SPECIAL SUPPLEMENT: MAP OF THE HEAVENS

VOL. 138, NO. 2 AUGUST 1970

NATIONAL GEOGRAPHIC

OFFICIAL JOURNAL OF THE NATIONAL GEOGRAPHIC SOCIETY WASHINGTON, D.C.

August 1970

NATIONAL GEOGRAPHIC

THE NATIONAL GEOGRAPHIC MAGAZINE VOL. 138, NO. 2

Voyage to the Planets

By KENNETH F. WEAVER
Assistant Editor

Paintings by LUDEK PESEK

To take us in imagination to the farthest reaches of our solar system, the NATIONAL GEOGRAPHIC has teamed its award-winning science writer Kenneth F. Weaver with the noted Czech painter of astronomical subjects, Ludek Pesek. Their work reflects the knowledge gained from American and Soviet deep-space probes. It incorporates the latest thinking of leading U. S. authorities on each of the planets, and for their many contributions to the interest and accuracy of this presentation we are deeply grateful.—THE EDITOR

I have reached these lands but newly
From an ultimate dim Thule—
From a wild weird clime that lieth, sublime,
Out of Space—out of Time.
—EDGAR ALLAN POE, "DREAMLAND"

AS SHEPHERDS OF OLD watched the starry arch of night wheel majestically overhead, they took comfort in the apparent constancy of the heavens. Save for an occasional meteor whose brilliant trail flashed across the vault, each heavenly lamp stayed firmly fixed in its niche.

Well, not quite all. Amid the thousands of naked-eye stars, several of the brightest disobeyed the usual pattern. Unaccountably and mysteriously, they drifted from night to night across the winking field of lights in their own fashion, coming and going. Sometimes they disappeared for weeks at a time.

To some ancient shepherds, who in imagination saw a herdsman in the constellation Boötes, these five mavericks were stray animals. The Greeks called them *planetes,* or wanderers. The Romans gave them names of their gods: Mercury, Venus, Mars, Jupiter, and Saturn. And from earliest recorded times, astrologers ascribed mystical qualities to these celestial bodies, as well as to the sun and the moon, teaching that they affected the destinies of nations and of kings.

The Babylonians, who embraced the notions of astrology, associated the planet Jupiter with the god Marduk, a benign power. Saturn they linked to Ninurta, the god of war. Mars, whose ruddy color suggested blood, was a sign of Nergal, god of the underworld.

A Babylonian clay tablet of about 700 B.C. warns: "When Ishtar [Venus] grows dim and disappears . . . there will be a slaughter. . . . When Ishtar appears . . . the crops of the land will be prosperous."

Fancies such as these persisted through the centuries—in Greece, in Rome, in the Moslem East, in medieval Europe, and in

the Orient. Astrologers advised princes and kings, casting their horoscopes to determine the positions of sun, moon, and planets in relation to the zodiac at some crucial moment and studying the charts for omens of good and ill.

With the intellectual ferment of the Renaissance, men began again to study the nature of the universe, and astrology became discredited in the Western World. (It is, perhaps, a sign of our unsettled times that the occult practices of astrology are currently enjoying a new vogue.)

When Galileo, in 1609, first trained the newly invented telescope on the heavens, scientific investigation of the planets became more exact and much more exciting.

What a world of marvels could be glimpsed through the new instrument! No longer were the planets simple points of light; they were small disks. Venus, brightest of all, showed phases like those of the moon. And Earth was not the only planet to have a satellite: Jupiter had its own family of moons. As for Saturn, it was in time revealed as the most beautiful object in the sky, with a gleaming girdle of rings about its equator (cover and page 184).

IMPORTANT DISCOVERIES soon changed man's most fundamental concepts of the universe. Already Copernicus had pronounced (in a book published the year of his death, 1543) that the sun, not Earth, was the center of things. Now Kepler showed that the orbits of planets about the sun are elliptical, not circular; Newton, with his law of gravitational force, enabled men who followed him to work out those complicated orbits. By the 1840's, two additional planets, Uranus and Neptune, had been spotted.

But even through the telescope, the planets yielded their secrets grudgingly. Astronomers still had to peer through Earth's shimmering atmospheric veil, which made details come and go in the most tantalizing way. Much depended on the observer's imagination.

By World War I these dark bodies, which shine only by reflected sunlight, seemed to lose their appeal. In the '20's and '30's most professional astronomers turned their attention to the distant stars, whose abundant outpourings of light and other radiant energy soon told us more about stellar interiors many trillions of miles away than we knew about even the surfaces of our closest neighbors.

All that has been changing in the past dozen years. Solar-system astronomy is again in ferment, and the '70's promise to be the decade of planetary investigation. Powerful new tools, such as radar and radio telescopes, sensitive detectors of infrared and other invisible radiations, sounding rockets and spacecraft that climb beyond Earth's clouded atmosphere, are beginning to produce an avalanche of information and a number of surprises. They have challenged many of our most cherished notions about the planets, and have proved how little we really knew about our neighbors.

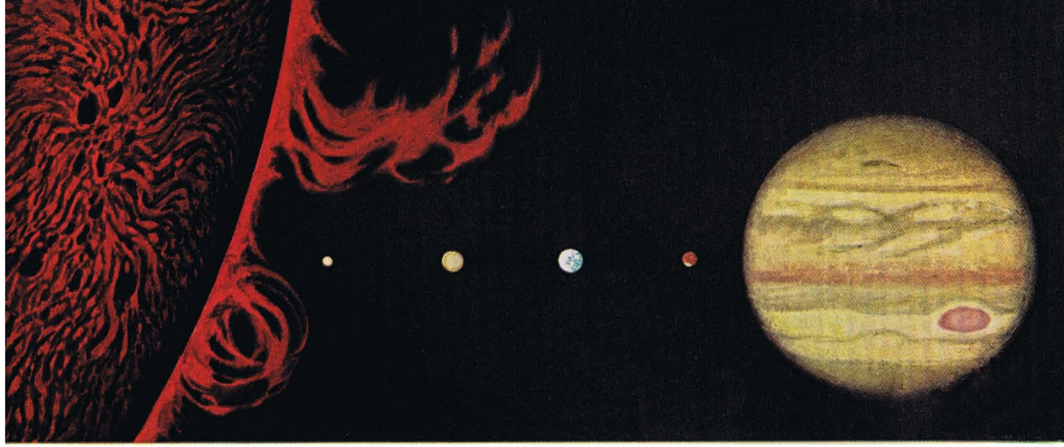
Venus, for example, once supposed to be a well-watered twin of Earth, is really an inferno. Ridiculously, it rotates backward!

Mercury, which was long thought to keep the same face steadfastly toward the sun, so that its front side was a furnace and its eternally dark back side the coldest place in the solar system, embarrassingly does indeed turn its face from the fire.

And Mars, the abode of a race of intelligent canal builders in the eyes of Percival Lowell and his followers at the turn of the century, has proved to have no canals and offers no evidence of water in liquid form, or of anything else that would encourage life as we know it on Earth.

One of today's specialists on planets, Dr. Bruce C. Murray, Professor of Planetary Science at the California Institute of Technology, sums it up this way: "We find that most of the ideas we had about Mars were wrong; in fact, most of the ideas we have about any celestial body prove wrong when we get real knowledge about it."

During the past decade, besides landing men on the moon, the National Aeronautics and Space Administration has completed



Colossus in the pageant of planets, banded Jupiter stares down with baleful red eye on its giant satellite Ganymede, foreground. Big enough to swallow 1,300 Earths, Jupiter with its powerful gravity controls a dozen moons and tugs at every other body in the solar system. Another moon, Europa, floats at far right. PAINTING BY LUDEK PESEK © N.G.S.

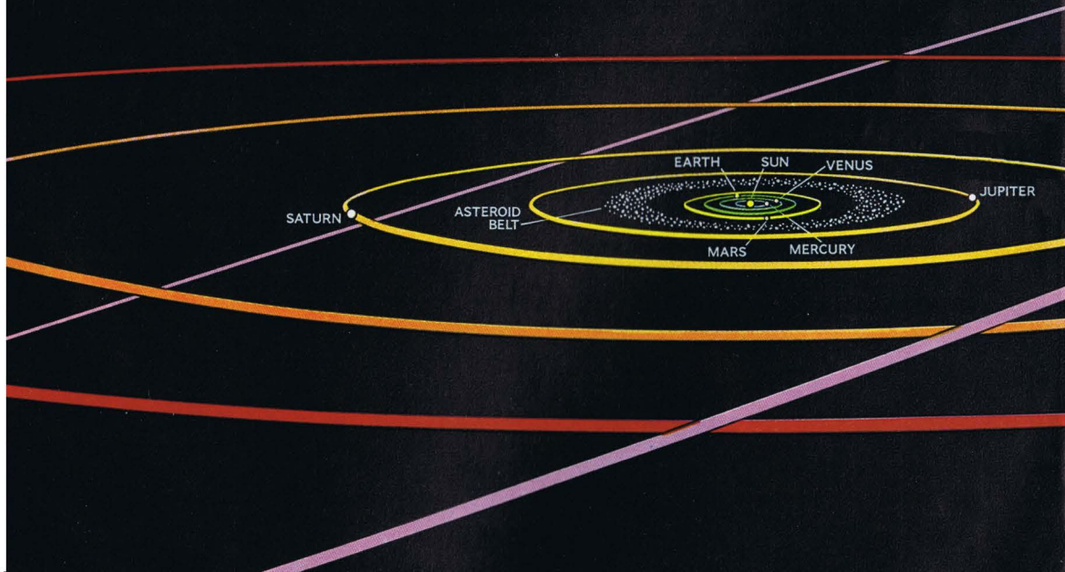
THIS PAGE FOLDS OUT

	MERCURY	VENUS	EARTH	MARS	JUPITER
EQUATORIAL DIAMETER (EARTH=1 or 7,926.4 miles)	0.38	0.95	1	0.53	11.19
MASS (EARTH=1)	0.06	0.82	1	0.11	317.9
VOLUME (EARTH=1)	0.06	0.86	1	0.15	1318
DENSITY (WATER=1)	5.50	5.27	5.52	3.95	1.33
EQUATORIAL SURFACE GRAVITY (EARTH=1)	0.39	0.91	1	0.38	2.31
NUMBER OF SATELLITES	0	0	1	2	12
ROTATION ON AXIS (EARTH TIME)	58.65 days	243 days	1 day	1.03 days	9.93 hours
REVOLUTION AROUND SUN (EARTH TIME)	88 days	224.7 days	1 year	1.88 years	11.86 years
MEAN DISTANCE FROM SUN (EARTH=1 or 92,956,524.4 miles)	0.39	0.72	1	1.52	5.20

