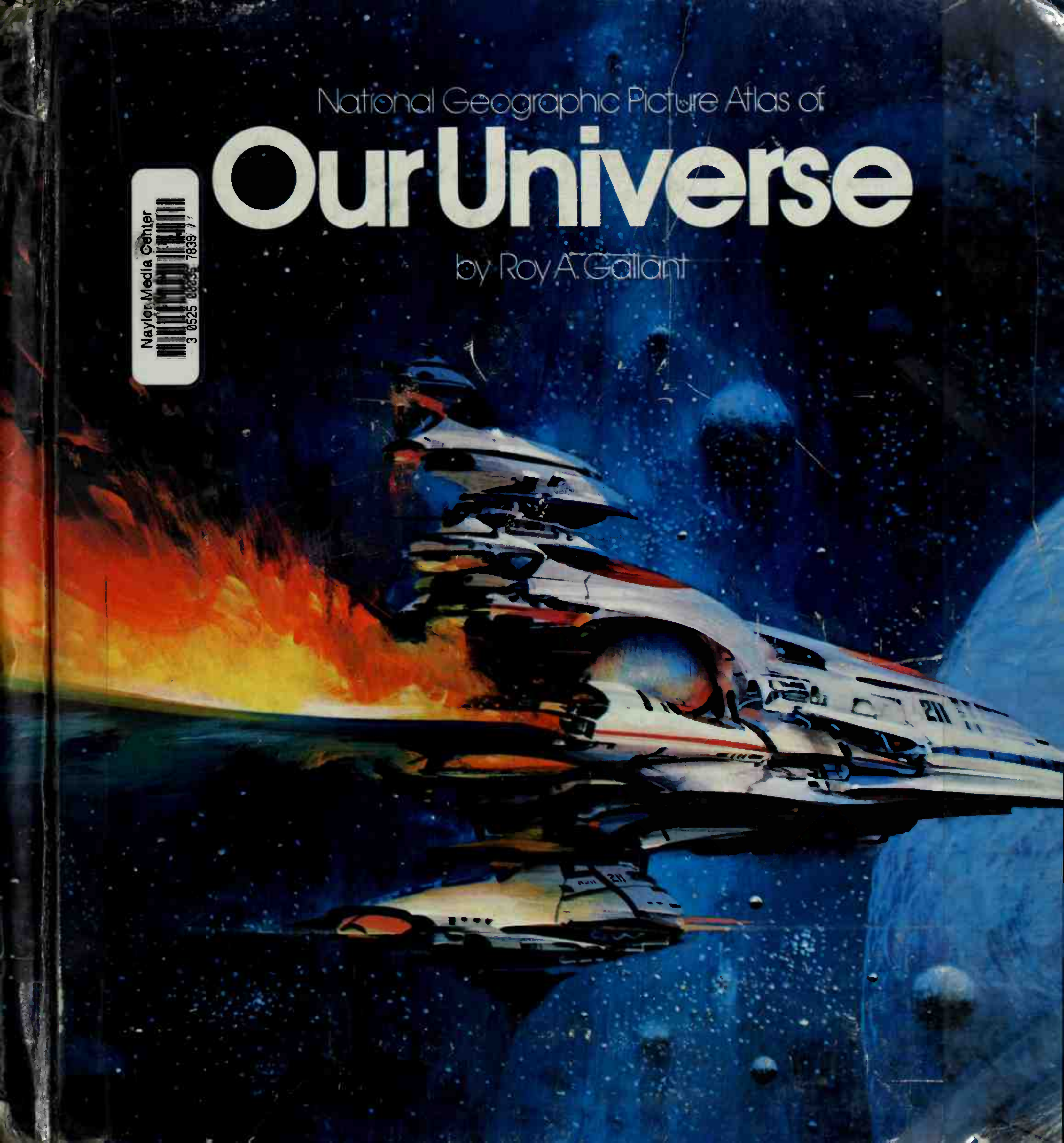
National Geographic Picture Atlas of

Our Universe

by Roy A. Gallant

Naylor Media Center
3 0525 00... 7839



Naylor Media Center
3 0525 00036 7839

523 3-019653 1/87
Ga Gallant, Roy 16.95
c.5
OUR UNIVERSE

DATE DUE

6-8	SEP 2 3		
	NOV 1 8 1992		
6-25	MAR 3 1 1992		
6-D	APR 1 4 1993		
T	OCT 3 1 1994		
SEP 2 1 1994			
OCT 2 2 1998			
SEP 0 9 1999			
SEP 2 4 1999			
OCT 0 1 1999			
[illegible]			

NAYLOR MIDDLE SCHOOL LIBRARY

niverse

National Geographic Picture Atlas of

Our Universe

4.5

TAYLOR MIDDLE SCHOOL LIBRARY


National Geograp
our Univ

National Geographic Picture Atlas of

Our Universe

by Roy A. Gallant

Published by
The National Geographic
Society

Melvin M. Payne
Chairman of the Board

Robert E. Doyle
President

Owen R. Anderson
Secretary

Melville Bell Grosvenor
Editor Emeritus

Gilbert M. Grosvenor
Editor

Prepared by
National Geographic Book Service

Charles O. Hyman
Director

Kenneth C. Danforth
Managing Editor

Anne Dirkes Kobor
Illustrations Editor

Staff for this book

Margaret Sedeen
Editor

David M. Seager
Art Director

Constance Brown Boltz
Associate Art Director

Linda B. Meyerriecks
Picture Editor

Elizabeth L. Newhouse
Research Editor

Ross S. Bennett
Seymour L. Fishbein
David F. Robinson
Jonathan B. Tourtellot
Editor-Writers

Melanie Ann Corner
Mary B. Dickinson
Shirley L. Scott
M. Washburn Swain
Research

Editorial Contributions by
Wendy W. Cortesi
Suzanne P. Kane
Lise Swinson
Anne Withers

Robert C. Firestone
Production Manager

Karen F. Edwards
Assistant Production Manager

Richard S. Wain
Production Assistant

Paulette L. Claus
Editorial Assistant

John T. Dunn
Engraving and Printing

John D. Garst, Jr.
Virginia L. Baza
Charles W. Berry
Gary M. Johnson
Mark Seidler
Alfred L. Zebarth
Geographic Art

George I. Burneston III
Index

Art Consultation and Contributions by
Ron Miller

Planet views and landscapes by
Ludek Pesek

Planet maps by
Jay L. Inge

Scientific Consultants

Mark R. Chartrand III
American Museum-Hayden Planetarium

J. David Bohlin
NASA

Geoffrey A. Briggs
NASA

Owen Gingerich
Harvard-Smithsonian Center for Astrophysics

Noel W. Hinners
National Air and Space Museum

Henning W. Leidecker
Dept. of Physics, The American University

Stephen P. Maran
Goddard Space Flight Center

Peter L. Munroe
Educational Consultant

Copyright © 1980 National Geographic Society, Washington, D. C. All rights reserved. Reproductions of the whole or any part of the contents without written permission is prohibited.

First edition 670,000 copies.
Library of Congress CIP data page 276.
338 paintings, drawings, photographs, and maps.

Contents

Foreword by Michael Collins 6

Sun Gods to Gamma Rays
Beginnings 9

Our Solar System Home
The Sun & Planets 37

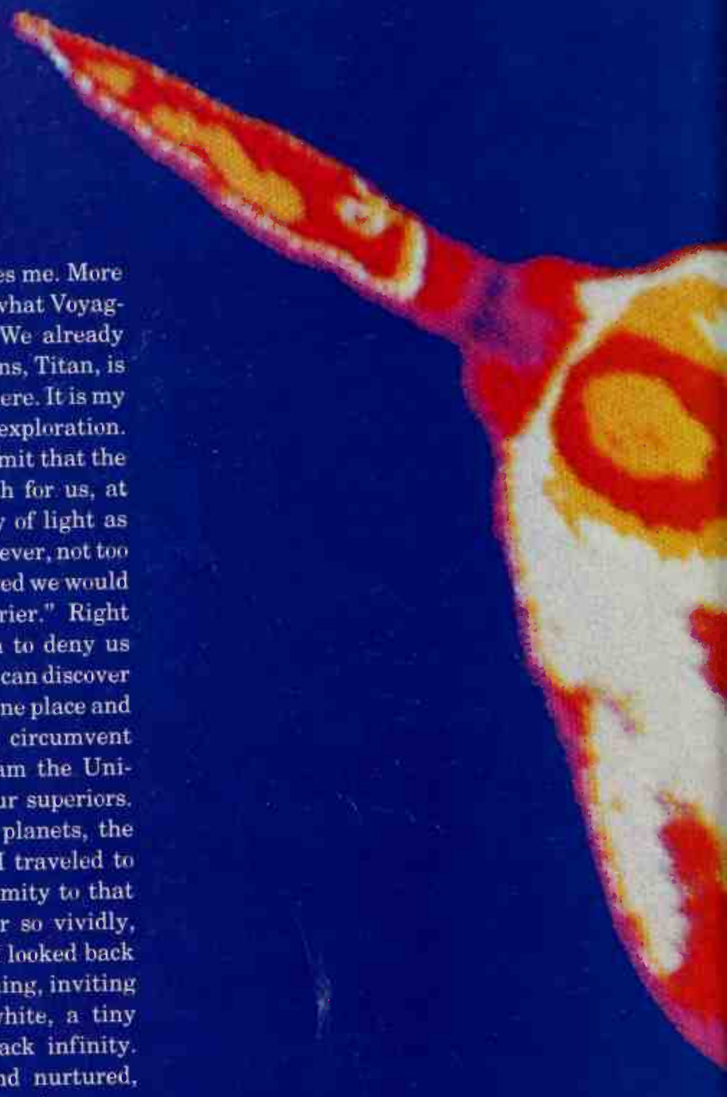
The Star We Know Best	**The Sun**	49
The Swiftest Planet	**Mercury**	69
A Veiled Planet	**Venus**	81
The Planet We Know Best	**Earth**	93
The Red Planet	**Mars**	125
A Planet That Never Was	**Asteroids & Meteors**	143
King of the Planets	**Jupiter**	153
The Planet with Ears	**Saturn**	173
A World on Its Side	**Uranus**	183
Last of the Giants	**Neptune**	191
A Double Planet?	**Pluto**	197
Snowballs in Space	**The Comets**	203

To the Stars & Galaxies
Deep Space 215

The Future
Shuttles & Starships 251

Space Age Highlights	264	Observing the Universe	272
Glossary	270	Index	274
Measuring the Universe	271	Illustrations Credits	276

Foreword



When I was young, I used to look up into the sky and see airplanes. Later, when I flew those airplanes, I realized I still hadn't gotten very high, that I couldn't go wherever I could see. I kept trying and I did get as far as the Moon. To Neil Armstrong, Buzz Aldrin, and me, that seemed a very long trip, but compared to reaching the nearest star it was like moving past a dozen grains of sand on a beach. The Moon is about 385,000 kilometers from Earth, while the nearest star, Proxima Centauri, is 40 trillion kilometers away! Now, back here on Earth with a better appreciation of distances, I borrow the eyes of astronomers to show me those places I will never visit. This beautiful book will help you to do that.

Throughout history, the genius of astronomers has been their ability to let their minds roam to the far reaches of the Universe while their bodies were trapped on Earth. Kepler, tracing the planets in their orbits; Einstein, seeing the Universe emerge from his chalkboard – they have freed our minds if not our bodies.

And perhaps our bodies will not be far behind. Rockets have propelled astronauts to the Moon and fired Pioneer spacecraft completely out of the Solar System. It is now technically possible for people to visit Mars, approximately nine months away. The other planets are almost within our grasp and the moons of Jupiter and Saturn may be the unrealized gems of our Solar System. The cameras of the Voyager spacecraft have transformed Jupiter's moons from mere pinpoints of light in a telescope into intriguing, colorful spheres. Io . . . Europa . . . Ganymede . . . Callisto. Even the sound of their names excites me. More enticing still is the prospect of what Voyager will tell us about Saturn. We already know that one of Saturn's moons, Titan, is surrounded by a thick atmosphere. It is my favorite candidate for human exploration.

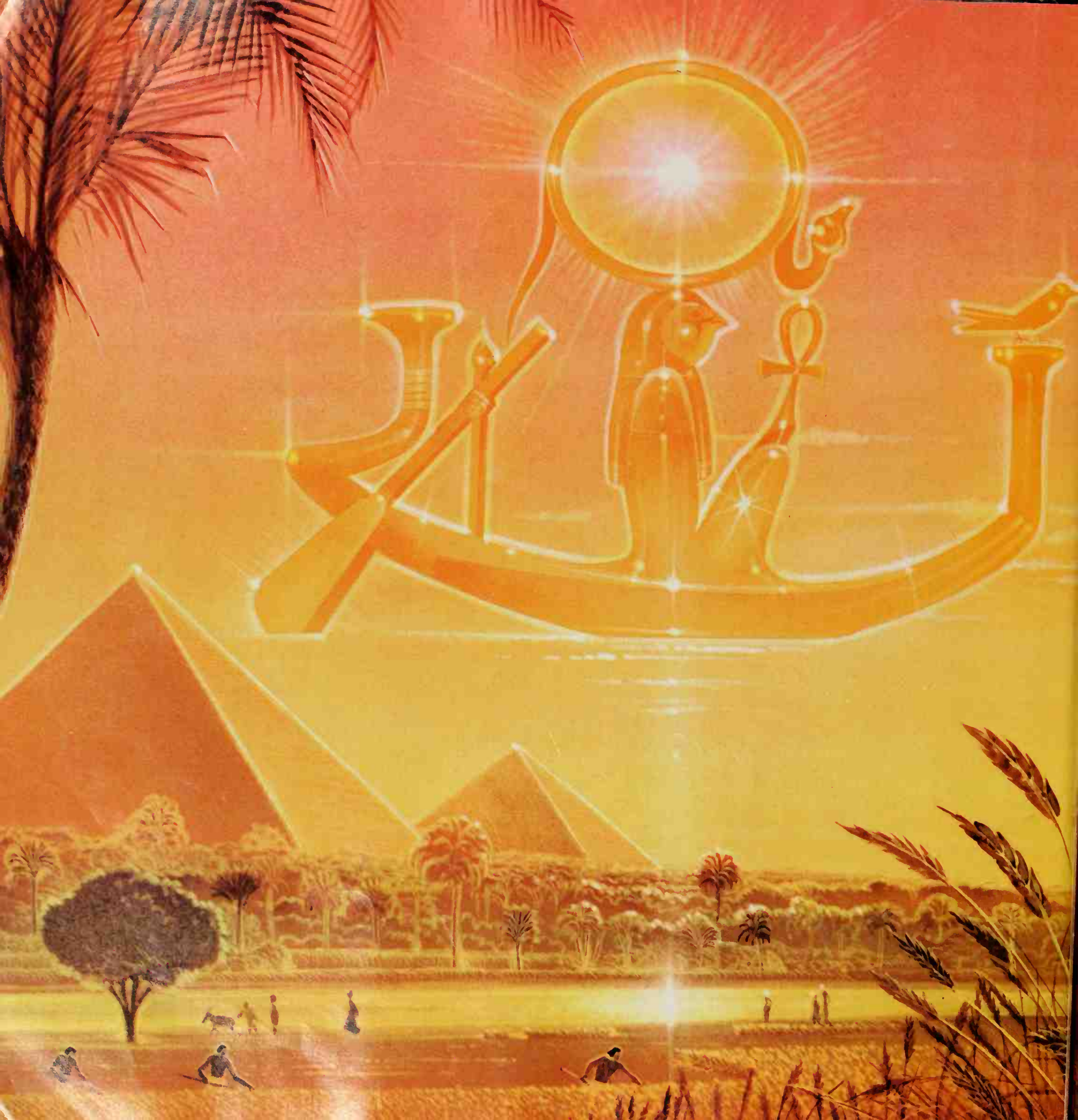
Beyond Pluto, we have to admit that the distances seem to be too much for us, at least if we regard the velocity of light as the universal speed limit. However, not too many years ago, experts believed we would never break the sound "barrier." Right now, Einstein's theories seem to deny us the stars. Perhaps someday we can discover how to disembody humans in one place and recreate them elsewhere, to circumvent Einstein's barrier, and to roam the Universe, seeking our peers or our superiors.

The more we see of other planets, the better this one looks. When I traveled to the Moon, it wasn't my proximity to that battered rockpile I remember so vividly, but rather what I saw when I looked back at my fragile home – a glistening, inviting beacon, delicate blue and white, a tiny outpost suspended in the black infinity. Earth is to be treasured and nurtured, something precious that *must* endure.

The next two decades should be the most productive years astronomers have ever known. With space telescopes we will accumulate more information about the Universe than we have since humans began to study the heavens. May we be intelligent enough to comprehend it and sensible enough to use it to solve some of the pressing problems of our unique home.

Michael Collins

A spectacular night launch of Apollo 17 crowns the mission series that landed 12 U.S. astronauts on the Moon.



Sun Gods to Gamma Rays

Beginnings

An Egyptian myth about 4,000 years old tells us that a sacred boat carried the Sun god Ra. Each morning the boat rose over the eastern horizon and slowly sailed across the heavenly ocean. At night the boat sank below the western horizon and continued its journey through the underworld until once again it rose in the east and began a new day.

When ancient Egyptians, harvesting wheat near the Nile River, looked at the Sun, they may have pictured the god Ra—or Re, as he is often called—in his boat. The sky has always been a source of wonder. Ancient peoples the world over knew almost nothing about what the stars and planets were, or how they moved through space. The sky seemed to be the home of gods, demons, and spirits, and sky events seemed to be the workings of the gods. Unusual occurrences—like eclipses, comets, meteors—often brought great fear to people in ancient times.

The Egyptian mythmakers wove a creation story that was linked to the annual flooding of the Nile. In the beginning, says the myth, there was nothing but a vast world-ocean called Nun. The Sun god, then known as Atum, created himself out of the waters. At first Atum made a small mound

The "world tree" of the Norse connected sky, Earth, and underworld. From the top, an eagle surveys the world. Below, an evil serpent gnaws on the tree roots. Mimir, a giant, guards the fountain of wisdom. The three Fates—past, present, and future—braid the thread of life.

Brahma, says Hindu tradition, created the Universe from a golden egg. First he made the waters and in them put a seed. It grew into an egg, which Brahma split open. From the golden half came the heavens, from the silver half, Earth. From the egg came all creation.

of earth to stand on and it became the land. Next, he created lesser gods, one to rule over moisture and another to rule over the atmosphere.

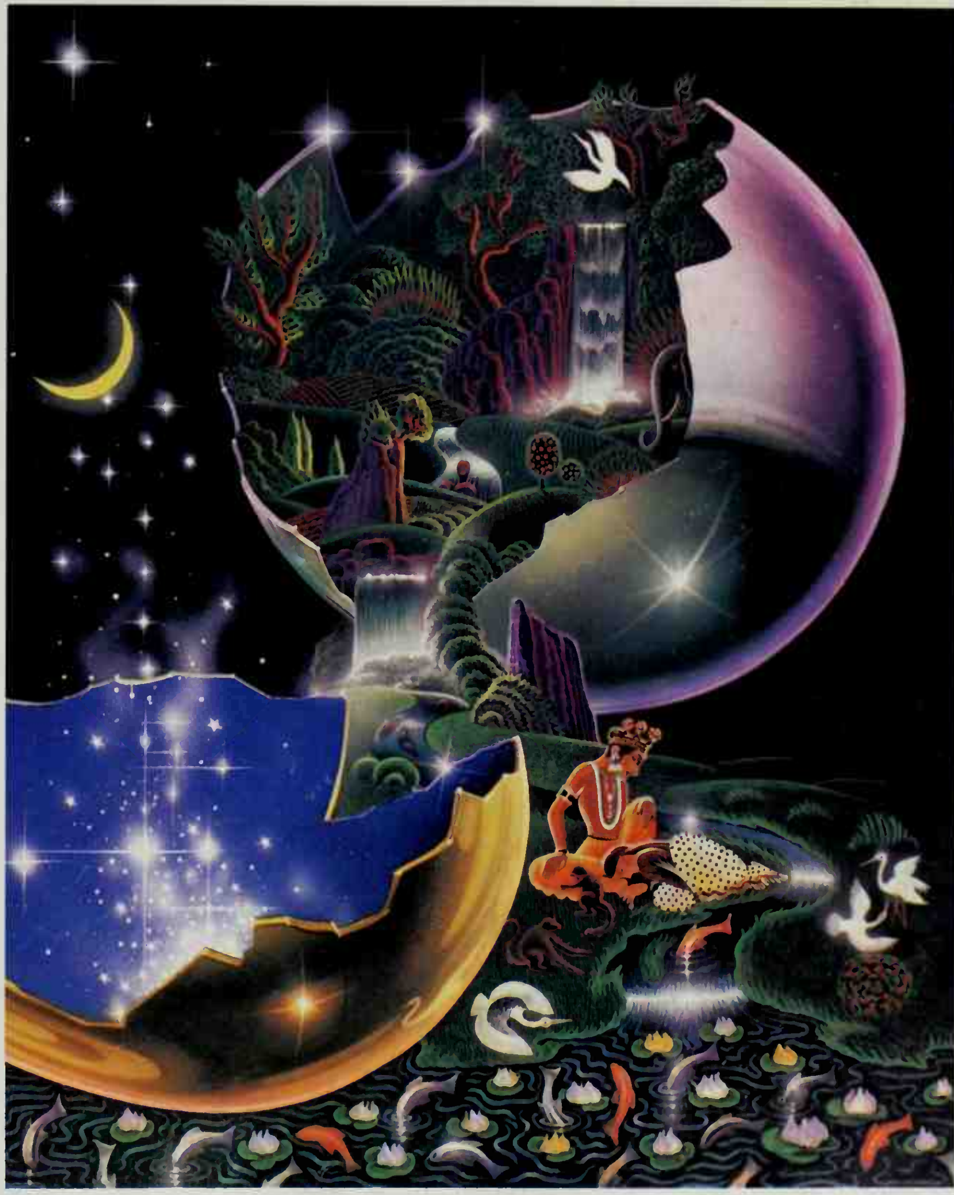
Each year from July to October the great Nile River overflowed its banks. When the flood waters lowered, fine muddy soil, called silt, was left heaped along the flood-plain. The first appearance of the mounds of silt reminded people of the small mound of earth which they believed Atum had created to stand on. Warmed by the Sun, this rich river-earth nurtured many kinds of life, both plant and animal. No wonder the ancient Egyptians looked on the Sun as a creator-god.

The world tree Yggdrasill

In the beginning there was nothing, a Norse myth written down about A.D. 1200 tells us. "There was no sand nor sea, nor soothing waves / No earth anywhere, nor upper heaven / A gaping chasm and grass nowhere." Then the gods Odin and Thor shaped the world. Earth was flat and in the center grew the great tree of life, Yggdrasill. The ash tree was watered by three magic springs that never ran dry, and the foliage was always thick and green.

Patterns in the sky

After many ages of observing the constellations, planets, Sun, and Moon, ancient peoples learned to recognize and predict patterns. For example, they knew when the Moon would next be full, quarter, or crescent. Such knowledge could be used to make calendars. And, in fact, the world's first calendars were based on the phases of



A calendar ring called a medicine wheel told early Indians in Wyoming's Bighorn Mountains that summer had arrived. The rising of the Sun in a line with two piles of rocks, or cairns, marked the summer solstice. According to legend, on this day "the sun is highest and the growing power of the world the strongest." The 28-spoke wheel is about 24 meters wide, with a central cairn for a hub and six others around the rim. Sighting along different sets of cairns, Indians also observed the summer solstice sunset and the positions of three rising stars (below).

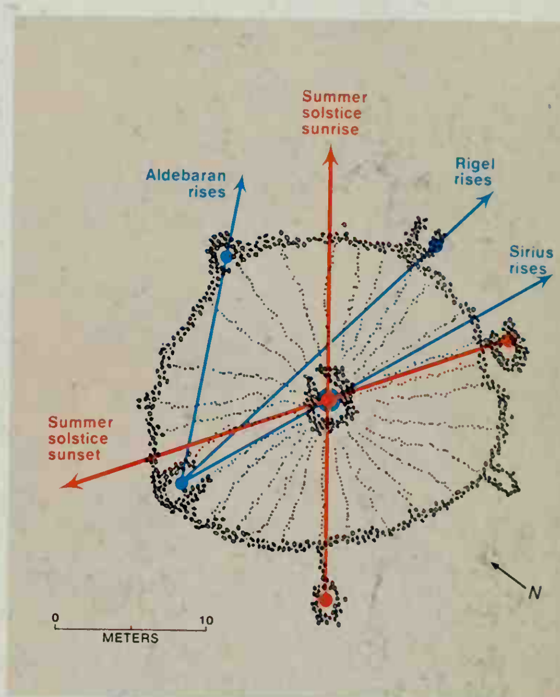
the Moon. Sky watchers noticed that between two full Moons there were sometimes 29 days and other times 30 days. The year could be arranged in 12 "moonths," adding up to about 354 days. For a few years this lunar calendar would work well, but each yearly cycle ended 11 days too soon. So, after eight years, the lunar calendar would be about three months ahead of the seasons. As agriculture became more important, people realized that the seasons related more closely to the movements of the Sun and stars than to the Moon.

The solar calendar

In Egypt, successful crops depended on the Nile River's annual flood. After measuring time in lunar months for thousands of years, the Egyptians developed a more accurate calendar with the help of a star.

Astronomers observed that, shortly before the Nile reached flood stage each year, the star Sirius appeared on the horizon just before dawn. Such careful observations helped them keep the lunar calendar in step by adding extra months. By 2800 B.C., Egypt had established a 365-day year, about a quarter of a day shorter than the actual solar year. This was the first recorded solar calendar.

By watching the Sun's rising point on the horizon each morning, ancient astronomers found that the point shifted each day. In summer it inched its way a bit farther south each morning. In winter it inched its way back toward the north again. June 21 signals the Sun's most northern point—called the *summer solstice.* Some ancient monuments were positioned to pinpoint

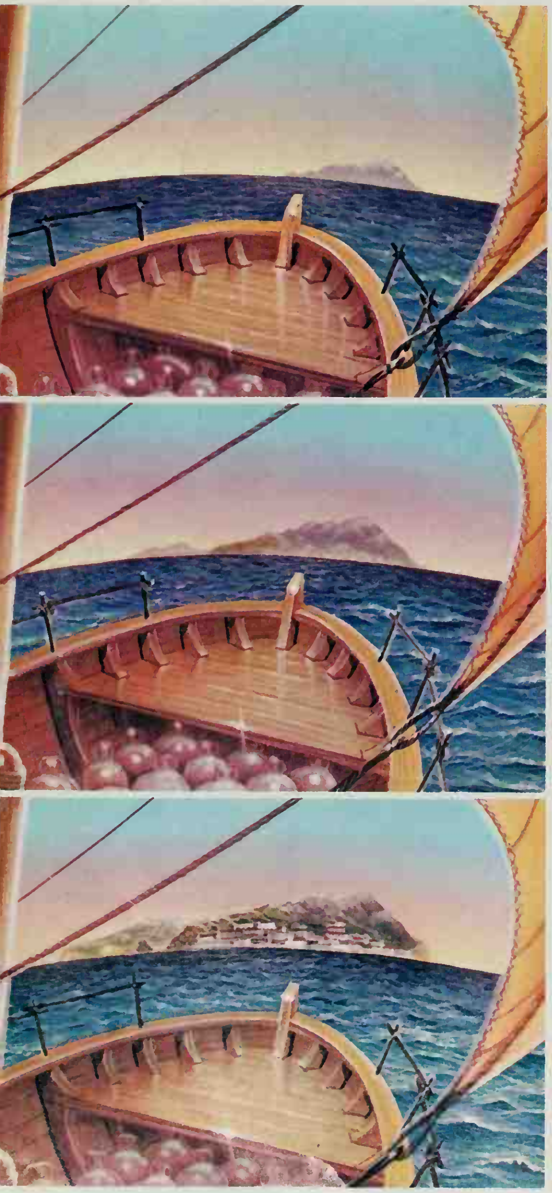


that day: At Stonehenge, England, the Sun rose over a stone marker. Inside the circle of stone blocks, people probably held ceremonies to salute the sunrise and to pray for a season of good crops.

From myths to measurements

Night after night as the stars flowed across the sky, people wondered about those pinpoints of light and asked: What are the stars? Where do they come from? How large are they? How far away? And what is Earth's place in the grand cosmic scheme? Is it really fixed motionless at the center of all creation as it appears to be? In Greece

Sailors of ancient Greece approaching a distant island first saw only the highest point of land. As they drew closer, the island seemed to rise from the sea. Their reports supported the theories of some philosophers, such as Pythagoras and Aristotle, that Earth was round.



around 600 B.C., people began to question the old myths about the Universe. Colorful tales of dragons, demons, and Sun gods no longer seemed satisfactory. New thinkers began looking for natural, not supernatural, causes for events in the sky.

The spheres of Eudoxus

One such thinker was Eudoxus, born around 400 B.C. He tried to account for the motions of the stars and planets. To our eyes the stars seem to move as a group across the sky from east to west. But we cannot see them move in relation to each other. So they were called the *fixed stars*.

But certain starlike objects—the planets—move against the background of fixed stars. Stargazers of old counted seven moving objects—the Sun, Moon, Mercury, Venus, Mars, Jupiter, and Saturn—and called them *wanderers*. Usually the planets moved from west to east among the background stars. But then, one of these wanderers would seem to slow down, stop, and mysteriously reverse its direction, or *retrograde*, for a few weeks. (See page 21.) Then, just as mysteriously, it would resume its eastward course.

Eudoxus had a solution to this puzzle. He supposed that Earth was motionless and located at the center of the Universe. And this is just what our eyes tell us. He imagined that a series of nesting transparent spheres enclosed Earth and rotated about its center. He supposed that all of the fixed stars were attached to the inside of the outermost, and largest, sphere. So people saw them move across the sky as this star-sphere turned on its axis. The next innermost set of spheres caused the motion of Saturn against the background of fixed stars. The next caused the movement of Jupiter, the next Mars, the Sun, Venus, and so on. Eudoxus never built a model. His system was only a theory and it was complicated but, except for Mars, it did account to some extent for what people observed as the planets moved against the stars.

Earth's shape, size, and motion

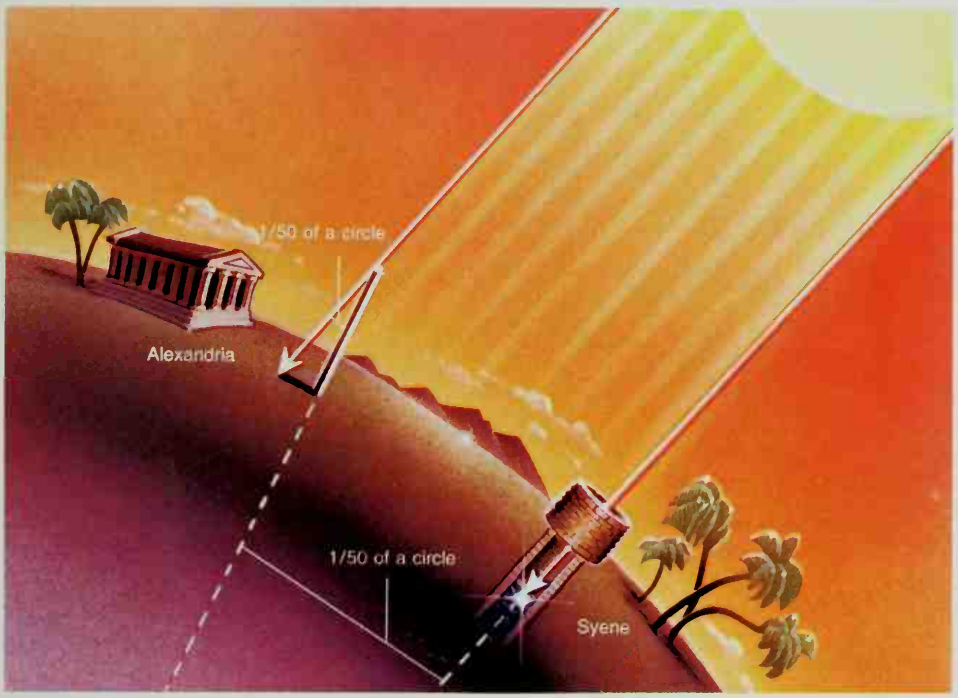
While most people thought that Earth was flat, the great Greek teacher Aristotle reasoned otherwise. He had observed that during an eclipse Earth cast a curved shadow on the Moon. Aristotle also believed that of the four elements—earth, air, fire, and water—the heavy ones, earth and water, pulled together into a spherical shape. In Aristotle's time no one knew Earth's size. Later, Eratosthenes made an amazingly accurate measurement using basic geometry.

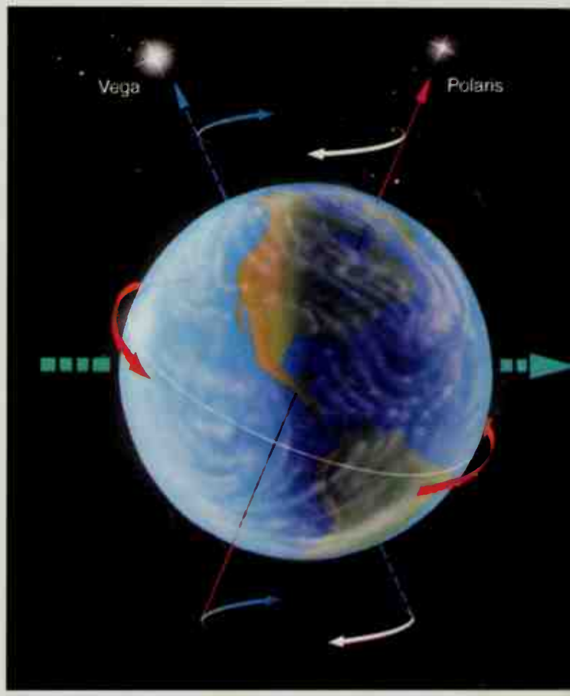
Aristarchus was possibly the first astronomer to suppose that Earth was simply one of several planets all revolving about the Sun. Also, he said that the stars seemed to parade nightly across the heavens because Earth rotates on its axis. Scholars of his time refused to accept either idea. Their picture of a Universe with a motionless Earth at the center made too much sense to be abandoned easily.

Around 150 B.C. lived a man who has been called the greatest astronomer of ancient times—Hipparchus. By measuring the size of Earth's shadow cast on the Moon during an eclipse of the Moon, Hipparchus estimated the Moon's distance and size

Eratosthenes, a Greek scholar living in Egypt about 230 B.C., knew that every June 21 sunlight fell directly down a well at Syene (now Aswan). Erecting a pole in Alexandria some 800 km to the north, he measured the angle of the pole's shadow at high noon. Geometry told him that if the well and the pole were extended to meet at the center of Earth, the two lines would form the same angle. Both would be 1/50th of an entire circle. Multiplying 50 times the distance from pole to well, he came close to Earth's circumference of about 40,000 km.

Earth wobbles like a spinning top. This causes its north-south axis to point to different parts of the sky during a 26,000-year cycle called precession. Today the North Pole points to Polaris, which we call the North Star. In 13,000 years Earth's North Star will be Vega.





very accurately. He also drew up the most complete star catalog that had ever been made. It showed the brightness and positions of 850 stars. By comparing his observations with those of earlier astronomers, Hipparchus made another important discovery—*precession* (above right).

Ptolemy's epicycles

Greek scholars greatly influenced thinking in the ancient world. Around A.D. 130 the leading astronomer was Claudius Ptolemaeus, called Ptolemy. His views set the climate of astronomical thought for the next 1,500 years. Though he studied the idea of a Sun-centered Universe, Ptolemy supported the old Earth-centered concept. He also rejected the idea that Earth rotates on its axis. If Earth rotated, he reasoned, birds would have their perches whipped out from under them. But Ptolemy did work out a much better scheme to explain the motions of the planets. With a complex arrangement of circles called *epicycles*, he accounted for retrograde motion and for the periodic brightening of the planets as they came nearer to Earth. Ptolemy's system, using numerical data, was the first to make accurate, day-by-day predictions about planetary motion.

The Roman calendar

Roman scholars showed more interest in the superstition of astrology than in astronomy. But Rome did make one significant contribution to the science of astronomy. By 46 B.C., the calendar had fallen hopelessly out of pace with the seasons, and Julius Caesar decreed that the length of the year should be 365 days plus one extra day every four years. But, by the 1500's, people realized that the Julian calendar had been falling behind the seasons at the rate of one day every 125 years. In 1582 Pope Gregory XIII corrected the error. He ordered that three leap years be


Cancer
Leo
Virgo
Libra
Scorpius
Sagittarius
Capricornus

The Roman zodiac, one of several in the ancient world, is used by astrologers today. An imaginary star path through which the Moon and planets traveled, it had a constellation, or sign, for each of its 12 divisions. The Romans believed that the Sun revolved around Earth.

skipped during every 400 years. This Gregorian calendar is the one we use in the Western world today.

The Arabs as preservers

After the time of Ptolemy, much quarreling broke out among the nations surrounding the Mediterranean Sea. In Alexandria, the greatest library of antiquity was destroyed. Fortunately, in the early 800's, there lived an enlightened Arab ruler, Caliph Harun-al-Rashid. He set up a collection of ancient works which later became a research center called the House of Wisdom. Scholars gathered there, in Baghdad, bringing priceless copies of old Greek texts, which they translated into Arabic and so preserved. One of these was Ptolemy's principal work, which they titled *Almagest*. The Arabs had many fine instruments for measuring the positions of the stars and planets. Among them was one called the astrolabe. With this circular instrument and star map, they could sight stars and perform many astronomical calculations. Westerners later used a simplified version to navigate by the Sun and stars. To this day, stars with Arabic names—such as Algol, Zubenelgenubi, Betelgeuse—remind us of the important role the Arabs played in astronomy.

Copernicus and a new revolution

By the 1500's European scholars were rereading the old Greek masters. One such scholar was the Polish astronomer, Nicolaus Copernicus. Over nearly 30 years, Copernicus worked out the details of a Sun-centered, or *heliocentric*, planetary system.

Tycho Brahe, a 16th-century star watcher, points to the heavens in this painting of his observatory, Uraniborg, on the Danish island, Hven. His precision instruments measured the positions of 777 stars and five planets then known. His work marked the beginning of modern astronomy.

This concept, more logical and harmonious than Ptolemy's Earth-centered, or *geocentric,* system, gave the necessary blueprint for progress in astronomy.

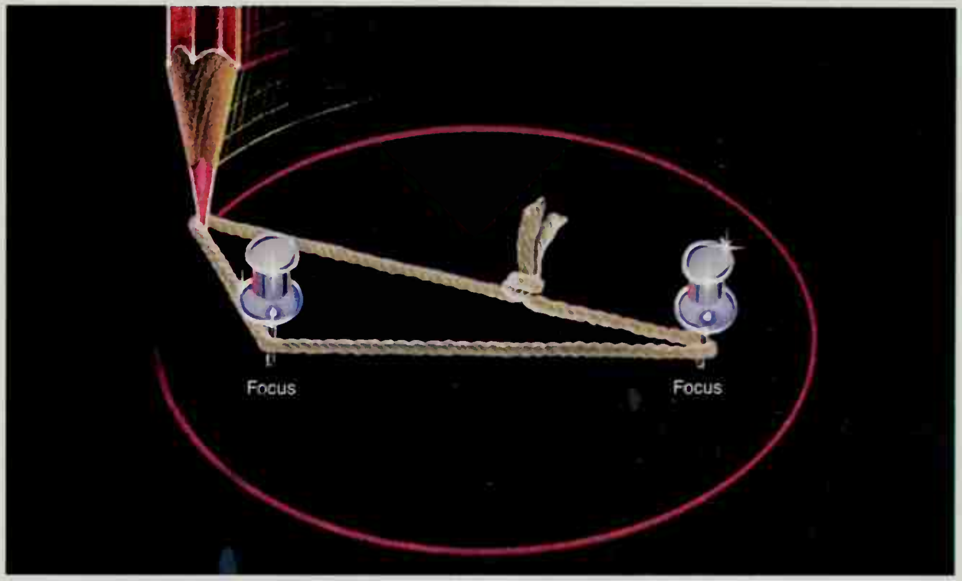
Copernicus wrote a detailed mathematical explanation of his theories—the greatest scientific work since Greek times. But he hesitated to publish it for fear of ridicule, and because he knew there were still flaws in the details. However, a young admirer persuaded Copernicus to have the manuscript published. It was called *On the Revolutions of the Heavenly Spheres.* On May 24, 1543, at the age of 70, and only hours after first seeing a complete copy of his printed book, Copernicus died.

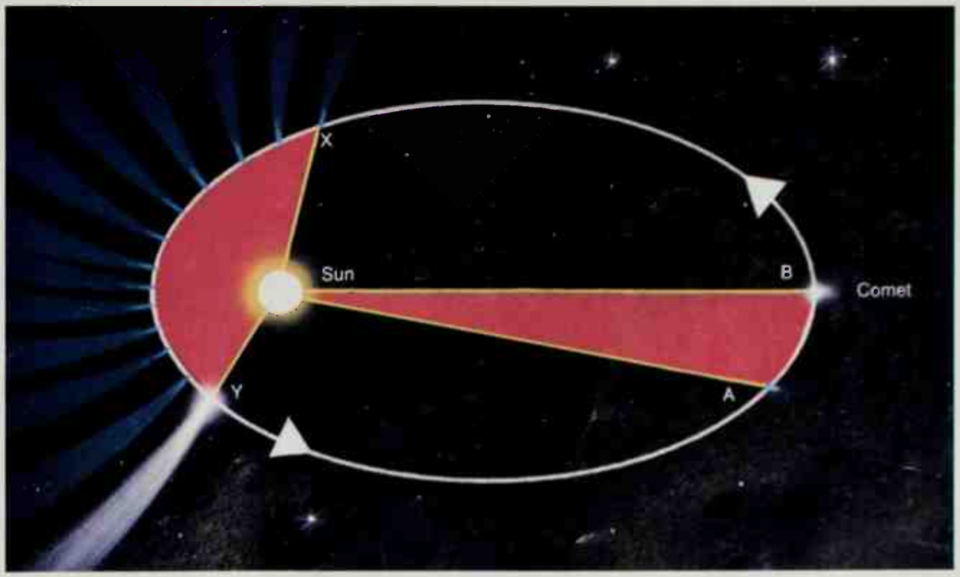
Tycho builds an observatory

Accurate scientific observations were needed to test the new theory of Copernicus. The person to produce them was a fiery Dane, Tycho Brahe, often known as Tycho. By the time he was 30, Tycho had earned a reputation in several countries—a reputation for being a gifted astronomer as well as for getting into arguments. As a student, Tycho lost part of his nose in a duel and for the rest of his life wore a false nose made of gold and silver.

In 1576 King Frederick of Denmark gave Tycho the island of Hven, a handsome salary, funds to build a small castle, and the finest instruments to work with. Over the next 20 years, Tycho measured the changing positions of the planets, sometimes using a large wall quadrant that appears in the painting on this page. The telescope had not been invented; Tycho's instruments sighted stars as a rifle sights a

Johann Kepler, a German astronomer using Tycho's observations, found that he could plot Mars' supposedly circular orbit only on an ellipse, or oval. The discovery led to Kepler's First Law: Planets move in elliptical orbits with the Sun at one focus. Construction of an ellipse is shown with two tacks acting as the foci. Kepler's Second Law says: A line from the Sun to a body in orbit sweeps over equal areas in equal time. The shaded areas are equal. Because of the Sun's great mass and gravitational pull, the comet (or any planet) moves fastest nearest the Sun.





target. Tycho watched the *nova,* or "new star," of 1572 and the Great Comet of 1577. His accurate measurements showed that both were more distant than the Moon. Therefore, the comet must have passed through a number of those nesting crystal spheres, by then commonly thought to carry Ptolemy's epicycles. Here was proof that such spheres could not exist! The appearance of the nova proved Aristotle to be wrong when he said that the heavens do not change. Tycho's observations of Mars enabled Johann Kepler to develop his laws of planetary motion.

Kepler frames his laws

In 1600 the 28-year-old Kepler joined Tycho in a new observatory near Prague in Czechoslovakia. The following year Tycho died. Kepler inherited the rich harvest of observations and settled down to discover how the planets move in their orbits. After six years of effort, Kepler worked out his first two laws—among the most important discoveries in the history of science. But one question bothered him very much: What force moves the planets around the Sun? He imagined that the Sun sent out "rays" that whipped around as it rotated and drove the planets in their orbits. However, a better answer to the problem was still 50 years in the future.

Galileo and his telescope

Scholars the world over came to respect Galileo Galilei as a giant of astronomy. He was Italian, born in 1564. He had great fun punching holes in widely held scientific beliefs that had not been tested by

A page from Nicolaus Copernicus' book, On the Revolutions of the Heavenly Spheres, *illustrates a theory that brought a new life to astronomy in the 16th century. It shows Earth and the other planets orbiting the Sun. At the time, most people still believed the Sun revolved around Earth. Copernicus also explained why the planets sometimes seem to fall back, or retrograde, in orbit. In the diagram opposite, as the faster moving Earth catches up and passes an outer planet, Mars, the latter appears to observers on Earth to make a loop.*

experiment. For instance, some professors argued that since air does not fall it must be weightless. Galileo compressed air into a leather flask and weighed it. Then he emptied the flask and weighed it again. Since it was lighter than before, he proved that air has weight.

Aristotle had taught that objects fall faster according to their weight. Galileo reasoned that if they were all of the same material, weight wouldn't matter. He tested this by dropping large and small objects of the same material from a high tower. His students, waiting below, saw the objects hit the ground at about the same time.

In 1609 Galileo heard of the invention, in Holland, of a "spyglass," with which distant objects could be seen as though they were nearby. He made himself one of these instruments—a refracting telescope—and began observing the Sun, Moon, and planets. He published a book, *The Starry Messenger,* telling of the wonder of seeing for the first time things which had been invisible to the naked eye. Tradition said that the heavenly bodies were smooth, unblemished spheres of perfection—but Galileo's telescope showed mountains, valleys, and craters on the Moon. When he studied the hazy band known as the Milky Way, he discovered that it was made of countless individual stars. Later, Galileo saw the phases of Venus as positive proof that the Sun formed the center of the planetary system.

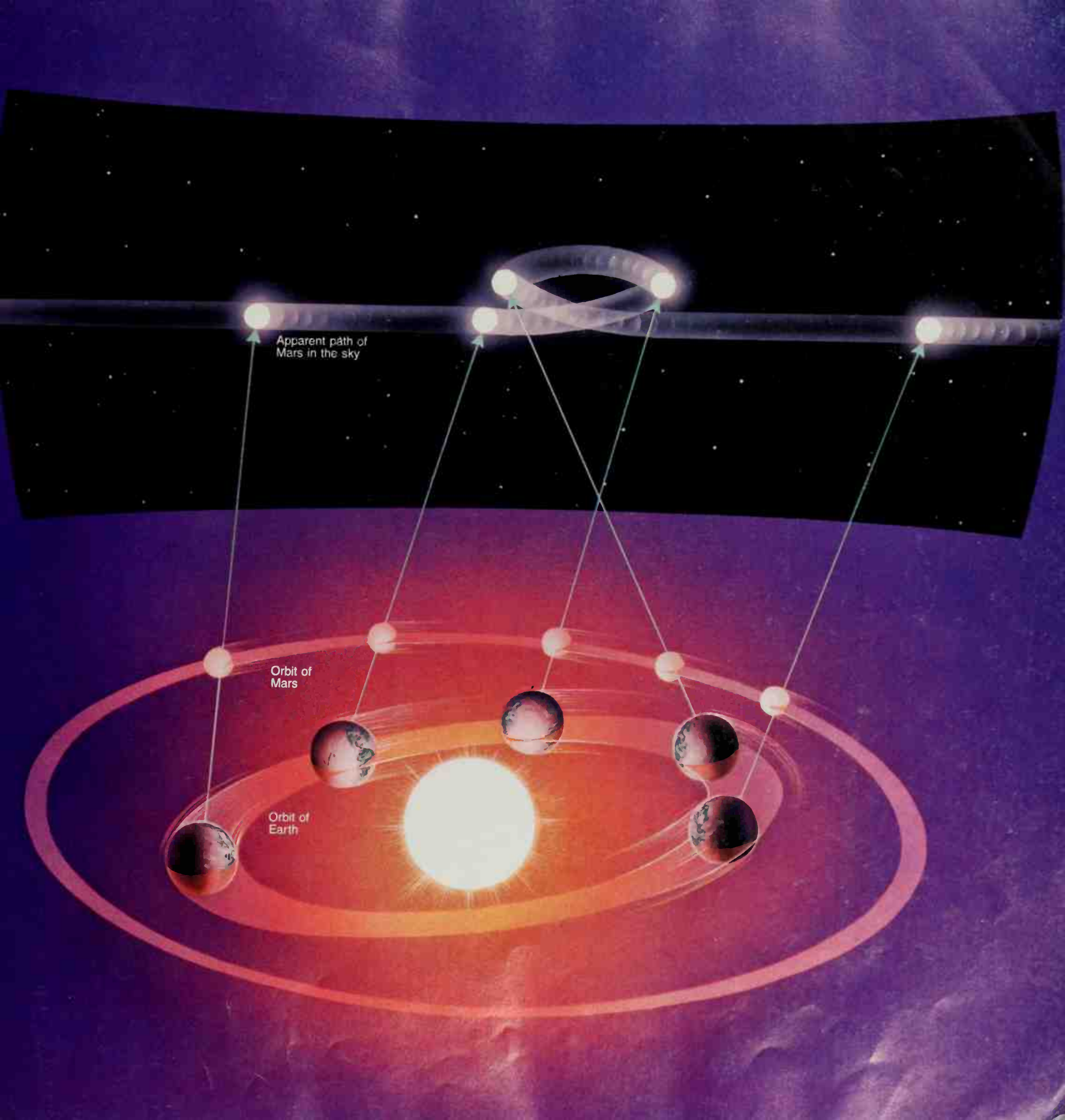
Although his discoveries made Galileo known all over Europe, some scholars refused to believe in them. A few refused even to look through the telescope. They still clung to the old ideas of Aristotle and Ptolemy. Church officials warned Galileo not to support the Copernican view that Earth moves around the Sun as the other planets do. For years, he remained silent on this matter.

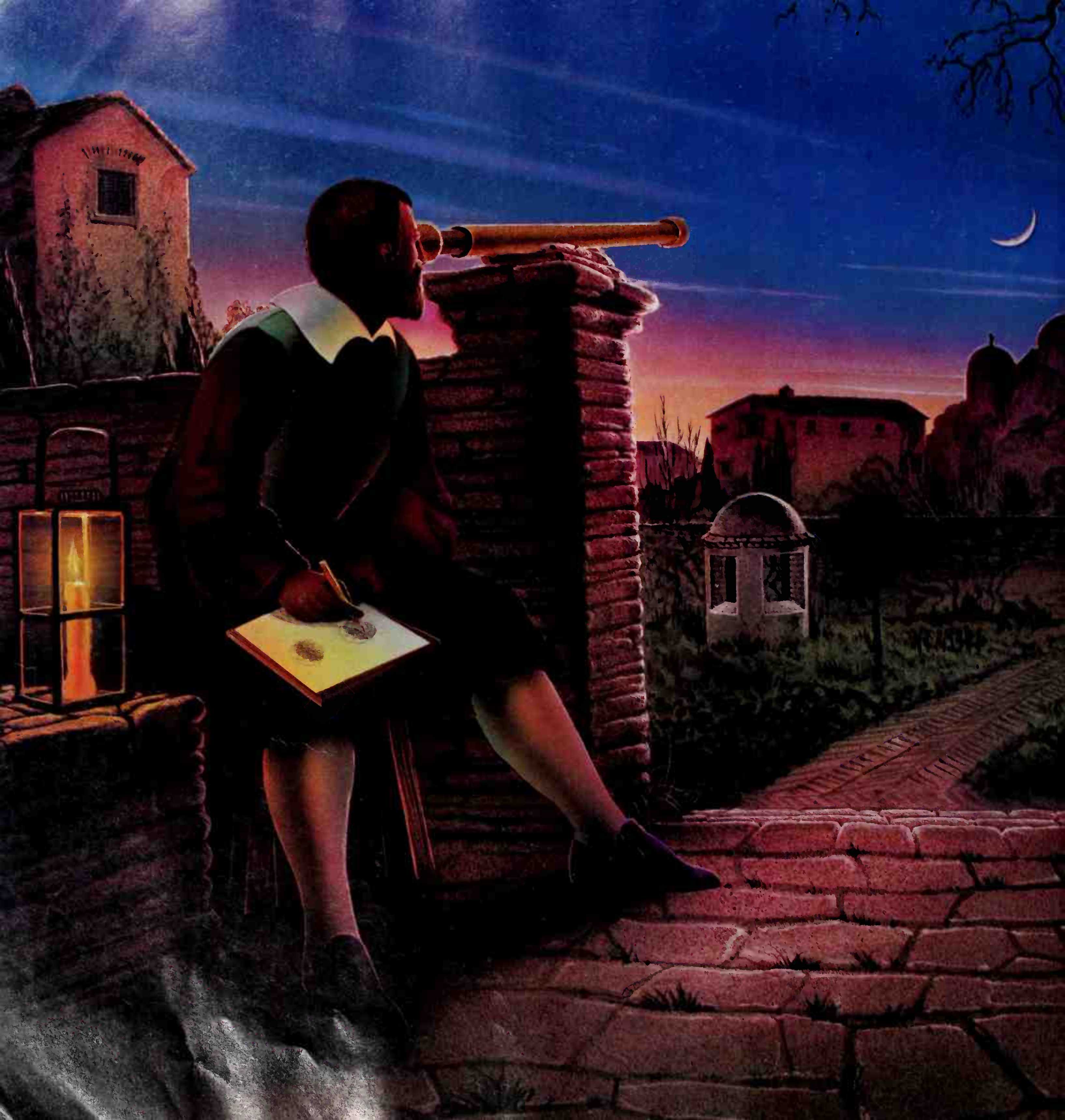
In 1632 he published a book attacking all arguments against Earth's motion. The Pope turned the matter over to the Roman Inquisition. The next year, Galileo was tried in Rome and forced to deny that Earth moves and that "the Sun is the center of the World." He was kept under house arrest for his few remaining years. By 1637 Galileo had gone blind. But meanwhile, he had written his greatest scientific book—on mechanics and motion. This book is known today as *Two New Sciences.*

Newton and gravitation

The year Galileo died, 1642, Isaac Newton was born in Woolsthorpe, England. Newton solved the problem that had bothered Kepler so much: What force keeps the planets moving around the Sun? And Newton finished Galileo's work on the motion of objects through space.

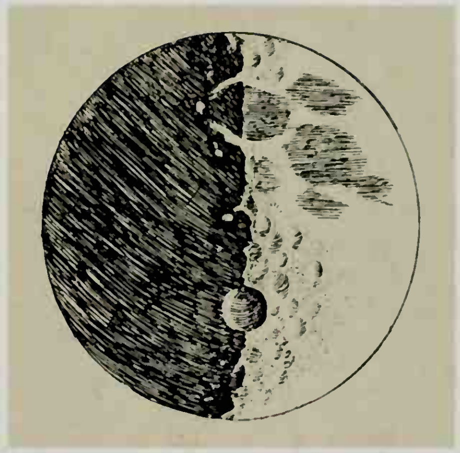
In 1665 Newton was a student at Cambridge University. That year a deadly plague broke out in London. The University closed and sent everyone home until the


Apparent path of
Mars in the sky
Orbit of
Mars
Orbit of
Earth



C. 5

Galileo looks through his homemade "optic glass" and draws pictures of the Moon. It is 1609 in Padua, and the Italian astronomer for the first time sees celestial bodies closer than they really are. On what was then thought to be a smooth lunar surface he found mountains and craters. For many weeks Galileo studied the Moon and sketched its various phases. One of his drawings (below right) appears next to a photograph of a similar phase (below left). Building more powerful telescopes, he observed countless stars never before seen in the skies. He saw the four moons of Jupiter and the phases of Venus, and proved that the Moon shines with light reflected from the Sun. In 1612 he saw spots on the Sun. Watching them move across the disk, disappear, then reappear, he concluded that the Sun rotates on its axis.



epidemic ran its course. As a mathematics student, Newton had become very interested in geometry and the motions of the planets. At age 23, and with a long vacation ahead, Newton set out to investigate the force that seemed to hold the planets captive to the Sun.

He began by wondering why the Moon stayed in orbit around Earth. Why didn't it go flying off into space as a stone whirled around at the end of a string does when the string is let go? Was the force holding the Moon in orbit the same that pulls an object to the ground when it is tossed into the air? Did this force also hold the planets in orbit around the Sun?

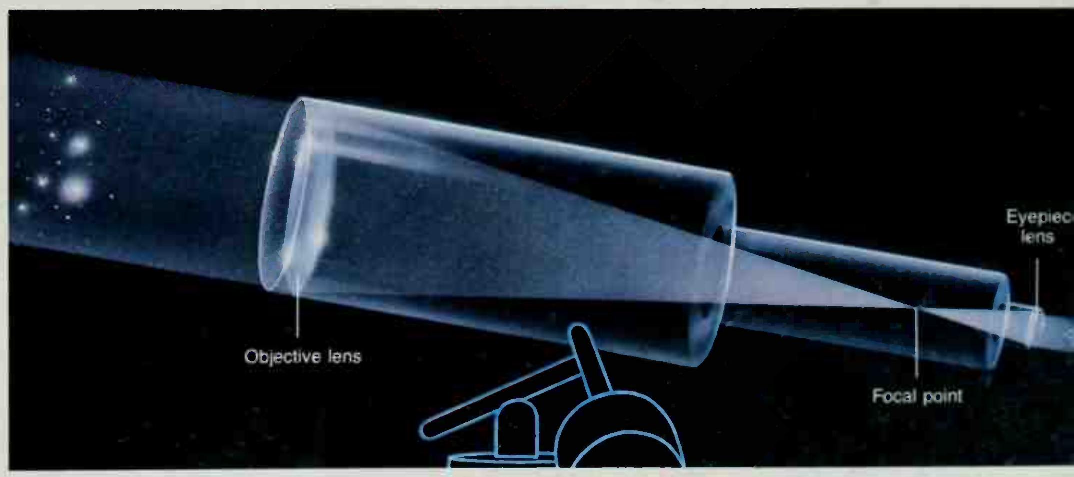
Having the idea was one thing. Proving it was another. Newton had to invent a new kind of mathematics—calculus. By the time he returned to Cambridge, he had begun to think about gravitation.

Over the next 20 years, Newton formulated his three laws of motion:

Newton's First Law—An object in motion will keep moving at the same speed and in the same direction unless an outside force acts on it. An object will remain at rest unless a force acts on it, such as the horse pulling the log (page 25).

Newton's Second Law—If a force acts on an object, the object will change velocity—that is, speed up, slow down, or change direction. Change in speed will be in the same direction as the force and proportional to it, but inversely proportional to the body's mass. This means it is easier to move a light body than a heavy one.

Newton's Third Law—For every action, there is an equal and opposite reaction. For



Refractor telescopes used by Galileo and Kepler had two lenses. A convex () objective lens collected the light and bent, or refracted, it to a focal point. The eyepiece lens magnified the image. Galileo placed a concave)(eyepiece in front of the focal point and saw the image right side up. Kepler used a convex eyepiece behind the focal point (above) for greater magnification. But it captured an inverted image. A third lens reinverted the image but dimmed the light. So it was discarded, and astronomers continue to study the stars "upside down."

NAYLOR MIDDLE SCHOOL LIBRARY

1

2

3

4

When Isaac Newton saw an apple fall to the ground, he decided that gravitation must also hold the Moon in its orbit. According to his laws of motion, the Moon would continue in a straight line unless Earth's attraction pulled it into a curved path. Similar forces acting on the planets keep them in orbit around the Sun. The horse in the picture (opposite) illustrates Newton's Third Law: When the horse pulls against the log, the log resists. The cannonball (left) cannot escape Earth's gravitational pull unless a big enough blast sends it flying into space.

instance, if you blow up a balloon and let it go, the balloon shoots forward. The forward movement is a reaction equal to the action of the air rushing through the neck of the balloon.

According to Newton's *Law of Universal Gravitation*, any two objects in the Universe attract each other, and, the more massive the objects are, the stronger the attraction. Two elephants would attract each other with greater force than two tennis balls an equal distance apart. The law also says that the closer the two objects are, the more strongly they will attract each other. So Kepler's "mysterious force" holding the Universe together was gravitation. In 1687 Newton's theories of motion and gravitation appeared with the title *Principia*—one of the most important scientific works ever published.

While doing experiments with light and lenses, Newton became interested in telescopes. At the time, there were only refracting telescopes, like Galileo's. One problem with a refractor was that a disturbing rim of color surrounded the circular image. The lens acted like a prism to separate the colors. Newton used a mirror instead of a lens to produce a sharper image. This was the first reflecting telescope (see page 31).

By the time Newton died in 1727, people had come to believe in Copernicus' Sun-centered system. They also accepted the idea that space was infinite and held a vast number of stars. The next big task was to discover the grand plan of the Universe: What was its shape? Where was the Sun's place in it?

Measuring and mapping

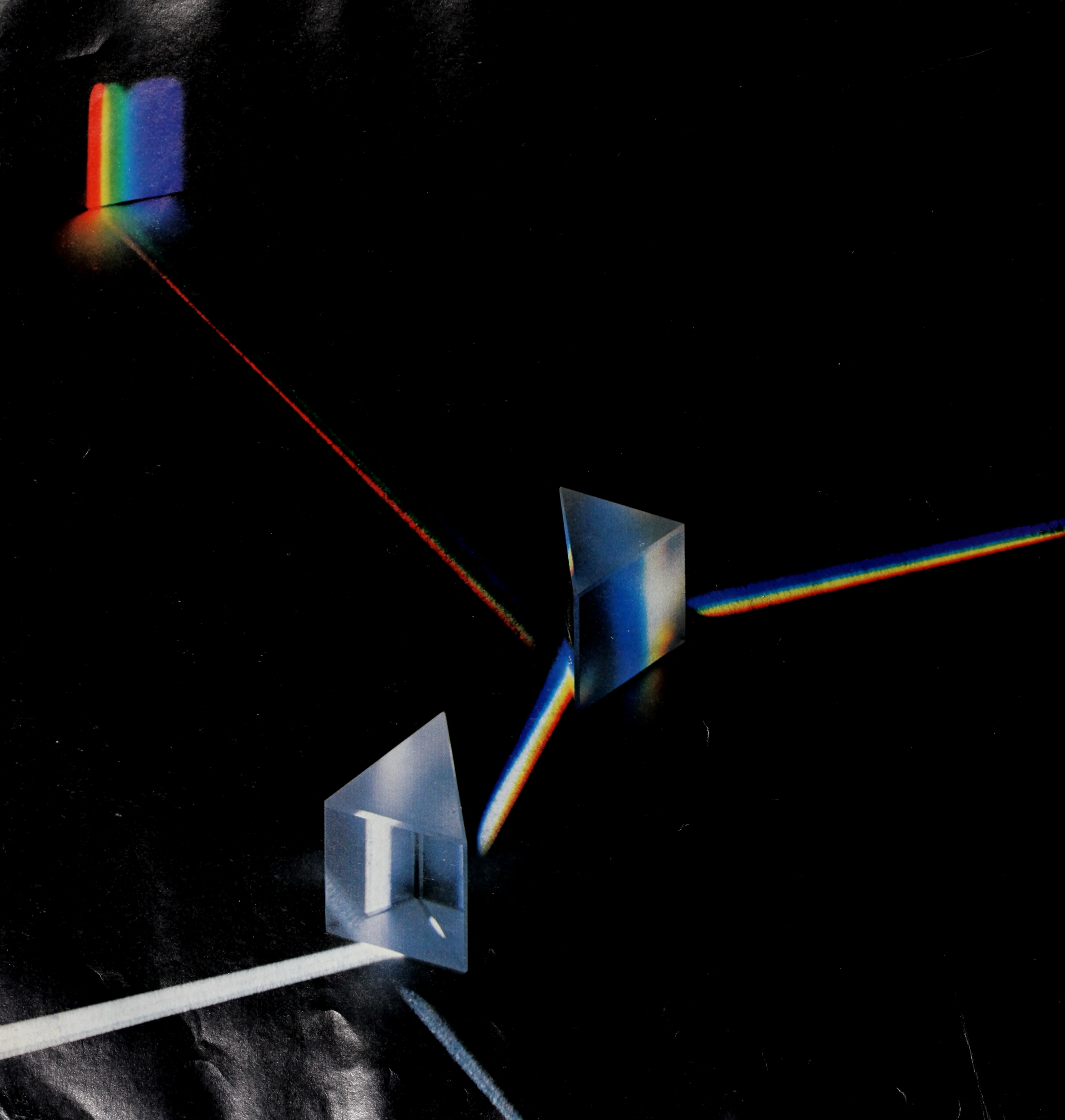
The great crystal sphere once thought to hold the stars in fixed places was gone forever. This meant that the stars were free to move about. But did they? No one had seen them move. In 1718 the English astronomer Edmund Halley showed that they do. He compared his own star observations with those made by Greek astronomers about 1,500 years earlier. He was surprised to find that three bright stars, Arcturus, Aldebaran, and Sirius, had changed position.

Herschel gives the Universe a shape

In 1781 a music teacher and amateur astronomer named William Herschel gained fame almost overnight. He had built a fine telescope and with it discovered Uranus. This was the first discovery of a planet since ancient times.

Herschel became a professional astronomer and turned his attention to the motion of stars and the nature of the Milky Way. What arrangement of stars could explain this bright band of light in the sky? In the 1780's Herschel began to count stars systematically, using a method he called *star gauges*. His 18-inch reflecting telescope revealed millions of them!

After examining his data carefully, Herschel came to the conclusion that the Sun was not, in fact, fixed at the center of the Universe. It was moving through space, which made the other stars change their positions. Herschel also reasoned that the Milky Way was shaped like a giant powder puff, with the Sun located close to the center.



Newton sits among objects of his genius: a reflecting telescope and his Principia, *which explained his ideas of gravitation and motion. He holds a prism, which was to become a key to the Universe. In a dark room he placed a prism in front of a sunbeam. The light split into a spectrum. Then he turned it back into white light with a lens. Later scientists studied lines in the spectrum and thus learned much about a star's makeup, speed, and temperature. For this* Atlas, *an experiment similar to Newton's was performed at the National Geographic Society (opposite).*

The idea of a galaxy

Herschel's powder-puff picture of the Milky Way remained pretty much unchanged until the early 1900's, when the American astronomer Harlow Shapley examined the sky. Shapley reasoned that the center of our Milky Way system must be toward the constellation Sagittarius, where the sky is most crowded with stars. Shapley had noticed many ball-shaped collections of stars—*globular clusters.* He counted several dozen in the region of Sagittarius but only a few in the opposite direction toward Auriga. He reasoned that globular clusters must be arranged around the center of our star system. Then he measured the distance to the globular clusters and decided—correctly—that the Sun is located near the edge of the Milky Way.

Around 1924 another American astronomer, Edwin Hubble, discovered that the Universe is much larger than Herschel and Shapley had thought. Here and there among the stars were many dim, hazy patches. What were they? Some proved to be clouds of gas and dust blocking the view of rich star fields beyond. Others, Hubble discovered, were systems of stars like our own. Like Herschel, he called them "island universes." Today we call them *galaxies.*

Secrets of the stars shower down on us in the elusive energies of the electromagnetic spectrum. Light and some radio waves reach earthbound receivers. But our atmosphere blocks much of the rest. With planes, balloons, rockets, and satellites, science takes the pulse of space.

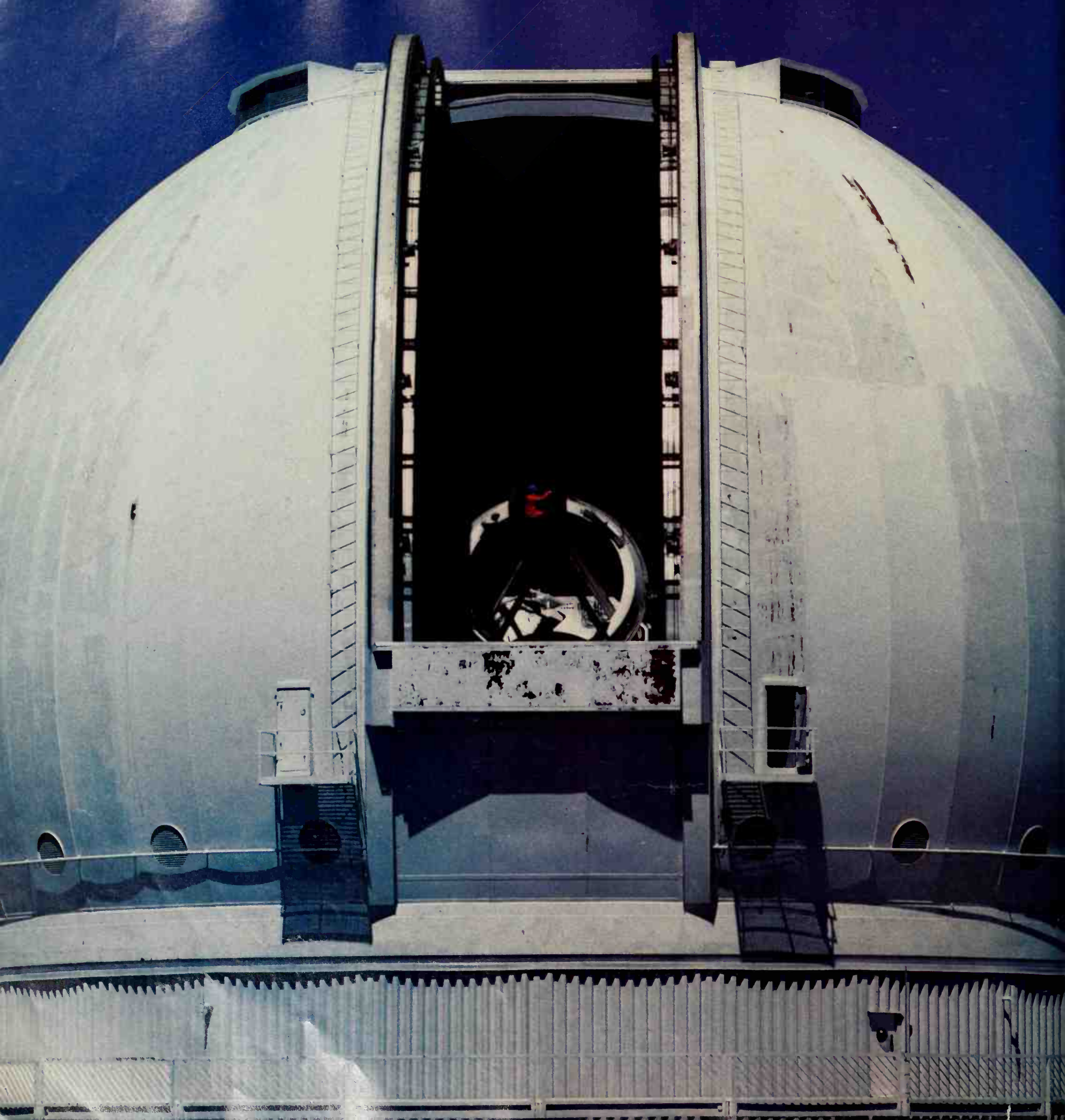
Big eyes on the Universe

We learn about the stars and galaxies by studying the light and other energy they radiate into space. Light energy does not need air or any other substance to carry it, contrary to some 19th-century beliefs. Sound-wave energy does. That means radiation can travel through empty space.

To detect light energy, you need no instruments other than your eyes. Light is only one form of radiation sent out by stars and galaxies. Light that appears white to our eyes can be broken up into a rainbow of colors called the *visible spectrum*. We can think of the different colors of light as waves of energy. The waves of any one color differ from the waves of all other colors. Violet light has the most energy and the shortest wavelength, or distance between wave crests. Blue light is a bit less energetic and has a longer wavelength, and so on through green, yellow, orange, and red. Red light has the least energy and the longest wavelength.

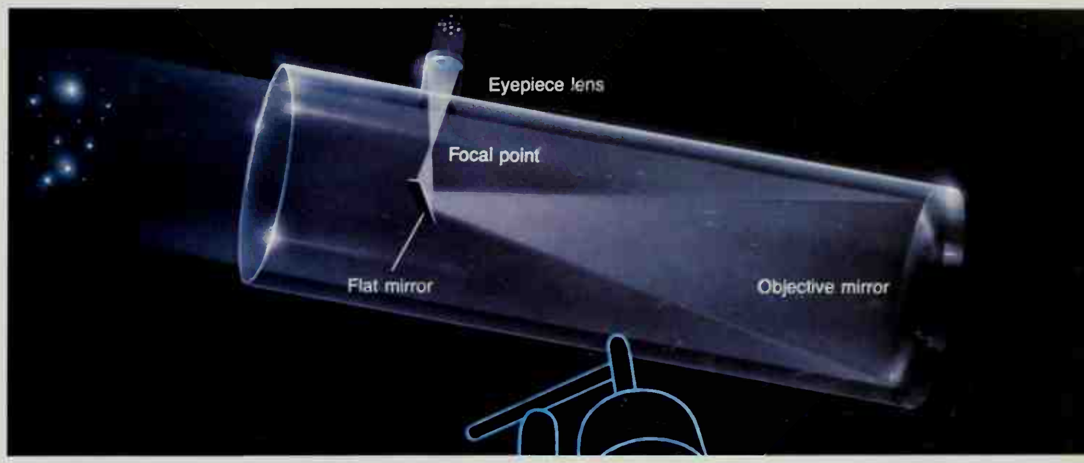
The visible spectrum is only a small slice of a larger spectrum of radiation called the *electromagnetic spectrum*. The shortest wavelength and highest energy radiation of the electromagnetic spectrum is *gamma* radiation. This ranges from 50,000 to many million times more energetic than visible light. The second most energetic radiation, with a slightly longer wavelength, are *X rays*. This radiation is 50 to 5,000 times more energetic than visible light. Both gamma rays and X rays can damage the cells of living tissue but in small amounts they have many uses in medicine and science.

raviolet
Visible light
Infrared
Radio waves



One of three giant reflecting telescopes at Hawaii's Mauna Kea Observatory opens its glassy eye on the skies. But here science "sees" what human eyes cannot: infrared radiation from deep in space. Several nations participate in this venture on a 4,200-meter mountaintop.

A reflecting telescope gathers light and bounces it off a concave glass or ceramic "dish" called the objective mirror. This curved mirror focuses the light on a small flat mirror which deflects it toward an eyepiece. There you glimpse wonders too faint for the eye alone.



Next to the X-ray region are longer wavelengths called *ultraviolet* (beyond violet) radiation. Then comes the visible spectrum. At wavelengths longer than those of visible light is *infrared* (below red), or heat, energy. And beyond the infrared is the least energetic radiation of all, with the longest wavelengths—*radio* energy.

We can think of each energy level along the electromagnetic spectrum as a special window through which we can "view" the Universe. Our view depends on which energy window we open. (Some examples are shown on pages 66 and 67.)

High-energy astronomy

If Newton and Galileo were alive today, they would be amazed by the new telescopes and the new field of high-energy astronomy, which is only about 20 years old. Gamma rays, X rays, and most ultraviolet radiation are blocked by Earth's atmosphere, so the new gamma-ray telescopes, X-ray telescopes, and ultraviolet-ray telescopes must do their observing from space satellites. Among the newest of these devices is the gamma-ray telescope-satellite HEAO-3 (High Energy Astronomical Observatory), launched in 1979. From its 480-kilometer-high orbit, the 2,950-kilogram spacecraft promises to unlock secrets about *supernova* remnants, and to provide information about exploding galaxies and the formation of chemical elements far out in the Universe.

Launched in 1977, HEAO-1 examined the sky through the X-ray window. Over 17 months it increased the known number of sources of X-ray emission from 350 to 1,500. Launched the following year, the largest X-ray telescope ever built—HEAO-2, nicknamed Einstein—has provided detailed images of X-ray objects in globular clusters, in the nucleus of the Andromeda Galaxy, and in supernova remnants. (See page 245.) Any high-energy sources, including *quasars, black holes,* and exploding galaxies, are targets for X-ray and gamma-ray telescopes. Orbiting telescopes viewing the Universe through the ultraviolet-energy window give us information about wind blowing from hot stars, and identify specific atoms and ions in the atmospheres of cooler stars like the Sun.

In time these new instruments may help astronomers solve the puzzle of how the Universe is evolving. They also may reveal how clusters of individual galaxies formed and have developed over time. And they may tell whether there is enough matter in the Universe that it may eventually, by gravity, stop the Universe from expanding.

Optical telescopes

Most big optical telescopes are designed to operate from the ground, preferably high on a mountaintop above atmospheric haze and far from the glow of city lights. Future optical telescopes in satellites orbiting Earth high above the atmosphere will give us our clearest pictures of sky objects.

Among the best known optical telescopes are the five-meter reflector atop California's Mount Palomar, which is 1,871 meters high, and France's famous Pic du Midi Observatory perched atop the Pyrenees at a height of 2,865 meters. Pic du Midi has 12 telescopes and other observing instruments. In the past, Pic du Midi has specialized in lunar and planetary study, but a new two-meter reflecting telescope will allow its astronomers to study distant galaxies as well.

At the present, the world's largest reflecting telescope is the six-meter reflector in the Soviet Union. But a new reflector

France's Pic du Midi Observatory has been peering through the thin clean air above the cloud-choked Pyrenees for a century. A new telescope, built to produce very sharp images, will study objects beyond the Milky Way. Others study the Sun, the Moon, and the planets.

proposed for the University of California should be nearly double that size at 10 meters. The new telescope would have four times as much light-gathering power as the Mount Palomar mirror and would be able to detect and photograph much fainter objects. It should give us new information about the way galaxies evolve. If a faint haze of light is detected around those mysterious objects called quasars, this may indicate that quasars are explosions inside galaxies in the early stages of development. The new telescope also might prove useful in detecting other planetary systems.

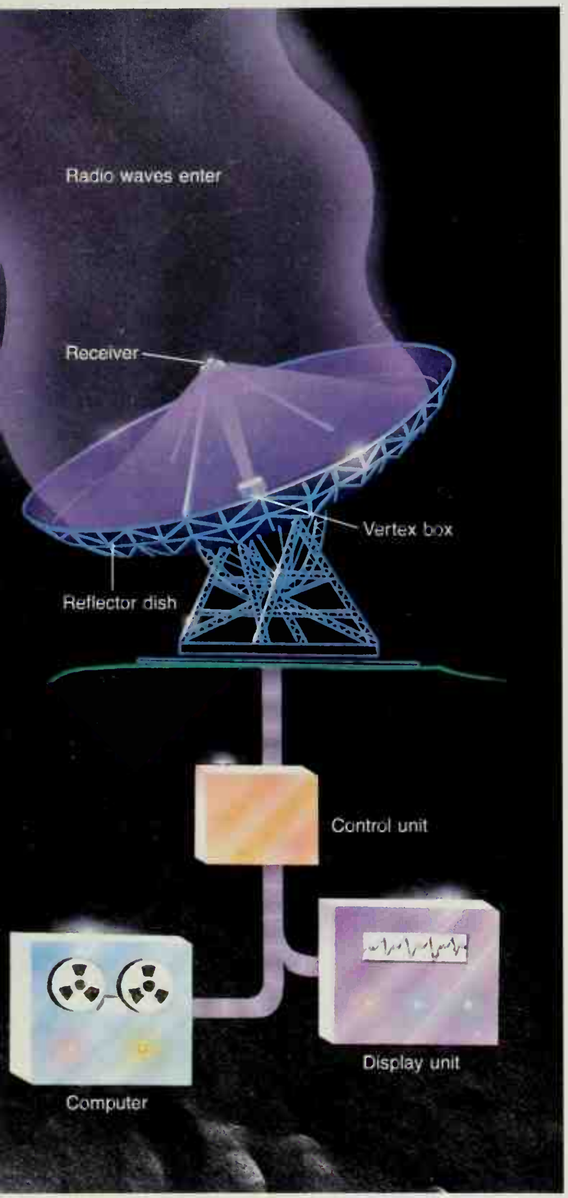
Infrared and radio telescopes

Infrared and radio telescopes give us still other "views" of parts of the Universe invisible to our eyes. Infrared telescopes, such as those on Mauna Kea, Hawaii, help to reveal the structure of galaxies and provide information about *nebulae* and quasars. They also study relatively cool, newborn stars, which are "brightest" at infrared wavelengths. So the life history of some stars can be viewed through the infrared window.

Radio-wave energy comes from many sources. In 1931 a physicist named Karl Jansky built a large moveable antenna to study radio static. The antenna picked up radio hiss coming from space. Jansky ruled out the Sun as the source and realized that the waves did not come from within the Solar System but from throughout the Milky Way galaxy.

In 1937 Grote Reber, a radio engineer, built the first radio telescope in his yard in

As an optical telescope gathers light, so a radio telescope gathers radio waves. Bounced from dish antenna to receiver, they are converted to electronic signals by a vertex box and amplified by a control unit. Computer and display unit produce graphs that show the "noise" of space.

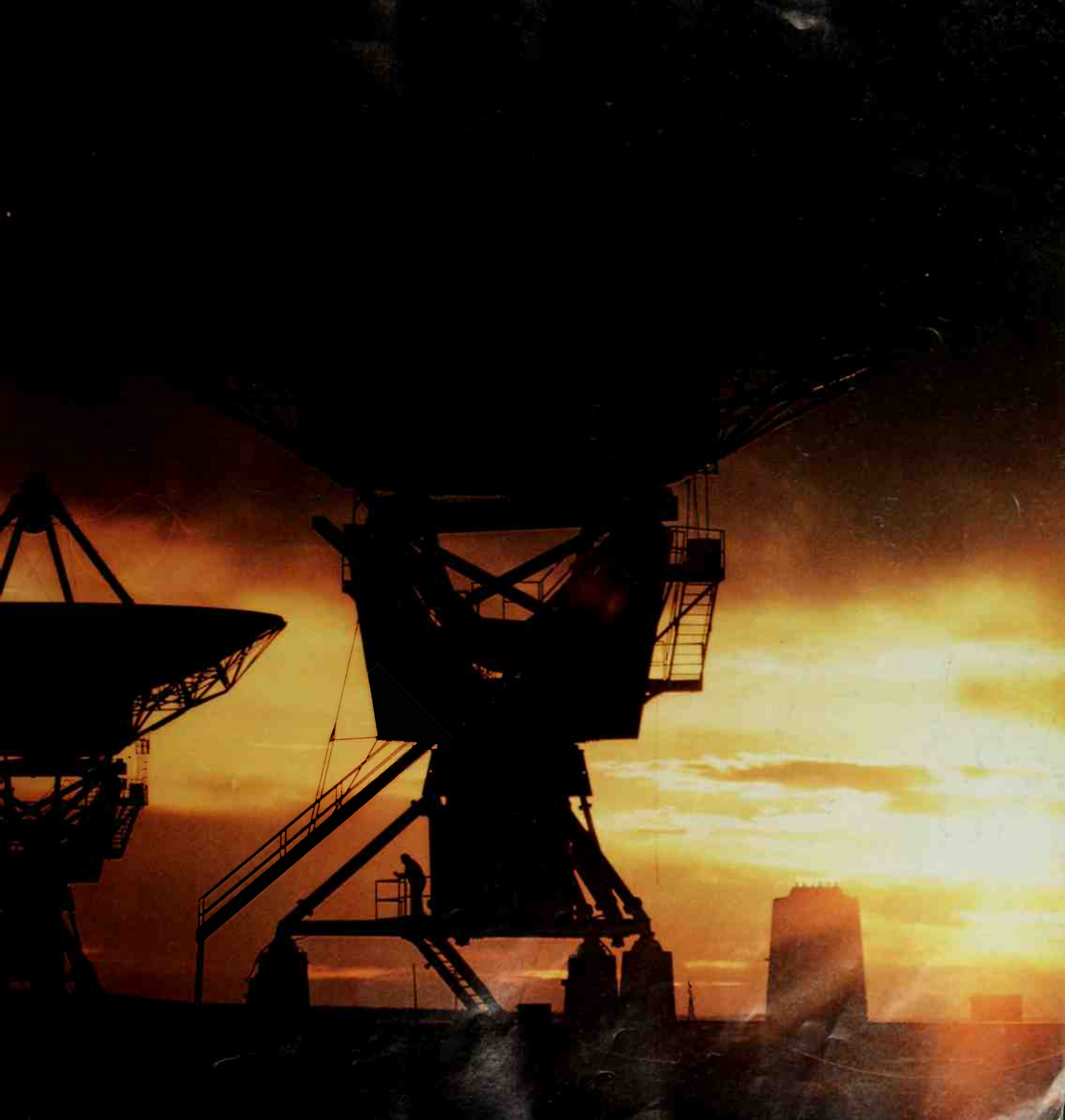


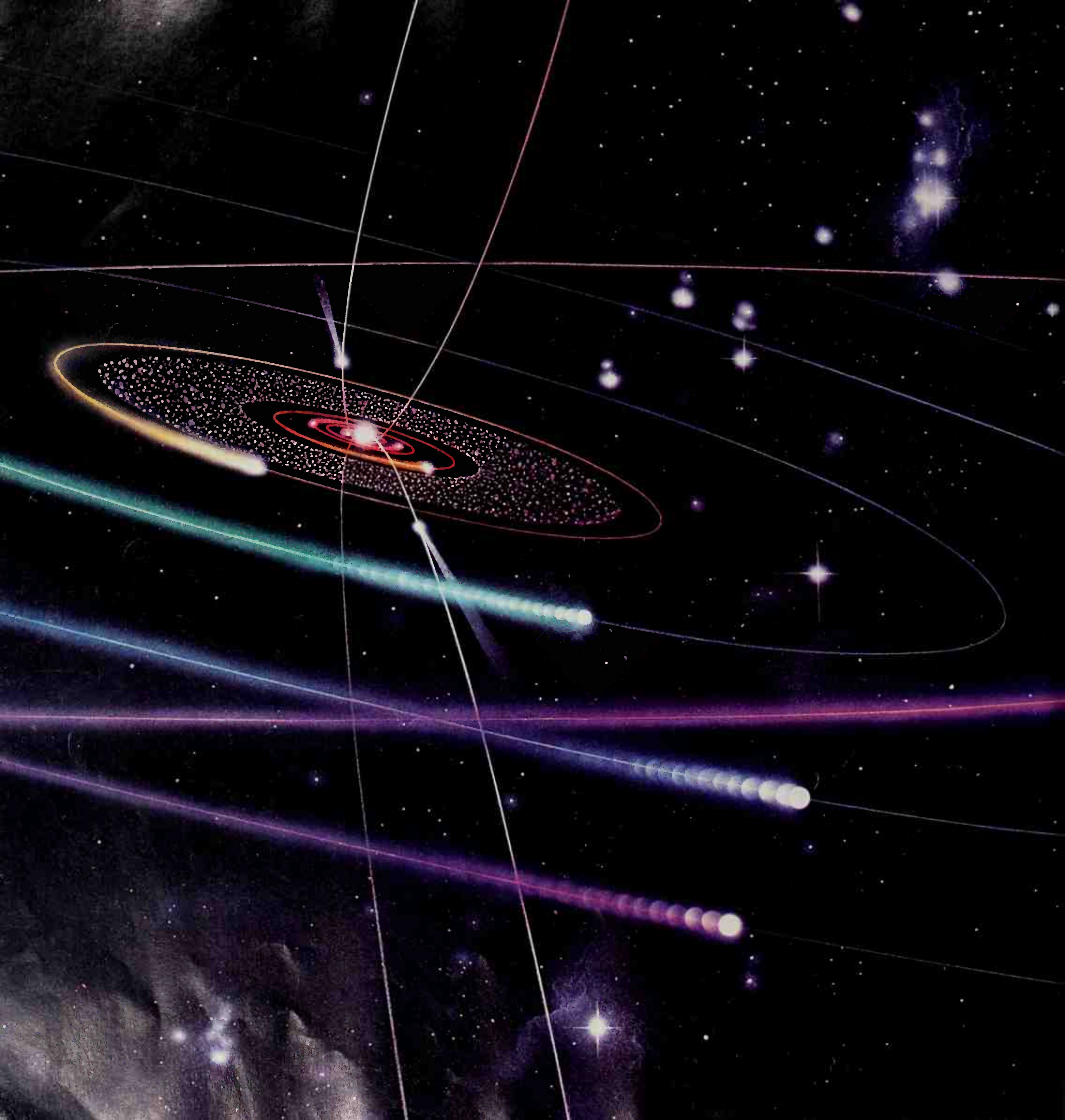
Seven giant bowl antennas tower over a worker at the Very Large Array in New Mexico. These titans and 20 more like them crawl about the desert on some 60 km of special track. Together they make up a single radio telescope—the biggest, most powerful, most sensitive ever built.

Wheaton, Illinois. By studying emissions from different parts of the sky, Reber made the first radio map of the Milky Way. The English scientist J. S. Hey detected radio waves from the Sun in 1942, and 13 years later the American astronomers B. F. Burke and K. L. Franklin discovered that Jupiter sends out radio signals. Since then astronomers have detected radio noise from supernova remnants such as Vela X and the Crab Nebula, from the mysterious quasars, from other galaxies, and from the hydrogen gas spread throughout our galaxy.

Radio telescopes give us much information about the Universe that other kinds of telescopes cannot detect. In the late 1960's and 1970's radio telescopes showed that many different chemicals drift through interstellar space. Among them are water vapor, carbon monoxide, ammonia, and formaldehyde, for example. Radio telescopes—by means of radar—also can "see" through Venus's dense cloud layer and map the planet's surface. These telescopes have become important tools with which to study those parts of our galaxy that are veiled behind clouds of space dust or located on the opposite side of the Milky Way behind the dense central region.

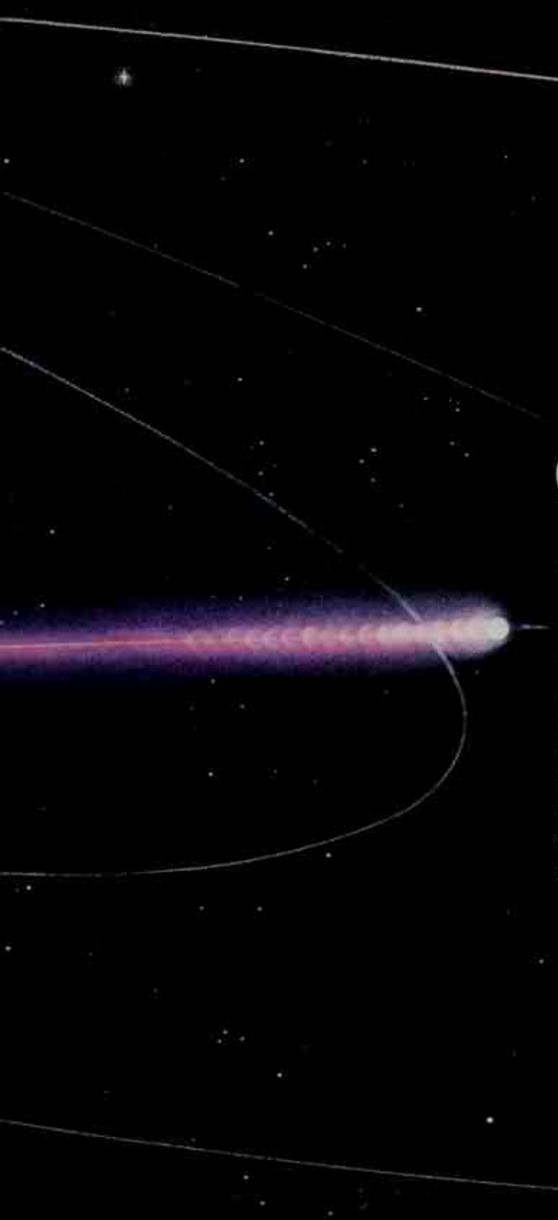
Astronomy's giant mechanical eyes view the Universe through invisible windows and reveal that the Universe is many, many times more complex and grander than we humans can detect with our unaided senses. If we ever manage to communicate with intelligent beings beyond Earth, it almost certainly will be through one of those windows on the Universe.





Our Solar System Home

The Sun & Planets



Our Solar System is an orderly community of one star, nine known planets, at least 36 moons, thousands of miniature planets called asteroids, and billions of meteoroids and comets.

This sweeping view is from beyond Pluto. The Sun, some 6 billion kilometers away, contains 99 percent of the matter in the Solar System. The inner planets – Mercury, Venus, Earth, Mars – orbit close to the massive Sun. The asteroid belt of rock-metal fragments separates these planets from the outer – Jupiter, Saturn, Uranus, Neptune, and Pluto. All but Pluto and Mercury move in nearly the same plane, unlike most comets, whose long, steeply tilted orbits loop around the Sun.

Stars radiate light of their own but planets shine by the light they reflect from the Sun. They all orbit in the same direction – the closer to the Sun the faster they go. Except for Venus, Pluto, and Uranus, the planets also spin, or rotate, the same way – counterclockwise in this view.

Between the planets the "solar wind" blows. Planetary dust and debris flicker in sunlight and starlight. Speeding meteoroids carry material that may be left over from the birth of the Solar System. But the Solar System is mostly empty space.

