Joseph Lalumia

SAVING THE PHENOMENA

AND SCIENTIFIC CHANGE

Scientific astronomy began with the Greeks. The background for it was a knowledge which the Greeks had in common with older peoples such as the Babylonians and Egyptians of certain celestial regularities: the apparent daily movement of the sun from East to West, the apparent annual motion of the sun in the foreground of different constellations of stars and around the earth, the apparent nightly movement of the moon and visible stars from East to West, the periodic waxing and waning of the moon, and the different periodic displacements of the visible planets, Mercury, Venus, Mars, Jupiter, and Saturn. All of this antecedent astronomical knowledge and more was knowledge that was sought, acquired, classified, transmitted, and improved because it had practical importance or was deemed to have practical importance, as for calendar-making, time-keeping, and advice to rulers of society concerned about making state decisions under auspicious conditions.

All the sources having to do with the conditions attending the beginnings of scientific astronomy agree that it began with a problem that Plato put to mathematicians in his Academy. The problem was: to devise a system of orbits representing tracks of bodies moving uniformly in perfect circles and consistent at the same time with the motions actually observed in the heavens.

In other words, the question was: supposing that any heavenly body moves with uniform speed in a circle, construct a geometrical model or representation in keeping with this supposition from which theorems would follow deductively constituting descriptions of the motions actually observed. The task to be done was a logical one, namely to supply or invent suppositions in addition to the principle of uniform motion in a circle. The point of the task was to explain celestial phenomena, or, in Plato's words, "to save the phenomena."

To understand the problem fully and appreciate its interest to the Greeks, several things need to be kept in mind. First, while most bodies in the heavens seem to move with uniform speed in circles or segments of circles, a small number, namely the five planets visible with the naked eye (it has to be remembered that we are dealing with pre-telescopic astronomy), sometimes appear to have stopped moving, sometimes appear to be moving slowly but gaining speed, sometimes appear to be moving fast but slowing down, and sometimes appear even to be changing their general direction so as to be moving from East to West instead of from West to East. Moreover, even when the planets are progressing from West to East, they seem to weave like drunken men first to one side and then another of the sun's apparent circular path around the earth in the course of a year. The planets would thus appear to be out of step and inconstant among a great many more heavenly bodies whose dynamical behavior seems uniform and constant. Since the number of the planets is small compared to all the other stars, is it reasonable to believe that the planets are really exceptions to the rule of uniform motion in a circle, or is it more reasonable to believe that they are not exceptions at all but only look like exceptions? One sense of Plato's question is that it is more reasonable to believe that they only look like exceptions, and his demand is for a theory that assumes they are not exceptions and that enables us to understand nevertheless why they should look like exceptions.

Another consideration underlying the problem was the following. The mathematicians were not being asked to decide whether the heavenly bodies moved uniformly in circles or not. Physics, the science of bodies in motion, said that uniform motion in a circle was the form of motion of *any* heavenly body. The Greek physicists had their reasons for this conclusion; for our purposes there is no need to go into what they were. On the other hand, observation showed—and the Greek physicists knew this as well as anyone else—that there were five apparent exceptions in the case of the planets and that in the case of the sun and moon there was no simple motion in a circle to be seen but at least two motions (the diurnal and zodiacal) combining to produce their apparent changes of position. What Plato was doing, therefore, was turning to the mathematicians, as it has been standard for scientists to do many times since, and asking them for a model that applied the decision of the physicists and that at the same was consistent with, and explained, the facts observed by astronomers. A theory, mathematical or otherwise, has been called upon in the history of science to do this often. Moreover, from the theory of homocentric shells, about to be described, through the Ptolemaic theory to Copernicus and to theories in modern science, the logic of decision-making about an acceptable model has been the same, so that it is worth paying close attention to the type of model to be described and to the kind of reasons that led to its rejection.

