4

RECASTING THE TRADITION: ARISTOTLE TO THE COPERNICANS

European Science and Learning to the Thirteenth Century

Aristotle was the last great cosmologist of antiquity, and Ptolemy, who lived almost five centuries after Aristotle, was its last great astronomer. Until after the death of Copernicus in 1543, the writings of these two men dominated the astronomical and cosmological thought of the West. Copernicus seems their immediate heir, for in the thirteen centuries that separate Ptolemy's death from Copernicus' birth no large and enduring modification had been imposed upon their work. Because Copernicus began where Ptolemy had stopped many people conclude that there was no science during the intervening centuries. In fact, there was much intense though spasmodic scientific activity, and it played an essential role in preparing the ground for the inception and success of the Copernican Revolution.

If there is a paradox here, it is only apparent. Thirteen centuries of spasmodic research did not materially modify the substantive beliefs of the researchers. Copernicus' teachers still believed that the structure of the universe was about as described by Aristotle and Ptolemy, and their beliefs place them in an ancient tradition. But their attitude toward those beliefs was not ancient. Conceptual schemes age with the succession of the generations that behold them. At the beginning of the sixteenth century men still believed in the ancient description of the universe, but they evaluated it differently. Their concepts were the same, but they saw new strengths and weaknesses in those concepts. Just as we have explored the sources and the strengths of the ancient astronomical tradition, so we must discover what happened to it as it aged. We shall have to begin by finding out how the

ancient tradition was lost and then rediscovered, for the first changes in European attitudes toward the tradition arose from the necessity of recovering it.

The West's loss of ancient science occurred in two stages, the first a slow decline in the quality and quantity of scientific activity, the second a genuine disappearance of traditional learning. After the second century B.C., Mediterranean civilization was increasingly dominated by Rome, and it declined with the decline of Roman hegemony during the first few centuries of the Christian era. Ptolemy, the astronomer, and Galen, the physician, were the last great figures in ancient science, and they both lived in the second century A.D. After their time the major scientific works of the West were commentaries and encyclopedias. When the Moslems invaded the Mediterranean basin during the seventh century, they found only the documents and the tradition of ancient learning. The activity had largely ceased.

The Islamic invasions shifted the geographic center of European Christendom northward from the Mediterranean and thus enforced the continued decline of Western learning. During the seventh century Europeans were deprived even of the documents in which the ancient learned tradition was embodied. Euclid was known only in the incomplete Latin translation prepared by Boethius early in the sixth century; that version stated only the more important theorems and included no proofs. Ptolemy was apparently totally unknown, and Aristotle was represented only by a few works on logic. Encyclopedic collections by men like Boethius and Isidore of Seville preserved fragments of ancient science, but even these fragments were too often inaccurate, intellectually debased, and heavily interlarded with fable. There was little learned activity of any sort. The economic level of European Christendom barely provided subsistence. Science was particularly neglected because, as we shall see in the next section, the Catholic Church was initially hostile to it.

During the centuries when European learning reached its nadir, there was a great renaissance of science in Islam. After the middle of the seventh century the Moslem world rapidly expanded from an Arabian oasis to a Mediterranean empire, and this new empire inherited the manuscripts and the tradition that Christendom had lost. Moslem scholars first reconstituted ancient science by translating Syriac versions of original Greek texts into Arabic; then they added contributions all their own. In mathematics, chemistry, and optics they made original and fundamental advances. To astronomy they contributed both new observations and new techniques for the computation of planetary position. Yet the Moslems were seldom radical innovators in scientific theory. Their astronomy, in particular, developed almost exclusively within the technical and the cosmological tradition established in classical antiquity. Therefore, from our present restricted viewpoint, Islamic civilization is important primarily because it preserved and proliferated the records of ancient Greek science for later European scholars. Christendom recovered ancient learning first from the Arabs and usually in Arabic translation. The title *Almagest* by which we know Ptolemy's major work is not its Greek name at all, but a contraction of the Arabic title which it received from a ninth-century Moslem translator.

Europeans rediscovered ancient learning in Islam during the period of general European recovery which makes the tenor of the later Middle Ages so different from that of the Dark Ages. Beginning slowly in the tenth century and culminating in what is now known as the Twelfth Century Renaissance, there was a gradual increase in the tempo of all aspects of European life. For the first time Christendom achieved relative political security; with it came a great increase of population and trade, including trade with the Moslem world. Intellectual contacts with Islam multiplied as commerce grew. New-found wealth and security provided leisure to explore the newly opened horizons of learning. The first Latin translations from the Arabic were made in the tenth century and multiplied rapidly in those that followed. Late in the eleventh century students from all over Europe began to assemble informally but in steadily increasing numbers to hear some master read and comment upon a new translation of an ancient text. In the twelfth and thirteenth centuries these initially informal gatherings became so large that they required the regulations and charters that transformed them officially to universities, a new sort of learned institution indigenous to Europe. Starting as centers for the oral propagation of ancient learning, these universities rapidly became the home of an original and creative tradition of European scholarship, the critical and combative philosophical tradition known as scholasticism.

The rediscovery of ancient astronomy was a part of the larger reclamation of the science and philosophy of the ancient world. The first astronomical tables to be widely exploited by Europeans were imported from Toledo in the eleventh century. Ptolemy's *Almagest* and most of Aristotle's astronomical and physical writings were latinized during the twelfth, and in the following century they were steadily, though selectively, integrated into the curriculum of the medieval university. Copernicus studied them there at the end of the fifteenth century, and his return to these classics of ancient science makes him the heir of Aristotle and Ptolemy. But they would scarcely have recognized as their own work the inheritance that Copernicus received. Old problems, though still unsolved, had disappeared; new ones, though sometimes merely pseudo problems, had taken their place. In addition, the purposes and methods of the revived learned tradition differed significantly from the ones that had guided ancient scholars.

Some of the new problems were purely textual in origin. Ancient texts were recovered piecemeal, in an order governed more by chance than by logic. Arabic manuscripts were seldom completely faithful to their Greek or Syriac sources; the medieval Latin into which they were retranslated did not at first possess a vocabulary adequate to their technical and abstract subject matter; even good translations inevitably deteriorated during successive transcriptions by men who did not fully understand them. Discovering how Aristotle or Ptolemy had answered a particular question was often difficult and sometimes impossible. Yet medieval scholars repeatedly insisted on reconstructing ancient thought before venturing a judgment of their own. The brilliance, scope, and coherence of their unexpected legacy dazzled men emerging from the Dark Ages; they naturally felt that their first task was to assimilate their heritage. Problems of interpretation and reunification therefore bulked large in scholastic thought.

The task of the medieval scholar was further and artificially complicated by a foreshortened historical perspective. He expected to reëstablish a broad and coherent system of knowledge modeled on Aristotle's, and he did not always recognize that the "antiquity" from whom the system was to derive had had a number of different opinions about a great many questions of detail. Though the scholastics found it hard to recognize (often pleading errors of transmission or translation), Aristotle himself had not always been consistent. Nor had his contemporaries accepted all his views. Occasional equivocations and contradictions had characterized the ancient tradition from the start. Their range had been immensely broadened by the Hellenistic and Islamic commentators, whose works, written during the fifteen centuries separating Aristotle from his European disciples, were recovered with, and sometimes before, those of the master. To us these inconsistencies in the tradition seem natural products of its evolution and transmission, but to the medieval scholar they often appeared as internal contradictions in a single body of knowledge, the hypothetical unit "ancient wisdom." In part because of this confusion, the comparison and reconciliation of conflicting authorities became a distinctive characteristic of scholastic thought. As we shall see more concretely later in this chapter, the revived tradition of learning was less empirical, more verbal, logical, and rational, than its ancient counterpart had been.