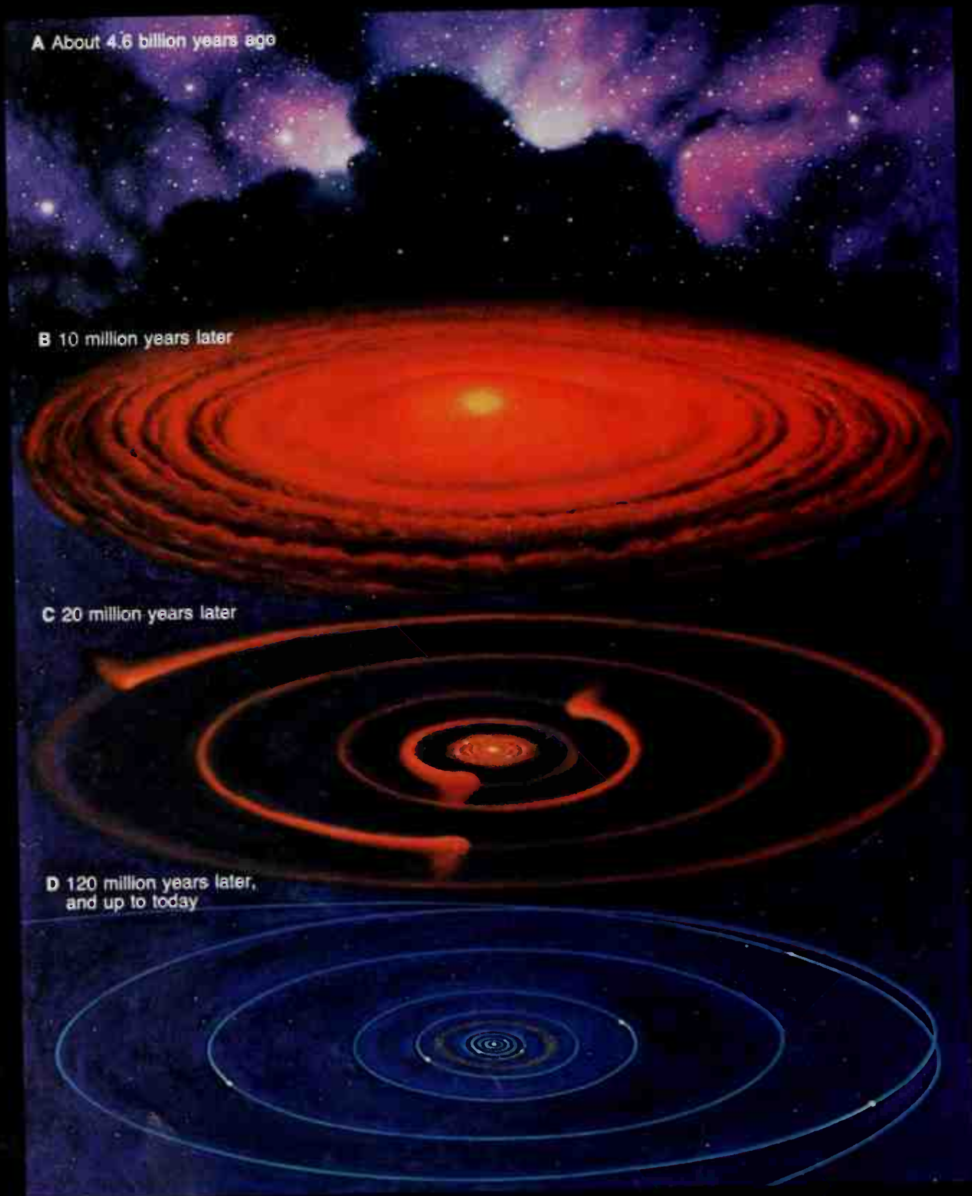
Facts about

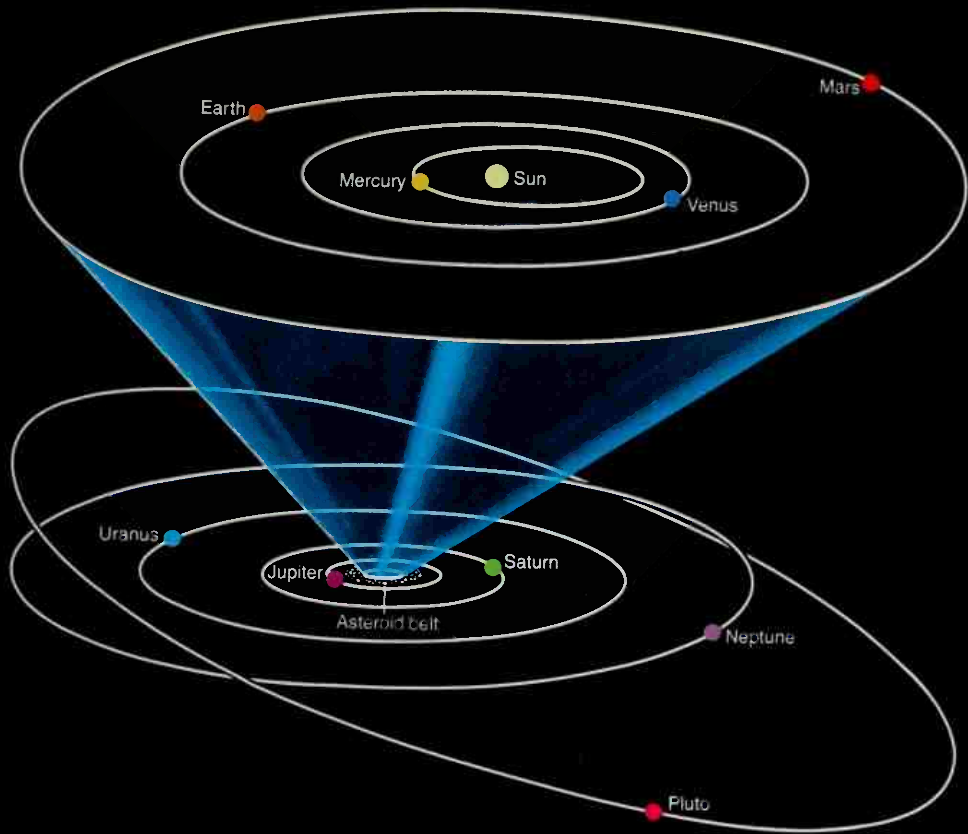
The Solar System

What it's mostly made of:

	Number of atoms for every one million hydrogen atoms
Hydrogen	1,000,000
Helium	85,000
Oxygen	661
Carbon	331
Nitrogen	91
Neon	83
Silicon	33
Magnesium	26

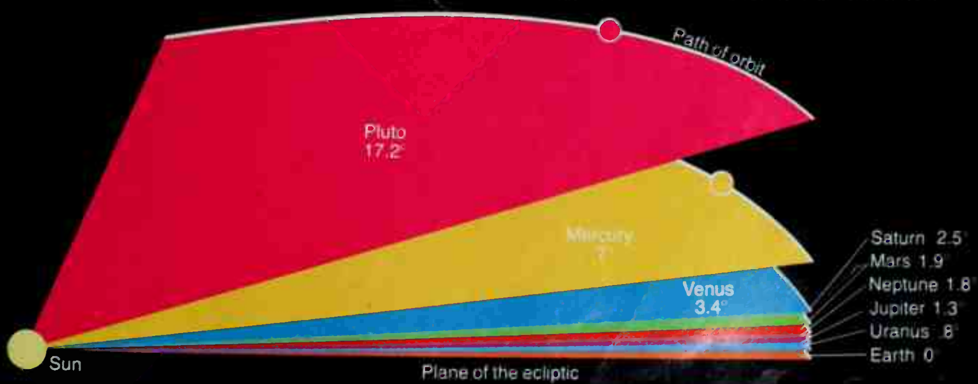
The birth of our Solar System remains a puzzle. Some 4.6 billion years ago, scientists think, a vast cloud of gas and dust (A), perhaps shaken by a nearby exploding star, collapsed into a spinning disk (B). Gravitation pulled so much material to the center that pressure and heat there lit a nuclear fire; the Sun began to shine. Other material slowly collected into lumps of hot solids and gases (C), which cooled into planets (D). All are built, like Earth and everything on it, of chemical elements evolved from that original cloud amid the stars—even the oxygen in our lungs, the iron in our blood, the calcium in our bones. And so, in a way, we all are made of stardust.



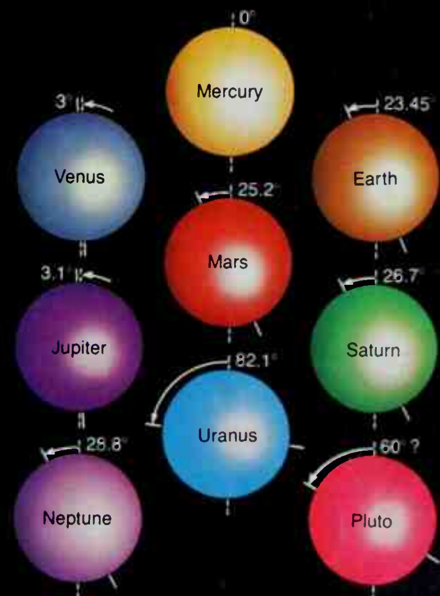


This view of our Solar System (above) compares distances. If Pluto's path were about the size of a bicycle tire, the orbits of the four inner planets would fit on the face of a quarter. All planetary orbits seem to form circles, but actually the circles stretch out a little, into *ellipses*.

Orbital tilts—Think of an orbit drawn on a piece of cardboard. The flat cardboard is the *plane of the orbit*. Planetary orbits tilt with respect to each other (see below). To measure the tilts, we use the angles between Earth's orbital plane, called the *ecliptic*, and the other orbital planes.



Speaking in turns—To describe how the planets move, we talk of *rotation* and *revolution* (above). A planet spinning on its axis *rotates*. A single rotation equals one of that planet's days. The planet also orbits around the Sun, or *revolves*. Each revolution equals one planetary year.



Like a tipsy top, each planet spins on a leaning axis (above). Only Mercury's axis stands perpendicular to its orbital plane.

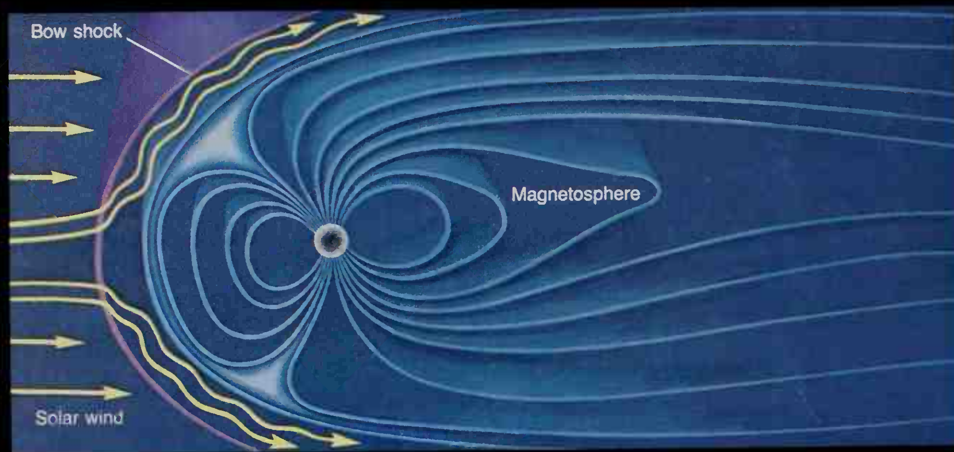
A family portrait of the planets, in order by orbit, compares sizes. The inner planets—Mercury, Venus, Earth, Mars—are called *terrestrial*, or Earthlike: small, rocky worlds with metal cores and (except for airless Mercury) shallow atmospheres.

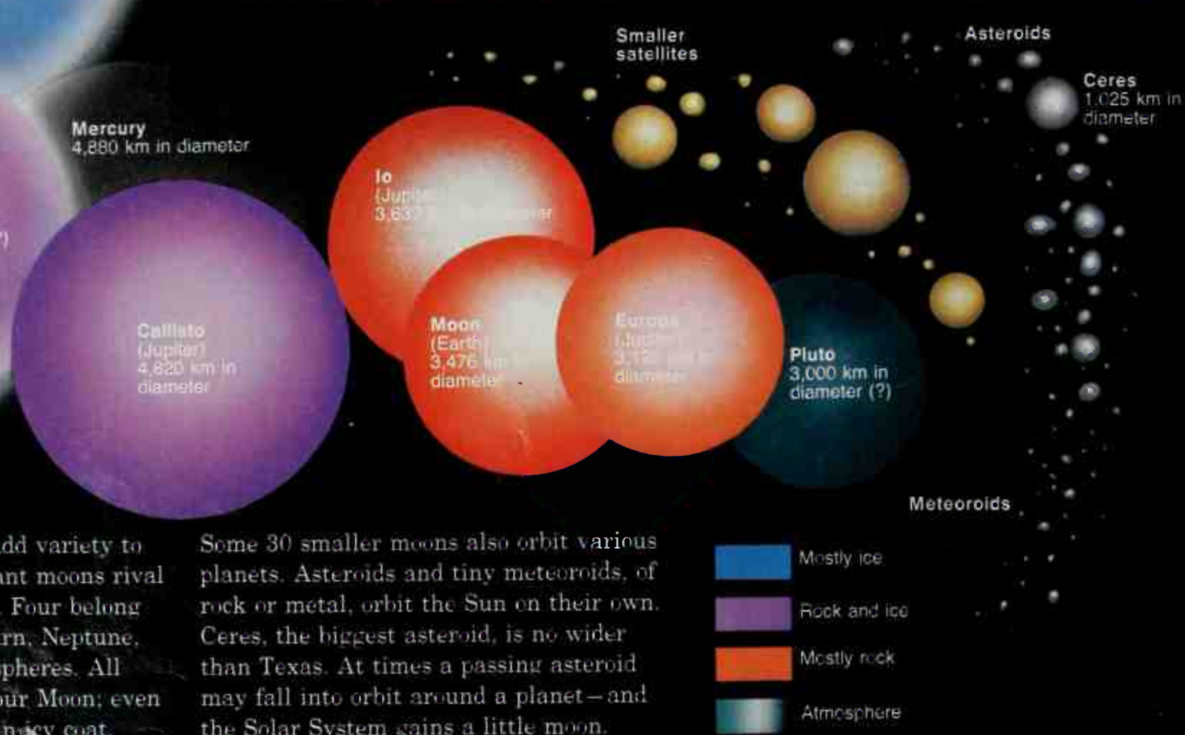
Outward lie the four *gas giants*. No solid surfaces here; deep atmospheres thicken into hot liquid, which reaches all the way to rocky cores. Joining Saturn's famous ring system are the faint, newly found rings of Jupiter and Uranus. Some observers suspect rings may also circle Neptune. The last planet, Pluto, is the Solar System's odd man out. Smaller even than Mercury, Pluto seems mostly ice. Satellites orbit every planet except Mercury and Venus. Jupiter and Saturn rule miniature solar systems, totaling five giant moons and many smaller ones.

By studying what our Solar System is like today, astronomers seek to know its past. They ask why some planets are mostly rock and metal, others mostly gas and ice. Did the terrestrial planets begin life as gas giants, only to lose most of their gases to the early Sun's wind and tides? Or did heat and motion near the Sun keep these newborn inner planets from collecting much gas to begin with?


Saturn
Uranus
Neptune
Pluto

Invisible forces clash as the *solar wind*, a steady spray of charged particles from the Sun, batters a *magnetosphere*—the region formed by a planet's magnetic field. A shock wave, or *bow shock*, takes shape where the solar wind is turned aside. It flows around the magnetosphere like a river gurgling around an island sandbar. As the river molds the sandbar, so the wind from the Sun molds the magnetosphere, creating a cometlike magnetic tail that streams away from the planet. Some planets have no magnetic field; no one knows exactly why.





Satellites and asteroids add variety to the Solar System. Seven giant moons rival the smallest planets in size. Four belong to Jupiter, one each to Saturn, Neptune, and Earth. Two have atmospheres. All are part ice, except Io and our Moon; even rocky Europa hides under an icy coat. Some 30 smaller moons also orbit various planets. Asteroids and tiny meteoroids, of rock or metal, orbit the Sun on their own. Ceres, the biggest asteroid, is no wider than Texas. At times a passing asteroid may fall into orbit around a planet—and the Solar System gains a little moon.

Mass, density, gravity—what do they mean? *Mass* is the amount of material that something contains. All objects have mass—even you. Mass floating in space weighs nothing, but it acquires weight in the field of gravity belonging to another mass—like a planet. Jupiter's mass equals 318 Earths, and Earth's equals the Moon, Mercury, Venus, and Mars put together.

Density tells us how tightly mass is packed. A dense object feels heavy for its size. A one-pound rock and a one-pound pillow have the same mass, but the rock is denser; it takes up less space. The density of the inner planets averages partway between stone and iron. In our giant water glass, they would sink. But Saturn, mostly gas and ice, is less dense than water; we can imagine it floating.

Gravity: The more mass a planet has, the stronger the pull of its gravity, and the more you weigh there—although the mass of your body stays the same. Your Earth weight falls to one-sixth on our Moon, but more than doubles on massive Jupiter. Yet if Jupiter's mass is 318 times Earth's, why aren't you 318 times heavier at its surface? The reason: gravitational attraction weakens with distance. Jupiter is not dense and compact like Earth, so its surface lies far from its massive center.

	☿ Mercury	♀ Venus	⊕ Earth	♂ Mars	♃ Jupiter	♄ Saturn	♅ Uranus	♆ Neptune	♇ Pluto
Average distance from the Sun (Millions of kilometers)	57.9	108.2	149.6	227.9	778.3	1,427	2,870	4,497	5,900
Revolution	88 Days	224.7 Days	365 Days	687 Days	11.86 Years	29.46 Years	84 Years	165 Years	248 Years
Rotation	59 Days	243 Days Retrograde	23 Hours 56 minutes	24 Hours 37 minutes	9 Hours 55 minutes	10 Hours 40 minutes	13-24 Hours (?) Retrograde	18 Hours 30 minutes (?)	6 Days 9 hours 18 minutes Retrograde
Average orbital speed (Kilometers per second)	48	35	30	24	13	9.7	6.8	5.4	4.7
Equatorial diameter (Kilometers)	4,880	12,100	12,756	6,794	143,200	120,000	51,800 (?)	49,500 (?)	3,000 (?)
Mass (Earth = 1)	.055	.815	1	.107	317.9	95.2	14.6	17.2	.002 (?)
Density (Water = 1)	5.4	5.3	5.5	3.9	1.3	.7	1.2 (?)	1.7 (?)	3-.8 (?)
Surface gravity (Earth = 1)	.33	.91	1	.38	2.54	1.07	.90 (?)	1.15 (?)	.05 (?)
Known satellites	0	0	1	2	14 (?)	12 (?)	5	2	1

What if . . .

. . . there really were creatures on other planets? Scientists now suspect that in our Solar System only Earth cradles life. We cannot yet rule out Mars, but so far our spacecraft have not detected anything obviously alive. Some experts still hope to find life elsewhere—perhaps under the ice of Jupiter's moon Europa, or even floating in the atmosphere of a gas-giant planet—but chances are slim. Yet we can still try to imagine how life might adapt to the environments of other worlds. Just for fun, let's go on an imaginary safari to real places faithfully described, and see some creatures that never were.

Titan On dim, cold Titan, Saturn's giant moon, *stovebellies* might live—perhaps by the icy shores of a methane sea. To avoid freezing, they keep fires burning inside their bodies. How? Stovebellies eat ice, which forms much of Titan's surface. Their fuel is made of oxygen from the ice and methane from the dense atmosphere. By squirting flame like a rocket, they can make long leaps in Titan's low gravity. Amphibious *fishimanders* like to crawl out of the sea and cuddle by a handy stovebelly for warmth—until their host blasts off, sending its guests flying.

Mars Whisper-thin winds hiss along a dry, dusty canyon. Deadly ultraviolet radiation pours from an unshielded Sun. Nighttime cold reaches –80°C. Perfect weather for a fellow like the *Martian waterseeker*. Its parasol tail can lift three meters in Mars' low gravity, shading it from ultraviolet sunburn. The long snout can probe for pockets of ice under dried-up channels. And the giant ears, needed to hear well in the thin air, also serve as blankets: In Mars' frigid nights the waterseeker stays snug by clamping its ears tightly around its whole body.

Europa Flat ice covers the second of Jupiter's four major satellites. Europa may be the smoothest globe in the Solar System. And here *brinker-roos* might frolic, on feet shaped like skates. They lead a carefree life, living on pure energy as they zoom across the endless frozen plains. Since there's no air to breathe and no food to eat, brinker-roos need no mouths or noses. Their green skins can carry out photosynthesis in sunlight, as plants do. And the coils on their backs pick up energy from Jupiter's strong magnetic field, which Europa must travel through as it orbits the giant planet.

Pluto Electrical, crystal beings like these *Plutonian zistles* would find -250°C too hot for comfort. At night, when it's colder still and electricity flows perfectly, zistles feel best. Highly intelligent, they spend most of their time radioing great thoughts to each other. When zistles do get going, they can spring 20 meters high in Pluto's feeble gravity. Zistles think Pluto is the only planet with life —it's too hot everywhere else!

Venus To survive Venus's heat—lead would melt here—you might need a body that feeds on rock and metal. This *oucher-poucher* (above) snacks on a space probe from Earth. Venus's surface is so hot that oucher-pouchers keep shifting from one foot to the other. They travel by inflating their pouchlike bodies and bouncing along the ground. Every time one lands, it utters its customary cry, which sounds remarkably like "ouch!"

Jupiter From birth to death, any life in Jupiter's wild atmosphere would have to stay airborne (right)—there's no place to stand. Hanging from their gasbags, floating *jellyblimps* would be easy prey for hungry *swordtails*. A swordtail uses Jupiter's strong gravity and its own pointed body to dive right through its victim. All creatures here must avoid winds blowing toward the freezing layers above or the scorching pressures below.

The Star We Know Best

The Sun

The Sun, like a sea of flame, is never still. Restless and seething, it is the star nearest Earth, so it is the star we know best. Here, a great, looping prominence explodes out of a strong magnetic area around a sunspot, hurtles hundreds of thousands of kilometers skyward, then arcs back down. An especially active Sun produces many sunspots, some large enough to gobble up several Earths. Across the surface, hot gases well up in cells called granules. The dancing gas spikes that seem only to rim the Sun actually cover its entire surface and form the lower atmosphere. The outer atmosphere, the corona, extends millions of kilometers beyond the surface gases. A tuft of the prominence has been caught in the Sun's magnetic field.

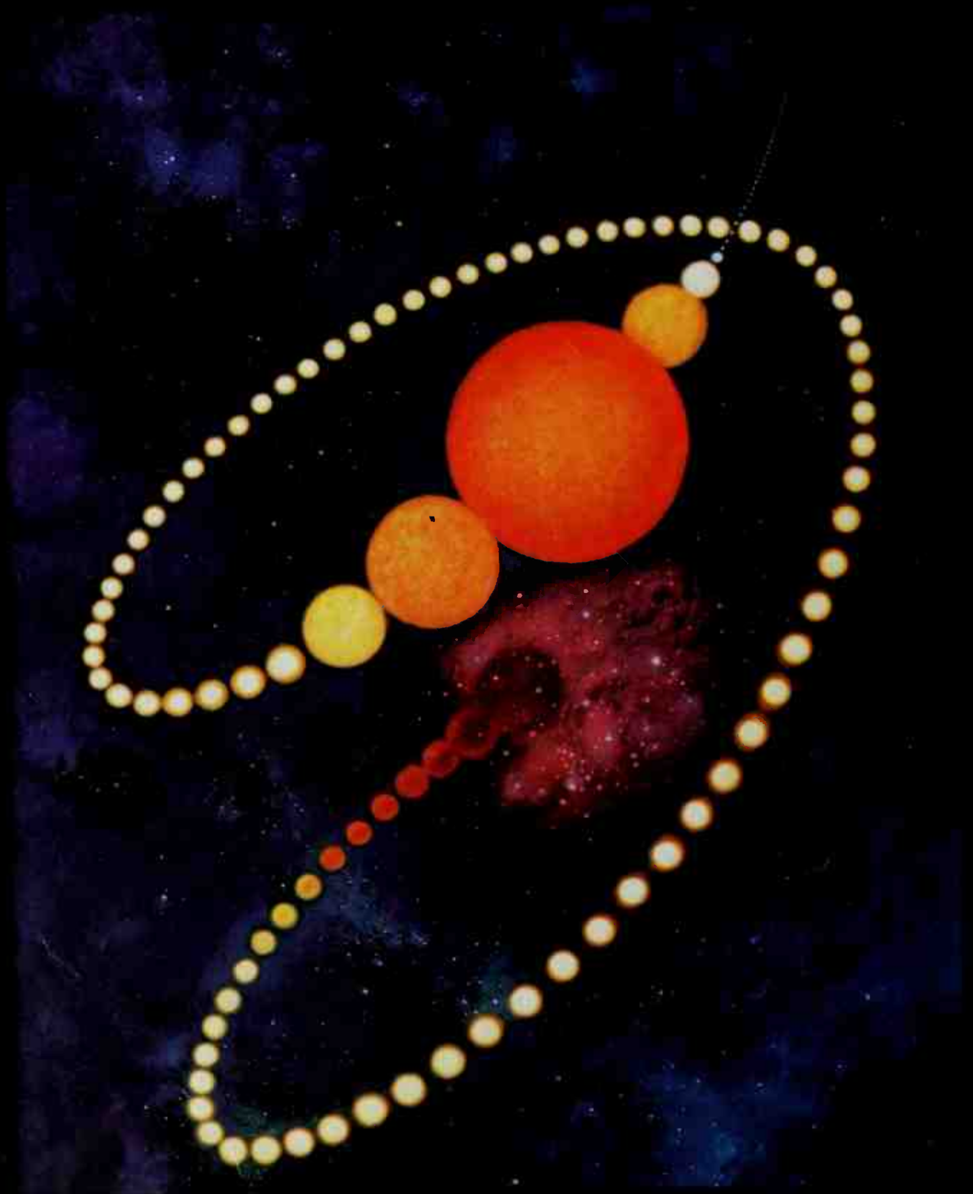
In ancient times, people thought of the Sun as a perfect sphere of celestial fire created by the gods. Later it was seen as a solid object or a ball of liquid. Sunspots were a puzzle to astronomers of old: Were they clouds? Were they mountain peaks? Were they windows to a cool surface? We will answer these questions as we descend through the Sun's atmosphere, through its gaseous "surface," and into the core where its great nuclear furnace generates the energy that makes possible our life on Earth.

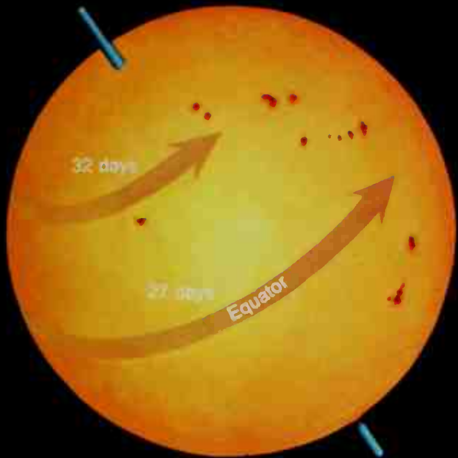
Facts about

The Sun

Apollo the Sun god brings life-giving heat and light to Earth. As patron god of musicians and poets, he carries a lyre. Symbol: ☉ the egg of creation.

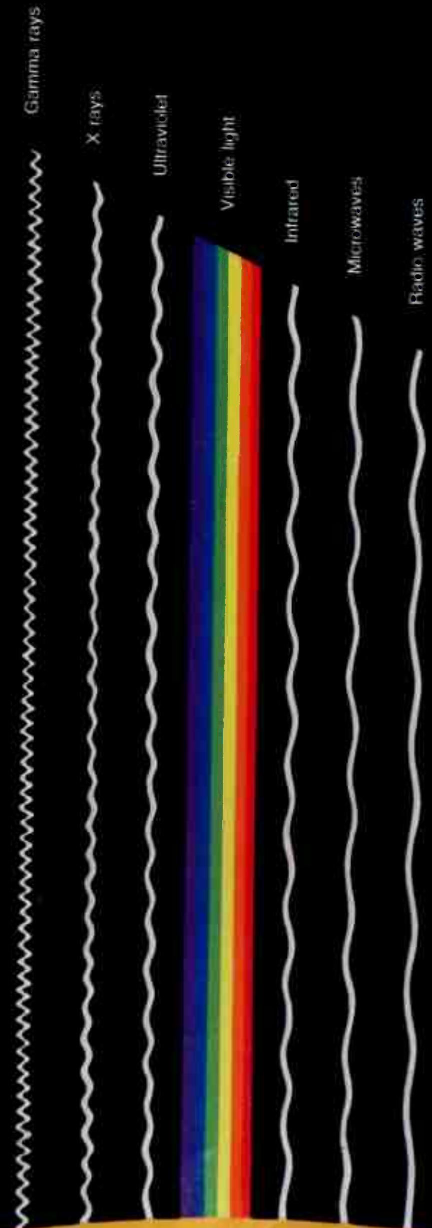
Birth and death of the Sun: About five billion years ago, the Sun began to form in a huge cloud of gas (right). As the material condensed, high temperatures and great pressures built up at the center. This set off a nuclear reaction that still releases energy and causes this star to shine. In another five billion years, as the Sun's hydrogen is used up, it will expand to the *red giant* stage, swallowing Venus and Mercury and making Earth's surface semi-molten. The outer layers will expand into space, leaving a *white dwarf*. When the Sun cools, only a *black dwarf* cinder will remain.





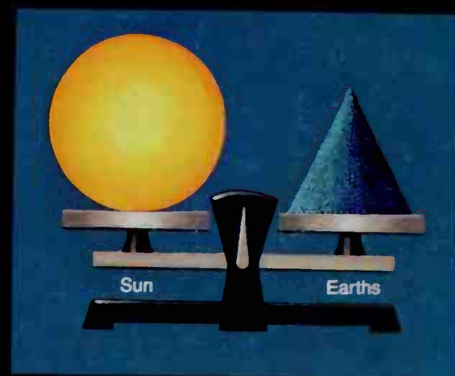
Tilted about 7° to the plane of Earth's orbit, the Sun spins on its axis from left to right, as we see it from Earth. By tracking dark specks called sunspots, astronomers first observed that the Sun rotates unevenly. Sunspots near the equator are carried faster than sunspots near the poles. This uneven rotation produces strong magnetic fields and leads to violent solar storms. The Sun's surface bubbles and explodes constantly in a raging inferno of gases.

Radiation from the Sun travels in waves (right). Each wavelength – from gamma rays to radio waves – carries a different amount of energy. Only light, the wavelengths that make up the band of rainbow colors, is visible to the human eye. But we can feel infrared rays as heat, and ultraviolet rays tan our skin. Some radio waves reach Earth, heard with special instruments as a low static noise. The other radiation does not pass through Earth's atmosphere.



WARNING!

Never look at the Sun directly or through a telescope or binoculars. If you do, you can damage your eyes permanently.



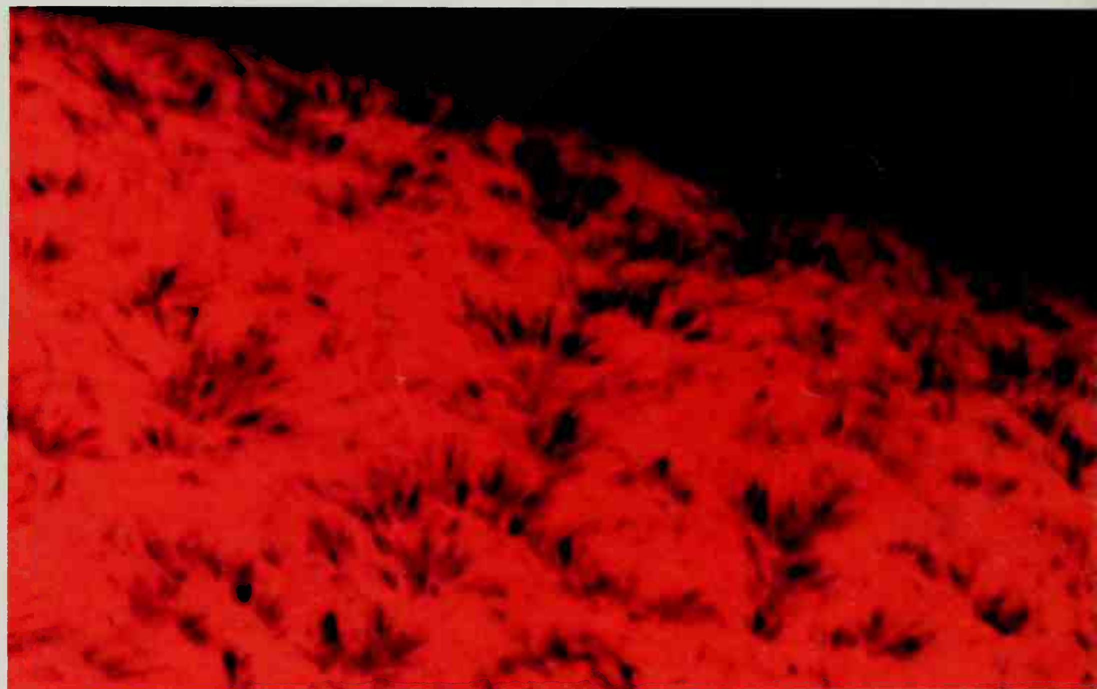
Mass of the Sun: It would require about 333,000 Earths to equal the Sun's mass. But more than a million Earths could fit inside. This is because the Sun's volume is greater. Solar matter averages one-fourth as dense as earthly matter.

Comparing sizes: The Sun is an average size star, but it dwarfs our planet (below). About 109 Earths could fit side by side across the diameter of the Sun.

Only a sliver remains (left) as the Moon eclipses the Sun in February 1979. Scientists take advantage of eclipses to study the Sun's corona—bright streamers that become visible when the Sun's disk is covered. Several prominences appear around the rim as bright orange spots.

Clumps of spicules (below) sprout up through the Sun's lower atmosphere into the corona. These jets of glowing gas may rise as high as 10,000 km before the Sun's gravity pulls them down. Spicules form along lines of magnetic force and last for an average of five to ten minutes.

On the next page: *At the Sun's edge, a huge bubble of gas erupts to form an arching prominence. A filter on the camera lens permitted only light from a wavelength of hydrogen called H alpha to pass through. This is the strongest line in hydrogen's visible spectrum.*



The Sun is always changing. And its changes are what interest us most as we try to learn about our local star—what it is made of, what makes it shine, and how long it will keep shining. The more we find out about the Sun, the more we will know about other stars. Another reason to study the Sun is that it shapes our lives on Earth in many ways. Weather and climate are only two of them. So the more we know about the Sun, the better we can predict its changes and their effects on Earth.

By bouncing radar signals off the Sun and timing their return, we can measure the Sun's distance from us—about 150 million kilometers. If we could fly to the Sun in a jet airliner traveling 1,000 kilometers an hour, the journey would take us about 17 years. But if we traveled at the speed of light—300,000 kilometers a second—we would make the trip in only eight minutes!

A journey through the atmosphere

During a total eclipse of the Sun, the Moon blocks the glaring disk. Then we can see the Sun's atmosphere fanning out into space. The main outer part of this atmosphere, the *corona,* glows in a frail, flamelike pattern. Its brightness is about that of the full Moon.

The corona begins about 2,500 kilometers above the surface and stretches out beyond the orbit of Earth. But the corona's shape changes from day to day. Sometimes it swells up and shoots hot streamers of matter across millions of kilometers.

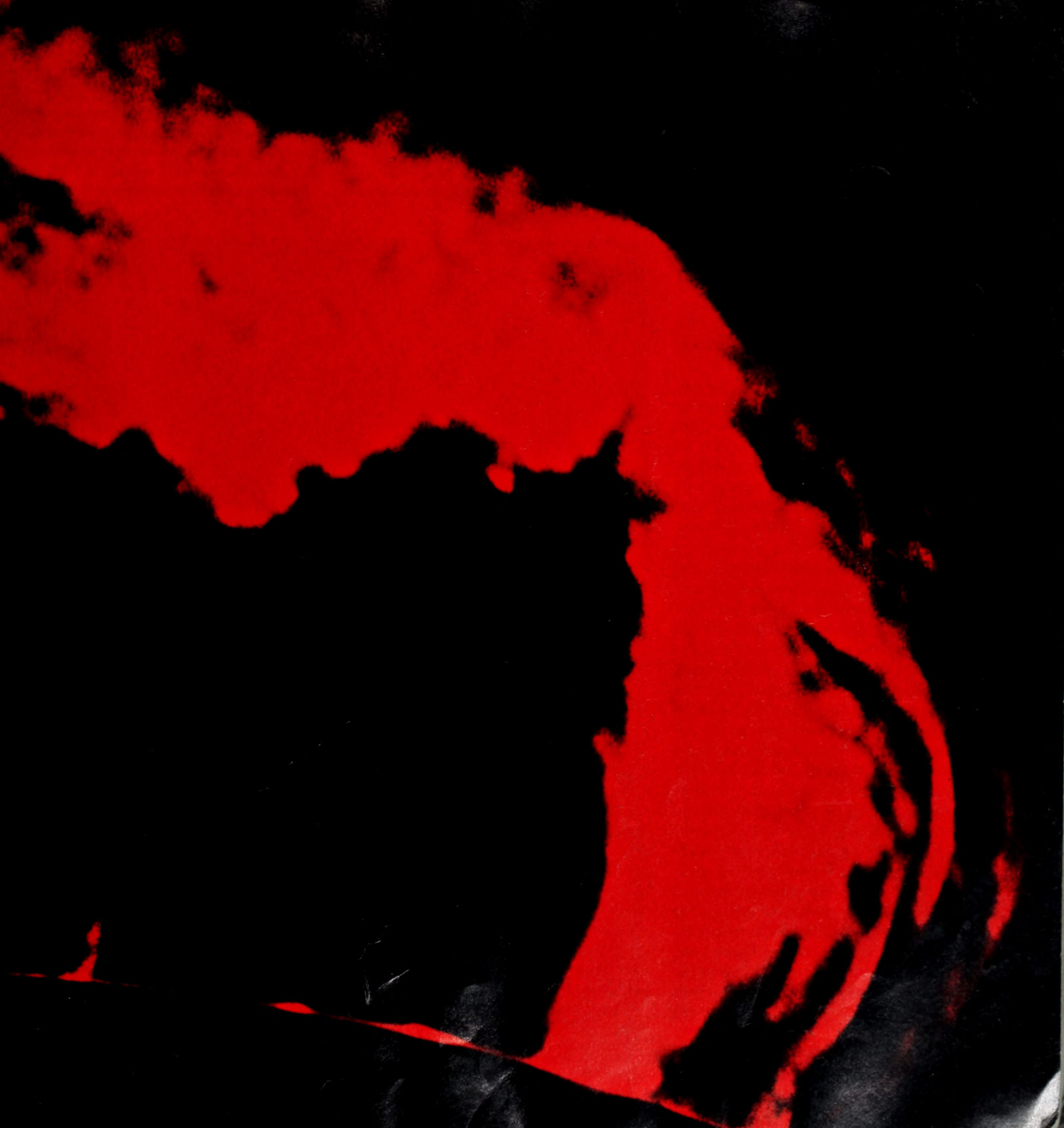
Photographs of the corona usually show fanlike patterns of gas at opposite poles of the Sun. These patterns are evidence that the Sun has a magnetic field. This great magnetic field is made of many small magnetic areas which force their way out and spread over the surface. These slowly changing fields act together to vary the corona's shape over days or weeks.

The Sun is composed mostly of hydrogen, with some helium and other elements. There are no whole atoms inside the Sun, since high temperatures would cause them to collide and smash to bits. Individual pieces swim about freely as a thin solar soup called *plasma.* Tons of this plasma are cast off by the Sun each day and stream into space as the *solar wind.*

Gas storms in the chromosphere

Sandwiched between the corona and the Sun's surface is the lower atmosphere, the *chromosphere,* or "color sphere." During an eclipse we see it as a thin, ragged, pinkish rim of light. This is a denser layer of gas than the corona but it, too, is almost empty of matter—a near vacuum. The temperature of the chromosphere is much lower than that of the corona because its atomic particles are moving about more slowly.

The chromosphere is torn by eruptions. Its entire surface dances with bursts of gas 1,000 times higher than the highest mountains on Earth. Called *spicules*—"little



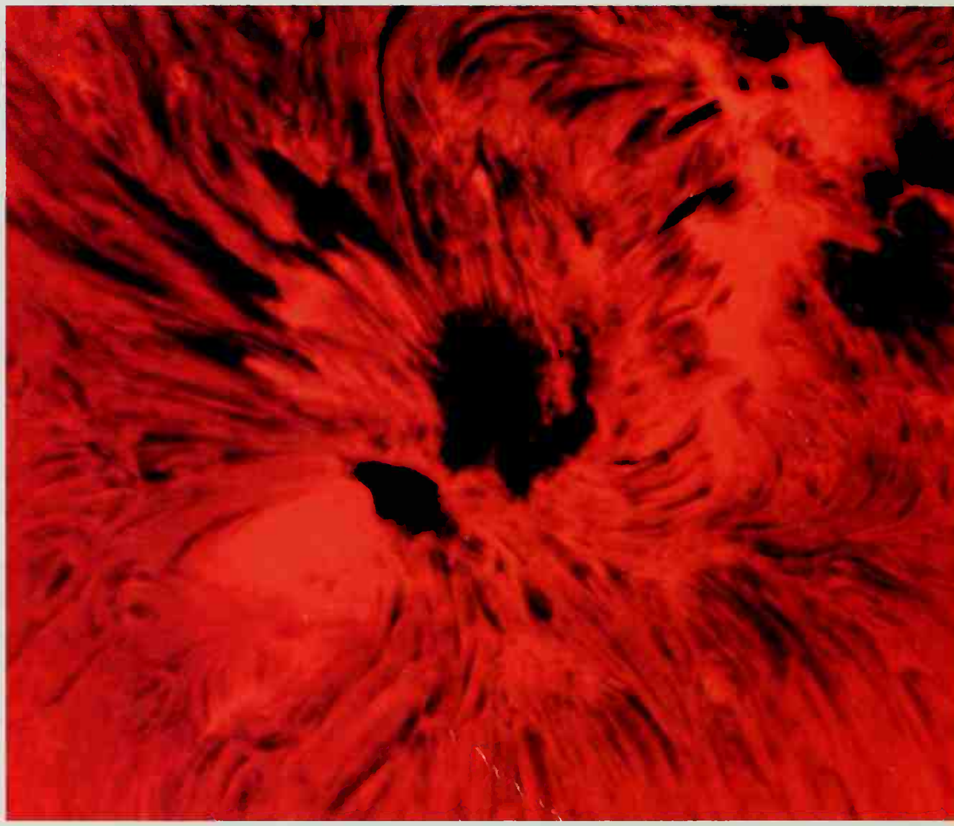
Close-up: A powerful solar telescope zeros in on sunspots below the Sun's seething chromosphere. In this hydrogen-alpha photograph, they appear dark because they are cooler than surrounding gases. At lower left, a violent but short-lived eruption called a flare surges upward.

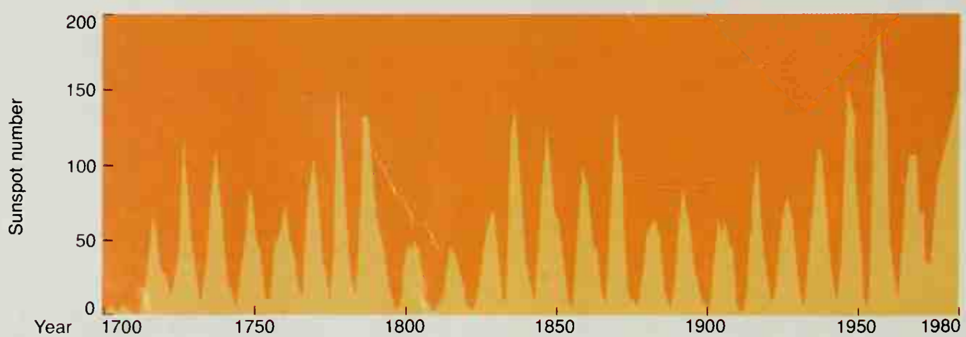
Sunspots vary in number on an 11-year cycle (bottom). With a maximum expected in 1980-81, NASA's Solar Maximum Mission has launched a satellite to study flares and other eruptions that accompany sunspots. Flares cause various disturbances in Earth's magnetic field.

spikes"—these pointed eruptions encircle large cells of upwelling gas. Fenced in by spicules, each cell of gas measures about 30,000 kilometers across and is called a *supergranule*. A supergranule may last half a day. It wells up, spreads out, and dissolves. Then a new one replaces it.

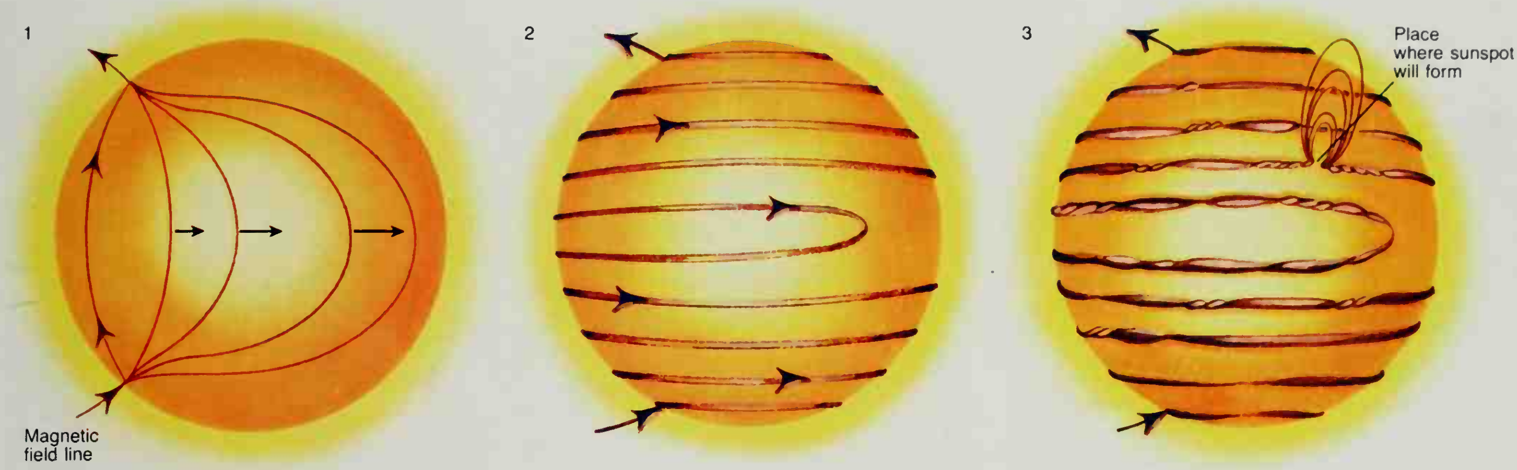
The most violent events on the Sun are *flares,* fiery eruptions like the flash explosion of a huge pool of gasoline. Just one sets free the energy of 10 million hydrogen bombs. When a flare erupts in the chromosphere, the energy of twisted magnetic fields is suddenly released as intense light and streams of particles. When the solar surface is especially active, astronomers see flares every hour or two. But when the Sun is quiet there may be none for days or weeks. Flares help to cause the "northern lights," or *aurora borealis,* and can disrupt shortwave radio signals.

Great clouds of gas—*prominences*—hang above the chromosphere, held by magnetic fields. As they come out through the surface, the magnetic fields continually stretch and change, sometimes hurling vast amounts of plasma high into the solar sky. Gigantic geysers of glowing gas may surge upward more than 100,000 kilometers at speeds as great as 500 kilometers a second. These prominences often make graceful loops. Sometimes they float for several months, like summer clouds—but clouds at temperatures as high as 10,000 kelvins. (Kelvins are units of temperature; room temperature is about 300 kelvins.) Some eventually cool and fall back into the Sun. Others are thrown out so fast that they escape from the Sun's





How sunspots form: According to the "twisted rope" concept, a pair of sunspots may start with a single line of magnetic force lying north-south. (1) Because the Sun rotates faster at the equator, the middle of the line progresses faster. (2) The line has wrapped several times around the Sun. (3) The line has stretched and twisted like a rubber band, creating very strong local magnetic fields. Finally, a kink of tangled magnetic field erupts through the surface and produces a pair of sunspots. Flares and prominences form in the sunspot area.



gravitational pull and are lost in space.

Beneath the chromosphere is the Sun's surface, called the *photosphere,* or "sphere of light." It is a bubbling sea of hot gas cells called *granules*. These are like the chromosphere's supergranules but much smaller and with a life of only about six minutes. The photosphere gases have a temperature of about 6,000 kelvins. Most of the light and other energy we receive comes from the Sun's thin photosphere layer.

Sunlight

The sunlight we see every day is made of tiny units of radiant energy called *photons*. Born in the inferno of the Sun's core, they spend millions of years slowly wandering up to the surface. Then in eight minutes they speed across the 150 million kilometers to Earth—if they happen to be headed in our direction. Depending on the amount of energy a photon has, it may be absorbed by Earth's atmosphere. Or it may zip down to Earth's surface and help warm a flea or a blade of grass for a fraction of a second. Each photon carries only a tiny amount of energy but trillions of them hit each square meter of Earth every second. Together they form sunlight. Of course, clouds, water, and the ground itself reflect a lot of sunlight back into space. It is this reflected sunlight that allows us to see Earth from a spaceship.

Spots on the Sun

More than 2,000 years ago, Chinese astronomers reported seeing sunspots when thin clouds, smoke, or dust dimmed the Sun's blinding disk. In 1612 the Italian astronomer Galileo studied them with the help of a telescope. By focusing the Sun's image on a piece of paper, he could trace the spots. (No one should ever look directly at the Sun, especially with a telescope.) Day after day he watched them glide across the Sun's face near the equator. Each spot took about 13 days to move from one edge and slip around the opposite edge. This movement told Galileo that the Sun rotated.

Since Galileo's time, people have kept track of sunspots. When there are a lot, we say that the Sun is active, and when there are few, we say it is quiet. An active sunspot period begins when several spots break out about midway between the poles and the equator in both hemispheres of the Sun. Then year after year the new spots emerge closer and closer to the equator.

A large sunspot may be five times larger than Earth. Around the edge, thin gas streamers make a pattern of magnetic force lines. This suggests that each sunspot is the location of extremely powerful magnetic fields—several thousand times stronger than Earth's average magnetic field. Such powerful magnetic fields prevent the usual flow of energy upward, making the Sun's surface cooler and thus darker in the area we call a sunspot. Thus sunspots are not the

Portrait of the Sun shows its most widely studied features and a cross section of its interior. From the core, nuclear energy radiates out to the convective zone, where giant bubbles of hot gas rise and sink. The chromosphere and corona make up the Sun's lower and outer atmospheres.

raging tornadoes people once thought. They are giant magnetic fields that cool areas of the Sun. Also, sunspots contain the strong magnetic forces that ignite solar flares, trigger prominences, and change the shape and size of the corona. When there are many sunspots, there are many flares and prominences. Sunspots announce the coming of storms on the Sun. They are a storm alarm for the entire Solar System.

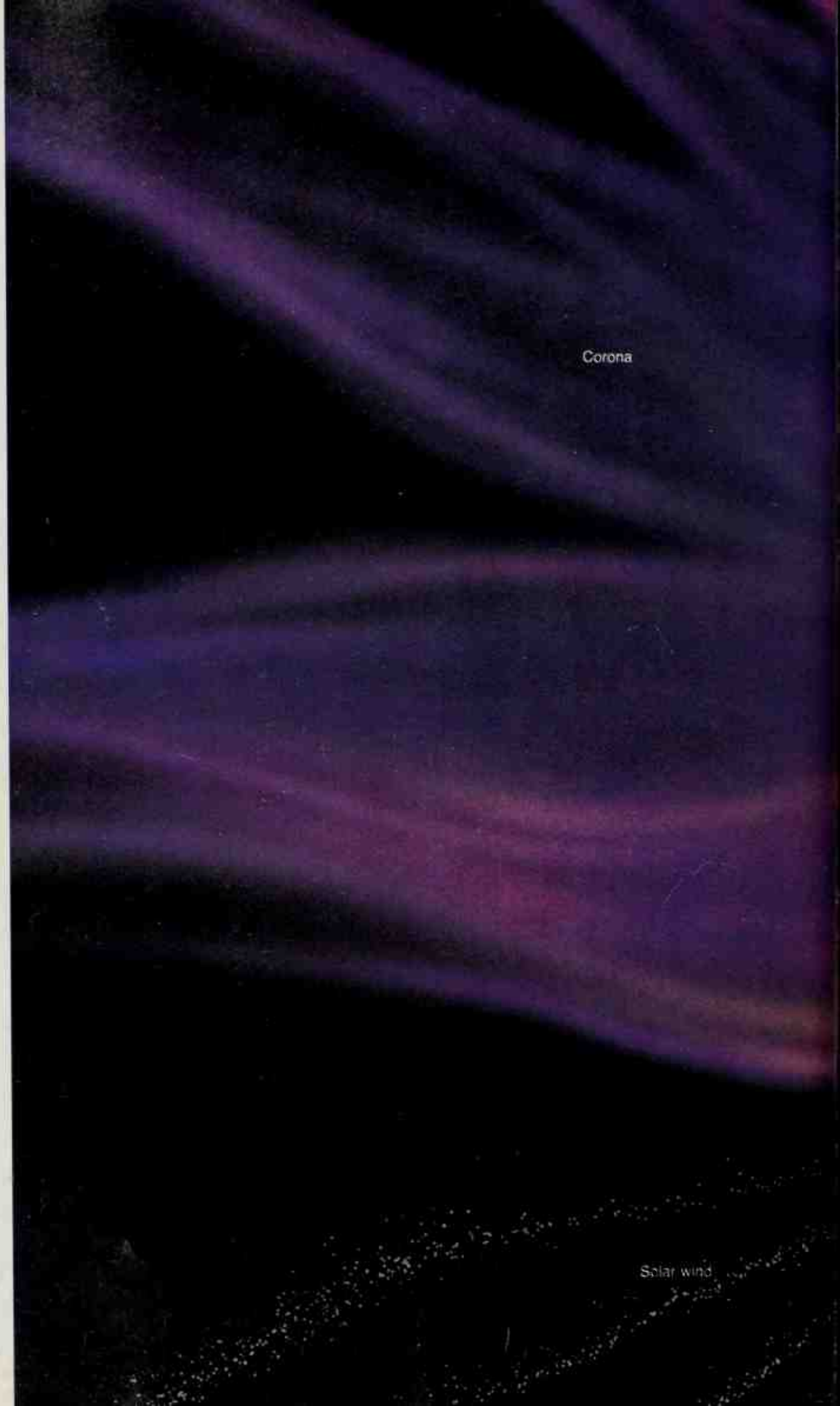
The sunspot cycle and climate

The Sun's activity seems to bring about changes in Earth's climate. From about 1645 to 1715 few sunspots erupted—the Sun was fairly quiet—and those 70 years were unusually cold. They were part of a period later called the Little Ice Age, which extended from about 1400 to 1850.

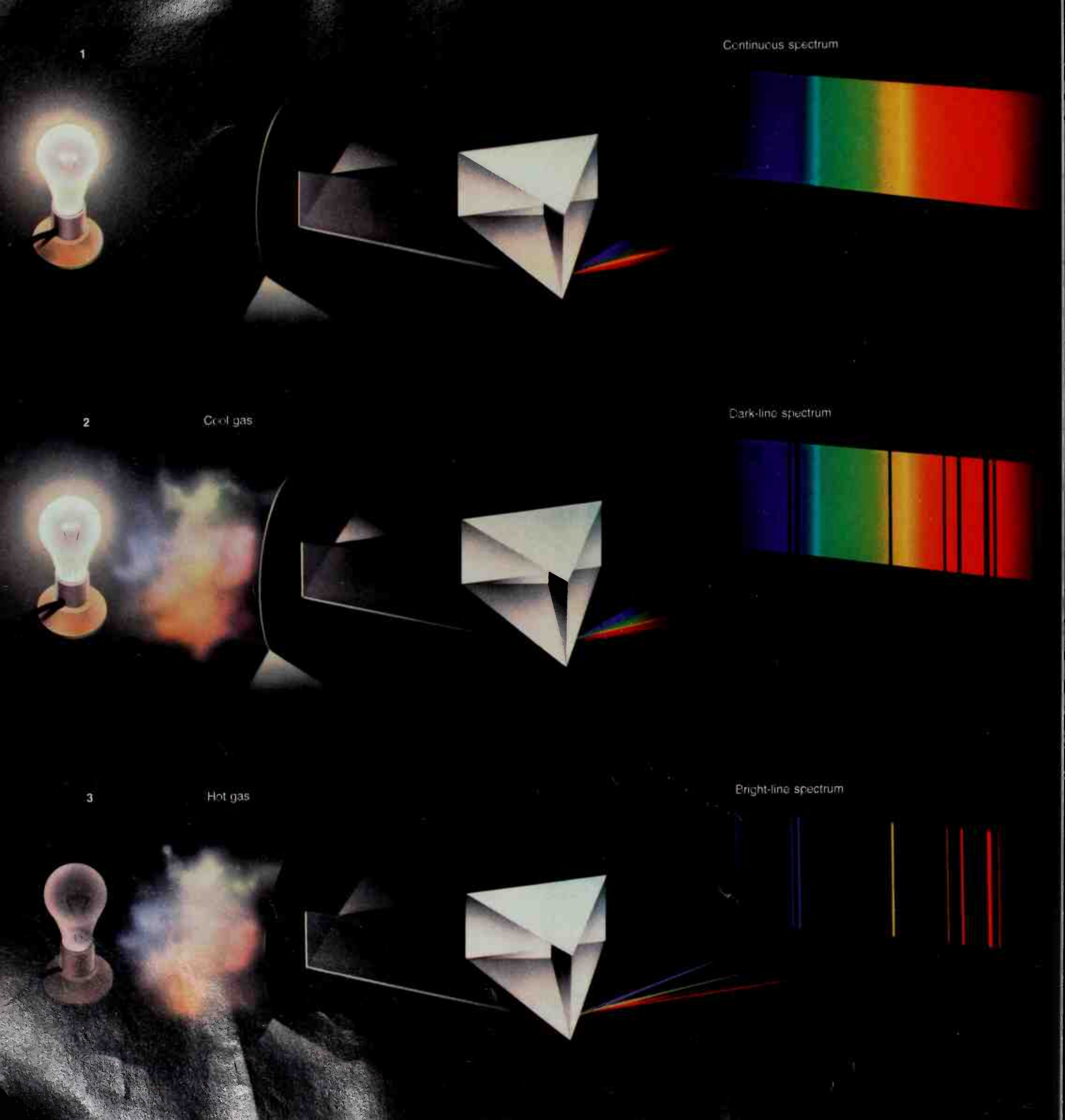
Astronomer John A. Eddy has shown that for 7,000 years glaciers on Earth have advanced and retreated in step with the Sun's activity. When the Sun is very active, the glaciers retreat. When it is fairly quiet, they advance again. So sunspots may well have far-reaching effects on all of Earth's life, effects we are only now beginning to learn about.

How does the Sun shine?

If we could make our way deep beneath the boiling photosphere, we would find three things happening. One: The temperature steadily rises, to some 15 million kelvins in the core. Two: The weight of the bits and pieces of atoms pushing from above creates extremely high pressure. Three: Core matter packs so tightly that it is about 10 times denser than silver or iron.

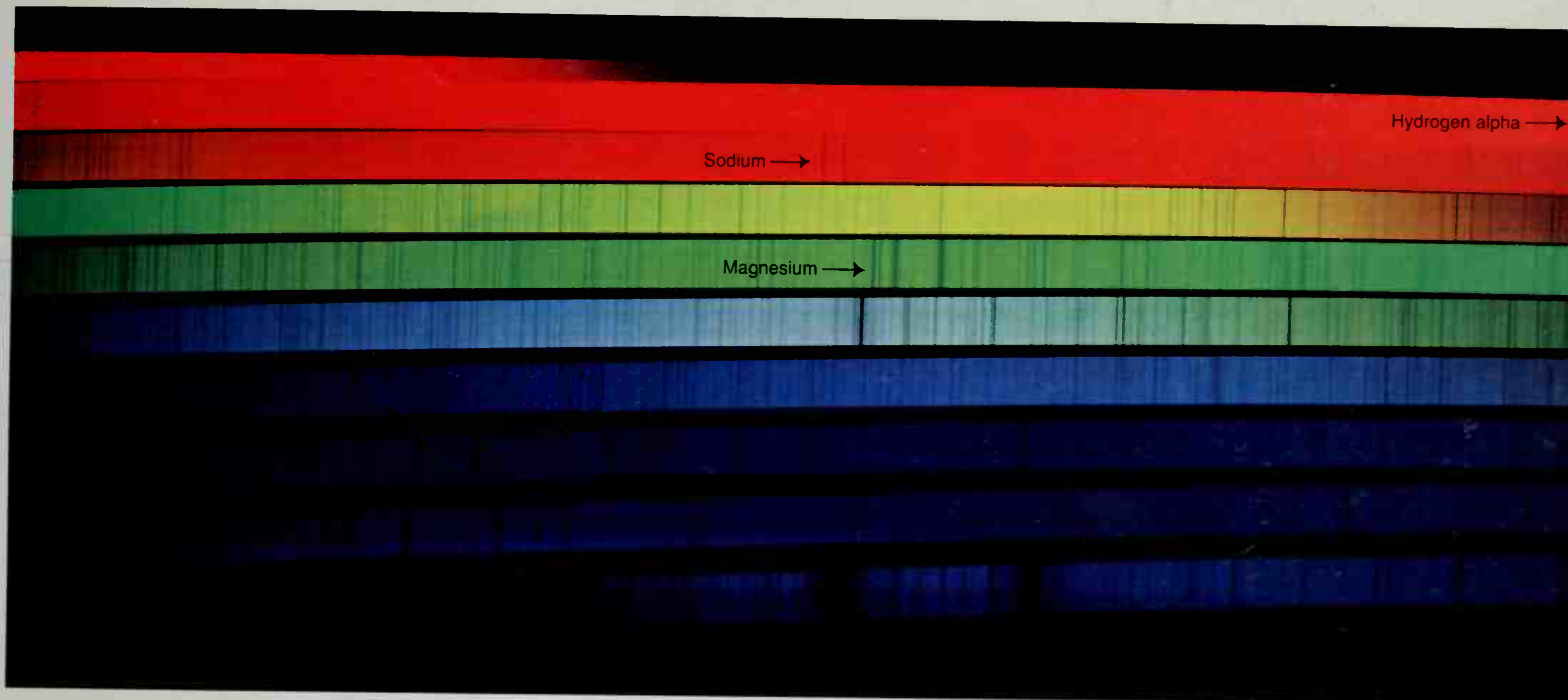


Photosphere
Core
Loop prominence
Radiative zone
Convective zone
Prominences
Solar wind
Coronal hole
Pole
Sunspots
Prominences
Pole
Coronal hole
Corona
Chromosphere and spicules
Granulation
Loop prominence
Sunspots


1
Continuous spectrum
2
Cool gas
Dark-line spectrum
3
Hot gas
Bright-line spectrum

Scientists decode starlight with spectra. Light from a bulb's hot filament passing through a prism produces a continuous band of colors (left). If the light goes through a gas, certain wavelengths are absorbed, resulting in dark lines. A hot, glowing gas creates bright lines.

Sunlight produces a dark-line spectrum (below) because it passes through gases in the Sun's atmosphere. Each line identifies a particular form of chemical element. For example, the H-alpha line of hydrogen appears at the far right on the top red band. A strongly marked pair in the middle of the second red band indicates the presence of sodium. Magnesium is identified by three lines in the green region of the spectrum. These dark lines in the solar spectrum are called Fraunhofer lines in honor of the man who first studied them carefully.



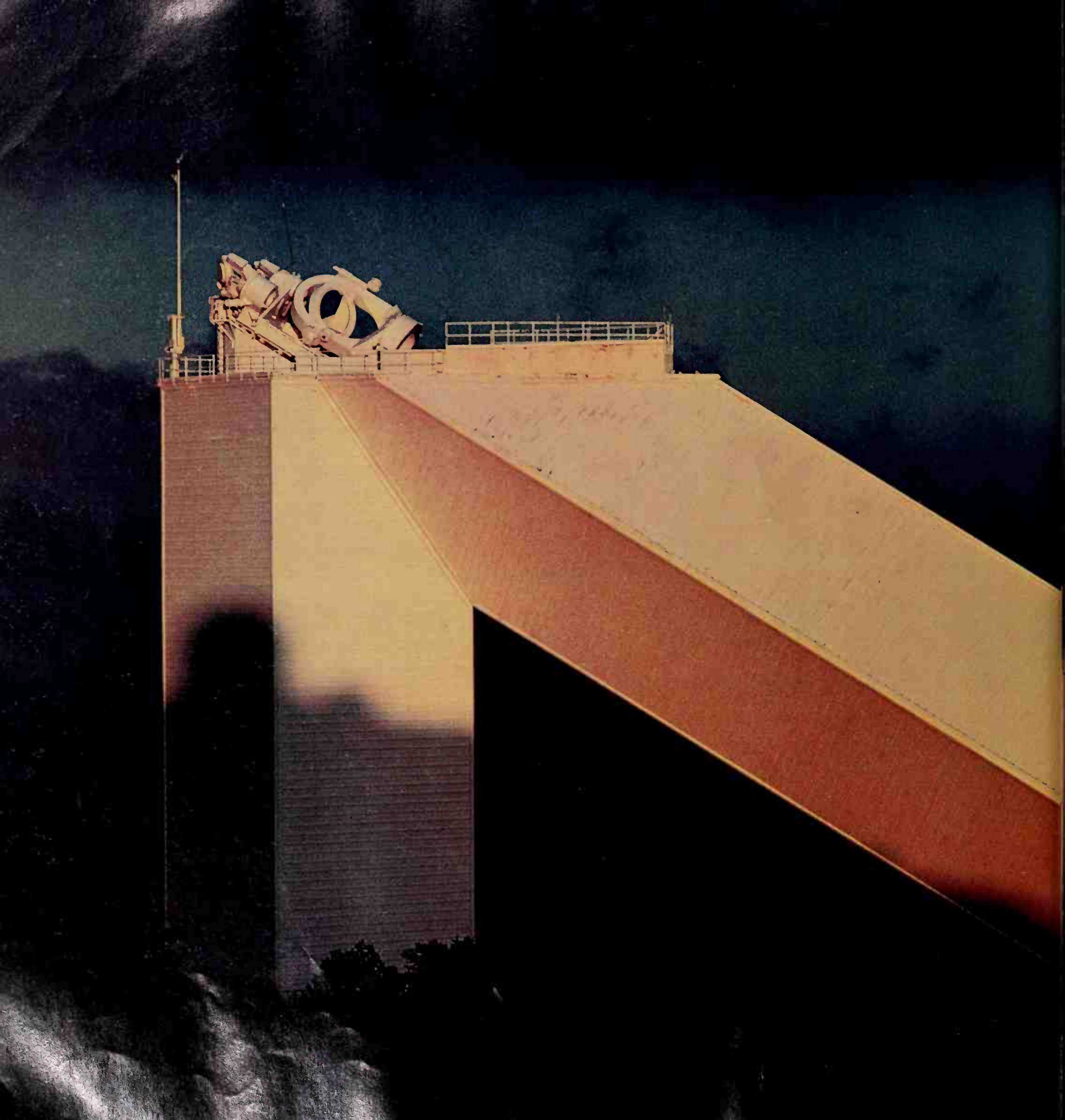
Hundreds of years ago people thought the Sun was a ball of fire. Today we know it cannot be. A lump of coal the size of the Sun would burn out in a few thousand years, and the Sun is much older than that. Another theory was that the Sun gave off its tremendous energy by shrinking and packing its matter tightly around the core; a star in its forming stages does that. But the Sun does not shine that way now. It would have shrunk to nothing long ago.

Do we have an answer? In the early 1900's Albert Einstein said that matter—a block of wood, a piece of chalk, you, anything—can be changed completely into energy. This was a startling idea, but one that we now know is true. Another scientist, Hans Bethe, used this idea in the 1930's to suggest how the Sun has been producing energy. Bethe received the Nobel Prize for this work in 1967. To understand Bethe's theory and others since, we must revisit the Sun's inner core—a huge ball twice the size of Jupiter. Here the great pressure and the high density and temperature cause the crowded jumble of atomic particles to smash into each other violently and often. Sometimes certain of these particles ram into each other so hard that they stick together in a process called *fusion*.

Our H-bomb Sun

Here is what we think happens: Two hydrogen *nuclei*, or *protons*, smash into each other hard enough to fuse, forming a deuterium nucleus with one proton and one *neutron*. As the protons fuse, they release energy, partly in the form of a *neutrino*. Neutrinos are odd particles that seem able to penetrate almost anything, including us and Earth as if neither existed.

Next the deuterium nucleus rams another free proton and fuses with it, giving off energy in the form of gamma rays. Finally, this clump of three particles smashes into another clump like itself and forms



Giant Sun-watcher, the McMath Solar Telescope at Kitt Peak, Arizona, stands 11 stories high and slopes 50 stories down into the ground. Atop the tower, movable mirrors follow the Sun, reflecting its rays down the slanting tunnel. Other mirrors focus the light to form the Sun's image.

a helium nucleus. In this last collision two protons are knocked loose and the process begins again. In each step, energy is given off in the form of photons. It is this energy that keeps the Sun shining and Earth alive. And this is how a hydrogen bomb works. The Sun is an enormous hydrogen bomb that just keeps on exploding.

A 50-million-year trip

How does the energy get out of the core? Neutrinos whiz up at the speed of light, but most of the energy takes a long, winding route to the surface. Scientists call this a "random walk." By the time a bundle of the original core energy reaches the photosphere, 50 million years have passed. That bundle, which started as gamma rays, now contains photon energy all along the electromagnetic spectrum. (See pages 28-29).

In one second the Sun gives off more energy than all people have produced during their entire stay on Earth. It is hard to believe that a tiny amount of mass can produce such a large amount of energy, but it can. If a piece of any matter weighing only one kilogram could be turned completely into energy, it would supply all of the electricity needed by the entire United States for two months! Yet our planet receives only about a billionth of the total energy output of the Sun. The rest streams out in all directions into space. On the average, each square meter of Earth's surface receives enough solar energy to heat and light one small room. If only we knew how to capture more of that energy.

If the Sun is using up its hydrogen to produce energy, won't there come a time when it runs out of hydrogen and goes out? Such a time must one day come. But even though the Sun uses four million tons of its hydrogen fuel every second, it has enough to keep shining for five billion more years.

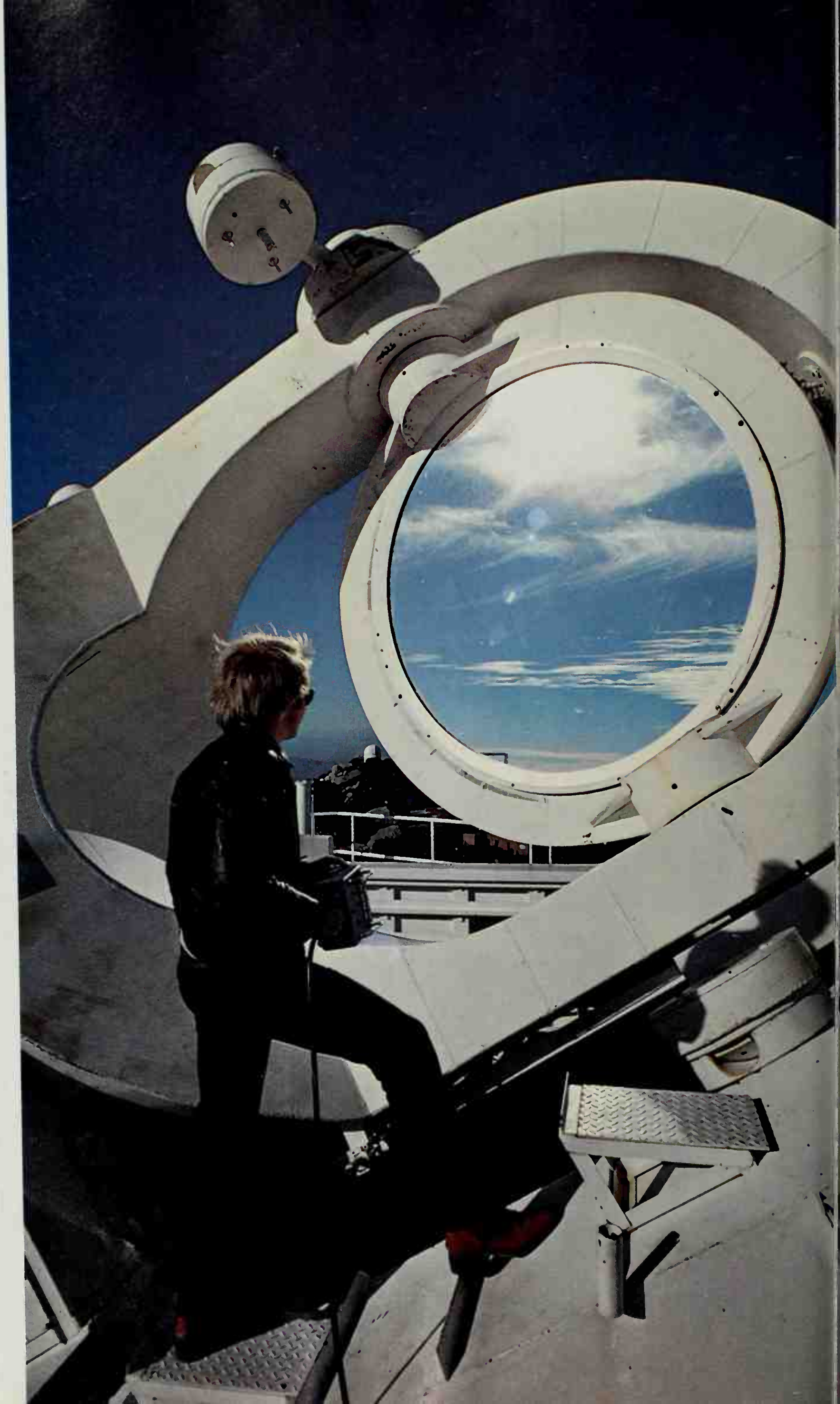
The message of sunlight

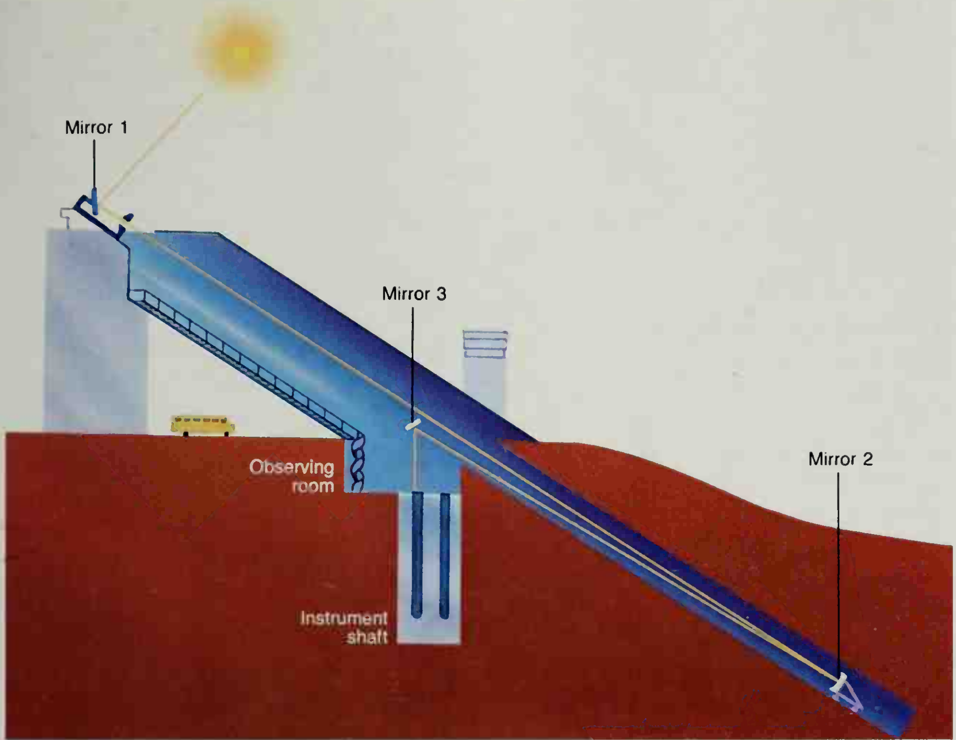
When fitted to a telescope, a *spectroscope* acts like a prism. It spreads light out in the rainbow band called a *spectrum*. Once we can read that spectrum, it reveals dozens of secrets about the Sun or any star.

If light from a glowing bulb passes through a slit and then a prism (see page 60), we see the smoothly graded band of colors called a *continuous spectrum*. Now, if we put a gas between the bulb and the slit, a pattern of dark lines crosses the spectrum, which is no longer "continuous." This is a *dark-line* or *absorption spectrum* (because the gas has absorbed some specific wavelengths of the light energy). Every chemical element produces a unique "fingerprint" pattern of dark lines.

Now, let's turn off the light bulb and look at the spectrum of the same gas after it has been heated. Where there was a pattern of dark lines before, there is now a pattern of brightly glowing lines called a *bright-line* or *emission spectrum*. The gas is *emitting*—putting out—its fingerprint.

When we look at the Sun through a spectroscope, it is like looking at light from the bulb shining through a gas. The gases of the Sun's atmosphere lie between the Sun's surface and our spectroscope. So we see a dark-line spectrum and can identify the fingerprint patterns of hydrogen, helium, iron, magnesium, and about 70 other





Cutaway drawing at left shows how the solar telescope works: Sunlight striking Mirror 1 travels down the diagonal shaft. A second, image-forming, mirror at the end sends the light back up to a mirror at ground level. This third mirror projects the beam to the observing room and to the instrument shaft. On top of the tower (far left), astronomer Bruce Gillespie adjusts the position of the large tracking mirror, called the heliostat. Inside the telescope (below), Bruce watches Mirror 3 as he lines it up with the concave mirror at the far end of the tunnel. Dark glasses shield his eyes from the Sun's glare. *(See page 66 for more on solar telescopes.)*

Each section of this composite picture records a different feature or layer of the Sun. Scientists use spectrographs to make images at different wavelengths, such as H alpha and the ultraviolet light of helium. A coronagraph blocks out the Sun's disk so the corona becomes visible.

elements of the chromosphere and corona.

Spectra show much more than what the stars are made of. They tell us the temperature of the stars' gases, their pressure, density, and motion. They even show us where magnetic fields are located.

Solar telescopes

Astronomers use telescopes with very long focal lengths to study the Sun. The McMath Solar Telescope at Kitt Peak, Arizona, the largest in the world, gives an image of the Sun that is almost one meter across. It shows features such as sunspots in great detail. Because it is the only telescope of this magnitude ever built, the McMath draws astronomers from all over the world. Stable air temperature is important in using a telescope, so the McMath has an inner skin of 36 tons of solid copper tubing. Some 64,000 liters of antifreeze flow through this tubing and prevent hot air currents which would blur the image.

Behind the McMath telescope (pages 62-63), is a smaller vertical tower containing a solar vacuum-telescope. Its long vacuum shaft has practically no air in it, producing a sharper, though smaller image. This telescope makes daily magnetic maps—or *magnetograms*—of the Sun.

The McMath operates 24 hours a day, observing not only the Sun but the Moon, planets, and stars. Instruments such as the McMath do double duty by enabling scientists to study the makeup of both sunlight and starlight. Another Kitt Peak telescope, the Mayall, produced the picture of the star Betelgeuse on page 222.

The many faces of the Sun

Viewing the Sun through a spectroscope is something like viewing a landscape through binoculars. With binoculars we can first focus on nearby objects. By changing the focus we can bring into view objects farther away. At any moment we see clearly only those parts of the landscape we choose to keep in sharp focus. The others are either fuzzy or invisible.

By "focusing" the spectroscope at red wavelengths in the visible spectrum, and blocking out other wavelengths, we photograph cooler, low-energy gases in the lower photosphere and nothing else. When we slowly change the focus up through the shorter and shorter wavelengths of orange, yellow, green, blue, and violet, to ultraviolet and X rays, we can examine the Sun's atmosphere layer by layer, photographing each as we go. By the time we reach the ultraviolet and X rays we are focused on the hot corona above the chromosphere.

NASA's first experimental space station, Skylab, was fitted with ultraviolet and X-ray telescope-cameras that gave us many thousands of pictures of the Sun—views never before possible. Skylab's ultraviolet telescopes photographed the very energetic gases of the high upper chromosphere. The X-ray telescopes photographed the even more energetic gases with temperatures of more than one million kelvins in the high corona. For the first time we saw the Sun's coronal holes. The coronagraph, ultraviolet, and X-ray segments in the composite photograph shown here were taken by telescopes carried on Skylab.

Ultraviolet
White light
X ray
Coronagraph
H alpha
Magnetogram

The Swiftest Planet

Mercury

The spacecraft Mariner 10 silently glides past the night side of the innermost planet in our Solar System. Mariner's television eye examines the battered surface of Mercury from thousands of kilometers away. It sent back our first detailed pictures of Mercury's Moon-like surface in early 1974.

One of the spacecraft's most important findings was that Mercury has a magnetic field strong enough to turn aside the mighty solar wind. Another was that Mercury's surface is covered with craters. These probably were made early in Mercury's history, when rocky meteorites up to several kilometers across crashed into the young planet and produced the landscape that Mariner's cameras photographed. Between many of the craters are smooth plains, perhaps volcanic in origin, and huge slopes—*scarps*—that formed in the ages after the bombardment ended.

If we could face the Sun from Mercury, the way Mariner's solar energy panels do, we'd see it covering an area in the sky nine times larger than it does from Earth. We would see tufts of solar gases caught up in the Sun's strong magnetic field. We would also understand why a summer vacation on Mercury would not be much fun.

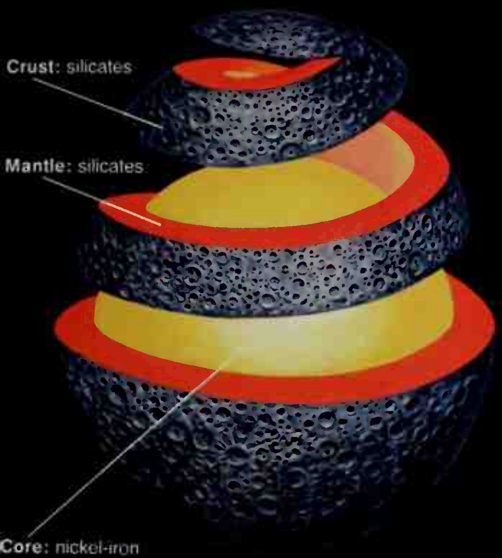
Facts about

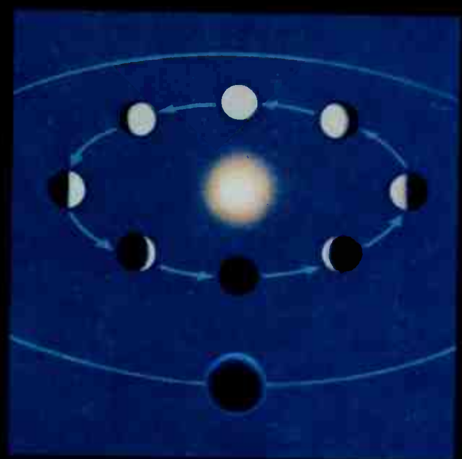
Mercury

Snakes entwined on his staff protect Mercury, messenger of the Roman gods. With imagination, you can see the snakes entwined in Mercury's symbol, too: ☿

Innermost of the planets, Mercury swoops to within 46,000,000 km of the Sun, then slows down as it swings out to some 70,000,000 km away. Mercury's orbit is more elliptical than the path of any other planet except Pluto. And if orbits were racetracks, speedy Mercury would leave the other planets behind. It zips along at about one and a half times the speed of Earth. But, for all its speed, its spin is slow—so slow that six Earth months go by before the Sun moves from one high noon on Mercury to the next high noon.

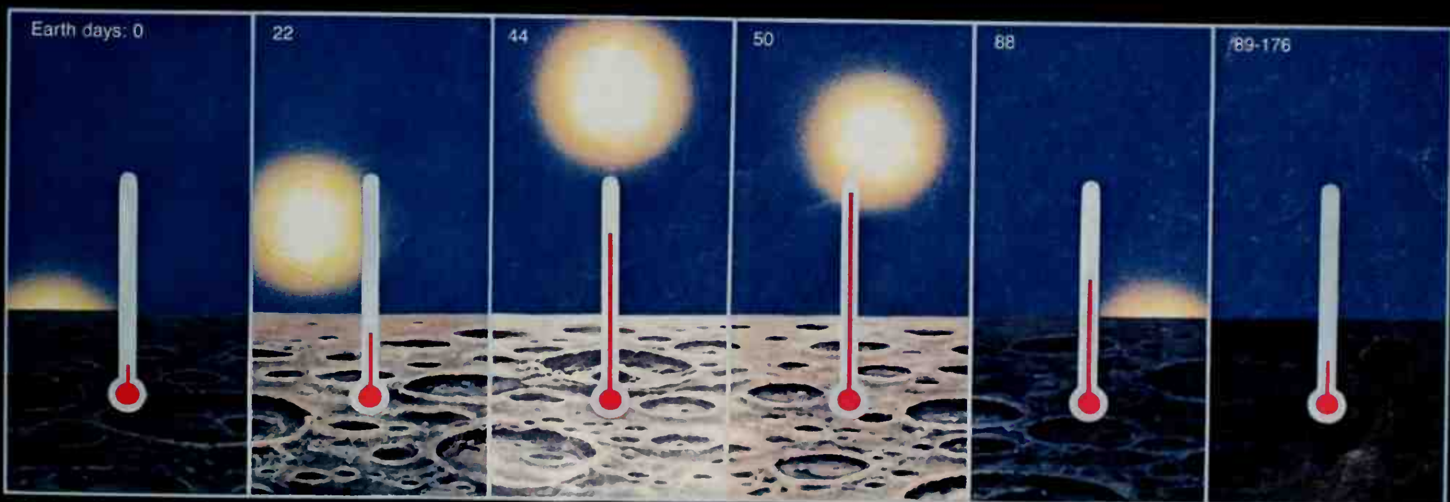
Telescopes see Mercury in phases like our Moon's because the planet's orbit lies inside our own. But they see it poorly, for Mercury stays close to the Sun – lost in its glare by day, blurred by our atmosphere when viewed low in the sky at dusk, gone with the Sun by night.



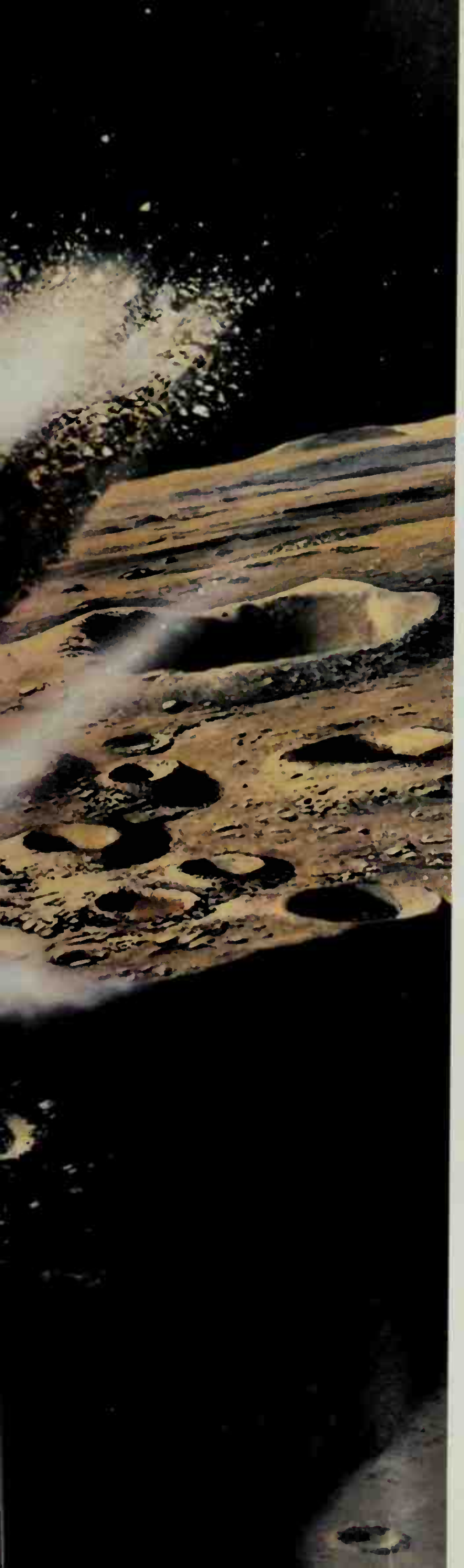


Mercury's rocky rind hides an iron core about as big as the Moon. Twice as iron-rich as any other planet, Mercury is almost as dense as Earth. That makes its gravity about a third that of Earth, though its mass is only one-eighteenth.

A thermometer on Mercury would show freezer-to-furnace extremes in a single day at the equator. At sunrise, an imaginary thermometer hovers at −183°C, almost 300° below zero on the Fahrenheit scale. No spot on Earth gets nearly so cold. Some 22 Earth days later it's mid-morning on Mercury and about as warm as a summer day here. But in another Earth month, Mercury at early afternoon would melt lead with a peak temperature above 800°F.



Before dawn −183°C **Mid-morning** 27°C **Noon** 407°C **Early afternoon** 427°C **Sunset** −23°C **Night** −23°C to −183°C



A scar is born on Mercury's cratered face as a meteoroid slams down. If this were Earth, debris and air would mix in great dusty billows and the boom of impact would echo afar. But on airless Mercury the debris sprays up and spreads out in a silent, veil-like splash of rock and dust.

Mercury is a swift little world, the fastest planet in the Solar System. Until recently, people thought it was also the smallest. But new observations and measurements indicate that Pluto is smaller. One of the hottest – and coldest – planets, Mercury would seem a very strange place indeed, if we landed on its surface.

As we approached the planet in our spacecraft, we would see thousands upon thousands of craters. On a momentous day in March 1974, television cameras on the NASA spacecraft Mariner 10 began sending pictures of those craters back to Earth. Until then, Mercury's landscape had been completely unknown to us. Since Mercury is so close to the Sun, our largest telescopes cannot see the planet as well as we can see the Moon with our unaided eyes.

Bombs from space

Mercury's craters come in all sizes. They range from as small as 100 meters to basins nearly the width of Texas. These craters make the surface of Mercury look like our Moon. One of the brightest spots on this small planet is the crater Kuiper, named after the U. S. astronomer Gerard P. Kuiper, a member of the Mariner 10 television science team. About 60 kilometers across, crater Kuiper looks as though it had been formed when a gigantic sack of flour smashed into Mercury and splashed out white, powdery rays. At least 100 of these *rayed craters* scar Mercury's surface and most of them are named to honor artists, musicians, and writers.

How were Mercury's craters formed? Some four billion years ago, early in the history of the Solar System, the newly forming planets and moons were bombarded by objects from space. Millions of such rock fragments are found today in the asteroid belt between the orbits of Mars and Jupiter. The asteroid belt may contain material which did not gather into a planet as the Solar System formed.

Wherever these objects came from, they varied greatly in size, some as small as a sand grain, others up to the size of a football stadium. A rare one was even larger. They blasted down on Mercury with explosive force. Geologists think that when this space rubble crashed onto Mercury's surface, the chunks made *primary craters* and ejected blocks of bedrock. The larger blocks then fell back to the surface and formed smaller, *secondary craters*. Many of Mercury's big craters have these smaller craters clustered around them.

Bright rays

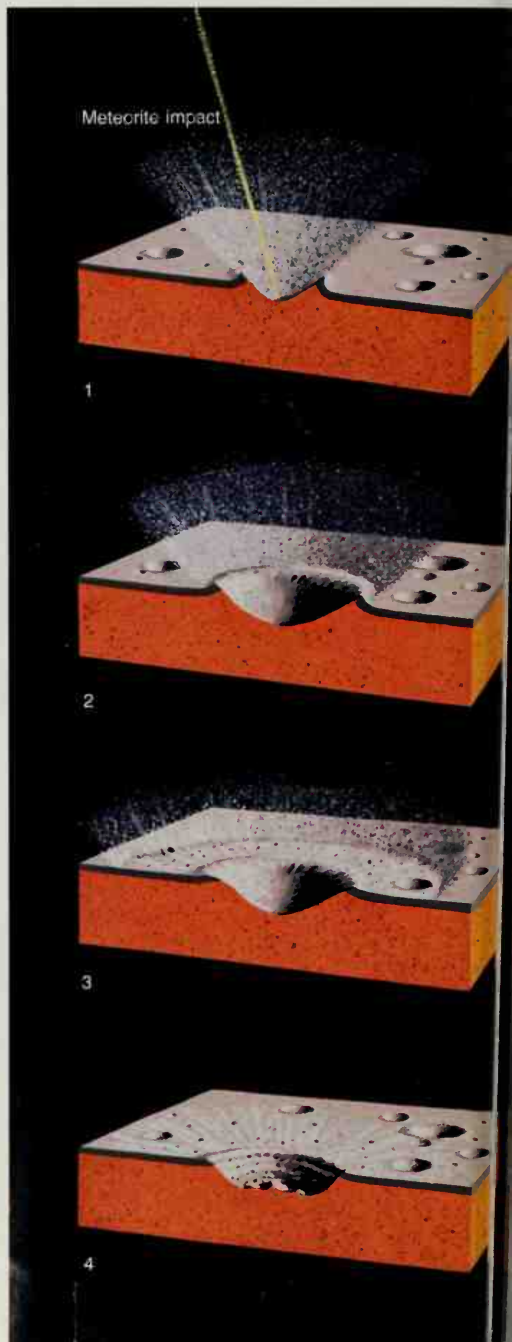
Primary craters may also have bright rays that spread outward like the spokes of a wagon wheel. These are made of fine-grained material that was thrown out of the crater when it formed. This material reflects sunlight more than the area around it does, so the rays are "bright." Some craters have rays that reach out great distances. Copley is one, where the rays extend some 400 kilometers. Yet others, such as Beethoven, have no surrounding rays at all.

A prune-faced planet

What scientists call "peculiar" terrain makes up a large part of Mercury's surface

Autograph of a meteorite, Degas Crater stretches its rays from a pit 45 km wide. Rays from the impact formed when ejected material settled to the surface. Rayed craters here don't match the Moon's, for Mercury's gravity is twice as strong, so debris doesn't fly as far.

An impact crater forms on Mercury: Up leaps a plume of debris (1). Some shoots out in bands like umbrella ribs. Much is still moving outward as the pit reaches final size (2). Debris settles in a widening circle (3). Rays mark where the "ribs" landed as the crater collapses in time (4).



at a point exactly opposite the 1,300-kilometer Caloris—"hot"—Basin (see the illustration on page 75). These jumbled, chaotic hills range in height from a few hundred meters to two kilometers, giving the land a wrinkled-prune look. Planetary geologists think that one of the largest objects ever to hit another in the history of the Solar System—a meteoroid more than half as broad as Lake Michigan—smashed into Mercury at the Caloris Basin.

The only other place in the Solar System where similar terrain has been found is the Moon, and there it also lies opposite large basins—Imbrium and Orientale. Comparison of these examples helps geologists determine what caused the jumbled hills in Mercury's southern hemisphere. They think the object that hit Mercury was much larger than the objects that hit the Moon because Mercury's hilly region is more jumbled and more widespread than the Moon's.

Rupes, scarps, and plains

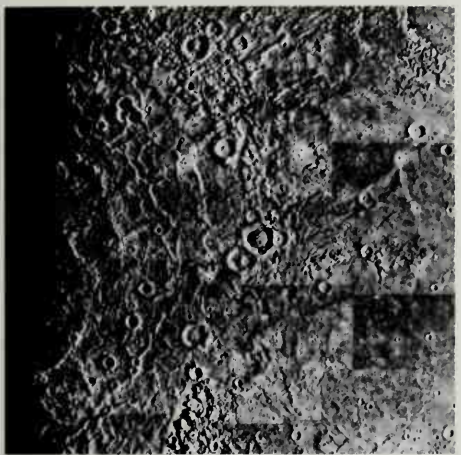
Long steep cliffs cut Mercury's rocky—silicate—crust. Some are hundreds of kilometers long and as much as two kilometers high. A cliff is called a *rupes* or a *scarp*. The international group of scientists who have been naming Mercury's newly found features have named the scarps for ships of discovery. One honors Capt. James Cook's ship, *Discovery*. Captain Cook was an English explorer whose first voyage carried astronomers to the Southern Hemisphere to observe stars and planets. Discovery Rupes is about 550 kilometers long and cuts across two fairly large craters. This shows that the craters were there before the scarp. The scarps may be long sections of rock that were pushed upward when Mercury shrank during its early cooling.

