C. G. WALLIS: INTRODUCTION TO PTOLEMY, COPERNICUS, AND KEPLER

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Why did Copernicus refrain so long from publishing De revolutionibus orbium coelestium?

Because, at least in part, he feared that at a time of ecclesiastical jitteriness, which arose out of the dissensions between Catholics and Protestants, his work might occasion sufficient scandal for him to be charged with impugning the authority of the Church on the grounds that the assertion that the earth was neither at rest nor at the centre of the world might be construed as contradicting one possible literal interpretation of certain passages in the Bible. But he does not explicitly foresee that anyone would be scandalized by construing as a loss to man's dignity the assertion that the corporeal heavens do not revolve around man's domicile. And, as a matter of fact, in scholastic theological thought man was a rather humble creature: the highest of the animals but the lowest of the created intellects, one whose original dignity had been corrupted by original sin, and whose present little dignity arose from the assumption of human nature by the Word of God in the Incarnation and not from any supposed revolution of the corporeal heavens about man's domicile.

But was not the humanistic effect of the Copernican revolution actually to lower the dignity of man in the imaginations of men?

Maybe so. But do not forget that the so-called Copernican revolution may only be a part of a story we have constructed in order to explain why we no longer understand in what the real dignity of man might consist. If we wish to talk poetically and humanistically, we may still ask out of what feeling about man's rank in the universe can the assertion of the earth's motion be said to spring.

How shall we go about answering that question?

First, let us try to find out how "true" Copernicus considered the mobility of the earth to be; then, let us look into the workings of the history of astronomy itself; and, thirdly, the relation of the mobility of the earth to certain larger ideas which entered into the speculation of the times. And I shall leave it up to you to apply our discussion of these topics to the burning question of the dignity of man.

Will you first say something about what the job of an astronomer is?

Let us define the job of the astronomer in the classical phrase as "saving the appearances" of the celestial movements. Now we may distinguish two sides to saving the appearances. First, an astronomical theory must "save" in the sense of "preserve"– that is to say, it must not deny any of the apparent celestial movements as appearances, and in this bare sense, it might merely comprise a record of observed positions of the planets. But, if that were all, it would not be [482] taking into account all the apparent movements but would be merely including past movements and leaving out future movements and thus, in order to take into account all the apparent movements, it must be able to predict apparent movements in the future from those observed in the past. But in order to be able to look backwards and forwards beyond recorded positions of the planets, it must arrange the celestial movements in a pattern of orderly recurrence. And by setting up this pattern of order, it saves the appearances in a second sense; I mean to say, that it gives them salvation, as it were, by making them intelligible and by explicating them in terms of a permanent order.

Does Copernicus lay down any general rules or principles as to how appearances must best be saved?

He talks as if the principle of intelligibility and order can be fulfilled only if the astronomer takes the movements of the celestial bodies to be regular, circular, everlasting, or compounded out of circular movements; that is to say, in case the moving planetary body does not appear to describe a perfect circle, its path must be reconstructed as the resultant of a configuration of purely circular movements, whereof in any given circle equal arcs are traversed in equal times. Those are the general limits within which there is a field free for the further delimitations demanded by given apparent movements. That is to say, the moving circles which combine with one another may be homocentric (circles of equal radii and of the same centre but of different axes of revolution), or eccentric (circles or equal radii but of different centres), or epicyclical (where the centre of one circle is located on the circumference of another), or related according to any number of permutations and combinations of those elements.

Now, the formulation of those general limits has been called classically by the name of "axioms" or "principles," and the further determinations within those limits by the name of "hypotheses." As Copernicus always employs the term principia in conjunction with hypotheses and as he refers to the proposition that the movements of the celestial bodies are regular and circular as an axiom, I shall employ the term "axiom" to denote the formulation of the limiting conditions of intelligible order. But he clearly uses the term "hypothesis" to signify any determination made within the field delimited by the axiom, in order to explain given apparent movements and to provide a geometric basis for computation and prediction.

How true does Copernicus consider the axioms and hypotheses to be?

He argues at some length to the effect that the state of affairs defined by the axiom of regular and circular movement must really exist in the heavens and that the mind would shudder at any other supposition.