One of the inconsistencies embedded in the tradition played a particularly significant role in the development of astronomy: the apparent conflict between the spheres of Aristotelian cosmology and the epicycles and deferents of Ptolemaic astronomy. Though we have not previously noted it, these were really characteristic products of two distinct ancient civilizations, the Hellenic and the Hellenistic. Hellenic civilization centered on the Greek mainland during the period when Greece dominated the Mediterranean basin. The science to which it gave rise was predominantly qualitative in method and cosmological in orientation. Aristotle was its greatest representative and also its last. Just before his death the evolution of Hellenic science came to a premature halt at the time when Alexander the Great conquered Greece and joined it to a great empire embracing all of Asia Minor, Egypt, and Persia to the Indus river. The Hellenistic civilization that emerged after Alexander's conquests centered in commercial and cosmopolitan metropolises like Alexandria. There scholars of many nations and races merged elements of their diverse cultures to produce a science that was less philosophical, more mathematical and numerical, than its Hellenic predecessor had been. Astronomy perfectly illustrates the contrast. The cosmological framework of ancient astronomy is largely a product of the Hellenic tradition which culminated in the works of Aristotle. The mathematical astronomy of Hipparchus and Ptolemy belongs to

the Hellenistic tradition which, in astronomy, flourished only two centuries and more after Aristotle's death.

The Hellenistic astronomers who measured the universe, catalogued the stars, and grappled with the problem of the planets were clearly not indifferent to the cosmology developed by their Hellenic predecessors. But neither were they much concerned with cosmological minutiae. They ridiculed the authors of cosmologies that differed radically from the established norm, and they occasionally wrote short cosmological treatises of their own. Ptolemy himself composed a thoroughly cosmological work, the *Hypotheses of the Planets*, which includes a rather unsatisfactory physical mechanism for epicyclic motions. But when designing mathematical systems to predict planetary position Hellenistic astronomers seldom worried about the possibility of constructing mechanical counterparts for their geometric constructs. To them the physical reality of the spherical shells and the mechanisms which kept the planets moving within them had become at most secondary problems. In short, Hellenistic scientists acquiesced without apparent discomfort in a partial bifurcation of astronomy and cosmology; a satisfactory mathematical technique for predicting planetary position did not have to conform entirely to the psychological requirement of cosmological reasonableness.

In the sixteenth century this bifurcation offered an important precedent to Copernicus. Because he too saw astronomy as essentially mathematical, the physical incongruity of a moving epicycle in a universe of spheres could provide a dim anticipation of the physical incongruity of a moving earth. But this was not the bifurcation's first contribution. Four centuries earlier, at the time when Aristotle and Ptolemy were first recovered by Europeans, it had also helped pave the road to revolution, though in a very different way. Because their ignorance of the preceding centuries had telescoped their sense of history, the scholastics viewed Aristotle and Ptolemy very nearly as contemporaries. They appeared as exponents of a single tradition, "ancient learning," and the differences between their systems became very like inconsistencies in a single body of doctrine. Changes that Ptolemy had seen as the natural evolution of knowledge over the five centuries separating him from Aristotle, often seemed contradictions to the scholastics, and contradictions raised novel problems of reconciliation. Since the passage of time proved reconciliation to be both difficult and inconclusive, these apparent contradictions, like other conflicts in medieval thought, finally helped to cast doubt upon the entire tradition.

As revived in the Middle Ages, the ancient tradition of learning had acquired a new look, and the preceding pages indicate that some of the important novelties derived from the mere necessity of revival. But there were also more substantive changes in the revived tradition, changes produced by indigenous characteristics of the Middle Ages and the Renaissance. For example, though science played a large part in the thought of the later Middle Ages, the dominant intellectual forces were theological, and the practice of science in a theological milieu shifted both the strengths and the weaknesses of the scientific tradition. Besides, medieval science was not itself static. Aristotle's scholastic critics developed important alternatives for some of his doctrines, and a few of these alternatives played a major role in preparing the way for Copernicus. By the sixteenth century still other forces — intellectual, economic, and social — were at work, and among these are some with a direct bearing upon the problems of astronomy and of the earth's motion. These changes demand an independent treatment, to which we now turn.

Astronomy and the Church

Throughout the Middle Ages and much of the Renaissance the Catholic Church was the dominant intellectual authority of all Europe. Medieval European scholars were members of the clergy; the universities in which ancient learning was assembled and studied were Church schools. From the fourth century to the seventeenth the Church's attitude toward science and about the structure of the universe was a determining factor in the progress or stagnation of astronomy. But the Church's attitude and its practice were not uniform during these centuries. After the Dark Ages the Church began to support a learned tradition as abstract, subtle, and rigorous as any the world has known. But before the tenth century and again after the sixteenth the Church's influence was, on balance, antiscientific. The Copernican theory evolved within a learned tradition sponsored and supported by the Church; Copernicus himself was the nephew of a bishop and a canon of the cathedral at Frauenburg; yet in 1616 the Church banned all books advocating the reality of the earth's motion.

No single generalization will describe the Church's overwhelming influence upon science, for the influence changed with the changing situation of the Church.

In the early centuries of the Christian era the Church fathers were crusaders and proselytizers for a new faith, fighting for its very existence. Their calling itself demanded that they deprecate the pagan learning of their predecessors and maximize the attention given to the problems of Christian theology by the rapidly contracting learned world. In addition, they deeply believed that Scripture and Catholic exegesis contained the sum of knowledge necessary for salvation. To them science was secular learning. Except when essential for daily life it was useless at best, dangerously distracting at worst. Therefore, in his *Enchiridion* or handbook for Christians, St. Augustine, the most influential of the early Church fathers, counseled the faithful as follows:

> When, then, the question is asked what we are to believe in regard to religion, it is not necessary to probe into the nature of things, as was done by those whom the Greeks call *physici;* nor need we be in alarm lest the Christian should be ignorant of the force and number of the elements, — the motion, and order, and eclipses of the heavenly bodies; the form of the heavens; the species and the natures of animals, plants, stones, fountains, rivers, mountains; about chronology and distances; the signs of coming storms; and a thousand other things which those philosophers either have found out, or think they have found out. . . . It is enough for the Christian to believe that the only cause of all created things, whether heavenly or earthly, whether visible or invisible, is the goodness of the Creator, the one true God; and that nothing exists but Himself that does not derive its existence from Him.[1]

This attitude was not incompatible with an admiring knowledge of ancient learning, at least not before the Moslem invasions. Augustine himself had read Greek science attentively, and his writings testify to his admiration of its accuracy and scope. But his attitude was incompatible with the active pursuit of scientific problems, and it readily lent itself to further negative elaboration. In the writings of Augustine's less liberal contemporaries and successors, his spiritual depreciation of pagan science was usually coupled with an outright rejection of its content. Astronomy, because of its ties to astrology, was particularly scorned, for the explicit determinism of astrology made it seem incompatible with Christian doctrine.

At the beginning of the fourth century, for example, Lactantius, tutor to the son of the Emperor Constantine, devoted the third book of his *Divine Institutions* to "the false wisdom of the philosophers" and allowed himself one chapter to ridicule the concept of the spherical earth. For him it was sufficient to point to the absurdity of a region in which men hung head down and to the impossibility of the heavens' being below the earth. Later in the century the Bishop of Gabala achieved the same effect with Biblical evidence. The heavens are not a sphere, but a tent or tabernacle, for "it is He . . . that stretcheth out the heavens as a curtain, and spreadeth them out as a tent to dwell in" (Isaiah 40:22). There are "waters . . . above the firmament" (Genesis 1:7). The earth is flat, for "the sun was risen upon the earth when Lot entered into Zoar" (Genesis 19:23). By the middle of the sixth century Kosmas, an Alexandrian monk, could replace the pagan system with a detailed Christian cosmology derived primarily from the Bible. His universe is shaped like the tabernacle that the Lord instructed Moses to build in the wilderness. It has a flat bottom, perpendicular sides, and a semicylindrical roof, like an old-fashioned traveling trunk. The earth, the footstool of the Lord, is a rectangular plane, twice as long as it is broad, and resting on the flat bottom of the universe. The sun does not travel below the earth at night, but is hidden behind its northernmost portions, which are higher than the regions to the south.

The cosmologies of men like Lactantius and Kosmas never became official Church doctrine. Nor did they entirely supplant the ancient universe of spheres which survived in fragmentary descriptions within the more erudite medieval encyclopedias. There was no Christian unanimity about cosmology during the first half of the Middle Ages. Science and cosmology were not significant enough to demand it. But though these cosmologies, compounded from the naïvest sense perceptions plus a smattering of Scripture, were never official, they are representative. They illustrate the decadence of secular learning that characterized the Dark Ages, and they therefore prepare us for the surprise and awe with which later Christian scholars greeted the rediscovery of ancient knowledge during the eleventh and twelfth centuries.