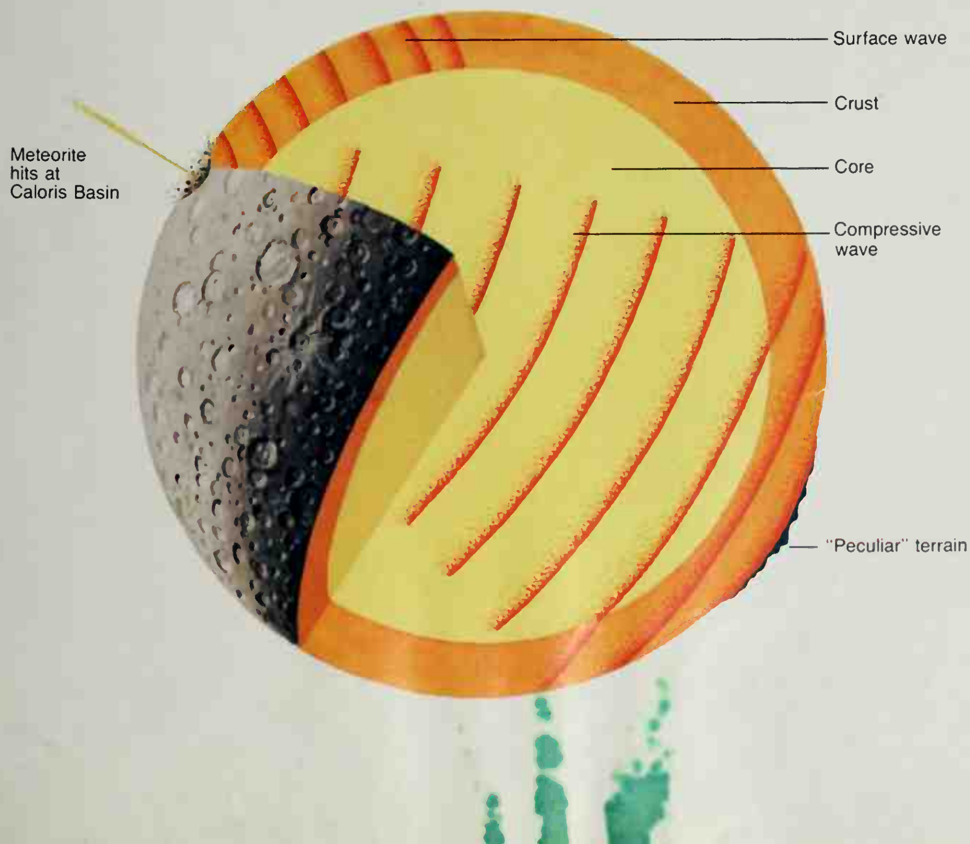
Mercury also has sprawling areas called *planitiae*, or *plains*. They are nothing like the plains we know on Earth. An outpouring of volcanic lava late in Mercury's youth—and after the major hail of rock bombs had made the craters—most likely created the plains and partly filled some craters. Some of Mercury's plains are named after other gods of ancient mythologies, such as Tir and Odin, who played roles similar to the Roman Mercury.

Mercury is a world without air, without oceans or rivers. And, because there is no evidence of surface erosion, there is no reason to believe that Mercury ever had oceans or an atmosphere. Thanks to the pictures from Mariner 10, today we see the barren, rocky planet almost exactly as it must have been three billion years ago.

Two bruises from one blow—that's how science explains the terrain on opposite sides of Mercury. Ages ago, a meteoroid blasted out the vast Caloris Basin. Like pond ripples, mountain ranges two km high now ring the spot. Night partly hides it in the Mariner 10 photo (left below). When the blow struck, shock pulses called compressive waves sped through the core as slower, surface waves spread through the crust. On the far side, the waves converged in great shudders that left shattered landforms (right below) like no other spot on Mercury.

On the next page: *A lofty scarp named Discovery stretches 550 km across battered, barren Mercury. Half a crater perches at clifftop; its other half stayed below as the crust split and rose some three km—pushed aloft by crustal compression as the planet's core cooled and shrank.*





A cotton-ball planet

Observing Mercury from Earth has always been difficult. It is the innermost planet. Since its orbit lies between ours and the Sun, we must always look toward the Sun's glare. But Mercury is so indistinct that, until Mariner 10, astronomers had never been able to get a clear view of its surface. Through telescopes it appears, at best, as only a fuzzy whitish disk.

The plane of Mercury's orbit is tilted with respect to Earth's, so Mercury usually passes a little north or a little south of the Sun. But occasionally—about 14 times a century—Mercury crosses directly between us and we see it as a little black spot against the Sun. Such crossings are called *transits*. The next two transits of Mercury will take place in 1986 and 1993.

As Mercury orbits the Sun, we see it first on one side, then on the other. At different times of the year it rises just before the Sun, as a "morning star" or sets after sunset as an "evening star." Ancient astronomers thought Mercury was two different objects. The one they saw in the morning they called Apollo and the one they saw in the evening they called Mercury.

An "exquisite celestial billiard shot"

In these words, space scientist Bruce Murray described the trajectory of Mariner 10. Like one billiard ball played off another, Mariner 10 was the first spacecraft to use the gravitational attraction of a planet to change its direction and speed. The gravitational field of Venus slowed Mariner 10 down and spun it off toward Mercury. In 1974 Mariner 10 approached

Mercury to within 705 kilometers. Mariner 10 continued on around the Sun, returned for a second flyby, looped around the Sun again, and came back, a year after its first flyby, for a third look at Mercury.

One of the main objectives of the Mariner 10 team was to find out what kinds of surface features Mercury has. In the three visits, Mariner television cameras photographed about half of the planet. These pictures were put together in sections, and maps such as ours were made from them.

The spacecraft also discovered that Mercury has a magnetic field. Like Earth's magnetic field, Mercury's is pushed out of shape by the steady blast of atomic particles from the Sun called the solar wind. The first flyby had detected the magnetic field. The third confirmed that it is squashed up close to Mercury on the sunlit side and stretched out into a long tail on the side away from the Sun.

Although weak—about one percent the strength of Earth's—the magnetic field of Mercury is much stronger than that of Mars. Perhaps it is strong enough to capture a very thin veil of gas given off by the Sun. However, because the gas is of such a low concentration, we cannot call it an "atmosphere." Our own atmosphere at 1,000 kilometers altitude has the same pressure as Mercury's at the surface. That is more than a million times lower than the pressure on Earth's surface. Mercury's veil is far too thin to block out even a little of the Sun's radiation. And, at such a close distance to the solar furnace, Mercury's surface gets many times more radiation than Earth's surface does.

The hot and cold planet

At *perihelion*—the planet's closest approach to the Sun—Mercury is only about 46 million kilometers away from it. This is close enough that, on the equator at high noon, the surface temperature reaches 427°C. That's more than twice the temperature it takes to bake a cake. But on the opposite, shaded surface the temperature plunges to −183°C. How can it be so hot and so cold at the same time?

Temperatures rise on Mercury's sunlit side partly because the solar radiation is so intense and partly because Mercury days are so long—from sunrise to sunset each one lasts nearly three Earth months. This is a long time for the crustal rock to heat up. But Mercury's night side does not see the Sun for the same long period of time. So it gets very cold. On Earth, the dense blanket of air shields the planet's day side from some of the radiation, and holds in heat on the night side.

Mercury's high orbital speed and slow rotation (each is a result of the Sun's gravitational attraction) produce the long days and nights. The planet takes 88 Earth days to complete one revolution around the Sun.

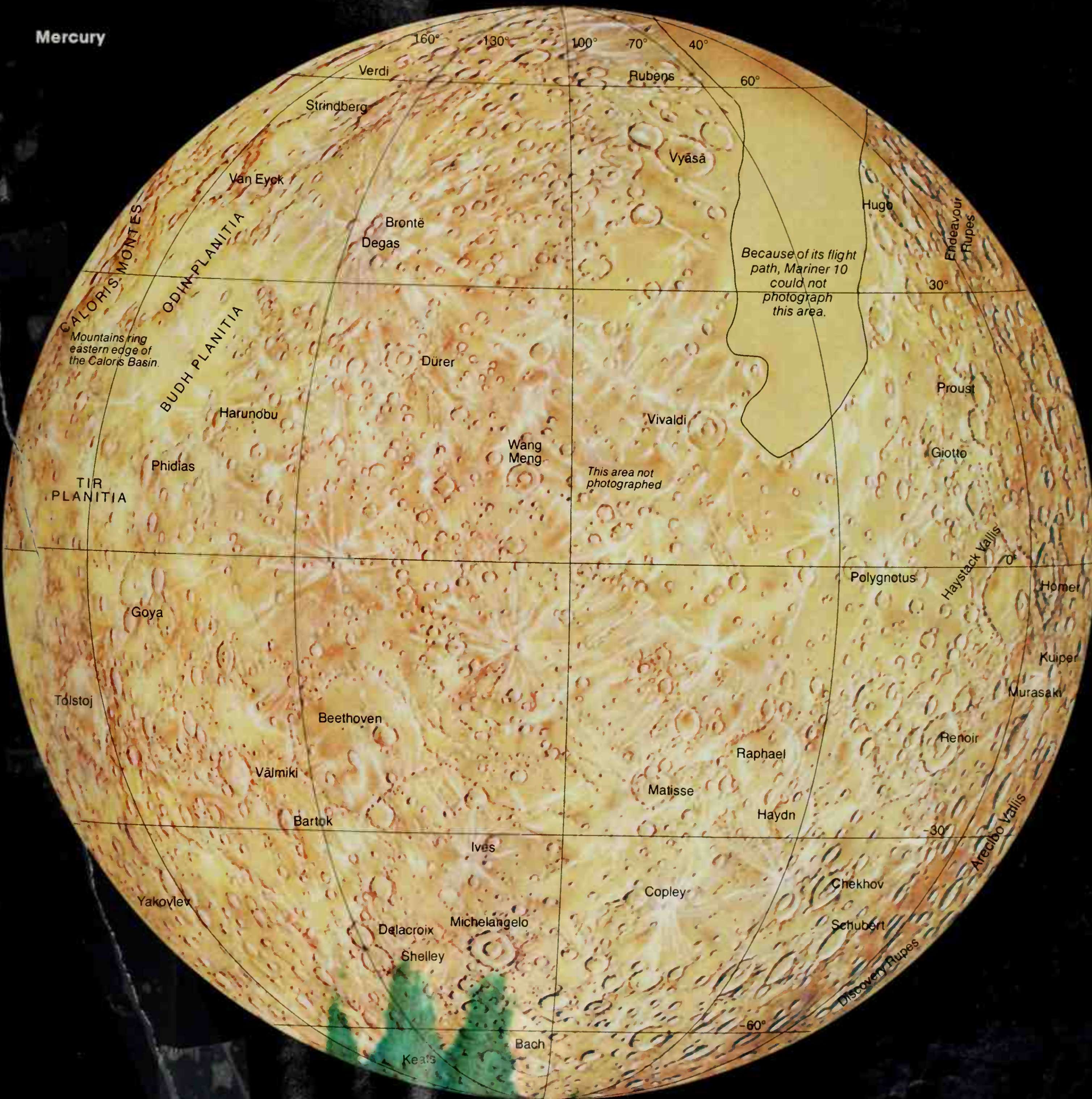
Until recently, scientists thought that Mercury also took 88 days to rotate once about its axis, which would make a day on Mercury equal to its year. They thought that the planet always kept its same face toward the Sun. This would have given it a permanent day side and a permanent night side. But in 1965 astronomers at the Arecibo Observatory in Puerto Rico beamed radar impulses at the planet, measured the returning impulses, and determined that Mercury rotates once about its axis in 59 days. This means that every time Mercury makes two revolutions around the Sun, it has made exactly three rotations on its axis. Because of its short year, you would be one year older about every 88 days if you were a Mercurian. A 15-year-old, by Earth time, would be 62 years old on Mercury, and could expect to live to a ripe old age of 300 Mercurian years.

A Sun that seems to do tricks

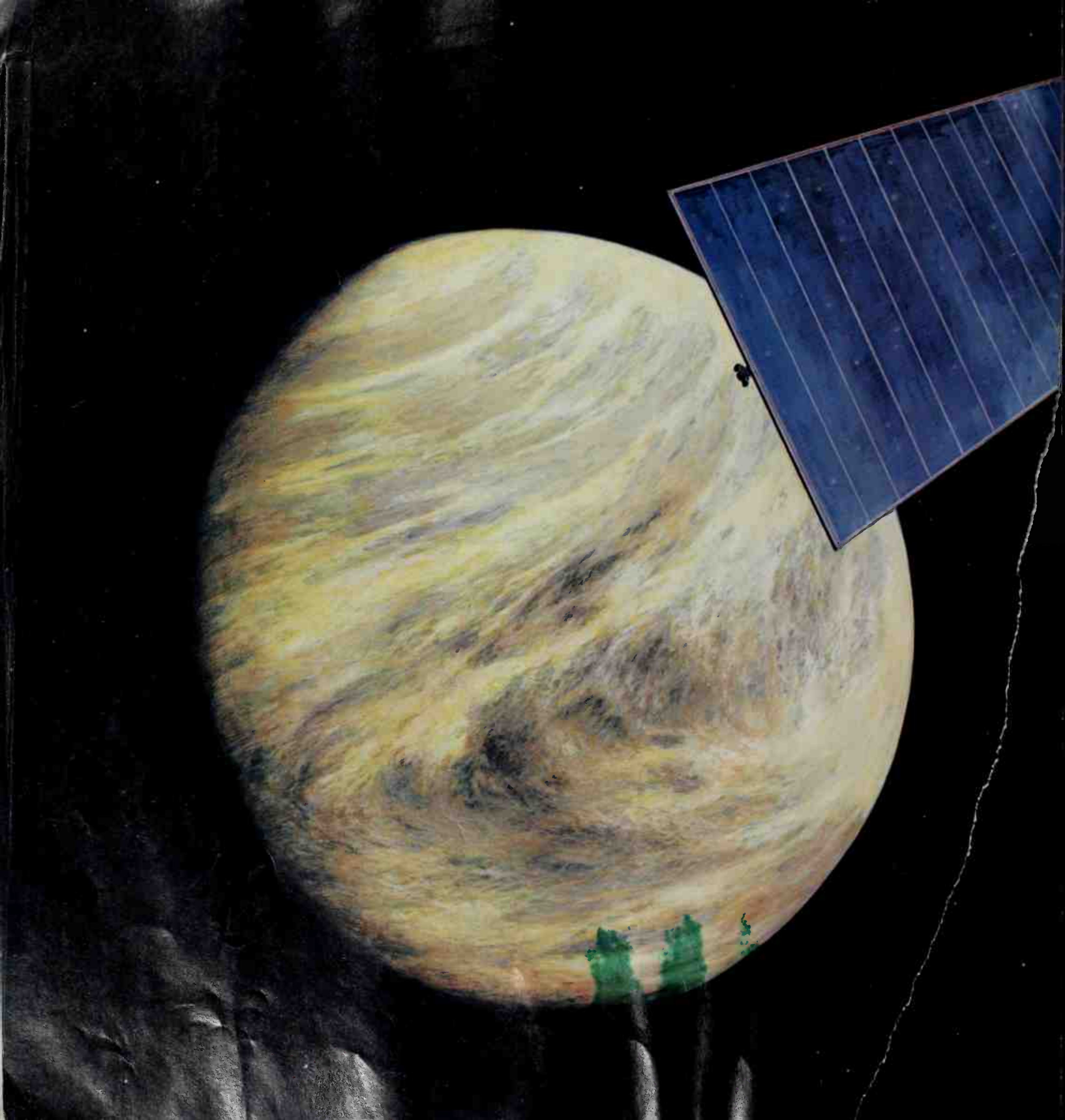
From some spots on Mercury we could see the Sun rise in the east and climb for about a month and a half of Earth time. Just before high noon it would seem to "loop"—slow down, stop, back up, stop again, and then resume its westward movement until it set a month and a half later. At other places on the planet, we could watch two sunrises and two sunsets every day. These things happen because of the planet's highly elliptical orbit and because at perihelion Mercury's spin speed is slower than its orbital speed.

Although we do not look to Mercury as a place to live, scientists are especially interested because it is such a close neighbor to the Sun. They would like to test crust samples. If a spacecraft could land instruments, they might tell whether the planet's inner core is liquid or solid. An orbiting spacecraft could take up the photography and mapping where Mariner 10 left off. Someday, instruments on an orbiter or lander will measure changes in the strength of the Sun's gravitation, the solar wind, and other characteristics of the Sun.

Mercury



160°
130°
100°
70°
40°
60°
Verdi
Rubens
Strindberg
Vyāsā
Van Eyck
CALORIS MONTES
ODIN PLANITIA
BUDH PLANITIA
Brontë
Degas
Hugo
Endeavour Rupes
Because of its flight path, Mariner 10 could not photograph this area.
30°
Mountains ring eastern edge of the Caloris Basin.
Dürer
Proust
Harunobu
Vivaldi
Wang Meng
Giotto
Phidias
This area not photographed
TIR PLANITIA
Haystack Vallis
0°
Polygnotus
Homer
Goya
Kuiper
Murasaki
Tolstoj
Beethoven
Renoir
Raphael
Vālmiki
Matisse
Haydn
Bartok
-30°
Arecibo Vallis
Ives
Chekhov
Copley
Yakovlev
Schubert
Michelangelo
Delacroix
Shelley
Discovery Rupes
-60°
Bach
Keats



A Veiled Planet

Venus

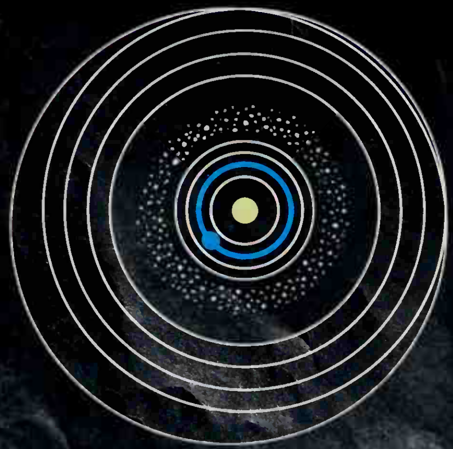
Venus's upper clouds of poisonous sulfuric acid swirl in a pattern of yellowish mists. Moving at speeds almost three times faster than winds in a hurricane, they race around the planet once every four days. Mariner 10 had this view of mysterious Venus before speeding on to Mercury. Of seventeen space missions—twelve Russian and five American—several have given us glimpses of the cloud-veil and the planet's rocky surface.

People once imagined Venus as a Garden of Eden with lush vegetation, sparkling streams, and life. They regarded Venus as Earth's twin because its size, mass, and density are so much like Earth's. But there the likeness ends. Beneath the acid clouds is a planet we could not imagine in our wildest dreams. Day and night, lightning flashes across a rainless sky more often than we could count. Thunder booms continuously. On the surface, the pressure is as strong as the pressure about one kilometer below the surface of the oceans on Earth. The atmosphere is so dense we could nearly swim through it.

But many of Venus's mysteries remain: Were there ever oceans? How did the lower atmosphere become so hot? And why does it glow so strangely?

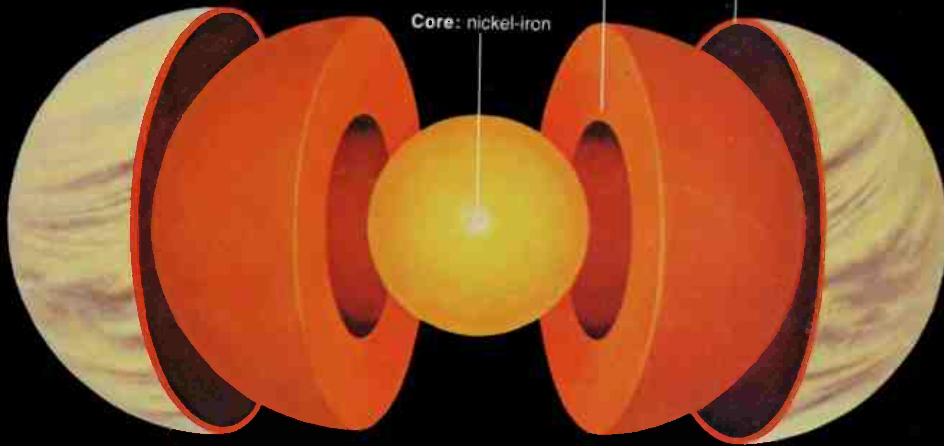
Facts about
Venus

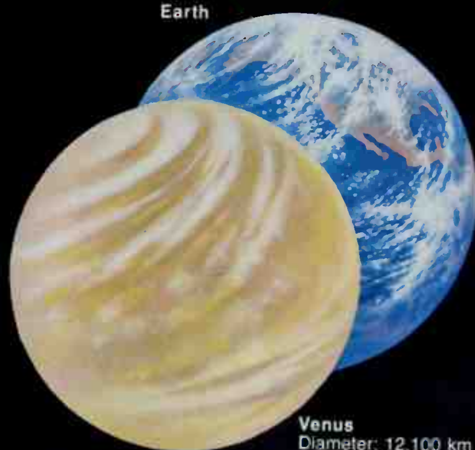
Love and beauty, springtime and flowers: the Roman goddess Venus ruled them all. What better symbol for her bright planet than a hand mirror? ♀

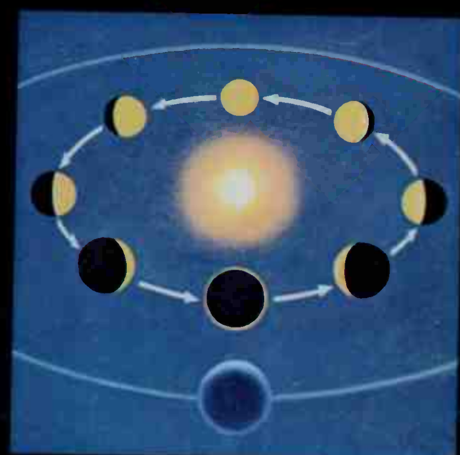


Second from the Sun, Venus traces an orbit that is closer to a perfect circle than any other planet's. And yet it moves in odd ways. Its rotation is retrograde, or "backward," so the Sun rises in the west and sets in the east. That spin is so slow that four Earth months go by between one Venus sunrise and the next. And by only the third sunrise, the planet has completed a full swing around the Sun. Thus on Venus a year is less than two days long. But as it orbits, Venus is a speedster at 35 km a second. Only Mercury can outrun that.

Earth's near-twin beneath the skin, Venus encases a nickel-iron core in a rocky mantle and crust. These add up to a mass about four-fifths that of Earth. Venus is not as dense; a slice would be lighter than a same-size slice of Earth. You'd weigh a bit less on Venus.







Three blankets of cloud – the top one thin and hazy – wrap Venus and perhaps help to keep it warm. Earth knows no clouds like these. Their droplets are sulfuric acid, their "snowflakes" still mysterious. Sunlight filtering through them may add to the intense surface heat. Upper winds that top 350 km an hour spread the heat fairly evenly around the planet. Down on the surface the winds calm to about 4 km an hour. You'd move slowly too, for on Venus's surface the carbon dioxide atmosphere is 91 times denser than on Earth.

An orbit inside Earth's makes Venus appear in phases. Its night side faces us every 584 Earth days; with a telescope we can glimpse its sunlit atmosphere. With the Sun between us, we see Venus as smaller but brighter. Sometimes we can even spot Venus during the day.

A short life awaits a Soviet Venera spacecraft on the brutal surface of Venus. Six of twelve Venera probes soft-landed in the 1970's; the hardiest operated for less than two hours in the searing heat and crushing pressure. But from two of them came views of the stark planet.

Perched on a rock shelf, Venera 10 photographed what may be ancient lava. Dark patches probably show where heat and the corrosive atmosphere have crumbled the lava to rubble. This panorama looks down at Venera's base and out toward the horizon.

On the next page: *Thunderbolts tear the veil of clouds that hides the face of Venus. Because the dense atmosphere scatters the red wavelengths of sunlight more than the others, we see an eerie red light bathing the desolation of craters, rift valleys, and lava flows.*

The brightest object in our sky, except for the Sun and the Moon, is the planet Venus. When its orbit brings it closest to Earth, Venus is about 42 million kilometers from us, only 100 times farther away than the Moon. If you know exactly where and when to look, you can see Venus in the daytime. And on a clear night, when Venus is at its brightest, it casts shadows on Earth. Because its orbit, like Mercury's, lies between us and the Sun, we must look to the right or left of the Sun to see Venus. But since Venus's orbit is twice as big as Mercury's, Venus often is seen far enough away from the Sun that it is not lost in the glow. At certain times of the year, we see Venus either in the western sky after sunset or in the eastern sky before dawn.

If our imaginary spacecraft travels at the same speed as Mariner 10, Earth's nearest planetary neighbor would be only three months away. As we approach Venus, we see a dense cloud veil around it. The radar signals we send down through the clouds return echoes that tell us the planet has a solid surface. Since we know that Venus resembles Earth in many ways, we are surprised to learn from our instruments that there is no magnetic field. Our radio receiver picks up increasingly loud static as we descend to the cloud tops—possibly the sign of electrical storms in the layers below.

Sulfuric acid clouds

The top of the cloud deck is yellow-white rather than white like Earth's cloud tops. Why? Earth's clouds are water droplets but Venus's upper clouds are droplets of sulfuric acid. The yellow color suggests the presence of sulfur with some other material, possibly iron, dissolved in it.

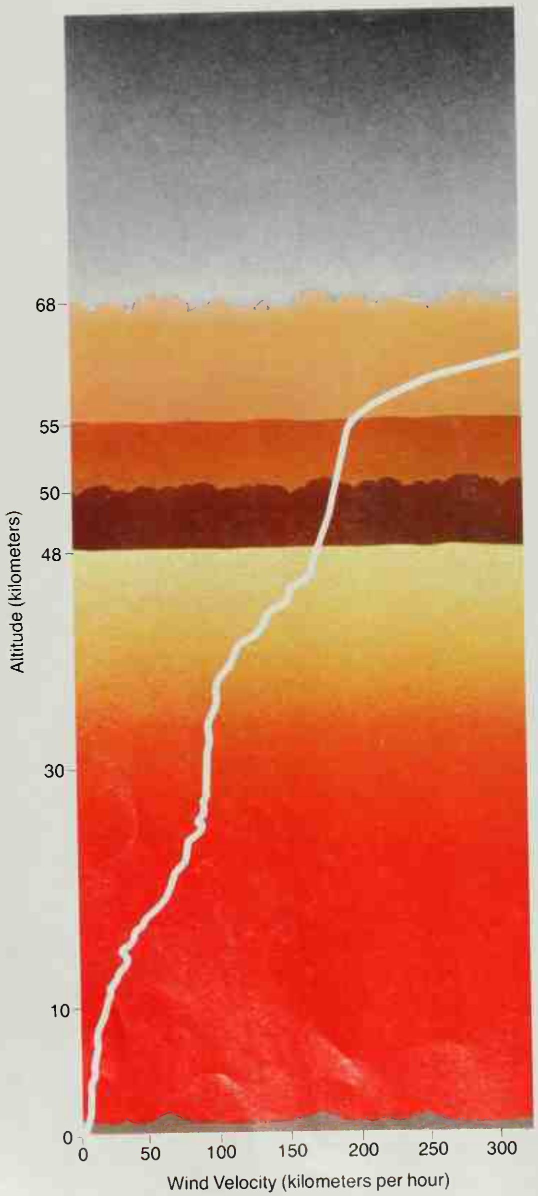
At the top of the clouds we are swept along by a jet stream at 360 kilometers an hour. These winds carry the cloud tops around the planet once every four days. The temperature at this altitude of about 70 kilometers above the surface is a frigid –43°C, some 25° colder than a home freezer.

We begin our descent

At about 55 kilometers we enter another cloud layer, a much warmer one. The clouds here contain lots of tiny particles which seem to be solid but have not yet been identified chemically. The fine mist of sulfuric acid falling from above joins the solid particles, and all drift downward, heating up as they pass through warmer regions of the atmosphere.

At an altitude of about 48 kilometers we begin to break out of the clouds. It is now so hot that the sulfuric acid droplets and solid particles break down chemically into water, oxygen, sulfur dioxide, and other sulfur compounds. These lighter materials are then driven back upward into the higher clouds where the cycle begins again—something like the cycle of rain

The winds of Venus vary with altitude. Upper clouds whip by at 360 km an hour. But a slow breeze at the surface moves no faster than a walk. Venus is a forecaster's dream; its weather scarcely varies. In many places Pioneer and Venera probes logged the wind speeds shown below.



Venus knows only one wind direction: westward. Night or day, near equator or pole, its entire atmosphere moves in the same direction the planet spins, but much faster. Upper winds circle Venus in only four Earth days. Cloud patterns unseen by visible light leap into view in these colored ultraviolet photos from an orbiting Pioneer spacecraft. Eight Earth days separate the top view from the middle; another day separates the middle picture from the bottom. Yet all show similar patterns as cloud decks move from right to left, driven by the Sun's heat.

and evaporation on Earth. The energy that drives this sulfur cycle may be ultraviolet radiation from the Sun.

On reaching the bottom of this lowest cloud layer we find that the winds have slowed to about 175 kilometers an hour. But the temperature has soared to 90°C, and soon another surprise greets us. We find the source of the radio static that grew louder as we descended. All around us is continuous lightning, with as many as 25 flashes a second. Deafening booms punctuate an unending roar of thunder.

Below the clouds we pass through a hazy belt of fine particles. For the remaining 30 kilometers down to the surface the air is very clean. Even so, we have trouble making out details because the atmosphere has become so dense that our view is like one through clear water. A saucer-shaped object drifting down through Venus's atmosphere at this height would zigzag as a dish does when it sinks in water.

Down to the surface

By the time we are 20 kilometers from the surface the temperature zooms to almost 300°C and the atmospheric pressure is a crushing 21 times the pressure on Earth at sea level. It is little wonder that, until now, no spacecraft has been able to survive these conditions very long.

When our imaginary craft finally touches down, it kicks up a cloud of fine ash or sand. Nearly five minutes go by before the dust settles out of the dense air. Other areas, photographed in October 1975 by the Soviet spacecraft Venera 9 and 10, are rocky. The Veneras returned two pictures to Earth before expiring in the forbidding temperatures and corrosive atmosphere. Those are the only two pictures we have of the landscape of Venus.

Winds on the dry surface are slight, not much more than four kilometers an hour. However, the air is so dense that even this breeze sweeps us along as if it were a river current, and a fiery one. Our temperature sensors now register a blistering 460°C. What makes it so hot?

A carbon dioxide greenhouse

Most of the atmosphere is carbon dioxide, a heavy gas. Nitrogen is present, too, but only 3 percent compared to 78 percent in Earth's atmosphere. But there is little, if any, oxygen. Since carbon dioxide "covers" the planet the way glass covers a greenhouse, we can think of Venus as a planet-wide greenhouse. The atmosphere lets shortwave radiation from the Sun pass through to the ground, where it turns into heat. When the ground radiates this heat back up as longwave infrared rays the carbon dioxide traps it. This dense heat trap keeps Venus hot even at night.

The atmospheric pressure on the surface of Venus is more than 90 times our own. (That much pressure is what you would feel nearly a kilometer down in the ocean.) Thunder booms everywhere. We walk through the dense atmosphere in a dream-like slow motion. The distant landscape shimmers. Only those objects nearby stand out in sharp outline, since we cannot see things clearly for more than 100 meters—about the length of a football field. And because the atmosphere refracts, or bends, light as a prism does, we seem to be standing in a great shallow bowl, with the horizon its rim.

Where does the Sun shine?

A huge hollow in the clouds over Venus's north pole may be 1,000 kilometers wide. Perhaps the Sun shines through this window. Also, shadows in the Venera photographs suggest that there may at least be a hazy Sun shining over Venus's surface.

One big question is how Venus became a hothouse planet. Some scientists speculate that Venus once was more like Earth than it is now. Maybe it had an atmosphere something like our own. Maybe it also had rivers and oceans.

Possibly a runaway greenhouse effect took over, driving the temperature so high that all the surface water boiled away. A lot of water vapor in the air would become an additional heat trap and send the temperature even higher. Eventually it would be hot enough to free large amounts of carbon dioxide, perhaps locked up chemically in the rocks. And so the planet would slowly build up its dense atmosphere of carbon dioxide. Maybe that is what happened, but it is a theory. If it's true, what became of the water vapor that began the process? Some scientists think it broke up into hydrogen, which escaped into space, and oxygen, which was trapped in the rocks of Venus's crust. If only we had some Venus rocks to examine in the laboratory!

Venus's average orbital speed of 126,000 kilometers an hour takes it once around the Sun every 224.7 Earth days. This makes it the second fastest planet in the

Solar System—because it is the second closest to the Sun. Since a Venus year is much shorter than an Earth year, a 15-year-old by Earth time would be 24 years old on Venus and could expect to live to the age of 122.

The longest day

A Venus day would seem endless to us. In fact a Venus day is longer than a Venus year. The planet rotates on its axis once every 243 Earth days with respect to the stars. That is, every 243 days we would see the same stars in the same positions in the sky from Venus, compared to every 24 hours from Earth. But in the meantime, we would have watched two sunrises and two sunsets because Venus has moved along its orbit. All of this movement makes a Venus day—the period of rotation with respect to the Sun—117 Earth days long. From sunrise to sunset on Venus would last 117 times longer than on Earth. And since Venus rotates retrograde we would see the Sun rise in the west and set in the east.

A sunset once every 117 days would not only be a rare event but a spectacular one. Through the dense atmosphere, because of refracted light, we would see the Sun bent all out of shape, greatly flattened and stretched out along the horizon.

Lava lakes and venusquakes

We continue our exploring past lakes of molten lava. Eventually we find ourselves standing at the edge of one of the largest canyons in the Solar System—almost four times as long as the Grand Canyon and nearly twice as deep. Every 150 kilometers along this huge canyon the ground zigs or zags, as it does along earthquake fault lines on Earth. This may mean that the Venus canyon was not scoured out by erosion as the Grand Canyon was. Instead, the Venus canyon may be a scar formed when the planet's crust split in ages past. And since Venus is probably much like Earth in composition, there may be venusquakes going on now.

We also find shallow craters on Venus. Many appear to have central peaks. One scientist said, it is "as if a rock were dropped into chocolate pudding." Some may be impact craters. Others may have arisen from volcanic eruptions.

In one large area—called Alpha—parallel ridges, like the wrinkles on a person's brow, stretch for hundreds of kilometers. Although these ridges look something like the parallel ridges of the Appalachian Mountains, how they formed is another Venus mystery.

Scientists first "saw" Venus's surface with radio telescopes at the Goldstone Deep Space Network Tracking Station in California, and the National Astronomy and Ionosphere Center at Arecibo, Puerto Rico. They bounced radar waves off the planet's surface and picked up the reflected signals to put images together. However, Earth-based observations are limited because the same side of Venus faces Earth each time the planets are closest together. Also, the best surface images are limited to a narrow band along the equator.

In December 1978 two NASA Pioneer Venus spacecraft reached the planet. Pioneer Venus 2 dropped four probes into the atmosphere. They observed many of the same features described in our imaginary space mission. Pioneer Venus 1, an orbiter, still circles the planet once a day, dipping as close as 80 kilometers to the cloud tops. The orbiter's radar has confirmed many suspected features and discovered others that Earth-based radar could not detect. Our shaded relief map is made from Pioneer's data.

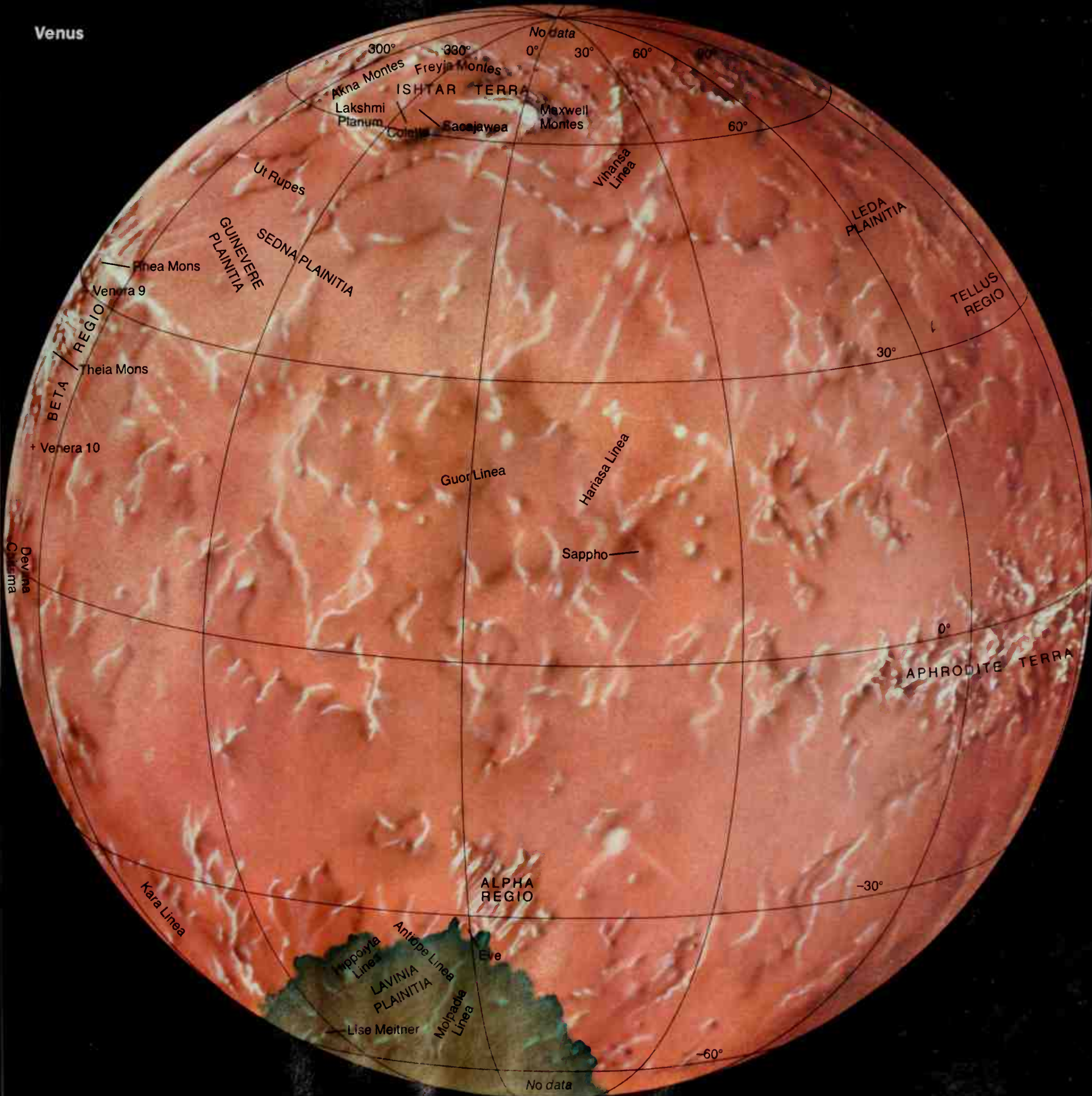
In a region called Beta, 6,000 kilometers northwest of Alpha, Pioneer mapped a chain of peaks that appear to be volcanic. They stretch south along a ridge for more than 2,000 kilometers—farther than the Hawaiian Ridge in the Pacific Ocean.

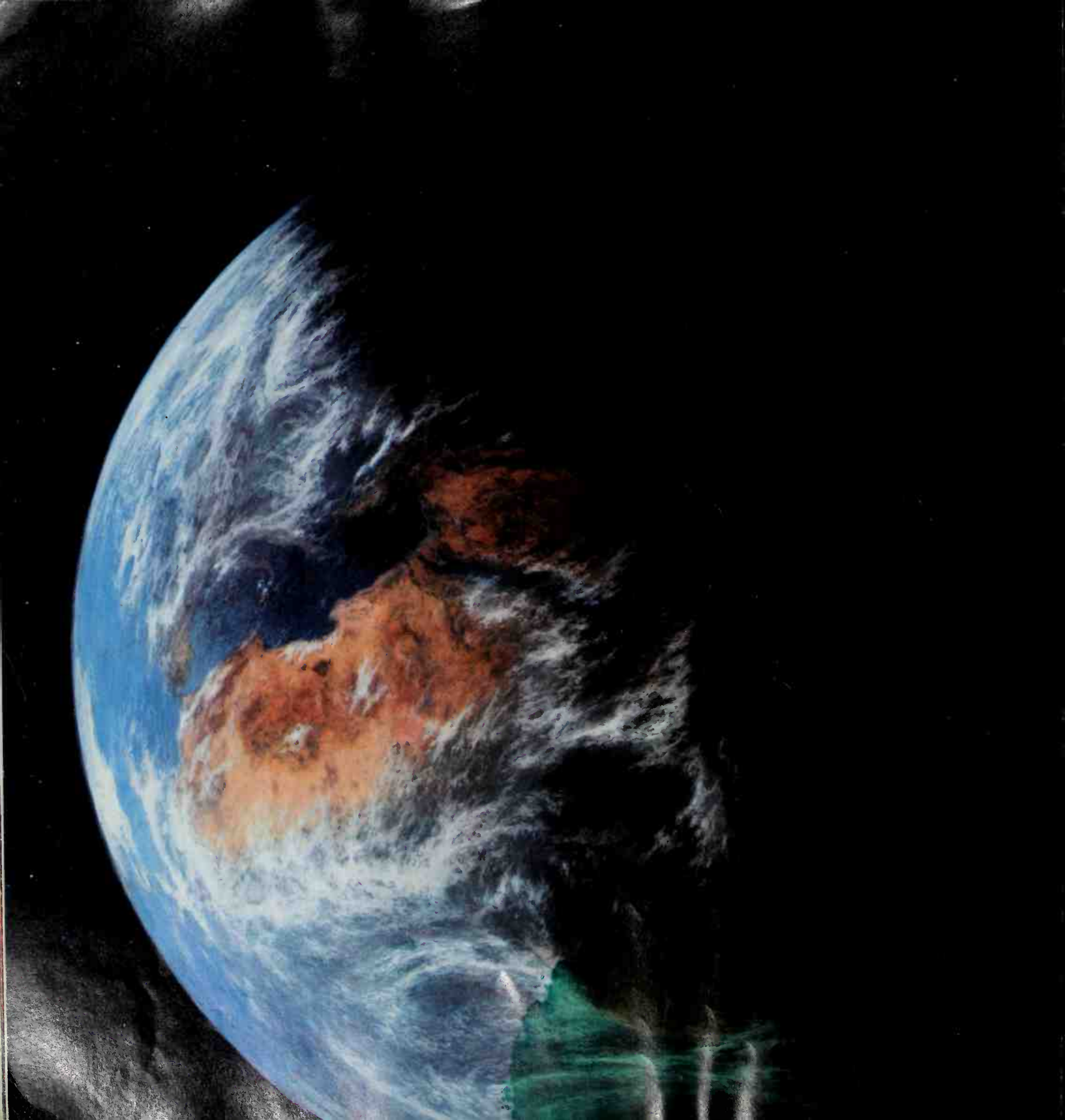
Pioneer's instruments also measured the height of Maxwell, a mountain that had shown up as only a bright image on Earth-based radar. Maxwell is higher than Mount Everest and overlooks Venus's highest plateau, Ishtar, named after the Babylonian goddess of love. Ishtar is about the size of the contiguous United States.

A new Venus

The abundance of new information about Venus makes us envision the planet as much less like Earth than we once thought. Although some of Venus's surface features remind us of places on Earth, geologists now say that these plateaus, craters, volcanoes, valleys, and mountains resulted from crustal movements different from those that shaped Earth's surface. The VOIR space mission—Venus Orbiting Imaging Radar—planned by NASA for the 1980's should give us a better understanding of our mysterious neighbor in space.

Venus


No data
300°
330°
0°
30°
60°
Akna Montes
Freyja Montes
ISHTAR TERRA
Lakshmi Planum
Colette
Sacajawea
Maxwell Montes
60°
Vihansa Linea
Ut Rupes
LEDA PLAINITIA
GUINEVERE PLAINITIA
SEDNA PLAINITIA
Rhea Mons
Venera 9
BETA REGIO
Theia Mons
TELLUS REGIO
30°
Venera 10
Guor Linea
Hariasa Linea
Sappho
0°
APHRODITE TERRA
ALPHA REGIO
-30°
Kara Linea
Antiope Linea
Hippolyta Linea
Eve
LAVINIA PLAINITIA
Molpadia Linea
Lise Meitner
-60°
No data



The Planet We Know Best

Earth

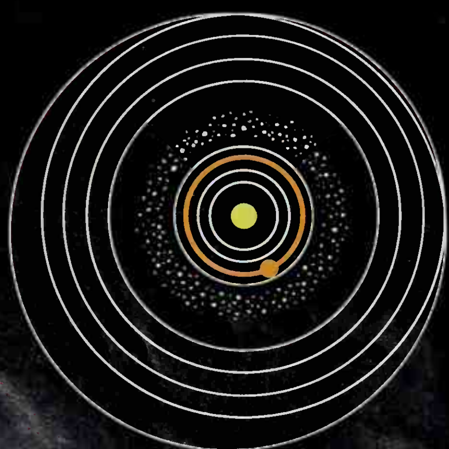
Delicate feather-like clouds that have formed from water vapor drift over and partly blanket Earth's surface—a surface mostly of water. So Earth deserves to be called "the watery planet."

With its one satellite, the Moon, Earth makes a breathtaking sight as we might see it from an orbiting spacecraft thousands of kilometers away. The Sahara sprawls across North Africa. You can locate the Mediterranean Sea to the north, with the Red Sea and the Arabian Peninsula to the east and, to the west, part of Spain and the blue of the Atlantic Ocean. But Earth's surface is never quite the same from one age to the next. Vulcanism and earthquakes change it, sometimes violently. Shifting sands and flowing water also bring changes. The forces of erosion hide or erase our planet's past.

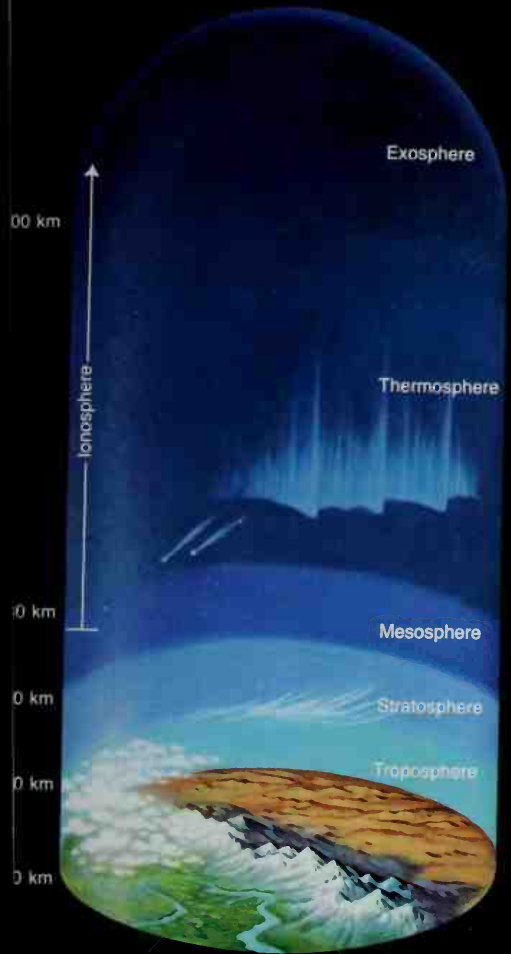
But the Moon has no atmosphere, no water to alter its face. So the surface we gaze on today is largely a relic of geologically ancient times. Here on the Moon we can see the giant rayed crater Copernicus midway between the terminator and the limb. To the left of Copernicus is another big crater, Kepler, and Oceanus Procellarum, the Ocean of Storms. On the Moon, though, as we will see, oceans are not oceans at all.

Facts about
Earth

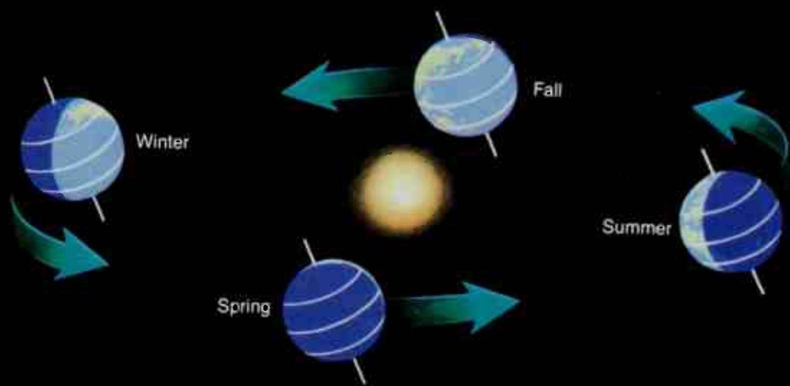
Gaea, Earth goddess of the ancient Greeks, was called *Terra Mater*—Earth Mother—by the Romans. Symbol: ⊕ Greek sign for *sphaira*, sphere.



Earth and its satellite, the Moon, follow a slightly oval-shaped path around the Sun. This causes our planet at one point to travel 2,500,000 km farther from the Sun than its average distance. Even so, Earth stays within a region of tolerance called the "ecosphere." In this safety zone, which roughly extends from the orbit of Venus to that of Mars, temperatures never get too high or too low to support our varied forms of life. If our orbit changed and carried us closer to the Sun, we would sizzle. Swinging too far away from the Sun, we would freeze into a ball of ice.

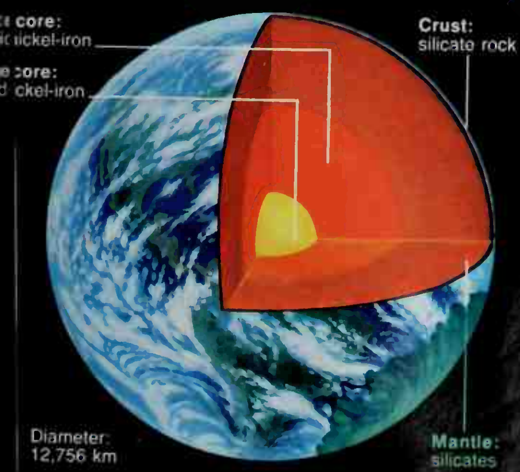


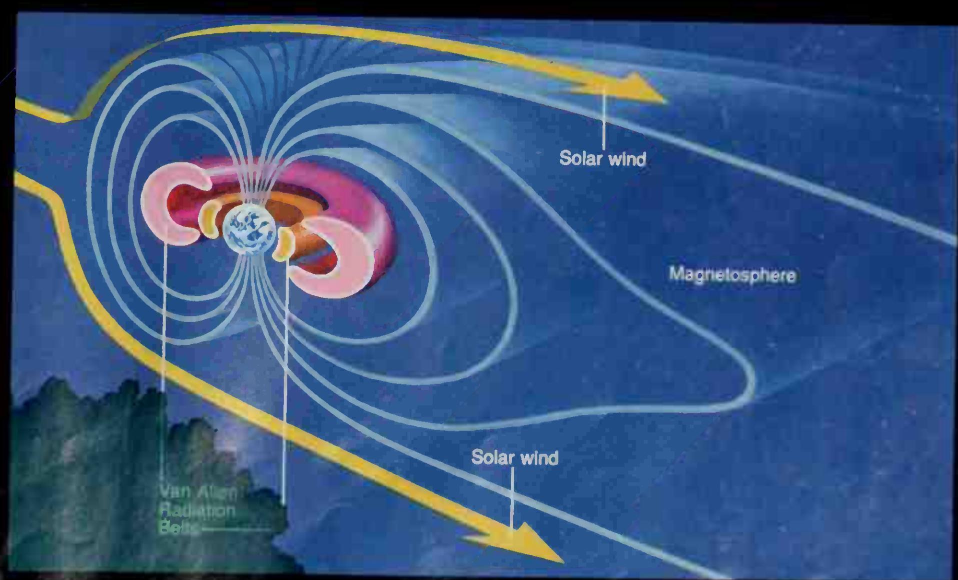
Earth's tilt causes the seasons. When the North Pole slants toward the Sun, the Northern Hemisphere has summer. Although Earth is then farthest from the Sun, the sunlight is less slanted and lasts longer. Winter comes to the hemisphere when the North Pole tilts away from the Sun.

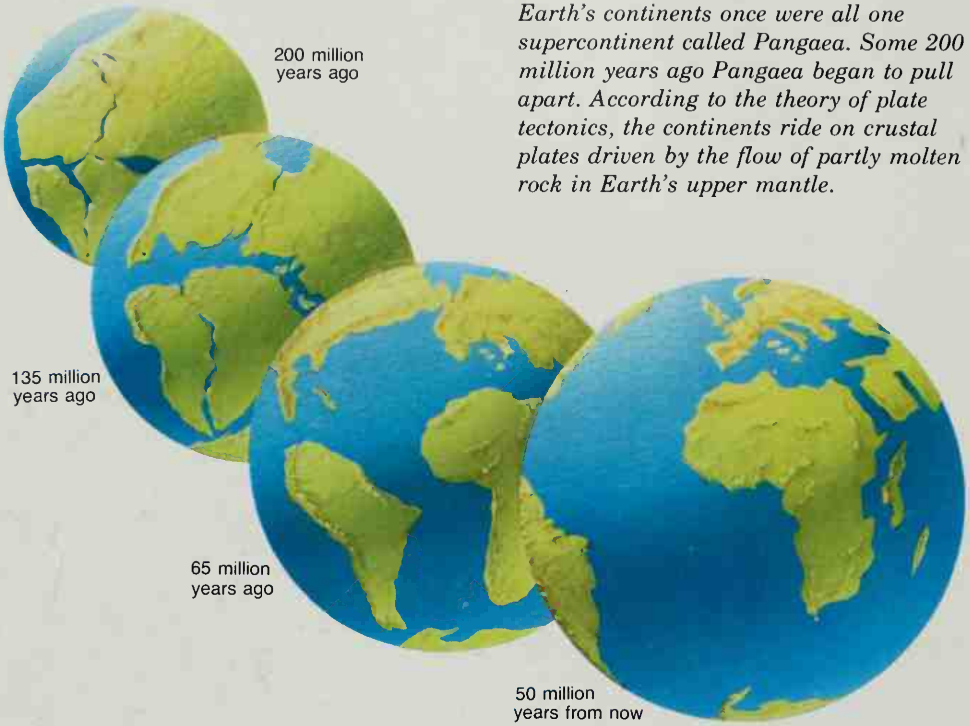


Our layered atmosphere presses down on Earth. Most of our weather occurs in the troposphere. Air, mainly nitrogen and oxygen, also contains small amounts of water vapor and other gases. Meteors blaze into the atmosphere, while a curtain-shaped aurora glows brightly.

A magnetic field acts as our shield against the solar wind, creating a region called the magnetosphere. The wind carries deadly, electrically charged particles as it streams outward from the Sun. Some particles are trapped in the Van Allen Belts, two bands that circle Earth.







Earth's continents once were all one supercontinent called Pangaea. Some 200 million years ago Pangaea began to pull apart. According to the theory of plate tectonics, the continents ride on crustal plates driven by the flow of partly molten rock in Earth's upper mantle.

This NASA photograph from 756 km up shows how the Arabian Peninsula has torn away from Africa, creating the Red Sea (left) and the Gulf of Aden (right). Further drifting in ages to come will widen the Red Sea. The Horn of Africa may break off to become an island (left).

From dust to Earth

Within a spinning cloud of gas and dust tiny grains of matter collide and grow into larger and larger clumps.... The clumps sweep each other up and form a ball, producing enormous heat.... This is how scientists think Earth may have formed about four and a half billion years ago. Inside an already hot Earth, temperatures rose further as decaying radioactive elements released heat, until the ball became a soupy mass simmering at 2,000°C. While heavier matter, such as iron, sank toward the center and formed a super-dense core, lighter-weight crystals floated up toward the surface and began to form a crust.

Fissures cracked the hardening crust, and lava and trapped gases bubbled to the surface. They formed a primitive atmosphere, vastly different from the one we know today. It was made up mostly of nitrogen, carbon dioxide, carbon monoxide, and water vapor with, possibly, small amounts of methane and ammonia. As the water vapor rose above the planet and cooled, it condensed and fell as rain. In some places the surface remained so hot that the rains kept evaporating back into water vapor as quickly as they fell.

As time passed, surface rock absorbed most of the first rains. When the crust could not sponge up any more, the waters slowly collected in vast basins and became our first seas. Through thinning clouds the Sun at last shone on a planet of jagged rock and sparkling water.

One continent

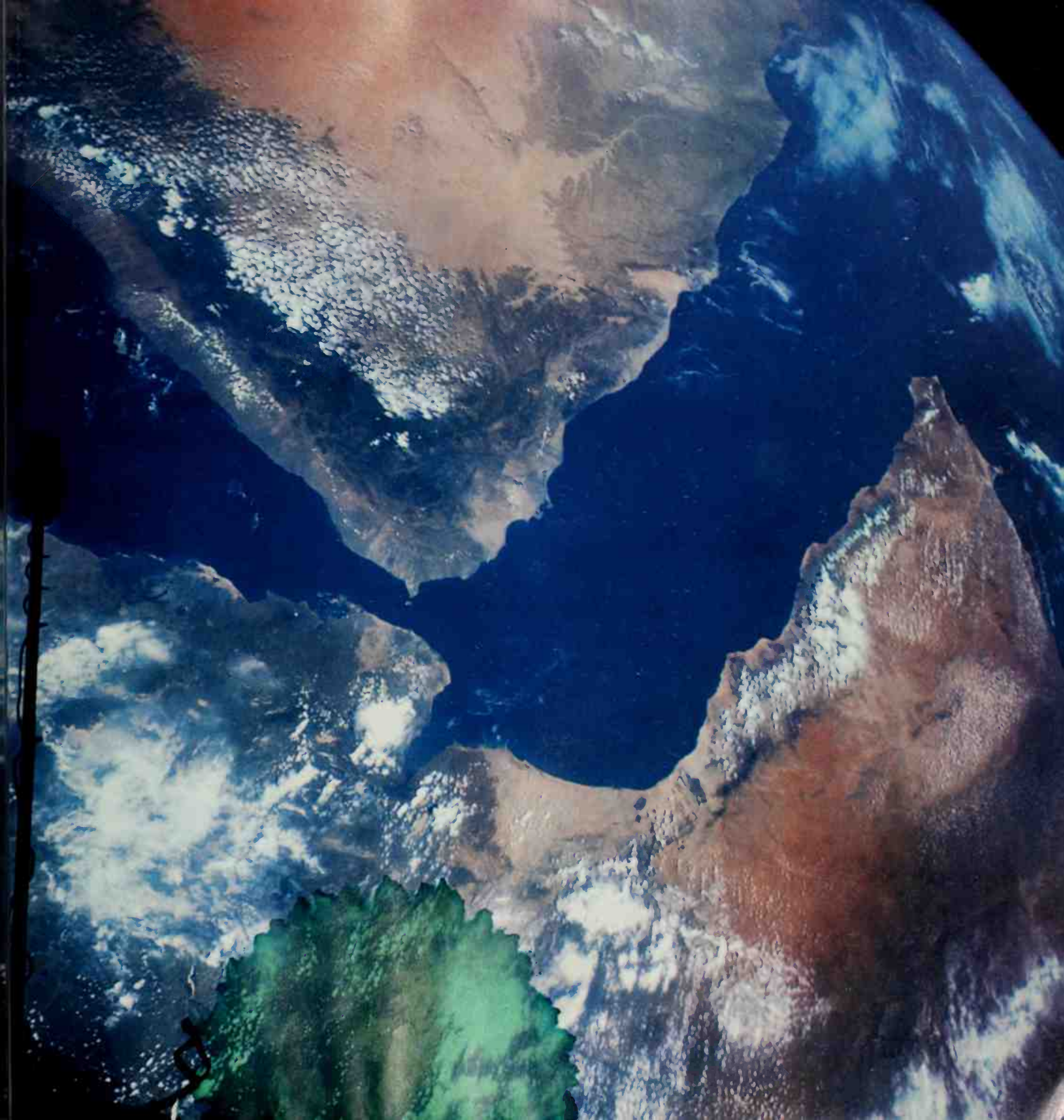
The continents we know today did not exist then. But continental masses did exist, and about 220 million years ago they had merged into the single supercontinent of Pangaea. By 135 million years ago, Pangaea had broken up and drifted apart into a northern half called Laurasia and a southern half called Gondwana. By 65 million years ago these two huge land masses had split further and the pieces had drifted toward the positions of the continents we know today.

The changing planet

The continents are still drifting. They rest on crustal plates that are moved by convection currents in the partially molten mantle, like large pieces of rock on conveyor belts. The energy that produces these motions is heat welling up from deep within our planet. Where the plate edges grind against or ride over each other, volcanoes sometimes erupt, earthquakes rumble, or an edge crumples up and forms mountains. When two plates beneath an ocean pull apart, the shape of the ocean floor gradually changes. The Atlantic Ocean floor spreads some four centimeters a year, while the Pacific Ocean floor shrinks.

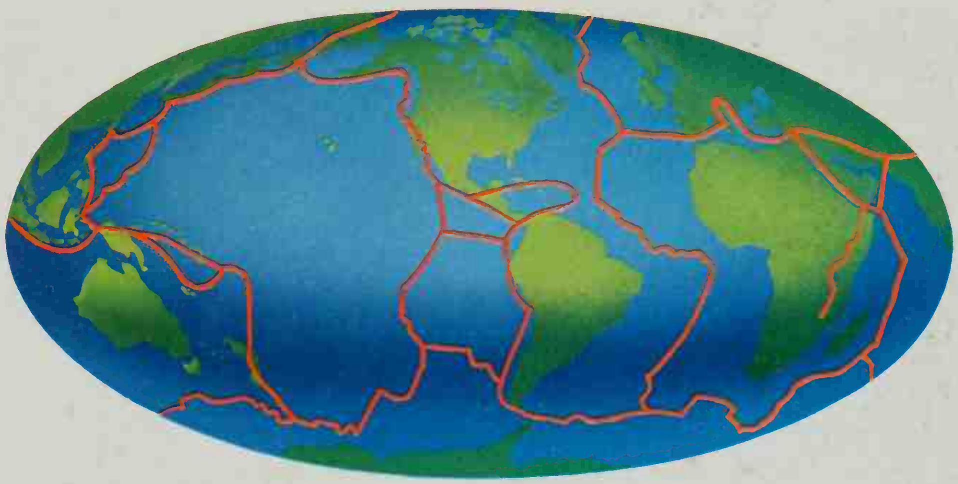
World climate also changes, influenced by polar ice. Ice ages alternate with warm periods. Over the past two million years—the Great Ice Age—there may have been as many as 18 glaciations. At the peak of the last ice advance, some 18,000 years ago, about 30 percent of the land surface was under ice. In the polar regions, the ice seems permanent, but it is not. At times in Earth's past, the average global temperature was about 22°C, warm enough to keep even the poles free of ice. Today the average temperature, 14°C, keeps Greenland (once covered with forests) and Antarctica under ice caps many kilometers thick.

If a warm period melts the sheets of ice on Greenland and Antarctica, so much water will be released that the level of the



Molten rock burst through a new vent of Kilauea volcano on the island of Hawaii in 1977. Lava poured from the vent and down the mountain in a river of fire 10 m deep, 300 m wide, and nearly 10 km long. Kilauea, one of the world's most active volcanoes, erupts every 2.5 years.

Red lines show the boundaries of Earth's crustal plates. Along these seams—called lines of fire—the surface is weakest. Edges rub and override each other, causing earthquakes. Volcanoes are created when magma, under tremendous heat and pressure, oozes out through cracks.



oceans will rise and drown coastal cities and towns around the world.

Mountain building

Earth is a living planet, its face sculptured by ice, wind, and water, and altered by the slow uplift of mountains. The Appalachian chain began to take shape over 400 million years ago. About 230 million years ago, these mountains south of New England crumpled up as the North American and African continents came together. The ancestral Sierra Nevada mountain range rose 140 million years ago, when molten rock pushed into the upper crust. The modern Sierra Nevada in California were thrust up in the last several million years. The earliest Rocky Mountains were formed about 300 million years ago. But the modern Rockies, which are still rising, were formed 70 to 100 million years ago.

In great outbursts of fire and lava about two million years ago Mount Shasta was born in California and Mount Rainier in Washington. The eruption of Washington's Mount St. Helens, which blew its top in 1980, reminds us of how quickly Earth can change. But an example of slow change goes steadily on in Arizona. There, for millions of years, scouring wind, beating rain, rock-cracking frost, and the surging water of the Colorado River have been carving out the Grand Canyon.

Mountains under the sea

Covering most of our planet's surface, the oceans reach an average depth of 4.5 kilometers. But trenches in the ocean floor are twice that deep. The Mariana Trench in the Pacific, deepest point on Earth, plunges to 11 kilometers below sea level. It is deep enough to hold seven Grand Canyons stacked in a pile. Another gaping chasm in the Pacific, the Kermadec-Tonga Trench, is long enough to stretch from New York City to Kansas City.

More than four billion years ago gas and dust particles combined into the ball we call Earth. Intense internal heat turned solid matter into molten rock. Lava poured from fissures, cooled, and formed a thicker crust (upper). Locked inside the emerging lava were the elements hydrogen and oxygen in the form of water vapor. At the surface the water vapor, along with other gases, formed a primitive atmosphere. During Earth's first billion years, surface heat diminished. The water vapor condensed, and heavy rains fell. On hitting hot spots, the rain evaporated as steam (lower), then fell again. Eventually the surface cooled. Gradually the cracked crust absorbed water until underground spaces could hold no more. Surface water then began to collect in basins and depressions (opposite), and the first oceans were born.

Earth's longest mountain range is not on the land but under the sea—the Mid-Oceanic Ridge, about 64,000 kilometers long. Some of its peaks poke up to the surface: Iceland, the Azores, Easter Island.

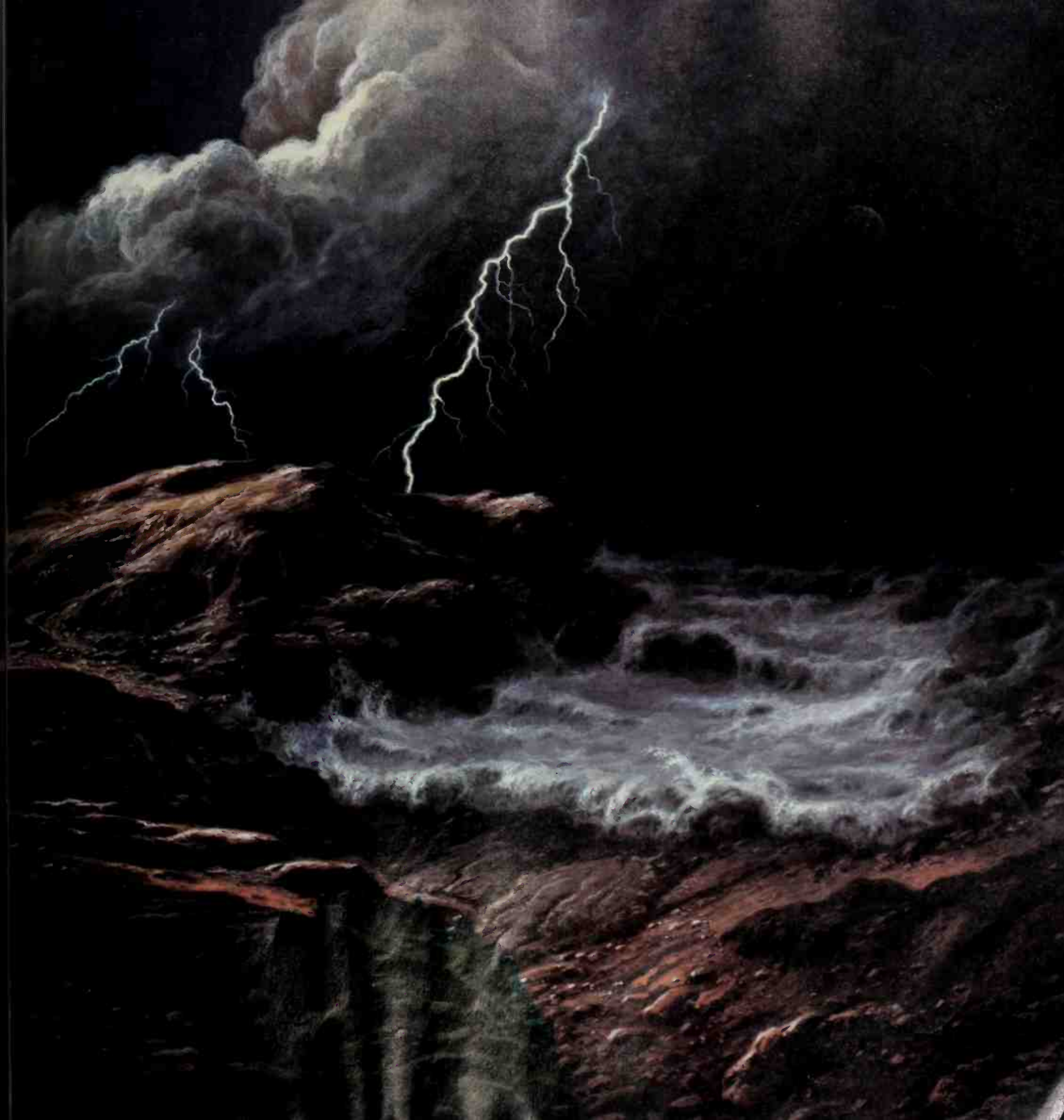
Like the land, the seafloor continually changes its shape. The major land masses have shallow *continental shelves* that extend seaward as much as 1,000 kilometers, then slope gently down to the deep ocean floor. Thick layers of mud pile up at the edge of these continental shelves and then break loose and tumble down as undersea avalanches. They scour out deep canyons in the slopes and the sediments glide far out onto the deep ocean floor.

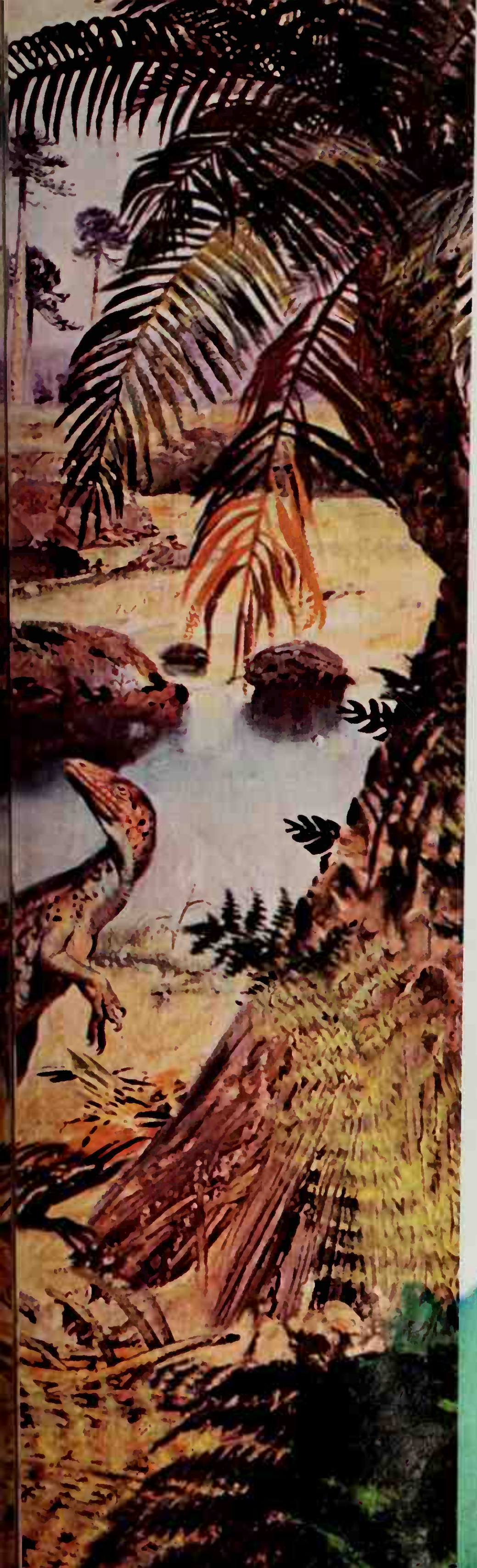
Rivers in the sea

Blown by winds, the surface waters of the oceans flow around the continents. They move in currents like rivers within the ocean itself.

One of the best known of the warm currents is the Gulf Stream. It sweeps up the East Coast of the United States, then curves gently north and eastward past Britain toward Iceland.

Heat carried by the Gulf Stream warms northern lands. There also are cold currents, such as the Labrador Current that flows out of the Arctic near Greenland. There are deep, almost freezing, currents that inch northward along the sea floor from Antarctica. Just as air interacts with the land, it also interacts with the oceans, exchanging materials with them and driving their motion. The chief energy source for this activity—both on the land and within the sea—is the Sun.





Life on Earth 150 million years ago saw lush vegetation and many forms of reptiles. Two pterosaurs—reptiles, not birds—soar in the distance, while a pair of feathered, flightless Archaeopteryx—*the earliest known bird—team up to confront a* Compsognathus, *a small, bipedal dinosaur.* Archaeopteryx *shows links to reptiles (sharp teeth, claws, and a long, bony tail) and modern birds (wings and feathers). Because it lacked a strong breastbone to anchor muscles, the bird could probably only flap in pursuit of prey, using its wings like a net.*

Exploring Earth's Interior

The center of our planet lies nearly 6,400 kilometers below the surface. In recent times, we have drilled down into the crust to learn more about Earth. So far we have reached a depth of only eight kilometers. But geologists dream of drilling a hole to the center and bringing up a sample of material. That would tell us exactly what our planet's interior is made of. Since we cannot drill that far, we must get our information in other ways. One important way is to study and measure earthquakes.

During an earthquake different kinds of shock waves, called *seismic* waves, shiver around and through the planet. Several kinds of waves travel away from the focus of the earthquake at different speeds. The primary waves are important to science because they travel all the way through the planet. Because we know how these waves behave as they pass through different materials, such as rocks and liquids, we can piece together the structure and composition of Earth's interior.

But to study the crust we don't have to wait for earthquakes. Geophysicists make their own mini-quakes by setting off explosives underground. These set up seismic waves which are recorded on instruments called *seismographs,* and we then have a meaningful record to read.

Seismic waves tell us the density of the rock they happen to be passing through. The waves travel through very dense rock, such as basalt, faster than they travel through less dense rock, such as sandstone. We also know that certain waves can travel through solids, liquids, or gases, while others, such as secondary waves, can pass only through solids—not through liquids. By recording the travel times and paths of seismic waves through Earth, scientists have drawn this profile:

There are three main layers—the crust, mantle, and core. The lightweight surface rocks of the *crust* are about 2.8 times denser than water. The crust extends downward to about 40 kilometers under the continents and to about 5 kilometers under the seafloor. The rocks of the crust are those familiar to us at Earth's surface. Although 40 kilometers sounds like a lot, in this case it is not. The crust makes up only one percent of Earth's volume. If Earth were an apple, the apple's thin skin would equal the thickness of the crust.

From high above Earth's "skin" a number of surface features can be seen in detail. Among them are impact craters made by meteorites. For instance, the remains of at least 17 craters are scattered over the Canadian Shield, a vast area of two-billion-year-old rock that cups Hudson Bay. The oldest parts of Earth's crust show the most craters. Younger parts of the crust formed after most meteorite activity was over. During the millions of years since the craters formed, the majority have been removed by erosion or buried under sedimentary rock. Early in Earth's history its surface probably was pitted everywhere with impact craters. Today we know of nearly 80 (see the map on page 151). They range from less than 100 meters to more than 100 kilometers across. One, in Vredefort, South Africa, measures 140 kilometers in diameter.

Hurricane Gladys, photographed by Apollo 7 astronauts, swirls over the Gulf of Mexico. The Coriolis effect, caused by Earth's rotation, governs the direction of spin in such storms. The movement is counterclockwise in the Northern Hemisphere, clockwise in the Southern.

Below the crust lies the *mantle,* a layer of rock that extends halfway to the center of Earth, or to a depth of 2,900 kilometers. Its upper part seems to be brittle rock, for earthquakes have been recorded as deep within the mantle as 700 kilometers. Parts of the mantle get so hot that the rock becomes molten and moves slowly in vertically rotating currents.

Earth's *core* has a fluid outer layer enclosing a solid inner region, both mostly of iron and a little nickel. The inner core is a ball about 2,600 kilometers across. Earth's temperature increases from about 15°C at the surface and may reach 4,000°C in the inner core. The pressure in the inner core is extremely high, more than three times that inside Earth's mantle, and over three million times that of our planet's atmosphere at the surface.

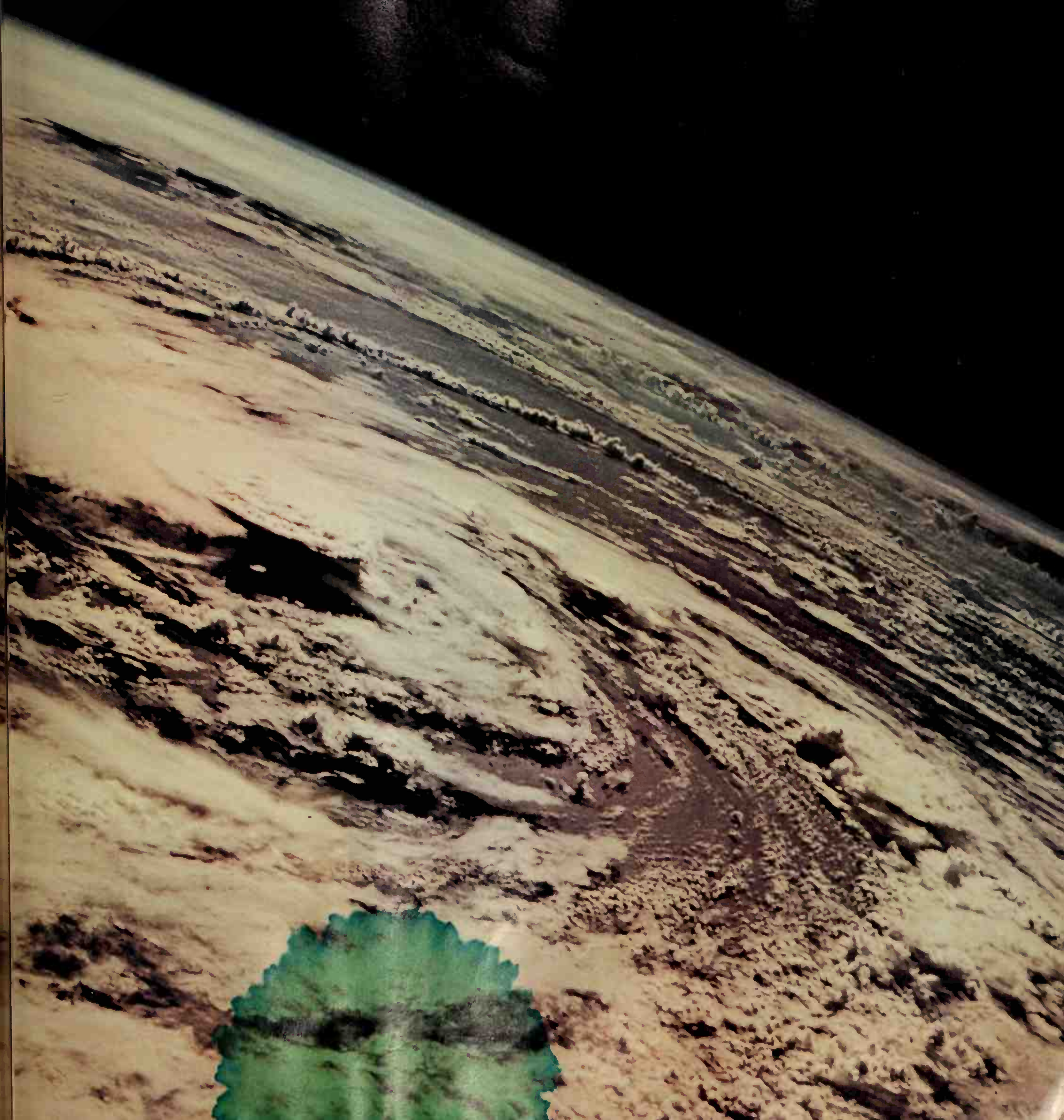
The marvel of life

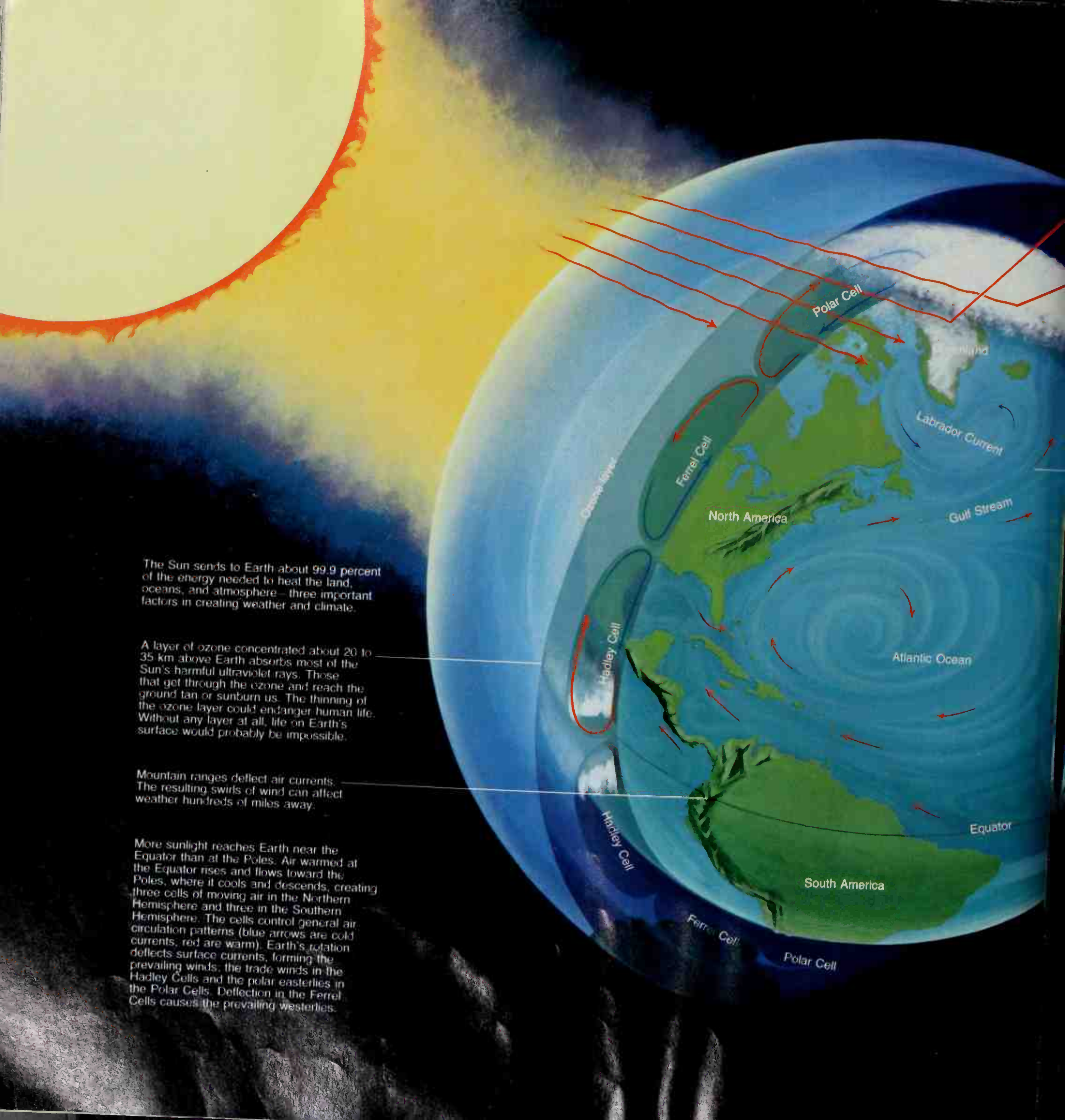
Some 3.5 billion years ago, most scientists believe, bacteria and tiny plantlike organisms began to grow in the seas. Over millions of years some evolved into complex plants. They gradually developed a process called *photosynthesis.* By this process, plants containing a green substance, chlorophyll, use sunlight to make their own food. They take in carbon dioxide and water and change them into sugar, which they use as energy. As a result of the process, they give off oxygen and produce water.

These plants were so successful that they changed Earth's atmosphere in an important way. The oxygen they gave off first reacted with iron dissolved in sea water, causing it to oxidize, or rust, and settle on the ocean floor. When most of the iron was used up, the surplus oxygen accumulated to such an extent that it started escaping into the atmosphere, forming part of the air we breathe today.

As hundreds of millions of years passed, water plants took up life on land and spread far and wide. So did fish-like organisms that inhabited the seas in the Age of Fishes, 395 to 345 million years ago. Much later, during the Age of Reptiles, 225 to 65 million years ago, those magnificent "terrible lizards," the dinosaurs, ruled Earth for well over a hundred million years. When dinosaurs became extinct, some 65 million years ago, their place of dominance in the animal kingdom was taken by mammals, which later included humans. We still live in the Age of Mammals.

Today 1.4 million different kinds of animals and 500,000 different kinds of plants are known to inhabit Earth. If that seems a lot, then think of this: 99 percent of all the kinds of plants and animals that ever lived on Earth are extinct. Some very old types have escaped extinction by adapting to a changing environment. The cockroach and the shark were abundant 250 million years ago. The 19th-century naturalist Charles Darwin marveled at Earth's varied life when he wrote: "We may well affirm that every part of the world is habitable! Whether lakes of brine, or those subterranean ones hidden beneath volcanic mountains—warm mineral springs—the wide expanse and depths of the ocean—the upper regions of the atmosphere, and even the surface of perpetual snow—all support organic things."



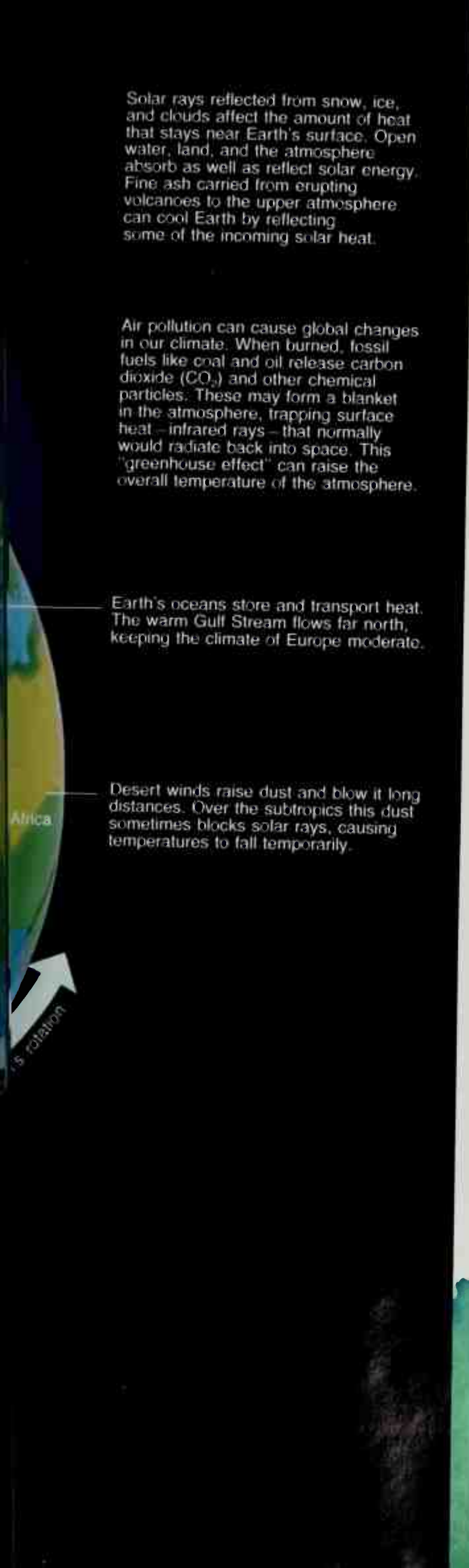


The Sun sends to Earth about 99.9 percent of the energy needed to heat the land, oceans, and atmosphere – three important factors in creating weather and climate.

A layer of ozone concentrated about 20 to 35 km above Earth absorbs most of the Sun's harmful ultraviolet rays. Those that get through the ozone and reach the ground tan or sunburn us. The thinning of the ozone layer could endanger human life. Without any layer at all, life on Earth's surface would probably be impossible.

Mountain ranges deflect air currents. The resulting swirls of wind can affect weather hundreds of miles away.

More sunlight reaches Earth near the Equator than at the Poles. Air warmed at the Equator rises and flows toward the Poles, where it cools and descends, creating three cells of moving air in the Northern Hemisphere and three in the Southern Hemisphere. The cells control general air circulation patterns (blue arrows are cold currents, red are warm). Earth's rotation deflects surface currents, forming the prevailing winds: the trade winds in the Hadley Cells and the polar easterlies in the Polar Cells. Deflection in the Ferrel Cells causes the prevailing westerlies.



Solar energy regulates Earth's climate. Hot air rising at the Equator moves toward the poles. Cold polar air sinks and moves toward the Equator. Water evaporates; the vapor rises, then cools and falls as rain or snow. Earth's rotation and topography help establish wind and weather patterns.

On the next page: *Running water, like Iguazú Falls in Brazil, is one agent of erosion changing Earth's face. Wind, rain, freezing, and thawing also wear away the rock. Over millions of years, they may scour a mountain down to a plain or carve a ditch as big as Grand Canyon.*

Our ocean of air

On the average, Earth's air is a mixture of dust and gases—78 percent nitrogen, 21 percent oxygen, and one percent other gases that include argon, neon, carbon dioxide, water vapor, and ozone. As we descend into the atmosphere from outer space, we pass through the *exosphere*. In this region the air is so thin and gravity so weak that atoms escape into space.

We next descend through four major layers. The first layer, which begins about 500 kilometers above the ground, is the *thermosphere*. Up here so few air molecules exist that the Sun's radiation has too little to strike against in order to scatter light. Thus, the sky is very dark. The thin atmosphere also means that there is no transfer of heat from the air to any object in the air. Any living creature exposed to the thermosphere would broil on its Sun side and freeze on its shadow side. At the bottom of the thermosphere, 80 kilometers above the surface, temperatures are –90°C.

Below the thermosphere is the *mesosphere* layer, about 30 kilometers deep. The sky here is nearly dark, since the air still is very thin. At the base of the mesosphere the temperature climbs to about 0°C. The *ionosphere* also begins about here. It makes long-distance radio communication possible. Radio waves sent from stations on the surface of Earth travel up to the ionosphere, glance off it and back down to radio receivers many miles away. Without the ionosphere, radio signals from our transmitters would pass right on out through the atmosphere.

The next layer down is the *stratosphere*, about 40 kilometers deep. At the bottom of this layer the temperature dips to about –50°C, much colder than at the top. How can this be, since the air is supposed to get steadily warmer as we move deeper into the denser lower region of our ocean of air?

The answer is a strip in the middle of the stratosphere called the *ozone layer*. Ozone is a special form of oxygen with molecules that have three atoms instead of two. This layer of gas shields us from damaging ultraviolet energy entering the atmosphere from the Sun. Absorption of this energy causes the ozone layer to heat up.

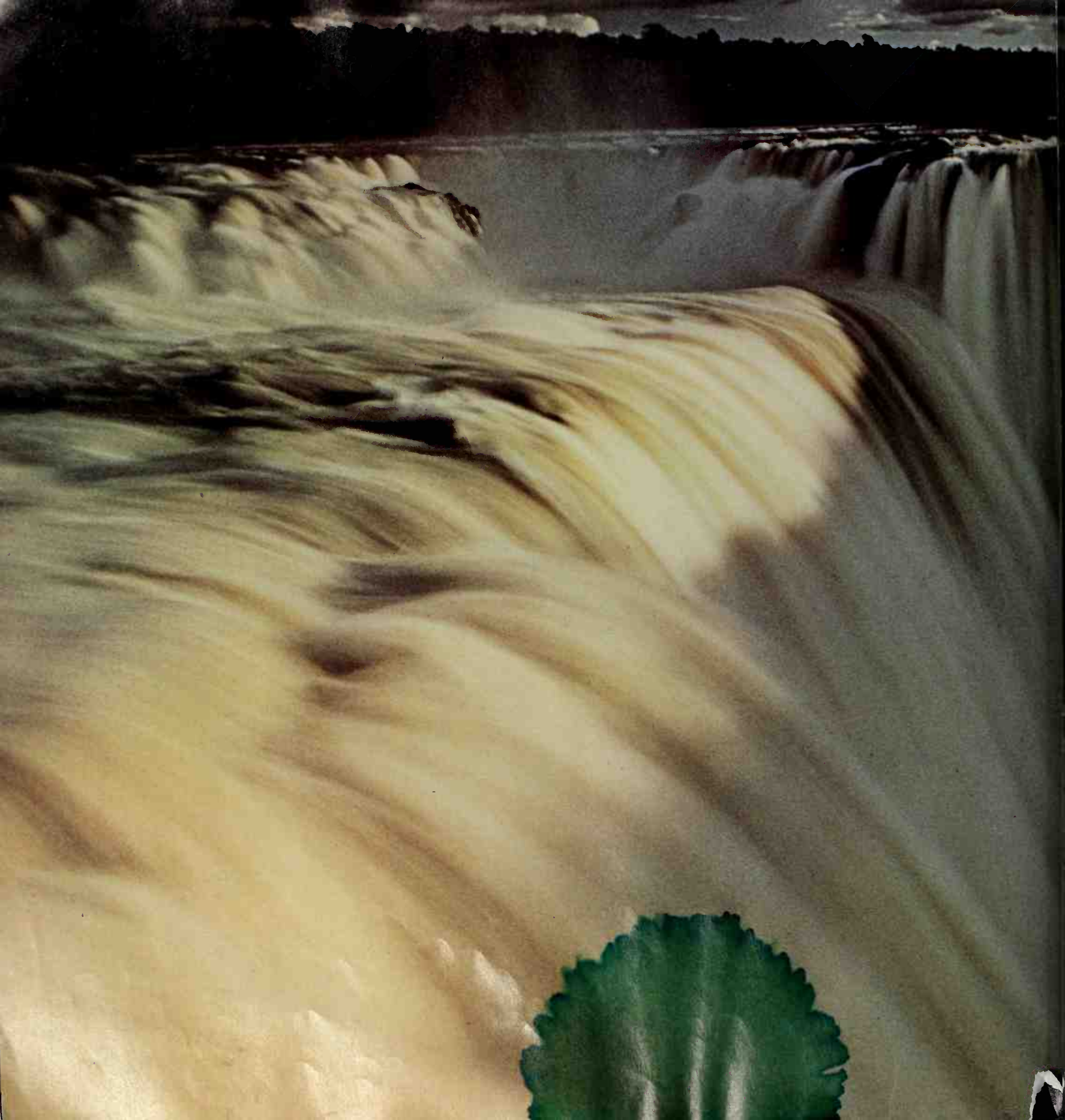
The bottom air layer is called the *troposphere*. As we descend through it into denser and denser air, we become gradually warmer. The warming comes about when short-wavelength energy from the Sun heats up the ground and the oceans and is returned to the atmosphere as long-wavelength (heat) energy.