PLANETARY DATA FROM JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

ORBITS OF THE PLANETS

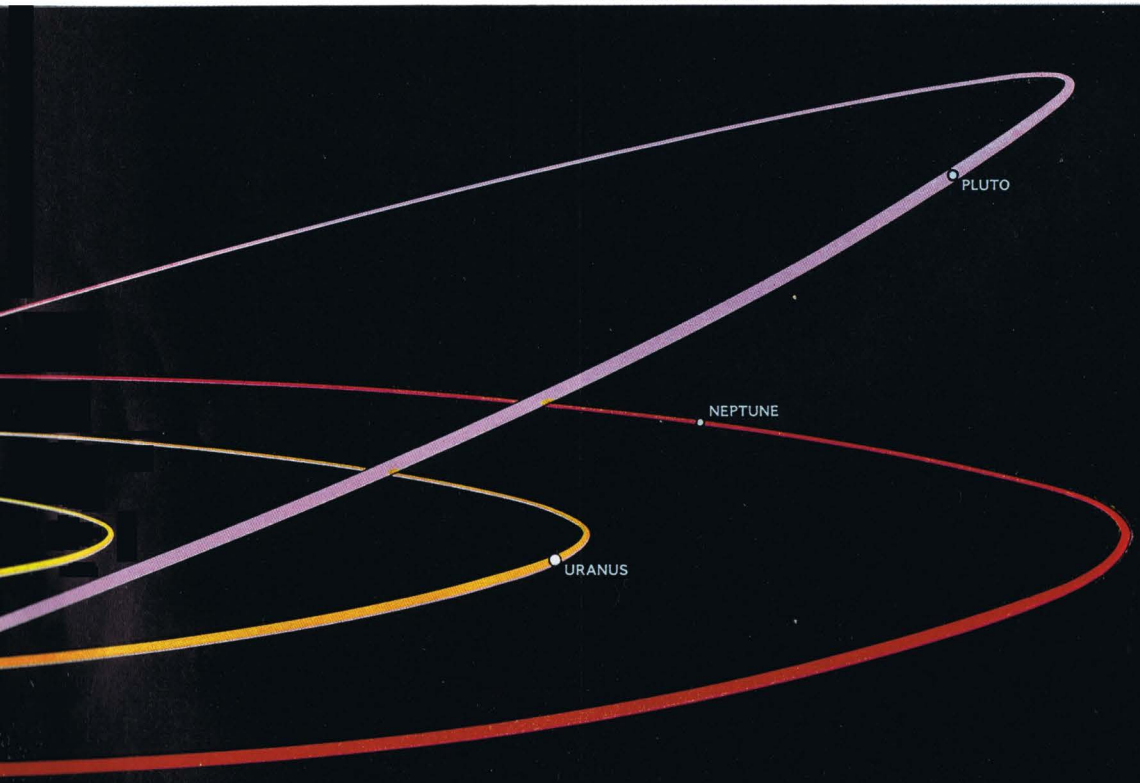
Like ripples on a pond, paths of the planets range outward from the sun in this view of their positions on August 1, 1970. Most of the orbits lie approximately on the ecliptic, the plane of Earth's movements about the sun. But Pluto revolves at an angle of 17° from the ecliptic, and the orbital plane of Mercury tilts 7°. Between Mars and Jupiter, a wide belt swirls with perhaps 100,000 asteroids that can be detected through Earth's largest telescope.

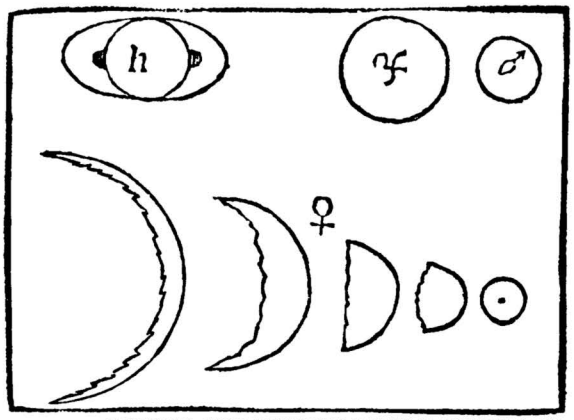


RELATIVE SIZES OF SUN AND PLANETS

SATURN	URANUS	NEPTUNE	PLUTO
9.5	3.7	3.9	0.5?
95.1	14.5	17.3	0.18?
769	50	59	?
0.69	1.7	1.6	?
0.88	1	1.1	?
10	5	2	0
10.23 hours	10.8 hours?	15.8 hours?	6.39 days
29.46 years	84.01 years	164.1 years	247 years
9.52	19.16	29.99	39.37

PAINTING (ABOVE) BY DAVIS MELTZER AND DIAGRAM BY LEO ZEBARTH, GEOGRAPHIC ART DIVISION © N.G.S.

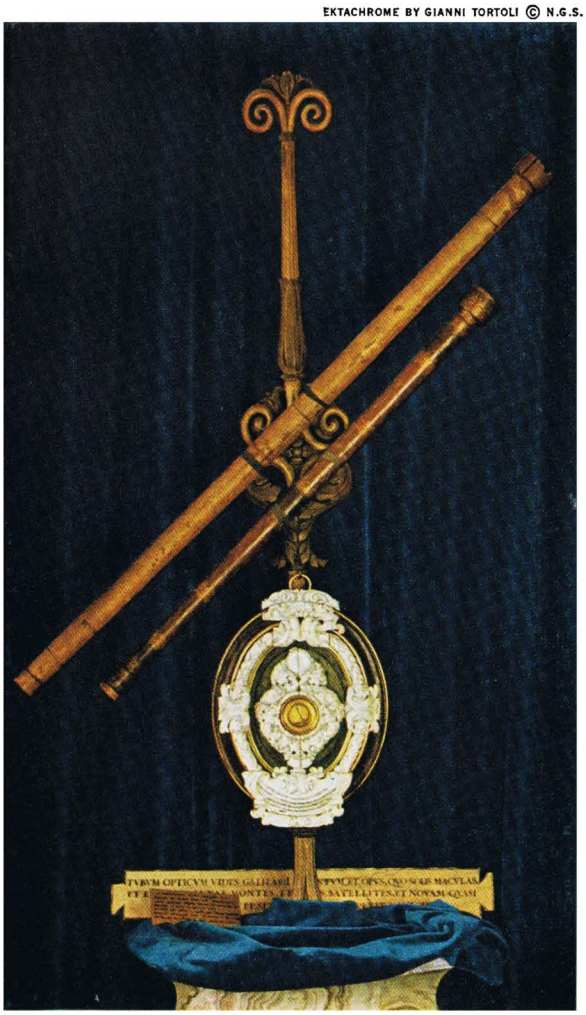




COURTESY MRS. SIMONE GOSSNER FROM GALILEO'S "IL SAGGIATORE," 1656

Galileo's own sketches, bearing the planetary signs (page 158), illustrate his epochal discoveries: the phases of Venus (next to a sun symbol at lower right), the rings of Saturn, and the blank disks of Jupiter and Mars, which man had seen earlier only as points of light.

EKTACHROME BY GIANNI TORTOLI © N.G.S.



First to explore the planets by telescope, Galileo Galilei (below) beheld awesome vistas. He launched the era of modern astronomy 360 years ago.

Gazing at Venus, the Italian mathematician detected its moonlike phases. This told him it revolves around the sun instead of Earth, supporting the then-heretical theory of the Polish astronomer Copernicus of a sun-centered solar system.

He delightedly observed four "little stars" attending Jupiter—the Galilean satellites—and puzzled over the strange configuration of Saturn. Training on the fiery solar disk itself, he saw sunspots—and discovered that they moved about.

PAINTING BY GIUSTO SUSTERMAN, UFFIZI GALLERY, FLORENCE; PHOTOGRAPH FROM SCALA

Crude challengers of the infinite, two of Galileo's telescopes, each about 30 power, still point skyward. Ivory mount below them holds one of his cracked lenses. Although a Dutch lens maker had invented the telescope a year earlier, in 1608, Galileo was the first to train it on the heavens, using instruments he himself made.

Treasures of the Institute and Museum of the History of Science in Florence, Italy, Galileo's telescopes escaped the 1966 Florence flood only when the director risked her life to snatch them from the torrent (GEOGRAPHIC, July 1967).

five successful flybys of the planets—two to Venus and three to Mars. The Soviet Union has plunged three transmitting space probes into the dense atmosphere of Venus.

"This decade," says NASA Administrator Thomas O. Paine, "the entire solar system is the goal. No one knows how ambitious the Russian plans are, but before the end of the 1970's the United States hopes to send unmanned spacecraft racing toward every single one of the planets."

These robots from Earth will take pictures, sniff the atmospheres, gauge temperatures and pressures, measure radiations and magnetic fields, and—in the case of Mars—look for evidences of life.

Major scientific questions underlie this program of exploration—questions of consummate interest to all mankind:

1. How did the solar system begin, and how did it evolve?

2. How did life begin—and is there life elsewhere?

3. What can we learn about the missing chapters in the history of our own planet that will help us to understand better the workings of Earth and to solve the problems of our environment?

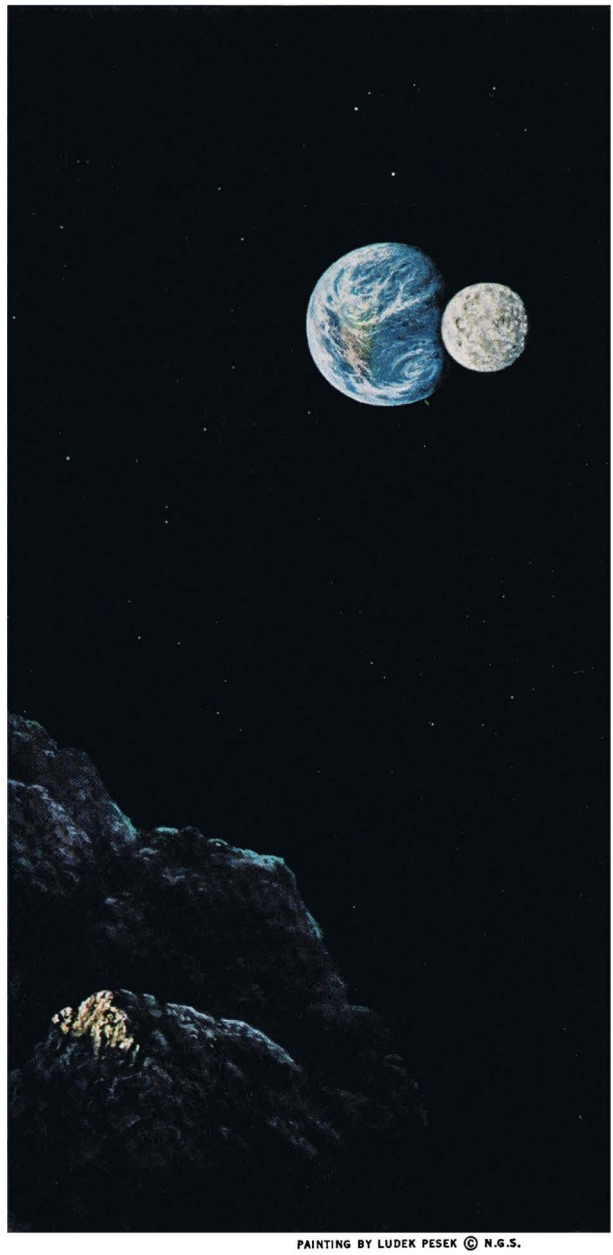
Dr. Von R. Eshleman, of Stanford University, echoes the feelings of many scientists when he says, "We need examples from other planets to guide our thinking and to throw new light on our attempts to understand puzzling terrestrial phenomena."

Let us take a look at this family of the sun, with its 9 planets and 32 satellites and thousands of asteroids and comets, stretching over a domain at least 8 billion miles across—so far that light, traveling at 186,282 miles a second, requires *half a day* to cross it.

If you think of the sun as a grapefruit, then a grain of sand 40 feet away would represent Earth, a cranberry 200 feet away would be Jupiter, and another grain of sand nearly a third of a mile away would be Pluto, the outermost planet. The nearest star would be another grapefruit, 2,000 miles distant.

Earth

Suppose we visit each planet, seeing it as if we were aboard an unmanned NASA spacecraft that will approach it sometime within the next few years. As a base for comparison, let us start with Earth. How would our planet look to men and instruments in spacecraft from another planet, orbiting above and then landing on the surface to make observations?



