Program 1: Skies of Sumer

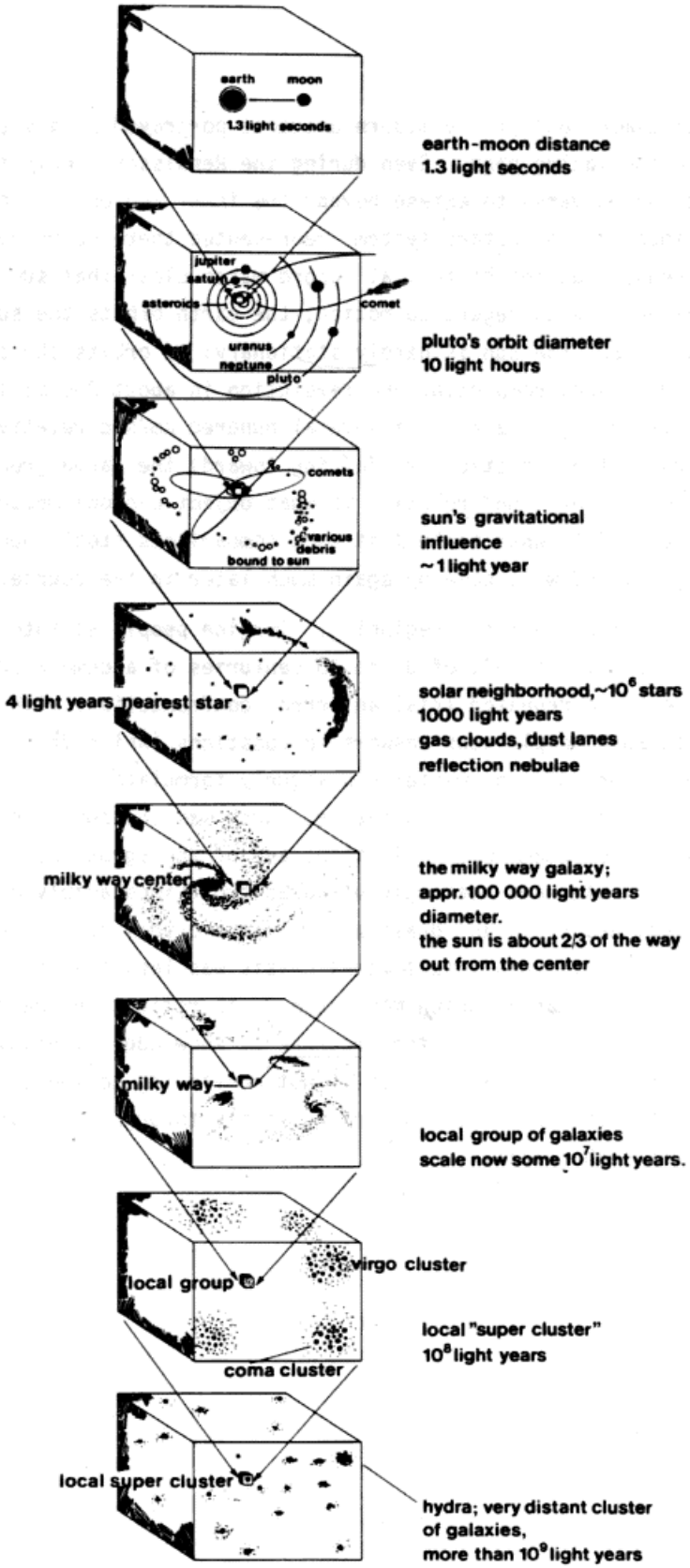
Our minds are continuously preoccupied by an endless series of everyday matters--from shoe tying to television watching. Distraction and diversion might even be considered to play a basic role in our culture; perhaps because beneath the flurry of practical and incidental considerations lurk questions for which we have no satisfactory answers-the kind of tantalizingly ominous, even vaguely dangerous questions that break to the surface when one is quietly gazing at a starry sky on a clear, dark, moonless night. They are not small questions: What does it mean to exist in a universe of incomprehensible size? Is the universe perhaps infinite in space and time? If the universe evolves, are we swept towards annihilation or eternity-what is the fate of the universe? Such concerns are in a sense primordial: they have, in some form, lain at the base of the brain for thousands of generations...waiting. Stripped of romance these questions come out like: What is the structure and evolution of the universe? How does it work? How does it fit together? What is the underlying order that explains the "world"? These are the questions of cosmology-the scheme of the universe as a whole.