Now an hypothesis must fulfil two conditions: first, it must conform to the axiom; and second, it must underlie particular propositions about the combination of regular, circular movements and the planetary tables. That is to say, it further delimits the ground covered by the axiom; for example, the generality of regular circular movement may, in a given case, be further determined as movement on the second epicycle of an eccentric circle, where the magnitudes of 'the circles and directions and periods of the movements are given; and by this delimitation the hypothesis makes possible the accurate prediction of particular movements. Thus within the single field of the axiom there is room for many [483] equivalent or alternative hypotheses: these hypotheses are equivalent in that the same set of appearances may be saved formally just as well by one hypothesis as by another; for example, an epicycle on a homocentric circle or an eccentric circle whose eccentricity is equal to the radius of the epicycle may be the geometric formal causes which account for the same apparent movement; they are alternative in the sense that, if interpreted physically, in terms of solid circles or something else necessary for the mechanical explanation of the phenomena by efficient causes (in contradistinction to the geometric explanation through formal causes), the two configurations of circles cannot both exist in the heavens, for example, a planet cannot wheel around on the rim of an epicycle revolving on an homocentric at the same time that it wheels around on the rim of a rotating eccentric, even if the path described in space by the planet affixed to the epicycle coincide with the circumference of the eccentric circle.

Now, just as Copernicus regarded the axiom of regular circular movement as designating a reality in the heavens, so too he regarded alternative hypotheses not merely as devices for prediction, whereof the one or the other might be relatively more convenient for use in constructing planetary tables, but as designating real possibilities within the field of physical actuality defined by the axiom–although, as he admits, it is difficult or impossible to determine, in a given case, whether it is eccentric or epicycle which really exists in the heavens.

Now, what about the mobility of the earth?

Ptolemy had remarked that although it would be possible to save the appearances by treating the earth as if it were in motion but that such a supposition would be no more than a convenient device for computation, since Aristotle's cosmology demanded an unmoving earth at the centre of the world; he preferred to make the supposition which would be physically true in the light of the Aristotelian analysis.

Osiander's unauthorized preface to *De revolutionibus* tries to reduce the mobility of the earth to a point of mere convenience in constructing tables of movements; but that attempt is clearly at variance with the intentions of the author as exhibited in the body of the text itself. For if Copernicus had looked upon the mobility of the earth mereIy as a fiction useful as a computing device, he would have had, on the outside, no reason to fear that his book would occasion a scandal; and, on the inside, no reason for composing arguments on behalf of the natural possibility of the movement of the earth.

Then, is the movement of the earth to be regarded as the one of two hypotheses designating alternative real possibilities which is chosen, say, for the sake of convenience? That is to say, supposing the movement of the earth is really possible, does Copernicus find it hard to determine whether it is actually the case in the heavens?

No. Copernicus looked upon it as more certain than that. For he appears to find the astronomical consequences following from the supposition of the mobility of the earth sufficiently weighty to place it in the same order of truth as the sphericity of the earth, since he insinuates that his opponents are to be classed with Lactantius, who had denied that there were antipodes. [484]

Then if Copernicus regarded the motion of the earth as certain, why did he refer to it as an hypothesis?

Because it underlies all his other hypotheses, as he indicates in speaking of the movement of the earth as a principium and hypothesis–a starting point in reference to which he maps out his hypotheses as to the given apparent movements of other bodies besides the earth. The application of the term "hypothesis" signifies not that the motion of the earth is advanced merely as a tentative proposal to be taken or left but that it forms an underlying principle from which further determinations of celestial movements may be deduced.

Why did time wait so long for a man to declare that the earth was in movement?

That is not wholly the case. The school of Pythagoras had held that the earth as well as the sun were in motion around the central fire. Herakleides of Pontus, who may have studied under Plato, taught the daily rotation of the earth, and Aristarchus of Samos, who studied under a student of a student of Aristotle's, suggested that the annual movement as well, belonged to the earth and not to the sun. And some early Renaissance philosophers, of whom I shall speak later, also imputed movement to the earth in various ways. But none of these men used that supposition as a starting point for giving a detailed and systematic account of the apparent celestial movements.

Why did not Ptolemy himself do so?

Because, as I have said, the supposition of the earth's motion was contrary to the conclusions of Aristotelian physics. Now Aristotelian cosmology might be termed an hypothetical construction designed, among other reasons, to save the appearances given by the following simple experiment: if you light a fire, the flame rises upwards through the air; and if you shake earth, air, and water together in a closed container and then allow them to settle, the air will rise in bubbles to the surface and the earth will sink to the bottom. Therefore the earth, as the heaviest element, will always be at the bottom of things, or, in a spherical cosmos, at the centre, which is the earth's natural place, just as the elements of water, air, and fire belong to concentric spheres arranged around the earth. Now since the earth is in its natural place, it is in possession of its end, and therefore there is no reason for it to move, either by rotating or in any other fashion; while conversely, the stars, the sun, and the five planets (which are unchangeable except with respect to place) attain certain natural ends by their diurnal and other movements.

