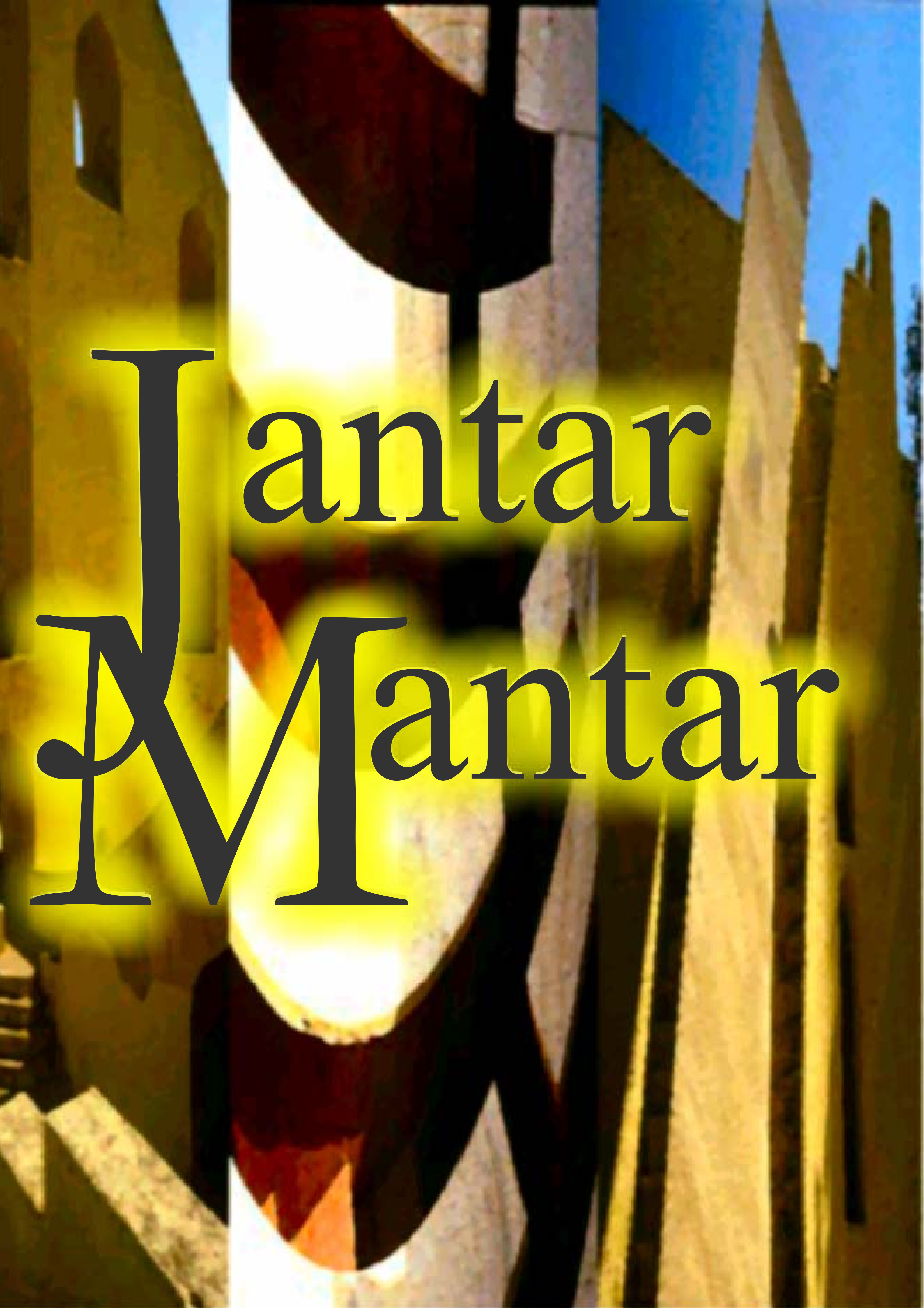
# Jantar Mantar



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# Introduction

Clearly visible from afar, the structures of the Jantar Mantar in Jaipur are striking to behold. They rise up, serendipitous stone monoliths from another age, impervious to the transition of time even as the buildings that surround them rise and fall.

Characterised by stark angular shapes, one subconsciously attempts to consign them architecturally. They are not of typical Indian design; in fact they are a stark departure from the conventional form. Standard Hindu conceptions are inseparably entwined with temples of elaborately-worked surfaces, leaving hardly any surface left unadorned; those at the observatory are starkly bare and almost entirely devoid of any cosmetic markings.

As one nears the compound, smaller assemblies, previously dwarfed in the distance by their larger equivalents, become visible. These too, appear taken out of time, reminiscent of an era long over.

The surreal forms reveal their true size when one enters the observatory. Inevitably, questions spring to mind: what are these structures? Who built them? And to the astronomically initiated, how were they used and what was their application?

The founding concept of the Jantar Mantar is rooted in the conquest of science and the betterment of knowledge. Yet to constrain oneself to this view would be painting but a small part of a larger picture. How the Jantar Mantar came about has intimate and binding connections with a large number of issues – socio-political motivations, architectural and town planning norms, its builder and his rationale …. the list goes on. Such matters must be visited to enable one to form a holistic opinion of what the Jantar Mantar is all about.

The above issues will be examined in realizing the aim of this discourse. The term *Jantar Mantar* does not denote a particular, physical site; rather, it is the epithet given to a number of astronomical observatories built at the time. The one in New Delhi is the most accessible and is visited yearly by the local and international traveller, and, being an important contributor to the tourism coffers, is scrupulously maintained by the Indian government. Two smaller, less prominent versions in Ujjain and Beneres have fallen into disrepair under a cash strapped government arm. The one at Matura counterpart is no longer in existence, having been irresponsibly and irreparably damaged by  building constructors.

Here, in line with the mathematical lean of our submission, the emphasis shall instead be on the Jantar Mantar in Jaipur, Rajasthan. This is even larger than its Delhi counterpart, and is situated within the palace compound. While the others are no less deserving of merit, the Jaipur site is unique in that a concerted preservation effort was made in the early 19$^{th}$ century. This left important intricacies intact for the accurate analysis required for the astronomical slant in this work, which the Delhi version is unable to provide.

# SECTION I

## The Political Stage in Early 18th Century North India

The Mughal Empire that was founded in 1526 by Bahadur Shah I of Kabul, went through a Golden Age that met its inevitable decline towards the 18th century.

North India, then at a transition phase which began in the 17th century, was marked with internal turmoil of political struggle and external assimilation, especially from the Portuguese and French. However, the Mughal Empire was somehow still enjoying its glorious reign -- the kingdom under Emperor Aurangzeb was under good leadership, and, with the exception of the Marathas, faced minimum opposition threats.

The reign of Aurangzeb began in 1658 after he successfully consolidated his power and eliminated all sources of threat – threats arising mainly from his siblings. He secured his kingship at Delhi and Agra and was fabled for imprisoning his father Shah Jahan in the Agra Fort. Aurangzeb led the empire with high capability until his retreat into Deccan in 1682 and in his prime years of kingship, managed to subdue several territories, including Assam, Kashmir, Tibet and Deccan.

The only thorn in his flesh were the Marathas, who were stationed at the northwest of Jaipur state. The Marathas were under the leadership of Shivaji, who disregarded all Mughal rulers. Stirring unrest in the territories of the Mughal Empire, the Marathas seized every opportunity to encroach on Mughal land. Though Aurangzeb managed to overcome these threats in general, he was never entirely successful in eliminating the power of the Marathas completely.

Following Aurangzeb's death in 1707, North India was plagued with yet greater turmoil and unrest. It was termed the "Dark Age" of North India which marked the downfall of the Mughal Empire. Its ruling chiefs were basically engrossed in fighting to overtake India's trade and gain a firm foothold in its political arena.

**Maharaja Sawai Jai Singh II**

It was also amidst such a politically unstable situation in North India that came along a rare talent: Jai Singh II.

Jai Singh was born on November 3, 1688 AD into the well-established Kucchwaha Rajputs, a clan which rose to power in the $12^{th}$ Century.[1] Their power was distributed to the northeast of what is present day Jaipur, comprising of the kingdoms of Mewar (Udaipur) and Marwar (Jodhpur). Being politically savvy, they were one of the clans who pledged alliance with the Mughal Empire. The Kucchwahas Rajputs had deep-rooted theories about their celestial positions in the universe and their heavenly identities as the descendants from the Sun. They claimed that their lineage dated back to Kusha, the son of Lord Rama, the legendary hero in the great Hindu epic the Ramayana. Rama was said to be a descendant of Surya, the sun god. Thus, the Kucchwahas undoubtedly referred to themselves as the solar race.

Jai Singh entered the political scene at the young age of eleven to succeed his father Maharaja Bishan Singh in 1699 A.D. as the ruler of Amber, a few years after Aurangzeb's death. Jai Singh was deemed a highly intellectual individual way beyond his age. He even won the praises of emperor Aurangzeb when he was first presented to the Delhi court at the age of seven in 1696 A.D.

Legend has it that at that time, Jai Singh had gone to pay his respects to the emperor who held his hands and asked, " How do you expect to be powerful with your hands tied?"

With sheer confidence and composure, Jai Singh replied " When a bridegroom takes his bride's hand, he pledges to protect her for life. With your Majesty taking my hand, what for do I need power?"

Emperor Aurangzeb was deeply impressed by such an intelligent reply and bestowed upon Jai Singh the title *sawai*, meaning one and a quarter of an average man in worth.

Maharaja Bishan Singh too, saw great potential in Jai Singh when he was a young boy. Obviously Bishan Singh had plans for Jai Singh to succeed his throne and thus, made

[1] Although not the emphasis of this essay, the lineage of the Kucchwaha Rajput is diverse and merits a further look for the curious reader. The Kucchwahas are most noted for building the majestic Amber Fort in Jaipur.

tremendous efforts in nurturing his son. Jai Singh received the best education and learnt from the best teachers and scholars in the fields of art, science, philosophy and military affairs.

**Astronomical Interests and Influences**

In particular, Jai Singh was extremely interested in arts and science, especially astronomy. As a scholar, he studied the works of Ptolemy, Euclid and Persian astronomers and showed the greatest interest in Arabic-Persian astronomy. However he remained a firm follower of the geocentric system of Indian tradition and of Ptolemy.

Jai Singh's knowledge on western astronomy was derived from mainly Spain and Portugal, with no prior knowledge of the progress made in Rome and England. It is believed that he probably never read the works of Galileo, Kepler or even Newton.

Western astronomy was introduced into India many centuries before Jai Singh's time. The pioneer source of western astronomy can be dated back as early as 520 B.C., when India was exposed widely to Babylonian influences. Further contacts with the Persians opened India to Greek astronomy works, intensifying further when the Greco-Bactrian Empire was established in Northwest India. Centuries of accumulated exposure to these external sources provided a concrete foundation for Jai Singh's education in astronomy. Many new ideas from western astronomy by then had also been incorporated into the traditional Indian astronomical system.

It is noteworthy that the reason why astronomy was a much-pursued aspect in ancient times was that people were generally obsessed with its religious notions. Celestial phenomenon were often associated with gods and the sacred Truth. As a result, people firmly believed that secrets were revealed by the Gods in the movement and position of every star up the sky.

Likewise in Jai Singh's case, it was not surprising that astronomy aroused such strong passion in him. Since his family had previously traced their lineage back to the Sun god, it may be concluded that Jai Singh felt every need to feel in touch with his “ancestral origin”. This was dealt with a strong religious belief yet rational scientific approach.

**Jai Singh’s Political Career**

At the start of his political career, Jai Singh did not enjoy a peaceful time seated in his throne of Amber. Initially, he was very much involved in political struggles when he supported Aurangzeb’s son Azam Shah as the heir to the throne following Aurangzeb’s death. However, Azam Shah was defeated by his brother Bahadur Shah. Bahadur Shah then demanded Jai Singh to be stripped of his title and be replaced by Vijay Singh as the ruler of Amber.

Jai Singh intuitively fought back by gaining a strong backing with other alliances from the Rajput states and reconsolidated his authority against the Mughals. He finally gained full control over the province of Amber in 1908. It was not however, until the reign of Farrukh Siyar Muhammad Shah in 1719 that Jai Singh managed to establish a level power which propelled him to the pinnacle of his political career.

Emperor Muhammad Shah ruled the empire for nearly 30 years. His reign was marked by infamous raids of Delhi led by Nadir Shah of Persia and the Afghan Ahmad Shah Abdali. At the same time, Muhammad Shah faced constant threats from his long time foe, the Marathas, who were constantly attacking Delhi. It was therefore crucial for the Emperor to seek alliance with the Hindu rulers in order to secure his throne.

Jai Singh became one of the important allies that Emperor Muhammad Shah depended on. Recognising him as a man of talent, Muhammad Shah offered him governor posts at Agra and subsequently, Malwa.

# SECTION II

## The Delhi Observatory

It is intriguing to note that the construction of the magnificent Delhi observatory can be traced back to a dispute. The controversial debate over certain planetary positions took place in 1719 at the Delhi public courtroom of the Red Fort. The Emperor Muhammad Shah was to embark on a long expedition and an auspicious date had already been fixed. However, some astrologers determined certain discrepancies over planetary positions which, at that time, were believed to influence life on Earth.

The heated disagreement between the Hindu and Muslim astrologers failed to reach conciliation based on their own astrological observations. Witnessing this, Jai Singh bore the sentiments that the reason leading to the disagreement was largely due to inaccurate astrological tables.

The idea of building an observatory dawned on Jai Singh who then requested Emperor Muhammad Shah to allow him to undertake the responsibility of correcting the astrological tables. Seeing that Jai Singh was himself a learned man in astronomy and mathematics, the Emperor readily granted this request.

It is likely that the Emperor was willing for a more political reason: his plan for building the Delhi observatory, and subsequent ones, was tempered in the fact that the India of that era was a land saturated with superstitious beliefs and strong mythical influences. Important events such as religious ceremonies and sacrificial rites were to be strictly carried out on auspicious days. As such, with the longevity of the Empire said to depend on sacrificial rites and ceremonies, accuracy of planetary positions became a topmost priority.

Jai Singh, in his later published work *Zij Muhammad Shahi*[2] illustrated this point:

> ‘Seeing that very important affairs, both regarding religion and the administration of the Empire, depend upon these; and that in time of rising and setting of the planets, and the seasons of eclipses of the sun and moon, many considerable disagreements of a similar

[2] The Zij Muhammad Shahi will be covered later, under ‘The Sawai’s Magnum Opus, p 16.

> nature were found – he represented the matter to his Majesty of dignity and power, the sun of the firmament of felicity and dominion, the splendour of the sovereignty, the incomparable brightest star of the heaven of the empire, whose standard is the sun, whose retinue the moon, whose lance is Mars and whose pen is Mercury, with attendants like Venus whose threshold is the sky, whose signet is Jupiter, whose sentinel is Saturn—the Emperor descended from a long race of kings, an Alexander in dignity, the shadow of God, the victorious king Muhammad Shah. May he ever be triumphant in battle.'

## **Blueprints of an Astronomical Observatory**

Initially, Sawai Jai Singh started out using brass instruments but soon abandoned the idea when he realized the presence of several flaws inherent to the small size of the instruments. This resulted in the destabilization of their axes and the consequent displacement of the centre.

Gathering his inspiration from the 15th century Afghani ruler Ulugh Begh's observatory at Samarkand, Uzbekistan, the idea of building massive masonry instruments favoured Jai Singh's architectural tastes and apparently promised to be more accurate because of sheer size. [3]

The Delhi observatory was eventually completed in 1724 and was believed by the Indians to be an ingenious creation attributed solely to Jai Singh. However, this is now known not to be the case. The construction of the Jantar Mantar was in actuality adopted from Samarkand. At least two of the instruments at Delhi (viz. the Rama Yantra and the Samrat Yantra) took on strong semblances to those of its Uzbekistani antecedent. The only marked differences are in their size, inner construction details and the external surfaces of the instruments; the basic concepts in building style are essentially the same.

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[3] It is tempting to assume that Jai Singh's actions were grounded nobly in the conquest of science, yet his accomplishment had fundamental persuasions which were of an entirely disparate nature. In order to fully appreciate this, one must first examine the workings of his instruments. This shall be deliberated under 'Ratiocination of the Maharaja', p34.

To illustrate: the Rama Yantra at Delhi retained the outline of a multi-storeyed circular shape with integrated arches. The Samrat Yantra took on the interior structural arrangement of its predecessor at Samarkand.

Besides taking reference from Samarkand, Jai Singh also employed the assistance of European advisors.[4] They aided Jai Singh in areas of astronomy and mathematics, and in return, were granted permission to set up a church for missionary duties. One of the more prominent figures who helped with the technical minutiae was Father Emmanuel de Figuerego, who, under the authority of Jai Singh, led a legation to Lisbon in search for the latest astronomical knowledge and advances. Subsequently, the French Jesuits took over the responsibilities in offering assistance to Jai Singh in 1734 and, eventually, a succession of German priests.

## The Sawai's Magnum Opus

Jai Singh, upon completion of the Jantar Mantar at Delhi, proceeded on with his work to correct the astrological tables. He compiled his work in a book named after the Emperor, *Zij Muhammad Shahi*. The Zij Muhammad Shahi included a new and accurate star catalogue of 1018 stars. The imperial calendar was improved upon, and it was also at this time that Jai Singh came to discover the value of obliquity at $23^0$ 28'.

His work was however, based heavily on Ulugh Begh's tables and on European sources. It was in no way, as he claimed as in the Zij, astronomical tables of his own creation.

Another noteworthy point is that contrary to popular belief; Jai Singh did not really make use of the huge Yantras to derive his results in the Zij Muhammad Shahi. Instead, he merely made use of a few small instruments made of stone and metal.

The Delhi observatory functioned for a mere seven years, most probably only for the sake of compiling a more accurate astrological table.

