WANDERING STARS AND FLYING ARROWS[1]

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THAT the earth is a sphere was already known to the Greeks by the time of Plato; and most of them were agreed that the sky too is spherical, as suggested by the daily wheeling motion systematically shared by all but seven of the stars. So far so good, but with the seven exceptions, Sun, Moon, Mercury, Venus, Mars, Jupiter and Saturn, the attempt to understand the structure of the universe ran into difficulties. These seven circled the earth every day just like the 'fixed' stars, but in addition they moved against the background of the fixed stars without, it seemed, rhyme or reason. However, as the lunar month and the seasonal years showed,[2] the apparently random movements of the 'wanderers' or 'planets' concealed regularities that were not always evident at first sight, and this raised the question of 'saving the appearances' of the planets, of explaining their movements by displaying the geometrical patterns underlying them.

This was the problem that dominated astronomy in the two thousand years that separated Plato from Kepler: a highly technical challenge, of such complexity that in the thirteenth century, Alphonso X of Castile, exasperated by the difficulties of preparing the Alphonsine planetary tables, said he wished God had consulted him when creating the world. Yet, despite its technicality, the problem of the wandering stars is one of the most significant issues in the whole history of science; for when in the sixteenth century Copernicus proposed a solution according to which the earth was itself merely one of several planets which circle round the sun, his specialist monograph sparked off one of the most profound revolutions ever to occur in human thought.

As was to be expected, the first attacks on the problem assumed that the earth is at rest at the centre of the world with the stars, fixed and wandering, circling round. After all, we live on *terra*

1 The substance of the first Edmund Whittaker Memorial Lecture, read to the Whittaker Society of Edinburgh on March 24th, 1958.

2 Cf. Plato, *Timaeus*, 39.

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firma, in the middle of the orbits of the sun and moon, and whenever we look at the sky we always see just half the celestial sphere. And so we find Eudoxus, a former pupil of Plato, suggesting that the planets move as though they are attached to nests of spheres clustered round the earth like the skins of an onion. The 'sphere' to which a given planet is attached is spinning about a certain axis and with a certain speed, but it is also carried round by the spin of the sphere next outside it, which again is carried round by a third and perhaps a fourth sphere as well.

Eudoxus was a brilliant mathematician, and although as we now know he was tackling the problem along the wrong lines, he succeeded with his handful of spheres remarkably well. But his method presupposed that the planets are at unvarying distances from the earth, and though the Greeks knew very little of these distances the variations in the brightness of Venus or in the apparent size of the moon were enough to show them that Eudoxus was mistaken in this presupposition. As a result, his elegant scheme had to be abandoned.

With the rise of Alexandria, Greek science came into contact with the practical outlook of the more ancient civilizations, and careful observations began to play a fundamental role in astronomy. As astronomers were agreed that the appearances must be saved in terms of uniform circular motion, whereas in fact the planets move in ellipses that are not quite circular, it was not easy for them to produce for the paths of the planets mathematical models that fitted their observations. They adopted very flexible methods of combining circles, methods that would have allowed them to reproduce almost any curve given enough circles with which to work. As a result, Copernicus was forced to admit that those following the Alexandrians 'appear to have well-nigh established the apparent motions by calculations conforming with their assumptions'[3] and that their work could not therefore be rejected on observational grounds as that of Eudoxus had been.

On what grounds, then, could their work be rejected? At the detailed, technical level, as Kepler later showed, a handful of ellipses in a heliocentric system could do the work of the scores of circles used by Ptolemy of Alexandria. But Copernicus, like Ptolemy, was under the 'spell of circularity', and the best authorities do not agree with the common assertion that his system,

3 *De Revolutionibus*, preface.

though complicated, was a marked improvement on Ptolemy's. Neugebauer, for example, says 'the popular belief that Copernicus's heliocentric system constitutes a significant simplication of the Ptolemic system is obviously wrong'.[4] It is true that Copernicus was able to avoid the dubious device of the 'equant' introduced by Ptolemy in his anxiety to obtain predictions for astrological purposes, but in sheer complexity the two systems were about equally threatened with death by elephantiasis.