The simplest motion to be provided for was that of the so-called "fixed stars" which appear to sweep in a circle around the earth daily while maintaining their relations to each other. Accordingly, to "save" or explain this appearance Eudoxus of Cnidus represents these stars as points on the surface of a single shell that rotates with uniform speed daily around the earth situated inside at the center. This is the model or the theory for the apparent daily revolution of the fixed stars. Next, Eudoxus has to provide for the apparent motion inside of the sphere of the fixed stars of the planets and the sun and moon, in the order of the apparent diminishing distance of these bodies from the central earth. And, here again, Eudoxus offers a separate model or theory for the motion of each of these bodies. For example, to "save" the appearances for the motion of Saturn, he represents this planet as a point P on a shell A rotating with uniform speed around the earth at the center. Shell A, however, is attached at the poles of its axis or rotation to another larger concentric shell B which rotates with still another uniform speed about still another axis whose poles are attached to a larger concentric shell C. Shell C rotates in the meantime with still another uniform speed about still another axis whose poles are attached to a fourth concentric shell D, and finally this fourth shell is assigned another uniform speed about still another axis of rotation. The complete arrangement, illustrated in Fig. 1, thus asks us to regard the observed irregularities in the motion of Saturn as appearances that are the resultant of several primary motions that are uniform and circular, namely the motions of the four shells. Finally, the motions of the remaining heavenly bodies are dealt with in a similar way, with four shells each for Jupiter, Mars, Mercury, and Venus, and three shells each for the sun and the moon, making 27 shells in all.

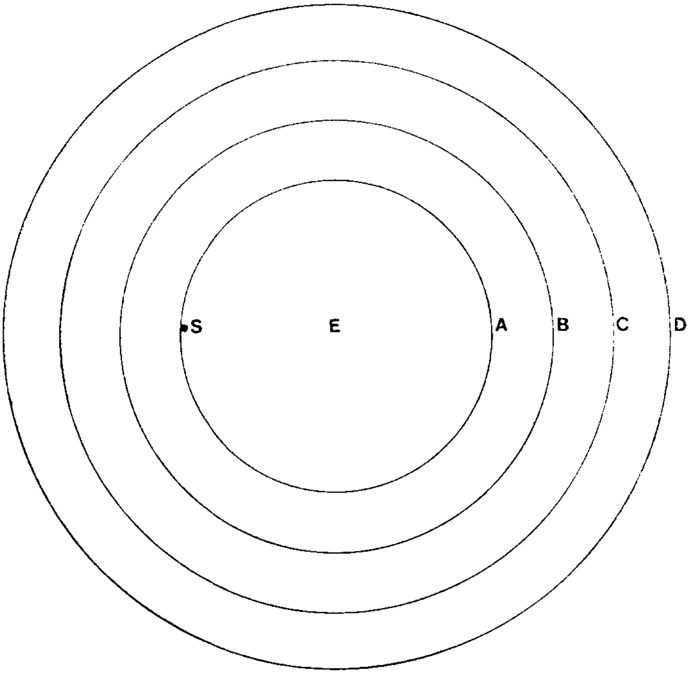

FIG. 1
The axes of rotation of the shells A,B,C,D and their angles of inclination are not shown. S represents Saturn, whose apparent motion would be the resultant of the primary motions of the shells.

In a brief description like this, the reader is apt to fail to realize the ingenuity this theory required and the excellence, mathematically speaking, that it really had. It had deficiencies which Calippus, a pupil of Eudoxus, was able to appreciate by means of comparison of some results of the theory with astronomical phenomena that Eudoxus does not appear to have known about when he framed his theory. These deficiencies were repaired by Callippus by adding one shell each for the models for Mars, Venus, and Mercury, and two each for the sun and the moon, making a total of 34.

