Higher Surveying
Dr. Ajay Dashora
Department of Civil Engineering
Indian Institute of Technology, Guwahati

Module – 03
Time and Astronomy
Lecture – 05
Fundamentals of astronomy

Hello, everyone. Welcome, back in the course of Higher Surveying and today, we are in the new module called Time and Astronomy. This is Module – 3. Before going into this module, I would like to just summarise our earlier learning in last module. In the last module, we discussed about the terrestrial reference system, reference frame, coordinate system and other aspects of that.

We learned that there are some reference systems and reference frames required in order to define the 3D position on the surface of earth and so, we defined three kind of reference frames; local reference frame; geodetic reference frame and geocentric reference frame. All these frames are non inertial frame which means they are also rotating with the earth or rather they are attached with the earth and as a result we said that we do not need to measure the time.

So, suppose now you believe or you realise that we also need one inertial reference system and inertial reference frame. So, that we can also look at the position of a point on earth with time; that means, I need to measure the time also time and 3D position together.

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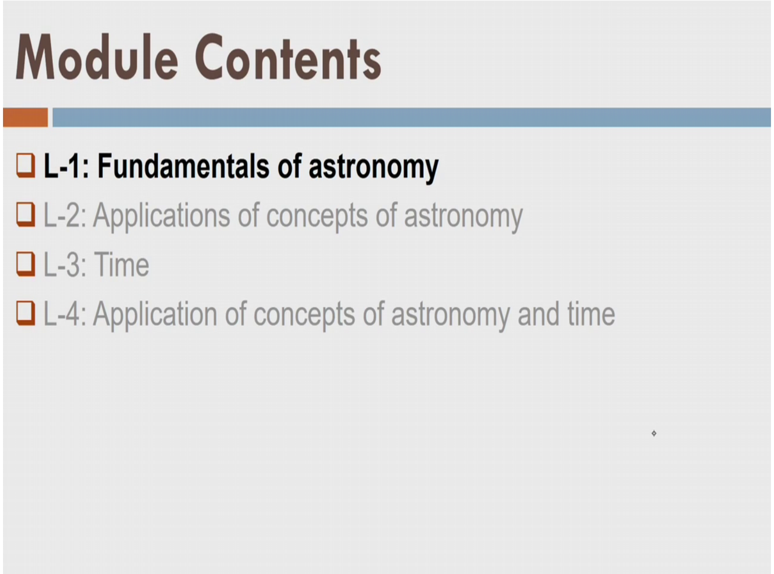

So, this module has four lectures and in this lecture we are going to talk about fundamentals of astronomy. So, these are the books one can refer.

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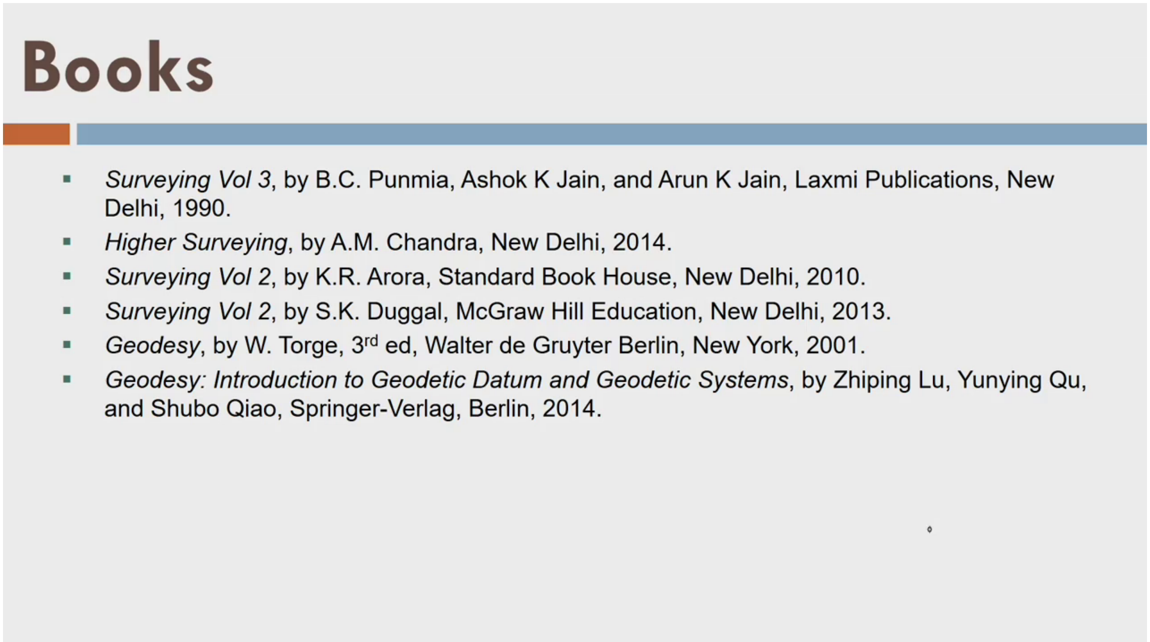

Let me tell you, what is astronomy? Astronomy is the study of motion of heavenly bodies. So, what are these heavenly bodies? What do we mean by heavenly bodies? So, all the stars which are appearing to you in the night, if you are going to your roof top or if you go to an open ground; so, these stars including sun, moon they are called heavenly bodies or sometimes celestial bodies. So, we are studying the motion of these starts and we call this science as astronomy. Let us go into the astronomical reference systems.

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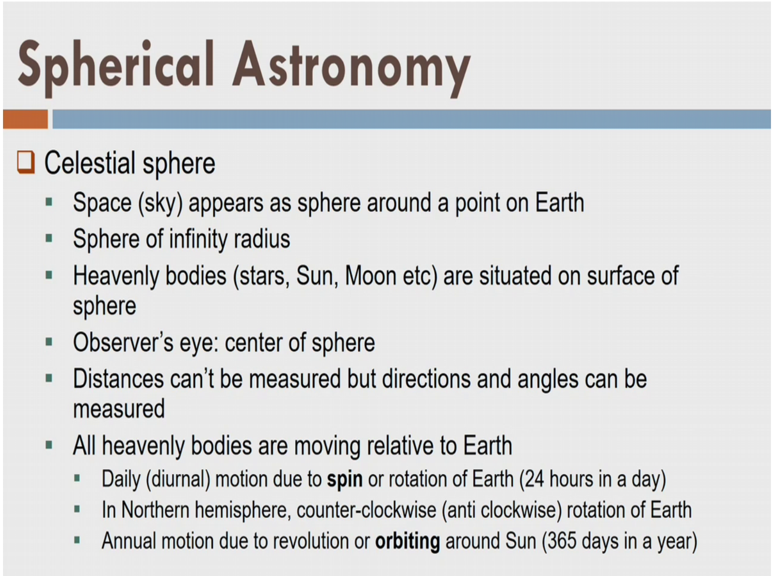


Now, it is slightly different from the terrestrial reference frame in a certain way, ok. Just imagine if you go to on your rooftop of a building or if you go on a open ground, let us say cricket ground or football ground or hockey ground or any open ground if you can avail and if you can go there, go in the night time you will feel that the sky which is appearing black to you having lot of stars on that. Well, it is not surprising, right.

So, have you ever seen the black sky or the stars on the black sky? Well, there is another feeling if you go in the day time, well, if sun is not intense and there are no clouds in the sky, then you can see the blue colour of the sky especially in the morning as well. If you go in a evening or if you go any time when there is no sun or sun is not that intense that you cannot see above your head, go to the open sky and go to the open ground and try to see what can you see there around you.

You will feel that there is a sphere that a surrounding you and the day time it is appearing as a blue colour sky and that is basically appearing to half sphere and which is like that around you and that is what we call as celestial sphere. Well, in the night time this blue sky will not be there, because it will not be visible as blue, but still there is something and we can see lot of stars around us.

Surprisingly, you may feel that a star which is appearing bright to you perhaps it is closer to you or a star which is little dull it is away from you compared to the bright star. Sometimes you feel there is star is a big star because it is appearing little bigger to you, but do you know that the stars distance cannot be measured in a way that even with your naked eyes you cannot measure these distances.

Secondly, even you measure those distances by your naked eyes or by some instrument there of no use. Why because even we know the stars distance what will you do with that calculation or how will you implement into that calculation. So, the thing here is we assume that that there are stars which are situated on a celestial sphere which is appearing to me as a hemi sphere around the surface or around my position.

