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The Astronomical Endeavours of Sawai Jai Singh

IDC School of Design अभिकल्प विद्यालय

Front

The Astronomical Endeavours of Sawai Jai Singh

A book on the journey behind the Jantar Mantar observatories


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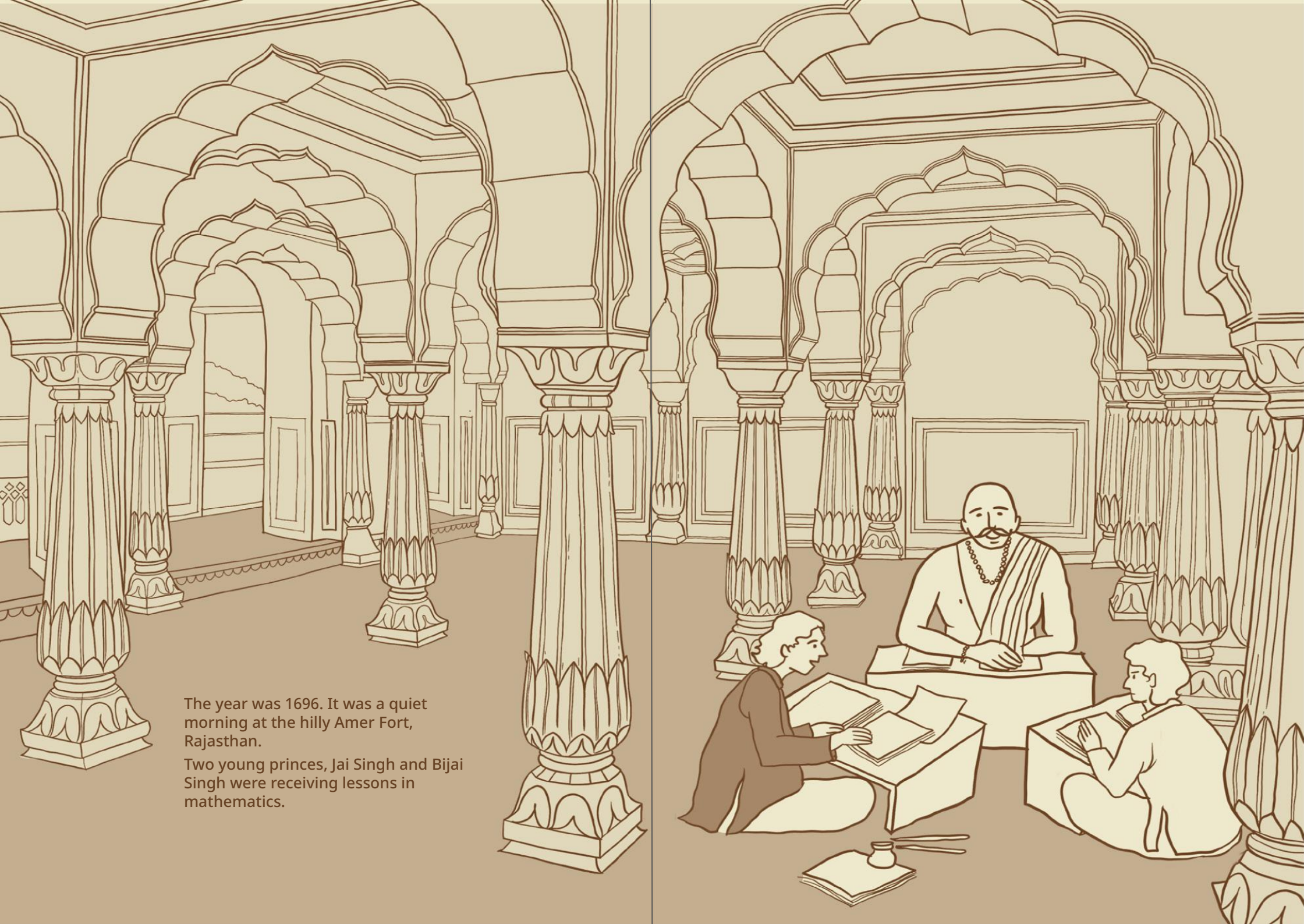
The Astronomical Endeavours of Sawai Jai Singh

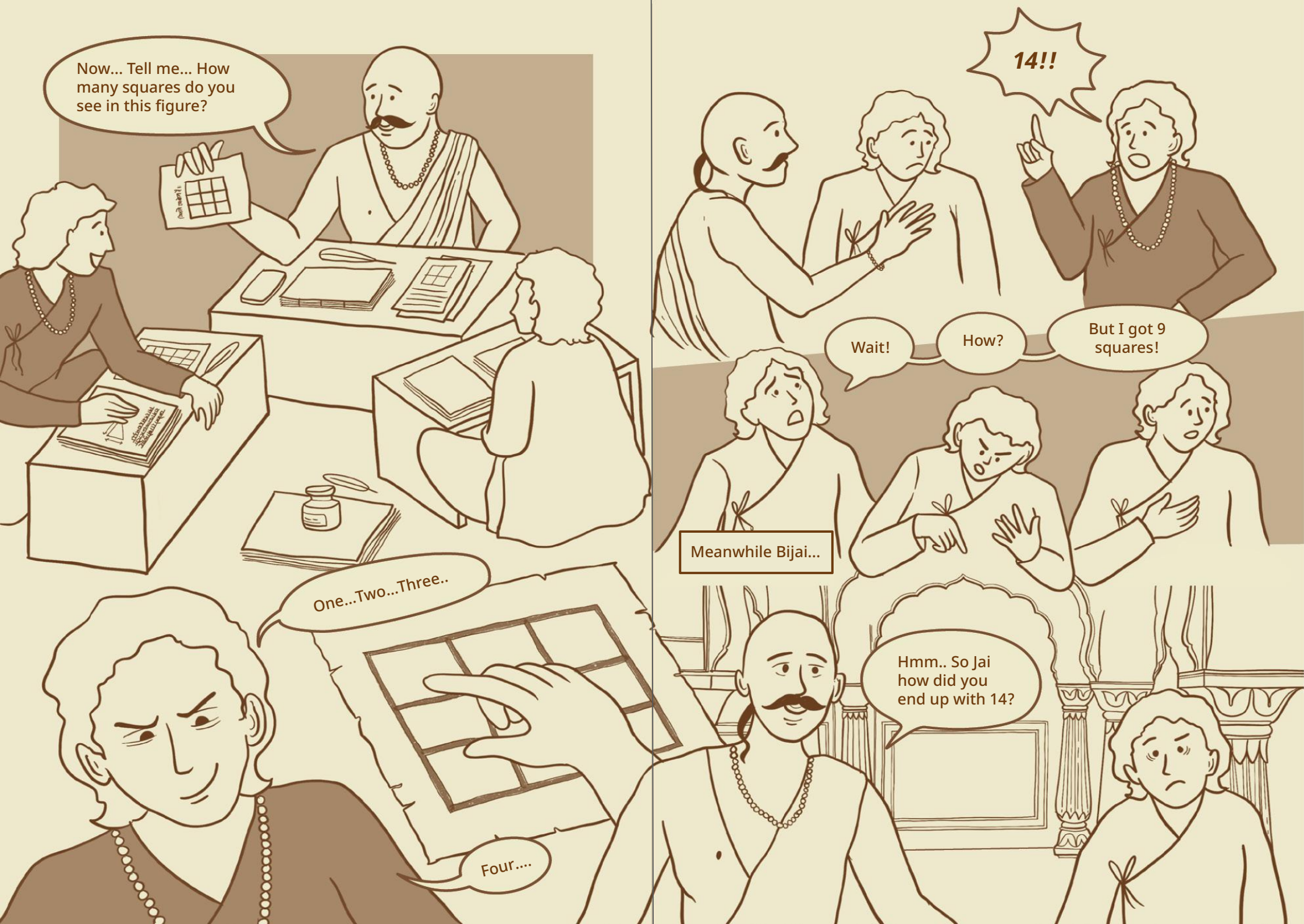
Chapter I

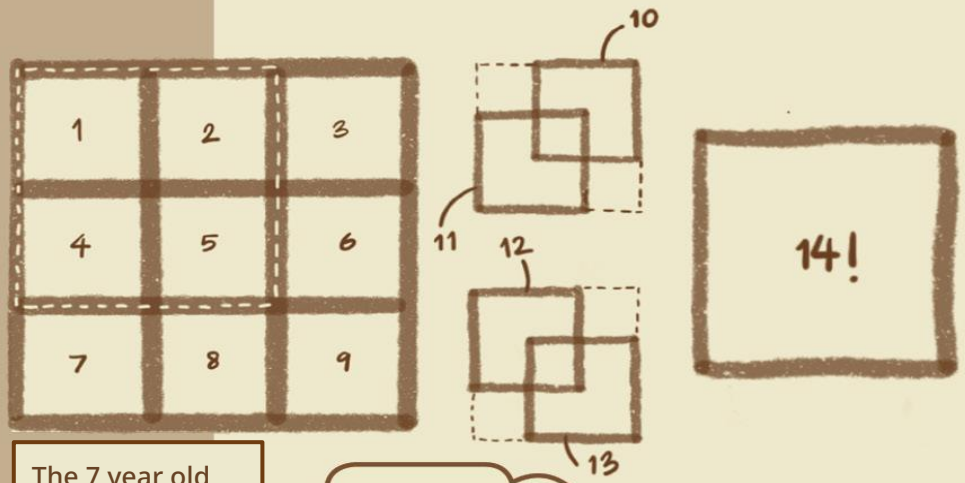
The Birth of a Curious Mind



The year was 1696. It was a quiet morning at the hilly Amer Fort, Rajasthan.

Two young princes, Jai Singh and Bijai Singh were receiving lessons in mathematics.


Now... Tell me... How many squares do you see in this figure?
One...Two...Three..
Four....
14!!
Wait!
How?
But I got 9 squares!
Meanwhile Bijai...
Hmm.. So Jai how did you end up with 14?



The 7 year old Jai Singh chirps..

Firstly I saw the 9 individual squares!

Secondly, there were slightly bigger squares starting from each vertex. So, 10..11..12..13

And lastly, the biggest square encompassing all others, 14!!

Well done Chimnaji Sahib*, once again.

Now it's time to solve the next pr...

Meanwhile distant figures appear in the pavilion...

*Jai Singh was also called by the name Chimnaji Sahib

Forgive me, for interrupting your lessons with the boys.

Oh not at all Maharaj, I am deeply honoured to have you grace us with your presence.

I hope the boys are doing well..

Absolutely Maharaj, and especially Jai shows a wonderful aptitude for maths!

It’s wonderful to see you both do well, but unfortunately the state needs us right now.

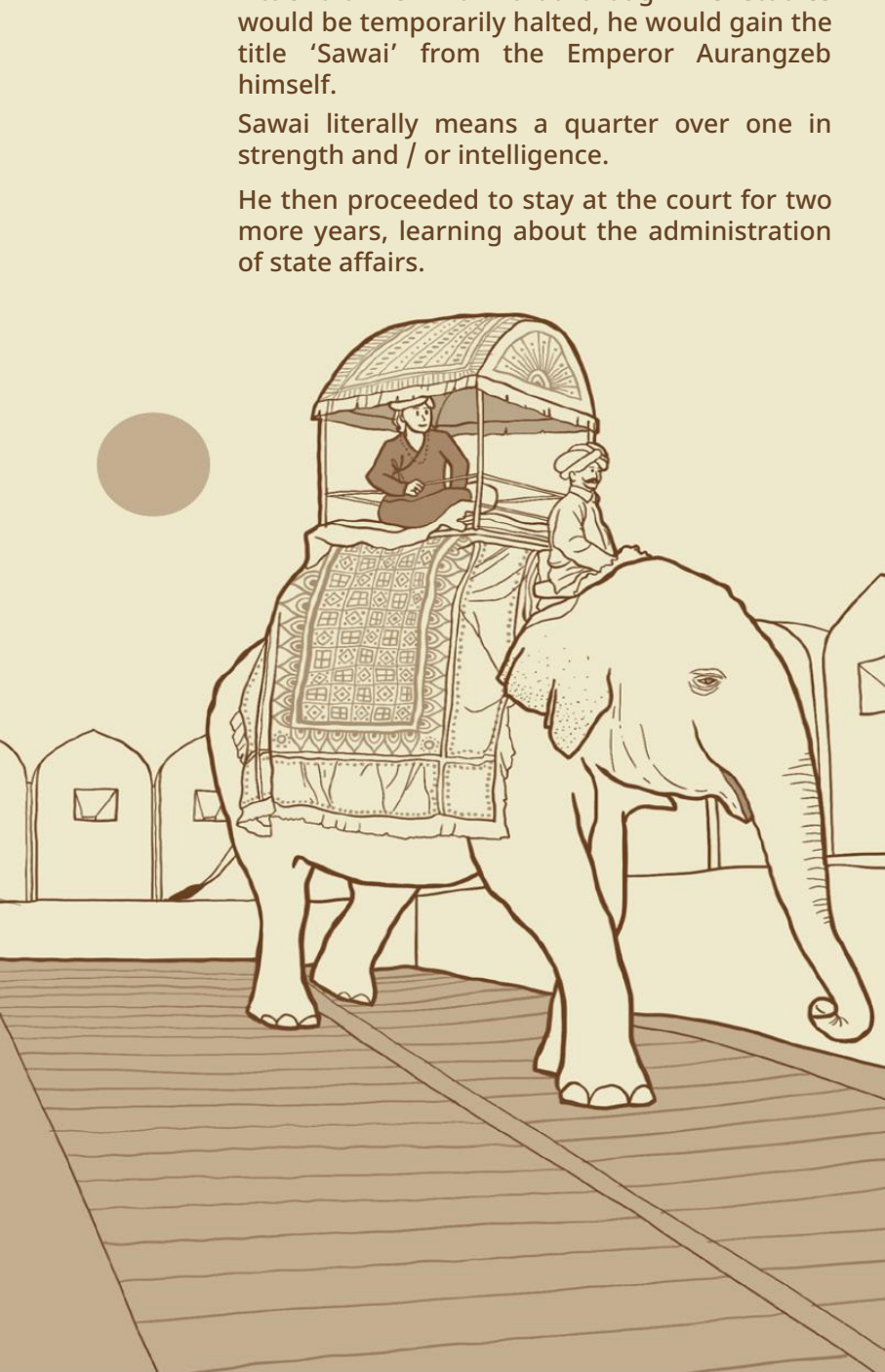
Jai... you must visit the Emperor’s Court, for he orders an audience with the Kachhwahas.

Yes Father.

The obedient prince, at once set for the Court. Little did he know that though his studies would be temporarily halted, he would gain the title ‘Sawai’ from the Emperor Aurangzeb himself.

Sawai literally means a quarter over one in strength and / or intelligence.

He then proceeded to stay at the court for two more years, learning about the administration of state affairs.



On returning home in 1698, he resumed his studies. As a Rajput Prince he was trained in multiple aspects. Cultural Arts, Literature, Martial Arts, and so much more...

He learnt languages like Dingal, Sanskrit, and Persian, as well as Arabic and Turki.

Horse-riding...

Sword Fighting...

