Journal of Astronomical History and Heritage 5(1):89-98 2002

From Pythagoreans to Kepler: the dispute between the geocentric and the heliocentric systems

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Abstract
Some ancient Greek philosophers and thinkers questioned the geocentric system and proposed instead a heliocentric system. The main proponents of this view – which was seen as heretical at the time – are believed to have been the Pythagoreans Philolaos, Heraclides, Hicetas, and Ecphantos, but mainly Aristarchos of Samos, who placed the Sun in the position of the 'central fire' of the Pythagoreans.

The geocentric system, reworked by Claudius Ptolemaeus (Ptolemy), was the dominant one for centuries, and it was only during the sixteenth century that the Polish monk-astronomer, Copernicus, revisited the ancient Greek heliocentric views and became the new champion of the theory that we all accept today.

Key words: *Pythagoreans, Aristarchos the Samian, geocentric system, heliocentric system*

1 THE PYTHAGOREAN SCHOOL

The Pythagorean School considered the *number* as the essence of all beings; it was something that was abstract, unperceived by the senses, and only of the mind. Therefore, the nature of all beings was not material, nor accessible to the senses. Only through abstract thought, according to the Pythagoreans, could the essence be conceived. Thus, the philosophers of this School reduced infinity to a material element, which was beyond counting and definition. That is, they introduced the notion of 'matter' as an element that denied any definition, and was the source of ontological and ethical imperfection.

For the Pythagoreans, the world was created after the initial 'One' was formed. This entity, created in the very beginning, attracted the infinity and assigned to it the end. The Pythagoreans considered an initial single element as the beginning of Creation, which continuously expanded and included infinity. This corresponds, in a certain sense, to the cosmological hypothesis of the universe being a static sphere, continuously expanding, after starting from an initial point. The Pythagorean School stated that the universe evolved from an infinitesimal nucleus, which was expanding spherically upon the infinity. As we know from Aristotle *The Metaphysics* (Book XIV, iii. 12-15, 1091a 15), the Pythagoreans

> ... clearly state that when the One had been constituded – whether out of planets or seed or out of something that they cannot explain – immediately the nearest part of the Infinite began to be drawn in and limited by the Limit. (Aristotle, 1939).

2 THE HYPOTHESES OF PHILOLAOS OF CROTON

In the middle of fifth Century BC, the Pythagorean hypotheses about the very beginning were made more widely known by Philolaos of Croton (in South Italy), who was saved from the revolt against the Pythagoreans along with Archippos, Lysis, and others. Philolaos settled in Thebes, where he taught Pythagorean philosophy and wrote the books *Bacchae* and *On Nature (ABC)*. The following passages are found in the first book: "The world is one, and it was created beginning from the middle, i.e. from the central point which is equidistant from both the upper and the lower." (Fragmente 17. [B. 90] Stob. Ecl. I 15, 7 [p. 148, 4W.]) (Plutarch Chaeronensis Scripta Moralia), and "The initial one, consisting the beginning of the creation of the universe, is called Hestia." (Fragmente [B. 91] Stob. Ecl. I 21, 7 [p. 189, 17W.] (Philolaos of Croton, 1996).

At the beginning of second century AD the doxographer (this is, a writer who records the theories of older philosophers), Aetius (1879), wrote:

> Philolaos held the view that in the middle of the world approximately at the centre lies the fire which he calls the hearth of the universe, the Jupiter's abode, the mother of Gods, the Altar and Unity and Measure of Nature. There is also another fire in the upper part of the world which surrounds it. First comes by nature the centre around which ten divine bodies revolve the heavens, the sphere of fixed stars, the five planets, then the Sun under which the Moon, the Earth and the Counter-Earth (Antichthon) come in succession; at the very end comes the fire which is the focus around the centre. (Aetius II 7, 7).

And drawing his information from Theophrastus, Aetius (ibid.) writes:

> Philolaos the Pythagorean believed that the centre of the world was occupied by the fire (because this is the focus of the universe), then came the Counter-Earth (Antichthon) and thirdly the inhabited Earth which lies opposite the Counter-Earth and revolved around the centre along with the Counter-Earth; thus the inhabitants of the Counter-Earth are not visible to those who live on Earth ... [Aet. III 11, 3 (D. 377 aus Theophrast.)].