The actual questions change from era to era, depending on what needs to be explained and the kinds of answers that are deemed satisfying. For the Mesopotamian ancients there were the clearly predictable, orderly, celestial phenomena that had observable correspondence to rhythms on Earth. For them the problem was: What do eclipses, phases of the Moon, positions of Sun, Moon and planets mean for the lives of men? For the early Greeks: What was the mathematical (and later mechanical?) principle that explained motion in the heavens, especially the planets among the stars? Following the sobering aberrations of medieval science, these same questions about motion and mechanism were attacked with new optimism by the figures of the Renaissance. Today we ask: Is the universe finite (yet unbounded) or infinite? Will it stop expanding or continue forever? For the future, we see questions on the horizon such as: How did the universe come into being? Why is there something instead of nothing? Why this kind of something? Considering man as an extension of the universe come to self-awareness, does man's role transcend that of an observer?

Clearly cosmology provides an enduring link between philosophy and science for it is always formulating questions that seem to lie at or beyond the boundary between the knowable and the unknowable, always forcing the intellect to take a new step. In the past, such questions have not always been posed in scientific terms, nor is it clear that we meet them with total objectivity today-an observation that brings us to the goals of this course. First of all, this is an introduction to modern cosmology that in its advanced form is a highly technical subject, and despite the suspicions introduced in the previous statements, it is not built on vague notions or daydreams, but specific concepts of physical science. One goal then is to introduce these concepts and when coupled with astronomical observations, to develop a substantial framework for understanding the nature of the universe. Clearly such a goal cannot be attained without some quantitative reasoning, charts and diagrams, and even a few equations. These are not introduced to diminish the magic of a starry night, but to enhance one's appreciation and understanding.

Perhaps I should add that this is not a course about stars, planets, and comets, etc. Although we will mention these, our concern is not so much with the contents of the universe as with the nature of the universe as a whole, its structure and evolution.

We not only aim for an understanding of the modern ideas about cosmology, but also how we have come to hold these ideas-this is the second goal. Arriving at our present viewpoint has been a long and difficult task. We will ask what have been the key questions, crucial observations and insights (or oversights), the blind spots, the dogma, the stumbling blocks. Then to see our present scientific problems in the context of the history of efforts and achievements must necessarily raise



questions such as: How much have we really progressed? How objective are we? How much are present concepts, however sophisticated, based ultimately on dogma? This then is the third and most difficult goal to attain, to strive for a cosmic perspective--to be as free as possible from the accumulated "scientific" preconceptions and dogma of past centuries.

Fig. 1a

The reverse is also true. To appreciate past efforts, one must be aware of the present viewpoint. Because cosmology in the past (most of natural science in fact) even up through the Renaissance was mainly a study concerned with the organization, size and motion of the solar system, we fortunately need only review the modern astronomical picture of the spatial organization and relative motions of the contents of the universe. In the accompanying diagram, Fig. 1a, we see the hierarchy of dimensions of the modern universe portrayed by a series of concentric boxes. Even during the Renaissance only the "crackpots" considered the universe to extend beyond the inner region of the second box. Perhaps the heliocentric planetary system represented there seems now to be a matter of common sense; but the historical record makes clear that such a concept is hardly self-evident. With regard to motion, the Earth orbits the Sun at a speed of 30km/sec. But the Sun is hardly stationary; it orbits the center of our galaxy at about 250 km/sec, completing one revolution in about 250 million years. The galaxy as well is moving at a rate of several hundred km/sec relative to its galactic neighbors in the direction of (falling toward) the large group of galaxies known as the Virgo cluster. And relative to

what object can one measure the motion of the Virgo cluster? At what scale must such comparisons stop? Such questions are largely cosmological and will come up again much later in the course.