The general outlines of Aristotelian cosmology were acceptable to Ptolemy as a framework within which to work out a detailed account of the movements of the celestial bodies, because Aristotle's physics on the whole was more sophisticated than that of the atomists and was more fully elaborated and less oracular in statement than Plato's physics (in, say, the *Timaeus*, which was itself perhaps even more sophisticated than Aristotle's in its grasp of fundamental problems). Ptolemaic astronomy however differed specifically from the Aristotelian in that Aristotle constructed an elaborate system (based on that of Eudoxus, Plato's pupil) of many solid spheres having the same centre but different axes of rotation in order to account both geometrically and mechanically for the apparent ceIestial movements, while Ptolemy, employing systems of circles on circles and circles off centre, left it doubtful as to whether these epicycles and eccentrics, [485] were to be accorded a physical and mechanical interpretation as well as the geometrical, with respect to saving the phenomena.

Do you want to say something about the history of astronomy between Ptolemy and Copernicus?

Most of the astronomers of Islam were more concerned with the problem of efficient causation than Ptolemy had been in the Syntaxis (which was translated into Arabic about A.D. 820), and they endeavored to reformulate any plane geometry of planetary motions as the projection on a plane of the movements of a system of spheres. Thus A1 Kaswini, Abu'l Faraj, and A1 Jagmini– three astronomers probably of the thirteenth century– would transform an epicycle on a homocentric into an epicyclic sphere between two homocentric crystalline spheres, which was tangent to the inner surface of the outer and to the outer surface of the inner sphere and which rolled around within their space in between–with further permutations and combinations of eccentric, epicyclic, and homocentric spheres for apparent movements of greater irregularity.

In similar fashion, Al Betrugi, an astronomer of the twelfth century, tried to renovate the homocentric spheres of Aristotle and Eudoxus so as to take care of the irregularities in celestial movements which had made their appearance to observers since the time of Aristotle. And in the thirteenth century a great and very ingenious astronomer, Al Tusi, constructed a system of spheres, within which a single configuration would involve two homocentric spheres with an episphere in between and a series of spheres internally tangent within the episphere. But as far as formal causes go; Al Betrugi's system was not better at saving the appearances than Ptolemy's; nor was A1 Tusi's more intrinsically simple than Ptolemy's.

The important astronomers of Christendom at first followed closely after Ptolemy but with an eye on the astronomers of Islam. The *Syntaxis* was translated from the Arabic into Latin by Gerard of Cremona in 1175. Amateurs at astronomy were more inclined than professionals to play with the supposition that the sun was at the center of some planetary movements or that the earth was in motion. The encyclopedist Martianus Capella, in the *Wedding of Philology and Mercury*, had placed the orbits of Venus and Mercury around the sun, and in the ninth century, John Scot Erigena, the great neo-Platonist theologian, extended this heliocentricity to Jupiter and Mars as well.

In the fifteenth century theological reasons led Nicholas, Cardinal of Cues, to assert that the world, although not infinite, was without centre or circumference and that consequently everything in the world participated in motion to some extent. In *On Learned Ignorance* he goes no further than to suggest that the earth has some movement of rotation but none of translation; but a note of his on the fly-leaf of another man's work draws a fuller sketch of a system of solar and terrestrial motion, as follows: there is a general proviso that there are no perfect circles described by bodies or absolutely fixed poles of rotation. The appearances of the diurnal movement are saved by making the sphere of the fixed stars and the stars revolve from east to west twice in twenty-four hours, and the earth in the same direction once in twenty-four hours. The apparent annual movement of the sun is accounted for by two hypotheses: first, it lags slightly behind the heavens in the daily rotation: but that retardation by itself would give the sun merely an annual motion in a plane identical with or parallel [486] to the celestial equator, hence there is need of some other movement to account for the oblique direction along the ecliptic. Therefore, secondly, there are situated in the plane of the equator two poles, around which the earth revolves once in twenty-four hours (and the sphere of the fixed stars in slightly less time, in order, unsuccessfully, to account for precession), while the sun is on a small circle about 23° distant from one of the poles and revolves in slightly less time than the earth wherefrom the sun thus appears, in its annual passage around the heavens, to move from the tropic of Cancer to the tropic of Capricorn and back again. Nicholas' numbers here were a little off, as he made the sun's retardation in both cases equal to be a 1/164th of a circle instead of 1/165th. Although it is unlikely that Copernicus was acquainted with this particular theory, that is the sort of thing which was germinating in the seed-bed of the times out of which Copernicus' own system grew.

A younger contemporary of the Cardinal's, George Peurbach, published a highly reputed textbook, *New Theories of the Planets*, wherein he adapted solid spheres to the accepted Ptolemaic planetary theory; and he was engaged in the search for Greek manuscripts of Ptolemy, as the available translation from the Arabic were not wholly trustworthy. It was not until 1515 that the twelfth-century translation of Ptolemy's *Syntaxis* was printed for the first time, and in 1528 was published a new translation, made from the Greek by George of Trebizond; and finally the original, together with Theo of Alexandria's *Commentary*, was printed at Basle in 1538. A pupil of Peurbach's, John Regiomontanus, collected Greek astronomical manuscripts in Italy, settled in Nuremberg, where he erected an observatory and started a printing press, and completed a textbook begun by Peurbach, *Epitome of Ptolemy's Almagest*. Men like Peurbach and Regimontanus were instrumental in keeping alive the scientific grammar, which a great talent like that of Copernicus had to have before him in order to transform it.

