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Historical Perspective of the theory of planetary motion

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Abstract
The ideas which contributed towards transformation from Geocentric to Heliocentric theory are discussed. Major Contributions in this field were made by Copernicus, Kepler, and Galileo. All of them worked independently to formulate a mathematical model which provided a sound logic to the heliocentric theory. The social setup at that time which posed a serious threat to their ideas and challenges they had to face from irrational religious beliefs were seen.

Keywords: areal velocity, geocentric, heliocentric, retrograde motion, telescope

1. Introduction

Around 350 BC there lived a Greek astronomer, Aristarchus, who wrote a short treatise On the Sizes and Distances of the Sun and the Moon. In this treatise, he proclaimed that the Sun and not the Earth was at the centre of our world and that all planets revolved around the Sun. His book became a classic of antiquity and he was considered one of the foremost astronomers of his time. Both Archimedes and Plutarch knew about his work. Incredibly enough, Aristarchus was forgotten. Wrong ideas arose in due course of time and established their roots in the society. During the different stages of development original thinkers put forward their views on the basis of scientific facts and experiments. Many hardships they had to face to spread their knowledge in those times. Here we put forward some aspects of that struggle and try to view the things in a historical manner. How the scientific ideas were struggling to get freedom from the clutches of so called religious people. What type of obstacles people had to face who oppose the prevailing system. All these things are discussed.

2. Stages of Development

The geocentric [1] system of Ptolemy, a much more complicated and aesthetically unappealing one, held sway even around the second and third centuries AD. From then on, throughout the Dark Ages, there was no hope of revival. Later, as Europe went through the Renaissance, one would have hoped for the right ideas to emerge. But the strong religious dogmas and theological interpretations of Aristotle's outdated ideas suppressed the truth for centuries.

Fig 1: The pre-copernican universe in which the earth is at the centre, and the sun, the moon, planets and the stars go around the sun in con-centric circles.

3. Copernicus View of Universe

In 1543 Nicholas Copernicus wrote a book *De Revolutionibus Orbium Coelestium* (On the Revolution of the Heavenly Bodies) in which he gave heliocentric [2] model in which Sun was at the centre. Born in 1473 in Torun in Eastern Poland, Copernicus lost his father early. Thereafter, his uncle brought him up, and he gave Copernicus a very good education. In 1496, Copernicus travelled to Italy and studied medicine and canon law for 10 years. This was when he got interested in astronomy. In those days, the positions of the planets were calculated by the system evolved by Ptolemy.

In spite of its complexity (and detailed mathematics), this system was cracking up. The predicted positions of planets were getting to be far away from the observed ones in spite of the several ad hoc corrections introduced by later astronomers. The observation of the trajectories of planets revealed some strange anomalies. The planets Mercury and Venus were always seen close to the Sun, just after sunset or just before sunrise and never overhead at night. The other three planets, Mars, Jupiter and Saturn, showed irregular pattern of motion every once in a while. They travelled in one direction for some time, stopped in their tracks and then seemed to move backwards.

These features are difficult to understand (in a natural manner) if the planets were moving around the Earth. It occurred to Copernicus that the calculations could be simplified if one adopted the heliocentric system. Copernicus's genius – if you could call it that – was in putting this idea into practice and meticulously working out the details of the new model. Copernicus realised that his model could explain several things, which Ptolemy could not. The retrograde motion of planets is also easy to understand: if the Earth revolves around the

Sun at a faster rate than the outer planets, then the Earth will 'overtake' these planets.

Fig 2: The copernican universe with the Sun at the center and moon going around the Earth.

Seen from the Earth, the outer planets will appear to go backwards. Also, since the distance between the Earth and Venus varies quite a lot, the appearance of this planet will be altered periodically. Nicholas Copernicus wrote a book *De Revolutionibus Orbium Coelestium* (On the Revolution of the Heavenly Bodies) the publication of which he had delayed by nearly 30 years as he hesitated to publish it knowing well that he could get into trouble with the Church. The only place where Copernicus erred was in sticking to the circular motion [3].