And archery were a must for any Rajput Prince.

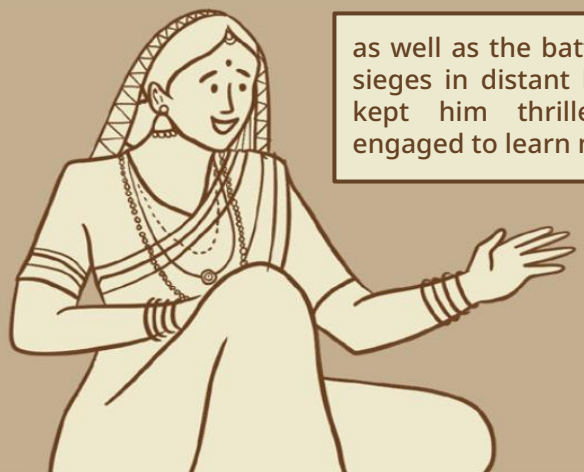
In 1698, their father, Bishan Singh was posted in Kabul, so Jai would write letters to keep him updated on their progress.

Matters of the state, the position of crops, the water levels in the state, all matters were informed to the King.

In return, his father would keep them updated with the developments in Kabul with the Mughal Empire.

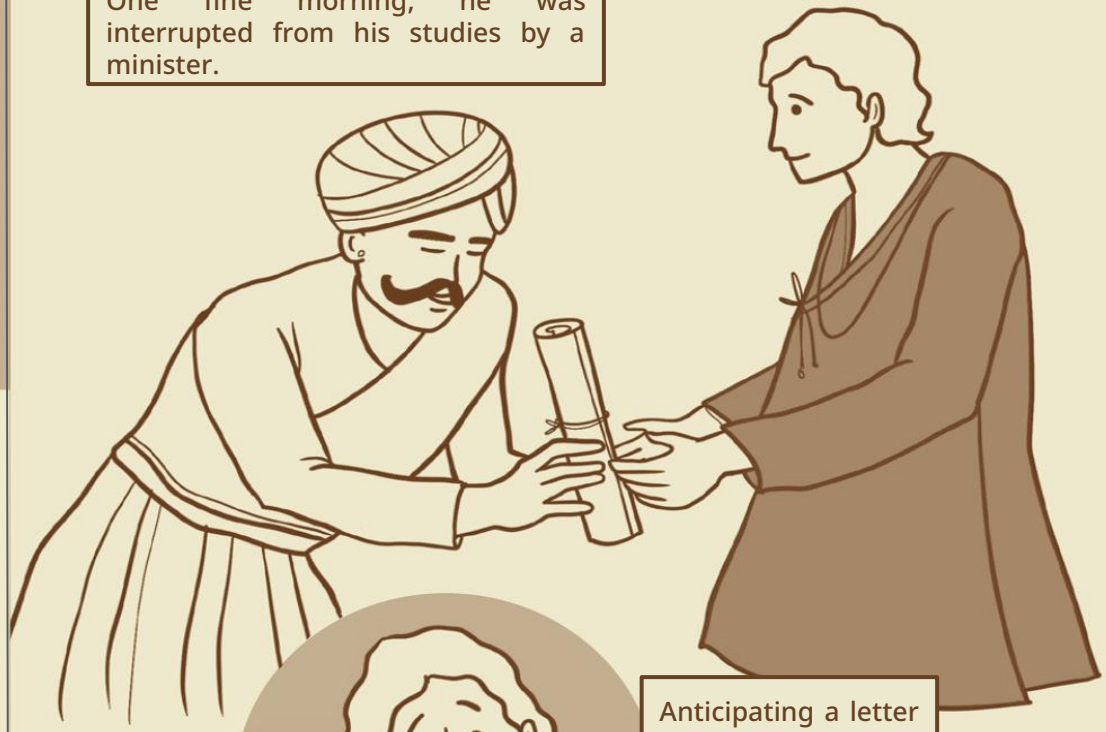
Jai Singh continued his studies under the care of his mother and learned tutors.

The stories of his ancestors, incidents of the Mughal Court, the numerous Emperors & their Begums and princes,



as well as the battles & sieges in distant lands, kept him thrilled & engaged to learn more.

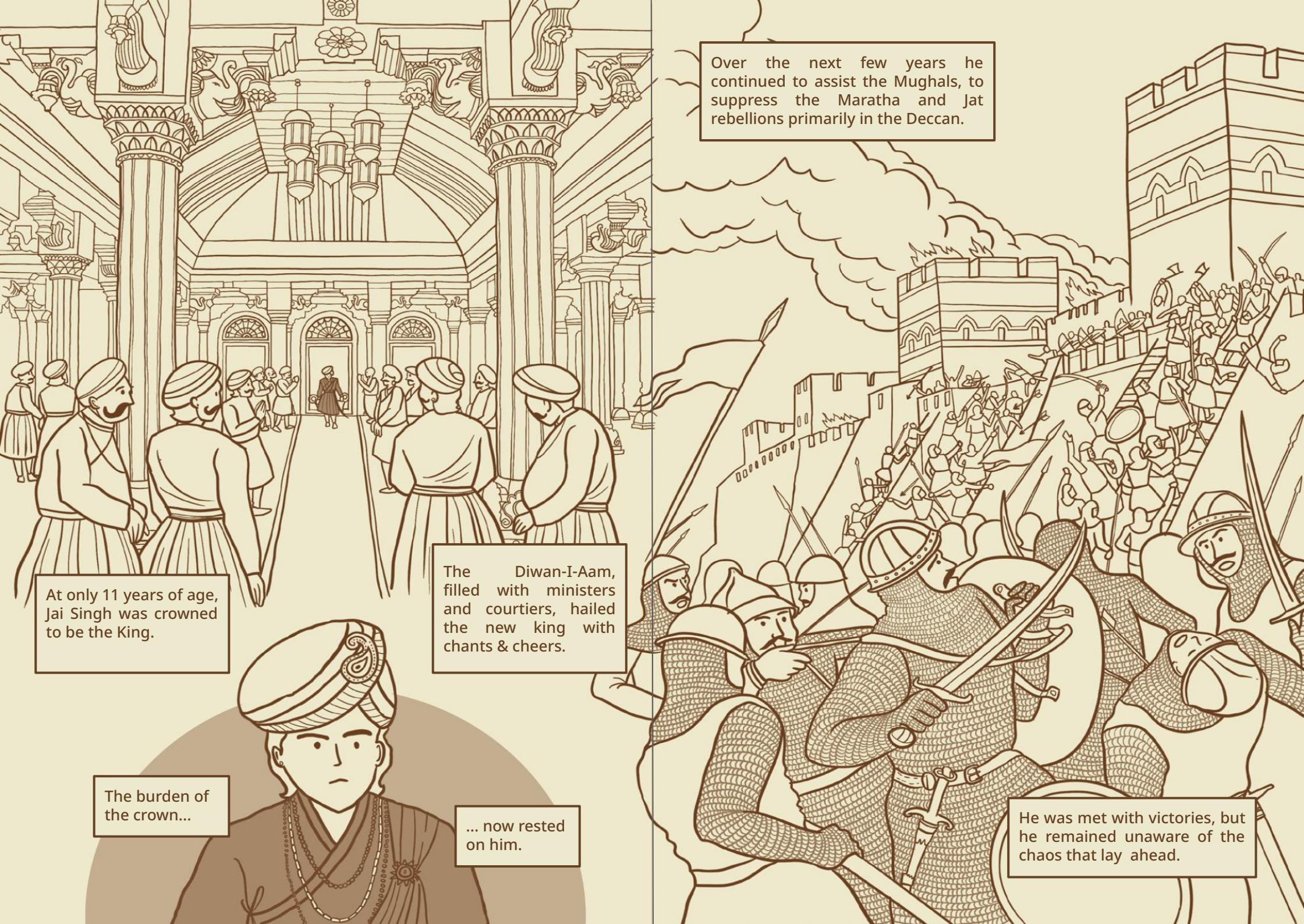
One fine morning, he was interrupted from his studies by a minister.



Anticipating a letter from his father, he promptly started to read it.

But alas...

The letter carried the news of his father's death...


At only 11 years of age, Jai Singh was crowned to be the King.
The Diwan-I-Aam, filled with ministers and courtiers, hailed the new king with chants & cheers.
The burden of the crown...
... now rested on him.
Over the next few years he continued to assist the Mughals, to suppress the Maratha and Jat rebellions primarily in the Deccan.
He was met with victories, but he remained unaware of the chaos that lay ahead.

With the death of Aurangzeb in 1707,

a terrible war of succession broke out between the three sons, Bahadur Shah, Azam Shah and Kam Baksh.

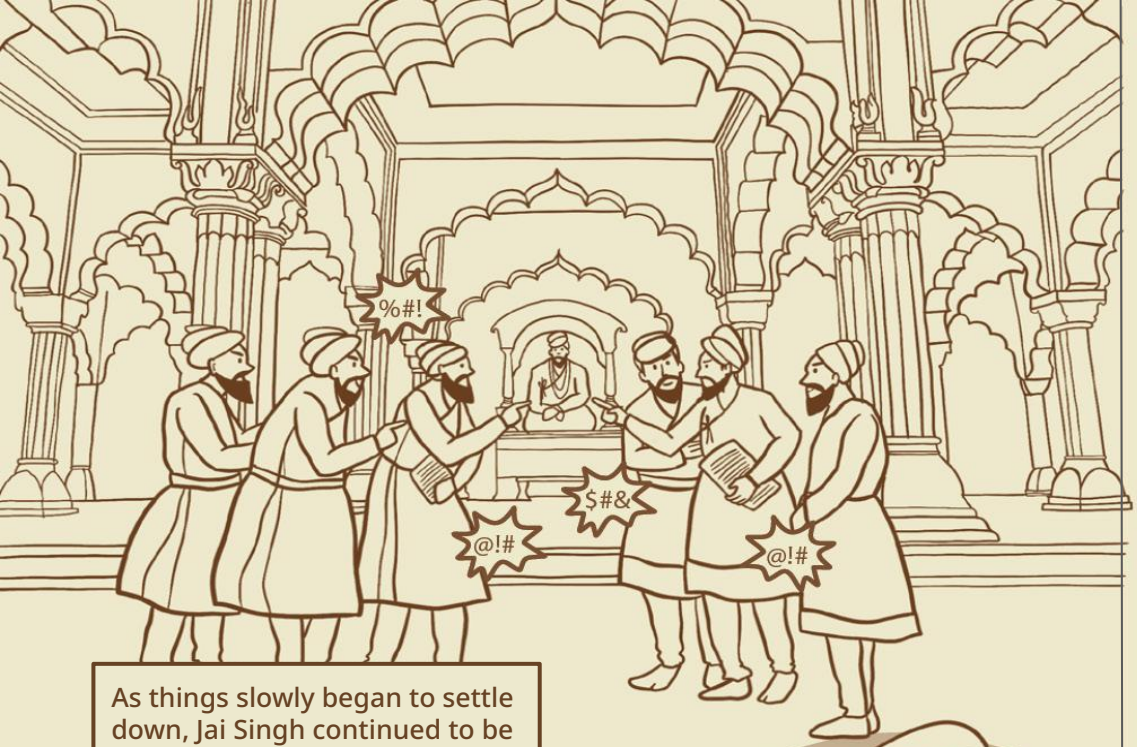
The bloody battles resulted in Bahadur Shah acquiring the Mughal throne.

He then forgave Jai Singh and other rulers who sided with his opponents.

But his policy towards the Rajputs did not reflect that.

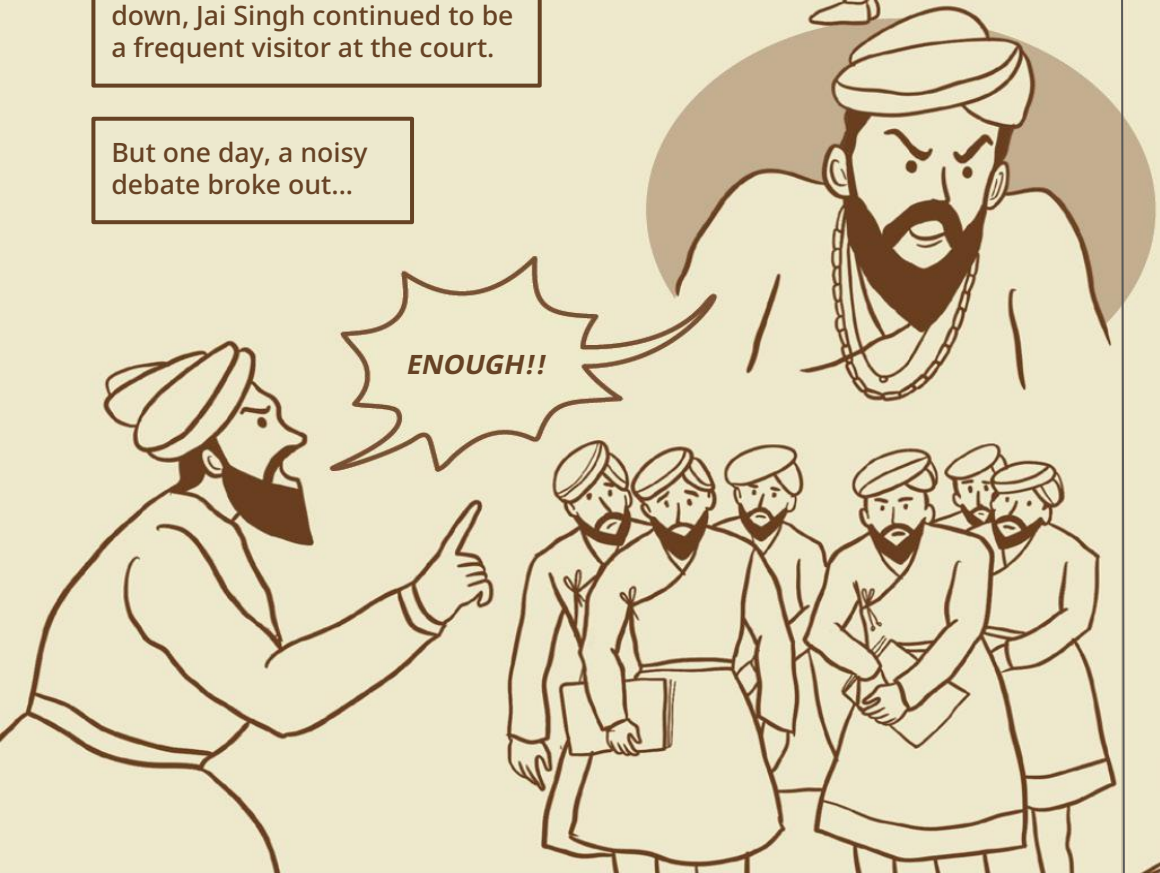
He soon ordered the Fort of Amber to be taken under Khalisa.

Jai Singh, his mother and sister were forced to leave their ancestral home of more than 7 centuries.