By the time that Christian Europe reëstablished commercial and cultural ties with the Eastern Church in Byzantium and with the Moslems of Spain, Syria, and Africa, the Church's attitude toward

pagan wisdom had changed. The main areas of continental Europe had been converted; the Church's intellectual and spiritual authority was complete; the hierarchy of ecclesiastical administration was fixed. Pagan and secular learning were no longer a threat, provided that the Church could maintain intellectual leadership by absorbing them. Churchmen therefore devoted some of the leisure provided by new-found prosperity to a vigorous pursuit of the rediscovered learning. By broadening the range of knowledge acceptable for Christian scholarship, they preserved for five more centuries the Catholic monopoly of learning. In the twelfth century "the nature of things," including the heavens and the earth, again became a suitable topic for intensive study. By the thirteenth, if not earlier, the main outlines of the two-sphere universe were once more taken for granted in the discussions of educated Christians. During the last centuries of the Middle Ages the setting of Christian life, both terrestrial and celestial, was a fully Aristotelian universe.

We have been calling the process by which Christians discovered that they lived in an Aristotelian universe a recovery of ancient learning, but "recovery" is clearly an inadequate word. What occurred was far more nearly a revolution in both Christian thought and the ancient scientific tradition. From the fourth century on, Aristotle, Ptolemy, and other Greek writers had been attacked by Churchmen because of the conflict between their cosmological opinions and Scripture. Those conflicts still existed in the twelfth and thirteenth centuries, and they were recognized. In 1210 a provincial council at Paris prohibited the teaching of Aristotelian physics and metaphysics. In 1215 the Fourth Lateran Council issued a similar, though more restricted, anti-Aristotelian edict. Other interdictions issued from the papacy throughout the century. They were unsuccessful, winning lip service alone, but they are not insignificant. The edicts testify to the impossibility of simply adding ancient secular learning to the existing body of medieval theology. Both ancient texts and Scripture required modification in the creation of a new fabric of coherent Christian doctrine. When the new fabric was completed, theology had become an important bulwark for the ancient concept of a central stationary earth.

The physical and cosmological structure of the new Christian universe was predominantly Aristotelian. St. Thomas Aquinas (1225–1274), the scholastic who contributed most to the final pattern of the fabric, describes the perfection and appropriateness of the celestial motions in words that, except for their clarity, might have been written by Aristotle himself:

> It is therefore clear that the material of the heavens is, by its intrinsic nature, not susceptible to generation and corruption, since it is the primary sort of alterable body and closest in its nature to those bodies which are intrinsically changeless. [The only truly changeless body in the Christian universe is God, from whom all change on earth and in the heavens derives.] That is why the heavens experience only the absolute minimum of alteration. Motion is the only sort of change they experience, and this sort of alteration [unlike change of size, weight, color, and so on] does not modify their intrinsic nature in the least. Furthermore, among the sorts of motion which they might experience, theirs is circular, and circular motion is the one which produces the very minimum of alteration because the sphere as a whole does not change place.[2]

Aristotle could not always be embraced quite so literally. Many scholastics felt forced, for example, to abandon his proof of the absolute impossibility of a void, because it seemed arbitrarily to limit God's infinite power. No Christian could accept Aristotle's view that the universe had always existed. The first words of the Bible are, "In the beginning God created the heaven and the earth." Besides, the Creation was an essential ingredient in the Catholic explanation of the existence of evil. On a matter of this significance Aristotle had to give way; the universe had been created at a determinate first instant of time. But more often the Bible gave way, usually to metaphorical interpretation. For example, in discussing the scriptural text, "Let there be a firmament made amidst the waters; and let it divide the waters from the waters" (Genesis 1:6), Aquinas first outlined a cosmological theory that would preserve the literal sense of the passage and then said:

> As, however, this theory can be shown to be false by solid reasons, it cannot be held to be the sense of Holy Scripture. It should rather be considered that Moses was speaking to ignorant people, and that out of condescension to their weakness he put before them only such things as are apparent to sense. Now even the most uneducated can perceive by their senses that earth and water are corporeal, whereas it is not evident to all that air also is corporeal. . . . Moses, then, while he expressly mentions water and earth, makes no express mention of air by name, to avoid setting before ignorant persons something beyond their knowledge.[3]

By reading "water" as "air" or "transparent substance" the integrity of Scripture is preserved. But in the process the Bible becomes, in some sense, a propaganda instrument, composed for an ignorant audience. The device is typical, the scholastics employed it again and again.

The painstaking thoroughness with which Aquinas and his contemporaries attacked the task of reconciliation is illustrated by the difficulties they discovered in the Biblical account of the Ascension. According to Scripture Christ "ascended up far beyond all heavens, that he might fill all things" (Ephesians 4:10). Aquinas succeeded in fitting this bit of Christian history into a universe of spheres, but to do so he had to resolve many varied problems, among which were the following:

> It seems that it was not fitting for Christ to ascend into heaven. For the Philosopher [Aristotle] says (*On the Heavens*, Book II) that *things which are in a state of perfection possess their good without movement.* But Christ was in a state of perfection. . . . Consequently, He has His good without movement. But ascension is movement. Therefore it was not fitting for Christ to ascend. . . .
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> Further, there is no place above the heavens, as is proved in *On the Heavens*, I. But every body must occupy a place. Therefore Christ's body did not ascend above all the heavens. . . .
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> Further, two bodies cannot occupy the same place. Since, then, there is no passing from place to place except through the middle space, it seems that Christ could not have ascended above all the heavens unless [the crystal spheres of] heaven were divided; which is impossible.[4]

Aquinas' answers need not concern us. It is the objections themselves that are astounding, particularly since the Ascension is only one of the aspects of Christian history to present problems and since Aquinas is only the greatest of the many Churchmen concerned with them. Aquinas' *Summa Theologica*, from which most of the preceding quotations were taken, is a compendium of Christian knowledge, often printed in twelve fat volumes. In all of them Aristotle's name (or his more revealing designation as "The Philosopher") occurs again and again. Only through a multiplicity of works like these could ancient learning, particularly Aristotelian learning, have again become a foundation for Western thought.

Aquinas and his thirteenth-century contemporaries certified the compatibility of Christian belief with much of ancient learning. By making Aristotle orthodox they licensed his cosmology to become a creative element in Christian thought. But the very detail and erudition of their works obscured the over-all structure of the new Christian universe that was emerging late in the Middle Ages. If we are to understand the pregnant meaning which gave that universe, including the central, stable earth, its hold upon the medieval and Renaissance mind, we require a more comprehensive view. That larger view can scarcely be discovered in the thirteenth century at all. It evolved only after Aristotle had been licensed, appearing perhaps first and certainly most forcefully in the works of the Italian poet Dante, particularly in his great epic, the *Divine Comedy*.

Taken literally, Dante's epic is a description of the poet's journey through the universe as conceived by the fourteenth-century Christian. The journey begins on the surface of the spherical earth; descends gradually into the earth via the nine circles of Hell which symmetrically mirror the nine celestial spheres above; * and arrives at the vilest and most corrupt of all regions, the center of the universe, the appropriate locus of the Devil and his legions. Dante then returns to the surface of the earth at a point diametrically opposite the one where he had entered, and there he finds the mount of purgatory with its base on the earth and its top extending into the aerial regions above. Passing through purgatory, the poet travels through the terrestrial spheres of air and fire to the celestial region above. At the last he journeys through each of the celestial spheres in turn, conversing with the spirits that inhabit them, until finally he contemplates God's Throne in the last, the Empyrean, sphere. The setting of the *Divine Comedy* is a literal Aristotelian universe adapted to the epicycles of Hipparchus and the God of the Holy Church.

