Astronomy in Ancient, Medieval and Early Telescope Era of India

Prof. Amitabha Ghosh
Department of Physics
Indian Institute of Technology Kanpur

Session 04

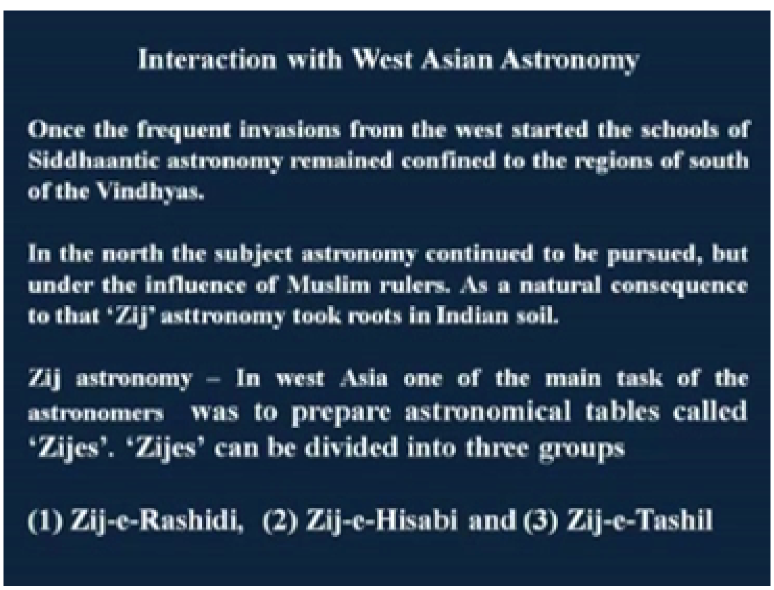
Astronomy in Medieval India

Professor 1: And as a request those who want the ppt files, you are welcome to send the mails but do it on or after month. I still do not have the ppt files. Person who has written my mail and responding technique also, then I will be having the ppt files from tomorrow. So from Monday I will be in a position to send them in PDF version. Okay?

Professor 2: So I think according to our plan today we start discussion on the astronomy in medieval India. And medieval India I mean to say actually siddhantic astronomy was continuing but main thing that because of outside invasions started coming again and again and the rulers were also coming from outside, this is not like previously the shorts coming, who is coming but they are getting absorbed here.

But this time the rulers are coming from outside, so lot of activities were interrupted and many were south of Vindhya but at the same time the new influence came and some new types of astronomical activity started. And some of those things we will discuss.

(Refer Slide Time: 1:33)



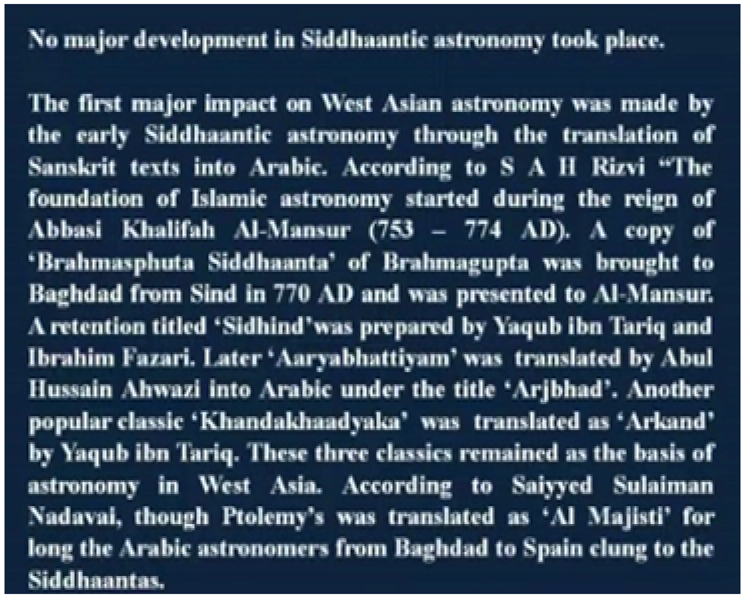
So today what we will discuss is that interaction with the West Asian Zij astronomy which we call. And then important contribution by Sawai Jai Singh and it will be interesting because though he did not do any fundamentally new work but his observatories you all see and they stand still as more or less as tourist attraction I must say. And he played some role in astronomy. Now the northern part of India, the astronomy continued to be pursued but under the influence of West Asian astronomers and Muslim rulers.

And as a natural consequence to that, Zij astronomy took roots in Indian soil. What is Zij astronomy? Now in west Asia, one of the main task of the astronomers was to prepare astronomical tables called Zijes. Now Zij is a table, astronomical table and they needed it very badly because they follow also strictly a lunar calendar as you all know. And this kind of astronomy which is primarily based upon the Zij that is table, they are called commonly Zij astronomy.

So there are three types of Zijes, one type of Zij is Zij-e-Rashidi and Zij-e-Hisabi and Zij-e-Tashil. From the word I think those who know, do well, they can find out. One is with observation and one table is based primarily on calculations used some other person's observation and the last one I am not very sure what is that. Zij-e-Tashil is simplified tables for easy application to specific tasks like studying the motion of the moon alone not the whole of astronomy.

And Zij-e-Hisabi, Hisab word is familiar to you, these tables presented with the calculated data taking care of various types of corrections and effects in the observed data but it does not involve observation directly. And Zij-e-Rashid, Rashidi not this, Rashidi, these are tables of raw data obtained from the direct observations. So these three types of Zijes were there. And there is nothing fundamentally new but the name was this because of that historical connection.

(Refer Slide Time: 4:23)



The first, the no major development in Siddhantic astronomy took place during this period. Much much later of course you will find that towards the end of 19th century the Samantha Chandrasekhar also developed some new types of instruments and improved the accuracy substantially. But otherwise there was no difference. The first major impact on West Asian astronomy was made by the early siddhantic astronomy as I mentioned yesterday.

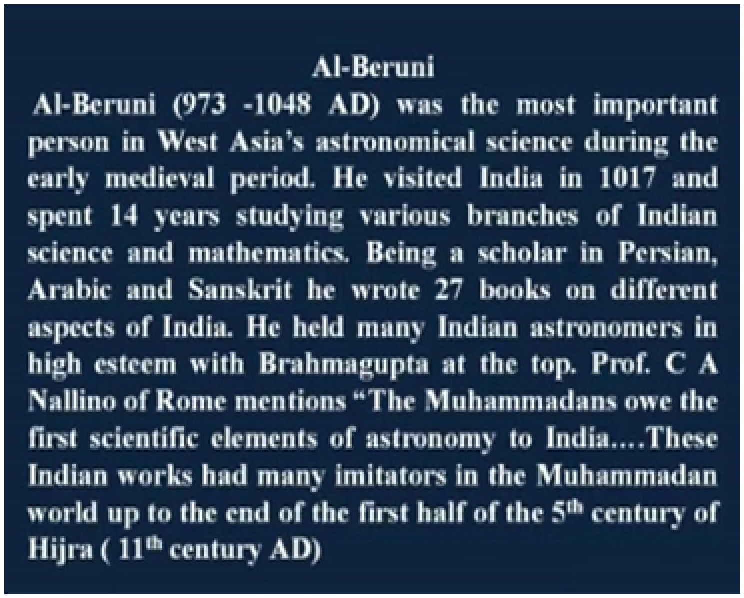
And it was done through the translation of Sanskrit text into Arabic. According to S A Rizvi, he quote, “The foundation of Islamic astronomy started during the reign of Abbasi Khalifah Al-Mansur in 753 AD. A copy of Brahmagupta’s siddhanta or Brahma Siddhanta or Brahmasphutasiddhanta, that is the same thing was brought to Baghdad from Sind in 770 AD and was presented to Al-Mansur.

A retention titled Sindhind it was translated, and name was called Sindhind was prepared by Yaqub - Ibn – Tariq and Ibrahim Fazari. Later Aryabhattiyam was also translated by Abul Hussain Ahwazi into Arabic and the title was Arjbhad. Another popular classic was Khandakhadyaka, it was a Karana text of Brahmagupta's Brahmasphutasiddhanta. Now Karana text were simplified algorithms for direct calculation without going into theory et cetera.

And this Khandakhadyaka was a very popular Karana text and that was also translated as Arkand by Yaqub - Ibn – Tariq. And these three classics remained as the basis of astronomy in West Asia.

According to Saiyyed Sulaiman Nadavai, though Ptolemy was translated as Al Majisti, that is why we call it al-Majist. If you now buy a copy of, in our library we have it, Ptrolemy's, it is called al-Majist but actually originally it is Al Majisti. For long and the Arabic astronomers from Baghdad to Spain clung to the siddhantas on the primary.

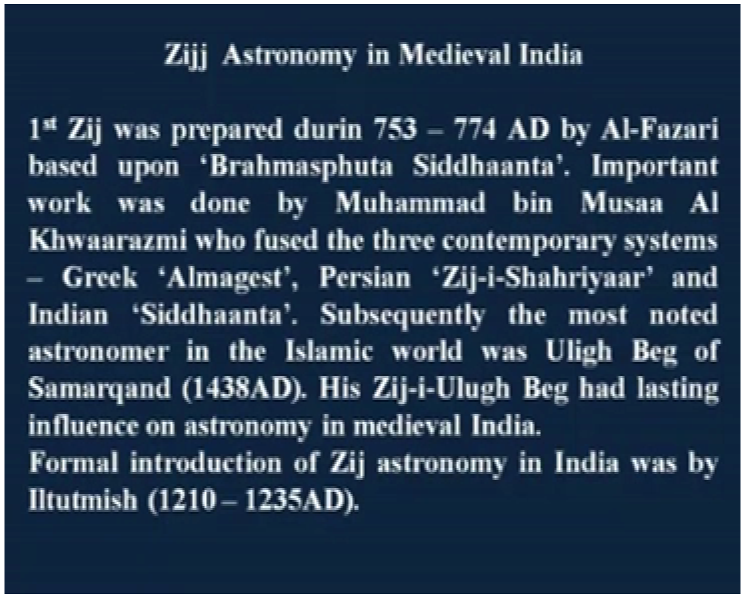
(Refer Slide Time: 6:54)



Now Al-Beruni was very important person in the history of West Asian astronomy. He reigned during the 973 to 1048 AD, he was the most important person in West Asia's astronomical science. He visited India in 1017 AD and spent 14 years studying various branches of Indian science and mathematics. Being a scholar in Persian, Arabic and Sanskrit he wrote 27 books on different aspects of India. I have a couple of them.

He held many Indian astronomers in very high esteem with Brahmagupta at the top. Like Prof. C A Nallino of Rome mentions quote, "The Muhammadans owe the first scientific elements of astronomy to India. These Indian works had many imitators in the Muhammadan world up to the end of the first half of the 5th century of Hijra, that is 11th century AD." Till that time it is the transition of siddhantic texts were taking.