In the third decade of the sixteenth century, just before the publication of *De revolutionibus*, were printed two works which tried to renovate systems of homocentric spheres, namely Fracastoro's *Homocentrica*, which had the novelty of employing spheres whose axes of movement were situated at right angles to one another, and which demanded seventy-nine spheres, all in all, in order to account for the celestial phenomena, and *On the Movements of the Celestial Bodies according to Peripatetic Principles without Eccentrics and Epicycles* by Giovanni Amici, a brilliant young man, who, incidentally, was murdered before he was thirty.

But by now the unpublished work of Copernicus had acquired an underground reputation; Cello Calagnini, once a soldier of fortune and now a cleric, who had visited at Cracow in 1518, composed before 1524 a highly periphrastic essay in which he attempted to argue that all the apparent movements in the heavens could be saved by rotatory movements of the earth!

What induced Copernicus himself to think of the earth's being in motion?

You will read Copernicus' own answer to that in Book I of *De revolutionibus*, insofar as it was occasioned by astronomical considerations. [487]

You are implying that it was occasioned by other considerations besides the astronomical?

Yes. For in any given age distinct arts and sciences may share in formal patterns which are not the peculiar property of any single one of them. Or there may be a certain leading idea which serves to organize apparently diverse materials: I speak roughly, but consider the continuum as a master-builder idea which has received varying embodiments in modern biology, mathematics, physics, psychology, metaphysics, and the novel; or the modern preoccupation with time from Calvin's theology and Galileo's physics to Proust's *Remembrance of Things Past*. Sometimes some special science lays claim as to its own property to the discovery and analysis of these formal patterns or leading ideas, and sets up rules for. the reduction of many other disciplines to some single one which is viewed as architectchic. For example, the Marxists today have contrived a method of exegesis which reads poetry, theology, mathematics, and politics as symbols for economic realities, just at St. Augustine saw human nature as made up of mirror-images of the Trinity, and St. Bonaventura found foot-prints of the Incarnation, the Christian way of life, and the beatific vision in all the arts which human beings practice. Similarly, the Freudians would like to reduce the world that man constructs for himself to a number of erotic categories, the most justly famous, of which is the Oedipus complex.

What analogous architectchic idea do you find at the time of Copernicus?

As formulated mythologically, it is the doctrine of the microcosm and the macrocosm, the "little world" and the "big world." Pico della Mirandola tells the story of it as follows: "God by the laws of his hidden wisdom had constructed the world. Creation was complete: everything was filled up; all things had been laid out in the highest, the lowest, and the mean orders. He had adorned the supercelestial region with intelligences, and He had animated the celestial globes with immortal souls and with the primal animals. But now that the work was all done, the Master-Builder desired some creature that should contemplate the organization of the created world, love its beauty, and wonder at its greatness.. But there was nothing left among the archetypal ideas from which He could form a new sprout nor anything in his storehouses which He could bestow as an heritage upon this new son nor an empty judiciary seat where this contemplator of the universe could sit. But the paternal power could not fail. in the final birth-throes, as if worn out through child-bearing; wisdom, in a case of necessity, could not be at a loss for want of a plan, the loving-kindness which would praise liberality in others could not be forced to condemn itself. Finally, the Master-Builder decided that that to which nothing which should be its very own could be given should be, in composite fashion, whatsoever had belonged individually to each and every thing." Therefore He made man to be a mirror of the whole universe, a creature whose nature was distinguished from all other natures by being limited to no single nature but embracing all natures in the world: a body which tends towards the centre of the earth, a growing vegetable rooted in one place, an animal having desire and local movement, and an angel uniting contrary forms in oneness of intuition. [488]

I can see how man may be regarded poetically as a small world which mirrors the great world of which he is a part. But what does that have to do with Copernicus?

As you will see, Copernicus substituted the daily rotation of the earth for the rotation of the total heavens, made the precession of the equinoxes depend upon a conical revolution of the axis of the terrestrial ecliptic around the axis of the terrestrial equator (rather than upon a conical revolution, so to speak, of the axis of the celestial ecliptic around the axis of the celestial equator), and transferred the annual revolution from the sun to the earth. By this last step he telescoped into one circle (viz., the annual orbit of the earth) five planetary circles (viz., the eccentric circles of Mercury and Venus and the major epicycles of Mars, Jupiter, and Saturn). Thus the Copernican earth is to the Ptolemaic heavens as microcosm is to macrocosm; or, to keep the metaphor sharp, perhaps we should say that the Copernican earth is a little heaven, or microi-ranus, while the Ptolemaic heavens are a big earth, or *macrogë*. If you choose to interpret either system literally, you may read the other as a mirror-symbol of the first by way of the microcosm-macrocosm transformation.