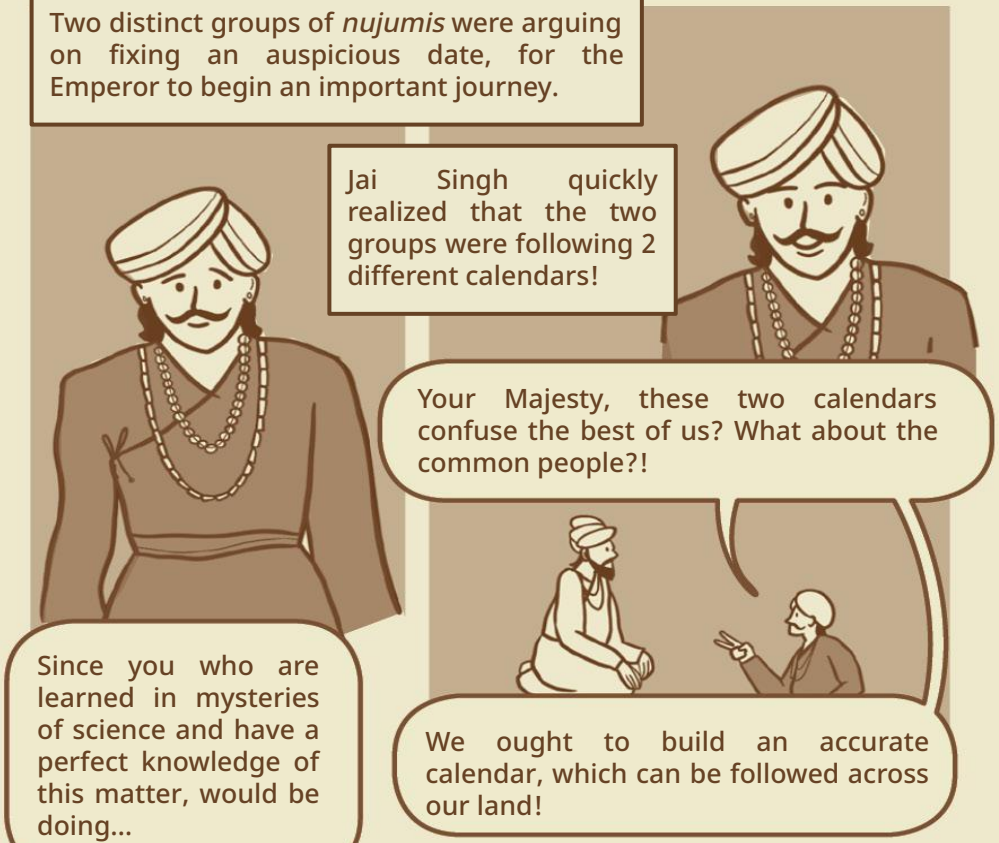
As things slowly began to settle down, Jai Singh continued to be a frequent visitor at the court.

But one day, a noisy debate broke out...



Two distinct groups of *nujumis* were arguing on fixing an auspicious date, for the Emperor to begin an important journey.

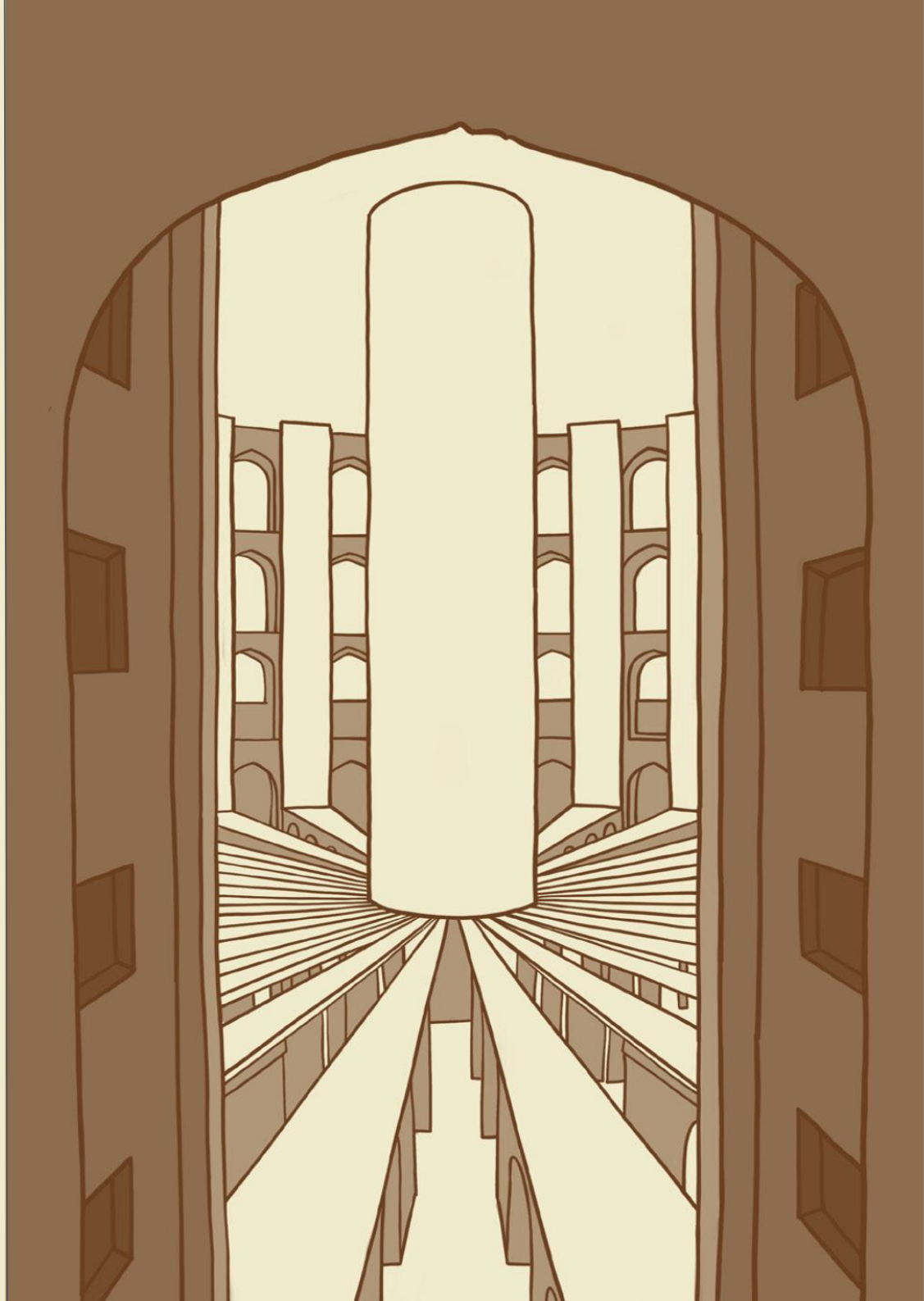
Jai Singh quickly realized that the two groups were following 2 different calendars!



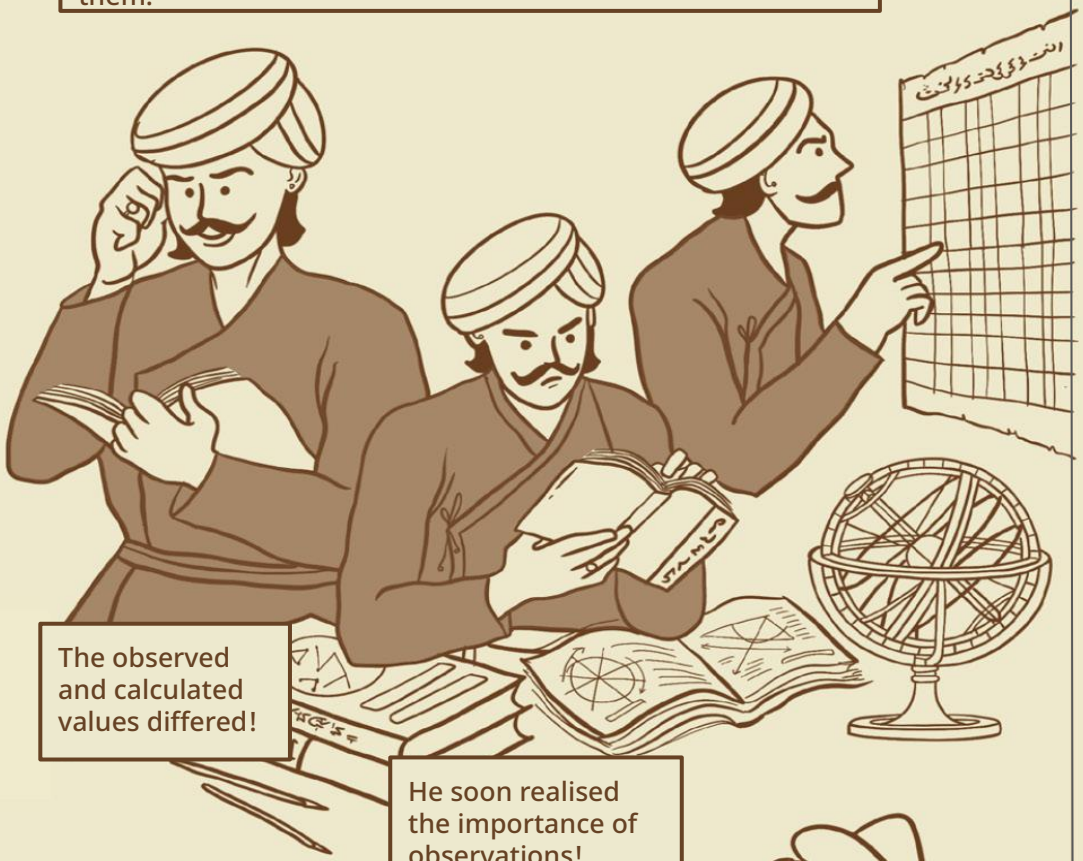
And so began the journey of building the celestial observatories...

Chapter II

The Celestial Apparatus



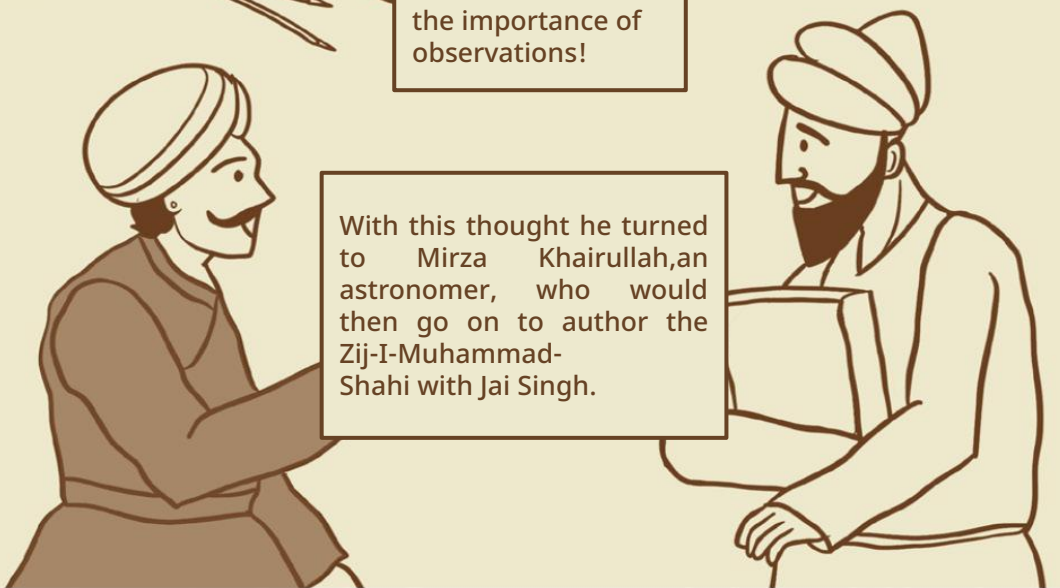
Surrounded by multiple calendars, the Gurgani, Ilkhani, Ilahi & Hijra calendar he found certain discrepancies between them.



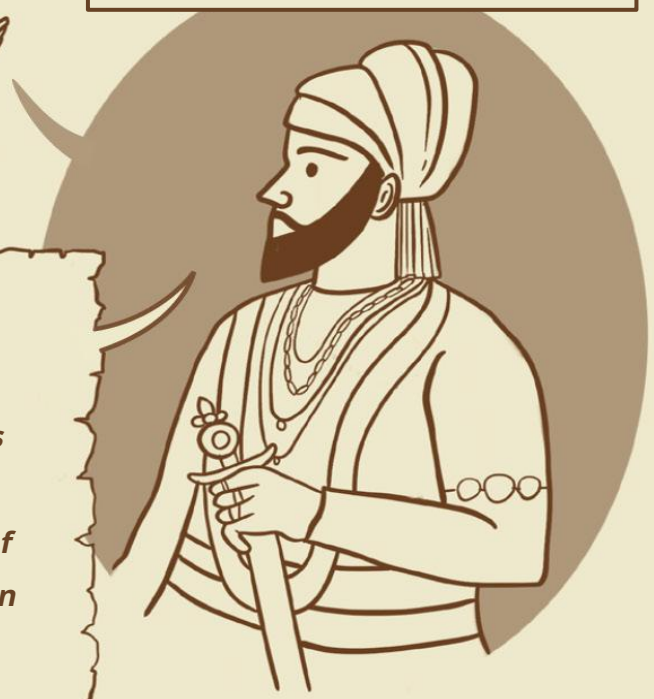
The observed and calculated values differed!

He soon realised the importance of observations!

With this thought he turned to Mirza Khairullah,an astronomer, who would then go on to author the Zij-I-Muhammad-Shahi with Jai Singh.



Mirza introduced him to the works of Ulugh Beg, a secular king & astronomer, who was trying to develop secular policies but was murdered at the hands of his own narrow-minded people, who felt threatened by them.



"Religion disperses like mist, kingdoms are destroyed, but the works of scientists remain forever."

Jai Singh truly admired Ulugh Beg for this reason and closely studied the Samarkand Observatory, & decided that he too might need to build such structures.

Before embarking on this task he made multiple observations & studies by himself. Using a telescope he noted down the phases of the moon, the shape of Saturn and much more.

But...

... he recorded the oval shape of Saturn, which tells us that he was actually using not a very efficient telescope!