EARTH

The good planet Earth, sun-blessed sanctuary of life, travels in tandem with its sterile moon. Artist Pesek imaginatively portrays them from the vantage point of the asteroid Hermes, as it swept to within a mere 500,000 miles of Earth in 1937. So large is the moon —a fourth Earth's diameter—that many astronomers regard the pair as almost a double planet. Here the moon, closer to the asteroid, appears abnormally large.

PAINTING BY LUDEK PESEK © N.G.S.

I can imagine that these extraterrestrial astronauts might make brief entries in their log something like this:

Blue-and-white planet—only one in this system. Water covers 71 percent.

Low cloud masses, in swirling patterns, block much of view. Atmosphere: 78 percent nitrogen, 21 percent oxygen, and 1 percent argon, carbon dioxide, and other gases; water vapor variable; no appreciable hydrogen or helium. Atmospheric pressure, 14.7 pounds per square inch. Atmosphere and water vapor block part of radiation from the sun, 93,000,000 miles away. Planet acts like a magnet. Many meteoroids reach atmosphere; most burn up before striking surface.*

Land surface chiefly silicates; heavily modified by water and wind. Smooth in places; elsewhere rough and marked by steep uplifts. Crust shudders and spews molten material. Must be very hot underneath.

Temperature variations moderate. Coldest near poles (frozen water); minimum −127° F. Hottest near equator; maximum 136° F.

Life abundant; many forms; heavily dependent on liquid water and—in most cases—oxygen. Vegetation shows seasonal changes because planet is tilted, with first one hemisphere, then the other, toward sun during a 365-day orbit. Rotation on axis, 24 hours.

One large moon; with Earth, essentially a double planet.

*See in the GEOGRAPHIC: "The Earth From Orbit," by Paul D. Lowman, Jr., November 1966; and "Historic Color Portrait of Earth From Space," November 1967, and "The Flight of Apollo 11: 'One Giant Leap for Mankind,'" December 1969, both by Kenneth F. Weaver.

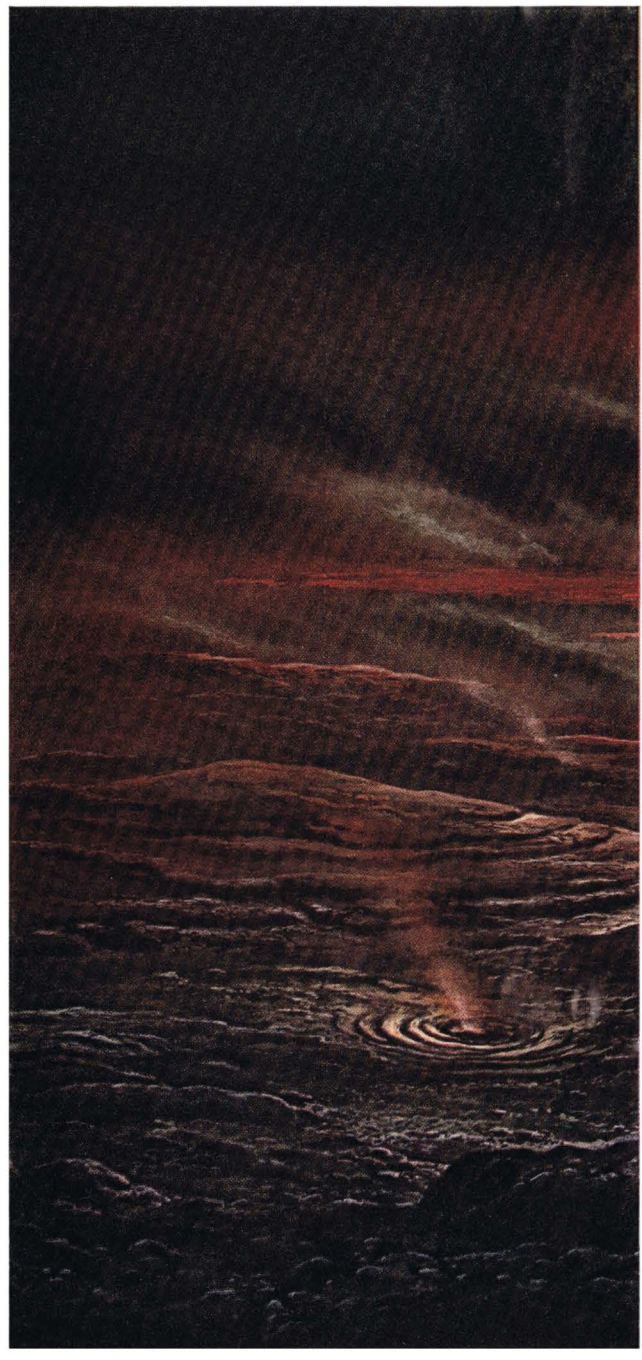
VENUS

Hades of the heavens, Venus seethes with fumaroles and glowing lava in this vivid conception of Earth's cloud-veiled neighbor. In reality, even an observer on the surface of Venus could see no such panorama, for the planet's atmosphere—about a hundred times denser than Earth's—would blind like a thick fog.

Brutally hostile, the planet broils at nearly 1,000° F. beneath a smothering carbon-dioxide atmosphere that traps solar heat by the "greenhouse effect." Yet Venus works her charms. For us she glows faithfully as the morning and evening "star." Light from Venus, the brightest heavenly body except for the sun and the moon, can cause earthbound objects to cast a faint shadow on moonless nights.

Venus

In the autumn of 1973, if NASA's plans hold, an Atlas-Centaur rocket will launch a Mariner spacecraft on a voyage to Venus and Mercury, the two planets lying between Earth and the sun. It will be the first United States attempt to fly past Mercury and the first gravity-assisted mission to a planet: That is, the spacecraft will be aimed so that as it passes Venus the gravitational field of that planet will help swing it,



somewhat like a ball on a string, and send it with the proper speed and direction toward Mercury.

This mission, like all those planned for the planets in the '70's, will be unmanned. But imagine that you are aboard as the spaceship approaches its first goal, Venus. The date is between February 3 and 6, 1974, and your spacecraft has been on the way for more than three months.*

Time: One hour before closest approach. We are coming in on Venus's dark side. Only a sliver of the lighted side of the planet is clearly visible.

Behind us, 28 million miles distant, our home planet has shrunk to a brilliant "star"—

*All flight information in this article is based on tentative plans now being refined by Caltech's Jet Propulsion Laboratory and (for the Pioneer missions to Jupiter) NASA's Ames Research Center. Figures may vary on the actual missions.

the brightest in the heavens except for the sun. Our messages, traveling at the speed of light, take two and a half minutes to reach the 210-foot radio dish at Goldstone, California.

The sun, only 67 million miles away, has grown a third larger than it appears from Earth. Now twice as much solar heat and light beat down upon our spacecraft.

As we curve around the planet, the glowing crescent rapidly enlarges. At closest approach —about 3,100 miles away—a half Venus nearly fills our field of vision, shining brilliantly with a slightly yellowish color. Then the entire dazzling spectacle sweeps into view as we swing on around and head for Mercury; Venus is more than three times as bright as Earth if seen from the same distance.

During the flyby, our cameras are taking pictures of the scene and our instruments are recording temperatures and other information about the planet's environment.

All we can see, however, is an expanse of dense clouds. That is all any man has ever seen of Venus. And it may be all any man will ever see, for what lurks below that veil is an awesome world of unbearable heat and pressures and of terrifying distortions.

Back on Earth, scientists have just begun to crack the many mysteries of Venus. By piecing together evidence from earth-based radar, from the Soviet probes (Venera 4 in October 1967 and Venera 5 and 6 in May 1969), and from our own Mariner 2 in December 1962 and Mariner 5 in October 1967, they are beginning to find out what makes Venus such a grim place.*

Key to the matter is a remarkable atmosphere, now thought to be about 95 percent carbon dioxide, that exerts a pressure of a hundred atmospheres (that is, a hundred times the pressure of Earth's atmosphere). Equivalent to the weight of water more than half a mile under the sea, this enormously dense atmosphere is believed to have crushed the three parachuting Soviet probes like so many eggshells when they were still 15 miles or more above the surface of Venus.

LAYERS OF THICK CLOUDS above Venus reach the astonishing altitude of 35 miles. (On Earth, even the highest clouds seldom go above ten miles.) They may block much of the sun's light. In addition, molecules in the extremely dense atmosphere scatter light as does a fog. The result, according to some scientists, may be a murky twilight; others see it as an eerie whiteout, or like living at the bottom of a dust storm or a dense smog.

The thick atmosphere that weighs so oppressively on the surface tortures it in another way: It traps the sun's energy and helps build up the most furnacelike heat yet found on any planet.

At least, this is the theory held by many scientists, based on the well-known "greenhouse effect." Solar energy filtering down through the clouds is absorbed by the surface, then re-radiated as longer-wavelength infrared, or heat. Much of this heat would escape to space and thus cool the planet but for the fact that the atmosphere (like the glass in a greenhouse) effectively blocks infrared.

Some specialists feel that the greenhouse effect is not sufficient to explain the riddle of Venus's ultrahigh temperatures: At the equator they are observed to reach as high as 1,000° F., and, because heat is transferred so efficiently by a dense atmosphere, even the poles probably are not much cooler. At such temperatures lead, tin, and zinc will melt, and any number of compounds vaporize.

If you could stand on the surface of Venus, few obstacles would block the view. Recent observations with the 120-foot Haystack radar telescope (opposite), operated by the Massachusetts Institute of Technology's

*See "Mariner Scans a Lifeless Venus," by Frank Sartwell, NATIONAL GEOGRAPHIC, May 1963.

The planetary symbols

☿ **MERCURY:** stylized caduceus, staff of the messenger of Roman gods

♀ **VENUS:** mirror, emblem of the Roman goddess of beauty

⊕ **EARTH:** Equator and meridian on a globe

♂ **MARS:** shield and spear of the Roman god of war

THE ASTEROIDS: National Geographic-devised symbol representing the many minor planets

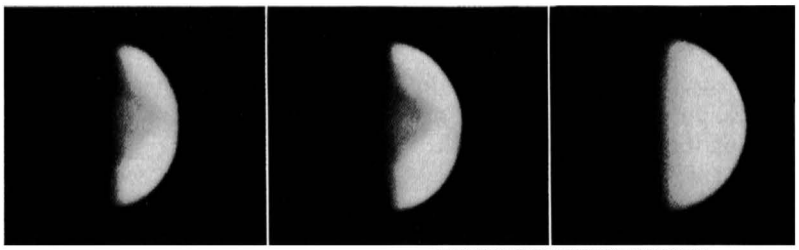
♃ **JUPITER:** modified Z for Zeus, Greek counterpart of Rome's chief deity

♄ **SATURN:** scythe of the Roman god of harvest

♅ **URANUS:** symbol of the heavens, representing the sky god

♆ **NEPTUNE:** trident of the Roman god of the seas

♇ **PLUTO:** monogram formed from the planet's first two letters



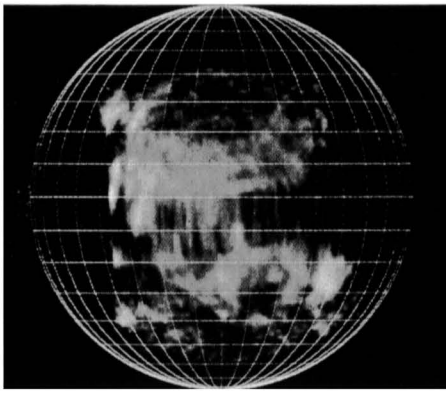
NEW MEXICO STATE UNIVERSITY OBSERVATORY

High Venus clouds, smudges as seen three hours apart in the two ultraviolet images at left, appear to circle the planet 60 times as fast as Venus itself rotates. No features mark a green-filtered image, right.