Do any anologies hold between Copernican astronomy and any other sciences of the times?

There is an anology between Copernican astronomy and the analytic geometry developed out of the work of Descartes. Or, more fully, as Copernicus is to Ptolemy, so is analytic to the synthetic geometry of Euclid or Apollonius of Perga.

Now Ptolemy, as you have seen, built up separately his schemes for each of the planets and established the relative magnitudes of the maj or epicycle and the epicycle-bearing circle of one and the same planet. But, on his own grounds, he had no way of determining the relative magnitude of the epicycle-bearing circle of one planet in comparison with that of another, and therefore no way of determining intrinsically the distances and order of the planets. Later on, Proclus– the disciple of Plotinus and commentator on Plato and Euclid– proposed the rule which was adopted by the Moslem and Renaissance astronomers, namely, that, if the order of the planets be taken according to the speed of their revolutions, then, within that order, their relative distances should be determined by making the apogee of the nearest planet immediately precede the perigee of the next planet and so on, the apogee of the higher immediately following the perigee of the lower. But that was a surmise or an extrinsic hypothesis. However, within the Ptolemaic set-up, it was remarkable and unexplained that the period of the epicycle-bearing circles of Mercury and Venus should be equal to a year and the sun should always be on a line with the centre of the epicycle, and that in the case of Mars, Jupiter, and Saturn (within any cycle of time common to the epicycle-bearing circle and to the epicycle), the sum of the revolutions of the two circles should be equal to the number of solar years, the number of revolutions of the sun within that same cycle of time.

Now Copernicus, as you will see and as I shall not explain right now, interpreted as mirror-images of the earth's annual movement the epicycle-bearing circles of Venus and Mercury and the epicycles of the upper planets (in such fashion that the difference between the movement of an upper planet on its epicycle in one year and the movement on the epicycle-bearing circle is redefined as the difference between the earth's movement and the planet's during that [489] same time). In this way, by telescoping five circles into one, he set up an hypothesis which should underlie the Ptolemaic hypotheses and from it was able to deduce the distances of the planets in comparison with one another.

Similarly, Apollonius of Perga had built up elaborate demonstrations, for example, of the constructibility of conic sections, separate and distinct demonstrations for the circle, parabola, hyperbola, and ellipse, which analytic geometry redefines with greater symbolical and operational simplicity, in the general equation of the second degree:

$$ax^2 + bxy + cy^2 + dx + ey + f = 0.$$

That is to say, the operational unity of symbols to which analytics reduces synthetic Euclidean geometry is like the notorious Copernican simplification of Ptolemaic hypotheses.

Do analogies hold between Copernican astronomy and anything else outside the strict, scientific field?

Yes, for his astronomical system is neo-classical, in a way that the tragedies of Corneille and Racine were neo-classical a century later. For Renaissance literary critics rigorously interpreted Aristotle's unity of action, which was merely the explicit statement of a property which would be found in any good tragedy, as a formal rule for the construction of a plot, and from it deduced unity of time and unity of place. Thus they transformed a generalization about existing tragedies into a law which must be obeyed by all future tragedies and an insight into a system.

Similarly, Copernicus interpreted the axiom of regular circular motion with a neo-classical rigor that Ptolemy had not employed. For example, in his lunar and planetary hypotheses, Ptolemy would set up a circle, on the circumference of which regular movement took place. But (to state the simplest case) the regularity of the movement would be measured, not according as equal angles at the centre measured equal times but according as equal angles around some other fixed point measured equal times; that is to say, the "centre of distance" was not the same as the "centre of regular motion." Ptolemy found that all right: there was one circle on whose circumference the motion took place, and another circle around whose centre the regularity of the motion could be measured. Hence the requirement of regular and circular motion was fulfilled.

But Copernicus argued that such a reading of the axiom destroyed it while purporting to save it, that the notion of regular, circular movement was parodied by having the movement on one circle and the regularity on another, and that the axiom strictly demanded that equality of distance and regularity of motion be measured on one circumference–or, in other words, that the circles of distance and regular movement be one and the same.