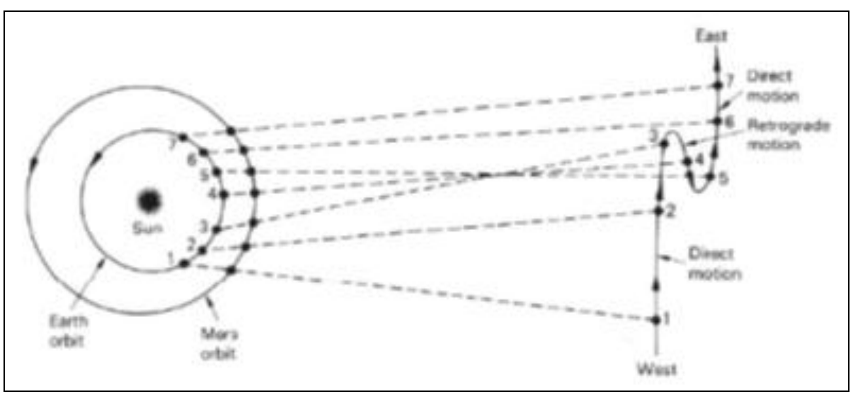

Fig 3: The retrograde motion of Mars

4. Tycho Brahe's View

Tycho Brahe (1546–1601) grew up to be the most accurate observational astronomer before the days of the telescope. Tycho had an excellent education in law, but his heart was set on astronomy. Right from his student days, he kept a careful record of the night sky, day after day. The real turning point in his life probably came in August 1563 when he was observing the 'conjunction', or the close appearance, of Jupiter and Saturn. He discovered that all the almanacs were widely off the mark in predicting this event! This convinced him of the need for exact and accurate observations with good instruments – a task, which he set himself.

He travelled all over the Europe acquiring the instruments and set up a small observatory at Scania in 1571. He had a chance, literally of a lifetime, on 11 November 1572, when he spotted a 'newstar' near the constellation Cassiopeia. This new star was brighter than Venus. And Tycho's careful observations showed that this star was too far away from the Earth, definitely farther than the Moon, and therefore among the fixed stars. This conclusion, set out in his book *De Nova Stella* in 1573, shattered prevailing dogmas. For, according to the accepted Aristotelian principles, all change and decay were confined to the Earth and the realms of the stars were immutable.

The appearance of a new star was therefore a blow to this idea. Tycho's astronomical observatory was a masterpiece of workmanship and was extremely accurate in making observations. (Ptolemy's observations were correct to 10 minutes of arc while Tycho's were exact up to two minutes of arc!) In 1577, a great comet appeared in the sky of which Tycho kept a careful track. His measurements again confirmed two facts: (i) the comet was much farther than the Moon, and (ii) its path was very different from a circle. These further damaged the credibility of Aristotle's ideas.

Tycho corrected every single astronomical measurement for the better. He observed the motions of the planets, especially that of Mars, with unprecedented accuracy. He also determined the length of the year to an accuracy of almost a second. This measurement had a bearing on calendar reforms. However, Tycho's good fortunes declined with the death of Frederick II in 1588. Having picked fights with the new king, the nobility and the clergy, Tycho had to abandon his observatory and finally settle in Prague, under the patronage of Rudolf II.

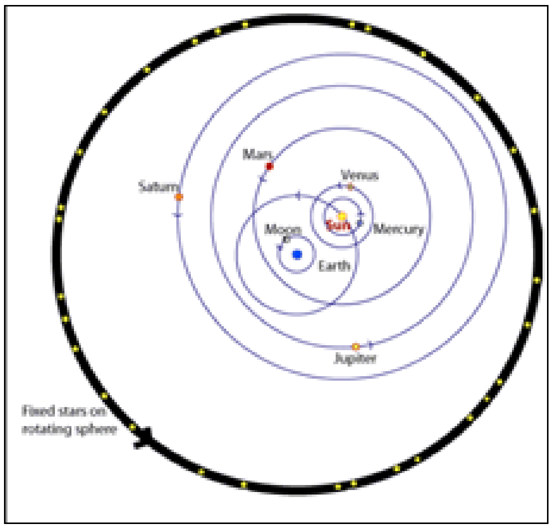

Fig 4: Brahe's model solar system in which Sun revolves around Earth and all other planets revolve around Sun.

5. Kepler's Contribution

Johann Kepler (1571–1630) was everything Tycho was not. He was born in Germany. As an astronomy student, Kepler was strongly influenced by Copernican concepts. Though his early attempts to fix planetary orbits based on platonic solids were not very successful, it brought him in contact with Tycho. In 1597, as religious disputes became intense in his hometown, Kepler accepted a position in Tycho's observatory in Prague. With the death of Tycho in 1601, Kepler inherited the vast amount of astronomical observations which Tycho had recorded. Kepler started to find simple rules describing the motion of the planets – especially that of Mars [4].