## Conception of a New City

Sometimes referred to as the Machiavelli of his time, Jai Singh stood out among the rest as a highly intellectual figure in court, gaining status and power. As his influence grew, there

[4] These European advisors to the court were (initially) the Jesuits, who were in India to spread their faith.

became a rising demand to initiate the construction of a new city to resolve the problem of limited resources in his sovereign state of Amber.

This hailed the conception of Jaipur city, by and large his largest accomplishment. In the town planning process, Jai Singh decided to put theoretical architectural design into reality. Out of several town plan designs, he immediately expressed his enthusiasm on the particular one that adopted the architectural style from the sacred texts of the Shilpa Shastra.

Jai Singh's interest in a holistic urban format for his city of Jaipur stemmed from his desire to display his powers and portray himself as a divine figure, particularly Indra, Ruler of the universe. Jaipur was an excellent opportunity to put forth this self-proclaimed image. Therefore, details of the layout and building of every section of the city was planned in such a way that it played a significant role in implying this close relationship he had with the celestial world.

## The Vastu Shilpa Shastra

It is inevitable that to discuss the planning of Jaipur, it is essential to elaborate somewhat on the Hindu architectural text Vastu Shilpa Shastra, a South Asian architecture and planning theory in Sanskrit. In fact, none of the architectural forms in ancient India should be introduced before first explaining the functions of the *Shilpa Shastra*. This theoretical literature (consisting of geometrical and rectilinear concepts for building) plays a very essential role. It guides the way and provides a skeletal framework on how the buildings are located and built as they are believed to be based on divine models, revealed by the Hindu architect of the gods, Visvakarma. Some may perceive it as a superstitious practice, but the Shastras has been the cornerstone of beliefs that guided and moulded the Hindu way of life.[5] Fundamentally, it is the main vehicle to project and carry-on the tradition and literature of the Hindu culture. Thus its contents are regarded sacred, important not only to Kings and sages, but also to the common people.

Vastu, meaning "dwelling", was once believed to be the residing places of both god and man. In modern times, however, its meaning has come to refer to all types of buildings regardless of function. Viewed as a science, the Vastu Shastras has most probably gone through many stages of being refined and edited through a process of trial and error. It is also

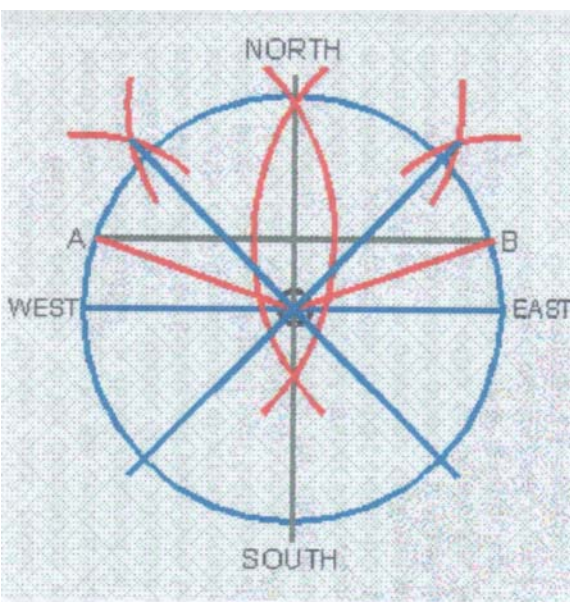
[5] In this respect, the Shilpa Shastras are very much akin to the Chinese 'Feng Shui'.

the medium of Hindu tradition and liturgy. It soon evolved to become linked to fields of astrology and the magnetism of the Earth, although its principles are still based on architecture and engineering. Responsible for regulating standards in these fields by associating it with the gods and making it sacred, it is considered today as superstitious and discharged as obfuscation.

The origins of the Vastu Shilpa Shastra can be traced back to as early as the Early Vedic Period. When the Aryans first settled down in the Indus Valley, they brought along with them the Vedas from which the Shilpa Shastra originated. Until the advent of the Sanskrit script, these books of knowledge were passed down strictly by word of mouth only. The *Atharvaveda*, the fourth book that encompasses the Vastu Shastras, was systematically compiled only when the Aryans had settled into an agrarian way of life.

As time passed, the early settlers came together to form larger communities. Perhaps it was then that they decided to include the Vastu Shastra into the Atharvaveda in order to provide a framework for uniformity in the overall planning of things, ranging from the home to the larger community. Initially, this system was still under considerable flexibility, tailored for individual requirements and local conditions. However, during the later Vedic period, as it evolved into a set of hard and fast rules, only the pandits and sthapatis were cognisant of it.

**Fundamental Architectural Tenets**




According to the rules of the Vastu, a building erected must be situated in such a way that it benefits from both solar and cosmic energies. Indian architecture mainly depends on *Diknirnaya* – Principles of orientation, *Vastupada vinyasa* – Siteplanning, *Maana* –Proportions, *Aayadi Sadvarga* – 6 principles and *Pataakaadi Sadchandas* – Aesthetic of the building. As mentioned above, much emphasis is placed on how the building is situated so that it is parallel to the alignments in space and the celestial sphere (cosmic model).

To do so, a gnomonic compass is used to draw the axes. Firstly, a pole is placed vertically in the middle of the construction site. A radius of the height of the pole is then drawn on the ground. The shadow of the pole is plotted at sunrise and sunset to give the east-west axis. Following this, the drawing of parallel and perpendicular lines to obtain the cardinal directions would just be simple geometry.

According to the *Vastu Pada Vinyasa* (site planning), a square plot would be the best since it connects all the four points, North, South, East and West. On the other hand, if it were a rectangular plot of land, the ratio of its length to its breadth would be most ideal if it's 1:1.5. Till today, the fundamental principals of the Vastu are still very much relevant.[6]

Everything built is based on the five basic elements of air (*Vayu*), water (*Jal*), earth (*Bhumi*) and space (*Aakasha*) collectively known as *Panchabhutas*. The rules formulated for the Vastu is called "Vastu Shastra". There are several kinds of Vedas. They are *Atharvaveda* revealing the statecraft, *Ayur Veda* that deals with health and medicine, *Dhanur Veda* a military science that is derived from *Yajur Veda, Gandharva Veda* a science, which aids the music and arts and finally the *Sthapatya* that laid the basic rules of architecture.

**Mystical Component of the Shilpa Shastra**

Ancient mythology believed that the *Vastu Purusha* (cosmic man) is present in every plot organism. According to myth, he was a giant who was captured and conquered by the deities by sitting on his back. Desperate to be set free, he prayed to the god who was then facing him in the northeast corner. The giant blessed him with a boon and told him that he will give his protection to those who do not endanger him. The northeast of the plot of land is hence kept empty since his head was placed in that position. Purusha resides in the Vastu Purusha Mandala (the planned site) that symbolizes any polygon.

**Integration into the Town Plan of Jaipur**

So far, the canons laid down by the Shastras have been discussed. But how were these applied in the context of Jaipur and the perpetuation of divine leadership beliefs?

[6] For example, the Vastu also advises people to face north or east when sitting down – a logical notion, since the glare of the sun is most powerful in the west and south during the day.

To strengthen his political power and expand his territory from Amber, Jai Singh promoted his identity as a descendant of the solar race. By presenting himself to the world as a Solar King through identification of himself as a worldly representative of the cosmic ruler, Jai Singh incorporated divine order within the town planning of Jaipur.

Details of the layout and building of every section of the city played a significant role in bringing out the close relationship of Jai Singh to the celestial world. Therefore, Jaipur city was undoubtedly the first town that deviated from pre-existing town building formats.

The city of Jaipur was built according to the principles of the Shilpa Shastra with such fidelity that it was veritably an imprint of the Shastras architectural style. We can see distinct features that show a connection with the idealized town plan. For example, the King's palace is found geographically in the centre of the town, while the temple built for the glory of Govinda (Krishna) is within its surrounding precincts. A lot of attention is placed on the positioning of the King's palace and has been compared and likened to Mount Meru.[7]

The most obvious and essential element is perhaps the wide, 108 ft wide axial road that runs along from east (the Sun Gate) to west (the Moon Gate) -- the pathway of the sun. This east-west axis is in line with a site of pilgrimage, four miles away from the city at the Galta mountain pass. The 'Pole Star Gate' (Druv Pol) is dictated by the North Celestial star.[8] It is located off-centre in the town plan and faces Delhi. The Pole Star is ritually interpreted as a gift from the Gods to keep the Kingdom in a stable state of affairs. These three cardinal points form the fundamental triangulation of Hindu Kingship and are expressed through the architecture of Jaipur.

The city plan of Jaipur is interpreted widely as a square Mandala[9], one that is deformed and open to several other interpretations depending on how one chooses to view the town plan. Some see it consisting of nine squares symbolizing the "nine directions of the universe" whilst others see it as a seven part Mandala. The number seven, for the Indians is a significant number when seen in the light of the cosmological way.

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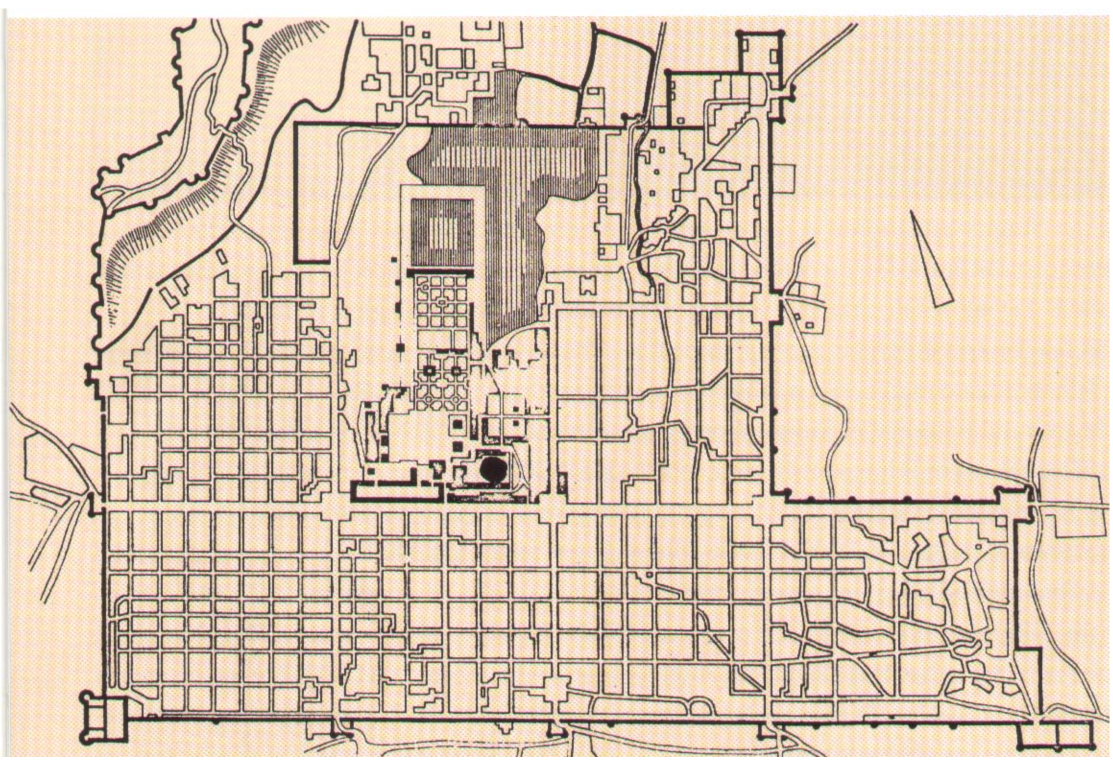
[7] Mythical place in Hindu religion which embodies the focus of the universe. At the peak lies the Golden Palace, residence of Indra, king of all Hindu gods.
[8] It is of interest to ponder how the exactitude of Druv Pol, due to precession, has probably become invalid over time. There does not, unfortunately, seem to be any academic source which addresses this issue.
[9] 'Mandala' in Sanskrit means polygon, circle, connection and community. The mandala is an enduring symbol with various interpretations across cultures and time.

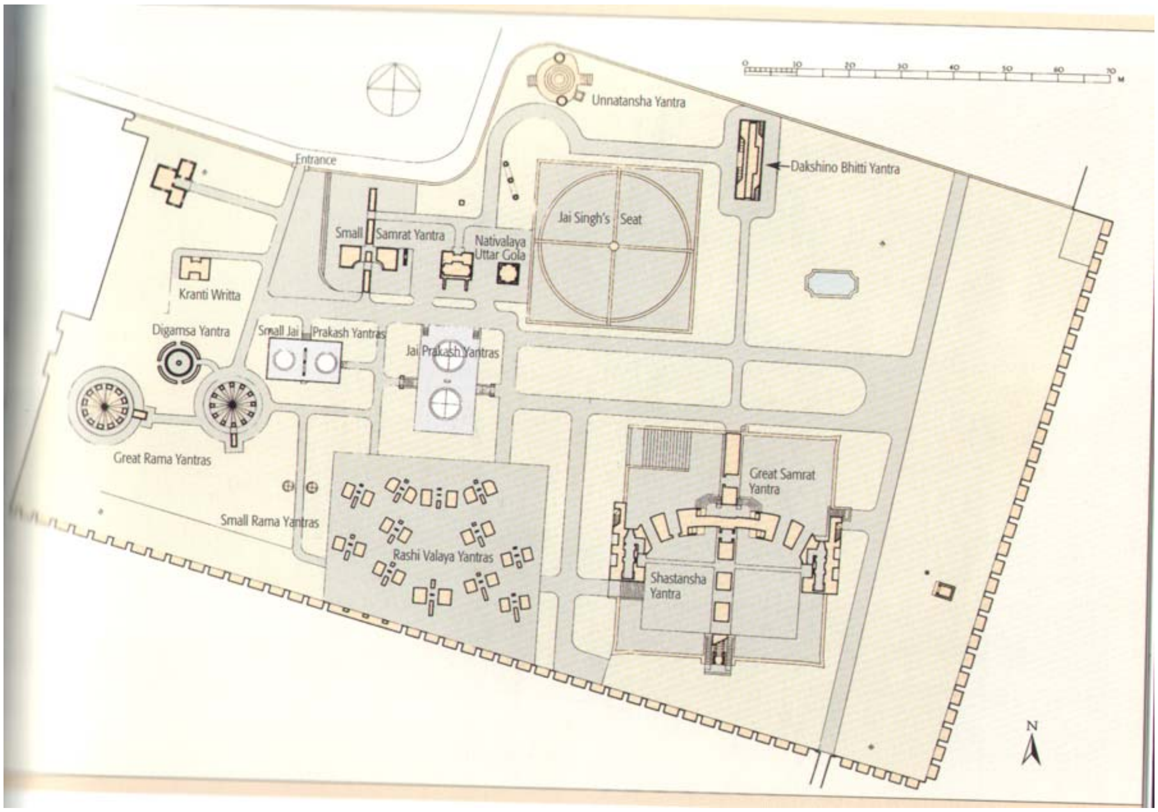
During those times, stories that link epic heroes to kings are common. The association of the Cosmo order and political ones date as far back as the Vedic period and as old as the Indo-Aryan civilization. Thus, divine orders are linked to worldly ones through rituals. The Shilpa Shastra merges the mystical and socio-political and reflects itself through architecture. However, it has never been regarded as a science until 700A.D, after the Indians became involved in massive temple building projects that eventually became a tradition.

According to the Shilpa Shastra, the temple, which was regarded with the utmost importance, was to be placed in the middle of the town. The way plots of land were given out to the people of that period was based on hierarchy and considered as divine order. The highest-ranking officials in town were often given the most auspicious spots on which to build their houses whilst the lowliest of ranks would be given the least auspicious ones available.



Jaipur was one of those few in India built on a rectilinear street plan. However, contrary to popular belief that the city blueprint was based solely and entirely on the principles of the Shilpa Shastra, there is an exception in the actual layout, in that it is not built in a rectilinear manner. The orientation of the streets deviates considerably from the four compass points. The houses, as well as palace, which lie in the center of the town, took their orientation from the streets.

The observatory of Jaipur, which was the largest amongst those that Jai Singh had ever built, was located in one of the palace's courtyard. As a result, the orientation of the instruments were noticeably off that of the courtyard walls. They were tilted diagonally with respect to the courtyard walls (see Fig). The reasoning behind this was simple: the way the instruments were laid out aligns them to the four compass points. They had to be: most of them had parts -- such as gnomons – which, to carry out their function, had to be aligned to certain important features of the globe and celestial sphere.[10]




There are however, flaws to this intricately designed observatory and its beautifully crafted monumental instruments. It is situated on a low-lying open plain with courtyard walls surrounding it, making it almost impossible to observe the rising and setting of the stars. Also, parts of the instruments, like the gnomons and scales are made of plaster making it extremely hard to obtain accurate readings.

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[10] Some examples of important features are the North Star, axis of the Earth and the ecliptic axis.

## Jai Singh's Assistants

Besides employing assistants from the west, Jai Singh had by his side other assistants of native origin. Among them was a key figure who had worked closely with Jai Singh in the revival of textually sanctioned practices, be it ritual or architectural in nature. He was a Bengali Brahmim called Guru Vidyadhar or "Bearer of the sacred knowledge".

Together with another priest, Raj Guru Jagannath, Vidyahar held great authority over the construction progress and detailed plans of the city as well as the building of the palace and other buildings. Vidyahar was regarded in high esteem and greatly appreciated for his wide knowledge in arts. His contributions to the construction of Jaipur city and other buildings were duly recognized and acknowledged by Jai Singh himself.

Vidyadhar, with his reputation as a well-known architect for Jai Singh, drew comparison of him to the divine craftsman Visvakarma, who was believed in the traditional context, built palaces and cities for the gods. More precisely, Visvakarma was said to plan the layout of the palace of Indra, the tutelary god of the Indo-Aryans, a figure whom Jai Singh liked to align himself with. Therefore, the extraordinary relationship between Jai Singh and Vidyadhar was heavily emphasized and made use of in order to create the close link between Jai Singh and Indra himself.