As mentioned by Diogenes Laertius, in the book *On Nature (A B C)* Philolaos writes that "Nature in the ordered Universe was composed of unlimited and limited elements, and so was the whole Universe and all that is therein." (Diog. VIII 85, chapter 7. [A1 I 398, 20]). (Diogenes Laertius, 1925:400).

Pythagoras laid the foundations of mathematical philosophy and mathematical physics by correlating the order and the harmony of sounds with the order and the harmony of the universe. We must not forget, of course, that this great thinker believed that the Earth was spherical, just as we do today. Aristotle informs us in his work *On the Heavens* (II, Chap. xiii, 293a, 293b) that the Pythagoreans also supported a pyrocentric theory of the World, according to which the Earth was revolving around a central fire, called 'Dios Phylake' (the Watch-tower of Zeus) (Aristotle, 1933). This theory, which must be attributed to Philolaos, did not place the Sun at the position of that central fire; this was only done in the third Century BC by Aristarchos the Samian, the astronomer and natural philosopher who must also be classified as a Pythagorean.

Therefore, the Pythagoreans as a whole were the ones who questioned for the first time the geocentric theory of the universe, and in so doing they opened the way for the (essentially Pythagorean) heliocentric theory, which was made widely known many centuries later by Copernicus.

Cicero reports the following in his *Academica Priora* (II, xxxix, 123):

> Hicetas Syracusius, ut ait Theophrastus (Phys. Opin. Fr. 18, D. 492), caelum lunam stellas, supera denique omnia stare censet neque praeter terram rem ullam in mundo moveri: quae cum circum axem se summa celeritate convertat et torquerat, eadem effici omnia quae si stante terra caelum moveretur (Vgl. Aet. III 13, 2 [s. Zeile 23]. Diog. VIII 85: 44 A1 [I 398, 12]) atque hoc etiam Platonem in Timaeo dicere quidam arbitrantur, sed paulo obscurius. (Cicero, 1933).

This translates as:

> The Syracusan Hicetas, as Theophrastus asserts, holds the view that the heaven, the Sun, the Moon, the stars, and in short all the things on high are stationery, and that nothing in the world is in motion except the Earth, which by revolving and twisting round its axis with extreme velocity produces all the same result as would be produced if the Earth were stationery and the heavens in motion; and this is also in some people's opinion the doctrine stated by Plato in Timaeaus (40B) but a little more obscurely.

3 ANAXIMANDER, ECPHANTOS, AND HERACLIDES OF PONTUS

According to Theon of Smyrna (1878) who lived in the time of Emperor Hadrian, in addition to the Pythagoreans, Anaximander considered the Earth to be a moving body, and the Sun to be a circle twenty-eight times the size of the Earth.

Meanwhile, Aetius (1879) informs us that

> Heraclides of Pontos and Ecphantos the Pythagorean think that the Earth moves not being displaced from its position in space, but rotationally, as the wheel rotates around its axis, from the west to the east around its centre. [Aet. III, 13, 3 (D. 378)].

According to Simplicius, Heraclides of Pontus, "... by supposing that the earth is in the centre and rotates literally ['moves in a circle'], while the heaven is at rest ... thought by this supposition to save the phenomena." (Simpl., on Arist. De Caelo, II, 13, 293 b 30; p 519, 9-11, Heib) (Heath, 1965, I:317).

So Heraclides, Ecphantos and other Pythagoreans accepted the notion that the Earth moved only rotationally, as a wheel, fixed to an axis, from the west to the east. But they believed that the stars and the planets Mercury and Venus were moving around the Sun. Sir William Cecil Dampier (1946:48) has written about this hypothesis:

> It was known that the Earth was a sphere, and some idea of its true size began to be formed. This growth in knowledge was not favourable to the ideas of the counter-earth or central fire imagined by Philolaus, and those parts of Pythagorean astronomy were thenceforward discredited. But the knowledge gained of the variations with the latitude in the length of day and night led Ecphantus, one of the latest of the Pythagoreans, to the simpler conception of the revolution of the Earth on its own axis at the centre of space. This was also taught about 350 by Heraclides of Pontos, who held that, while the Sun and major planets revolve round the Earth, Venus and Mercury revolve round the Sun as it moves.

Heraclides believed that the sphere of fixed stars was at rest, and he proposed a model where the Earth was at the centre of planetary motion but rotated on its axis daily. As far as the composition of the material of the universe is concerned, Heraclides conceded that it was made of small molecules of matter not connected with each other. It seems that he had modified the theory of Democritus, and he thought that the first elements that existed in the world were not atoms, but the molecules which these atoms constituted. Heath (1965, I:317) says that: "But there is no doubt of the originality of the other capital discovery made by Heraclides, namely that Venus and Mercury revolve, like satellites, round the Sun as a centre."