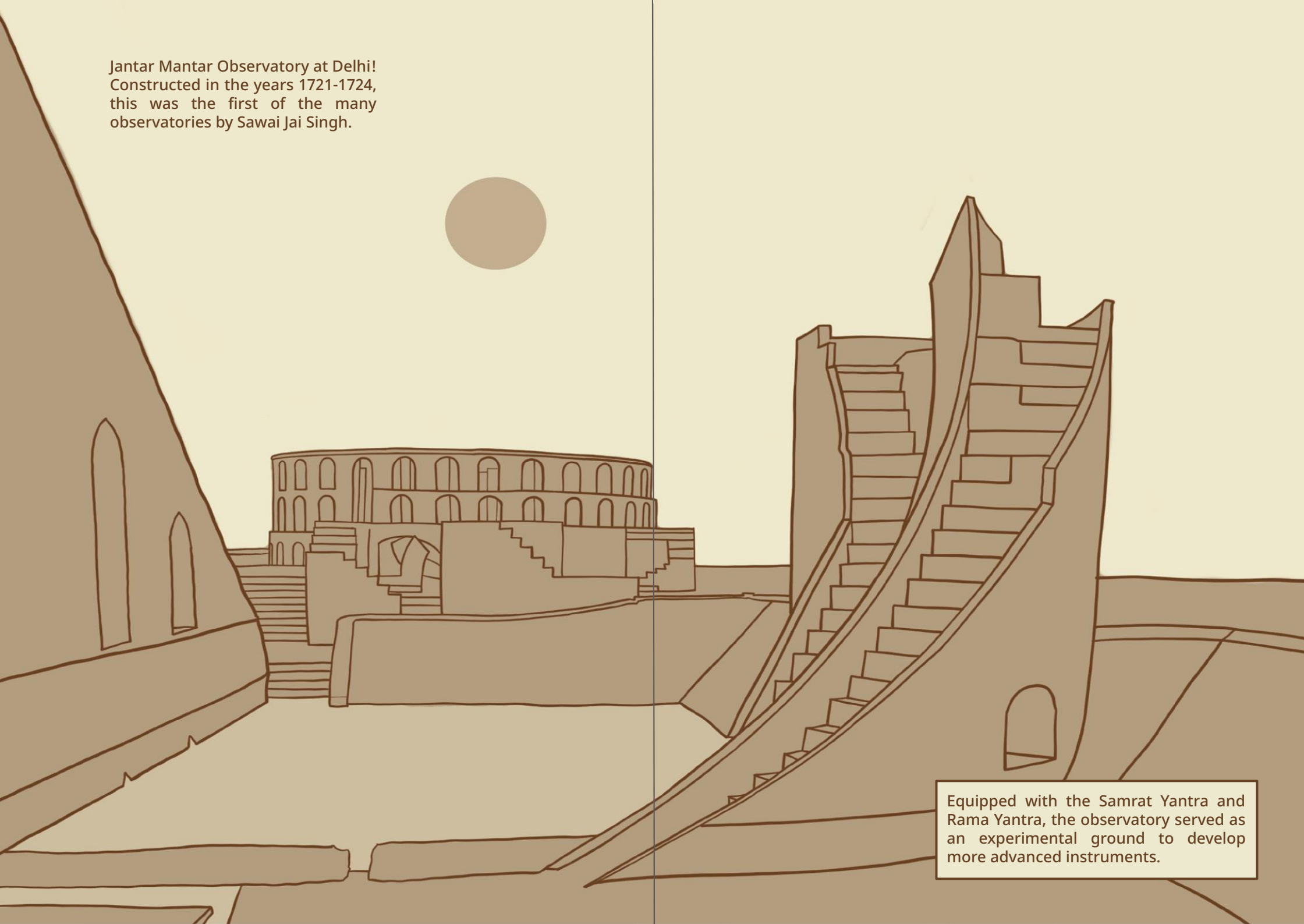
Frustrated with the brass instruments, for their continuous use would lead to wear and tear of their axes..

... he ordered for gallons of wax and began sculpting models with his own hands.

He wanted to achieve the highest level of accuracy possible to naked eye observations!

Which then lead to one of the first...

Jantar Mantar Observatory at Delhi! Constructed in the years 1721-1724, this was the first of the many observatories by Sawai Jai Singh.



Equipped with the Samrat Yantra and Rama Yantra, the observatory served as an experimental ground to develop more advanced instruments.

Samrat Yantra

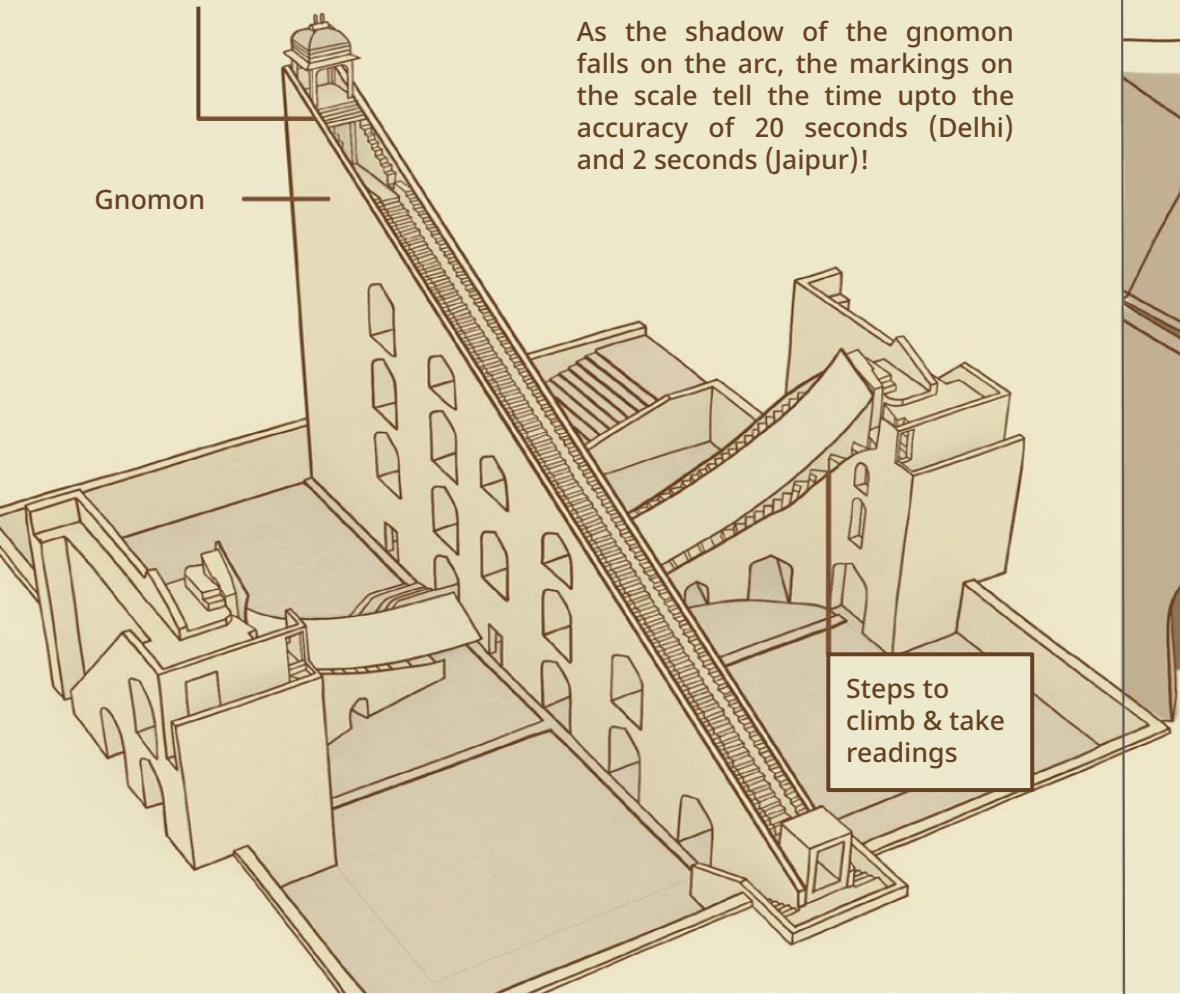
A symmetrical instrument built in stone, with a right-angled triangle in the centre and two arcs on either side of it, are used to tell the local time.

Understanding the time would directly impact the astronomical tables and the calendar, which needed to be corrected!

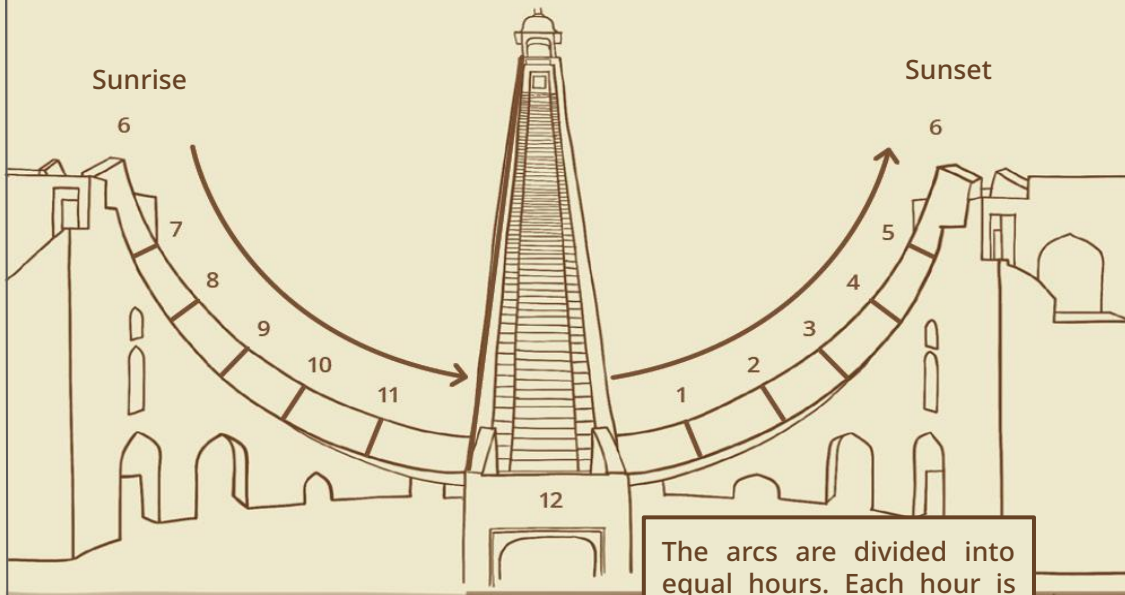
Style - Refers to Style as the time-telling edge of the gnomon, in the Samrat Yantra.

Gnomon

As the shadow of the gnomon falls on the arc, the markings on the scale tell the time upto the accuracy of 20 seconds (Delhi) and 2 seconds (Jaipur)!



Steps to climb & take readings



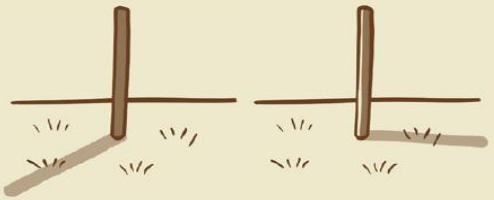
The arcs are divided into equal hours. Each hour is divided further into 4 parts (15 mins each). And each 15 mins segment is divided into 3 parts (5 mins each).

Five mins divided by five, mark one minute and that one minute is further divided into 3 parts (20 secs each).

But how did Sawai Jai Singh arrive at these measurements?!

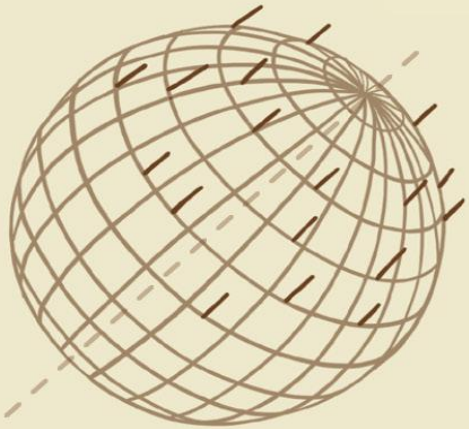
Now, let's do a quick exercise in imagination!

Now, imagine standing with a stick in one hand.

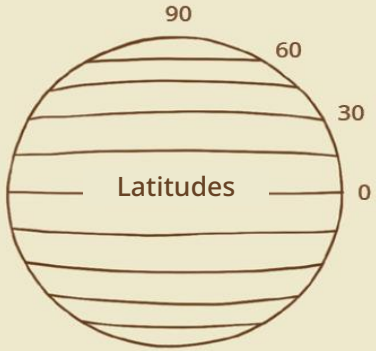


If all of us on Earth did this we would probably look something like that, with a distorted perspective of course.

But more importantly our shadows would be different everywhere and we would not have a constant method of measuring time.



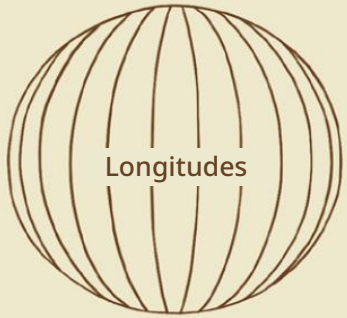
But if we all aligned our sticks, parallel to the Earth's Rotational Axis, we would have a constant for measuring time!



Remember the graticule?!

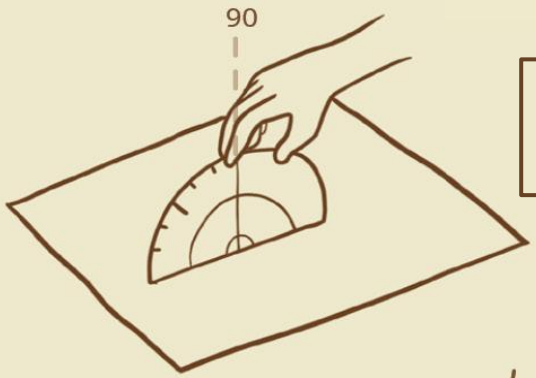
Parallel lines that run horizontally along the equator, are known as **LATITUDES.**

Whereas the lines originating and converging at the two poles are called **LONGITUDES!**



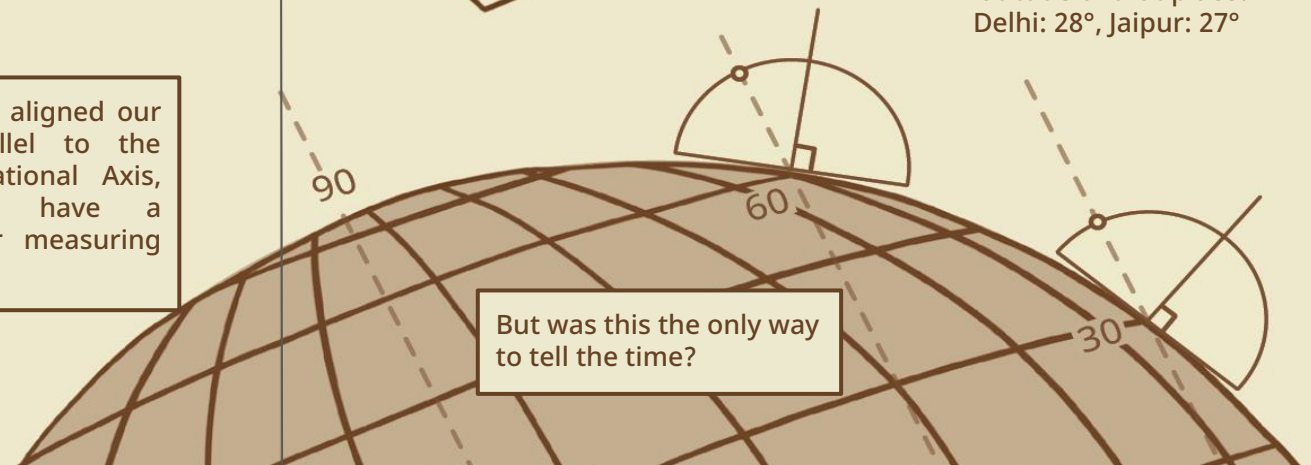
So let's try an exercise!