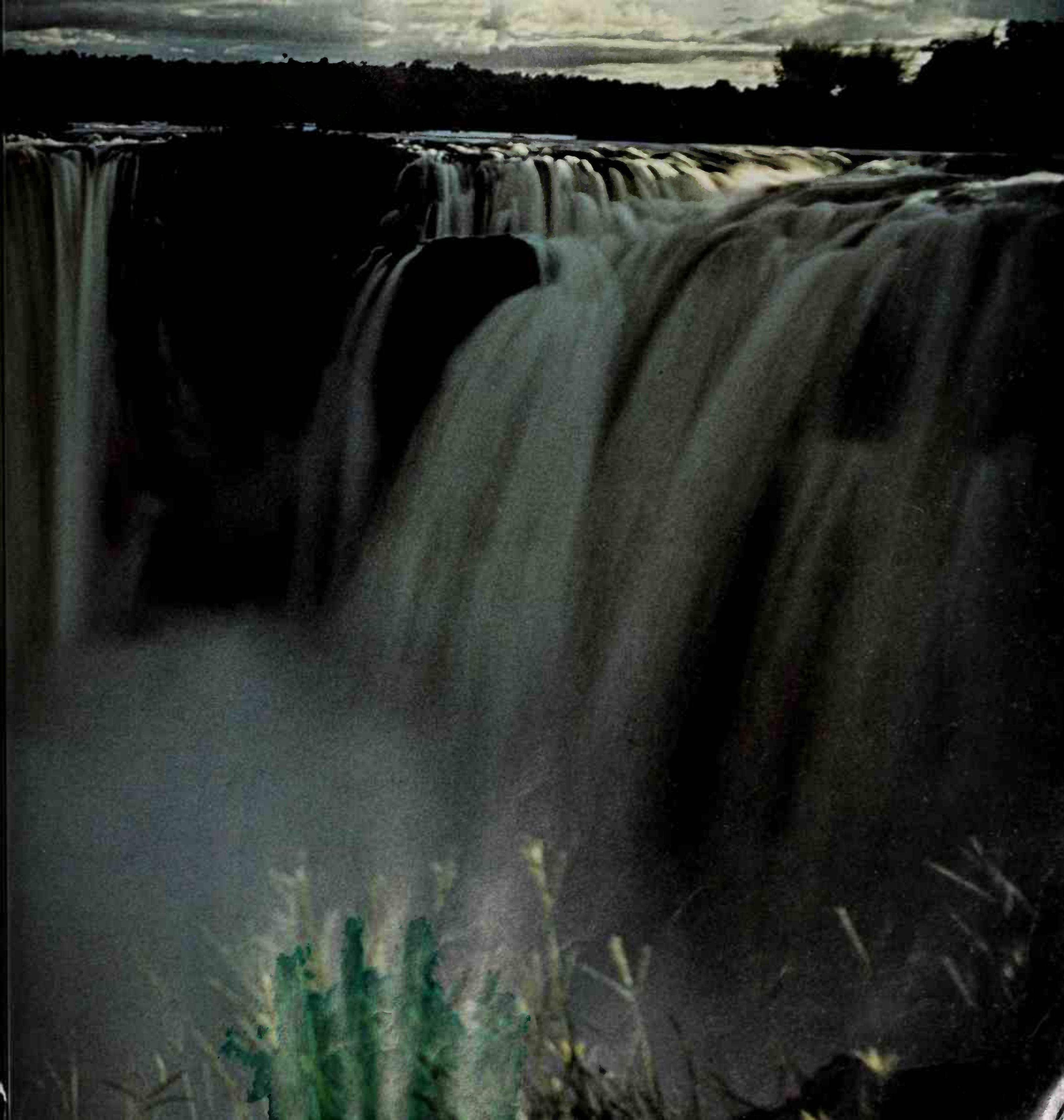
High in the troposphere we find ourselves battered by jet-stream winds blowing 400 kilometers an hour. As we continue down, the winds lessen and the sky gradually changes from deep to lighter blue. The sky is blue because the short, blue wavelengths of light get scattered more than the longer, red wavelengths.

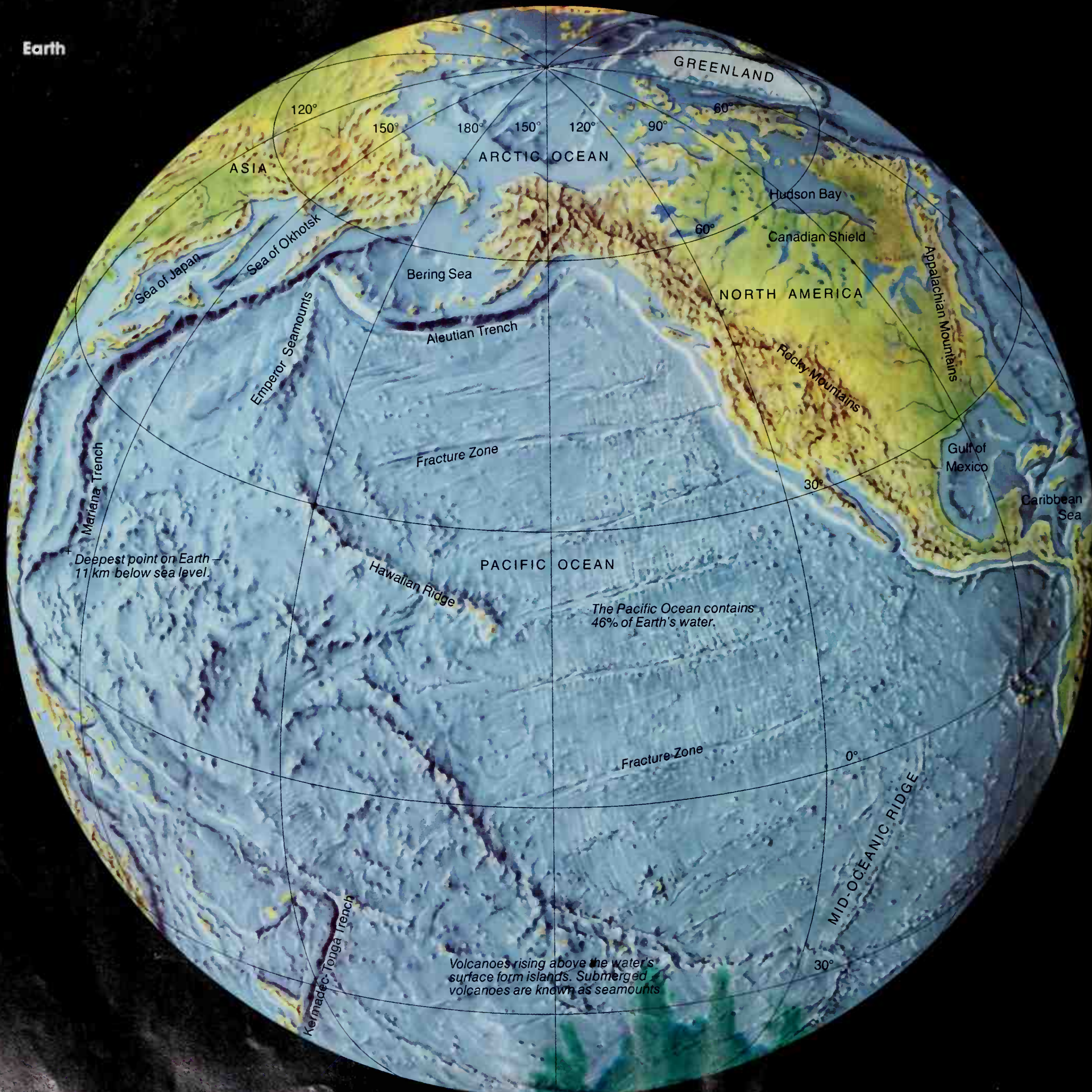
In this blue layer of air—which reaches from the ground up to about 10 kilometers—all of Earth's weather takes place. Here we find the westerlies, the gentle trades, thunderstorms, and lightning.

Earth as a magnet

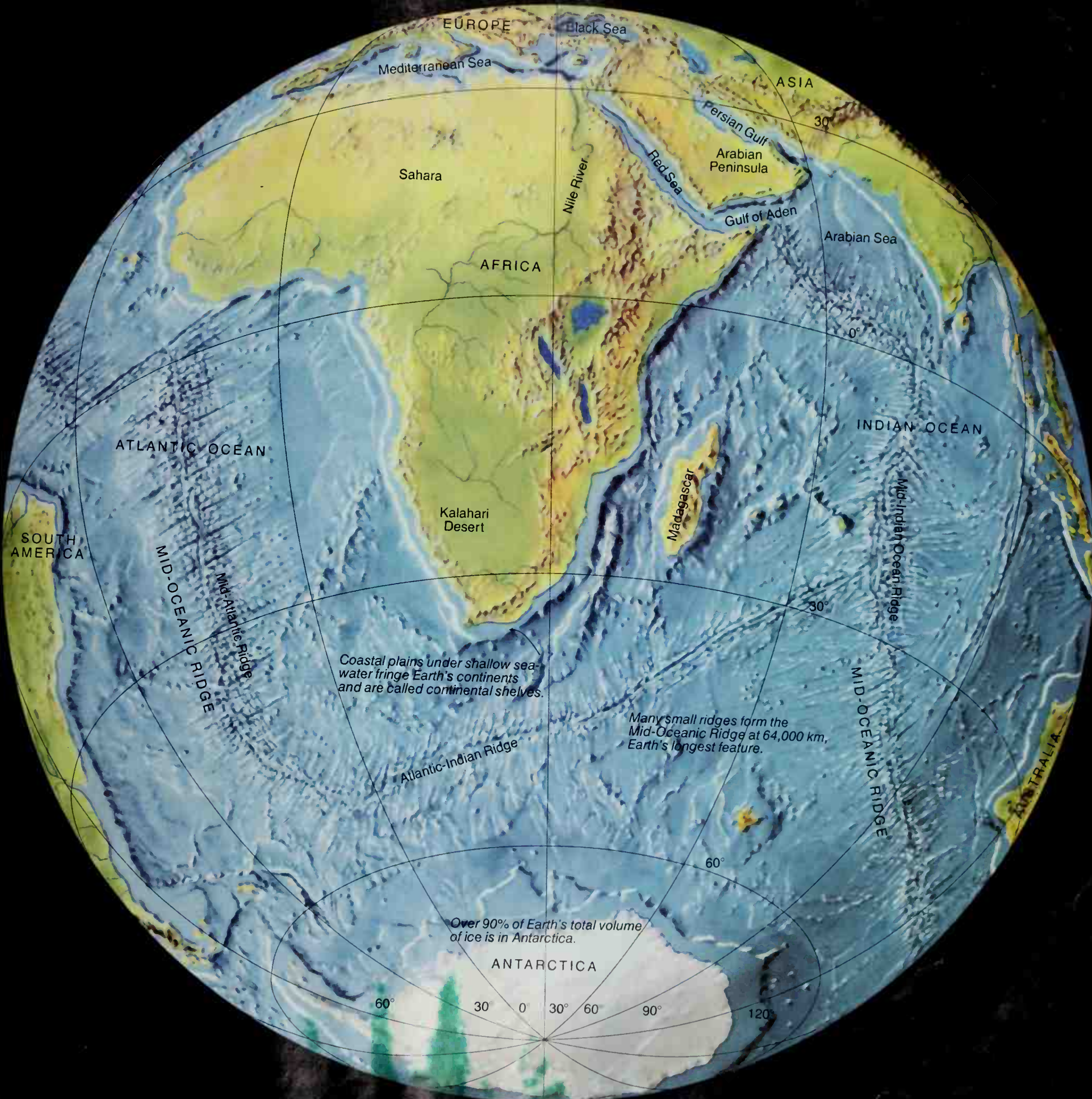
Earth behaves as though it had a giant bar magnet inside, running from north to





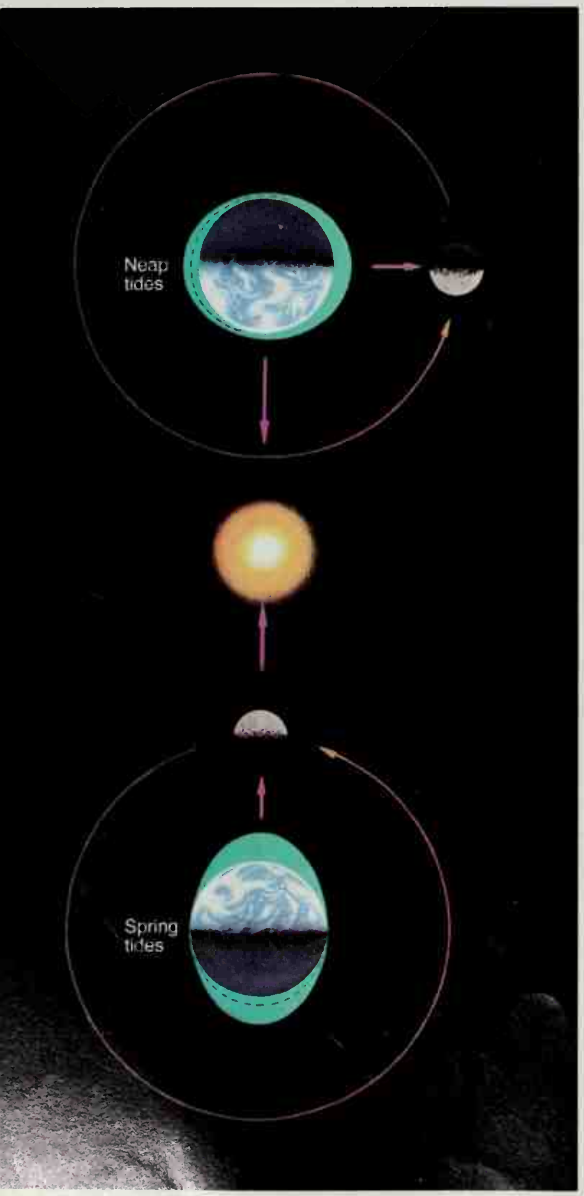


GREENLAND
120°
150°
180°
150°
120°
90°
60°
ASIA
ARCTIC OCEAN
Hudson Bay
60°
Canadian Shield
Sea of Japan
Sea of Okhotsk
Bering Sea
NORTH AMERICA
Appalachian Mountains
Emperor Seamounts
Aleutian Trench
Rocky Mountains
Mariana Trench
Fracture Zone
Gulf of Mexico
30°
Caribbean Sea
Deepest point on Earth – 11 km below sea level.
PACIFIC OCEAN
Hawaiian Ridge
The Pacific Ocean contains 46% of Earth's water.
Fracture Zone
0°
MID-OCEANIC RIDGE
Kermadec-Tonga Trench
Volcanoes rising above the water's surface form islands. Submerged volcanoes are known as seamounts
30°


EUROPE
Black Sea
Mediterranean Sea
ASIA
Persian Gulf
30°
Arabian Peninsula
Red Sea
Sahara
Nile River
Gulf of Aden
Arabian Sea
AFRICA
0°
INDIAN OCEAN
ATLANTIC OCEAN
Madagascar
Kalahari Desert
Mid-Indian Ocean Ridge
SOUTH AMERICA
MID-OCEANIC RIDGE
Mid-Atlantic Ridge
30°
Coastal plains under shallow sea-water fringe Earth's continents and are called continental shelves.
Many small ridges form the Mid-Oceanic Ridge at 64,000 km, Earth's longest feature.
MID-OCEANIC RIDGE
Atlantic-Indian Ridge
AUSTRALIA
60°
Over 90% of Earth's total volume of ice is in Antarctica.
ANTARCTICA
60°
30°
0°
30°
60°
90°
120°

Earth's lowest tides occur when Moon, Earth, and Sun form right angles. When the bodies line up on one side, the combined gravitational pull causes the highest tides. Dotted lines show how our globe is pulled away from the seas on the opposite side, leaving a bulge of water.

Under a full Moon, high tide creeps up the sand at Myrtle Beach, South Carolina. The Moon's gravitational attraction pulls at our oceans as Earth rotates, making most coastal waters rise and fall. About every 12.5 hours tides are highest (or lowest) on opposite sides of Earth.



south. Heat flow within the molten outer core of Earth causes slow convection, or circulatory, currents in the liquid metal. This motion in the outer core is thought to generate lines of magnetism between the magnetic north and south poles, producing Earth's *magnetic field*. The solar wind squashes the magnetic field against Earth on the Sun side and stretches it out on the shadow side, creating the *magnetosphere*.

Earth's magnetic field protects us from dangerous solar radiation. Most of the charged atomic particles from the Sun are deflected around Earth by the magnetic field. But some are trapped—for a while—in a great doughnut-shaped "holding" area around Earth called the Van Allen radiation belts. The particles eventually leak off into space as new ones are taken captive. Under certain conditions, when solar wind particles strike the Van Allen belts they are speeded up. As they hit the upper atmosphere, they then glow as "northern lights," or the aurora borealis (aurora australis in the Southern Hemisphere).

Some radio waves—generated by lightning—are transmitted along the magnetic field lines between the poles. When they reach one pole, they are repelled and bounce back toward the opposite pole. Back and forth they go. During their journeys they make whistling sounds that we can hear by radio. A whistler makes one trip from pole to pole in about one second!

A watery planet

Water covers 70 percent of Earth's surface and is part of the atmosphere as well. Essential to life, water is so widespread that plants and animals are found almost everywhere. They help to recycle and renew the atmosphere. Plants take up water through their roots and return it to the air through their leaves as water vapor. When animals breathe, they exhale water vapor. You can see the moisture when you breathe on a window or mirror. When animals die, the water that makes up as much as 70 percent of their bodies is released and returned to the air or the ground.

Plants and animals are only a small part of the exchange process called the *hydrologic cycle,* or water cycle. Ocean water evaporates and changes into water vapor. Rising in the atmosphere, it cools and condenses into droplets. These collect in clouds, which return the water to the surface as rain and sometimes snow. Some of this *precipitation* is evaporated right away, some flows in rivers back to the ocean, and some seeps into the ground.

Ocean water is recycled another way. Some scientists say that, over the course of six to eight million years, water equal to the volume of all the oceans enters cracks where plates pull apart the ocean floor. Deep below, the water heats up, changes its chemistry, and reappears along with welling lava.

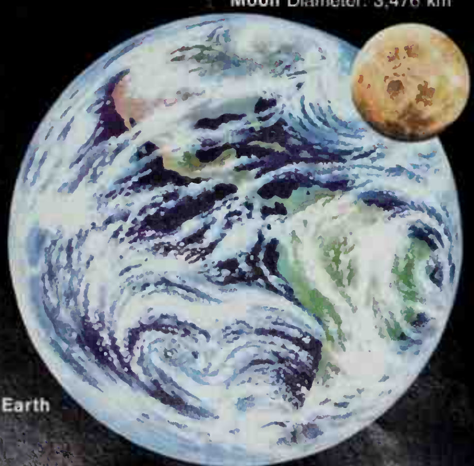
Tides and the Moon

Earth has one natural satellite, the Moon. It is an airless world with a diameter almost one-fourth that of Earth. In our Solar System only Pluto, with its companion Charon, has a satellite so close to its own size. We look on the Earth-Moon system as a double planet. *(Continued on page 116)*

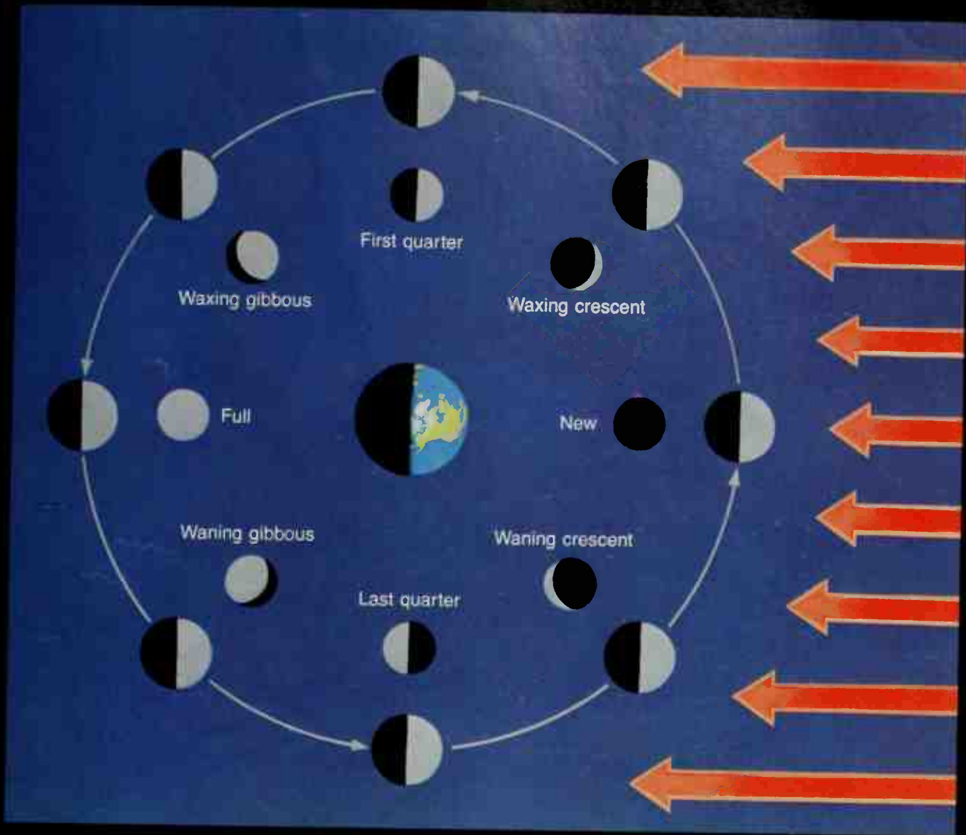
Facts about

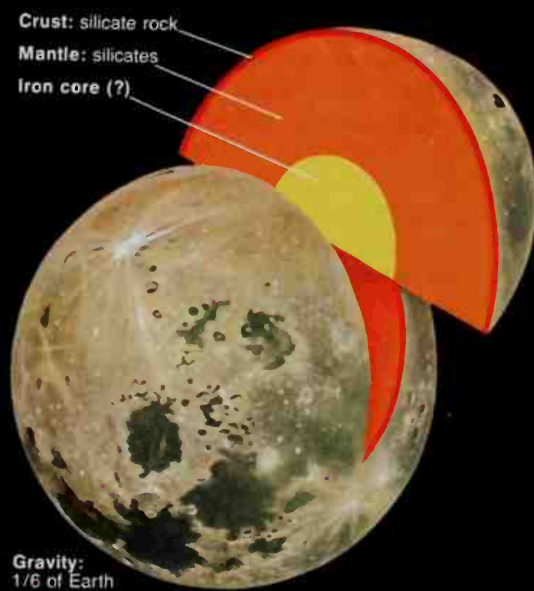
The Moon

Diana, or Luna, was the Roman goddess of the Moon, animals, and hunting. From Latin *lucere,* to shine, Luna gives us "lunar." Symbol: ☾ a crescent Moon.



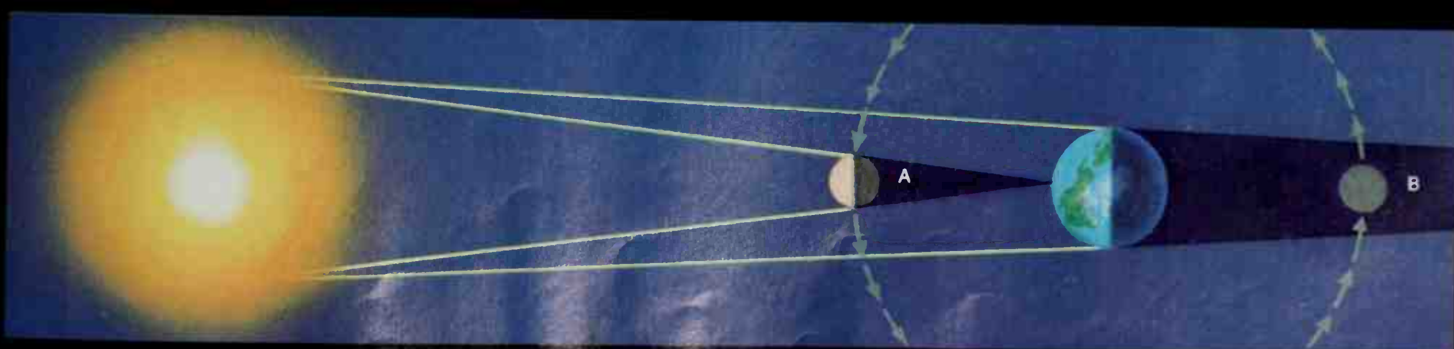
Moon and Earth, tied together by gravitational attraction, revolve as a double planet. Think of them as unequal ends of a weight-lifter's barbell. Because Earth's mass is 81 times greater than the Moon's, the center of gravity of the Earth-Moon barbell lies about 1,700 km below Earth's surface. It is called the *barycenter.* This pivot point – not Earth's geographical center – follows the smooth orbital line in the diagram. As the barbell spins around its eccentric center of gravity, both Earth and the Moon trace wobbly orbital paths through space.



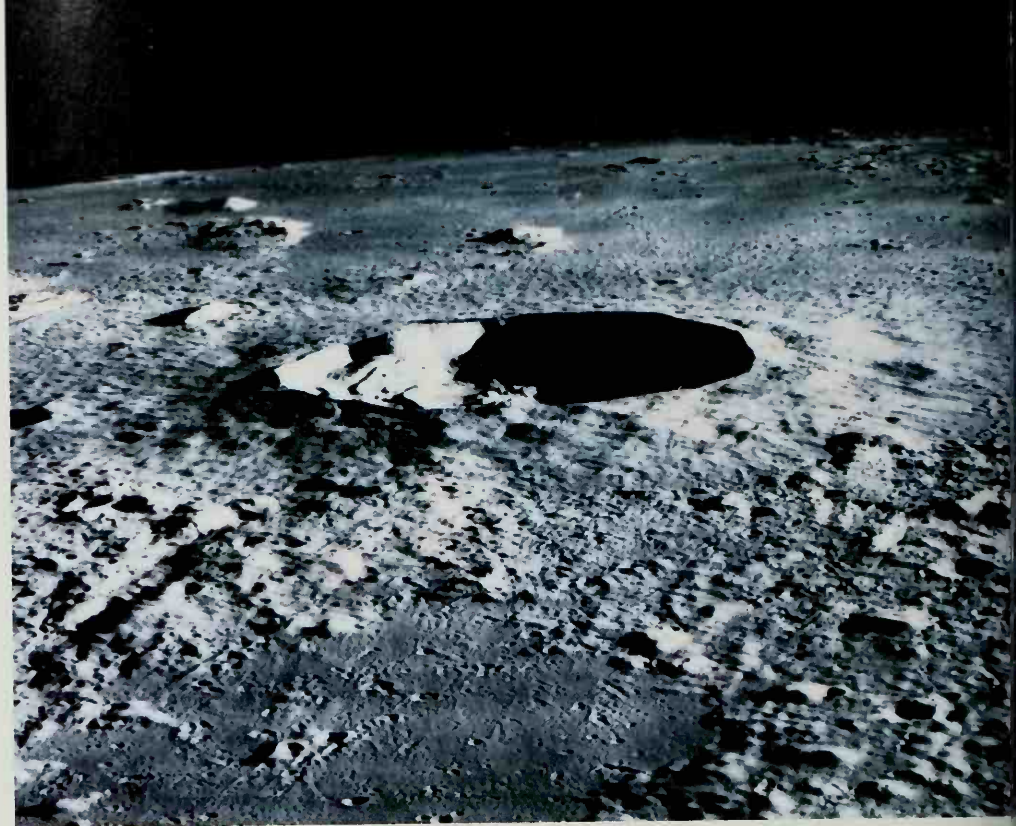


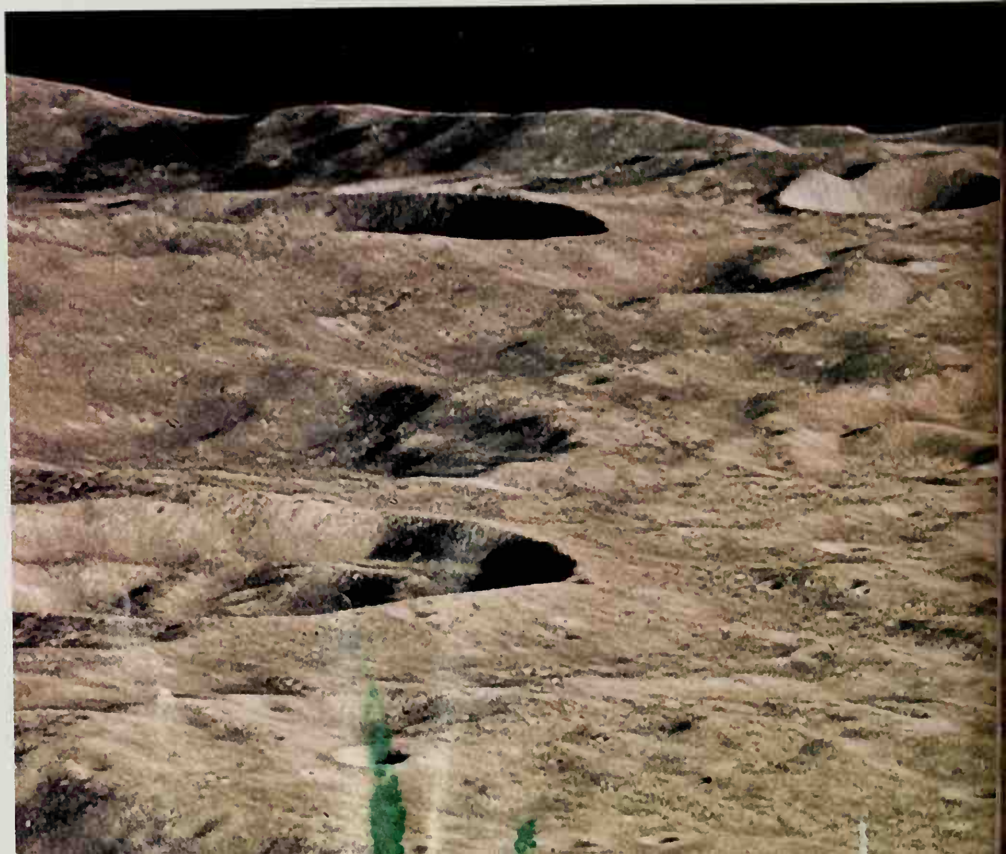
Total eclipses occur when the Moon and Earth line up perfectly with the Sun. During a solar eclipse, the Moon passes between the Sun and Earth, hiding the Sun on a small area of Earth (A). During a lunar eclipse, the full Moon moves into Earth's shadow and is blacked out (B).

On its trip around Earth, the Moon passes through phases of reflected sunlight. The inner circle above shows the phases we see from Earth. The outer circle shows the Moon as seen from high above our North Pole. Because Earth spins faster than the Moon revolves, the Moon rises an average of 50 minutes later each night. During the new phase, Moon and Sun rise and set at the same time. From then on, the Moon appears in different parts of the sky: in the west as it waxes larger towards gibbous (hump shaped), in the east as it wanes smaller.



Near side of the Moon (upper) shows the crater, Kepler. Kepler is 35 km in diameter and over 1.6 km deep. The Moon always keeps the same side facing toward Earth because the Moon rotates once for each time that it revolves around Earth.

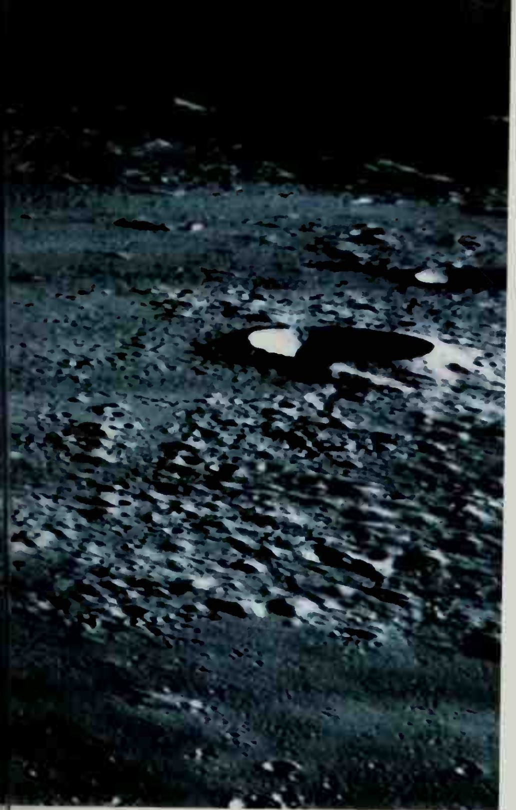




The gravitational force of the Moon, and to a lesser extent the Sun, raises the ocean tides on Earth. A great bulge of water is pulled up on the side of Earth facing the Moon and held there. As Earth rotates beneath the bulge, *high tides* occur. Because of Earth's rotation, the tide seems to move from east to west. If there were only the one bulge, we would have only one high tide a day. But there are two tidal bulges which cause two high tides each day—one every 12 hours and 25 minutes, each followed by a *low tide*. What causes the second tidal bulge?

Gravitation, remember, weakens as distance becomes greater. So the Moon tugs with greater force on that side of Earth facing the Moon, with less force on matter at Earth's center, and with the least force on Earth's far side. A second tidal bulge thus forms on the far side where a hill of water is "left behind." Since this water is farthest away from the Moon, it is tugged with the least force.

The Moon also raises tides in Earth's atmosphere and in the ground beneath our feet. In fact, the Moon tugs on every object on Earth's surface—including you. The ground tides amount to only a slight bulge spread across a great expanse of surface, while the highest ocean tides on Earth reach 16 meters. As Earth rotates beneath its tidal bulges, friction gradually slows it down, by a tiny fraction of a second each century. This is not very much in a human lifetime, but in Earth's lifetime of several billion years it adds up. In 100 million years from now an Earth day will be almost half an hour longer than it is now.



Far side of the Moon (lower), first seen in photographs taken by unmanned space vehicles, reveals a surface heavily pitted with craters caused by the impact of meteorites. It has few of the lava-filled basins called seas, or maria, apparently because the far side has a thicker crust.

As Earth's rotation slows down, the loss of speed causes the Moon to spiral outward from Earth about three centimeters more each year. A hundred million years from now our Moon will be almost 3,000 kilometers farther away.

Whenever the Sun, Moon, and Earth are lined up, the Sun's gravitational force added to that of the Moon causes especially strong tides. We call these *spring tides* (but they are not related to the seasons). They happen twice a month, once at new Moon and again at full Moon. When the Sun, Moon, and Earth form a right angle with Earth at the corner, we have especially weak tides called *neap tides.*

Where did the Moon come from?

Some scientists once thought that the Moon was torn out of Earth's side when Earth was young and still nearly molten. The scar that was left would be that hollow we call the Pacific Ocean basin. There is a little evidence to support this idea. The material of the Moon resembles the crust and mantle rock of Earth. But the drifting of Earth's continents now seems to account for the great ocean basins.

According to another idea, long ago Earth captured a small planet—and that planet is the Moon. The trouble with this theory is that if Earth had captured the Moon, the Moon's orbit would be a stretched-out ellipse. But it is not. It is nearly circular. Besides, the Moon would have been difficult to capture. It might have whizzed right on by, just as the Pioneer and Voyager satellites whizzed right on past Jupiter and Saturn.

Maybe the Moon and Earth were formed at the same time, out of the same gas and dust. The same elements are found on both—calcium, aluminum, titanium, magnesium, silicon, oxygen, iron—but in far different proportions. There is very little carbon on the Moon. And for reasons we do not yet know, the infant Moon did not pick up as much iron. That helps explain its low density—only 60 percent of Earth's.

Rocks brought back by astronauts give clues to the Moon's age. The youngest rock, a piece of basalt, was radioactive dated as 3.16 billion years old. The oldest dated rocks were 4.6 billion years old, indicating that the Moon is the same age as the presumed age of Earth.

Shaping the Moon's surface

Early in its life the Moon melted to a depth of several hundred kilometers. Later the surface cooled and formed a rocky crust. For a long time huge meteorites bombarded the surface and left hundreds of thousands of impact craters. Some are gigantic. Copernicus crater measures 91 kilometers from rim to rim, and Tycho is 87 kilometers across.

Some of the craters have central peaks and circular mountainous walls about six kilometers high. Other craters measure only a few meters across. And rock samples show tiny craters made by high-speed dust grains from space. They are so small that a hundred of them would fit on your little fingernail.

The Moon has seas, but they are not seas of water. On the Moon a sea is called a *mare,* Latin for "sea." *Maria* are seas of

Split Rock dwarfs U. S. astronaut Harrison Schmitt east of Mare Serenitatis on the Moon's near side. Schmitt holds a "gnomon," an instrument which the astronauts used to measure scale and color for their surface photography. This December 1972 trip was the final Apollo mission.

hardened lava. They are found in basins that take the form of either irregular depressions or deep impact craters. From 3.7 to 3 million years ago, many maria were formed when molten rock rich in iron and magnesium broke through the floors of the basins and spread over the surface. Some lunar seas are as much as 1,000 kilometers across—one-third the width of the contiguous United States. Most maria are found on the Moon's near side.

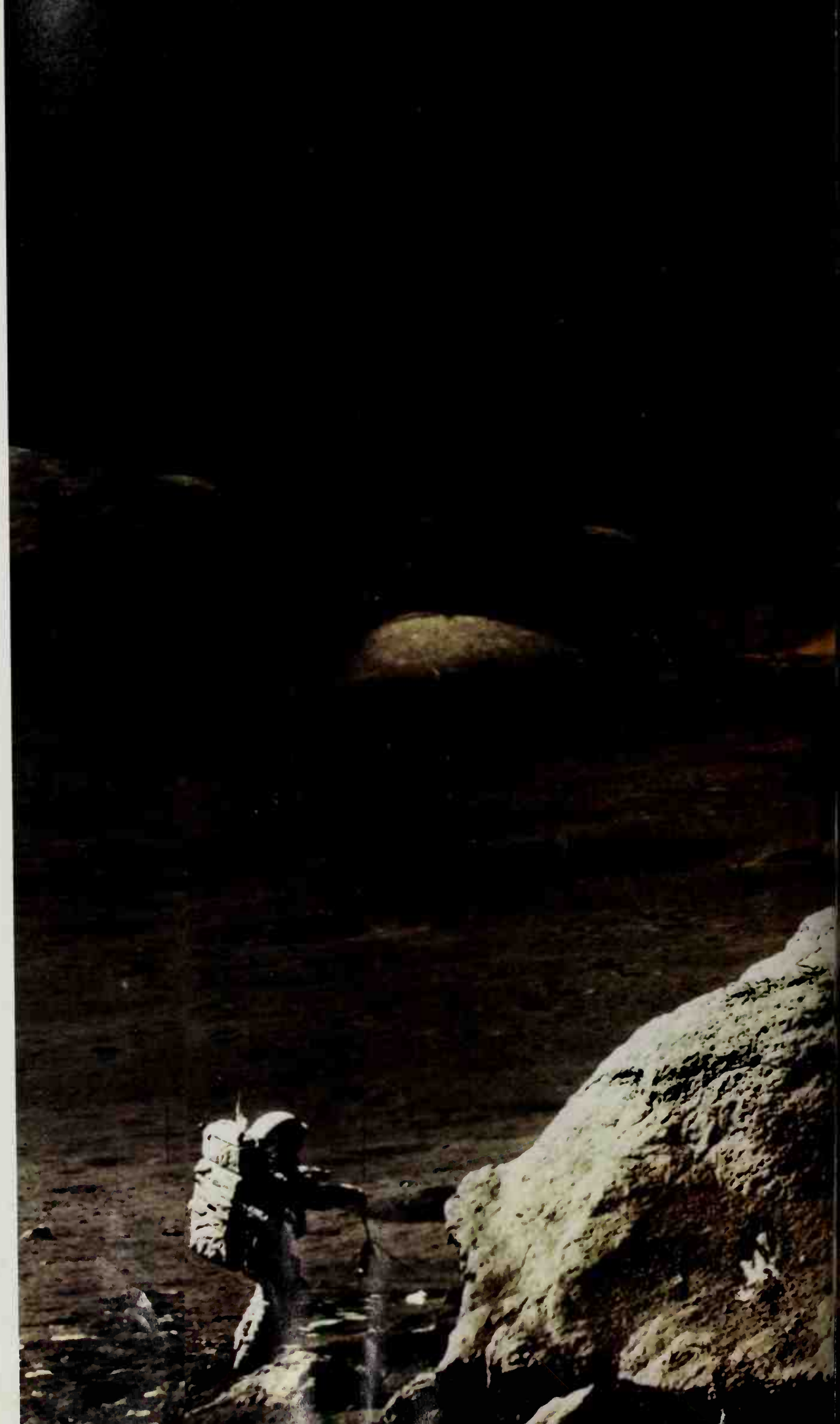
Mountain chains, like the lunar Apennines (Montes Apenninus), sometimes border the maria for hundreds of kilometers and rise five kilometers. But unlike Earth mountains, which were formed during thousands of years, our satellite's mountains were thrust up instantly by the impact of asteroids or meteorites.

Because the Moon lacks air, it is a hot and cold little world like Mercury. The lunar high noon temperature reaches 134°C. On the Moon's night side the temperature drops to about –170°C.

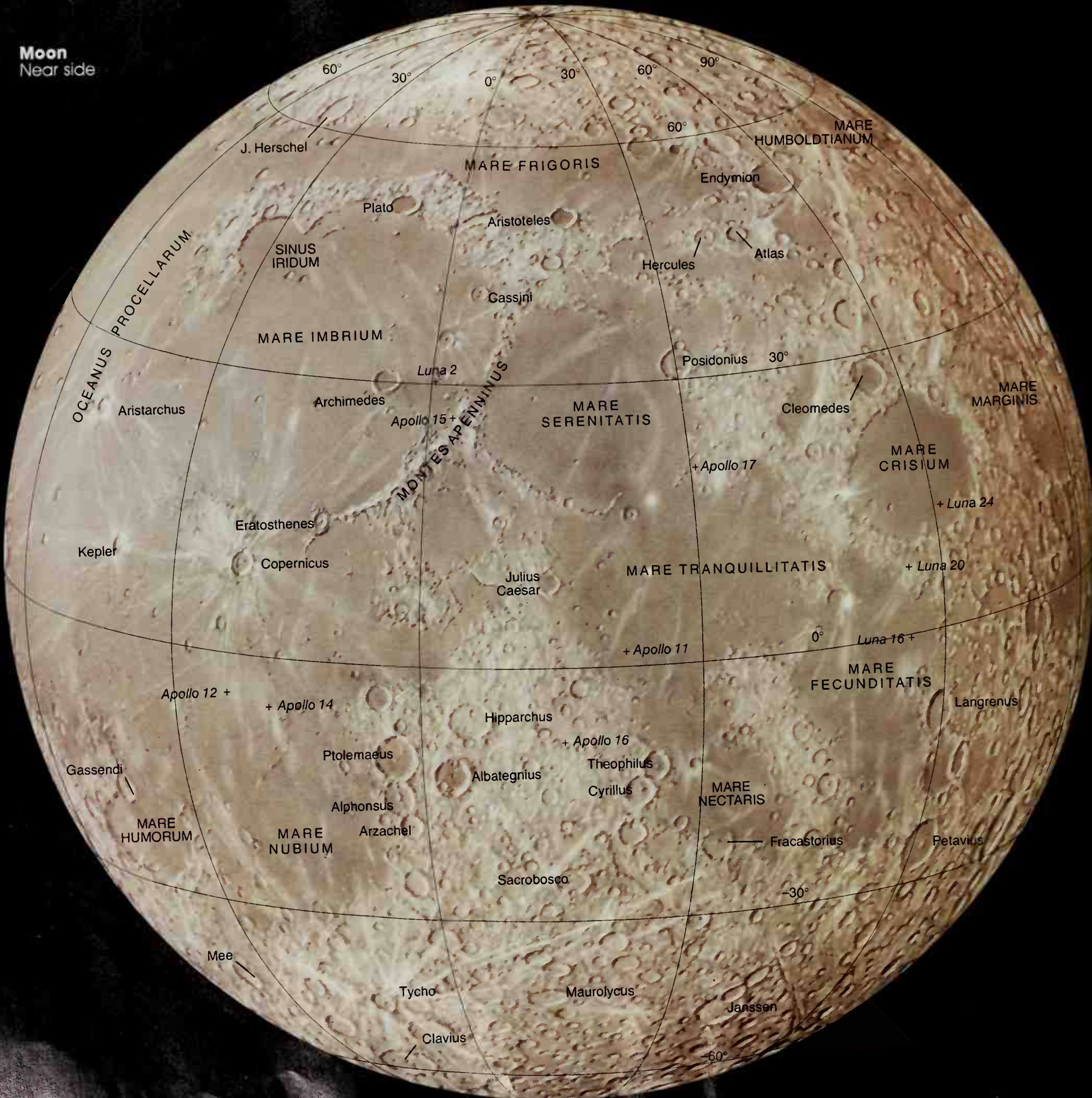
Moonquakes and motions

Our Moon is not geologically dead. Because the Moon is so close to us, Earth's gravitational force has enough strength to raise ground tides there. These tidal forces may touch off moonquakes. There can be as many as 3,000 a year, but generally the interior of the Moon is much quieter than the interior of Earth.

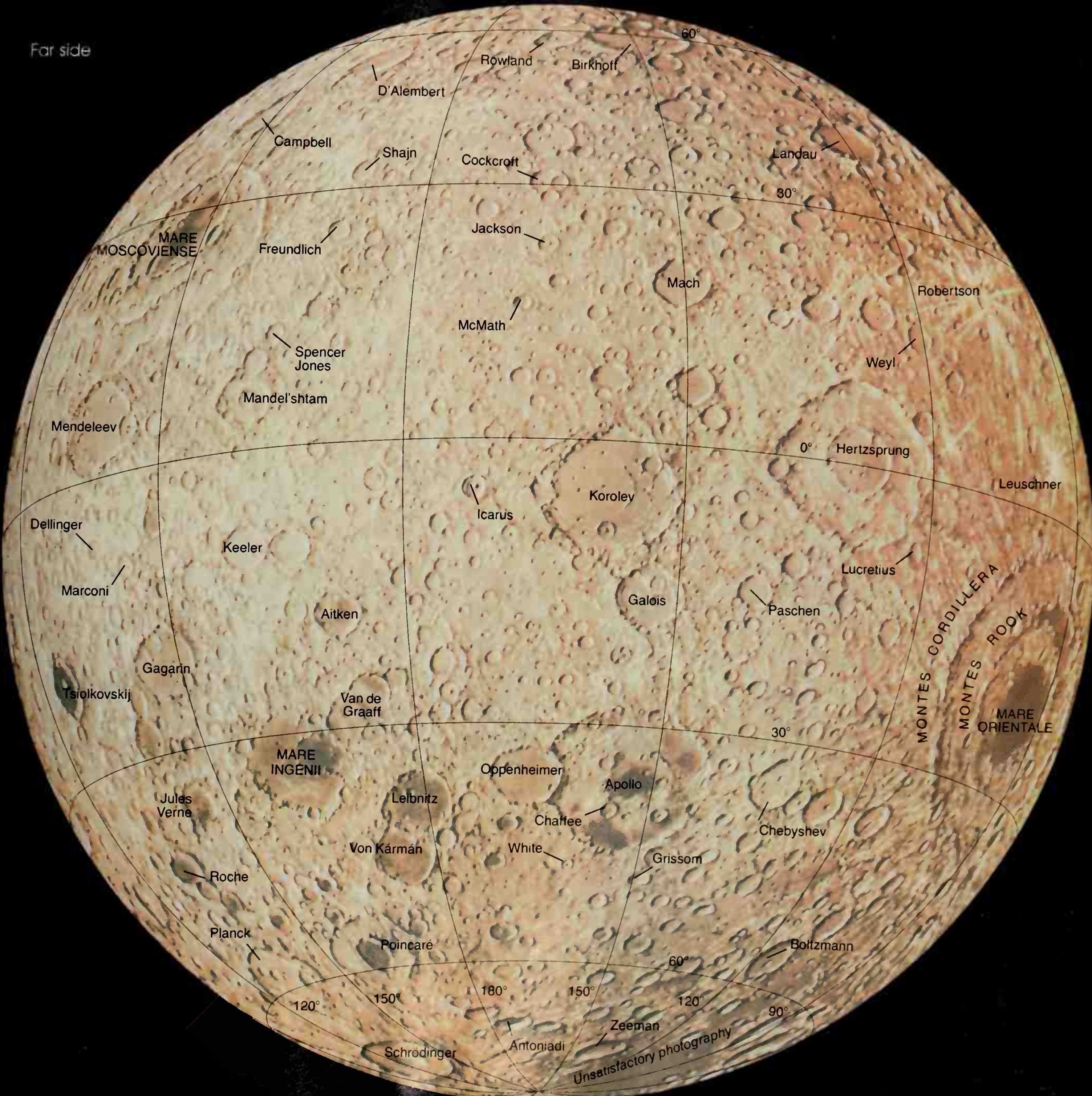
In its youth the Moon stopped rotating in relation to Earth. Now, with one ground tidal bulge facing Earth, and another on the opposite side, the Moon appears "frozen" with the same face always toward us.



Moon
Near side



Far side



60°
Rowland
Birkhoff
D'Alembert
Campbell
Shajn
Cockcroft
Landau
30°
MARE MOSCOVIENSE
Freundlich
Jackson
Mach
Robertson
McMath
Spencer Jones
Weyl
Mandel'shtam
Mendeleev
0°
Hertzsprung
Leuschner
Koroley
Icarus
Dellinger
Keeler
Lucretius
Marconi
Galois
Paschen
MONTES CORDILLERA
MONTES ROOK
Aitken
Gagarin
Tsiolkovskij
Van de Graaff
MARE ORIENTALE
30°
MARE INGENII
Oppenheimer
Apollo
Jules Verne
Leibnitz
Chaffee
Chebyshev
Von Kármán
White
Grissom
Roche
Planck
Poincaré
Boltzmann
60°
120°
150°
180°
150°
120°
90°
Zeeman
Antoniadi
Schrödinger
Unsatisfactory photography

Men about to land on the Moon saw Earth rise over the lunar horizon. Michael Collins kept the mother ship Columbia *in orbit, while Neil Armstrong and Edwin Aldrin set their small lunar module* Eagle *down in the barren Sea of Tranquillity (Mare Tranquillitatis).*

But from space, we would see the Moon complete one rotation every 27.3 days.

Men on the Moon

On July 20, 1969, humans first set foot on the Moon during the flight of Apollo 11. Leaving Earth on July 16, Neil Armstrong, Michael Collins, and Edwin Aldrin, Jr., reached their destination on the near side of the Moon and set up scientific experiments. Their mission completed, they returned to Earth on July 24 with the first Moon rocks. Theirs was the first of six United States lunar landings of the Apollo program, which ended in 1972 with Apollo 17. Eugene Cernan and Harrison Schmitt, the first geologist-astronaut to reach the Moon, landed December 11 near the Sea of Serenity (Mare Serenitatis).

Along with several unmanned Soviet Luna landings beginning in 1966, the Apollo explorations solved some of the mysteries about the Moon but also raised some questions. There is no life, but there are substances that may be the forerunners of amino acids – the building blocks of life. Nothing exists that can be called an atmosphere, but tiny amounts of gases – argon, neon – are found above the surface.

The Moon lacks a magnetic field and does not have magnetic poles, yet surface rocks are weakly magnetized. Were they magnetized by a core of liquid iron, once strongly magnetic? From its volcanic maria we know the Moon once baked with internal heat, and that it has been cooling for ages. But beneath the Moon's rocky mantle, there may still be a small, weakly magnetic core with some molten iron.

The Red Planet

Mars

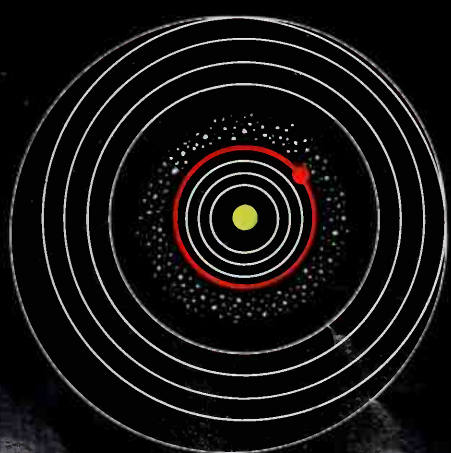
Three enormous volcanic mountains line up northeast to southwest – the Tharsis Montes. Each one is about twice as broad and over twice as high as the volcanic island of Hawaii measured from the seafloor. Almost hidden in shadow is Olympus Mons, an even larger volcano. Above it, wisps of water ice clouds hover. Farther north, the pole displays a shrinking cap of carbon dioxide snow typical of early spring.

East of the Tharsis Montes, a system of giant canyons stretches some 5,000 kilometers east to west. These canyons, as well as dried-up stream channels, many craters, and the great volcanoes, show that Mars had a very active geological past. But we don't know what tore open the giant canyons or created the channels.

We do know that the red color of Mars comes from a rustlike coating on the surface soil which sometimes is picked up and blown furiously in great storms. Here we see the Red Planet from its outer moon, Deimos, in orbit around Mars some 20,000 kilometers away. At its widest – 15 kilometers – Deimos is only about one-fortieth as broad as Olympus Mons. It is heavily scarred with craters. So is Mars' other, larger moon, Phobos, the small object to the right of the planet's lighted limb.

Facts about
Mars

Like a badge of blood in the sky, the Red Planet has long stood for gods of war. Mars was the Roman war god. His shield and spear form the planet's symbol: ♂

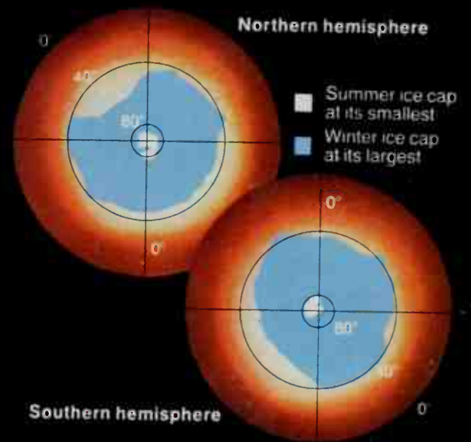


An off-center orbit: At one extreme, Mars loops 42.4 million km farther from the Sun than at the other. If Venus swung out that far, it would cross our own path. As on Earth, Mars' tipped axis causes seasons. Because Mars moves fast when close to the Sun, slower when far away, seasons differ in length. Northern spring lasts 52 Martian days more than fall. Two miniature moons zip around Mars. Deimos, 20,123 km high in the sky, orbits every 30 hours. Phobos, only 5,973 km up, takes less than 8 hours. Phobos rises and sets twice a day.

Meteors streak into Mars' thin carbon dioxide atmosphere (above). Winds near the surface can whip up planetwide dust storms. Yet air pressure on Mars is low—about as Earth's would be at a height four times that of Mount Everest. Craters scar Mars and its two moonlets (right).

A rocky interior that's low on metal gives Mars only one-tenth Earth's mass, two-thirds its density, and weak surface gravity—just over a third that on Earth.

Ice caps of frozen carbon dioxide—dry ice—grow in Martian fall and shrink in spring (below). As one cap expands, the other retreats. One puzzler: At the south pole, the small ice cap remaining in summer seems to be carbon dioxide, but the cap in the north is frozen water.



Glowing moment in a Martian afternoon: On July 20, 1976, the jeep-size Viking 1 lander settles onto Chryse Planitia (Plain of Gold) in the northern hemisphere. After orbiting a month, as cameras sought level sites, it 'chuted partway down, then missed "Big Joe" the boulder by nine meters.

More than any other planet, Mars has caught our imagination. One reason is the possibility of life on the Red Planet, now or sometime in its past.

We set out on our voyage to Mars when the Red Planet is closest to Earth, some 56 million kilometers away. Earth and Mars make side-by-side approaches about every 780 days, but the closest occurs only once every 15 or 17 years.

As we near the planet, we see two gleaming ice caps at the poles. Between them the globe is mottled in varying shades of red. By timing the motion of land features across the face of the planet, we confirm that Mars rotates once every 24 hours and 37 minutes. So a Martian day is nearly the length of ours. But Mars' slower orbital speed—and, more important, its larger orbit—give the Red Planet a longer period of revolution. A Martian year lasts 687 Earth days. Mars is only a little more than half the size of Earth, and its weaker gravity would cause a 100-pound Earthling to weigh only 38 pounds on Mars.

Martian secrets revealed

It takes us about 15 minutes to descend through the atmosphere and touch down on the surface. We find that most of the air is carbon dioxide. Nearly all of the Red Planet's water supply is frozen in the ground and locked up as ice in the polar caps. In fact, an ice age seems to grip Mars.

On our way down through the Martian atmosphere we saw countless craters marking the surface. They range up to several hundred kilometers across. We notice that they have been worn much smoother than the craters on our Moon. We sample the Martian soil and find much that is familiar to us in Earth rocks. In chemical composition the soil is mostly in the form of the elements silicon and oxygen bound up with metallic elements such as iron and magnesium. The grains of soil appear to be coated with iron-oxide rust. That hue, seen from Earth, long ago gave Mars the name Red Planet. In its southern hemisphere violent summer winds sweep up great clouds of reddish dust, which sometimes hide the entire Martian surface for months.

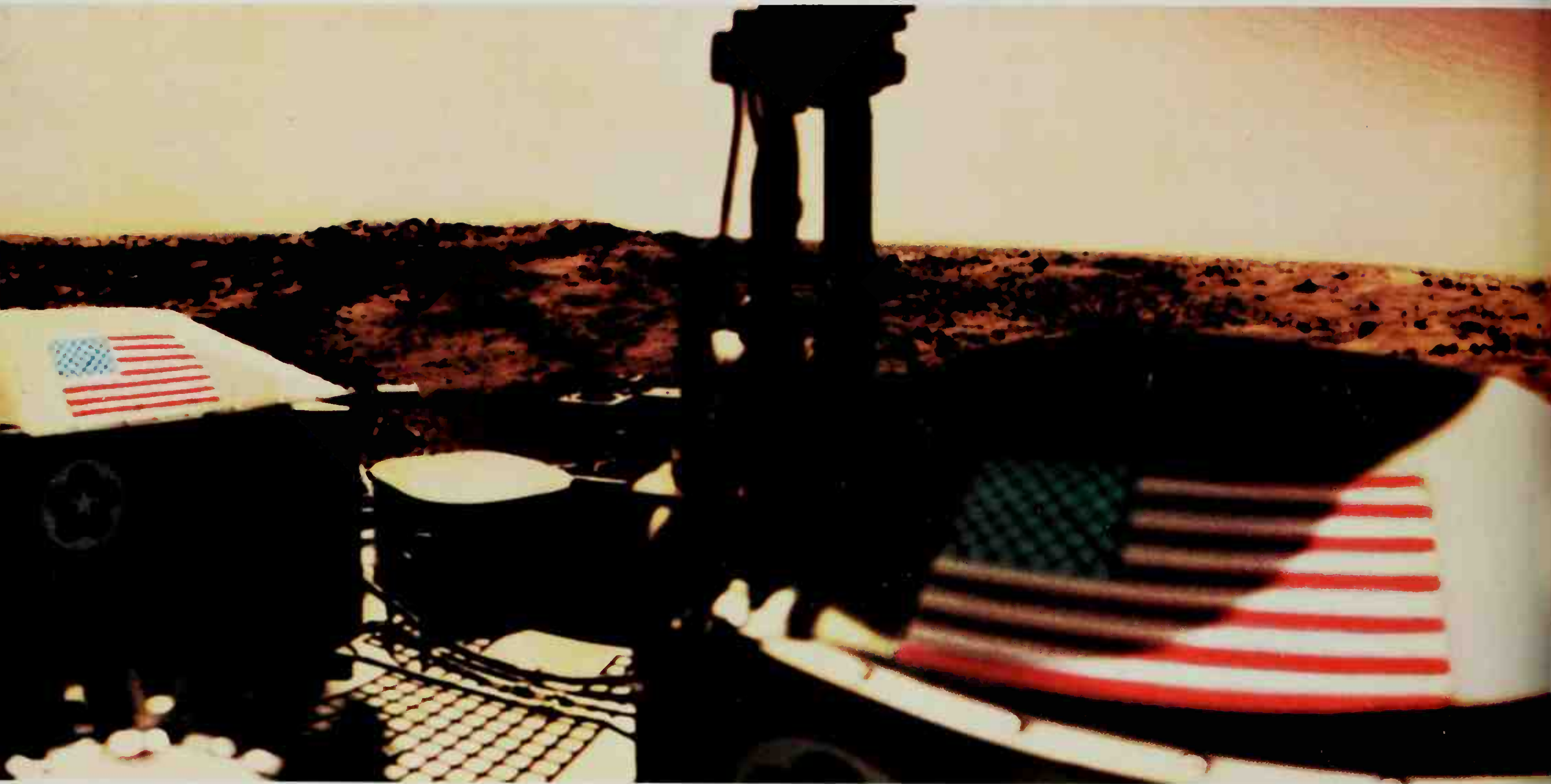
Volcanoes and canyons

In the equatorial region of Mars we climb up onto a broad dome that measures about 5,000 kilometers across, a thousand more than the distance between New York and Los Angeles. Called Tharsis, it rises about seven kilometers above the cratered surroundings. Four giant volcanoes soar up out of the Tharsis upland. Two lie north of the equator, one on it, and one to the south. At 27 kilometers their tops are three times higher than Mount Everest.

White clouds of water ice often shroud their slopes and can be seen from Earth by telescope. The largest volcano, Olympus Mons, is so huge that it would take us more than six hours to drive across its base at our highway speed limit of 55 miles an hour. This may be Mars' newest volcano, about 200 million years old. But the dating is uncertain; it may be much older. Many other ancient volcanoes are found here and elsewhere on Mars.

Along the eastern flank of the Tharsis dome is the series of canyons called Valles

Rock and barren dunes spread away from the Viking 1 lander, unlimbered for action on this Martian summer day—July 23 on Earth. Windscreens show the flag. Boom at right samples weather data; struts at left support an antenna. Cameras (housed in silos seen on page 129) send their wondrous imagery to the Viking orbiter when it comes into range, and the orbiter sends the images to Earth—a 20-minute trip across 360 million km at the speed of light. Weeks after this day, Viking 2 landed and sent data until 1980. Viking 1 may operate until 1994.



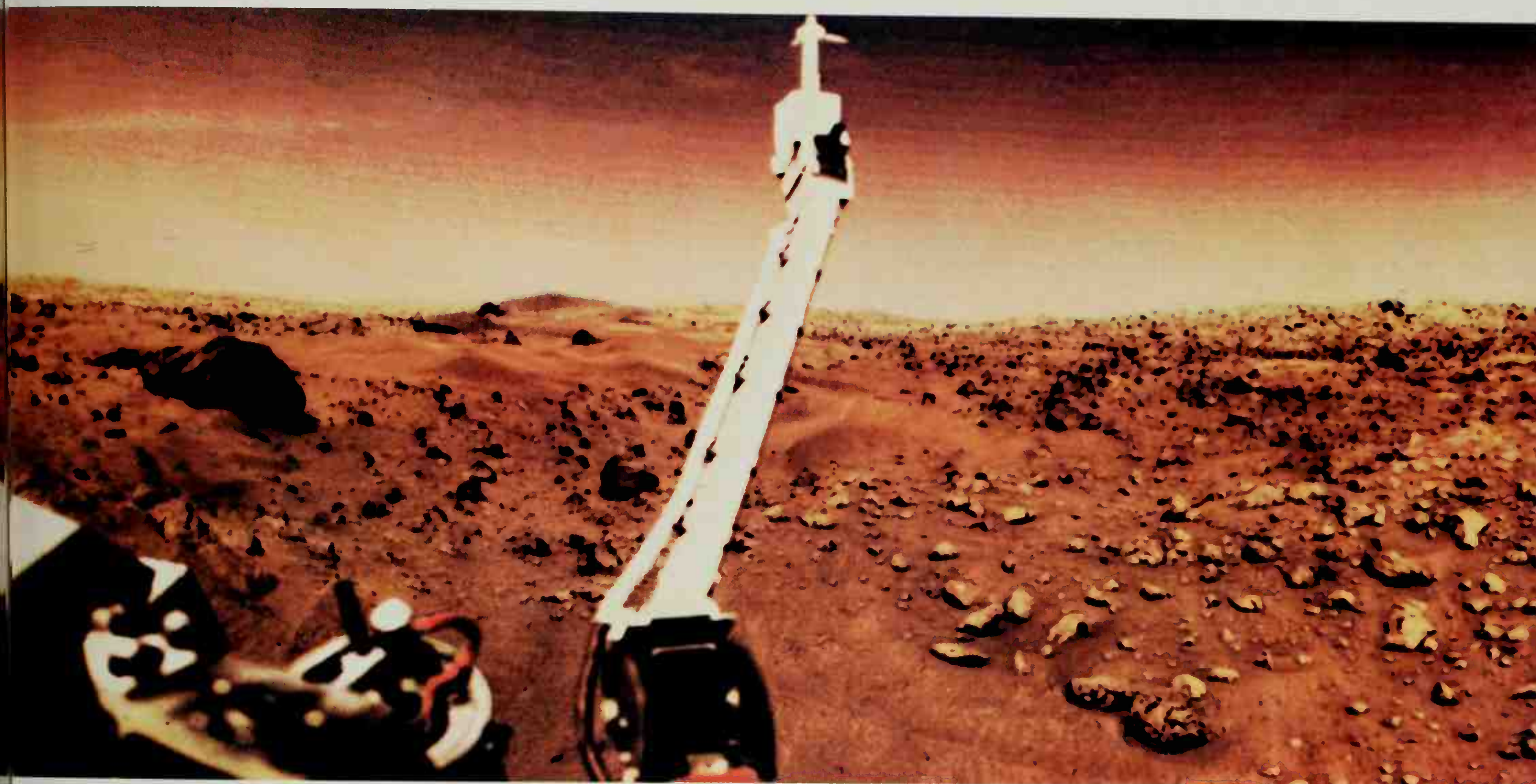
Marineris. In places the canyons are four times deeper than the Grand Canyon, and in length would span the United States, coast to coast. The width varies up to 500 kilometers. Most experts think the rifts were formed by massive marsquakes, then eroded by landslides and wind.

We find volcanoes in the southern hemisphere, but not as many as in the north. Some impact craters have been blasted into their slopes. This shows that the volcanoes were active early in the history of the planet, when meteoroid bombardment was still quite heavy.

The evidence of that bombardment is most noticeable in the southern hemisphere, heavily pocked with craters. Photographs sent by the first three Mariner spacecraft made it seem as if the whole surface of Mars had the same rugged look. But they had shown only a part of the planet. In 1972, after waiting for one of those giant dust storms to clear up, Mariner 9 photomapped the entire globe. We then learned that the Red Planet's surface divides into two quite different landscapes. If a line were drawn between them, it would cross the Martian equator at an angle of about 35 degrees. So the two landscapes are not quite the same as Mars' northern and southern hemispheres.

We see few craters in the northern landscape. This area has been heavily worn and

On the next page: *Wind-scoured Valles Marineris scar the planet's middle. The valleys, named for the Mariner flights, total 5,000 km in length, compared to 450 for Arizona's Grand Canyon system. A dust storm kicks up in this scene based on images from Mariner 9 and Viking.*

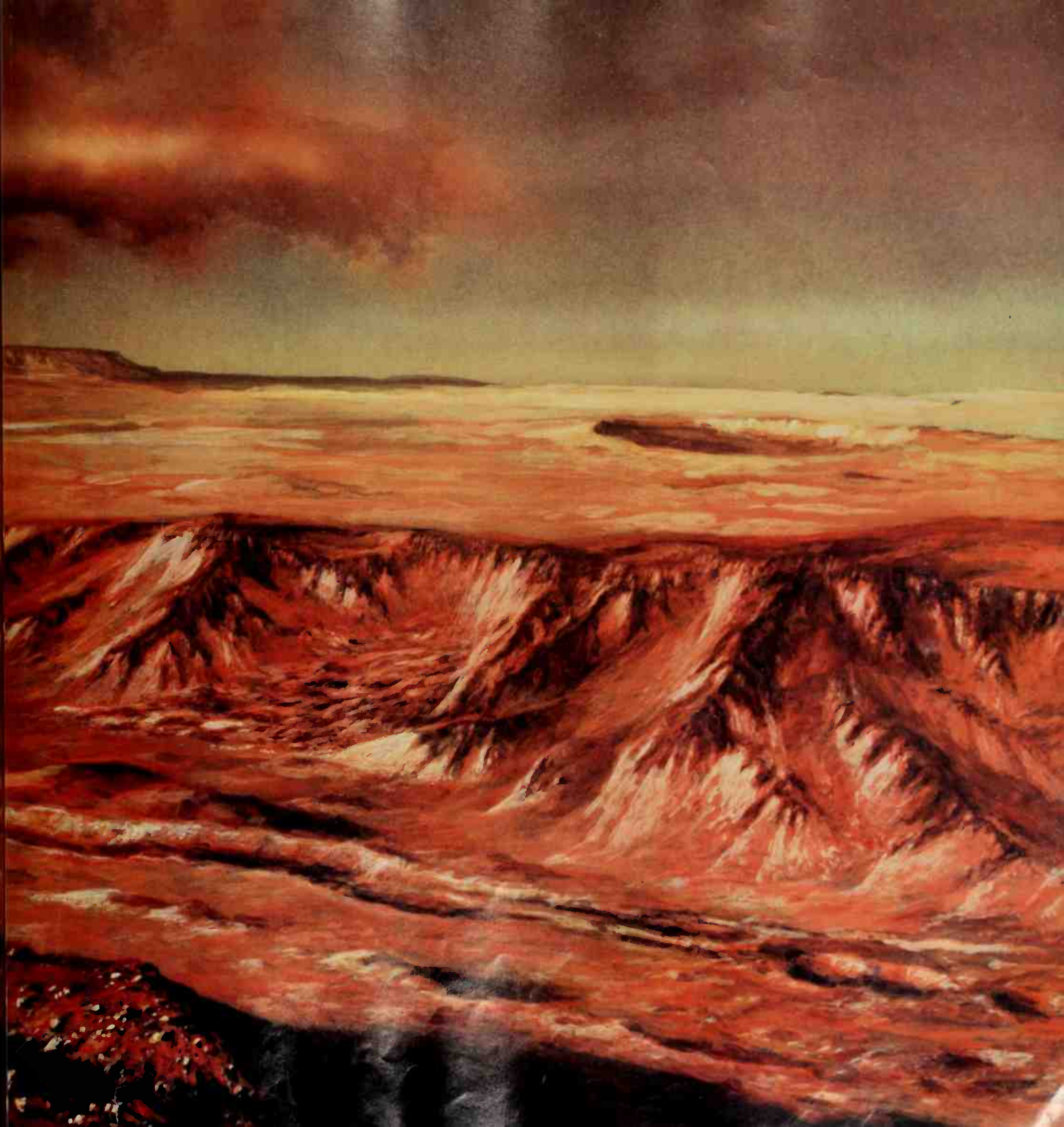


resurfaced by lava flows and sediments carried from other parts of the planet.

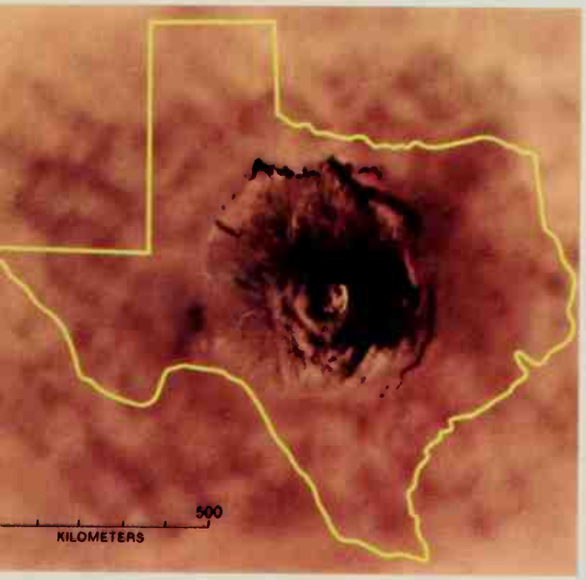
By contrast, parts of the southern landscape are cratered to saturation. The most heavily cratered areas appear to have received a bombardment equal to that on the bright highlands of our Moon. Rocks brought back from those highlands suggest that the blasting occurred more than four billion years ago. If Mars was bombarded at that time, as seems likely, then nearly half its landscape is very ancient. Some major landforms have remained largely unchanged for billions of years.

Right in the middle of the heavily cratered surface is a spectacular sight. Called Hellas, it is a sprawling circular basin that could swallow up Alaska with room to spare. A giant bowl up to four kilometers deep, the Hellas basin probably was excavated when a meteoroid several kilometers across smashed into Mars.

As the Martian seasons change, so do the polar ice caps. During spring in the northern hemisphere the ice cap shrinks and by midsummer nearly disappears; meanwhile the southern hemisphere ice cap grows larger with the autumn and winter seasons there. Most of the polar ice is frozen carbon dioxide—"dry ice" as we call it—with a little water ice. During spring in one hemisphere, the polar cap shrinks because increasing solar heat turns the carbon



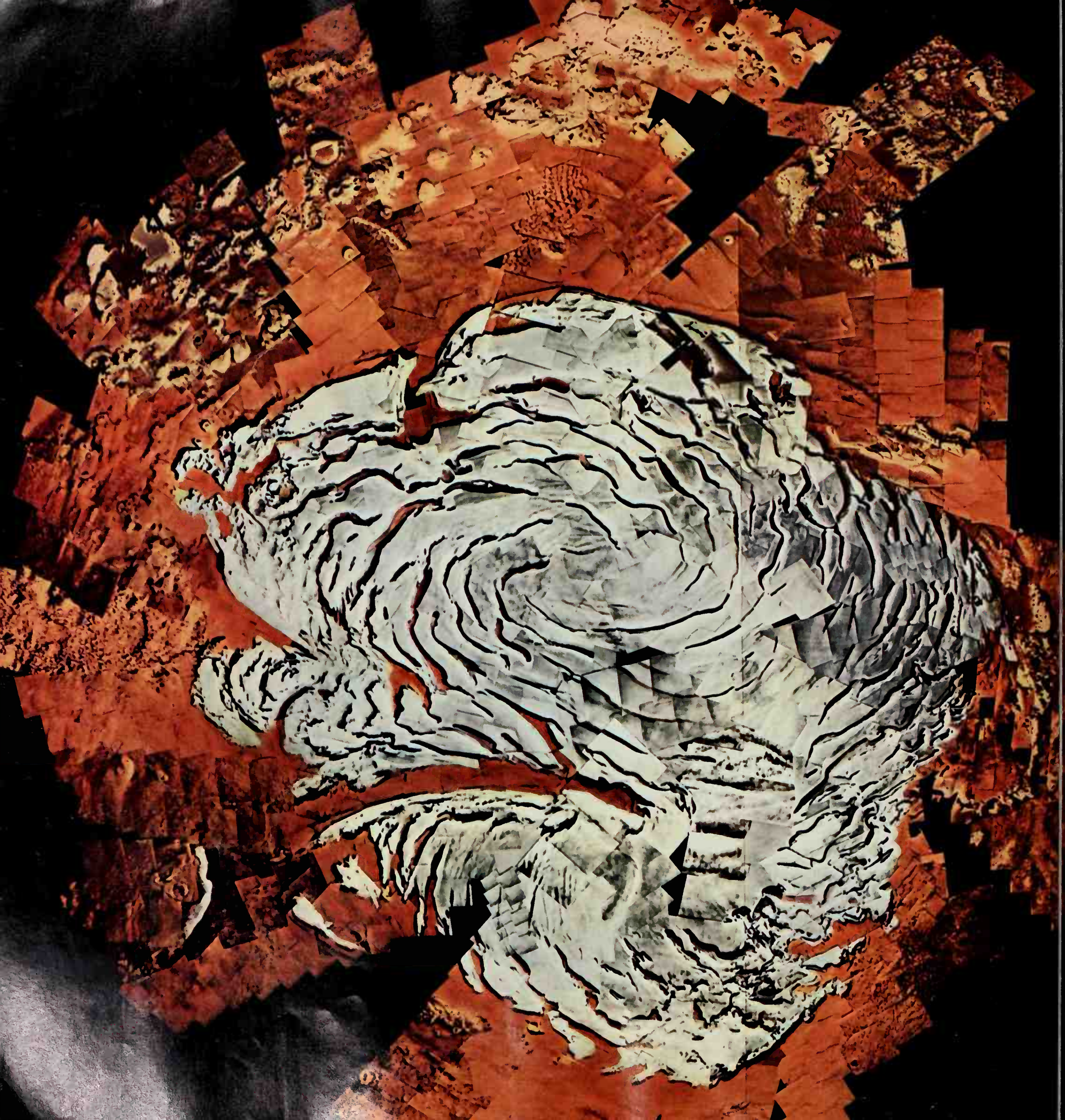
What mighty fountains heaped up the lava dome of Olympus Mons, 20 times bulkier than any Earth volcano? In this painting ice clouds climb the slopes as the atmosphere cools. The caldera, rings within rings, spreads 80 km across. The base would blot out the heart of Texas.



dioxide ice to gas. The gas enters the atmosphere. At the opposite, cooling pole the gas freezes and builds up a cap. The small patches of ice left at each pole during their summers seem to differ from each other. In the north the patch is probably nearly all water ice. In the south, more likely it consists of carbon dioxide ice. Why the difference? We are not sure.

Potato moons

Mars has two moons, each of which looks like a giant orbiting potato. More than 300 years ago Johann Kepler guessed that Mars had two moons, though he had not a shred of evidence for his claim. Kepler figured that since Earth had one Moon and Jupiter had four (all that were known then), the planet in between—Mars—



Surprising mosaic of Mars' north pole, formed from hundreds of pictures, reveals dark spirals in the ice cap. They appear to be slopes layered with "dirty ice"—snow and dust—perhaps deposited during changes in orbit. Such cycles of change in Earth's orbit may help bring on ice ages.

ought to have two. It wasn't until 1877 that the tiny bright dots were seen moving near Mars. The observer named them for sons of the Greek war god: Phobos and Deimos—Fear and Terror. Then, in late 1971, while a dust cloud made photographing Mars impossible, Mariner 9 put its waiting time to good use with a detailed scan of the satellites. At last it was possible to judge the real shape and size of the Martian moons.

Phobos speeds around Mars in 7 hours, 40 minutes. The more distant Deimos takes more than a day. From Mars' equator we see Phobos in the night sky for about 4 hours; Deimos takes 60 hours to cross the sky. From Mars the moons are seen to move in opposite directions. This is because Phobos takes less time to revolve once around the planet than Mars takes for a daily rotation, while Deimos takes a few hours more. From Mars' surface, Phobos appears one-third the size of Earth's full Moon, but tiny Deimos looks only like a very bright star.

Reading geological history

Geologists have tried to put together a history of Mars based partly on reports from unmanned spacecraft such as Viking and partly on what we know about Earth. According to one theory, the violence involved in the formation of the planets produced enough heat to partially melt the young planet. Heavy metal, mainly iron, sank to the center and formed a core. Silicate material formed a mantle. At the cool surface an early crust took a battering by meteoroids. After one or two billion years, decaying radioactive elements produced more heating. Melting of the mantle let lighter materials float upward and form a thicker crust.

This time of strong internal heating led to expansion of the globe, probably accounting for the fractures observed in Mars' crust—including the great Valles Marineris. This probably was also the time of maximum volcanic activity.

An outpouring of gases from the hot interior could have formed a denser atmosphere than we see today. Heated by the "greenhouse effect," the atmosphere would contain lots of water vapor. Mars then enjoyed a period, perhaps lasting millions of years, when rain fell on the surface.

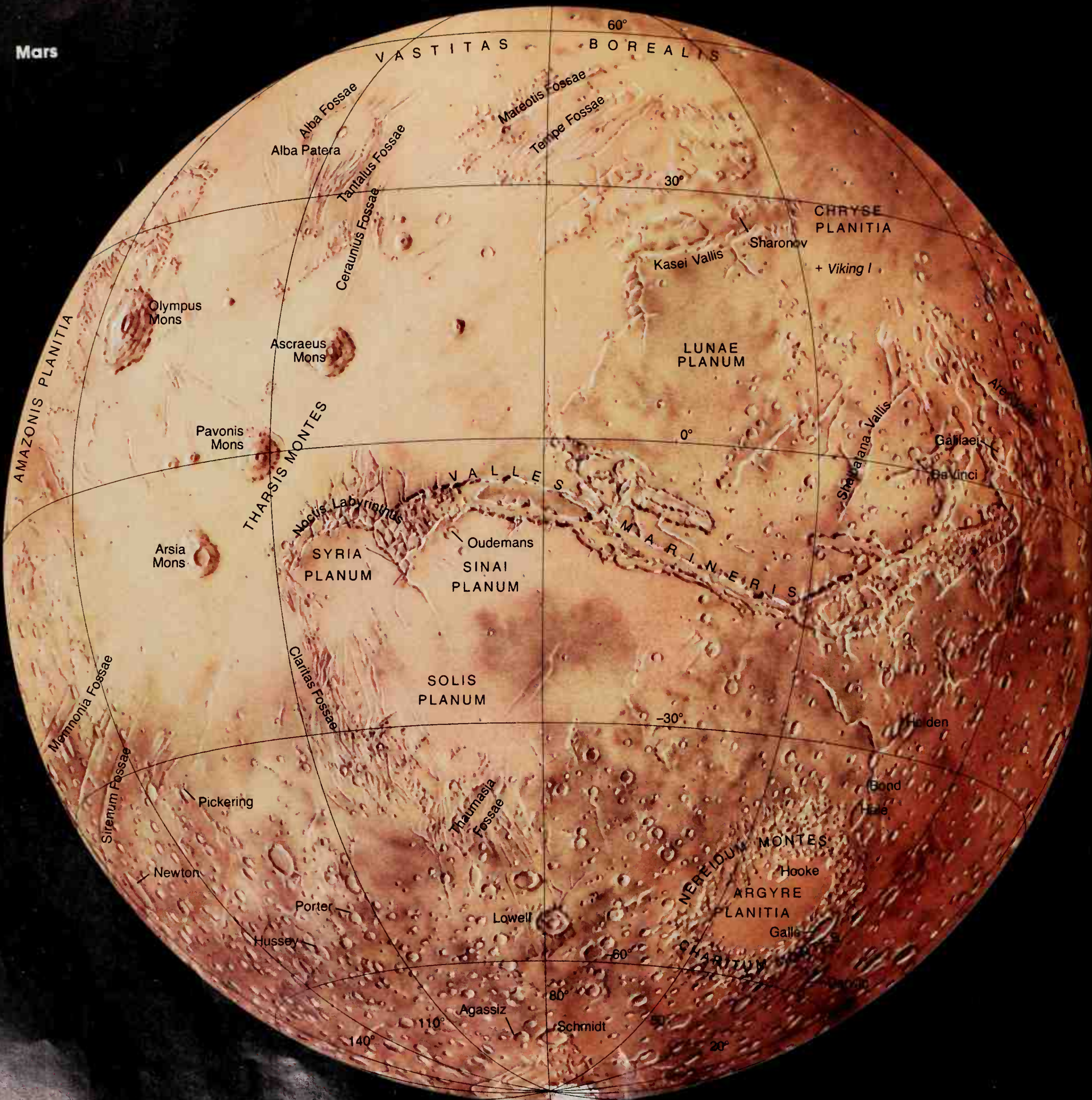
This led to water erosion, including the formation of networks of drainage channels. When the ice-age conditions we see today returned, liquid water could no longer survive at the surface. It was lost to the permanent polar ice caps and to underground permafrost. Afterward, as a result of volcano activity, or perhaps the impact of large meteoroids, some of the permafrost was melted in places—causing sections of the surface to collapse and the release of lots of water. Raging floods then cut great channels into the crust.

What about life?

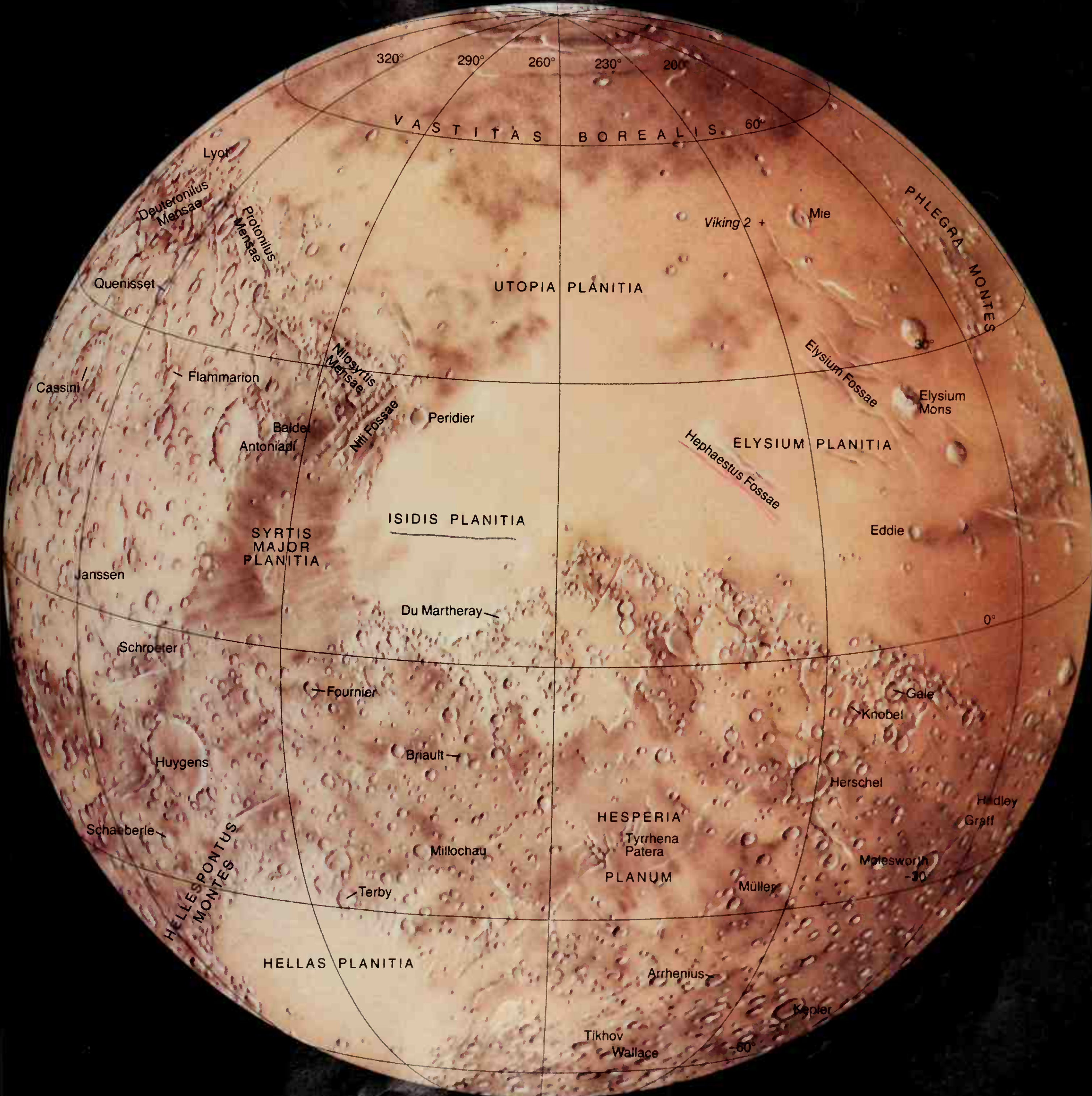
If Mars once had water, did it have life? Does it today? Living things on Earth must have liquid water to survive. On Mars' surface, liquid water does not exist. Mars' atmosphere is so dry that water vapor cannot reach the pressure needed to turn to liquid. So when ice is heated, it passes into vapor without melting. By one estimate, if all the

Down cratered slopes weave tributaries and main streams, dry channels hinting of ancient floods. Where did the water come from? Still a mystery. The channels in this mosaic flow to the right, toward the site where Viking 1 landed. Some craters formed before the flooding, others after.

Mars



VASTITAS BOREALIS
60°
Alba Fossae
Alba Patera
Mareotis Fossae
Tempe Fossae
Tantalus Fossae
30°
Ceraunius Fossae
CHRYSE PLANITIA
Sharonov
Kasei Vallis
+ Viking I
Olympus Mons
Ascraeus Mons
LUNAE PLANUM
AMAZONIS PLANITIA
Pavonis Mons
THARSIS MONTES
0°
Shalbatana Vallis
Galilaei
DaVinci
VALLES MARINERIS
Noctis Labyrinthus
Oudemans
Arsia Mons
SYRIA PLANUM
SINAI PLANUM
SOLIS PLANUM
Claritas Fossae
Memnonia Fossae
–30°
Holden
Sirenum Fossae
Pickering
Bond
Hale
Thaumasia Fossae
NEREIDUM MONTES
Newton
Hooke
ARGYRE PLANITIA
Porter
Lowell
Galle
Hussey
–60°
CHARITUM
80°
Agassiz
Schmidt
110°
140°
50°
20°



320°
290°
260°
230°
200°
VASTITAS BOREALIS
60°
Lyot
Deuteronilus Mensae
Protonilus Mensae
Viking 2 +
Mie
PHLEGRA MONTES
Quenisset
UTOPIA PLANITIA
30°
Elysium Fossae
Cassini
Flammarion
Nilosyrtis Mensae
Elysium Mons
Peridier
Baldet
Nili Fossae
Antoniadi
ELYSIUM PLANITIA
Hephaestus Fossae
ISIDIS PLANITIA
Eddie
SYRTIS MAJOR PLANITIA
Janssen
Du Martheray
0°
Schroeter
Fournier
Gale
Knobel
Briault
Huygens
Herschel
Hadley
HESPERIA
Graff
Schaeberle
Tyrrhena Patera
Millochau
Molesworth
-30°
PLANUM
HELLESPONTUS MONTES
Terby
Müller
HELLAS PLANITIA
Arrhenius
Kepler
Tikhov
Wallace
-60°

The computer as artist paints an eerie afterglow to a Martian sunset. The Sun had sunk below the horizon; in the image sent by Viking 1's lander, the land lay dark. As the computer "stretched" data to detail the foreground, Mars flamed and colors rippled out from the ebbing light.

vapor in the atmosphere could turn to water, it would fill a small lake. The kind of life we know could not exist on Mars today. Maybe it did once. Maybe it had time to adjust to the new conditions, as the planet became dry, and remains in existence somewhere on Mars.

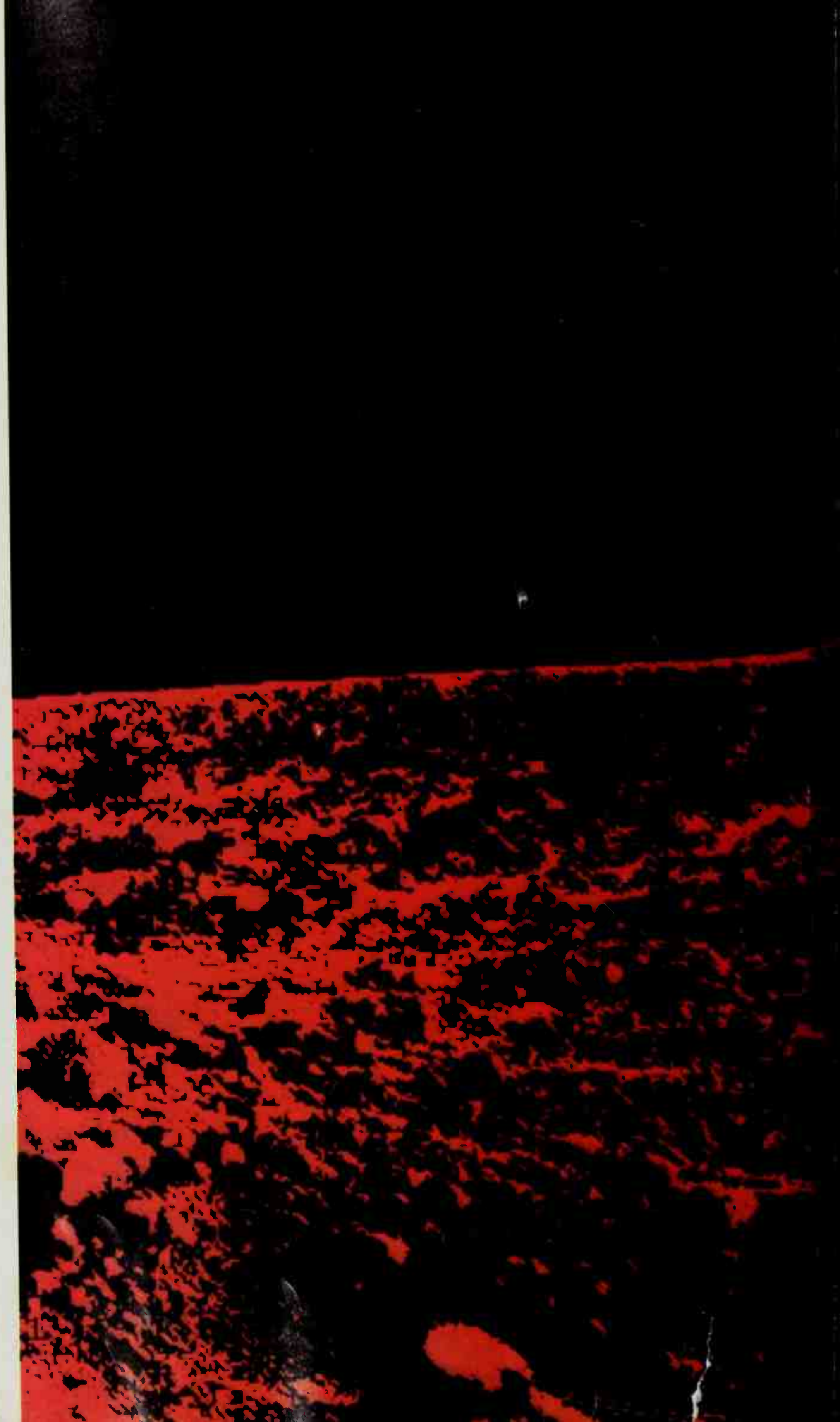
The Viking landers tried to find evidence of life in five different ways. One was with cameras. They sent numerous pictures, but none revealed "macrobes," the larger life forms, plant or animal, living or fossil, that we could recognize.

Another way was with an instrument to analyze soil, to detect organic molecules containing carbon. Such molecules are the building blocks of our living things. The Martian soil revealed none. Viking also carried three laboratories to test for tiny life forms, microbes, in the soil.

One test tried to find out if anything in the soil changed carbon dioxide into chemical compounds the way our plants do. In another little lab, water and nutrients were put into a soil sample to see if anything in it released oxygen or carbon dioxide the way plants or animals in our soil do. A third lab tested for anything in the soil that might consume chemical compounds the way humans and other animals do.

Although the experiments did not give us entirely clear answers, there is general agreement that Viking did not detect life. But the results from only two locations cannot rule out the possibility that Mars somewhere shelters life—or once did.

Perhaps this most fascinating of all Martian mysteries will not be solved until we send astronauts to explore the Red Planet.