At the non-technical level there remained what were essentially matters of taste, and, surprising though it seems, it was principally through these that the issue between the geocentric and the heliocentric approaches was decided. In the first place, both in ancient times and in the Renaissance, there were those who thought it fitting that the sun be given a central place. Copernicus was among them, and we find him suddenly throwing off the technicalities and breaking out into praise of the sun:

> 'In the middle of all sits the sun enthroned. In this most beautiful temple could we place this luminary in any better position from which he can illuminate the whole at once? He is rightly called the Lamp, the Mind, the Ruler of the Universe; Thrice-Great Hermes names him the Visible God, Sophocles's Electra calls him the all-seeing. So the sun sits as upon a royal throne, ruling his children the planets which circle round him.'[5]

In the second place, the neo-Platonist God of Copernicus was 'orderly'.[6] As was proper, the heliocentric system showed 'an admirable symmetry in the Universe, and a clear bond of harmony in the motion and magnitude of the orbits such as can be discovered in no other wise'.[7] But with Ptolemy, who dealt with each planet independently of the rest, 'it is as though an artist were to gather the hands, feet, head and other members for his images from divers models, each part excellently drawn, but not related to a single body, and since they in no way match each other, the result would be monster rather than man'.[8]

In particular, Copernicus was able to give a much more satisfactory explanation than Ptolemy of two of the most curious features which we see in the movements of the five planets

4 *The Exact Sciences in Antiquity*, 2nd edition, p. 204.
5 *De Revolutionibus*, i, 10.
6 *ib.*, preface.
7 *ib.*, i, 10.
8 *ib.*, preface.

Mercury, Venus, Mars, Jupiter and Saturn. Two out of the five, Mercury and Venus, never seem to move far from the sun. Ptolemy has to produce this with an *ad hoc* device; but if the earth is a planet circling round the sun then we would *expect* other planets to circle the sun on the inside of the earth and these planets would seem to us to behave just as Mercury and Venus do. Again, each of the five planets from time to time reverses its usual movement against the background of the stars, travels backwards for a time and then resumes its onwards journey. On the geocentric view this is an extraordinary phenomenon, though one that can be 'saved'. But it is a phenomenon to be expected on the heliocentric view, as we can see with the help of a pencil and the back of an envelope: as Mercury or Venus sweeps past us on the inside as we travel round the sun, the planet will seem to us to reverse its direction, and the same will happen to one of the outer planets as we pass it on the inside.

Arguments such as these do not require the fully-developed system of Copernicus, and it would be surprising if they had not occurred to the agile Greek mind. In fact, in the third century B.C. Aristarchus of Samos proposed a full heliocentric theory, and presumably for reasons such as these. Yet he attracted almost no support, and this raises the very interesting question as to why Copernicus succeeded when Aristarchus had failed. Why did the 'Copernican' revolution have to wait another eighteen hundred years?

Although it is risky to compare two men so widely separated in time, there are interesting parallels between them. Aristarchus was attacked for impiety, Copernicus feared condemnation from 'idle babblers . . . by reason of a certain passage of Scripture basely twisted to their purpose'.[9] Again, neither man could give a convincing answer to the problem of parallax. This is the objection that, if at intervals of six months we look at the stars from opposite sides of the sun, then the stars ought to present different appearances to us. In fact they do not (unless we have a very powerful telescope), and Aristarchus[10] and Copernicus[11] could only give the true but feebly-sounding reply that the differences are there but are too small to see. But whatever the similarities

9 *ib.*, preface.
10 Archimedes, *Sandreckoner*, i.
11 *De Revolutionibus*, i, 10.

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between the two men, one feature of the centuries that separated them is particularly significant: the developments in a branch of natural science which seems at first sight to have nothing to do with astronomy, namely, the study of projectiles.

For, throughout the classical period, the compelling and unanswerable objections to any form of terrestrial motion came from the observed behaviour of objects near to, but detached from, the surface of the earth. If the earth were moving, clouds and birds and arrows in flight would be left behind. As Aristotle reminds us, 'heavy objects, if thrown forcibly upwards in a straight line, come back to their starting place, even if the force hurls them to an unlimited distance'.[12]

The same arguments were still to be reckoned with long after the death of Copernicus. As Galileo's Salviati puts it,

> 'a ball shot out of a cannon erected perpendicular to the horizon spends so much time in ascending and falling that, in our parallel, both we and the cannon should be carried by the earth many miles towards the east (if the earth were to rotate), so that the ball in its return could never come near the piece but would fall as far west as the earth had run east'.[13]

The issue then was for the time being decided *not in astronomy but within another discipline*, as Ptolemy clearly recognized. For him, those who advocated the daily spin of the earth had forgotten