Similarly, Raj Guru Jagannath's contribution to Jai Singh's building program is also significant. Jai Singh employed him because of his Arabic linguistic abilities and knowledge. In addition, Jai Singh also had Hindu astronomers skilful in Greek astronomical methods and Muhammadan assistants for Muslim astronomical works.

## Completion of Jaipur and the Jantar Mantar

The city of Jaipur was completed in 1727 A.D. A ceremonial celebration was held which marked the shift of Jai Singh's capital city from Amber to Jaipur. Characteristic of Jai Singh, an observatory was also built in his new capital city which naturally was to be the largest of all his observatories. In fact, the Jantar Mantar at Jaipur is known to be the most extensive out of all the observatories he constructed.

## Instrument Nomenclature and the Mandala Correlation

A large portion of the instruments constructed was based heavily on Hindu tradition. The significance of mandalas was illustrated through the architecture of Jai Singh's building program. The stone blocks that serve as bases for instruments such as the Ram Yantra a similar orientation to the bricks in the Vedic fire altar.

The instruments of Jai Singh all bear the word "Yantra" towards the end of the name. This has a lot to do with the much-emphasised Mandala. The Yantras, which have an intermittent link with the mandala, represent the Truth determining the lives of Man and even the Gods. They encompass the secret meaning of the sacred truth, precisely the message that Jai Singh planned to convey: that he was the truth bearer, the quintessence of the divine, the ultimate King of the universe.

## Rituals and Ceremonies of the Solar King

One of the official routines that Jai Singh undertook was to travel around the city in his chariot on Hindu holy days. It seemed that the symbolic figure -- that of a *cakravartin* -- was one of Jai Singh's planned strategies to establish his solar extraction. His chariot was compared to the Indra Vimana, the transport of Indra. From this, the juxtaposition of himself with the world ruler was obvious.

A more elaborate move on Jai Singh's part was to carry out ancient sacrificial rites as was described in the Vedas. One of these rituals was the horse sacrifice, believed to exemplify the greatness of Indra and act as a symbol of unchallenged power. The sacrificial act of slaughtering a horse was performed when Jai Singh was drawing near the end of his life. In this rite, the horse was allowed to roam freely and with uncontrolled authority in the King's country for a year. At the end of the year, it was then captured, killed and its body cut up in accordance to a strict system of acceptable rules. Perhaps the significance of this was to show the King's sovereign rule and power over everything – that it was under his command as to whom he wished to grant favour and his whim on withdrawing it. Re-enactments of the ritual on an annual basis to reinforced the notion that the sun was an everlasting source of rejuvenation.[11]

[11] Despite the association of such grandiose rituals with other great rulers in ancient times, it was later regarded by the Brahmin priests as cruel, abhorrent and eventually abandoned.

# SECTION III

## The Instruments of the Jantar Mantar

Like its Delhi counterpart, the observatory at Jaipur consists of nine different instruments of which smaller implements, such as the sextant and the astrolabe, are contained within. The Jantar Mantar is unique in this aspect as these are still in an excellent state of repair, unlike in Delhi:

- The Samrat Yantra
- The Digamsa Yantra
- The Jai Prakash Yantra (Great and Small)
- The Unnatasha Yantra
- The Rama Yantra
- The Dakshino Bhitti Yantra
- The Rashi Valaya Yantra
- The Shastansha Yantra
- The Narivalaya Uttar Gola Yantra

The functions, operation and coordinate measurements of these nine instruments vary. Some of them actually complement one another -- for example, the Digamsa Yantra was built to complement the Samrat Yantra because of the latter's limitations in taking azimuthal and altitudinal readings of the stars in certain positions.

There are basically four types of coordinate measurement systems to determine the positions of objects and celestial bodies within the celestial sphere, as listed in the table below.

| Location | Base Circle | Base Point | Coordinates |
|---|---|---|---|
| Earth | Equator | Where Greenwich Meridian Intersects the Equator | Latitude and Longitude |
| Celestial Sphere | Horizon | Due North | Altitude and Azimuth |
| Celestial Sphere | Celestial Equator | Spring Equinox | Declination and Right Ascension |
| Celestial Sphere | Ecliptic | Spring Equinox | Latitude and Longitude |

The coordinate measurement systems that the instruments in the Jaipur observatory are related to may deviate slightly from the above four. For example, the Samrat Yantra and the Jai

Prakash Yantra use the horizon as the base circle, but instead of using due north, the zenith is used as their base point instead. However, both the measurements of altitude and azimuth remain the same.

The instruments at the Jaipur observatory can be generally categorized into three different coordinate measurement systems:

1) The Horizon and the Zenith.
2) The Equator and the Earth's axis.
3) The Ecliptic and the Pole of the Ecliptic.

Below is the table of the five different instruments and their respective coordinate measurement systems.

| Instruments (Yantras) | System Based on | Coordinates Measurements |
|---|---|---|
| The Rama | Horizon and Zenith. | Altitude and Azimuth |
| The Digamsa | Horizon and Zenith. | Altitude and Azimuth |
| The Samrat | Equator and Earth's axis. | Declination and Right Ascension |
| The Rashi Valaya | Ecliptic and Pole of the Ecliptic. | Latitude and Longitude |
| The Jai Prakash | Horizon and Zenith, Polaris and the Celestial Equator. | Altitude and Azimuth, Declination and Right Ascension |

Opinion of exactly which instruments were built during Jai Singh's time differs. In 1785, Josef Tieffenthaler, a Jesuit missionary who travelled to India, recorded his observations of the Jantar Mantar. Since before that no independent records had been made, significant issues remain as to which of the masonry instruments had been built by Jai Singh and which were the ones constructed after his reign.

Out of these uncertainties, it emerges that at least three instruments have their design and construction attributed to Jai Singh: the Samrat Yantra ("Supreme Instrument"), the Ram Yantra ("Rama's Instrument") and the Jai Prakash Yantra ("Light of Jai"). The three are distinct in that they are described by Jai Singh to be “of his own invention” in the Zij Mohammed Shahi. Additionally, they stand apart in terms of nomenclature, being the only three designated by epithets: ‘Supreme’, ‘Light of Jai’ and ‘Ram’. This is in contrast with the other instruments, which are defined by function: Rashi Valaya (Zodiac Circle); or transparently derived by way of form: “Bowl Instrument”, for example.

It is these three instruments which shall be the emphasis of this work. Their distinctiveness is also manifest in the application of astronomical concepts which are in the curriculum: each uses a different coordinate measurement system and hence offers comprehensive coverage. [12]

However, the instruments do not operate as effectively by themselves. It is largely for this reason that many of the other structures were subsequently constructed in an effort to complement and enhance the existing edifices. In an effort to further elucidate the functions of the three main instruments, these ‘supplementary instruments’ shall also be discussed where appropriate.

## The Samrat Yantra

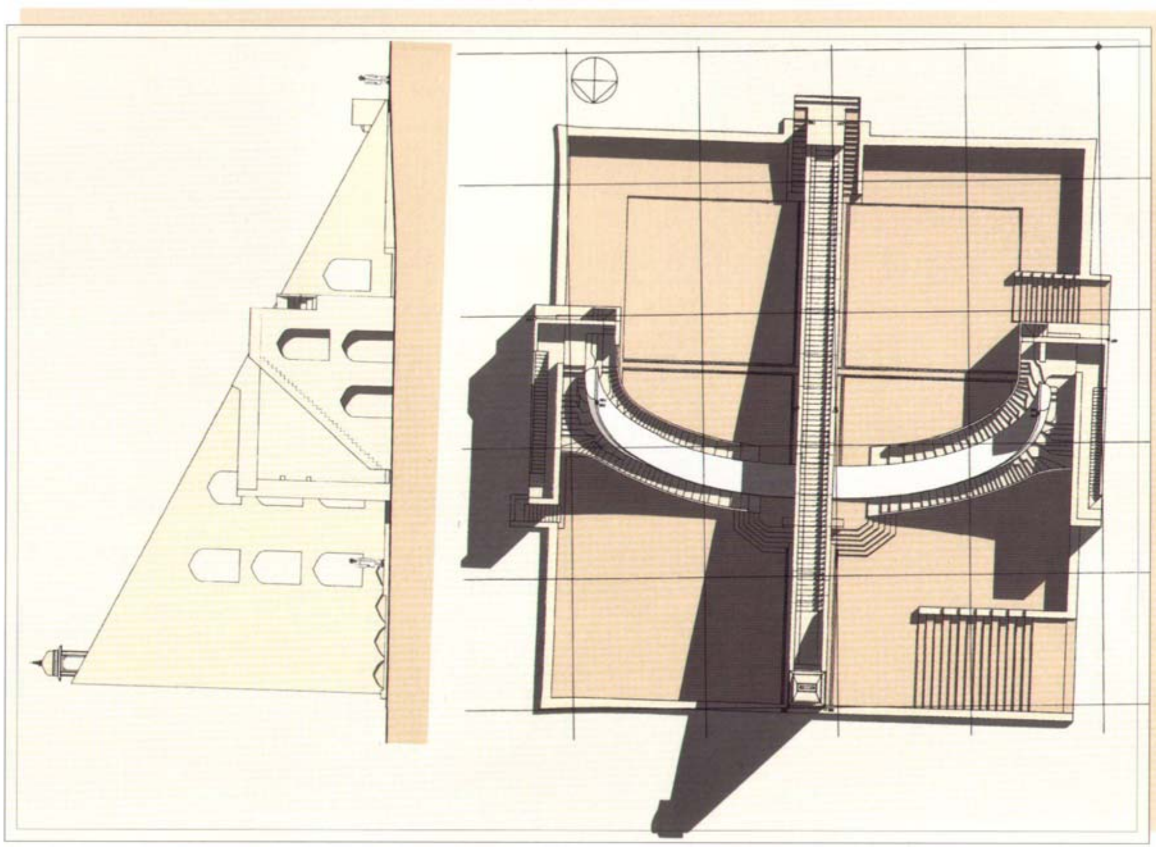
The Samrat Yantra (Supreme Instrument) dominates the landscape of the observatory and is very much the crowning glory of the Jaipur observatory. Widely accepted to have been constructed by Jai Singh himself in 1724, its aspect and rationale is not unfamiliar in any astronomical context: in essence it is a large sundial. Hence its principal purpose was to conduct solar time-reading duties. Additionally, as an extrapolation of its function, it was able to trace the path of stars, reveal the duration of day-night, and verify the location of the Pole Star.

Versions of the Samrat Yantra may be found at all the observatories built by Jai Singh; indeed also in other archeo-astronomical sites around the world.[13] It is certainly not a departure from the primary time-telling concept of the simple sundial and bears testament to the evergreen fundamentals which form the backbone of modern-day astronomy.

[12] The exception to this is the Jai Prakash Yantra, which utilises a combination of categories one and two.
[13] The concept of the sundial is well established in many cultures throughout history. Sundials in all designs and sizes may be found – from the basic gnomon of Anaximander of Miletus, to more sophisticated versions conceived during the Han Dynasty in Ancient China.

**The lesser counterpart**

There actually exist two sundials at the Jantar Mantar, large and small. Although both are termed Samrat Yantra, the latter carries a distinguishing prefix *Laghu*. Due to its lesser dimensions – it is four times smaller than its counterpart – it is inherently less accurate. The logic behind building in the same observatory two sundials, both which appear to perform the same function, is unknown. It is likely that the Laghu Samrat Yantra was built first, with the second one constructed later to dwarf the Delhi version. In any case, it is difficult to envision the conditions in which the relative chronology would have been otherwise[14].



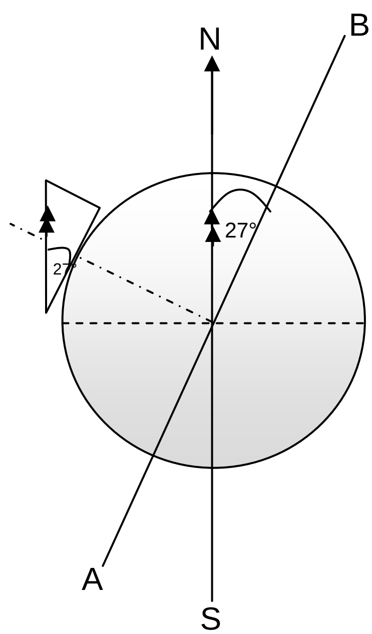
**Façade and Architectural Style**

The façade itself proffers a remarkable view even to the untrained eye. Due to its size, the structure rises above its surroundings and surrounding instruments and is discernible even from outside the observatory precincts. The main edifice consists of a triangular ramp or gnomon inclined to align North - South with the axis of the earth. The base of the gnomon spans

[14] The Laghu Samrat Yantra is not independently described even in 1785 in records by Josef Tieffenthaler.

44 meters and ascends to 27 meters. To the east and west of the right triangle rise two massive quadrants (or wings) of 15-meter radial centred on the nearest edges, which are calibrated with fine divisions of hours, minutes and seconds. As is the case with the edges of the ramp, they are constructed of marble to endure erosion of the graduations and surface. The balance of the edifice is built of local stone.

Stairs run the length of the ramp and culminate in a *chatri* (lit. parasol) whose sides are oriented in the four main directions and ribs in the minor ones.[15] Typical of Rajput architecture, the axes symbolised the major axes of the universe. The chatri was used as a platform for determining wind direction, announcing eclipses and onset of monsoons[16] and is still used today for religious purposes. Predictably, it is closed to the visiting public[17].



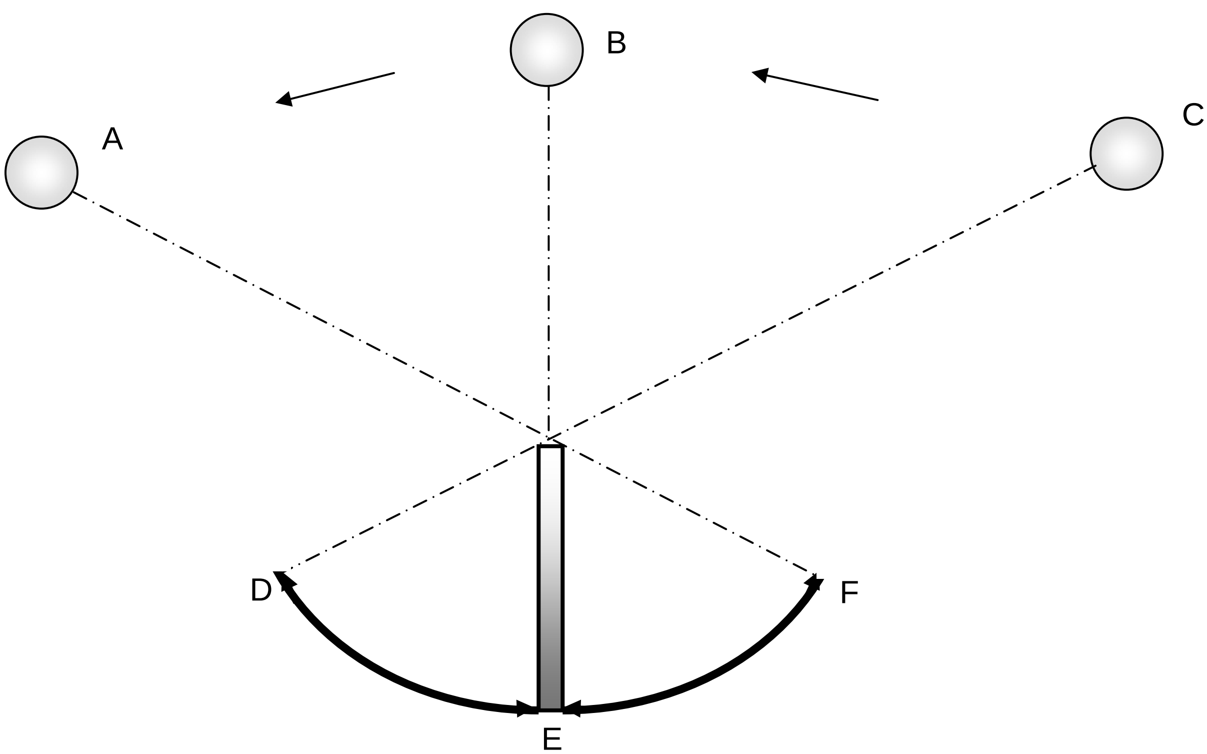

**Astronomical application**

With the latitude of Jaipur being 27 degrees, the local horizon is naturally tilted 27 degrees from the N-S axis to form horizon A-B (see Fig. 1). To compensate for this, an

[15] It is of interest to note that in Hindu architecture, the parasol is a recurring iconographic convention. A traditional emblem of kingship, it figures prominently in the vocabulary of Rajasthani design.
[16] G.E. Kidder Smith, *Looking At Architecture*, 1990.
[17] However, the smaller Samrat Yantra remains open and offers excellent photographic opportunities.

offsetting ‘tilt’ was introduced in the form of a gradient on the hypotenuse. This gradient was angled at 27 degrees also, to bring the hypotenuse back in line with the North Celestial Pole. Hence, by nature of its location, the position of the North Star may be pinpointed by the gnomon.

As previously observed, the Samrat Yantra is a sundial. Refer to Fig. 2. As the sun rises in the east, its shadow is cast upon the edge of the western quadrant and runs length D-E when at position C. Throughout the day, the shadow creeps down the edge toward the base of the gnomon as the sun traces a higher path in the sky. At local noon, the sun is in the meridien (position B) and its shadow falls directly upon the hypotenuse of the right triangle (i.e. there is no shadow). This is followed by an increase in the height of the shadow on the edge of the eastern quadrant, as the sun descends in the sky through the course of the afternoon (through position A and corresponding length E-F).




The graduations also allowed the duration of the day (and hence, night) to be determined. The first discernible marking at daybreak was noted along with its corresponding marking (on the eastern wing) at sunset. The consequent duration of time derived from the markings between these two points provided the length of the day.

Every hour, the shadow on the gnomon moves approximately 4 metres. This translates to 6 cm every minute and, with each minute sub-divided into thirty fractions, the sundial is theoretically able to provide a remarkable accuracy of 2 seconds. The bona fide precision, however, differs in accordance with the sceptical eye, with claims ranging from half a second to as far wide as half a minute.

