Dawn of Science

13. The Paths of Planets

T Padmanabhan

The confusing pathways in the heavens are finally charted.

T Padmanabhan works at IUCAA, Pune and is interested in all areas of theoretical physics, especially those which have something to do with gravity.

Previous parts:
Resonance, Vol.15: p.498, p.590, p.684, p.774, p.870, p.1009, p.1062. Vol.16: p.6, p.110, p.274, p.304, p.446.

Brahe was a nobleman and governor of the Helsingborg castle in Denmark in the sixteenth century. Around AD 1540, he promised his brother, Joergen, that if he had a son, the latter could adopt him. But, when, in 1546, Brahe did have a son, he went back on his promise. Joergen waited till another son was born to Brahe and promptly kidnapped – and adopted – the first son.

The son was Tycho Brahe (1546–1601) and he grew up to be the most accurate observational astronomer before the days of the telescope. Tycho's foster-father died when Tycho was still very young, leaving him with a vast inheritance. Joergen jumped into a river to rescue Ferdinand II, the king of Denmark; though he succeeded in the attempt, he caught pneumonia and died. 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 Europe acquiring the instruments and set up a small observatory at Scania in 1571.

Keywords
Tycho Brahe, Kepler, ellipse, epicycle.

He had a chance, literally of a lifetime, on 11 November 1572, when he spotted a 'new star' 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.

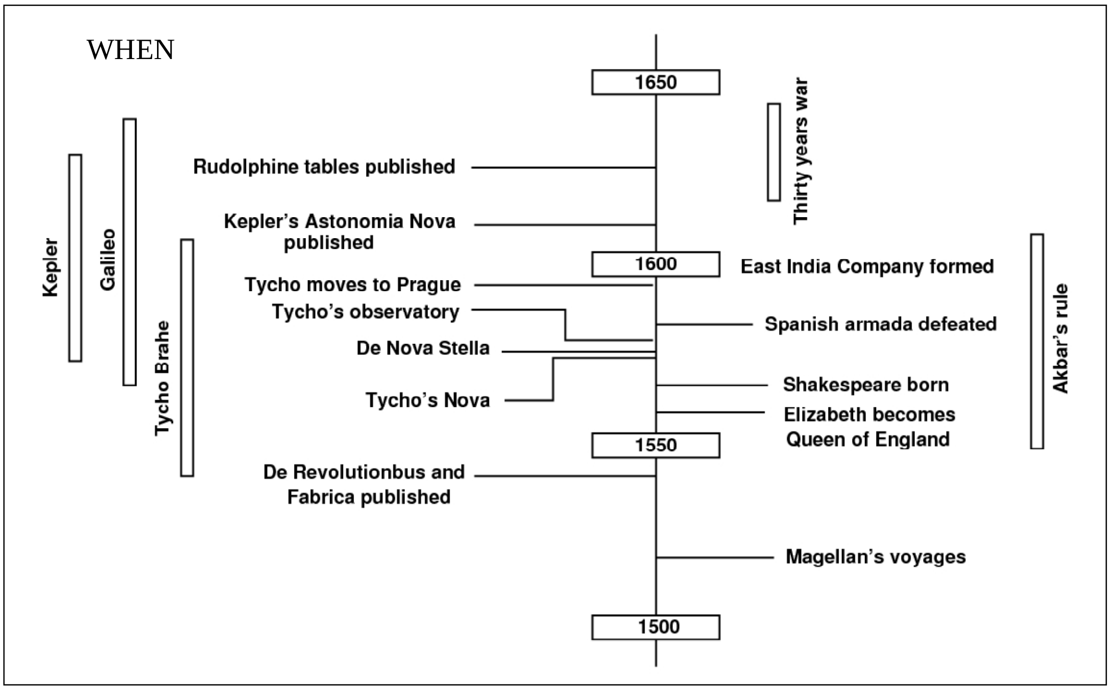


Figure 1.