Plato had not only put the question that started scientific astronomy on its way; in his question he had also indicated the principle that should guide the revision and tentative acceptance or outright rejection of a theory. A theory had to "save the phenomena." The principle of concentric shells was finally rejected by the Greek astronomers because it soon became clear that theories applying it could not save the phenomena, no matter what repairs might be made. And here it is important to make a distinction between two meanings that the expression "save the phenomena" can have put upon it. If by "phenomena" in this expression one means only those specific observed events that prompt the construction of a theory, then it is scarcely a matter for surprise or genuine satisfaction that a theory should fit those events. The theory is meant to, and any number of different theories might be constructed to fit the facts in question. On the other hand, if by "phenomena" is meant a class or family of events of which the specific events inspiring the theory are a *part*, then the theory must not only fit this part but it must also fit other events in the class concerned as they become noticed. These new events that the theory is required to fit may be events that become noticed by chance or they may be events that become noticed because it is a logical consequence of the theory that they should occur, in which case the scientist notices the events because he has been influenced by the theory itself to look for them.

The whole history of astronomy shows that Plato's principle that theories should "save the phenomena" was interpreted in the second way, and the same thing seems to be true about a theory and its relation to phenomena in other sciences. A theory's saving the phenomena that inspired its creation functions only to determine its plausibility or its likelihood of capturing enough scientific interest to seem worth trying or testing. Its election or adoption is determined by other phenomena, phenomena that did not influence its creation because the scientist who created it either did not know about them or did not realize their relevance to his theoretical task, phenomena whose relevance would have been seen and which would have influenced the theory's construction in the first place if they had been known. These considerations have importance for a number of problems in the philosophy of science, notably the so-called problem of induction. They imply, for instance, that induction is really a deductive game played under unavoidably unsatisfactory conditions because all the needful information does not, and cannot, present itself at once (as a logician or mathematician might prefer), but instead takes time without end to appear. They imply also that when a theory has been adopted by scientists this is only because new phenomena have added strength to its believability or plausibility as distinguished from providing certainty. Finally, a social implication of the logic of science is worth noticing. Callippus, for instance, had every right to believe, and probably never doubted, that his predecessor Eudoxus would have made the same repairs on the theory of concentric shells had the phenomena to be saved been the same for Eudoxus as they were for himself. Callippus worked from several advantages: first, his knowledge of the phenomena that inspired Eudoxus to create his theory; second, his knowledge of the theory itself, that is to say, his indebtedness to Eudoxus; and, third, the phenomena that he knew about that the theory was also required to cover and that Eudoxus did not know about. Callippus had a right to believe that the last advantage would have been as much valued by Eudoxus as he valued it himself. In short, not only is a scientific theory affected by the fact that the phenomena supposed to be covered by it never present themselves all at once; it is affected also by the fact that different scientific workers, engaged in the same task, but separated in space or time or both and knowledgeable about different phenomena, cannot act as one man. The logic of scientific change as exhibited in the way in which scientific theories undergo change thus cannot be understood except as an eternal combat against spatial and temporal provinciality. Since experience itself is not ever transcended by theory, whether this be experience that inspires it or experience that strengthens or weakens its believability, one might even say that the logic of scientific change cannot be understood except as an act of faith in the value and possibility of a higher solipsism through cooperation.

As has been mentioned, it soon became clear that the principle of concentric shells would not work for providing a theory that would save the phenomena. This did not happen, however, before the scientist and philosopher, Aristotle, applied it once more in a manner that merits attention because it raises a question that has been important in the philosophy of science ever since.