Heraclides (390-339 BC) was a student of Plato, but also studied with Aristotle and with Speusippus, who was Plato's successor as head of the Academy. Heraclides believed planets to be divine entities revolving around the Earth and that the Earth was rotating on its axis, a rather interesting idea due to the fact that the eigenorbit simplifies the celestial movements that must be defined. For example, the daily orbit of the Earth explains the daily movement of the celestial sphere, whereas in Eudoxus's model of homocentric spheres this movement was described from the outer sphere of the system. Heraclides accepted the fact that the Sun revolved around the Earth in one year, and assumed that Venus was at the same time in circular motion around the Sun. This orbit had a radius smaller than the distance between the Earth and the Sun, and had a period equal to the duration of the synodic period of Venus.

Dreyer (1953), who reconstructed the semi-heliocentric model of Heraclides, agrees with the above scenario, a view against which Neugebauer expressed some not very persuasive doubts. According to a translation by Neugebauer (1972:601), in a commentary by Chalcidius (fifth century AD) on Plato's famous Timaeus: "Heraclides Ponticus, when describing the circle (circulum) of Venus as well as that of the sun, and giving the two circles the same centre (unum punctum) and the same mean motion (unam medietatem), showed that Venus is sometimes ahead (superior), sometimes behind (inferior) the sun." A number of scholars have pointed out the significance of this passage: in saying that Venus was sometimes above and sometimes below the Sun, Heraclides must have believed that this planet was in orbit around the Sun. On the contrary, Neugebauer (ibid.) believes that the above passage simply means that Venus is sometimes ahead of the Sun, and sometimes behind it. This was a new interpretation of Heraclides's hypothesis.

In writing about Heraclides's hypothesis, Angus Armitage (1956:40) points out:

> The Greeks actually hit on the idea that the Sun might be the fixed centre about which the Earth and the planets moved in circles. This interesting development began in the fourth century B.C. with one Heraclides trying to account for the peculiar behavior of Venus and Mercury. These planets are never seen far from the Sun and they appear sometimes on one side of him and sometimes on the other. Heraclides suggested that perhaps they each described a circle about the Sun, while he revolved about the Earth.

4 ARISTARCHOS THE SAMIAN

Circa 280 BC Aristarchos the Samian (310-230 BC) assumed that the Sun was at rest and that the Earth revolved around the Sun in a circular orbit. Aristarchos's hypothesis is recorded by Archimedes in his work *Psammites* (Arenarius or The Sand-reckoner):

> Aristarchus uero Samius hypothesium quarundam descriptiones edidit, in quibus ex iis, quae supponuntur, adraret, mundum multiplicem esse, quam supra diximus. Supponit enim, stellas fixas solemque immobiles manere, terram uero circum solem in medio cursu positum secundum circuli ambitum circummolui. (Arenarius, I. 8-13) (Archimedes).

An English translation is:

> Aristarchos the Samian has published in outline certain hypotheses from which it follows that the universe is greater than formerly believed. He assumed that the fixed stars and the Sun are at rest, while the Earth revolves in an orbit the centre of which is occupied by the Sun. On the other hand, the sphere of fixed stars, having the same centre as the Sun, is so large that the circular orbit of the Earth around the Sun has the same ratio to the distance of the fixed stars, as that existing between the centre of the sphere and its surface.

This hypothesis is also verified by Plutarch, who states in his book *De Placitis Philosophorum*: "Aristarchos Solem fixis stellis adjungit, terram [al. lunam] autem moveri ait circum Solis orbem, et suis inclinationibus umbram disco inferre." (Liber Secundus, XXIV. De Solis defectu, 6), which translates as: "Aristarchos held the view that the Sun and the fixed stars are at rest while Earth is revolving around the solar circle; also that during the Earth's obliquely circular motion the Sun's disc is shadowed (causing a solar eclipse)." (Stamatis, 1973:31-34).

These references by the ancient writers show that Aristarchos is the father and founder of the heliocentric theory, and this is also confirmed by Claudius Ptolemaeus (Ptolemy) in his second century AD *Great Mathematical Syntaxis*. This important astronomer writes that Aristarchos suggested the heliocentric system, as also did Hicetas and Ecphantos. Furthermore, Aristarchos combined this with the rotation of the Earth on its own axis. He supported a model where the Earth had a double motion: it rotated on its axis daily and it revolved around the Sun annually.