A Planet That Never Was

Asteroids & Meteors

Some call them "minor planets." Others have called them "planetoids." They are the asteroids, tens of thousands of tumbling, sometimes bumping lumps of rock-metal fragments that wheel around the Sun, most of them in a broad orbit between Mars and Jupiter. About 102 million kilometers beyond the orbit of Mars we come to the inner edge of this belt of asteroids. It stretches on for about 165 million kilometers toward Jupiter's orbit.

Here, as we look toward rosy, banded Jupiter, we can see that there is a lot of space between individual asteroids. Although we have never landed on an asteroid, or even gone very close to one, we picture them pitted with many craters, like Mercury or our Moon.

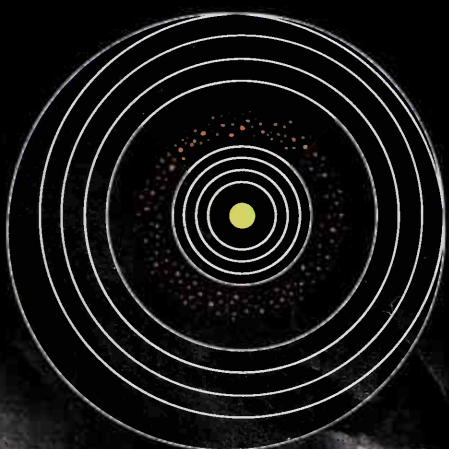
During the early ages of our Solar System, thousands of these cosmic bombs plunged into Mercury, Venus, Earth, Mars, and Jupiter, as well as into the planets' moons and into each other. And most likely small pieces of them – the meteoroids – will keep doing so from time to time over the billions of years left in the life of our Solar System.

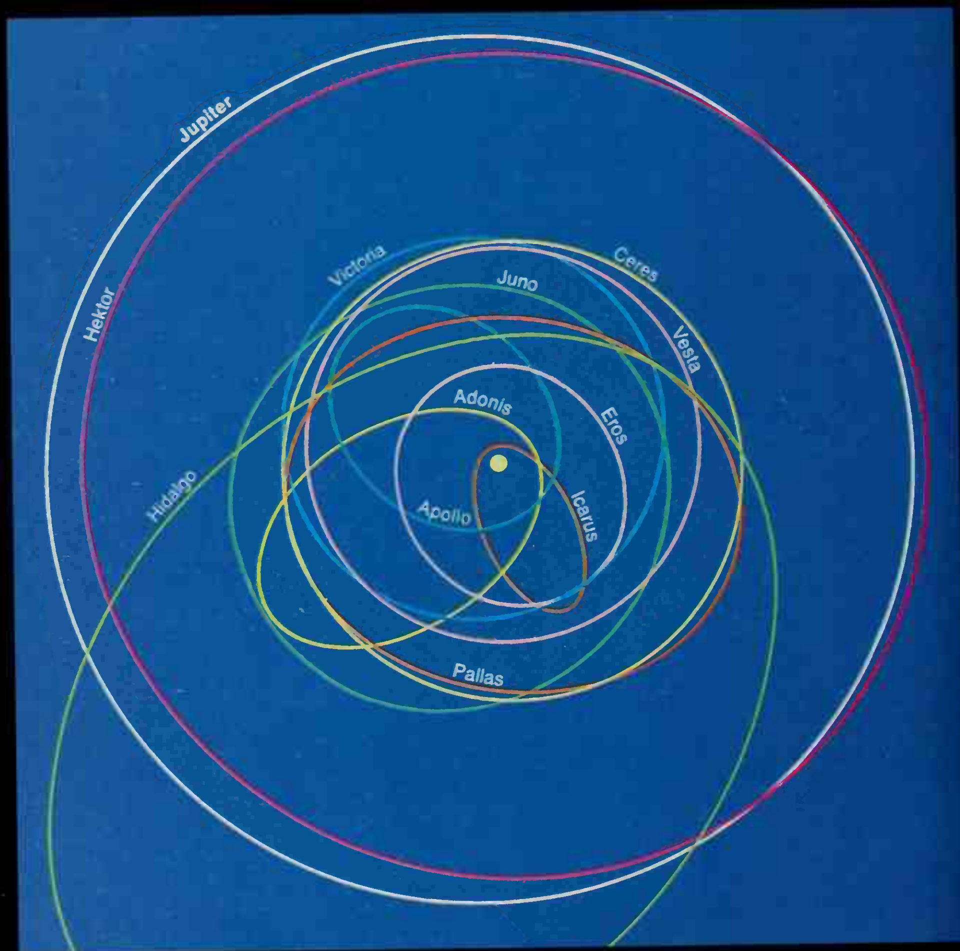
Because the asteroids batter each other, and because they are so small, few of them are neatly sphere-shaped.

Facts about

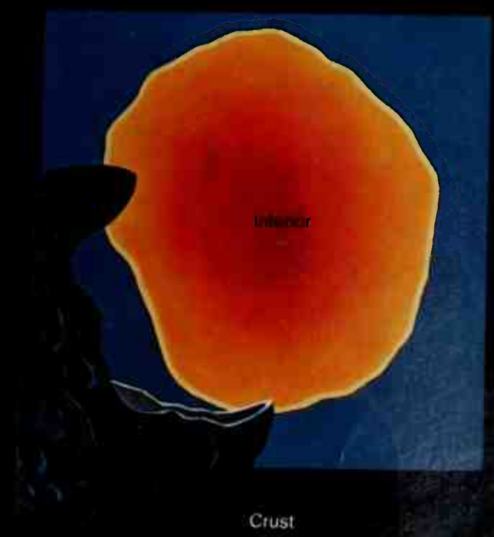
Asteroids

An asteroid, by tradition, is named by its discoverer. One honors England's Queen Victoria, another the mythical Icarus who flew too near the Sun.





There are as many asteroid orbits as there are asteroids. Many of these objects, like Ceres, stay within the asteroid belt, a wide band between Mars and Jupiter. A planet ought to be there, astronomers once said; when they found asteroids instead, they thought these must be its pieces. But that's unlikely. All known asteroids lumped together would still be smaller than the Moon. Now and then a big one crosses Earth's orbit. Every million years or so, three or four of them ram into Earth and blast out craters many kilometers across.



Small asteroids have irregular shapes and the same composition outside and in – nickel and iron, or stone, or a little of both. Some asteroids may also contain large amounts of carbon, which gives them a dull, blackish color. Asteroids range in size from big Ceres to tiny lumps. On Ceres you would weigh 1/33 your Earth weight – and on a very small asteroid you would weigh so little that you might jump up and never come down.

Oddballs of the Solar System, asteroids come in many sizes and shapes. First to be discovered was Ceres, the largest known. Some 2,000 are now named and numbered; hundreds of thousands more may whirl about, too small to be seen. Phobos, a moon of Mars, may be a captured asteroid. Some asteroids are so massive their own gravitation has molded them into spheres. Collisions may shatter them or join them into odd shapes.

A small asteroid crashes into one almost 10 times its size. The larger asteroid will suffer only a few new craters and ridges but the smaller asteroid is shattered. Asteroids often collide and break into pieces. These smaller chunks are also called meteoroids.

If we ever got close enough to an asteroid to take its picture, chances are it would look a lot like Phobos (below), one of Mars' two moons. Astronomers think that both may be captured asteroids. By studying the heavily cratered surfaces, they may learn about neighbor asteroids.

In the late 1700's a group of German astronomers, calling themselves "celestial police," began to search with telescopes for a missing planet. They did this because in 1772 an astronomer, Johann Bode, had publicized a mathematical "law" which gave the relative positions of the planets in the Solar System. However, something was amiss. In the great gap between the orbits of Mars and Jupiter, Bode said there should be a planet.

Minor planets

On January 1, 1801, the Sicilian astronomer Giuseppi Piazzi found something which he thought was the missing planet. Later named Ceres, it turned out to be a mere pebble of a planet about 1,000 kilometers across—a third the size of the Moon. Then in 1802 another small planet, Pallas, was discovered in the gap. It was half the size of Ceres. In 1804 a third such object, Juno, was found—less than half the size of Pallas. Then in 1807 the celestial police saw a fourth, Vesta—the brightest asteroid and the only one that can be seen with the naked eye. By 1890 astronomers had found 300 of these planets in the Mars-Jupiter gap. Today we know the orbits of about 2,000. There may be hundreds of thousands. Most are boulder-size to mountain-size lumps of rock and metal that we call *asteroids*, or *minor planets*.

Earth-grazers

The average time an asteroid takes to go around its orbit is about five Earth years. A few have long, stretched-out orbits that take them very close to the Sun—and to Earth. These are called Apollo Objects, or Earth-grazers, because they swoop in so close and intersect the orbit of Earth from time to time. (Their name comes from the asteroid Apollo, the first seen to cross our orbit.) In all, we know of about 20 Apollos. Some astronomers suggest that certain Earth-grazers may be the remains of old comets while others are asteroids.

Eros hurtles end over end through space like a tumbling football. It has come within 23 million kilometers of Earth. Apollo has come within about four million kilometers of us. And Hermes has zoomed to within 770,000 kilometers, only twice the Moon's distance from Earth.

Astronomers don't worry too much when the Earth-grazers sweep in "close" to us. The chance of one of these cosmic mountains crashing into us is pretty small—we may get one direct hit about every 250,000 years. Some experts think the interval may be more like one million years. But if a

giant should strike, it could produce an explosion as great as 20,000 megaton hydrogen bombs, and might blast out a crater hundreds of meters deep and as broad as a large city.

We had one near miss on August 10, 1972, but this bright meteor, or bolide, was not a giant. Thousands of people saw a bright streak of light blaze a path in broad daylight through the sky over the United States and Canada (above). It whizzed on out of our atmosphere again, but it had come as low as 60 kilometers and created sonic booms. Based on factors such as speed and brightness, scientists tried to work out the object's mass and size. By one estimate, it measured 10 meters across and weighed 1,000 tons.

Where did these rock and metal chunks the size of footballs, houses, and mountains come from originally? Astronomers used to think that early in the history of the Solar System there was a planet in the gap between Mars and Jupiter. Then the planet was gradually pulled closer to Jupiter until it came so close that Jupiter's powerful gravitation shattered the smaller planet, breaking it up into the asteroids. Now they think that the asteroids may be chunks of rock and metal left over from the time the planets were being formed. Jupiter's gravitation, they say, prevented the asteroid fragments from ever collecting into a planet-size object.

Messengers from space

On the night of November 13, 1833, a shower of meteors lighted up the sky. "The stars fell like flakes of snow," said one observer. Others, also believing that meteors were falling stars, thought that no stars would be left in the sky the next night.

Away from the city lights on any clear night you can see between 10 and 20 "falling stars" in an hour. They are not stars, of

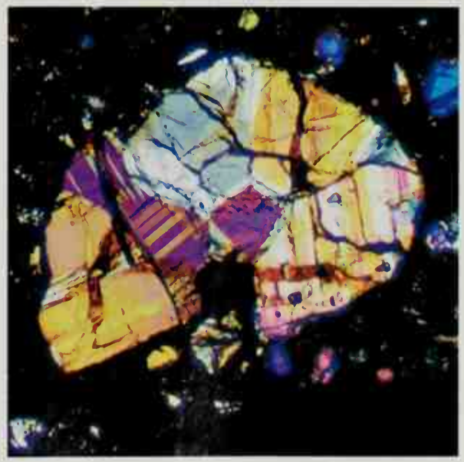
The Great Fireball of 1972 streaks over the heads of vacationers in the Teton Range in western Wyoming. Traveling 15 km a second—faster than a Titan Centaur rocket—the gigantic meteor skipped in and out of Earth's atmosphere like a stone across the surface of a pond.

course, but lumps of rock and metal which range from the size of dust grains to—once every several thousand years—a rare piece more than 10 meters across. When they are in space these objects are called *meteoroids*. Most come from the asteroid belt. When one enters Earth's atmosphere at a speed from 15 to 72 kilometers a second it burns up from frictional heating and glows as the quick streak of light that we call a *meteor*. If it survives the hot journey through the atmosphere and strikes the ground, we call it a *meteorite*.

Every day meteorites plunge to Earth and add at least a quarter of a ton to our planet's mass. The largest meteorite found on Earth is in Namibia. It weighs some 60 tons. The next largest, about 30 tons, is on display at the American Museum of Natural History in New York. Another 10 tons a day are added by space-dust particles called *micrometeorites*, which are captured by Earth's magnetic field and float gently to the ground. Some of these have even been found on the petals of flowers. If you are lucky, someday you may find a micrometeorite on a magnolia.

Sporadic meteors are the ones we see on just about any night, falling out of the sky from any direction. These come from the asteroid belt. But others, the *shower* meteors, seem to be the remains of old comets and travel in swarms. The swarms return year after year and shower down on us from certain parts of the sky. Those showers that seem to come out of the constellation Leo are called the Leonids; those coming from the direction of Orion are called the Orionids; and those we see in the

At 2,758 kg, the Old Woman (above) is the second largest meteorite ever found in the U. S. Made of iron and nickel, it was discovered by gold prospectors in 1976. Marines pry it out of the Old Woman Mountains in California, where it fell hundreds of years ago.



This fragment of the stony-iron Mt. Padbury meteorite was photographed through a microscope in polarized light. The microscope blocks out certain types of light, giving the bright colors. Found in Australia, the Mt. Padbury meteorite may be a piece of the asteroid Vesta.

Over 20,000 years ago a meteorite the size of a railroad car crashed into a desert, producing a crater 1.3 km wide. It blew out about 400 million tons of rock. Meteorites this large rarely collide with Earth. Barringer Crater, Arizona (left), resulted from this impact.

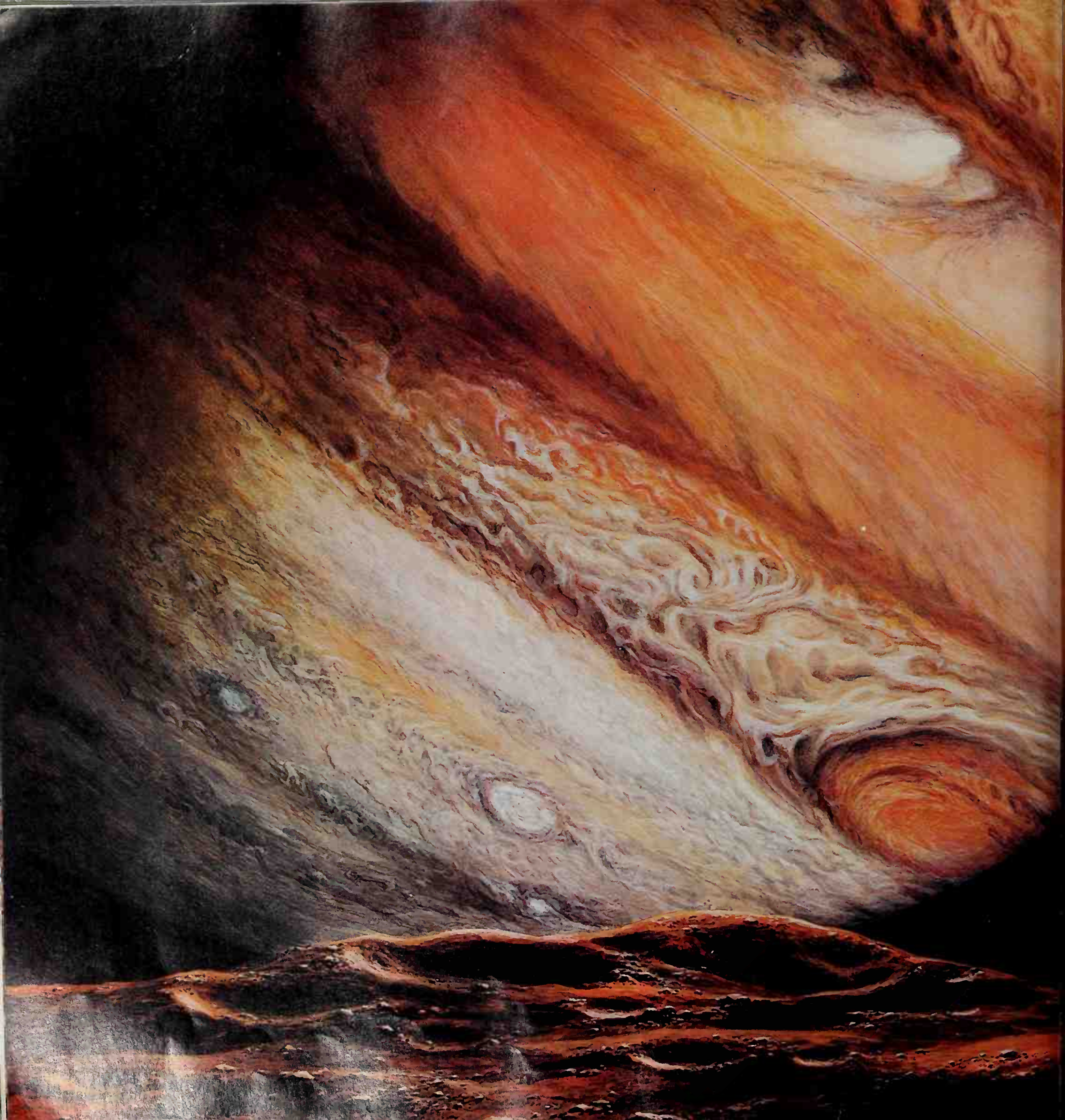
About 80 large meteorite craters have been discovered on Earth's surface. Most of them lie in highly populated areas of North America and Europe, where people are likely to find them. If we could fully explore the jungles of Africa and South America, we might find many more.

constellation Gemini are called Geminids. Shower meteors seem to radiate toward us from a point in a particular constellation, but this is an illusion. Actually, they travel in parallel lines, just as snowflakes fall in more or less parallel lines but appear to radiate from a particular point as we see them through the windshield of a moving car. Also, we see more snowflakes ahead of us, through the windshield, than when we look through the rear window. Likewise, we see more meteors when we look in the direction of Earth's orbital motion—Earth's "windshield"—than when we look "back." This happens, in our daily rotation, between midnight and noon, so the best times for meteor watching are the dark hours between midnight and dawn.

Classes of meteorites

If meteoroids and asteroids really did form at the same time as the planets, we would expect to find them made of some of the same materials as the planets. And this is just what we do find. There are three classes of meteorites—iron, stony, and the stony-irons. The irons are a blend of iron and nickel. The stony meteorites are mostly silicate rock with a little iron and nickel. Midway between the irons and stony meteorites are the stony-irons, made up of about half stone and half metal.

Of all the meteorites people have found on Earth, the majority are stony. And of the total number which fall through space, about 90 percent are stony while only a small percent are iron. So stony meteoroids are more common both in space and on Earth. The stony meteorites, once on the ground, are harder to recognize. They also decay faster than the irons—both during their burning passage through the atmosphere and because erosion attacks them once they land. The irons are tougher but, since they are so outnumbered by the stony meteorites, we find fewer of them.



King of the Planets

Jupiter

Jupiter's colorfully banded atmosphere is ever churning, ever changing. This would be our view of the colossal, belted globe from Amalthea, one of its inner moons. Amalthea is a reddish, rocky little world about 110,000 kilometers from the top of Jupiter's clouds.

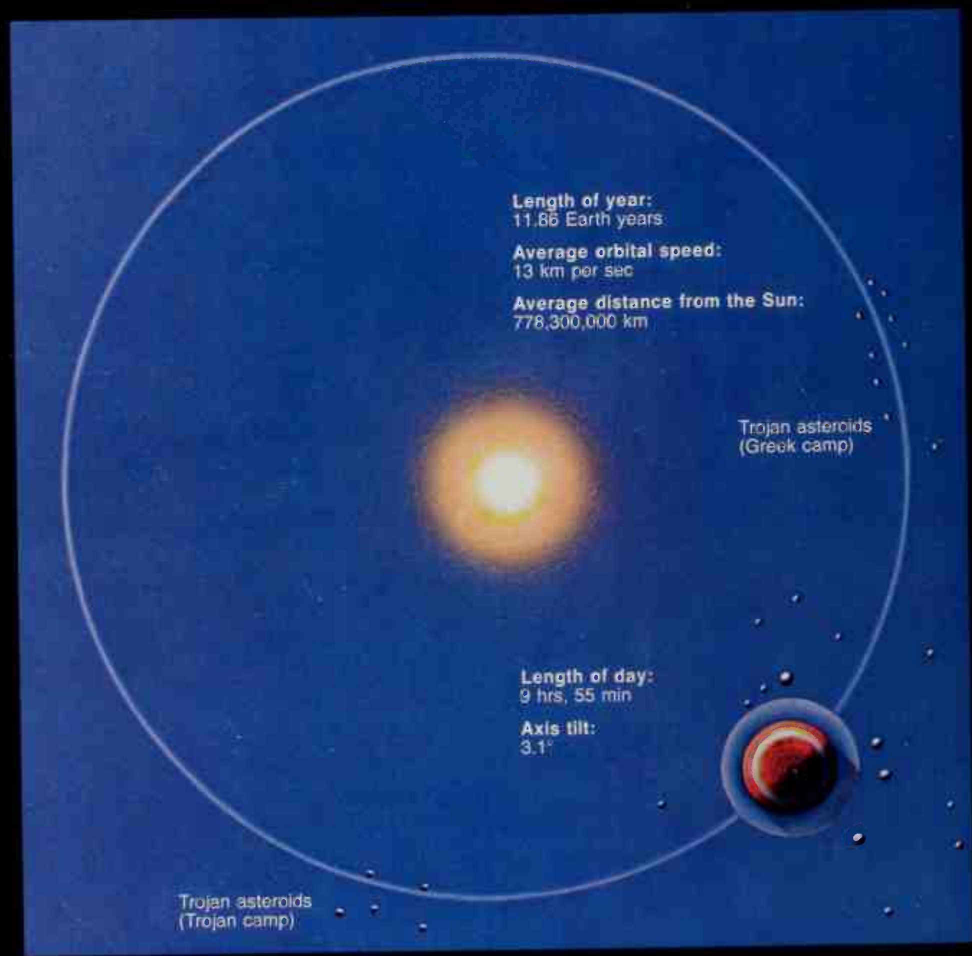
Jupiter's most prominent feature is its Great Red Spot, a hurricane-like storm that has probably been raging for centuries. At lower left are three smaller, white storm areas. The soft colors of Jupiter's bands shimmer against the black sky. These bands may be upwelling atmospheric gases composed of giant molecules.

This king of the planets is one and a half times larger than all the others put together. It also has more known moons, and it spins faster than any other planet.

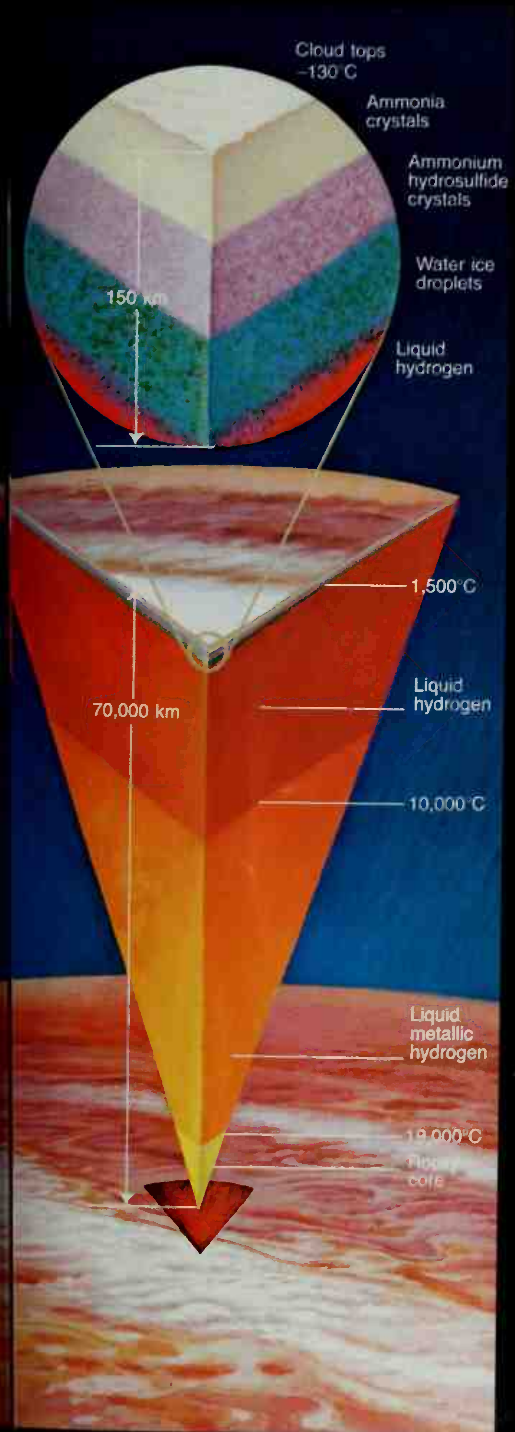
Pioneer and Voyager flybys of Jupiter told us much about the planet. The two Voyagers discovered the 14th moon and the ring. (Here we see it as a thin line slanting from upper left to lower right along the equator.) But they also left many interesting questions: How did Jupiter get its ring? Does Jupiter's dense atmosphere support primitive forms of life? Does Jupiter have more moons? What is the planet like beneath its massive cloud cover?

Facts about
Jupiter

King of Roman gods: Jupiter. His name is a fitting one for our largest planet. A traditional sign for his lightning bolt gives the planet its symbol, ♃



Master of its orbit, the fifth planet holds a faint ring and at least 14 moons in the firm grip of its gravitation. Four moons are as big as small planets. The combined pulls of Jupiter and the Sun also keep two asteroid groups, called the Trojans, in Jupiter's orbit. One group moves along a sixth of the way ahead of Jupiter, the other equally far behind. They bear heroes' names from the ancient Trojan War—the first group represents Greece, the second Troy. Jupiter's tiny outer moons may be Trojan asteroids, trapped when they strayed too close to the planet.



Heavyweight champion of the worlds, Jupiter (right) accounts for more than two-thirds of all material in the Solar System outside the Sun. It would take 318 Earths to equal Jupiter's huge mass. Gravity two and a half times stronger than our own creates intense pressures in the swirling gases of its atmosphere. The single ring, a thin veil of dust found by Voyager I, may reach all the way to the planet—a distance of 55,000 km.

An icy frosting of clouds (left), several layers thick, covers what most of Jupiter is made of—hot liquid hydrogen. The atmosphere above is cold, but farther down it could be well over 1,000°C. In this pressure-cooker level, gases would turn liquid and form a kind of steamy slush—the top of an enormous hydrogen ocean. About halfway downward to the planet's rocky core, increasing heat and pressure force the hydrogen to act like molten metal. Scientists think electrical currents in this zone may create Jupiter's giant magnetic field, which extends past the orbits of several of its moons.

"The eye of Jupiter," astronomers call the Great Red Spot. The giant storm, its winds whirling up to 360 km an hour, appears in this Voyager view with some colors brightened to show details. To see how big the spot really is, set a grapefruit on the picture; that's Earth to scale.

On our make-believe journey through the Solar System we pass safely through the asteroid belt, just as the two Voyager spacecraft did in 1978. First they were flung out from Earth at a send-off speed of 52,000 kilometers an hour. Earth's and the Sun's gravitation gradually slowed them down. Eventually the Voyagers entered the gravitational field of Jupiter which sped them up. The Voyagers flew for one and a half years to reach Jupiter.

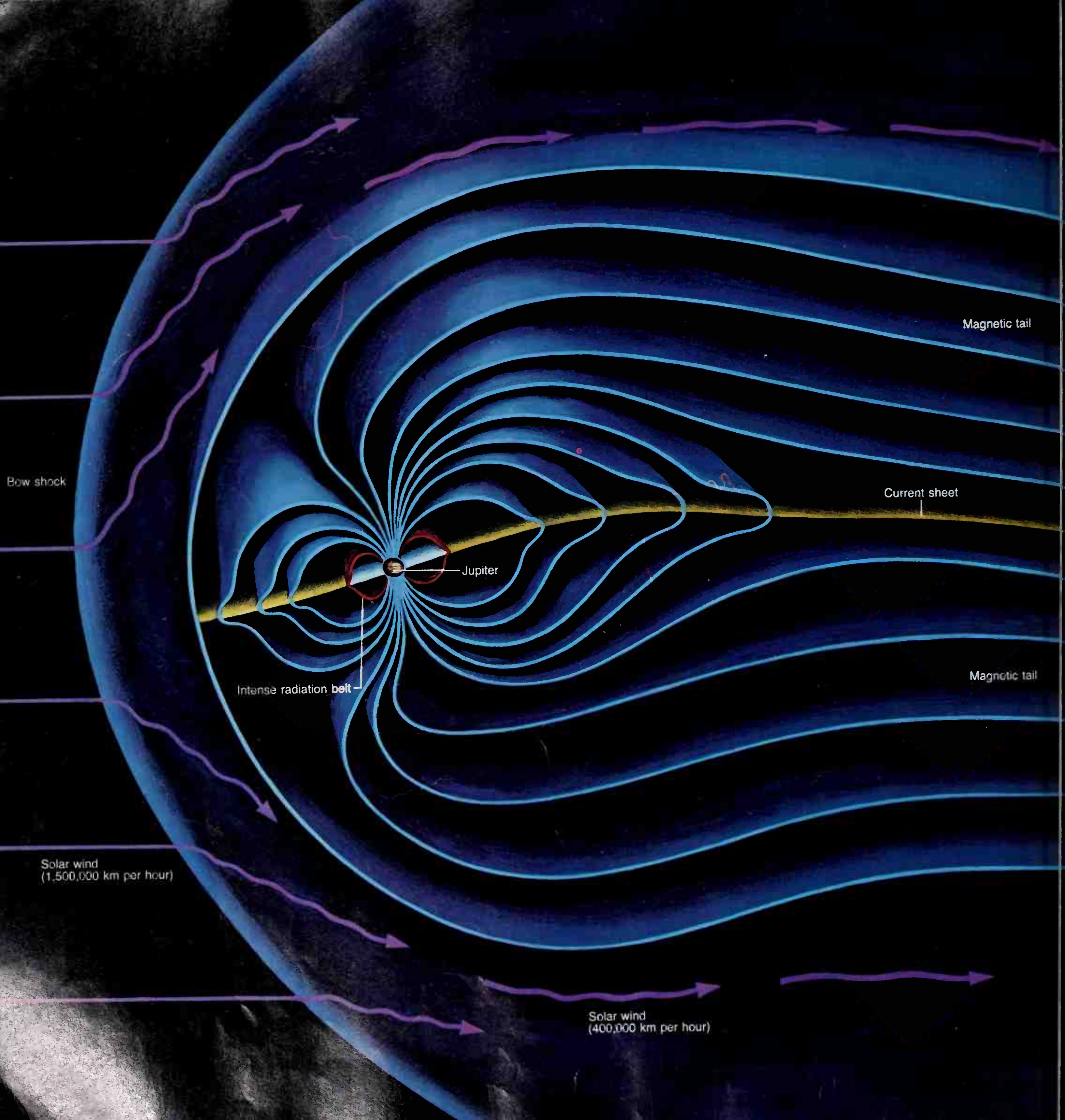
Jupiter is the largest planet in the Solar System. It is about five times farther from the Sun than Earth is. More than 11 Earths could be lined up along the giant planet's diameter and 1,300 Earths could easily be packed inside.

A giant planet with giant surprises

Seven million kilometers out from Jupiter, Voyager 1 entered the planet's powerful magnetic field. (See pages 158 and 159.) Voyager safely crossed the boundary where the solar wind clashes with Jupiter's magnetic field – an electrically turbulent area called the *bow shock.*

Jupiter's inner moons orbit within the magnetic field and are continually showered with high-speed charged particles, mostly protons and electrons. The current is spread too thin to harm a spacecraft, except perhaps in the highly-charged region between Jupiter and its moon Io. The movement of Io through the magnetic field sets up an electrical current five million amperes strong. The current flowing in a 100-watt light bulb is only one ampere.

The electricity linking Io with Jupiter is gradually eroding Io's surface. Gases



Magnetic tail
Bow shock
Current sheet
Jupiter
Intense radiation belt
Magnetic tail
Solar wind
(1,500,000 km per hour)
Solar wind
(400,000 km per hour)

Jupiter's invisible magnetosphere is far bigger than the Sun itself. If we could see it pulsing in our night sky, it would look about twice as big as the full Moon. The bow shock, where the magnetic field and solar wind meet, surges back and forth with gusts in the solar wind. A magnetic tail stretches outward – beyond the orbit of Saturn. Particles spun off from Jupiter's ionosphere collect in a thin sheet of electrical current (yellow). Near Jupiter, deadly radiation – thousands of times stronger than Earth's Van Allen belts – batters Jupiter's major satellites.

In 1979 NASA scientists watched in relief as Voyager 1 survived the magnetosphere's searing radiation and sent back floods of information about Jupiter. Voyagers 1 and 2 also began our exploration of the four big moons Galileo discovered: Io, Europa, Ganymede, Callisto.

explode out of Io's volcanoes and break up into charged atomic particles. Jupiter captures them, along with surface particles. They form an invisible doughnut-shaped electrical cloud around the planet. As Io circles Jupiter, the planet keeps the satellite a prisoner within this enormous energetic cloud.

A major surprise from Voyager 1 was that Jupiter has a ring. It reaches out 58,000 kilometers from the planet's cloud tops. The ring is very faint, with a sharp outer boundary, and seems to be about one kilometer thick. Its fine particles glimmer faintly, like dust specks floating in a beam of light. What are these particles captured by Jupiter's gravitation? Possible candidates include debris from comets and meteoroids; material splashed out as meteorites hit the inner moons; and volcanic material ejected by Io. Also, Jupiter's newly found 14th moon orbits at the ring's edge and may be disintegrating.

The Great Red Spot

Jupiter's atmosphere is a churning sea of rising and sinking clouds of many colors. Jet winds of super-hurricane force tear at the clouds and add to their motion. It has been compared to an enormous boiling kettle of brightly colored dyes that cannot be made to blend. The reason may be that these cloud cells contain different chemicals which originate at various depths within the lower Jovian atmosphere.

For more than 100 years astronomers have studied the Great Red Spot, a storm area in Jupiter's southern hemisphere near the equator. This reddish, football-shaped blob of gases has been a prominent feature of Jupiter's atmosphere for at least 300 years. Its color sometimes fades; its size also changes. At present it seems to be shrinking, but it is still large enough to swallow up two Earths.

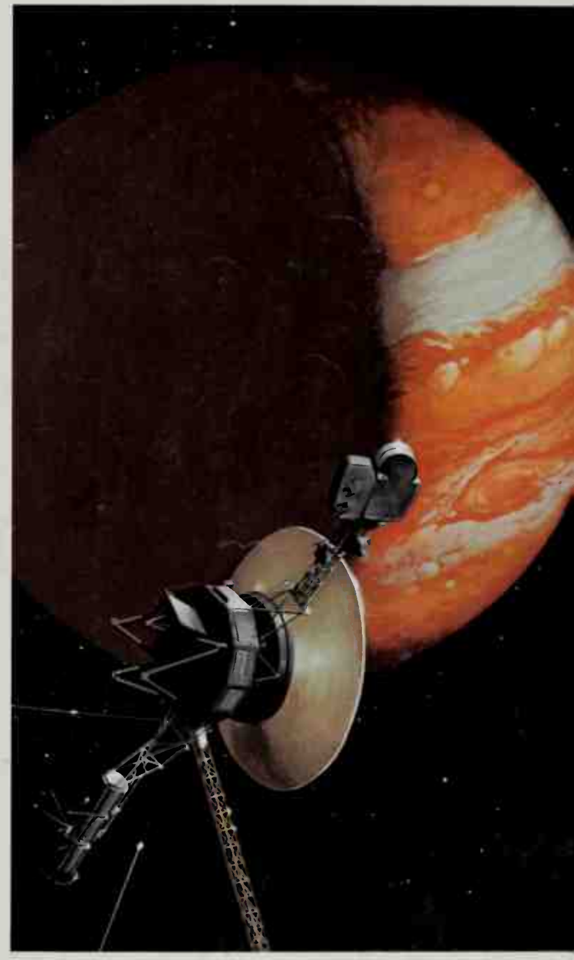
The Great Red Spot revolves along with the rest of the cloud bands, but at a slower speed. Other cloud features sometimes catch up to the Red Spot and pass beneath it or around it. The spot also spins counterclockwise on its own axis, at the rate of one spin every six Earth days. So if you were watching Jupiter from one of its outer moons, you could almost use the Great Red Spot as a clock, with "hands" of clouds that dissolve and form anew from time to time as they rotate around the edge of the great storm.

The Little Red Spot

Below the Great Red Spot are three white oval storm areas. Astronomers watched them form only 40 years ago. Like the Great Red Spot, they are pretty much a mystery. There are many more of these storms. In 1973 the space probe Pioneer 10 photographed one in the northern hemisphere, the Little Red Spot. But a year later, when Pioneer 11 flew by, the Little Red Spot had disappeared. Voyager 1 saw its reappearance or, perhaps, a new spot.

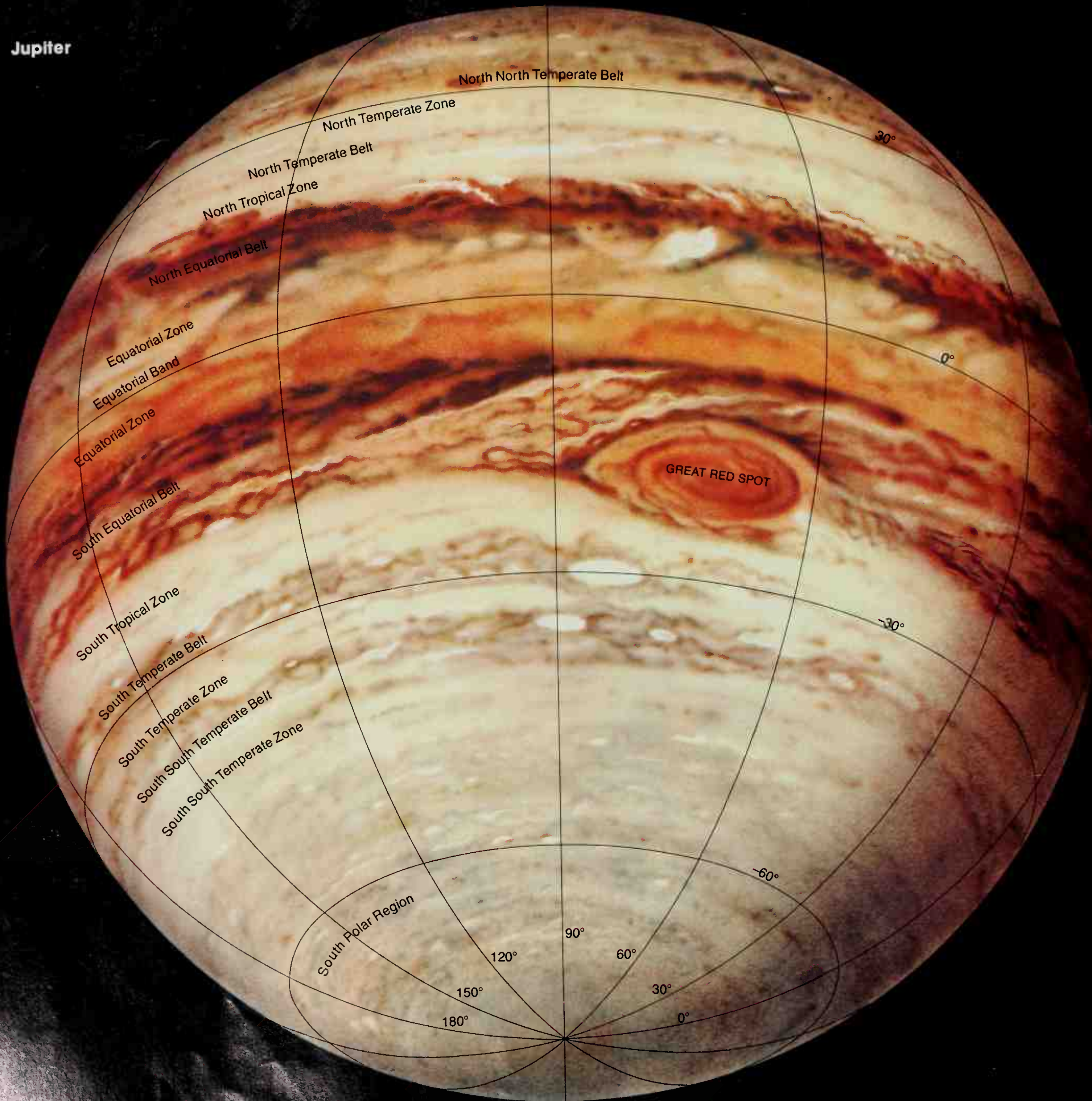
The atmosphere

Because of its strong gravity Jupiter has kept much of its original atmosphere. The bulk of Jupiter's air is hydrogen, with helium making up about 10 percent. There are other gases as well, gases that may also



On the next page: *In this artist's view across the Great Red Spot, a chilly Sun and crescent Io float above a cloudscape vaster than any Earthly ocean. Below, lightning stabs into layers churning with chemicals needed for life. But life seems unlikely to form amid such violence.*

Jupiter


North North Temperate Belt
North Temperate Zone
North Temperate Belt
North Tropical Zone
North Equatorial Belt
Equatorial Zone
Equatorial Band
Equatorial Zone
South Equatorial Belt
South Tropical Zone
South Temperate Belt
South Temperate Zone
South South Temperate Belt
South South Temperate Zone
South Polar Region
GREAT RED SPOT
30°
0°
-30°
-60°
90°
120°
60°
150°
30°
180°
0°

Jupiter's swift rotation creates bands of cloud called belts and zones. Rivers of jet-stream winds rushing eastward carry the high-flying, light-colored zones. At lower altitudes, between the zones, dark-colored belts border jet streams that tear around Jupiter to the west.

have been in the original atmospheres of Mars, Earth, and Venus. Those gases include methane, water vapor, and ammonia. The upper regions of Jupiter's clouds are cold, about –130°C, and the temperature of the Great Red Spot is even lower.

Into the clouds

All we can see of Jupiter is the top of a cloud deck about 100 kilometers deep. But the bottom of its atmosphere may be at a depth of 1,000 kilometers.

Jupiter probably lacks a solid, Earthlike surface. An explorer of Jupiter would first pass through a dense atmosphere of gaseous hydrogen that, little by little, changes to a strange lifeless ocean of liquid hydrogen. About 20,000 kilometers beneath this liquid layer, there may be a layer of a form of hydrogen so dense that it acts like a metal. Beneath this metallic hydrogen layer Jupiter may have an inner ball of iron and silicate rock somewhat larger than Earth. Temperatures in this core region may reach 25,000°C, four times higher than the Sun's surface temperature. And pressures may reach 40 million times the pressure at Earth's surface.

If this is what Jupiter's interior actually is like, then its metallic hydrogen layer probably carries the electric currents that produce the powerful magnetic field measured by both of the Voyager spacecraft.

Life on Jupiter?

As Voyager gradually moved into Jupiter's shadow zone it revealed more surprises. Toward the polar region of the planet grand auroras brightened the sky – the first auroras seen on any planet other than Earth. While Earth's auroras are caused by charged particles of solar wind, Jupiter's auroras seem to be caused by charged particles from its moon Io.

Voyager found that Jupiter's upper atmosphere is alive with lightning superbolts. Astronomers believe that this lightning may cause Jupiter's whistlers – bursts of radio noise.

Lightning bolts may also provide the atmospheric energy which triggers many of Jupiter's chemical reactions. Not far below the frigid cloud tops there must be a region that is "comfortably" warm – a region where water, methane, and ammonia gases react chemically, energized by the lightning. When these substances join they can form organic molecules, the chemical beginnings of life. Is it possible that within this zone simple living organisms evolved long ago and have adapted to a floating existence within the clouds? Most scientists are not hopeful. They think that Jupiter's rapidly churning air has prevented the development of atmospheric life forms, since the complex molecules necessary for life would be swept down into hot regions of the clouds and be destroyed.

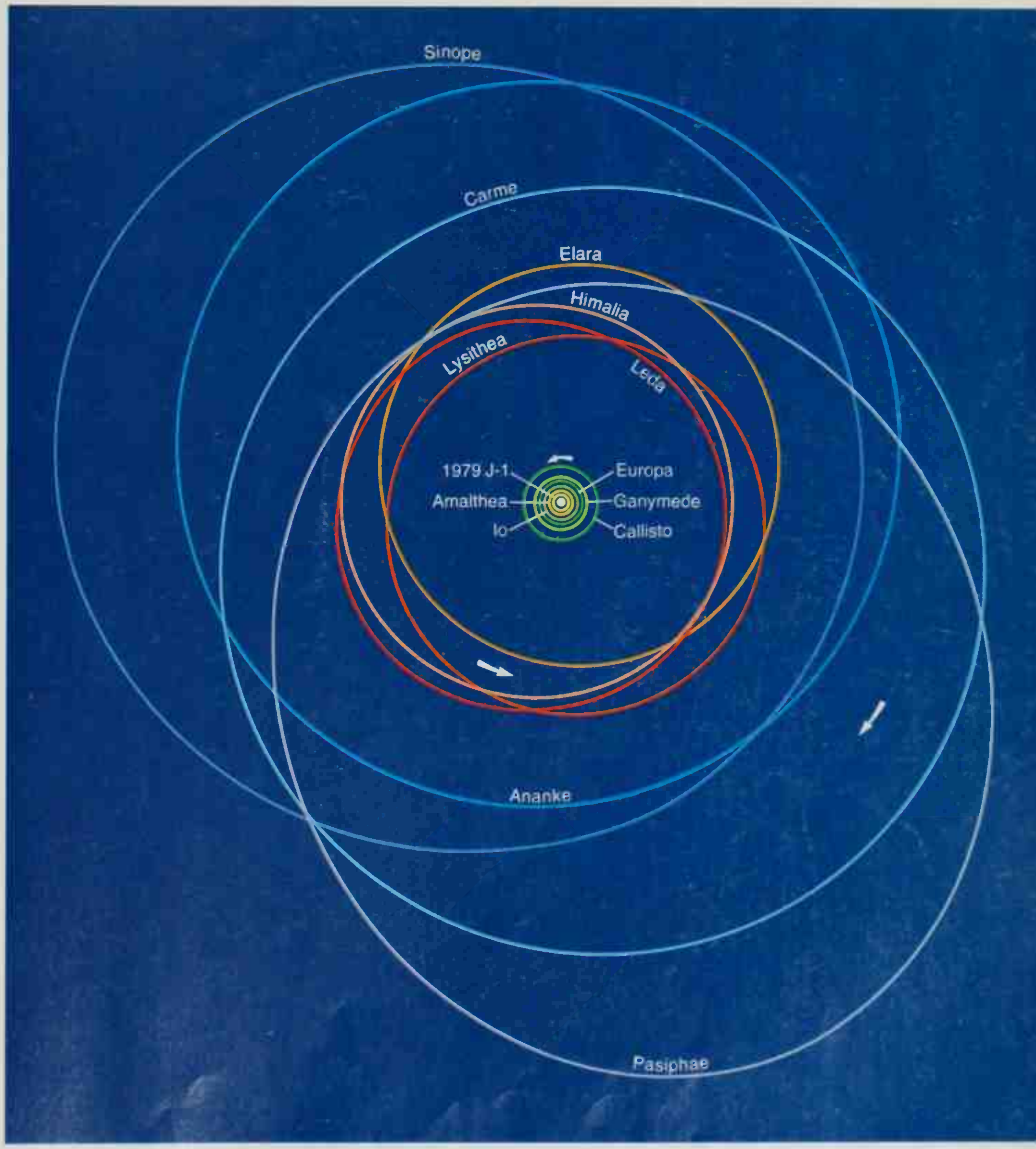
If Jupiter's organic molecules have not combined and provided Jupiter with living organisms, they may enrich the planet in a less dramatic way. Rust-colored, they may well up and help color the Great Red Spot and redden some of the cloud bands.

Jupiter—a star that failed?

Jupiter emits more energy than it receives from the Sun – twice as much, as measured

A Voyager camera captures two moons as they drift across a looming Jupiter. Sulfur colors Io (left), innermost of the Galilean satellites. Europa (right) displays an icy crust. Like our Moon, all four keep the same side inward, frozen that way in Jupiter's gravitational grip.

Jupiter's moons weave a jumble of orbits. An outer group (shown in blues) revolves retrograde, in tilted, elliptical paths that take as long as two Earth years to travel. The middle group (red colors) revolves direct—along with Jupiter's spin—in different tilts from the outer. These small moons may all be asteroids captured by Jupiter's gravitational field. The big Galileans (greens) follow more circular tracks, above Jupiter's equator. So do the little inner moons (yellows). One, found by Voyager and temporarily coded 1979 J-1, zips around Jupiter every seven hours.



by Pioneer 10. Could Jupiter have been much hotter in its early history, maybe hot enough to warm its four large moons as the Sun warms the inner planets?

It seems so. Imagine the scene 4.6 billion years ago when the Solar System was taking shape. Jupiter, two and a half times as massive as all the other planets combined, began as an enormous gas ball that contracted and heated up, just as the infant Sun was doing. But, unlike the Sun, Jupiter had far too little mass to send its core temperature high enough to start fusion reactions. Instead of reaching the millions of degrees needed, the core heated up only a few tens of thousands of degrees. So Jupiter became only hot enough to glow cherry-red, like a red dwarf star, and for a while it bathed its inner moons in light and heat that faded as Jupiter slowly cooled.

Probably only the inner moons formed as satellites at the same time Jupiter formed as a planet. The eight small outer moons are all believed to be former asteroids captured by Jupiter's gravitation. And there may be even more moons in Jupiter's grip. Astronomers who are studying the data sent back by the Voyager spacecraft have tentatively identified a fifteenth moon, designated 1979 J-2, orbiting between Amalthea and Io.

The Galilean satellites

Voyager gave us our first good views of the giant planet's four largest moons—Io, Europa, Ganymede, and Callisto, the moons discovered by Galileo on January 7, 1610.

Looking through his telescope, Galileo at first saw only three moons in a straight

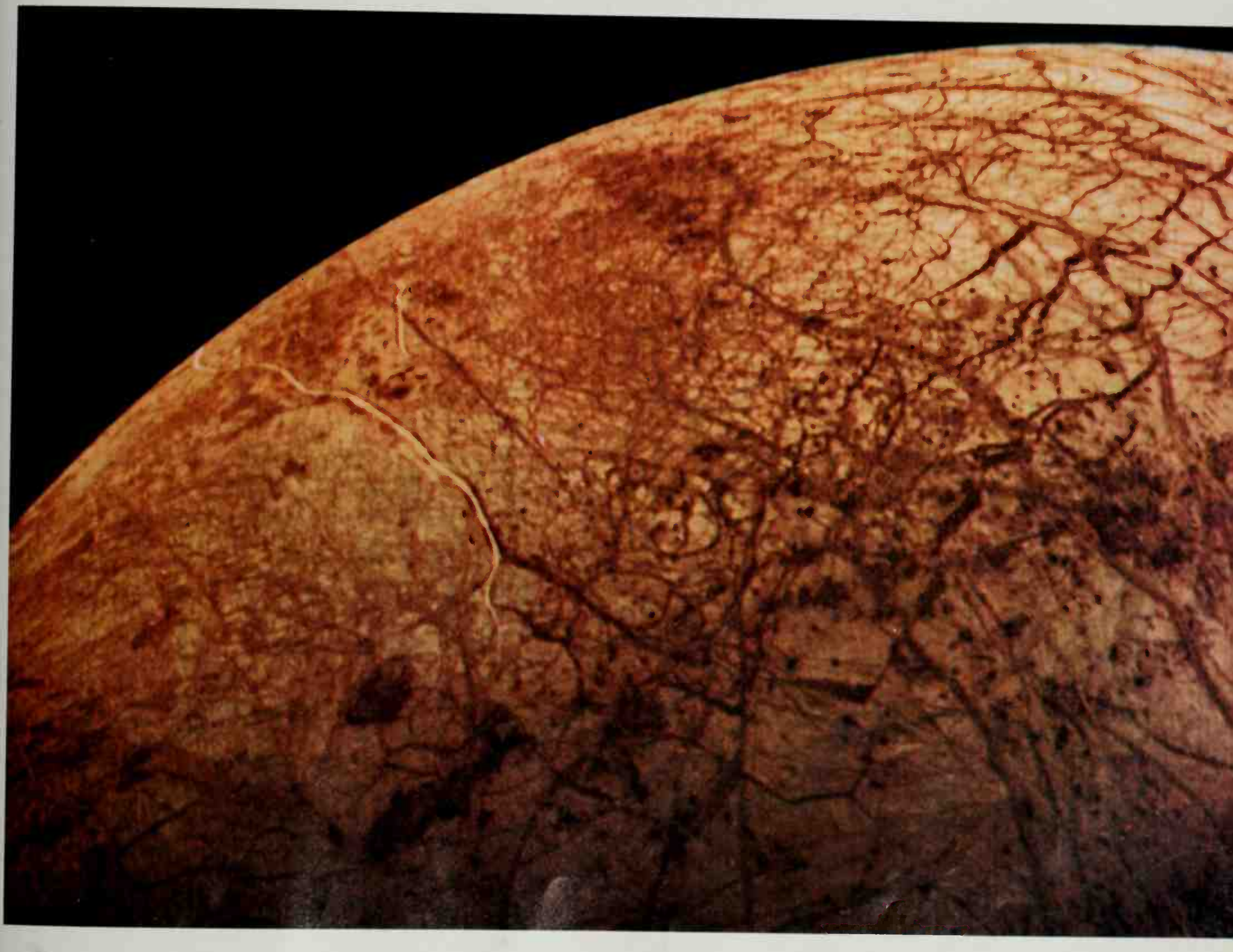
Ganymede (below)—Ice flung from fresh impact craters whitens Ganymede's surface. Dirt and rock darken older zones. Fault lines show that the thick ice crust may have broken into plates, like those of Earth. Ganymede is the largest Galilean moon, three-fourths the width of Mars.

line across Jupiter, two at the left and one at the right. The next night he saw all three to the right. Galileo thought he was looking at distant stars and wondered how Jupiter had managed to move to the left of them. Two nights later he saw only two, and they were to the left of Jupiter. (The third was behind the planet.) Eventually Galileo counted four objects and realized that they were orbiting Jupiter: Their behavior made them moons, not stars.

The discovery caused great excitement. When Johann Kepler heard of Galileo's discovery he longed to see the new moons but did not have a telescope, and it was not

Callisto (left)—Like a frozen explosion, the huge Valhalla basin ripples Callisto's ice crust, which melted and refroze here after a giant meteoroid strike. Undisturbed by faults or volcanoes, the ancient face of the outermost Galilean moon may be the most cratered place in the Solar System.

Europa (below)—Since few craters mark the smallest Galilean moon, scientists think its cracked cue-ball landscape is relatively young. Water seeping through faults may have smoothed the surface ice, leaving the long stains. A global ocean may lie in the darkness underground.



Io—Eroded by radiation, jolted by arcs of electricity from Jupiter, pinched and torn by tides . . . Io's tortured surface deserves to look bruised. Volcanoes like the one on the horizon blast out enough material to "repave" the entire moon every million years—a geological wink of an eye.

until August 1610 that he finally did see them, and it was through a telescope that Galileo had made. Some astronomers refused to believe Galileo's claim. They felt that the Solar System with its seven "planets" was complete and were very upset that an age-old belief could be wrong. Some of them refused even to look through Galileo's telescope. But eventually even Galileo's bitterest enemies had to admit that Jupiter had moons.

Ganymede's grooves

Measuring 5,275 kilometers in diameter, Ganymede is Jupiter's biggest satellite. It circles the planet at a distance of about a million kilometers. Voyager 1 sent back pictures of the side of Ganymede that is locked to Jupiter. Voyager 2 photographed the opposite side. Both showed a satellite peppered with craters which make Ganymede look remarkably like our Moon. Many of the craters have bright rays. There is also a lighter terrain, with long grooves that look as though they were made by a giant rake pulled in curved and crisscross patterns. The parallel ridges and troughs of the grooved terrain are from 5 to 15 kilometers wide and run on for hundreds of kilometers. Scientists who try to determine the age of Ganymede's surface find that some areas are heavily cratered and lack grooves, while others are grooved but have few craters. It seems that the grooved terrain was present early in Ganymede's history and developed all during the time meteoroid fragments were bombarding Ganymede.

One Ganymede feature, so big we can see it through telescopes from Earth, is a huge, circular area of old craters. Crossing the region are bright streaks, parallel and slightly curved. It is tempting to suppose that a meteoroid long ago blasted out these rings of ridges but that erosion erased most of them. There are also many "ghost" craters, mere stains of craters once prominent when Ganymede's icy crust was too warm and soft to preserve the original features. But near the south pole are large craters with sharp, fresh features. These must have been made sometime after the crust had cooled.

There are ice fields and great tile-like blocks that may be plates of ice. They range from several hundred to about a thousand kilometers across. Beneath Ganymede's crust, there may be a liquid water mantle and below that a solid core rich in silicate rock, similar to the rock making up Earth's crust.

Callisto's ringed terrain

Nearly twice Ganymede's distance from Jupiter is Callisto, 4,820 kilometers in diameter. The biggest attraction on airless Callisto is Valhalla, a gigantic group of rings raised by shock waves. A large meteoroid smashed into Callisto when it was still a young moon. The impact left a hole half as wide as Florida and perhaps 20 kilometers deep. When the monstrous chunk of rock and metal struck, it instantly must have melted a large area of Callisto's icy crust, sending out clouds of steam and creating a small sea. But the water would have frozen soon and left Valhalla as the shallow icy basin we see today.

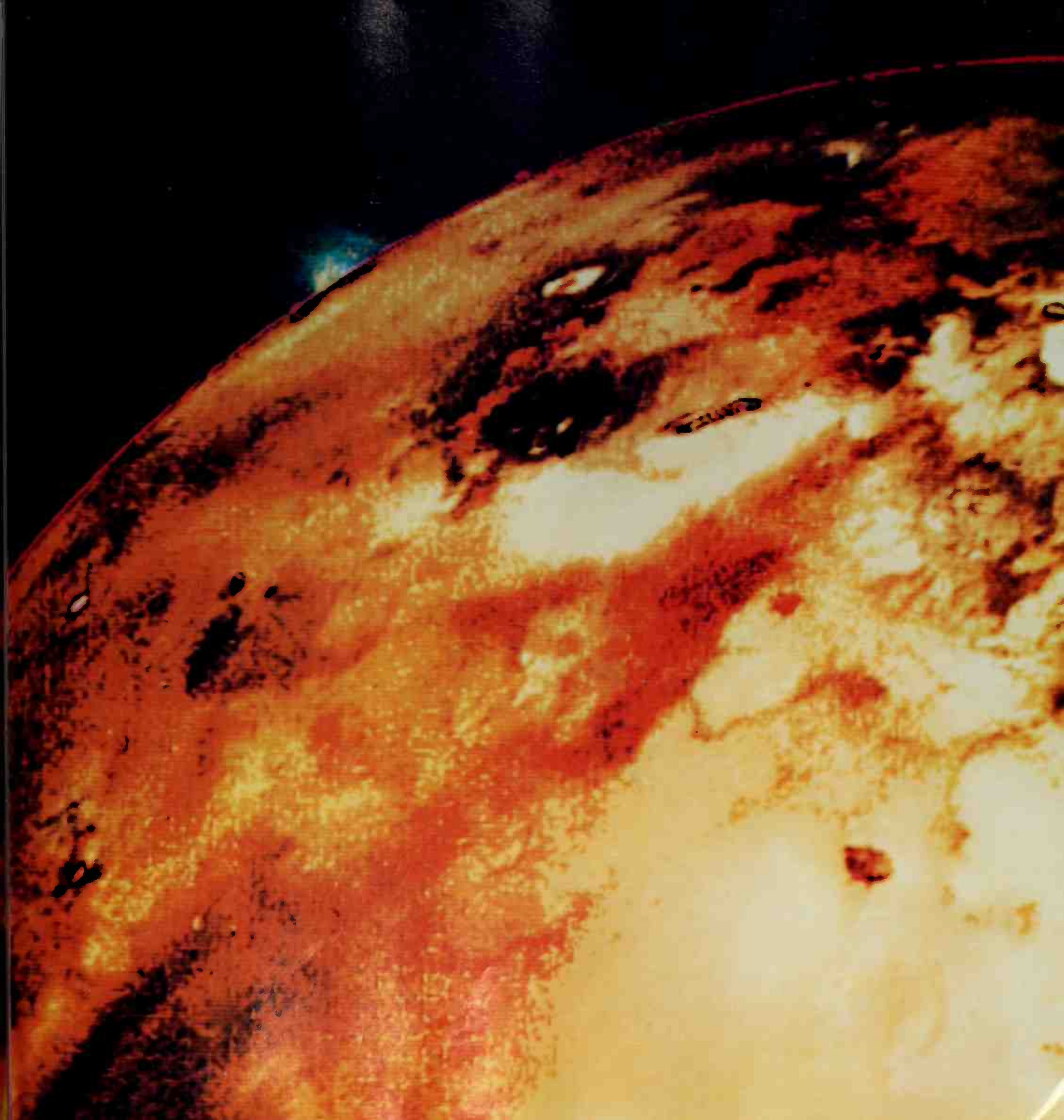
Europa's icy plates

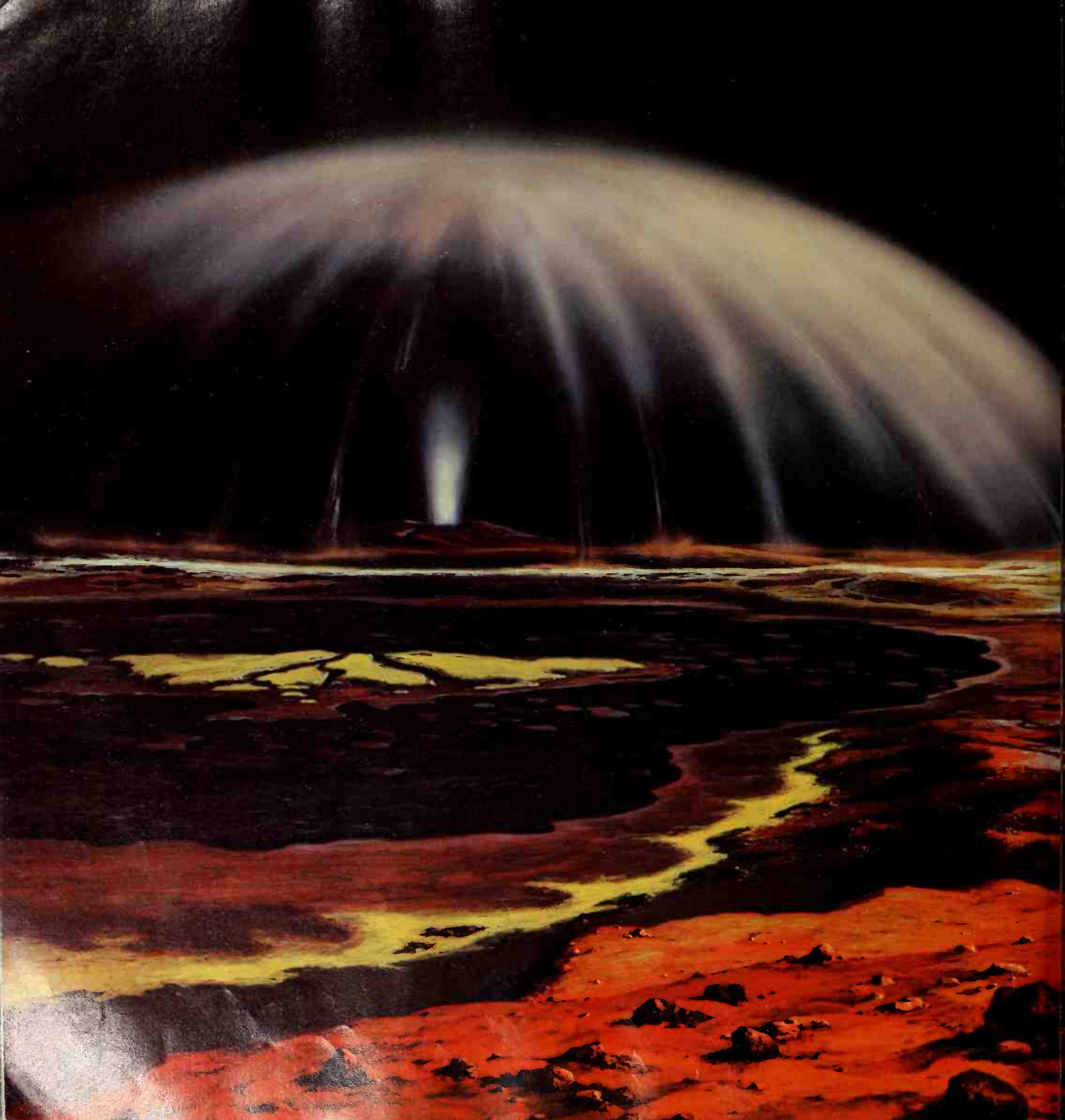
Europa is 3,130 kilometers in diameter, nearly as large as Earth's Moon. It orbits Jupiter at almost twice the distance that our Moon orbits us.

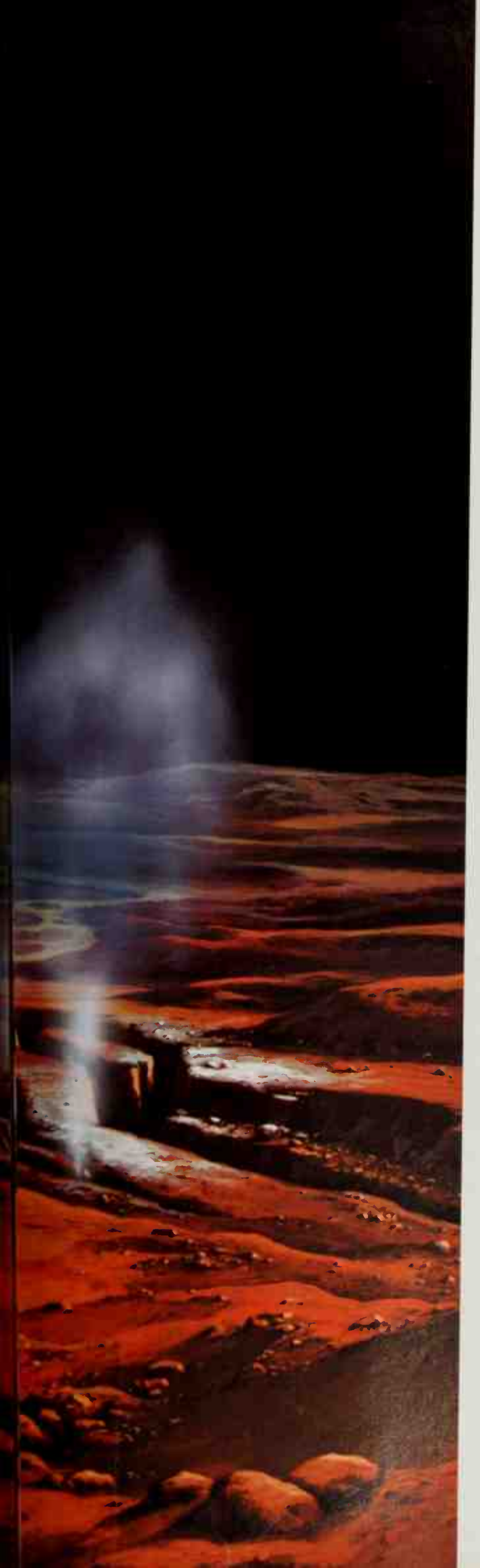
Europa appears to have an unusually smooth surface and only a few large impact areas. It is laced with dark, crisscrossing lanes tens of kilometers wide and several thousand kilometers long. What caused this moon-wide network? One guess is that Europa is still hot and active in its core. If it is, forces within the satellite would keep the crustal plates of ice moving about. Another guess is that Jupiter's strong gravitational grip—plus gravitational forces of the other satellites—keeps breaking Europa's icy plates and disturbing the material beneath. This may cause gases and dirt to float up to the surface where they freeze as the dark lanes of ice. Under them, about 100 kilometers down, there may be an ocean of liquid water, and beneath that, an active rock-metal core.

Volcanoes on Io

Io is one of the most fascinating objects in the Solar System. With a diameter of 3,630 kilometers, it is only slightly larger than our own quiet Moon. But Io is anything but quiet. The Voyager spacecraft clearly showed 10 violent volcanoes. There are many dead volcanoes on the Moon, Mars, Mercury, and Venus. Earth is the only other place in the Solar System where volcanoes are known to be now active. What makes Io so active? Astronomers are still studying Voyager data to find out more about this highly energetic moon.







Fed perhaps by an underground ocean of sulfur, a distant volcano erupts into Io's airless sky. In the low gravity here, such fountains can shoot 300 km high and cover a distance as far as from New York to Detroit. Sulfur dioxide gas spurts from vents near a field of cold, blackened lava.

Io circles Jupiter in a wobbly orbit. While Jupiter tugs on Io from one direction, Europa and Ganymede sometimes tug on it from the opposite direction. This causes Io to weave first inward toward Jupiter and then outward. Its changing distances from Jupiter raise 100-meter ground tides. This means that Io's surface heaves up and down as if it were an ocean tide – to about the height of a redwood tree. The pumping action first stretches and then compresses Io's inner materials and so heats them. Is this heat the energy source for Io's volcanic activity? Or is the powerful electrical current from Jupiter the source? Or could it be a combination of the two? Whatever the source, Io's volcanoes seem to explode their sulfurous material with terrible force, propelling the particles to speeds as great as 3,600 kilometers an hour. This is several times the force of Earth's volcanoes, including Mount St. Helens and Mount Etna.

Io's sulfur snow

Astronomer Bradford A. Smith has said that Io looks something like a pizza. From space its surface appears bright orange-red with many large white patches and smaller dark spots. Strolling across Io would be like strolling across the Painted Desert in Arizona. But in place of hot desert sand we would find foul-smelling sulfur and sulfur dioxide snow. All around us volcanoes would hurl blobs and frozen flakes high into the sky, flakes of blue-white, yellow, and orange. Io's ancient impact craters long ago were erased or covered (just as Earth's once-cratered surface has been eroded over the ages). Io itself is as old as the other Galilean satellites. But, because of the volcanic snowfalls, some parts of Io's surface are only a few weeks old and it now seems doubtful that any part of its surface is over a million years old, so rapid is the change there.

Now and again we would come upon the remains of collapsed volcanoes and eroded slopes, the ghosts of an earlier crust. Voyager saw black spots, probably crusted-over lakes of lava that well up from below Io's top layer of frozen sulfur. These spots measure as high as 600°C, hot enough for sulfur to be molten, and much hotter than the surrounding surface of −145°C. From time to time we also would come upon vast lakes of molten sulfur. If we dug only a few kilometers down through Io's crust we might discover an ocean of liquid sulfur.

The Voyager spacecraft added an immense store of new data to our knowledge of Jupiter, but there is still much to learn. NASA is planning a new mission that will include dropping a probe into Jupiter's atmosphere (see illustration on page 256). The mission has been named, appropriately, Project Galileo.

Jupiter's enormous gravitational field has been speeding up our imaginary spacecraft ever since we came near this king of the planets. Now as we loop around we are flung off toward Saturn. Jupiter's gravity whip more than doubles our speed to about 135,000 kilometers an hour – about 50 times faster than the fastest jet airliners. Perhaps Saturn and its many moons will offer us a more promising environment for life. Or will they?

The Planet with Ears

Saturn

A crescent Saturn looms large over the desolate, icy low hills of Rhea, one of the planet's dozen or so moons. Rhea, about half the size of our Moon and more than half a million kilometers from Saturn, gleams bluish in the cold light of the distant Sun.

Saturn's magnificent ring system appears as only a thin line from Rhea because Rhea orbits Saturn at about the same plane as the planet's rings. But sunlight casts a wide ring shadow on Saturn—the dark patch that links the terminator and limb just above the thin ring line. When Galileo studied Saturn with his telescope in 1610, he saw the rings faintly as two knob-like shapes. He called them "ears."

Saturn's moon Tethys, about two-thirds the size of Rhea, is seen in crescent phase left of the terminator. The moon Dione is just right of the ring. Although nearly the same size as Tethys, Dione appears larger because it is closer to Rhea.

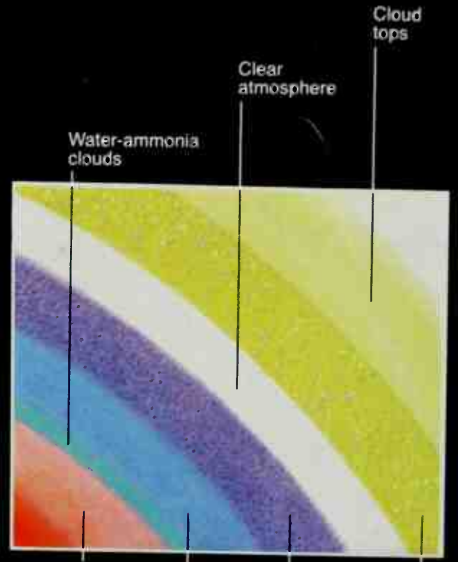
Rapid rotation causes Saturn to bulge a bit at the equator and flatten at the poles. The second largest planet in our Solar System, Saturn is a gas giant, like its larger neighbor, Jupiter. But because Saturn's clouds of ammonia snow are not so stormy, it's sometimes called the "quiet Jupiter."

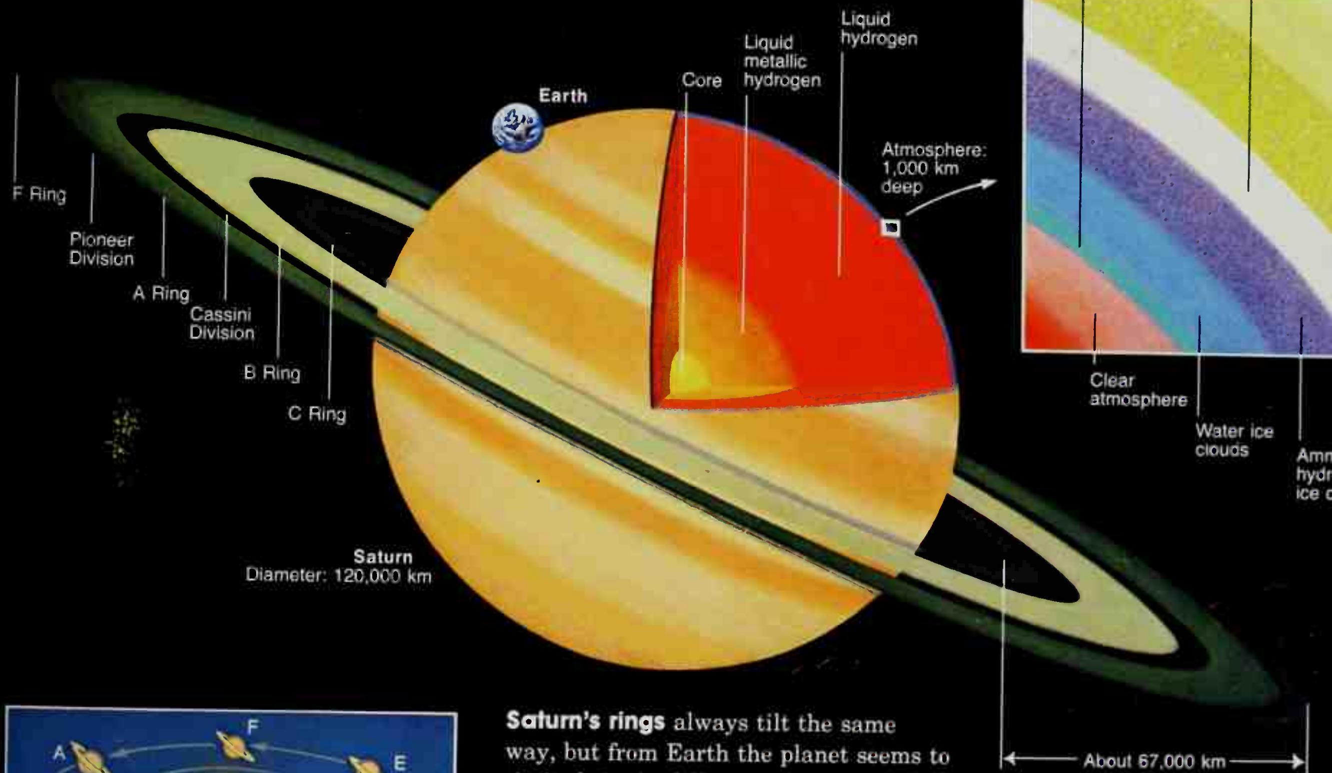
Facts about
Saturn

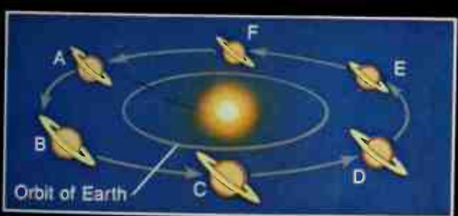
Harvest time in ancient Italy belonged to the god of reaping, whom the Romans called Saturn. A symbol curved like his sickle – ♄ – represents the planet.

How far is it to the orbit of Saturn? Imagine going all the way from Mercury to Mars, through the asteroid belt, and on to Jupiter. You would have to travel almost as far *again* to reach Saturn. Here you see the sixth planet from high over its north pole – a view impossible from Earth, since the poles never point our way. Scientists think at least 12 moons orbit Saturn. Titan, the biggest, holds a thick atmosphere. Phoebe, the most distant, seems here to be partway around the Sun – but only because the Sun is shown closer and larger than it really is.

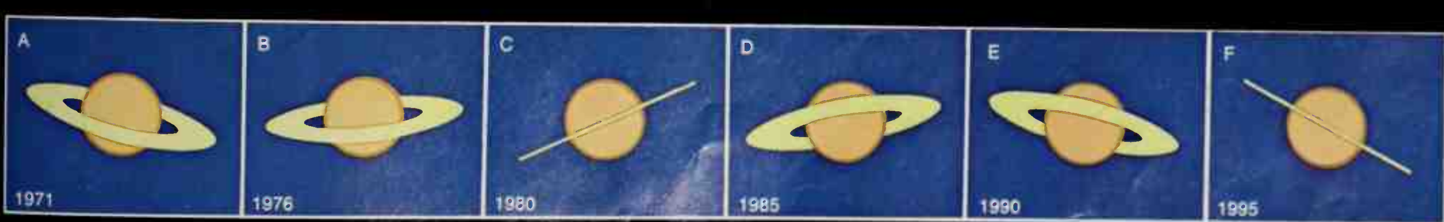
Icy particles form the wide, thin rings that wheel slowly above Saturn's clouds. Frigid at the top, the atmosphere grows thicker and hotter without ever reaching solid ground. Atmospheric hydrogen turns to liquid. Saturn still gives off warmth left over from its formation. Its mass equals 95 Earths, but it takes up about 800 times as much room. That makes it the least dense gas giant—70 percent as dense as water. Because of Saturn's fast spin and flat shape, gravity varies—at the poles, a third more than on Earth; at the equator, a thirteenth less.





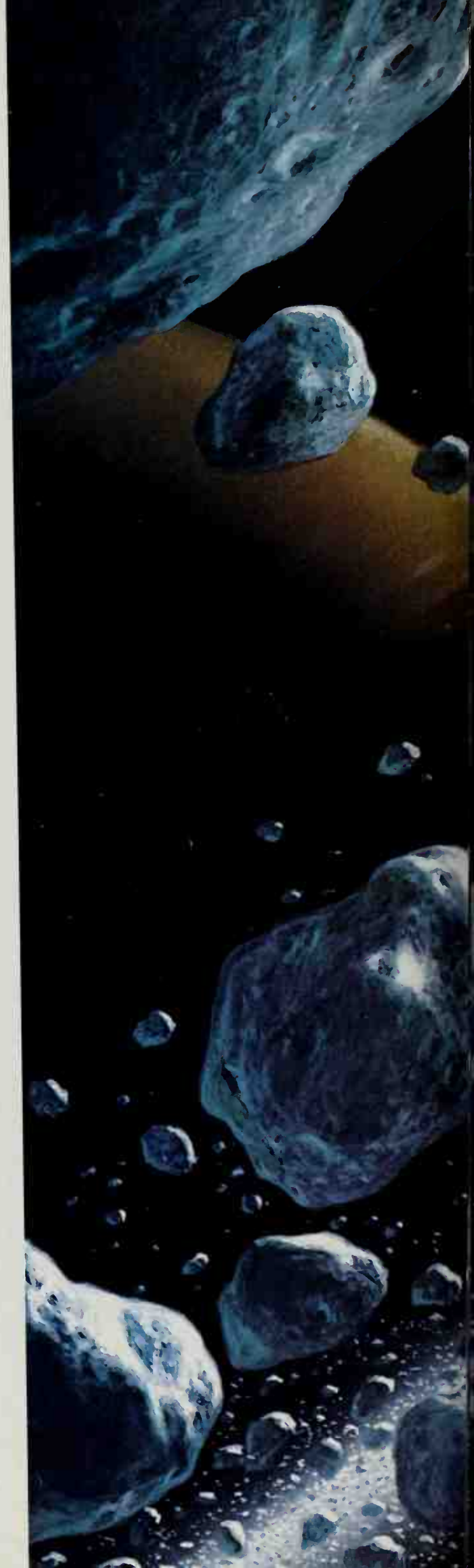


Saturn's rings always tilt the same way, but from Earth the planet seems to tip its brim in different directions, depending on where it is. The orbit at left shows Saturn at points about five Earth years apart. At each position (below), we see the rings from a different angle.



A telescope portrait, one of the best ever, displays Saturn's halo of rings. Scientists combined 16 images to make the picture. The rings are gigantic. If you could take a space walk around the outer edge of the A Ring, going 25 km a day, you would be back at your starting place in 95 years.

A broken moon? Or a moon that never was? Astronomers do not yet know how Saturn's rings came to be. Full of icy particles (right), a ring seems to blur into a band of unearthly hail around the planet. One ring is so thick with rubble that almost no light can pass through it.



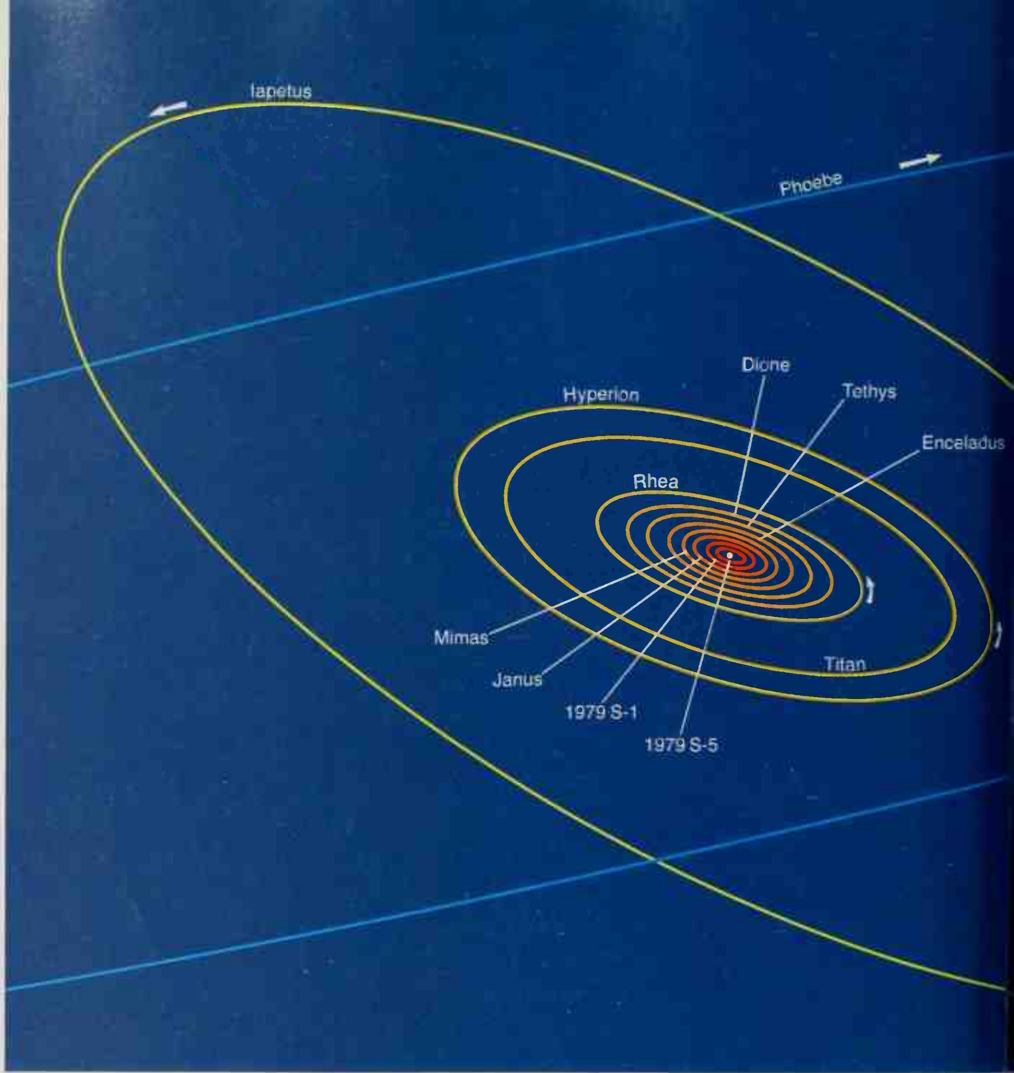
Our journey across space from Jupiter to Saturn has taken us a year and a half, traveling at an average 50,000 kilometers an hour, about the same speed as Voyager 1. Saturn now looms ahead of us, a huge, misty, yellowish globe. Its giant system of rings makes the planet one of the most splendid sights in our Solar System.

Of the planets, Saturn is second in size only to Jupiter. About nine Earths could be lined up along Saturn's diameter. This giant has about 95 times more mass than Earth has, but the mass is loosely packed—more liquid than solid. So Saturn's density is very low, only 70 percent that of water. It is the least dense of the planets, except possibly Pluto.

Saturn's rapid rotation—10 hours and 40 minutes—gives it a big bulge at the equator. There the diameter is 10,500 kilometers greater than from pole to pole. Saturn is the most oblate, or flattened, planet. Jupiter spins faster, but being denser is less "flexible," so it does not bulge as much.

We have now traveled far from the Sun, about 1.5 billion kilometers, but when we look back we still see our local star as a small disk of light thousands of times brighter than our full Moon. Saturn receives only a hundredth of the heat and

Saturn's moons form a mini solar system. Tiny Phoebe's tilted, retrograde orbit suggests it's a captured asteroid. A deep atmosphere makes Titan, largest moon of any planet, a prime target for exploration. There are signs that an "asteroid belt" of moonlets orbits between Titan and Rhea.



light that we do on Earth. It is extremely cold at Saturn's cloud tops, although deep below them the temperature soars.

We are so far from home now that radio signals take about one and a half hours to reach Earth, and replies from our mission control take just as long to get back. If we needed Earth's advice on something likely to happen in two hours, we would have to do without; the reply to our question would reach us an hour too late to be of use.

Saturn's magnetic field

At about a million kilometers from Saturn we meet the planet's powerful magnetic field. A thousand times stronger than Earth's, this magnetic "bubble" pulses in and out with the changing force of the incoming solar wind. As with Earth and Jupiter, Saturn has radiation belts—charged solar wind particles trapped by the planet's magnetic field. If we entered these belts unprotected, the radiation would sizzle us.

The closer we come to Saturn, the bigger the sprawling ring system appears. It is so huge now that it fills the sky. From one outer edge to the other the rings stretch 279,000 kilometers, nearly three-quarters the distance from Earth to the Moon.

"Saturn has ears"

Galileo saw Saturn's rings through his telescope in 1610. Probably he was the first person to do so, but he could not see them clearly and reported them as mystifying blobs. "Saturn has ears," he wrote. In 1656 the Dutch astronomer Christian Huygens identified the "ears" as a ring.

At first, astronomers supposed that Saturn had only one large ring. But in 1675 the Italian astronomer Giovanni Cassini spotted the gap between the A and B rings. It is now called the Cassini Division. Then in 1850 others discovered the C Ring, also known as the Dusky Ring or Crepe Ring. Its particles are so thinly spread that we can see right through it.

Saturn's ring story seems to have no end. The bold little spacecraft Pioneer 11 discovered at least one more ring, the F Ring, and scientists continue to search for signs of suspected rings D, E, and G.

Saturn's rings seem to be lumps made mostly of ice. Some astronomers think these chunks are the size of golf balls or smaller. Others say they may be as big as beach balls or even boulders. Pioneer 11 swept below the rings and back up again without harm. But the spacecraft did report being struck at least four times by what may have been ring particles.

Pioneer had been ticking off a high radiation count, but when the spacecraft passed under the rings, the count fell off sharply. The radiation was lower than that which Pioneer had experienced on the launching pad at Cape Canaveral. This surprise showed that Saturn's rings are a very good radiation shield.

In 1979 the Pioneer spacecraft gave us a vista (below) we cannot see from Earth—Saturn's rings, sunlit from behind. The F Ring and a small moon, both found by Pioneer, appear in the upper right corner. The B Ring blocks out light, forming the wide dark band opposite the moon Tethys.

How Saturn's rings formed is still a mystery. The ring fragments may be leftover matter that did not collect into a moon-size body when the Solar System formed. Or they may be the remains of a moon that wandered in too close to Saturn and was torn apart by the planet's gravitation.

Ammonia ice and a hydrogen sea

As we circle Saturn we see that its yellowish-white cloud deck is banded, like Jupiter's. But the activity in Saturn's clouds is much quieter. Like Jupiter, Saturn has an atmosphere mostly of hydrogen and helium, along with some methane. At -180°C, Saturn's upper clouds are too cold for ammonia to exist as a gas. We would find ammonia ice crystals there.

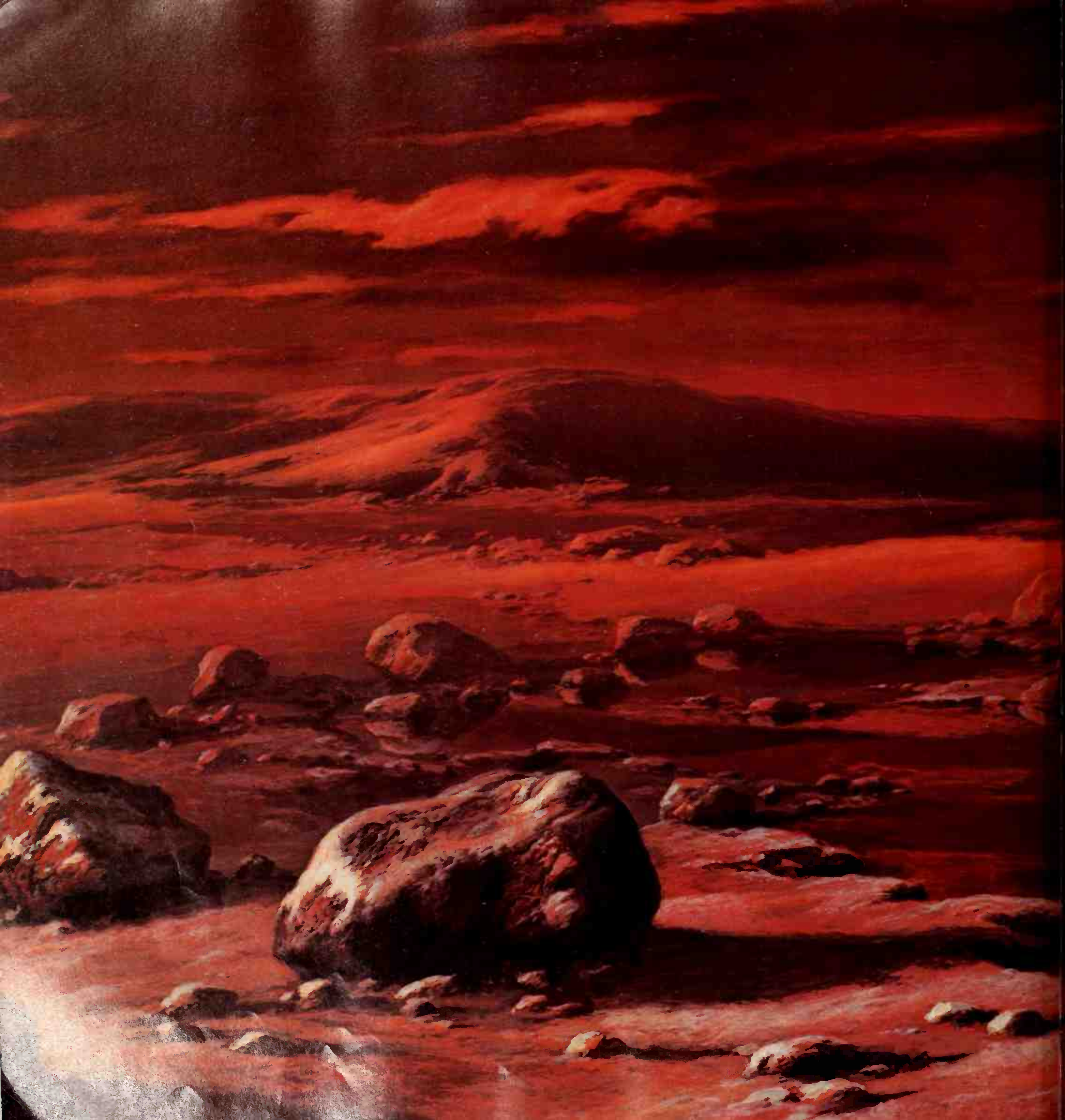
Saturn's very low density means that it must be mostly a big ball of gas. What lies beneath the clouds? In the intense pressures there, gases would liquefy. Possibly an ocean of liquid hydrogen surrounds a rock-metal core. Saturn's core might be no more than twice as big around as Earth is.