Let's start near the beginning. Imagine people as intelligent and non-objective as us, yet bereft of 30 to 40 centuries of accumulated common sense, the kind that comes from repeated trial and error confrontations with the physical world. How would such people seek answer to questions (which from the beginning have seemed of prime importance, no matter how vaguely formulated) about the nature of the Earth and sky around them...the universe. Such was the condition of the Sumerians and subsequent Mesopotamian civilizations and of the Egyptians. The skies of Sumer were untouchable, and seemingly unknowable but inescapably observable and so had to be defined, described and dealt with on an everyday basis. As might be expected, their response to this intellectual crisis was less than objective but nonetheless satisfying in a manner that may cause us to reflect on the foundations of our own ideas. Their response was the pretense of knowledge, fantasy, the construction of mythical cosmologies-which even if not convincing to the originators, became (after several generations) quite comforting simply through familiarity and a willingness to presume authenticity.

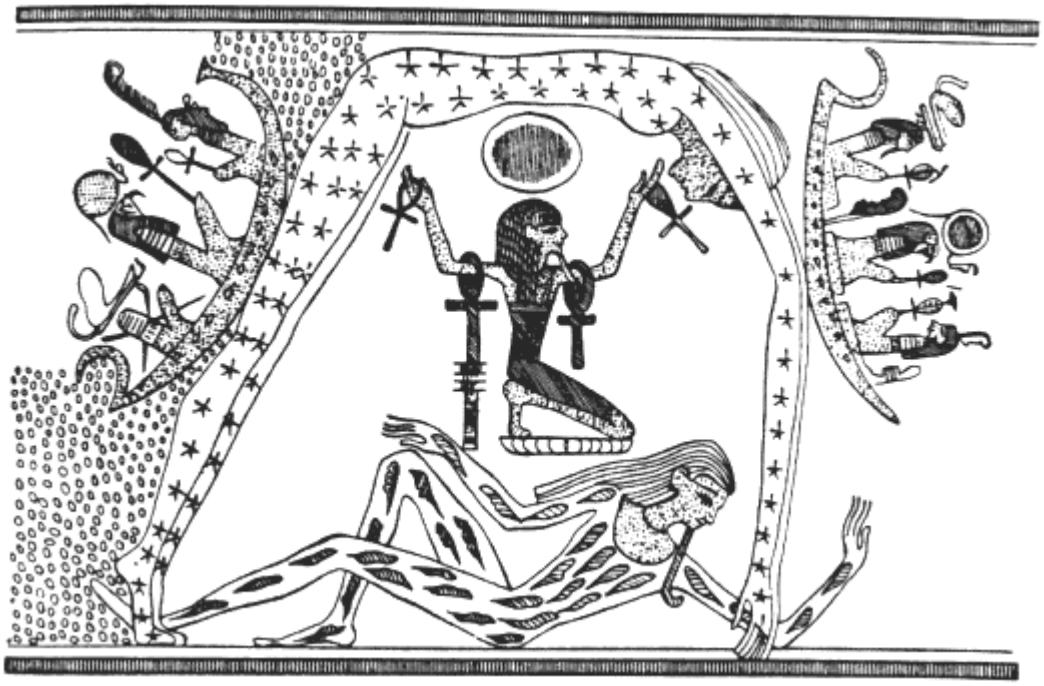


Fig. 1b.

A world-view of the ancient Egyptians, showing the starry heavens represented by the goddess Nut, with her body arched over the Earth (the reclining figure decorated with leaves). The ship of the sun is shown in both rising and setting positions.

Early world pictures had a strong common element-the sky was a window to the supernatural. There was an absolute distinction between heaven and Earth, between the realm of the gods and the world of man. But there was also an interesting but understandable confusion about the contents of heaven: stars, planets, comets, meteors, auroras, clouds, lightning, hail, rain and even locusts. All different, but how different-where does one draw the line between celestial and terrestrial? (Not that today we are trying to decide whether quasars are relatively nearby or lie at extreme, "cosmological" distances).