If we were to vertically place a protractor on the ground, but at different latitudes on the Earth, say 30° and 60° and then mark out the same degree on that protractor, corresponding to our latitude.



We would end up with lines that would be parallel to the Earth's Rotational Axis!

Hence the gnomon of the Samrat Yantra is placed at an angle equal to the latitude of that place!
Delhi: 28°, Jaipur: 27°

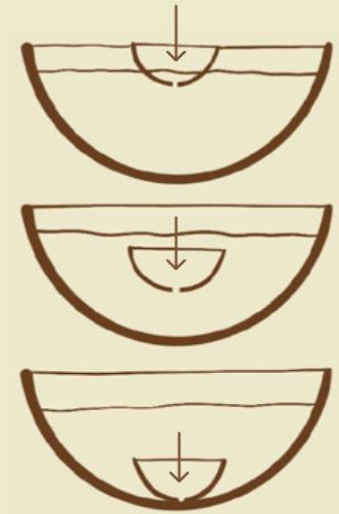


But was this the only way to tell the time?

Ghatika

The Water Clock

A small hemispherical copper bowl with a very fine perforation at the bottom is submerged into a larger bowl.



As the smaller bowl slowly sinks to the bottom, it completes one cycle, which approximately takes 24 mins.As we repeat this process 60 times, we complete one day!

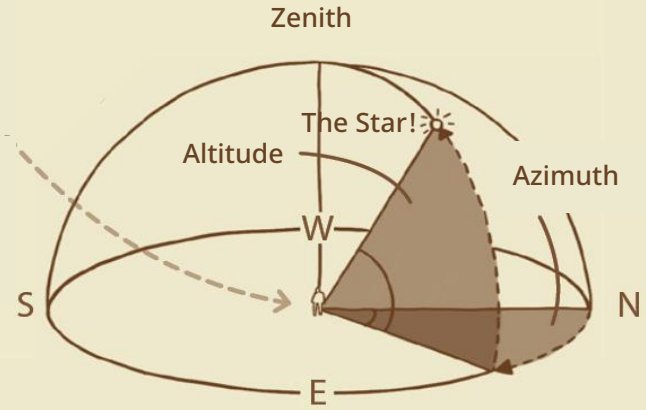
The second thing required for the astronomical tables were the locations of the stars and celestial bodies.

But how did they actually manage to take these angular measurements?

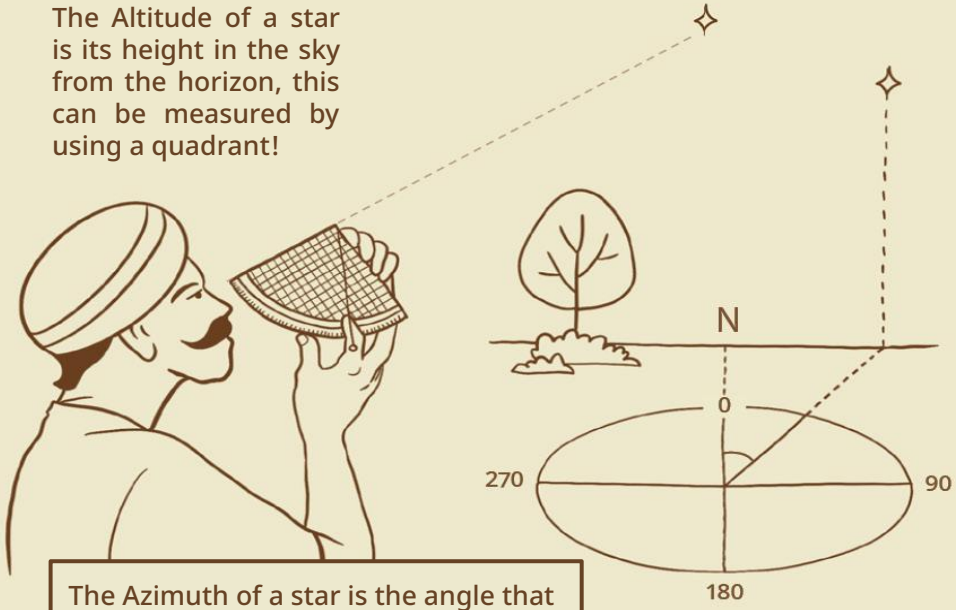
Its me again

For that we would have to understand the basics of the Horizontal Coordinate System!

This system is based on the point of view of the observer in relation to the horizon.



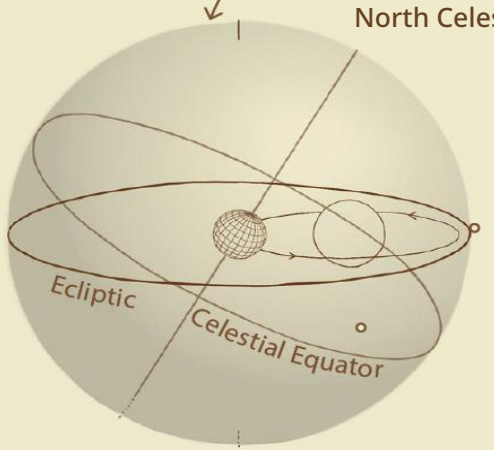
The Altitude of a star is its height in the sky from the horizon, this can be measured by using a quadrant!



The Azimuth of a star is the angle that it makes with the North.

The second system is the Equatorial Coordinate System. Here its plane of reference is the celestial equator.

A Celestial Sphere is a larger imaginary sphere centered on the Earth, onto which we map celestial bodies.



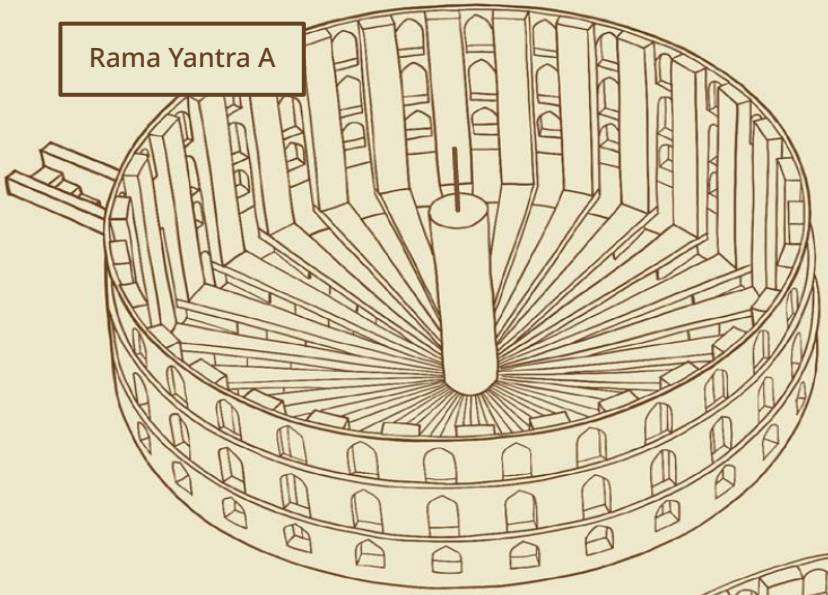
The changes in the planetary motions can be mapped across this celestial sphere, as the stars serve as a constant background for reference.

We can identify the change of seasons by monitoring the position of the sun across the nakshatras.

Rama Yantra

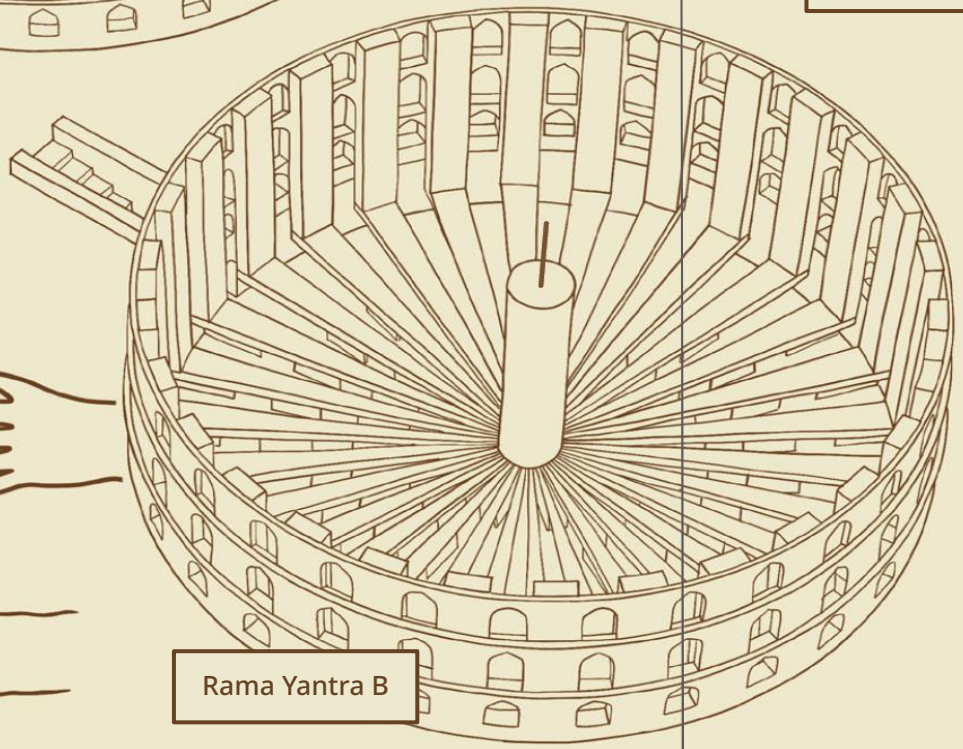
It is an instrument that helps in determining the altitude and azimuth of celestial bodies.

Rama Yantra A

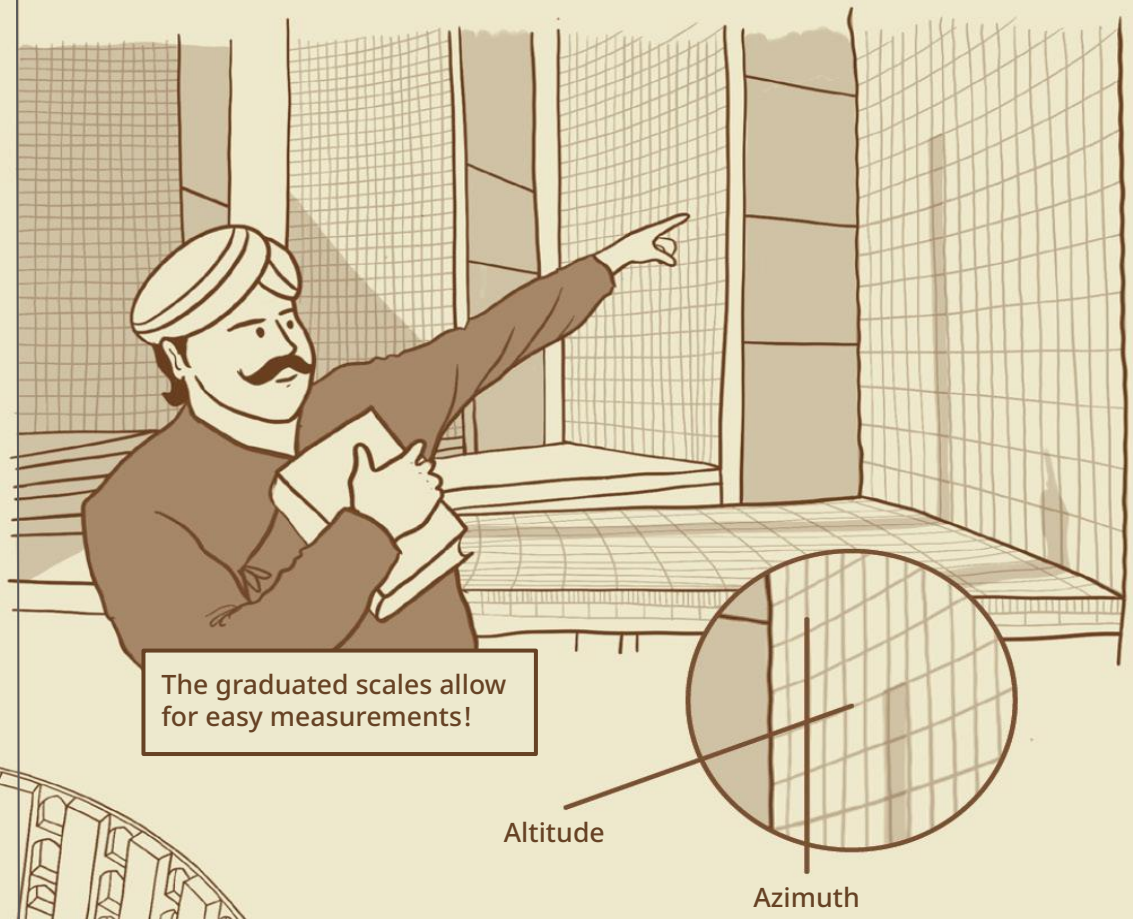


It is divided into 2 complementary instruments, which when combined become one whole.

Just like our hands!



Rama Yantra B



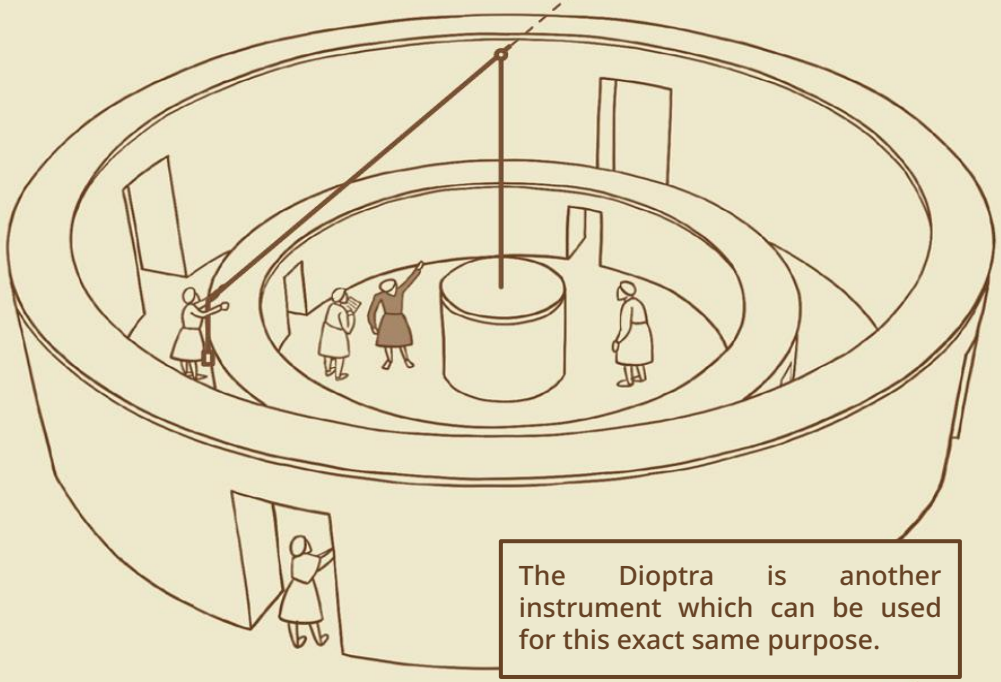
The graduated scales allow for easy measurements!