And, then we say that let us assume these stars are situated on the surface of this sphere and the sphere is of infinite radius and because of that infinite radiu, I cannot measure the distance between two stars or the distance between a one star or particular star from the observer. Suppose, if am standing on open ground or you are standing on open ground then you feel that this star could be nearer or another star is farther to you but, still you can only make a difference like that.

However, you cannot make the difference between the two, because of the distance because all stars are situated on a sphere and that has an infinite radius. Well, what is this idea why are we making this assumption? So, we are basically interested in to measure the two position of a star and both are angular positions. That means, we are not interested to measure the distance of a star to star or distance of a star and observer.

So, that is the reason we are making this assumption, but if you imagine the earth which is at the at the centre of this sphere and the whole space around it. So, you can imagine there is a whole complete sphere; it is not a half sphere anymore. Now, well that is what we call celestial sphere. I hope that I have repeated this concept many a times now ok. So, on all the heavenly bodies like sun, moon or any star is appearing or situated on the surface of that sphere, well.

Observer's eye; for example, I am observing on an open surface or in an open ground. So, the observer's eye is the centre of that sphere. Well, you may imagine why not or you can ask why is it so? Well, the idea here is when I assume that infinite radius sphere around me the radius of the surface of a point on the surface of earth which is approximately 6400 kilometres does not mean anything. Why? because compare to the distance of an observer to the celestial sphere which is almost infinite 6400 kilometres does not make any sense.

So, even I can assume that the observer is located at the centre of the earth. But, he can direct his eyes like this to visualise two stars or he can make the difference there is a one star, and there is another star, there is a lower star, there is an upper star like that. So, all the differences he can make, but still the distance between this position and the stars position cannot be determined. Well, I hope that we are now getting involved in the astronomy.

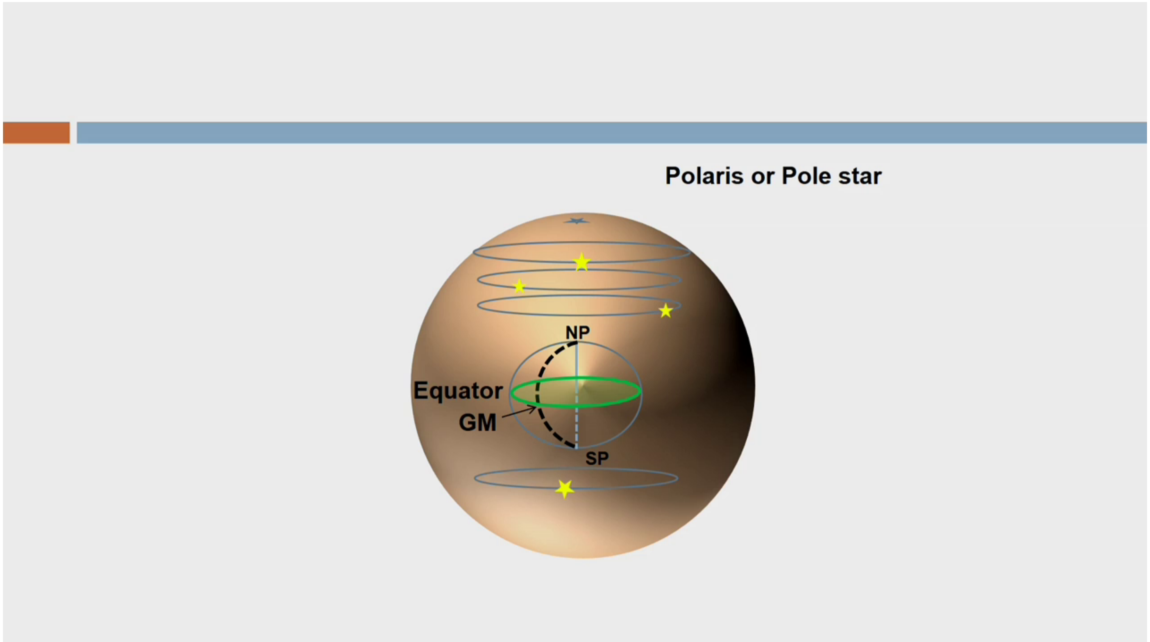
So, the idea is the all heavenly bodies are moving relative to the earth. But, most of the stars which are far away from the earth they might be moving we do not know, but at a given time let us say 8 pm in evening. If I go every day, I will find their location remained fixed. So, such fixed stars are also known as fixed stars. So, remember in general that all the heavenly bodies are moving around the earth because earth is spinning around its own axis.

Now, earth spins about its own axis in a counter clockwise or anti clockwise direction, because of that what appears to us all the stars maybe sun, moon or any other star all they appear to move around the earth in a clock wise direction. So, let us say earth is moving in this direction for example, like this. So, all the stars are moving in the clockwise direction, fine. So, that is the idea here. So, we can assume that all the stars relative to earth are moving in a clockwise direction around the earth.

Well, now there is one more motion that is earth revolves around the sun or it orbits the sun in a 1 year. So, or must we can say 365 days in a year. Well, this is the simple idea for developing and basic concept or the basic idea of the astronomy all the stars are relatively moving if I assume earth as a stationary.

Now, I can say here one thing that we know that earth rotates in 24 hours or earth completes when 365 rotation in 24 hours duration, what we call at day. During that day I can say that if earth is stationary all the stars which are around the earth they will rotate and they will complete one 360 degree rotation or they will complete their 360 degree rotation in 24 hours.

Is it not a good idea to understand the time and astronomy as a together, as a combined concept? Because astronomy is the science of study of motion of the heavenly bodies and I am saying that now heavenly bodies are rotating and their completing one rotation in 24 hours. So, time and astronomy are connected and let us start from the celestial sphere again.(Refer Slide Time: 10:47)



So, here I am showing you the earth well and there is a ellipsoid I am showing instead of earth. Let us assume that earth is a ellipsoid and so, I am showing you with the blue line which is vertical here, the line that is rotation axis of earth that is joining the North Pole and South Pole. Then we have a green circle which is equator and, then we have a dotted line which is showing the Greenwich meridian.

So, let us see what is this is what I am showing you here. So, you can see North Pole and South Pole. And, so, line connecting the North Pole and South Pole is the rotation axis of the earth and time being assume that it is an instantaneous or it can be an average rotation axis does not matter we are just developing few concepts. So, you assume that it is a kind of fixed rotation axis that is in this position remains always.

Well, with this now, let us see these are the stars around this shown in the yellow colour. So, I am showing you here four stars. Let see there is a one more star what we called Polaris which is exactly above the North Pole if you someone goes to the North Pole exact position this pole star will always appear exactly at the North Pole above this; that means, if suppose right now if I am at North Pole and here if I see like that I can see the north pole and it will remain stationary with respect to the earth.

So, this is my Polaris or pole star. So, now, let say these are these stars which are shown here in the yellow colour they are appearing to me as rotating in this circle, they are spinning in the circle around the earth in the clockwise direction now we can make out what is the clockwise direction here right now, could be from here to here like this, f.ine Try to imagine yourself perhaps if I am wrong correct me, ok.

Now, let us see if I project all these stars on the sphere. So, then they will be appearing as if they are situated on the surface internally on a sphere. So, what I am doing let us say there is a star like that. So, there is observer I am connecting the star here and I am projecting it back to the sphere, such that all the stars are appearing to me on a sphere and that is what we call the celestial sphere.

So, since now I have placed all the stars on the celestial sphere because I am not interested in the distance between the two stars or distance between observer and then star. So, distances are no meaning for us, hence we can place then each and every star on the sphere. Whether it is really lying on the sphere or not does not matter because they are interested in only directions. So, we are basically placing then on the sphere, ok. Let us go ahead with that.

So, now, this is my celestial sphere, ok. So, let us remove the circular path of the stars because since I have already placed them on the celestial sphere. So, even they are moving they are moving on the celestial sphere; that means, are expanded their rotation rings or the rings are matching with the celestial celestials sphere now.

So, let us if I see that if I extend the axis what we call as the rotation axis meeting the North Pole and South Pole of the earth. So, if I extend this axis it will be passing through the Polaris or Pole star. So, this axis we call axis of heaven.