**Instrument inaccuracies: the conundrum of shade diffraction**

The premise behind such broad estimates is not unfounded. In the quest for accuracy through size, the designers had perhaps overlooked one fundamental flaw – that of *shade diffraction*. The volume of the shadow cast behind any object illuminated by an area light source

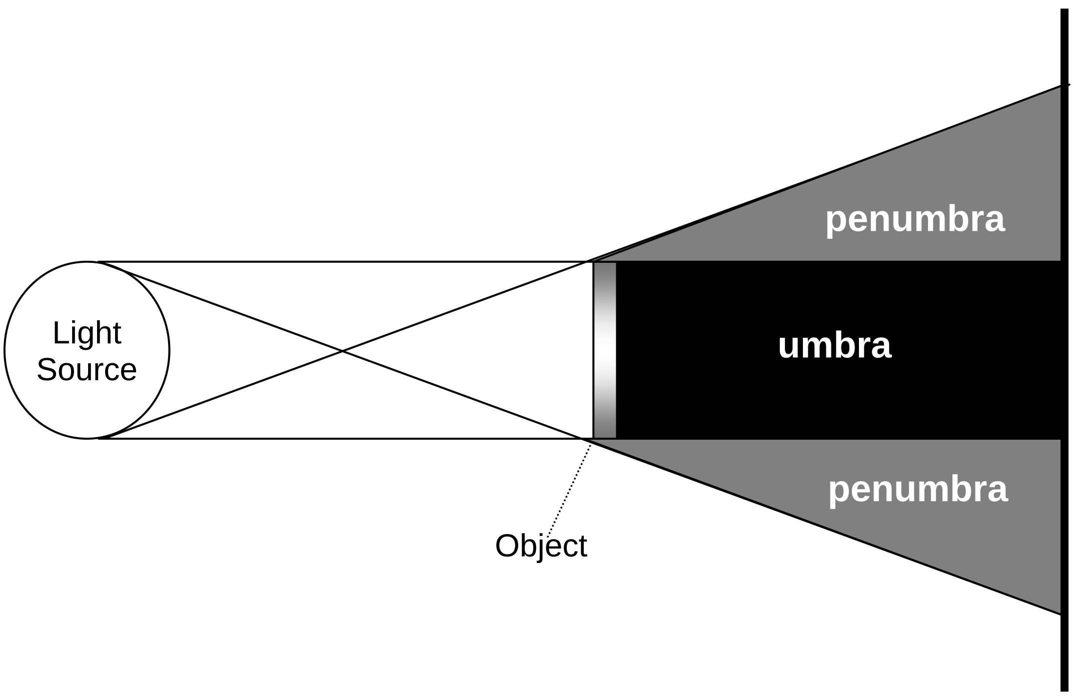



Fig. 3

does not possess clearly defined boundaries. Every point within the boundary area is instead in partial shadow. The area of full shadow is known as the *umbra*, and the area of partial shadow is termed the *penumbra*. (See Fig. 3) Note that the diagram is only an approximation, since the penumbra is characterised by a shadow-light gradient rather than homogenous shadow density.

In the context of the large sundial, the area light source is the sun. By nature of its great distance from our planet, the sun emits light rays which may be taken to be parallel upon reaching earth. This is in contrast with a point source emanating rays which originate and spread outward from a single point. The shadow cast by the Samrat Yantra would have been more focused had the structure been smaller and hence closer to the ground. It can thus be seen that this problem is compounded with an increase in size. The penumbra in the Samrat Yantra is not small, spanning a width of about 10 centimetres. With every 2 seconds being 0.2 centimetres on the scale, such a large area cast in half-light would make for poor astronomical timekeeping.

The court pundits creatively circumvented this problem by employing the use of a small lead instrument or sidestick. This could be a fine needle, sharp stick or any other similar object. By running the sidestick up or down the length of the ramp and locating it in accordance with the shadow of the gnomon cast on the quadrants, it became possible to determine the hour exactly. The resourceful usage of such tools negated appreciably the effects of shade diffraction, making the Samrat Yantra the largest, and effectively the most precise sundial available.

**The merit of size**

A pragmatic consideration behind building in such large dimensions the instruments in the Jantar Mantar, was the aim of increasing accuracy. This is notably palpable in the case of the Samrat Yantra.

Jai Singh, in the Zij Muhammad Shahi, laid down reasoning which purports to a scientific motivation:

> 'It should be maintained that these instruments [of the Europeans] were not large, and therefore, the calculation and observations were somewhat inaccurate, since the atmospheric conditions had a strong influence on those instruments; we explained that the inadequate inaccuracy of the observatories and measurements by Hipparchus, Ptolemy and the others particularly indicated this.'

Such a notion is not incorrect: theoretically, an increase in precision should logically follow an augmentation in size. Take, for example, a wing of the Samrat Yantra. Assuming an instrument of smaller dimensions, a shadow would, in an hour, move say 2 metres. A minute would therefore occupy about 3.33 centimetres. Contrast this with the actual dimensions of the Samrat Yantra: in 1 hour a shadow moves 4 metres. Consequently, a minute would cover approximately twice the length, at 6.66 centimetres. This would then allow for more detailed measurements, especially taking into consideration the degree of accuracy of instruments at that time.

**Ratiocination of the maharajah**

At this point, it is reasonable to make a perceptive deduction – two attributes, each contradictory to the other, are ascribed to the Samrat Yantra: the advantage of increased accuracy from ‘building big’, and the problem of shade diffraction, which undermines accuracy with increases in size. The question of how to reconcile the two naturally arises. Did the use of a sidestick compensate sufficiently for the size of the instrument? Or was the purported precision overshadowed by the drawback of shade diffraction?

Perhaps the best way to answer this would be to adopt a different approach. Although Jai Singh, in the Zij Muhammad Shahi, proffered a mathematical basis for his actions, the building of such large instruments has aspirations from socio-political motivations.

It is believed that through his European advisors, Jai Singh was aware of the European astronomical findings and observatories. Thus, he must have known the contemporary astronomical instruments at that time, which were the alidades and telescopes. He displayed little interest in the smaller instruments and the European tables that were derived from them. As a point of fact, the smaller metal instruments were able to produce readings no less accurate than the larger ones, and one postulates that Jai Singh was erroneous in not admitting to it. In addition, he did also own a set of exclusively made traditional metal instruments for his own use that most certainly contradicted his reasoning behind erecting enormous instruments at the observatory.

The Jantar Mantar at Jaipur thus evidently served a different purpose from that of Delhi. The latter was essentially built for the sole purpose of improving the Indian astrological tables and calendar. These had already been completed by the time the Jaipur observatory was constructed, thus obviating the need for further astronomical data collection. Instead, the Jantar Mantar at Jaipur was built mainly for religious purposes. With the benefit of hindsight, his judgement in abstaining from the use of sighting equipment apposite to instruments of that age is perhaps more related to Hindu philosophy: depiction of the cosmos and godly realms endow upon the expert the mandate of knowledge and power over this world far exceeding the information they truly provide. In doing so, Jai Singh would then have become the apotheosis of all things divine.

## The Jai Prakash Yantras

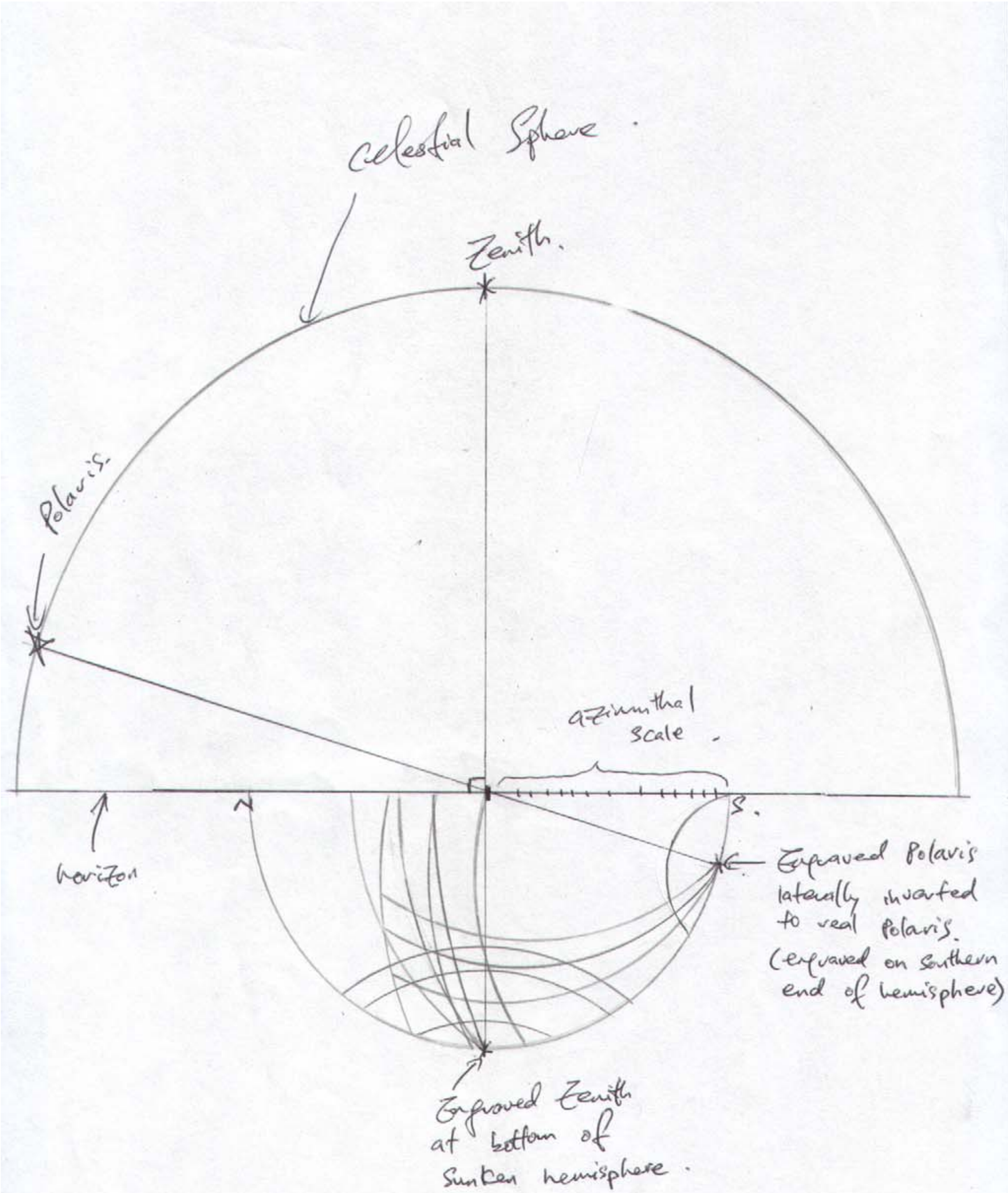
### Introduction

The fundamental principle upon which the Jai Prakash Yantras were designed was that a hemisphere recessed in the ground would inversely represent the heavens above the observer. Appropriate scales such as the azimuthal, altitudinal, declination and right ascension lines; and important celestial reference markers such as the zenith and the North Celestial Pole, were inscribed onto the hemisphere to allow observations of the sun and stars.

The Jai Prakash Yantras were special in the sense that their observations were actually based on two different coordinates measurements systems, the horizontal and celestial equatorial systems. As a matter of fact the Jai Prakash Yantras were the only instruments discussed here that uses more than one coordinates measurement system. The exact reason as to why two different systems were used within one instruments were unknown. A good guess would be for greater accuracy.

### The Small Jai Prakash Yantra

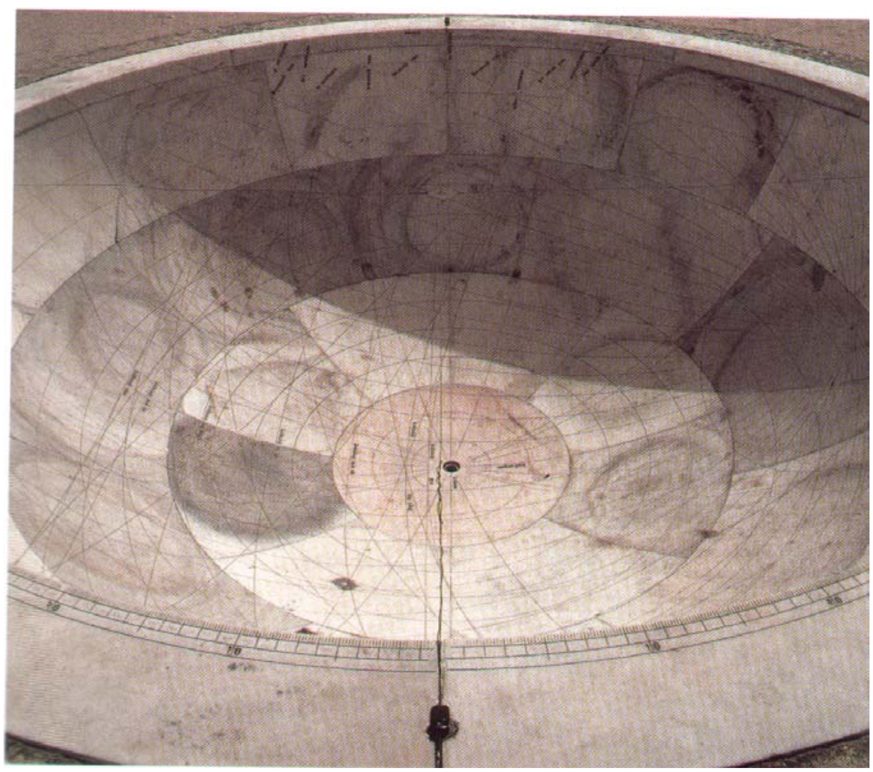
The Small Jai Prakash Yantra is a complete hemisphere made of sections of white marble sunk into a horizontal platform with its top open. This sunken hemisphere, as described, inversely represents the celestial sphere above it. As such, the North Celestial pole is laterally inverted in with respect to the surface of the hemisphere in comparison with the celestial sphere. This enables easy reading for the observer. The diagram should clearly illustrate this concept. This is, in essence, similar to the concept of seeing the sun moving clockwise in the northern hemisphere and counter clockwise in the southern hemisphere, i.e. things appear laterally inverted if views are taken from vertically opposite sides of the earth.


Celestial Sphere.
Zenith.
Polaris.
azimuthal scale.
N
S.
horizon
Engraved Polaris laterally inverted to real Polaris. (engraved on southern end of hemisphere)
Engraved Zenith at bottom of sunken hemisphere.

**Function**

**First Coordinate Measurement System: Horizontal**

Azimuthal scale is inscribed around the edges of its open top and aligned to the four compass points. The horizontal platform actually represents the horizon of the observer. A wired string cross with a ring at the intersection is affixed to the open end of the instrument. The ends of the wired string cross are secured to the north, south, east and west points. (Below)

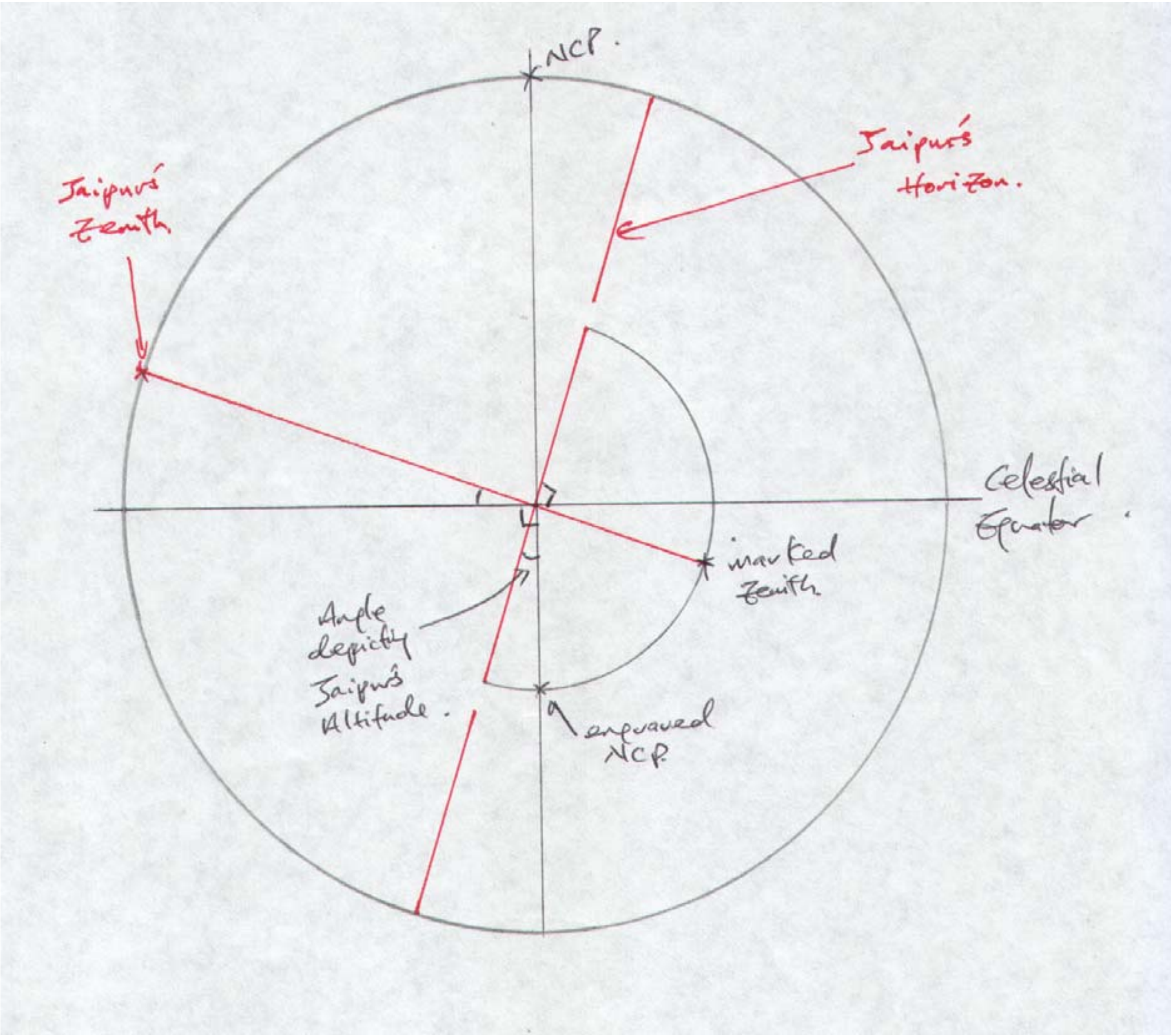


Immediately below the ring is the lowest point of the hemisphere, which is marked to represent the zenith. The marked zenith in the hemisphere maintains its position relative to its celestial counterpart because both are exactly perpendicular to the horizon; thus lateral inversion has no effect. Concentric circular lines representing altitude are engraved around this point. Larger circles of azimuthal lines that stem from fixed intervals of the horizontal azimuthal scale intersect the altitudinal lines perpendicularly and meet at the marked zenith at the bottom of the hemisphere.

