Chapter 2: Rise of Rational Cosmology

For the people of Babylon the sky was a two-dimensional vault across which moved a continual procession of sun, moon, planets, and stars. In this ever-changing pattern they read the fate of kings and of nations. In the sense that careful observations were required, such activity might be considered scientific. But surely this was a priestly science, confined by ritual, offering only dogmatic answers to cosmic questions. Their achievement was in recognizing regularities in the heavens that enabled them to predict celestial phenomena and consequently to believe themselves to prophesy.

But the Greeks were philosophers not prophets. What had been serious, demanding business for the Mesopotamians — searching the night sky for signs and omens, was a fascinating intellectual challenge for the Greeks — seeking the mechanism underlying motion in the celestial spectacle. Their motivation was a quest to understand cosmic harmony, to relate the changing appearances of the sky to permanent, invariable principles. Specifically, to grasp the natural order underlying the variety of patterns traced by the planets against the background of stars.

But what an incredible leap from the mythic tales told by the astronomer priests! To think in terms of *cause* and *effect* rather than sign and interpretation was a monumental transformation, but the genius of that age was faith, faith in the existence of those yet undiscovered underlying principles. Anyone could paint a picture or construct a fantasy, but to come up with a few fundamental axioms to rationally explain a host of phenomena...that was a real challenge, and they were eager to pursue it — such splendid optimism! And what needed to be explained? One starts with the most orderly, regular natural phenomenon, motion of the sun, moon and planets, which directly leads to the search for the celestial mechanism.

How did such a clearly revolutionary, rational approach to natural philosophy begin? Little information survives from before the 5th century BCE; but if a choice of origin has to be made, one might pick the seafaring town of Miletus on the Anatolian coast of Asia Minor, a region known as Ionia. There, in the 7th Century B.C., appeared one Thales, founder of the Ionian school of philosophy. The Milesians were a practical people who approached problems in terms of everyday experience not myths. Perhaps that is why a central notion of the Ionian school was that the entire Cosmos functioned much like the bits and pieces of it we can examine here on earth. What a seemingly modern, clear-headed starting point! But their innovation did not stop there. They not only were dedicated to a search for basic principles to provide a fundamental description of nature, but they considered such a quest both a right and responsibility.

For Thales, the principle of existence was based on substance; the concept of a fundamental stuff that could, by simple rearrangement of its elements, take on various aspects and explained the abundant variety of substance found in the material World. As the Ionian school progressed with famous contributors such as Anaxagoras, Anaximenes, and Anaximander, the notion of just what substance was truly basic shifted from earth to air and fire and water or a still more fundamental fifth essence, or "quintessence." At that time, viewing the universe as ordered by a hierarchy of substance (which later became a value hierarchy) not lead to any further rational insights, and although this turned out to be a durable concept in the history of natural philosophy, the important contribution of the Ionians (second to the legacy of intellectual integrity) was the concept of a theoretical model, their ability to compare the remote with the familiar. Heavenly bodies were not deities, the starry night sky was a great bronze shield, perforated with small holes with a great fire raging on the far side and shining through. They also came up with the idea that moon glows with light borrowed from the sun. Again a great leap away from the dogmatic distinction between the natures of heaven and of earth, toward the idea that the heavens are composed of and behaved much as familiar inanimate objects on the surface of the earth. Thales was not quite so direct in his attack on the supreme authority of the gods, but his challenge emboldened successors to reduce the sacred workings of the Cosmos to analysis with "paper and pencil." Revolutionary ideas gain general acceptance only very slowly. Anaxagoras was condemned to death (but escaped) for his attempts to demote the heavens, by suggesting that the sun and stars were no more than hot glowing stones, without mind or soul.

These were only the beginnings. The notions of fundamental principles and the abstraction of a theoretical model were carried forward by the Pythagoreans during the 6th Century. For the Pythagoreans, the "principle" was abstract mathematics, numbers not substance. Axioms, not ingredients, were the foundation of World order and structure. The laws of the heavens were based on the correspondence between numbers and natural phenomena in a manner strikingly similar to the formal basis of many studies in modern physical science where mathematical symmetries are important. To understand what they had in mind, consider the following summary by a 4th Century commentator:

> *The Pythagoreans said that the bodies in the planetary system revolve around the center at distances related by mathematical proportions. Some revolve more quickly, others more slowly. The slower ones emit deeper sounds as they move, and the quicker ones higher sounds. These sounds depend on the ratios of the distances, which are so proportioned that the combined effect is harmonious...*

Later this harmony came to be called the "music of the spheres." Their overall model for motions of celestial bodies was sophisticated not only because of its mathematical basis, but also because of the advanced practical knowledge of the heavens it represents:

1. The planetary bodies are spheres that shine by reflected light.
2. The bodies move about a center (which is neither the sun nor the earth, but the central fire... the watchtower of Zeus).
3. The principle of lunar and solar eclipses was understood.

In another sense their model was disturbingly primitive and represented a step backwards from the Ionians in that a compromise was made with the deistic orthodoxy of the time (or with their own mystical sentiments) — for celestial objects, whether divine or not, at least exhibited "divine perfection." Such was the beginning of a long series of retrenchments.

By the time Plato established the Academy in the 4th Century, the scope of philosophy had broadened to include concerns of the state, society and the human condition generally. Plato only dabbled in cosmology (which was still the main focus of natural philosophy) and his importance is mainly measured by the influence he had on members of the Academy. Most significant was his emphasis on geometry. To Plato, geometry was the singular triumph of man's intellect whereby he was able to manipulate the perfection of ideal figures. Indeed, Plato viewed geometry as the fundamental principle of order in the universe, a principle to provide not a description of the heavens but rather a means for understanding, for making sense of the celestial scheme. The following two guidelines summarize the Academy's' geometrical approach to cosmology.