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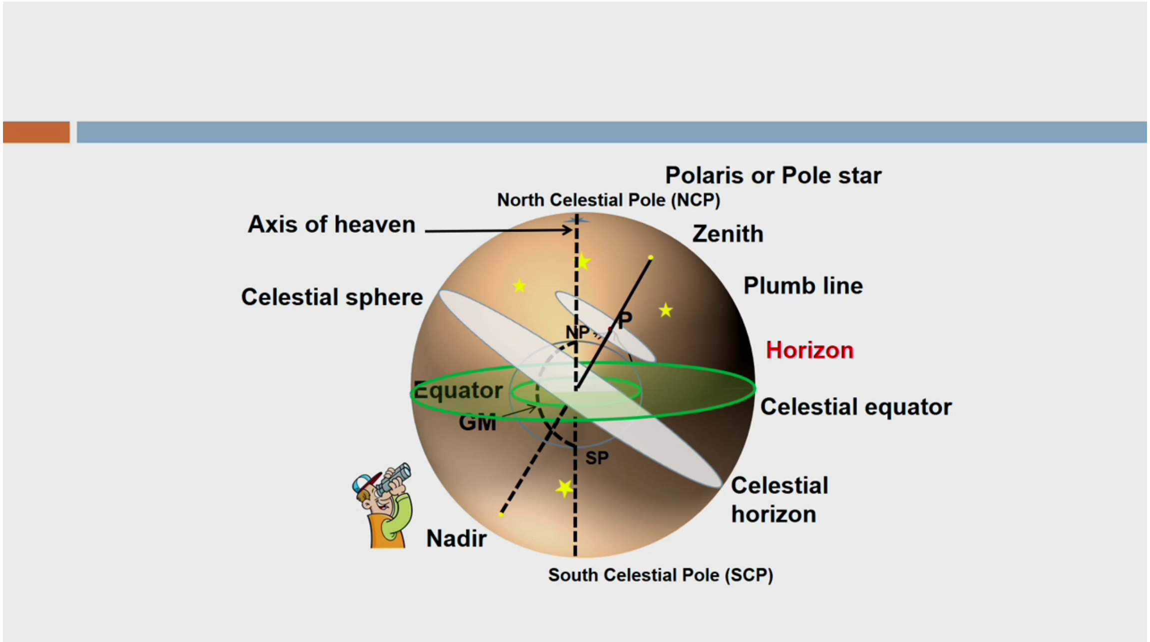

So, because we are calling all the stars has heavenly bodies or stars, right. So, same way, we are calling this axis which is passing through North Pole and South Pole of the earth or rather if I am extend the rotation axis of the earth. So, this axis is called axis of heaven.

Now, this axis is cutting the celestial sphere in two points; the first point which is above the North Pole it is called North Celestial Pole in bracket I am writing it NCP in further slides we will always write it NCP row remember north celestial pole is written as NCP. Similarly, below the South Pole the axis of heaven will interest the celestial sphere in celestial South Pole.

So, they are basically not North Pole and South Pole of the earth rather they are the poles of the celestial sphere which is made or which is created by intersection of the rotation axis of the earth when it is extended and we call it axis of heaven. So, when axis of heaven intersects with the celestial sphere we come to know about or we rather created two points called north celestial pole and south celestial pole. I hope we are together and moving very gradually ahead in the direction of learning astronomy with the help of astronomical reference systems ok, move ahead.

So, let us see there is a surface of the earth. On the surface of the earth there is a point P here shown by your red dot or first let me draw the horizon,. So, this is the horizon now you can imagine at this horizon at point P, if you are sitting at point P you can see few of the starts are visible to you rather few of the stars are below the horizon and which are not visible to you ok, let us goead.

So, it is I call it horizon, it is observer's horizon. Now, observer sitting there at point P. So, now, we want to make some assumptions here as we said in the last slide also. So, this is my gravity line or the plum line passing through point P and. So, it is cutting at two points the earth. Well, one point we know that where this observer is standing and another point it is just below down across the earth, across the equator.

Now, see that if I extend the observer's horizon it will be intersecting with the celestial sphere. Now, we can easily imagine, ok. As we told earlier as we discussed earlier as well that there is no meaning of the 6400 kilometre distance between the centre of earth and the observer on the earth. Why? Because the celestial sphere itself is having infinite radius. And, secondly we do not have any connection or any concern with the distance between the two points.

So, even I can bring this horizon which is passing through point P parallel to this horizon I can bring draw another horizon which is at the centre of the earth that will make my left little easy in a way that I can find out with respect to centre what are the locations of the different different stars. So, with this idea let us see I am putting this and extending the the horizon. So, there is a horizon which is passing parallel to the observer's horizon, but it is passing through the centre of the earth.

So, such a horizon is intersecting with the celestial sphere such a horizontal plane or such a circular horizontal plane which is intersecting with the celestial sphere. It is called celestial horizon and remember that for a particular position P of observer, this is the valid celestial horizon. For another position on the surface of the earth its orientation will be quite different.

So, right now let us see we are talking about point P only. So, for point P this is the celestial horizon, ok. Now, you have understood what is the difference between horizon celestial horizon what about if I extend now the line which is passing through point P centre of the earth towards both sides, what will happen it will intersect the celestial sphere at two points.

The top points above the observer let us say this point and another point which is below the horizon shown by another yellow dot. So, they are called these points are called zenith and nadir. Zenith is exactly above my head and the nadir exactly below my head cutting the celestial sphere that is the idea here, ok.

Now, where is the observer? Observer is sitting at the centre of the earth where all the axis rotation axis and the zenith nadir line they are meeting. Now, the observer can direct his eyes, like this. So, he can visualise all the stars, he can see all the stars, he can find out the relative angle between the two stars at the centre of the earth; that means, this angle it can find if there is a one star another star is here this angle or also, it can change its location like this to another two stars and it can find out, fine and since this is a celestial horizon of observer he can look around like this on the whole this 180 degree whole this 180 degree, complete semi semi sphere he can look around it. So, that is the idea of celestial horizon and how is it interacting with the celestial sphere.

So, similar fashion if there is a equator on of the earth and if I extend the equator of the earth in a such a way that it intersects with the celestial sphere, it will create an circle or it will create a circular plane and that plane is called celestial equatorial plane and the circle where the celestial equator will plane intersects with the celestial sphere is called celestial equator.

You can see the green line here which is developed by extending the equator of the earth, so that green line or the green circle that is containing the equator of the earth and also the centre of the earth it will create a plane. In this plane I have celestial equator of the earth and the centre of the earth. So, such a plane formed by the celestial equator is called celestial equatorial plane, ok. So, this is my real situation here. You can understand now easily what is the celestial sphere, what is axis of heaven, what is north celestial pole, zenith, nadir, celestial equator, celestial horizon and south celestial pole and all these features, there are fundamental things to learn the astronomy.

If you are still confused or still if you want a still some kind of more clarification you can repeat this video and try to see it again,. So, let us go ahead let us try to understand the basic terminology.

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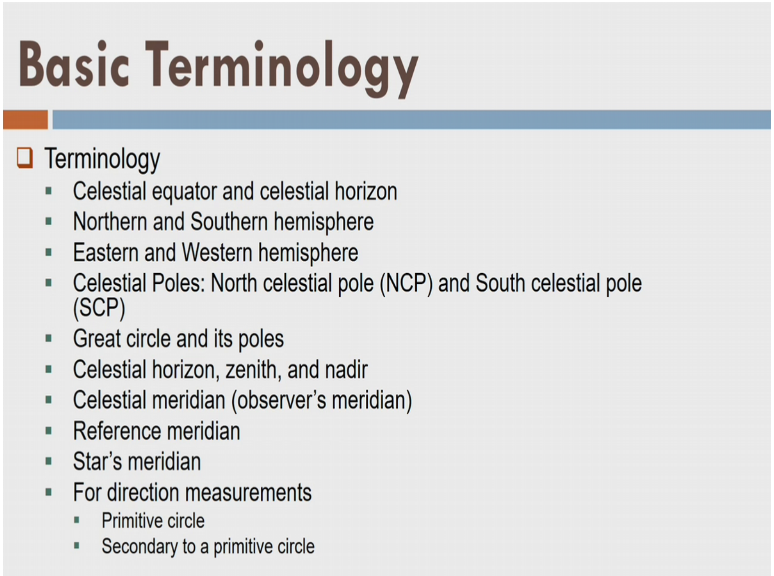

The first we have already covered what is celestial equator, we also defined what is the celestial equatorial plane and then we also understood what is the celestial horizon or we can also say what is celestial horizon or celestial horizontal plane, we can also define that, ok. Then we have seen that northern and southern hemisphere, what does it mean.