However, one thing was clear: Despite their apparently distinct natures there was a fundamental correspondence, a resonance between celestial and Earthly phenomena. The seasons passed with corresponding changes in the patterns of stars in the night sky; the flooding of the Nile could be predicted by watching the stars. The yearly cycle was subdivided by the lunar cycle, though in a complicated, ever-changing way since the year does not consist of an integer number of lunar months. And months could be further divided into days by the passage of the Sun. The rhythms of the sky provided a way to anticipate the time for planting and thus regulate agriculture and the associated commercial activity of early civilizations. But the crucial ability to anticipate events depends on the constructions of a calendar in advance of its use. The celestial rhythm must be understood to the extent that the changing position of the Sun and Moon against the background of stars could be predicted. I would like to emphasize the scheme used by the ancients to meet this problem both because next to the invention of the written word it was their most remarkable achievement, and because it constitutes one of the three profound themes in the history of the development of cosmology (or even natural science). This first theme is the direct mathematical description of observational data, the empirical method.

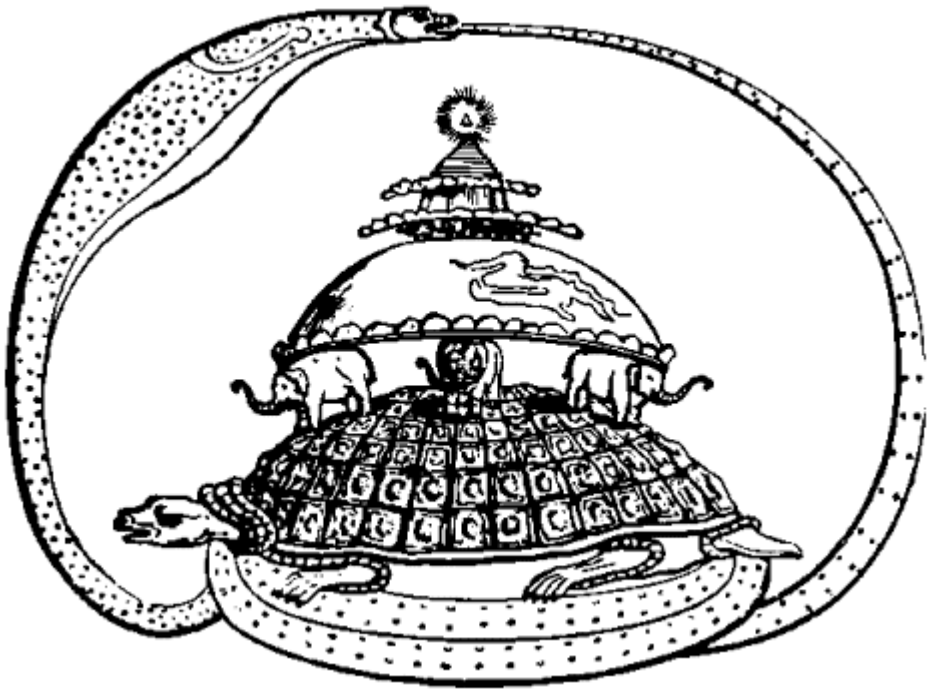


Fig. 1c.
A Hindu concept of the Universe. The Earth is carried by a tortoise resting on the great serpent, the symbol of eternity.

The problems in constructing a calendar that predicts the correlation between lunar phases and solar seasons are complex even to this day. We know from the written record that the Babylonians and Assyrians were aware of the subtleties of this task and employed remarkably sophisticated mathematical techniques the details of which are not of interest here, only the spirit of the method. For this reason I will oversimplify-suppose the maximum altitude of the Sun above the southern horizon is recorded each day for several years as shown in the accompanying Fig. 1d. For northern hemisphere dwellers the highest maximum altitude occurs in midsummer, the lowest in midwinter. Even is we have no ideas about reasons behind this periodic change in altitude or why it should be correlated with the season (the early Greeks thought the cold air of winter forced the Sun to move to the south), as long as we believe there **is** a definite correlation we

can fit a zigzag line to the data then mathematically extend that zigzag pattern **beyond** the data into the future and thereby set up a crude calendar to anticipate future events. The more cycles of data one has, the more precisely this periodicity is determined, and the farther into the future