(Refer Slide Time: 8:05)

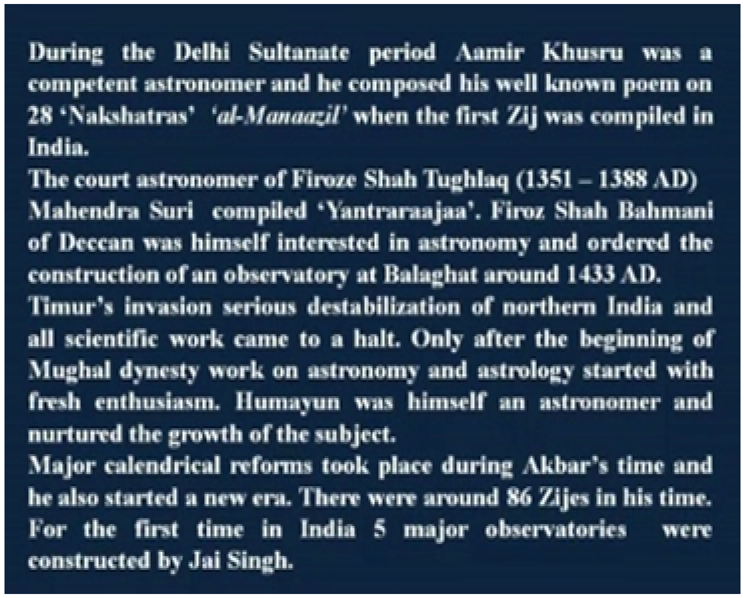


Of course what really the progress was made was through observation. They contributed substantially through continued observation which were more accurate and as I will tell you some of the good observatories were developed there much much before Jai Singh developed the observatories in India. Now Zij astronomy in medieval India, the first Zij was prepared during 753 to 774 by Al-Fazari based upon Brahmagupta's siddhanta as I mentioned.

Important work has done by Muhammad bin Musaa Al Khwaarazmi who fused three contemporary systems like Greek Almagest, Persian Zij-i-Shahriyaar and Indian Siddhaanta. And subsequently the most noted astronomer in the Islamic world was Ulugh Beg. Spelling is wrong, I think it is Uligh, it is Ulugh. Ulugh Beg was the most famous and competent astronomer from Samarqand in the 15th century AD.

His Zij-i-Ulugh Beg had lasting influence on astronomy in medieval India. And formal introduction of Zij astronomy in India was by Iltutmish, we have heard about Iltutmish in history in the 13th century AD. He was the first to bring Zij astronomy in India and got it introduced in the system here.

(Refer Slide Time: 9:30)



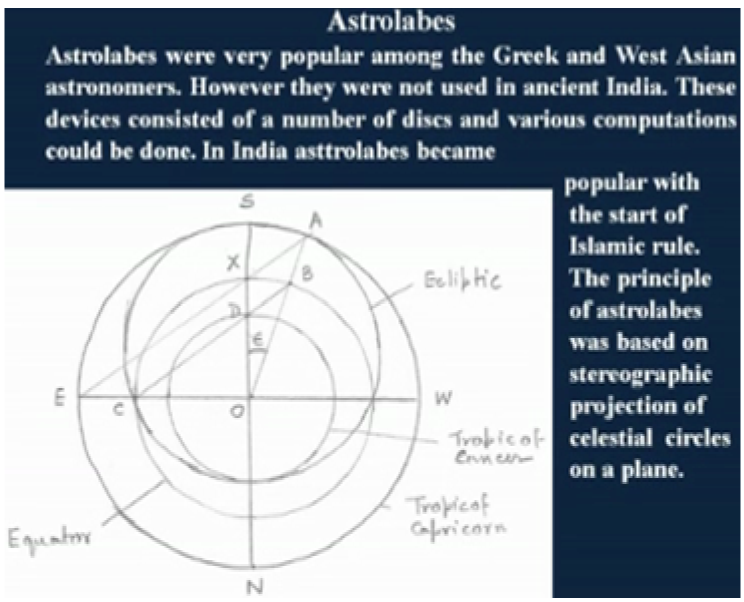
During the Delhi Sultanate period Aamir Khusru was also a very competent astronomer and he composed his well-known poem on 28 nakshatras as al-Manaazil when the first Zij was compiled in India. The quote astronomer of Firoze Shah Tughlaq in 14th century AD, Mahendra Suri compiled Yantraraajaa. And Firoz Shah Bahmani of Deccan was himself interested in astronomy. And actually he thought of constructing the first observatory in Balaghat in the 5th century, 15th century AD but I think it did not come up because there is no trace of it.

Timur's invasion really destabilized whole of north India and all scientific work into the part. Only after the beginning of Mughal dynasty work on astronomy and astrology started with fresh enthusiasm. Humayun himself was a very good astronomer and nurtured the growth of the subject. Actually it is told that he fell from the stair while viewing Venus and he also had his astrolabe and he used to decide timing et cetera, everything based on his astrological calculation. So he fell while observing Venus and going backwards and that fall was quite serious for him as you might have read in history books. Ultimately he died.

So Humayun was of course not only an astronomer but he helped development of astronomy. And major calendrical reforms also took place during Akbar's time. Akbar did lot of things and that was another thing, the reform of the calendars. And he also started a new era not the Hijra but another one. And there were around 86 Zijes in his time and for the first time in India after the Mughal dynasty, that means what is in the going time, that means the grandson of Alamgir, five major observatories were constructed by Jai Singh which I will discuss.

Discussing more Zijes and this is not much important because they do not have any fundamentally new contribution to astronomy so far as India is concerned. So I think what I will do now that I will discuss the instruments which are used for naked eye astronomy and you have seen the accuracy. Say Jai Singh's observatories except one, rest had an accuracy of 3 minutes of arc and the biggest one which you see in, that is what that? Parliament Street, is not it? That is, that has accuracy of 1 minute of arc.

(Refer Slide Time: 12:28)



Now this is one instrument which was very popular amongst the West Asian astronomers even Hellenistic astronomer and it came to India along with the Muslim rulers, astrolabes. And they are very popular among the Greek also. But however in Indian ancient astronomy the astrolabes are not mentioned and it is quite obvious that they are not here. So these devices were for astronomical and astrological computations.

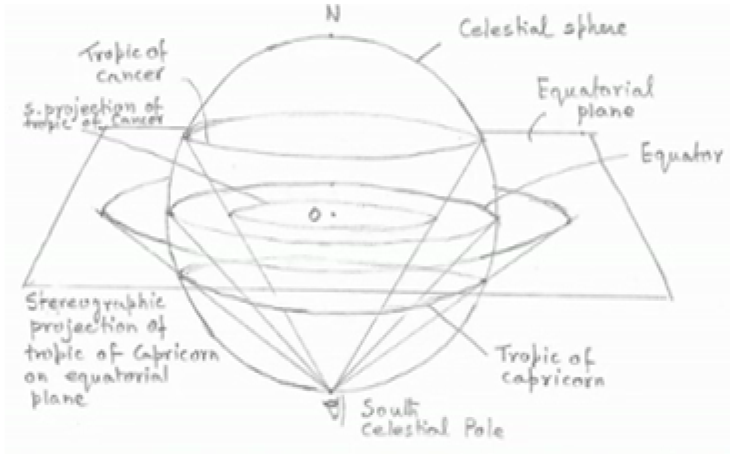
So it consist of number of disks with various markings, somewhat like a circular slide groove and many computations could be done, calculations could be done. And of course the astrolabe just like any sky map you have to see it like this. Do not try to see it like that, it will be totally confusing. So just as you see sky, it has to be done like that. And this is the basic picture what astrolabe represented. And the principle of astrolabe was based on stereographic projection of the celestial circles on a plane. So what you do, the outer circle here that represents the Tropic of Capricorn. Tropic of Capricorn means Makar kranti, not Kirkuk kranti but Makar kranti.

Then what you do, you divide by two perpendicular lines, north-south, east-west. Now you can easily see, you have to view it putting it over head, then only directions will match. Then with this over center and I think what happened, this epsilon was I think our 23.5 degrees. The point A was the first point you have to get and this point A was represented by the intersection of the outer circle and the radian line which is drawn and this angle is the inclination of earth's axis with the ecliptic plane, 23.5 degrees. So after getting this point, you join E point and A point. Where it intersected this SO line at X and you draw a circle with OX as diameter, radius and this is the equator.

Next what you do after you get the equator, then point B and C are found out because this circle intersected at this point with the line OA at B. And you draw a line where this circle intersects line EW, that is C. You join this line, then this intersects the line SO at D and then draw a circle with O as center and OD as the radius. And this represents the Tropic of Cancer. And when you draw a circle like this, this is that, sorry, then you have to draw another circle with this as diameter.

This point and this point, this is the circle. And this circle represent the ecliptic and this is the Tropic of Cancer and this is Tropic of Capricorn and this is the I think equator was this one. Where is the equator, this one is the equator. This is the equator. So now I think this is just the stereographic projection keeping your eye at the south pole.

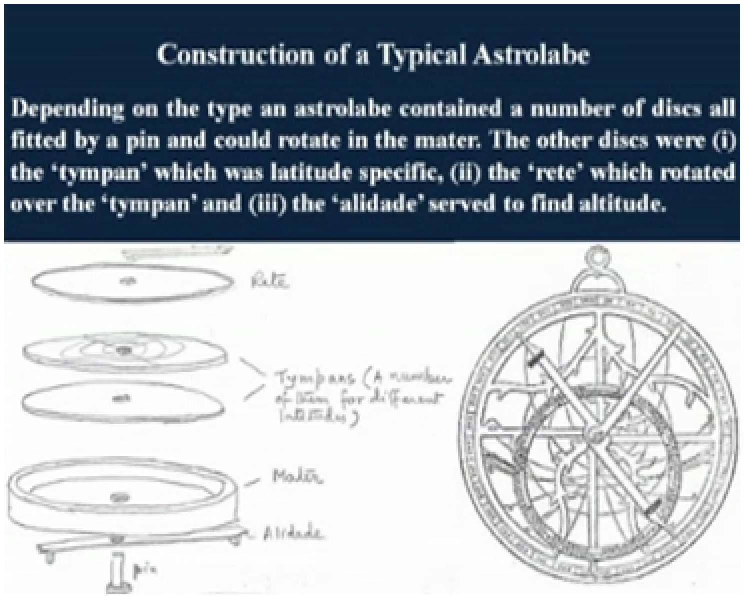
(Refer Slide Time: 16:35)



The figure above shows the stereographic projection of the celestial sphere on the equatorial plane keeping the eye on the south celestial pole. The main purpose was to represent the 3 dimensional sky on a flat plane.