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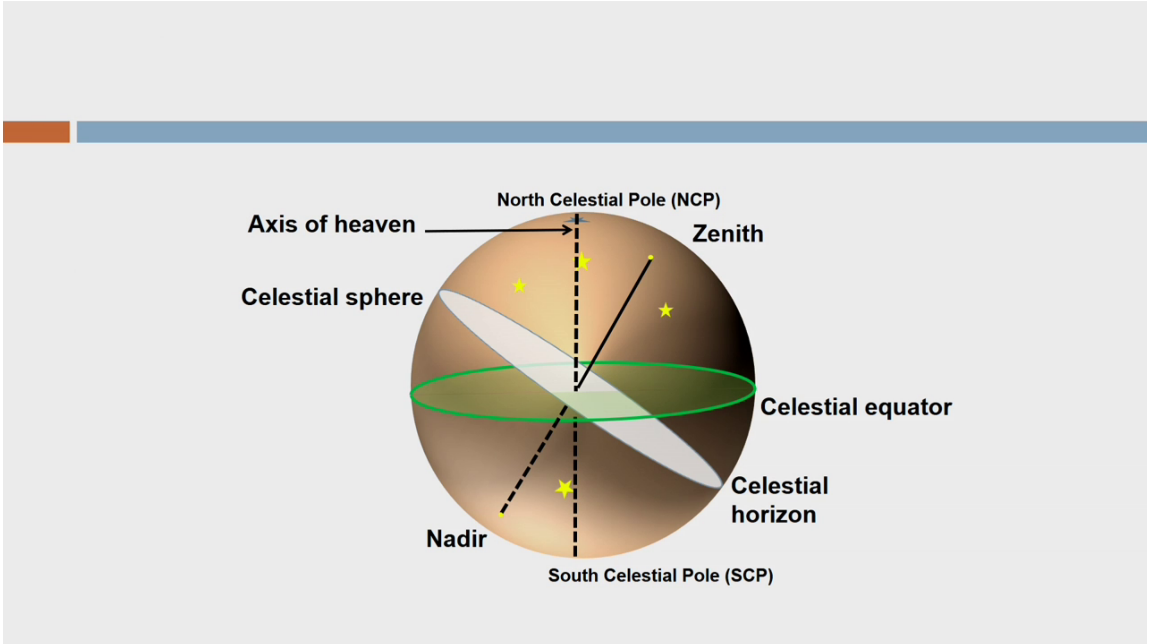

I can see in the last figure if I go there is a celestial equator or celestial equatorial plane above this plane there is a hemisphere. I call it northern hemisphere and below the celestial equator I call it southern hemisphere. Going back, I am going ahead. Similarly, if I divide the celestial equator vertically so, there will be an eastern hemisphere and there will be a western hemisphere on the two sides of the vertical plane passing through the north celestial pole and south celestial pole, well.

Then, we have great circle and its pole. So, what do you mean by great circle? Now, imagine that any circle which is passing in the celestial sphere or I am defining any circle on the celestial sphere, but that should contain the centre of the earth on the centre of the sphere celestial sphere more specifically, then I will call it the great circle. So, any great circle you can imagine there are infinite number of great circles there.

So, celestial horizon is a great circle because it is containing the centre of the earth, celestial equator is another great circle it is containing this thing or if I draw any circle passing through a north celestial pole or south celestial pole it will also be great circle, because it will contain the centre of the earth. I hope the definition of great circle is very clear ok.

If I take any great circle now, with respect to that circle there will be two points which are joined by the line perpendicular to that circle. For example, axis of heaven is defining two poles for celestial equator. What does it mean? The meaning is I have a celestial equator and it defines the celestial equatorial plane and with respect to that plane. If I draw a line perpendicular to that so, that will be the line passing through the centre of earth and that line will be the axis of heaven and that axis of heaven have two ends one is north celestial pole and south celestial pole. So, NCP and SCP are the poles of celestial equator.

Similarly, if I consider another great circle that is the celestial horizon, zenith and nadir which are lying on a line; so, these two points zenith and nadir are the poles of the celestial horizon. Well, now you can imagine any circle just close your eyes and try to imagine any circle that is containing the centre of the earth and it is subscribed or described on the surface of the celestial sphere. So, that circle is great circle and now you can imagine two poles of that circle.

So, then we have celestial horizon. So, we have zenith and nadir. So, zenith and nadir are the poles of celestial horizon. Further we have a reference meridian. Remember in case of celestial reference frame we defined the Greenwich meridian as a reference meridian. In the same fashion we can take any take meridian on the surface of the celestial sphere and then we can define it as a reference meridian. We will see how to define that.

Further we have stars meridian, ok. Let me tell you what are the celestial meridian before we define stars meridian. The celestial meridian is a circle on the circle that is passing through zenith, nadir and NCP and SCP. Definitely it will contain the centre of the earth. We can imagine it or you can draw on the paper, well. So, this is the idea here.

So, that is the call that is that circle which is passing through zenith, nadir NCP and SCP. It is celestial meridian or it is also called observer's meridian. You can see this terminology in different different books. Remember they are basically same celestial meridian and observer's meridian. Similarly, if a great circle that is passing through north celestial pole south celestial pole and the star it is called a star meridian. It is very easy to understand now, because once we can imagine the celestial sphere we can imagine celestial horizon, and you can if you can imagine celestial equator everything is very very easy here.

So, for the direction measurement now, I need to define fundamentally two type of circles here. Since we are interested in direction measurement only or we are interested in angle measurement only, well. So, first we need to define the primitive circle.

Primitive circle is a great circle. So, along which I will measure one angle and. Secondly, is the circle which is perpendicular to the primitive circle and again that will be great circle also. So, there are two type of circle I need to define in order to measure two angles in order to fix a star well, let us see this in the more in the graphical sense.

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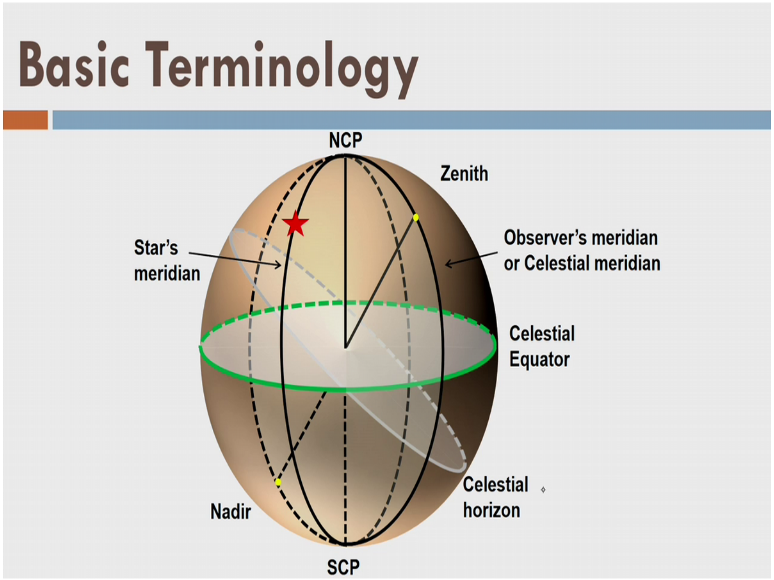

So, let us see this is your celestial equator and that is a celestial sphere. So, let us this is my celestial horizon. So, that is my NCP, SCP fine, that is my axis of heaven and that is the line zenith and nadir fine that is what we have already seen in the last slide, well. So, that is the great circle passing through north celestial pole, zenith, south celestial pole and nadir.

So, it is partly visible to you because it is on the front side and partly not visible because it is on the backside of the equator and backside of your celestial horizon. So, we are drawing it by dotted line which is not visible or which is appearing on the back side. Well, in the books you can find out this is drawn sometimes with the firm line, complete firm line no problem concept is same. So, this is my observer's meridian or celestial meridian let us go ahead.

Let us say there is a star situated on the celestial sphere and then if I now as I defined any circle that is passing any great circle that is passing through north celestial pole star and south celestial pole will be called stars meridian the way we have defined observer's meridian same way we will define the stars meridian. So, let us see this is the stars meridian.

So, concept of primitive and secondary are let us see there is celestial equator is my primitive circle. So, any circle let us say any meridian circle which is perpendicular to the equator celestial equator, ok. So, let us see there is a celestial equator which is now primitive circle and any circle that is any meridian because I will say any celestial meridian, I am sorry it is not celestial meridian it is only meridian any meridian is a great circle is perpendicular to the celestial equator. So, all the meridian circles are the secondaries to the celestial equator because the celestial equator has been defined as a primitive circle.

So, I can measure some angle along the equator line or along the celestial equator. Similarly I can measure the perpendicular to the equator also along the meridian circle. Well, that is the idea here; that means I can define 2-dimensional position of a star, ok. So, I have given an example of celestial equator as a primitive circle. Even I can take the celestial horizon as a primitive circle.