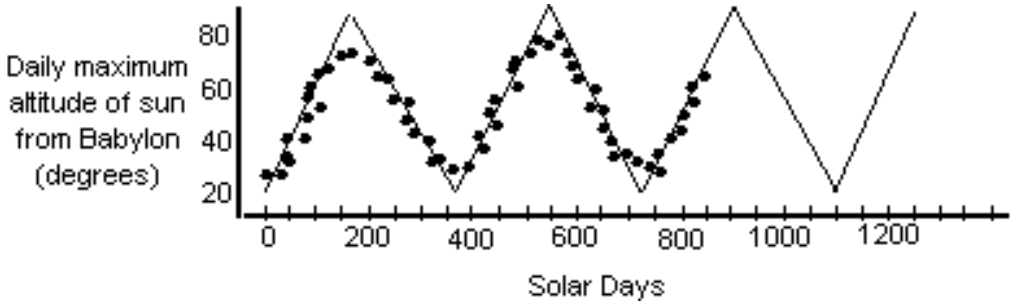


Fig. 1d

precise predictions can be made.[1] The empirical method, the system whereby one extracts a mathematical scheme directly from the data then extends it, or generalizes it, was a major scientific tool for Greek and Renaissance cosmology, and is used regularly today at the frontier of all scientific fields. However, there is an important distinction in the manner in which everyone from the Greeks onward has employed it. The Mesopotamians not only didn't have any ideas about why their methods worked, they didn't even consider such ideas to be possible. The rational spirit of the pre-Hellenistic Greeks allowed them to try to understand celestial observations in terms of mathematical or even mechanical principles with the aid of empirical analysis. We use it in the same spirit today with an occasional exception: Tide tables are constructed empirically. Even though we understand the basic principles of hydrodynamics and to a large extend the gravitational influences of the Sun and Moon on large bodies of water, it is such a complex problem to calculate accurately the flow which depends crucially on the off-shore underwater topography of the coastline, that the simple expedient is to measure the times and amplitudes of tides at a particular location, choose a mathematical representation which describes those measurements then extend that periodic mathematical model to construct a table for future occurrences. In any case the empirical method is an important element in the history of cosmological thought and a concept to which we will return again and again.

The second aspect of ancient cosmology, which stands as a major theme in the development of cosmological ideas, is related directly to the reason why the ancients were not interested in making theories about the cause of patterns and cycles in the heavens. In addition to the obvious correspondences between the motion of the stars, Moon and Sun and events on Earth, early civilizations discovered objects in the night sky, which seem to have their own vitality. They moved at various uneven rates against the background of stars, thereby forming a rich sequence of every-changing patterns. These were the wanderers, the planets, and for early-civilized man they were the manifestations of gods if not gods themselves. And the patterns were astrological signs to man from those deities. Therefore the skies were divine, removed from the scope of rational inquiry. For them as for many who came after, astrology was not a quaint delusion but a genuine challenge to read the fate of mankind as signaled from the heights. From Nineveh and Babylon, from all the center of Mesopotamian culture cam a continuous stream of communiqués from the astrologer-priests to the Assyrian kings. Many were preserved in cuneiform on clay tablets:

[1] Obviously this is a trivial example. The problem closer to that of the ancients would be to plot the lunar cycle, e.g., the phase of the Moon from new to full, along the vertical axis against solar days along the horizontal axis. Or, instead of the phase of the Moon, to mark the occurrence of an eclipse. Again, with an appropriate (rather complex) mathematical model, the Mesopotamians were able to predict eclipses rather precisely. In fact, they had so many years of observations to work from that the precision of their predictions was not exceeded by post-Renaissance science until the 19th century.

> When the star of Marduk (Jupiter) appears at the beginning of the year, in that year corn will be prosperous....
>
> When Venus (the star of Ishtar) fixes its position, the day of the king will be long; there will be justice in the land....

In the next lecture we find rationality gaining an upper hand with the pre-Socratic Greek faith in something beyond myth to explain the nature of the world and the starry sky above. This faith in rationality is the third major theme in the history of cosmological thought. The first theme, empirical analysis, was an unconscious step toward rationality-the very success of astronomical prediction by the ancients unintentionally diminished the sanctity of the heavens and provided a natural transition to alter Greek modes of thought. But the second astrological theme seems at first thought to constitute a countercurrent to the advancement to science. Yet in a curious way, with the possible exception of two or three brief centuries of atypical rationality culminating with Aristotle and perhaps the most recent two or three centuries, it has been mysticism, not a desire for what we would call scientific truths, that has provided the true driving force behind our attempts to understand the Universe over the past 25 centuries.