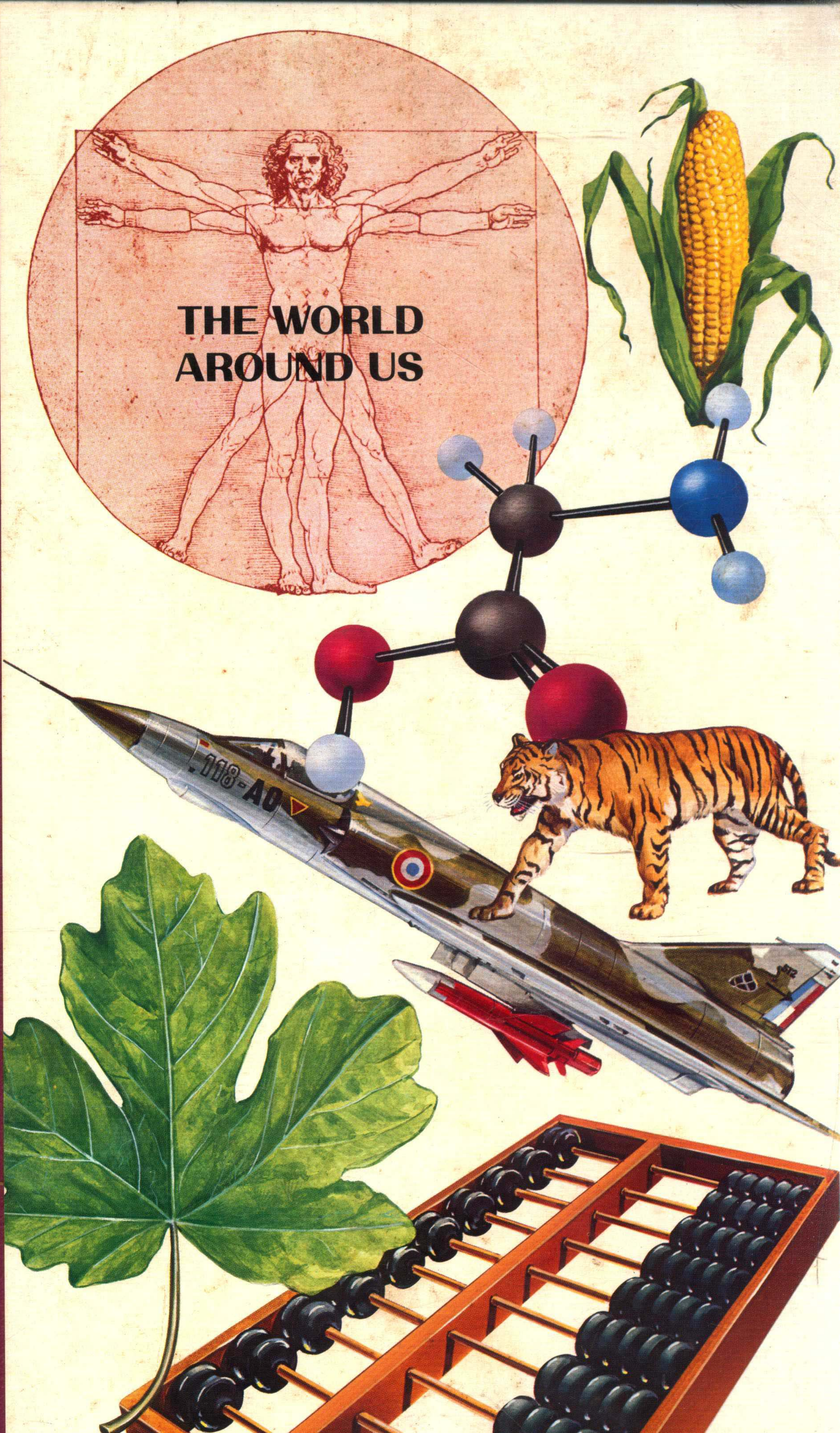
SCIENCE AND TECHNOLOGY ILLUSTRATED

THE WORLD AROUND US



Science and Technology Illustrated

The World Around Us

Library of Congress Catalog Card Number: 84-80129

International Standard Book Number: 0-852229-425-5

English language edition by license of Gruppo Editoriale Fabbri

Title page photograph courtesy of Hale Observatories;
California Institute of Technology and
Carnegie Institution of Washington

Printed in U.S.A.

Science Technology

The World Around Us

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Encyclopaedia Britannica, Inc.
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Volume 3

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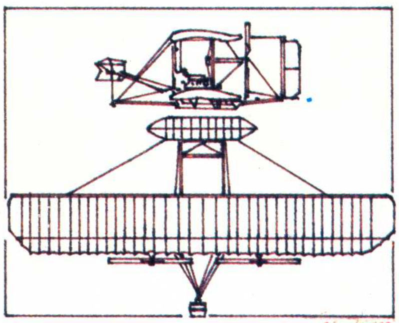