### Second Coordinates Measurement System: Celestial Equatorial

Next, we examine the other coordinate measurement system that is also inscribed onto the sunken hemisphere, i.e. the celestial equatorial system.

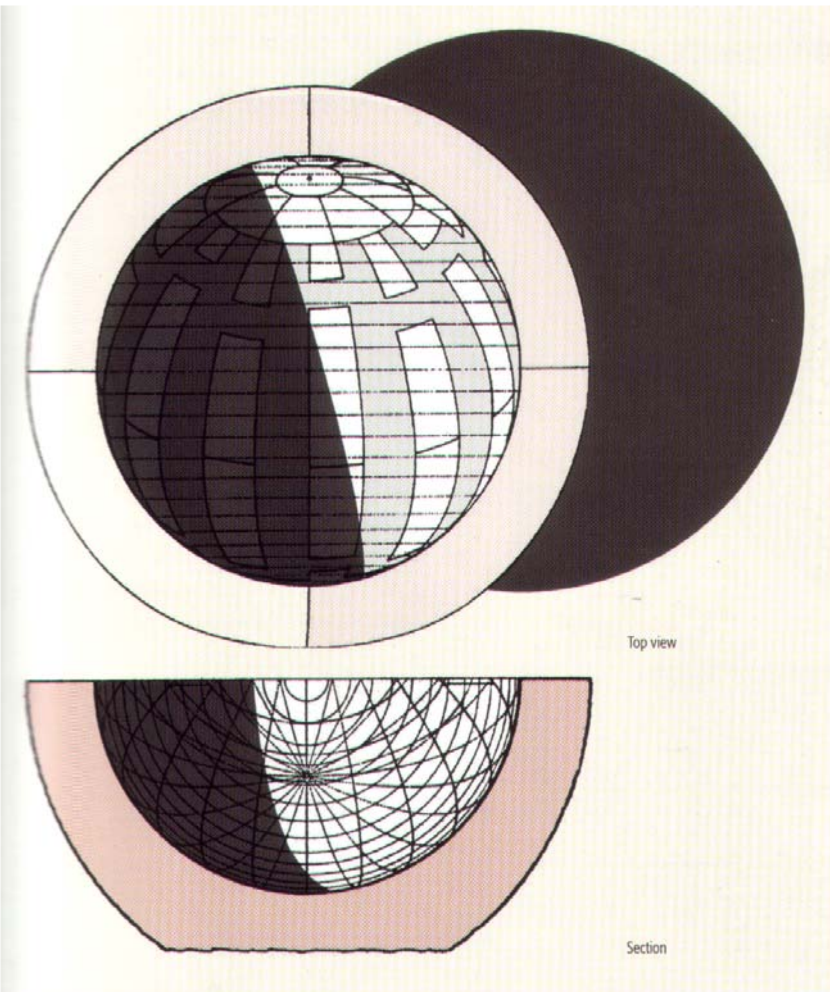
Notice that the North Celestial Pole is inscribed at a specific angle off the horizon in the hemisphere. This angular difference actually represents the geographical latitude of Jaipur. The drawing below should clearly illustrate this concept.




Concentric circular lines around the engraved north celestial pole represent declination lines. Larger circular lines that perpendicularly intersect these declination lines represent right ascensions, completing the network of scales of the second coordinate measurement system that the Jai Prakash Yantra is based on.

**How it Works**

The ring that is positioned exactly over the lowest point of the hemisphere i.e. the marked zenith, actually acts as a gnomon. As the sun travels across the sky during the course of the day, it casts a shadow that moves across the surface of the hemisphere. The readings can be taken in two different measurements due to the two different coordinates measurement system. The sketch on the following page should illustrate this clearly.

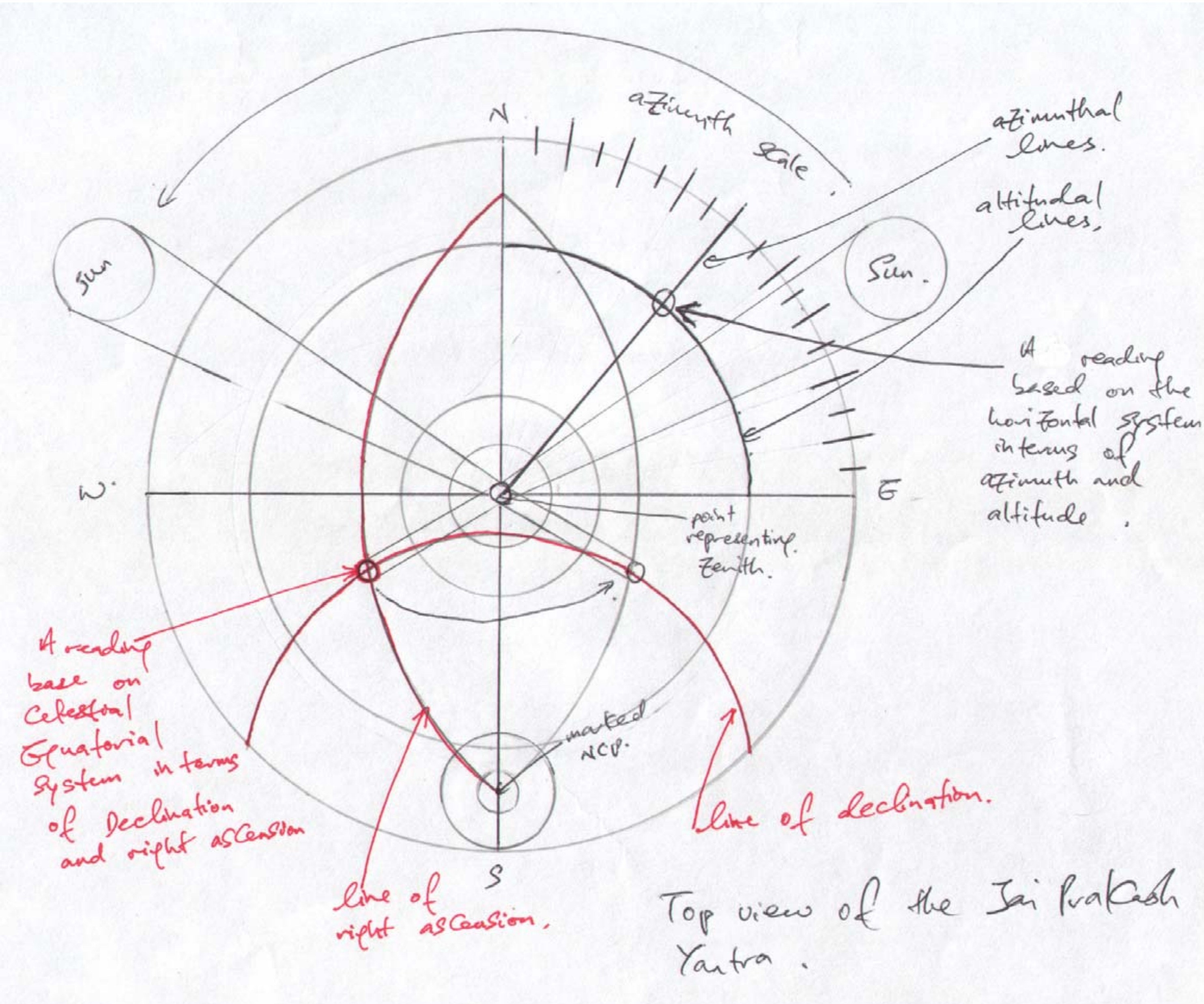



**Limitations**

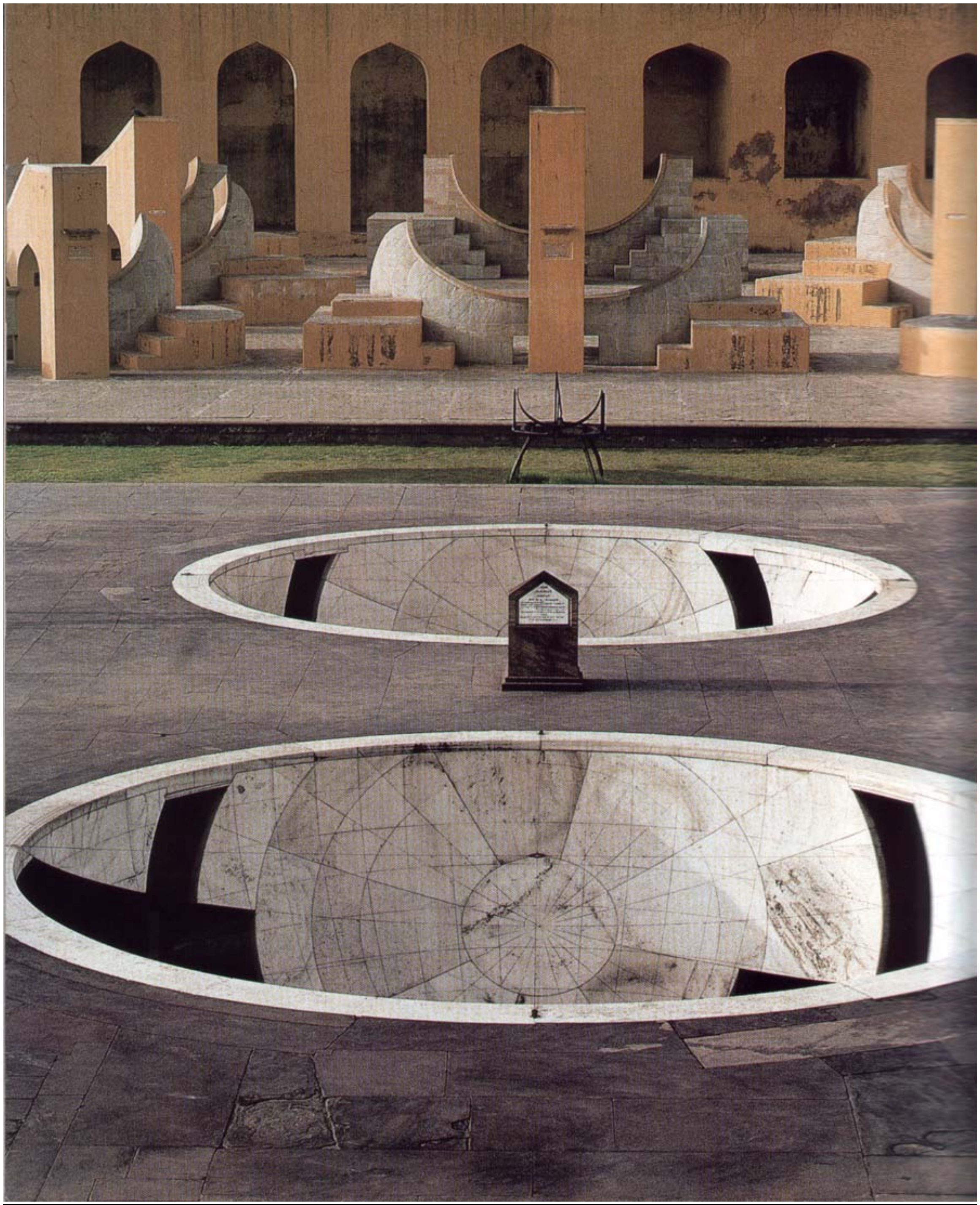
While the daily path of the sun could be read clearly on the white marble surface of the hemisphere, it was not possible to observe stars.

The reason is obvious: had the hemisphere been made of transparent material, the observation of the stars could have been possible. A transparent surface would give a clear reflection of the stars at night. However, this was technologically not possible in that age.[18]

[18] Yet, even if it were possible, in the day the shadow of the ring would simply pass through the transparent surface, rendering the instrument useless for observing the sun. In this imaginary context, perhaps Jai Singh should have built two instruments: an opaque one for the sun, and a transparent version for the stars!



N
azimuth scale.
azimuthal lines.
altitudal lines.
Sun
Sun.
A reading based on the horizontal system in terms of azimuth and altitude.
W.
E
point representing zenith.
marked NCP.
A reading base on Celestial Equatorial System in terms of Declination and right ascension
line of declination.
S
line of right ascension.
Top view of the Jai Prakash Yantra.

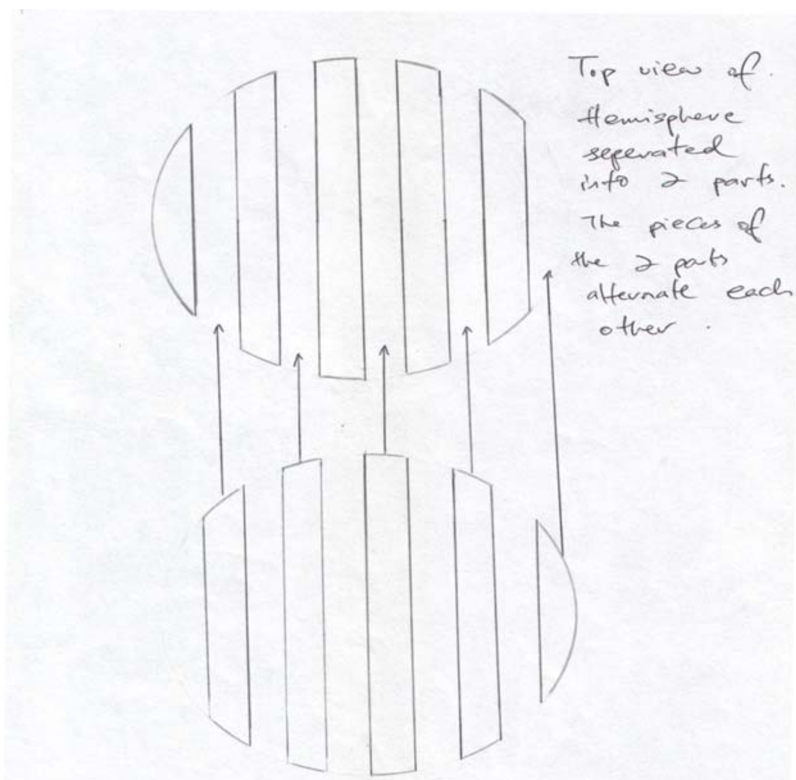


## The Great Jai Prakash Yantra

It was the limitation of the Small Jai Prakash Yantras that caused Jai Singh to build the Great Jai Prakash Yantras.

## Description

Not only was the hemisphere enlarged substantially, the surface was divided into sections. Each alternate slab was reassembled into a second hemisphere. In the second hemisphere the pieces were assembled in such a way that the gaps between the pieces would fit exactly into the position of the pieces in the first hemisphere, such that the two hemispheres when fitted together make a whole. The drawing below should illustrate this clearly.



**How it works**

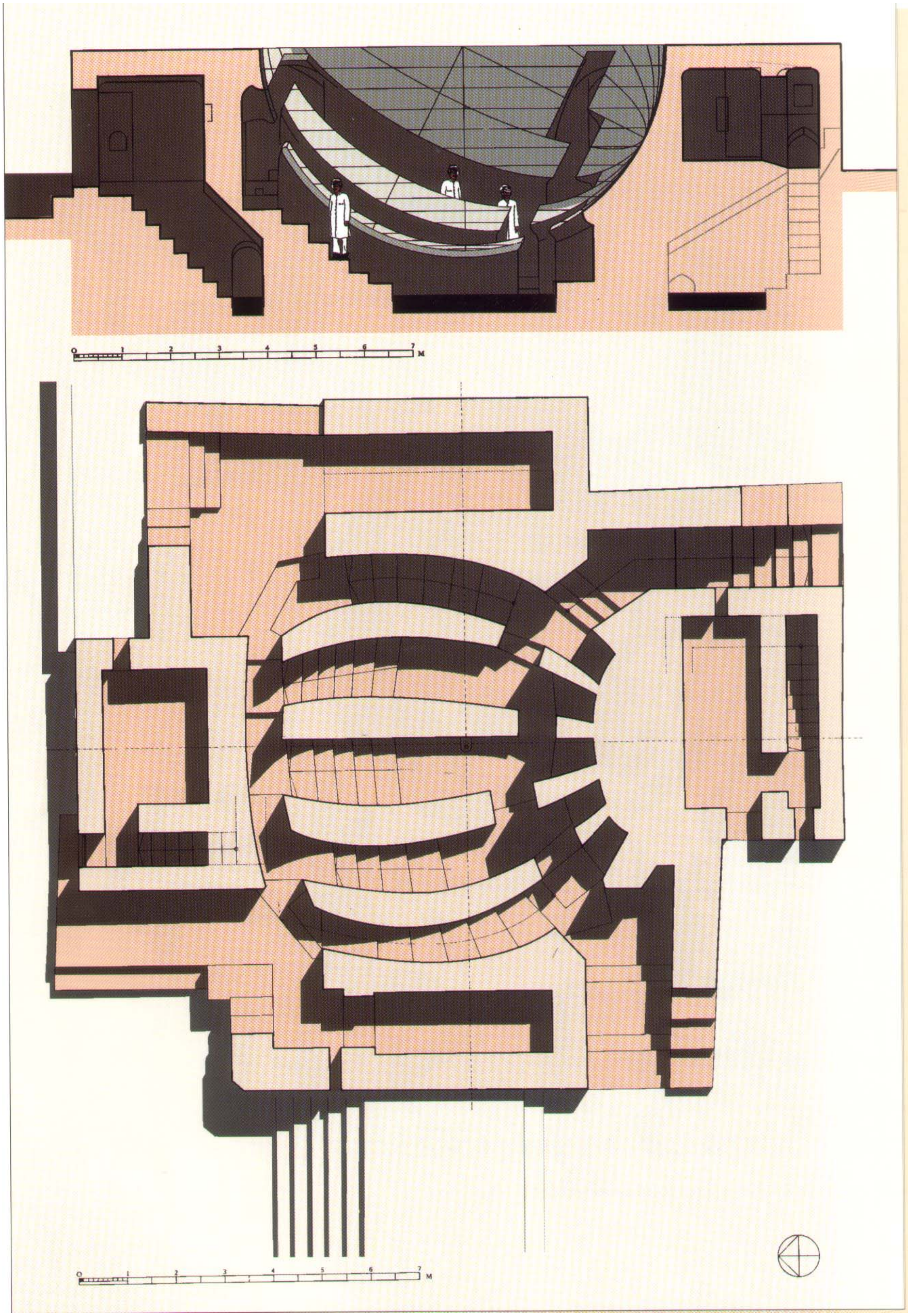
The gaps were made accessible from underground, i.e. steps and passage ways in between the slabs were built so that the observer could walk right up to the edge of the slabs, align his eye to the surface level of the slab and then to the star he wished to observe.