For both Eudoxus and Callippus the shells postulated to explain the motions of the planets, the sun and moon, and the fixed stars, appear to have been abstractions, purely geometrical devices, designed to codify the phenomena and permit their deduction in keeping with a common presumption about all of them (the presumption that the movements of heavenly bodies are movements with uniform velocity in a circle or functions of such movements). Moreover, both Eudoxus and Callippus offered in reality a number of discrete theories or models employing the principle of concentric shells, one for each of the bodies whose movement had to be accounted for. Thus, as has been seen, though all the shells in each set were connected with each other by their axes of rotation, no set of shells was connected with any other set. Aristotle's theory of concentric shells is different in both of these respects. First, the shells in his theory constitute actual physical machinery, as distinguished from purely logical premisses, for the phenomena. Accordingly, he infers that each shell must be made of a material crystalline and transparent in character, the reason being that unless this were so the visibility of heavenly bodies beyond the moon could not, on account of the intervening shells, be saved or accounted for. Second, Aristotle installs 22 additional shells with appropriate axes of rotation, velocities, and directions of motion, velocities, and directions of motion to the purpose of connecting and tying all the Callippan sets of shells to each other and to the single shell supposed to carry the fixed stars. He appears to have made this change from a conviction that motive power came ultimately from the outer surface of the universe and was transmitted inward to the moon, and he was possibly also motivated by a desire for a unified astrophysical picture. This task was complicated by the fact that the additional shells, though connected to the sets of shells devised by Callippus, could not be permitted to transmit their own motion to these sets in such a way as to change the resultant motions Callippus had aimed at getting in order to save the phenomena.

These differences between the theory of concentric shells of Aristotle, on the one hand, and of Eudoxus and Callippus, on the other hand, are significant in that they illustrate two entirely different views that philosophers since have tended to take on what a scientific theory's function really is. One of these views holds that the function of a theory is to provide axioms, symbols, formulae, that describe nothing factual in themselves but that function to codify facts insofar as the theorems deducible from the axioms are equivalent to descriptions of the facts, i.e., the phenomena. This makes a theory serve an economic function and it calls for theories to be assessed in terms of convenience as instruments that codify. Hence, in this view, if a theory postulates atoms, shells, waves, and similar objects because theorems then follow which describe phenomena, the objects postulated ought not to be taken to exist and theory ought not to be taken to say that they exist; what matters is that the theorems desired follow from the postulates and are held together logically and economically in this way. The second view, contrary to this, holds that the function of a theory is to explain phenomena by showing what the hidden causes of them are. This makes the postulates descriptions of the causes of phenomena, hypotheses as to what the properties of these causes are, so that it is proper in this view to raise the question as to whether a theory provides new knowledge and is true or false as distinguished from convenient or inconvenient for codification. Aristotles illustrates this well when he infers from the theory of concentric shells that the shells must be made of some transparent material, a new element which he called the aether, as distinguished from the elements earth, air, fire, and water which he believed to be the constituents of terrestrial bodies. To him a theory not only codifies, it explains and is a means of discovering what the external causes of physical experience are.

Perhaps these differences between Eudoxus and Callippus, on the one hand, and Aristotle, on the other, are reflections of the fact that the former come to their task primarily as mathematicians whereas the latter comes to the same task primarily as a physicist. Here Aristotle's view may be usefully compared to the theory of an earlier physicist, Democritus. Democritus' atomic theory means to offer a constitutive account of matter such that phenomenal change and variety are explained. The phenomenal qualities of bodies are, in Democritus' theory, subjective effects, sensory registrations of the observer, for which the qualities of bodies in themselves—their shapes, solidness, rigidity, displacements, and impacts—constitute the external causation. That is to say, Democritus is also a realist rather than a conventionalist. There is a tendency to realism in the interpretation of scientific theory discernible from Aristotle to Galileo, Newton, Dalton, and Faraday; but there is a tendency to conventionalism discernible from Eudoxus to Aquinas and Bellarmine and, in our own day, Mach, Poincare, and Duhem.

