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COPERNICUS AND MODERN ASTRONOMY

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Nicolaus Copernicus was born in 1473 in Torun in what is known as Poland today. The year 1973 has seen many celebrations all over the world to mark the 500th anniversary of the birth of this great astronomer. It is fitting that India, with its ancient astronomical traditions, should take part in paying tribute to Copernicus and his work. I feel greatly honoured that I have been invited to speak on today's occasion.

It sometimes happens, particularly in this country, that speakers called upon to pay tributes to a great personality, go to extremes. They make him out to be 'perfect' in every sense of the word. This does justice neither to the achievements of the person being honoured nor to the intelligence of the audience who knows that no one is 'perfect'. In the case of a scientist, the greatest appreciation we can show is not by way of garlands or medals but by trying to understand his work in its limitations as well as its greatness. It is in this spirit that I wish to speak about Copernicus today.

What was Copernicus's major achievement? To say that 'he discovered that the Earth and the other planets go round the Sun' scarcely does him or his predecessors any justice. Nor does this statement convey the enormous impact that the work of Copernicus was to have on the subsequent development of astronomy, and of science in general. To understand the significance of his work we have to go back several centuries, to the golden age of Greek astronomy.

By examining the night sky over several centuries the ancient astronomers had tried to understand the pattern in the motions of heavenly bodies. Of these, the stars had reasonably simple trajectories—they seemed to go round in circles, with uniform angular motion. But, other objects, that we now know as planets, seemed to have more confusing motions. For example, unlike stars, they sometimes went forward sometimes backwards—the paths of some of them seemed to go through the Sun! Take for example the planet Venus. As shown in the Fig. 1, it seemed to move backward and forward relative to the position of the Sun as it went round the Earth. Its motion to and fro did not seem uniform or simple

* Based on the lecture given at the Birla Industrial and Technological Museum, in connection with the 500th birth anniversary of Copernicus.

harmonic (like that of a pendulum bob). For instance it took less time from extreme left point L to extreme right point R than vice versa. Also its brightness changed during the motion. The mystery of the motion of Venus was resolved when the astronomers discovered that it moved in a circular path with uniform speed around the Sun as the Sun moved in a circle round the Earth. This is shown in Fig. 2. The points L and R now correspond to the two tangential directions to the circle

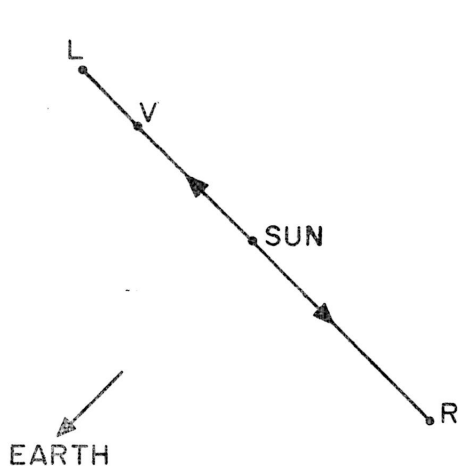


Fig. 1. Apparent motion of venus.

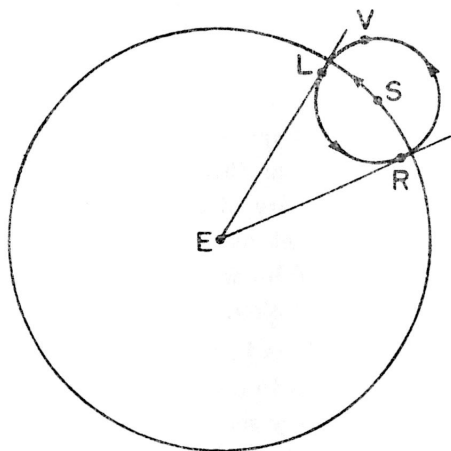


Fig. 2. A model for the motion of venus.

of Venus, drawn from the Earth. The arc LR in the sense shown in the figure is smaller than the arc RL , which explains the time discrepancy. The distance of Venus from the Earth changes during the whole period, which is why it appears with different brightness. From Fig. 2 it is also possible to compute the ratio of the distances of the Earth and Venus from the Sun.

Venus, as we know is an inner planet. It is closer to the Sun than the Earth. There are planets beyond the Earth—the so called outer planets. For these a similar, but slightly more complicated construction than that of Fig. 2 can be given. Fig. 3 shows three circles. Of these one describes the circular motion of the Sun round the Earth and the other two describe the circular motions of an inner planet (Venus) and an outer planet round the Sun. This picture was known to the famous Greek astronomers Hipparchus and Ptolemy. From this the transition to the picture shown in Fig. 4 is straightforward: it describes all the planets moving in circles round the Sun. This was suggested by the Greek astronomer Aristarchus and was independently arrived at many centuries later by Copernicus, as a starting point.