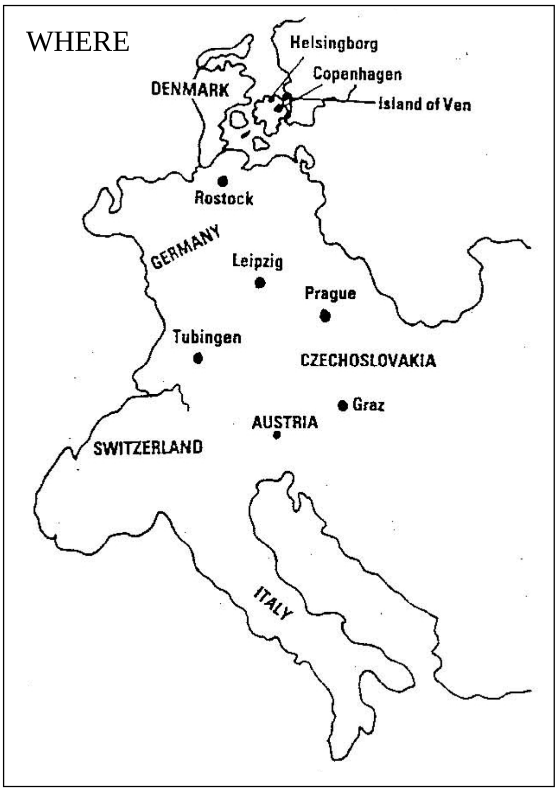


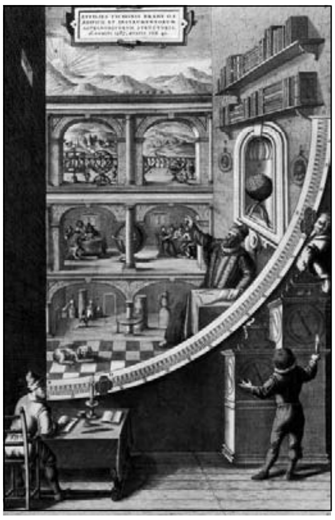
Figure 2.

Figure 3. Tycho Brahe.
Courtesy:
http://en.wiki-pedia.org/wiki/Tycho_Brahe

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.

This discovery brought Tycho royal patronage. Denmark's king, Frederick II, gave him the island of Ven and also financial support to build an astronomical observatory. Tycho used it well; the 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.

Figure 4. Tycho Brahe's observatory.
Courtesy:
http://images.google.com/hosted/life/)



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. And here he made his most important discovery – Johann Kepler (1571–1630).

Kepler was everything Tycho was not. He was born in Germany to a good-for-nothing mercenary soldier and a quarrelsome mother who, in her later years, almost got burnt at the stake as a witch; he was sickly and depressed, but managed a good education only because his superior intelligence was recognised by the local duke who gave him a scholarship.

Kepler was training to be a Lutheran minister after his formal

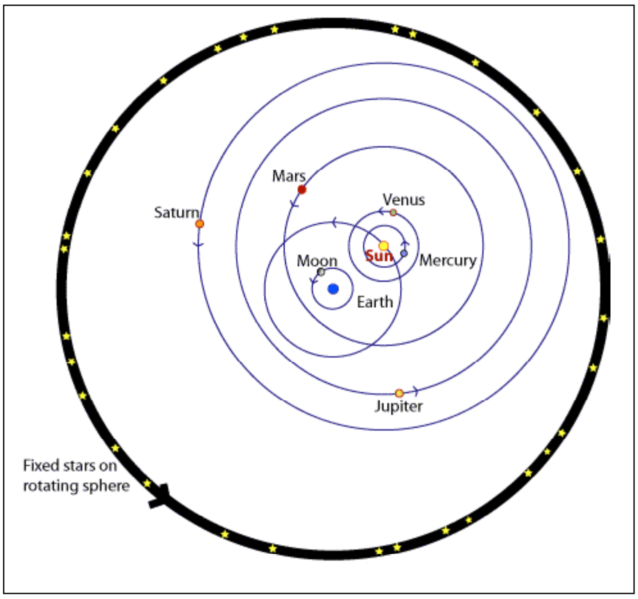


Figure 5. Brahe's model of the solar system in which the Sun revolves around the Earth but the other planets revolve around the Sun.
Courtesy:
http://outreach.atnf.csiro.au/education/senior/cosmicengine/renaissanceastro.html)

education at Tubingen University but by accident became a mathematics teacher in a Lutheran school at Graz in Austria (he was recommended for the job by the university on the death of the earlier teacher). 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.

Figure 6. Johann Kepler.
Courtesy:
http://en.wiki-pedia.org/wiki/Johannes_Kepler

Kepler started, somewhat erratically, to find simple rules describing the motion of the planets – especially that of Mars. The failure of simple models finally forced Kepler to assume that 'the path of planets around the Sun are ellipses with the Sun at one focus'. The extraordinary accuracy of Tycho's observations was instrumental in eliminating several other simpler models; some models differed from that of elliptical orbits only by eight minutes of arc in their predicted positions which would have been ignored in Ptolemy's days.