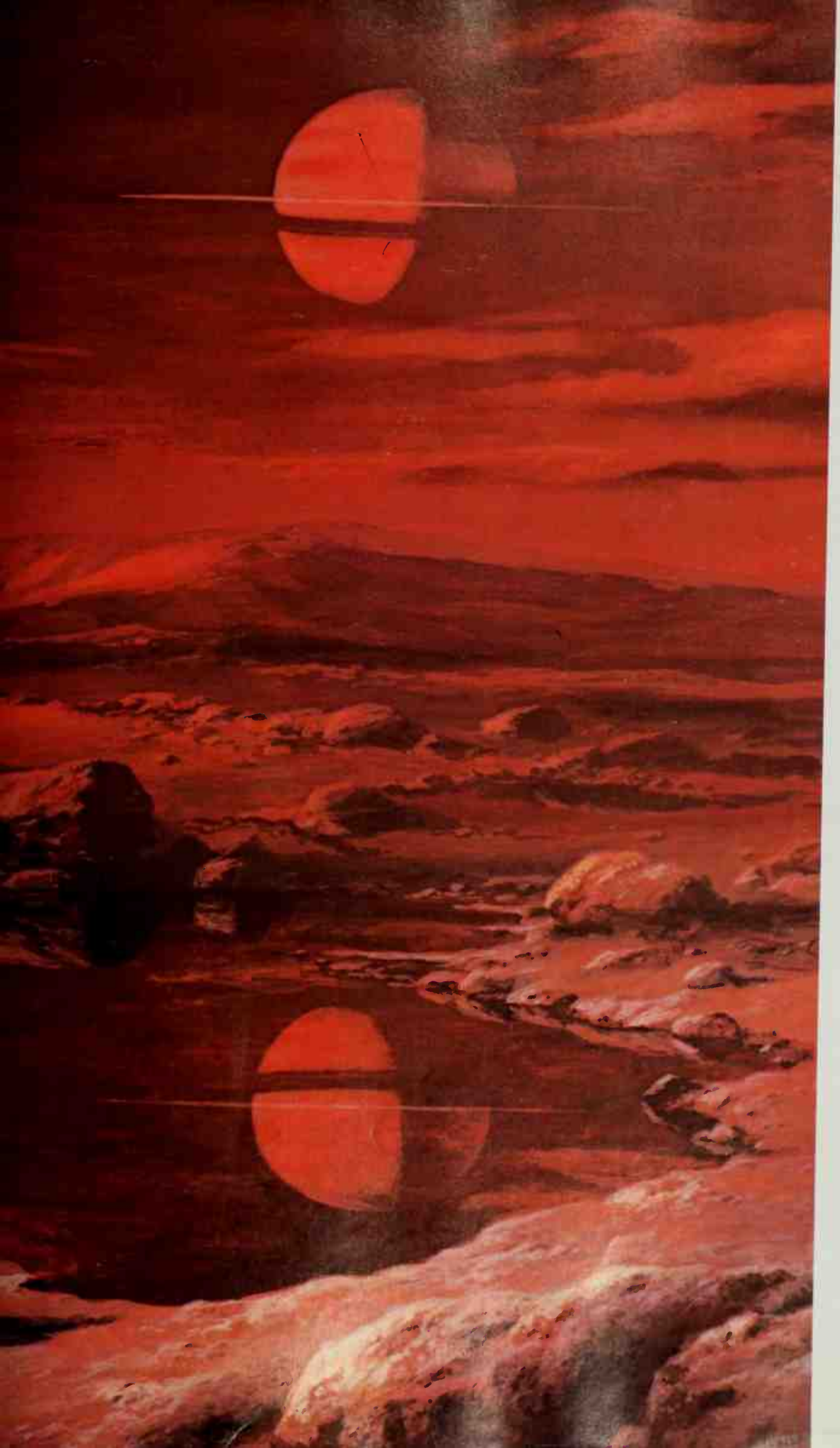
Titan—king of moons

Saturn's many moons range in size from moonlets less than 200 kilometers wide to giant Titan, whose diameter is about 5,800 kilometers—more than Pluto or Mercury.

Titan is special. It is the only satellite in the Solar System with a deep atmosphere. Pioneer's pictures of Titan show a murky orange cloud cover. The clouds are heavy with methane, the same chemical that forms marsh gas on Earth. Atmospheric pressure at Titan's surface, although low, is probably higher than on Mars. This means that, among all the worlds we know, the thickness of Titan's atmosphere is most like Earth's.

Although Titan is big, its density is so low that the whole moon may be more ice than rock. One scientist has even imagined





Visitors to Titan will find cold weather, perhaps –140°C. Sunlight seeps through layers of foggy methane, casting dim, reddened light on a land made mostly of ice. Liquid methane might pool on the surface. Perhaps a spaceship could refuel here by using gas from the atmosphere.

volcanoes of ice, spouting "lava" made of ammonia, methane, and water.

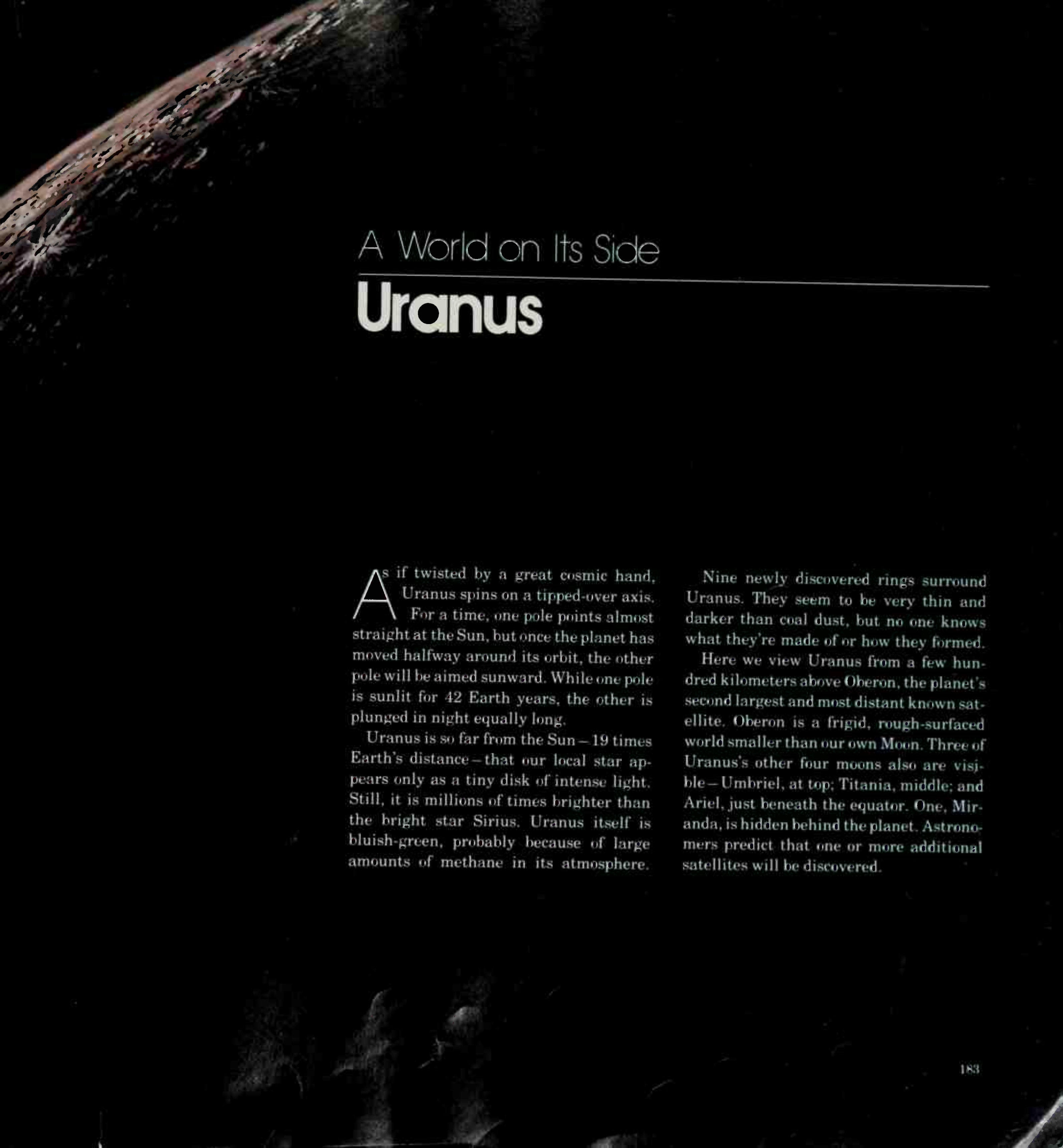
Titan probably revolves with the same face always turned toward Saturn, so its day lasts as long as one complete orbit – almost 16 Earth days. But under the smoggy atmosphere even the daylight half of that period may be very murky.

Could there be life on Titan? Like Earth, it has an atmosphere, a solid (or liquid) surface, and organic chemicals. It is far outside Saturn's deadly radiation belts. Unlike Earth, however, the cloud tops on Titan are a frigid –200°C. It is probably warmer at the surface, but still far colder than Antarctica. Earth life depends on liquid water. Titan's water is frozen. There may be liquid methane on Titan, and life based on methane may not be impossible – but biochemists think it very unlikely.

With luck we may find out, for Titan should be easy to land on. Its gravity is only two-thirds that of our smaller but denser Moon, and its atmosphere would help brake an incoming spacecraft.

Titan is at least three times the width of Saturn's next largest moons, Rhea and Iapetus. Iapetus has puzzled astronomers for years because one side of it shines more brightly than the other. An undetermined number of small moons orbit very close to Saturn, just outside the rings. Farthest of all the moons is lonely Phoebe, 13 million kilometers out. Because Phoebe alone revolves backwards, one astronomer wrote:

Phoebe, Phoebe, whirling high
In our neatly plotted sky,
Phoebe, listen to my lay,
Won't you swirl the other way?



A World on Its Side

Uranus

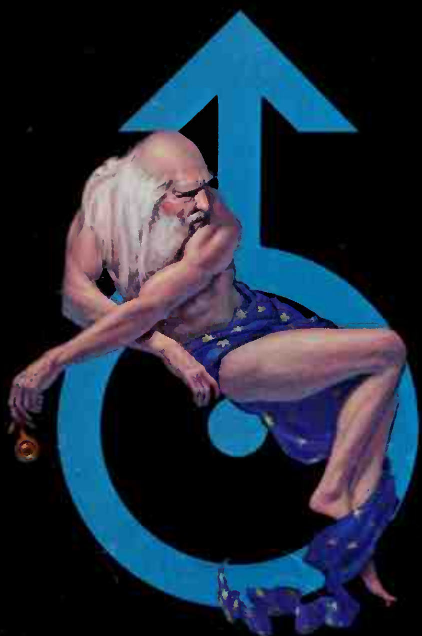
As if twisted by a great cosmic hand, Uranus spins on a tipped-over axis. For a time, one pole points almost straight at the Sun, but once the planet has moved halfway around its orbit, the other pole will be aimed sunward. While one pole is sunlit for 42 Earth years, the other is plunged in night equally long.

Uranus is so far from the Sun – 19 times Earth's distance – that our local star appears only as a tiny disk of intense light. Still, it is millions of times brighter than the bright star Sirius. Uranus itself is bluish-green, probably because of large amounts of methane in its atmosphere.

Nine newly discovered rings surround Uranus. They seem to be very thin and darker than coal dust, but no one knows what they're made of or how they formed.

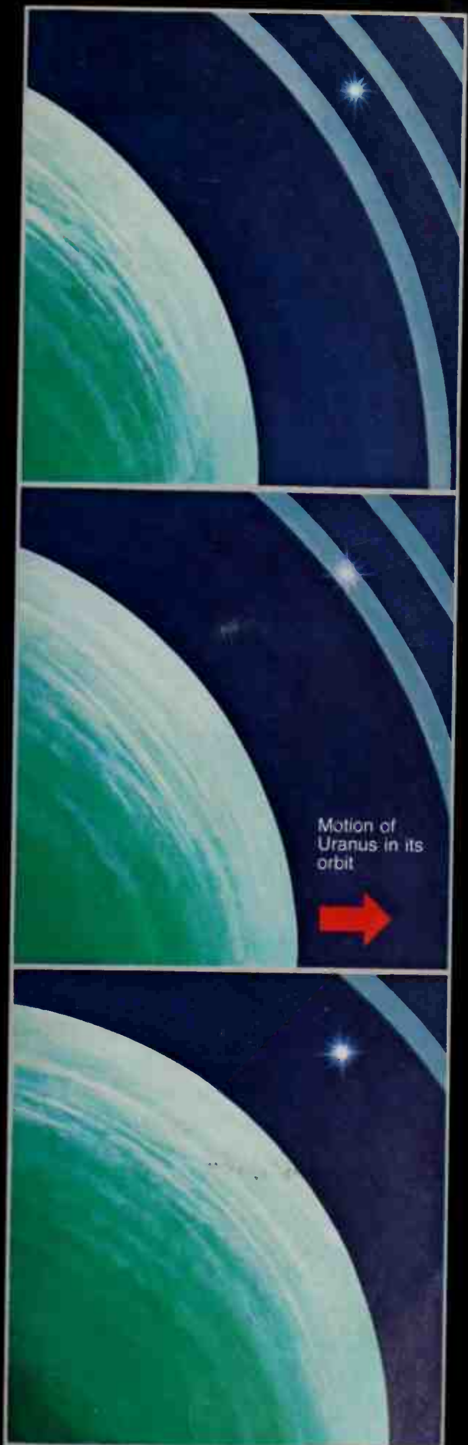
Here we view Uranus from a few hundred kilometers above Oberon, the planet's second largest and most distant known satellite. Oberon is a frigid, rough-surfaced world smaller than our own Moon. Three of Uranus's other four moons also are visible – Umbriel, at top; Titania, middle; and Ariel, just beneath the equator. One, Miranda, is hidden behind the planet. Astronomers predict that one or more additional satellites will be discovered.

Facts about
Uranus

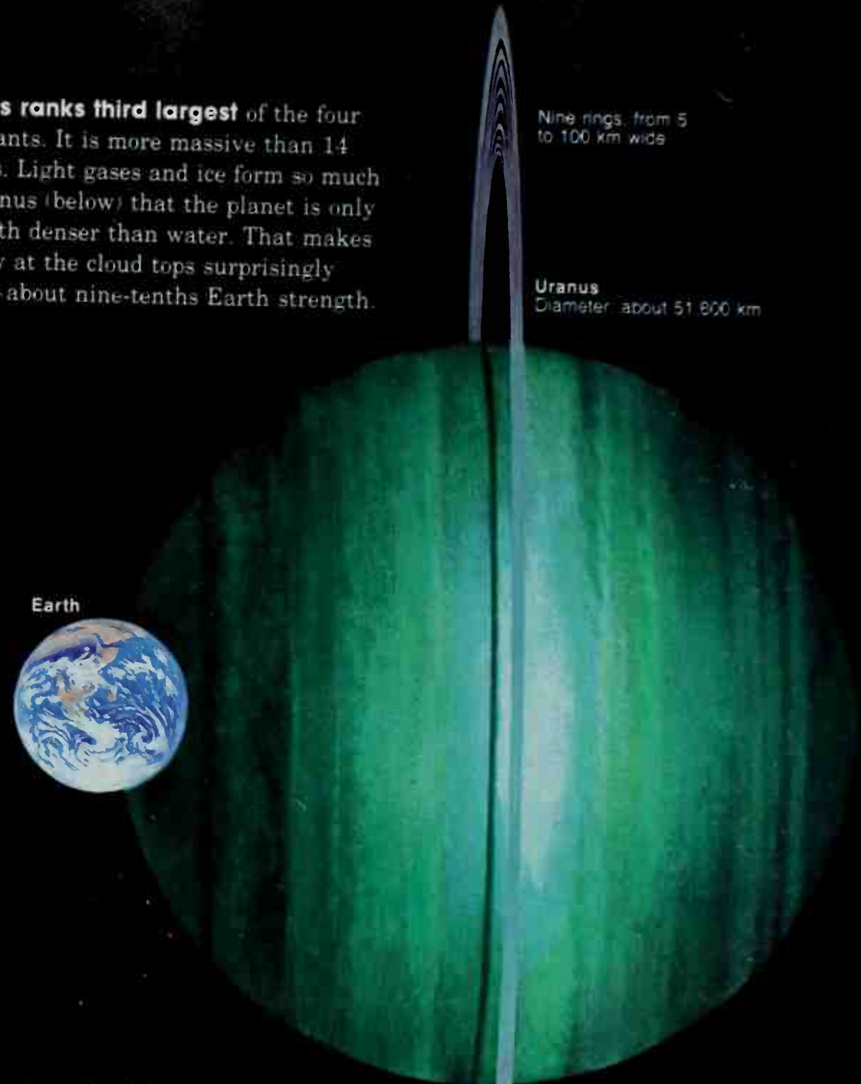


Astronomers named the seventh planet for the old Roman god Uranus—father of Saturn and grandfather of Jupiter. Symbol: ⛢, from a sign for the metal platinum.

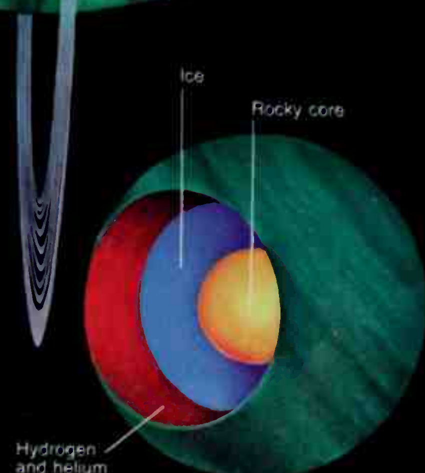
Like a lazy green giant with five gray dwarfs, Uranus and its known moons tour our Solar System on their sides. As the planet orbits the Sun, its tipped-over axis stays aimed in the same direction—just as your foot keeps pointing forward on a revolving bicycle pedal. Here you see the Sun above the north pole; Uranus spins with one side in endless day, the other in night. But when Uranus reaches the top of our diagram, sunlight strikes it sideways, giving day and night from pole to pole. And a quarter-orbit later only the southern hemisphere sees light.



Uranus ranks third largest of the four gas giants. It is more massive than 14 Earths. Light gases and ice form so much of Uranus (below) that the planet is only one-fifth denser than water. That makes gravity at the cloud tops surprisingly weak—about nine-tenths Earth strength.



A peekaboo star led to the discovery of Uranus's rings (left). In 1977 Uranus was due to pass in front of a faint star, and scientists aimed their telescopes to watch. As the space between planet and star grew smaller, the star seemed to flicker—five times. Then Uranus covered it. When the star reappeared, it winked again . . . five times. The watchers had seen five rings. As each ring went by, it blocked out the star—just as a distant streetlight seems to blink if you pass your outspread fingers across it. Later searches found four more rings. All nine are dark, thin, and narrow.



"I perceived the visible planetary disk as soon as I looked at it," William Herschel wrote of his discovery of Uranus in 1781. His drive to examine the stars led him to build his own telescopes, among the best of the day. His sister Caroline and son John became famed astronomers as well.

Our view of space

Sped on our way by Saturn's gravity, we set course for Uranus across the vastness of interplanetary space. The Solar System is mostly empty space, we discover. So great is the distance separating Uranus from Saturn that our journey will take us four and a half years. When we arrive at Uranus and send radio messages back to Earth, the exchange of signals will take five hours—two and a half hours each way.

Uranus is about 19 times Earth's distance from the Sun—nearly three billion kilometers away. Yet by the time we reach Uranus we will be barely halfway out of the Solar System.

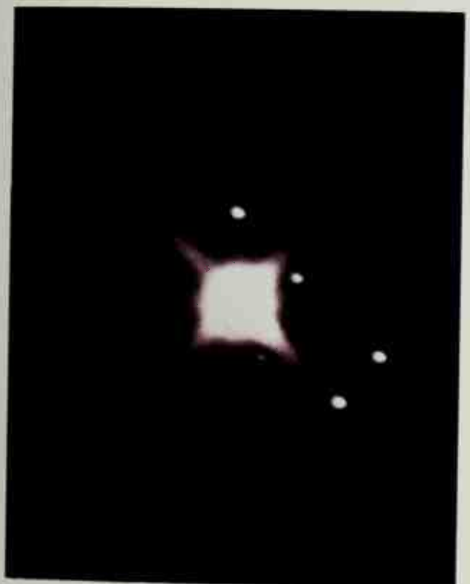
Our view of the planets has changed month by month during our journey, and now we will look back toward the Sun and see it as a barely distinguishable disk, but so bright that it is 1,100 times brighter than a full Moon back home. When we search the sky off toward the outer edge of the Solar System we see a remote dim world, Neptune. But this is a rare view from Uranus. By the time we reach Uranus, it will be just overtaking Neptune. So the two will be nearly side by side for a few years. As Uranus speeds away from Neptune, Neptune will gradually fade from view and remain invisible from Uranus for 148 years. Then Uranus will once again slowly overtake its remote outer neighbor.

The discovery of a planet

Saturn is the outermost planet that we can easily see without a telescope. For that reason, people since ancient times had thought that Saturn marked the outer edge of the Solar System. But on the night of March 13, 1781, in England, William Herschel became the first person in recorded history to discover a planet. Through a telescope he was studying the constellation Gemini. Suddenly he noticed a strange "star" that seemed different from the others. He saw a disk rather than a starlike pinpoint of light. For several nights he studied this mysterious object and eventually saw that it was moving across the background of stars. He thought he had found a comet. Soon astronomers all over Europe were studying Herschel's "comet."

They saw that it moved in a nearly circular orbit beyond Saturn. This was very unlikely behavior for a comet. Finally they agreed that it was a planet. Since Uranus

Five moons go into action in time-lapse pictures of Uranus (overexposed to show the moons). Their orbits align neatly with Uranus's equator. Here we see the planet pole-on, so the moons trace circles. When the equator faces us, they seem to go up and down, like seats on a Ferris wheel seen from behind. This odd motion was the clue revealing Uranus's wild tilt. Moons of other planets bear names from Greek and Roman myth, but not these; Miranda, Ariel, Umbriel, Titania, and Oberon are characters in writings by William Shakespeare and Alexander Pope.



is twice Saturn's distance from the Sun, its discovery instantly doubled the reach of the Solar System as people then knew it. Herschel wanted to name his new planet the Georgian Star, after England's King George III; other astronomers called the planet "Herschel." But it was the German astronomer Johann Bode who suggested the mythological name that finally won general acceptance—Uranus, father of Saturn and god of the heavens.

Some astronomers said that Herschel discovered the planet accidentally. He denied this, saying: "It has generally been supposed that it was a lucky accident that brought this star into my view; this is an evident mistake. In the regular manner I examined every star of the heavens, and it was that night its turn to be discovered."

Uranus and its rings

To the unaided eye, Uranus is a faint gleam. Even with modern telescopes it is hard to make out details of the planet. It turned out to be another gas giant, though much smaller than Jupiter and Saturn. Its spin flattens the planet a bit at the poles and bulges it a bit at the equator. Uranus shines with a blue-green light, evidence that its atmosphere contains methane.

One thing makes Uranus a most unusual planet. It is flopped over so that it lies almost on its side. From Earth we sometimes see Uranus with its north or south pole pointed at us. Then at other times its equator faces us.

As our spacecraft continues toward Uranus, the computers tell us that on a certain date Uranus will cross directly in front of a star and briefly eclipse it. This type of eclipse is called an *occultation*. Astronomers studying Uranus during the March 10, 1977, occultation of the star known as SAO 158687 were in for a surprise. They watched the occultation both from ground observatories and from NASA's Kuiper Airborne Observatory (KAO). The KAO is a C-141 jet aircraft carrying a telescope. The plane can fly high enough in Earth's atmosphere to give its telescope a much clearer view of the stars than telescopes have from the surface.

Thirty-five minutes before Uranus was due to eclipse the star, astronomers on the plane saw a dip in the strength of the light coming from the star. (See the illustrations on page 185.) A few minutes later there was another dip, then three more before

Uranus's rings don't look like Saturn's or Jupiter's; they're like black hoops. One theory proposes that chunks of a former moon may be orbiting very close to Uranus, where gravitation slowly tears them apart. The debris forms rings, each with a gap around its decaying moonlet.

the star disappeared behind Uranus. Could it be that unknown moons of Uranus were briefly blocking the star's light? After the main occultation was finished the astronomers saw five more dips, but in reverse order of the first five. The matching dips told the astronomers that Uranus must have rings.

The mystery of the rings

Astronomers who study Uranus debate about the nature of the rings and how they came to be. (One theory is illustrated opposite.) So far, nine rings have been identified. They seem to be much narrower and to have sharper edges than the rings of Saturn. Seven of Uranus's rings seem to be less than 10 kilometers across. Another may be about twice that width, and another up to about 100 kilometers wide. From one edge to the other, the ring system of Uranus spans about 100,000 kilometers—about one-third the width of Saturn's.

The rings of Uranus may be composed of lumps of dark rock. They lack the icy coating that makes Saturn's rings shine so brightly. But one scientist suggests that Uranus's rings are invisible, that is, that they are made of gas. Another theory says that the rings are horseshoe-shaped with a small, as yet unseen, satellite in the gap of each ring. Some of the rings seem to be nearly circular; others may be highly elliptical and wobble like hula hoops. Still another theory suggests that small satellites orbit on both sides of each ring. Almost all of these theories involve small satellites. Astronomers may someday discover that Uranus has many more than five moons.

What is Uranus like inside?

Uranus seems to be a ball of gas 14 times more massive than Earth but with only one-fifth the density of Earth. A 100-pound Earthling on Uranus would weigh only 90 pounds. The atmosphere seems to be mostly hydrogen, helium, and methane. The temperature at the cloud tops is about –215°C. Unlike Jupiter, Saturn, and Neptune, Uranus seems to give off very little, if any, heat of its own making. What the planet is like below its cloud tops we can only guess. Like Jupiter and Saturn, Uranus may not have a solid "surface." It may have just a soupy ocean of hydrogen. Astronomers have suggested that a journey down through Uranus's atmosphere and to its core might be like this:

Descending through the outermost thin layers of hydrogen, we find the temperature dropping even lower. Then it begins to warm as we pass through methane clouds and into a dense, deep fog of ammonia crystals. Below are clouds of still another kind—water vapor.

Now we are hundreds of kilometers down. Clouds change to slush and then to hot liquid hydrogen. About 8,000 kilometers deep, the temperature has soared above 2,000°C and we enter a layer of slushy or frozen water and ammonia.

At the center of the planet we find a rock-metal core only slightly larger than Earth but estimated to be 7,000°C. This is hotter than the surface of the Sun.

With our next giant step across the Solar System we are in for more surprises, and our sense of the emptiness and loneliness of space grows ever stronger.

Last of the Giants

Neptune

Pale blue Neptune glows phantom-like against the Milky Way. The smallest and the last of the four gas giants, Neptune lies far out in "Solar Siberia," more than 30 times Earth's distance from the Sun. Here we see Neptune from its inner satellite, Triton, about 350,000 kilometers away. Directly behind us the Sun lights Triton's hilltops.

Of Neptune's two known moons, Triton is the closer and the larger, about a third larger than our own Moon. Its rocky surface seems to be covered with methane frost. Haze along the horizon is a sign of Triton's thin atmosphere of methane gas.

Along Neptune's equator a pronounced dark band separates the bright areas of the northern and southern hemispheres. These bright regions may be high-altitude clouds of methane ice crystals.

Because of its great distance from us, Neptune is hard to study, and we still have many questions about the planet: Does Neptune have rings? What about its unusual two moons? Is the outer one a captured asteroid? Some astronomers wonder if Neptune once had more moons—one of which escaped and became Pluto. Why does Neptune, unlike Uranus, radiate more heat than it receives from the Sun?

Facts about
Neptune

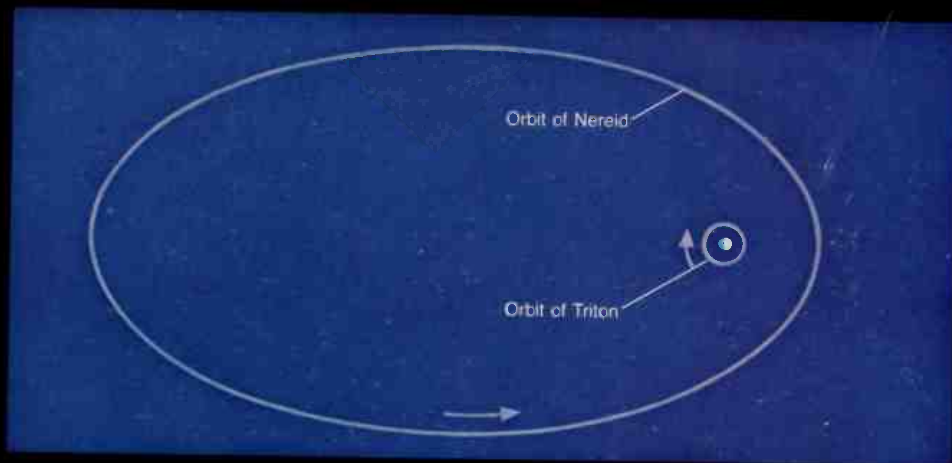
An ocean god for an ocean-colored planet – Neptune, Roman god of the sea. Astronomers use his fishing spear, the trident, for the planetary symbol: ♆

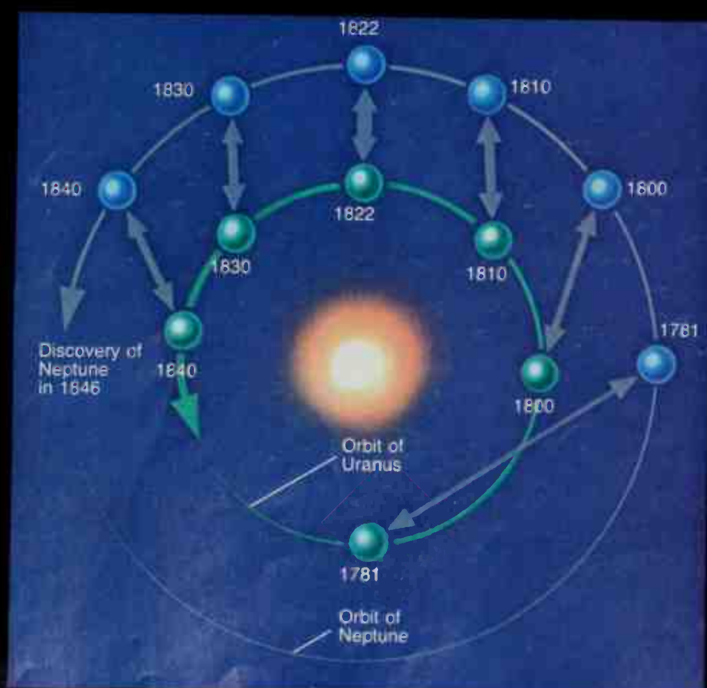
Neptune creeps in its path. Discovered in 1846, the eighth planet will not return to the position where scientists first saw it until 2011. Neptune orbits slowly because it is far from the Sun. We cannot see it without a telescope. In size and color Neptune seems to be a twin to Uranus. But Neptune does not spin on its side; its axis tilts only a little more than Earth's. The orbits of two moons, Triton and Nereid, crisscross the equator diagonally. That's puzzling; more often satellites revolve roughly in line with the equators of the planets they circle.

The smallest gas giant has the mass of 17 Earths and a density two-thirds greater than water. Thus Neptune's surface gravity is actually stronger than that of larger but less massive Uranus.

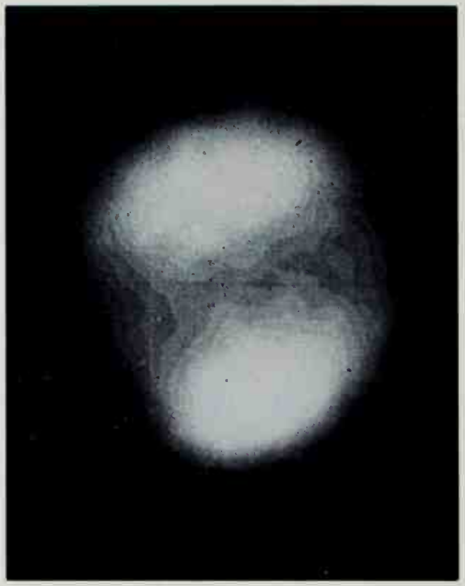
How to find an "invisible" planet? From a hidden source gravitation was pulling at Uranus (right), moving it along its orbit faster than expected. But farther on, Uranus slowed; the mystery planet now tugged from behind. Telescopes searched the likely area. Sure enough—Neptune!

The odd couple—Neptune's puzzling moons (below) don't act like any other planet's. Nereid, only 300 km wide, follows the most elliptical path of any satellite. It needs an entire Earth year to complete one orbit. Triton, a giant perhaps 5,000 km across, takes less than six days to circle Neptune—backwards. No other large satellite moves opposite to the direction in which its planet spins. Some scientists think ancient Neptunian satellites might have collided, throwing some moons out of orbit and leaving the two we see today in their strange courses.





A rare weather report from Neptune appears in this 1979 picture from the University of Arizona's observatory. A dark equatorial belt of methane gas separates two zones of methane ice crystals. This was the first photograph of distinct features on the planet's disk.



Above Neptune's misty cloud tops, the giant moon Triton eclipses a snowflake Sun. Triton, already nearer Neptune than our Moon is to us, is spiraling inward inch by inch. Eons from now, if it drifts too close, Neptune's gravitation may break Triton up into a huge ring.

The newly discovered planet Uranus was behaving in a strange manner. Instead of orbiting the Sun smoothly, it sometimes sped up and at other times slowed down along its path. Why?

The Solar System grows

The year was 1841. John Couch Adams, a college student in England, read a report about Uranus's odd motion. Was it possible, as astronomers were suggesting, that an unknown distant planet was tugging at Uranus and so causing it to move unevenly? Adams was fascinated and decided to study the matter after he graduated from Cambridge University.

By September 1845 Adams had calculated the orbit of the suspected planet and pointed out the place in the sky where the planet should be found. He presented his work to the Royal Observatory in Greenwich, but no one took him seriously. Meanwhile other astronomers had joined the search. In France, Urbain Leverrier also worked out the new planet's orbit. On September 23, 1846, the planet was sighted in the place where Adams and Leverrier had said it would be. It was the first time a planet had been found by mathematics. Adams and Leverrier share the credit.

Before Neptune's discovery the known Solar System stretched out to almost 20 times Earth's distance from the Sun. The new planet increased the span to 30 times.

Rings around Neptune?

Through a telescope on Earth, Neptune appears as a faint bluish-green disk two-thirds the size of Uranus. Actually it is nearly the same size but much farther away. Four Earths could be lined up across Neptune's diameter. The planet is about 17 times more massive than Earth. A Neptune year is 165 Earth years. It is hard to make out "landmarks" on Neptune so we are not sure how fast it rotates, but a Neptune day may be only 18 hours long.

Soon after Neptune was discovered, at least two astronomers reported sighting rings. In recent years when rings were found around Jupiter and Uranus, astronomers again began wondering whether Neptune might also have rings. Telescopes have not yet detected any, but they have seen cloud movements, which means that the planet has weather patterns.

Astronomers now regard Neptune and Uranus as twin planets, somewhat alike in size, density, mass, and rotation. In all physical respects except size they closely resemble Jupiter and Saturn.

What is Neptune like inside?

We can make some intelligent guesses based on our knowledge of the planet's mass, density, and size, and on recent photographs taken through telescopes. Neptune's upper atmosphere may be made up mostly of hydrogen but also seems to contain helium, methane, and other gases. The cloud-top temperature is a frigid –200°C. The atmosphere probably consists of a thin layer of methane clouds and below that a layer of ammonia clouds that "snowed out" of the upper air. These cloud layers are the outer edge of a layer of liquid hydrogen that may be 8,000 kilometers deep and rest on an equally thick mantle of ice. This may be water ice mixed with ammonia ice, but no one knows for sure. Neptune's core may be a ball of rock-iron material slightly larger than Earth, with a temperature around 7,000°C.

Neptune's larger moon, Triton, has a thin methane atmosphere, thinner than Mars' air and too thin to form clouds. But some of its gases may freeze out as frost on Triton's dark side and at its polar regions, where the temperature is –230°C.

We now know that Neptune emits more energy than it receives from the Sun. But how? Probably Neptune's heat source is the same as that of Jupiter and Saturn: Matter packed in the core region when the planet was forming still gives off heat that wells up and is radiated away at the planet's cloud tops.

A Double Planet?

Pluto

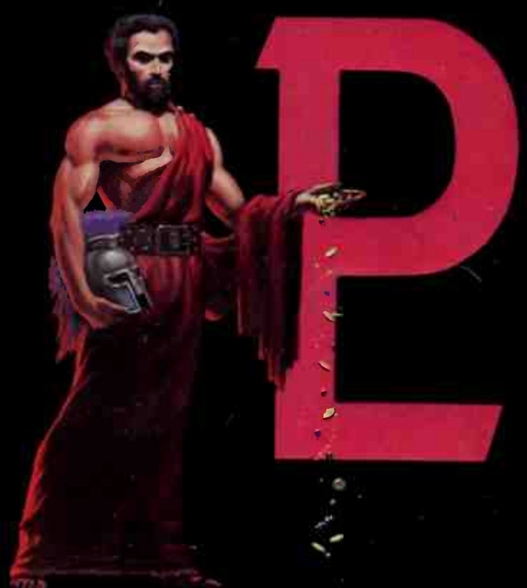
The planetary sentinel stationed at the distant border of the Solar System, Pluto is almost 40 times farther from the Sun than Earth is. We view Pluto from its icy and pitted companion Charon. Only recently discovered, Charon is believed to be about 1,200 kilometers in diameter and orbits about 20,000 kilometers from Pluto's icy crust. Here Pluto, in thin crescent phase, is dimly lit by the distant Sun, the bright point of light at lower right, as the night side of the planet glows feebly in light reflected from Charon.

Pluto is not much more than twice the size of Charon. Both are so small and so far away from us that they are hard to study with even the best telescopes. Both planet and satellite seem to wear a coating of methane ice, but astronomers do not know what the interiors are like.

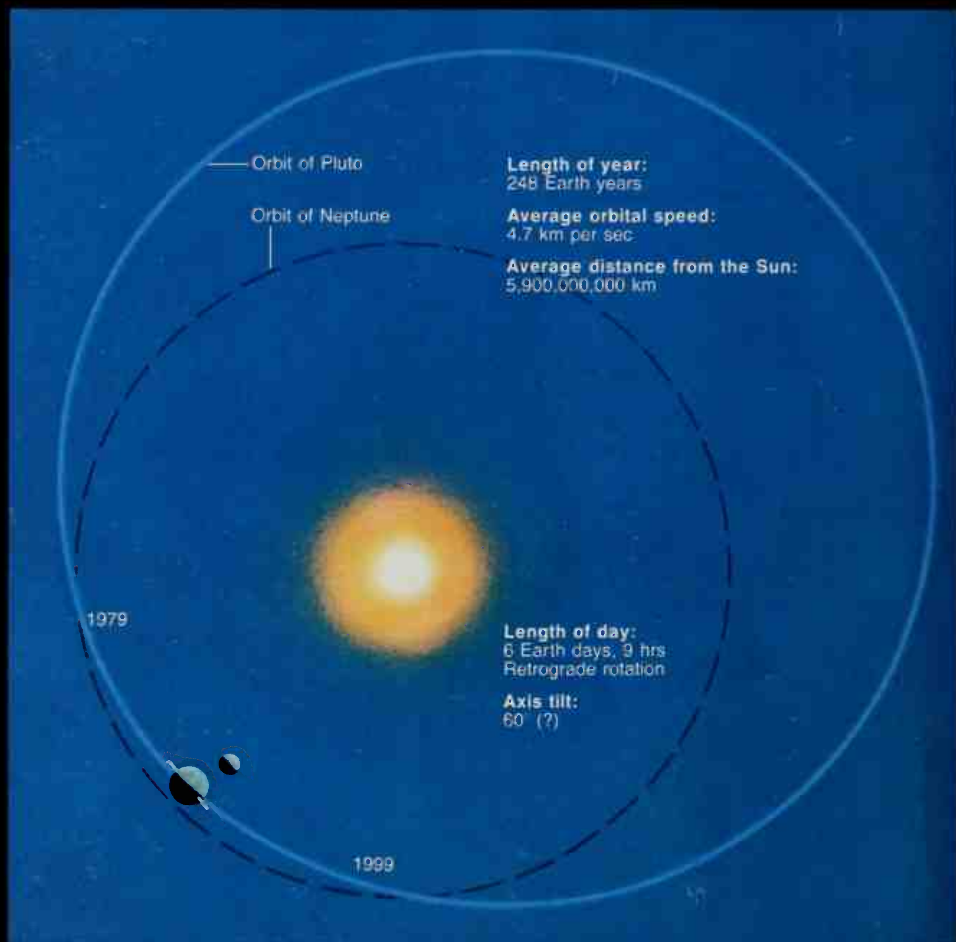
Is it possible that Pluto and Charon are remains of a shattered moon once belonging to Neptune? Or might Pluto and Charon be lumps of matter almost unchanged from the time the Solar System formed?

The closeness and similarity in size of Pluto and Charon make some astronomers consider them a double planet rather than a planet with a satellite. Others doubt that Pluto is a planet at all.

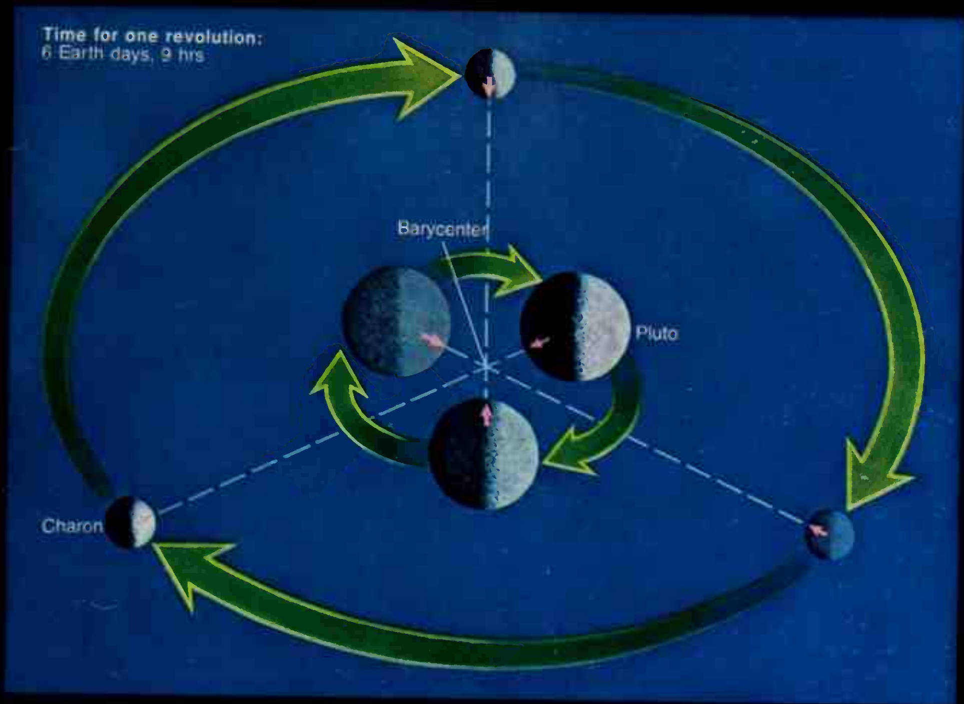
Facts about
Pluto



Greek god of wealth, Pluto ruled the dark underworld of myth. Now the darkly lit outermost world bears his name. The "Pl" of Pluto is the planet's symbol: ♇



Last and least, tiny Pluto follows the most elliptical orbit of any planet. It ranges between 4.4 and 7.4 billion km from the Sun. From 1979 to 1999 Pluto will actually lie closer than Neptune. The last time that happened, about one Plutonian year ago, George Washington was in his boyhood. Will Pluto ever hit Neptune? No; Pluto's orbit tilts, missing Neptune's, and the planets always pass when far apart. The large size of Pluto's moon, known as Charon, may qualify Pluto as a double planet; the two are close neighbors as well (right).

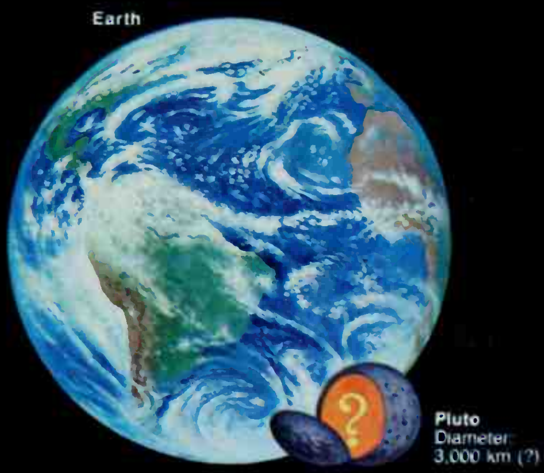


Pluto and Charon appear to spin like two twirling dancers, one light and one heavy. Just as the lighter dancer whirls in the wider circle, so Charon revolves farther from the balance point, or barycenter, than more massive Pluto. Each keeps the same side to the other.

A riddle—Gravity, maybe 4 percent of Earth's. Density, less than ice. Mass, about one-sixth of our Moon. Core, unknown. Pluto's small size (below), low mass, and odd orbit make some scientists ask if this seeming ball of frozen gases really is a planet. But if not, what is it?

Discovery of Charon—In 1978 a photo like the one above puzzled astronomer James Christy. Why was Pluto bulging?

Then he decided he had found a moon, about 1,200 km wide, so close to Pluto that the telescope blurred them together.



Two pictures of the same star field, taken days apart, led to Pluto's discovery in 1930. Clyde Tombaugh used a device that flashes quickly from one such photograph to the other. If anything has moved—such as a planet—it blinks. He flashed pictures for months before Pluto winked at him.

Stuck in eternal moonrise, Charon hangs in the Plutonian sky as if frozen by the –230°C cold. A pinpoint Sun, intensely bright, glints on a field of methane ice. Since Charon and Pluto probably spin locked face to face, the big moon seems always to hover over the same place.

Something still seemed wrong. Not only was Uranus not staying on schedule as it orbited the Sun, but Neptune also seemed to be out of step. Could a ninth planet be tugging on Uranus and Neptune from the far reaches of the Solar System? In the early 1900's, one astronomer who thought so was Percival Lowell. He devoted his life to looking for what he called Planet X.

Lowell did not live to see his planet. But in 1930, Clyde Tombaugh, a young assistant at the Lowell Observatory in Arizona, was continuing the search. After months of tedious work he found Planet X. The name of the Greek god Pluto fit the new discovery especially well, since it began with the initials of Percival Lowell.

A cold little world

Some scientists think they may have detected a thin atmosphere, but the planet seems to be only a snowball of frozen gases, not massive enough to affect either Uranus or Neptune. Probably their orbits were measured inaccurately. It was thus a great coincidence that Pluto was where Lowell had predicted it to be.

From Pluto, the Sun is a tiny point of light but, for the next few decades, a point about 440 times brighter than the full Moon from Earth. Temperatures hover only a little above *absolute zero,* the point at which there is no heat at all and molecules stop moving completely.

In 1978 James W. Christy, of the U. S. Naval Observatory, discovered that Pluto has a moon. He called it Charon, after the mythical boatman who ferried souls across the river Styx into the Greek underworld.

Should Pluto be called a planet?

A number of things about Pluto make astronomers wonder if it is a true planet. For one thing, there is the unusual, stretched-out orbit; it tilts sharply from the orbits of the other planets, and it crosses Neptune's path. Nowhere else in the Solar System does the orbit of one planet cross that of another. Pluto's small size—about the same as our Moon—also is unusual. And finally, as a world of frozen gases, it seems to resemble some of the outer planets' moons.

Could Pluto be an escaped moon of Neptune? Some astronomers think so. Long ago a large planet may have swept in close to Neptune. Its gravitation could have pulled Pluto away, flinging it into its long elliptical orbit around the Sun and breaking off a piece that became Charon.

But what happened to the intruder planet? Is it possible that the mystery world might be Planet Number 10 in the Solar System? Some astronomers speculate that the near miss with Neptune threw it into an orbit far from the Sun, and that it is out there somewhere, too dim to see from Earth. But so far there is no evidence for it.

In 1977 at Mount Palomar Observatory, Charles Kowal discovered an object out beyond Saturn. At first he thought it might be Planet 10, but it turned out to be a small world like the outer moons of Saturn and Uranus. Called Chiron, this minor planet also has a stretched-out orbit, one that takes it across Saturn's path.

It is tempting to think that both Pluto and Chiron are escaped moons but there is a much more likely possibility: Pluto, Charon, and Chiron could be leftovers from the Solar System's formation some 4.6 billion years ago. For some reason the giant planets never scooped them up. They could be museum relics, and in their frozen landscapes may lie secrets from the age when the Sun and planets took shape.

Snowballs in Space

The Comets

A giant beam shining out of the dark, a long-tailed comet passes Earth and our Moon on its way around the Sun. Sunlight and the solar wind keep a comet's tail always pointed away from the Sun, so when the comet leaves the inner Solar System, it will speed away tail first.

Here both Earth and the Moon are lighted not by the comet—which gives off little light of its own—but by the Sun.

People of old were terrified when a comet came this near Earth. They believed that comets brought earthquakes, wars, and famine. They feared that gases of the tail would poison them.

A comet's solid nucleus is hidden within its surrounding gas cloud. The cloud is blown out into two tails—a whitish one made of tiny particles that have been freed from the ice-ball nucleus as the ice heats and vaporizes, and a bluish one made of electrified gases including carbon monoxide, water vapor, and nitrogen.

Some comets travel through the Solar System and do not return for a thousand years or more. Where do they come from? Where do they go? "Comet dust," analyzed by scientists, seems to be more than 4.5 billion years old. Are comets part of the original matter of our Solar System?

Facts about

Comets

Most comets are named after their discoverers. Ikeya-Seki honors Japanese amateur astronomers Kaoru Ikeya and Tsutomu Seki. Halley's Comet recalls England's Edmund Halley. Caroline Herschel of England discovered eight comets between 1786 and 1797.

Tangling the Solar System with orbits, comets zip past the Sun, each at a frequency called its period. Encke has the smallest orbit, thus the shortest period: 3.3 years. Kohoutek, seen in 1974, may not be back for a million years or more. First it will loop far out toward the Oort Cloud, a vast region of widely separated comets. The comets we see originated there. If one breaks up in its travels, the pieces string out along its orbit, in a comet group. One group, the sun-grazers, passes within a Sun's diameter of the solar surface.

A comet begins as a nucleus of frozen gases and dust less than a hundred kilometers across. When near the Sun, its heated gases spread in a cloudlike coma and stream away from the Sun as a gas tail. Dust is forced out into a second tail by the pressure of sunlight.

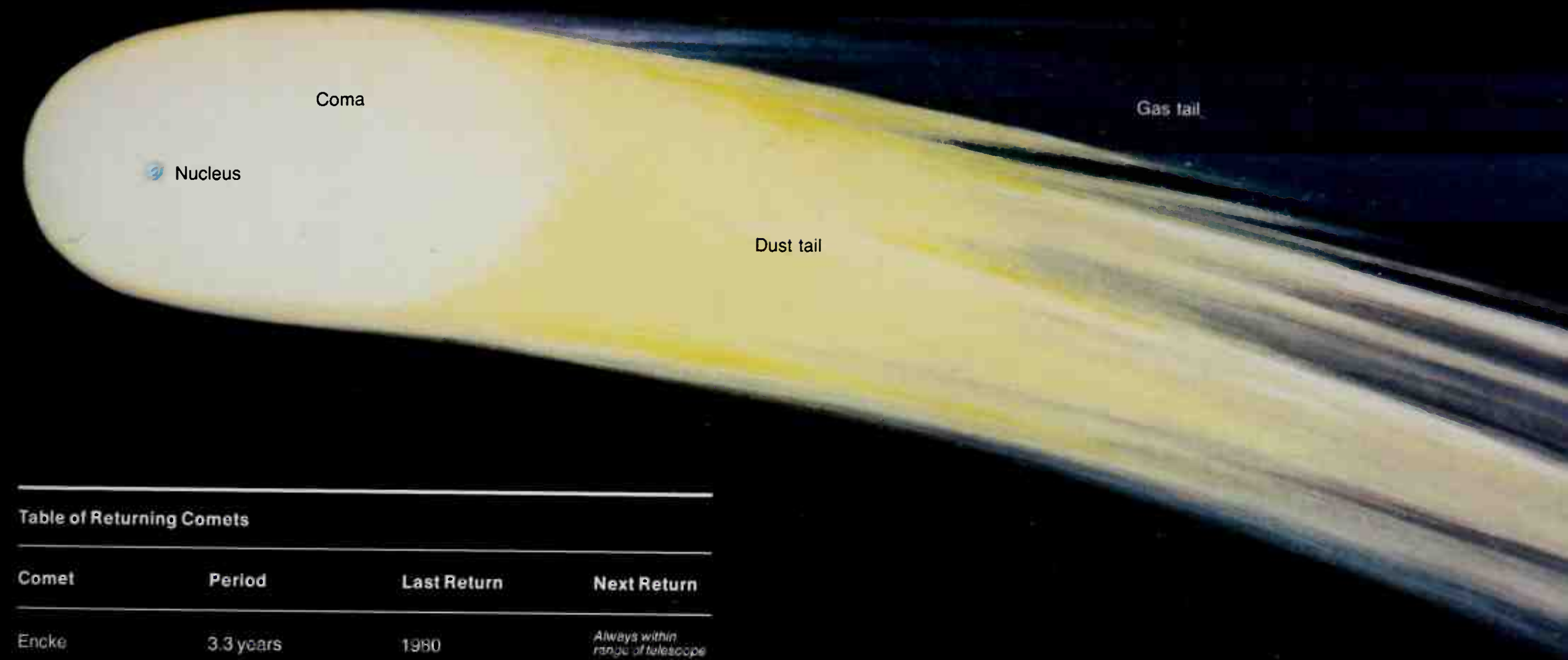
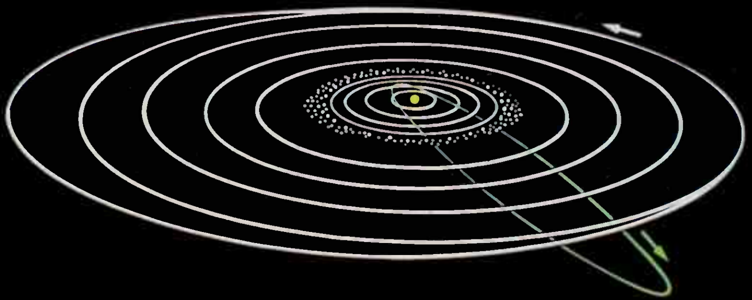


Table of Returning Comets

Comet	Period	Last Return	Next Return
Encke	3.3 years	1980	*Always within range of telescope*
Tempel 2	5.3 years	1978	1983
Holmes	7.1 years	1979	1986
Faye	7.4 years	1977	1984
Halley	76 years	1910	1986



Orbit of Halley's comet

A comet's period is like a planet's year: the time it takes to complete one orbit. But each time a comet approaches a planet, its orbit may be changed by the planet's gravitational pull. Many comets are eventually pulled close to the orbit of giant Jupiter—and there they stay.

Halley's Comet returns to our view about every 76 years on a long orbit that tilts some 18° from Earth's orbital plane. On each pass, the Sun melts away some of its material and the pull of the planets shrinks its orbit slightly. Soon the comets may have company: a space probe (see p. 257).

On clear nights, you may see it—a wedge of light in the west after sunset, or in the east before dawn. Since this glow lies in the zodiac, we call it zodiacal light. It is really sunlight, caught by billions of dust motes orbiting the Sun—dust most likely from comets and asteroids.

In 1965 the Sun-grazing comet Ikeya-Seki lighted the sky for months. Here it heads outward, a 120-million-km brush stroke across the stars. Sunlight and solar wind push the tail ahead as a gale would blow a girl's long hair from behind. "Comet" is from the Greek kometes: *"long-haired."*

Some people of ancient times believed that a comet blazing through the sky was the soul of a hero or a king on its way to heaven. Others thought that comets were messengers of widespread disease and doom. They called comets "terrible stars" or "death-bringing stars." Until fairly recent times, superstitious people feared that the tails of comets were made of evil gases and that if Earth passed through a comet tail all life would surely die. When Earth swept through the splendid tail of Halley's comet in 1910 (with no noticeable effect), enterprising merchants sold "comet pills" as protection against disaster.

One present-day writer has described comets as "about as close to nothing as something can get." And another has said that comets are "a visible nothing."

What comets are made of

They are like "dirty snowballs," says astronomer Fred L. Whipple, collections of rocky matter and dusty ice. The solid part of a comet is called the *nucleus*. It may contain empty pockets, as a sponge does. Whipple thinks of the comet nucleus as a weak crust of rock dust wrapped around a ball of icy matter.

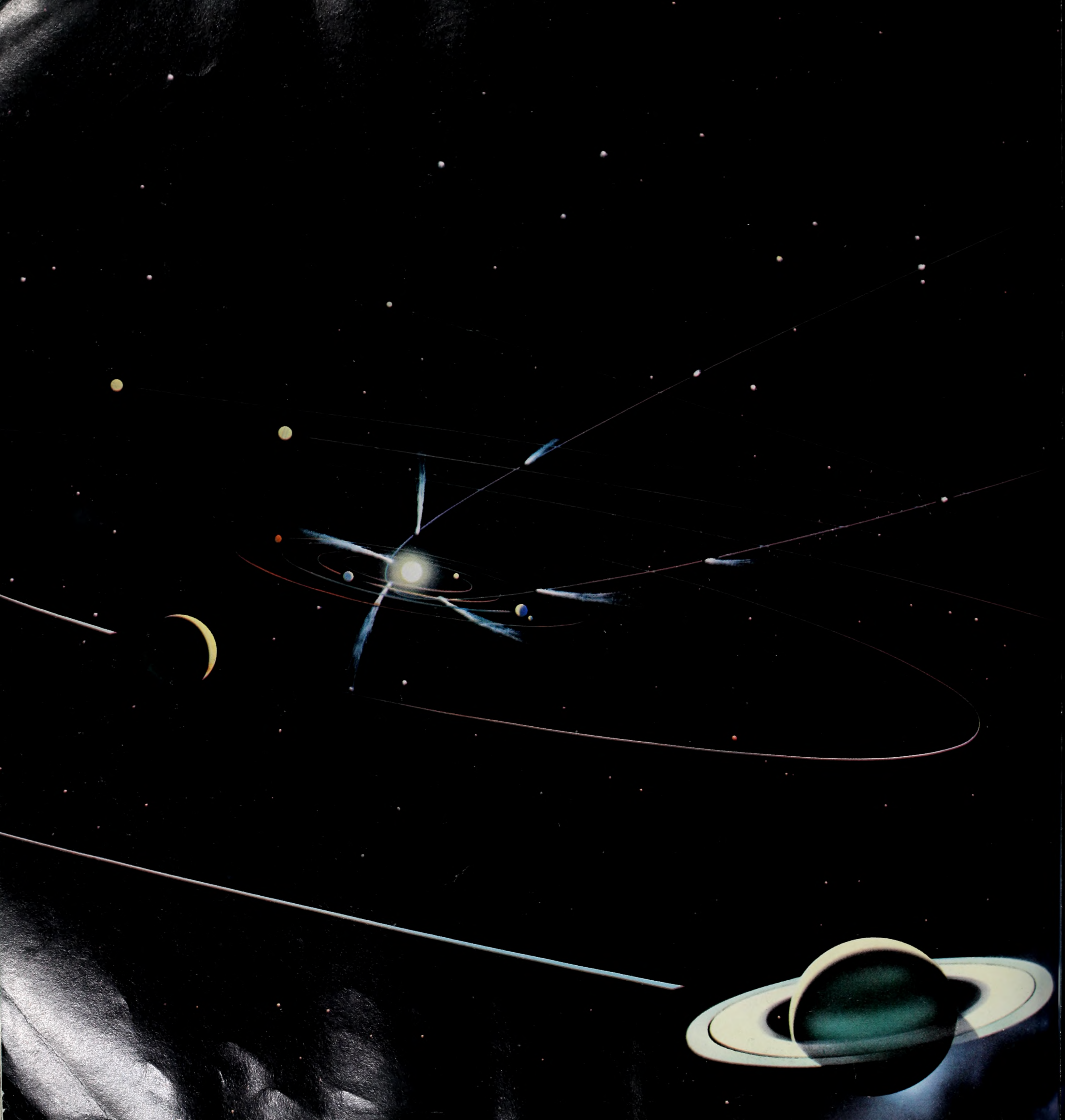
When a comet sweeps in near the Sun, heat boils off the ice, making a gas cloud. This cloud encloses the comet in a misty cocoon called the *coma*. The nucleus of a comet may be anywhere from 100 kilometers across to less than one kilometer in diameter. But the coma may reach out great distances, sometimes more than one million kilometers.

When we look at a bright comet, we can sometimes see that its tail has two distinct parts. Each is pushed out from the coma by a different process. The yellow part—the *dust tail*—gets its color because sunlight reflects off the dust grains. It is smooth and curved. The pressure of sunlight photons pushes out this part of the tail. The streaming solar wind pushes out electrified atoms (ions) from the coma and forms the *gas tail*, often known as the *ion tail* or *plasma tail*. Some of these ions are carbon monoxide, and glow with a blue light. The ion tail may contain kinks or twists. Because of this pushing action of the Sun, the tail of a comet is always kept pointing away from the Sun.

Parents and daughters

When the frozen matter of the nucleus evaporates, the material breaks down into what scientists call "daughter products of the parent molecules." The coma and ion tail of a comet are made up almost entirely of daughter particles, since the parent molecules are broken up deep inside the coma, close to the nucleus. If Whipple's theory is correct, the most common parent molecule is water. But there may be much "dry ice," or frozen carbon dioxide, in a comet. Comets are hard to study from Earth. This is why NASA scientists hope someday to send a spacecraft with instruments swooping into the head of a comet.

As a comet nears the Sun, the tail stretches out behind for many thousands or millions of kilometers and it is so thin that we can see stars shine through it. As the comet next loops around the Sun and then speeds away in the same direction from



As a comet dives inward, solar heat boils off bits of its nucleus; its tail grows, always pushed away from the Sun. On the outbound trip, the tail fades out into space. A weakened comet may fall apart. If Earth passes through the orbiting cloud of debris, we see bright meteor showers.

Streaks on streaks in a time exposure record the Leonid meteor shower. Stars leave the short, diagonal arcs (see page 221); longer, horizontal lines are tracks of the meteoroids as they glow in the atmosphere. This 1966 shower turned into a storm: over 6,000 meteors per hour!

which it came, its tail is then ahead of it rather than trailing behind.

Where do comets come from?

Astronomers have studied enough comets to be pretty sure that these visitors from afar are members of the Solar System, but very distant members.

Comets seem to have a "home ground" in the farthest reaches of the Solar System, at least 15 trillion kilometers away from the Sun—about 100,000 times farther from the Sun than Earth is. This home ground is a sphere called the Oort cloud, after the Dutch astronomer Jan H. Oort. Oort's idea is that some 100 billion comets swarm there. Most astronomers think that this enormous collection of rock dust and icy matter is left over from the time the Sun and planets were formed out of interstellar matter some 4.6 billion years ago. The comet rock dust may be much like the dust grains in the Horsehead Nebula, for instance. The molecules of frozen gas in the comet nucleus may resemble the gases found in the dark clouds of the Milky Way.

Another theory holds that these dirty snowballs once orbited among the giant planets and were flung out into their distant deep-freeze by Uranus and Neptune. Still another idea is that the Sun may have captured its comet-cloud matter from deep space far outside our Solar System.

From time to time the gravitational tug of a distant passing star snatches a comet from the Oort cloud and flings it into a cigar-shaped elliptical orbit that brings it close to the Sun. Some comets stay in this path, with the Sun near one end of the long orbit and the Oort cloud way out near the other end. These comets take thousands of years to complete one orbit. For every comet snatched out of the Oort cloud and sped toward the Sun, there probably is another that is gravitationally whipped away and lost to deep space.

Comet families

As it sweeps in among the planets, a *long-period comet* may be disturbed by the gravity of Jupiter or one of the other gas giants. Its orbit may then become much shortened, one end near Jupiter, say, and the other end in near the Sun. These *short-period*

June 30, 1908—An explosion as powerful as a two-megaton atomic bomb rips the morning sky over a Siberian wilderness—long before atomic bombs existed. It levels 3,000 sq km of forest in the Tunguska River valley, yet digs no crater. People hear it 1,400 km away; just before, reports say, a fireball streaked overhead. The Tunguska debate still goes on—was it a meteor? Antimatter? UFO cultists suggest an alien spaceship. Some scientists think they know: A small comet, made of loosely packed dust and ice, blew up from its fiery collision with the atmosphere.

comets are members of the inner Solar System. Encke is the shortest period comet known. It orbits the Sun in only three years and four months. Jupiter has "captured" several comets and thus has its own *comet family,* as do Saturn, Neptune, and Uranus. Jupiter has the largest family. While Jupiter, for instance, may tug a long-period comet into a smaller orbit, it is just as capable of flinging a short-period comet into a larger orbit—but always around the Sun, not the planet.

Halley's comet

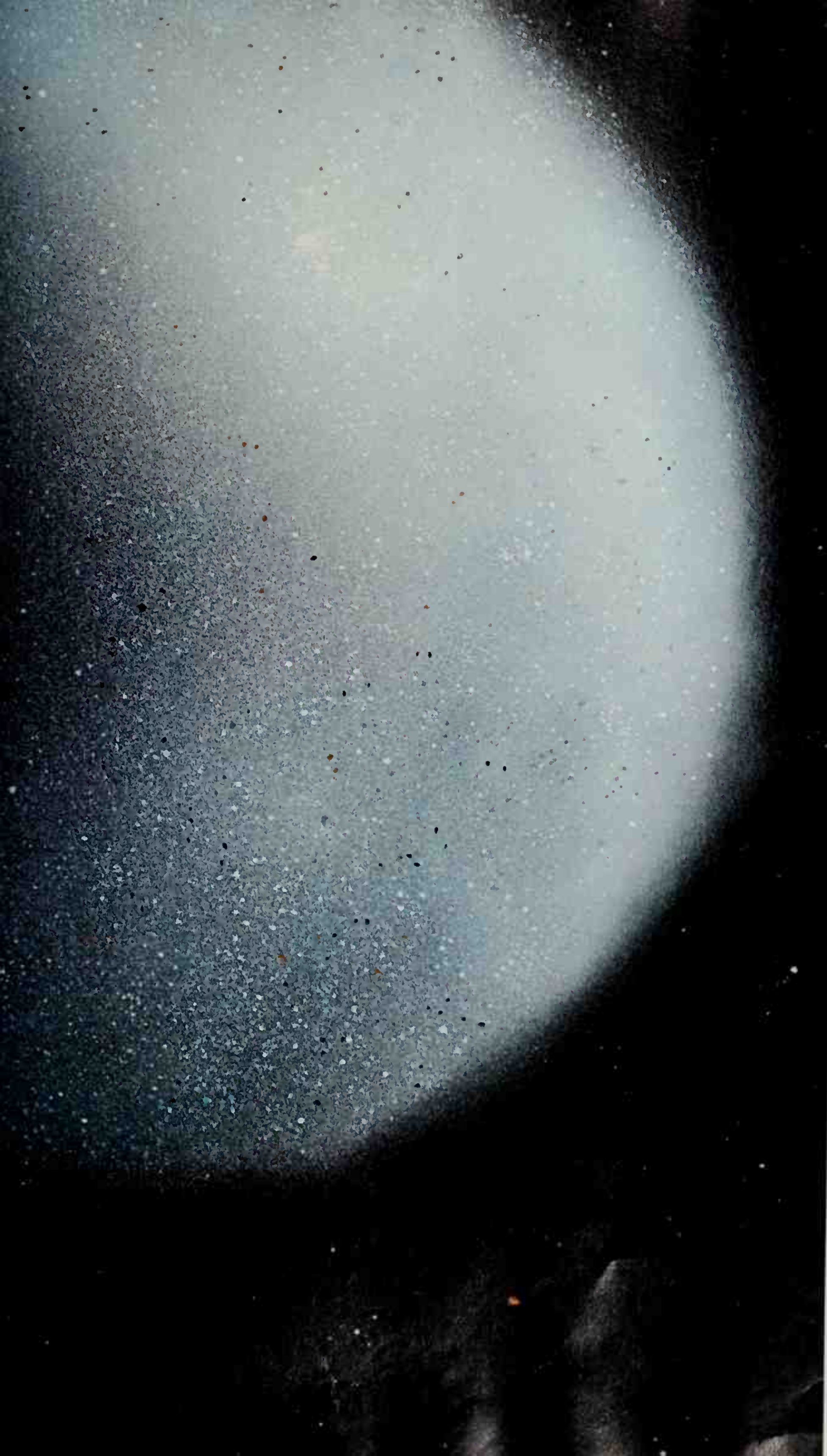
After studying the reported appearances of many comets, around 1700 Edmund Halley said that the comets sighted in 1531, 1607, and 1682 were not different comets but the same one that had returned again and again in a period of about 76 years. That famous comet was named after Halley, but he died 16 years before its next sighting in 1758, which he had predicted.

When a comet loops around the Sun and is heated up, jets of gas may spurt out of its nucleus and act like the thrusters of a rocket. This may set the nucleus spinning, or speed up the comet, or slow it down, and so change its orbital path. Then the comet may be a few hours or days off schedule. Sometimes the nucleus breaks into two or more pieces. This may be caused by the force of the gas jets, or by heat and gravitational force when a comet nears the Sun. If the fragments stay in orbit together, they are called a *comet group.* We know of about 15 such groups. Sometimes a comet group does not survive; it breaks up completely and vanishes.

The Sun-grazing comets

Some comets sweep in so close to the Sun that they are called *Sun-grazers.* We know of nearly a dozen. Some come as close to the Sun as the Sun is wide. Probably the Sun-grazer of January 1887 holds the record. Known as the "Great Southern Comet," it swept through the Sun's hot corona, perhaps as close as 27,000 kilometers from the visible surface. Sun-grazers have long periods—from 500 to more than 1,000 years. Together they make a comet group that may be the remains of an ancient, giant comet that broke up when rounding the Sun. They head in toward the Sun from below Earth's orbit and whip around in a clockwise direction, opposite from the planets' motion around the Sun.

One of the most recent Sun-grazers, and one of the most famous, is Ikeya-Seki (officially called 1965 VIII). That year Ikeya-Seki put on a grand show which millions of people saw. It was brighter than the full



The Oort cloud, a vast sphere of comets around our Solar System, might look like this artist's dramatization. Theory says comets lie in cold storage here, until a passing star pulls off a few (opposite), and sends others deep inside the cloud, on a fall sunward for thousands of years.

Moon and, when nearest the Sun, could be seen during the day.

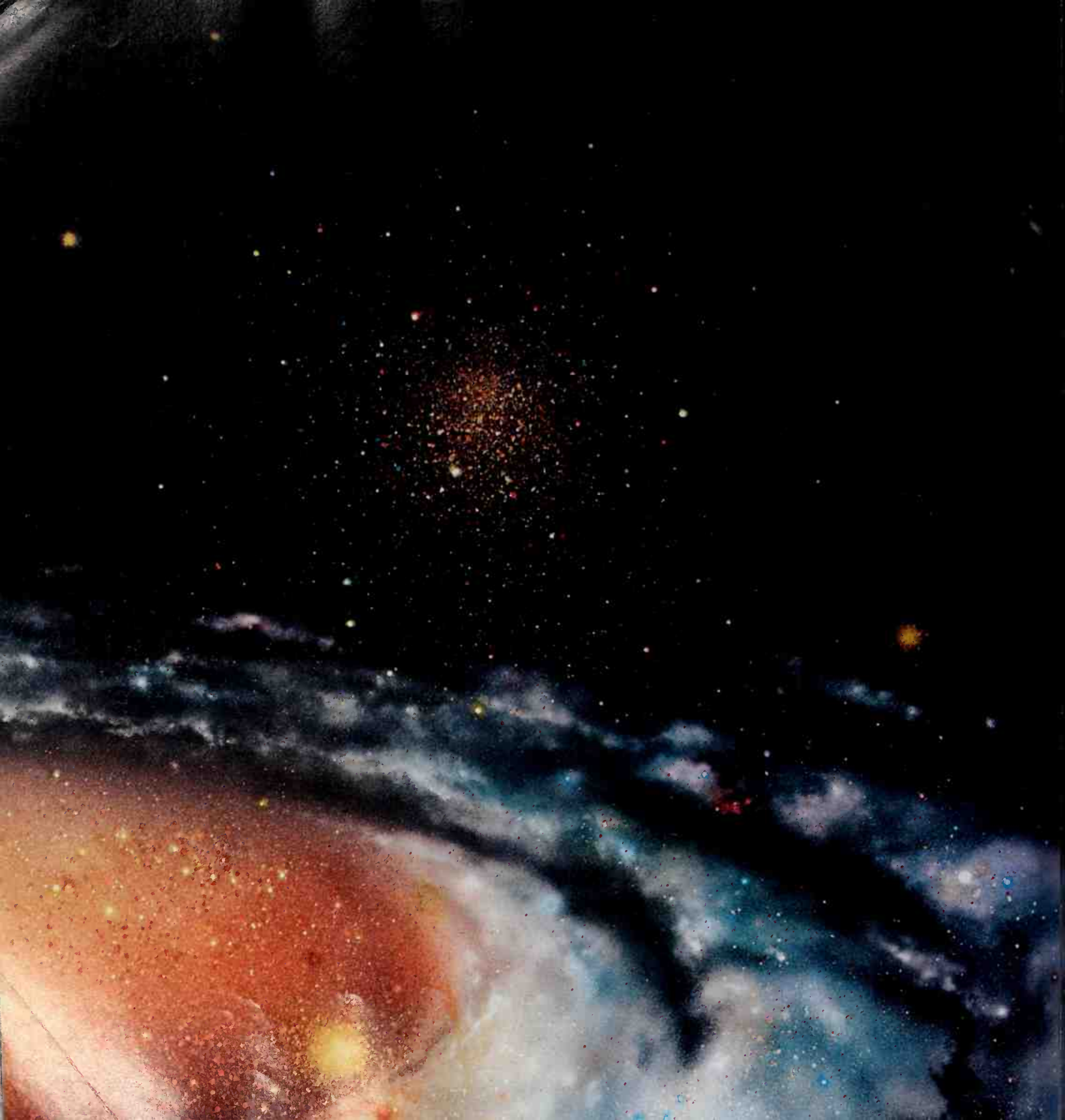
Soon after Ikeya-Seki's closest approach to the Sun, the nucleus broke into pieces, split by the heat and gravitational force of the Sun. The same thing had happened to another brilliant Sun-grazing comet, 1882 II, which has been called "a near twin of Ikeya-Seki." The nucleus of the 1882 comet broke into four pieces, of which two survived. Although there is no reliable evidence, it has been suggested that Ikeya-Seki and the 1882 comet were once a single Sun-grazer seen in the year 1106.

What happens to comets?

Each time a comet rounds the Sun and flares out with its coma and tail, it loses part of its material to space. Frozen gases evaporate, stream into the coma and tail, and eventually are lost not only from the comet but from the Solar System itself.

As the nucleus gradually evaporates, it sometimes breaks up. Pieces the size of pebbles and sand grains drift apart and form long swarms sharing the same orbit. At regular times each year, Earth passes through these swarms. Then the fragments rain down through our atmosphere, where they are heated. They glow like spacecraft on reentry. They are the familiar meteor showers.

So far as we know now, the outer boundary of the Oort cloud marks the limit of the Solar System. Beyond lies interstellar space. There distances are so great that we must shift the gears of our minds to imagine – if we can – the immense size of our local universe of stars.



To the Stars & Galaxies

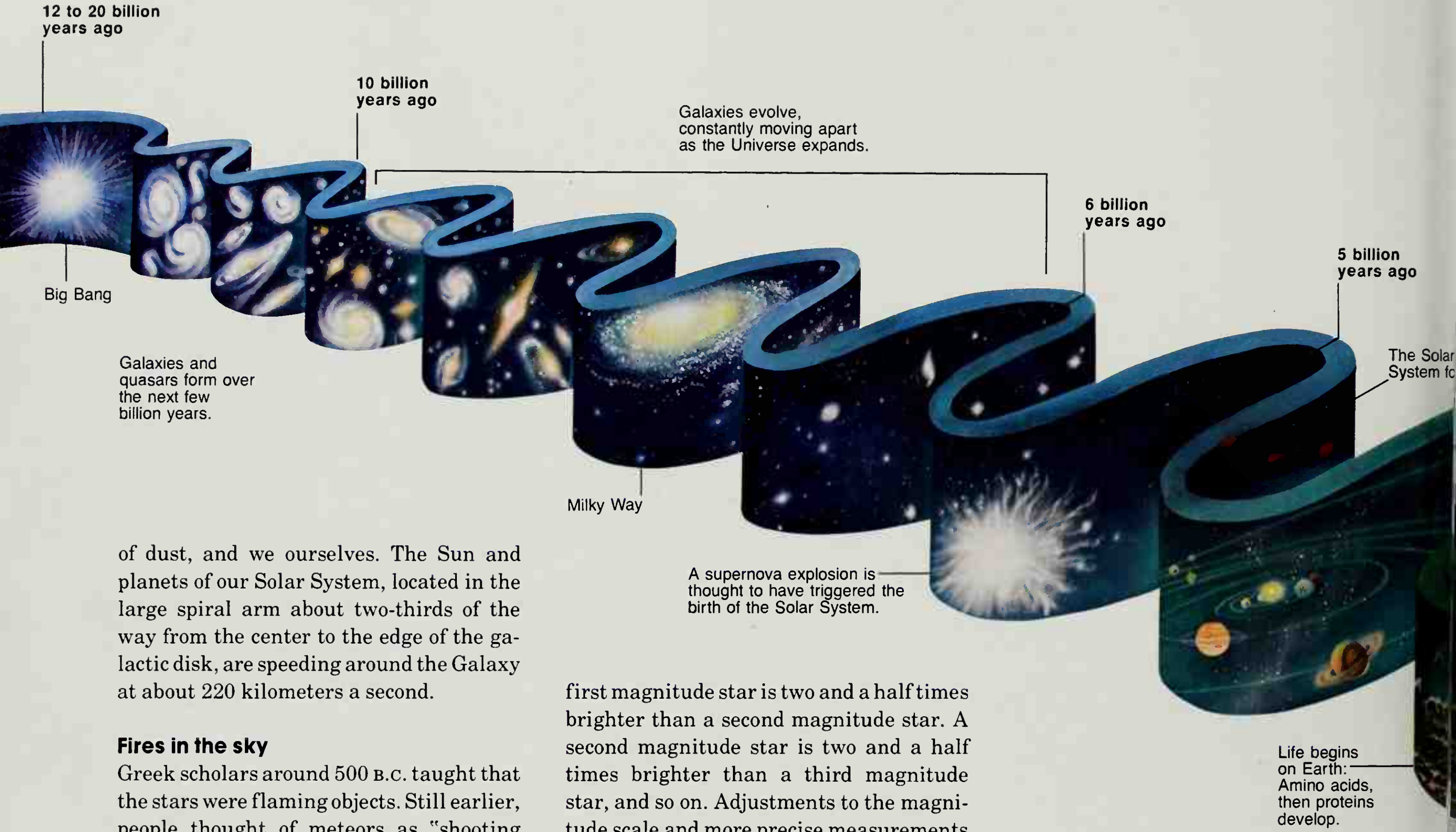
Deep Space

Our home galaxy, the Milky Way, spins its spiral arms of gas, dust, and billions of stars. Sweeping some 50,000 light-years across the disk of the Galaxy, this view reveals the blue-white stars of the spiral arms. These are extremely hot giant stars, much younger than the Sun. The orange-red glow of the nucleus comes from its red giant stars. Within the disk are deep red patches – nebulae where newborn stars are found.

The huge ball of stars is one of over 100 globular clusters that form a halo around the Galaxy's center. A typical cluster contains over 100,000 stars billions of years older than the Sun. Many are cool red giants. But there are hotter stars too, stars that shine with blue-white, yellow, and orange light. The small, fuzzy, orange-red globes are distant globular clusters.

About two million light-years away, to the right of the nearest globular cluster, we can see the Andromeda Galaxy, with its two companion galaxies. And to the upper right of Andromeda is another nearby galaxy, M33 in Triangulum. These are our backyard neighbors in a Universe that seems to be endless.

Everything in the Galaxy rotates about the nucleus – the gases, the stars, every bit



of dust, and we ourselves. The Sun and planets of our Solar System, located in the large spiral arm about two-thirds of the way from the center to the edge of the galactic disk, are speeding around the Galaxy at about 220 kilometers a second.

Fires in the sky

Greek scholars around 500 B.C. taught that the stars were flaming objects. Still earlier, people thought of meteors as "shooting stars" which fell to Earth. Today we know that the stars do not fall out of the sky and that they are not burning lumps of solid matter, but glowing balls of gases.

On any clear, dark night away from city lights, you can count about 2,000 stars. The measurement of a star's light as seen from Earth is its *apparent magnitude,* or *apparent brightness.* Since the time of Hipparchus, around 130 B.C., apparent magnitude has been a handy way of measuring the relative brightness of stars. Hipparchus and, later, Ptolemy rated stars on a descending scale from the brightest they could see (magnitude 1) to the faintest (magnitude 6). Our system is similar. A first magnitude star is two and a half times brighter than a second magnitude star. A second magnitude star is two and a half times brighter than a third magnitude star, and so on. Adjustments to the magnitude scale and more precise measurements have made negative numbers necessary for the brighter-appearing stars. Sirius, for instance, is –1.5 and the Sun is –26.7. The faintest stars you can see with your unaided eye are of apparent magnitude 6.

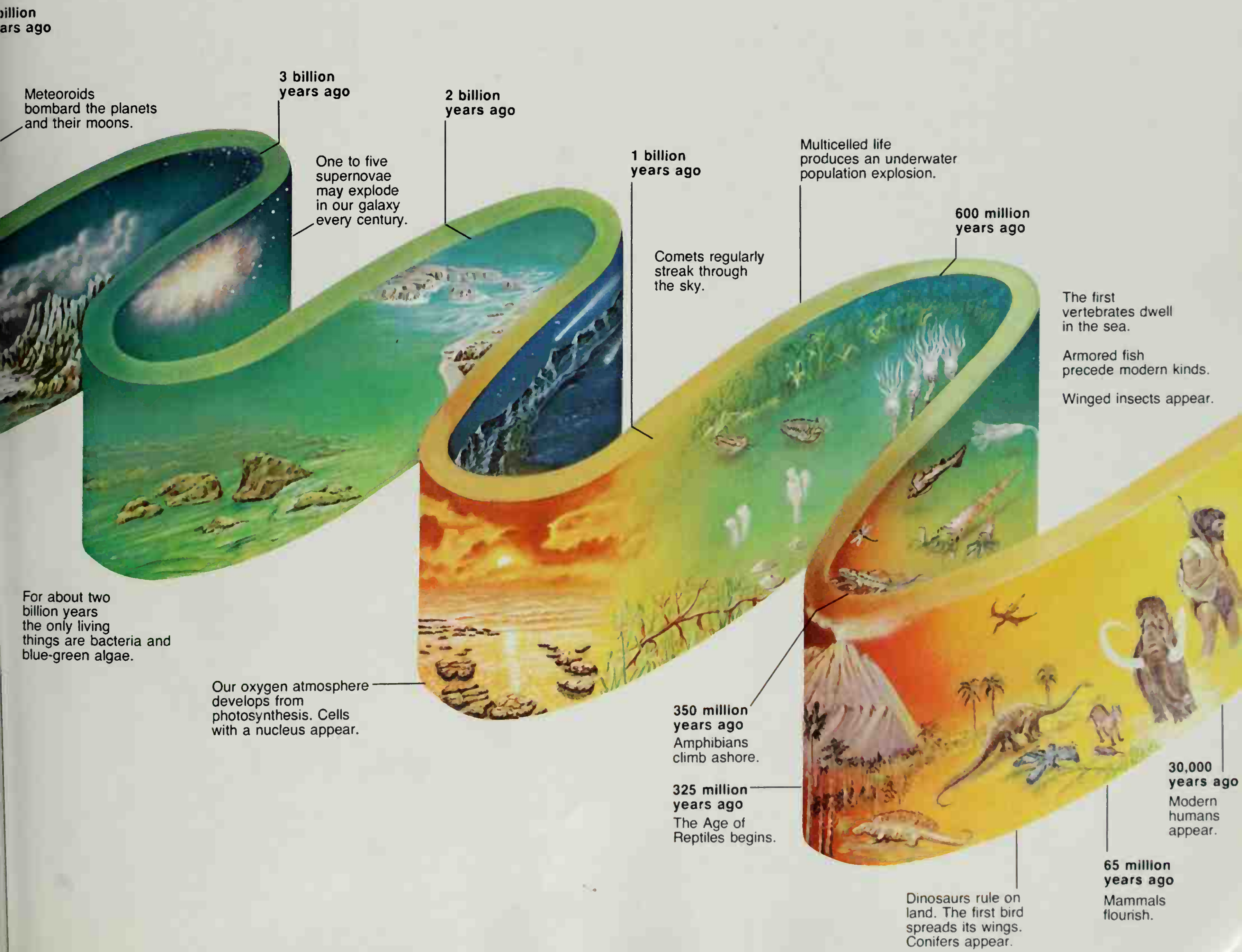
With 7-power binoculars you can see over 50,000 stars, and with a 3-inch telescope you can see hundreds of thousands. Even though the Sun's bright light masks other stars from view during the day, they are there. As the sunlight fades in the evening, the stars blink into view, twinkling as their light is disturbed by the shimmering atmosphere. Have you ever wondered how far away those stars are? What makes them shine?

Orion the hunter

The constellation Orion, which dominates the winter sky from December through March, offers a wealth of interesting sky objects. It has more bright stars than any other constellation. Among them is the red supergiant Betelgeuse, of magnitude 0.4. It marks Orion's right shoulder. Betelgeuse is so large that if it were in the Sun's position, it would fill the Solar System out beyond the orbit of Mars.

Astronomers' figures for the sizes and distances of stars beyond the Sun are estimates, not precise measurements. Betelgeuse is estimated to be 520 *light-years*

Some 12 to 20 billion years ago, astronomers think, a "primeval atom" exploded with a big bang sending the entire Universe flying out at incredible speeds. Eventually matter cooled and condensed into galaxies and stars. Planets formed around at least one star. Aeons after life began to develop on Earth, humans appeared. Here are major events in the history of the Universe. If all events until now were squeezed into 24 hours, Earth wouldn't form until late afternoon. Humans would have existed for only two seconds.



Orion, the Mighty Hunter of Greek myth. If you look at the sky on a clear winter night, you can't miss this constellation. Three bright, evenly spaced stars descend from right to left to form Orion's belt. Orion's brightest stars—Betelgeuse and Rigel—locate the giant's right shoulder and left leg. The Great Nebula marks his sword. In ancient times people populated the sky with imaginary figures. These patterns of stars—constellations—don't look much like what they were named for. Modern astronomers have blocked out 88 regions of the sky as constellations.

away from us. (One light-year is the *distance* light travels in one year at nearly 300,000 kilometers a second. That means it moves at 186,000 miles a second or 669,600,000 miles an hour. This is the speed of light.) If the light reaching us tonight from Betelgeuse left that star 520 years ago, we are seeing Betelgeuse as it was about 30 years before Columbus set sail for America. If Betelgeuse exploded tonight, the flash would not be seen from Earth for 520 years. So when we look at the distant stars we look back in time. We can never see a star as it is in our "now" time.

Orion is also famous for its blue supergiant star Rigel, 900 light-years away and with a magnitude of 0.1. Rigel marks Orion's left leg and is the seventh brightest star in the sky. A small telescope shows that Rigel has a companion, Rigel B, which actually is a double star, or *binary*. Rigel B's two bluish-white stars revolve around each other. Bellatrix, 470 light-years away, marks Orion's left shoulder. The topmost of the three stars that form Orion's belt—1,500 light-years away—is Mintaka, another binary, of magnitude 2.2. The bottom star of the belt is a triple star, consisting of a blue-white binary with a faint, distant companion.

Three stars seem to form Orion's sword, but binoculars show that the middle "star" is actually an enormous cloud of hot glowing gas. Known as the Great Nebula, or the Orion Nebula, it contains a star group called the Trapezium. Just below Orion's belt is another nebula, the Horsehead. Both nebulae are 1,500 light-years from Earth. But the dark Horsehead can be seen only by a long camera exposure which brings out its bright background.

The sky is a marvelous theater of wonders. There are stars that differ greatly in color, brightness, and size. There are single, double, triple, and multiple stars. There are dark clouds of gas and dust, and clouds hot enough to glow as brightly as beacons in the eternal night of space.

The constellations

Stargazers of very long ago invented the constellations. The earliest of these imaginary shapes probably included that great belt of 12 constellations we call the Zodiac (shown on pages 16-17). From Earth the planets appear to glide through the constellations of the Zodiac.

By Ptolemy's time 48 constellations were listed, and by 1600 astronomers recognized about 60. Today the official number has grown to 88. In this celestial zoo of star groups are 19 land animals, 13 humans, 10 water creatures, nine birds, a couple of centaurs, one dragon, a unicorn, and a head of hair. Don't be disappointed if you can't make out the fanciful figures as they are shown in books. No one else can either. The constellations are beautifully false figures. Because the stars move in relation to one another, all the constellations are ever so slowly changing their shapes. Although some stars move along at more than 100 kilometers a second, they are so far away we cannot see them moving.

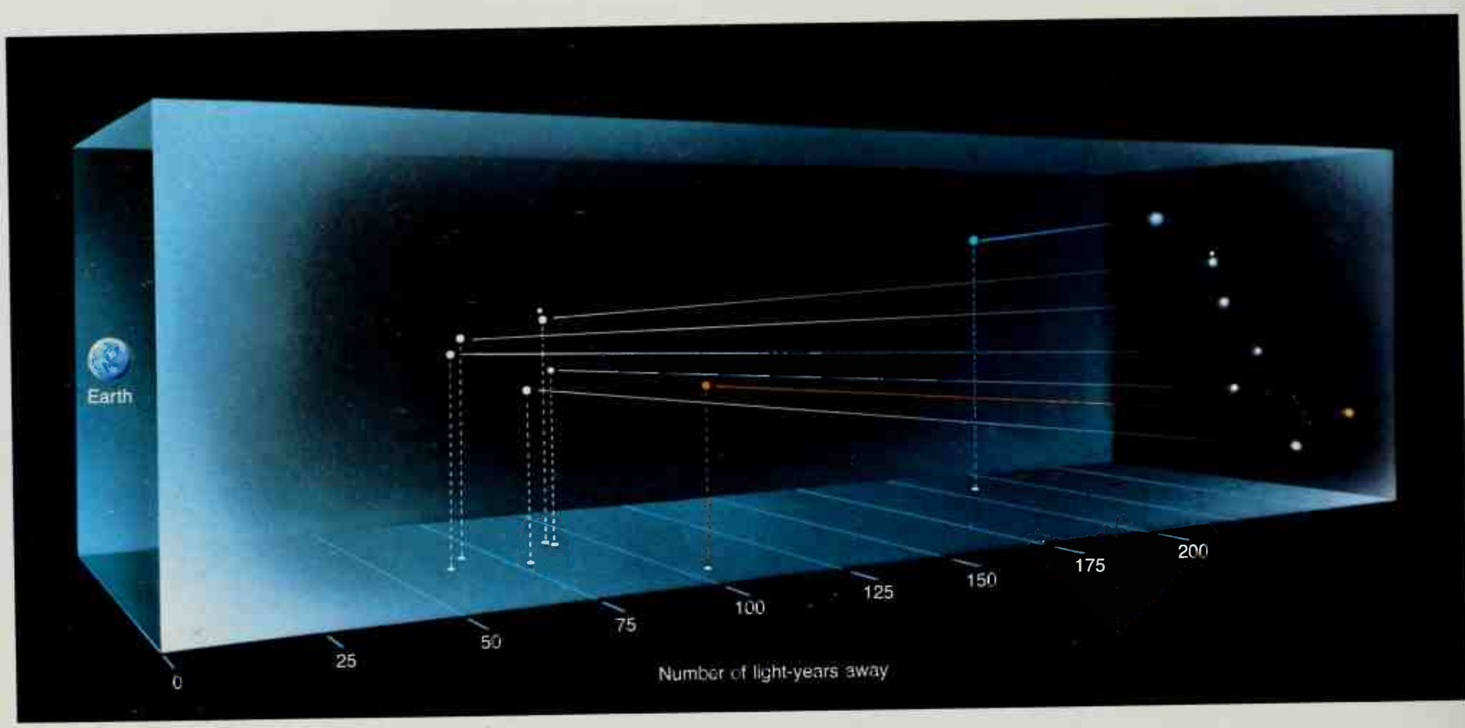
Grouping stars by luminosity

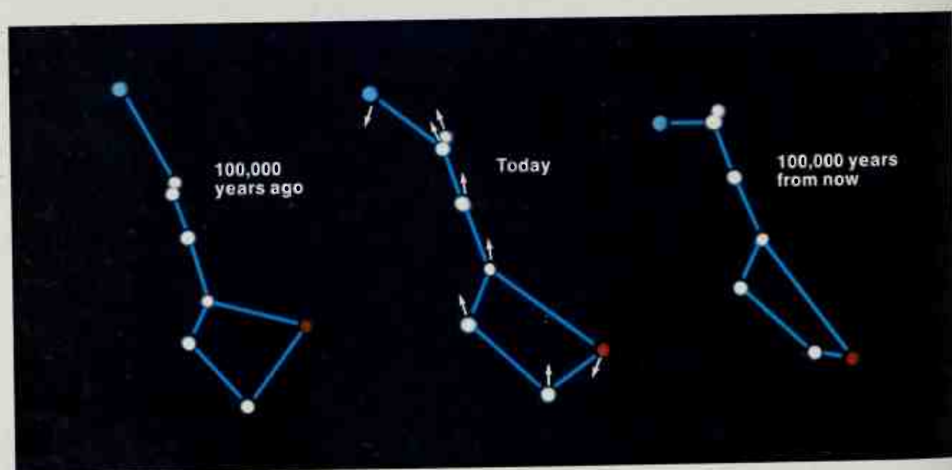
The constellations are not a scientific way of grouping the stars. A better way is to relate certain features of stars. For instance, a blue star is hotter than a red star. So there is a relationship between color and temperature. A blue star radiates more energy than a cooler red star the same size. So there also is a relationship between the rate at which stars pour out energy—called *luminosity*—and their size and surface temperature. This relationship is a useful way to classify stars.

Between 1911 and 1913 two astronomers—a Dane named Ejnar Hertzsprung and an American, Henry Norris Russell—had discovered how useful this relationship was and how much it could teach them

The Big Dipper's stars seem to be the same distance from us, but they're not. The diagram below shows (right) how we see them from Earth, and (center) their true distances from us. Red giant Dubhe looks farthest from blue Alkaid, but actually it's Alkaid's nearest neighbor.

A time diagram of the Big Dipper (bottom) shows that although the patterns of stars may seem permanent, they slowly change. Arrows in the center indicate the direction of real motion. These stars zip along at up to 20 km a second, but they are too far away for us to sense the motion.





about stars. (See the graph on page 223.) Hertzsprung and Russell plotted the *absolute magnitude* against the *spectral class* and color of many stars. This type of graph was named in their honor the *Hertzsprung-Russell,* or *H-R, diagram.* It is also called the temperature-luminosity diagram.

When the two astronomers arranged stars on the diagram, they found that most fell along a narrow band from upper left to lower right—called the *main sequence.*

At the upper end of the main sequence are the massive and very luminous hot blue stars with surface temperatures up around 40,000 kelvins. Along the middle of

This one-hour time exposure centers on the north celestial pole. As the camera turns with Earth, it records the light of "star trails." Although these stars appear to be revolving, they are not. Their apparent motion around the sky is caused by Earth's rotation on its axis.

