Abstract

Sawai Jai Singh II, Maharaja of Amber and Jaipur, constructed five observatories in the second quarter of the eighteenth century in the north Indian cities of Shahjahanabad (Delhi), Jaipur, Ujjain, Mathura, and Varanasi. Believing the accuracy of his naked-eye observations would improve with larger, more stable instruments, Jai Singh reengineered common brass instruments using stone construction methods. His applied ingenuity led to the invention of several outsize masonry instruments, the majority of which were used to determine the coordinates of celestial objects with reference to the local horizon. During Jai Singh’s lifetime, the observatories were used to make observations in order to update existing ephemerides such as the Zīj-i Ulugh Begī. Jai Singh established communications with European astronomers through a number of Jesuits living and working in India. In addition to dispatching ambassadorial parties to Portugal, he invited French and Bavarian Jesuits to visit and make use of the observatories in Shahjahanabad and Jaipur. The observatories were abandoned after Jai Singh’s death in 1743 CE. The Mathura observatory was disassembled.
completely before 1857. The instruments at the remaining observatories were restored extensively during the nineteenth and twentieth centuries.

Introduction

Sawai Jai Singh II was born on November 3, 1688 CE (Kâti Südi 10 V. S. 1745), to the Maharaja of Amber, Bishan Singh, and a Rathor queen, Indra Kamvari. Before his ninth birthday, he was charged with representing the kingdom at the Mughal court and on January 25, 1700 (Mâgh Südi 5 V. S. 1756), he formally ascended the throne of Amber. While a prince, Jai Singh received a conventional education in Sanskrit, Persian, Arabic, and Jaipuri (bhâṣā), as well as in the customary Shastric texts on statecraft, warfare, and mathematics (Bhatnagar 1974). By 1706, he developed an interest in astronomy and commissioned copies of thirteen astronomy manuscripts in Sanskrit (Pingree 1999). In 1721, he petitioned the newly seated emperor, Muhammad Shah (r. 1719–1748), for permission to correct errors in the ephemerides used to calculate the imperial calendar. In order to accomplish this task, Jai Singh constructed astronomical observatories on property governed by his Kaccawaha clan in the northern cities of Shahjahanabad (Delhi), Jaipur, Ujjain, Mathura, and Varanasi (Benares).

Conventionally, the reach of Jai Singh’s power has been considered to have been limited by the boundaries of the hereditary state of Amber; however, he was the patron of several large-scale construction projects in northern India, including a network of astronomical observatories built between c. 1721 and 1743. While many South Asian rulers maintained an interest in the conjoined practices of astrology and astronomy and newly seated emperors frequently called for the issue of new calendars with epoch dates based on their accessions, it was not until the era of Jai Singh that the ephemerides on which these calendars were based were reevaluated in empirical terms.

Working with common brass instruments, such as the Dhât al-Shuʿbatayn (triquetrum or parallactic ruler) and Suds-i Fakhrî (sextant), Jai Singh made a series of observations and compared the results with positions predicted by the tables of the Zīj-i Khâqânî (c. 1420) and the Zīj-i Ulugh Begî (c. 1437). Noting many discrepancies, Jai Singh appealed to the emperor, Muhammad Shah (r. 1719–1748), for permission to correct the tables. As his work continued, Jai Singh concluded that his instruments lacked the accuracy needed to make the revisions. The small size of instruments prohibited the graduation of scales in minutes and the weight and mutability of brass threw axes out of true. To compensate, Jai Singh designed sturdier and larger models. Just outside the imperial capital Shahjahanabad, in a suburb governed by his family, he commissioned the construction of five stone instruments, founding the first of five observatories credited to his patronage.

In concept, Jai Singh’s instruments were familiar; they marked the coordinates of celestial objects with reference to horizontal and equatorial systems. In fabrication, they were unusual, in that they relied on masonry construction techniques.
Most were built at a scale expected of architecture, their rubble cores and mortarless ashlar masonry dressed with finish stone or plaster. The size of the observatories was not without precedent in Asia – stone instruments were erected during the thirteenth century CE in Maragha (Iran) and Dengfeng (China), and during the fifteenth century CE in Samarkand (Uzbekistan) – but the massiveness of the instruments marked a departure from the modest brass tools then popular in India (Zhang 1976). Like the brass instruments, however, Jai Singh’s inventions were designed for naked-eye observations. They required the observer to position an eye along a graduated stone edge and move until a celestial object was aligned with two or more scales.