So this is three-dimensional view. I will not go into detailed explanation, it will take time. And I also, I have never seen any astrolabe in my life. But I see, you can see if you go to Jaipur and visit that, only thing that Jai Singh had a big astrolabe but his grandson or son I do not remember, he used it as a target practice, he damaged it very much. For his gun he was practicing, no interest in astronomy. So this figure above shows the stereographic projection of the celestial sphere on the equatorial plane keeping the eye on the south celestial pole. And the main purpose was I think I realized is representing the three-dimensional sky on a flat plane.

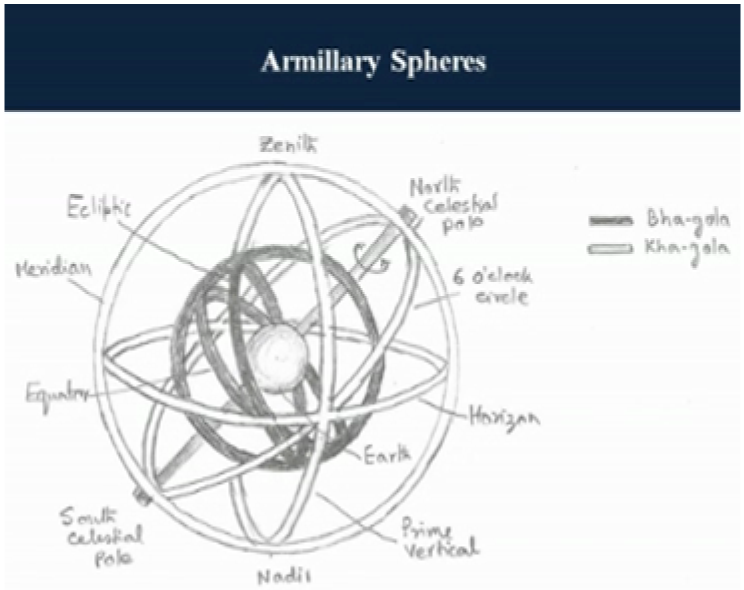
(Refer Slide Time: 17:25)



So these instruments look like this. You have seen in history book or history of science book, it consisted of number of discs. So the main container was called rete and then tympans these are number of thin, number of them for different latitudes. Each latitude has one with lot of markings et cetera and they used to be kept in the frame and they could, they are joined by a pin and they could be moved primarily to all different adjustments.

You could make lot of astrological (calc), astronomical calculations and computations. The details you can go to Internet, you can see the website, detailed explanation is there how it is done. Actually I will also request some of you if you are interested in this, things are done, why do not you make good astrolabe here for IIT Kanpur, okay and keep it somewhere. I will be very happy if I find it next time when I come. Make one, you can go with all the details in the Internet, how it is making and they look like that.

(Refer Slide Time: 18:33)



And I think with the help of with your extra knowledge and modern foundation in science, maybe you can develop a better one. Another kind of device which used to be used which was also in ancient Indian astronomers, they are called armillary sphere. Now the astrolabe was 2-dimensional projection of the sky on a flat plane whereas armillary spheres were actually three-dimensional system representing the sky, earth et cetera.

So this is one typical armillary sphere I am saying. You see, even Aryabhatta describes, Aryabhatta starts saying quote, “The sphere or gola yantra, they used to call it gola yantra which is made of wood, perfectly spherical, uniformly dense all round but light in weight. Should be made to rotate keeping pace with time slowly as earth rotates with the help of Mercury, oil and water by the application of one’s own intelligence.”

So you can think of, you can apply your intelligence and make a device which will rotate with the earth. Now here you see that it was having, I have used different colors which is of course not detailed. So this is the bhagola, bhagola means surface represented the earth things and this is the khagola, that is the sky. So here you can see that the circles and this is the prime vertical meridian. Then I think equator is this one. Where is the equator? This one.

This is the equator and this is the ecliptic, they are two circles at 23.5 degree angle. This is one meridian and this is the axis about which earth rotates. And this is the 6 O’clock circle, there is to be one. And this is the south celestial pole, this is the north celestial pole. This is nadir, this is zenith.

“Professor-student conversation starts.”

Student: Khagola means?

Professor: Khagola comes….

Student: Celestial sphere.

Professor: This is the celestial sphere, yeah. And this is the horizon circle. So these were used even in India. And I think if you look into history of science books, scientist setting an astronomer, you will find an armillary sphere there. So nowadays of course it is of no use because you can have much better things with the help of computer. You have seen that how we can have the planetarium software.

There are far far superior softwares which you can buy but the software I have shown you and I am leaving it here, it is free student version and you can get it easily. Those who want I think, request Professor Amit Dutta, I think you can copy it from here.

Professor 1: I am not sure. Someone has to come to my office and take it in a pen drive.

Professor 2: No, I am saying that…..

Professor 1: I am sending over mail.

Professor 2: One can copy a software from after it is installed. I am not sure about these things.

Student: You can email me in cc.

Professor: The computer science people will be able to tell.

Student: It is hard….

Professor 2: Because it is already installed here, can you take it?

Student: It is not saved, you can scroll to keep that file from the…..

Professor 1: Website.

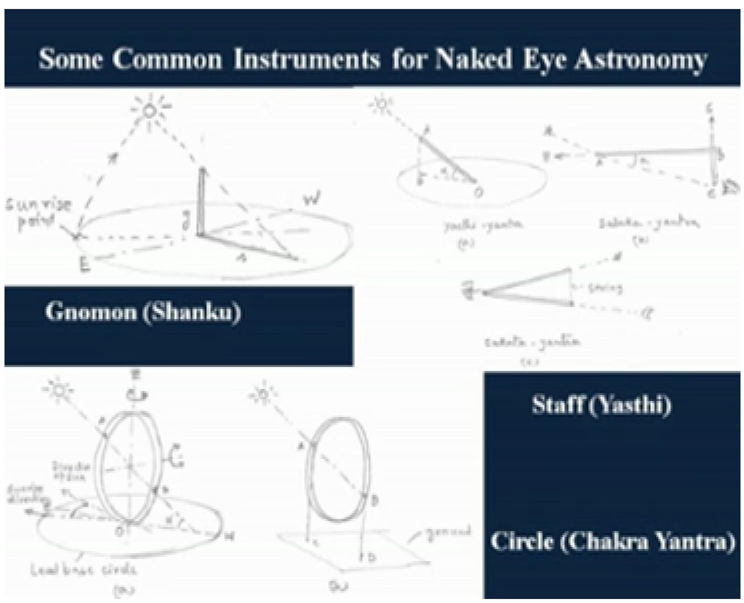
Professor 2: I think that will be better then. Yeah, yes, now I think I will discuss some….

Student: Having (())(22:12). Sir, in 1 minute of arc, typographic signal setup is astrolabe or the other? Typographic setup was this figure, typographic his setup was one showed in the previous slide?

Professor 2: No, his main things were, his things were actually a quadrant. You will find that in those days, I will show that more or less these are the instruments which I am going to explain now. But even from ancient times they used to use these as the common instruments. It will look to you not like instruments like children's toys kind of thing. But it could give that kind of accuracy you can see it. So do not have any disrespect towards these things.

"Professor-student conversation ends."

(Refer Slide Time: 23:00)



One thing is most important instrument is gnomon or shanku. This stick put at right angles to the horizontal and shadow of that is to be used for different purposes. For example, if you have, you are asked to find out the true north and true east, how I am going to do it? You can easily do it. Go to the ground and find out the true north and true east and true south. So it is simple what they will do that they will draw a circle and at sunrise, so after sunrise, sunrise is here, sometime you will find there is a shadow, some length.

After few hours, you again take the shadow and do it in a manner so that the length of the shadow is same. So how it is done? You draw a circle and whenever the shadow touches that circle, you take two such shadows and then bisect it, it will show the, in the northern hemisphere the it will show the northern direction and perpendicular to the space. So that is the simplest way on a sunny day of course not on a cloudy day. You can find out the true north, true south et cetera and that was primarily what they have done.

And shanku had other kinds of things and it is not only for finding out the true east, true west and true north but also as a time indicator for the whole day. That has been, that is why sundial, sundials are also basically a similar instrument. And you will see that Jai Singh's main things are basically similar things typically. There is one yasthi yantra, that is as a stick, it is only to find out the altitude kind of thing. The angle with the horizontal with the particular thing. It could be sun, it could be other thing.

But in case of sun it will be done in such a manner that there will be no shadow at that instant and this is the angle which is the altitude of the sun. There is another kind of, just they are two sticks. One is long, another is perpendicular short. So I want to find out the angle between one direction and a star for example. So I put the main stick towards the direction with which I want to measure the angle of the star and then this way I move this along this till this point and this point aligns with the star and then the sun will be measured. You can measure it.

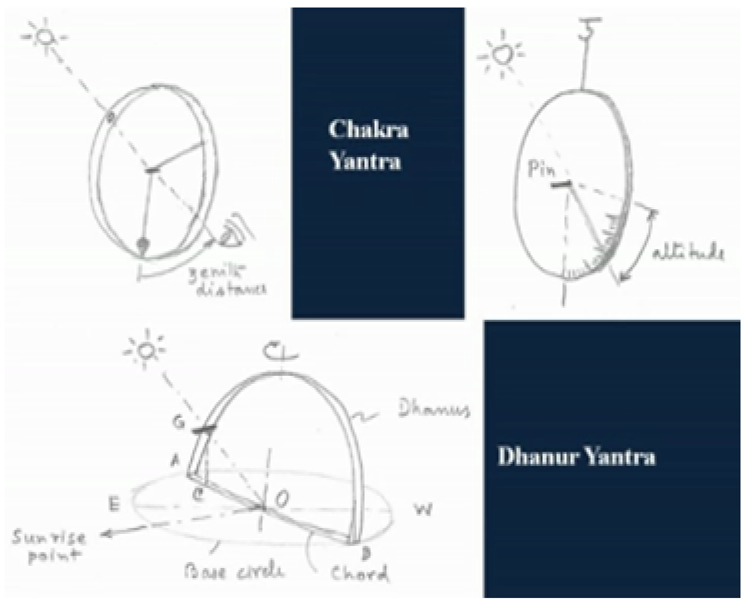
That is, that was used for finding out the, this is shalaka yantra, this is yasthi yantra. So they are used for finding out the angle between a star and a particular direction. It could be another star also. Then we had staff, yasthi yantra, again another type of yasthi. And this is (())(26:18) yantra, so there is one stream and there are two sticks used here. So that is also there how to measure the angle between two heavenly objects like this.