For the Christian, however, the new universe had symbolic as well as literal meaning, and it was this Christian symbolism that Dante wished most of all to display. Through allegory his *Divine Comedy* made it appear that the medieval universe could have had no other structure than the Aristotelian-Ptolemaic. As he portrays it, the universe of spheres mirrors both man's hope and his fate. Both physically

* The ninth sphere, which appears throughout medieval astronomy, was added to the eight spheres of ancient cosmology by Moslem astronomers in order to account for the precession of the equinoxes, and the motion of the pole of the heavens (see the Technical Appendix, Section 2). In the Moslem system it is the ninth sphere that rotates every 24 hours, as the sphere of the stars had done in the older system.

and spiritually man occupies a crucial intermediate position in this universe filled, as it is, by a hierarchical chain of substances that stretches from the inert clay of the center to the pure spirit of the Empyrean. Man is compounded of a material body and a spiritual soul: all other substances are either matter or spirit. Man's location, too, is intermediate: the earth's surface is close to its debased and corporeal center but within sight of the celestial periphery which surrounds it symmetrically. Man lives in squalor and uncertainty, and he is very close to Hell. But his central location is strategic, for he is everywhere under the eye of God. Both man's double nature and his intermediate position enforce the choice from which the drama of Christianity is compounded. He may follow his corporeal, earthy nature down to its natural place at the corrupt center, or he may follow his soul upward through the successively more spiritual spheres until he reaches God. As one critic of Dante has put it, in the *Divine Comedy* the "vastest of all themes, the theme of human sin and salvation, is adjusted to the great plan of the universe." [5] Once this adjustment had been achieved, any change in the plan of the universe would inevitably affect the drama of Christian life and Christian death. To move the earth was to break the continuous chain of created being.

No aspect of medieval thought is more difficult to recapture than the symbolism that mirrored the nature and fate of man, the microcosm, in the structure of the universe, which was the macrocosm. Perhaps we can no longer grasp the full religious significance with which this symbolism clothed the Aristotelian spheres. But we can at least avoid dismissing it as mere metaphor or supposing that it had no active role in the Christian's nonastronomical thought. One of Dante's prose works, written in part as a technical handbook to aid his contemporaries in interpreting his verse, concludes a literal physical description of the spheres and epicycles employed in medieval astronomy with the following words:

> However, beyond all these [crystalline spheres], the Catholics place the Empyrean Heaven . . . ; and they hold it to be immovable, because it has within itself, in every part, that which its matter demands. And this is the reason that the *Primum Mobile* [or ninth sphere] moves with immense velocity; because the fervent longing of all its parts to be united with those of this most quiet heaven, makes it revolve with so much desire that its velocity is almost incomprehensible. And this quiet and peaceful heaven is the abode of that Supreme Deity who alone doth perfectly behold himself.[6]

In this passage the astronomer charts the position (and elsewhere the dimensions) of God's abode. He has become theologian, and in the fourteenth and fifteenth centuries the astronomer's theological functions did not always end with the measurement of heaven. Dante and some of his contemporaries also turned to astronomy to discover the kinds and occasionally even the numbers of the angelic inhabitants of God's spiritual realm.

Dante himself outlines one typical medieval theory of the relation between the spiritual hierarchy and the spheres in a passage from *The Banquet* immediately following the description of the spheres referred to above:

> Since it has been demonstrated in the preceding chapter what this . . . heaven is, and how it is ordered within itself, it remains to show who they are who move it. Therefore be it known, in the first place, that these are Substances separate from matter, that is, Intelligences, whom the common people call Angels. . . . The numbers, the orders, the hierarchies [of these angelic beings], are recounted by the movable heavens, which are nine; and the tenth announces the unity and stability of God. And therefore the psalmist says, "The heavens recount the glory of God, and the firmament announceth the work of His hands."
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> Wherefore it is reasonable to believe that the motive powers [that is, the beings who move the spheres] of the Heaven of the Moon are of the order of Angels; and those of Mercury, Archangels; and those of Venus are the Thrones. . . . And these Thrones, which are allotted to the government of this heaven [of Venus], are not many in number, and the astrologers [or astronomers] differ about their number, according to their differences about the revolutions [of this heaven], although all are agreed in this, that their number is equal to that of these revolutions; which, according to the *Book of the Aggregation of the Stars* . . . are three: one by which the star revolves within its epicycle, the second by which the epicycle and the whole heaven revolves equally with that of the Sun, and the third by which all that heaven revolves, following the [precessional] motion of the stellar sphere from west to east, one degree in a hundred years. So that for these three motions are three motive powers [which are three members of the angelic order of Thrones].[7]

When angels become the motive force of epicycles and deferents, the variety of spiritual creatures in God's legion may increase with the complexity of astronomical theory. Astronomy is no longer quite separate from theology. Moving the earth may necessitate moving God's Throne.

Aristotle's Scholastic Critics

The effects of medieval scholarship were not all so conservative as the integration that made theology a bulwark for the universe of spheres. Aristotle and his commentators were the invariable starting point for scholastic research, but they were often no more than that. The very intensity with which Aristotelian texts were studied guaranteed that inconsistencies of doctrine or proof would be quickly noticed, and these inconsistencies were often the seeds of important creative achievements. Medieval scholars caught scarcely a glimpse of the new astronomy and cosmology produced by their sixteenth- and seventeenth-century successors. But they extended Aristotle's logic, discovered fallacies in his proofs, and rejected many of his explanations because they failed the test of experience. In the process they forged a number of the concepts and tools that proved essential to the accomplishments of men like Copernicus and Galileo.

Important anticipations of Copernican thought can be found, for example, in the critical commentary on Aristotle's *On the Heavens* written during the fourteenth century by Nicole Oresme, a member of the important Parisian nominalist school. Oresme's method is typically scholastic. In his long manuscript Aristotle's text is broken into fragments, each a few sentences in length, and these fragments are interspersed with long critical or explanatory comments. On finishing the work a reader discovers that Oresme agrees with Aristotle on almost every substantive point except the Creation. But the reasons for his agreement are far from clear; Oresme's brilliant critique has destroyed many of Aristotle's proofs and suggested important alternatives for a number of Aristotelian positions. These alternatives were seldom adopted by the scholastics themselves. But medieval scholars continued to discuss them, and that discussion helped to create a climate of opinion in which astronomers could imagine experimenting with the idea of a moving earth.

Oresme was, for example, quite critical of Aristotle's principal argument for the earth's uniqueness.[8] Aristotle had said that if there were two earths in space (and when the earth becomes a planet, there will be six "earths"), then they would both fall to the center of the universe and coalesce, because earth moves naturally to the center. This proof, says Oresme, is invalid, because it presupposes a theory of motion that is itself unproved. Perhaps earth does not move naturally to the center, but simply to other nearby bits of earth. Our earth has a center, and it may be to that center, wherever in the universe it is located, that loose stones return. On this alternative theory the natural motion of a body is governed, not by its position in an absolute Aristotelian space, but by its position relative to other portions of matter. Some such theory was prerequisite to the new cosmologies of the sixteenth and seventeenth centuries, cosmologies in which the earth was neither unique nor at the center. Similar theories, in various disguises, are common to the work of Copernicus, Galileo, Descartes, and Newton.

Even more important anticipations of Copernican arguments emerge when Oresme criticizes Aristotle's refutation of Heraclides, the Pythagorean who had explained the diurnal motion of the stars by positing an eastward axial rotation of the central earth. Oresme does not believe that the earth rotates, at least he says he does not. But he is concerned to show that the choice between a stable and a rotating earth must be made on faith. No argument, he says, whether logical, physical, or even scriptural, can disprove the possibility of the earth's diurnal rotation. For example, nothing can be concluded from the apparent motion of the stars, because, says Oresme:

> I suppose that local motion can be perceived only when one body alters its position relative to another. Therefore if a man in a smoothly riding boat, *a*, which is moved either slowly or rapidly, can see nothing but a second boat, *b*, which moves in just the same way as *a*, . . . then I say that it will seem to him that neither boat is moved. And if *a* is at rest and *b* moves, it will seem to him that *b* moves; and if it is *a* that moves and *b* is at rest, it will still seem to him that *a* is at rest and that *b* is moved. . . . Therefore I say that if the higher [or celestial] of the two parts of the universe mentioned above were today moved with a diurnal motion, as it is, while the lower [or terrestrial] part remained at rest, and if tomorrow on the contrary the lower part were moved diurnally while the other part, i.e., the heavens were at rest, we would be unable to see any change, but everything would seem the same today and tomorrow. It would seem to us throughout that our location was at rest while the other part of the universe moved, just as it seems to a man in a moving boat that the trees outside the boat are in motion.[9]