**Shahjahanabad**

Five instruments were constructed at Shahjahanabad. The largest, the *Samrāṭ Yantra* (“Supreme Instrument”), was an equinoctial sundial with a height of 21.3 m (Fig. 192.1). The scales of the gnomon and quadrants were surfaced in lime plaster and graduated such that the instrument could be used to measure local time as well as right ascension and declination. The terminus of the instrument’s eastern quadrant contained the chamber of the *Sāṣṭhaṃśa Yantra* (“60-Degree Instrument”), a mural sextant with a radius of 8.25 m. At the apex of the gnomon of the *Samrāṭ Yantra* was the *Agrā Yantra* (“Principal Instrument”), a horizontal sundial.

**Fig. 192.1** Northern exposure of gnomon and quadrants of Large *Samrāṭ Yantra*, Delhi (Photograph: Catherine A. Johnson-Roehr)
Two additional instruments, the *Jaya Prakāśa Yantra* (“Light of Victory Instrument”) and the *Rāma Yantra* (“Ram’s Instrument”), were also constructed at Shahjahanabad (Fig. 192.2). The *Jaya Prakāśa Yantra*, which could be used to record local time as well as horizontal and equatorial coordinates, stood south of the *Samrāṭ Yantra*. The instrument’s complementary bowls, each of which had a diameter of 8.33 m, were approached by short flights of stairs that led to viewing positions both above and below grade. Southwest of the *Jaya Prakāśa Yantra* were the dual rings of the *Rāma Yantra*, an arced structure used to measure altitude, zenith distance, and azimuth. The rings of the *Rāma Yantra* stood 7.5-m high, with an inside diameter of 16.65 m.

The addition of the *Miśra Yantra* (“Mixed Instrument”) to the observatory is credited to Jai Singh’s younger son, Madho Singh I (r. 1751–1758) (Sharma 1995). This was a conglomeration of instruments that included a *Samrāṭ Yantra*, a *Daksinottara Bhitti Yantra* (“Transit Wall Instrument”), the *Karkarāśī Valaya* (“Cancer Ring”), and *Niyati Cakras* (“Fixed Circles”). The four fixed arcs of the *Niyati Cakras*, used to measure the declination of the sun over the course of the day, comprised the structure’s southern exposure (Fig. 192.3). The *Daksinottara Bhitti Yantra*, a north–south transit wall, was inscribed on its eastern wall. The *Karkarāśī*
Valaya, which may have been used to mark the arrival of sun at the summer solstice, was inscribed on the north wall of the Misra Yantra.

Jaipur

In 1728, Jai Singh founded the new capital city of Jaipur. Over the course of several years, he moved the kingdom’s political and cultural center from Amber to Jaipur’s City Palace. Within the walls of the City Palace, he also built a courtyard observatory. With the exception of the Large Samrāt Yantra, which stood 22.6-m high, the instruments erected here were more modest than those in Shahjahanabad (Fig. 192.4). The collection included the Small Samrāt Yantra, a Rāma Yantra, a Jaya Prakāśa Yantra, a Kapāla Yantra (a close relation to the Jaya Prakāśa Yantra), four Ṣaṭṭhāṁśa Yantras, and a Dīgaṁśa Yantra (“Azimuth Instrument”) (Fig. 192.5). The Dīgaṁśa Yantra consisted of two masonry walls encircling a central pillar. The upper surfaces of walls and pillar were graduated such that an observer at the center of the circle could use the scales to determine the azimuth angle of a star or planet. Unique to the Jaipur observatory were the Rāṣṭālayas (“Zodiac Instruments”), a group of twelve stone quadrants that may have been used to measure the longitude and latitude of the leading star of a zodiacal sign as it arrived at meridian. The Dakṣinottara Bhitti Yantra was added to the observatory in 1876 to replace a transit wall instrument that was decayed beyond repair (Sharma 1995). The collection at Jaipur included a number of brass instruments represented today by the Yantraraja, a massive astrolabe oriented to the latitude of Jaipur (Sarma 1999).
Fig. 192.4 Large Samrāṭ Yantra with platform of Jāya Prakāśa Yantra in foreground, Jaipur (Photograph: Catherine A. Johnson-Roehr)