**Limitations**

Although these inventions circumvented  the handicap in observing stars of the smaller version, they were still limited in terms of accuracy. Note that the observer had to align his vision to the surface of the scaled slabs and then to the stars, meaning that observations of the stars were only possible off the edges of the slabs. Jai Singh divided the pieces of slab into longitude at intervals of fifteen degrees.

Hence accurate readings of the stars could only be observed if it had covered fifteen degrees of its orbit. If the position of the star being observed fell in onto the surface of the slab, only an estimate reading could be taken.

Apart from physical size and the division of the surface of the hemisphere to enable the readings of the stars, the Great Jai Prakash Yantras were not radically different from the smaller ones. Conceptually both followed the same fundamental structure of using sunken hemispheres to represent the heavens above, in order to make observations of the celestial bodies. In terms of basic features, both had ring gnomons suspended at the cross intersection of the two wires to take readings of the sun. Both had markings of the zenith at the lowest point of their hemispheres and the markings of the north celestial pole at the southern end which were laterally inverted to the real north celestial pole or Polaris.



0 1 2 3 4 5 6 7 M
0 1 2 3 4 5 6 7 M

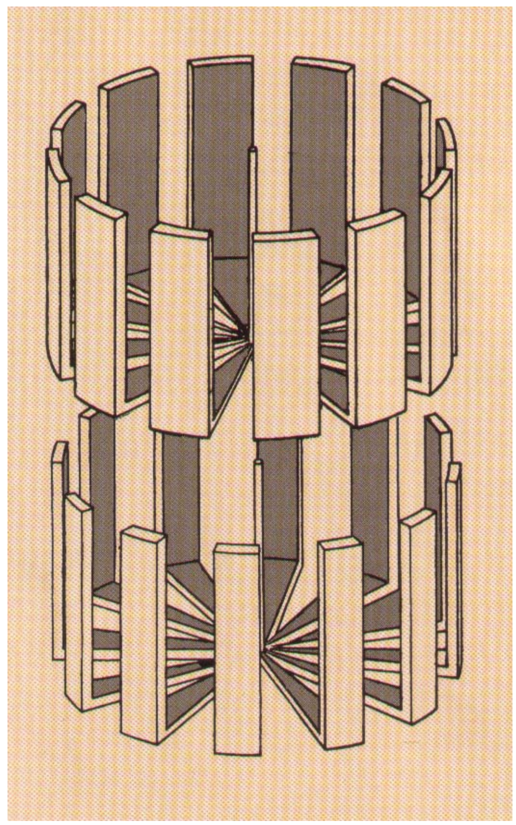
## The Rama Yantra

### Brief Introduction

The Rama Yantra was used to measure both the position of the sun and stars. Unlike the Jai Prakash Yantra, which used a ring as its gnomon, the Rama Yantra used a stick in the center of a flat elevated circular scaled surface as its gnomon. Also, it used only one coordinate measurement system, instead of two. It was based on the horizon and zenith system.

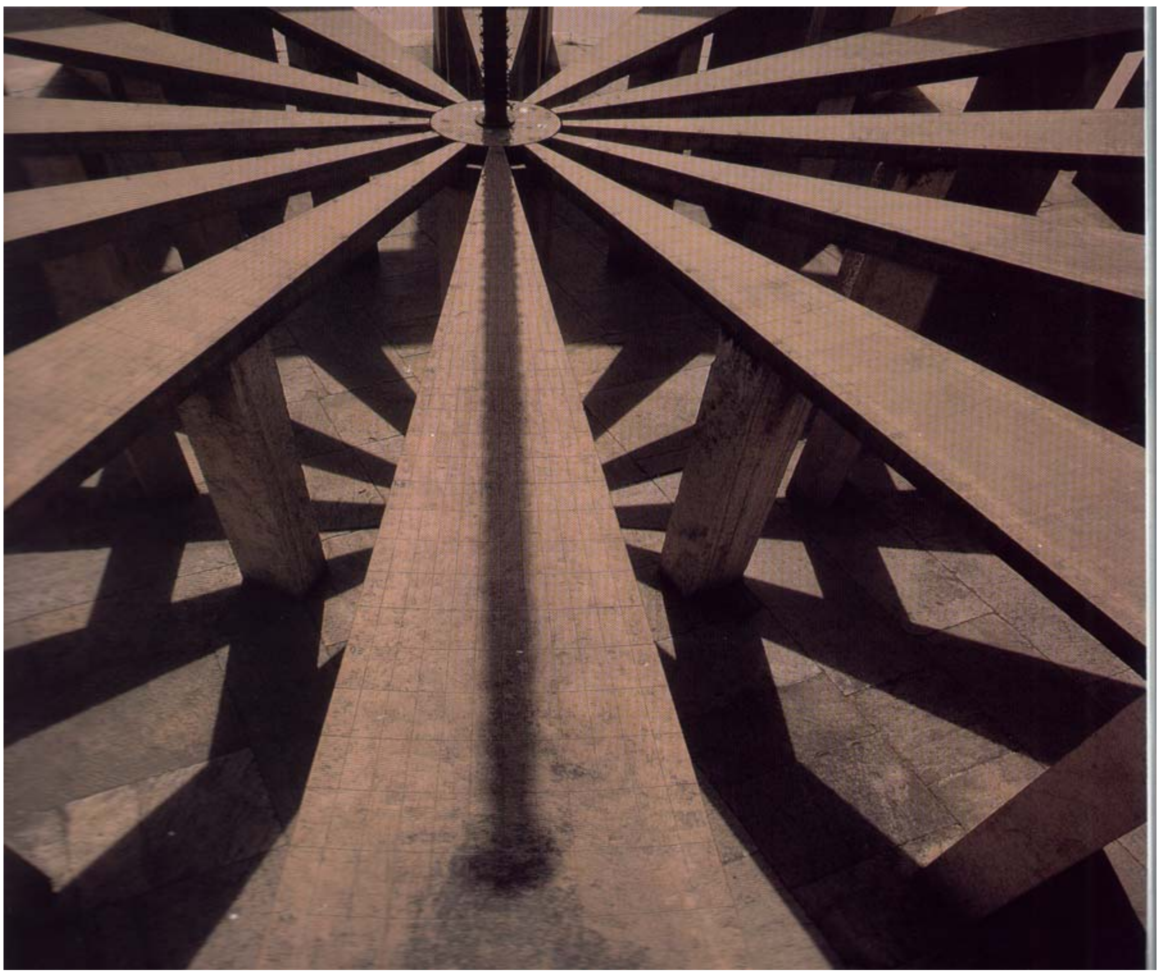
### Description

The Rama Yantra is best described as a large hollow drum with its top end uncovered and a pole erected in the center. Architecturally, it was somewhat like the Jai Prakash Yantra in that the flat circular surface and wall were separated at specific intervals of two different degrees -- twelve and eighteen -- to enable an observer to walk along the scales to make the necessary observations. The alternate pieces (i.e. the eighteen-degree flans) were assembled in another drum. The position of the flans corresponded to each other in such a way that if the drums were slotted together, the alternate pieces of flans would constitute a whole circle. (Picture, left)



### Solar Application

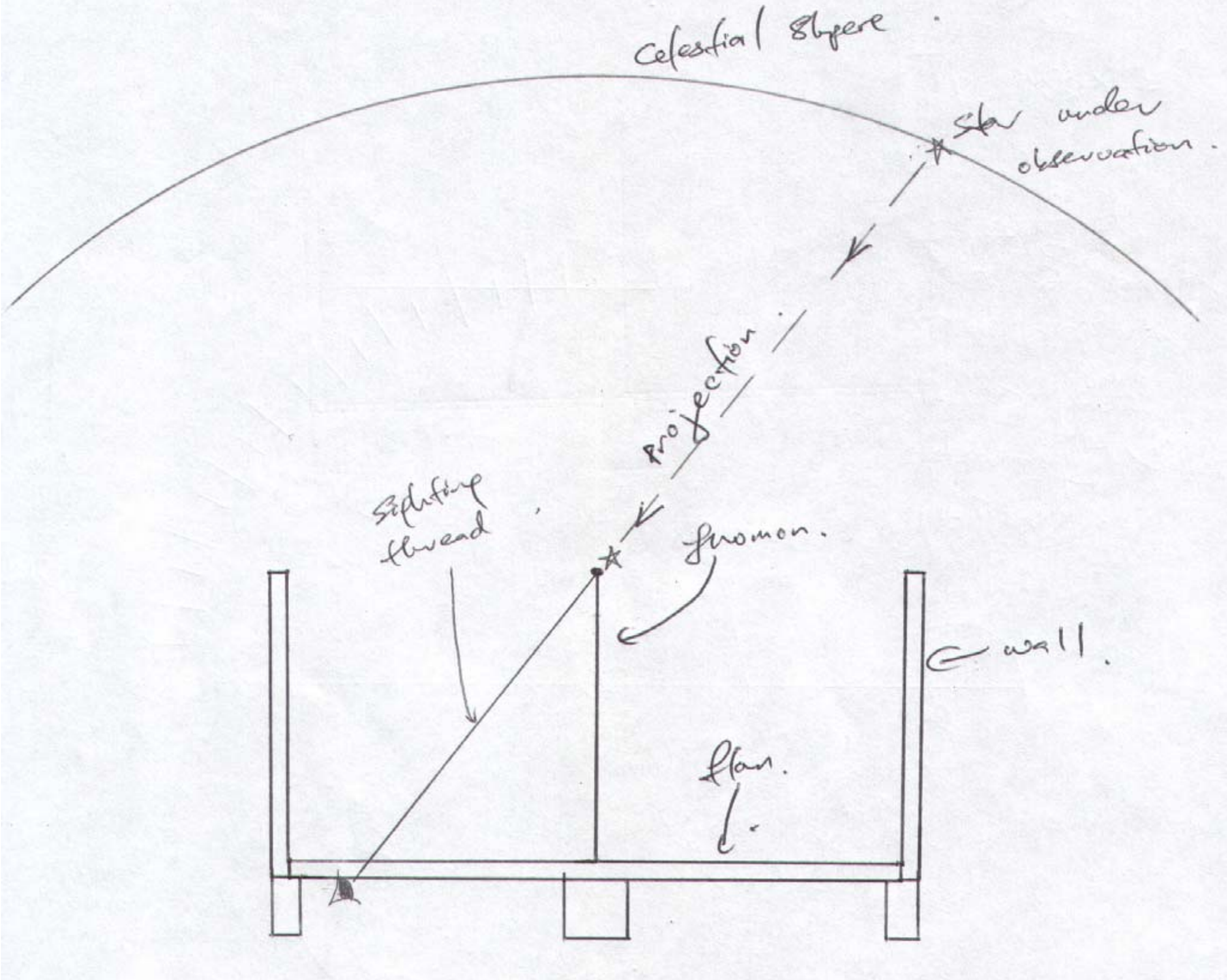
An elevated circular horizontal surface of graduated altitudinal scale radiating from the center was used. A vertical pole was erected at the centre. Azimuthal scale was inscribed around the circumference of the circular and azimuthal lines ran from the scale at the circumference to the center on the circular surface intersecting the altitudinal lines perpendicularly. To take the reading of the position of the sun, the observer walked along the spaces in-between the flans and read directly from the shadow cast by the gnomon onto the circular scale to determine the azimuth and altitude of the sun. Both the corresponding Rama Yantras had to be used interchangeably, i.e. if the shadow of the gnomon fell in the area where there was no scaled flan in one Rama Yantra, the observer had to go to the other corresponding Rama Yantra to get the reading of the sun. Since the flans of were assembled at corresponding intervals in the two Rama Yantras, if the shadow of the gnomon missed the surface of the scaled flan in one of them, it would definitely fall on one of the flans in the other.



**Sidereal Application**

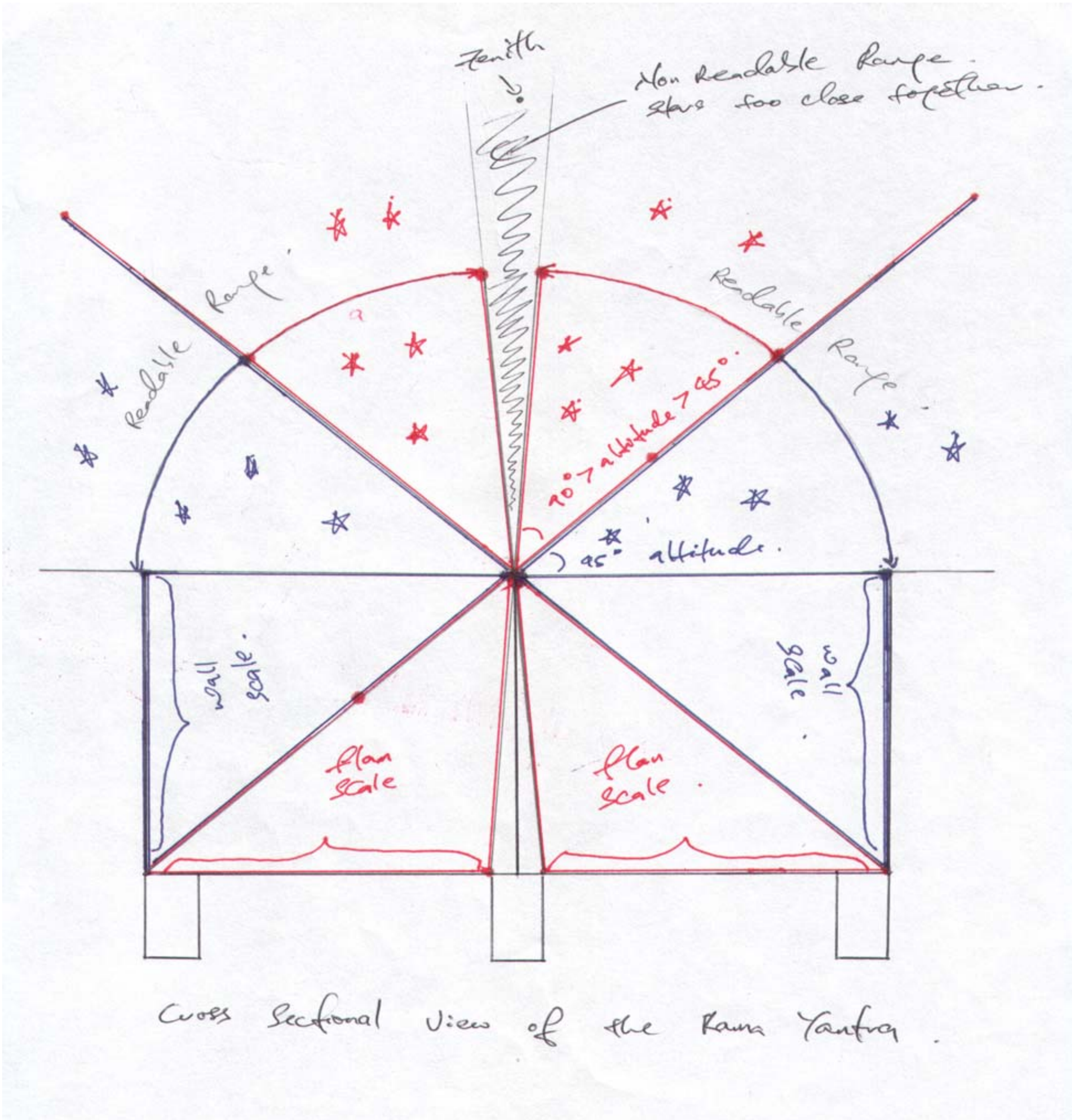
The procedures for making observations of the stars were a little bit more complicated than that of the sun.