When phenomena become known that are incompatible with a theory supposed to provide for them, the theory can often be repaired in some detail or other in order to deal with the situation. The theory of concentric shells, however, floundered on a phenomenal fact that made it irreparable. In each of the sets of shells postulated to account for the observed motion of the sun and moon and planets, the body concerned had to be imagined to be a point fixed on the inside of the innermost shell. As the innermost shell in each set had a motion which was the resultant of its own motion on its axis and the motion of each of the other shells on their axes, this made the bodies concerned appear to be moving with variable velocity in curves different from the circle but just like the curves they actually appear to describe in space. By the same type of theory, however, none of the bodies concerned should ever appear to have come nearer the earth or got farther away from it; that is to say, the distance from the earth of all the points on a body's apparent curve, no matter how different from a circle this curve might be, had to appear to be exactly the same. Just the opposite could be observed, however. There are definite times when Venus, for instance, appears at points in space nearer to the earth and times when it appears farther off. Many adherents of the principle of concentric shells, including Aristotle, knew of this, and the difficulty made the theories employing the principle unsatisfactory to them, but the principle was upheld by them nevertheless, apparently because of its congeniality with the principle of the earth's central place. But even this principle, the principle of the earth's central place relative to the orbits of the heavenly bodies, was not of supreme importance. What really mattered was the principle that the heavenly bodies moved with uniform velocity in a circle and, as subsequent developments show, the Greek astronomers were ready, with both moderate and radical solutions, to scuttle the doctrine of the earth's central place, if saving the phenomena in keeping with the principle of uniform motion in a circle made it necessary to do this.

The moderate solution came with the introduction after Aristotle of the deferent circle and the epicycle. Heraclides of Pontus (*ca.* 388 - *ca.* 310 B.C.) dealt with Mercury and Venus, for example, by supposing them to move with uniform velocities in different circles concentric with the sun while the sun itself moved with uniform velocity in a circle around the central earth, thus providing for these planets to be nearer to the earth when they were on one side of the sun and farther from the earth when they were on the opposite side (Fig. 2). It is easy to see

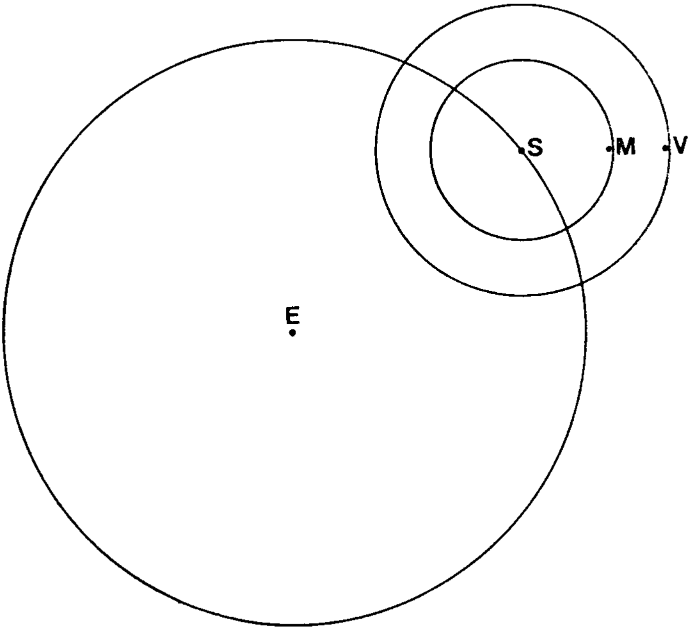

FIG. 2

Here the path of the sun around the earth is the deferent for the circles (epicycles) representing the paths of Mercury and Venus around the sun.

what is moderate about this solution. With appropriate deferent circles and epicycles postulated for the remaining planets, a system would result making the earth central to the circle of the fixed stars and the apparent annual revolution of the sun, but not to the planets. The eccentric circle, used by Hipparchus (*ca.* 130 B.C.) to account for the apparent inequality of the seasons, corroded the principle of the earth's central place still further, for here the earth is not the center of the sun's orbit but a point that provides for the sun to move with uniform speed while traversing the quadrants of the circle of the fixed stars in unequal times corresponding to the different lengths of the seasons (Fig. 3).