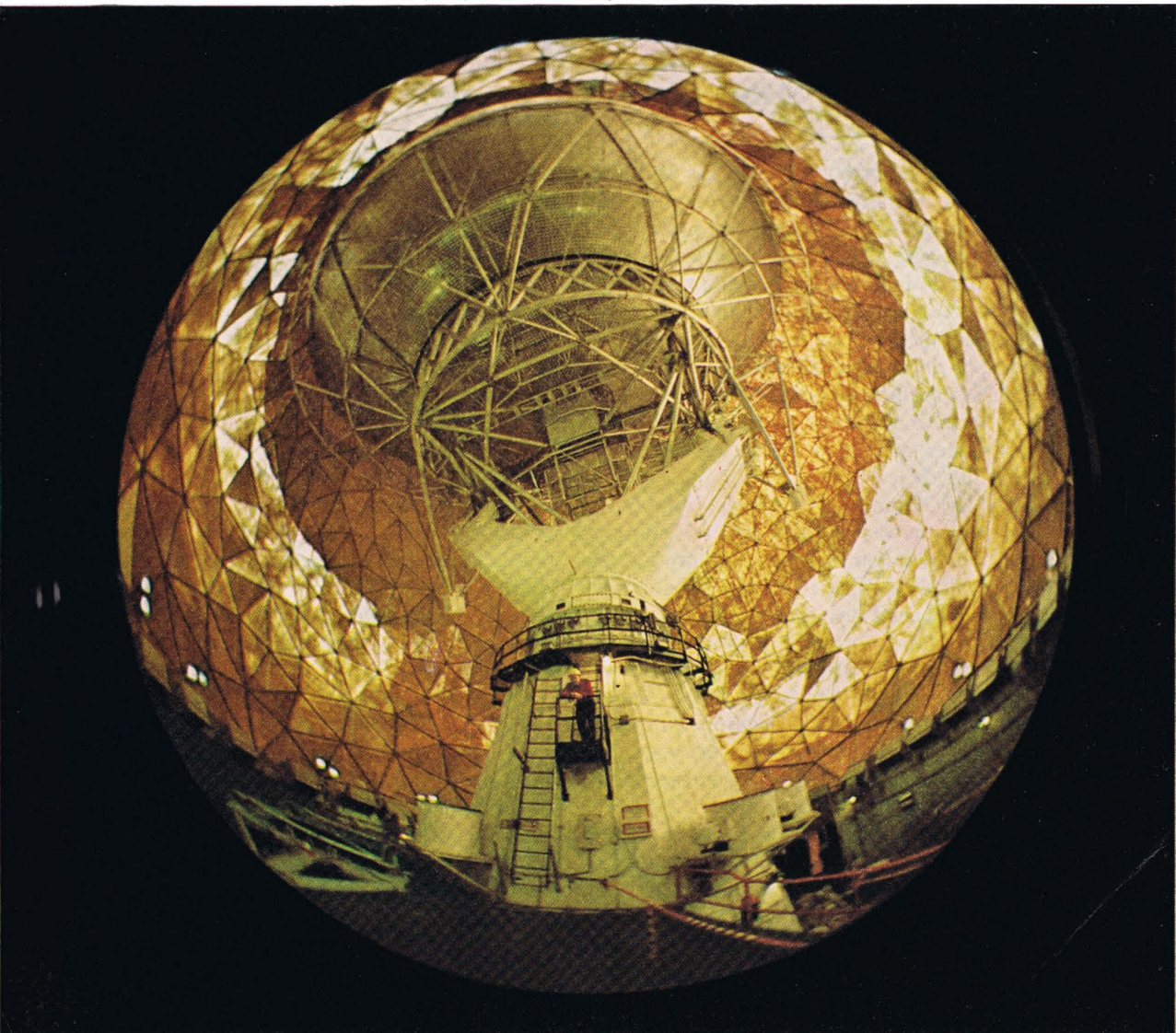
To part the shroud that wraps Venus, astronomers on Earth feel her torrid face with radar waves, broadcast by such mammoth facilities as MIT's Haystack antenna (below). Located in Tyngsboro, Massachusetts, the 120-foot dish transmits through a radome that shields it from the weather.

Haystack's invisible waves fill in blurred but meaningful Venus features. In a 1969 image (right), bright regions of high reflectivity betray rough terrain, possibly mountains. Fainter echoes tell of smooth areas. The waves also see a surface apparently very solid, though perhaps dust-covered.

Radar astonished astronomers with its 1962 revelation of Venus's unorthodox rotation. Instead of spinning counterclockwise like its neighbors, the planet rotates the other way—one leisurely clockwise turn every 243 earth days.



KODACHROME (BELOW) BY ERNEST MELANSON © N.G.S.; MASSACHUSETTS INSTITUTE OF TECHNOLOGY, LINCOLN LABORATORY (ABOVE)



Lincoln Laboratory near Boston, have detected a low mountain range, but in general the surface of Venus is thought to be quite gentle in slope. Bright areas showing up on radar pictures at Haystack, and at the Jet Propulsion Laboratory's Goldstone installation, are generally interpreted as local rough spots, not necessarily elevations.

But of far greater effect on visibility would be the thick atmosphere of Venus and its capacity to bend light rays sharply, just as a prism does. This refraction would make it seem that you were standing in a bowl, with the horizon turning up in every direction.

In fact, the light bending is so extreme that, were it not for the low visibility, if you shone an enormously powerful light ahead of you, the light would go completely around the planet, hitting you in the back of the head. That is the whimsical suggestion of Dr. Von R. Eshleman, who has studied the way light and radio waves act in the atmosphere of Venus. Put another way, if such an atmosphere were totally transparent, you could theoretically see all the way around the planet.

IN THE LATE 18TH CENTURY, Sir William Herschel, Britain's Court Astronomer, believed that life existed on all the planets, as well as the sun. What a shock Venus would be for him today! Although some terrestrial organisms can withstand unbelievably hostile conditions, such as salt lakes and boiling hot springs, no organisms that we know could live on the hot surface of Venus. Nor is water in liquid form thought to be there, and some liquid water seems to be an essential for earthly life, at least.

Dr. Carl Sagan, of Cornell University, points out, however, that life on another planet would not in any case require terrestrial conditions—that it would be adapted to its own special environment. He suggests that microscopic forms of life may exist at some level in the clouds, like plankton in Earth's seas. At the top layer of the Venus clouds, temperatures have been measured at about −35° F., and somewhere between the frigid cloud tops and the searing surface must be a "comfortable" temperature.

One of the many mysteries about Venus is where its water has gone—if, indeed, it ever had any. Was Venus made from materials that lacked water? Or did it outgas or exhale water in large amounts over the ages, just as has Earth, through volcanoes and fumaroles, and then somehow lose it?

All we know for sure is that recent observations of the planet's infrared absorption indicate that the amount of water vapor in the upper atmosphere is extremely low—no more than 1/1,000 the amount in Earth's atmosphere. Controversy surrounds the question of whether water droplets or ice crystals could exist in the Venus cloud layers.

It is an astonishing fact that Earth has nearly as much carbon dioxide as does Venus, even though only a small fraction of a percent is found in our atmosphere. Most of our carbon dioxide has dissolved in the oceans, where it has become locked up in calcium carbonate, such as in sea shells and limestone. If that lock were picked, Earth would have a dense carbon-dioxide atmosphere, very much like that of Venus.

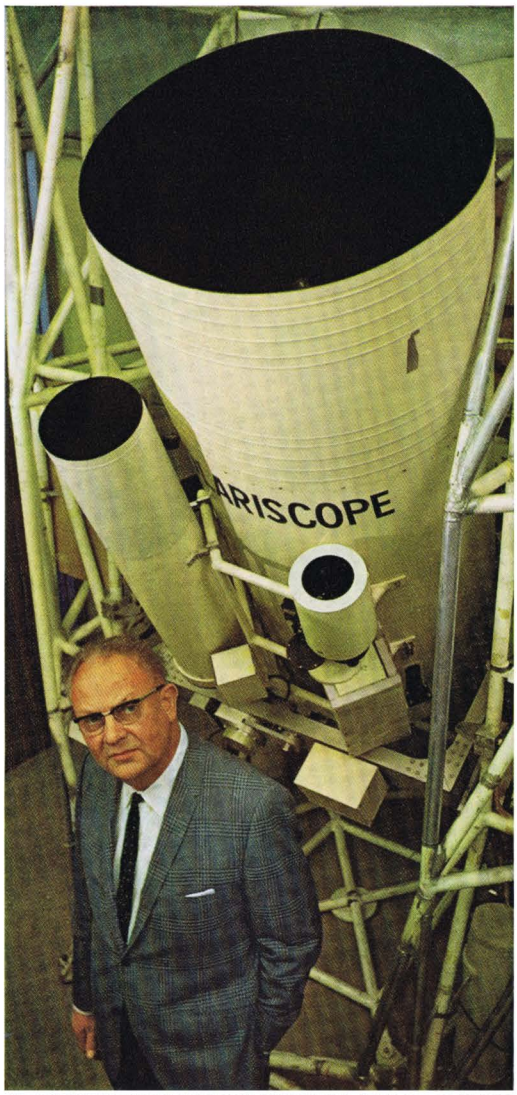
THE ROTATION PERIOD of Venus was for centuries a matter of dispute. Published guesses varied from 22 hours to 365 days. But nobody knew for sure, because they couldn't see the surface of the planet itself.

Increasingly sensitive radar observations, which pierce through the clouds, have settled the matter. Venus makes a complete rotation on its axis once every 243 days. To everyone's astonishment, it turns clockwise, backward to the typical motion of the planets.

Because of the combination of this slow backward rotation and the 225 days it takes the planet to make one orbit around the sun, Venus "sees" the sun come up *in the west* every 117 earth days.

One of the controversies raging most vigorously in planetary astronomy today centers on the question of what makes up the Venus clouds. When I posed the matter to Dr. Donald Hunten, of the Kitt Peak National Observatory, he commented wryly, "We get many answers to that question, which means we just don't know."

Some specialists insist that they find evidence of water droplets or ice crystals; others see dust. Among other substances that have been suggested are compounds of mercury and a form of iron chloride which might explain the yellowish color so characteristic of Venus. The truth, most likely, is that the Venus clouds will prove to contain a mixture of substances.



KODACHROME BY NATIONAL GEOGRAPHIC PHOTOGRAPHER EMORY KRISTOF © N.G.S.

Veteran viewer of the solar system, Dr. Gerard P. Kuiper has discovered two satellites of outer planets: Miranda, a moon of Uranus, in 1948, and Neptune's Nereid in 1949. Director of the Lunar and Planetary Laboratory of the University of Arizona in Tucson, he stands beside a balloon-riding telescope that records ultraviolet radiation.

Mercury

Catapulted by Venus's gravitational field, our spacecraft bends its flight path by some 40 degrees and races on toward Mercury, the solar system's innermost and smallest planet.

On March 30, 1974, we reach this second goal. Mercury has only about a third the diameter of Earth. We approach it so fast and it looms so swiftly that we almost feel vertigo. Now our cameras and instruments race to record information. After years of preparation and 5½ months in flight, we have only two hours to gather all the close-up information on Mercury we will get in this decade.

Earth lies 93 million miles behind, still a very bright point of light. The scientists there, at the Jet Propulsion Laboratory in Pasadena, California, wait tensely for the information from our instruments and tape recorders; the signals take more than eight minutes to reach Earth.

The sun, now only 43 million miles away, appears more than twice as large as when seen from Earth; the solar radiation bombarding us is five times as intense as that striking Earth's atmosphere. If our spacecraft were truly designed for manned flight, it would require much more radiation shielding and temperature control.