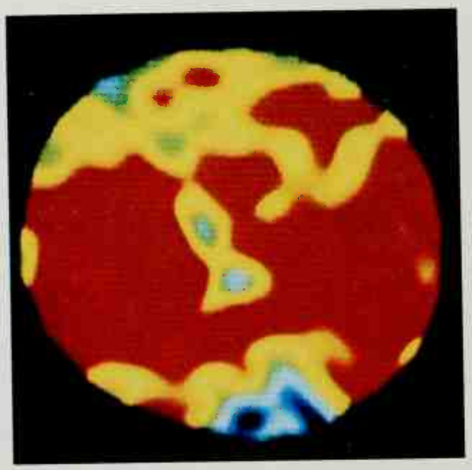
the main sequence are less luminous and cooler stars, like the Sun. These stars shine with a yellowish-white light and have surface temperatures around 6,000 kelvins. At the lower end of the main sequence are the least luminous and still cooler red dwarf stars with surface temperatures of only about 3,000 kelvins. Although astronomers think that many very dim stars lie off the main sequence, about 95 percent of the stars we know today fall along the main sequence.

But where along the main sequence do most of the stars lie? When astronomers arranged the 100 stars nearest to Earth on a temperature-luminosity diagram they found that most fell along the lower end of the main sequence in the region of the red dwarfs. So most of the stars we can see are less luminous than the Sun. It turns out that the temperature-luminosity diagram is a very useful tool to help us study stars. The 100 brightest-appearing stars, for example, have been arranged on the diagram. Most of these are more luminous than the Sun but only a few are nearby. This reveals that highly luminous stars are rare among the nearest stars. Stars fainter than the Sun seem to be the rule.

Stellar mass and luminosity

Since stars differ so greatly in luminosity and size, do they also differ greatly in mass? In fact, the luminosity of a main sequence star depends on its mass. So here is another important relationship. The general rule is that the more luminous a main sequence star, the more mass it has. But it turns out that there is not nearly as much

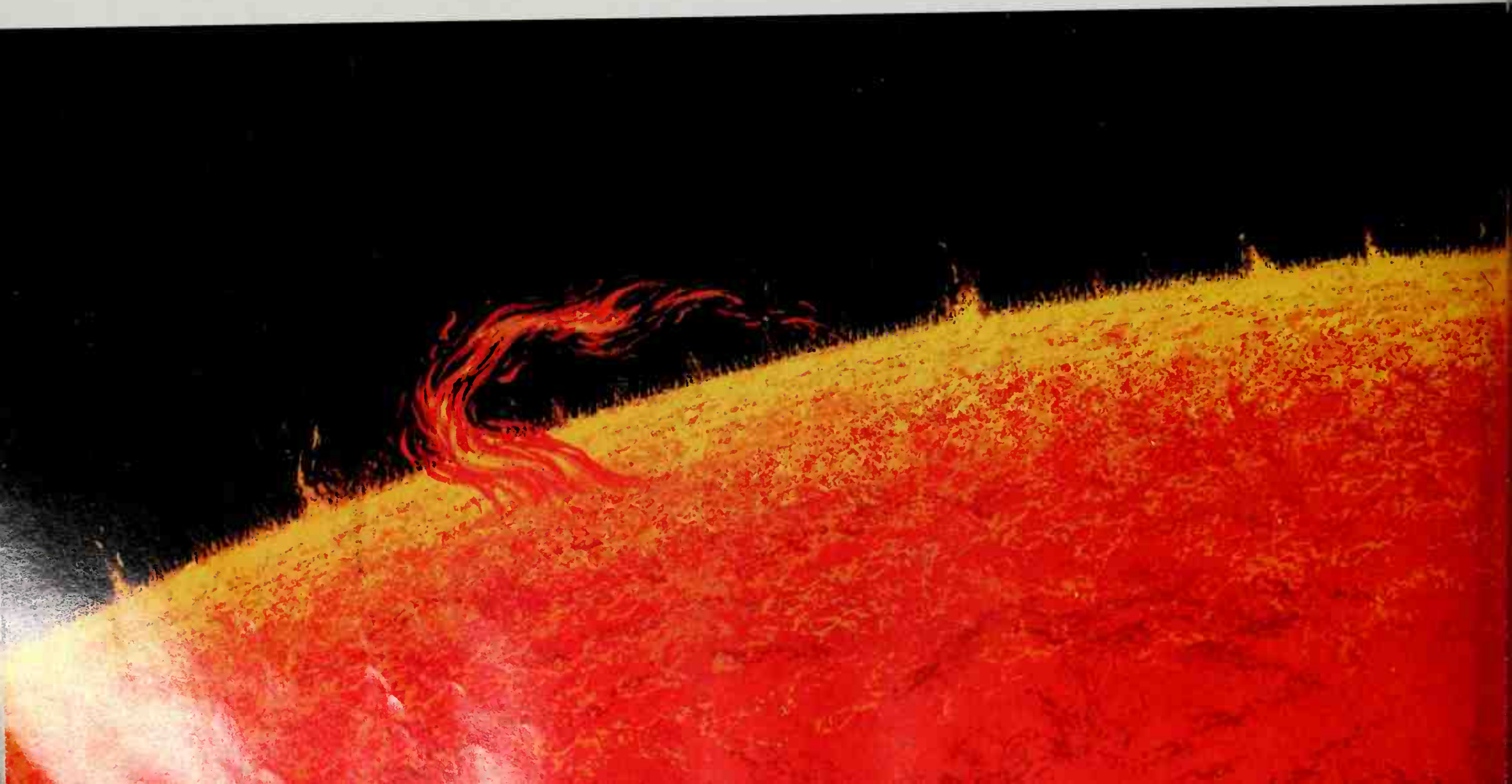
A computer portrait of Betelgeuse colors hot areas orange and cooler ones blue. These huge blotches may be convection cells like our Sun's granules (see page 49). Photographing Betelgeuse across 520 light-years is like photographing a sand grain a mile away.

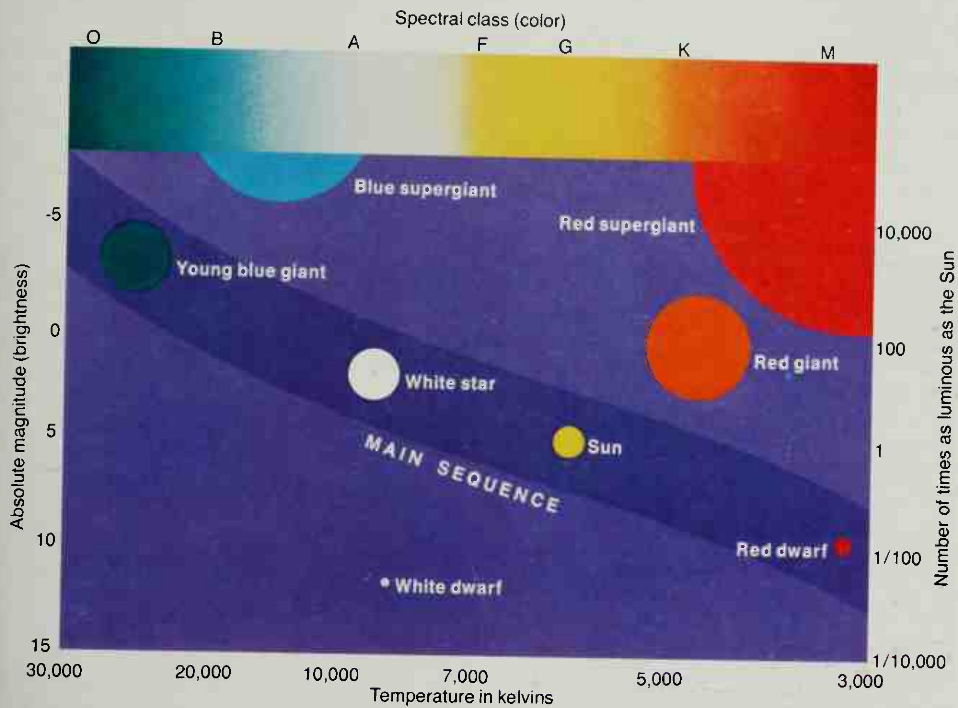


difference in the mass of stars as there is in luminosity. Most of the stars that we can see range from about a tenth as massive as the Sun to about 10 times more massive. There are some exceptions where a star may be much more or much less massive. But we know of few such stars.

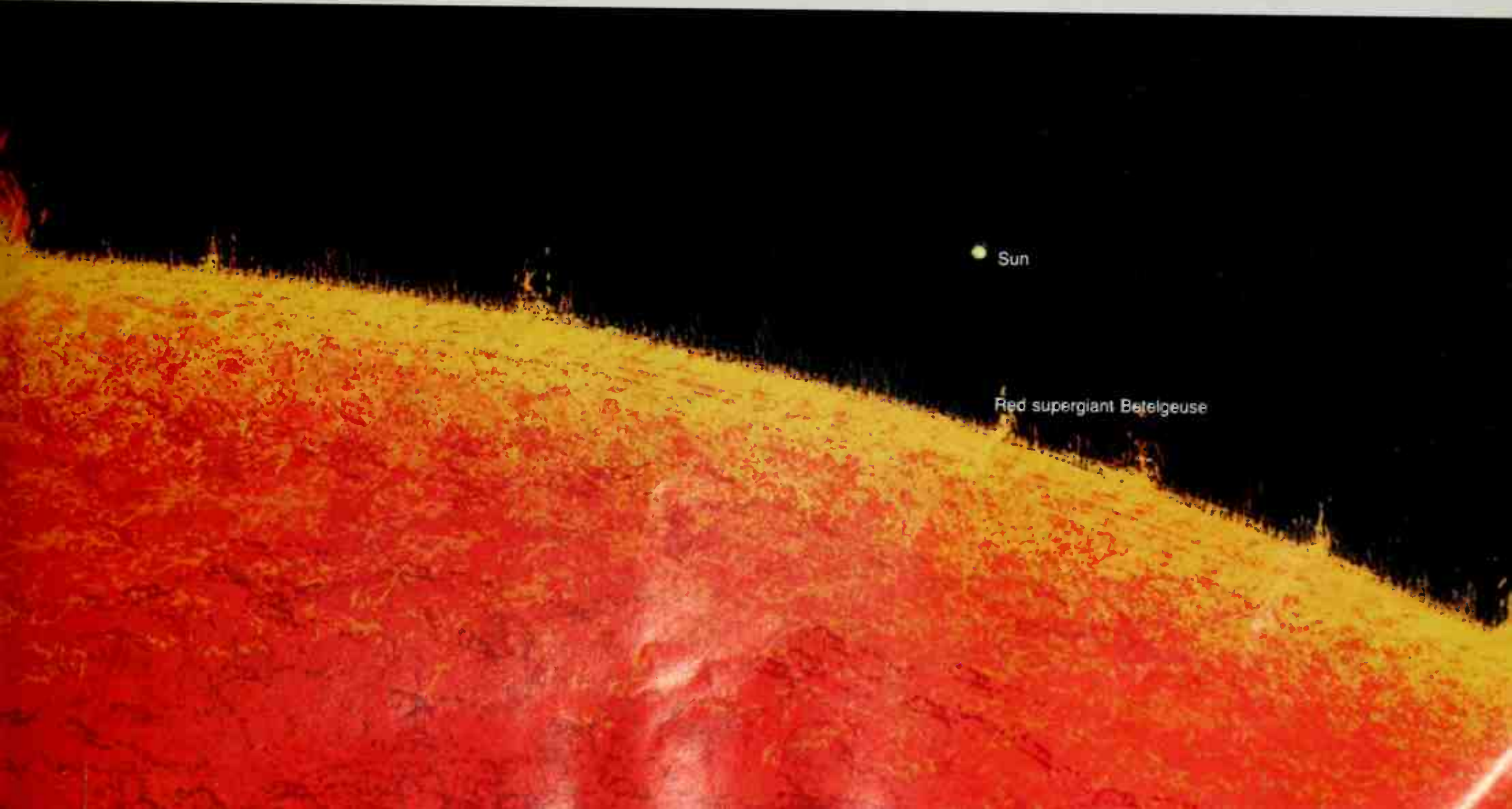
A star that is very massive shines and eventually goes out in a way very different from the way a red dwarf star with very little mass shines and ends its life. And a medium-mass star like the Sun has a lifestyle and fate different from those of a massive supergiant or a low-mass dwarf. The stars seem eternal and unchanging, but they are not. Stars are born, shine for a while, and eventually go out.

Because the life span of a star like the Sun stretches over billions of years, we cannot watch what happens to the star from the time it is formed until it goes out. But here and there in the sky we can see what appear to be stars forming. We also can study certain other stars in their youth, others in old age, and the remains of others that long ago blew themselves to bits in catastrophic explosions. So by splicing together these single scenes in the life of a certain type of star, we can make intelligent guesses about the evolution of a star





This H-R diagram plots the actual brightness (absolute magnitude) of stars against their temperature, luminosity, and spectral class (the characteristics of the spectrum of each star). Absolute magnitude is the brightness stars would have if measured a standard distance away. A –5 magnitude star is very bright. Most stars fall along the main sequence. Surface temperature and size are related to brightness (but sizes at left aren't to scale): The hotter and bigger a star the brighter it glows. Red supergiant Betelgeuse is very bright, though cool, because its surface is huge—about 800 times bigger than our Sun.



Red gas circles Beta Lyrae in this classic painting of the double star, seen from an imaginary planet. As the stars orbit one another, gravitation pulls them both into egg shapes. Gas streams between them, and some escapes in a widening spiral. Most stars exist in pairs or groups.

like the Sun, a blue supergiant like Rigel, or a red dwarf like Ross 128.

The birthplaces of stars

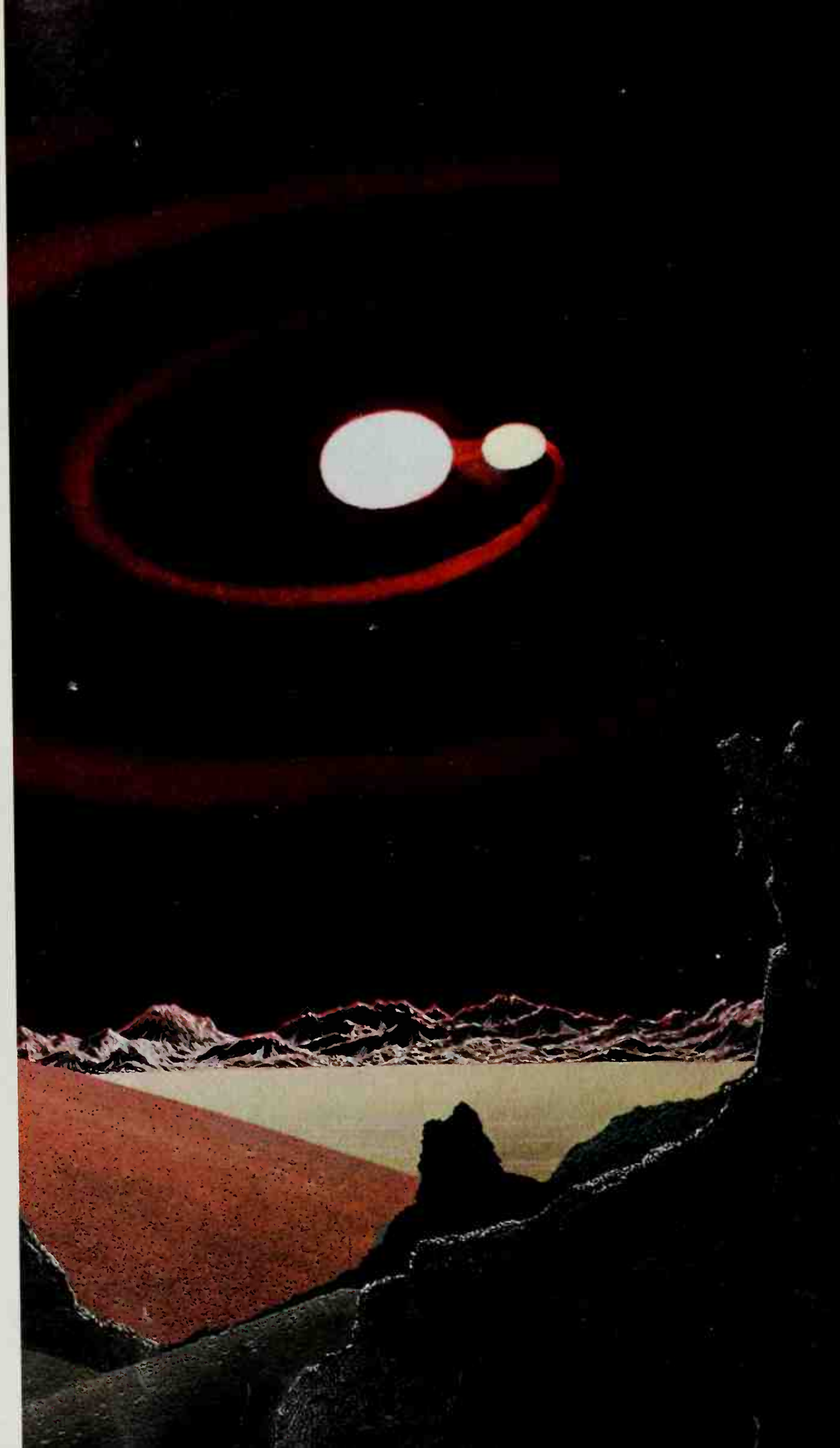
Astronomers think that stars are born in the *nebulae,* those clouds of gas and dust that we see in the Milky Way and that exist in many other galaxies. The gas is mostly hydrogen with some helium. Space dust is made up of tiny particles of solid matter.

Some are *dark nebulae.* These are clouds sometimes silhouetted by the light of stars or gas shining behind them, such as the Horsehead Nebula. The large dark band, or *rift,* visible along the summer Milky Way is a series of dark nebulae. When a cloud of gas and dust has one or more stars inside or nearby, the nebula may shine by reflecting the starlight. These are called *reflection nebulae.* The Pleiades star cluster (page 229) contains several well-known reflection nebulae.

If the star or stars inside a nebula heat the gas to about 10,000 kelvins by ultraviolet radiation, the hydrogen of the nebula is excited and glows with a fluorescent light. Nebulae that emit light in this way are called *emission nebulae.* The most famous one is the Great Nebula in Orion.

How stars are born

Stars form out of especially dense clouds of gas and dust. A globe of this matter grows as it keeps sweeping up surrounding matter by gravitational attraction. As such a *protostar* globe continues to gain mass, gravitation packs the matter tighter and tighter in the core region, where the pressure, density, and temperature steadily



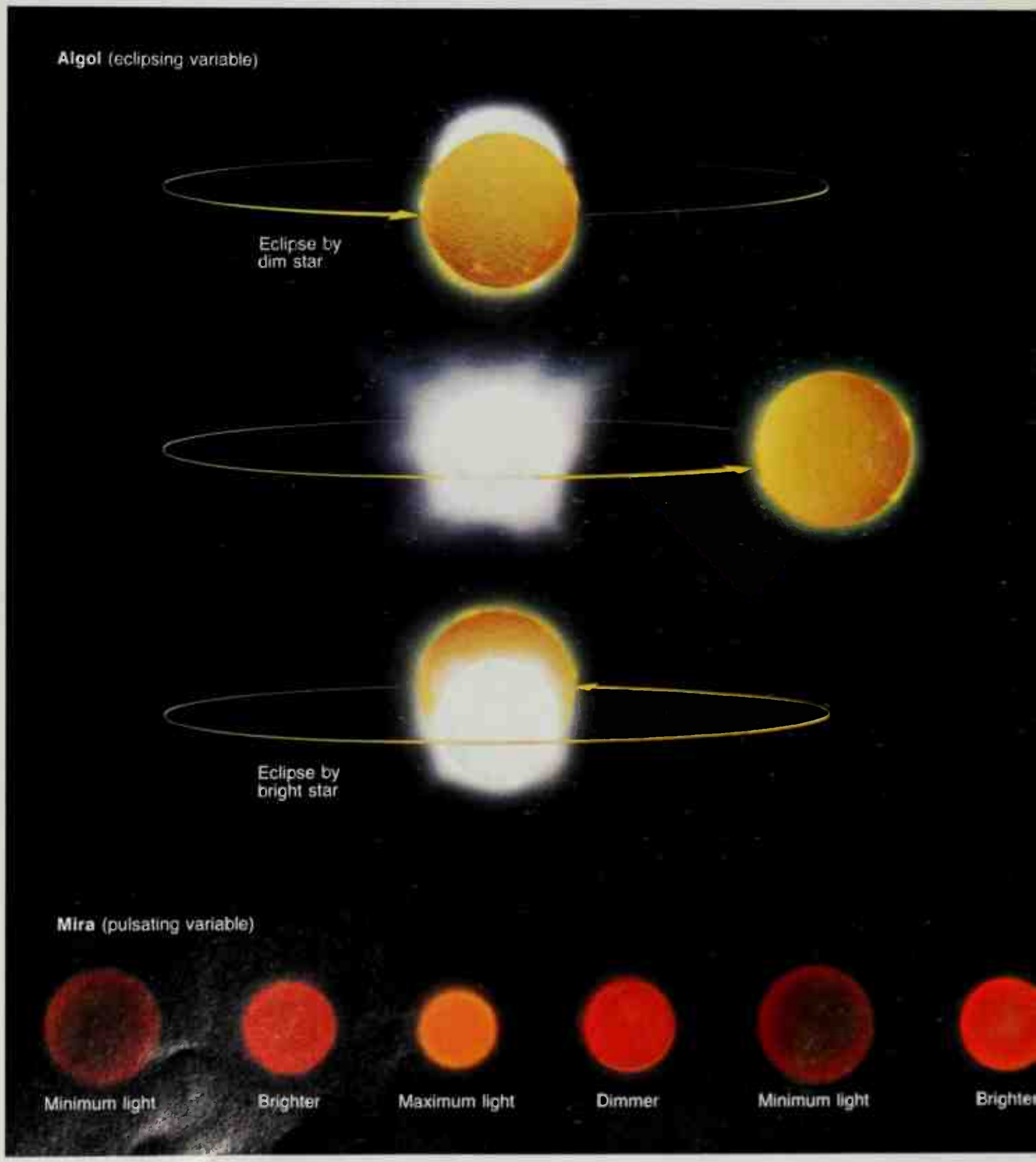
Double stars that orbit one another in our line of sight can block each other's light. The binary Algol dips its light every 69 hours as its dim star obscures its bright one (top). Known as the "winking demon," Algol's brightness dips again, but less so, when the dim star is eclipsed.

Mira, Mira, burning bright, growing larger dims your light. Like the red giant Mira "the miraculous" (bottom), some stars change size periodically, varying their brightness. Over an 11-month cycle, Mira expands and contracts. It's brightest when small, dimmest when large.

climb. The core of the protostar heats up enough so the star glows a dull red. As it becomes still hotter it glows a brighter red. Eventually, when the core temperature reaches about 10 million kelvins, nuclear fusions of hydrogen into helium begin. (Page 61 explains fusion.) Soon after its nuclear furnace ignites, the new star becomes a main sequence star.

During the time a protostar is pulling in matter from its parent nebula, it is spinning faster and faster. A large disk of revolving matter forms around it. Small globes of matter may form out of a star's disk material and become *protoplanets*. These do not have enough mass to heat up and become stars. Instead they condense and become planets. It may be that whenever star formation takes place, planets also form. If so, there may be billions of other planets in our galaxy alone. Barnard's Star, six light-years away, is one of several nearby stars that may have planet-size companions. A protoplanet may also develop its own disk of matter, and one or more moons may form from it.

During the protostar stage of star formation, a planetary system must be a foggy place, glowing dull red with the feeble light of its new star. Eventually, however, the star may go through a stage in which it pours out gas particles in the form of a powerful wind. If so, the wind, called the T Tauri wind, will sweep the planetary system clean of gas and dust. According to this theory, if the Sun passed through a T Tauri stage, it is possible that the strong wind stripped Mercury, Venus, Earth, and Mars of their primitive hydrogen and helium

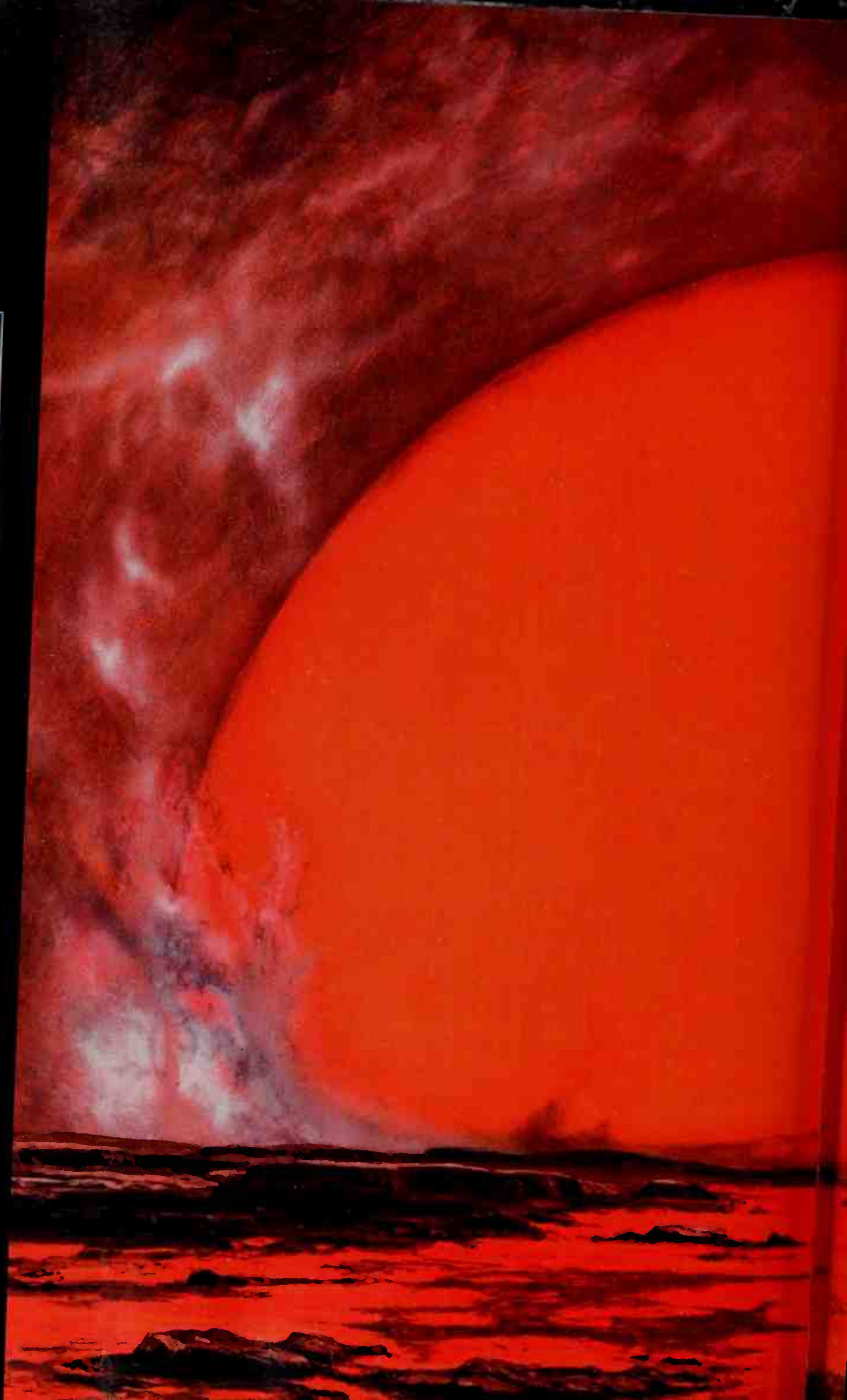


The life of a star

1 Nebula and protostar

2 Star and planets forming

3 Star on the main sequence



4 Looming red giant

5 Planetary nebula and central star

6 White dwarf seen from a cold planet

(1) A star like our Sun is born inside a huge cloud of gas and dust; gravity condenses part of the cloud into a warm, red protostar. (2) Spinning flattens it into a disk, the infant star at its core; planets may form from rings in the disk. (3) Contraction heats the core until the start of nuclear reactions that make the star shine for billions of years. (4) Its hydrogen fuel spent, the star's core contracts further, yet radiation swells the outer layers to an enormous size. (5) Later, these layers blow off in an expanding cloud of gas and (6) leave the star's burnt-out core to cool and fade.

The Trifid Nebula glows red as ultraviolet rays from its hot central star excite its hydrogen gas. Called an "emission" nebula because it emits visible light by a fluorescent process, the Trifid is one of hundreds of these nebulae in our galaxy. They are birthplaces of stars.

Bright halos of cloud surround the stars of the Pleiades, or Seven Sisters cluster. These nebulae glow by reflecting light from stars. Dust grains in the halos scatter the blue-white light of the nebulae's young stars the way Earth's atmosphere scatters sunlight and makes the sky blue.

atmospheres. Jupiter and the other present-day gas giants managed to hold on to their gases, perhaps because of their greater distances from the Sun.

Once a protostar becomes a main sequence star, it shines more or less steadily for millions or billions of years. But just how stable an adult star remains, and just how long it stays a main sequence star, depends on how much mass the star has.

The red dwarfs are the least massive stars we know of. Because of their low mass, their core temperatures reach only about 10 million kelvins, just hot enough to start hydrogen fusion reactions. So these stars shine with a cool red light and have surface temperatures of only about 3,000 kelvins. The red dwarfs burn up their hydrogen fuel very slowly so they have very long lives, perhaps a trillion years or so.

Stars like the Sun, about 10 times more massive than the red dwarfs, have core temperatures around 15 million kelvins. They radiate energy much more rapidly and so have surface temperatures around 6,000 kelvins. Since Sunlike stars use up their hydrogen fuel more rapidly than the red dwarfs do, they have shorter lives, around 10 billion or so years.

Very massive stars, like the Orion belt stars, are so hot that they shine with a bluish-white light. Some of these stars have surface temperatures around 30,000 kelvins or more. Their enormous mass of about 35 times that of the Sun drives their core temperatures up to 40 million kelvins. These stars are energy spendthrifts and use up their fuel supply rapidly. Their lives span only millions of years.

How stars die

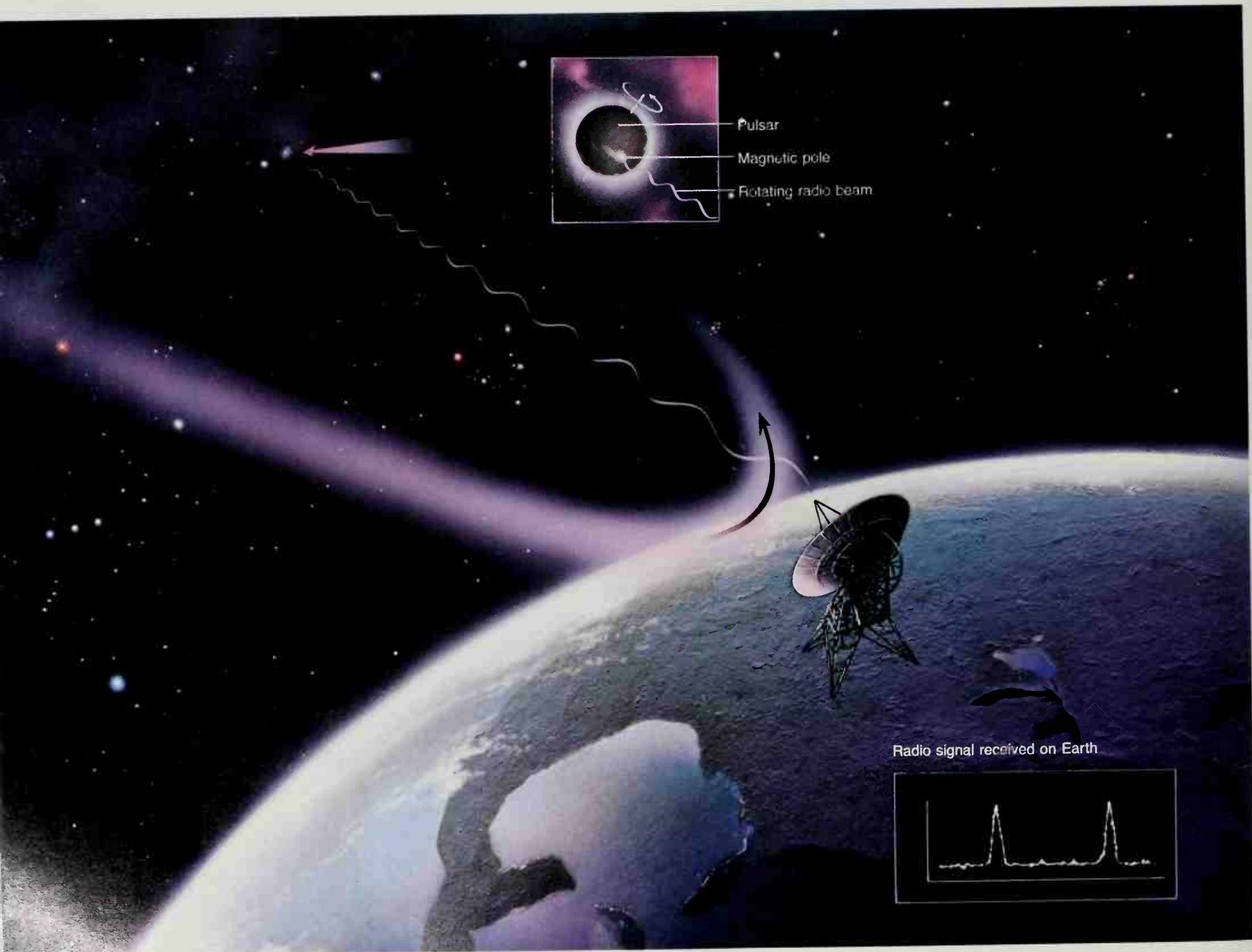
The smallest red dwarfs evolve so slowly that even one formed in the earliest days of the Universe is burning unchanged on the main sequence and will stay there for the entire lifetime of the Universe. But a star that does leave the main sequence, no matter how much or how little mass it has, eventually swells up into a red giant before burning out. The star's mass determines how dramatically it ends its days. Picture a low-mass star down in the red dwarf region of the main sequence nearing the end of its hydrogen fuel supply. Gradually it sends less and less energy out from the core region and so begins to cool. A cooling core is a core with decreasing pressure, so the star collapses in on itself.

This sudden gravitational fall of matter into the core temporarily sends the temperature and pressure zooming. The star swells up and becomes a red giant for a while. Many stars that pass through the red giant stage cast off one or more shells of hydrogen and other gases. These shells balloon out and become *planetary nebulae.* (In spite of their name, they have nothing to do with planets.) The famous Ring Nebula in the constellation Lyra is a splendid planetary nebula. These gas shells cast off by a dying star glow with fluorescent light for 100,000 years before they fade.

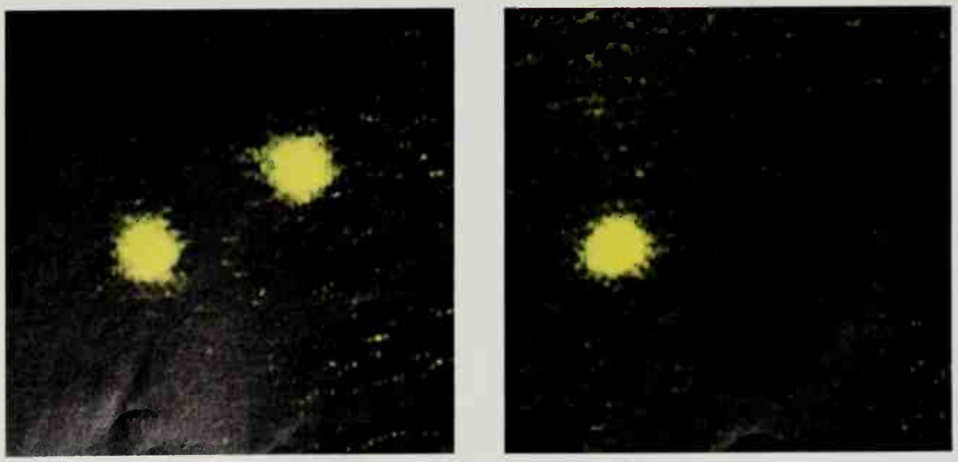
A lower main sequence dwarf star passes through the red giant stage and then slowly cools and contracts. Its nuclear furnace has been turned off for good. It now radiates heat and shines by the infall of its matter packing itself tighter in the core. Eventually the star shrinks to about the

The Horsehead Nebula rears up against a bright background in the constellation Orion, blocking out stars behind. Dark nebulae like this resemble other nebulae but lack stars to make them shine. Two centuries ago William Herschel thought they were holes in the heavens.

Like a celestial lighthouse, a spinning neutron star—called a pulsar—emits a strong radio beam that we detect as a pulse as it sweeps past Earth. When radio telescopes first picked up pulsar bursts in 1967, scientists thought they could be messages from space and called them LGM, "little green men." A pulsar's energy may come from a "hot spot" near its surface, at or above a magnetic pole. Some pulsars send out X rays, and two emit light waves also. Neutron stars are so dense, a teaspoonful of one would weigh a billion tons on Earth.



The Crab Nebula is the gas cloud left over from a supernova explosion in A.D. *1054. In the center lies the fastest-spinning pulsar known, a large star's crushed core. Photographed with another star (bottom), the pulsar flashes on (left) and off (right) in time with its radio pulses.*



size of Earth. It now has so little surface area from which to send out its energy that it shines with a faint white light. It has become a *white dwarf.* Over billions of years it continues to cool, gradually dims, and goes out, a *black dwarf.*

Higher up along the main sequence are medium-mass stars like the Sun. When such a star burns up its hydrogen fuel and collapses in on itself, it also swells up as a red giant. The core temperature zooms much higher than in a low-mass dwarf star, high enough so that the helium is fused into carbon and other elements. This burst of heat also causes a shell of hydrogen just outside the core to fuse into helium, so the red giant's nuclear furnace is still blazing away. Because the star lacks enough mass to keep the temperature high, the fusions stop and these medium-mass stars also collapse into white dwarfs and finally go out. But like less massive dwarfs, these medium-mass stars also may go through a planetary nebula stage.

Extremely massive stars—30 or more times more massive than the Sun—keep the fusion process going until their cores are almost pure iron. Wrapped around the iron core is a hot shell of silicon fusing into iron, then a less hot shell of carbon and oxygen fusing into silicon, then a still less hot shell of helium fusing into carbon and oxygen, then a cooler shell of hydrogen fusing into helium, and finally an outer atmosphere of hydrogen. At this stage the very massive dying star is a supergiant large enough to fill much of our Solar System.

As far as we know, elements heavier than iron—gold, lead, silver—cannot be

Can you imagine a star so massive that its gravitation eventually crushes it out of existence, leaving only a black hole in the sky? Many scientists can. In this artist's dramatization (opposite), a black hole's powerful gravitational field sucks in a light ray. A red star is beyond its reach.

What goes in never escapes a black hole. That includes light and other energy, so scientists can't observe one directly. But they have found a suspect (below). Called Cygnus X-1, it seems to pull gases off a companion star to form a rotating disk that heats up and emits detectable X rays.

fused in any star's core. Then where do the heavier elements of the Universe come from? A high-mass star with an iron core heated to a billion kelvins collapses, causing a catastrophic explosion known as a *supernova*. The Crab Nebula is the remnant of a supernova seen to explode in the year 1054. Such explosions are thought to produce all the known elements heavier than iron. Dying stars, then, are the element factories of the Universe.

Neutron stars

A supernova may leave an extremely dense core—a tightly packed ball of subatomic particles called neutrons. Because neutrons, unlike protons, do not have an electrical charge, they do not repel each other. Therefore they can be packed together extremely tightly. Stars that are from about one and a half to four times more massive than the Sun seem to become neutron stars—tiny super-dense objects only about 10 kilometers across.

Radio astronomers first detected neutron stars in 1967. Some exist in binary systems that release huge amounts of X rays. Others emit a continuous beam of radiation as they rapidly spin. Each time the beam crosses Earth, astronomers can detect a radio "pulse." These rotating neutron stars are called *pulsars*. The central bright object in the Crab Nebula is now known to be a pulsar rotating about 30 times a second. All pulsars slow down and are destined eventually to fade away.

Black holes—the end?

Stars even more massive than those that

become neutron stars have a strange fate in store—that of a *black hole*. One astronomer describes a black hole as an object which dug a hole, jumped in, and then pulled the hole in after itself! Some astronomers doubt that these mystery objects exist.

Those who do believe in black holes describe them this way. When a burned-out star, say one 10 times more massive than the Sun, shrinks to about 60 kilometers in diameter it becomes very special. It is so dense, and its gravity so strong, that virtually nothing can escape from it, not even light. At this great density the star disappears inside itself, or within its so-called *event horizon*. After a dying star contracts into a black hole, it continues to contract until it is a point called a *singularity*.

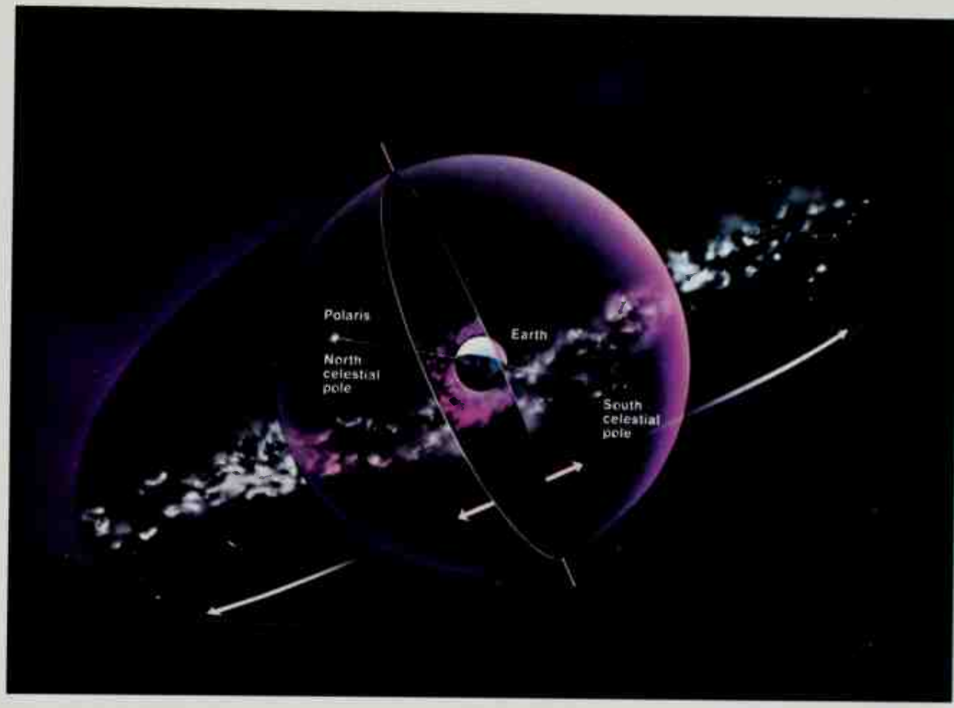
If energy cannot escape from a black hole, how do astronomers detect one? Gaseous matter pulled violently into a black hole from a nearby star seems to get heated to about a billion kelvins. Just before this matter disappears over the black hole's event horizon it sends out strong bursts of X rays. Such X-ray bursts seem to be the evidence of black holes. To date, the X-ray source known as Cygnus X-1 is the most promising candidate for a black hole, with a mass four to eight times that of the Sun. Some astronomers suspect that at the center of the galaxy M87 is a black hole one billion times more massive than the Sun.

Variable stars

Many stars go through cycles of brightening and dimming. They are then called *variable stars*. Over 25,000 have been catalogued, but most stars may become variables at some stage. They fall into three main groups: explosive, such as novae and supernovae; eclipsing, such as the Algol binary (page 225); and pulsating variables, which rhythmically swell up and shrink. What makes the latter go from bright to dim and then back to bright again in regular *periods* is not well understood. A few Mira-type variables, such as Mira itself (page 225), are visible to the naked eye, but most are too faint to be seen without a telescope. These are red giant or red supergiant stars with surface temperatures only about 2,000 kelvins and periods that range


North galactic pole
Arcturus
Spica
Polaris
North celestial pole
Vega
Antares
Galactic equator
Hadar
Alpha Centauri
Andromeda Galaxy
South celestial pole
Small Magellanic Cloud
Fomalhaut
Mira
South galactic pole

Because we're inside the Milky Way Galaxy (see page 239), what we see of the spiral arms around us is a cloudy band, also called the Milky Way, that stretches across the night sky. Think of a transparent sphere around Earth with all the visible stars fastened inside. If you slit the sphere and stretched it back (see below) you'd have a map something like this (left), with constellation shapes distorted at the edges of the projection. The equator extends along the plane of the Milky Way Galaxy. The Galaxy's center lies hidden, more than 30,000 light-years away.



from 80 to 1,000 days. When bright, a Mira variable emits about three times more energy than when dim, but its apparent brightness increases about 200 times.

We know of about 5,700 variables called RR Lyrae variables. These are white or yellow-white giant stars with short periods of less than a day. They all seem to have the same luminosity, thus the apparent brightness of such a star tells us how far away it is. The center of our galaxy and the globular clusters contain RR Lyrae variables. Since astronomers can find the distance to these variables, they can estimate the distance to the globular clusters.

The 900 or so Cepheids are the best known variables. They are huge, highly luminous stars with periods of a few days to about 50 days. These stars are so bright that astronomers use them as celestial "yardsticks" to estimate the distance to galaxies beyond our own. After a few million years of pulsating, a variable star may resume shining at a steady rate.

Exploring our galaxy

We live in a vast swirling city of stars called a *galaxy*. Our home galaxy is called the Milky Way, or the Galaxy, and is much like the Andromeda Galaxy (page 236).

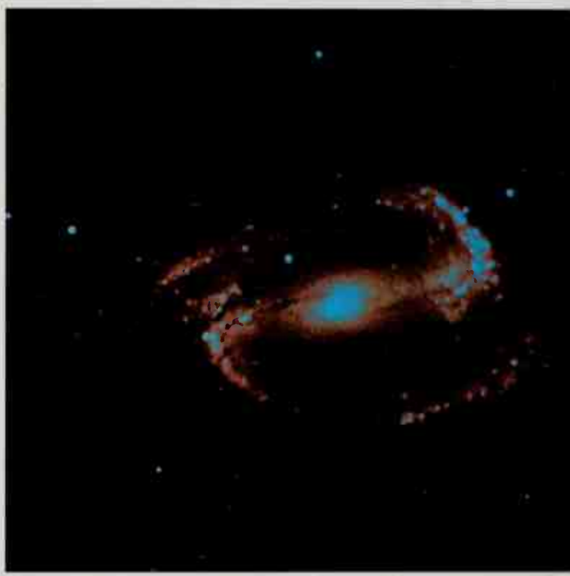
More luminous than 20 billion Suns, Andromeda Galaxy (opposite) looks from Earth like a thin cloud twice the size of our Moon. Astronomers used to wonder about this and other fuzzy patches in the sky. Were they "island universes" of their own? In 1924 Edwin Hubble proved they are other galaxies far beyond ours. He classed them as spiral, barred spiral, elliptical, irregular. Like our galaxy, Andromeda is a spiral; its two companions are elliptical. NGC 5128 is "peculiar" because of its dust lane. The Large Magellanic Cloud is nearest to Earth.

The Milky Way is a discus-shaped collection of about 200 billion stars. It stretches more than 100,000 light-years from edge to edge and is over 1,000 light-years thick. In addition to its stars, there are huge amounts of interstellar gas and dust and there may be untold billions of planets with their moons. At the center is the *galactic nucleus,* surrounded by a huge central bulge of stars about 10,000 light-years across. Around the fat galactic center is the thin *galactic disk* with stars of every description and age: stars now being born and stars ending their lives; open clusters of 100 to 1,000 stars—such as the Pleiades—born out of a single nebula; and a seemingly endless number of nebulae.

All of these objects are arranged in a pinwheel pattern of spiral arms. All revolve around the galactic nucleus, much as the planets revolve about the Sun. So Newton's law of gravitation works just as well for a galaxy as it does for an apple or a planetary system. Speeding along at some 220 kilometers a second, the Sun takes about 230 million years to circle the Galaxy once. This is a *galactic year*. Optical telescopes cannot see through the dense nebulae to the center of the Galaxy and beyond. But radio telescopes can penetrate the murky soup and map the distant corners of the Milky Way.

The spiral arms contain the blue giant stars and clouds of gas and dust—the birthplace of stars. Between the arms are the older Sunlike stars. Our Sun is out in the galactic suburbs some 30,000 light-years from the center. Our galaxy has a spherical halo of globular clusters, hundreds of

M33 Spiral



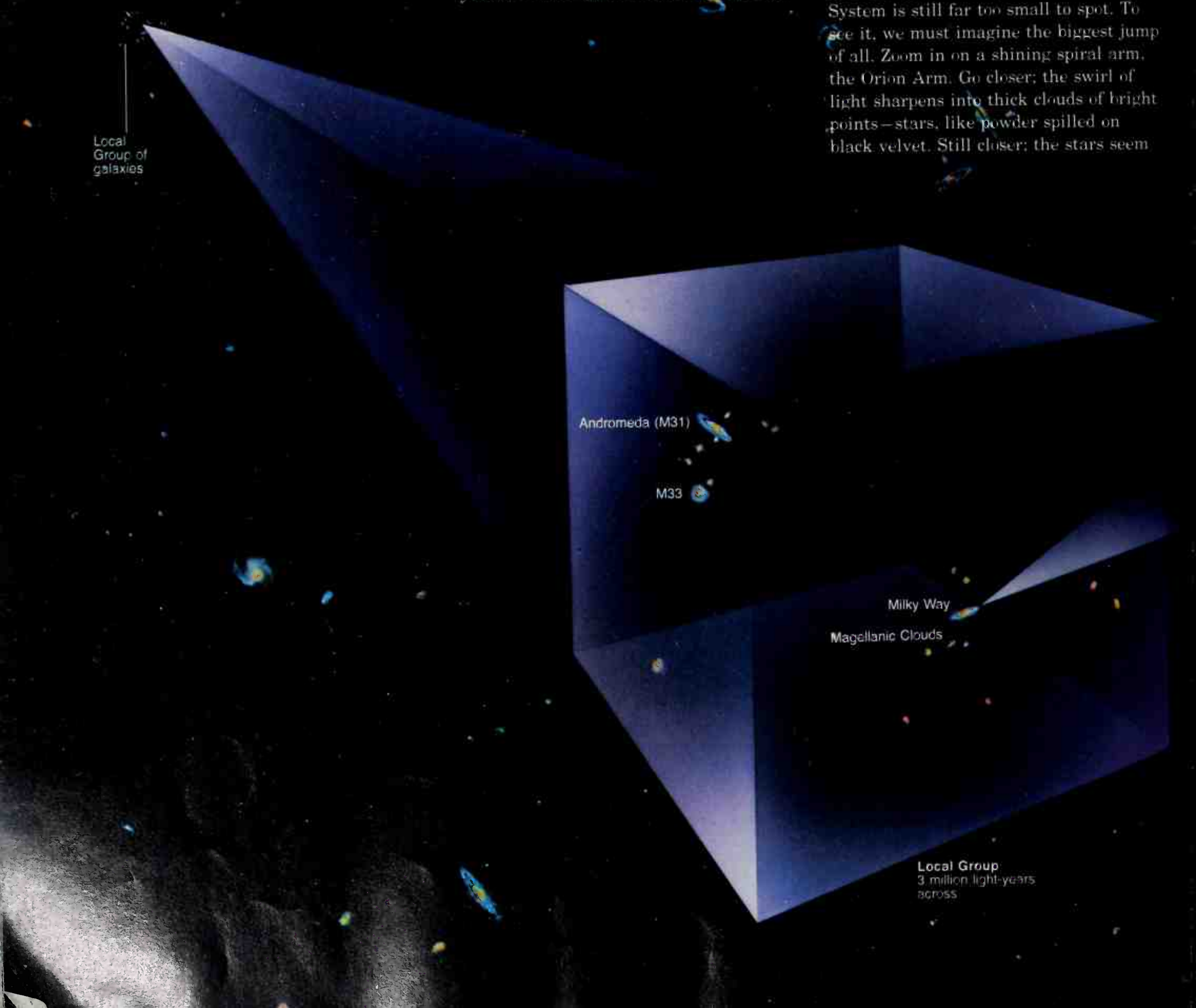
NGC 1300 Barred spiral

NGC 5128 Elliptical (peculiar)

Large Magellanic Cloud Irregular

One corner of the Universe

So vast is space, so insignificant our tiny corner of it, that we need a four-stage view—four leaps of scale—just to find the Solar System. The Universe extends from Earth for at least 10 billion light-years. In the background on these two pages, you see a mere sliver of the Universe, yet even the smallest dots are not stars, but entire galaxies. Think of seeing this scene in an imaginary telescope. Turn up the power and search. Our Local Group of galaxies pops into view (below). More magnification, and the Milky Way alone fills the eyepiece (right). But our Solar System is still far too small to spot. To see it, we must imagine the biggest jump of all. Zoom in on a shining spiral arm, the Orion Arm. Go closer; the swirl of light sharpens into thick clouds of bright points—stars, like powder spilled on black velvet. Still closer; the stars seem



to separate, parted by the light-years of emptiness between them, until one bright spark lies alone in the darkness: the Sun. But we must zoom nearer still before the planets finally appear (lower right). The area inside this circle is magnified *400 billion times* from our original view.

thousands to millions of stars. We know of about 125 clusters. They contain the oldest known stars in the Galaxy. Measurements of their age suggest that the Galaxy formed about 15 billion years ago.

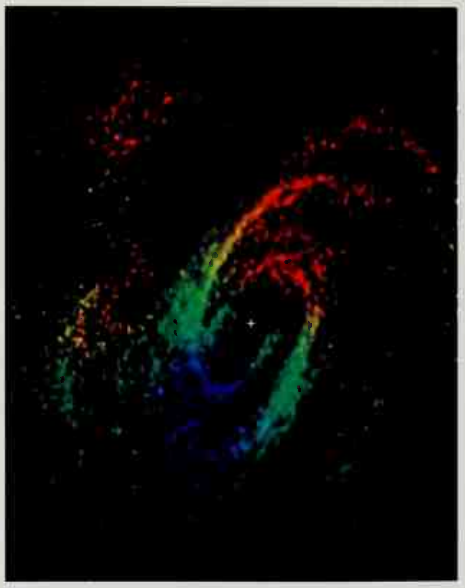
Galaxies galore

In the late 1700's William Herschel said that certain fuzzy patches which looked like nebulae might actually be galaxies. In 1924 the American astronomer Edwin Hubble, using the 100-inch Mount Wilson telescope, clearly showed that the so-called Andromeda "nebula" was actually a spiral galaxy far beyond our own. By the study of Cepheid variables, we know that Andromeda is about two million light-years away.

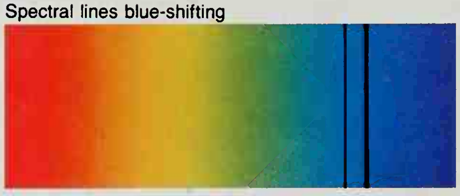
As stars differ from one another, so do galaxies. There are *spiral galaxies* like Andromeda and the Milky Way. While some have tightly wrapped arms, in others the arms are loosely wrapped. Spiral galaxies have reddish-orange centers because of the many old red giant stars located there. Red dwarfs make up about 90 percent of the stars in the galaxies, but are very faint. The young bright stars out in the disk contribute most of the light. Some spirals have bars running through their centers (like the barred spiral galaxy on page 237). There also are *elliptical galaxies,* some shaped like a football, others like a sphere. Elliptical galaxies also seem to contain mostly old stars.

Irregular galaxies, such as the Large Magellanic Cloud, have no special shape. *Peculiar galaxies* have some rare or particular feature—an exploding central region, for instance. Supergiant elliptical

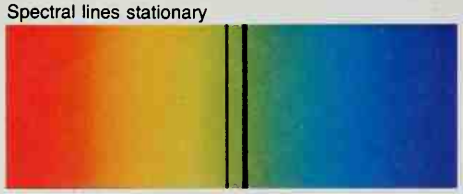
The spaceships (opposite) suggest what happens to the spectral lines of a star or galaxy zooming away from us or moving toward us: they shift to the red or blue end of the spectrum (see diagrams below). That's because of the Doppler effect—a change in light or sound wavelengths when their source moves in relation to the observer. The light waves of an object hurtling away through space will stretch into longer wavelengths, or "red-shift". In this color-coded radio map of a rotating galaxy (top picture) blue areas advance while red ones recede.



Spectral lines blue-shifting



Spectral lines stationary



Spectral lines red-shifting

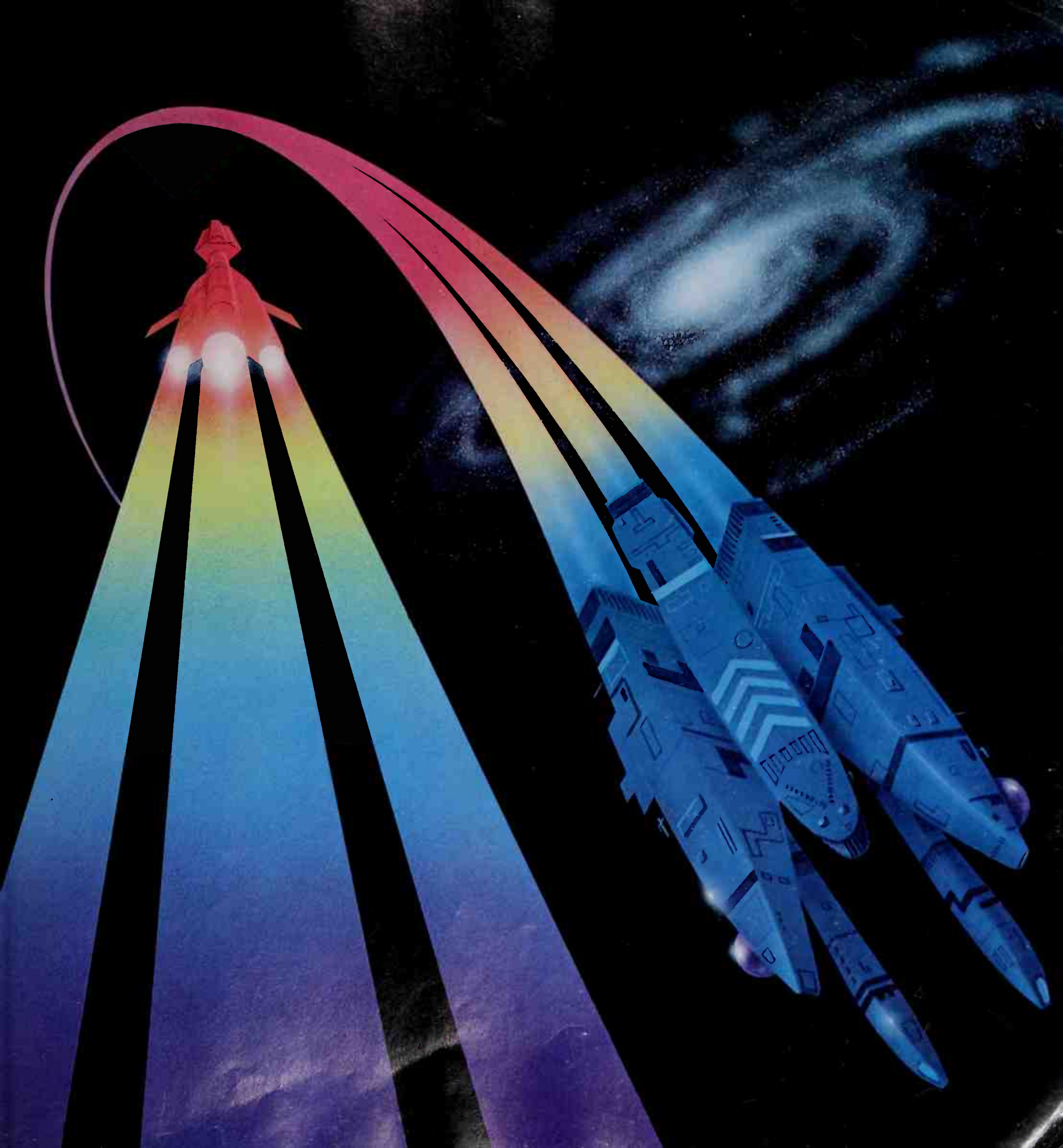
galaxies are the largest known, while some dwarf ellipticals are not much larger than a globular cluster. The dwarf ellipticals greatly outnumber the supergiant ellipticals, just as red dwarf stars greatly outnumber supergiant stars.

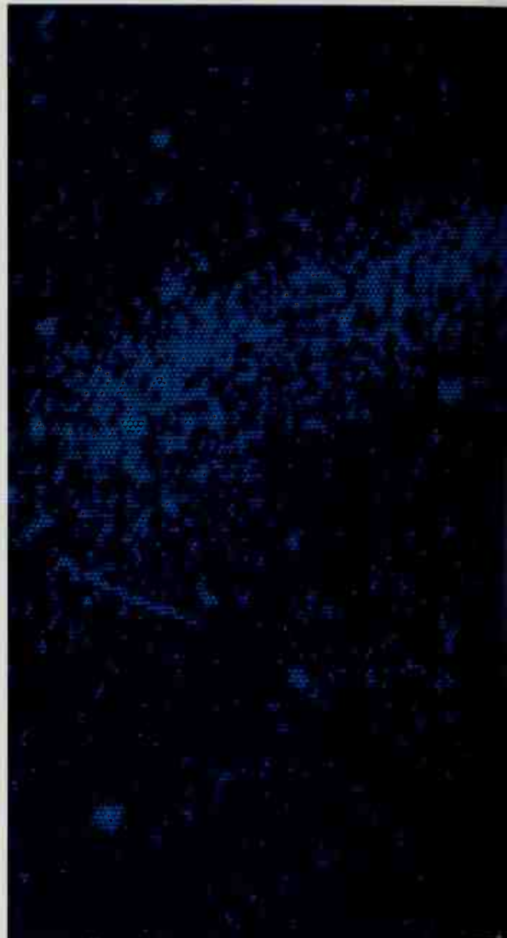
Most galaxies are arranged in large groups called *clusters*. The Andromeda Galaxy has two elliptical companions (see page 236) and the Milky Way has two irregular companions, the Large and Small Magellanic Clouds, visible only from the Southern Hemisphere. Our *Local Group* cluster of galaxies contains about 21 galaxies, more than half of which are ellipticals. The Local Group has a diameter of about three million light-years. Clusters of galaxies stretch off into space for as far as we can see with telescopes. Within 50 million light-years of us are many dozens similar in size to our Local Group.

Clusters of galaxies form superclusters. One supercluster in the constellation Hercules is thought to be 350 million light-years across. Possibly the system of clusters and superclusters continues into super-superclusters. So far as we can tell now, our lumpy Universe of galaxy clusters stretches off in every direction for at least 10 billion light-years.

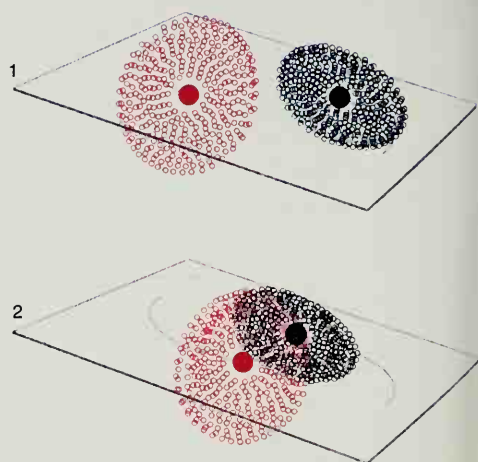
The runaway Universe

No matter which direction we look in space we see the same thing—countless billions of galaxies all rushing away from us. A person in any one of those other galaxies would see the same rushing-away motion. Around 1930 Hubble discovered that the farther away a galaxy is from Earth, the





Long "tails" give this pair of colliding galaxies a nickname: the Mice. Mutual gravitational forces pulled out tails and formed a bridge of stars, gas, and dust. A computer sequence (below) shows what can happen when two galaxies like these get close: Gravitation pulls their disks apart.



faster it is speeding away. For example, the Coma Cluster, 291 million light-years from us, is speeding away at 6,700 kilometers a second; the Leo Cluster, 847 million light-years distant, has a speed of 19,500 kilometers a second; and the Hydra Cluster, 2.6 billion light-years away, has a speed of 60,600 kilometers a second.

The real speed demons are the *quasars,* the most luminous objects known in the Universe. These mysterious points of light are the most distant things we can see and therefore have the highest red-shift velocity. They travel over 90 percent the speed of light—more than 270,000 kilometers a second. One quasar releases enough energy in one second to supply all of Earth's present electrical needs for a billion years.

So we live in a Universe that seems to be expanding at breakneck speed. What evidence do we have that the galaxies actually are rushing away from us? Just as astronomers photograph stars with a spectrograph to obtain the star's spectrum, they also photograph the spectrum of a galaxy. Such spectra show two dark lines produced by the element calcium. These dark lines are important bits of information. The light waves of an object speeding toward us get bunched up and its spectral lines shifted toward the violet end of the spectrum, away from their normal position. But the light waves of a galaxy speeding away from us get stretched out and are shifted down toward the red end of the spectrum. And that is just what happens to the dark calcium lines in the spectra of galaxies. The faster the runaway speed of the galaxy, the greater the red shift. For really distant objects, like quasars, other lines must be used. But all lines are shifted toward the red end of the spectrum.

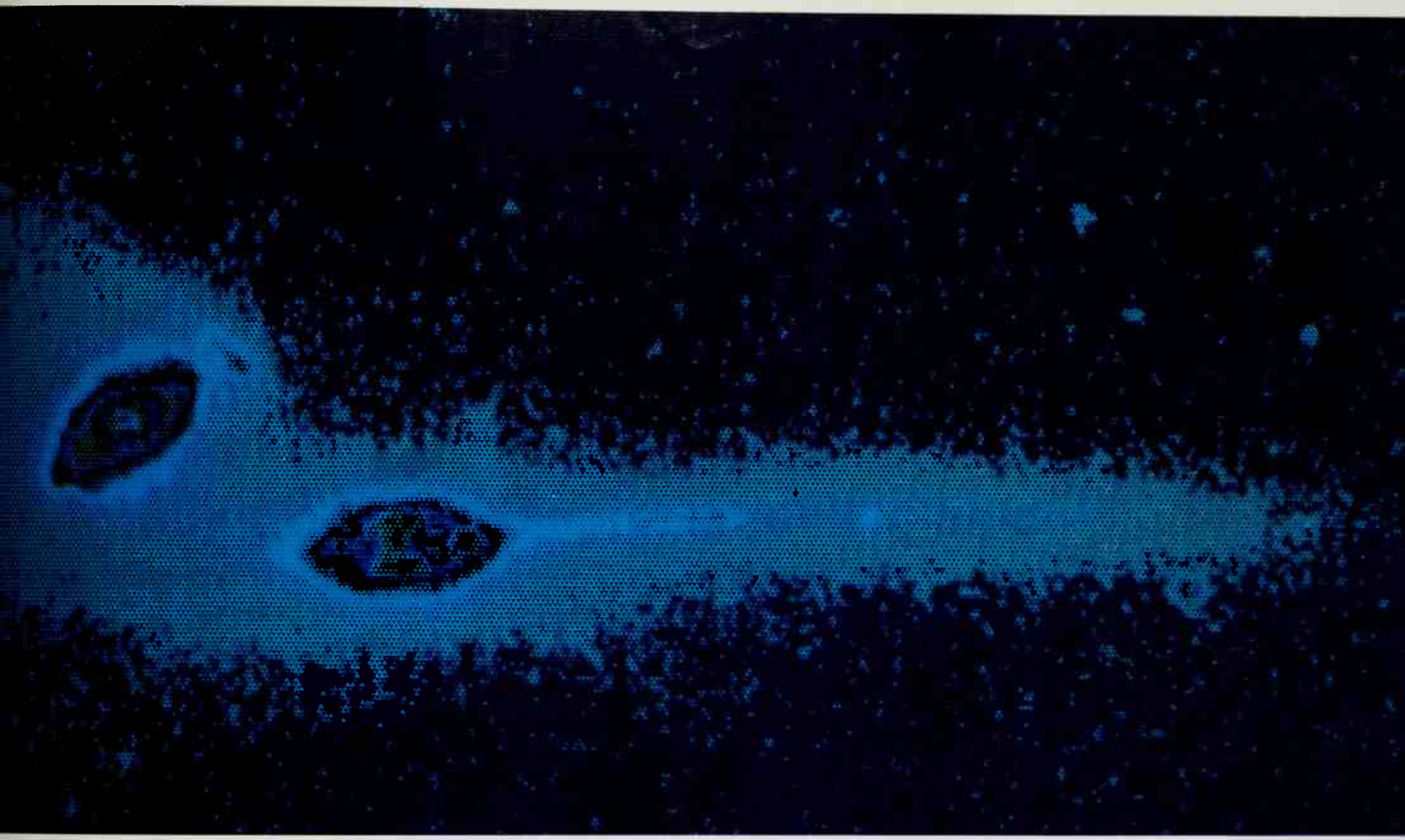
The Big Bang

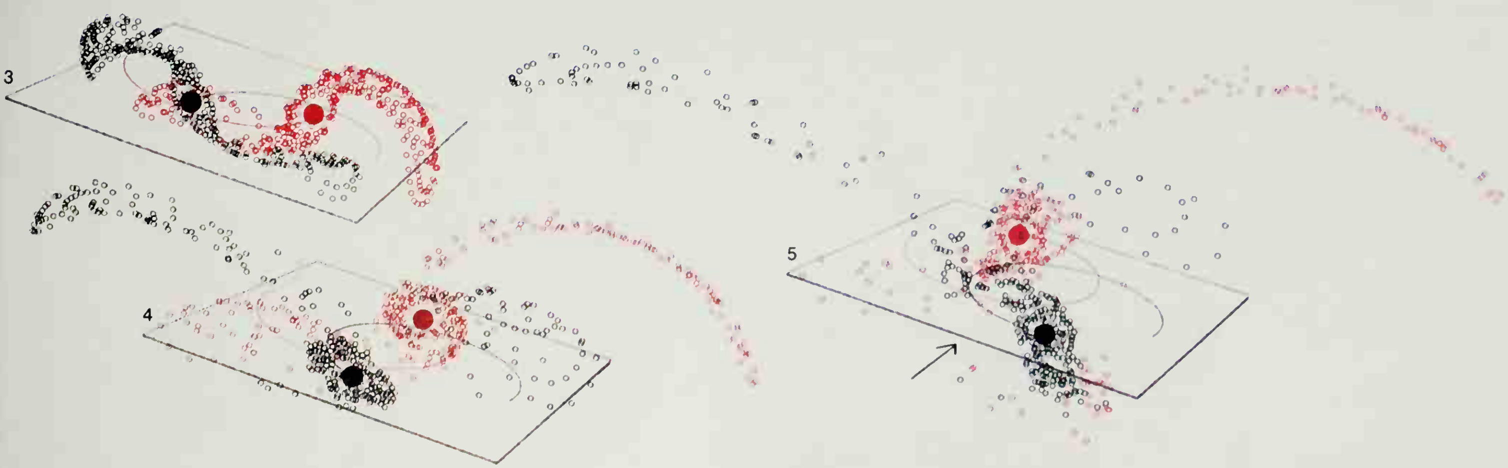
Has the Universe always been expanding? Will it go on expanding forever? Many astronomers favor the Big Bang explanation of the expansion of the Universe, first proposed in 1927 by Belgian cosmologist Georges Lemaître. According to the Big Bang theory, between 12 and 20 billion years ago the entire Universe was an incredibly dense "primeval atom." This "atom" exploded with tremendous force and all matter and space began expanding at speeds nearly that of light.

Between 100,000 and a million years after the Big Bang, enormous clouds of hydrogen and helium began to form. These were the only two elements in existence then. The clouds of gas became the protogalaxies. Eventually star formation began. It seems that all the galaxies formed during the first few billion years after the Big Bang. We do not know of any new ones. All seem to be 10 billion years old or more.

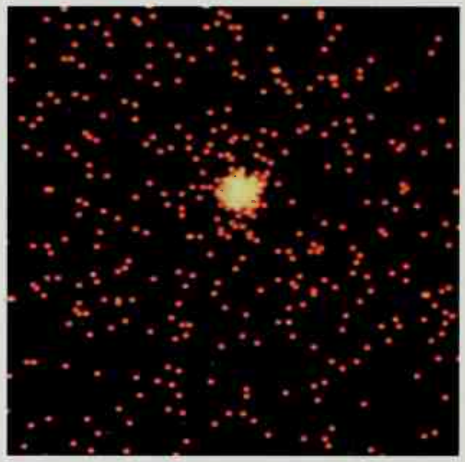
The first stars to form in those early galaxies were protostars of high mass, stars that became supernovae. On exploding, the supernovae enriched surrounding nebulae with heavy elements. Later generations of stars, like the Sun, formed out of these enriched nebulae and so contain a wide variety of elements.

Sometimes galaxies "collide." When they do they simply pass through each other, so great is the distance between individual stars. During such a sweep-through,




3
4
5

This X-ray image of a quasar was made by the Einstein Observatory (opposite). Quasars baffle scientists: They look like stars but emit more energy than a trillion Suns. High-energy observatories above our atmosphere study the radiation and probe the secrets of far-out objects.



the less massive galaxy may be cleaned of its gas and dust. Star formation can no longer take place there.

First the short-lived blue giants will flicker out, then the longer-lived yellow-white stars. Eventually the galaxy will glow dull red as the sole remaining stars, long-lived red dwarfs, themselves burn down and eventually leave the galaxy a dark, cold desolate place.

Will the Universe keep on expanding forever? Will something stop it? If the Universe is dense enough, gravitational attraction will slow down the expansion and reverse it, just as Earth's gravity slows down and reverses a handful of marbles tossed high into the air. Like the marbles, eventually the galaxies would slow down, stop and hang motionless for an instant, and then begin falling inward. Astronomers of the future would then see blue-shifted galaxies.

The Big Squeeze

If this happens all matter will tumble together again in the Big Squeeze billions of years from now. The Big Squeeze may form another cosmic egg that will explode in another Big Bang and start the process all over again. This is the oscillating Universe theory. Some astronomers call it the Bang-Bang-Bang theory.

One trouble with this idea of a Universe forming and destroying itself in cycles is that the Universe may not be dense enough to stop the present expansion. Perhaps we live in a Universe that will expand away forever and simply run down, never to be reborn.

Life in the Universe

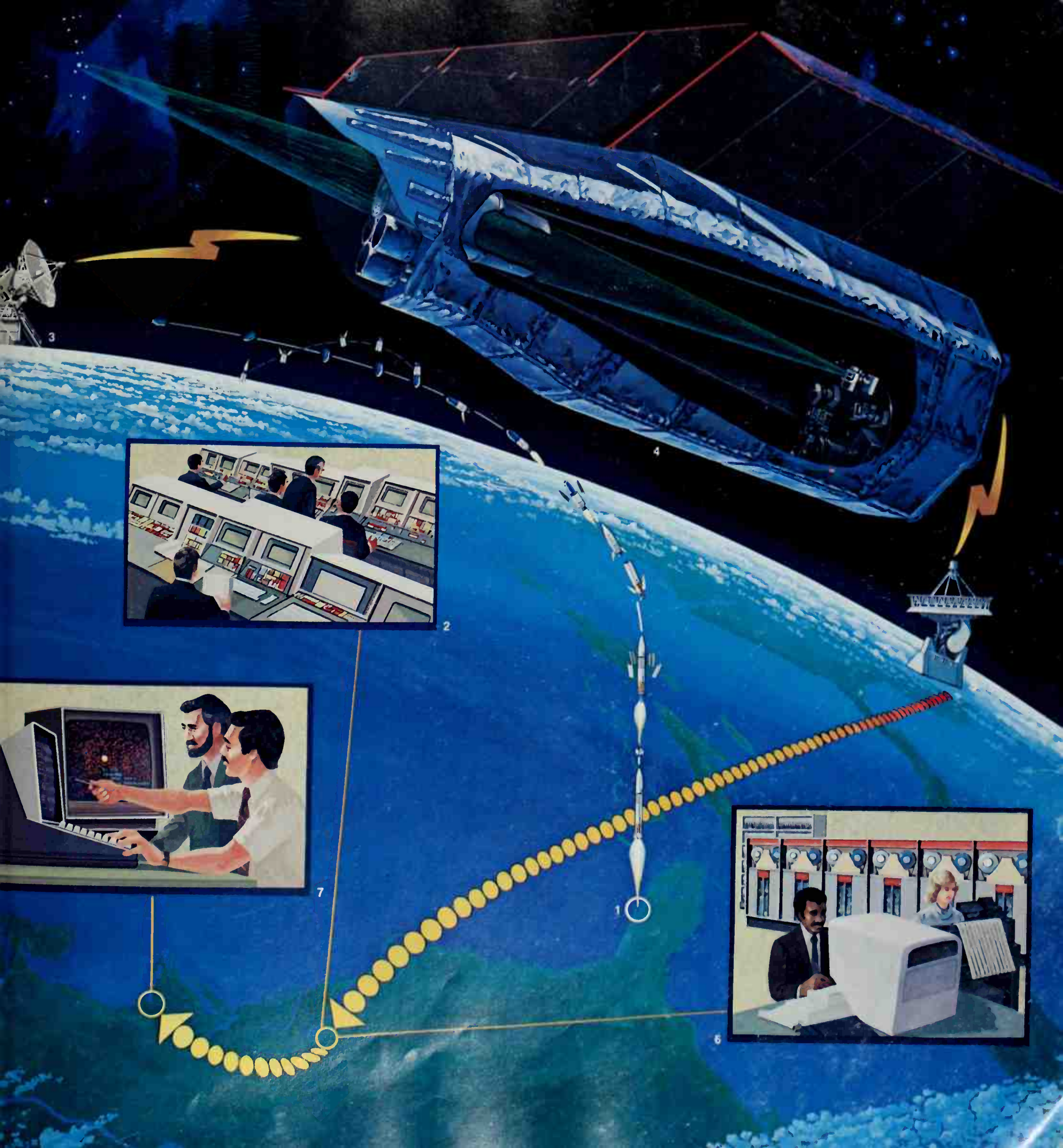
One of the most exciting questions we can ask is whether life exists on worlds other than our own. If so, what is it like?

Biologists looking into the origin of life on Earth have come to think that life may abound in our galaxy, and in other galaxies. Scientists have found evidence that bacteria and simple plantlike organisms existed on our planet some 3.5 billion years ago. Biologists think these organisms evolved from simpler nonliving matter. Then for about two billion years the plantlike organisms themselves evolved. Eventually they gave rise to the millions of plants and animals we find in the fossil record down through geologic time.

What conditions seem necessary for intelligent life to develop on a planet? First, a planet must not be too near or too far from its local star. If too near it will be too hot for certain life-giving molecules to form. And if too far it will be too cold for the liquid water needed for life-producing reactions. Another important thing is the planet's mass. Too much mass may lead to harsh conditions such as the atmosphere on Jupiter or Saturn, poisonous to the life we know. Too little mass may lead to different, but equally harsh, conditions such as the lack of atmosphere and the extreme temperatures on Mercury and the Moon.

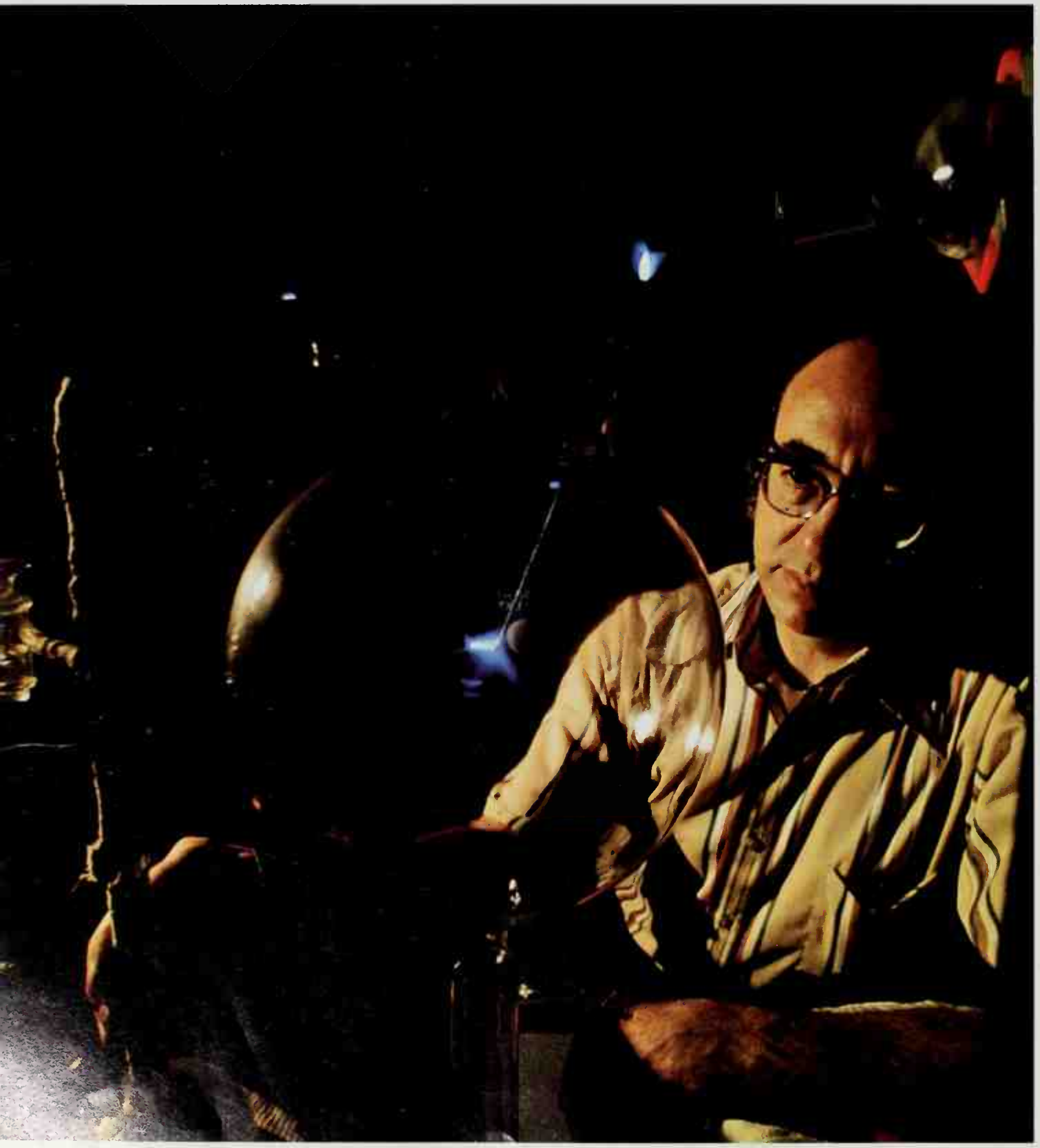
The kind of local star a planet has also is important. If it is a blue giant with a life span of only a few million years, the star will end its life before intelligent beings could evolve. If we use Earth as a model, a planet needs about four billion years

A High Energy Astronomy Observatory called Einstein orbits Earth, examining deep space for X-ray sources such as quasars. (1) Launched from Cape Canaveral, Florida, Einstein's booster section, insulation panels, and other auxiliary parts are jettisoned in stages until only the payload remains in orbit. (2) Controllers at Goddard Space Flight Center, Greenbelt, Maryland, direct the mission. (3) A radio antenna on Ascension Island in the South Atlantic Ocean links Einstein with Goddard. (4) Einstein's X-ray telescope receives signals from a quasar. (5) Einstein radios data to Earth, where it is received by a dish antenna such as this one in Quito, Ecuador. (6) Processors at Goddard assemble the data from Quito, then relay it by tape and telephone circuit to (7) the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. There a computer displays the data as a TV image of the quasar above.



3
4
2
7
1
6

How did life on Earth begin? In a laboratory experiment Stanley Miller mixed gases of our primitive atmosphere—hydrogen, ammonia, and methane—with steam, and sparked them with electricity to simulate lightning. Result: amino acids, the building blocks of life on Earth.



to develop a technological civilization.

In spite of these needs, some astronomers estimate that in our galaxy alone there are hundreds of millions of planets able to support a technological civilization. They also think there are now about a million civilizations at or beyond Earth's level. Other astronomers doubt this.

Can we expect other life, if it exists out there in the Universe, to be like ours? We might expect to find certain general likenesses based on the biological principles we know—the kinds of molecules that make up an organism and the way the organism's chemistry works. Although we might expect to find organisms that walk on legs, swim, crawl, or fly, we should not expect to find pigeons, dogs, or humans on any other planet in the Universe.

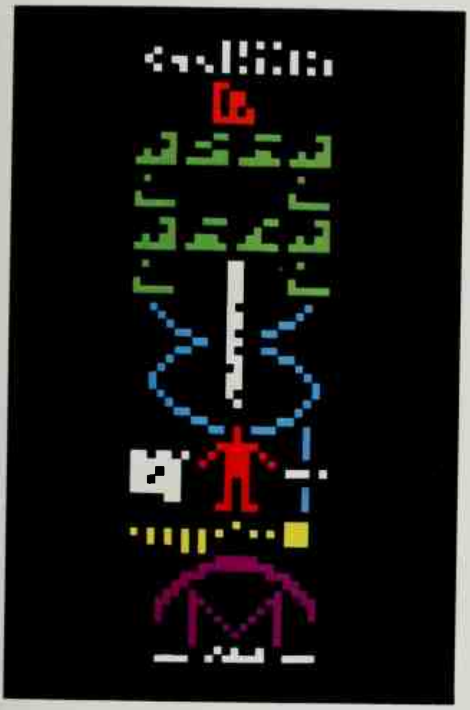
Like Earth, other planets with life would change continually through the ages. And no two are likely to change in the same way. This means that evolution is not likely to follow identical pathways on any two planets, or ever to repeat the same pathway on any one planet. No, it is almost certain that there cannot be even one carbon copy of Earth life anywhere else in the Universe. There may be intelligence, love, even wisdom, but nowhere should we expect it to wear a human shape.

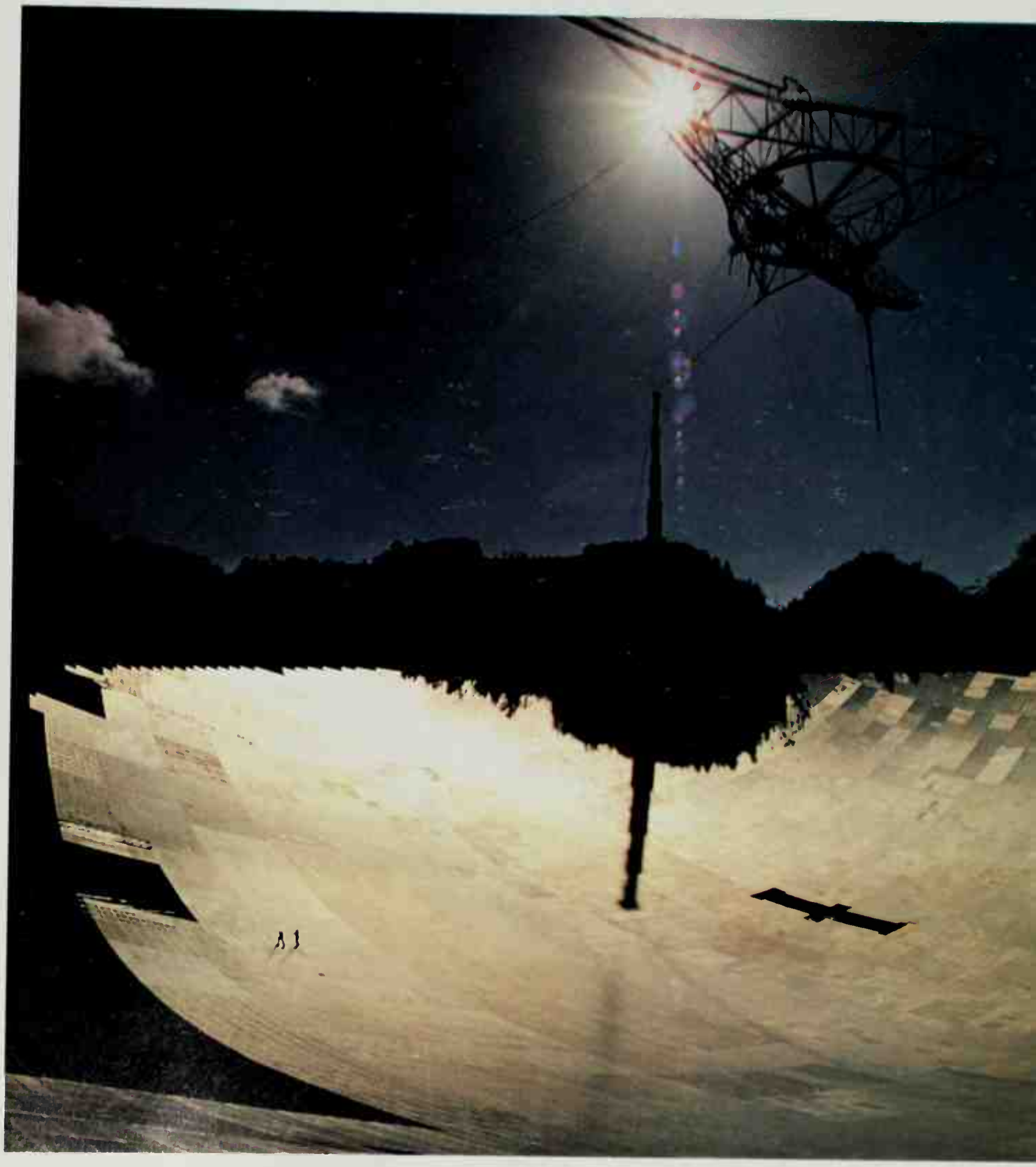
"Hello, out there"

If there are other intelligent beings out there in the dark, will we ever be able to communicate with them? And if so, how?

Radio telescopes are our interstellar telephones. Their signals travel at the speed of light. Since our cosmic "hello"

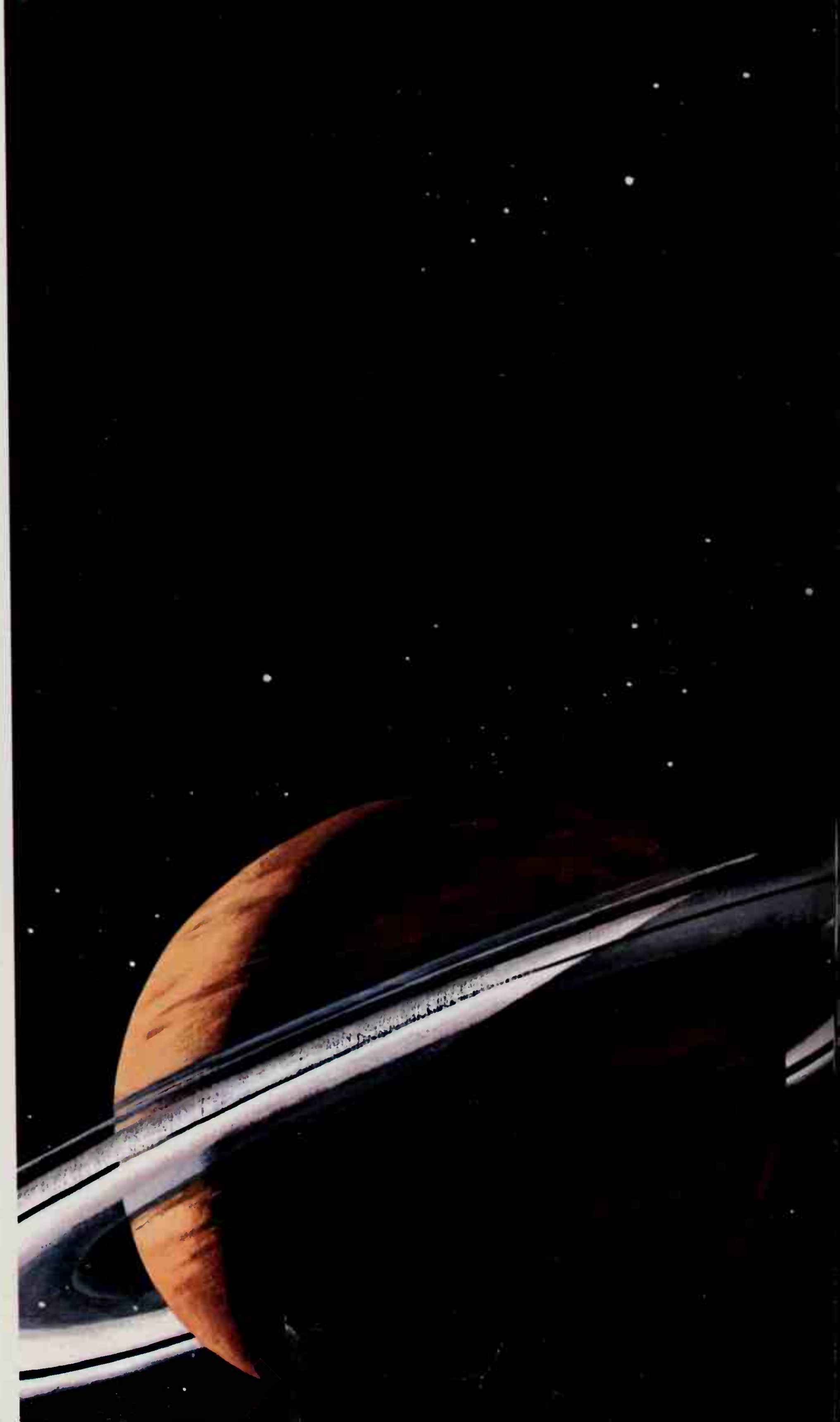
If intelligent beings are out there, maybe they will learn about us someday. In 1974 the giant radio telescope at Arecibo, Puerto Rico (right), sent a coded message into space. Shown here in a decoded image, the message begins at the top with binary numbers 1 to 10 and the atomic numbers of major elements. Green, white, and blue describe DNA, the molecule that determines heredity. Marks on either side of the human figure tell its height and Earth's population. The Solar System is yellow. Outlined at the bottom is the Arecibo telescope with its size.





cannot travel faster than light, we would do well to beam a message at a nearby star if we expect to receive a reply in our lifetime.

Within a distance of 100 light-years from us are some 10,000 stars. One out of every 200 may have an Earthlike planet. So there may be about 50 such planets only 100 light-years away. But at that distance it would take 200 years to exchange a message! Staying closer to home, within 20 light-years from us are 15 stars like the Sun. Some may have Earthlike planets. The nearest stars to us are those of the Alpha Centauri star system. It would take our message four years and four months to



Voyager 1 swings by Saturn in 1980, carrying a message encased on its side. If spacefarers encounter Voyager among the stars, they can see electronic photographs and hear Earth sounds: Rain, surf, a train whistle, laughter, a kiss, barking dogs, music, greetings in 55 languages.