Unfortunately, Aristarchus could not prove his hypothesis with the astronomical instruments of his time,. For many centuries humans had been happy to believe that the Earth was the centre of the universe, and views like those put forward by Aristarchos were, to say the least, disrespectful to the heavenly divine order. But more than this, they shocked the foundations of the geocentrically- and egocentrically-founded solar system.

Plutarch mentions that as a result of his radical views Aristarchos was accused of atheism, and it may have been for this reason the great philosopher of Samos did not develop his hypothesis mathematically. Nor did he create a system of planetary orbits in order to support it, as he did in the case of the geocentric system. Thus, one of his treatises, with the title 'Peri ton megethon kai apostematon Heliou kai Selenes' ('On the sizes and distances of the Sun and Moon'), is based on the geocentric system (see Heath, 1932).

However, it is an indisputable fact that Aristarchos proposed the heliocentric theory, and he was the first astronomer, who around 280 BC, dared to speak openly about the Earth's movement in a heliocentric system. Many later astronomers rightly give him this credit. In the original text of Copernicus's *De Revolutionibus Orbitum Celestium* (Lib. i, cap. x) was the sentence: "Similar reasons probably lead Philolaus to assume the Earth's rotation and movement, an opinion that among others, Aristarchos from Samos accepted.", but for some unknown reason this was deleted and was never published (although one can find it in the manuscript preserved at the University Library in Warsaw). Since Copernicus's day, many research papers and books have been touched on this topic (e.g. see Armitage, 1956, Dingle, 1953, Dreyer, 1953, Fraser, 1948, Gibbs, 1979, Gingerich, 1985, Heath, 1981, Neugebauer 1972, Stahl, 1945 and Wall, 1975), and the following comments are characteristic: "Aristarchos of Samos, proposed a heliocentric theory which was an anticipation of the Copernican theory of the solar system." (Fraser, 1948:49); "Aristarchos of Samos, who is best known for proposing, long before Copernicus, that the Sun was the center of the solar system." (Gibbs, 1979:47); and "If the Greeks had followed Aristarchos the latter achievement – i.e. the problem of celestial motions – might have been completed by the time of Ptolemy." (Dingle, 1953:116). And in referring to the theory of Aristarchos, Armitage (1956:41) wrote:

> Then it was realized that everything would look just the same if, instead of the Sun revolving round the Earth, the Earth went round the Sun, just as the five planets were being supposed to do. This step was taken in the 3rd century B.C. by a Greek astronomer called Aristarchos who came from the same island of Samos as did Pythagoras. He also accounted (as Heraclides too had done) for the daily rising and setting of the heavenly bodies by supposing the Earth to turn round once a day on its axis. He thus arrived at the complete Copernican theory of the solar system, and earned his title of the Copernicus of Antiquity.
>
> Aristarchos did not work out his theory in detail as Copernicus did.... So little more was heard of this sun-centred planetary system until 1800 years later, when Copernicus began to establish it as the accepted theory of modern times.

Finally, the title of Gingerich's 1985 article is characteristic: 'Did Copernicus owe a debt to Aristarchus?'

5 ARISTOTLE AND CLAUDIUS PTOLEMAEUS

In that period the geocentric system was the dominant one, since it served human vanity to have our little planet at the centre of the universe. Many astronomers supported the theory of the geocentric system, but it was under the weight of the great Aristotle that this system was maintained for many centuries in Western Europe.

According to Aristotle, the visible 'corporality' of the stars – of the divine bodies – was in a continuous circular motion. The fixed stars and the planets were mixed together in a series of hollow spheres, and moved in circles with various directions and velocities. According to this theory, there should be as many spheres as is needed to explain all celestial motions, and in his scenario Eudoxos required 55 spheres in order to attain this goal. Therefore, one should take into consideration 55 'stellar gods', consisting of a 'moving spirit' and a body in circular motion. Meanwhile, the Sun was moving around the Earth normally, but varied in distance, which explained summer and winter.

