.

92. *Yantrarājavicāraviṁśādhyāyī* by Nayanasukha Upādhyāya, ed. Bhaṭṭācārya, Vibhūtibhūṣaṇa, Sampurnanda Sanskrit University, Varanasi, 1979. Although the author of the work is identified as Nayanasukha here, the inscription to this effect on the manuscript is in a different hand and might have been added at a later date. See photograph No. 2, and p. 33. The Jaipur Museum copy of this text, on the other hand, does not have the name of the author.

93. Bahura II, p. 35, No. 5483, 13ff, The Museum. Also the Museum, Puṇḍarīka Collection No. 28. 8ff.

94. Pingree, having compared a manuscript at the Trinity College, Cambridge, (Cat. No. R. 15.139), with a manuscript of Nayanasukha's *Ūkara*, suggests that Nayanasukha wrote the *Jarkālīyantram*. See Pingree (1987), *Op. Cit.*

95. For a description of the astrolabe see Kaye, pp. 27-30.

96. Pingree suggests this work to be identical with Jagannātha's *Samrāṭ Siddhānta*. Pingree (1987), *Op. Cit.*

97. CESS, Vol. A3, p. 22.

98. Pingree suggests that this Kṛpārāma is different than the favorite scribe of Jai Singh with the same name. Pingree (1987), *Op. Cit.*

99. *Pratibimba Siddhānta*, the Museum, No. 2016. Although the book does not have any date, its script suggests it to be of the Jai Singh period. For details of the *Pratibimba Siddhānta*, See Sharma, Virendra Nath, *Pratibimba Siddhānta* of Jai Singh's Library, to appear in *Indian J. Hist. Sci.*

100. According to a genealogy given to the author by de Silva family of Jaipur, there was only one Pedro among its ancestors – the one who came originally from Portugal in 1730 A.D. The genealogy had been obtained from the R.S.A. for a court case.

101. *Laiyara Vedha Patrāṇi*, The Museum, No. 5183, 12ff.

102. *Navīna Sāraṇī Vedha*, The Museum, No. KM 43, 28ff.

103. R.S.A., Pothikhana records of Jaipur Rajya.

104. R.S.A., file No. 424/1, Pothikhana-Suratkhana, Jaipur State.

105. The copy was purchased for Rs. 20. The R.S.A. preserves the deed papers of this purchase. *Ibid.*

106. *Muhūrtaśiromaṇi* of Hari Lāla Miśra, The Museum, No. 5017. See Bahura II, pp. 406-408.

107. *Muhūrtaśiromaṇi* Hari Lāla recounts 6 generations of his ancestors. In ascending order they are: Bhānu Paṇḍita, Kṛṣṇa Śarmā, Harivaṁśa Tripāthī, Dayālu, Sukhadeva and Vaṁśīdhara. Bhānu Paṇḍita was Hari Lāla's grandfather.

108. See Ātmā Rāma's, *Savāī Jaya Siṁha Carita*, p. 129, Jaipur, 1979. Also Bhatnagar, pp. 162-163.

109. The Museum, No. 5017, 49ff and No. 5502. The second work is entitled *Muhūrtakalpadrum*. Bahura II, pp. 83, 408.

110. This work is listed in the inventory of Jai Singh's library. The manuscript had 49 folios to it. R.S.A., Pothikhana records, Jaipur State.

111. Bahura II, pp. 406 and 408.

112. *Muhūrtakalpadruma*, Bahura II, No. 5502, p. 407. The library of Jai Singh also had a copy of it in 35 folios. R.S.A., Pothikhana records, Jaipur State.

113. Führer, A. "Ueber indisches Bibliothekswesen II", *Centralblatt für Bibliothekswesen* 2 41-58, 1885.

114. *Mantrabhāṣyam*, The Museum, No. 4523, Bahura II, pp. 223, 398.

115. *Jātakasārapaddhati* of Yaśasāgara, The Museum, No. 5402, Bahura II, p. 255.

116. The Museum, No. 5575. Bahura II, p. 128.

117. R.S.A., Imaratkhana Records for the year 1734 A.D. (1791 V.S.).

118. *Ibid.*

119. *Lettres Édifiantes et Curieses, ecrites des Missions etrangeres, Nouvelle Editions. Memoires des Indes*, p. 778, Paris, 1843.

120. Bahura II, p. 75.

121. Bahura II, p. 54.

122. Bahura II, p. 20.

123. Bahura I. p. 63.

124. Bahura I, pp. 62-63, and Bahura II, p. 58.

125. Bahura II, p. 58.

126. Pingree has identified *Hayatagrantha* with the *Risālah dar hay'at* (Monograph on astronomy) of al-Qushjī. Further, he believes that the translation into Sanskrit was done in the 17th century. See Pingree, David, Islamic Astronomy in Sanskrit, *J. Hist. Arabic Sci.*, **2** (2), 315-330, 1978.

127. The Museum, No. 5372 and 5373, Bahura II, p. 432.

128. Bahura I, p. 99.

129. Bahura II, p. 241. One of the Museum copies bears the seal of the imperial library, the *Kutubkhānā* of Shahjahan.

130 Sharma, Virendra Nath, and Mehra, Anjani K., "Precision Instruments of Sawai Jai Singh", *Indian J. Hist. Sci*, **26**(3), 249-276, 1991.

131. A similar situation once prevailed in medieval Europe, when the works of Ptolemy and Aristotle were considered infallible and the final authority.

132. This subject has been dealt by the author elsewhere. See Sharma, Virendra Nath, "Jai Singh, His European Assistants and Copernican Revolution," *Indian J. Hist. Sci.*, **17**(2), 333-344, 1982.

133. NSF Grant No. INT-8016996.