Very simple thing, child's play, not even tier 1 level thing. So these are called chakra yantra, so these chakra yantra, they are used by Aryabhatta also. So this chakra yantra was a hook and diametrically opposite, they are two holes. So you put it on a horizontal plane, you rotate the plane of the hook about a vertical axis till it matches with the plane in which the sun is contained.

Then rotate the hook without changing the plane so that the sunray pass through the two holes and falls here.

So then using the dimensions et cetera you can find out its azimuth and altitude, all those things you could measure. Another one is of course that from the two vanes there are two hanging strings and which is held in hand and from the later, from the length of the strings you can find out the angle. Just variation of the same principle of course.

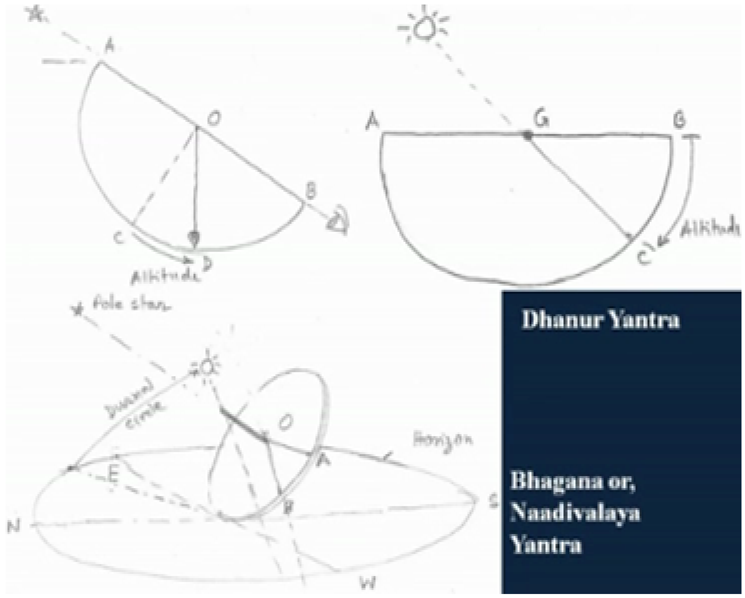
(Refer Slide Time: 27:41)



Chakra yantra, again some more chakra yantras. So here the vertical is indicated by pendulum kind of thing, that is what our (plum) or plumbers do, they use. And then from the center there is a pin and there is plumb and there is a hole and you adjust the hole in such a way that you can see. And this angle you call the zenith distance or the angle it makes with the vertical and so on. And here this pin is here and this is a disk which is hanging vertically. And then this shadow wherever it falls, so it will automatically, this is a perpendicular line to this and which has to be vertical because it is hanging. So this is, could be called as altitude obviously.

And this is dhanur yantra, this is like a semi-circle or dhanush. So you put one diameter on the horizontal floor and rotate it so that the it matches the plane of this dhanush, matches with the plane of the sun. And there is a pin here, you shift the pin along this till the shadow of the pin falls at the center. So therefore this I think gives various things like this: this is the base circle, so you can get the angle, altitude of this and also this is the sunrise point east-west like that. So this is called dhanur yantra.

(Refer Slide Time: 29:26)



These are other types of dhanur yantra. Here it is a semi-circle and there is a plumb and this is one of the radius perpendicular to this. Now you align this side diameter with the star with your eye and measuring this plumb location here you can see that what is the angle and that is the altitude of the star. Obviously because if this is a plumb, it has to be vertical. Similarly here also you will find, one thing you have noticed perhaps in some cases I am showing sun, in some cases it is star.

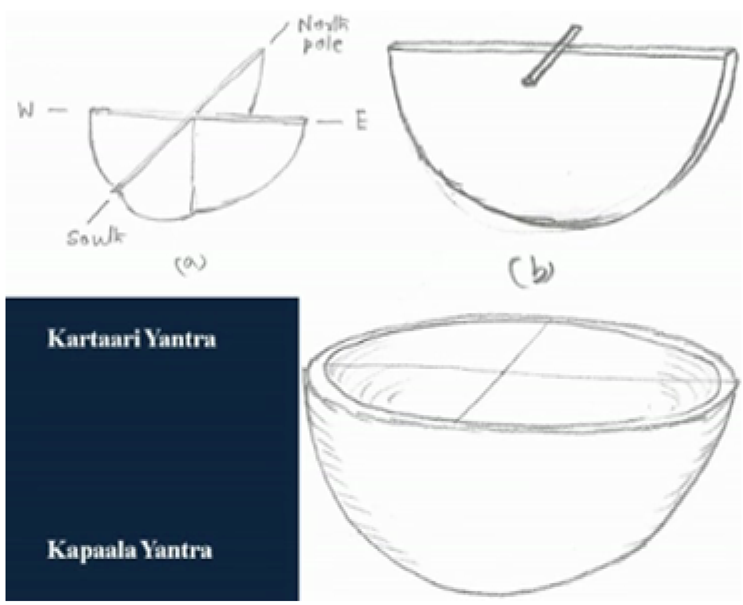
Wherever you are using shadow kind of thing, it is because it is the sun and when direct viewing you can see it is a star. Say of course you cannot look at sun like this, in no time you will become blind. You know that when we are asked not to look at solar eclipse, it is not any religious stigma, it is dangerous. The reason is very simple that when the sun is full you cannot look at it, it is so bright, you cannot. Your units will automatically close.

But when there is only a crescent of the sun, you can very easily look at it, it is so nice to look at. But the image which is formed on retina of that crescent of the sun, its intensity is the same, so it damages the retina. This is proven fact and that is why it is said that not to look at. Because you can easily look it is a very thin line or diamond ring, all kinds of things are told but the image which is formed is as dangerous as the real full sun.

So therefore whenever there is a sun kind of thing, it is always the shadow. There is a pin here, and so this shadow is cast here and you can say this is the altitude. These are all variations of the same thing. Now this is Bhagana or Naadivalaya yantra. As you will see even Jai Singh did this, Naadivalaya yantra, this plane is actually parallel to equatorial plane. And this is a pin perpendicular to this at center and here this shadow, on the equinoctial day shadow will not fall or it will fall on both sides.

And in the Uttarayana period you will find, when the sun is on the north and shadow will fall here. When the sun is towards the south, then shadow will fall on the other side. And this way you can find out all dimensions measuring this angle and all those things. You will see more detailed Naadivalaya yantra constructed by Jai Singh.

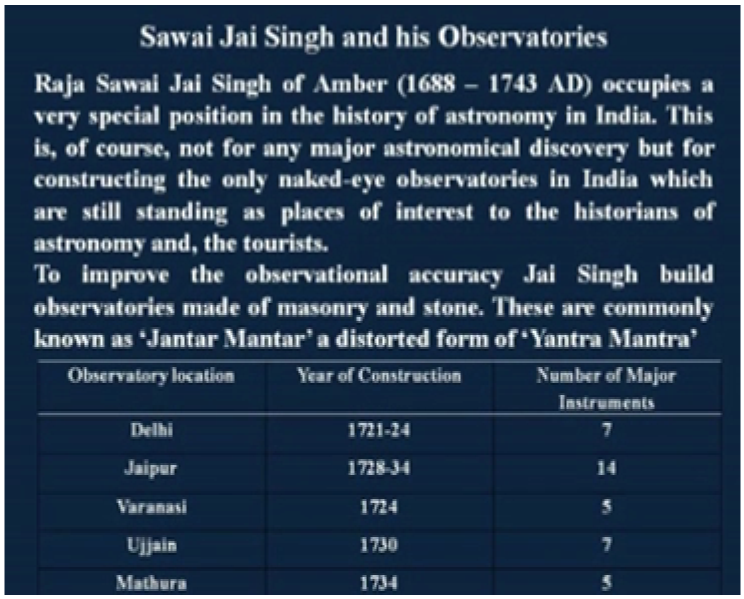
(Refer Slide Time: 32:29)



This is called Kartaari yantra. These are all various, kartaari yantra is again two semi-circular disks at right angles. One is east-west, one is north-south and if you point it to the north pole, and this will be the east-west. Measurements and the markings are there, shadow et cetera, you measure. This is also type of kartaari yantra but this kapaala yantra is interesting. It is nothing but a huge bowl, hemispherical bowl.

And at the top there are two cross-wires. These are two thin wires at right angles, 2 diameters. And so this point will be the center of the circle here. And inside surface of this hemispherical surface, there are given all kinds of markings. Then when the shadow of this cross-wire falls on that, looking at the location of this point, you can get many things like time, altitude, everything you can get. So these are called kapaala yantra.

(Refer Slide Time: 33:44)



Now you see I come to Sawai Jai Singh and you should know little bit of his life, this is very interesting. Now Jai Singh, the Raja Sawai Jai Singh of Amber, he was born in 1688 and lived till 1743. Now we have told that his position is very unique but also I think there are some unfortunate things. So whatever the Eurocentric western scholars might find regarding the absence of observation in ancient Indian astronomy but there are ample evidence as we have told.

Now the what happened that when Jai Singh inherited the throne of Amber after his father Vishnu Singh died in 1700 AD at the age of only 27 at Kabul, he was fighting along with the Mughal. At that time Mughal empire was on the decline and to control, the Marathas engaged in constant Guerrilla warfare in the Deccan. Jai Singh was sent by Aurangzeb to the south. Jai Singh was only 14 years old at that time.

There when he was in the south, he met a young mathematician and astronomer Jagannath and that friendship was a lasting friendship and did everything. So what happened as such, the foundation for a lasting friendship, the theme was laid and after Aurangzeb's death in 1707 when Jai Singh was still in the south, the political situation in Delhi became very uncertain. The whole thing was being controlled by actually a group of people, they are called counsel of emirs or emirates.

And then Aurangzeb's great grandson, Muhammad Shah as the emperor, Jai Singh was on reasonably good terms. Aurangzeb was very old and served him in various capacities. Though Jai Singh's control was over in his native area Amber, that measured no more than 7,500 square kilometer. By 1730 his authority extended to a much much larger territory from Delhi to Narmada. In fact during that period Jai Singh enjoyed more power and respect than the emperor according to French Traveler. Now observators of Jai Singh which is our interest.