Although this transition from Fig. 3 to Fig. 4 seems simple, why did Hipparchus or Ptolemy not make it? Why did they continue to regard the Earth as fixed—the so called geocentric point of view? Why did Aristarchus who in fact proposed the arrangement of Fig. 4—the heliocentric point of view—not pursue it further?

This is because the observational astronomy in the Greek era was already fairly sophisticated and imposed stringent limits on the predictions of theoretical astronomers.

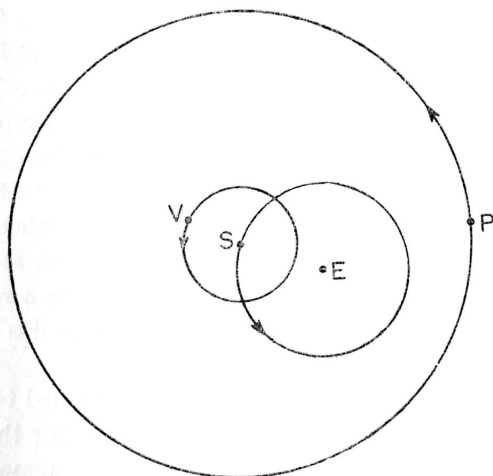


Fig. 3. A geocentric picture of planetary motions.

If we take the arrangements shown in Fig. 3 or 4, we can theoretically predict the relative positions of the planets on the sky at different instants of time. It is because these predictions did not match with the observed ones that Ptolemy sought to modify the simple arrangement of Fig. 3 and Aristarchus could not confidently advance the heliocentric point of view. To understand this discrepancy we will make use of our present knowledge of planetary orbits. The situation is illustrated in Fig. 5 for a typical planet P . We know that P moves in an elliptic orbit with

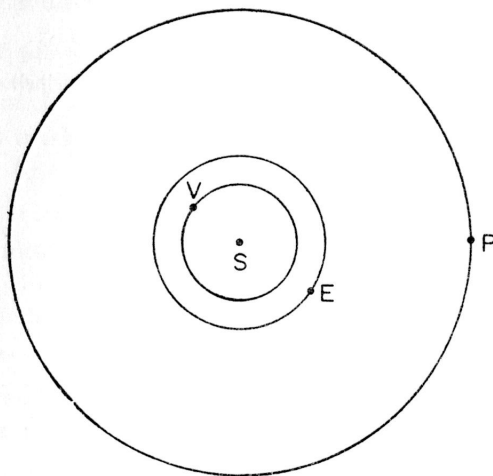


Fig. 4. A heliocentric picture of planetary motions.

the Sun as one of the foci. The departure of an elliptical orbit from a circular one is measured by a parameter known as the eccentricity e . For a circle $e = 0$, for an ellipse e lies between 0 and 1. Now the line joining the Sun to the planet does not move with uniform angular velocity in space—as assumed in the simpler pictures of Figs. 3 and 4. The discrepancy becomes larger as e moves further and further away from $e = 0$. Thus for Mercury it is the largest, while it is not too large for Venus. However, the situation as viewed from the Earth is a little more complicated and it is the planet Mars which shows the greatest discrepancy. In the case of Mars the theoretical predictions and the observed positions on the sky differed by upto 10° . Such discrepancies were simply unacceptable to the theoretician of the calibre of Ptolemy. He proceeded to improve the theoretical position by modifying the simple picture shown in Fig. 3 by more elaborate geometrical constructions. We shall come to the details of these later. As a result of these constructions Ptolemy was able to reduce the discrepancy to less than 1° for planet Mars and did even better for other planets.

When Copernicus began his attack on the problem he had to achieve two goals. First in proposing a heliocentric picture, he had to do better than Aristarchus and thus improve on Fig. 4. Secondly he had to match the remarkable performance of Ptolemy's geocentric picture which we have just seen. That he succeeded in doing so represents his remarkable achievement.

In a recent book on Copernicus, Sir Fred Hoyle has given a comparative description of the work of Ptolemy and Copernicus from a modern stand-point. At the risk of becoming a little technical I wish to outline this description since it describes beautifully the magnitude and limitations of the achievements of Copernicus.