This is the argument from optical relativity that plays such a large part in the writings of Copernicus and Galileo. Oresme does not stop with it, however. His treatise proceeds immediately to the demolition of an even more important Aristotelian argument, the one that concludes for immobility because an object thrown vertically upward always returns to the point on earth from which it departed:

> [In response to Aristotle's and Ptolemy's argument] one may say that an arrow shot straight into the air is [also] moved rapidly eastward with the air through which it passes and with the whole mass of the bottommost [or terrestrial] portions of the universe described above, the whole [earth and air and arrow] being moved with a daily rotation. Therefore the arrow returns to the spot on the earth from which it was shot. This appears possible by analogy: if a man were on a ship moving rapidly eastward without his being aware of its motion, and if he drew his hand rapidly downward, describing a straight line against the mast of the ship, it would seem to him that his hand had only a vertical motion; and the same argument shows why the arrow seems to us to go straight up or down.[10]

Galileo's famous defense of the Copernican system, the *Dialogue on the Two Principal Systems of the World*, is filled with arguments of exactly this sort, and Galileo may well have been elaborating hints derived from Copernicus' scholastic predecessors, including Oresme. But that does not make Oresme a Copernicus. He does not conclude for even the diurnal rotation of the earth; he does not dream of an orbital motion about the center of the universe; and he has no notion of the benefits that astronomers might derive by positing a mobile earth. He does not, for that matter, even share Copernicus' motive, and its absence makes his work all the more astounding. When Oresme's arguments recur in the writings of Copernicus and Galileo, they have a different and a more creative function. The later scientists wished to show that the earth *could move* in order to exploit the advantages that would accrue to astronomy if, in fact, it *did move*. Oresme wished to show only that the earth *could move*; he was investigating only Aristotle's proof. Like many of the other most fruitful contributions of scholastic science, his Copernican arguments are products of the preëminence that the late medieval mind accorded Aristotle. Men who agreed with Aristotle's conclusions investigated his proofs only because they were proofs executed by the master. Nevertheless their investigations often helped to ensure the master's ultimate overthrow.

We cannot, of course, be certain that Copernicus or Galileo read Oresme. The tradition that requires the scholar and scientist to name his sources was not established until long after the scientific revolution of the sixteenth and seventeenth centuries. But Aristotle had many scholastic critics, and they wrote numerous manuscripts which were repeatedly copied in the years after their deaths. Five and a half centuries after the composition of Oresme's commentary there are still six extant medieval manuscript copies, several dating from the fifteenth century, after Oresme's death. At the time of Copernicus' birth there must have been many more. Furthermore, the tradition of scholastic criticism was a continuous tradition. Key concepts which originated at Paris in the fourteenth century can be traced to Oxford in the same century and to Padua in the fifteenth and sixteenth. Copernicus studied at Padua and Galileo taught there. Though we cannot be sure that Copernicus derived any particular argument in the *De Revolutionibus* from any particular scholastic critic, we cannot doubt that the critics as a group facilitated the production of those arguments. At the very least they created a climate of opinion in which topics like the earth's motion were legitimate subjects for university discussion. Quite probably a few of Copernicus' key arguments were borrowed from earlier and unacknowledged sources.

The preceding discussion of Oresme has illustrated the most typical sort of scholastic criticism: the testing of Aristotelian proofs and the investigation of possible alternative doctrines, usually discarded once their logical possibility was demonstrated. But not all medieval science was of this limited critical and perhaps evanescent variety. The scholastics also introduced a few new areas of investigation and a few permanent doctrinal modifications into the Aristotelian scientific tradition. Among these the most significant were in the fields of kinematics and dynamics whose subject is the motion of heavy bodies on the earth and (after the Middle Ages) in the heavens. Some of Galileo's most significant contributions, particularly his work on falling bodies, can appropriately be viewed as a creative reordering of previously scattered physical and mathematical insights gained with difficulty by medieval scholars. But even before the seventeenth century, when Galileo wove them into a new dynamics, one of these insights, the impetus theory of motion, had had an important, if indirect, bearing on astronomical thought.

The impetus theory was erected on the rubble of one of the weakest explanations in the body of Aristotle's physics, the explanation of projectile motion. Aristotle had believed that, unless it was moved by an

external push, a stone would either remain at rest or move in a straight line toward the center of the earth. It was a natural explanation for a large number of phenomena, but it could not easily be fitted to the observed behavior of a projectile. When released from the hand or from a sling, a stone does not drop straight to earth. Rather it continues to move in the direction toward which it was initially impelled even after its contact with the initial projector (hand or sling) is broken. Aristotle, who was a shrewd observer, knew how a projectile moves, and he patched his theory by conceiving the disturbed air as the source of a push which prolongs the projectile's motion after contact with the first propellant is broken. He does not seem to have been too pleased with this solution, for he provided at least two incompatible versions of it, and he was always a bit argumentative on this point. But for him it was never important; his fundamental interests lay elsewhere; he treated the projectile only as an aside and apparently only because it might create difficulty for his theory.

It did create difficulties, apparently almost immediately. John Philoponus, the sixth-century Christian commentator who records the earliest extant rejection of Aristotle's theory, attributes his own partial impetus-theory solution to the Hellenistic astronomer Hipparchus. Most other commentators were at least troubled by this aspect of Aristotle's thought. Perhaps no one, including its author, ever took the air as pusher quite seriously. But it was not until the fourteenth century, when difficulties in Aristotle's text were problems in their own right, that the issue of the projectile was fully faced and resolved by a substantial modification of Aristotle's theory. Though its source was a terrestrial problem, that modification proved to have immediate implications for astronomy.

Both the problem and its medieval solution can be recovered in brilliant detail from the *Questions on the Eight Books of Aristotle's Physics* (a typical title for scholastic science) by Oresme's teacher, Jean Buridan:

> It is sought whether a projectile after leaving the hand of the projector is moved by the air or by what it is moved. . . . This question I judge to be very difficult because Aristotle, as it seems to me, has not solved it well. For he . . . [at one point] holds that the projectile swiftly leaves the place in which it was, and nature, not permitting a vacuum, rapidly sends air in behind to fill up the vacuum. The air moved in this way impinges upon

> the projectile and impels it along. This is repeated continually for a certain distance. . . . [But] it seems to me that many experiences show this method of proceeding to be valueless. . . .
>
> [For example, one among many that Buridan gives,] a lance having a conical posterior as sharp as its anterior would be moved after projection just as swiftly as it would be without a sharp conical posterior. But surely the air following could not push on a sharp end in this way since the air would be easily divided by the sharpness [whereas it could push on a blunt end, thus moving the lance with the blunt end farther]. . . .
>
> Thus we can and ought to say that in the stone or other projectile there is impressed something which is the motive force of that projectile. This is evidently better than falling back on the statement that the air would [continue to] move the projectile, for the air appears to resist. . . . [The projector] impresses a certain impetus or motive force into the moving body, which impetus acts in the direction toward which the mover moved the moving body, either up or down, or laterally or circularly. And by the amount the motor moves that moving body more swiftly, by the same amount it will impress in it a stronger impetus. It is by that impetus that the stone is moved after the projector ceases to move. But that impetus is continually decreased by the resisting air and by the gravity of the stone which inclines it in a direction contrary to that in which the impetus was naturally predisposed to move it. Thus the movement of the stone continually becomes slower until the impetus is so diminished or corrupted that the gravity of the stone wins out over it and moves the stone down to its natural place.[11]

This is only a fraction of Buridan's elaborate discussion, and countless parallel treatments can be found in the works of his successors. By the end of the fourteenth century impetus dynamics, in one of a number of forms very like Buridan's, had replaced Aristotelian dynamics in the work of the principal medieval scientists. The tradition endured: it was taught at Padua around the time Copernicus studied there; Galileo learned it from his master Bonamico at Pisa. Both of them used it, explicitly or implicitly, as did their contemporaries and successors. On a number of occasions and in a variety of ways the impetus theory played an essential role in the Copernican Revolution.