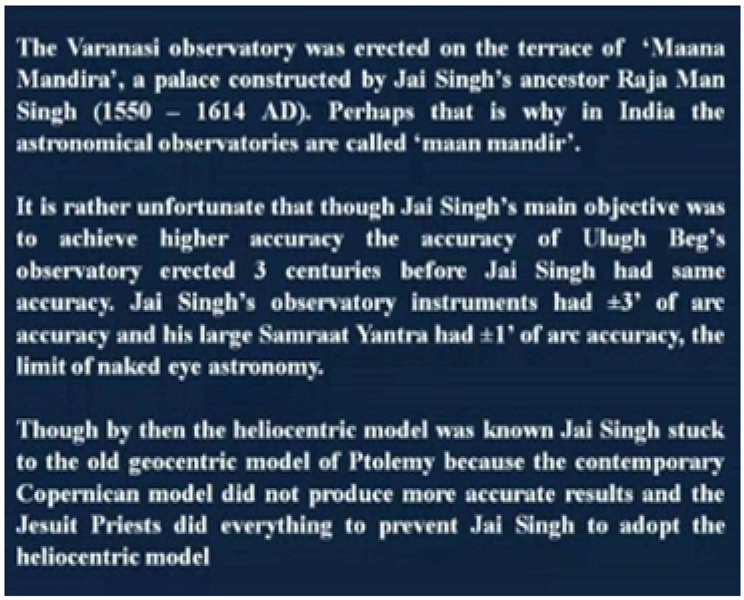
So whether Jai Singh had more interest in ruling a kingdom or pursuing astronomy is not known. But he knew Arabic and Persian and as well as Sanskrit and was quite familiar with Islamic astronomy along with the siddhantas. He had a number of astronomers in his court. The most important among of them was of course Jagannath and who translated al-Tusi Arabic version of Ptolemy's al-Majist into Sanskrit under the title Samraat Siddhanta.

His other quote astronomer was (())(36:56) from Gujarat and he wrote dozen books et cetera. And Jai Singh also compiled a zij called Zij-i Muhammad Shahi in the name of his friend Muhammad Shah. But actually it was nothing but based, these days it will be called plagiarism, what he did was Ulugh Beg's zij actually. Now interesting thing is that he was at a time when Copernican theory et cetera was there, it was known.

But he was unaware, he thought that the, he checked all the tables. He was finding the results were not accurate now and he thought that this on accuracy is due to inaccuracy in observation. He never suspected that our model of this system, the universe was wrong. So he thought, his main concern was tackled by like tackled by, to improve the accuracy and he thought that making instrument with small wood or metal pieces they are subject to many distortion.

He thought he will make observatories using machineries, stone, concrete, and something like that. And that is how, and he wanted to make them big and that is why actually there were quite a few observatories he set up and primary aim was improving the observational accuracy. And these are known as Jantar Mantar which originally called Yantra Mantra, Sanskrit term. In Delhi it was constructed during 1721 to 1724 and there are 7 major instruments. In Jaipur the construction was from 1728 to 1734 and there are 14 major instruments. Varanasi, 1724 and there are 5 instruments. Ujjain, there are 1730, there are 7 instruments. And Mathura, 1734, there are 5 instruments. So these 5 Jantar Mantars were there.

(Refer Slide Time: 39:20)



In Varanasi I think the Jantar Mantar or the observatory was erected on the terrace of Maana Mandira, that was the name of a palace constructed by Jai Singh's ancestor Raja Man Singh. You all know about him, Man Singh. That is why today astronomical observatories are called Maana Mandira in India in Hindi, is not it? And that originated from that. The Varanasi observatory was erected on the roof of Maana Mandira, was the name of the palace. So we call astronomical observatory also as Maana Mandira.

Now you see that though his objective was to improve accuracy by having bigger system made of stone and machinery et cetera, so the accuracy of Ulugh Beg's observatory erected 3 centuries before Jai Singh has the same accuracy. Jai Singh's observatory instruments as I mentioned had plus minus 3 minutes of arc accuracy and his the largest one, Samraat Yantra which I will explain and discuss, it had plus minus 1 minute of arc accuracy, better than typographic observation. And that is also considered the limit of naked eye astronomy. Yeah.

“Professor-student conversation starts.”

Student: Those instruments were there, sectional type. So there if you, I mean 1 minute of arc, which one was 1 minute of arc, ones you respect?

Professor: Accuracy, that is suppose you are measuring the angle between two objects, or you are measuring the altitude or measuring the azimuth. Whatever it is, any angle because astronomical observation is nothing but angle measurement. There is nothing like distance. It is only angle. So the actual value and the accuracy with which you could measure it, that is this.

Student: So the extent ones, I mean feels like there will be only one degree, like 1 minute is that they have to really decide on….

Professor: Yeah, so that is why here we say it is like this. But in real life it is not that simple. They were all, then he has to make the accuracy. This is why, so I am told that each reading they used to take very accurately and there used to be large number of assistance also. It is not impossible to handle those, all those things by one person. So typographer also had a large number of assistance, same thing with Jai Singh. They had large number of assistance.

Student: Just previous one, just you can make the what the modern (())(41:44) thing here to….

Professor: No, I must say that one gear kind of thing like your micrometer comes with, no, they did not have that. Micrometer principle was discovered in towards the end of 19th century. So I think this is very unfortunate thing. And why it happened? Why Jai Singh did not, it was there Kepler things were there, the heliocentric model concept by Galileo. You can see, you show the Galileo and Jai Singh, they are contemporaneous, is not it?

“Professor-student conversation ends.”

Galileo was born in 1565 or so and died at 1642 and Jai Singh’s date I told was 1688. Actually he was after Galileo, almost at the time of Newton. So I think why by that time, gravitational law et cetera all are known. The reason is there. Now he at that time interaction with the West started and lot of Jesuit priest used to come from Europe. And Jai Singh and they used to bring I think all knowledge of West, I think European astronomy.

And Jai Singh took lot of interest in that and he used to depend quite a lot on them. So once he sent a team to Spain I think or Portugal I do not remember with Jesuit priest to bring more information, more modern information. Now all the Jesuit priests were very much against heliocentric model, you know that. That is why Giordano Bruno was burnt alive, Galileo was put in jail. So they did their best to prevent Jai Singh in getting active in heliocentric astronomy.

So that is why Jai Singh depended on them so much on the modern development but they almost isolated him from them. But it is told that Jai Singh had a telescope, I will read it later. And he had something which is not known but I have read in history of science book published by your Indian National Science Academy. This I also did not know, I will tell you here. I could tell it later but I think it will be better to tell.

Now Jai Singh knew certain things and perhaps did some experiment with telescope that need to be done. So S.M.R. Ansari, he is scholar who deals with the history of astronomy. I have read his paper and he refer, he reference to Jai Singh's knowledge based on telescopic astronomy are found on the following topics: the ellipticity of the lunar and solar orbits, the existence of four Jovian satellites, oblate shape of planet Saturn because that time the ring was not clearly visible.

Galileo saw it first, he first thought that planet has two ears and in those days the scientists used to do very funny things. He observed something and then he thought whether to publish it or not. He thought that if it is something stupid, he should not publish it because there are so much of acrimony and other thing because of the paradigm shift was taking place. So what he did, he sent a secret message which could be deciphered as the discovery of Saturn's these two bulges and sent it to some other scientist hoping that when later it is discovered and it is found to be true, he will claim his priority.

Okay, but after some time he was horrified to see that those bulges are gone. So he was so scared that then again after quite long time he again was then, what happened actually the Saturn, the ring planes, at that instant the plane of the ring was coinciding with our line of vision. So we could not see the bulge and plate, the rings are very thin. So if you are looking along the, and the edge of the ring you will not see them and that is precisely happened.

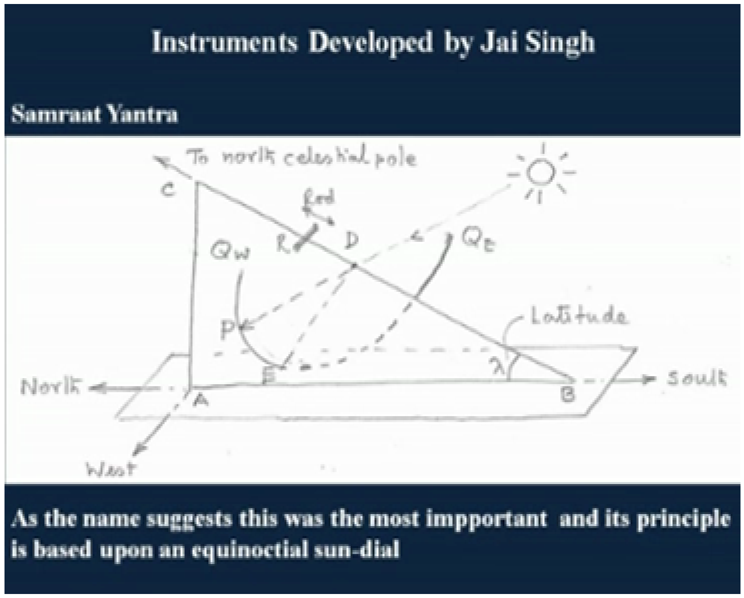
With time at that location Jupiter, Saturn's ring plane was matching with the line of vision. But again after some time those bulges reappear. And then he told that I have observed these, please, also it was a new discovery, the planet with ears. And later he found that there are two circles but he did not know that they are rings. So therefore the oblate shape of planet Saturn was the kind of knowledge they had. And phase of planet Venus and Mercury.

So why Jai Singh did not pay too much effort and attention to telescopic observation, there is another theory because with telescope at that time was a qualitative measurement. Till the cross-wire was invented and attached to telescope, it was not measuring instrument, it was just like binocular kind of thing. Once the cross-wire thing was developed, it started giving numerical quantitative planets.

So telescope was not very useful as his objective was to have more accurate observation. That means he has to get measurements. With telescope measurements were not possible at that time. Secondly the heliocentric model of Copernicus, the results are no better than the geocentric model of Ptolemy. So there was no impetus from Jai Singh to really go for heliocentric model but I do not know S.M.R. Ansari found this but he says that these are there in the writings where Jai Singh, he had a telescope and he had these observations.

I will now discuss something about Jai Singh's instruments developed by Jai Singh. This is the most important and most prominent instrument, samraat yantra. And you have seen that it is nothing but equinoctial sundial kind of thing. Equinoctial sundial something like that Naadivalaya yantra, that the plane which is parallel to the plane of the equator. That is sometime they are called equatorial sundial, that is same thing. And then there is a shanku and the shadow falls on that.

(Refer Slide Time: 48:58)



So here you see what was the samraat yantra's basic principle that this is thin just like x square. A thin slab vertical and this angle is equal to the latitude of the place or the location. And it is oriented towards in the north-south direction exactly. And then perpendicular to this plane there was a circular arc, Q east to Q west and starting from here. Then what happened, and this was a solid thing. So when sun comes, the shadow of this edge will fall at some location here.

And that will tell you the time accurately. Have you gone to Delhi to see Jantar Mantar? You have seen the markings on the marble, the piece of marble there. So if the sun is there, this will cast a shadow on the quadrant. In the morning the shadow will be on the western quadrant and in the afternoon it will be on the eastern quadrant obviously. And that will give you the time of the day just like a sundial.