These cylindrical structures carry a vertical rod (gnomon) at the centre and as the tip of the shadow falls on the graduated scales one can mark the azimuth and altitude from it.
If the shadow falls in between two scales, it means that the other instrument should be used for measurements.

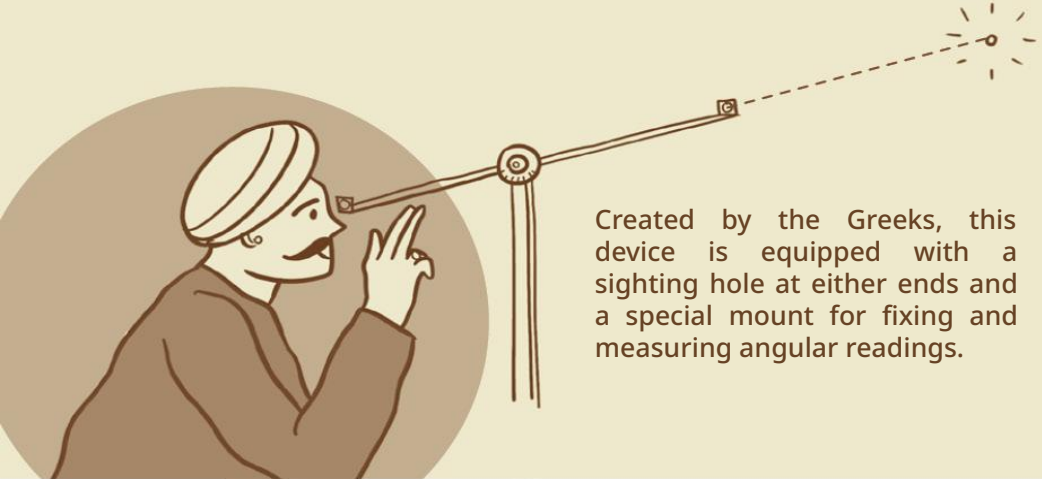
But if one were to take measurements at night, how would they be possible?

Digamsa Yantra

Similar to the Rama Yantra, this instrument is its complete version. At night, the celestial bodies can be measured by aligning them with a taut weighted string with the gnomon.

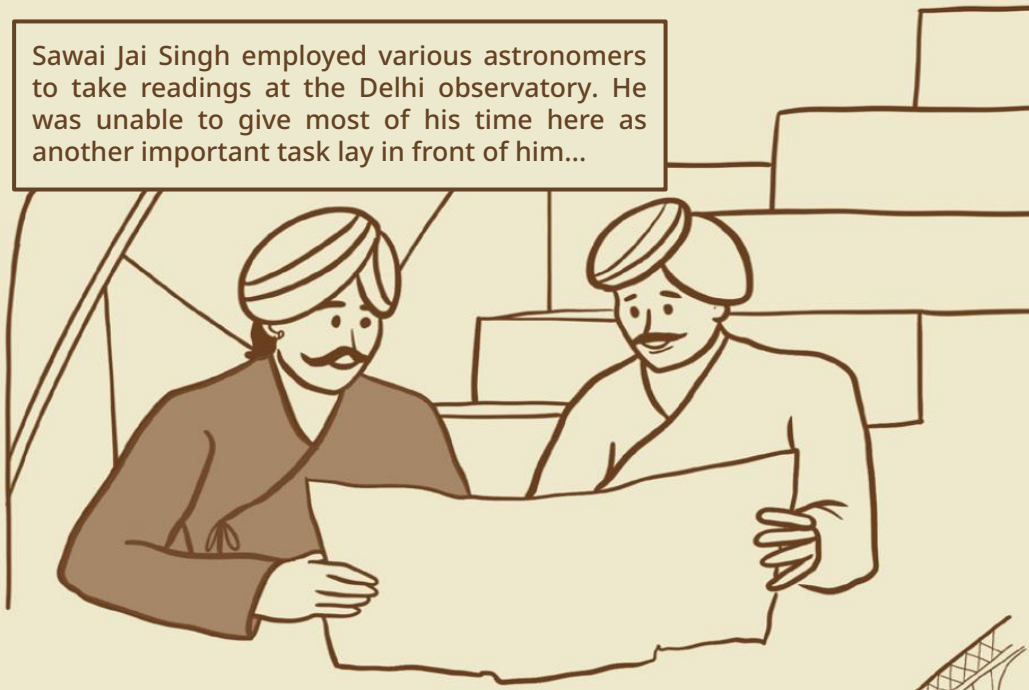


The Dioptra is another instrument which can be used for this exact same purpose.



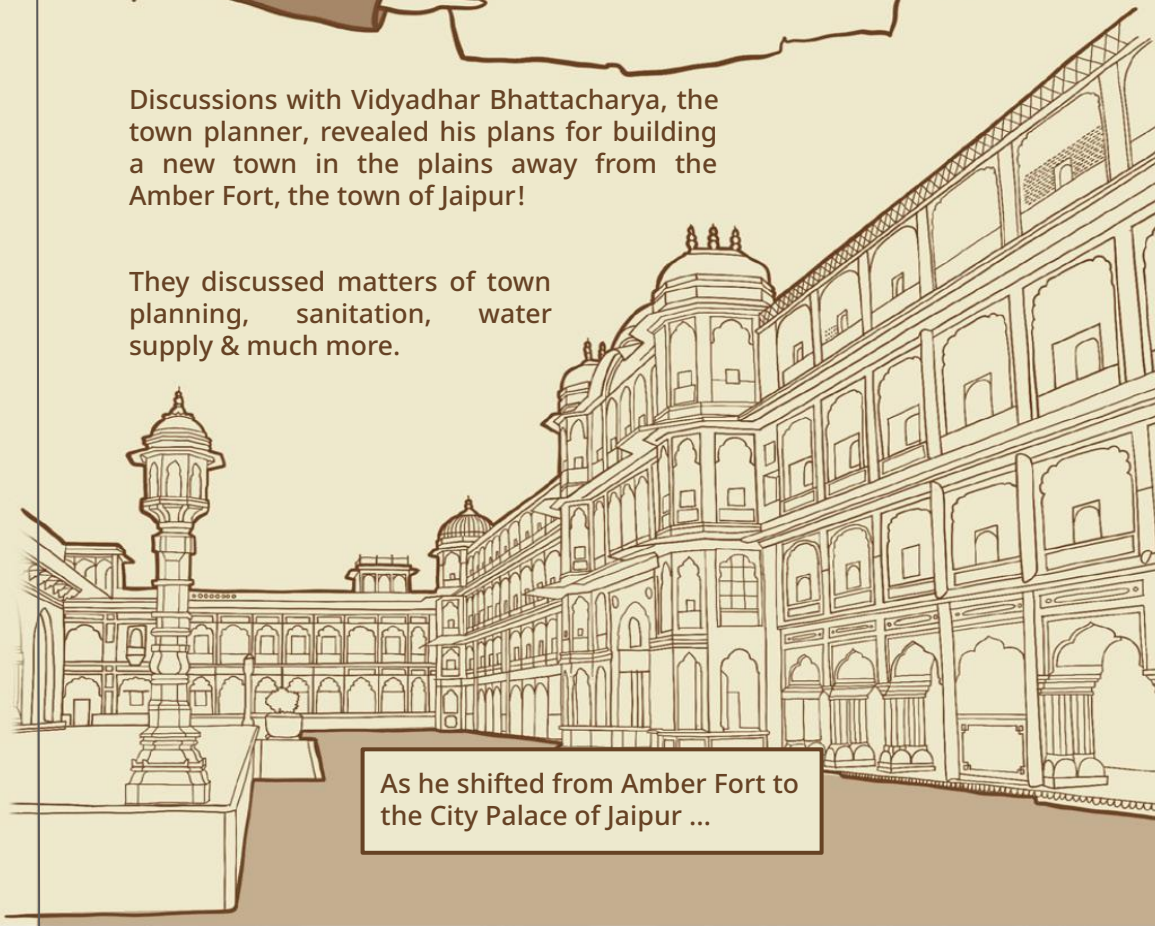
Created by the Greeks, this device is equipped with a sighting hole at either ends and a special mount for fixing and measuring angular readings.

Sawai Jai Singh employed various astronomers to take readings at the Delhi observatory. He was unable to give most of his time here as another important task lay in front of him...



Discussions with Vidyadhar Bhattacharya, the town planner, revealed his plans for building a new town in the plains away from the Amber Fort, the town of Jaipur!

They discussed matters of town planning, sanitation, water supply & much more.



As he shifted from Amber Fort to the City Palace of Jaipur ...

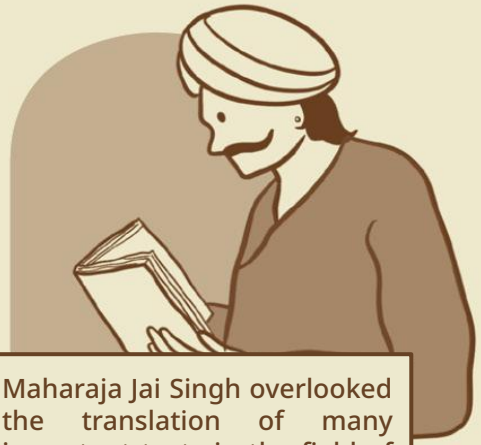
As he shifted from Amber Fort to the City Palace of Jaipur ...

... he brought together a school of scientists. They were talented mathematicians, astronomers, and town planners.

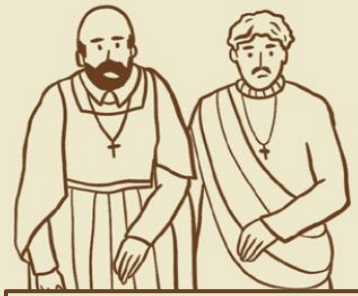
Samrat Jagannath translated Almagest & Tahrir-i-uqlidas, i.e. Ptolemy's text on astronomy and geometry of Euclides & other books.

Keval Ram wrote on mathematics & astronomy.

Mohammad Huzoor Allahi was the author of the first Indian book on logarithms, and the translator of the work of Ulugh Beg.



Maharaja Jai Singh overlooked the translation of many important texts in the field of mathematics, astronomy, spherical trigonometry from Middle East Asia and Europe.



As he was examining one such work of translation he was interrupted by Father Emmanuel de Figuerado and Padre Manuel.

I wish to acquire the latest books & advancements in the field of science and astronomy from the West.

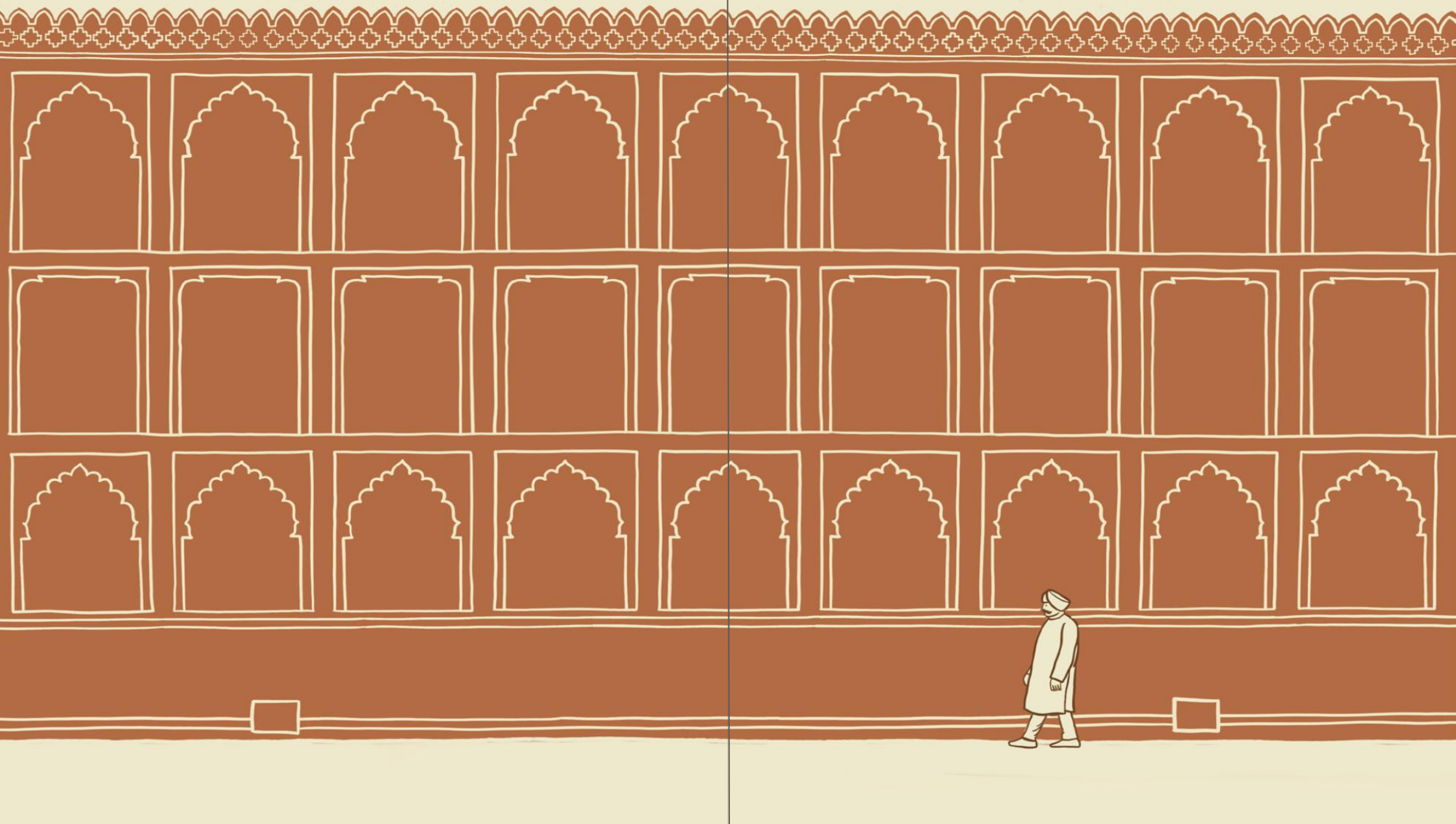
This mission is very important to me, as my Hindu astronomers refuse to cross the sea and go to Europe, for their caste might get washed off if they cross the sea.

Father Figuerado & Padre Manuel seemed to understand the importance of this mission & reassured the Maharaja that they would return with success!

The two of them along with a few other assistants & students set out to Portugal in 1727.