The surface of Mercury filling our view is a rare sight, never clearly seen from Earth. Now we can see it with perfect clarity; no atmospheric effects block the vista. We are only about 600 miles from the surface, and our eyes can distinguish objects as small as 1,700 feet across. Everywhere we see evidence that this rocky cinder has been cratered by comets and asteroids, and it is not hard to imagine that it was once scorched by tremendous heat.

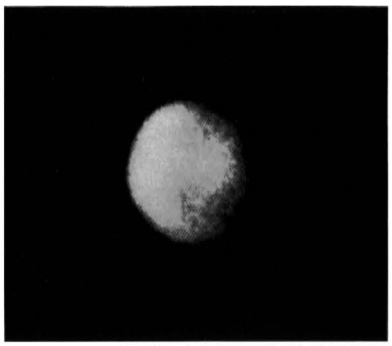
Dr. Gerard Kuiper (left), Director of the Lunar and Planetary Laboratory of the University of Arizona, explains Mercury's heated past this way: "Early in solar-system history, I believe, the sun blazed for a short time, maybe ten thousand years, with a luminosity as much as thirty times greater than that of today. Mercury was probably twice as massive then as it is now, but the sun evaporated away half its substance. The lighter, more volatile elements escaped, leaving a heavy planet that is probably about 30 percent silicates, or rock, and 70 percent metals. It is 5½ times as dense as water."

Even today Mercury bathes constantly in ferocious heat. When the planet is at aphelion, the farthermost point from the sun in its eccentric orbit, the flow of solar energy is five times as great as that reaching the vicinity of Earth. When Mercury comes into perihelion, its closest approach, the searing radiation is ten times as great. Temperatures reach 650° F. on the equator, though they probably drop during the long night to −300° F.

MERCURY

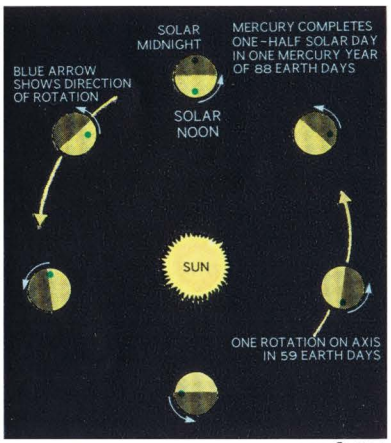
Desolate cinder scorched by the sun's fiery breath, Mercury unfolds a moonscape of meteorite pits and ridgelike crater rims. Apparently devoid of protective atmosphere, the copper-hued orb cooks at 650° F. on the daylight side, while nights plunge to a brittle −300° F.

Orbiting close to the blinding sun, Mercury confounds earthbound observers. But radar, uncannily reading echoes as weak as if bounced from a dime 10,000 miles away, detects huge areas of rough terrain.



NEW MEXICO STATE UNIVERSITY OBSERVATORY

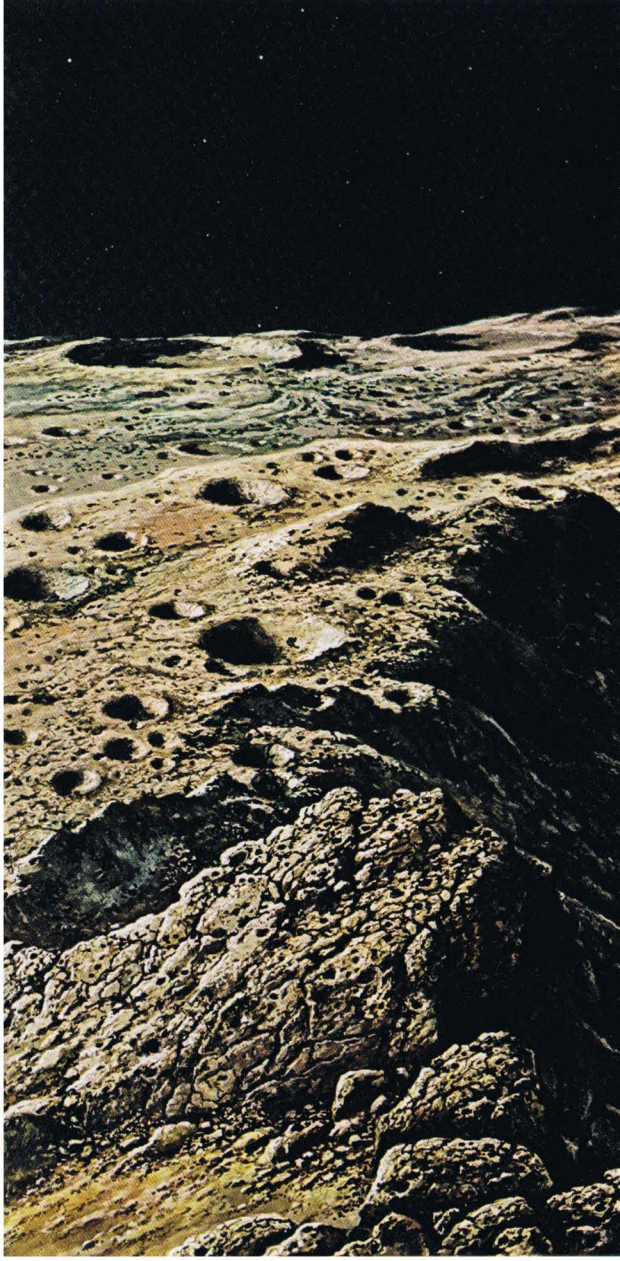
Best likeness of Mercury, taken through a 24-inch telescope, captures only faint, undecipherable shadings.



GEOGRAPHIC ART DIVISION © N.G.S.

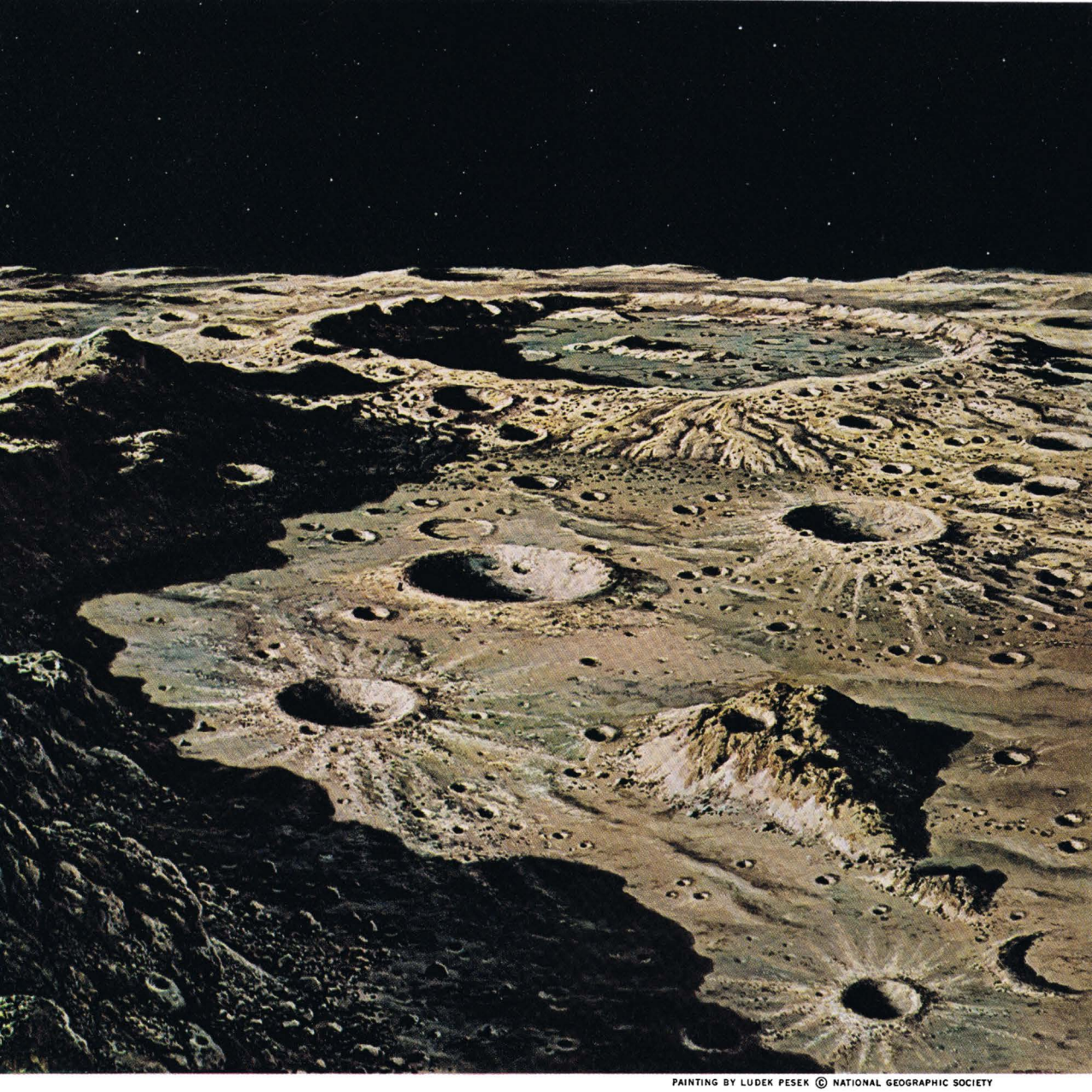
Mercury's new twist: Radar proved in 1965 that the planet rotates on its axis every 59 earth days, as indicated here by an imaginary spot on the surface. Earlier dogma held the rotation to be synchronous with the orbit—once every 88 earth days.

Actually, in those 88 days the spot would move precisely from noon to midnight. Thus a Mercury year lasts only half a Mercury day.



And there is apparently no atmosphere such as our own planet enjoys for a shield. At any rate, the way Mercury reflects and polarizes light is similar to that of the airless moon. With low gravity (only a third that of Earth) and high temperatures, atoms and molecules of most gases would move so rapidly that, over the eons, they would escape to interplanetary space.

The pictures telemetered back to Earth in the Mercury mission will arouse unprecedented interest among scientist and layman alike. Astronomers have never seen Mercury really well, even though it is reasonably close to Earth as distances go in the solar system. The planet stays so close to the sun in its relatively tiny orbit that, to the naked eye, it is



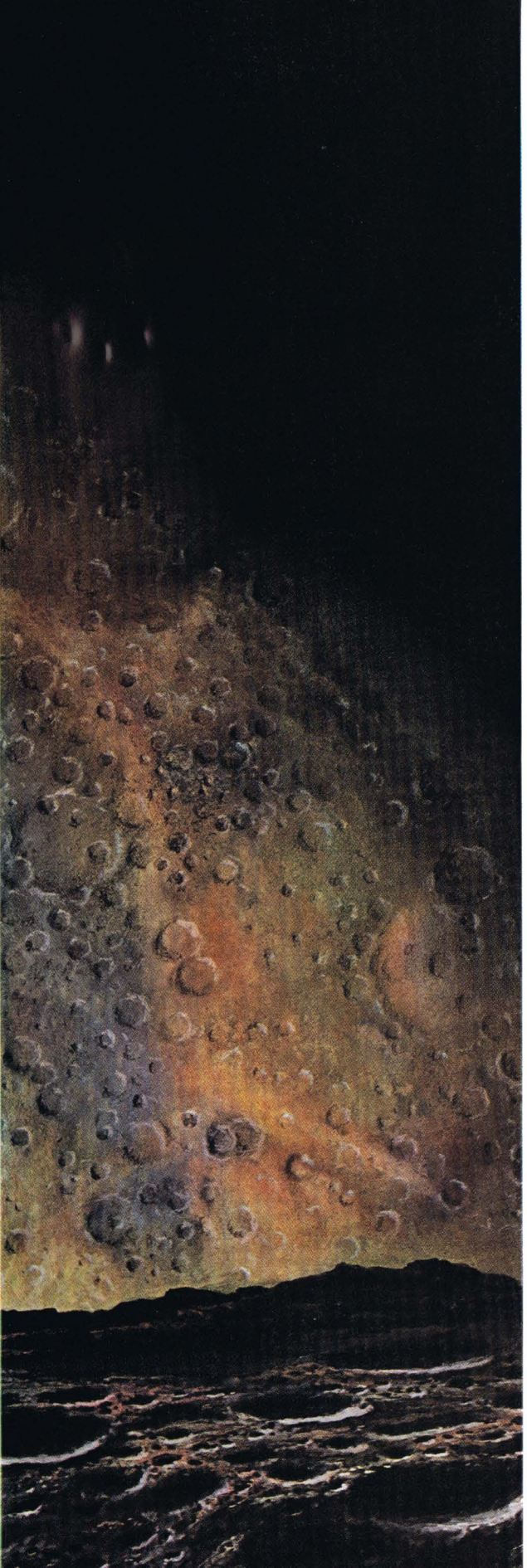
PAINTING BY LUDEK PESEK © NATIONAL GEOGRAPHIC SOCIETY

almost always swallowed up in the glare. On Earth it can sometimes be seen briefly as an evening star just after sunset, or as a morning star (the ancients called it Apollo) just before dawn. But Earth's thick, haze-and-dust-filled atmosphere on the horizon often blots it out.