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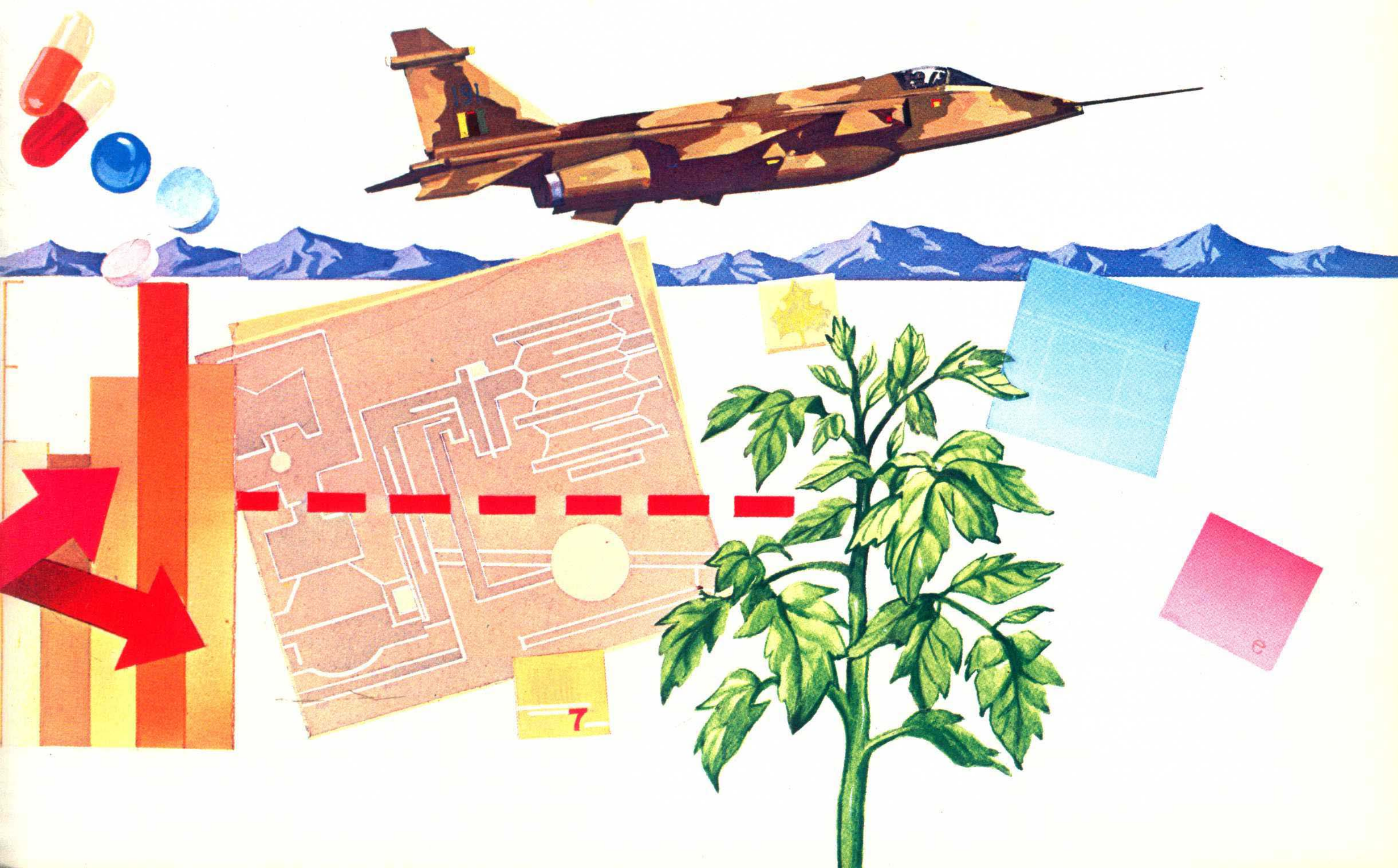
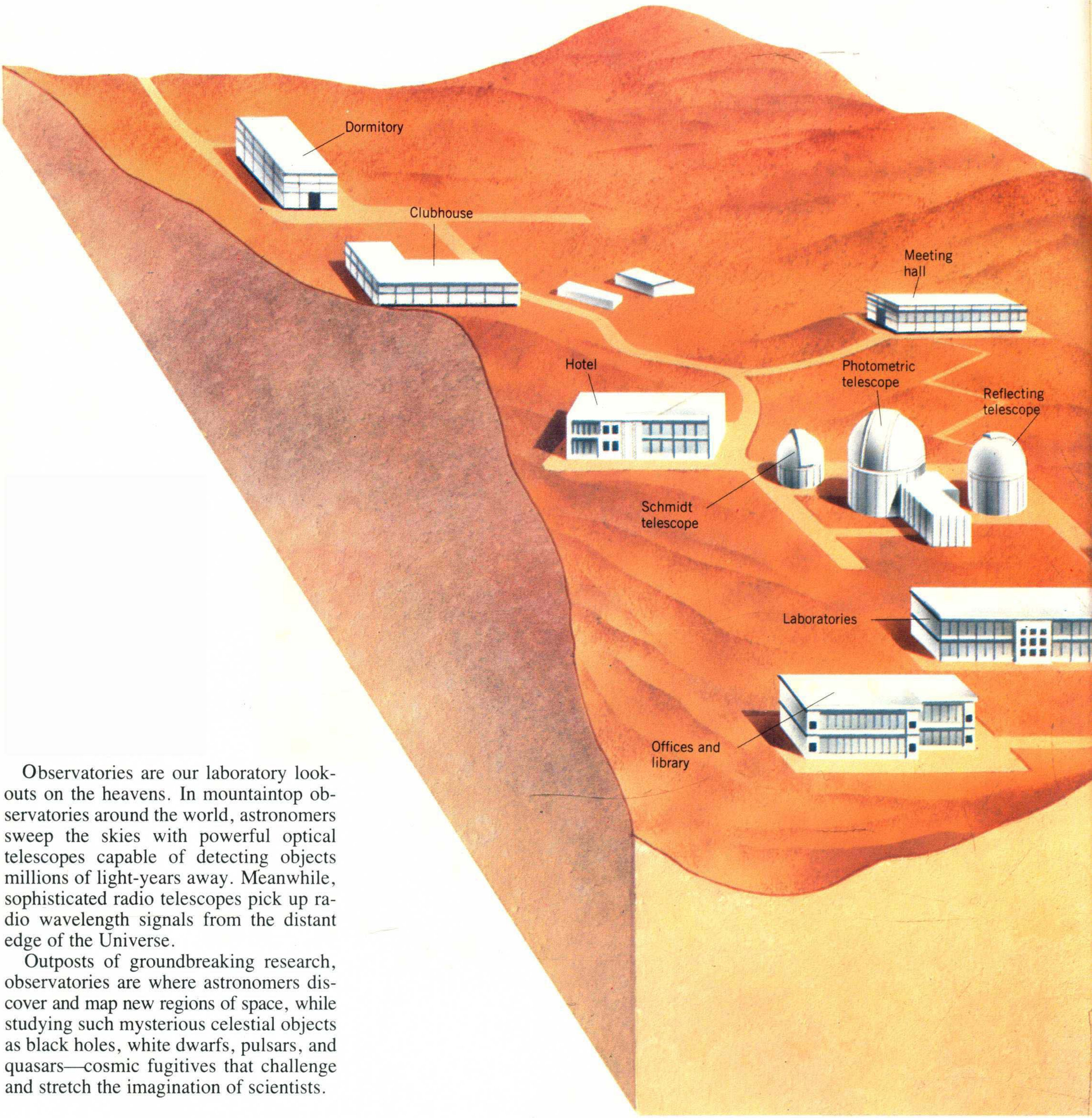


Astronomical Observatory



Observatories are our laboratory lookouts on the heavens. In mountaintop observatories around the world, astronomers sweep the skies with powerful optical telescopes capable of detecting objects millions of light-years away. Meanwhile, sophisticated radio telescopes pick up radio wavelength signals from the distant edge of the Universe.

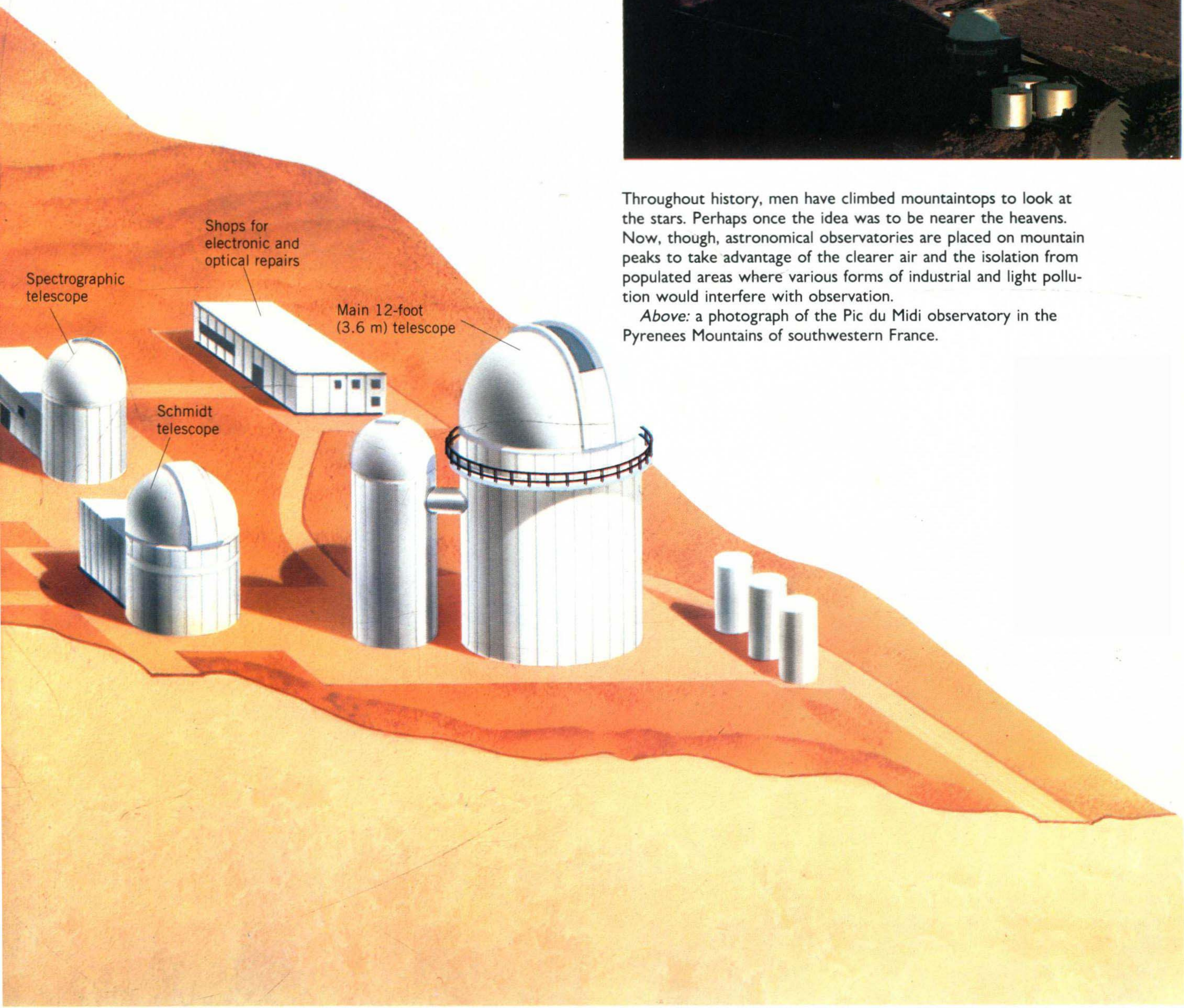
Outposts of groundbreaking research, observatories are where astronomers discover and map new regions of space, while studying such mysterious celestial objects as black holes, white dwarfs, pulsars, and quasars—cosmic fugitives that challenge and stretch the imagination of scientists.