The geocentric system became widely known as the Ptolemaic system, due to the fact that Claudius Ptolemaeus or Ptolemy (second century AD) was the one who worked out the planetary orbits in detail and tried to explain them. In the first book of the *Great Mathematical Syntaxis* (more generally known as *The Almagest*) Ptolemy gives an account of his arguments in support of a motionless Earth in the centre of the universe. He argues that, if the Earth were moving, then certain phenomena should be observable as a result of its motion. For example, since all bodies tend to fall towards the centre of the universe, the Earth should be motionless in this centre. Otherwise, the falling bodies should not move towards the centre of the Earth as they do. Moreover, if the Earth were rotating on its axis once every 24 hours, an object thrown vertically should not fall in the same place, as in fact seemed to happen (Ptolemy, 1984).

6 THE PTOLEMAIC SYSTEM

Nevertheless, Hipparchus and older Greek astronomers knew of the irregularities observed in the motions of the planets, and this led them to introduce a system of deferents and epicycles in order to explain them. This system was not invented by Ptolemy, but by the great geometrist of antiquity, Apollonios of Perge (262-190 BC), and of special interest is his work on the determination of the points where a given planet appears to be motionless.

The ancient Greek astronomers considered the motions of the planets uniform and circular. Thus, the deferents were the larger circles having the Earth at their centre, while the epicycles were the smaller circles, the centres of which were moving on the circumferences of the deferents. The motions of the Sun, the Moon, and of the known planets were taking place on the circumferences of their own epicycles. On the moving eccentre there was only one circle, which had as its centre a point outside the Earth, and the planet was moving on the circumference of this circle. Although these two constructions were mathematically equivalent, it was impossible to explain all observed planetary phenomena.

Ptolemy expanded the conclusions of Hipparchus and, from references found in *The Almagest*, it seems that he was influenced considerably by the geometrical views of Apollonios.

Thus, he introduced one more concept: he supposed that the Earth was offset by a small distance from the centre of the deferent of each planet, and moreover that the centre of the deferent was moving with a uniform circular motion around a point which he called the 'equant'. This was a hypothetical point, and Ptolemy placed it on the diameter of the deferent in such a way that it was opposite the Earth in respect to the centre of the deferent. In other words, the centre of the deferent was always between the Earth and the hypothetical equant, and the distance between the Earth and the centre of the deferent was equal to the distance between the centre of the deferent and the equant. With all these conjectures, Ptolemy could at last satisfactorily explain many of the observed planetary phenomena.

In general, the plane of the ecliptic in the Ptolemaic geocentric system was the one followed by the Sun during its annual 'apparent' motion amidst the fixed stars. The planes of the planetary deferents were believed to intersect the plane of the ecliptic at a small angle, while the planes of the planetary epicycles intersected at the same angles the planes of the deferents. As a result, the planes of the epicycles were parallel to the ecliptic plane. For the planes of Mercury's and Venus's deferents, it was supposed that they were oscillating on both sides of the ecliptic plane, and that the planes of their epicycles were oscillating with respect to the planes of their deferents.

Ptolemy believed that the planets were much closer to the Earth than the fixed stars. However, he apparently believed in the existence of crystal spheres upon which the fixed stars were attached. Beyond the sphere of the immovable fixed stars there were other spheres and ultimately, as he proposed, the 'first cause of moving', the force which caused the motion of the other spheres in his perception for the universe. Possibly Ptolemaeus may have felt intuitively that the geocentric theory was incorrect, but he remained faithful to it and tried to avoid any theories that would shake this world-image. Thus, he spent a lot of time trying to prove that space could not have more than three dimensions!

Later on, the geocentric system was accepted by the Christian Church as a dogma, and in spite of its shortcomings it then became almost impossible to replace. It continued to withstand astronomers' criticisms until the sixteenth century, when more detailed observations of the planetary orbits and of other heavenly bodies complicated it to such a degree (for example, epicycles over epicycles had to be created in order to explain the observations) that its validity was seriously disputed.

7 THE EMPEROR JULIAN

In the meantime, we should not assume that support for the heliocentric system died off completely. The Emperor, Julian (336-363 AD), was deeply affected by his knowledge of, and respect and admiration for, ancient Greek civilization. Strongly influenced by the Neoplatonic philosophers, he believed in the right of the individual to carve a path towards the truth. Julian thought that it was an unalienable right of each person to search and to doubt, and at the same time he was afraid that this right could be lost forever because of the prevailing religious attitude which tended to characterize any doubter as a heretic. As a result, he became known as a 'parabate' and a 'renegade', high-handed terms that indicated that he never became a Christian and that he never reneged on anything; and history and the Church continued to brand him as such, even after his death. Nevertheless, Julian was a passionate idealist, and he envisioned the revival of the ancient Greek spirit and values, which he wrongly combined with the revival of the ancient Greek religion, a religion that had irrevocably declined. Thus, when Julian consulted the Oracle of Delphi, he was advised: "Tell the Emperor everything is destroyed, Apollo has no roof over his head, Pythia has no bay leaf, not even the mountain spring speaks, even the water has stopped its voice." (Julian, 1913).