Chapter III

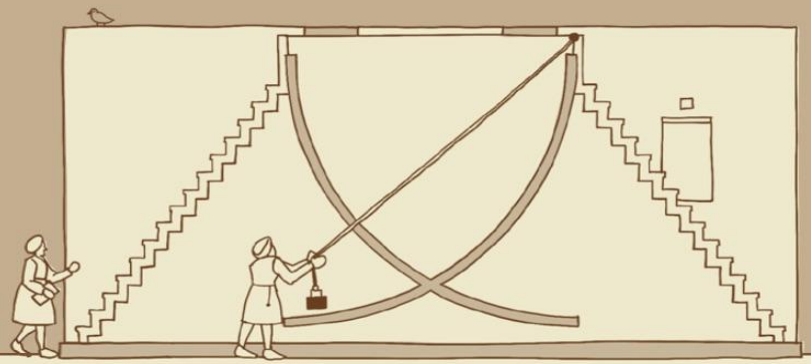
The Truth of Fallacies



Dakshinotra Bhitti Yantra

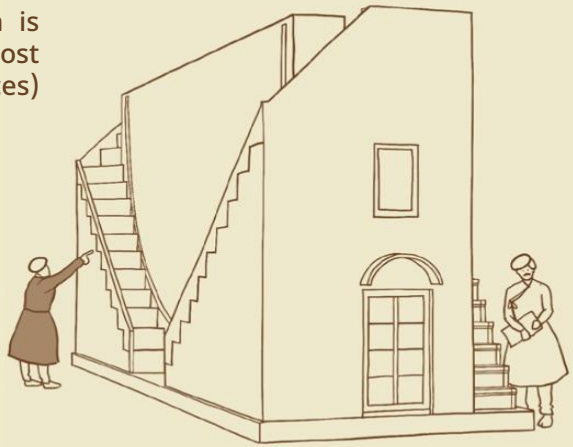
This is an instrument to mark the noon passage of the Sun. At noon as the sun is directly above our heads, we would be unable to see it passage through the sky simply with the Samrat Yantra and Rama Yantra.

A pin at the centre casts a shadow on this scale at noon, which gives us the maximum altitude and hence the declination of the Sun; basically the coordinates of the Sun!



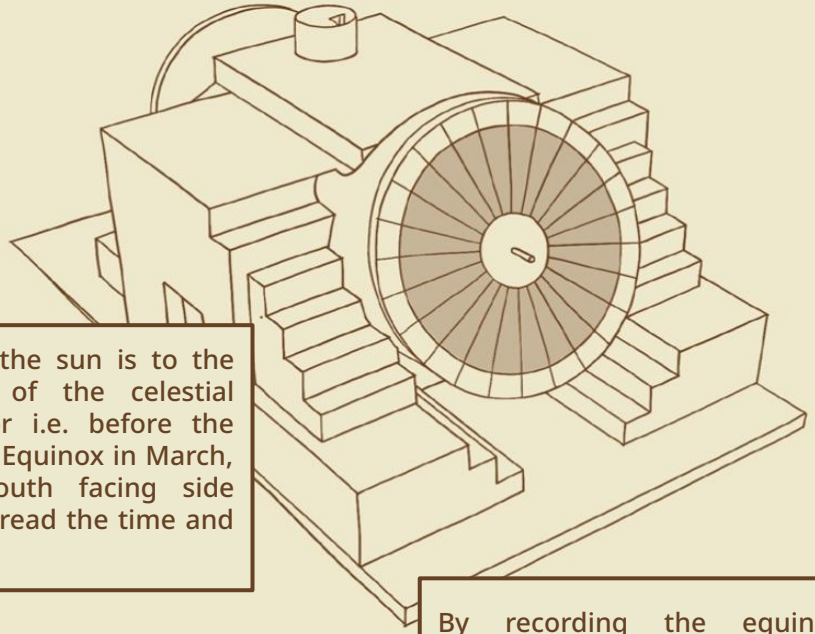
The North-South shift of the Sun is important in fixing the Northern most and Southern most points (Solistices) for the calendar.

For the intersecting arcs, two pegs at the top are suspended with a taut weighted string, which serve as a sighting tube to take the readings, just like the Digamsa Yantra!



Nadivalaya Yantra

A 24 hour clock that can be used for six months on either sides! The Nadivalaya Yantra marks the passage of the Sun across the Celestial Equator!

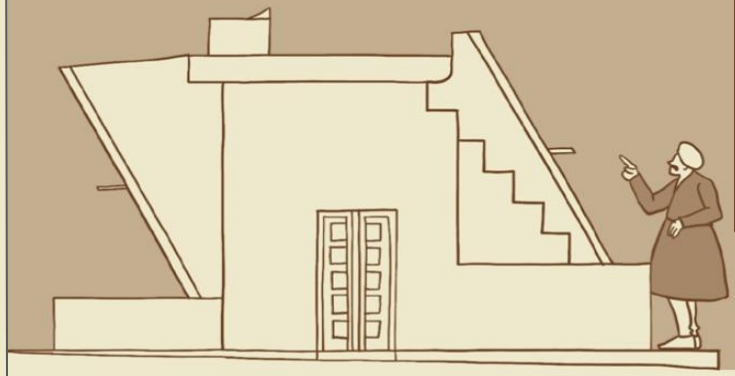


When the sun is to the South of the celestial Equator i.e. before the Vernal Equinox in March, the South facing side would read the time and ...

as the Sun moves North, the North facing side would cast the shadow, to read out the time!

By recording the equinoxes through this device, one is able to keep a track of the change of seasons, as well as...

... Understanding the date for celebrating the New Year! Followers of the Solar and Luni-Solar Calendar celebrate their New Year during March-April (Vernal Equinox)

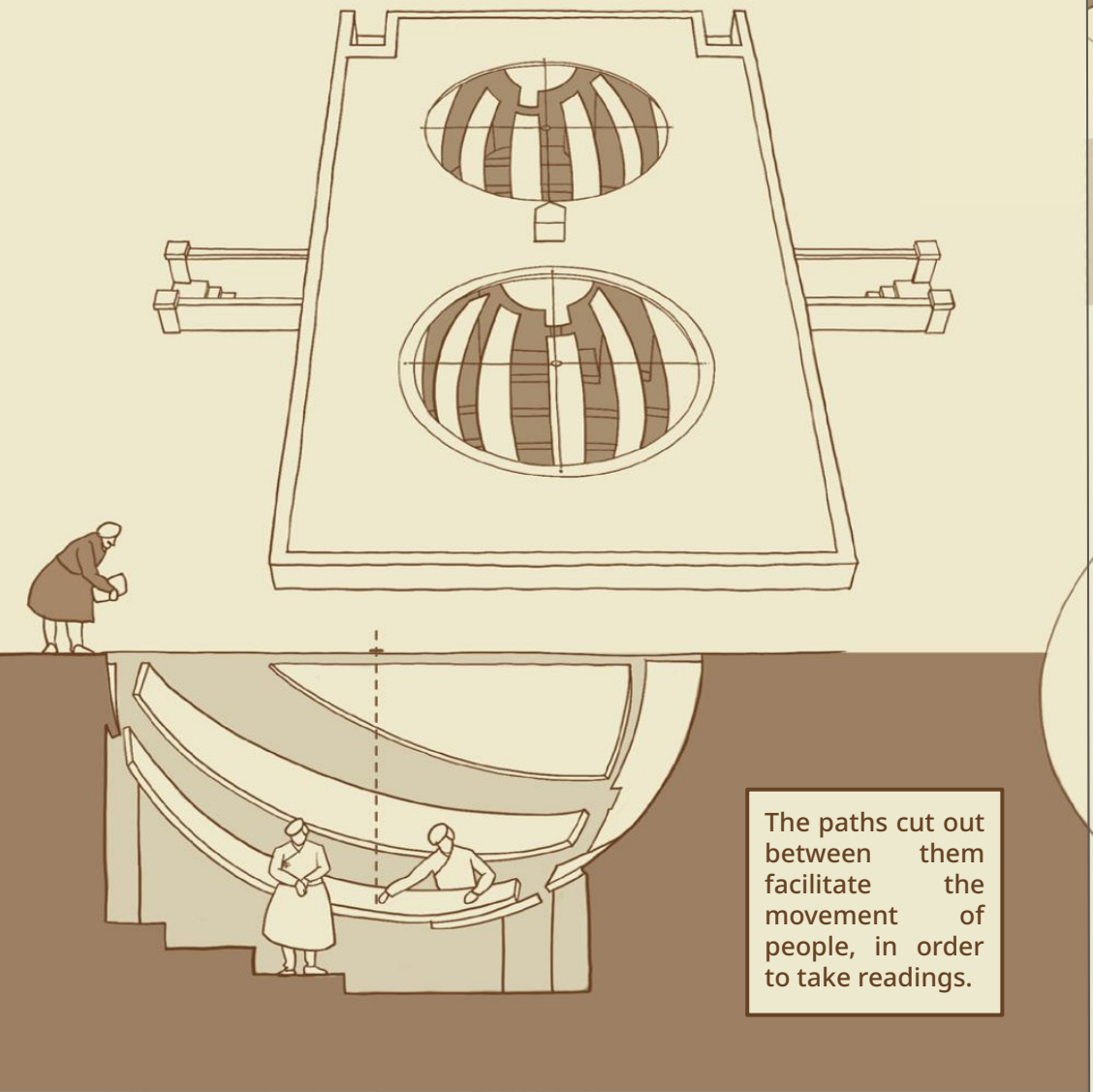


Jaiprakash Yantra

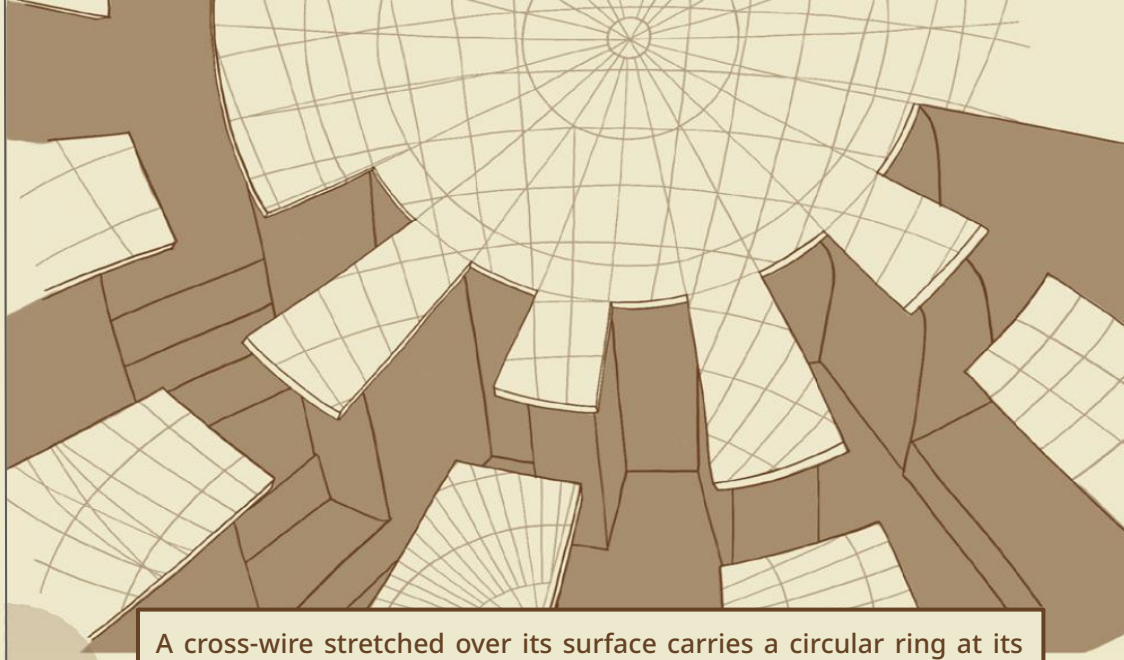
Sky in a bowl !

Similar to the Rama Yantra in terms of being two complementary instruments, the Jaiprakash Yantra are hemispherical bowls, which are the reflection of our celestial sphere.

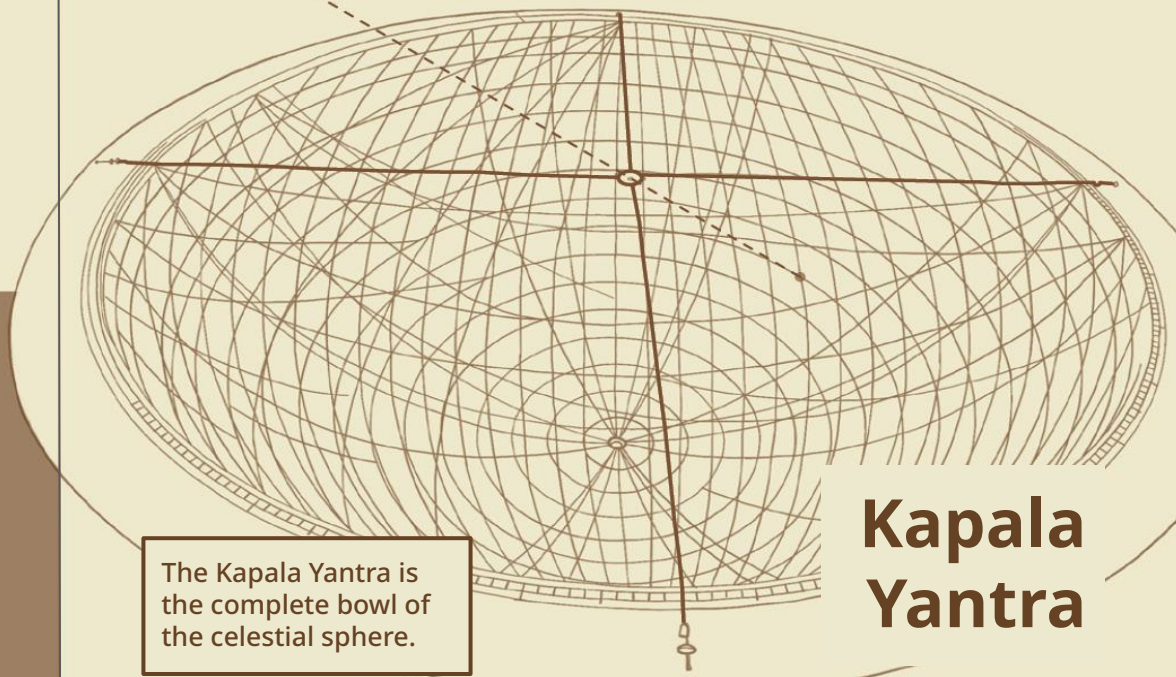
It's used for reading out the Altitude & Azimuth for the Sun, Planets & Stars.



The paths cut out between them facilitate the movement of people, in order to take readings.



A cross-wire stretched over its surface carries a circular ring at its centre. This ring then casts a shadow, by which one can determine the coordinates of the Sun in the sky!

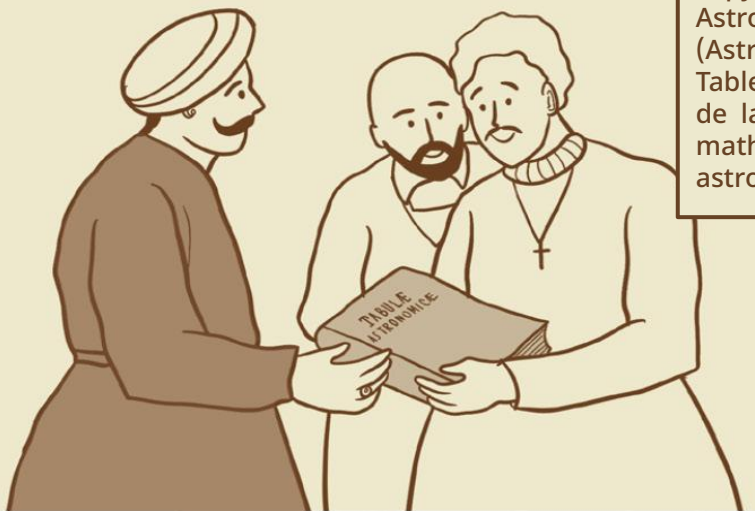


The Kapala Yantra is the complete bowl of the celestial sphere.