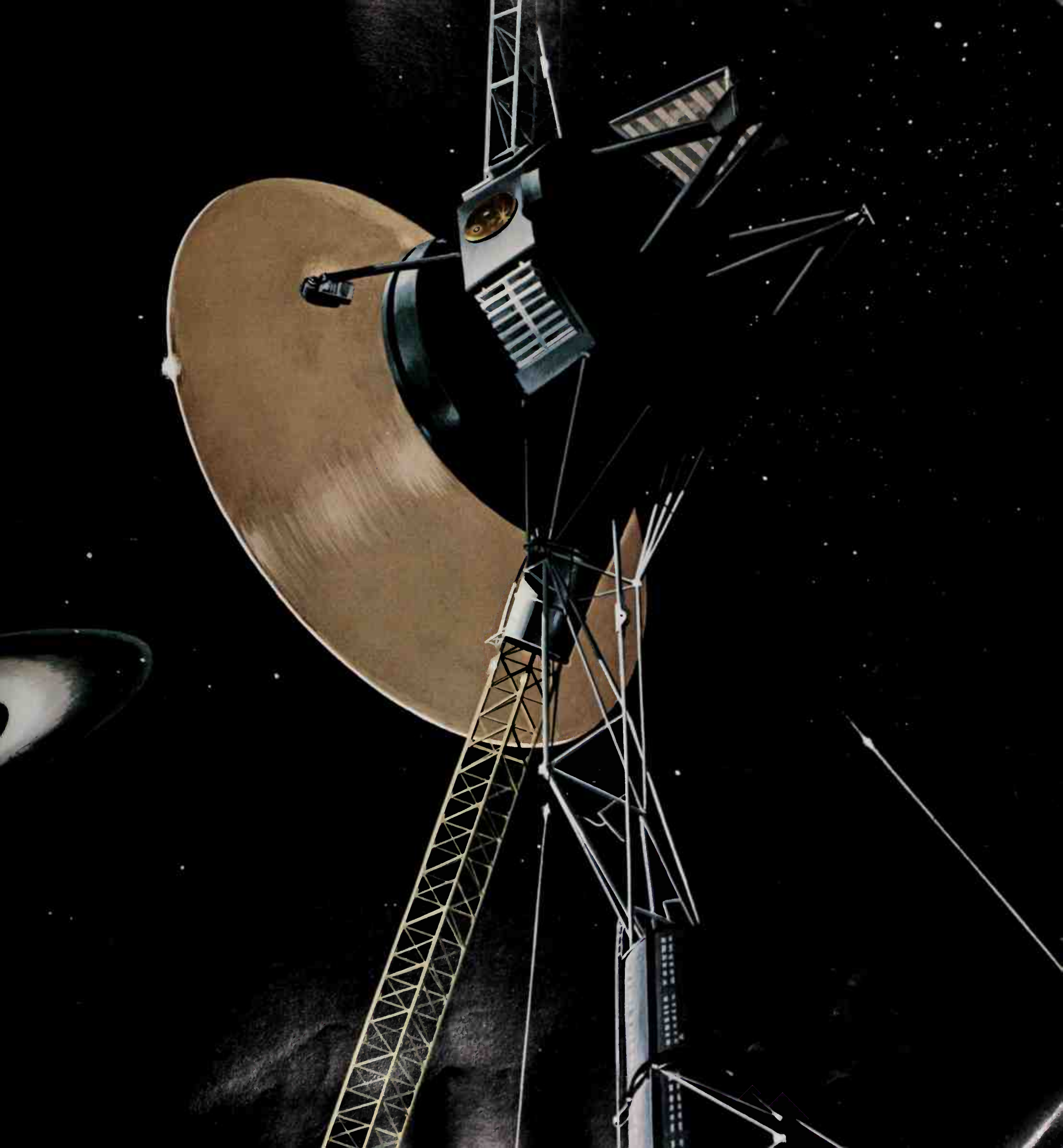
reach Alpha Centauri, then another four years and four months for an Alpha Centaurian radio astronomer to answer.

For three months in 1960 a radio telescope at the National Radio Astronomy Observatory at Green Bank, West Virginia, was tuned in to the nearby stars Tau Ceti (11.9 light-years away) and Epsilon Eridani (10.7 light-years). The astronomer in charge, Frank Drake, named his project Ozma, "for the princess of the imaginary land of Oz, a place very far away, difficult to reach, and populated by exotic beings." During his short listening period Drake did not hear a single intelligent whisper. Since 1960 other listening posts have been set up, and some operate regularly. So we *are* listening.

Even so, expecting to pick up an interstellar greeting is like expecting to find that needle in the haystack. To stand just a fair chance of picking up a message we would have to tune in on 200,000 stars. So far we have listened to only a few hundred.

Perhaps some day alien radio astronomers will receive the Arecibo message (page 247) beamed to the Great Cluster in Hercules, 21,000 light-years away, in 1974. If they answer, their reply will not reach Earth for 42,000 years!

Meanwhile we keep listening to likely stars in hopes of receiving a cosmic greeting—perhaps from an Earthlike planet thousands of light-years away, whose civilization no longer exists. No matter. If we ever do receive such a message it will be the most exciting event in the history of life on Earth, for it will tell us that we are not alone in the Universe.



The Future

Shuttles & Starships

Taking off as a rocket, it orbits Earth as a spaceship, and lands back on Earth as a heavy glider. It's the 37-meter-long space shuttle, a cosmic pickup truck designed to carry almost 30 tons of communications or weather satellites, a 9-ton space telescope, and other spacecraft, and place them in orbit around Earth.

The astronaut crew member of the orbiting shuttle shown here is maneuvering into position to perform maintenance chores on a telescope satellite. A backpack equipped with small thruster jets enables the astronaut to move in any direction with precision.

Far in the future, shuttle spacecraft will have many tasks. They probably will ferry assembled parts of Earth-orbiting space cities housing a thousand or more people, and components of settlements on the Moon, Mars, and moons of Jupiter and Saturn. Later will come the design and construction of spacecraft able to cross the still greater distances to remote Neptune and ice-encrusted Pluto and return. These planets, too, are bound to be explored during the coming century.

Is this idle dreaming? Perhaps it would have been, a hundred years ago, but not today. We now have the technology for such

A shuttle mock-up stands on a launch pad in Florida. A plane-like orbiter clings to a tank that fuels its engines at launch. At its sides are two boosters, the most powerful solid-fuel rockets ever to lift humans into space. All but the tank can be reused; when empty it drops to the sea.

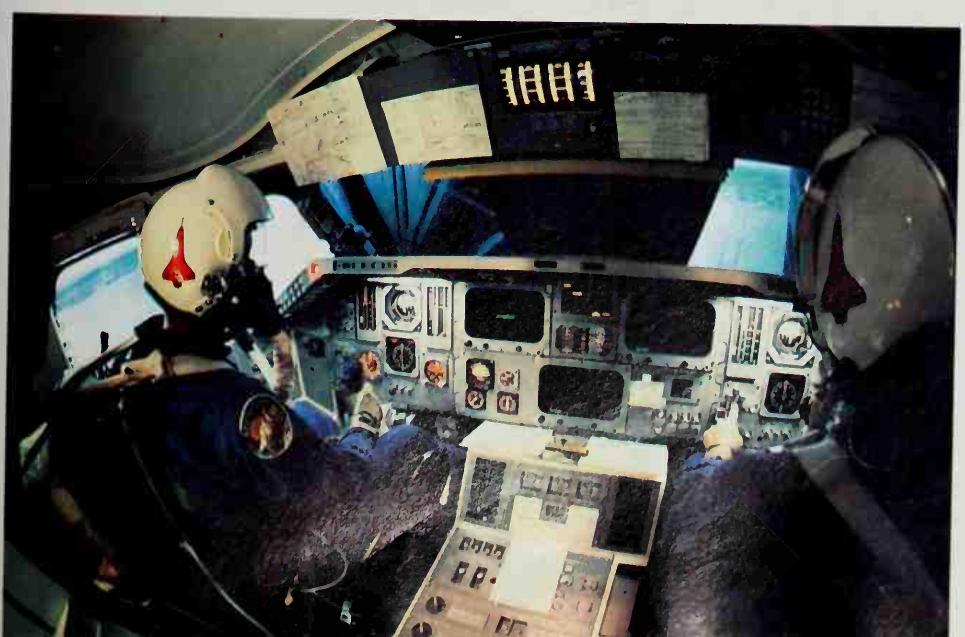
exploration. And we have enjoyed a taste of space. The human will to explore even deeper cannot be denied.

The next leap begins, not in deep space, but in the low Earth orbit typical of our earliest space efforts. There NASA's space shuttles will circuit the globe, loaded with experiments, satellites, and space probes that are the cooperative venture of many nations. The first 40 shuttle flights are already booked: Governments, universities, and private companies have reserved all space available for scientific experiments. Probes will be launched on many missions. They will catch up to a comet to see what it's made of, plunge into Jupiter's blanket of gases to study its density and composition, pierce the clouds of Venus to photograph and map that mysterious planet.

Springboard to space

Eventually, advanced shuttle craft will carry workers and materials high above Earth to begin the next chapter in space exploration, the building of the first permanent space structures: manufacturing plants, laboratories, solar power stations, and, in time, the first space settlement.

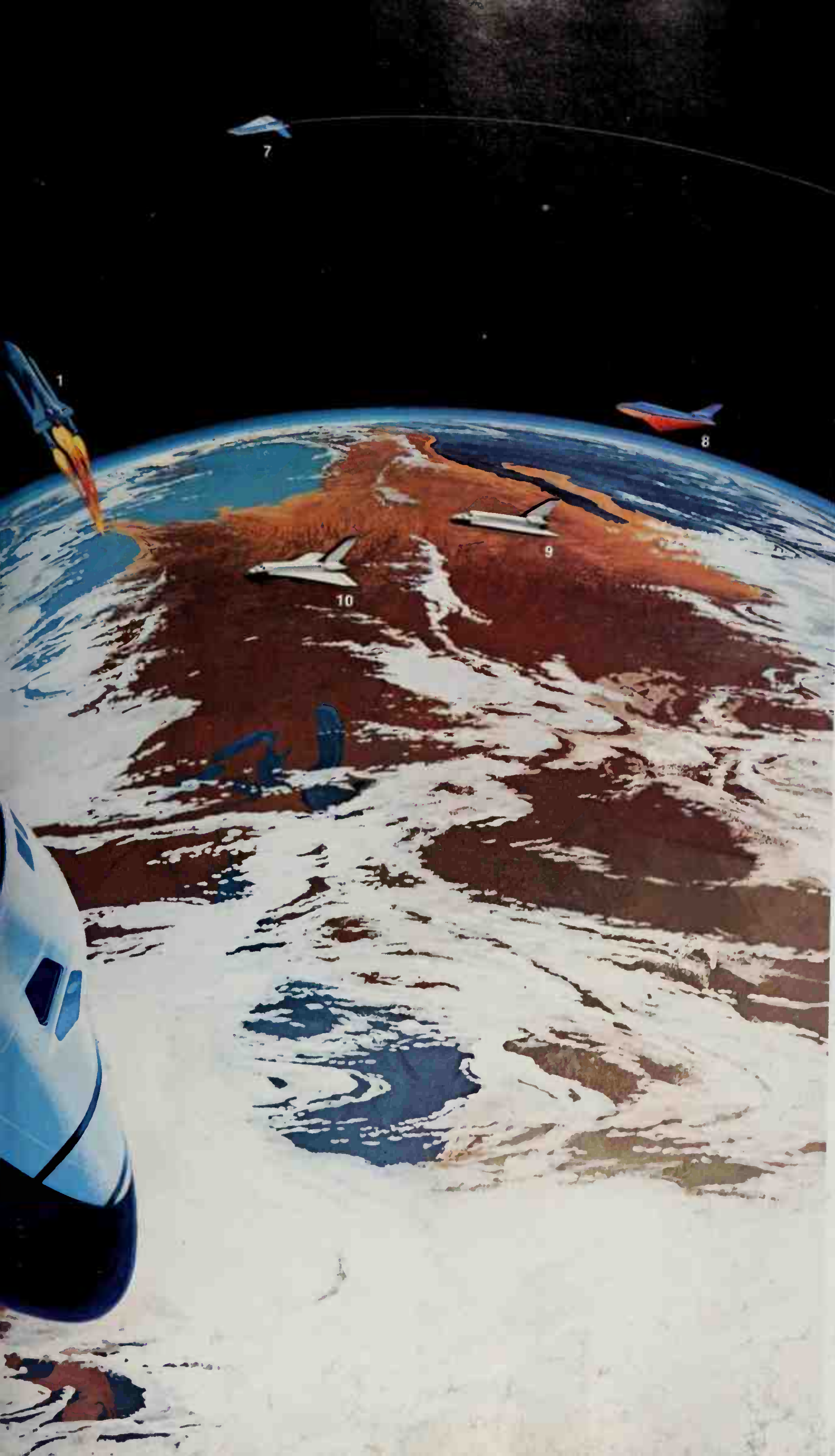
In 1975 some 30 scientists and engineers met for a 10-week NASA study program to design a city in space. In their design, millions of tons of raw materials from mines on the Moon and asteroids will be used to construct a gigantic circular tube—a wheel nearly two kilometers across (see pages 260-261). This tube, called a torus, is designed to house 10,000 people. They will lead normal lives, working, playing, raising families and flower gardens, going to



A light moment eases tough training as shuttle crewmen pretend to be weightless in a mock-up of a spacelab. Built by the European Space Agency, spacelabs will ride shuttles into orbit and back to Earth.

Sounds, instrument readings, the motion of flight, even the view out the windows surround Earthbound astronauts with realism as they learn in a simulator (left) to fly the orbiter in space. On windows that are video screens, computers "paint" moving scenery from launch to landing. Linked to controls and gauges—and to tracking stations worldwide—computers test the team with mock emergencies.


USA
2
4
3
11
5
6
13
USA



schools, theaters, and sports arenas. The colonists will breathe an Earthlike atmosphere and, because the wheel will rotate at the rate of once a minute, they will feel at home in the normal Earth gravity produced by the spinning of the wheel. Eventually their city in the sky will be self-sufficient.

Space colonists could construct solar power satellites large enough to supply all the energy Earth needs. Space factories, detached from the settlement or located at the wheel's hub, could produce a host of articles to near-perfection in a state of zero gravity. Gigantic instruments for astronomy could be built – radio telescopes many kilometers across, enormous optical telescopes. New spacecraft cities could also be

Each space shuttle may make as many as 100 missions, in about this sequence: (1) Seven seconds after launch, shuttle begins roll to tail-down attitude. (2) In 2 minutes, boosters separate about 50 km up. (3) Boosters parachute to sea for recovery. (4) Main engines continue to about 110 km up. (5) After 8 minutes, main engines stop; empty tank separates; small engines thrust craft into orbit. (6) Tank falls into Indian Ocean. (7) Orbiter coasts in equatorial orbit about 275 km up. (8) Mission complete, parts of orbiter glow with heat of entry into atmosphere. (9) Orbiter glides toward landing site. (10) Wheels extend just before touchdown.

Crew in orbit (11) works in pressurized spacelab. Cabin and flight deck (12) connect with lab by tunnel. On another mission, orbiter's manipulator arm (13) lifts satellite from hold, puts it in orbit.

Shedding its red-hot heat shield, a probe plummets into Jupiter's clouds to sample the atmosphere until crushed by its pressure. A second craft parks in orbit to relay data to Earth. Named Galileo, the mission—like others pictured here—would be launched from a space shuttle.

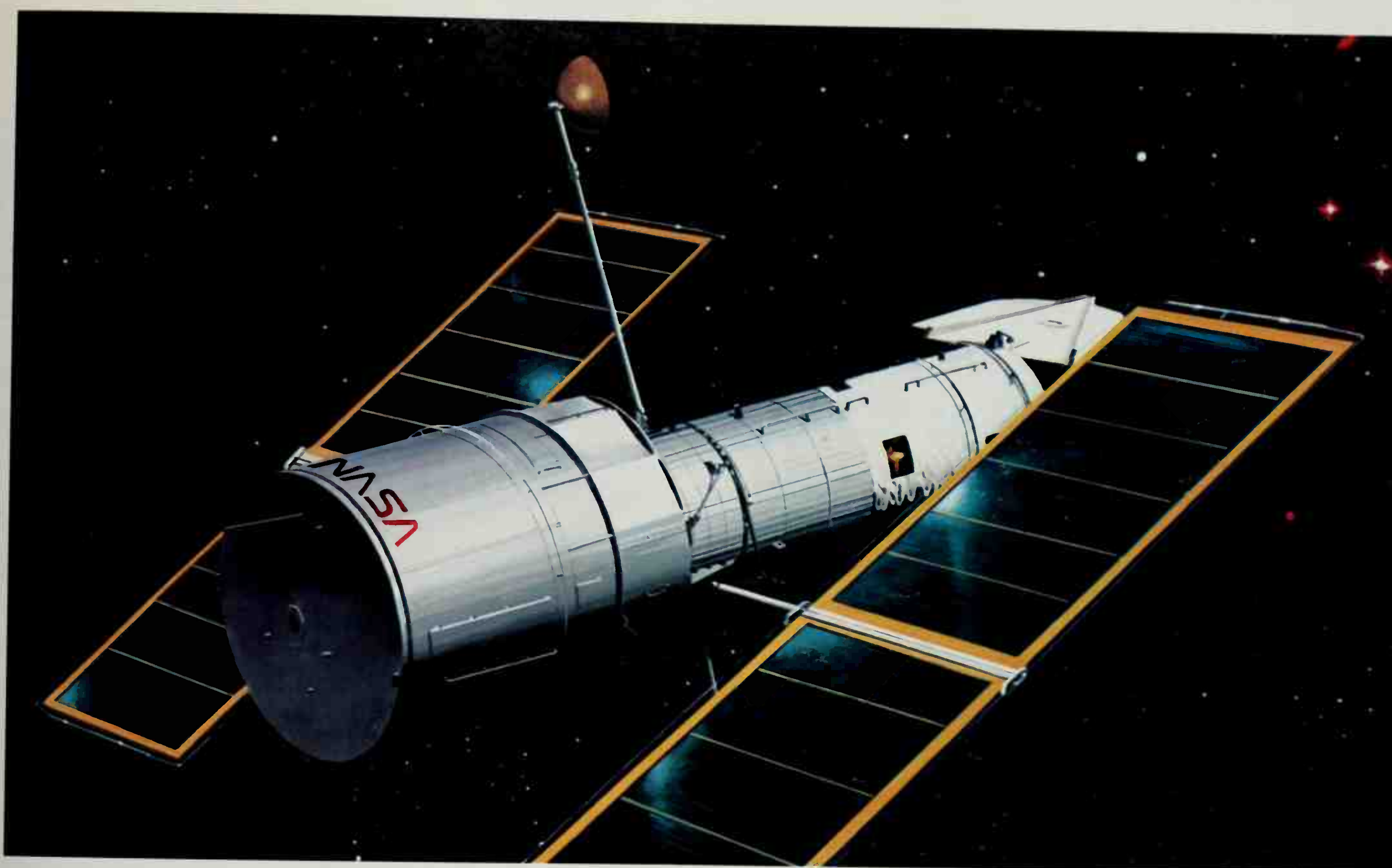
built to carry people far from Earth. Some of these sky-islands might explore the ultimate frontier—intergalactic space.

Tomorrow's starships may be propelled by a process known as controlled fusion. (Page 61 explains fusion.) Laser (electron) beams would be focused on tiny pellets of liquefied fuel to squeeze molecules together under such great pressure that fusion begins, releasing energy to power the ship.

The laws of physics tell us that there is a speed limit we cannot exceed or even reach—the speed of light. Since light from even some nearby stars takes many years to reach us, a starship traveling at the snail's pace of today's fastest spacecraft would take millions of years to journey to one of those nearby stars and return.

Breaking the time barrier

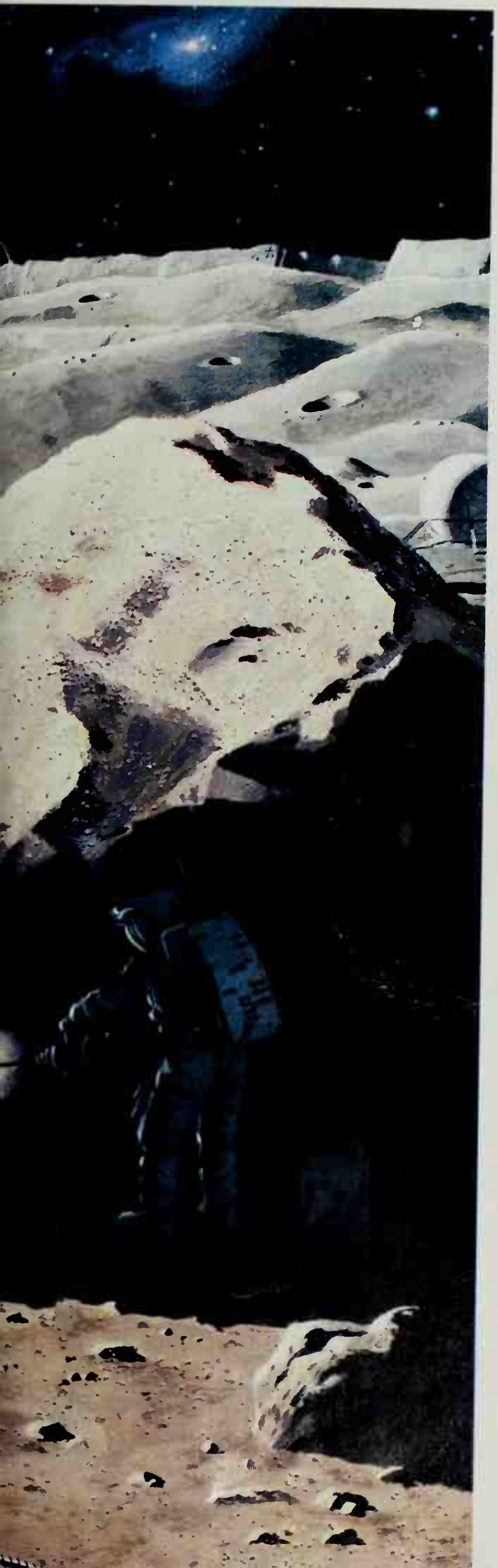
Right now we know of no way to break this barrier. But can we someday? As Apollo astronaut Michael Collins says in the Foreword to this book, experts once believed we would never break the sound "barrier," but we did. Perhaps there is a way of cheating time. We have evidence that as space travelers approached the speed of light, time would slow down for them. This is called *time dilation* and is part of Einstein's special theory of relativity. Suppose a starship crew voyaged to the star Mira, about 100 light-years away. If they traveled at 99 percent the speed of light they would make the round trip in only 28 years their time. But on returning home they would find that their friends were not 28 but 200 years older! Because of time dilation, starship crews will be able to explore the far reaches



In orbit 500 km up, a telescope of the future opens its eye to wonders unseen by Earth telescopes. With no atmosphere to mar its view, it can study 350 times the volume of space ever seen before, peering to the edge of the observable Universe. With shuttle crews servicing it, the space telescope should last at least 20 years.

A comet-chaser greets its target with open arms, each covered with solar cells that power its electric drive system. Such a spacecraft could examine the chemical and physical makeup of a comet's coma, nucleus, and tail. It would also give us clues to the origin of the Solar System.


4
UNITED STATES
10



On the Moon's far side, a research base seeks data above and below. Free of Earth's radio noise, dish antennas listen for signals from space. An observatory scans the airless sky. Geologists drill rock samples, then ride a rover to homes and labs buried in protective coats of dirt.

Prospectors of the 21st century hitch up to an asteroid and scout its mineral wealth. They may mine it on the spot, or tow it to a space factory better equipped to extract its deposits of metals, carbon, possibly water—necessary raw materials for a zero-gravity manufacturing plant.

of the Milky Way, and even distant galaxies, and return in their lifetime.

Setting out for the stars

Now let's go back to one of our space settlements that has existed near Earth for several generations. We find that the majority of the inhabitants have voted to embark on stellar travel. The group decides to build up speed gradually at a comfortable acceleration rate of one g. The term *g* stands for one unit of gravity, which is the amount you feel when you stand still on Earth's surface. When you take off in a jet liner you are pushed back in your seat with a force of less than one g. When the Apollo astronauts re-entered Earth's atmosphere they experienced about six g's. For a short time that many g's isn't harmful but it is very uncomfortable—your face sags, your skin pulls, your arms and legs feel as heavy as lead. Accelerating the starship with a force of one g would cause no problem for our space travelers.

A stellar timetable

They decide to make a round trip to the star Epsilon Eridani, 11 light-years away, which they have reason to believe may have a habitable planet. The voyage out

Cities in space may look like big bicycle wheels, each with a free-floating mirror to gather in sunlight (left). High-rise spokes contain shops, labs, and offices. Transport tubes whisk the city's 10,000 residents between homes in the outer tube—or torus—and work and play areas at the hub. A long tube links the wheel with a spacecraft dock, power plant, and factory unit. Like tread on a tire, Moon rock shields the torus from meteoroids and radiation. Inside, farm workers adjust water and nutrients (below) for crops ripening in soil-less racks.

and back would take 10 years their time, but on Earth 22 years would have passed. Longer round trips would follow the same kind of timetable. To travel to the center of our galaxy, 30,000 light-years away, and back would take 40 years starship time but 60,000 years of Earth time would have passed. The Andromeda Galaxy is two million light-years away. To travel there and back would require 55 years by starship while on Earth four million years would go by.

As the spaceship heads toward Epsilon Eridani, it will be speeding into the light waves of the star, just as a fast boat speeds through waves on a lake. For the starship crew, the frequency of the light waves (the rate at which they pass the starship) will increase as the starship speed increases. In the same way, the frequency of water waves striking the boat increases as the speed of the boat increases.

Because they are accelerating *toward* the light source, the starship crew will see the light from Epsilon Eridani blue-shifted, or shifted toward the violet end of the spectrum. This is the Doppler effect (see pages 28-29 and 241). The crew will see the star change color, although the star itself is not actually changing. At first the star will appear yellowish, as it does from Earth. Then, as the starship speeds up, the light will shift through higher frequencies into the green region of the spectrum, then into blue, and then violet.

At still faster speeds, Epsilon Eridani will be seen to shine with a pure violet light. Then it will fade as its light shifts off the visible spectrum into the ultraviolet.

Boxy robot craft called wardens tend the fuel globes of an unmanned Daedalus starship. Two Enzmann starships wait nearby, each with its huge ball of frozen deuterium linked by manned modules to nuclear-pulse engines. Two designs, one goal: to reach a nearby star.

The star has become almost invisible, although it is still there!

Just the opposite happens when the travelers look homeward toward the Sun. Its light waves are not being crowded up. They are being stretched out to lower frequencies and are red-shifted. Gradually the familiar yellowish Sun will appear orange and then deep red. Then it will fade from view as its light shifts off the visible spectrum into the infrared. The Sun, too, has become almost invisible.

The quicker the starship reaches near-light speeds, the shorter the voyage will be for the travelers but the pace of Earth time will remain unchanged. A boost in the acceleration rate to three g's for a trip to Andromeda and back would shorten travel time from 55 years to 20, but Earth-time passage would remain at four million years.

How do you suppose the space travelers would feel on returning "home" to an Earth that had aged four million years in their 20-year absence? Possibly Earthlings would have evolved beyond recognition and would regard the "intruders" as dangerous alien life forms. But the scientists on the starship would have something unique to offer. They could make comparisons between species and geological forms as they remembered them from four million years earlier and as they appeared "today." Generations of stay-at-home scientists would be fascinated to talk to someone who had seen Earth so long ago. Such a starship would be a magnificent time machine.

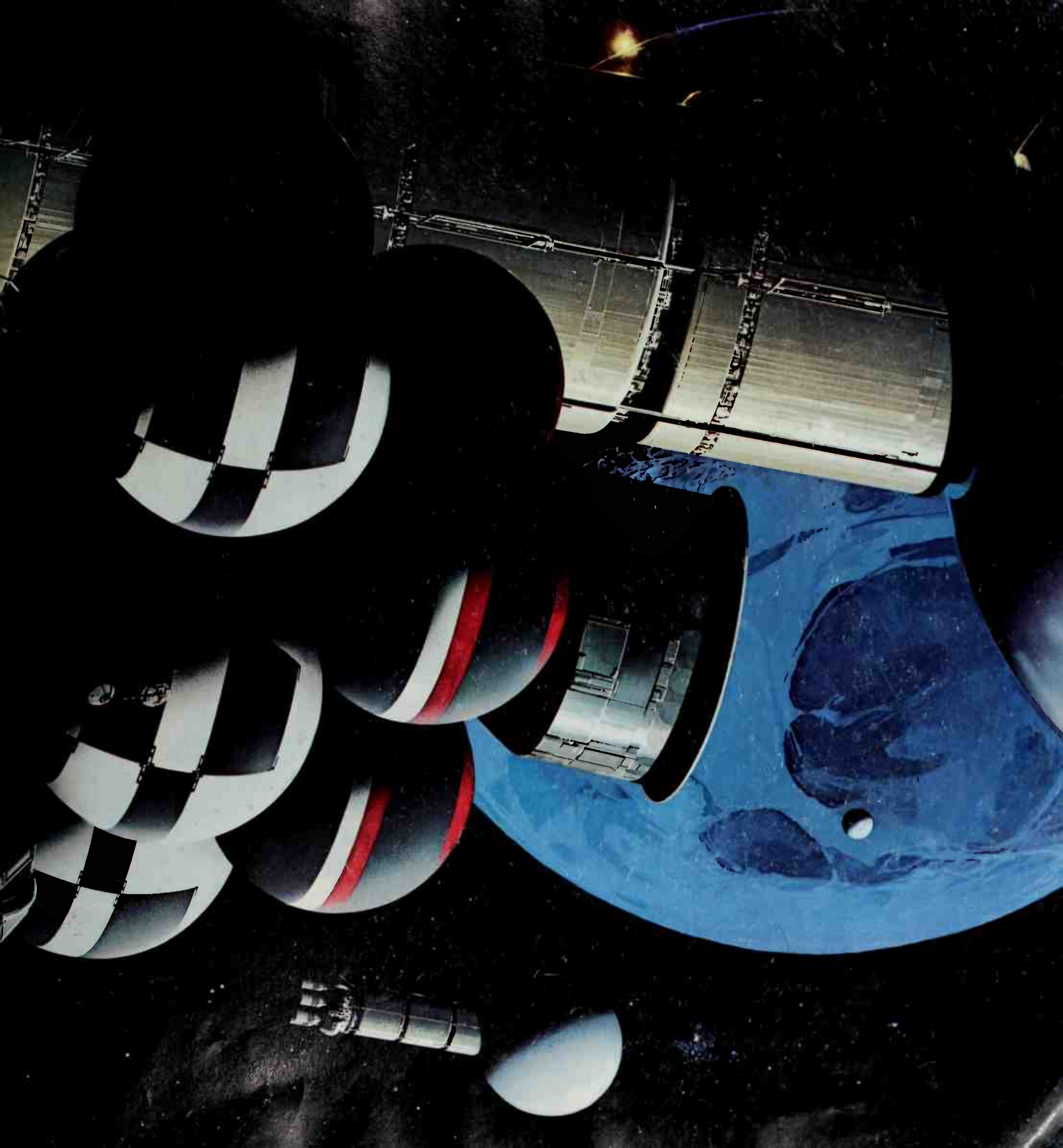
To "elsewhere and elsewhen"

If starships do journey to distant corners of the Universe, most likely the travelers will say goodbye to Earth forever. They will spend their lives comfortably within their space capsule. They will visit stars likely to have habitable planets or civilizations. The astronomer Carl Sagan wonders if tomorrow's space explorers will be whisked from one part of the Universe to another through black holes. Sagan suggests black holes could be entrance ways to "elsewhere and elsewhen." He speaks of a "federation of societies in the Galaxy that have established a black hole rapid-transit system. A vehicle is rapidly routed through an interlaced network of black holes to the black hole nearest its destination."

Can we reach the stars?

Some scientists think that we will never reach the stars, that time will forever keep us prisoners of our Solar System home. However, people once scoffed at the idea of huge machines carrying passengers through the air over the oceans, and of rockets sending people to the Moon. Yesterday's science fiction often becomes today's science fact.

It is hard to single out any one reason for venturing into space as *the* most important, for there are many important reasons. One is to give Earth a way of harnessing energy more efficiently. Another is to find out about other planetary systems and other stars in order to better understand our own Solar System home. And finally there is the driving curiosity to know whether we are alone in the Universe or whether intelligent beings and advanced civilizations abound out there.



Space Age Highlights

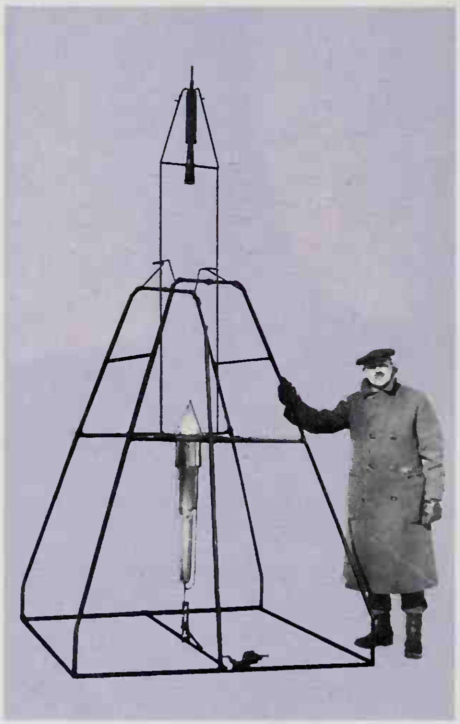
1903 Konstantin Tsiolkovsky, astronautics pioneer in Russia, publishes an article on spaceflight, the first mathematical proof that travel by rocket is possible.

1905 Albert Einstein (above) proposes his special theory of relativity, a description of the structure of space and time that revolutionizes science.

1916 Karl Schwarzschild, a German physicist, introduces the modern black hole concept. French astronomer Pierre Laplace first suggested the idea in 1796.

1917 U.S. astronomer Harlow Shapley determines the true size of our galaxy. This discovery puts the Sun not at the center, but 30,000 light-years out toward the edge.

1924 Astronomer Edwin P. Hubble proves galaxies exist outside the Milky Way. Hubble later studies galaxies with the powerful Schmidt Telescope (above) at Mount Palomar Observatory in California.



1926 In Auburn, Massachusetts, physicist Robert H. Goddard launches the first successful liquid-fuel rocket (above).

1927 Belgian cosmologist Georges Lemaître formulates the Big Bang theory. This proposes that all matter and space—the entire Universe—was born out of the colossal explosion of a "primeval atom."

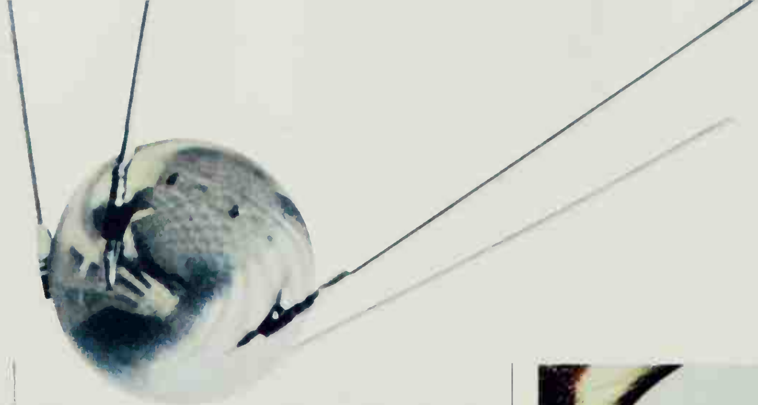
1929 Edwin P. Hubble finds that the more distant a galaxy, the faster it recedes. Hubble's Law demonstrates that the Universe is expanding.

1930 At Lowell Observatory, in Flagstaff, Arizona, Clyde Tombaugh discovers the ninth planet, Pluto, by following the calculations of Percival Lowell.

1931 American pioneer of radio astronomy, Karl Jansky (above), discovers radio waves coming from the Milky Way Galaxy.

1937 Radio astronomer Grote Reber follows up Karl Jansky's work and builds the first "dish" radio telescope.

1942 German scientists, led by Wernher von Braun, build the first successful V-2 rocket. After World War II, a captured V-2 (above) boosts the U. S. WAC Corporal to a record height of 402 km at the White Sands Proving Ground, New Mexico.



1957 *October* U.S.S.R. launches Sputnik 1, first man-made object to orbit Earth. (Sputnik means "traveling companion.")

November Sputnik 2 transports the first living creature into space. Confined in a small compartment, the dog Laika lives in orbit for seven days, proving that life can survive on "the final frontier."

1958 *January* Explorer 1, first U. S. satellite in orbit, lifts off at Cape Canaveral. Geiger counters on board confirm the existence of Van Allen radiation belts.

1959 Soviet probes make space history. Luna 1 is the first spacecraft to orbit the Sun. Luna 2, first to reach another celestial body, hits the Moon. Luna 3, aloft for 177 days, is the first to return pictures of the lunar far side.

1960 *April* U.S. launches Tiros 1, the first successful weather satellite.

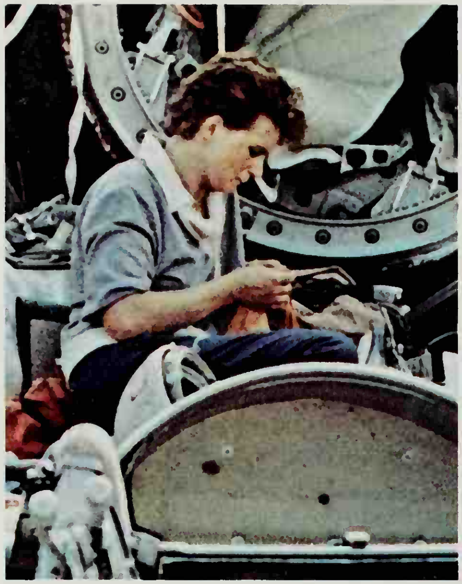
1961 *April* Soviet Vostok 1 carries the first man in space, cosmonaut Yuri A. Gagarin (above), once around Earth.

May Alan B. Shepard, Jr. (above), the first U. S. astronaut in space, makes a 15-minute suborbital flight in Mercury capsule Freedom 7, to an altitude of 187.5 km.

1962 *February* John H. Glenn, Jr., the first American in orbit, circles Earth three times in Friendship 7, reaching 261 km altitude. Celebrations greet his return. At Cape Canaveral he rides in a parade with President John F. Kennedy (above).

July U. S. satellite Telstar 1 beams the first live transatlantic telecast (above), from the U. S. to Europe.

December The first successful planetary spacecraft, U. S. Mariner 2, flies past Venus at a distance of 33,635 km.



1963 *June* Soviet cosmonaut Valentina Tereshkova sorts gear (above) after her flight as the first woman in space. In Vostok 6, she orbits Earth 48 times.

Maarten Schmidt at Mount Palomar interprets the unusual behavior of "radio star" 3C 273 – the first known quasar (above).

1964 *July* U. S. lunar spacecraft Ranger 7 relays the first close-range photographs of the Moon. The craft undergoes final inspection in California (above), before being shipped to Cape Canaveral for launching.

November Mariner 4 is launched by the U. S. and returns the first detailed data about Mars (above). From 9,846 km away, Mariner reveals Mars' surface craters.

1965 *March* Cosmonaut Alexei Leonov makes the first space walk, from the U.S.S.R. Voskhod 2. Duration of EVA (extravehicular activity) is 10 minutes.

June James McDivitt pilots Gemini 4 as Edward White II (above) takes the first U. S. space walk. EVA is 21 minutes.

December Walter Schirra, Jr., and Thomas Stafford, U. S. astronauts, make the first rendezvous in space, maneuvering Gemini 6 alongside Gemini 7 (right).

December Frank Borman and James Lovell, Jr., complete 206 Earth orbits in Gemini 7. The 14-day flight proves that travel to the Moon and back is possible.

1966 *February* The U.S.S.R. Luna 9 soft-lands on the Moon and relays the first pictures directly from the lunar surface.

March The U.S.S.R. launches Luna 10, the first spacecraft to orbit the Moon.

June Surveyor 1, the first U. S. spacecraft to soft-land on the Moon, takes a picture of its own shadow (above).

1967 In Cambridge, England, Antony Hewish (above) thinks at first of messages from outer space when his student, Jocelyn Bell, receives radio pulses from pulsars.

1968 *September* Soviet Zond 5 is the first spacecraft to orbit the Moon and return to Earth. Its cargo includes plant and animal life to test radiation danger in space.

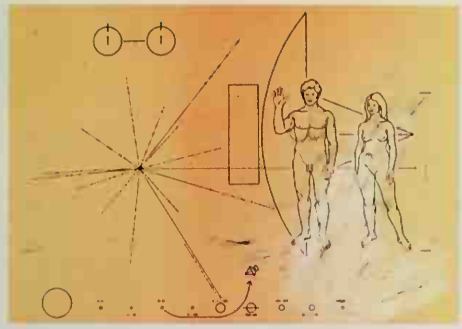
December U. S. launches Apollo 8, the first manned spacecraft to orbit the Moon.

1969 *July 20* Neil Armstrong and Edwin Aldrin, Jr., leave the first footprints on the Moon (above), as Michael Collins orbits in Apollo 11's command module. Eight days after blast-off (right), they return to Earth with samples of Moon rock (below).

1970 *December* U.S.S.R. Venera 7 is the first probe to soft-land on Venus. It transmits atmospheric data from the surface, confirming high temperature and pressure.

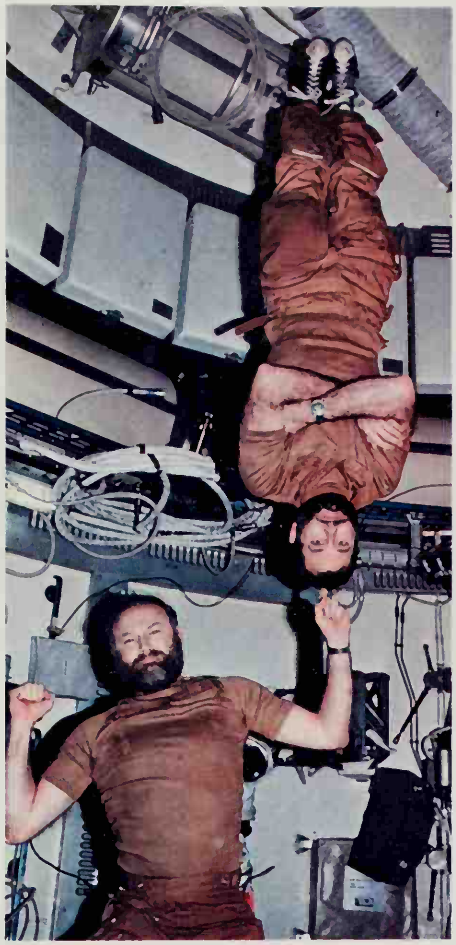
1971 *July* U. S. Apollo 15 astronauts David Scott and James Irwin drive the first Moon rover. A year later, Apollo 17's Harrison Schmitt, the first geologist-astronaut, mans a similar rover (above), which travels 35 kilometers during the mission.

November U. S. Mariner 9 is the first spacecraft to orbit another planet. For almost a year, it takes more than 7,000 pictures to help map the Martian surface.



1972 *March* U. S. launches Pioneer 10 toward Jupiter and interstellar space. Designed to acquaint alien life with Earth civilization, the Pioneer plaque (above) shows human figures, the spacecraft's trajectory on a Solar System diagram, and a pulsar map to help fix the time between takeoff and discovery.

December Using information from the X-ray satellite Uhuru, scientists designate Cygnus X-1 the first probable black hole.

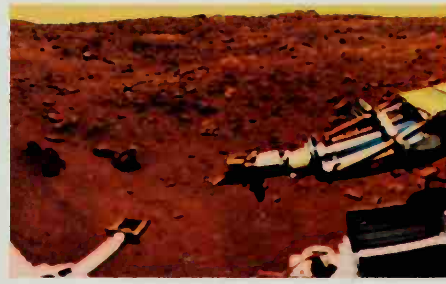


1973 *May* U. S. launches the Skylab space station. In Earth orbit 435 km up, Skylab crews work and live in zero gravity (above). Projects range from solar studies to astro-spiders Anita and Arabella, who show the world how to spin webs in space.

November U. S. Mariner 10 undertakes a double-planet mission. The spacecraft flies past Venus and on to Mercury, giving scientists their first good look at Mercury's cratered surface.

1974 *December* Pioneer 11 travels by Jupiter en route to Saturn, where five years later it discovers and photographs new moons and additional rings.

1975 *October* Venera 9 and Venera 10 transmit to Earth the first pictures of the Venusian surface. Findings classify Venus a still-evolving planet.



1976 *July* The first pictures of the rocky, red surface of Mars are returned by U. S. Viking 1. Soil samplers (above) search for life in the Martian soil but find none.

1977 *August* U. S. space shuttle Enterprise, after a piggyback ride atop a 747 aircraft, first separates from the mother ship and then glides to Earth.

August-September Voyagers 1 and 2 leave Earth for a 1979 date with Jupiter and a 1980 meeting with Saturn. If all goes well, Voyager 2 may reach Uranus in 1986 – the first spacecraft to fly by three planets.

1978 *December* Two Pioneer spacecraft reach Venus. One drops four probes into the atmosphere; the other, an orbiter, maps the surface with radar.

1979 *August* On Salyut 6, Soviet cosmonauts Vladimir Lyakhov and Valery Ryumin set a 175-day record for time in space.

1980 *February* U. S. launches the Solar Maximum satellite to study sunspots during their two-year period of peak activity.

Glossary

Most scientific terms used in *Our Universe* are explained in the text and appear in the Index. This Glossary lists some of the most important words with short definitions for quick reference.

Absolute magnitude: a measure of the true brightness of a star as if all stars were the same distance (32.6 light-years) from the observer.
Antimatter: material made of atomic particles having certain properties opposite to those of ordinary matter. If combined, matter and antimatter would explode.
Apparent magnitude: the brightness of a star as seen from Earth.
Apparent motion: the movement of a celestial body against the background of distant stars.
Asteroid: a rocky object, smaller than a planet, that orbits the Sun.
Astrology: a nonscientific system that attempts to explain or predict human actions and events by the position of celestial objects.
Astronomy: the branch of science that studies the Universe beyond Earth's atmosphere.
Atom: the smallest possible unit of a chemical element; an atom consists of a nucleus and one or more orbiting electrons.
Axis: an imaginary line around which a body, such as a planet, rotates.
Binary star: two stars orbiting a common center of gravity.
Black dwarf: a white dwarf which has stopped radiating energy.
Black hole: in theory, a collapsed object—perhaps a massive star—whose gravitational field is so strong that under most circumstances no light or matter can escape.
Comet: a small body made of ice and dust which orbits the Sun.
Compound: a substance formed by the chemical combination of two or more elements. Hydrogen and oxygen combine to form water.
Constellation: a pattern of stars; one of 88 areas dividing the sky.
Convection: the vertical movement of energy or mass by circulating currents.
Core: the innermost part of a moon, planet, or star.
Cosmic rays: nuclear and subatomic particles moving through space at high speeds; radiated from the Sun and other stars.
Cosmology: the study of the origin, evolution, and overall structure of the Universe; creation myths and the Big Bang are theories of cosmology.
Crust: the thin, outermost rocky layer of a moon or terrestrial planet.
Density: a measure of how tightly mass is packed into a given space.
Doppler effect: change in frequency of sound or light waves caused by relative motion of the source and the observer.
Eclipse: total or partial blocking of light from a celestial body caused by its passing into the shadow of another body; also, the hiding of one celestial body by another.
Ecliptic: the Sun's apparent circular path through the heavens; the plane of Earth's orbit.
Electromagnetic spectrum: the whole range of radiation; it extends from high-energy gamma rays to low-energy radio waves.
Electron: a negatively charged, low-mass particle which orbits the nucleus of an atom or exists free in space and in stars.
Element: the simplest form of chemical, made of identical atoms. Oxygen and gold are among the more than 100 known elements.
Energy: the ability to do work, such as produce motion, heat, chemical change.
Frequency: rate at which light or sound waves pass a given point, measured in cycles per second, or hertz. Shortwaves pass the point at high frequencies, longer ones at low frequencies.
Galaxy: billions of stars held together by gravitational attraction.
Gas giants: the planets Jupiter, Saturn, Uranus, and Neptune.
Giant: a large star that is highly luminous.
Globular clusters: dense groups of thousands to millions of stars.
Gravitation: the force by which two masses attract each other.
Gravity: gravitational force at the surface of a planet or other body that pulls mass toward its center.
Interstellar dust: small, solid grains of matter, thinly distributed between the stars; sometimes concentrated in nebulae.
Interstellar gas: matter in a gaseous state thinly distributed between the stars—mostly hydrogen with some helium and other elements; sometimes concentrated in nebulae.
Ion: an atom that has lost or gained one or more electrons, becoming positively or negatively charged.
Limb: the edge of a planet or other celestial body as seen from afar.
Luminosity: a measurement of the total amount of energy given off from a star.
Mantle: the layer of rock between the core of a moon or terrestrial planet and its surface crust.
Mass: the amount of matter contained in a body.
Matter: the substance of the Universe; made up of atomic particles, atoms, and molecules. Matter exists in four familiar states: solid, liquid, gas, and plasma.
Meteor: the streak of light caused by a meteoroid that passes through Earth's atmosphere; the burning meteoroid, called a "shooting star."
Meteorite: a meteoroid that survives passage through Earth's atmosphere and arrives on Earth's surface without completely burning up; also, a chunk of rock after it lands on a planet or moon.
Meteoroid: a solid body smaller than an asteroid that orbits the Sun. Both meteors and meteorites were meteoroids.
Molecule: two or more atoms chemically combined. A water molecule consists of two atoms of hydrogen and one atom of oxygen.
Moon: a natural satellite orbiting a planet.
NASA: National Aeronautics and Space Administration.
Nebula (pl. nebulae): a mass of interstellar gas and dust, appearing as a glowing or dark patch in the sky.
Neutrino: an atomic particle given off during nuclear fusion; it apparently has no mass or electrical charge, and moves at the speed of light.
Neutron: an atomic particle having high mass but no electrical charge. Neutrons are present in the nuclei of all atoms except hydrogen.
Neutron star: the core of a star left after a supernova explosion; made of very densely packed neutrons.
Nova (pl. novae): a star which suddenly explodes, temporarily increasing its brightness.
Nuclear fusion: a process by which matter changes to energy. The nuclei of lighter atoms fuse, or join, to form heavier nuclei, releasing energy.
Nucleus (pl. nuclei): of an atom, the central portion which has a positive charge and contains most of the atom's mass; of a comet, the chunk of solid matter at the center of a comet's head; of a spiral galaxy, the central portion, very dense with stars.
Occultation: the hiding of one celestial body by another.
Particle: any very small piece of matter such as a molecule or atom; also pieces even smaller such as electrons, protons, and neutrons; also larger ones, as in interstellar dust. Photons are particles of light.
Phases: of a planet or moon, the varying shape of the lighted portion, such as full, half, crescent, etc.
Photons: particles that make up electromagnetic radiation. Photons carry varying amounts of energy and travel at the speed of light.
Planet: a rotating body of substantial size held in orbit by the gravitational attraction of a star. A planet is not self-luminous; it reflects starlight. Its own gravity pulls a planet into its most stable shape, a slightly flattened sphere.
Plasma: a gas consisting of electrons and ions; called "the fourth state of matter" because the temperature is too high for whole atoms to exist.
Precession: a slow change in the direction of the tilt of Earth's axis, which results in an apparent change in the position of the stars.
Pressure: a measure of the force exerted on a surface.
Prism: a wedge-shaped piece of glass used to split light into a spectrum.

Proton: an atomic particle with high mass and a positive charge, present in the nuclei of all atoms. The nucleus of a hydrogen atom is a single proton.
Pulsar: a neutron star that rotates rapidly and emits a beam of radiation. Earth telescopes pick this up as a regular pulse.
Quasar: a mysterious, "quasi-stellar," or starlike, object—very small, very distant, and very bright. Most quasars are strong sources of radio energy.
Radar: radio signals transmitted to and bounced back from an object. RADAR is an acronym for RAdio Detecting And Ranging.
Radiation: energy transmitted through space as waves or particles.
Red dwarf: a small, relatively cool star with low luminosity.
Relativity: Theories of physics proposed by Albert Einstein. They say, among other things, that space and time cannot be considered separate ideas. The perception of space-time is different for a person standing still on Earth than it is for someone moving very fast away from or toward it. What we see is *relative* to (depends on) our acceleration as we move.
Retrograde motion: "backward"; opposite of direct motion; the apparent east to west motion of a planet as seen from Earth; clockwise revolution or rotation of an object, as seen from above the north pole.
Satellite: a moon or man-made body in orbit around a planet.
Silicates: a large group of minerals containing silicon and oxygen, usually combined with one or more metals. Most common rocks are silicates.
Solar wind: a stream of charged particles from the Sun.
Solstice: the moment when the Sun is at its northernmost or southernmost point in the sky; the first day of summer or winter.
Star: a hot, glowing sphere of gas, usually one that emits energy from nuclear reactions in its core.
Supergiant: a large massive star of low density and very high luminosity.
Supernova: a stellar explosion which increases the luminosity of the star to many thousands of times brighter than a nova.
Terminator: The shadow-line boundary between night and day on a planet or moon.
Terrestrial planets: Mercury, Venus, Earth, and Mars.
Tides: periodic changes in the shape of a planet, moon, or star caused by the gravitational attraction of a body near it. For example, the Moon tugs on Earth's oceans, causing high and low tides; Jupiter's gravitational attraction on its moon Io causes ground tides; and two stars very close together pull each other's atmospheres into distorted shapes.
Transit: the crossing of a small celestial body in front of a larger one. From Earth we see Venus and Mercury in transit across the disk of the Sun.
Vacuum: in theory, space that contains no matter.
Variable star: a star whose brightness changes over time.
Wavelength: the distance between two successive crests of a wave.
White dwarf: a type of star that has collapsed after exhausting its nuclear fuel. Leftover heat causes it to shine faintly.

Measuring the Universe

Our Universe gives measurements of length, weight, and area in metric units because scientists use the metric system in their work. In *Our Universe* you will find temperatures measured in degrees Celsius (°C), also called centigrade, and in kelvins (sometimes abbreviated K). Kelvins are used by astronomers to describe very high temperatures, such as those in the Sun and other stars. The equivalents given below will help to explain terms of measurement used in this book.

Length

1 millimeter (mm)	= 0.04 inches (A dime is 1 mm thick.)
1 centimeter (cm)	= 10 millimeters (A slice of bread is about 1 cm thick.) = 0.4 inches
1 meter (m)	= 100 centimeters (The maximum length of a baseball bat is about 1 m.) = 3.28 feet = 1.1 yards
1 kilometer (km)	= 1,000 meters (Five average city blocks are about 1 km.) = 0.62 miles

Mass (measured in weight on Earth)

1 gram (g)	= .035 ounces (A potato chip weighs about 1 gr.)
1 kilogram (kg)	= 1,000 grams (This book weighs 1.8 kg.) = 2.2 pounds

Area

1 square centimeter (cm^2)	= 0.155 square inches (A dollar bill covers about 102 cm^2.)
1 square meter (m^2)	= 10.76 square feet (A standard table-tennis table covers about 4 m^2.) = 1.2 square yards

Astronomical distances

1 astronomical unit (AU)	= 149.6 million km (The average Earth-Sun distance) = 93 million miles
1 light-year	= 9.46 trillion km (The *distance* traveled by light in one Earth year) = 5.88 trillion miles = 63,240 AU
Speed of light	= 299,792.5 km per second = 186,282.4 miles per second

Temperature scale comparisons

At sea level ice melts at:	273 kelvins 0° Celsius 32° Fahrenheit	Human body temperature	310 kelvins 37° Celsius 98.6° Fahrenheit
Room temperature:	293 kelvins 20° Celsius 68° Fahrenheit	At sea level water boils at:	373 kelvins 100° Celsius 212° Fahrenheit

Observing the Universe

The sites in this selective list represent U.S. and Canadian planetariums, observatories, and space or science museums open to the public. Readers are encouraged to call local schools, museums, and astronomical societies to learn of additional places of interest.

If you plan to visit one of these sites, be sure to telephone first for fees and schedules.

Alabama
Robert R. Meyer Planetarium, Birmingham Southern College, Birmingham.
Alabama Space and Rocket Center, Huntsville.
W. A. Gayle Planetarium, Montgomery.

Arizona
Lowell Observatory, Flagstaff.
Museum of Astrogeology, Great Meteor Crater, Flagstaff.
Center for Meteorite Studies, Arizona State University, Tempe.
Kitt Peak National Observatory, Tucson.
Steward Observatory and Flandreau Planetarium, University of Arizona, Tucson.
Barringer Meteor Crater, Winslow.

Arkansas
University of Arkansas Planetarium, Little Rock.

California
California Museum of Science and Industry, Los Angeles.
Griffith Observatory, Los Angeles.
Big Bear Solar Observatory, Pasadena.
Mount Wilson Observatory, Pasadena.
Palomar Observatory, Pasadena.
Reuben H. Fleet Space Theater and Science Center, San Diego.
Alexander F. Morrison Planetarium, San Francisco.
Lick Observatory, San Jose.

Colorado
Charles C. Gates Planetarium, Denver Museum of Natural History, Denver.

Connecticut
Henry B. DuPont III Planetarium, Museum of Art, Science, and Industry, Bridgeport.
Gengras Planetarium, Children's Museum of Hartford, Hartford.
Stamford Observatory and Edgerton Memorial Planetarium, Stamford Museum and Nature Center, Stamford.

Delaware
Mount Cuba Astronomical Observatory, Wilmington.

District of Columbia
National Air and Space Museum, Smithsonian Institution.
Rock Creek Nature Center.
United States Naval Observatory.

Florida
United States Air Force Space Museum, Cape Canaveral Air Force Station, Cocoa Beach.
Brest Planetarium, Jacksonville Museum of Arts and Sciences, Jacksonville.
NASA-John F. Kennedy Space Center, Merritt Island.
The John Young Museum and Planetarium, Orlando.
Science Museum and Planetarium of Palm Beach County, West Palm Beach.

Hawaii
Bishop Museum and Planetarium, Honolulu.
Mauna Kea Observatory, University of Hawaii, Honolulu.

Idaho
The Norman Herrett Museum, Twin Falls.

Illinois
The Adler Planetarium, Chicago.
Museum of Science and Industry, Chicago.
Dearborn Observatory, Northwestern University, Evanston.
John Deere Planetarium, Augustana College, Rock Island.

Indiana
Koch Planetarium, Evansville Museum of Arts and Sciences, Evansville.
J. I. Holcomb Observatory and Planetarium, Butler University, Indianapolis.

Iowa
Sanford Museum and Planetarium, Cherokee.
Sargent Planetarium, Des Moines Center of Science and Industry, Des Moines.
Grout Museum of History and Science Planetarium, Waterloo.

Kansas
University of Kansas Observatory, Lawrence.
Omnisphere Earth-Space Center, Wichita.

Kentucky
Hardin Planetarium, Western Kentucky University, Bowling Green.
Joseph Rauch Memorial Planetarium, University of Louisville, Louisville.

Louisiana
Zeiss Planetarium, Louisiana Arts and Science Center, Baton Rouge.
Lafayette Natural History Museum and Planetarium, Lafayette.

Maine
University of Maine Observatory and Planetarium, Orono.
Southworth Planetarium, Portland.

Maryland
Davis Planetarium, Maryland Academy of Sciences, Baltimore.
University of Maryland Observatory, College Park.

Massachusetts
Museum of Science, Boston.
The Center for Astrophysics: Harvard College Observatory and Smithsonian Astrophysical Observatory, Cambridge.
Maria Mitchell Observatory, Maria Mitchell Association, Nantucket.
Seymour Planetarium, Springfield Science Museum, Springfield.

Michigan
Cranbrook Institute of Science, Bloomfield Hills.
Detroit Science Center, Detroit.
Abrams Planetarium, Michigan State University, East Lansing.
Robert T. Longway Planetarium, Flint.

Minnesota
Minneapolis Public Library Science Museum and Planetarium, Minneapolis.
The Science Museum of Minnesota, St. Paul.

Mississippi
Russell C. Davis Planetarium, Jackson.

Missouri
Laws Observatory, University of Missouri, Columbia.
R. A. Long Planetarium, Kansas City Museum of History and Science, Kansas City.
McDonnell Planetarium, St. Louis.

Montana
Montana State University Physics Department, Bozeman.

Nebraska
J. M. McDonald Planetarium, Hastings Museum, Hastings.
Ralph Mueller Planetarium, University of Nebraska State Museum, Lincoln.

Nevada
Fleischmann Atmospherium/Planetarium, University of Nevada, Reno.

New Hampshire
Shattuck Observatory, Dartmouth College, Hanover.
Plymouth State College Planetarium, Plymouth.

New Jersey
Morris Museum Astronomical Society, Convent.
Newark Museum Planetarium, Newark.
New Jersey State Museum, Trenton.

New Mexico
R. H. Goddard Planetarium, Roswell Museum and Art Center, Roswell.
Sacramento Peak Observatory, Sunspot.

New York
Kellogg Observatory, Buffalo Museum of Science, Buffalo.
Vanderbilt Planetarium, Centerport.
American Museum–Hayden Planetarium, New York.
Strasenburgh Planetarium, Rochester Museum and Science Center, Rochester.
Andrus Space Transit Planetarium, Yonkers.

North Carolina
Morehead Planetarium and Observatory, University of North Carolina, Chapel Hill.
Charlotte Nature Museum Planetarium, Charlotte.

North Dakota
Minot State College Observatory, Minot.

Ohio
Mueller Planetarium and Observatory, Cleveland Museum of Natural History, Cleveland.
Battelle Planetarium, Center of Science and Industry, Columbus.
Dayton Museum of Natural History, Dayton.
Armstrong Air and Space Museum, Wapakoneta.

Oklahoma
Omniplex, Oklahoma City.

Oregon
Pine Mountain Observatory, University of Oregon, Eugene.
Oregon Museum of Science and Industry Planetarium, Portland.

Pennsylvania
William Penn Memorial Museum Planetarium, Harrisburg.
Franklin Institute Science Museum and Planetarium, Philadelphia.
Buhl Planetarium and Institute of Popular Science, Pittsburgh.

Rhode Island
Maribelle Cormack Planetarium, Roger Williams Park Museum, Providence.

South Carolina
Columbia Museum of Art and Science Planetarium, Columbia.
Howell Memorial Planetarium, Bob Jones University, Greenville.

Tennessee
Clarence T. Jones Observatory, University of Tennessee, Chattanooga.
Bays Mountain Park Nature Center Planetarium, Kingsport.

Texas
Texas Memorial Museum, Austin.
Dallas Health and Science Museum Planetarium, Dallas.
McDonald Observatory at Mount Locke, Fort Davis.
Margaret Root Brown Observatory and Burke Baker Planetarium, Houston Museum of Natural Science, Houston.
NASA-Lyndon B. Johnson Space Center, Houston.
Edward H. White II Memorial Museum, Brooks Air Force Base, San Antonio.

Utah
Hansen Planetarium, Salt Lake City.

Vermont
Fairbanks Museum and Planetarium, St. Johnsbury.

Virginia
Leander McCormick Observatory, University of Virginia, Charlottesville.
Chesapeake Planetarium and Observatory, Chesapeake.
NASA-Langley Research Center, Hampton.
Science Museum of Virginia Planetarium, Richmond.

Washington
Battelle Observatory (Rattlesnake Mountain Observatory), Richland.
Pacific Science Center, Seattle.

West Virginia
Charleston Children's Museum Planetarium, Charleston.
The National Radio Astronomy Observatory, Green Bank.

Wisconsin
Washburn Observatory, University of Wisconsin, Madison.
Yerkes Observatory, Williams Bay.

Wyoming
Wyoming Infrared Observatory, University of Wyoming, Laramie.

CANADA:

Alberta
Centennial Planetarium, Calgary.
Queen Elizabeth Planetarium, Edmonton.

British Columbia
H. R. MacMillan Planetarium, Vancouver.
Dominion Astrophysical Observatory, Victoria.

Manitoba
Lockhart Planetarium, University of Manitoba, Winnipeg.
Manitoba Museum of Man and Nature Planetarium, Winnipeg.

Nova Scotia
Burke-Gaffney Observatory, Halifax.

Ontario
Hume Cronyn Observatory, London.
National Museum of Science and Technology, Ottawa.
David Dunlap Observatory, Richmond Hill.
McLaughlin Planetarium, Toronto.
Ontario Science Centre, Toronto.

Quebec
Dow Planetarium, Montreal.

We'd like to thank...

It would have been impossible to put this book together without the help of our major consultants, listed on page 4, and many other people.

We are particularly indebted to the staff of NASA's Planetary Division, especially to Joseph M. Boyce, William E. Brunk, Angelo Guastaferro, Michael R. Helton, Gordon A. McKay, Rodney A. Mills, Robert E. Murphy, and William L. Quaide for their time and encouragement. Among others at NASA who assisted us are Donald L. DeVincenzi, Richard M. Farrel, Albert G. Opp, Erwin R. Schmerling, and Roger R. Williamson. We thank Paul D. Lowman, Jr., of the Goddard Space Flight Center; and Ray L. Newburn, Jr., Jurrie Van Der Woude, and Donald Yeomans of the Jet Propulsion Laboratory.

Donald M. Hunten and Bradford A. Smith of the University of Arizona gave us considerable help. We are also indebted to George O. Abell, A.G.W. Cameron, Dale P. Cruikshank, Stephen E. Dwornik, William K. Hartmann, William C. Miller, Roman Smoluchowski, Peter B. Stifel, and George W. Wetherill for sharing their knowledge.

We received valuable assistance from the staff of the National Air and Space Museum, especially James D. Dean, Frederick C. Durant III, and Catherine D. Scott. We thank the staffs of the many observatories we consulted, and Roger Cayrel, Pierre Bely, and Philippe Bourlon of the Canada-France-Hawaii Telescope. Connie S. Rodriguez at Kitt Peak National Observatory was especially generous with her time. Sally J. Bensusen, Robert S. Harrington, Paul M. Routly, P. Kenneth Seidelmann, and Thomas C. Van Flandern of the U.S. Naval Observatory also deserve special thanks.

Other people to whom we are grateful are: Don Campbell, Charles F. Capen, Clark Chapman, Charles C. Counselman, Raymond Davis, Jr., Amahl S. Drake, Stillman Drake, Diana Eck, John A. Eddy, Sidney W. Fox, Sharon Gibbs, Einar Haugen, Philip B. James, James G. Lawless, George Lovi, Brian Marsden, Brian Mason, Harold Masursky, Janet Mattei, Joanna A. McClellan, Jeffrey Meyerriecks, Derek Price, Frederick L. Scarf, and William A. Schopf. Dennis di Cicco and Dennis Milon of *Sky and Telescope* helped with photographs. The staff of our National Geographic Library was extremely helpful as always. We thank the girls and boys who acted as consultants on both text and illustrations.

Henning W. Leidecker computed data for the Lund Observatory map on pages 234-235, and for the asteroid and comet orbit diagrams on pages 144 and 204. Danny C. Kinsler gave us information and advice about drawing the crater map on page 151.

The editors also thank the Czechoslovakian publishers, Artia, for permission to reproduce the painting by Zdenek Burian on pages 102-103.

Index

Illustrations are in **boldface type** (**127**). Text references are in lightface type (56) and definitions in the text are in *italic type (218)*.

Adams, John Couch 194
Aldrin, Edwin E., Jr. 6, 123, 268
Algol 17, **225,** 234
Alpha Centauri **234,** 247, 248
Amalthea **40, 152-153**
Andromeda Galaxy 31, **214, 234, 236, 238,** 240, 261
Apollo missions **6-7,** 104, 123; pictures by **104-105, 116-119, 122-123, 268**
Apollo Objects 147
Arab astronomy 17
Arecibo Observatory, Puerto Rico 78, 90; radio message **247,** 248
Ariel **41, 182, 187**
Aristarchus 14
Aristotle 14, 19, 20
Armstrong, Neil A. 6, 123, 268
Asteroids 37, **42,** 73, **143-151,** 252, **259;** Trojan asteroids **154**
Astronauts **118-119,** 123, **250-251, 265-269;** first **265;** training **253**
Auroras: Earth 95, 112; Jupiter 163

Barringer Crater, Ariz. **150-151**
Barycenters *114,* **199**
Beta Lyrae **224, 234**
Betelgeuse 17, 216, 218, **218, 219, 222-223, 235**
Bethe, Hans 61
Big Bang **216,** 217, 242, 244, 264
Big Dipper **220, 234**
Binary stars *218,* **224, 225,** 233
Black dwarfs 50, 231
Black holes 31, **232, 233, 233,** 262, 264, 269
Blue giants **220, 223,** 244
Blue supergiants 218, 222, **223,** 224; *see also* Rigel
Bode, Johann 147, 187; law 147
Bow shock 42, **42;** Jupiter 157, **158**
Brahe, Tycho 18, **18,** 19

Calendars 11, **12-13,** 13. 15, 17
Callisto **40, 42, 166,** 167, 168
Caloris Basin, Mercury 74, **75**
Cassini, Giovanni 178
Cepheids 235
Ceres **42,** 144, 145, **145,** 147
Charon 112, **196-197,** 198, **199, 201;** discovery **199,** 200
Chiron: discovery 200
Christy, James W. 199, 200
Collins, Michael 6, 123, 256, 268
Comets 37, **203-213;** proposed mission **257**

Constellations 218, **218, 219, 234-235;** *see also* Orion; Zodiac
Continental drift *see* Plate tectonics
Copernicus, Nicolaus 17-18, 20, and retrograde motion **21**
Crab Nebula 34, **231,** 233
Craters: formation **72-73,** 73, **74;** meteorite **150,** map **151**
Creation myths **8-11;** *see also* Big Bang
Cygnus X-1 233, **233,** 269

Deimos **124, 126, 127,** 137
Density *43;* planets' 43
Doppler effect **240, 241,** 242, 261-262

Earth **14, 15, 21, 24, 25, 40, 42,** 43, **93-123, 250;** atmosphere **105,** 107; climate 58, **106;** craters 144, **150-151;** formation 96, **100, 101;** life **102-103,** 104, 112, **217,** 244, 246; magnetic field 95, 107, 112; map **110-111;** mountain building 99-100; plate tectonics 96-99, **96-99;** tides **112, 113,** 117; volcanoes and earthquakes **98,** 99, **99,** 103; *see also* Apollo; Gemini
Eclipses **52, 53;** diagram **115**
Egyptian astronomy 13; Sun god **8-9,** 11
Einstein, Albert 6, 61, 256, **264**
Einstein Observatory (HEAO-2) 31, **245;** image by **244**
Electromagnetic spectrum **28-29,** *28,* 31, **51,** 66, **66-67**
Ellipses: construction **19;** orbits 19, 39, 117
Encke **204,** 205, 211
Energy *see* Electromagnetic Spectrum; Fusion; Light; Stars; Sun
Eratosthenes 14, 15
Eros **145,** 147
Eudoxus 14
Europa **40, 42,** 45, **164, 167,** 168; imaginary life **45**
European Space Agency: Spacelab **253-255**
Extraterrestrial life: imaginary **44-47;** possible 163, 244, 246, 262, communications attempts 246-248, **247, 269**

Fraunhofer lines **61**
Fusion *61,* 63, 225, 227, 229, 231, 256

Gagarin, Yuri A. **265**
Galaxies *27,* 34, **214-215, 235-243, 277;** classification **237,** 240; collisions 242-244, **242-243;** recession 240, 242, 264; *see also* Andromeda Galaxy; Magellanic Clouds; Milky Way
Galileo Galilei 19, 20, **22,** 23, 57, 165-168, 173, 178
Galileo spacecraft, proposed 171, **256**
Gamma rays *28,* **28-29,** 31, **51,** 61, 63
Ganymede **40, 42, 166,** 168
Gemini missions: pictures by **97, 267**
Geocentrism 14-15, *18,* 20
Glenn, John H. **266**
Globular clusters *27,* 31, **214,** 235, 237-240
Goddard, Robert H. **264**
Gravitation *43,* 75, 78, 242, 244; stellar evolution 224, **227,** 229; theories 19, 23, 24, 27; *see also* Black holes
Great Red Spot, Jupiter **152, 155-157,** 159, **160-162,** 163, **164**
Greek astronomy 13-15, **15**
Greenhouse effect: Earth 107; Mars 137; Venus 89

H-R diagram 220, **223**
Halley, Edmund 24, **204,** 211
Halley's Comet **204, 205,** 206, 211
Heliocentrism 14, 15, *17,* 20, 24
Herschel, Caroline **186, 204**
Herschel, William 24, **186,** 186-187, 229, 240
Hertzsprung, Ejnar 218-220; *see also* H-R diagram
Hewish, Antony **267**
High Energy Astronomical Observatories (HEAO's) 31; *see also* Einstein Observatory
Hipparchus 14-15, 216
Horsehead Nebula 209, 218, 224, **229**
Hubble, Edwin 27, 237, 240, **264**
Hubble's law 240-242, 264
Huygens, Christian 178
Hydrogen-alpha 53, **61;** line **61;** photographs in **54-55, 56, 66-67**

Iapetus **41,** 181
Ikeya, Kaoru **204**
Ikeya-Seki **204, 207,** 211, 213
Indians, American: calendar **12-13**
Infrared radiation **28-29,** *31,* 32, **51;** telescope **30,** 32
Io 42, 157-159, **161, 164,** 168, **169,** 171; volcanoes 159, 168, **169, 170,** 171

Jansky, Karl 32, **264**
Juno **144, 145,** 147
Jupiter 34, **40-41,** 43, **153-171;** magnetic field 155, 157, **158,** 163; map **162;** moons 6, **40, 152-153,** 153, **154,** 157-159, **165,** discovery 23, 165, 166, *see also* Callisto, Europa, Ganymede, Io; organic molecules 163, imaginary life **47;** ring **40-41, 152-153, 154, 155,** 159; *see also* Galileo; Pioneer; Voyager

Kepler, Johann 6, 19, 24, 134, 137, 166-168
Kepler's laws 19, **19**
Kilauea volcano, Hawaii **98-99**
Kitt Peak Observatory, Arizona **62-65,** 66
Kowal, Charles 200
Kuiper, Gerard P. 73

Leonid meteor shower **209**
Lemaître, Georges 242, 264
Leverrier, Urbain 194
Life: evolution of **102-103,** 104, **216-217,** 244-246; Mars, question of 137-140; *see also* Extraterrestrial life
Light **26-29, 51, 66-67;** speed of 53, universal speed limit 6, 256; Doppler effect **240-241,** 242, 261; nature of 28, 57, 63; *see also* Electromagnetic spectrum
Light-year (distance) *218*
Lightning: Jupiter **160-161,** 163; Venus 81, **84, 86-87,** 89
Local Group **214-215, 238,** *240*
Lowell, Percival 200, 264
Luminosity *218;* variable stars 235

Magellanic Clouds **234, 237, 238,** 240
Magnetic fields: Earth 95, 107, *112;* Jupiter 155, 157, 163; Mercury 69, 78; Saturn 178; Sun 69
Magnetospheres *42,* **42;** Earth **95,** *112;* Jupiter **158**
Mariner missions: Mars 130, 131, 137, **266,** 268; Mercury **68,** 73, 74, 75, 78, 269; Venus **80-81,** 85, 266, 269; pictures by **74, 75**
Mars **21, 40,** 43, **125-141;** canyons **124,** 128, 130, **132-133;** life: imaginary **45,** question of possible 137, 140; map **138-139;** polar caps **124, 127,** 128, 131, 134, **136,** 137; quakes 130; volcanoes **124,** 128, 130, **134-135;** *see also* Mariner; Viking
Mass *43;* planets' 43
Mauna Kea Observatory, Hawaii **30,** 32
Medicine wheels, **12-13**
Mercury **40, 42,** 43, **69-79;** craters 69, 73, formation **72-75,** 73; map **79;** "peculiar" terrain 73, 74, **75;** scarps 69, *74,* **76-77;** *see also* Mariner
Mercury mission **265**
Meteor showers 148, *149,* 151, **209,** 213
Meteorites *149,* **149,** 151; crater formation **72-73, 74, 75**
Meteoroids 37, **146,** *149,* **209**
Milky Way 20, 24, 27, 34, **214-215,** 215-216, **216,** 235, 237, **238-239,** 240; map **234-235**
Mintaka 218, **218, 219**

Mira **225,** 233, 234, 256
Miranda **41,** 183, 187
Moon 20, **22-25, 40, 93, 94,** 112, 113, **114-123, 145;** calendars 11-13; far side **116-117;** map **120-121;** quakes 218; settlements 252, **258-259;** tides caused by 116, 117, 112
Moons 37; listed 40; relative sizes **40-41, 42;** *see also* by name
Mount Palomar, Calif. 31, 200, **264,** 266

Nebulae *32,* 218; supernova remnants **231,** 233; types 224, **227-229, 229**
Neptune **41,** 43, **191-195;** discovery **193, 194**
Nereid **41, 192-193**
Neutrinos *61,* 63
Neutron stars **230,** 233; *see also* Pulsars
Neutrons 233
Newton, Isaac 20-24, **27;** prism experiment **26-27**
Newton's laws 23-24, **24, 25**
Nova 19
Nuclear fusion *see* Fusion

Oberon **41, 182-183, 187**
Observatories **28-29;** American Indian **12-13;** Arizona: Kitt Peak **62-65,** 66, Lowell 200; California: Goldstone Deep Space Network Tracking Station 90, Mount Palomar 31, 200, **264,** 266; Einstein 31, **245;** France: Pic du Midi 31, **32-33;** Hawaii: Mauna Kea **30,** 32; HEAO *see* Einstein; Moon: future **258-259;** New Mexico: Very Large Array **34-35;** Puerto Rico: Arecibo 78, 90, **247,** 248; Skylab 66; Tycho Brahe's 18, **18;** West Virginia: Green Bank 248
Olympus Mons, Mars **124,** 128, **134-135**
Oort Cloud 204, 209, **212-213,** 213
Orion 216, 218, **218, 219,** 235

Pallas **144, 145,** 147
Phases: Mercury **71;** Moon 11, **115;** Venus 20, **83**
Phobos **40, 124, 126, 127,** 137, **145, 147;** asteroid, possible **145, 147**
Phoebe **41,** 174, 181
Photons *57,* 63
Piazzi, Giuseppi 147
Pic du Midi Observatory, France 31, **32-33**
Pioneer missions: Jupiter 153, 159, 165, 269; plaque **269;** Saturn 178, 179, 269; Venus 88, 89, 90; pictures by **88, 179**
Planets **37-43;** Bode's law 147; Earthlike 247; formation 38, 225-226; *see also* by name
Plate tectonics 96, **96,** 99; lines of fire **99**
Pleiades 224, **229,** 234, 237
Pluto **41,** 43, 112, **197-201;** discovery 200, **200,** 264; life, imaginary **46**
Precession **15**
Procyon **235**
Protons 61
Proxima Centauri 6
Ptolemy (Claudius Ptolemaeus) 15, 20, 216
Pulsars **230, 231,** *233;* discovery 230, 233, 267

Quasars 31, 32, 34, *242,* **244, 266**

RR Lyrae variables 235
Radar astronomy: Mercury 78; Sun 53; Venus 34, 85, 90
Radiation belts: Jupiter **158;** Saturn 178; *see also* Van Allen belts
Radio telescopes **28-29,** 32, 34, **34-35, 247,** 255, **258;** space communication attempts 246-247, **247,** 248; first 32-34, 264; pulsar detection **230, 231,** 233, 267
Radio waves **28-29,** *31,* **51**
Reber, Grote 32-34, 264
Red dwarfs 221, 229, 240, 244
Red giants **50,** 215, **226-227,** 231, 233, 240
Red supergiants *see* Betelgeuse
Retrograde motion 14, **21**
Revolution *39*
Rhea **41, 172-173, 178,** 181
Rigel 218, **218, 219,** 224
Rings: planets' *see* Jupiter; Saturn; Uranus
Rockets **6-7, 28, 264, 265, 268;** *see also* Space shuttle
Roman calendar 15; zodiac **16-17**
Rotation *39*
Russell, Henry Norris 218, 220

Sagan, Carl 262
Saturn **41,** 43, **173-181;** rings **41, 172-179,** discovery 173, 178; *see also* Pioneer; Voyager
Scarps: Mercury 69, *74,* **76-77**
Schmidt, Maarten 266
Schmitt, Harrison **118,** 123, **268**
Seismic waves *103*
Seki, Tsutomu **204**
Shapley, Harlow 27, 264
Shepard, Alan B., Jr. **265**
Sirius 13, 24, 216, 235
Skylab missions 66, **269;** pictures by **67, 269** (center)
Solar Maximum Mission 56, 269
Solar System **36-47;** evolution and history **38,** 73, 143, 148, **216;** location 216, 237, **239;** size 37, **39, 239;** *see also* Asteroids; Comets; Meteoroids; Moons; Planets; Sun
Solar telescopes **28-29, 62-65,** 66
Solar wind 37, **42,** *53,* **58-59,** 78, **95,** 112, 157, **158,** 163, 178
Space missions: U. S. **265-269;** *see also* Apollo, Einstein Observatory, Gemini, Mariner, Pioneer, Skylab, Solar Maximum Mission, Space shuttles, Viking, Voyager; U.S.S.R. **265-269;** *see also* Venera
Space settlements 251, 252, 255, **260, 261**
Space shuttles 251-252, 269; flight sequence **254-255;** mock-up **252;** probe launches 252, **256-257;** satellite launches 251, 252, **254-255,** 257, 269
Space travel **251-263**
Spacelabs **253-255**
Spectrum **26-27,** *28-31,* **28-29, 51, 60,** 64-66; Doppler effect **240, 241,** 242, 244, 261; Sun's **51, 61,** 64-66; types **60,** *64*
Stars **215-249;** life cycles 32, **50,** 222, 224, 225, **226-227,** 229; magnitude *216,* **223;** main sequence *220,* 221, 225, **226,** 229; multiple stars **224, 225,** *see also* Binary stars; variable **225,** 233, 235; *see also* Black dwarfs; Black holes; Blue giants; Blue supergiants; Neutron stars; Red dwarfs; Red giants; Red supergiants; Supernovae; Sun; White dwarfs
Stonehenge 13
Sun **38, 48-67,** 216, 221, 224, 229, 242; calendars **12-13;** eclipses **52,** 53, **115;** life cycle **38, 50,** 229, 231; myths **8-9,** 11; prominences **48, 52, 54-55,** *56,* 57, 58, **59, 67;** sunspots 23, **48-49, 51, 56-57,** 57-58, **59;** *see also* Solar wind
Supernovae **216,** *233;* remnants 31, 34, **231,** 233; *see also* Neutron stars

Telescopes 20, **23,** 24, **27, 28-29, 186,** 252, **257, 264;** infrared radiation **30,** 32; reflecting **31;** refracting **23;** solar **62-63, 64-65,** 66; space telescope 251, **257;** X-ray 31, 66, **245;** *see also* Radio telescopes
Tereshkova, Valentina **266**
Tethys **41, 172, 178, 179**
Tharsis, Mars 128; volcanoes **124,** 128
Tides: Earth-Moon 112, 116-117, **112;** Io 171
Time dilation *256,* 259, 261, 262
Titan 6, **41, 42, 178,** 179, **180-181,** 181; life, imaginary **44**
Titania **41, 182, 187**
Tombaugh, Clyde 200, 264
Trifid Nebula **228**
Triton **41, 190-193,** 194, **195**
Tsiolkovsky, Konstantin 264
Tunguska, U.S.S.R.: explosion **210-211**
Tycho Brahe *see* Brahe, Tycho

Ultraviolet rays **28-29,** *31;* photography: Venus **88;** Sun **51,** 66, **66-67,** 106
Umbriel **41, 182, 187**
Universe 215, 246; history **216-217,** 242, 244; size **238-239,** 240
Uranus **41,** 43, **183-189;** discovery 24, 186-187; rings **41, 182, 185, 188-189,** discovery **185,** 187, 189

Valhalla, Callisto **166,** 168
Valles Marineris, Mars 128, 130, **132-133,** 137
Van Allen radiation belts **95,** 112, 159, 265
Venera missions **84,** 89, 268, 269; pictures by **85**
Venus 40, 43, **81-91;** greenhouse effect 89; life, imaginary **46;** map **91;** phases 20, **83;** quakes 90; radar mapping 34, 85, 90; winds 85, **88-89;** *see also* Mariner; Pioneer; Venera
Vesta **144, 145,** 147
Viking missions **128-131,** 137, 140, **269;** pictures by **130-131, 136, 137, 140-141**
Volcanoes: Earth 96, **98-99,** 99; Io 159, 168, 171, **169, 170;** Mars **124,** 128, 130, **134-135;** Venus 90
Voyager missions 269; Jupiter 153, 155, 157, 159, **159,** 163, 168, 171, moons discovered 159, 165; Saturn **248-249;** pictures by **156-157, 164, 166, 167, 169**

White, Edward II **267**
White dwarfs *50,* **227,** *231*

X rays *28,* **28-29,** 233; Sun **51,** 66, **67;** telescopes **28-29,** 31, **245**

Zodiac **16-17,** 218
Zodiacal light **206**

Type composition by National Geographic's Photographic Services. Color separations by Beck Engraving Co., Inc., Philadelphia, Pa.; The J.Wm. Reed Co., Alexandria, Va.; The Lanman Companies, Washington, D. C.; Progressive Color Corporation, Rockville, Md.; and Chanticleer Company, Inc., New York, N.Y. Printed by Holladay-Tyler Printing Corp., Rockville, Md. Bound by Kingsport Press, Kingsport, Tenn. Paper by Westvaco Corp., New York, N.Y., and Mead Corp., Publishing Paper Division, New York, N.Y.

c.5

NAYLOR MIDDLE SCHOOL LIBRARY

X

Illustration Credits

Symbols used in this list: NGP-National Geographic Photographer. NGS-National Geographic Staff. GA-Geographic Art. CIT-California Institute of Technology. JPL-Jet Propulsion Laboratory. NASA-National Aeronautics and Space Administration.

Cover by John Berkey, Frank and Jeff Lavaty Associates. 1-3, Zeplin Productions Inc. 6-7, Howard Sochurek.

Beginnings
8-9, Peter Lloyd. 10-11, Peter Lloyd. 12-13, Thomas E. Hooper. 13, GA. 14-15, Peter Lloyd. 15 right, Ron Miller. 16-17, Peter Lloyd. 18, Charles and Ray Eames from Jagiellonian Library, Cracow, Poland. 19 top, Peter Lloyd. bottom, Ron Miller. 20, Charles and Ray Eames. 21, Peter Lloyd, after an illustration by Gordon Davies in *The Discovery of the Universe*, by Tony Osman, Usborne Publishing Ltd. 22, Peter Lloyd. 23 top left, Lick Observatory. top right, Owen Gingerich, courtesy of Houghton Library, Harvard University. bottom, Ron Miller. 24-25, Peter Lloyd. 26-27, Victor R. Boswell, Jr., NGP. 27, Jean-Leon Huens. 28-29, Peter Lloyd. 30, Ira Block. 31, Ron Miller. 32-33, Jonathan S. Blair. 34, Ron Miller. 34-35, Harold Sund, Image Bank.

The Sun & Planets
36-37, Peter Lloyd. 38, Davis Meltzer. 39 top and bottom left, GA. top and bottom right, Paul M. Breeden. 40-41, Ludek Pesek. 42 left, Paul M. Breeden. 42-43, Davis Meltzer. 43 center, GA. 44-45, Michael R. Whelan. 46-47, Michael R. Whelan.

The Sun
48-49, Ludek Pesek. 50 left, Michael R. Whelan. 50-51, Davis Meltzer. 51 top right, Metacolor. 52, William H. Regan and Maxwell T. Sandford, Los Alamos Scientific Laboratory. 53, Big Bear Solar Observatory, CIT. 54-55, Aura, Inc., Sacramento Peak Observatory. 56 top, Big Bear Solar Observatory, CIT. 56-57, GA. 58-59, Peter Lloyd. 60, Helmut K. Wimmer. 61, Aura, Inc., Sacramento Peak Observatory. 62-63, Ira Block. 64-65, Ira Block. 65 top, Ron Miller. 66-67, photo composite with photographs by Naval Research Laboratory, American Science and Engineering, High Altitude Observatory, all NASA, Sacramento Peak Observatory and Kitt Peak National Observatory, both Aura, Inc.

Mercury
68-69, Ludek Pesek. 70 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 71, Davis Meltzer. 72-73, Chris Foss. 74 left, JPL, NASA. right, Pierre Mion. 75, NASA. bottom, Pierre Mion. 76-77, Ludek Pesek. 79, Jay L. Inge.

Venus
80-81, Ludek Pesek. 82 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 83, Davis Meltzer. 84, Ludek Pesek. 85, National Space Science Data Center. 86-87, Ludek Pesek. 88 left, GA. right, Ames Research Center, NASA. 91, Jay L. Inge.

Earth
92-93, Ludek Pesek. 94 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 95, Davis Meltzer. 96, Jaime Quintero. 97, NASA. 98-99, Ken Sakamoto, Black Star. 99, Jaime Quintero. 100-101, Ludek Pesek. 102-103, Zdenek Burian. 104-105, NASA. 106-107, William H. Bond, NGS. 108-109, Loren McIntyre. 110-111, Jay L. Inge. 112, Pierre Mion. 113, Scott Bolden, NGS. 114 top left, Michael R. Whelan. 114-115, Davis Meltzer. 116-117 top, Lunar Orbiter 5, NASA. bottom, NASA. 118-119, Eugene A. Cernan, NASA. 120-121, Jay L. Inge. 122-123, NASA.

Mars
124-125, Ludek Pesek. 126 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 127, Davis Meltzer. top right, GA. 128-129, Vincent Di Fate. 130-131, NASA. 132-133, Ludek Pesek. 134, GA and NASA. 134-135, Graphic Films, JPL, NASA. 136, JPL, NASA. 137, NASA. 138-139, Jay L. Inge. 140-141, NASA.

Asteroids & Meteors
142-143, Ludek Pesek. 144, GA. top left, Michael R. Whelan. 145, Davis Meltzer. 146-147, Chris Foss. 147, JPL, NASA. 148, Mr. and Mrs. James M. Baker. 149 top, Albert Moldvay. bottom, Robert T. Dodd. 150-151, William K. Hartmann. 151, GA.

Jupiter
152-153, Ludek Pesek. 154 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 155, Davis Meltzer. 156-157, NASA. 158, Davis Meltzer. 159, Vincent Di Fate. 160-161, Ludek Pesek. 162-163, Jay L. Inge. 164, NASA. 165, GA. 166-167, NASA. 169, NASA. 170-171, Ludek Pesek.

Saturn
172-173, Ludek Pesek. 174 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 175, Davis Meltzer. 176, University of Arizona. 176-177, Ludek Pesek. 178-179, GA. 179, Ames Research Center, NASA. 180-181, Ludek Pesek.

Uranus
182-183, Ludek Pesek. 184 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 185, Davis Meltzer. 186, Jean-Leon Huens. 187, Lunar and Planetary Laboratory, University of Arizona, NASA. 188-189, Ludek Pesek.

Neptune
190-191, Ludek Pesek. 192 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 193, Davis Meltzer. 194, University of Arizona. 195, Ludek Pesek.

Pluto
196-197, Ludek Pesek. 198 top left, Michael R. Whelan. bottom left, GA. right, Davis Meltzer. 199, Davis Meltzer. center left, U. S. Naval Observatory. bottom, GA. 200, Lowell Observatory. 201, Ludek Pesek.

Comets
202-203, Ludek Pesek. 204 left, Michael R. Whelan. right, GA. 205 top, Davis Meltzer. bottom, GA. 206, NASA. 207, Victor R. Boswell, Jr., NGP. 208-209, Helmut K. Wimmer. 209, Donald Pearson. 210-211, Chris Foss. 211, GA. 212-213, Chris Foss.

Deep Space
214-215, Helmut K. Wimmer. 216-217, Jaime Quintero. 218, Michael R. Whelan. 219, photo composite by Ira Block. 220 top, Helmut K. Wimmer. bottom, GA. 221, Ira Block. 222 top, Aura, Inc., Kitt Peak National Observatory. 222-223, Pierre Mion. 223, GA. 224, "Beta Lyrae" by Chesley Bonestell, courtesy of Mr. and Mrs. Thomas J. Mullen, Jr. 225, Helmut K. Wimmer. 226-227, Ludek Pesek. 228, Aura, Inc., Kitt Peak National Observatory. 229, Palomar Observatory, CIT. 230, Helmut K. Wimmer. 231 top, Palomar Observatory, CIT. bottom, Lick Observatory. 232, Helmut K. Wimmer. 233, Victor J. Kelley. 234-235, Lund Observatory. 235, Helmut K. Wimmer. 236, Palomar Observatory, CIT. 237 top left, Lick Observatory. top right, Palomar Observatory, CIT. bottom left, Aura, Inc., The Cerro-Tololo Inter-American Observatory. bottom right, Hans Vehrenberg, Hansen Planetarium. 238-239, Helmut K. Wimmer. 240 top, Arnold H. Rots and Whitney W. Shane, National Radio Astronomy Observatory and The Netherlands Foundation for Radio Astronomy. 240-241, Ron Miller. 242-243 top, Aura, Inc., Kitt Peak National Observatory. bottom, From "Violent Tides between Galaxies" by Alar and Juri Toomre, copyright Dec. 1973 by Scientific American, Inc. 244, H. Tananbaum, R. Giacconi, Harvard-Smithsonian Center for Astrophysics. 245, Frank J. Krasyk. 246, Otis Imboden, NGP. 247 left, National Astronomy and Ionosphere Center, Cornell University. right, Robert W. Madden, NGP. 248-249, Vincent Di Fate.

Shuttles & Starships
250-251, Vincent Di Fate. 252, Jon Schneeberger, NGS. 253 top, Kerby Smith. bottom, Bruce Dale, NGP. 254-255, Sydney Mead. 256-257, Vincent Di Fate. 258-259, "Lunar Farside Research Base" by Pierre Mion, courtesy National Air and Space Museum, Smithsonian Institution. 259, "Mining an Asteroid" by Chesley Bonestell, courtesy of Ames Research Center, NASA. 260-261, Sydney Mead. 262-263, Sydney Mead.

Highlights
264 left, Archives, CIT. top center, Edwin L. Wisherd. bottom center, NASA. right, courtesy of Bell Laboratories. 265 left, U. S. Army, Official. top center, Sovfoto. bottom center, Novosti Press Agency. top right, Igor Snegirev, Novosti Press Agency. bottom right, NASA. 266 top left, Flip Schulke, Black Star. bottom left, BBC. top center, Novosti Press Agency. bottom center, Maarten Schmidt, CIT. top right, JPL, NASA. bottom right, Douglas S. Chaffee. 267 top left, James A. McDivitt, NASA. bottom left, Thomas P. Stafford, NASA. top right, Bruce Dale, NGP for NASA. bottom right, Jonathan S. Blair. 268 top left, Neil A. Armstrong, NASA. bottom left, A. Patnesky, NASA. top center, Eugene A. Cernan, NASA. 268-269, NASA. 269 top left, Carl and Linda Sagan, Frank Drake, National Astronomy and Ionosphere Center, Cornell University. center, Skylab 4, NASA. right, NASA. Inside of back endsheet, Jean L. Lorre, JPL and Palomar Observatory, CIT.

Library of Congress CIP Data
Gallant, Roy A.
National Geographic picture atlas of our universe
Includes index.
1. Astronomy – Pictorial works.
2. Astronomy – Charts, diagrams, etc.
I. Sedeen, Margaret. II. National Geographic Society, Washington, D. C. Book Service. III. Title
QB68.G34 523 80-19137
ISBN 0-87044-356-9 regular bind.
ISBN 0-87044-357-7 library bind.

Two galaxies known as NGC 1097 – a barred spiral and its small, elliptical companion – become a cosmic color splash in this computer-enhanced photograph.