Fig. 192.5 Complementary bowls of Jaya Prakāśa Yantra (foreground) and Rāśivalayas (background) (Photograph: S. N. Johnson-Roehr)
Ujjain, Varanasi (Benares), and Mathura

To create a certain level of redundancy for the cross-checking of observations, Jai Singh built additional observatories in Ujjain, Varanasi (Benares), and Mathura. The instruments at these sites were modest versions of those in Jaipur and Shahjahanabad, built out of locally available stone and lime plaster. The observatory in Ujjain stood on the banks of the Kshipra River in the imperial village awarded to Jai Singh after his appointment as governor of Malwa in November 1712. The observatory included a Samrāṭ Yantra (6.75-m high), a free-standing Dakšinottara Bhitti Yantra, a Nāḍivalaya (“Hemispheric Sundial”), and a Dīgaṃśa Yantra (Figs. 192.6 and 192.7). The Śanku Yantra (“Cone Instrument”), originally known as Gol Yantra (“Spherical Instrument”), south of the former administrative building, was added in 1934–36 by the astronomer Govinda Sadāsiva Apte in order to measure the amplitude of the sun (Gwalior State 1937, 1938).

The instruments of the Varanasi observatory were distributed across the split roofs of the Mān Mahal, a palace built on the Mānmandir Ghat c. 1600 by Man Singh I of Amber. The north roof contained two Samrāṭ Yantras (6.8-m high and 2.53-m high), a Dīgaṃśa Yantra, a Nāḍivalaya, and a brass Cakra Yantra (“Wheel Instrument”) (Figs. 192.8 and 192.9). A small Dakšinottara Bhitti Yantra was inscribed on the east wall of the Large Samrāṭ Yantra and a second was lodged in the southwest corner of the south roof.

Fig. 192.6 Southern exposure of Samrāṭ Yantra and Nāḍivalaya, with entrance to Dīgaṃśa Yantra at right, Ujjain (Photograph: S. N. Johnson-Roehr)
**Fig. 192.7** Scaled surfaces of *Digamśa Yantra* walls as viewed from eastern quadrant of *Samrāṭ Yantra*, Ujjain (Photograph: S. N. Johnson-Roehr)

**Fig. 192.8** Gnomon and quadrants of *Large Samrāṭ Yantra* on north roof of Mān Mahal, Varanasi (Photograph: S. N. Johnson-Roehr)
Jai Singh’s fifth observatory was located 150 km south of Shahjahanabad in Mathura, a temple town crowded between the imperial highway and the Yamuna River. The four instruments at Mathura – a Samrāṭ Yantra, an Agra Yantra, a Daksinottara Bhitti Yantra, and a Śanku Yantra – reportedly occupied a terrace of the city fort, Kans ka Kilā. The earliest known description of the observatory was penned by Joseph Tieffenthaler, an Austrian Jesuit who visited Mathura in May 1744. His description of the observatory gave the general dimensions of the instruments, but did not elaborate on their functions. The observatory and its instruments were demolished in the first half of nineteenth century (Growse 1882).

**Fig. 192.9** Cakra Yantra (center) and gnomon of Small Samrāṭ Yantra (right), with outer wall of Diganśa Yantra in background, Varanasi (Photograph: S. N. Johnson-Roehr)