Box 1. The Ellipse

The ellipse – the orbits taken by the planets – belongs to a class of curves called 'conics' first studied in detail by the Greek geometer Apollonius (third century BC). He showed that three different curves are generated when a plane intersects a cone. The ellipse, in particular, is the only closed curve out of the three. A more physical way of defining the ellipse will be the following. Think of a person walking in such a way that the sum of his distances from two different points F and S (see *Figure* A) remains constant; his path will be an ellipse. The fixed points will be called the 'foci' of the ellipse. When these two points coincide, the ellipse becomes a circle; the farther the points, the more elongated the ellipse will be from the circle. (The elongation is measured by a parameter called eccentricity which is zero for the circle.) According to Kepler's laws, the planets move around the Sun in elliptical orbits with the Sun located at one of the foci. Notice that Kepler's second law (*Figure* B) requires the planet to move faster while it is nearer the sun. (It takes the same time for the planet to move from P_1 to P_2 as it does to go from P_3 to P_4.)

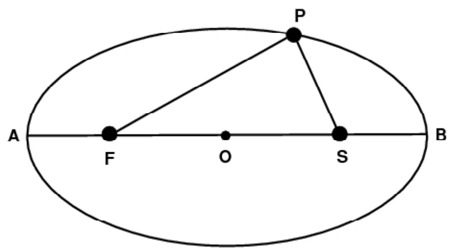


Figure 1A

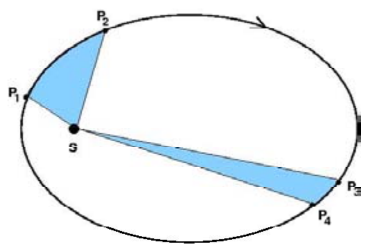


Figure 1B

Though Kepler replaced the circular paths by a less symmetrical elliptical path (*Box* 1), he could restore the symmetry in a different way. 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'. 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 the middle of which lies a gem: "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. This idea was very much present in Kepler's

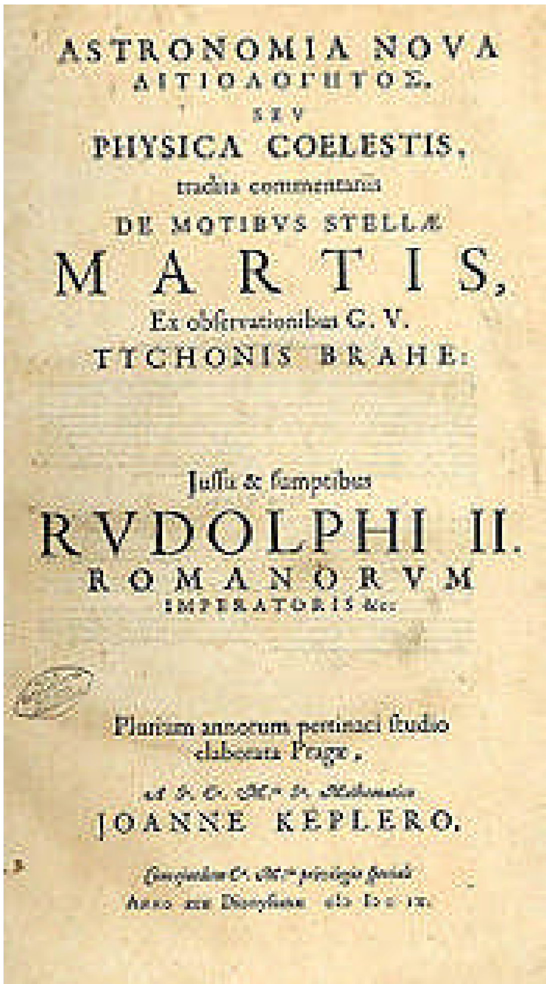

ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex observationibus G. V.
TYCHONIS BRAHE:
Jussu & sumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:
Plurium annorum pertinaci studio
elaborata Pragæ,
JOANNE KEPLERO.

Figure 7. The title page of Kepler's New Astronomy.
Courtesy:
http://en.wiki-pedia.org/wiki/Astronomia_nova)

writings but it took the genius of Newton to form a workable law out of this suggestion.

During the years 1620–1627, Kepler completed the new table of planetary motions based on Tycho's observations and his theory of planetary orbits. In spite of severe financial difficulties, continuing war and religious unrest, these tables – called Rudolphine Tables in honour of Kepler's first patron, and dedicated to the memory of Tycho – were published in 1627.

Incidentally, it would have taken considerably longer, but for the use of logarithms by Kepler! The tables also contained a set of logarithms.

Anyway, the pathways in the heavens were finally charted.

Suggested Reading

[1] Arthur Koestler, *Sleep walkers*, Penguin, 1959.

[2] David Layzer, *Constructing the Universe*, Scientific American Library, 1984.

Address for Correspondence
T Padmanabhan
IUCAA, Post Bag 4
Pune University Campus
Ganeshkhind
Pune 411 007, India.
Email:
paddy@iucaa.ernet.in
nabhan@iucaa.ernet.in