Julian himself studied the ancient wisdom at the philosophical schools of Athens. Captured by the beauty of the ancient Greek spirit, he wished to revitalize it. He became interested in philosophy and astronomy, and he warmly supported the heliocentric system. In his treatise *Hymn to King Helios dedicated to Sallust* he states:

> For that the planets dance about him as their king, in certain intervals, fixed in relation to him, and revolve in a circle with the perfect accord, making certain halts, and pursuing to and fro their orbit [i.e. the stationary positions and the direct and retrograde movements of the planets],

> as those who are learned in the study of the spheres call their visible motion. (The Orations of Julian, IV. Vol. I., 31, 135 B, p. 366). (Julian, 1913).

This quote shows that in the fourth century AD the heliocentric theory of Aristarchos was not forgotten, and that it still had its supporters.

8 THE RE-EMERGENCE OF THE HELIOCENTRIC SYSTEM

The original 'Ptolemaic' geocentric system remained unaltered and largely undisputed for more than fourteen centuries, but at the same time the heliocentric system was still alive in the memories of astronomers and in the writings of the ancient Greek Pythagorean philosophers. However, the geocentric system had one major flaw: it could not explain the retrograde motions of the planets in their orbits.

Yet it was only during the sixteenth century, an era of intense scientific investigation, that the Polish astronomer Nicolaus Copernicus (1473-1543) reintroduced the heliocentric theory, and from that point on it began to be accepted by scientists. After carrying out a long and detailed study of the ideas and hypotheses of the Greek philosophers he concluded that some of the difficulties with the Ptolemaic system could be eliminated if the Sun rather than the Earth was placed at the centre of the planetary system. Thus, the retrograde motions of the planets could be explained without the need for epicycles, since the inferior planets were moving faster than the superior, which were much further away from the Sun.

In Copernicus's analysis, the hypotheses of Aristarchos and the faith of the Pythagoreans in the heliocentric theory, emerged as crucial. For example, in the Preface of his work *De Revolutionibus Orbium Coelestium Libri VI*, which was addressed to the Pope Paul III, Copernicus (1995) refers to both Hicetas and Ecphantos, in writing:

> For this reason I took the labor to search all the books of the philosophers I could find easily, in order to ascertain whether someone was of the opinion that the motions of the heavenly bodies are different from those being taught by the teachers of mathematics in the universities. And I found initially in Cicero that Nicetas believed that the Earth moves. Later I found in Plutarch that other philosophers too had the same opinion. From them I took the motive and begun to think myself about the motion of the Earth.

(It should be noted that Copernicus followed an altered writing of the manuscripts, and he therefore refers to Hicetas as 'Nicetas').

Copernicus was convinced that the heliocentric system was correct, but even though his detailed study was completed in 1515, he did not dare to publish it at this time because of his fear of the Inquisition. As the Earth was then considered the centre of the universe with everything revolving around it, anyone who questioned this belief – which was by now Christian dogma – was automatically placed in a very difficult position. Therefore, although Copernicus's Austrian disciple, Georg Joachim (more widely known as Rheticus), exhorted his teacher to publish his new theory, the eminent Polish astronomer only did so in 1543, shortly before his death. Because the immortal work, *De Revolutionibus Orbium Coelestium Libri VI*, was dedicated to the Pope and would be read by clerics, Andreas Osiander (who suoervised he printing) wrote a forward where he stressed that the Copernican system was only 'a model' and not necessarily the true representation of the planetary system!

According to C G Fraser (1948:73):

> In the following quotation Copernicus proposed the heliocentric theory of Aristarchus. He developed that hypothesis and showed its superiority over the more cumbersome Ptolemaic system. Now it is universally accepted by astronomers.
>
> > "Every observed change of position is due either to the motion of the observed body or of the observer or to the motions of both. Since the planets appear now nearer, now farther from the Earth, this shows necessarily that the center of the Earth is not in the center of their circular orbits."
>
> He still holds with Aristotle that the orbit must be a circle, the perfect curve.