How was De revolutionibus *received by the men of the times?*

People were divided for and against it. Those who received it favorably numbered astronomers and ecclesiastics; those who received it unfavorably numbered ecclesiastics and astronomers. The objections raised against the mobility of the earth had to do both with theology and with natural science. One hundred years or more earlier all theologians would have been more sophisticated in their literal interpretation of certain parts of Scripture (just as St. Thomas Aquinas had remarked that analogical arguments raised by speculative reason [490] for the doctrine of the Trinity were of no greater probability than the epicycles and eccentrics of Ptolemy) and would not have found the motion of the earth in contradiction with Job's "who shaketh the earth out of her place and the pillars thereof tremble." But the dissensions between Catholics and Protestants made both sects fearful of any scandal which might appear to undermine respect for the Church of the Bible, and consequently they became over-literal in their reading of Scripture and were inclined to condemn any assertion which could be construed as contradicting any literal interpretation of any passage in the Bible. Luther blustered that "the fool will upset the whole science of astronomy, but as the Holy Scripture shows, it was the sun and not the earth which Joshua ordered to stand still." And even Melanchthon condemned Copernicus' opinion.

Giordano Bruno, however, the ecclesiastical reformer and philosopher, who in 1600 was burned at the stake for heresy, in his cosmology praised Copernicus highly; while Diego de Stuñiga, a doctor of divinity of the University of Toledo, in a commentary on Job interpreted the aforementioned passage in the light of Copernican astronomy. But in 1616 the Inquisition at Rome declared the assertion of the earth's motion to be heretical, and the Sacred Congregation solemnly suspended *De revolutionibus* and Stuñiga's *commentary* "until they should be corrected." Copernicus' book, along with Kepler's *Epitome* and Galileo's *Dialogue on the Two Chief Systems of the World* wherein he had sophistically ignored the existence of Tycho Brahe's system, were not removed from the Index until 1822.

The main difficulty raised by physicists was to the effect that, if the earth were in rotation, then falling bodies would not appear to describe a plumb-line but some other curve in relation to the merely apparent stillness of the earth. Galileo was probably the first experimenter to drop a stone from the top to the foot of the mast of a moving ship. There was no philosophic solution to the difficulty before Galilean kinetics: with respect to a short fall in a brief time, the motion of a body falling to the earth could be explained by analogy with the rectangle of movement of a projectile, where the rotation of the earth (as if the horizontal component) does not interfere with the pull of gravity towards the centre of the earth (as if the vertical component).

Tycho Brahe, nearly as great an astronomer as Copernicus or Kepler, found unanswerable the objections based on the Scriptures and on the apparent course of falling bodies; but approved the simplification introduced into the planetary theories by making a point around the sun the centre of all the planets' orbits. Accordingly, he adopted the Copernican system with a slight revision: he centred all the planets around the sun but kept the sun revolving round the earth, which remained motionless at the centre of the world. Tycho's main work, however, lay less in the construction of a new system of the heavenly motions (for the Tychonic is derived by a simple transformation of the Copernican) than in taking new observations in order to determine with greater accuracy the apparent course of the planets– and it was out of Tycho's observations as material that Kepler built his system.

As a young man, Tycho had met Pierre de la Ramée, professor of philosophy and rhetoric at the College Royal at Paris, who had been intellectually nursed in scholasticism but ever afterwards was a violent Orestes towards any Aristotelian Clytemnaestra. De la Ramée, who thought epicycles and eccentrics too [491] arbitrary a way of saving the appearances, demanded an " astronomy without hypotheses. " Tycho pointed out to him the unsophistication of his demand, inasmuch as motions would always need to be represented by geometric figures, and the simplest astronomical conception– that of a recurrence or cycle of movements, without which no science would be possible– presupposes something like a circle; but he agreed with de la Ramée that some other figures besides the epicycles and eccentrics of the ancients might form a more convenient or more beautiful way of saving the appearances; and consequently he gathered together his "storehouse of observations" not merely for the sake of making precise the eccentricities and the number of epicycles, but also for the sake of any revolutions in theory which they might make possible.

Among scientists who were not primarily astronomers the most influential Corpernican was William Gilbert, a physician of London, who in 1600 published *On the Loadstone and Magnetic Bodies* and on the *Great Magnet the Earth*, the first great treatise on magnetism.