Ancient Astronomers

Observatories go back in history a long way—to more than 5,000 years ago, when man began to study the Sun, the Moon, and the planets and recognize their influence in daily life. The priest-astronomers in ancient Babylon watched the heavens from the summit of their temples, fixing the start of each month by the appearance of the new Moon. The Egyptians designed solar temples, such as the temple at Amen-Ra, so that a narrow beam of sunlight falling upon the wall of a darkened sanctuary would serve as an indicator of the precise time of the summer solstice. The early Incas and Mayans studied the stars from their pyramid observatories, incorporating their understanding of the heavens into agricultural and religious ritual. Even Stonehenge is now recognized as a kind of rough-hewn observatory, in the sense that the ancient Britons who built Stonehenge measured stars by the vertical pillars and kept track of the movements of the Sun by following its shadows on the ground.

It was the invention of the telescope in 1609, however, that enabled man to extend his vision into the heavens, ushering in the age of modern astronomy. By enabling man to see clearly his celestial neighbors, the telescope helped bring to an end the belief that the Earth is the center of the Universe, around which the other planets revolve.

A large observatory requires more than just a few telescopes to function. Room must be found to house resident staff and visiting astronomers, and then these people must be fed. Complex observatory equipment must be built and maintained in specialized workshops. Photo laboratories, offices, libraries, and computer centers are all necessary to the activities of a major observatory. What is more, the entire observatory complex must be as self-sufficient as possible, since it may be located on a mountaintop far from civilization.



Throughout history, men have climbed mountaintops to look at the stars. Perhaps once the idea was to be nearer the heavens. Now, though, astronomical observatories are placed on mountain peaks to take advantage of the clearer air and the isolation from populated areas where various forms of industrial and light pollution would interfere with observation.

Above: a photograph of the Pic du Midi observatory in the Pyrenees Mountains of southwestern France.

But it was more down-to-earth interests that led directly to the establishment of observatories. Accurate time and positions of stars were needed for ship navigation, and early observatories were built in the late 17th century and into the 18th century to give mariners those coordinates. Only later, with the development of more sophisticated telescopes and a growing interest in the Universe, did the observatory come into its own. By the beginning of the 20th century, it had evolved into its present physical form: a domelike structure with a shutter bisecting the dome that could be thrown back to expose the telescope.

How an Observatory Works

Today, there are well over 100 major astronomical observatories in more than 30 countries around the world. Observatories with optical telescopes are located on high mountaintops, where telescopes have a generally clearer view into the skies. Even then, viewing time is limited to particularly clear nights, when atmospheric distortion is at a minimum. These mountaintop lookouts are also far away from population centers, sources of both air and light pollution that distort viewing; they are also in regions with stable climates. This combination has helped make the American Southwest—Kitt Peak

Observatory in Arizona is the centerpiece—along with Hawaii and the coast of Chile, become regions laced with observatories.

The postwar period has also seen the growth of the radio telescope. In the 1930s, it was discovered that radio waves emitted from distant points in the Galaxy could be picked up on Earth. Radio waves are part of the same electromagnetic spectrum that includes light. They form a faint but steady cosmic static emanating from clusters of gases, dust clouds, distant stars, and other celestial objects. Using radio telescopes, astronomers are able to pick up these waves from heavenly objects that eluded optical telescopes. Whole new vistas of our Galaxy suddenly opened up.

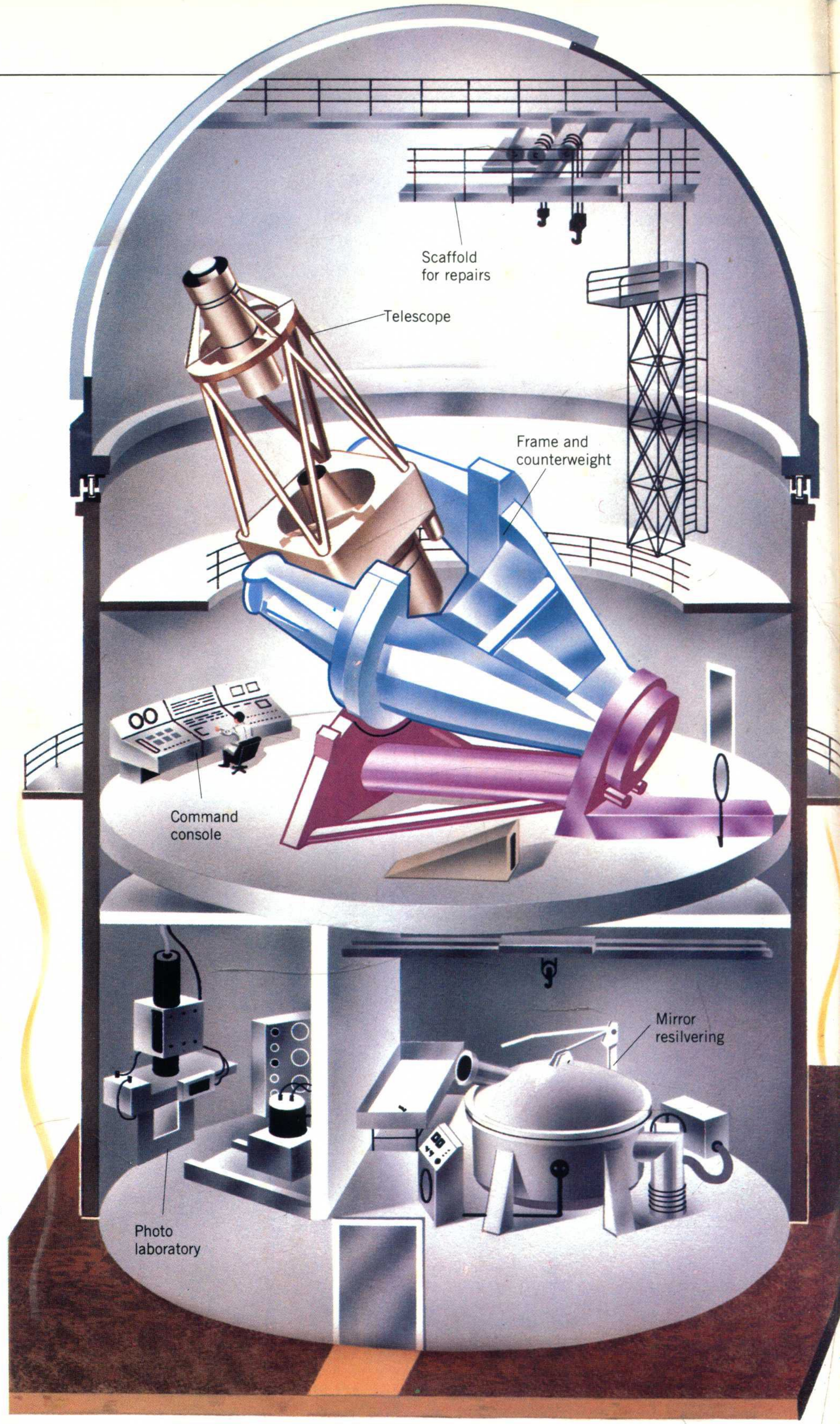
The dish of the radio telescope is a large, shallow, parabolic mirror that gathers radio waves from space and concentrates them on a small antenna at the point of focus. A receiver amplifies the sound of the radio waves, which are then sorted out and analyzed by a computer. Often, radio telescopes work in tandem with optical telescopes; they locate a radio source in the sky, and then astronomers train their most powerful optical telescopes on that region and focus on the distant target.