One of these roles we have already seen, though without recognizing it. Oresme's refutation of Aristotle's central argument for the earth's immobility takes the impetus theory, or something quite like it, for granted. On the Aristotelian theory of motion a vertically thrown stone must move along a radius fixed in space. If the earth moves while the stone is in the air, the stone (or arrow) cannot accompany it and will therefore not return to its point of departure. But it the earth's eastward motion endows the stone with an eastward impetus while the stone is still in contact with the projector, that impetus will endure and will cause the stone to pursue the moving earth even after contact is broken. The impetus theory enables the moving earth to endow terrestrial bodies with an internal propellant, and that propellant enables them to follow the earth afterward. Like his master Buridan, Oresme believed in the impetus theory, and though his refutation of Aristotle does not mention the theory explicitly, the refutation makes no sense without it. In one way or another the impetus theory is implicated in most of the arguments, both medieval and Renaissance, that make it possible to move the earth without leaving terrestrial bodies behind.

Some adherents of the impetus theory immediately extended it from the earth to the heavens. In the process they took a second long step toward the Copernicanism that was to come. Buridan himself said, in a passage that closely follows the preceding excerpt from his *Questions*:

> Also, since the Bible does not state that appropriate [angelic] intelligences move the celestial bodies, it could be said that it does not appear necessary to posit intelligences of this kind. For it could [equally well] be answered that God, when He created the world, moved each of the celestial orbs as He pleased, and in moving them He impressed in them impetus which moved them without His having to move them any more except by the method of general influence whereby he concurs as a coagent in all things which take place. Thus on the seventh day He rested from all work which he had executed by committing to others the actions and the passions in turn. And these impetuses which He impressed in the celestial bodies were not decreased nor corrupted afterwards, because there was no inclination of the celestial bodies for other movements. Nor was there resistance which would be corruptive or repressive of that impetus.[12]

In Buridan's writings, perhaps for the first time, the heavens and the earth were at least tentatively subjected to a single set of laws, and the same suggestion was carried further by Buridan's pupil, Oresme. He suggested that, "when God created [the heavens] . . . , He impressed them with a certain quality and force of motion, just as He impressed terrestrial things with weight . . . ; it is just the same as a man building a clock and leaving it to run itself. Thus God left the heavens to be moved continually . . . according to the order [He had] established."[13] But to conceive the heavens as a terrestrial mechanism, a piece of clockwork, is to break the absolute dichotomy between the superlunary and sublunary regions. Though the impetus theorists followed the suggestion no further, at least during the Middle Ages, it was just this dichotomy, drawn from both Aristotle and theology, that had to be broken if the earth was to be made a planet.

The possibility of the earth's motion and the partial unification of terrestrial and celestial law were the impetus theory's two most direct contributions to the Copernican Revolution. Its most important contribution, however, was an indirect one, to which we shall revert briefly in the last chapter. Through its role in the evolution of Newtonian dynamics, the impetus theory helped to bring the Revolution to a successful close more than a century after Copernicus' death. Copernicus in the sixteenth century provided only a new mathematical description of the way the planets move; he was not successful in explaining why the planets moved as he said they did. Initially his mathematical astronomy made no physical sense, and it therefore posed new sorts of problems for his successors. Those problems were only resolved by Newton, whose dynamics supplied the missing keystone to Copernicus' mathematical system, and Newton's dynamics, even more than Copernicus' astronomy, depended on the prior scholastic analyses of motion.

Impetus dynamics is not Newtonian dynamics, but by pointing to new problems, new variables, and new abstractions impetus dynamics helped to pave the way for Newton's work. Before the impetus theory both Aristotle and experiment had testified that only rest endures. Buridan and some other impetus theorists declared that, unless resisted, motion too would endure forever, and they thus took a long step toward what we now know as Newton's First Law of Motion. Again, in a passage omitted from the descriptive quotation above, Buridan equated the quantity of impetus in a moving body with the product of the body's speed and its quantity of matter. The concept of impetus became very like, though not identical with, the modern concept of momentum; in Galileo's work the words "impetus" and "momentum" are often used interchangeably. Elsewhere, to give one final example, Buridan's discussion came very close to saying that the gravity (or weight) of a freely falling body impresses equal increments of impetus (and therefore of velocity) upon the body in equal intervals of time. Galileo was not the first of Buridan's successors to say precisely this and to derive from it, with the aid of other analytical

devices supplied by the scholastics, the modern quantitative relation between time of fall and distance. Contributions like these give scholastic science an important role in the evolution of Newtonian dynamics, and Newtonian dynamics was the keystone in the structure of the new universe created by Copernicus and his successors.

During the seventeenth century, just when its full utility was being demonstrated for the first time, scholastic science was bitterly attacked by men trying to weave a radically new fabric of thought. The scholastics proved easy to ridicule, and the image has stuck. Medieval scientists more often found their problems in texts than in nature; many of those problems do not now seem problems at all; by modern standards the practice of science during the Middle Ages was incredibly inefficient. But how else could science have been reborn in the West? The centuries of scholasticism are the centuries in which the tradition of ancient science and philosophy was simultaneously reconstituted, assimilated, and tested for adequacy. As weak spots were discovered, they immediately became foci for the first effective research in the modern world. The great new scientific theories of the sixteenth and seventeenth centuries all originate from rents torn by scholastic criticism in the fabric of Aristotelian thought. Most of those theories also embody key concepts created by scholastic science. And more important even than these is the attitude that modern scientists inherited from their medieval predecessors: an unbounded faith in the power of human reason to solve the problems of nature. As the late Professor Whitehead remarked, "Faith in the possibility of science, generated antecedently to the development of modern scientific theory, is an unconscious derivative from medieval theology." [14]

Astronomy in the Age of Copernicus

In discussing late-medieval modifications of the Aristotelian-Ptolemaic tradition, we have said almost nothing about developed planetary astronomy. In fact there was almost none in Europe during the Middle Ages, partly because of the intrinsic difficulty of the mathematical texts and partly because the problem of the planets seemed so esoteric. Aristotle's *On the Heavens* described the entire universe in relatively simple terms; Ptolemy's elaborate *Almagest* dealt, for the most part, only with the computation of planetary position. Therefore, though the works of both Aristotle and Ptolemy were translated by the end of the twelfth century, Aristotelian logic, philosophy, and cosmology were assimilated far more rapidly than developed Ptolemaic astronomy. Thirteenth-century metaphysics rivals Aristotle's in profundity; fourteenth-century physics and cosmology exceed Aristotle's in depth and logical coherence. But Europeans produced no indigenous astronomical tradition to rival Ptolemy's until the middle of the fifteenth century, if then. The first widely known European astronomical treatise, written around 1233 by John of Holywood, slavishly copied an elementary Arabic treatise and devoted only one chapter to the planets compared with Ptolemy's nine. The next two centuries produced only commentaries on Holywood's book and a few unsuccessful rivals. Until two decades before Copernicus' birth in 1473 there was little concrete evidence of technically proficient planetary astronomy. Then it appeared in works like those of the German Georg Peuerbach (1423–1461) and his pupil Johannes Müller (1436–1476).

To Europeans of Copernicus' generation planetary astronomy was, therefore, almost a new field, and it was practiced in an intellectual and social environment quite different from any in which astronomy had been practiced before. In part that difference arose from the theological accretions to the astronomical tradition that we have examined in the work of Aquinas and Dante. Even more essential changes were produced by the logical and cosmological criticism of men like Buridan and Oresme. But these were medieval contributions, and Copernicus did not live during the Middle Ages. His lifetime, 1473–1543, occupied the central decades of the Renaissance and Reformation, and novelties characteristic of this later age were also effective in inaugurating and shaping his work.

Since stereotypes are most readily discarded during periods of general ferment, the turbulence of Europe during the Renaissance and Reformation itself facilitated Copernicus' astronomical innovation. Change in one field decreases the hold of stereotypes in others. Radical innovations in science have repeatedly occurred during periods of national or international convulsion, and Copernicus' lifetime was such a period. The Moslems again threatened to absorb vast areas of a Europe now convulsed by the dynastic rivalries through which the nation-state replaced the feudal monarchy. A new commercial aristocracy, accompanied by rapid changes in economic institutions and in technology, began to rival the older aristocracies of Church and

landed nobility. Luther and Calvin led the first successful revolts against Catholic religious hegemony. In an age marked by such obvious upheavals in political, social, and religious life, an innovation in planetary astronomy could at first seem no innovation at all.