The loadstone or natural magnet, he argues, is of the same nature as iron or iron ore. The attraction subsisting between a loadstone and iron is not due merely to the action of the loadstone but is the joint work of the two. The force of attraction, or "coition" (as he prefers to call it), is strongest at the poles of the loadstone but is present throughout its whole body, since a needle brought into contact with a loadstone will not move towards a pole, although it will turn until it is directed in line with the poles. On two magnetized iron bodies the force of coltion proceeds from unlike pole to unlike pole. But principally, the loadstone is of the same nature as the earth and is but a part of the earth homogeneous with the whole; and a spherical loadstone is a little earth, or *microgë*, while the earth itself (which possesses magnetic poles, meridians, and equator) is a big magnet or macromagnets–on the grounds that a piece of iron or a loadstone behaves in the same way towards the whole earth as a piece of iron or small loadstone does towards a larger spherical loadstone. And just as the human soul is the principle which gives order and unity to the various powers and operations of man, so the magnetic force of a loadstone is like a soul which underlies the diverse magnetic powers of coltion and direction. As a spherical loadstone has the power of rotating (as witnessed by the fact that it can rotate around the axis of a meridian, if one of its poles faces the like pole on another loadstone), then the daily rotation of the earth is probably due to its magnetic energy and to the influence of the sun; and more universally still, all the planetary motions may be due to magnetism. Although in neither case does he give a detailed explanation as to how celestial movements may be conditioned magnetically, yet he is here giving the bare suggestion for the transformation of the heavens into a *macrogë*, which Kepler attempted with more specificity and Newton carried out in a different fashion.

How did Kepler conceive of the task of saving the appearances?

He held a view of the nature of empirical science which is not fashionable today, nor was it fashionable among his contemporaries. As a pious Christian Kepler believed that the world had been created according to an archetypal plan in the intellect of God; and, as a philosopher, he held that the human mind was adequate to comprehend the order of the natural world by observation through the senses and by understanding; and that this order, when discovered and [492] understood, could be formulated with precision and certainty in a deductive system whose governing principle would be that nature was created according to an archetypal plan which was itself in the image of God.

Did he not affirm with dogmatic extravagance that he had deduced the appearances a priori *from archetypal principles*?

In so far as he seems to say that, he was carried away more by poetic enthusiasm than by unlicensed dogmatism. While he held that the appearances would ultimately be deducible from archetypal principles, he laid no claim to having made any final deductions. He calls upon any one to improve upon his work who can do so. His own deductions are designed to be tentative and exemplary rather than final. For example, in searching for some law that would bind together the distances of the planets, after a series of trials and errors he hit upon the circumscribed and inscribed spheres of the five regular solids as a measuring rod. And again, after many trials and errors, he at last discerned an aspect of the planetary movements that could be measured by the ratios of musical harmonies. But he judged that insofar as his particular conclusions were true, they must fit together into a final deductive system. And he himself merely strove to build up what should be a logical and rhetorical foreshadowing of the same. A reading of Book v of the *Harmonies* will make all that clear.

But is it not arbitrary to try to measure the distances of the planets according to the spheres in and around the five regular solids and fantastic to apply musical ratios to celestial movements?

In what way are the spheres of the five solids a more arbitrary measuring rod for the distances of the planets than successive increments of whole numbers as in "Bode's Law," or than an hyperbola as a measuring-rod for the relation between the volume and pressure of a gas under constant temperature?

Similarly, it would have struck Kepler as obscure that the set of numbers which measured the relative lengths of harmonically tuned strings should be said to be limited to them alone.

But does not Kepler also pretend to account for the number of the planets by means of the five solids? What would he say about the planets more recently discovered through the telescope?

Well, as Peter Johannides aptly remarked, do not the five regular solids save the appearances of all the primary planets which are visible to the naked, untutored eye?

Why have you chosen to translate these particular works?

De revolutionibus orbium caelestium is Copernicus' major and almost single work. I have not translated his *Commentariolus*, which is a brief sketch of his system, written at an earlier date, or the *Letter Against Werner*, which is concerned with the variation in the precession of the equinoxes, because these works are themselves of secondary importance and are already available in English.

In the case of Kepler, there might be some doubt as to why I have translated the *Epitomes astronomiae* rather than the *Astronomia nova*, and a part of the *Epitomes* rather than the whole. Now the *Astronomia nova* is a work designed [493] for study by the professional astronomer– one which presupposes in the reader a technical knowledge of astronomy and is, so to speak, built directly up out of observations and computations– while the *Epitomes*, as written for the educated amateur as well as for the practitioners, comprehends a fuller and more explicit account of the elements of Keplerian astronomy and is less wrapped up in the interplay of observation and computation. I have omitted Books I–III, because they deal merely with spherical astronomy (that is to say, the phenomena arising from the daily rotation) and add nothing to Ptolemy and Copernicus. I have omitted Books VI-VII principally for reasons of space and time. They can, without too great loss, be omitted, because they are subordinate to Books IV and V, as being concerned with the application of the general hypotheses and calculus established in Books IV and V to the specific details of the planetary movements. I have also included Book V of the *Harmonies* because it is the work which Kepler himself set most store by, because it is a model of elegance and dramatic suspense in scientific exposition, because it contains the original presentation of Kepler's "third law," because its discussion of the "music of the spheres" forms a needed supplement to, and explication of, parts of Book IV of the *Epitomes*, because it shows most clearly the role that Kepler conceived technical astronomy to play in a complete science of nature, because it shows very clearly the method followed by Kepler as a practising astronomer, and because it presents a system of mathematical measurement which is self-contained, speculative, and non-practical. I have been able to omit Books I-IV of the *Harmonices mundi* with a relatively clear conscience, because they are not concerned directly with astronomy.