Well, I hope that you are appreciating the simple concepts they are very very simple just only some kind of visualization is required and I hope that these graphical aids are able to help you to visualize those things. Let us move ahead.

So, this is my stars meridian. So, we will we are going to use this kind of two perpendicular circles and now, we are going to derive those circle in different different manners and accordingly we are going to say we have different different reference system to measure the position of a star. And finally, we will come to inertial reference system, but before that we need to understand how to connect that reference system to our understanding or to our measurements. Let us start.

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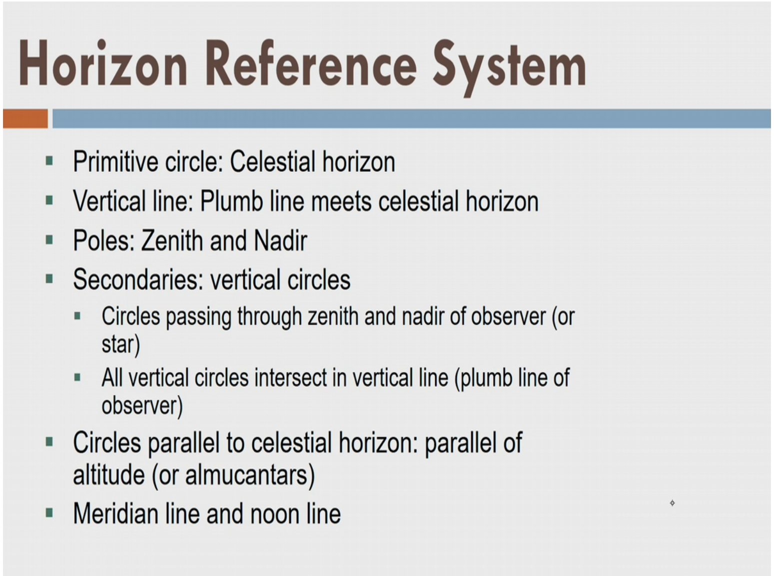

Let us see first horizon reference system. So, primitive circle is my celestial horizon. Remember, celestial horizon is different from celestial equator and celestial horizon depends on the observer's position. So, as observer's position changes celestial horizon we will change. But, equator is not going to change.

So, vertical line as we know the plumb line meets the celestial horizon, then we have poles with respect to celestial horizon. I have two poles zenith and nadir because they are lying on the line vertical line which is perpendicular to the celestial horizon,.

Secondaries are the vertical circles. So, what are the vertical circles? Vertical circle is a great circle passing through zenith and nadir, fine. So, any great circle which is passing through a zenith and nadir is a vertical circle, right. So, vertical circle is; obviously, perpendicular to the celestial horizon then circles which are parallel to their celestial horizon are called parallel of altitude or they are also called almucantars, right and then we have meridian line a new line. We will see in the animation here.

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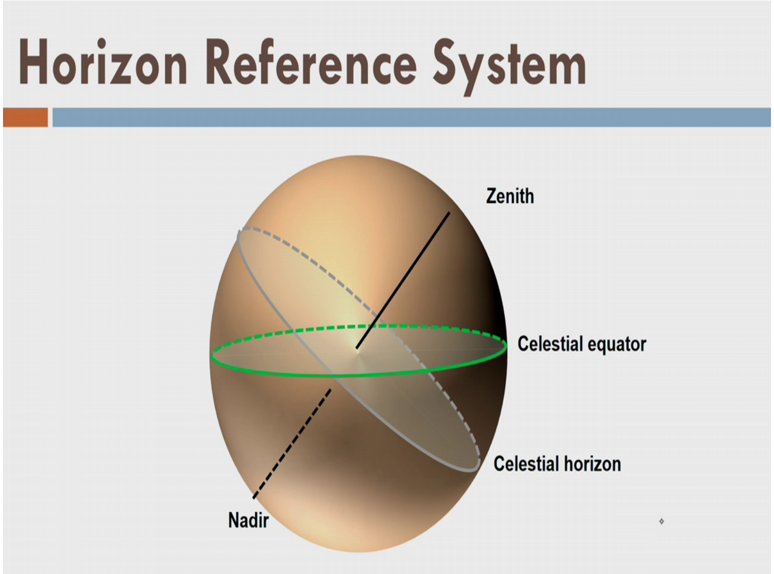

This is the standard animation we started with,. Now, this is celestial horizon, celestial equator, zenith, nadir. Let us rotate it for simplicity to understand the concept better for horizon reference system. So, now, my horizon is horizontal or in this screen it is becoming more convenient to me to understand. So, now, I am having my celestial equator tilted, ok, no problem.

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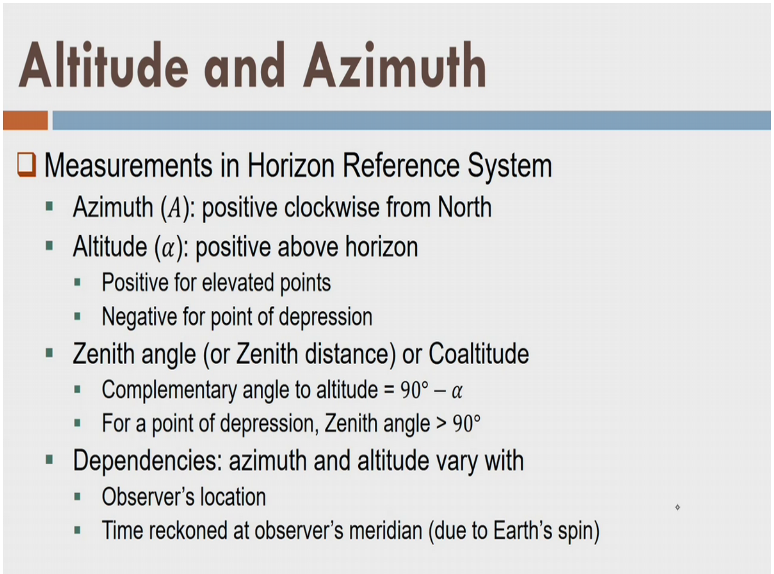

So, I am going to measure altitude and azimuth in horizon reference system. Remember, we are using the term reference system because it is just a concept now we are not realise it we have not realised it. So, measurements in the horizon reference system are azimuth and altitude. What is azimuth? Azimuth as you know from our standard definition, it is the angle measured in the celestial horizon from the astronomic north. Remember, we are not talking about any other north like magnetic north or any other north geographical or nothing. We are talking about astronomic north perhaps we know, it we may not know it no problem.

But, so, this is the azimuth then altitude any angle measured perpendicular to the celestial horizon, it is altitude of our star or of any point on the celestial sphere. I hope it is very easy you can imagine it very easily. So, altitude is positive for the elevated points that points which are observer's celestial horizon and negative for points of depression; the point which is below the celestial horizon.

So, zenith angle now we define a term zenith angle is nothing, but complimentary angle of altitude that is 90 minus alpha, if alpha is altitude,. So, for a point of depression I can see that altitude angle will be negative. So, the complementary angle which is co altitude will or zenith angle or zenith distance will be more than 90.

What about the dependences on the altitude and azimuth of a star? As we assume that earth is stationary and all stars are moving or altitude and azimuth depend on time. Not only that, both altitude and azimuth also depend on the observer's location. So, for my location so, at a given instant at my location and you location I will have different altitude and azimuth of a star, for example, sun.

At a same time now at my position now at one position on the surface of earth, if I vary the time; that means, if I am observing the sun at this movement and I observe the sun again after couple of minutes or couple of hours the position of sun will change. So, the altitude and azimuth depend upon not only the time, but the observer's location, but we need to connect it to the celestial reference system, which we are not derive the yet which we are not established the yet.

So, let us go ahead the and see how can we connect this horizon reference system in which we kindly perform on measurement that is the altitude and azimuth we perform or we measure, right and now, how to connect that azimuth and altitude angle to the other angles or to the other measurements to in order to reach to a celestial reference system,.

Let us go ahead.