Again there is a rod here which you can move along this and there are markings. So this rod you are moving till the shadow of the rod falls at this point and the marking here will tell you the altitude of the sun. So primarily the time and altitude of the sun, these are the two things you can get very accurately with an accuracy of 1 minute of arc.

“Professor-student conversation starts.”

Student: Sir, size is bigger.

Professor: Size is bigger I am telling you. Its size is, height of that end…..

Student: Size is….

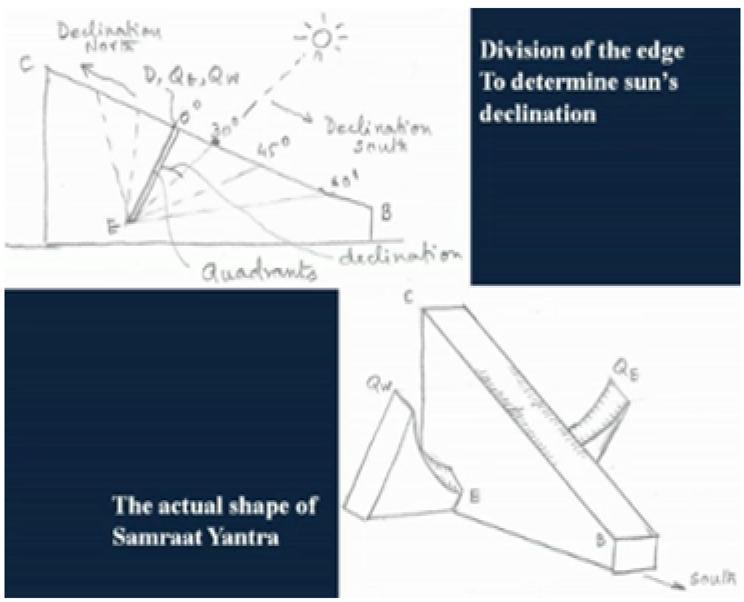
Professor: Height is 22.6 meter, 6-storey building I believe.

Student: That is why I think it is compressive at the…..

Professor: Obviously. So this is a 6-storey height, building height, 22 meters, 22.6 meters. The Delhi, that Delhi somewhat location.

“Professor-student conversation ends.”

(Refer Slide Time: 51:16)



It looks like this. And as I mentioned that the declination north and declination south to find out right ascension and declination, I told you in the equatorial system. So you have to shift this rod along this and when the shadow of the rod falls here, this angle is the declination and that is marked here. So one thing is very clear, the marking or (())(51:41) has to be non-linear, is not it? It is not linear, you can see that. So 45 to 60 is so much or 30 to 45 is so much and 0 to 30 is only this much. So marking if you go to Delhi, and you will see that they are non-linear. Now the actual shape of samraat yantra is something this, is not it?

(Refer Slide Time: 52:06)


Jaisingh's Observatory for Naked Eye Astronomy

And let me see the photograph, I have one. This is the one I am talking about, this is Jantar Mantar. That is a 6-storey building from here to here. And actually this is smaller version. These are the quadrants, eastern quadrant, western quadrant. And the steps are there because somebody has to go up and down. Yes…..

"Professor-student conversation starts."

Student: If this angle which you measured is not the latitude, then the angle if the latitude comes, why is that required first of all and if that is inaccurate, what will be the range?

Professor: If it is inaccurate, obviously everything will be inaccurate. But it is obvious because you see it is equatorial system, that means this whole these are parallel to equatorial plane. Okay, and it has to be perpendicular to that. So anything which is perpendicular, that means it is nothing but the shanku.

Student: Equinoctial?

Professor: It is nothing but equinoctial sundial, just that, very large signs. So if it is the perpendicular to the equinoctial plane, that means it has to point towards north pole, is not it? And this angle has to be latitude.

Student: So he had measured the latitude with some other instrument to make this instrumental?

Professor: That, maybe measuring latitude is relatively simpler problem. That is relatively simpler problem. Yes.

Student: Sir, but time depends on the declination on the scene.

Professor: Hah!

Student: So that is….

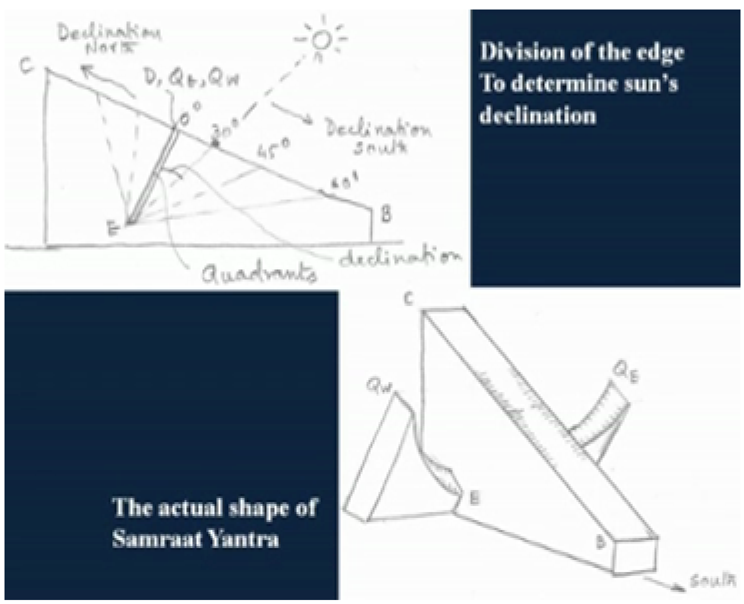
Professor: Seasonal.

Student: So latitude made on that….

Professor: So I think they had for that tables et cetera, they all had that. So that means depending on the season what is the declination, everything will change of course.

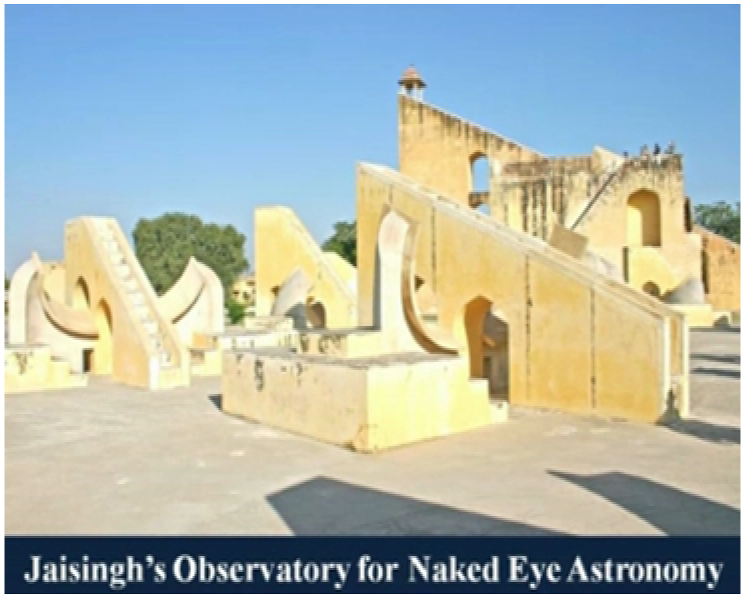
"Professor-student conversation ends."

(Refer Slide Time: 53:55)



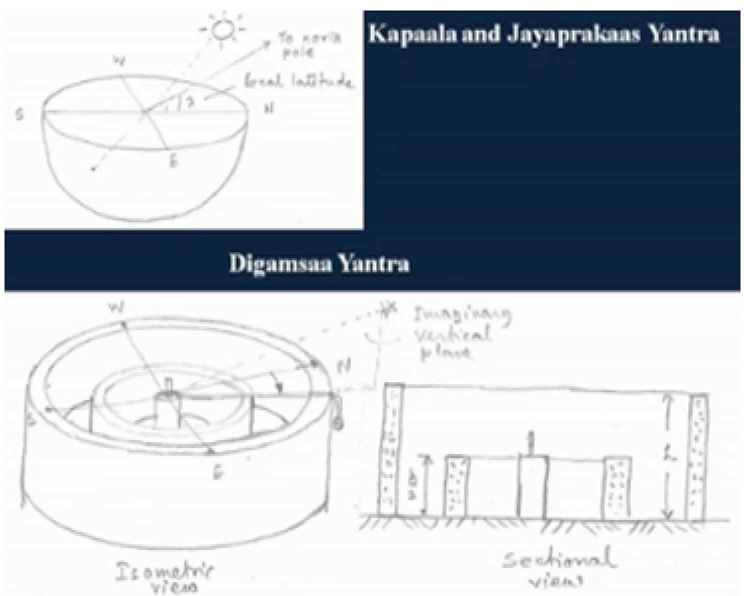
And actual shape is like this. I have gone one long back. These days only I passed by that Parliament street, somebody is giving dharna and all kind. It is used for that purpose I believe these days. And people take there, I think it is not allowed to take food inside or is it? Earlier it used to be your picnic spot I remember in 62 when I was there.

(Refer Slide Time: 54:19)



So these are the Jai Singh's observatory for naked eye astronomy. There are various yantras we can see.

(Refer Slide Time: 54:29)



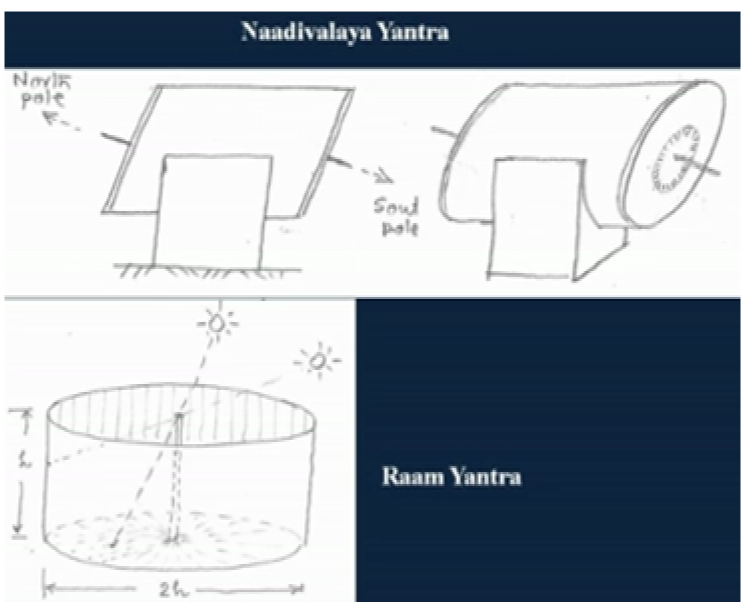
Other yantras as I mentioned Kapaala and Jayaprakaas yantra. The kapaala yantra, this is a huge bowl and I explained this and these are the two wires or ropes. This acts as a cross-wire. And inside the markings are there where the shadow falls. And from the shadow the marking gives that what is the reading and somebody will go inside and then see the, size of this kapaala yantra in Delhi I think the diameter of the this yantra, Delhi and Jaipur.