Space-age science has given astronomers many more tools for studying the skies besides the telescope. This hardware includes radar transmitters and receivers, telescopic cameras, seismographs, spectrum analyzers, a variety of cosmic-ray detectors, and high-speed computers. In turn, observatories may be specialized in function with equipment reflecting that specialty. For instance, there are observatories that study the Sun exclusively, relying greatly on an instrument, called a spectroheliograph, that breaks sunlight into a spectrum, which is then analyzed for its chemical constituents.

With this and other spectrum-analysis tools and conventional telescopes, astronomers at these solar observatories measure the composition and temperature of the Sun, monitor changes on its surface, and provide detailed photographic records of sunspot activity.

The Eye of the Telescope

The optical telescope, however, remains the traditional backbone of the observatory. It comes in two basic types—reflectors or refractors. A refractor telescope gathers light from celestial objects through an "objective" lens at the top of its long tube; the rays are then transmitted to an eyepiece, where they are focused by a series of magnifying lenses. The refractor telescope is often used for study of the Solar System; although it does not have

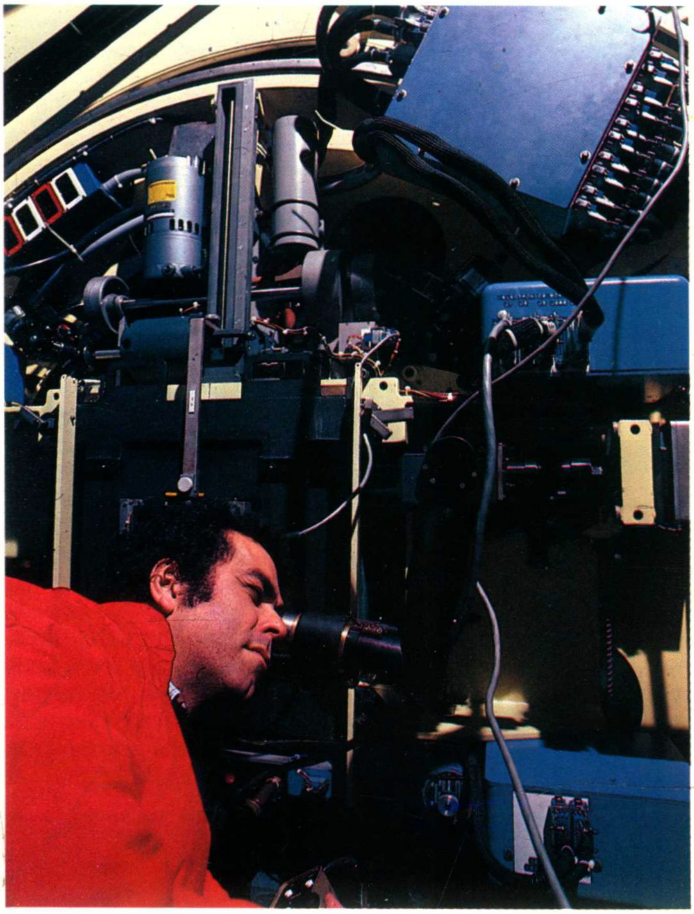


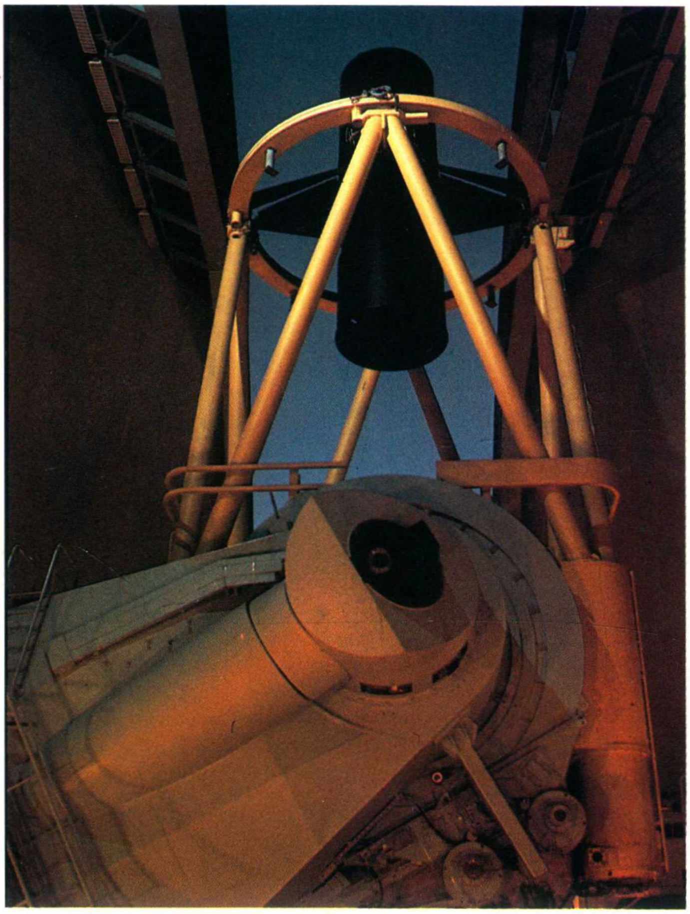
Above: a cutaway of the dome housing a reflecting telescope. A computerized control system automatically moves the telescope to compensate for the relative motion of the spinning Earth with respect to the stars and other objects under observation.

Services essential to the use of the telescope, such as the photo laboratory, which is used to develop photographs taken through the instrument, may be housed within the dome itself.

The large mirrors of reflecting telescopes are affected by air pollution and oxidation and require occasional resilvering. Since the mirrors are delicate and difficult to move, equipment for performing the task is located as near as possible to the telescope.

At the top of the facing page are two photos showing the reflecting telescope at the observatory at Mauna, Hawaii.





the depth of focus of a reflecting telescope, it can bring our nearby celestial neighbors into sharper focus.