For the same reasons that Mercury is difficult to see, it is a problem to photograph. In fact, only about 100 photographic plates have ever been made showing markings on the surface (opposite). Virtually all these were taken at the observatory of New Mexico State University, at Las Cruces. When I visited the observatory, I learned that in an intensive program spanning more than ten years it has taken some 800,000 pictures of the planets, more than any other observatory.

OVER THE DECADES, astronomers who patiently waited for glimpses of Mercury, and laboriously sketched the few bright and dark markings they thought they saw, were convinced that Mercury always kept the same face toward the sun. The widely held theory was that Mercury's rotation, like the moon's, was synchronous—that is, the body turned on its axis in just the same time as it took to orbit the sun. That period was 88 earth days.

But, in 1965, Dr. Gordon H. Pettengill, working at Cornell's huge 1,000-foot radio reflector set in the ground at Arecibo, Puerto Rico, monitored the planet's rotation at only about 59 days. Now there was a puzzle indeed! Astronomers almost to a man were astonished by the discovery.



Then it was noticed that 59 was almost exactly two-thirds of 88. Could that have meaning? It not only could but does. It means that Mercury spins three times for every two revolutions about the sun, showing astronomers nearly the same face with the same markings each successive time the planet is in the most favorable viewing position.

So Mercury's year is 88 earth days long, and its sidereal day (as seen from the stars) is 58.65 earth days. But its solar day—that is, the period from one midnight or noon to the next—is exactly twice as long as its year, 176 earth days (diagram, page 162).

All this strange combination of rotation and orbiting rates, with an eccentric orbit, brings about a most peculiar effect in the apparent motion of the sun over Mercury. If you were on Mercury at dawn just at perihelion passage, you would see the sun come up, hang for a brief time in the sky, drop back below the horizon, then rise again.

Because of this strange phenomenon, Professor Bruce W. Hapke, of the University of Pittsburgh, calls Mercury "the Joshua planet." He refers, of course, to the Old Testament prophet who commanded the sun to stand still over Gibeon during the battle between the Israelites and the Amorites.

Could there be life on Mercury? Conditions do not seem at all favorable, and no one seriously suggests it.

Mars

Years ago I learned a simple mnemonic device for keeping the order of the planets straight: "Matilda Visits Every Monday, Just Stays Until Noon, Period." Take the first letters of these nine words, and you have the initials of the nine planets.

And following that order brings us to the first of the planets outside Earth's orbit—Mars, the red planet, whose color suggested blood and once chilled the hearts of men. Mars, the planet of war, whose symbol represents a shield and spear, and whose two tiny

Raw flank of the red planet Mars looms less than 4,000 miles away, as depicted from the satellite Phobos. Dust storms swirl in the thin atmosphere, upper left, while the terminator, the line dividing day and night, recedes at right. Mars's dark regions, some scientists believe, may represent jumbled or cratered terrain of poor reflectivity.

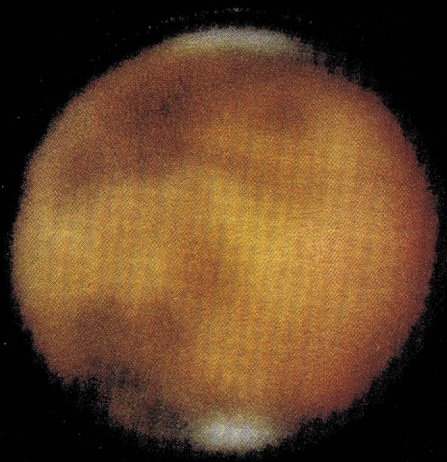
Phobos is the darkest body yet observed in the solar system, possibly because meteorites have scoured it clean of reflecting dust.

♂ MARS

PAINTING BY LUDEK PESEK © N.G.S.

DRAWN BY HUYGENS
1672

DRAWN BY SCHIAPARELLI
1886



PHOTOGRAPHED BY 60-INCH TELESCOPE AT
CERRO TOLOLO INTER-AMERICAN
OBSERVATORY, CHILE, 1969

MARS AS SEEN THROUGH THE CENTURIES

Revealing shadowy features through even early telescopes, Mars has long challenged astronomers to map its face. Christiaan Huygens of Holland identified the vast dark region of Syrtis Major and sketched in the south polar cap, which he located at the top because telescopes invert the image.

The Italian astronomer Giovanni Schiaparelli saw Mars as streaked with a web of *canali*—Italian for "channels" or "canals." Many took this to mean there was intelligent life on Mars. U. S. Mariner spacecraft 6 and 7 in mid-1969 revealed some to be alignments of craters or patches of dark terrain.

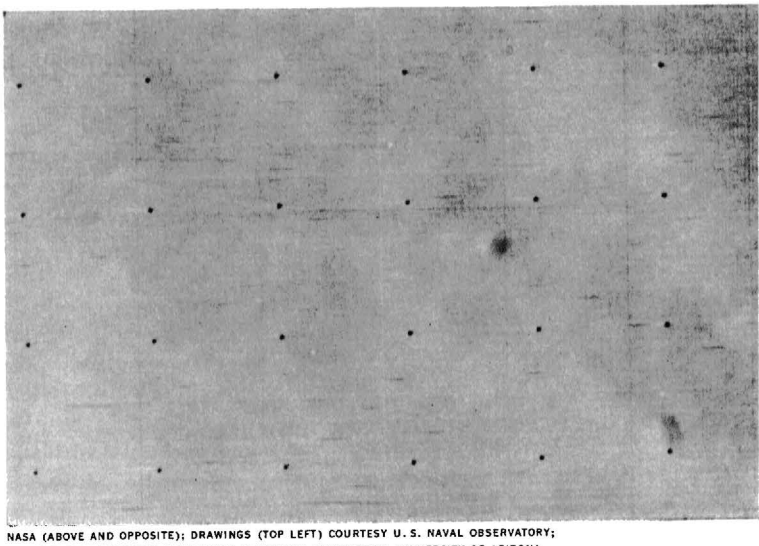
Polar areas gleam in the third view. Craters ringed probably by dry ice pit the south polar cap (below), as seen by Mariner 7 from 3,100 miles away.

satellites, Phobos (Fear) and Deimos (Terror), were named for the war god's attendants. Mars, the home planet of Dejah Thoris, Princess of Helium, if my boyhood memory of reading Edgar Rice Burroughs serves me right.

Time: November 14, 1971. Just 193 days ago our one-ton Mariner spacecraft left Cape Kennedy, propelled by an Atlas-Centaur rocket. It is unmanned, but let us imagine we are aboard. Now we are at our closest approach to Mars, only 1,000 miles above the ruddy surface. The colors are burnt ocher in the bright areas and a grayer red in the dark, with none of the greens and blues observers "see" in their telescopes. The bright greens and blues are very largely an optical illusion.

Our cameras are greedily recording the scene below. This time will be no simple flyby, such as the previous three Mariner Mars missions. Our spacecraft has gone into an orbit that will swing out to a distance of 10,500 miles and bring us back to a 1,000-mile altitude just 12 hours from now. For the next 90 days we will orbit in this fashion, photographing strip after strip, mapping 70 percent of the entire planet.

We scan the dark and light areas, searching for familiar outlines. Nix Olympica (Snow of Olympus), a bright-ringed crater 300 miles across, lies far to the northwest. Below us and to the west is Solis Lacus (Lake of the Sun),



From monotony to chaos: Mars shows varying terrain. Sweeping within 2,200 miles of the red planet in 1969, two unmanned United States spacecraft, Mariners 6 and 7, flashed back streams of television pictures. Poring over them on Earth, thrilled Mars-watchers beheld three distinctive landscapes: a vast featureless plain, cratered regions, and terrain rightly labeled chaotic.

Craters abound in the south polar area (left), one of the planet's more pitted regions. Two craters dubbed the "Giant's Footprint" lie near the dark line of the terminator. Mars has one huge crater 300 miles across—Nix Olympica (Snow of Olympus).

Finely crumpled ridges, each a mile or so wide and several miles long, wrinkle a chaotic region (right, upper), photographed by Mariner 6 from 3,300 miles. The rugged but almost craterless maze covers hundreds of thousands of square miles. Pondering the expanse, some scientists suggest it formed when a subterranean substance such as permafrost withdrew, causing surface areas to collapse.

A quarter-million square miles of featureless terrain fill a Mariner 7 picture of the Hellas "desert," made from 2,250 miles away (lower). The two dark smudges stem from TV defects. Mars specialists believe that a powerful erasing process—such as blanketing by wind-borne material—accounts for plains like Hellas.

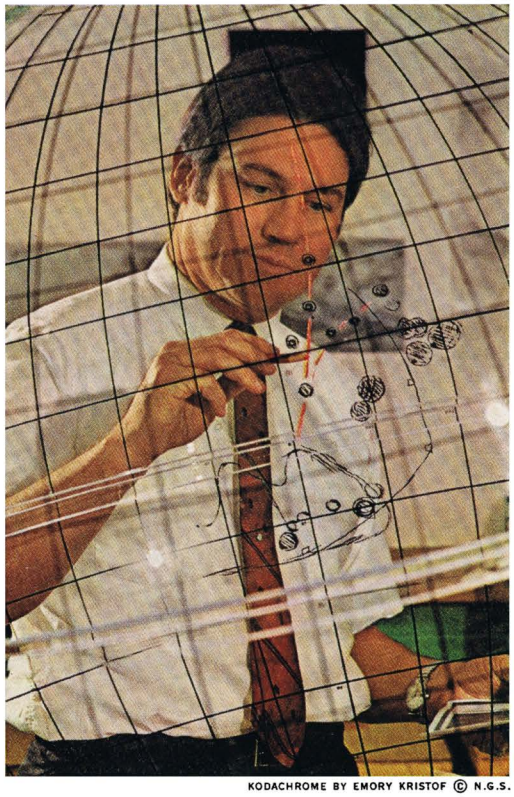
NASA (ABOVE AND OPPOSITE); DRAWINGS (TOP LEFT) COURTESY U. S. NAVAL OBSERVATORY; TELESCOPIC PHOTOGRAPH, LUNAR AND PLANETARY LABORATORY, UNIVERSITY OF ARIZONA

and just ahead are the dark region Aurorae Sinus (Bay of the Dawn) and the bright regions Candor and Xanthe. What romantic names these are, given at a time when every educated man was steeped in mythology.