Specific characteristics of the age had more concrete effects on astronomy. The Renaissance was, for example, a period of voyages and explorations. Fifty years before Copernicus' birth Portuguese voyages along the African coast had begun to excite the imagination and avarice of Europeans. Columbus' first landfall in America, made when Copernicus was nineteen, only capped this earlier series of explorations and provided the basis for a new series. Successful voyages demanded improved maps and navigational techniques, and these depended in part on increased knowledge of the heavens. Prince Henry the Navigator, the organizer and director of the early Portuguese voyages, constructed one of the earliest European observatories. Exploration therefore helped to create a demand for expert European astronomers, and having done so, it partially changed their attitude toward their field. Each new voyage disclosed new territory, new products, and new people. Men rapidly learned how wrong ancient descriptions of the earth could be. In particular, they learned how wrong Ptolemy could be, for Ptolemy had been the greatest geographer as well as the greatest astronomer and astrologer of antiquity. The astronomer's awareness – an awareness which we shall shortly discover in Copernicus himself – that Renaissance man could at last correct Ptolemy's geography prepared him for changes in his own closely related field.

Agitation for calendar reform had an even more direct and dramatic effect on the practice of Renaissance astronomy, for the study of calendars brought the astronomer face to face with the inadequacy of existing computational techniques. The cumulative errors of the Julian calendar had been recognized much earlier, and proposals for calendar reform date from the thirteenth century or before. But these proposals were ineffective until the sixteenth century, when the increasing size of political, economic, and administrative units placed a new premium upon an efficient and uniform means of dating. Then reform became an official Church project, with results for astronomy that are well illustrated in the biography of Copernicus himself. Early in the sixteenth century Copernicus was asked to advise the papacy about calendar reform. He declined and urged that reform be postponed, because he felt that existing astronomical observations and theories did not yet permit the design of a truly adequate calendar. When Copernicus listed the aspects of contemporary astronomy that had led him to consider his radical theory, he began, "For, first, the mathematicians are so unsure of the movements of the Sun and Moon that they cannot even explain or observe the constant length of the seasonal year" (see p. 137 below). Reform of the calendar demanded, said Copernicus, reform in astronomy. The preface of his *De Revolutionibus* closed with the suggestion that his new theory might make a new calendar possible. The Gregorian calendar, first adopted in 1582, was in fact based upon computations that made use of Copernicus' work.

Recognition of the inadequacies in existing techniques for astronomical computation was heightened by still another aspect of Renaissance life. During the fifteenth century, Europe experienced a second great intellectual revival associated with a second rediscovery of classical models. Unlike its twelfth-century predecessor, the Renaissance revival of learning was not primarily a scientific revival. Most of the newly recovered documents exemplified ancient literature, art, and architecture, subjects whose great tradition was then little known in the West principally because Islamic culture had been indifferent to it. The manuscripts discovered in the fifteenth century did, however, include a few important works of Hellenistic mathematics and, more important, a great many authentic Greek versions of scientific classics previously known only in Arabic. As a result, the Ptolemaic system's recognized failure correctly to predict celestial motions could no longer be blamed upon errors accumulated in transmission and translation. Astronomers could no longer believe that astronomy had declined since Ptolemy.

Peuerbach, for example, began his career in astronomy by working from second-hand translations of the *Almagest* transmitted via Islam. From them he was able to reconstruct a more adequate and complete account of Ptolemy's system than any known before. But his work only convinced him that a truly adequate astronomy could not be derived from Arabic sources. Astronomers, he felt, would have to work from Greek originals, and he was about to depart for Italy to examine manuscripts available there when he died in 1461. His successors, particularly Johannes Müller, did work from the Greek versions, and they then discovered that even Ptolemy's original formulation was inadequate. By making available sound texts of ancient authors, fifteenth-century scholars helped Copernicus' immediate predecessors to recognize that it was time for a change.

Developments like those discussed above can help us understand why the Copernican Revolution occurred when it did. They are essential parts of the climate for astronomical upheaval. But there are other, more intellectual, aspects of the Renaissance which played a somewhat different role in the Revolution. They are associated with humanism, the dominant learned movement of the age, and their effect was less upon the Revolution's timing than upon its shape. Humanism was not principally a scientific movement. The humanists themselves were often bitterly opposed to Aristotle, the scholastics, and the entire tradition of university learning. Their sources were the newly recovered literary classics, and, like literary men in other ages, many of them rejected the scientific enterprise as a whole. The early humanist poet Petrarch sounds a typical note, strangely and significantly reminiscent of Augustine's earlier depreciation of science. "Even if all these things were true, they help in no way toward a happy life, for what does it advantage us to be familiar with the nature of animals, birds, fishes, and reptiles, while we are ignorant of the nature of the race of man to which we belong, and do not know or care whence we come or whither we go."[15] If humanism had been the only intellectual movement of the Renaissance, the Copernican Revolution might have been long postponed. The work of Copernicus and his astronomical contemporaries belongs squarely in that university tradition which the humanists most ridiculed.

The humanists did not, however, succeed in stopping science. During the Renaissance a dominant humanistic tradition outside the universities existed side by side with a continuing scientific tradition within university walls. In consequence the first scientific effect of the humanists' dogmatic anti-Aristotelianism was to facilitate for others a break with the root concepts of Aristotle's science. A second but more important effect was the surprising fertilization of science by the strong otherworldly strain that characterized humanist thought. From this aspect of humanism, a first hint of which is contained in the preceding quotation from Petrarch, some Renaissance scientists, like Copernicus, Galileo, and Kepler, seem to have drawn two decidedly un-Aristotelian ideas: a new belief in the possibility and importance of discovering simple arithmetic and geometric regularities in nature, and a new view of the sun as the source of all vital principles and forces in the universe.

The otherworldliness of humanism derived from a well-defined philosophical tradition which had greatly influenced Augustine and other early Church fathers but which had been temporarily eclipsed by the twelfth-century recovery of Aristotle's writings. That tradition, unlike the Aristotelian, discovered reality in a changeless world of spirit rather than in the transient affairs of everday life. Plato, who is the tradition's ultimate source, often seems to dismiss the objects of this world as mere imperfect shadows of an eternal world of ideal objects or "forms" existing outside of space and time. His followers, the so-called Neoplatonists emphasized this tendency in their master's thought to the exclusion of all others. Their mystical philosophy, which many humanists took as a model, recognized only a transcendent reality. Yet for all its mysticism, Neoplatonism contained elements that gave a significant new direction to the science of the Renaissance.

The Neoplatonist leaped at once from the changeable and corruptible world of everyday life to the eternal world of pure spirit, and mathematics showed him how to make the leap. For him mathematics exemplified the eternal and real amid the imperfect and fluctuating appearances of the terrestrial world. The triangles and circles of plane geometry were the archetypes of all Platonic forms. They existed nowhere – no line or point drawn on paper satisfies Euclid's postulates – but they were endowed with certain eternal and necessary properties which the mind alone could discover and which, once discovered, could be observed dimly mirrored in the objects of the real world. The Pythagoreans, who had also envisioned the real world as a shadow of the eternal world of mathematics, exemplified the ideal of terrestrial science in their discovery that uniform strings whose lengths are in the simple numerical ratios $1 : \frac{3}{4} : \frac{2}{3} : \frac{1}{2}$ produce harmonious sounds. The mathematical strain in Neoplatonic thought is often attributed to Pythagoras and identified as Neopythagoreanism.