A reflecting telescope uses a curved mirror, instead of lenses, to focus this light. Reflectors bounce light from a parabolic mirror at the bottom of a tube to a small mirror near the top, which carries it to an eyepiece outside. In some telescopes, the observer sits inside a cage mounted within the tube of the telescope itself. These reflecting telescopes have greater light-gathering capabilities and provide us with views deep into space. Such cosmic phantoms as black holes, quasars, white dwarfs, and pulsars have been detected and observed by reflecting telescopes. Until recently, the biggest and most famous of the reflector telescopes was the 200-inch (508-cm) instrument at Mount Palomar in California. The seeing power of this giant mirror is 1,000,000 times that of the unaided eye. The Palomar giant is used mainly for photographing galaxies roughly 500 million to 1,000 million light-years away. The title of largest optical telescope, however, now belongs to a 236-inch (600-cm) reflector that is in a Soviet observatory in the Black Sea region.

These big optical telescopes rotate on precision mountings so that they can follow their heavenly targets accurately despite the daily rotation of the Earth.

Photographic astronomy helps bring distant stars and other faraway objects in space into clearer focus. Asronomers use cameras to make pictures of dim patches in the sky, exposing the film for a long period, so that the light is collected over a stretch of time—sometimes night after night. The telescope's light-gathering abilities are thus immeasurably increased, and a star too faint for human eyes can be made visible. In turn, these photographs are studied and analyzed by astronomers with high-speed computers to help extend our maps of the heavens.

The light of a distant object in space can also be studied through spectroscopic analysis. The spectroscope and other spectrum analyzers act like prisms, breaking starlight into its component wavelengths, a spectrum of the colors that reflect the chemical composition of a heavenly body. In this way, the spectroscope can analyze the chemical makeup and density of a distant light source. Through sophisticated spectroscopic analysis, astronomers have been able to measure the temperature of a star's surface, its magnetic field, and even its speed as it moves toward or away from the Solar System.

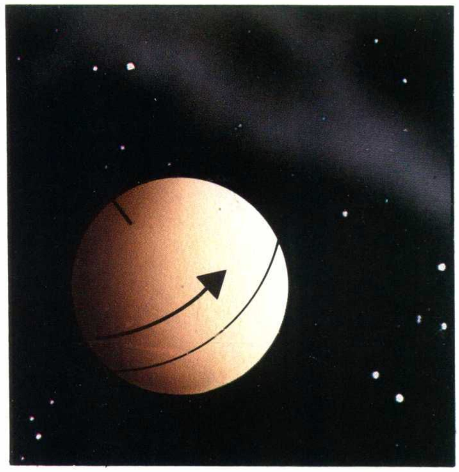
Modern Observatories

Self-enclosed, miniature scientific communities, the major observatories are a hive of offices, dormitories, and labs. In the offices, scientists measure, study, and compare photographs and spectrograms of heavenly bodies. Meanwhile, in nearby laboratories, they put their observations into practice by simulating with chemical experiments the processes that they have observed in the galaxies.

High-speed computers are an integral part of the modern observatory. They are invaluable in helping chart the positions of meteors, planets, and comets through analysis of their orbits. They convert information gleaned from spectrum analysis into a systematic breakdown of the chemical constituents of those distant objects. And they can help in the painstaking work of taking inventory of the stars that make up our Galaxy.

We have begun moving observatories into the frontier of space. The first space observatory was the Orbiting Solar Observatory (OSO) launched by NASA in 1962, which carried a telescope high above the Earth to give us an even clearer view of our Solar System and beyond. A permanent orbiting astronomical observatory has been designed to help see farther into the uncharted reaches of space.

Astronomical Time



The measurement of the apparent movement of stars and other bodies is the basis of all timekeeping. The cycle of the rising and setting Sun once measured a day. The modern atomic clocks that now measure time with greater precision are complex systems requiring ongoing maintenance. The skies, instead, are a watch that will not run down between the fall of one civilization and the rise of another.

Since astronomical time is of use not only to astronomers but also in day-to-day applications like marine navigation, various instruments have been developed to measure it. Below, a specialized telescope that measures the rotation of the Earth—the spinning globe in the image above—with respect to a chosen astronomical body.

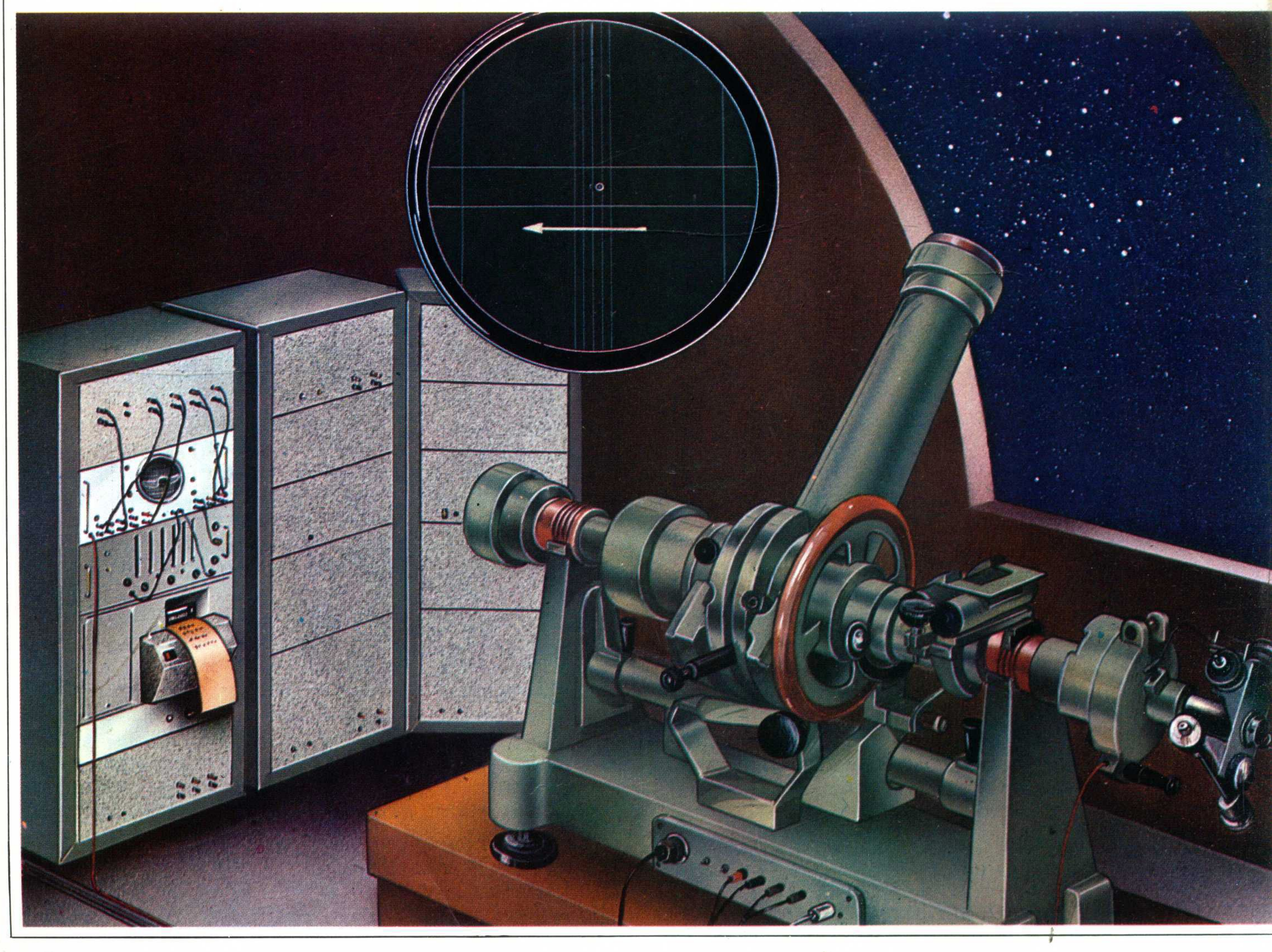
There is a clock so large that its movements can be observed every day, by every man, woman, and child on Earth. Though it has no hands or digits, its timekeeping mechanism is extremely precise, and it has remained accurate, year after year, millennium after millennium. The two components of this clock are the Earth and the Sun.