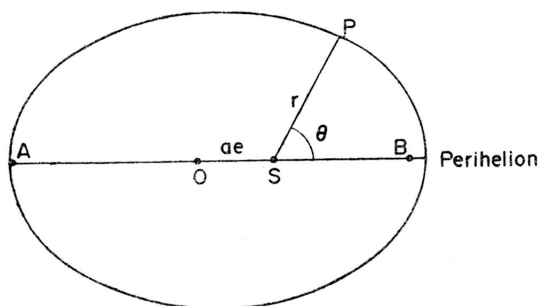


Fig. 5. A typical planetary orbit

$$\theta = nt + 2e \sin nt + \frac{5}{4} e^2 \sin 2nt + \dots$$

$$\frac{r}{a} = 1 - e \cos nt + \frac{1}{2} e^2 (1 - \cos 2nt) + \dots$$

In the elliptic orbit described in Fig. 5, AB is the major axis and O the centre of the ellipse. The planet is closest to the Sun when it is at B and this point is called the perihelion. The angle PSB is denoted by θ and the distance SP by r . The distance $OA = OB$ is denoted by a . The distance of the Sun from the centre

of the ellipse is ae , where e is the eccentricity mentioned before. Elementary co-ordinate geometry then tells us how r is related to θ :

$$r = \frac{a(1-e^2)}{1+e \cos \theta}.$$

Suppose now we start counting time when the planet was at the perihelion, and suppose we know that the planet completes one revolution in a period $2\pi/n$. Can we calculate r and θ in terms of time t ? This is the problem the ancient astronomers wanted to solve: to specify the position of the planet in space at any given time t . Now it turns out that, although the relation between r and θ given above is simple enough, the relations between r and t and θ and t are complicated. We get the following infinite series in eccentricity:

$$\theta = nt + 2e \sin nt + \frac{5}{4}e^2 \sin 2nt + \dots\dots\dots$$

$$\frac{r}{a} = 1 - e \cos nt + \frac{1}{2}e^2(1 - \cos 2nt) + \dots\dots\dots$$

The pictures described in Fig. 3 and 4 are crude approximations of these relations, obtained by taking only the first term of the series in each case:

$$\theta = nt, \quad r = a.$$

Ptolemy and later Copernicus improved these pictures by taking into account terms of the order of e . It so happens that the eccentricity values for different planets are small, the largest being $e = 1/5$ for Mercury. So the pictures developed by Ptolemy and Copernicus, although approximate ones in the above sense, were good enough to describe planetary motions fairly accurately.

The construction given by Copernicus is described in Fig. 6, with slight modifications which I will discuss later. If B is the perihelion and S the Sun, join BS and produce it to K where $SK = \frac{3}{2}ae$. With K as centre draw a circle of radius a . On it take point L such that $\angle LKB = nt$. With L as centre draw a circle of radius $\frac{1}{2}ae$. On it take point P such that PL makes angle nt with KL produced. P is the position of the planet.

This construction is equivalent to taking the series for r and θ only upto first two terms. Copernicus made two small 'errors' in his actual description. He omitted the small circle in the case of the Earth and when discussing the other planets he replaced the Sun by the point K determined for Earth. These departures from the above construction were probably motivated by his desire to correct further small irregularities in the observed planetary motions.

Ptolemy's construction is more complicated, although it achieves the same accuracy as the construction of Copernicus. This is described in Fig. 7. Here $CE = ae$ and L moves on a circle round C with radius a such that at time t , $\angle LAE$

to the question "What impact did Copernicus have on subsequent development of astronomy?" I now turn to this important question.

The heliocentric theory of Copernicus was the starting point for the exhaustive analysis of planetary motion completed by Kepler some hundred years later. It was Kepler who finally arrived at the exact relation between r and θ and hence at the elliptic nature of the planetary orbits. This then led to the next important development. Having sorted out 'how' the planets move, the next question was 'why' they moved in ellipses. This was resolved by Newton with his inverse square law of gravitation. And so began the march of science as we know it today. The work of Copernicus therefore marks a corner stone separating the medieval era from the modern era of science.

The Copernican point of view was concerned with the Solar System which forms a tiny part of the vast universe we look at today. However, this point of view has had an important influence on the thinking of the modern astronomer. Just as we learnt from Copernicus that the Earth has no special position in the Solar System, so we now know that the Solar System has no special place in the Galaxy which contains some 10,000 crore stars like the Sun. Nor does the Galaxy have any special position in the Universe whose observable part contains an estimated hundred crore galaxies like our own! Indeed the so called 'cosmological principle' which forms the basis of the modern theories of the structure of the universe says that the universe looks the same from wherever you observe it and in whatever direction you observe it; in other words there is no such thing as a 'special position' in the universe. This represents a complete turn-around from the Greek cosmology which made the whole universe revolve round the Earth. This above anything else, represents the impact of Copernicus on modern astronomy.