Delhi is 8.3 meter, is about 25, 30 feet, that is the diameter. Next is digamsaa yantra. digamsaa yantra is used primarily for measuring the azimuth angle of the heavenly objects and it consisted of two concentric circular walls with a central pillar. I have shown that here, this is a central pillar, gives two circular walls. And there is two ropes, one is east-west direction, one is north-south direction. Another rope with a hanging weight here.

So you can, when you want to view something, say image of a star, so then you have to move this along this till these and these are in the same plane and this angle is given as the azimuth angle. So the size of the yantra here in Delhi, it was built only in Jaipur, Varanasi and Ujjain. Delhi it is not there. And the wall height was, this was 3-storey building, this height. And this height was approximately just almost slightly less than one story.

So this was actually 3-storey building, so it will look like a huge circular enclave. And this is the cross-section, how it is looking. This is height h, this is h by 2, this is the sectional view. But in not all cases it is h by 2. In Ujjain it is different as I can see. But these are all pretty big machinery works as Jai, he wanted higher accuracy. But the accuracy unfortunately was not more than that of Ulugh Beg which was constructed 300 years back.

(Refer Slide Time: 57:20)



These are two important yantras, naadivalaya yantra. These are again nothing but equinoctial sundials, two. One on the north face, another is the south face. These are parallel to equinoctial plane. And this is pointing towards north pole, this is pointing towards south pole, it looks like this. And again a dial is there. So it is for measuring the time and identifying the equinoctial point.

Equinoctial day what will happen that it will be exactly parallel and both will cast shadow. So that day and other days only one side will be having the shadow of it. Next was Raam yantra, so and this naadivalaya yantra in Jaipur, the plate diameter was 3.6 meters. That means how many feet? 12 feet kind of thing, 11-12 feet diameter. And the separation was about 16-17 feet. And raam yantra is, raam yantra name was given perhaps after his grandfather Ram Singh many people think that way.

And the instrument was in the form of a cylindrical structure with open top and a cone with the same height as the surrounding cylindrical walls. And the floor and the inner cylindrical surfaces or surface was engraved with scales indicating azimuth and altitude. It is very simple to follow. So there is a pillar here and these are all vertical line scales. And here there are radial lines. So when there is sun, the shadow falls here and from that you can easily find out the azimuth looking at where it is falling in vertical.

When it is going here, then its marking will be here. So you can measure at a time, measuring the shadow and its location and the reading you can get both azimuth and altitude. These are the main things, these angles. Astronomy is nothing but measuring these angles. So raam yantra, its size let me see if it gives. Yes, and raam yantra was constructed only in Delhi and Jaipur. Wall height and the radius for Delhi raam yantra about like a 2-storey building.

It is 7.5 meters. The accuracy for both of these in the order of 6 minutes of arc, all the marking et cetera. So 6 minutes of arc accuracy you had in this raam yantra. Then the most famous and most attractive yantra is there which is generally photographed but it is astronomically it was never used very much and neither it gives any better result. That is called misra yantra.

"Professor-student conversation starts."

Student: One small thing. The diameter of the sun is about 20 minutes or so?

Professor: No, 30 point something.

Student: 30 minutes.

Professor: Half a unit.

Student: 6 minutes means one side of the sun.

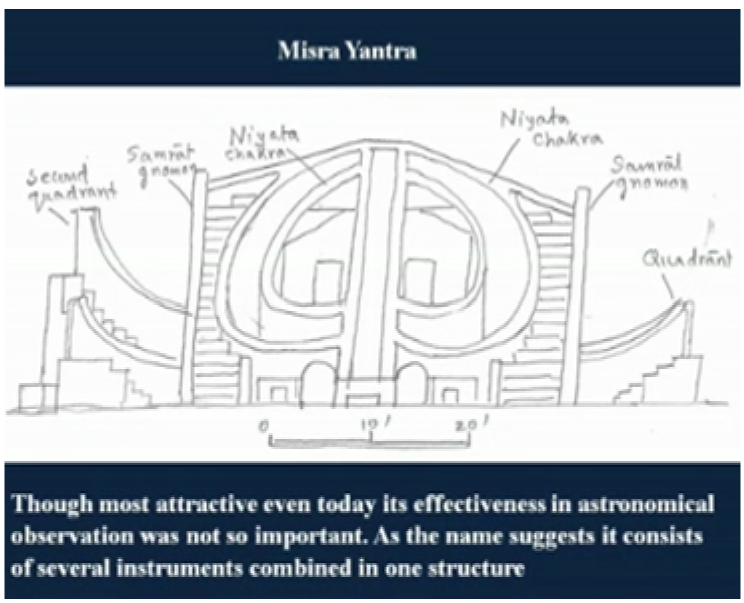
Professor: Only one side. They were very careful about it. When they touch one side, it comes, then only they take.

Student: So then okay.

Professor: Yeah. You are very careful.

“Professor-student conversation ends.”

(Refer Slide Time: 60:41)



So the misra yantra, you have seen this photograph many places, it is a very attractive structure and most photograph structure so far as this Jantar Mantar is concerned. But it is not clearly very useful. It was a combination of various yantras. It combine samraat yantra, this yantra and quite a few others. And observationally it was not very important, neither was it very used. Only it was kind of very nice looking sophisticated thing.

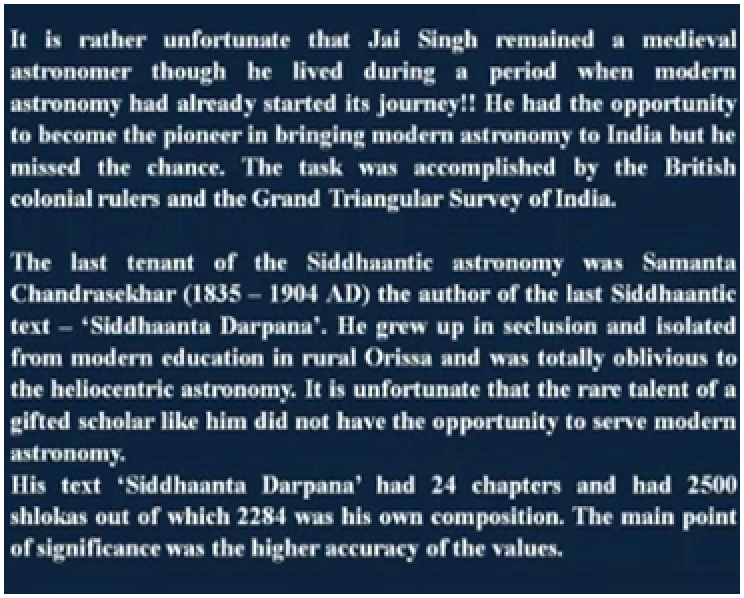
And I think your, also pretty big, I do not remember, the sizes are not given here. I think the scale is here. So this is 20 feet as I given the scale. So you can see the whole thing is about 100 feet kind of thing. So pretty big, massive thing. And you can see these are the quadrants and this size, this is one of the gnomon, samraat gnomon, this is another samraat gnomon. Symmetric thing, this is another quadrant. And this is a nitya chakra, I do not know all kinds of things.

Now I think Jai Singh's aim was to rejuvenate Indian astronomy rather than really pursuing the truth. And unfortunately he could not achieve. He clung to the geocentric model. To bring the wisdom from Europe, he chose wrong country, Portugal for sending his envoy, not Italy. Thus hardly any modern idea was brought back to him. He also spent money and effort on building perpetual machines that took lot of time and effort.

It was said that an amount of equivalent to US dollar 25,000 was spent by him on experiments in that direction, constructing perpetual machines. Even though Jai Singh was born after Newton's principle was published, Jai Singh's astronomy remained archive in character. He had the telescope but it did not occur to him to use it as an astronomical instrument. The reason I told you, it started becoming an instrument only after the technology of cross-wire was developed in.

So he died in 1743 and his second son, Madho Singh demonstrated some interest in astronomy. In fact it was he who built the misra yantra of Delhi that of course many may not know. Misra yantra was constructed by his son. And that is why it did not have much astronomical importance. And he had the opportunity to become a pioneer with his resources, his interest in astronomy, he, wonderful assistant like Jagannath but I think he chose wrong people and the result was this.

(Refer Slide Time: 63:48)



The last one in the whole history of siddhantic astronomy was Samanta Chandrasekhar of Orissa. Now the, he was born in 1835 and died in 1904. So you can see it is a very recent thing. He was even in the 20^{th} century. And the last siddhantic text was written by him which is called Siddhaanta Darpana. It had 24 chapters and had 2,500 shlokas out of which 2,284 was his own computations.

And he was definitely very talented person and in seclusion he grew up. So he was unaware of these happenings. You can see by that time in India itself telescopic astronomy was quite prevalent but he clung to the same old siddhantic astronomy and naked eye astronomy. So the in spite of that fact of course his Siddhaanta Darpana, he noticed the inaccuracies and he tried to improve the accuracy.

(Refer Slide Time: 64:48)

The values of the inclinations of the placatory orbits according to various Siddhaantic texts

Planet	Surya Siddhānta	Siddhānta Siromani	Siddhānta Darpana	Modern value
	° ′ ″	° ′ ″	° ′ ″	° ′ ″
Moon	4 30 -	4 30 -	5 09 -	5 08 33
Mercury	5 55 -	6 55 -	7 02 -	7 00 18
Venus	2 46 -	3 06 -	3 23 -	3 23 41
Mars	130 -	1 50 -	1 51-	1 50 59
Jupiter	1 00 -	1 16 -	1 18 -	1 18 18
Saturn	2 00 -	2 40 -	2 29 -	2 29 10

And you can see the improvement which is very apparent here. These are nothing but the inclination of the planetary orbits according to the various siddhantas. The planet orbits you know, various planet orbits are inclined to the ecliptic plane as I mentioned. So that angle is very important to make good estimate and do correctly. So you can see the five planets here and along with moon, their inclination to the ecliptic plane.

In Surya Siddhanta it is moon, 4.3 degrees. In Siddhanta Siromani it is 4.3; Siddhaanta Darpana, 5.09 and actual modern value is 5.0833. So you can see a substantial improvement which is the correct value and Siddhaanta Darpana, Samanta Chandrasekhar is this. Whereas the old values were quite inaccurate. So when you go to Mercury which is very difficult to observe, Mercury is so near sun, extremely difficult to observe.