Ephemeris Time

Man has been measuring time since the dawn of history, often basing his measurement on the movements of the Sun and the Moon. In the early part of the 20th century, astronomers realized that the slight irregularities in the apparent motions of the Sun and the Moon were in fact caused by the irregular nature of the Earth's rotation on its axis. Time measurement based on these movements was not exact enough for the purposes of astronomers, however, who need to measure the precise positions of objects in the sky, then to record them in terms of space as well as time. For this reason, astronomers reasoned that a time system independent of the Earth's rotation must be devised. A "dynamical" system was needed.

The concept of such a time system is based on the laws of gravitation and motion published by Sir Isaac Newton in 1687. From Newton's laws, dynamical time could be derived from the motions of any bodies subject only to gravitation. This method of time measurement is arrived at, in practice, from the observation of the orbital motions of planets and satellites and is called ephemeris time (ET). An ephemeris is a table that lists the positions of planets and satellites and the time these positions are reached.

As the Earth moves about the Sun, the apparent position of the Sun shifts slowly against the background of the stars, until, after one complete revolution, the Sun has "returned" to its original position. One such revolution is termed a tropical year. Simon Newcombe's *Tables of the Sun*



(1895) is the ephemeris of the Sun that has been used to define the basic measure of ET. (One second of ephemeris time has been defined as 1/31,556,925.97474 of the tropical year 1900, which was arbitrarily chosen as the standard tropical year.) Newcombe's tables give the Sun's coordinates in relation to the stars as they should be in successive points in time during the tropical year.

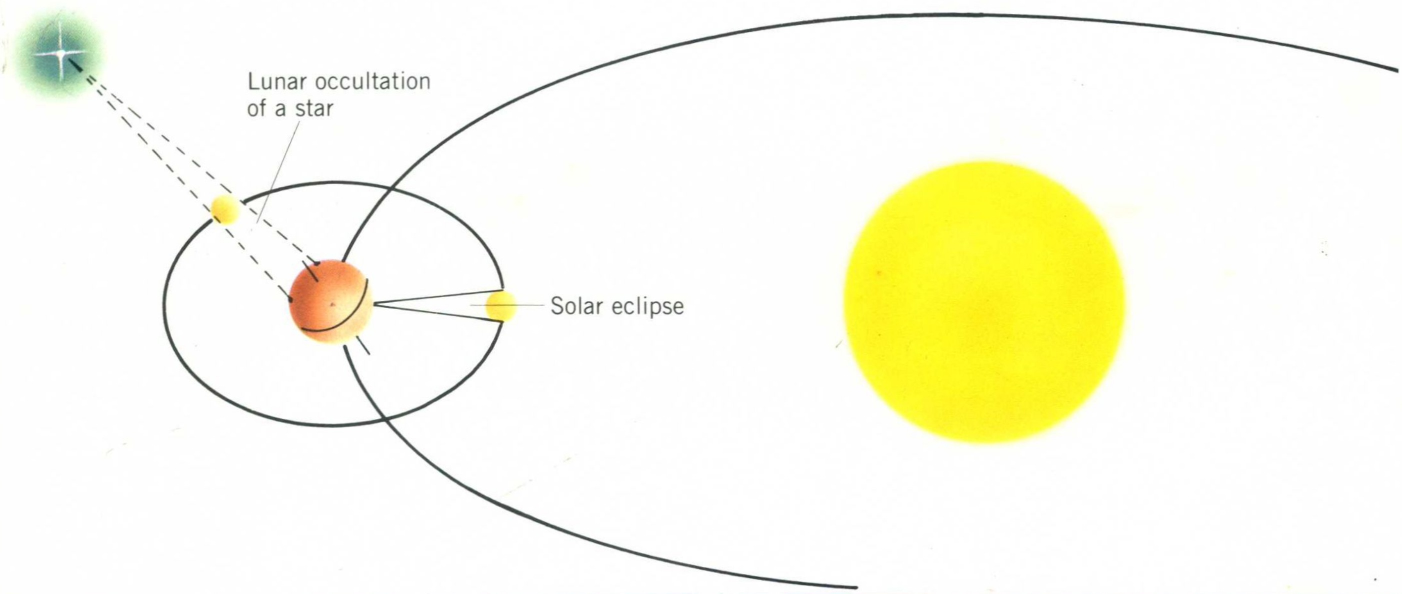
The Lunar Ephemeris

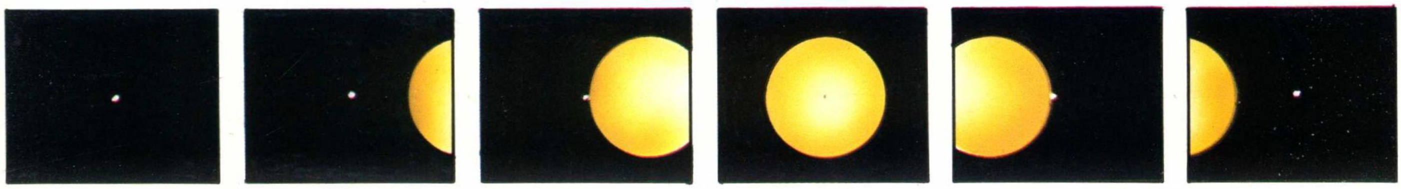
Ephemeris time can also be obtained from observations of the Moon's revolution about the Earth. In practice, the lunar ephemeris is used more frequently than the solar ephemeris to establish a time system, as the Moon's orbital period (the time it takes to make one complete trip around the Earth) is much briefer than the Earth's orbital period (27.33 days as compared to 365.24 days). Also, because the Moon is far less luminous than the Sun, its position relative to the stars can be judged more readily. The lunar ephemeris, however, is not so precise as the solar ephemeris, for the Moon's elliptical orbit and gravitational pull affect its revolution about the Earth. Because of this, the lunar ephemeris is not completely accurate, and every so often it must be brought into accord with the solar ephemeris, which is far more exact. Ephemeris time, both solar and lunar, is used almost exclusively by astronomers in establishing coordinates; it is not used for common "civilian" purposes.

Rotational Time

Another regularly occurring celestial activity upon which a time system can be based is the rotation of the Earth on its axis. There are two systems of time measurement derived from the Earth's rotation. The first is sidereal time, which measures the Earth's rotation relative to the fixed stars, with one day equal to one full rotation. The second is solar time, which measures the rotation relative to the Sun, with one full day being the period from one high noon to the next. Because of the Earth's movement around the Sun, though, the Sun appears to move eastward relative to the stars, which means that it takes the Earth longer to complete one full rotation in relation to the Sun than it does in relation to the stars. The solar day is, therefore, roughly 4 minutes longer than the sidereal day. (This fact was critical in the discovery of radio emission from the stars by radio astronomers.)

To complicate matters still further, all solar days are not equal. When the Earth is at perihelion (the position closest to the Sun during its orbit), the Sun moves more rapidly against the background of stars, creating a longer solar day than when the Earth is at aphelion (its position farthest from the Sun). For everyday purposes, the mean solar day (an average of the solar days throughout the year) is used. Mean solar time is what we set our clocks and watches by. Sidereal time, like ephemeris time, is used primarily by astronomers. *See also* RADIO ASTRONOMY.