What has been your method of translating?

There are two methods of translating which I have employed according to the topic of the discourse in the originals. One, in the case of expository passages which do not involve numerical computation to any great extent, I have used a straight prose and have not been concerned if I stayed very close to the syntax of the original. For while the job of a translator is not to reconstruct in one language the word-patterns of another but to put across into the new language the ideas expressed in the old, still only a presumptuous translator would suppose that he can recover all the interrelations among ideas which are as it were co-signified by the specific syntax of the original statements: therefore a certain strict awkwardness of English syntax may serve to roughen too smooth a flow of words and thus to remind the hurrying reader that there are relations of ideas that elegance must gloss over. On the other hand, in places where numerical computations occur at length, I have schematized the verbal format to the end that "he who runs may read," which is the manner whereby passages of computation should be read.

Are there any sign-posts so that the reader, if need be, can check the translation against the original text?

The pagination of the originals–is indicated by bracketed numbers within the English text. In the cases of *De revolutionibus* and *Epitomes Astronomiae* the page-numbers are those of the first editions, while in the case of *Harmonices mundi* the page-numbers are those of Frisch's edition. In translating explicit page-references made by Kepler himself in the body of the text, I have used the [494] term *folium* to signify that the page number refers to the original edition and not to the translation.

In conclusion, I should like to express my gratitude to Mr. Elliott Garter, who patiently read through my manuscript translation of Book V of *The Harmonies of the World*, suggested improvements in the musical terminology, and liberally placed at my disposal a set of notes on Kepler's musical system, which are incorporated in the present text; but needless to say, all the failings of the present translation are my own. I should also like to acknowledge my indebtedness to Dr. R. Catesby Taliaferro, to Dr. George Comenetz, to Dr. Jacob Klein, and especially to Mr. Peter H. Jackson for criticisms and suggestions as to the revision of the earlier drafts of these translations, and also for various kinds of labour in the preparation of these earlier drafts, which were published in mimeographed form at St. John's College, Annapolis, in 1938-9, to Mrs. Edward F. Lathtop, Mr. Hirsh Nadel, Mr. Lee M. Mace, and to Mr. Harvey Dubinsky.

C. G. WALLIS

SYMBOLS AND ABBREVIATIONS

The translator here appends a list of examples of symbols and abbreviations which have been used in these works:

♄ *for* Saturn	☉ *for* Earth
♃ *for* Jupiter	☿ *for* Venus
♂ *for* Mars	♉ *for* Mercury

♈ *for* Ram (Aries)	♎ *for* Balance (Libra)
♉ *for* Bull (Taurus)	♏ *for* Scorpion (Scorpio)
♓ *for* Twins (Gemini)	♐ *for* Archer (Sagittarius)
♋ *for* Crab (Cancer)	♑ *for* Goat (Capricornus)
♌ *for* Lion (Leo)	♒ *for* Waterboy (Aquarius)
♍ *for* Virgin (Virgo)	♓ *for* Fishes (Pisces)

sq. *AB for* square on *AB*
rect. *AB, CD for* rectangle *AB, CD*
trgi. *for* triangle
sect. *for* sector
AB : *CD EF* : *GH for AB* has to *CD* a greater ratio than *EF* to *GH*
ch. *AB for* chord *AB*

1/2ch. 2 *AB for* one half the chord subtending twice arc
dmt. sph. *for* diameter of the sphere
AB gr. circ. sph. *for* arc *AB* on the great circle of the sphere
AB : CD = AB : BC comp. *BC : CD for* the ratio of *AB* to *CD* is equal to the ratio of *AB* to *BC* compounded with the ratio of *BC* to *CD*.
AB = *CD* for *AB* is equal to *CD*
AB ~ *CD* for *AB* is approximately equal to *CD*
AB > *CD* for *AB* is not less than *CD*
add. *AB* = 6° 42' *for* addition-subtraction *AB* is equal to 6°42'
add. *for* additive addition-subtraction
-add. *for* subtractive addition,-subtraction [495]
5°10'12" *for* 5 degrees 10 minutes 12 seconds of the given circle of 360 degrees.
6^p 5' 4" *for* 6 degrees 5 minutes 14 seconds of the given diameter (or radius) of 60 degrees
seg. circ. *ABC for* segment *ABC* of the circle
ecc. *for* eccentricity
rad. ep. *for* radius of epicycle
gnom. *ABC for* gnomon *ABC*
comp. area *ABC* for composite area *ABC*
sag. *AB for* sagitta AB

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