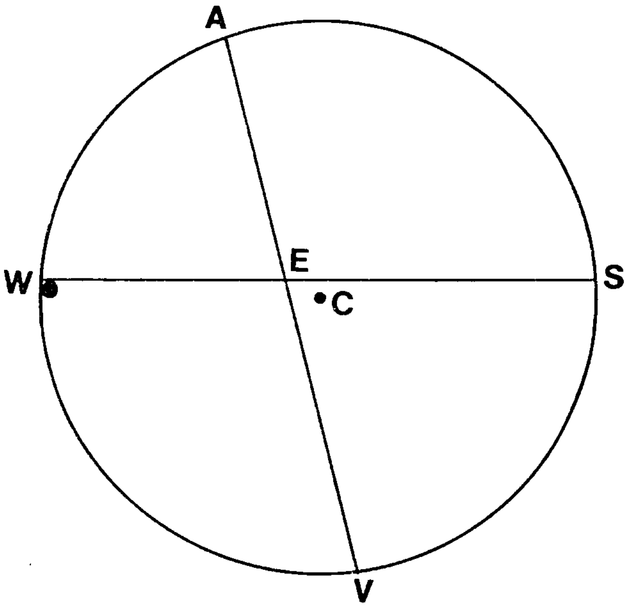

FIG. 3

V and A represent the vernal and autumnal equinoxes, and S and W the summer and winter solstices. C represents the center of the sun's orbit. E represents the earth's position and its relation to C had to be determined from the length of the seasons (ascertained by observation).

Our purpose is not to give a history of scientific astronomy from the Greeks to Copernicus, but to pick out steps in this history to help answer questions often asked about the respective functions and the relations of facts of regularity (phenomenal laws) and theories in science. Our purpose is to use the history of science to get such insights as we can about the logic exciting the invention of a theory and its career thereafter in the form of the changes it undergoes, the reasons for the adoption of these changes, and the reasons for its growing authority with scientists or its decline and rejection.

In the account of Greek astronomy given so far we can see how the elements and distinguishing characteristics of Ptolemaic astronomy came to be formed, particularly the deferent circles, eccentrics, equants, and other geometrical devices of a similar nature. Let us turn now to the radical solution mentioned before. It will show how, though the Copernican system was socially and culturally revolutionary, it was not *logically* revolutionary, was not discontinuous with Greek astronomy *logically*, and indeed was such that it would be fair to say that Copernicus was not, *logically* speaking, the first modern astronomer but rather the last Greek astronomer.

The epicycle required that, while the planets could still be regarded as going around the earth, the earth was no longer the center of their orbits and no longer the point with respect to which their velocities were constant. The eccentric, in the solar theory of Hipparchus, by making the sun's orbit have a different center than the earth, allowed for the sun to be regarded as going around the earth and explained at the same time why it should appear to be moving with variable velocity while it moved in fact with constant velocity. This was the moderate solution—geocentricity, but not concentricity with the earth.

The radical solution was to get rid of geocentricity altogether, and it was proposed by Aristarchus of Samos (*ca.* 310-*ca.* 230 B.C.). Exactly like Copernicus' theory in the 16th century A.D., it still required epicycles to explain the different apparent distances of the planets from the earth at different times, and it still required the eccentric to provide for the inequality of the seasons, but by making the sun the body around which all the heavenly bodies moved, by making the earth itself a planet, and by postulating moreover that the earth had a daily rotation, a theory was provided that saved all the phenomena without needing as many epicycles as a geocentric theory. And here we have heliocentricity, but not concentricity with the sun. The flaw in the theories of Eudoxus, Callippus, and Aristotle had been the concentricity the shells were required to have with the earth; the superiority of the geocentric theory of Ptolemy and the heliocentric theory of Aristarchus lay in the property which they had in common of getting rid of concentricity by the use of epicycles, eccentrics, and similar devices as needed to explain the phenomena; and the superiority of the heliocentric theory to the geocentric theory lay simply in the fact, not logically but practically important, that a heliocentric theory covered the facts more economically or in a mathematically more convenient way.