Plato himself emphasized the necessity of mathematics as training for the mind in pursuit of forms; over the door of his Academy he is said to have inscribed, "Let no one destitute of geometry enter my doors." [16] The Neoplatonists went further. They found in mathematics

the key to the essential nature of God, the soul, and the world soul which was the universe. A typical passage from the fifth-century Neoplatonist Proclus perfectly displays a part of this mystical vision of mathematics:

> The soul [of the world], therefore, is by no means to be compared to a smooth tablet, void of all reasons; but she is an ever-written tablet, herself inscribing the characters in herself, of which she derives an eternal plenitude from intellect. . . . All mathematical species, therefore, have a primary subsistence in the soul: so that, before sensible numbers, there are to be found in her inmost recesses, self-moving numbers; vital figures, prior to the apparent; ideal proportions of harmony previous to concordant sounds; and invisible orbs, prior to the bodies which revolve in a circle. . . . [We] must conceive all these as subsisting ever vitally, and intellectually, as the exemplars of apparent numbers, figures, reasons and motions. And here we must follow the doctrine of Timaeus, who derives the origin, and consummates the fabric of the soul, from mathematical forms, and reposes in her nature the causes of everything which exists.[17]

Proclus and the humanists who espoused his cause are a long way from the physical sciences. But they occasionally influenced their more scientifically inclined contemporaries, and the result was a new search by many late Renaissance scientists for simple geometric and arithmetic regularities in nature. Copernicus' friend and teacher at Bologna, Domenico Maria de Novara, was a close associate of the Florentine Neoplatonists who translated Proclus and other authors of his school. Novara himself was among the first to criticize the Ptolemaic planetary theory on Neoplatonic grounds, believing that no system so complex and cumbersome could represent the true mathematical order of nature. When Novara's pupil Copernicus complained that the Ptolemaic astronomers "seem to violate the first principle of uniformity in motion" and that they have been unable to "deduce the principal thing – namely the shape of the Universe and the unchangeable symmetry of its parts" (see p. 138 below), he was participating in the same Neoplatonic tradition. The Neoplatonic strain shows even more strongly in Copernicus' great successor, Kepler. As we shall see, the search for simple numerical relations runs through and motivates most of Kepler's work.

The origin of the liaison between Neoplatonism and sunworship is more obscure, but a hint about the ties that bound them together can be found in the preceding quotation from Proclus. Neoplatonic thought could never quite dispense with the real world. The "vital figures" and "invisible orbs" that Proclus found in the soul of the world, or in God, might be the primary philosophical entities, the only things that have complete reality and existence. But the Neoplatonist could not avoid granting some sort of existence to the imperfect bodies attested by his senses. He therefore regarded them as second-rate copies generated by the "vital figures" themselves. As Proclus said, the mathematical forms that determine the nature of the world soul were also the "causes of everything which exists." They generated countless debased and materialized copies of their own purely intellectual substance. The Neoplatonist's God was a self-duplicating procreative principle whose immense potency was demonstrated by the very multiplicity of the forms that emanated from Him. In the material universe this fecund Deity was suitably represented by the sun whose visible and invisible emanations gave light, warmth, and fertility to the universe.

This symbolic identification of the sun and God is found repeatedly in Renaissance literature and art. Marsilio Ficino, a central figure in the fifteenth-century humanist and Neoplatonic academy of Florence, gave it typical expression in his treatise *On the Sun*:

> Nothing reveals the nature of the Good [which is God] more fully than the light [of the sun]. First, light is the most brilliant and clearest of sensible objects. Second, there is nothing which spreads out so easily, broadly, or rapidly as light. Third, like a caress, it penetrates all things harmlessly and most gently. Fourth, the heat which accompanies it fosters and nourishes all things and is the universal generator and mover. . . . Similarly the Good is itself spread everywhere, and it soothes and entices all things. It does not work by compulsion, but through the love which accompanies it, like heat [which accompanies light]. This love allures all objects so that they freely embrace the Good. . . . Perhaps light is itself the celestial spirit's sense of sight, or its act of seeing, operating from a distance, linking all things to heaven, yet never leaving heaven nor mixing with external things. . . . Just look at the skies, I pray you, citizens of heavenly fatherland. . . . The sun can signify God himself to you, and who shall dare to say the sun is false.[18]

With Ficino as with Proclus, we are a long way from science. Ficino does not seem to understand astronomy. He certainly made no attempt to reconstruct it. Though the sun has a new significance in Ficino's

universe, it retains its old position. Yet that position was no longer appropriate. Ficino wrote, for example, that the sun was created first and in the center of the heavens. Surely no lesser position in space or in time could be compatible with the sun's dignity and creative function. But the position was not compatible with Ptolemaic astronomy, and the resulting difficulties for Neoplatonism may have helped Copernicus to conceive a new system constructed about a central sun. In any case they gave him an argument for the new system. As soon as he had discussed the new position of the sun, Copernicus adverted to the fitness of his new cosmology (see p. 179 below). His authorities are immediately Neoplatonic:

> In the middle of all sits 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; Hermes Trismegistus names him the Visible God, Sophocles' Electra calls him the All-seeing. So the sun Sits as upon a royal throne ruling his children the planets which circle round him.

Neoplatonism is explicit in Copernicus' attitude toward both the sun and mathematical simplicity. It is an essential element in the intellectual climate that gave birth to his vision of the universe. But it is often hard to tell whether any given Neoplatonic attitude is posterior or antecedent to the invention of his new astronomy in Copernicus' thought. No similar ambiguity exists with respect to the later Copernicans. Kepler, for example, the man who made the Copernican system work, is quite explicit about his reasons for preferring Copernicus' proposal, and among them is the following:

> [The sun] is a fountain of light, rich in fruitful heat, most fair, limpid, and pure to the sight, the source of vision, portrayer of all colors, though himself empty of color, called king of the planets for his motion, heart of the world for his power, its eye for his beauty, and which alone we should judge worthy of the Most High God, should he be pleased with a material domicile and choose a place in which to dwell with the blessed angels. . . . For if the Germans elect him as Caesar who has most power in the whole empire, who would hesitate to confer the votes of the celestial motions on him who already has been administering all other movements and changes by the benefit of the light which is entirely his possession? . . . [Hence] by the highest right we return to the sun, who alone appears, by virtue of his dignity and power, suited for this motive duty and worthy to become the home of God himself, not to say the first mover.[19]

Until after Copernicus' death the mathematical magic and the sun worship that are so marked in Kepler's research remained the principal points of explicit contact between Renaissance Neoplatonism and the new astronomy. But late in the sixteenth century a third aspect of Neoplatonism merged with Copernicanism and helped to reshape the structure of Copernicus' universe. Unlike the Deity of the Neoplatonists, whose perfection was measured by his immense fecundity, the God of Aquinas and Aristotle had been conceived as an architect who displayed His perfection in the neatness and order of His creation. Aquinas' God was well suited to the finite Aristotelian cosmos, but the God of the Neoplatonists was not so easily bounded. If God's perfection is measured by the extent and multiplicity of his procreation, a larger and more populous universe must connote a more perfect Deity. To many Neoplatonists the finitude of Aristotle's universe was therefore incompatible with God's perfection. His infinite goodness would, they felt, be satisfied only by an infinite act of creation. Even before Copernicus the resulting vision of a multipopulated universe, infinite in extent, had been the source of important divergences from Aristotelian doctrine. During the Renaissance the revived emphasis on God's infinite creativity may have been a significant element in the climate of opinion that bred Copernicus' innovation. Certainly, as we shall see later, it was a major factor in the post-Renaissance transition from Copernicus' finite universe to the infinite space of the Newtonian world machine.

Neoplatonism completes the conceptual stage setting for the Copernican Revolution, at least as we shall examine it here. For an astronomical revolution it is a puzzling stage, because it is set with so few astronomical properties. Their absence, however, is just what makes the setting important. Innovations in a science need not be responses to novelties within that science at all. No fundamental astronomical discovery, no new sort of astronomical observation, persuaded Copernicus of ancient astronomy's inadequacy or of the necessity for change. Until half a century after Copernicus' death no potentially revolutionary changes occurred in the data available to astronomers. Any possible understanding of the Revolution's timing and of the factors that called it forth must, therefore, be sought principally outside of astronomy, within the larger intellectual milieu inhabited by astronomy's practitioners. As we suggested at the beginning of this chapter,

Copernicus began his cosmological and astronomical researches very nearly where Aristotle and Ptolemy had stopped. In that sense he is the immediate heir of the ancient scientific tradition. But his inheritance took almost two milleniums to reach him. In the interim the very process of rediscovery, the medieval integration of science and theology, the centuries of scholastic criticism, and the new currents of Renaissance life and thought, all had combined to change men's attitude towards the scientific heritage that they learned in school. Just how great, and yet how strangely small, this essential change could be we shall discover in the next chapter as we take up Copernicus' innovation.