Restoration and Current State of the Observatories

Each of the four extant observatories has been restored or rebuilt and today, they exist as managed heritage sites. To the observatory in Jaipur, Madho Singh I added a Yasṭi Yantra (“Stick Instrument”) and armillary sphere. His successor, Prthvi Singh (r. 1768–1778), restored the Nāḍīvalaya. Pratap Singh (r. 1778–1803) dismantled several instruments to build the Anand Bihari temple and converted the remainder of the observatory to a gun foundry (Sharma 1995). Around 1876, Ram Singh II (r. 1835–1880) sponsored the renovation of the remaining instruments. Madho Singh II (r. 1880–1922) initiated limited restorations as early as 1891 and invested in a complete overhaul of the observatory in 1901–1902 under the
In 1945, the plaster scales of the *Samrāṭ Yantra* were refinished in marble. In 2007–2008, under the guidance of the Archaeology and Museum Department, the observatory underwent the first large-scale restoration in over a century. The major instruments were stripped to their rubble cores and resurfaced with fresh lime plaster (Fig. 192.10). Exhausted turf was replaced, a well was dug for a new irrigation system, the observatory walls were rebuilt with crenellations, and a new interpretive center and entrance were built in the western sector of the complex. In 2010, the observatory was inscribed on UNESCO’s World Heritage List as an outstanding example of an architectural ensemble that illustrates India’s cultural traditions and a significant stage in human history (UNESCO 2010).

In 1852, at the request of the Delhi Archaeological Society, Ram Singh II of Jaipur provided 600 rupees for the refurbishment of the Shahjahanabad observatory. Between 1909 and 1911, under the supervision of Gokul Chand Bhavan, Astronomer Royal at Jaipur, additional improvements were made to the instruments. In 1951, the plaster scales of the *Miśra Yantra* were refinished in marble under the supervision of Kedara Natha Sharma, Astronomer Royal at Jaipur (Sharma 1995). Between 1975 and 1981, the pit of the *Samrāṭ Yantra* was partially...
filled with concrete an effort to prevent the pooling of groundwater. A series of interventions into the site were proposed by members of the Astronomical Society of India in 1993, but only cosmetic repairs have been made during the past two decades (Babu and Venugopal 1993). In 2007, the Apeejay Group installed spotlights and completed patchwork in anticipation of the Commonwealth Games 2010.

In 1911, the Varanasi observatory was restored under the supervision of Gokul Chand Bhavan. Since 1947, the observatory has been under the management of the Archaeological Survey of India. In 1923, the instruments in Ujjain were repaired, also under the supervision of Gokul Chand Bhavan. Small patchworks to the instruments have been ongoing and recent renovations have included the construction of a new ghat and installation of an 8” Meade telescope on rails. An Interpretation Centre, developed by Madhya Pradesh Tourism and funded by the Ministry of Tourism, Government of India, was completed in 2008.

Because the observatories are managed by separate government agencies, the interpretive strategies employed from site to site are contradictory. In Jaipur, a city popular with tourists, the observatory is interpreted as part of a romanticized Rajput history. The astrological potential of the instruments is emphasized as evidence of Jai Singh’s identity as a Hindu king. In Delhi, the instruments are interpreted as emblematic of Islamic science, the practice of which demonstrated Jai Singh’s fealty to the Mughal emperor. Jai Singh’s work is more appropriately understood as one instance of the global inquiry into astronomy during the eighteenth century. Although he studied Hindu astronomy manuscripts, his familiarity of the Zı ¯j-i Ulugh Begı ¯ and facility with Graeco-Arabic instruments demonstrate that he looked beyond a conventional Rajput education to pursue a broader literature of science (Pingree 1999). By 1726, he was in contact with the Jesuit College in Agra, negotiating European representation for his work. He dispatched a scientific ambassador to Portugal in the company of Father Manuel de Figueredo and in 1730/31, he reached east to Chandernaggar to discuss Philippe de la Hire’s Tabulae Astronomicae with the Jesuit astronomer Claude Stanislaus Boudier (b. 1686-d. 1757) (Boudier 1732). Boudier, too, was entangled in the strands of a global science and dependent on cooperation from Jesuit astronomers in China and France to support his discourse with Jai Singh. In 1737, Jai Singh opened negotiations with the Viceroy of Goa to ensure the rapid and safe passage of the Jesuit mathematicians, Anton Gabelsperger (d. 1741) and Andreas Strobl (d. 1758), from Goa to Jaipur. On the eve of his death, Jai Singh was preparing a second embassy to Rome on the recommendation of Strobl (1726).

Cross-References

▶ Archaeoastronomical Heritage and the World Heritage Convention
▶ Astronomical Instruments in India
▶ Chinese Armillary Spheres
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