1. Uniform, circular motion of the heavenly bodies must be a basic ingredient of any theory. As Aristotle freely admits, the justification for such a sweeping rule stems from that period's developing dogmatic regard for divine perfection:

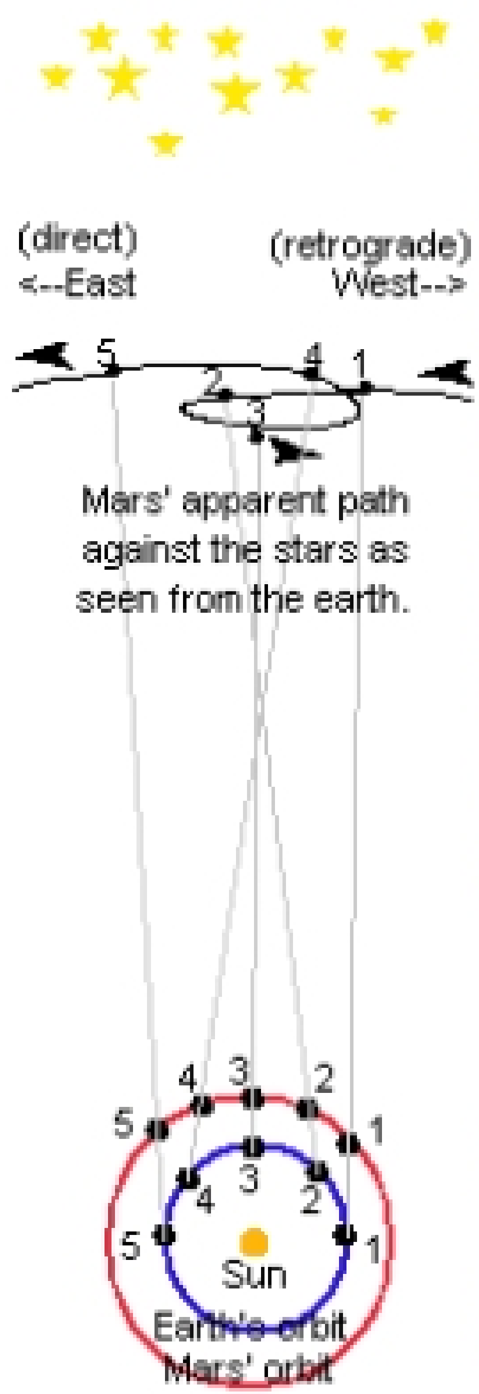
   From the Heavens other things derive their existence and life....so the popular idea about divine, celestial things is that, being primary and supreme, they are necessarily unchanging. This confirms what we have already said. For there is nothing else stronger that the Heavenly Sphere that could make it alter — since if there were, it would have to be more perfect. Whereas the Heavens have no defects, and are all they need to be. So the unceasing movement of the Heavens is perfectly understandable; everything ceases to move *when it comes to its natural destination, but for the body whose natural path is a circle, every destination is a fresh starting point.*

Although manifestly not objective, such a step was a crucial step since it allowed them to proceed with their cosmological modeling without a specific understanding of motion of bodies (or, in modern hindsight, without a theory of gravity).

2. Their circular paths must be concentric with the earth. Geocentricity was more of an attitude than a well-formulated and recognized assumption. The earth was *presumed* to be the center of the universe.

Plato's model consisted of 8 geocentric spheres rotating on a common axis all at different rates. The innermost carried the moon, the next carried the sun and the following 5 the known planets. The eighth sphere that held the stars completed the set. But what agency gives movement to this mechanism? At this point Plato lapses to mythology:

> *The axle turned on the knees of Necessity. Upon each of its circles was a Siren, who was carried round with its movement and gave out a single sound of constant pitch, so that all eight between them made up a single scale. Round about, at equal distances, the three daughters of Necessity-the Fates-were seated on thrones, robed in white with garlands on their heads. These were Lachesis, Clotho, and Atropos, and they chanted to the music of the Sirens: Lachesis of things past, Clotho of the present, and Atropos of things to come. From time to time Clotho laid her right hand on the outer rim of the axle and helped to turn it, while Atropos likewise turned the inner circles with her left hand and Lachesis took hold alternately of the inner and outer circles with either hand.*



But the use of allegorical figures was not considered to be the weakest element of the construction — there was a more troublesome problem. The model simply did not even qualitatively prescribe the observed motions of these bodies. The obvious difficulty was not with the sun, moon, nor stars; the crisis involved the planets, which were well known (even by the Greeks whose dedication to observing fell far short of the Mesopotamian's) to move in a highly non-uniform way, occasionally even stopping and reversing direction relative to the background of stars. This phenomenon, known to us as "retrograde motion," is easily understood in terms of our modern heliocentric picture of the solar system. As seen in the accompanying diagram, the line of sight from the earth to Mars shifts relative to the background of distant, stationary stars because the earth moves more quickly in its orbit, periodically overtaking Mars. This blatant discrepancy between theory and observation only fueled their resolve to reveal the true mechanism behind these seemingly irregular appearances. The challenge was to explain apparently non-uniform, non-circular motion in terms of some construction involving geocentric spheres in uniform motion.

Fig. 2a.
Mars's retrograde motion.

Eudoxus, another contemporary at the Academy, came up with an ingeniously contrived variation on this theme. Each planet was