Something that is not widely known is that Copernicus never did manage to remove the epicycles. Nor was he able to predict the positions of the planets with an accuracy that was greater than in the Ptolemaic system.

9 THE SYSTEM OF TYCHO BRAHE AND JOHANNES KEPLER

In 1583, a generation after Copernicus's death, the great Danish observer Tycho Brahe (1546-1601) proposed his own system to describe the planetary motions in the Solar System. Brahe's so-called 'Tychonic system' was a combination of the earlier Ptolemaic and Copernican systems. It adopted the Ptolemaic view that the Earth was the stable centre of the universe around which the Sun and the Moon revolved, but it also accepted that the remaining planets revolved around the Sun, in accordance with the new system of Copernicus.

Both the Ptolemaic and the Tychonic systems predicted the existence of an external sphere, the one with the fixed stars, executing a daily revolution around the Earth. Tycho's theory accounted for the observed changes in the phases of Venus, which were impossible to explain within the framework of the Ptolemaic system. In fact, a system analogous to the Tychonic one had been proposed – as has already been mentioned – by the Greek philosopher, Heraclides, who believed that at least Mercury and Venus revolved around the Sun.

Brahe's system became better known through the book *Astronomica Danica*, which was written in 1622 by his student, Christian Longomontanus. Meanwhile, Brahe greatly appreciated the astronomical insights of the German astronomer, Johannes Kepler (1571-1630), and in 1599 offered him a position as astronomical assistant in Prague. Kepler accepted, because he wanted to co-operate with the great Danish astronomer, who had accumulated an amazing quantity of data from many years of accurate observations. Unfortunately, each wanted to take maximum possible advantage of the other. Brahe wished to justify the Tychonic system by tapping Kepler's genius, while Kepler wanted to prove the validity of the Copernican system by using Brahe's accumulated observations. Kepler was an ardent supporter of Copernicus, having first heard of his theory in 1590 when studying at the University of Tubingen, and he hoped to improve it and thus make it more acceptable in astronomical circles.

Given these conflicting objectives, co-operation between the two men was difficult, and Brahe would not give Kepler access to his planetary data. This only became possible after Brahe's death in 1601, when Kepler inherited his teacher's records, and after many years of hard work he succeeded in identifying the precise imperfections of the Copernican system. Although Copernicus had correctly placed the Sun at the centre of the solar system, he had retained circular orbits for the planets. Moreover, he had supposed that each planet moved at a constant velocity, which had forced him to retain the epicycles in his system.

Kepler was the real founder of the new heliocentric system, and he then formulated his three laws of planetary motion which proved to be catalytic to the study of the solar system. In his first law he stated that the planets moved in elliptical rather than circular orbits, which was a heretic belief since from the beginning astronomers and philosophers had believed in the divine sanctity of circular orbits. He also realized that the planets did not move with a constant velocity, but instead, the line connecting the Sun with the respective planet described equal areas in equal intervals of times. Finally, in his third law, the harmonic law, he stated that the squares of the sidereal periods of any two planets are proportional to the cubes of their mean distances from the Sun. Kepler's third law was probably a decisive starting point for the law of universal gravitation that was subsequently formulated by Newton, a law that in fact was probably first discovered by the German astronomer but not analysed in detail. In any case, there is no doubt that Kepler's work paved the way for Newton.

Despite these advances, the widespread acceptance of the heliocentric system did not come automatically or easily. The case of the well-known French astronomer Jean-Baptiste Morin, who was Professor of Mathematics at the College de France, is typical. Morin was an exceptionally good astronomical observer, but in spite of his own high-quality observations he remained an ardent supporter of the geocentric theory. More than a century after Copernicus's death there were still astronomers who were trying to prove that the Earth was motionless at the centre of the solar system!

10 COMPLETE ACCEPTANCE AND JUSTIFICATION

The indisputable superiority of the heliocentric system lead finally to its full acceptance, at least by the astronomical community. However, the Vatican continued to include Copernicus's *De Revolutionibus Orbium Coelestium Libri VI* in its Index Librorium Prohibitorum until 1835, and it was only in 1999 June, when the Polish-born Pope John-Paul II visited Torun, the birthplace of Copernicus, that he delivered a speech at the city's University in which he restored and justified the work of the great Polish astronomer. The Pope stated that the discoveries and concepts of Copernicus strengthened our confidence in the wisdom of the Creator, and at the same time they exhibited the power of the human mind.

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