The failure of simple models finally forced Kepler to assume that 'the paths of planets around the Sun are ellipses with the Sun at one focus'. Based on Tycho's meticulous observations again, Kepler could conclude that 'the line joining the planet and the Sun traverses equal areas in equal amount of time' i.e areal velocity of planet remains constant. These two laws, published in his *Astronomia Nova* in 1609, earn Kepler a place in the history of science. Ten years later, he published another book full of mysticism in which he wrote: "The square of the period of revolution of a planet is proportional to the cube of its distance from the Sun". This third law took a significant step in a new direction. By relating the orbital properties of various planets to the central agency, the Sun, it almost suggested that the Sun is the cause of planetary motion. During the years 1620–1627, Kepler completed the new table of planetary motions based on Tycho's observations and his theory of planetary orbits. He dedicated this table to the memory of Tycho – were published in 1627. Almost around the time when Kepler was perfecting the laws of planetary motion, another man was laying the foundations of theoretical mechanics.

6. Galileo's Era

This was Galileo Galilei (1564–1642). Galileo was born on 15 February 1564 in Pisa, Italy. An accidental exposure to a lecture in geometry made Galileo turn to mathematics and later to Physics. His first invention was a hydrostatic balance about which he wrote an essay in 1586. The fact that a steady force acting on a body increases its speed continuously, raises a question: is it at all necessary to have a force acting on a body to keep it moving at constant speed?

Galileo thought – quite correctly – that motion in constant speed required no external agency. This principle – now known as the principle of inertia – played a crucial role in the later developments of dynamics and the theory of relativity. Galileo also used this principle effectively in calculating the trajectories of projectiles thrown from the ground. Around 1608, a spectacle-maker in Holland, Johann Lippershay, had invented an optical tube containing two lenses, which could make distant objects appear closer. Lippershay sold several of these models in the cities of Europe, and Galileo came to know of this invention in the spring of 1609.

Galileo could easily make for himself a telescope with a magnifying power of about 30 and he turned the new invention towards the sky. Thus began the age of telescopic astronomy [5]. Using his telescope, Galileo discovered several aspects of nature, which were until then hidden from the human eye. The stars and the planets appeared very different through the telescope and Galileo could see many more stars than were visible to the naked eye.

Galileo found that Jupiter was attended by four subsidiary objects, which circled it regularly, and, within a few weeks of observation, he could work out the periods of each of these satellites. Called Io, Europa, Ganymede and Call is to, these satellites clearly showed that not all celestial objects went around the Earth. His telescope also revealed the phases of Venus and ring-like structures around Saturn. Galileo announced his initial discoveries in a periodical, which he called Sidereus Nuncius (The Starry Messenger).

During the years 1611 to 1633, Galileo completed his masterpiece, *Dialogue Concerning the Two Chief World Systems*, in which he had two people, one representing Ptolemy and the other Copernicus, present their arguments before an intelligent layman. Needless to say, Galileo made the Copernican theory come out on top. The system of the world suggested by many Church astronomers of those days had planets orbiting the Sun with the Sun itself going around the Earth.

In the years to follow, Galileo was forced to enter into controversies [6] with jealous colleagues, Church astronomers, powerful members of the nobility and many others on whether the motion of the Earth around the Sun can be proved. Galileo found himself at a loss in providing the "proof", especially because he did not want to give credit to Kepler for the elliptical orbits. From then on, things took an ugly turn. The Pope asked the Qualifiers of the Holy Office to take a clear stand on the matter and this they did on 23 February 1616 – categorically against the motion of the Earth around the Sun. Six days later, Galileo had an audience with the Pope and he was told not to exceed the limits set by the Church. The Holy Office put Galileo on trial [7, 8] in 1633, essentially on the charge that the contents of his book, *Dialogue Concerning the Two Chief World Systems* published in 1632, went against the decree of 1616. Found guilty, he was allowed to spend the rest of his life in house arrest. Galileo died on 8th January, 1642 while still remaining under house arrest in accordance with the verdict of the Church [9].

7. Conclusion

Stages of development from geocentric model to heliocentric model were discussed. The ideas and views given by different philosophers were challenged on the grounds of experimental observations. Major contributions made by Copernicus, Brahe, Kepler, and Galileo towards this transformation were highlighted. Obstacles faced by them due to prevailing social structure which tries to snub scientific and rational thinking were also discussed. At the end we can conclude that development of science is continuous process and different people make their own contributions in that process.

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