Planetary motion gives another index of astronomical time. The Moon, for instance, periodically passes between the Earth and the Sun, causing a solar eclipse. The time this passage takes, the 'blackout,' is a measurement of time in terms of planetary motion.

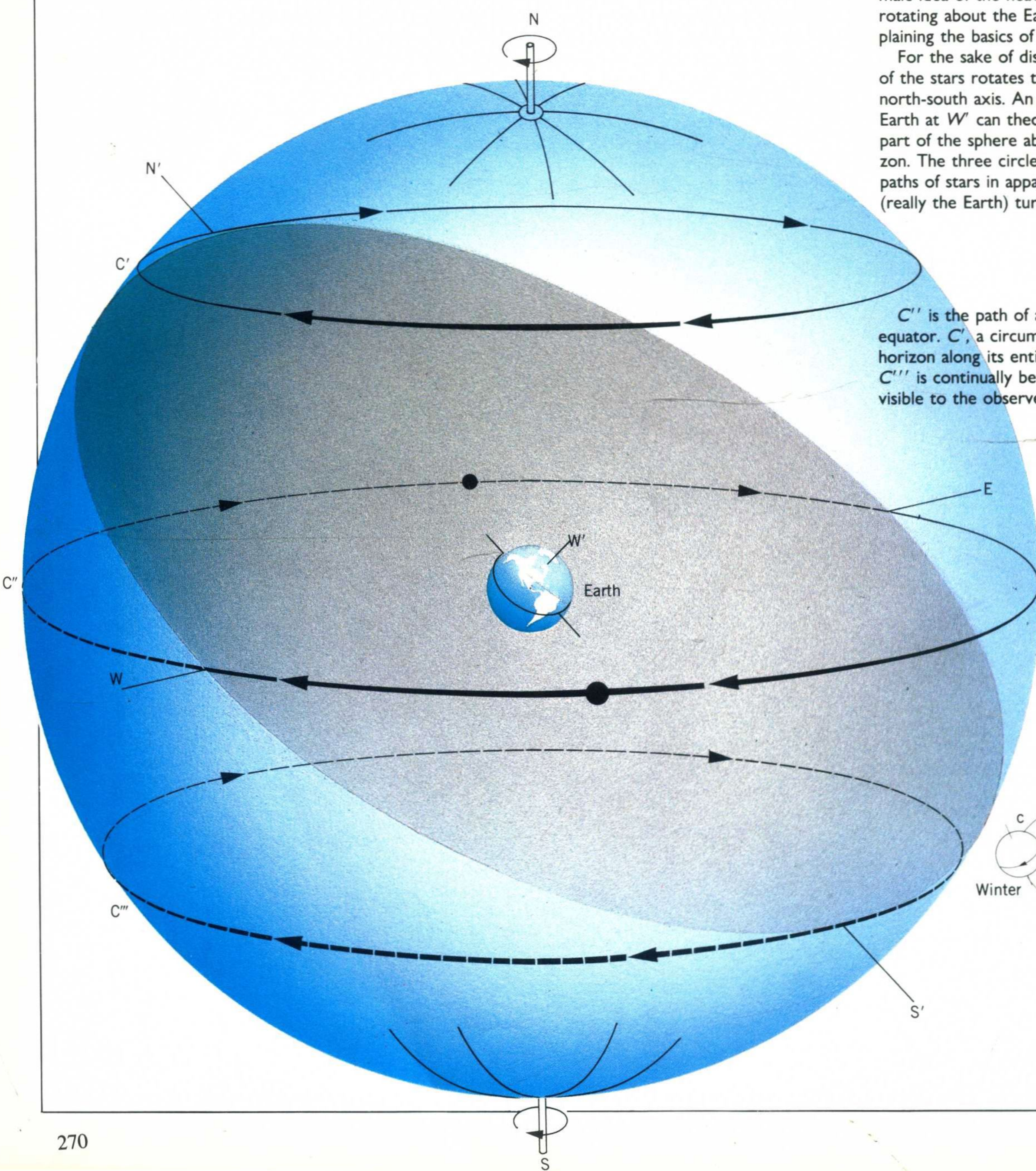
In practice, solar eclipses are relatively rare, and observation of them may require costly expeditions to the far corners of the Earth. It is far simpler to measure another kind of eclipse, called *occultation,* which is the passage of the Moon in front of a particular star. Astronomical events of this sort happen almost daily and are easily observed.

When primitive people first looked up into the sky, the Sun, Moon, and stars seemed to them magic forces—dazzling, unknowable, and even threatening. Today, in remote areas like the Andes Mountains of northern Chile, tribesmen still look at the night sky with the awe felt by their ancestors thousands of years ago.

But there are other stargazers in the Chilean mountains. They are an international group of dedicated astronomers who work in three observatories built where the atmosphere is cleanest and the night sky least affected by the lights of cities. These men and women use some of the most sophisticated scientific equipment in the world: great telescopes, which look millions of light-years into space (a light-year is the distance traveled in one year by light moving at about 186,000 miles [299,000 km] per second—a little less than 6 million miles, [about 9.5×10^{12} km]); radio telescopes, which penetrate even farther into space by picking up radio waves from the outer rim of the known Universe; and delicate spectroscopes, which analyze light that left distant galaxies hundreds or even thousands of millions of years ago.

The tribesmen looking up at the sky and the highly trained astronomers still have one point in common. They each examine the sparkling night sky with a deep sense of wonder at its vastness and beauty.

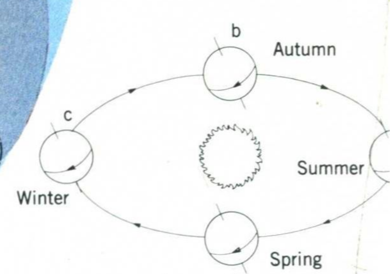
Some 25 centuries ago, when people had developed their first notions of mathematics, they began putting their observations of heavenly bodies to practical use in calendar-making and navigation (and to rather fanciful use in astrology in hopes of foretelling the future). The ancient Greeks looked at the Universe from a strictly common-sense point of view. To their eyes, the Sun obviously rose in the east in the morning and set in the west in the evening, and so they concluded that it revolved around the Earth, just like the Moon. As the seasons changed throughout the year, it seemed clear to them that the starry firmament, in which they identified five planets, also revolved around the Sun. However, Aristotle (384-322 B.C.), the philosopher whose authority was to remain unquestioned for another 1,500 years or so, did not agree. So for 15 centuries, kings, priests, and common people accepted his Earth-centered picture of the Universe, a picture formulated in great



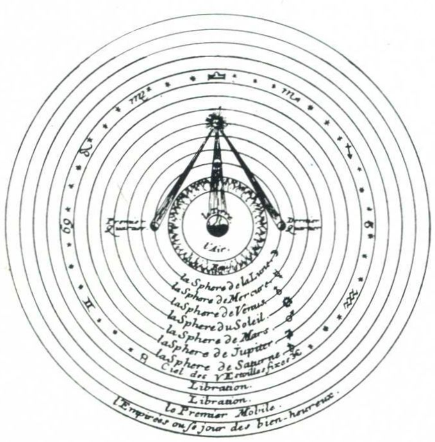
Though it no longer has practical value, the Ptolemaic idea of the heavens as being fixed in a sphere rotating about the Earth is a useful model for explaining the basics of astronomical motion.

For the sake of discussion, this 'celestial sphere' of the stars rotates toward the west about a north-south axis. An observer standing on the Earth at *W'* can theoretically observe the entire part of the sphere above the gray plane, the horizon. The three circles, *C'*, *C''* and *C'''*, show the paths of stars in apparent motion as the sphere (really the Earth) turns.