Craters dominate the landscape. We can see no mountain chains, no bodies of water, no canals. The atmosphere seems clear almost to the horizon, where a narrow rim of bluish haze, with an occasional bright patch, gives way quickly to the blackness of space.

And out in that blackness, 130,000,000 miles away, shines a diminished sun, two-thirds its remembered size. Only half as much solar energy is falling on Mars as on Earth.

Back on Earth, 400 seconds away as our telemetry signals travel, scientists at the Jet Propulsion Laboratory are processing Mariner's TV pictures and information from our instruments about temperatures, atmospheric constituents, and possibly some of the materials of the surface.



KODACHROME BY EMORY KRISTOF © N.G.S.

Re-creating a Mars on Earth, Bradford A. Smith plots features reported by Mariners 6 and 7 onto a globe for comparison with observations from Earth. Professor Smith directs planetary programs at New Mexico State University.

Ten days from now another Mariner exactly like ours will arrive, go into a somewhat different orbit, and for 90 days flash back to Earth findings about seasonal changes. Between these two Mariner 1971 missions, we hope to clear up some of the enigmas of Mars.

BEFORE the Mariner 4 mission in 1964-65, when all we knew of Mars had been painfully gleaned through telescopes, many people believed that Mars was much like Earth. It was the only planet, of course, whose surface we could clearly see. Its solar day lasted only about 40 minutes longer than ours. The tilt of its axis with respect to the orbit was only about two degrees greater than Earth's, which gave the two planets much the same seasonal variations.

Observations showed that Mars had a thin atmosphere. Surface temperatures, at least at midday on the equator, were comparable to air temperatures on Earth on a spring day.

We could clearly see polar caps like Earth's, presumably made of water ice, that waxed and waned with the seasons. The spring "wave of darkening," which some observers discerned, suggested vegetation responding to the advance of a wave of moisture from the polar regions.

And of course there were the "canals." Ever since the Italian astronomer Giovanni Schiaparelli in 1877 described seeing many straight lines on Mars, people had persisted in construing his word *canali* (channels or canals) as suggesting that intelligent beings had dug them. Percival Lowell, founder of the Lowell Observatory in Arizona, pyramided Schiaparelli's canali into a full-blown fantasy of intelligent beings on Mars.

But the three Mariners (one in 1964-65 and two in 1969) have demolished most of these notions. From close-up pictures sent back to Earth, showing some 20 percent of the Martian surface, and from infrared and ultraviolet studies, we now see a Mars that is quite different from Earth and, indeed, from anything else now known in the solar system.

The Martian atmosphere, chiefly carbon dioxide, measures less than 1 percent the density and pressure of Earth's. You would have to climb more than 20 miles above the surface of Earth to find air so thin. The planet enjoys little protection against the sun's radiations, especially ultraviolet, that would quickly

kill any unprotected Earth organisms. If there is any life on Mars, it clearly must have some kind of shield or filter.*

It will also have to be able to endure abrupt and extreme changes in temperature. At midday on the equator, a thermometer might measure as high as 80° F., but that night it could drop to 150° below zero.

Finally, Martian life would very likely have to get along without water; no liquid water has ever been detected on the surface. Mars appears to be much drier than Earth's most arid deserts.

Some scientists believe that Mars retains water in the form of permafrost, perhaps many feet under the surface. In addition, there is a very small amount of water vapor in the atmosphere. Although the thin haze that seems to hang high in the atmosphere probably consists of fine particles of frozen carbon dioxide, brightenings on the disk, chiefly in the equatorial regions, may be water-ice fog or clouds, or even surface frost.

The polar caps in all probability are dry ice—frozen carbon dioxide—with a small amount of water ice. As they warm up in spring, they do not melt but sublime, or evaporate. It's unlikely there is enough water in any form to support vegetation that might produce the "wave of darkening."

IN VIEW of these hostile conditions, I asked Dr. Norman H. Horowitz, Professor of Biology at Caltech, about prospects of finding life on Mars.

"Mariner's observations have certainly not improved the chances, although at the same time nothing in the Mariner findings disproves the possibility of life," he says. "If life does exist on Mars, it must be something very primitive, like bacteria; the idea of substantial plants or animals is out."

A few scientists are less pessimistic. In any case, no orbiter or flyby can answer the question, only a landing vehicle. That's why NASA hopes to send a spacecraft called Viking to Mars in 1976, landing instruments to scoop up soil and test for life (pages 172-3). Either way the answer goes, biologists regard it as of the utmost importance in helping to understand life on Earth.

"When men first land on Mars—as they may actually do before the end of this century—they will find rather uninteresting terrain for the most part," suggests Professor Robert Leighton (below), of the California Institute of Technology, who was in charge of the Mariner Mars television experiments.

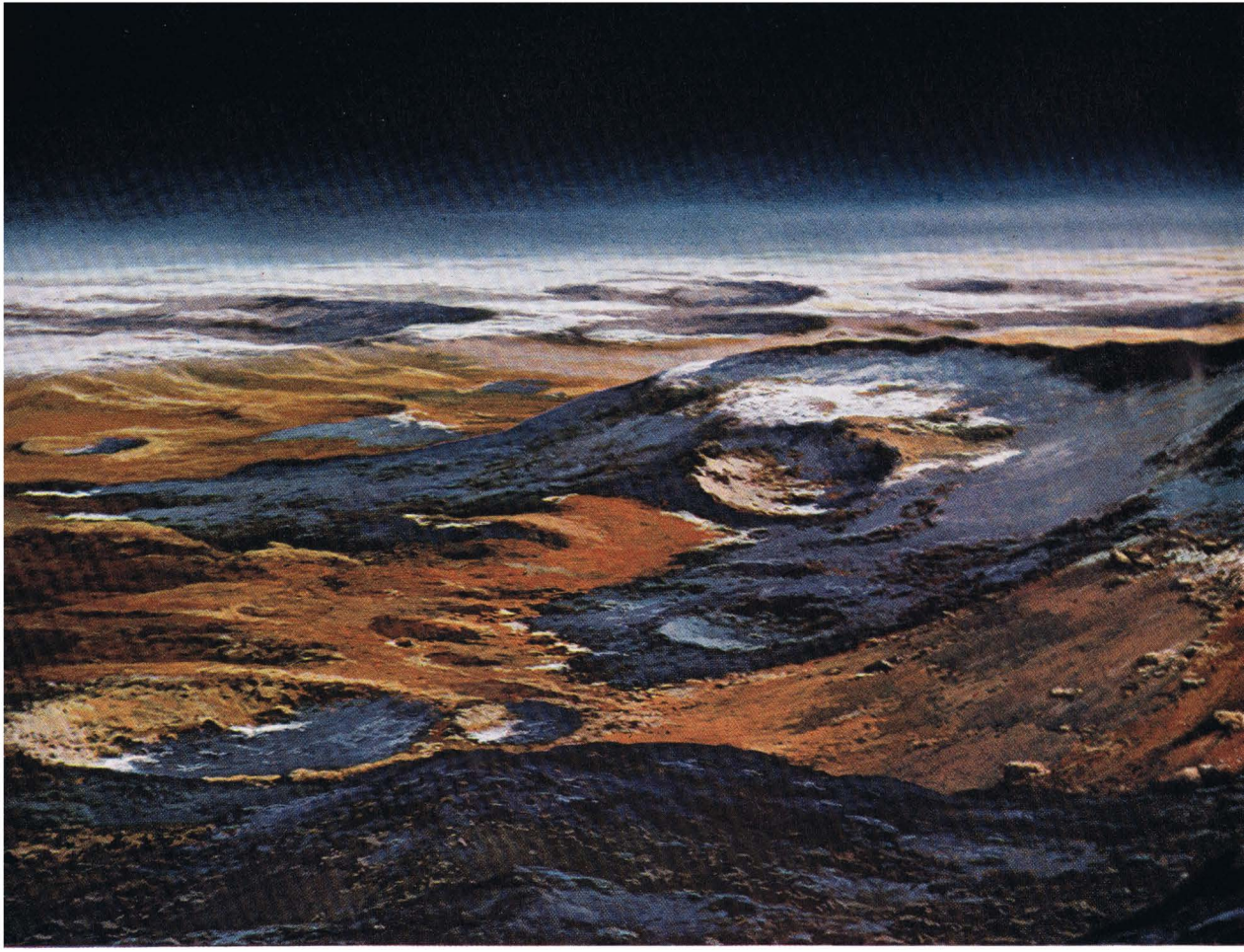
"Everything in the Mariner pictures indicates very gentle slopes on Mars. There are no mountain ranges, no great faults, no extensive volcanic fields, in fact no evidence of volcanic activity. You could stand in a crater on Mars and never know it— even one that appears sharp and clear in the pictures."

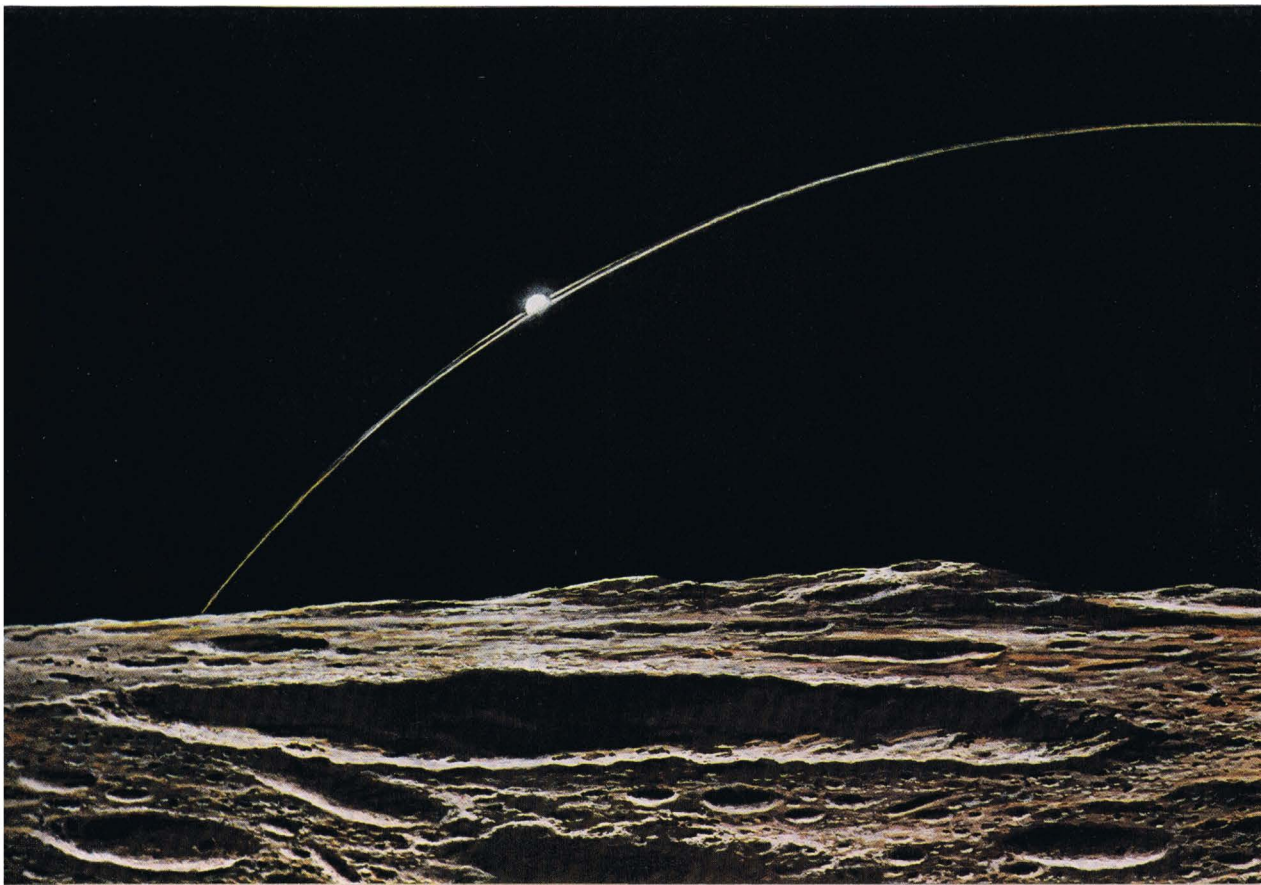
Mars does indeed have highlands and lowlands. Using Lincoln Lab's Haystack radar, Dr. Gordon Pettengill, now Director of the Arecibo Ionospheric Observatory, has found a difference of about eight miles in elevation between the highest and lowest point on the planet. But the changes in elevation are gradual and the slopes are gentle as one climbs from the lowland basins to the highest plateaus.