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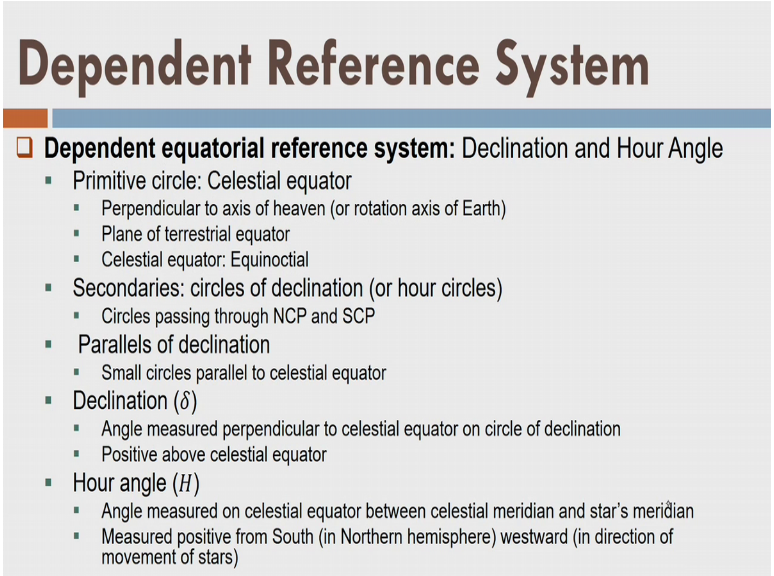

Now, we define a dependent reference system. As we see that azimuth and altitude in horizon reference system it is changing with time as well as changing with observer position, ok. Moreover in time I would like to specify there are two type of time; one is the annual time that is one year and another is daily time that is 24 hours. So, I can say the observer's position is changing with respect to time every movement as well as it is changing every month or every quarter and so on.

So, let us look into the different system called dependant reference system, right. Now, we are reaching to a reference system which is independent of time as well as independent of observer's position. Let us derive, try to derive it gradually which is the best step. So, the primitive circle here is celestial equator. As I told that celestial equator is not going to move with time rather it is going to spin only. So, does not matter it position is to going to change, ok.

Now, you can imagine that how nicely we are proceeding further in order to define the stars location which remains fixed or which remain unchanged let us see how do we do it interesting. So, the celestial equator I can say we can imagine it now. So, it is perpendicular to the axis heaven have you not to define all these thing it is tan of the celestial equator because we have extended the celestial equator and then we have created the celestial equator. So, they are the same or rather they are lying in the same plane I can say,.

So, celestial equator is also called equinoctial. Secondaries, what are the secondaries? So, now, you can imagine that meridians which are passing through NCP SCP and their great circles will be the secondaries to the celestial equator. Remember, we said the same thing before also. These secondaries are also called circles of declination or hour circles.

So, now, if I draw any circle which is parallel to the equator it is called parallel of declination and we define the angle declination and hour angle with respect to equator and circles of declination or hour circles. Let us see how do we delete I am not reading this thing rather I am going to show in the animation, ok.

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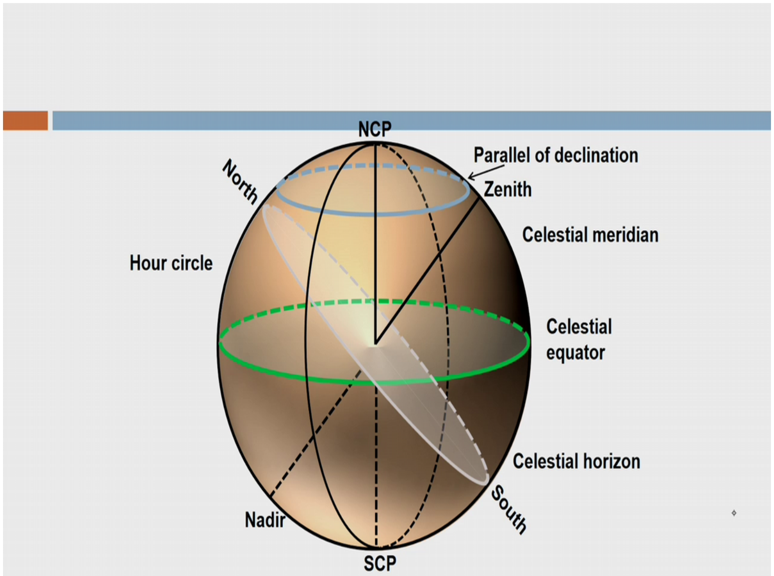

That is my celestial sphere, celestial equator now. So, this is my NCP and SCP. So, let us see this is the celestial horizon of an observer and now zenith and nadir are like this, ok. So, this is my celestial meridian north and south point as we have already defined all these thing, I am not doing anything new now.

Here, this is one of the circle of declination or hour circle like this,. So, this is the parallel of declination which is parallel to equator or celestial equator, ok. Just for the purpose of introduction we introduce two things. Now, we are removing it like this.

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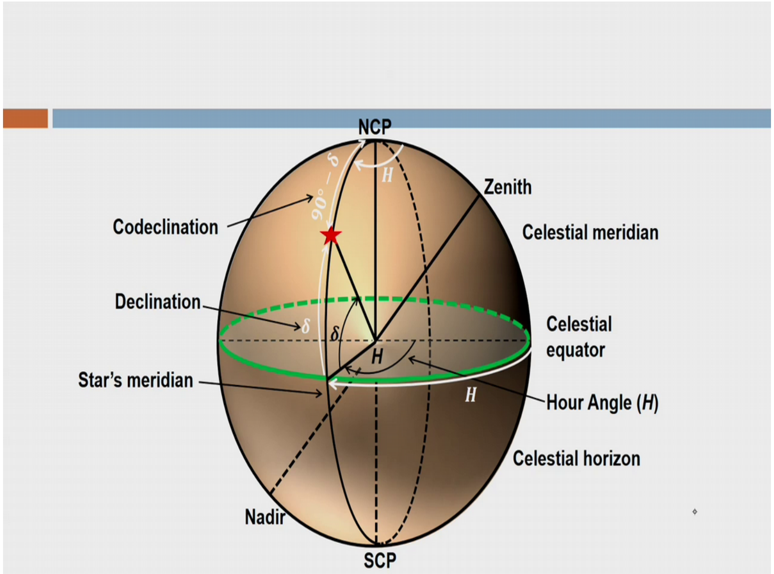

And, now let us see this is the star here at this given instant. So, this is my stars meridian, we have already defined celestial meridian you see. And, now this is stars meridian,. So, you can imagine the celestial equator is not primitive circle and stars meridian will be my secondary one of the secondary. Similarly, celestial meridian itself is one of the secondary, or celestial meridian itself is an hour circle I hope you can easily understand it now.

So, this angle which is just marked here; that means and angle measured perpendicular to equator and up to the star along the circle of declination is called declination this angle. So, declination and again I am showing the white colour like this. So, this is my declination. Similarly, I have this angle which is called codeclination, right and it is ninety degree minus delta. So, if my star is below equator 90 minus delta will be 90 plus delta opens the daily because delta will be negative.

Now, what about the hour angle? Hour angle is little tricky to understand. First of all we are going to measure the hour angle in the plane of celestial equator. Let us look how to measure it and it is always measured with the help of or with or with respect to celestial meridian of observer. So, now, we can the celestial meridian is cutting or it is intersecting in two points with celestial equator, right.

One is on the left hand side; one is on the right hand side in the screen. Which point should I take to measure the hour angle? The key here is if you take a point which is above the celestial horizon; that means, my reference point is on the celestial equator, but the point is above the celestial horizon of the observer. So, now, I can say in the screen it is on my right hand side so, there if I draw the line which are connecting the intersecting the points of celestial meridian and celestial equator. As I told I am going to take a point in celestial equator which is above the celestial horizon. So, now I am going to show you the hour angle in the celestial equator.

So, this is the hour angle measured here in the animation just try to re look into again and again if you do not understand again I am going to show in the white colour also. This is my hour angle H and this is again my hour angle H, they are same. Also, this is my hour angle again on the NCP I can see this is hour angle H, right. I hope you understood the concept of hour angle and declination.

What about the annual motion of the earth? Well, in the yearly motion or the revolution or orbit of the earth around the sun the centre of mass is also going to shift in the space, right and as a result since it is not a horizontal path around the sun it is the ecliptic path that we are going to see in the future slides in the coming slides. So, the declination will be changing not over the day or rather it will change over the day very small quantity, but it is definitely going to change over the year.

So, every month if you see the ephemerides, the stars catalogue we will find out that declinations going to change even every movement I can say, but the change it is not that rapid, but if you see the changes the values of declination over the agreement they will be changing because during a month earth is going to revolve also, but in a day it revolves ye sit revolves, but very small amount. So, now, we understood the concept of hour angle and declination.