> 'that, indeed, as far as the appearances of the stars are concerned, nothing would perhaps keep things from being in accordance with this . . . conjecture, but that in the light of what happens around us in the air such a notion would seem altogether absurd'.[14]

Unfortunately, the Aristotelians were not on their strongest ground when discussing 'what happens around us in the air'. For Aristotle, to fire an arrow into the air is to compel it to move in a manner opposed to the downward motion that is natural to it as to all heavy bodies; and throughout the upward, unnatural movement, an external cause must be at work. What is this cause? As long as the arrow is in contact with the bowstring we need look no further; but what moves the arrow after it has left the bow? We must answer 'the air', for it alone is in contact with the

12 *De Coelo*, ii, 14, 296b.
13 *Dialogue on the Great World Systems*, second day. Ed. de Santillana, pp. 140–1.
14 *Almagest*, i, 7.

arrow. Whatever the precise mechanics of the situation, it must be the air that takes over where the bowstring leaves off.

Now however firmly grounded in common-sense are most of Aristotle's physical theories, here he has been forced into evident absurdity, and this was recognized by many medieval authors. An early critic was the sixth-century Alexandrian, John Philoponus, who asks scornfully of what advantage it is for the bowstring to be in contact with the notched end of the arrow, if the bowstring moves the arrow by pushing the air. He suggests an alternative cause. 'Rather is it necessary to assume', he says, 'that some incorporeal motive force is imparted by the projector to the projectile.'[15]

Among the schoolmen, Francis of Marchia in the late thirteenth century seems to have been the first to reject Aristotle's explanation of the motion of projectiles. For him there is 'a power left behind (*virtus derelicta*)'[16] in the arrow after it has been fired. In the fourteenth century John Buridan of the University of Paris asked how the air could possibly compel a top or millstone to keep spinning, and after discussing other everyday experiences hard to explain on Aristotle's theory said: 'Therefore it seems to me that we must conclude that a mover, in moving a body, impresses on it a certain *impetus*, a certain power capable of moving this body in the direction in which the mover set it going'.[17] From the time of Buridan the notion of impetus attracted a great deal of support.

It is important not to confuse impetus with the inertia of Descartes and Newton. Impetus safeguards the distinction between natural and violent motion and with it the conceptions of natural place and, to some extent, of motion as a *process*. But a Newtonian body moving under inertia is indifferent to its movement, which, like rest, is a *state* capable of persisting indefinitely. The difference between impetus and inertia is, in fact, so fundamental that impetus gave way to inertia only on the collapse of the Aristotelian cosmos. Nevertheless, both impetus and inertia can be used to answer the objections of Aristotle and Ptolemy to the movement of the earth: in either case an arrow fired into the air from a rotating earth keeps pace with the earth throughout its flight

15 *Commentary on the Physics*, ed. Vitelli, p. 642.
16 Text in A. Maier, *Zwei Grundprobleme*, p. 174.
17 *Questions on the Physics*, in Maier, *op. cit.*, p. 211.

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because of the motion it formerly shared with the earth.

This point was explicitly made in the fourteenth century by Nicolas Oresme. He professed to believe that the earth was at rest, but he denied that this could be demonstrated, and from his time the motion of the earth was a possibility that could be canvassed. Impetus did not of course *dispose* of the physical objections to the motion of the earth either on its axis or, more particularly, around the sun. Difficulties remained to become the centre of Galileo's scientific work, and it was he who eventually abandoned the concept of impetus as unworkable and replaced it with something that was nearly, but not quite, inertia. What impetus did was to *weaken* the objections and to show that the issue of the stability of the earth was not as irrevocably decided as had been thought. This development in the understanding of projectile motion made it possible for the Renaissance to take seriously the matters of taste that formed the basis of the heliocentric case.

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Council meets, as also—in order that this prayer may be the more fervent and fruitful—to a deeper sympathy, knowledge and understanding of those ancient Christian traditions of the East for the present-day representatives of which the Holy Father has, throughout his life, so often shown his affection.

FATHER BERNARD DELANY. As this number goes to press it is with regret that we hear of the death of Fr Bernard Delany, O.P., the first Editor of this review. Of his devoted and generous pioneering work in laying the foundations of BLACKFRIARS throughout the 'twenties we hope to print an appreciation in a subsequent issue.