Explaining the Motion of Heavenly Bodies: Part-3 Why do we say the earth goes around the Sun?

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In the previous two installments of this series of articles, we looked at the apparent motion of various heavenly bodies caused by the rotation of the earth on its axis and further, what would be seen from the earth when the moon is also revolving around the earth. We are also taught at a very young age that the earth goes around the Sun, and that it takes one year (or 365 1/4 days) to do so. In this article, we shall first explore what we could expect to see in the sky if the earth were to go around the Sun contrary to all our basic intuitions. Like we did for the moon's motion around the earth, we shall try to figure out what our observations can tell us about the direction of revolution. Further, we shall try and make systematic observations of the night sky so that we can confirm these 'predictions'. Towards the end of this article, a few anomalies which got sorted out when we ditched the geocentric model for the heliocentric model shall be discussed; this will involve following the movement of those erratic citizens of the sky – the planets. That is, we shall begin by accepting the precepts of the heliocentric model and relate this to the observations that are possible over a period of a couple of months and only then talk about why the heliocentric model is a 'better' description of the solar system just because it is so much simpler.

The Sun is the Star of the Solar System:

The heliocentric model for the solar system posits that all planets revolve around the Sun (we will start by understanding the motion of the earth first), and that the solar system is surrounded by innumerable stars (and galaxies) which are very far away (the nearest star is more than 4 light years away). Even though the various stars, and galaxies too, are also moving, the change in their relative positions cannot be observed over the course of a life-time, so for the purposes of this article, we can assume that they are fixed with respect to each other and the solar system. This is why we see the same constellations over and over again, the stars in each constellations also maintain the same degree of separation from each other[1].

But do we see the same constellations at fixed positions in the sky as soon as it becomes dark throughout the year? You might have observed the stars when you sleep out in the open on warm summer nights, do you see the same stars (or constellations) in winter too? And what would we expect to see if the earth were part of the solar system surrounded by stars fixed relative to each other? See figure 1 which shows the earth in its orbit around the Sun at four different points; assume for the moment that we are looking down upon the earth from the direction of the pole star.

Caption for figure 1 : The earth in four different positions in its orbit around the Sun. Which stars will be visible from each position? When will each star or constellation rise or set?

The orbit of the earth around the Sun is not a perfect circle, it is an ellipse, but we shall see in the next article that the deviation from circularity is so slight that we can ignore it for

[1]This is of course an illusion. The stars in any one constellation need not be any closer to each other than other stars in reality. The apparent proximity is just because their light comes to us from the same region in space, the same area of our sky; they could actually be thousands of light years apart. And some of the stars in our beloved constellations are actually extremely distant galaxies!

now. The moon and other planets have not been shown to keep matters simple. Obviously, in each position, it will be night in the portion of the earth facing away from the Sun and day in the portion which is towards the Sun. The stars are of course very far away but have been shown close to the orbit of the earth for the sake of convenience. When the earth is at the position marked (1), the star F will be visible at night, but what about star B? Since star B is in the sky behind the Sun in this position, it will not be visible. Similarly, when the earth is in position (3) in its orbit around the Sun, star B will be visible but not star F.

What will the sky look like when the earth is in position (4)? For a person standing at the point marked Z, the time will be around midnight (note the position of the Sun, it will take about 12 hours for this person to see the Sun nearly overhead at noon). Remember from the earlier article that if we are looking down at the earth from the direction of the pole star, then the earth appears to be turning counter-clockwise when it rotates once on its axis in 24 hours. And for this person at point Z at midnight, the star D will be overhead while the star E will be in the western sky and will set soon while the star C will be in the eastern sky.

And what about the visibility of the stars E and C when the earth is in position (2)? Remember once again that if we are looking down upon the earth from the direction of the pole star, it appears to be turning counter-clockwise completing one rotation in 24 hours. So if we imagine two people on the earth at the points marked X and Y at position (2), one is at a place near sunset time and the other near the time of sunrise. I hope it is not difficult for you to figure out whether it is time for X or Y to wake up in the morning! Please work it out before reading further so that you can continue to follow without any confusion :-)

I hope you have realised that the star E will be in the eastern sky just before sunrise and the star C will be seen in the western sky just after sunset (and of course, both people standing at X and Y will not be able to see the star D since it is right behind the Sun and so the bright light of the Sun totally eclipses it). But how will this change over the days as the earth moves in its orbit around the Sun? If the earth is moving from position (2) towards position (1), then the star C will be behind the Sun as star D becomes visible in the early morning sky in the east; and the star E would have risen still earlier and would be visible in the eastern sky much before dawn. However, if the earth is moving from position (2) to position (3), then the star D will be visible in the western sky just after sunset while star C will be much higher above the horizon in the western sky at sunset. So, star D will set first followed by star C an hour or so later. And in this case, it will be star E which is going behind the Sun and so will not be visible in the sky.