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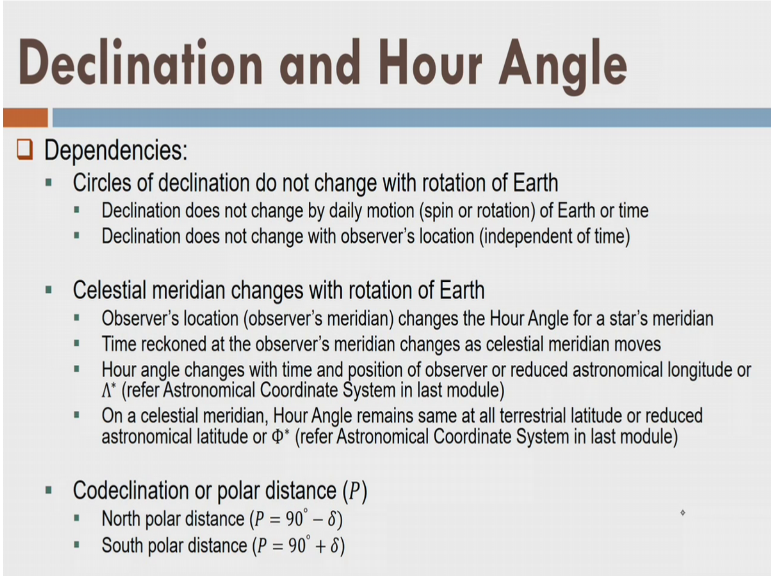

So, here again I am writing the dependencies the circle of declination do not change with motion of earth. So, declination does not depend by daily motion that is the diagonal motion or spin of earth. Declination does not change with observer's location also. So, it is independent of time. Which time? The spin time not the annual time right.

Secondly, coming to the hour angle; observer's location it is changing every movement and as a result hour angle is going to change every movement, but if you see carefully on a given celestial meridian even my latitude is changing, but hour angle remains same; that means, hour angle does not depend on the latitude of a place, rather it depends on the longitude of the place, ok. If you remember carefully, with respect to equator we have also measure the longitude and latitude in terrestrial reference frame.

So, if you recall in astronomic coordinate system we have reduced astronomical longitude and reduced astronomical latitude if we are talking about those latitude longitude. Remember, we are going to use those here and very surprisingly we will connect with our reduced astronomic latitude and longitude of a place to the declination right ascension and hour angle and so on. All these variables we are going to connect and even azimuth and altitude of a star, fine. Let us develop out further understanding in the subject.

So, as I told you hour angle changes with the reduced longitude or reduced astronomic longitude of a place and it is changing every movement. Definitely it is going to change every week and every month. So, it is change going to change annually, it is going to change daily, it is going to change every movement and it is also going to change with respect to the observer's position, well.

So, now, we derive the declination which is a quantity which does not depend on the observer's location. So, irrespective of the observer's location, for given star declination will remain same over a short period of daily path 24 hours something like that or little longer. So, now, I define a term co declination and polar distance P which is 90 minus delta and south polar distance become 90 plus delta if point is below equator.

Moreover, we have defined hour angle, I repeat at hour angle changes every movement every instant. So, hour angle of star for given celestial meridian or observer's location is going to change and that is why we can see that sun changes the hour angle every movement.

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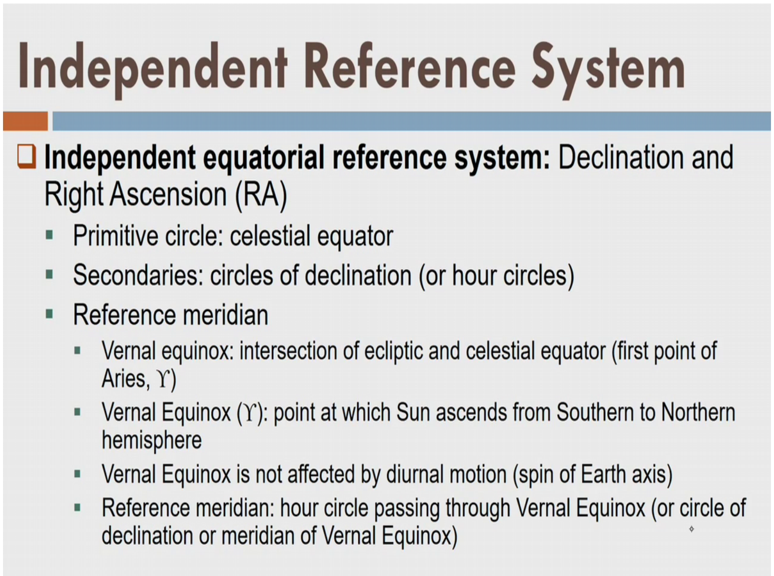

Now, we find an independent reference system. What do you mean by independent reference system? Remember, hour angle was still dependent on the observer's location. So, let us define a quantity like hour angle which does not depend on the location of observer because declination itself is independent of observer's location.

And, now define such quantity as a right ascension which is similar to our angle, but it does not depend on the observer's location. So, what do we for that? Ok, we find a point on the celestial equator which remain fixed and which does not change over the time,. So, let us define a point called vernal equinox, which is the intersection of ecliptic the relative path of the sun, what we called ecliptic and the celestial equator.

And, this path of the sun does not depend on the daily motion of the earth and as a result if you see the annual path of the sun around the earth that will intersect at one point and that point we called vernal equinox. If you can imagine it will also intersect when another equinox called autumnal equinox. At the vernal equinox sun ascends from southern hemisphere to northern hemisphere and this that is around twenty first March in a year.

Similarly, autumnal equinox where sun descends from northern hemisphere to southern hemisphere on its annual path not on daily path, right and that comes around twenty first September or twenty third September like that. So, so, there is a vernal equinox on point, now with respect to that will measure an angle we call it a right ascension and let us look what is a right ascension here. So, let us look into the animation to understand what is right ascension and declination, ok.

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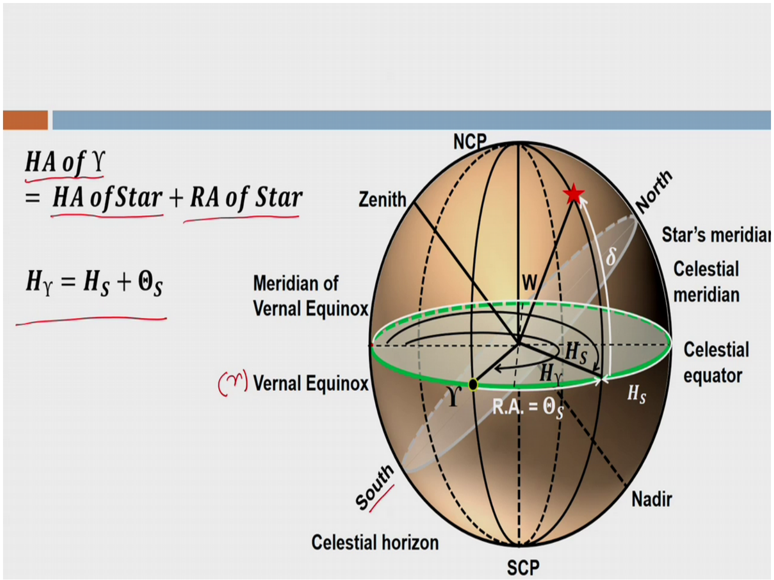

That is my celestial sphere and celestial equator is shown here. So, that is the NCP and SCP, that is my celestial horizon and we have deliberately titled it in order to explain the concept of right ascension. So, this is the zenith, nadir and this is the celestial meridian. So, till this point or concepts are same.

Now, so, this is the north and south on the celestial horizon and east and west are also shown. So, let us see this is the ecliptic or the annual path of the sun or sun is apparently moving around earth, annually on this path shown by the red colour red dotted line.

So, the intersection of the celestial equator and the ecliptic is called vernal equinox and so, the point shown by the black dot here is our vernal equinox written by this symbol, right and this symbol is very special here it is written like this and vernal equinox is also called the first point of Aries.

So, now, let us say there is a star here and this is the stars meridian, and let us say there is a meridian of vernal equinox passing through the vernal equinox. So, we have define the meridian of vernal equinox. Now, I went to measure a right ascension from the vernal equinox to the stars meridian. So, let us connect the star from the centre of earth and with equatorial plane. So, like this let us draw these two lines and this angle you already know that this angle is declination. So, this is my declination angle right.

So, now, let us define the right ascension. The right ascension is the angle between the vernal equinox to the stars meridian but, measured in the plane of equator. So, if I connect the centre of earth to the vernal equinox, this will be the line. Now, if I measure this angle it is my right ascension of the star ok. It is very clear from the animation how to measure the right ascension and how to measure the declination again.