So the Surya Siddhanta gave a value of 5.55. Siddhanta Siromani gave 6.55, your Siddhaanta Darpana gives 7.02 and here you can see it is 5 degrees, 09 I must say. You should keep that in mind up to minute of arc, second of arc you know. So 5.09 means 5 degrees 09 minutes. Here it goes up to second modern value of course. So 7 degree 02 minutes, Siddhaanta Darpana was so accurate, here it is 7 minutes and 0018 seconds.

So I think it is very clear that he made tremendous improvement in accuracy with his instruments, also simple naked eye instruments which he designed, he constructed and fabricated.

“Professor-student conversation starts.”

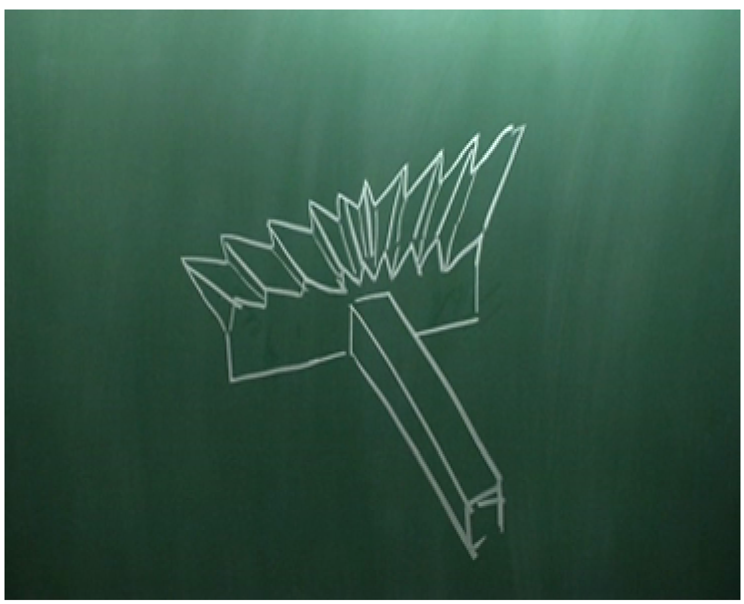
Student: Did it kind of give instrument like Jai Singh one?

Professor: No, only handheld. So and you can see the improvement in accuracy.

“Professor-student conversation ends.”

So his life history you can find in the book, I am not reading it. So his instrument, his own observational instruments is developed. Of course they will resemble some of the instruments in siddhantic text. But one of his instrument called Mana yantra, it is very interesting. It look like, I am unable to resist the temptation how it looks.

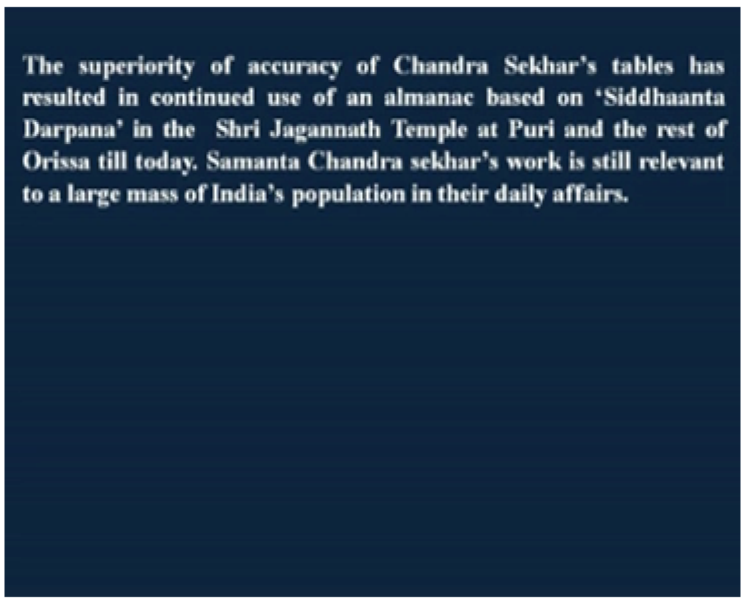
(Refer Slide Time: 67:30)



I am taking some approximate. So these are suggestions with different angles. And this was the one invention because no such instrument is found in any siddhantic or other text. And with this Mana yantra was his own invention, it was a multipurpose instrument that could measure you see latitude, altitude, zenith distance, sun’s declination, angular separation and the sun’s position in the zodiac.

And this instrument in the form of T as I showed and crossed up was engraved with 24 slots with progressively increasing inclination and it could do so much with such accuracy. He also designed chaap yantra for measuring, measurement of time. And golaardh yantra and that was also similar to kapaala yantra like that. So his Siddhaanta Darpana is still in use in Orissa because all things with the sacrifices et cetera in Jagannath Temple, they are all guided by Samantha Chandrasekhar's calculations. And not only there but even in the society of Orissa most of the households follow the panchang prepared following the Siddhaanta Darpana even today.

(Refer Slide Time: 69:37)



So however the fact remains that he was very much in the telescopic era but he devoted his whole life, actually he was not known, then one I think it is sometime just for the sake of history we should know. Samantha Chandrasekhar was reputed more as an astrologer. People thought he is an outstanding astrologer. He was a gifted astronomer and he was born in 1835 as I have shown in Khandapada, 100 kilometer west of Bhubaneswar.

It was a small state surrounded by hills and jungles. Samantha was born in a royal family when his uncle ruled the small state. His early education was primarily in Sanskrit and Sanskrit based literature. At the age of 10 his uncle introduced him to the basics of astronomy and Samantha himself learnt the siddhantic astronomy. When he was 15 he wanted to check the astronomical predictions of siddhantas through his own observations with the instruments made by him.

To his utter dismay Samantha found the predictions to fail in predicting correctly the positions of the planets and stars. Repeated checks finally convinced him that historic texts like Surya Siddhanta, Siddhanta Shiromani needed further correction. Then he took it as his life's ambition to incorporate all the necessary corrections in siddhanta astronomy. Amazingly he designed his own instruments for naked eye astronomical observations yielding results with much better accuracy.

Starting at the age of 15 Samantha Chandrasekhar began his astronomical observations and theoretical analysis for the next 8 years. Reaching the age of 23 Samantha started systemizing the huge data collected by him and at the age of 26 he started writing the text compiled by him, the last siddhantic text, Siddhaanta Darpana. He wrote the book in Oriya script on palm leaves. Because of his isolation from modern educated world, the text remain confined to a corner of his house for 30 years.

On his chance meeting with Professor Mahesh Chandra Nyayratna, principal of Sanskrit college Calcutta during one of his Orissa tours, professor Nyayratna was greatly impressed by his talent. And it was professor Nyayratna who introduced Samantha to professor Jogesh Chandra Roy of Pathak college, present day Ravenshaw College who played a key role in getting the Siddhaanta Darpana published in Devanagari script from Calcutta in the year 1898. Only after the outside world came to know about Samantha Chandrasekhar and his valuable work, so that is the end of siddhantic astronomy in India.

And I think tomorrow the last what I will do, I will give some interesting, very interesting and it in the history of astronomy they have remained as fascinating stories with tragic results. Sometime they are not, they are very tragic stories you will see. And beginning of telescopic astronomy but major part of tomorrow I will also discuss the whatever the recent research tells about the antiquity of Indian astronomy and also the originality, how much of it is original and some discussion on the controversies about the originality of nakshatra system, different scholar's view, I will discuss that.

I will not discuss much about the development of radio telescopy et cetera in India, that is at modern period and that is not the objective of this because they are all current things going on. So I think if there are few questions, we can discuss that. Yeah.

“Professor-student conversation starts.”

Student: This Jogesh Chandra Roy, is he the author of this book on, Bengali book on Jyotishi? Do you know him?

Professor: I do not know. Bengalis work done, lot of work in the 19th century was Kalinath Mukherjee, it was one. And 20th century I have told P C Sengupta and others. But in the previous century Kalinath Mukherjee was actually inspired by Hershel’s grandson. He was a civil servant in the district of Nadia where and he taught Hershel’s grandson Kalicharan Mukherjee and he was a lawyer but he used to practice astronomy at his home.

Professor 2: Any other questions?

Professor: So how is the story of siddhantic astronomy, I think it is very interesting. You have already found out, we are discussing about the Katapayadi system. So he was worked hard and he has found out yes, that slope gives the value of pi. I think it is that Shankaracharya….

Student: Puri Shankaracharya.

Professor: Puri Shankaracharya, who has also written that Vedic mathematics textbook. He has given that.

Professor 2: So was there interaction with physicians and astronomers, it is….?

Professor: Maybe they were actually same thing. Mathematics owe lot of development trigonometry and other things on astronomy. And astronomy also owe lot to mathematics. And since Indian mathematics was most developed, so it is obvious that our things will be superior to others.

Professor 2: So one more question. So they had their school effort, students will come to them, was some system built especially for Aryabhatta or later on?

Professor: They had recitals obviously. They have recitals. The whole subject I think there are thousands of astronomers who have worked. We have presented only absolutely small miniscule fraction of that. Even I have not been able to discuss Parameshvara or Nilkantha who were the Kerala very famous astronomers.

Student: Sir, you have shown main instruments. You have shown the picture of instruments. No one has used magnet as means using….

Professor: What?

Student: No one, you have shown many instruments. No one has this magnet.

Professor: For what?

Student: Direction purpose.

Professor: Magnet does not give you accurate direction at all. Magnet is not, magnetic north also varies from place to place, from time to time. It is also, they do not, you are interested in the celestial pole, true north, not the magnetic north. Magnetic north is different from the true north.

Student: But it was known like he has magnet.

Professor: It was known to Kepler, actually at that time I think his name was Gilbert, is not it? Who wrote the first book, that was at the time of Kepler and from that only Kepler got the idea of gravitation. The idea of gravitation first came from Kepler and he told that every object attracts every object and they move towards the common point and the amount of movement depends on their relative bulk. So it is, Newton is not the originator of gravitation theory.

Professor 2: This is part of his three books. The Kepler's idea of gravitation is not part of his book, is it written in the book of Kepler, this idea of gravitation?

Professor: Yeah, I can, you can even get it, I spoke it.

Professor 2: I see.

Professor: It is all very clear. Only thing, problem was with he thought that gravitational force, the force was proportional to velocity everybody's. The concept of accelerating and linking with force was first by (())(77:38). That was the real breakthrough. He showed that force is proportional to acceleration. And that concept of proportionality was aimed, that was in top priority.

Professor 2: So (())(77:51) code was known (())(77:52).

Professor: He developed it.

Professor 2: He developed that.

Professor: And using that and Kepler’s third law they found out that the gravitational force is inversely proportional to square of distance by (())(78:03). That was also known much before Newton.

Professor 2: Okay, any other question?

Professor: Okay.

Professor 2: If not, thank you for the whole.