Kapala Yantra

While the Maharaja was inspecting and discussing the Zij with Samrat Jagannatha and Mirza Khairullah, he was greeted by Father Figuerado and Padre Manuel.

The Maharaja, excited to know about the latest developments in astronomy in the West enquired about their travels and findings.



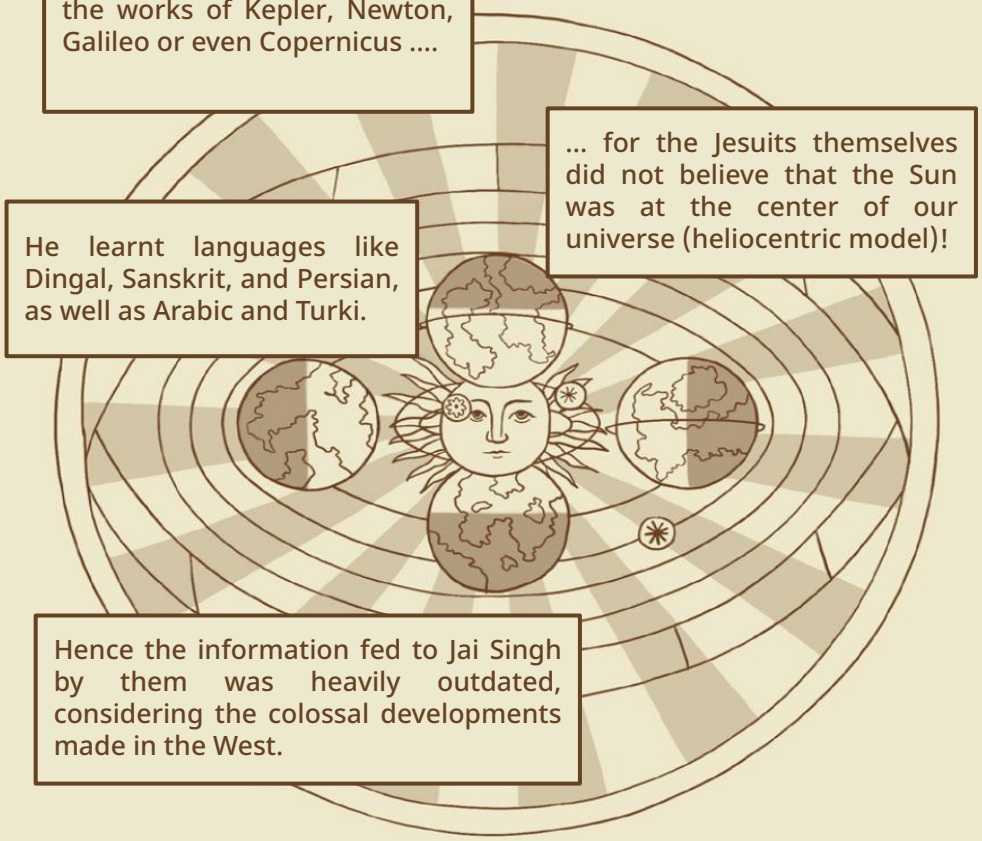
They presented a copy of the Tabulae Astronomicae (Astronomical Tables) of Philippe de la Hire, a French mathematician and astronomer.

But...

... they did not carry with them the works of Kepler, Newton, Galileo or even Copernicus ....

... for the Jesuits themselves did not believe that the Sun was at the center of our universe (heliocentric model)!

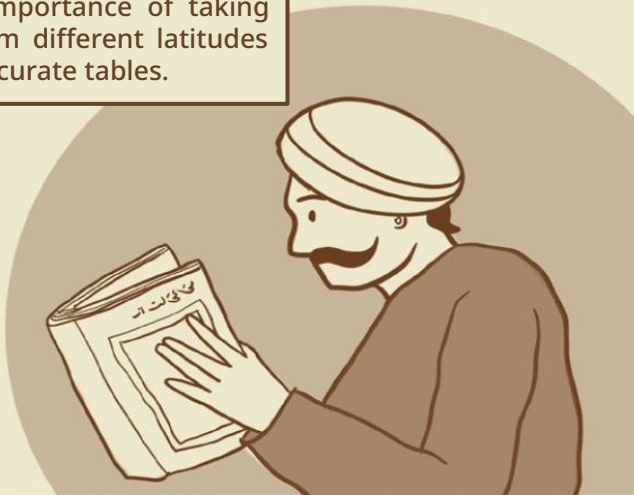
He learnt languages like Dingal, Sanskrit, and Persian, as well as Arabic and Turki.



Hence the information fed to Jai Singh by them was heavily outdated, considering the colossal developments made in the West.

Even though Jai Singh was detached from the latest knowledge in astronomy he continued to build more observatories, as he understood the importance of taking multiple readings from different latitudes to then make more accurate tables.

He continued to persevere for knowledge and gain assistance from the French Jesuits too.



One day Jai Singh was walking in the Jaipur observatory at noon, & examining the instruments ...

... he faltered and fainted. His attendants quickly rushed to him and carried him to his royal chambers.

Prince Ishwari Singh rushed over and tended to his father.

On recovering, Jai Singh told his son that he wished for him to take up the royal duties and matters of the state,

.. as he was no longer in a condition to handle both the political duties and astronomical pursuits.

Ishwari Singh was then declared as the Crown Prince of Jaipur.

The Maharaja continued to invite scholars, astronomers, and mathematicians from the West. Bavarian astronomers, worked with him from 1740 to 1743, at Jaipur.

He desired to find more accurate instruments from the West, even after he had built his own observatories.

He also planned to send a second fact-finding mission and he kept himself occupied with finding newer accurate tables and designing new instruments, but...

In the year 1743, Maharaja Sawai Jai Singh breathed his last.

Ishwari Singh ascended the throne at a difficult time, much like his father.

Forced by the fear of an upcoming war, he diverted all his resources to raising an army.

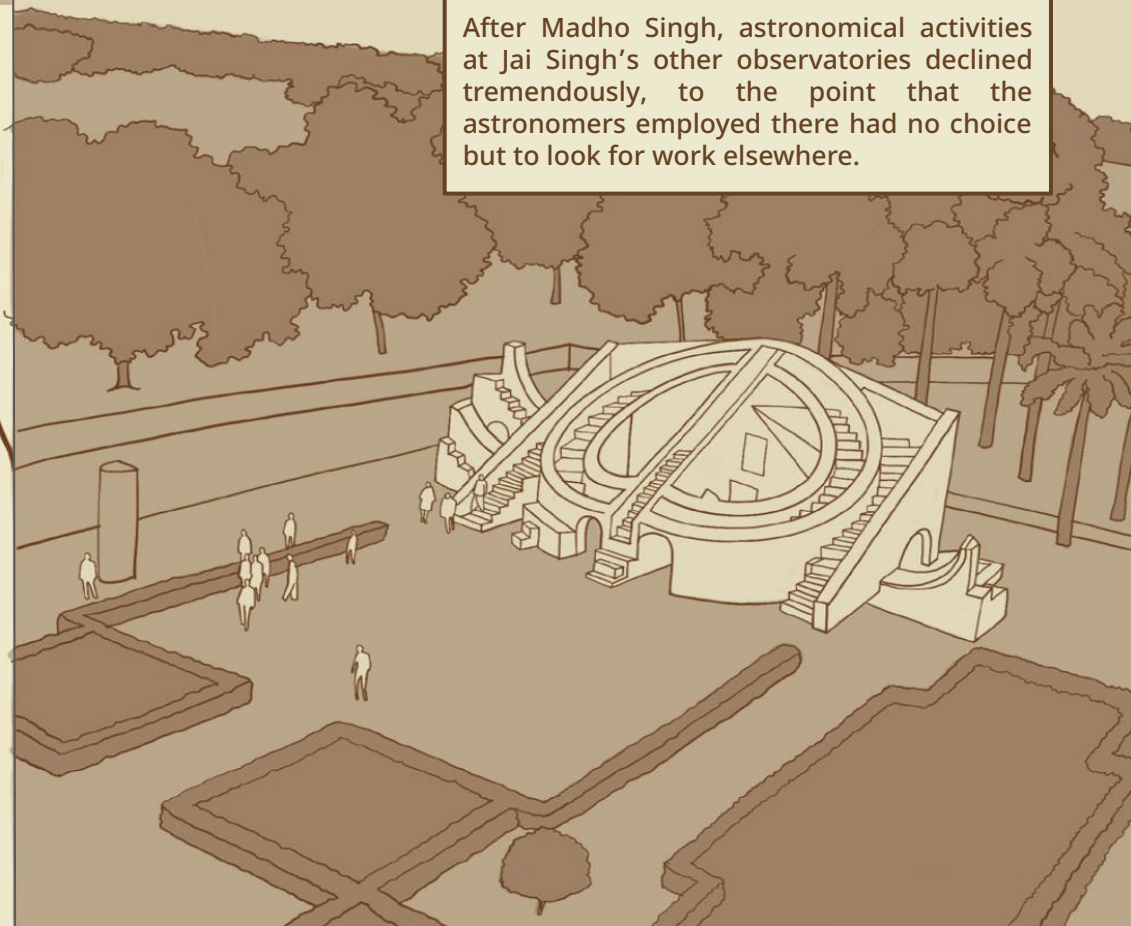
With these worries that threatened his own inheritance, he could not continue his father's astronomical tradition.

In 1750, seven years after Jai Singh's death, his second son, Madho Singh, ascended the throne and revived the astronomical interests of his father.

He built the Misra yantra of Delhi and had some brass instruments fabricated, which now are in storage at Jaipur.

In Madho Singh's own lifetime the Delhi observatory ceased to operate, and its instruments were vandalized for their material.

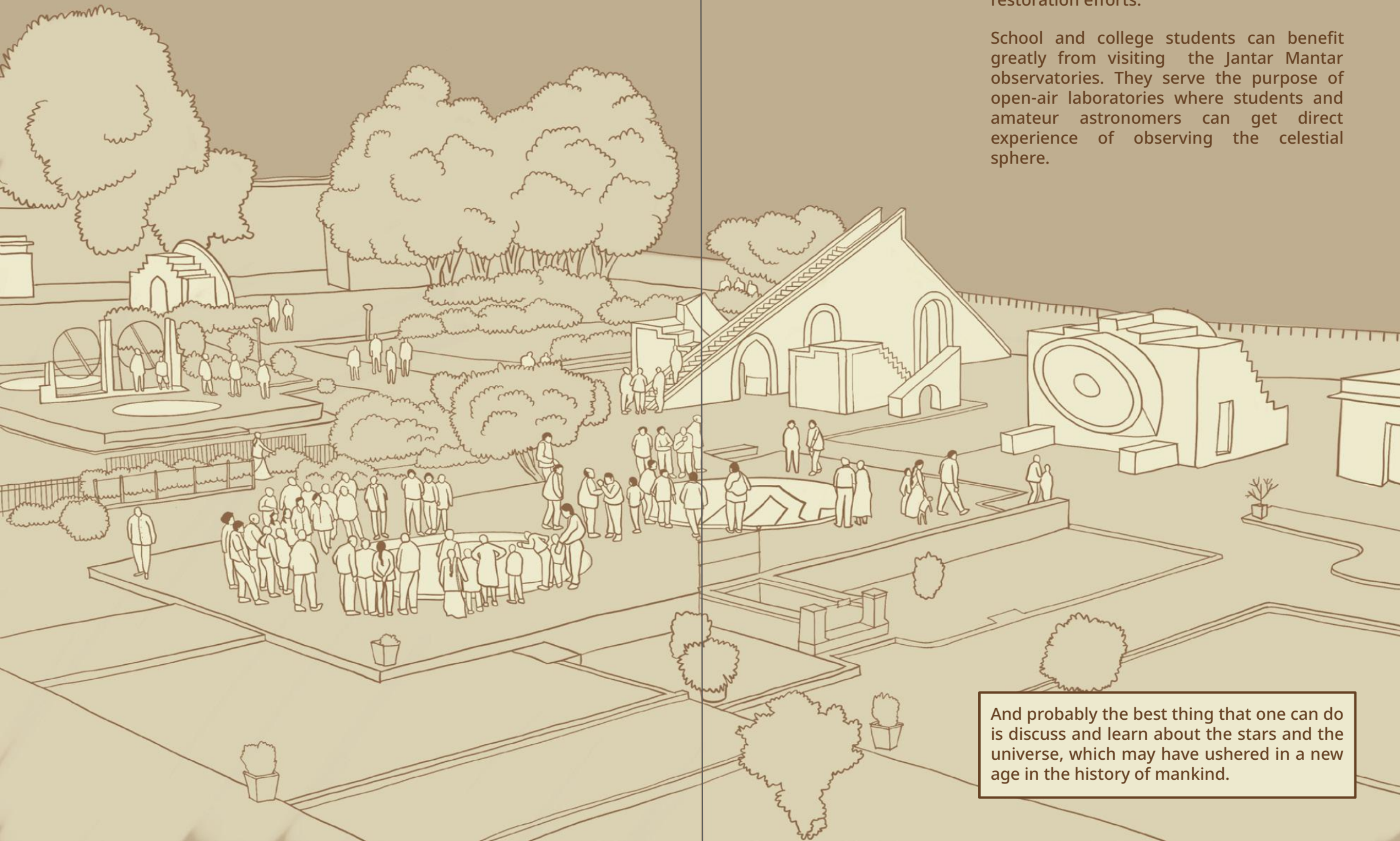
After Madho Singh, astronomical activities at Jai Singh's other observatories declined tremendously, to the point that the astronomers employed there had no choice but to look for work elsewhere.



Currently, the Jaipur observatory functions the best out of all the other ones. Restoration efforts over time, have only sometimes proven helpful.

But collaborative efforts between the Archaeological Society of India and Nehru Planetarium, offer hope in terms of restoration efforts.

School and college students can benefit greatly from visiting the Jantar Mantar observatories. They serve the purpose of open-air laboratories where students and amateur astronomers can get direct experience of observing the celestial sphere.



And probably the best thing that one can do is discuss and learn about the stars and the universe, which may have ushered in a new age in the history of mankind.

But to live in the times of Jai Singh, times of social and religious intolerance, political clashes and bigotry, and bring together scholars, astronomers, mathematicians of different faiths to work together towards one goal, was no easy task.

He tried ushering in a new age of science, possibly the Indian Renaissance. For science had no religion, no nationality.

But his advances in astronomy remained outdated for they did not respond to the Copernican Revolution, for various reasons.

Despite all this he displayed foresight and immense vigour, as is evident from his astronomical journey and the instruments that stood the test of time.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