The Greek astronomers who were the contemporaries of Aristarchus rejected his heliocentric theory, and it is important to consider their reason as it is a reason that was still valid during debates that raged over Copernicus' theory many centuries later. On a heliocentric hypothesis, a given distant star should appear in the course of a year to orbit in a circle opposite in direction to the orbit of the earth around the sun. Aristarchus' contemporaries objected to his heliocentric theory on the ground that no such phenomenon had ever been seen. The stars had an apparent daily movement together around the earth and it was easy for the astronomers to see how this movement might be simply an appearance due, as Aristarchus suggested, to the earth's daily rotation on its axis in the opposite direction, but this movement seemed nevertheless to be the only movement which the stars had. Nor did Aristarchus fail to appreciate the appropriateness of the objection. The objection, he replied, was good evidence against his view, but only if the distance from the earth to the circle of the fixed stars was small; the failure of astronomers to observe stellar parallax did not necessarily prove his theory wrong, but possibly proved instead that astronomy was influenced by an inadequate conception of the immensity of space and of the universe. The stellar parallax his theory implied would be a function of the earth's own movement around the sun, but its discernibility would be a function of how far from the earth the stars were. A star's apparent radius of orbit would be larger or smaller depending upon whether the star was near or far, and if the star were far enough away it would have no apparent annual motion whatever. In this Aristarchus happens to have been right, but we enjoy the advantage in saying so of being acquainted with phenomena that neither Aristarchus nor his contemporaries could have known about. As matters stood, his explanation had all the appearances of an *ad hoc* hypothesis—an hypothesis that provides an excuse for believing another hypothesis that phenomena appear to contradict—and the Greeks were therefore right in rejecting his theory. But on what grounds? To what purpose? Convenience or truth?

These questions can be dealt with profitably if we take into account other considerations surrounding the same issue after Copernicus published his *De Revolutionibus Orbium Coelestium* in 1543. The circumstances attending the publication of the work are of some importance. Georg Joachim, a contemporary astronomer who was to have supervised the printing of the work, was prevented by other affairs from doing so and entrusted the task to Andreas Osiander, who was a Lutheran clergyman and also a friend of Copernicus. Osiander, apparently in fear of hostility to the work on religious grounds, inserted a preface in which Copernicus appears as intending to offer, not a description of the actual motions and relations of the earth and the heavenly bodies, but merely a manner of dealing with these motions and relations in a mathematically more convenient way than Ptolemy. Copernicus himself, before his death on the day the book was published, appears to have rejected advice to write such a preface. Galileo, some sixty years later, undertook defense of the heliocentric theory as true and not merely convenient, as his opponents, scientific and ecclesiastic, would have been happy for him to admit. And Kepler, who was responsible for exposing the real author of the preface, was not disappointed at having thus nullified the drift of Osiander's preface, but took pleasure at having scored in this way a triumph for the truth of Copernicanism. Now all of these considerations suggest one thing: the opponents and friends of Aristarchus, no less than the opponents and friends of Copernicus, had the mathematical ability to appreciate and admit the superiority of a heliocentric theory over a geocentric one from the standpoint of computational and classificatory convenience. The decision of the contemporaries of Aristarchus to reject a heliocentric theory was excited by their comprehension that Aristarchus was making truth-claims for it and by their concern that the claims were not well-founded. The decision of Galileo, Kepler, Descartes and others to support Copernicus, the fear of hostile reception that motivated Osiander to insert his preface in Copernicus' great work, and the decision of the Church to suppress Copernicanism and silence its adherents, was excited by the fact that Copernicus clearly did not intend to say that his theory was merely more convenient mathematically than the Ptolemaic.