To take the readings of a star, the observer had to walk around the Rama Yantra, choose a particular flan such that the star, the top of the gnomon and the edge of the flan were in line with one another. I.e. if the star to be observed was exactly ninety degrees to the right of the gnomon at a particular flan, the observer would have to walk to the flan exactly clockwise ninety degrees to the present flan to align the star with the top of the gnomon. The star being observed would appear such that its position coincided with the top of the gnomon. To make observations easier, a thread was attached to the top of the gnomon so that it could be pulled towards the edge of the flan in use and align with the eye of the observer to serve as a sighting line. (Refer to sketch on following page)



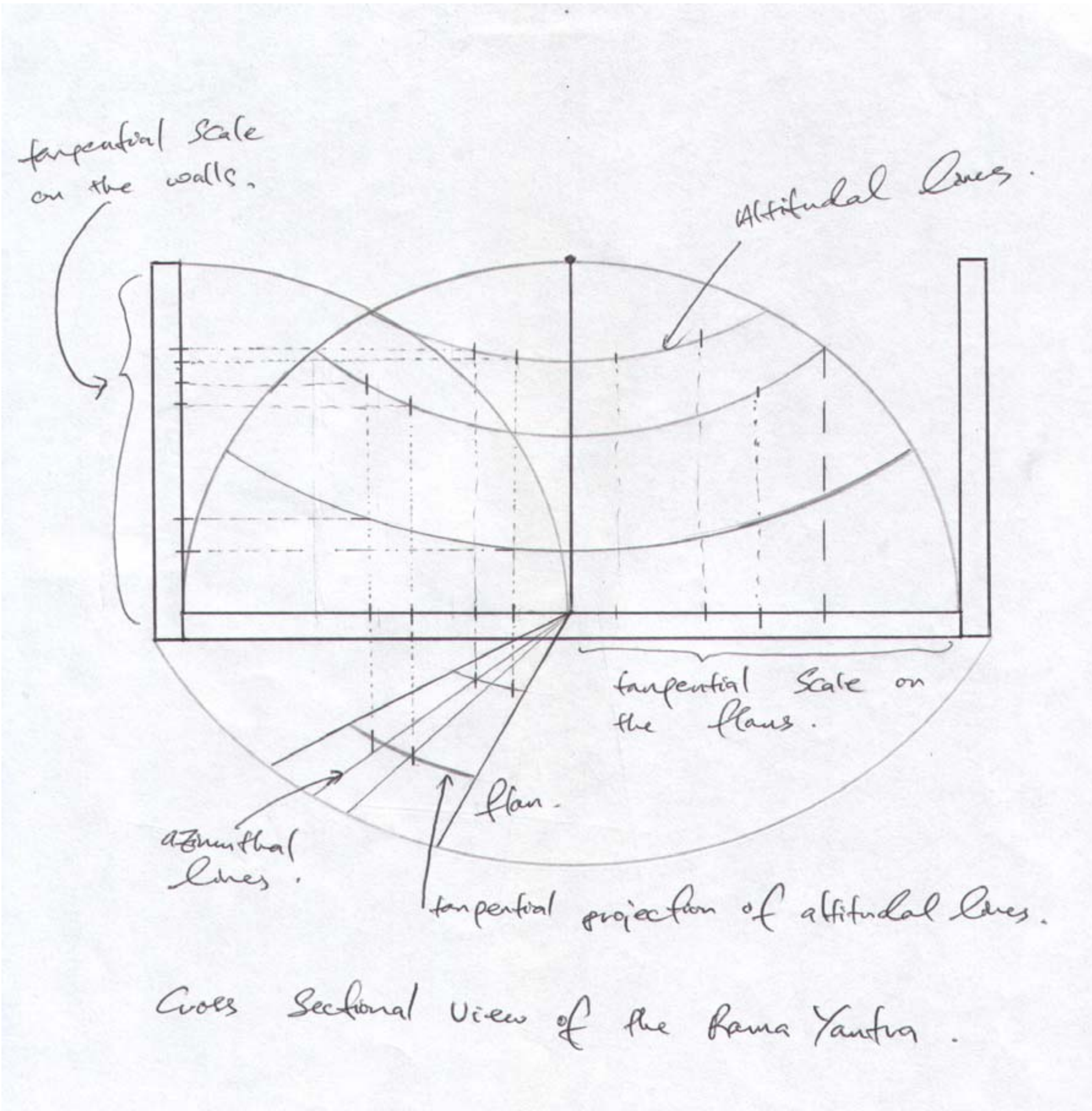

Cross-sectional view of the Rama Yantra.

To avoid having flans which were impossibly long, the architects of the Rama Yantra designed the radius of the flan to be the same length as the gnomon. Thus only stars with altitude up to a minimum of forty five degrees could be measured on the scaled flans. The remaining of the stars with altitude lower than forty five degrees had to be again tangentially projected onto and read off the circular walls which are perpendicular to the flans at the circumferential edge. (Figure on following page)




**The Tangential Scale**

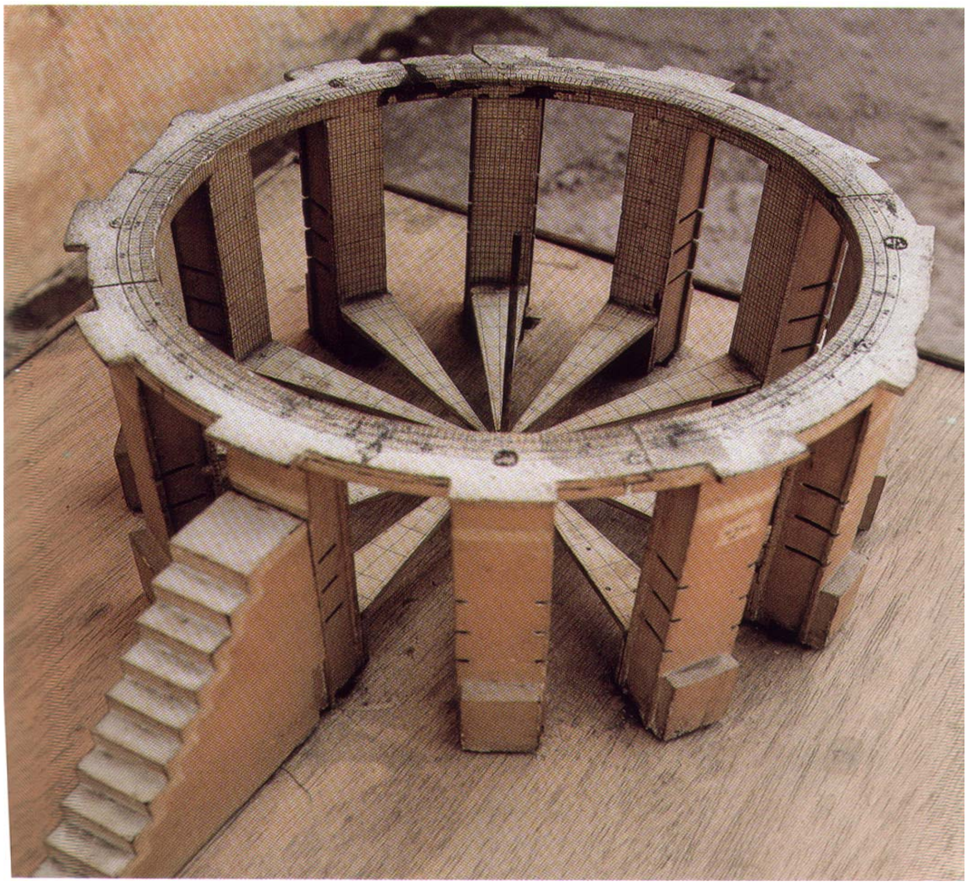
An interesting aspect of the Rama Yantra was how its architects managed to inscribe the concentric circular lines that represent the altitude on to the scale of the flans with such precision. Information on the technique and methods that they use to conduct this seemingly extremely difficult task is rare. However we do know that they used the vertical projection of the celestial sphere on a tangential scale. (Refer to diagram below)

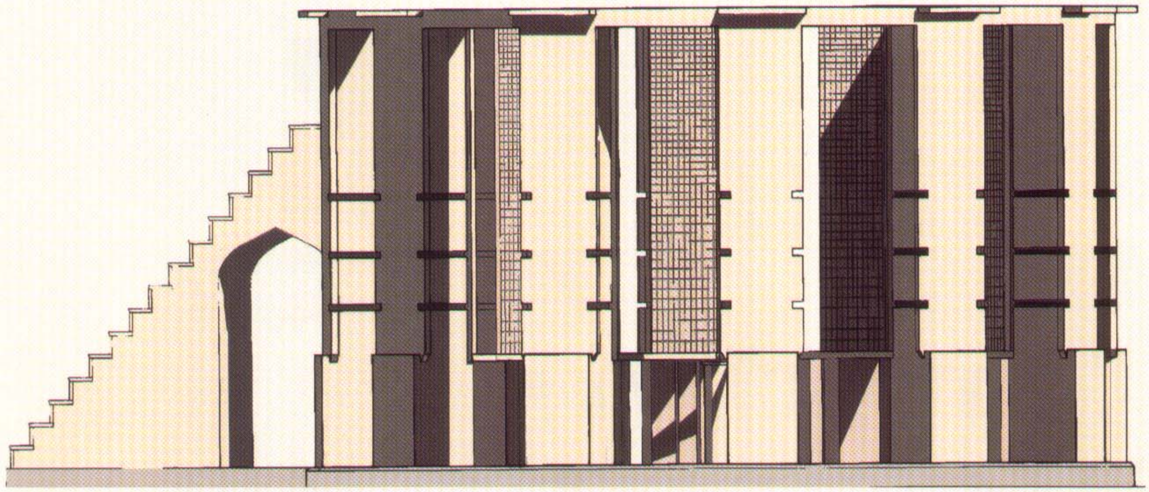



**<u>Limitations of the Rama Yantra</u>**

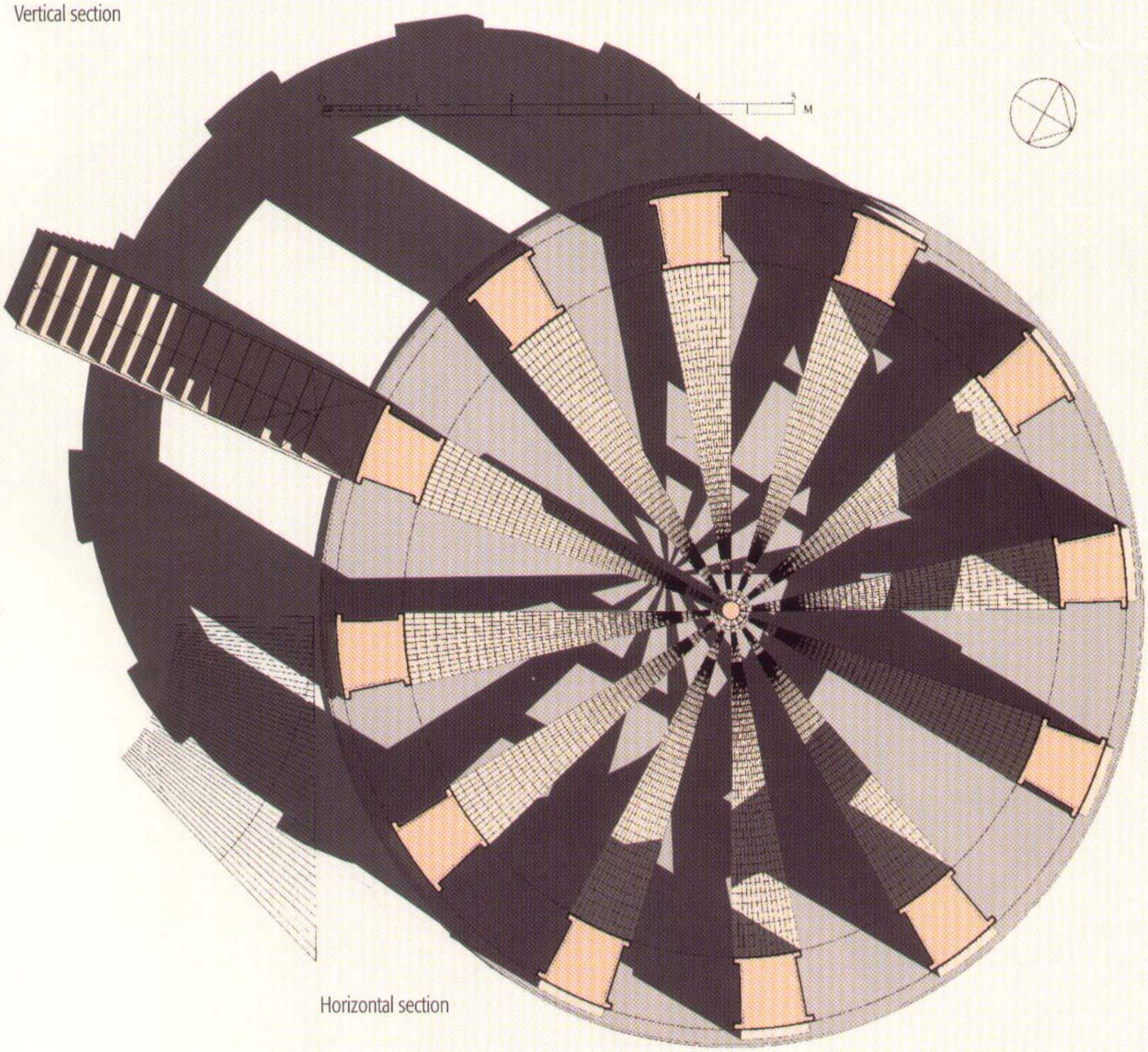
It was difficult to avoid touching intersection while observing two stars at very large altitude using the Rama Yantra, because they would then appear to be very close together -- especially so if both of them were located very close to the zenith, where the gnomon would become a further vision obstacle. However this could be countered by knowing the coordinate measurement of the zenith and making a close estimate of the stars very near to it.

The main problem with the Rama Yantra was that it was only possible to observe a star off the edges of the scaled flans when it had completed twelve or eighteen degrees of its orbit. To counter this shortcoming, the astronomers were made to design an extension the Digamsa Yantra.





Vertical section



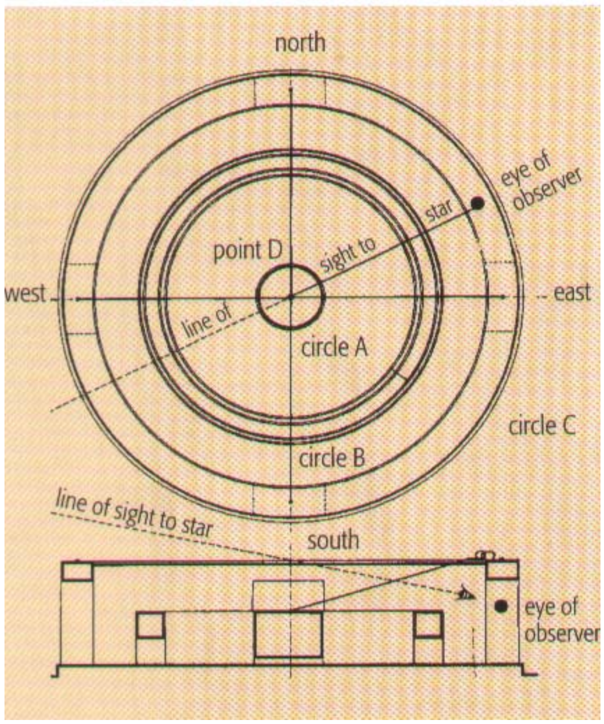
Horizontal section

## The Digamsa Yantra

### Introduction

The design and function system of the Digamsa Yantra was relatively less complex than the Jai Prakash and Rama Yantras. The only purpose it was built was to provide accurate azimuthal readings to complement the Rama Yantra.

## Description



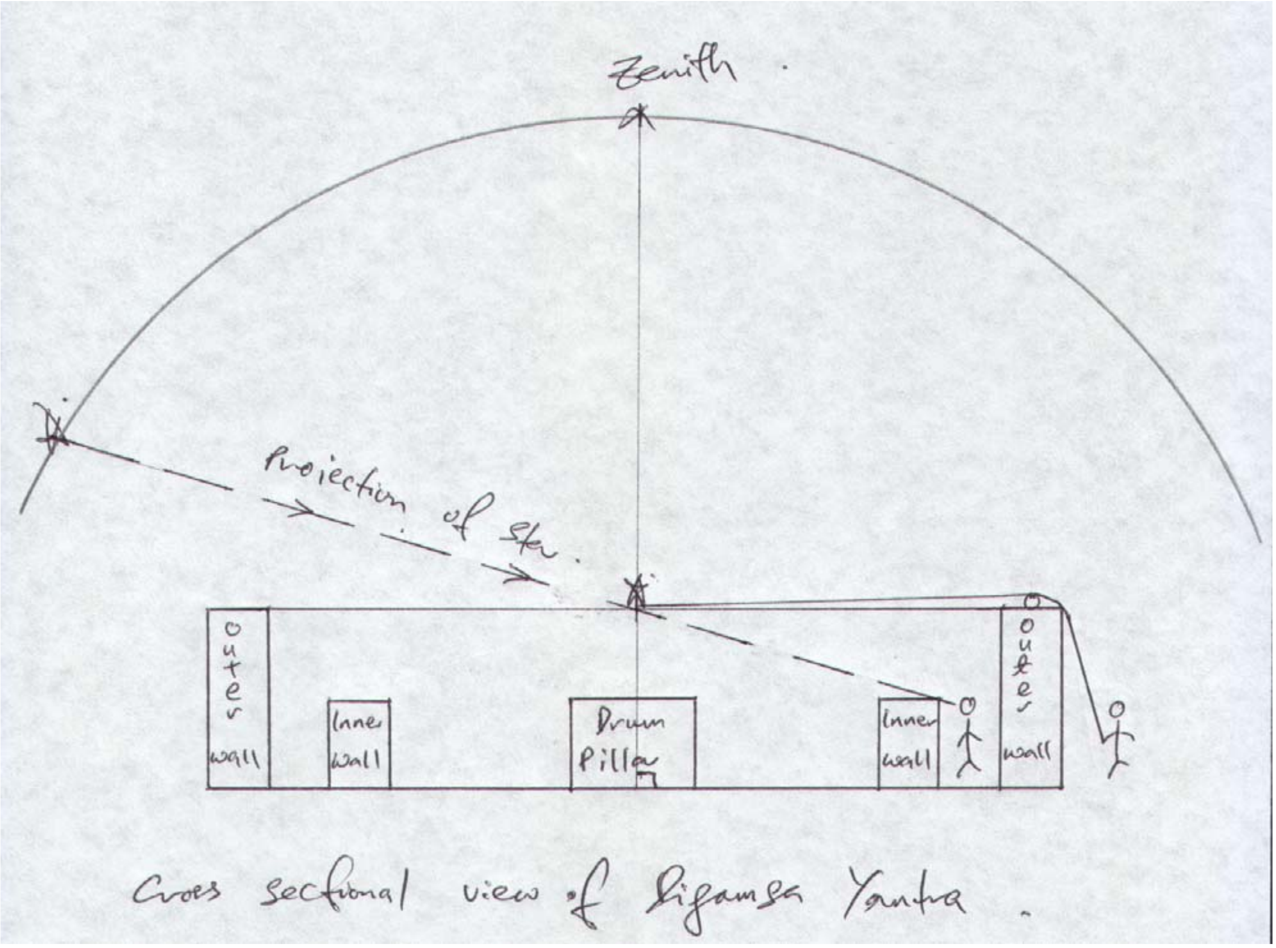

The Digamsa Yantra was structured on a horizontal plane. It was basically made up of one solid drum-like pillar right in the center with two circular walls surrounding the center pillar subsequently. The height of the first (inner) circular wall was similar to the height of the center pillar and the height of the second (outer) circular wall was double the height of the center pillar and first circular wall.