Obviously, we need to look at how the night sky changes over time to figure out the direction in which the earth revolves around the Sun, whether it is going from position (2) towards position (1) or position (3). Continuing to look down upon the earth from the direction of the north star, if the earth were moving from position (2) towards position (1), it is moving counter-clockwise around the Sun and if it is going from postion (2) towards (3) then it is moving clockwise in its orbit around the Sun. Which is the actual direction and how long will we have to observe the night sky to figure this out?

An exercise similar to what we did to figure out the direction of the motion of the moon around the earth needs to be done. Remember that the orbit of the earth around the Sun can be considered a circle and the earth takes roughly 365 days to complete this circle. Since the circle is 360°, the earth moves approximately 1° each day. So if we look at the sky at a given time each night, the position of all the stars will change by one degree every day. However, this

change is too slight to be discernible with the naked eye and without special instruments. But if we were to note the position of any star or constellation once it gets fully dark (how many degrees above the eastern or western horizon is it at a given time) and then we can observe how this changes after about 15 days. This will change by about 15° in 15 days and can be easily observed. Then note how this changes every 15 days for about one and a half months
(For the purposes of this exercise, it is not very useful to observe the stars that are towards the south or north; as you might have observed, the North star does not appear to move at all[2]!), and

Going back to the figure we were discussing earlier, if the earth were going clockwise around the Sun, any star which is close to the western horizon on a particular day will be much higher above the horizon after 15 days. While if the earth were going counter-clockwise, any star close to the western horizon will set with the Sun after 15 days and will not be visible at all once it becomes fully dark; that is, any star in the western horizon will set earlier and earlier after it gets dark when you observe it over a period of one and a half to two months. Similarly, what would happen to a star that is just rising as it gets dark on a particular day if you observe it over the next couple of months? Would it be higher above the horizon in the east at the time of sunset, or does it rise later? I hope you would have made the necessary observations and figured out the direction of the motion of earth's revolution around the Sun by the time the next article in this series is published in *Sandarbh*!

And our close fellow travellers in the night sky!

As mentioned earlier, the stars (except the Sun, of course) are very, very far away, the closest one is more than four light years away. But the solar system consists of eight planets and their satellites along with other minor objects that orbit around the Sun. Of these eight planets, standing as we do on the planet earth, we can see five of these in the night sky with our naked eyes, and these five planets have been known to all ancient civilizations. The two outer planets – Uranus and Neptune – can only be seen using telescopes. Further, the moons of Jupiter and the rings of Saturn were only observed once we turned telescopes on them! The planets have fascinated sky-watchers ever since people started noting the positions of all the different points of light that are seen in the night sky. The planets stand out for two reasons – (i) all the stars twinkle while the planets are steady sources whether they are bright like Venus or faint like Saturn; and (ii) they seem to move randomly across the constant background of the twinkling stars, sometimes even seeming to go backwards[3]. That is, the positions of the stars do not change relative to each other while the planets appear to wander from one constellation to another. And yet more eccentrically, each planet seems to have a mind of its own and goes at its own pace regardless of what the other planets are doing.

Caption for figure 2 : The stars seem to maintain their positions in the different constellations, but the apparent proximity of the stars in a constellation is an illusion, and they are also in motion, though the change in their positions cannot be observed in a lifetime.

Labels in figure: How great it is that we stay together
But don't come any closer
Yes, maintain one-arm distance
Which arm are you talking about

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[2]The apparent lack of motion of the North star not just through one night but over the whole year will be explored in the next article.

[3]This 'retrograde' motion of the planets was what was so difficult to explain using the geocentric model. More on that further in the article.

Don't confuse me all over again
These stars and constellation .... regardless of how many times I pass by them, they never change

Careful observations of all heavenly bodies over many centuries had helped people figure out the patterns to be seen in the motion of each planet and it was observed that Venus and Mercury were never seen throughout the night. In fact, Mercury is only visible for a very short period immediately after sunset or just before sunrise for a few days at a time. Most days it cannot be seen at all. Venus is the brightest object in the sky after the Sun and the moon, and it is either seen in the western sky after sunset for a couple of hours (when it is wrongly called the Evening *Star*) or in the eastern sky for a couple of hours before sunrise (when it is equally wrongly called the Morning *Star*!).

Mars, Jupiter and Saturn can be seen through the night at different times of the year, but they travel at different speeds and most of the time seem to move in one direction against the background stars, and then confusingly seem to move in the opposite direction for a little while before resuming their forward motion. Complicated calculations had to be done to predict when each of these would decide to change their direction, and also to explain this motion figure 3).