C'' is the path of a star located at the celestial equator. *C'*, a circumpolar star, stays above the horizon along its entire path and so never 'sinks.' *C'''* is continually below the horizon, thus is never visible to the observer at *W'*.

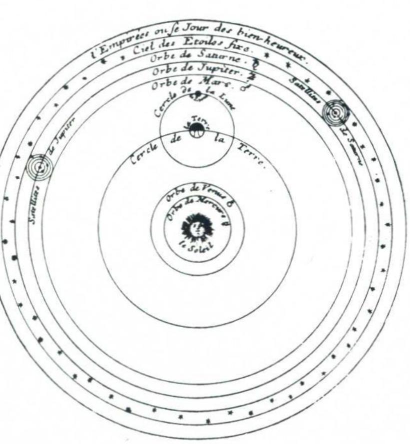


PTOLEMAIC SYSTEM
(GEOCENTRIC)



Ptolemaic system. The Earth was held to be the center of the Universe, and all bodies in motion around it were considered to be mounted in a system of concentric, transparent spheres. The outermost of these spheres, the one holding the 'fixed stars,' was opaque, unlike the others, and not at all transparent. It hid the celestial light coming from Heaven, just beyond.

COPERNICAN SYSTEM
(HELIOCENTRIC)



Copernican system. Copernicus dared to deny that the Earth was the center of the Universe, casting the Sun in that role instead. Like the Ptolemaic astronomers, he still considered planetary motion around the Sun as being circular.

Today, we know that the Sun is no more the center of the Universe than the Earth and that the planets move in elliptical and not circular orbits; it was Copernicus's feat of imagination that cleared the way for these discoveries.

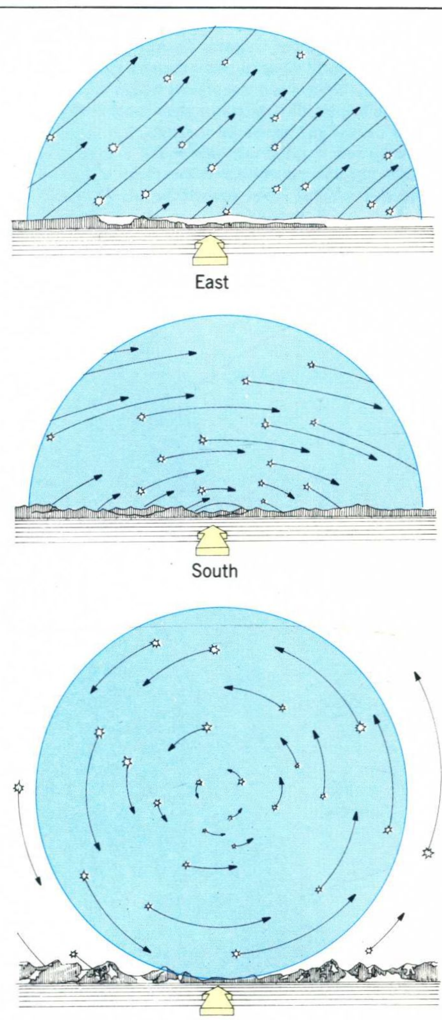
detail by Ptolemy, an Alexandrian Greek mathematician, astronomer, and geographer who lived two centuries after Aristotle.

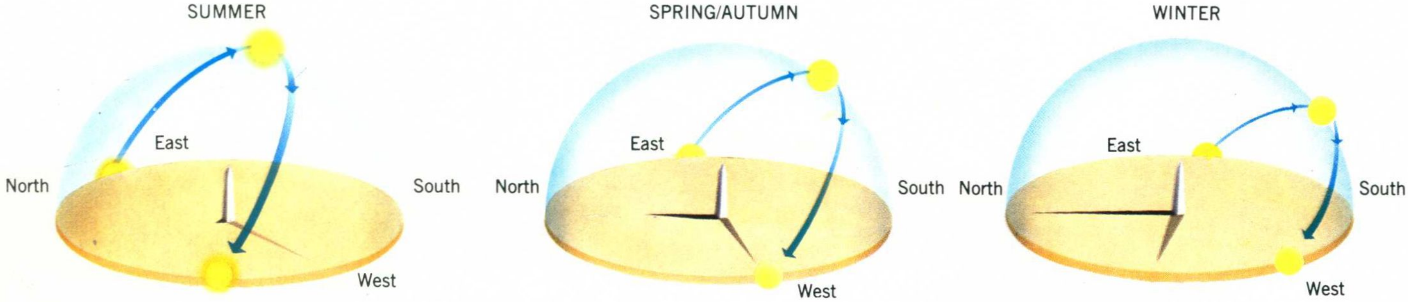
Ptolemy's Spheres and Epicycles

In the Ptolemaic system, the Earth lies motionless at the center of the Universe, with the Sun, Moon, and planets, set into crystal spheres, revolving around it at unchanging speeds and in circular orbits, all within an outer sphere called the *primum mobile* (first mover), which was supposed to contain the fixed stars. Whenever astronomers observed things that did not conform to their theory, Ptolemy and his followers invented a system of secondary orbits called epicycles, which were smaller circles sketched out by the planets as they revolved about centers that in turn followed a circular orbit around the Earth, like a bicycle wheel rolling inside a circular track. As more irregularities were observed and "corrected" by the addition of epicycles, the patched-up Ptolemaic system became more and more complicated and confused, until it included nearly 90 epicycles.

Copernicus, Kepler, Galileo

The person who finally challenged the Ptolemaic notion of our planet as the center of the Universe and thus laid the foundations of modern astronomy, was a Polish astronomer named Mikotaj Kopernik, better known by the Latin form of his name, Nicholas Copernicus. About 1530, he completed a book that was not published until just before he died in 1543. Entitled *De revolutionibus orbium coelestium* (On the Revolution of Heavenly Bodies), the book proved to be one of the great bombshells in the history of civilization. The heart of Copernicus' thinking was that the Sun is fixed at the center of the Solar System and that all the planets, including the Earth, revolve around it. Copernicus, however, still believed that the planets traveled in circular orbits, so he too was obliged to use Ptolemy's epicycles to explain facts that otherwise would remain challenging. From a purely astronomical point of view, Copernicus' picture was not, therefore, very much more efficient than Ptolemy's. Its astounding revolutionary importance lay in putting human beings in their place, so to





The motion of the Earth around the Sun explains the lengthening and shortening of the days over the course of the year and is responsible for the changing seasons.

Left: The Earth in orbit around the Sun. Note that the Earth is always at an angle with respect to its solar orbit. The result is that, in *a*, when the Northern Hemisphere is tipped toward the Sun, it enjoys more than 12 hours of sunlight daily. But as the Earth continues its orbit around the Sun, it reaches two points, *b* and *d*, equivalent to autumn and spring, where the number of hours of day and night are equal. Then, the hemisphere is relatively cooler. Finally, at point *c*, the hemisphere is inclined away from the Sun and receives the fewest hours of light, resulting in the cold typical of winter.

Seen from the Earth, the Sun appears to drop or rise in its path across the sky according to the seasons, as shown above.

This double-page illustration reflects the fact that modern astronomy studies the Universe according to two very different scales of distance. The planetary scale is limited to the Solar System and the objects within it, ranging from the Sun to the planets and their moons to phenomena like comets and meteorite showers.

The invention of the telescope in the 17th century brought the planetary system within range so that it could be studied in detail. Then, toward the end of the 19th century, the spectroscope was combined with the telescope, making it possible to study the chemical makeup of the stars. This step marks the birth of the modern discipline of astrophysics.

The two telescopes at the bottom of the page are typical of those used throughout the 19th century. Instruments such as these permitted the discovery of the planets and the other major bodies of the Solar System.