But, if you see carefully that right ascension is measured opposite to the hour angle or rather hour angle is measured from the point on equator which is above south of celestial horizon. We measure the hour angle positive in the westward direction or in the direction of the movement of the starts. However, right ascension is measured eastward opposite to hour angle or in the direction of terrestrial longitude.

Well, terrestrial longitude, what we call reduced astronomic longitude. Now, it is very clear to you that the right ascension since it is measured from the vernal equinox it is very much independent of the observer’s position, because the vernal equinox itself is a reference point now and the vernal equinox is not decided by the observer's position. So, now, we have derived a reference system and two coordinate's right ascension and declination both are independent of observer's position.

Moreover, I can say that vernal equinox itself does not depend on the rotation of the earth so, you can say that the right ascension and declination both are independent of the rotation of the earth. So, what about the hour angle? In this animation let us look into the hour angle. This is the hour angle of the star and H S. So, this is also H S ok.

What about the hour angle of vernal equinox? So, this is the hour angle of vernal equinox, fine, ok. You can see here very carefully that if I want to measure the hour angle of vernal equinox I can measure it as a summation of hour angle star and right ascension of the star; that means, if I want to find out what is the hour angle of vernal equinox what is the hour angle of vernal equinox it is summation of the hour angle of star which is my H S and the right ascension of the star.

So, I can write here this term very nice, you can see here very carefully in the graphics or the animation. What about the dependencies of the right ascension and declination? As we have already told the declination is independent of the rotation of the earth because the earth's equatorial axis or the earth equatorial plane is not going to change its position due to the rotation of its own rotation.

Due to the rotation of the earth, the equator will plane of the earth is not going to change its position and that is a reason declination is independent of the rotation or the rotation time of earth. Now, what about the right ascension? Right ascension is measured with respect to the vernal equinox and the vernal equinox itself is defined in a way that is independent of the rotation of earth. Remember, that vernal equinox is the intersection of ecliptic and equatorial plane or the celestial equator.

So, both ecliptic and the celestial equator does not depend on the rotation of the earth. Well, I hope that you got the concept that why right ascension and declination are not only independent of observer's position, also they are independent of the rotation time or the daily spin of the earth or the rotation or the spin of the earth.

But, what about the annual motion of earth? So far we have seen we have not discussed about the annual motion, but due to the annual motion of the earth the position of the celestial equator or the equatorial plane of earth also varies because earth is moving around sun in the ecliptic. And, as a result I can say that right ascension and declination although they change at minimum quantity along a day, but they changes significantly over the year or the annual motion or the time or the yearly time of the earth. So, we should be very very careful on these parts on these concepts.

Can we derive coordinates which are also independent of the anytime or rotation time or annual time as well as the position of the observer? So, let us device that. So, now we introduce a new system called celestial reference system an the full name is celestial longitude and latitude system, where we measure the celestial latitude and celestial longitude.

So, let us look in to the animation what do we mean by celestial latitude and celestial longitude.

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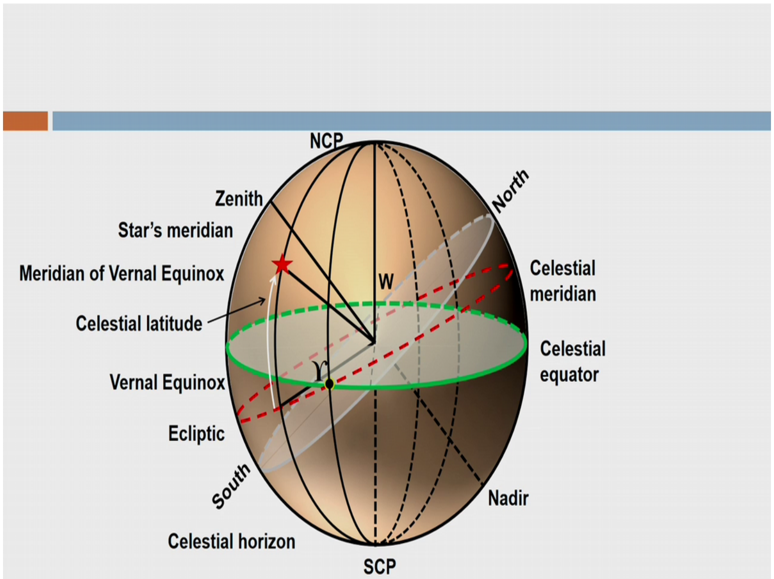

So, that is my celestial equator and celestial sphere, fine. NCP, SCP again the celestial horizon, zenith, nadir celestial meridian,. So, that is my south, east, west, north on the celestial horizon, then this is my ecliptic and so, this is the vernal equinox fine,. So, that is the meridian of vernal equinox and that is the star.

I want to measure two coordinates of the star which are independent of the anytime of earth either it is rotation or daily spin or it is a annual motion of the earth. So, how can I do it? So, we have already defined celestial longitude and latitude theoretically. Now, let us look into the animation. So, I have stars meridian, so, if I connect the centre of the celestial sphere to the star meridian to the stars meridian it will be this line, right.

Now, I measure the celestial longitude and celestial latitude. So, let us connect the centre of celestial sphere to the star, ok, then we have framed an angle we can see here in the animation. So, this is my celestial latitude. So, this angle which is measured in the plane of ecliptic from the vernal equinox to stars meridian is called celestial longitude.

So, this angle is celestial longitude. Remember, that both celestial longitude and latitude are independent; in the sense, like my vernal equinox is independent of time both annual time as well as daily time, right. Now, I measuring some angle called celestial longitude with respect to vernal equinox. It should be independent moreover; this angle celestial longitude is measured in the plane of ecliptic not in the equator. So, ecliptic itself is independent of earth motion.

So, an as a result now I can define the stars position using celestial latitude and celestial longitude. This position will be independent of the earth rotation, earth position and earth's motion.

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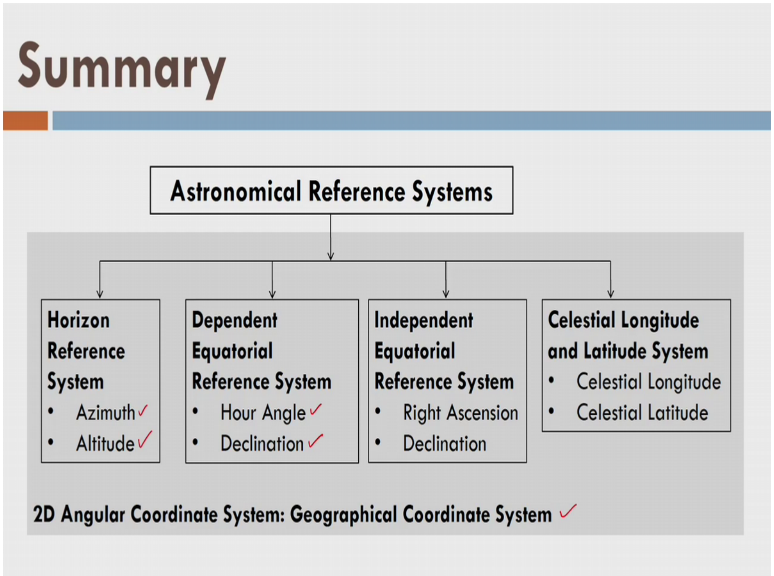

So, let us make a summary of our learning today. So, we have astronomical reference systems and we have defined four types of reference systems. So, first is horizon reference system, then we have dependent equatorial reference system, then we have independent equatorial reference system and then we have celestial longitude and latitude system.

Here in case of horizon reference system we measure the position of a star as azimuth and altitude. Again, in dependent equatorial reference system, we measure the position of star by hour angle and declination. In case of independent equatorial reference system we measure the position of the star by right ascension and declination. And finally, in celestial longitude and latitude system we measure the celestial longitude and celestial latitude of a star.

And, celestial latitude and celestial longitude are independent of any time or any motion of earth and whereas as well as the observer's position. In case of right ascension and declination we know that both the right ascension and declination are also independent of the rotation motion or the daily rotation of earth, as well as their independent of observer's position.

Now, what about the hour angle and declination; as we say that the hour angle depends on the celestial meridian or observer's position, but only on the longitude of the observer's position and not on the latitude, What about the azimuth and altitude? Both azimuth and altitude depend on the time as well as observer's position. Here we can see here that all these system all these four reference systems are using 2D angular coordinate system what we call as geographical coordinate system.

So, this is the total learning we have done today in this first lecture of module – 3, Time and Astronomy. In the next lecture we will see the applications of this reference system.