Caption for figure 3 : The explanation for the retrograde motion of Jupiter in the geo-centric model. It was believed that along with Sun, moon, stars, other planets and all the other heavenly bodies, Jupiter also revolved around the earth. For ease of understanding, only Jupiter has been shown here – in its orbit around the earth, after going around on the big circle, it moves in the smaller circle which has its centre on the big circle. And when Jupiter is in the portion of the smaller circle which is within the bigger one, then it appears to be moving backwards along the fixed background of the stars.
Labels – earth, epicycle, jupiter

When Copernicus proposed the heliocentric model, he was going against the powerful Church in Europe which decreed that the earth was the centre of the universe created by God. So he played it safe and said that the proposed model just made it simpler to do the calculations to figure out the positions of the stars, and more importantly the planets, at any given time (future positions too). In his model, Copernicus had all planets, including the earth, orbit the Sun, with Mercury and Venus having smaller orbits and being closer to the Sun than the earth while Mars, Jupiter and Saturn had orbits which were outside the orbit of the earth. We are so used to seeing this illustrated in our textbooks and other materials that it is not easy to appreciate how revolutionary this idea was. The best thing about it might have been the explanation it gave for Venus and Mercury never being visible at midnight – since they were closer to the Sun than the earth, they would rise and set not too long after sunrise and sunset; the earth could never come between these planets and the Sun for them to be seen late at night.

The next best thing about the heliocentric model was the much simpler explanation for the retrograde motion of Mars, Jupiter and Saturn. And before we go into this explanation, a short aside about what this tells us about scientific explanations. Scientific theories are basically stories we make up to explain any phenomena. There can be any number of stories to explain any one phenomenon. Scientific theories are distinguished by their ability to not only *predict* what would happen in the future if that theory were true, but their tendency to be minimal. That is, given a multitude of explanations, scientists prefer theories that are not only based on the simplest assumptions, but also explanations that are applicable to more phenomena. That is, if we need to make up different stories for each phenomenon, and then someone comes up with a story (theory) that explains many phenomena with just one overarching theory, scientists prefer the single theory each time (maybe because they are too lazy to learn many different theories!!).

Let us try and explain the motion of Mars against the background of the stars using the heliocentric model. We know that the earth takes one year to complete its orbit around the Sun. Since Mars is much farther away[4], it takes about two years to complete one orbit around the Sun. So imagine what we would see if we were to observe Mars over a period of time. If Mars were to be overhead at midnight today (that is, we mark its position relative to some constellation), when the earth gets back to the same position in its orbit after one year (that is, when the same set of stars are overhead at midnight), Mars would have moved only half-way across its own orbit and would be behind the Sun and thus invisible at this point. But if we were to look for it after two years (roughly), it would be back in the same position in the sky (figure 4).

Caption for figure 4 : Since the orbital periods are different for each planet, we see them moving against the unchanging background of the stars. If we see Jupiter in the zodiac sign Scorpio in October one year, it will be in some other zodiac sign the next October, and will reappear in Scorpio only after about 12 years. Similarly, if we observe Mars in some constellation today, then we will see it again in the same constellation after about two years.

Labels : Mars, so many years have passed since I met you!

Only one year has passed, dear Earth! Just one more year and then we will meet in the same place at the same time.

Thus, depending on the time taken for each of these planets to orbit around the Sun, they would take that long for us to observe them in the same position against the background stars. Not just this, as all the planets move around the Sun at their own paces, each of the inner planets will 'overtake' the outer planets at some point in their orbit. To us, sitting on the planet earth, when we overtake Mars, we are basically observing Mars against the constant background of the stars and it appears to us as if the position of Mars changes over the days to go backwards, and this is what is called retrograde motion. Note the position of Mars, Jupiter and Saturn with respect to the background stars and see how this changes over time. Jupiter takes twelve years to orbit the Sun and so its 'speed' against the background stars will be much slower than that of Mars, and Saturn will be still slower since it takes 29 years to go around the Sun.

The Zodiac Belt:

When we look at the motion of the moon and various planets in the night sky, we will observe that these never appear too far to the north or south. In fact, they are restricted to a fairly narrow path from east to west. That is, they appear to be moving across a restricted background of all the stars that are visible in the sky. This is, of course, explained by having all the planets orbit the Sun on the same plane, and the orbit of the moon is not very different from this plane[5]. The stars in this path were recognised long ago and grouped into constellations that form the various signs of the zodiac. Hence, the Sun, moon and planets move along this Zodiac Belt. Obviously, when a constellation corresponding to a particular zodiac sign is behind the

[4]And moves much slower too; the gravitational theory explains why the planets closer to the Sun move much faster than the outer planets; Mercury is a breathless 100m-sprinter as compared to Neptune which moves at a snail's pace :-)

[5]The plane of the orbit of the moon with respect to the orbit of the earth around the Sun will be gone into in detail when we look into the explanation for eclipses in the last article.

Sun, it will not be visible, and then the Sun is said to be in that zodiac. The year has been divided into twelve months corresponding to twelve zodiac signs. Similarly, if we note the position of the moon each day against the background stars, a lunar orbit will require one constellation for each day and this corresponds to the 'nakshatra' of the Indian astrological system. In the absence of accurate instrumentation to note the positions accurately, the division of the night sky into different zodiac signs and 'nakshatras' helped to map the path of the moon and planets over time in the attempt to understand their motion and predict where each of them would be after a given period of time.

That is, this heliocentric model which has the stationary Sun at the centre and the earth and other planets orbitting it at different distances and with different orbital periods, can explain what we can see in the sky at different times of the year and what cannot be seen.

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