Earlier it was remarked that, though he has generally enjoyed definition in history as the first modern astronomer, it would really be more accurate to say that Copernicus was the last Greek astronomer. This because the basic rules for theory-making under which he worked, the logical mold predetermining what theoretical alternatives he could bring himself to entertain and produce, were exactly the same as for the Greek astronomers. So far as the phenomena to be saved were concerned, he enjoyed no significant advantage on the Greek astronomers. For him, as for the Greeks, astronomical observation was still pre-telescopic, and his talents ran to mathematics and the arrangements and rearrangements of known phenomena that mathematics could create rather than to observation. And the principle that the heavenly bodies had primary movements characterized by uniform speed and circularity was as unbreakable for him as for the Greeks. Logically speaking, his work, therefore, was literally Aristarchus all over again. Nevertheless, psychologically, it was not. Violent as the opposition to his theory was immediately upon its publication in 1543, the violence itself implied a greater institutional fear of heliocentricity than in the time of Aristarchus, and the fear implied a consciousness that social and cultural condition were more favorable for its being more widely broadcast and favorably received in the 16th century than in the time of Aristarchus. But why should social and cultural conditions have been more favorable in the 16th century? Stellar parallax, the phenomenon the Greek astronomers needed for a heliocentric theory to be more plausible to them, was not observed until 1838 when astronomical instruments had been developed enough to make it possible, so that the only thing left that might make a heliocentric theory better received in 1543 was for conditions to exist that made Aristarchus' *ad hoc* hypothesis more plausible. That hypothesis was that the universe might be so immense as to make the fixed stars too far away for parallax to be evident. And there did exist conditions in 1543 that might make learned men more hospitable to such an idea than they could have been before.

Columbus' discovery some fifty years earlier and maritime explorations following it excited the imagination of men all over Europe to think beyond accustomed boundaries with respect to the extent of terrestrial space, and the Reformation presented the spectacle of respected ecclesiastical leaders questioning religious dogmas over a thousand years old. Why did it have to be true that the world was small, why might not the stars be as far away as Aristarchus had suggested in behalf of a heliocentric theory? The controversy that broke out upon the publication of Copernicus' work was a symptom of a psychological and cultural revolution already under way, a revolution to which the Copernican theory supplied a catalytic thrust.

The *logical* situation began to change with Galileo's telescopic discoveries in 1610, particularly his discovery of the satellites of Jupiter, in which he saw a miniature model of the relations of all the planets to the sun, and his discovery of the phases of Venus. The phases of Venus were of particular importance in connection with the reason why stellar parallax had never been observed. On either a geocentric or heliocentric theory, Venus ought to appear to have phases of different illumination just as the moon does, and Galileo's discovery of its phases with his telescope at least proved that the reason these phases had not been seen before was that Venus was farther off than astronomers had hitherto supposed it to be. This discovery added weight to the *ad hoc* hypothesis of Aristarchus that the starry universe was unimaginably large; it made men whose opposition to a heliocentric theory was strictly scientific more able to consider it hospitably, although it was far from enough to settle the question of geocentricity or heliocentricity scientifically. Nor would observation of stellar parallax have sufficed probably: the issue was already settled when that observation was made in 1838. No, the chief deterrents to a satisfactory scientific settlement were the principle that the heavenly bodies moved with uniform speed in circular orbits, disproved by Kepler's discovery of the first planetary law, and the link between this principle and Greek physics which needed other revolutionary discoveries, i.e., Galileo's work in dynamics, to be broken. A most interesting thing is that Galileo never suspected that there might be any connection between his work in dynamics and Copernicanism, and another interesting thing is that, as an astronomer, belief in Copernicanism or heliocentricity is all that he appears to have had in common with Kepler. Which is to say that, with respect to the principles of celestial dynamics in terms of which he thought, Galileo was not influenced by Kepler's new principle at all, so that he was logically, like Copernicus, a Greek astronomer who believed in heliocentricity.