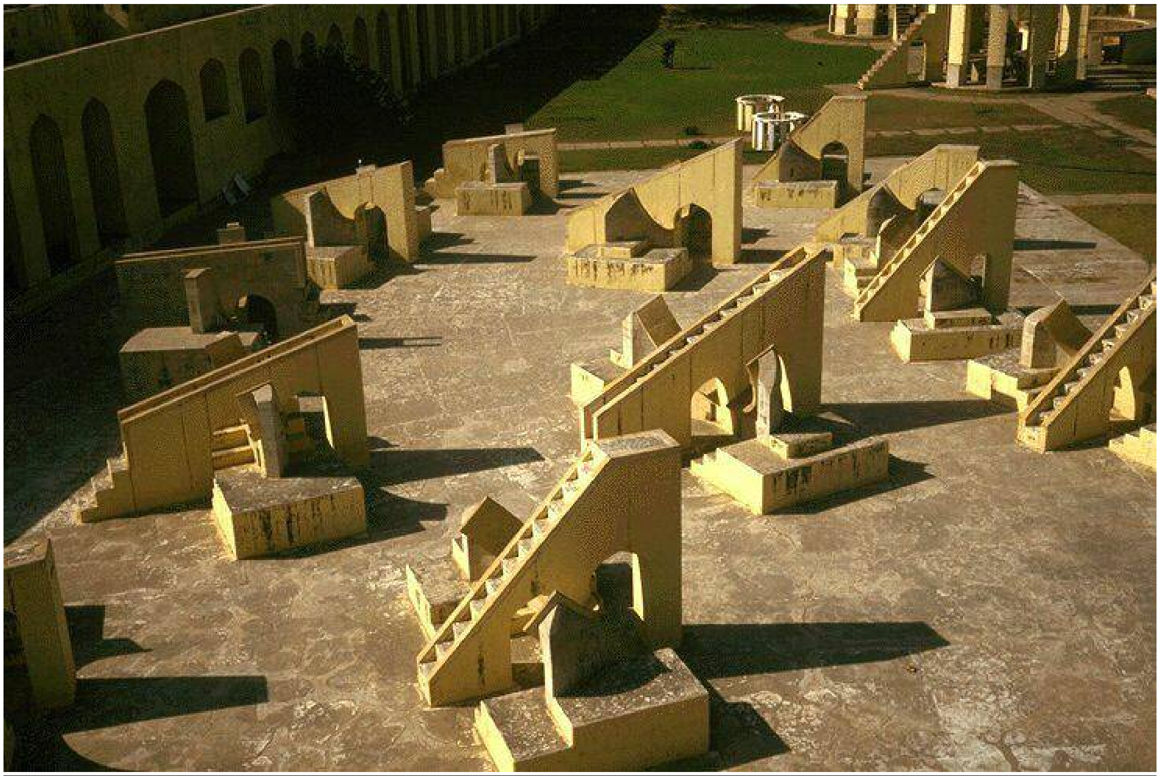
The top of each of the pillar and circular walls are separate pieces of marble slabs, crafted with precision to fit the circular surface shape of the pillar or wall that it is mounted on, with continuous azimuthal scales engraved.

Two wires were suspended on top the second circular wall from the north to south and east to west points respectively. The intersection point of these two wires was directly above the exact center of the center pillar which was in line with the zenith. A sighting thread was fixed to the intersection point of the two wires for functioning purposes.

## **Function**

The observer stands between the first and second wall with his assistant standing at the other (outer) side of the second wall. The observer moves along the passageway in between the first and second wall until the star under observation aligns with the intersection point of the wires. The observer's assistant moves simultaneously with him, pulling the sighting thread that is hung over the top of the outer wall along the azimuthal scale until the position where the star being observed, the intersection point of the wires and the sighting thread are in line with one another. (Sketch below)

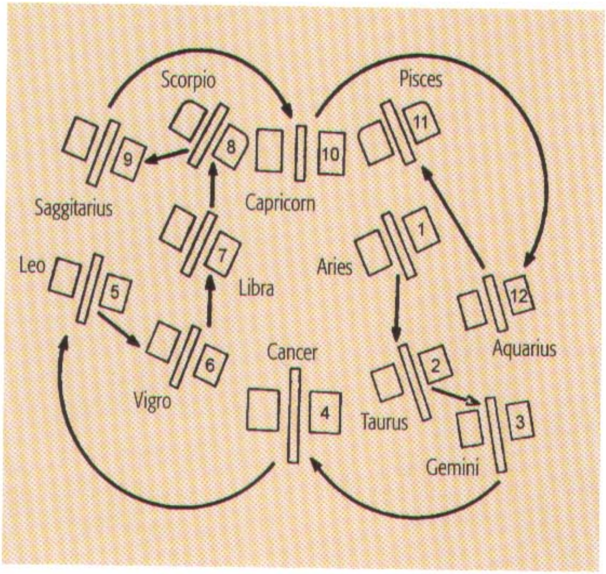


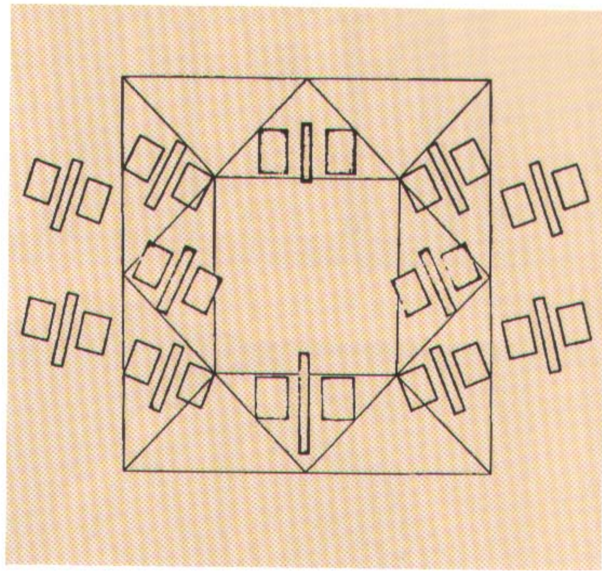


## The Rashi Valaya Yantras

### Description

As mentioned above, the manner in which the Rashi Valaya Yantras were constructed was similar to the Samrat Yantra. However, the slope of the gnomon of each of the twelve Rashi Valaya Yantras varied with respect to the horizon and pointed in different directions.
The twelve Rashi Valaya Yantras were intended to be built symmetrically on a platform that represents the horizon. However, the symmetry was somewhat broken to an extent by the positions of the Aquarius and Gemini Yantras which were shifted a southward with respect to the Sagittarius and Leo Yantras at the other and of the symmetrical formation. Save in the pictures below.



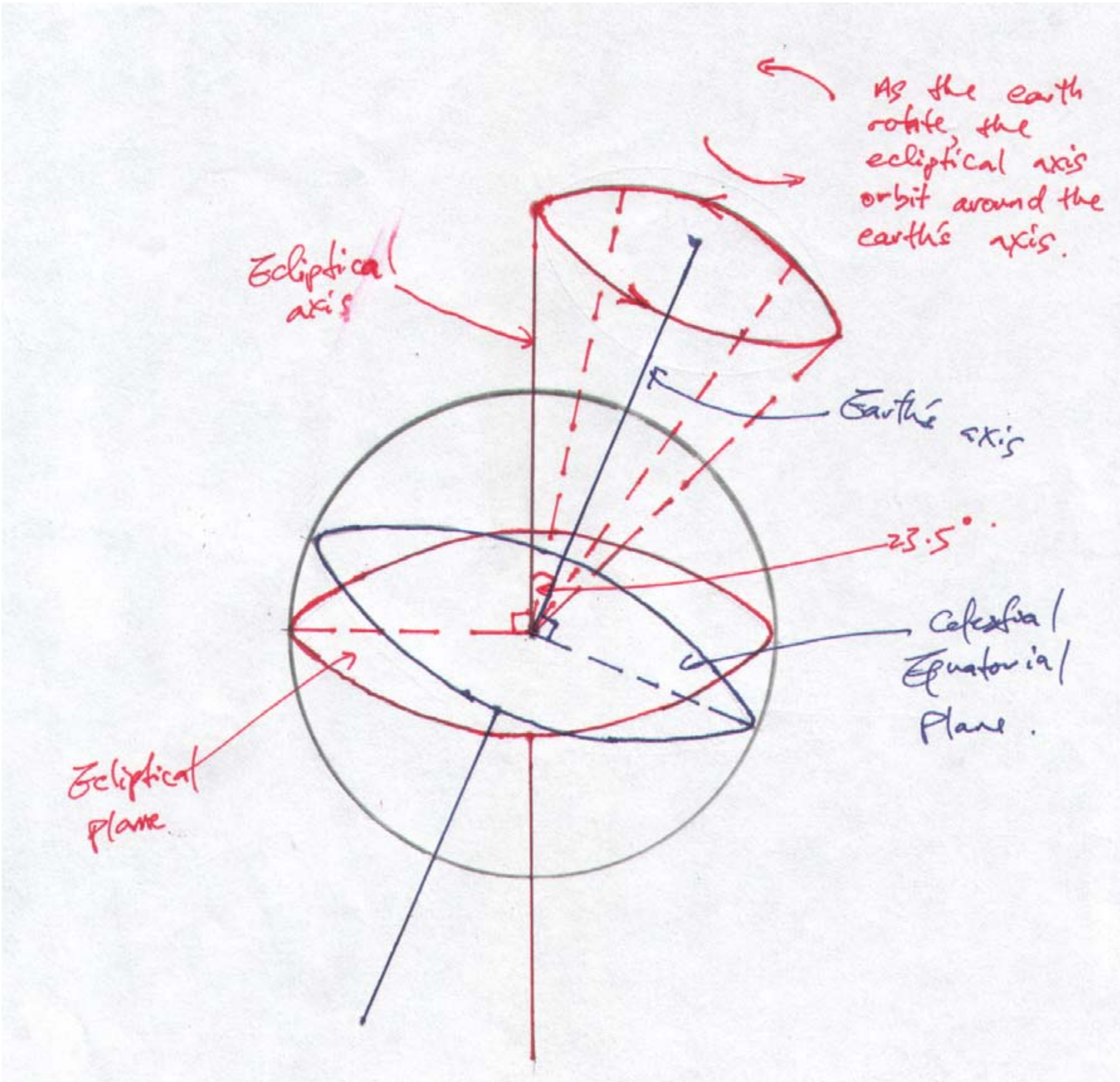


The main cause for this breakage in symmetry is the existence of a building not shown in the map of the observatory. The difference between in the orientation of the courtyard walls which was aligned to the rectilinear street plan and the orientations of the instruments which were aligned to the four compass points as mentioned earlier, made it impossible to extend the platform in such a way to achieve perfect symmetry of the instruments. This suggests that the obstructing building was built before the twelve Rashi Valaya Yantras.

**<u>Function</u>**

We begin by defining the ecliptic path which is the apparent yearly path of the sun amongst the stars. The ecliptic path is circular and is tilted 23.5 degrees to the Earth’s celestial equator.

The ecliptical axis is perpendicular to the ecliptical plane. This means it is tilted 23.5 degrees with respect to the earth’s axis that is perpendicular to the celestial equator. Hence, as the earth rotates around its axis, the ecliptical axis actually orbits around the earth’s axis. The sketch on the following page illustrates.




The basic concept of the function of the Rashi Valaya Yantras is this:
It takes the sun one solar year to complete one revolution along its ecliptic path. The positions of the twelve zodiac constellations on the celestial sphere are fixed. As the sun moves through the months, its position amongst the stars changes. In other words, the position of the sun amongst the stars changes in time length of roughly one month as shown in the picture below.

However to the observer on earth, there will be six of the twelve zodiac constellations the in the sky during the day at any particular month of the year which he cannot see due to the illumination of the sun and with the other six on the other side of the earth which he can see at night when the sun goes below the horizon. As the sun moves along its diurnal path, its position appears to change amongst the six zodiac constellations during the course of the day. The Rashi Valaya Yantras were actually used to tell which zodiac star the sun was at, or, more specifically, the relative position of the sun with respect to the position of the six zodiac constellations during its diurnal journey across the sky, hence determining its ecliptical longitude and latitude.

Recall earlier that we mentioned that the ecliptical axis actually makes an orbit around the earth's axis as the earth rotates. The slopes of the gnomon of the twelve Rashi Valaya Yantras were designed such that as the earth rotates, during some point of time in the day, the slope of one of the gnomon of one of the six relevant Rashi Valaya Yantras (depending on the month of the year) would be approximately parallel to the ecliptical axis momentarily during the day In other words, the function of the Rashi Valaya Yantras actually depended on dynamics of the rotation of the earth and the orbit of the ecliptic axis around the earth's axis. When this happened, the sun would be in such a position directly above the corresponding Rashi Valaya Yantra that very little or no shadow would appear to the left or right wing of it and the sun would be approximately in the position of the corresponding zodiac constellation of this particular Rashi.

# SECTION IV

## The Other Observatories

Jai Singh built an observatory at whichever city he was posted as governor. In all, he built other observatories at 3 other strategically important cities namely Varanasi, Ujjain and Mathura. From a different perspective, contrary to his claims of allowing anyone who was interested in making their own observations and promoting interest in astronomy, it seems instead that the Astronomical Observatory had become one of the prominent symbols of his dominance.

The observatories built following Delhi and Jaipur contain all the essential instruments used to record the motion, speed and properties of various stars and planets and other cosmic objects. However, the instruments are in much smaller proportions compared to the ones at Delhi and Jaipur.

It was Jai Singh's extensive building program involving extensive capital and manpower that eventually invoked the displeasure of Emperor Muhammad Shah. Though the Emperor was reliant on Jai Singh as his important ally, huge and magnificent buildings and monuments at the Mughal times were a symbol and indication of their supremacy in India. The Mughal emperor simply could not accept that Jai Singh was flaunting his political influence with massive construction projects.

It was then unsurprising that the Emperor Muhammad Shah felt such unease that he banned Jai Singh from his court. Jai Singh, in response and under pressure, eventually resigned his governor post at Malwa in 1734 A.D. to give way to the Peshwa.

## Conclusion

Jai Singh's commendable contributions in building the observatories and magnificent instruments earned him the reputation as a great builder and an astronomer king. Though perhaps Jai Singh may have had noble intentions of creating a renaissance in astronomy in India, his real intentions are still in doubt.

Firstly, Jai Singh knew that he could obtain accurate data from smaller instruments such as the telescope but was determined to erect huge observatories that exhausted not only manpower but also government assets.

Secondly, Jai Singh could have channelled his energy to improving existing instruments, but he never harboured intentions of doing so.

The reason why Jai Singh built these large fixed instruments and omitted optical devices had more to do with Hindu philosophy than astronomy. Through these astronomical structures, which were visible from great distances, Jai Singh was proclaiming his worldly power. Construction of massive instruments aimed at unravelling the facts of the cosmic world in the name of Science and welfare of the Empire undoubtedly gave Jai Singh an excellent opportunity to declare his heavenly relationship with the gods and his powers without having to resort to conventional political means like warfare.

In all, irrespective of whatever intentions he might have had, Jai Singh was a capable and intelligent individual who certainly visibly made efforts to promote astronomy on a large scale. Sad to say, his vision of a renaissance in astronomy in India never took off due to the political unrest in the country.

Though regrettably little is known on the details of construction of the observatories as well Jaipur city, we may however, put the possibility on Indian slaves and the prisoners of war in India at that time.

Jai Singh was regarded as an astronomer ruler who played a key role to promote a connection between Indian astronomy, the ancient cosmic world and the new scientific order. He is still much respected by people in India for his contributions. His astrological tables in Zij Muhammad Shahi still serves to this day as a reference to the lay and learned alike.

# ENDNOTE

One of the main obstacles that we faced in coming up with this report was the lack of information on how the instruments work. The main reference for this report (Cosmic Architecture in India, A. Volwahsen) focused on architecture and hence provided only vague descriptions of the actual operations of the Jantar Mantars. The major portion thus had to come from lengthy brainstorming sessions and logical and visual reasoning based on the application of the concepts learnt in the course. And of course, with a little touch of creativity and imagination!

But we've come out with a profound insight into the Jantar Mantar, and more relevantly, a deep understanding of astronomical principles and concepts. One of the issues that struck us was how people from 300 years ago managed to identify these concepts and build instruments based on them to find out more. These are the same concepts we are being taught today, presented neatly in lectures and properly-typed notes. In this multi-vitamin type package, it's difficult as it is, so we can imagine the brilliance required for someone in the 18th Century to figure it out!

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Scanned photographs obtained from *Cosmic Architecture in India, A. Volwahsen, 2001*
All other diagrams, handwritten or otherwise, are original.

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