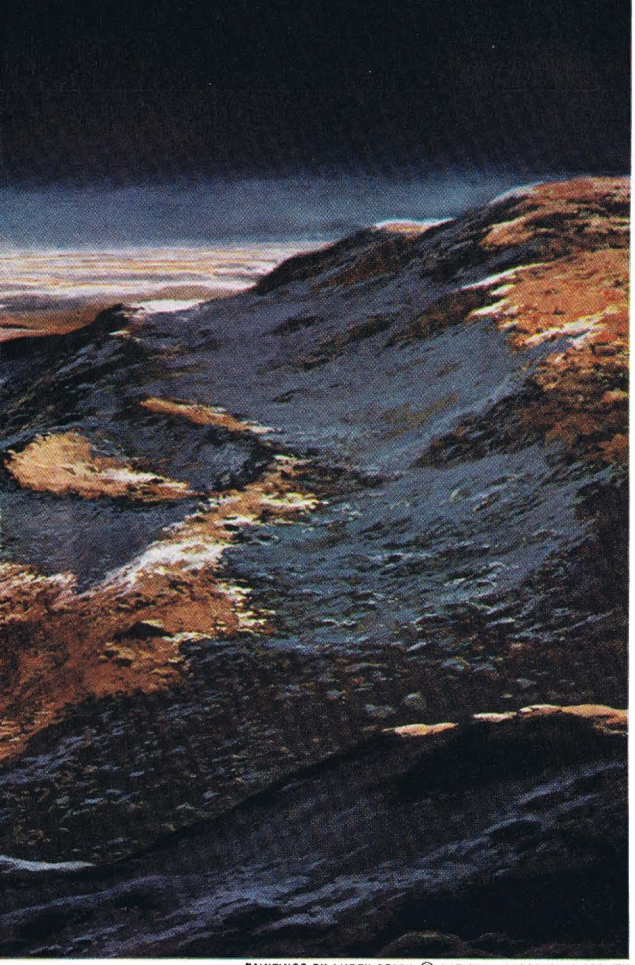
*See "Mars: A New World to Explore," by Carl Sagan, NATIONAL GEOGRAPHIC, December 1967.

KODACHROME BY EMORY KRISTOF © N.G.S.

Man behind the Mars pictures, Dr. Robert Leighton, Professor of Physics at the California Institute of Technology in Pasadena, had charge of the successful TV studies of Mars by Mariners 6 and 7, as well as by Mariner 4 in 1964-5.







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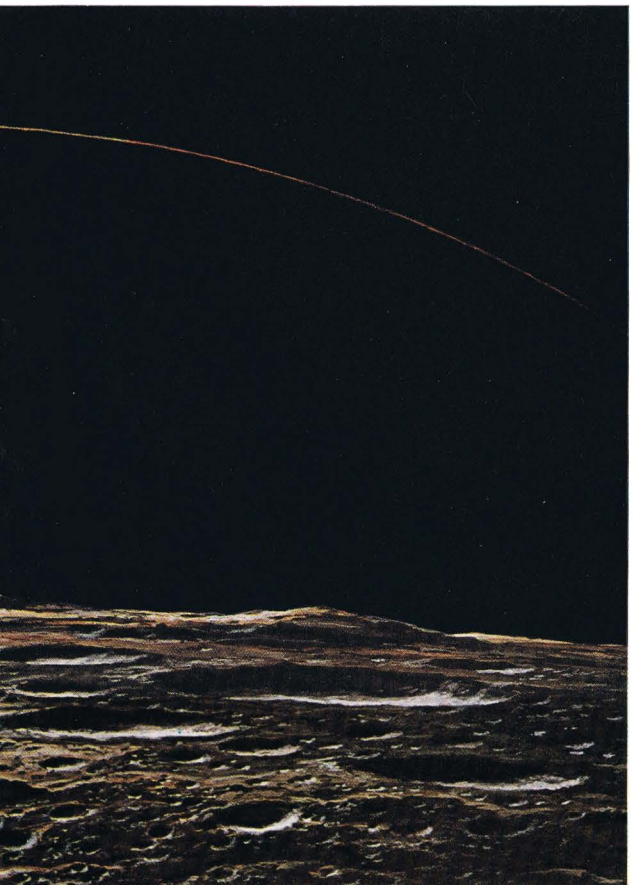


KODACHROME BY EMORY KRISTOF © N.G.S.

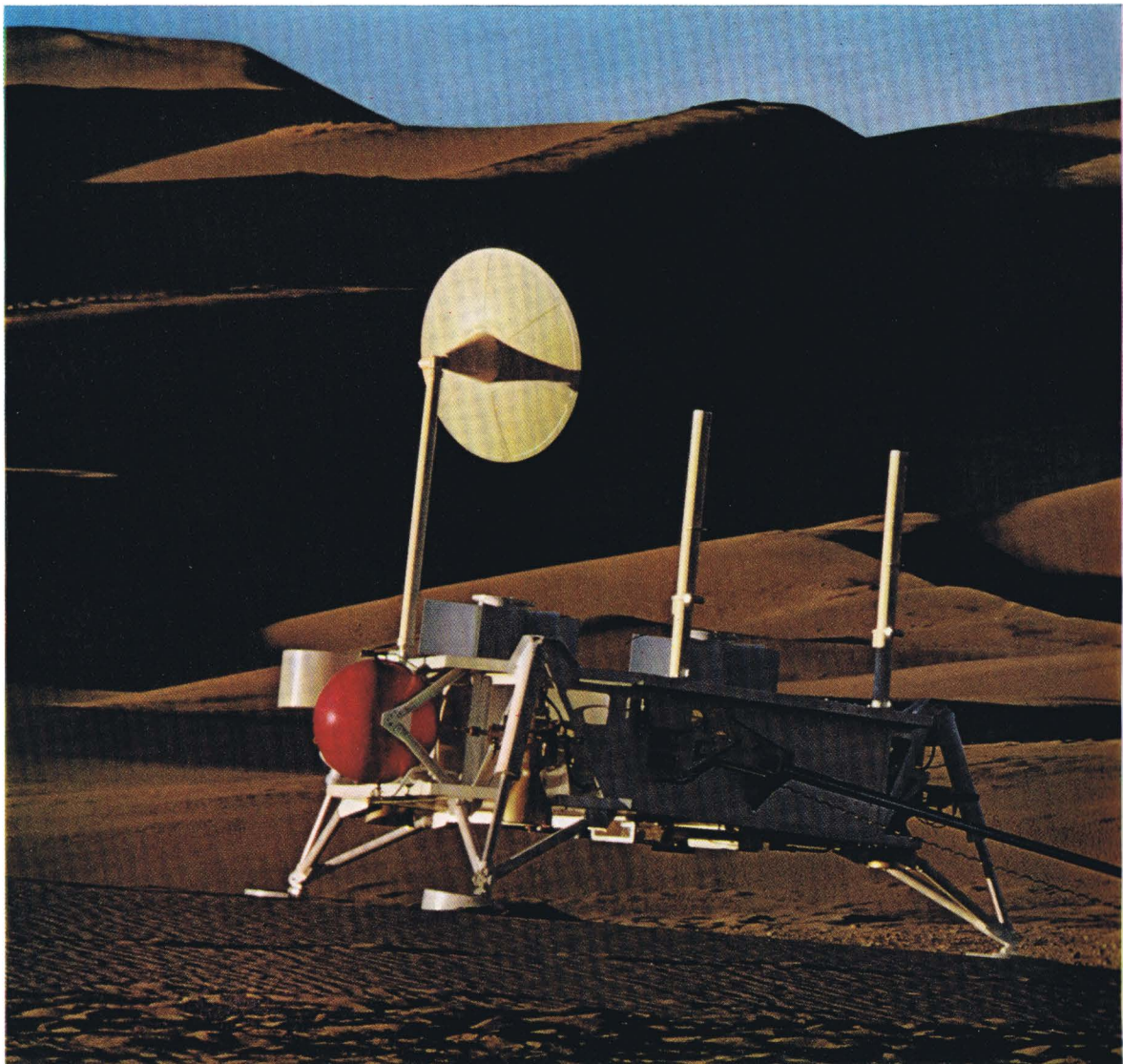
Portraitist for the family of planets, artist Ludek Pesek touches up his paintings at National Geographic headquarters in Washington, D. C. He worked more than a year preparing the illustrations for this article.

A native Czech who now lives in Switzerland, the versatile Mr. Pesek not only has illustrated two widely published books on the planets, but also has written five novels.

Summer nibbles at the south polar cap of Mars (upper painting), evaporating dry ice from sunlit slopes. Drifted fields of carbon-dioxide snow spread beneath a CO_2 haze.

View from Phobos, one of two Martian moons, shows a jewel-like sunrise glinting above the inky planet. The haze layer close by the sun, just above the rim, was first observed by Mariners 6 and 7. The latter, photographing Phobos from only 82,000 miles, revealed that this moon is shaped like a baking potato, 11 by 14 miles in size.

PAINTING BY LUDEK PESEK; KODACHROME (BELOW) BY EMORY KRISTOF © N.G.S.



"A dull uninteresting landscape," says Dr. Leighton of russet Mars. Here it stretches away in a dreary sameness of shallow craters. Despite Mariner pictures that captured features as small as 1,000 feet across, Mars has yet to reveal evidence of water in liquid form or of tectonic activity—the folding, faulting, and volcanic upheavals that still shape Earth.

Mission: to explore Mars. A test model of NASA's Viking probe squats at Great Sand Dunes National Monument in Colorado. Built by Martin Marietta Corporation of Denver for launch in 1975, the Viking lander is designed to ride to Mars on an orbital spacecraft, then descend by parachute and braking rockets to the surface. There it will send back photographs, assay the thin atmosphere, and stretch out a long arm, right, to snatch up soil samples. These it will analyze for possible life forms.

THREE radically different kinds of terrain show up in the Mariner pictures: cratered, "chaotic," and featureless (pages 166-7). As on the moon, craters appear prominently, even in the thin south polar cap. But in depth and slope, they vary distinctly from those of the lunar surface, suggesting differences in the geological processes that modify them. Many of the Martian craters appear as though their rims had been sandpapered off, and they show very flat bottoms.

A second kind of terrain, essentially free of craters, appears in the region between Aurorae Sinus and Margaritifer Sinus. Its irregular, jumbled topography of short ridges and furrows, covering in one area as much as half a million square miles—the size of Alaska—has been given the name "chaotic terrain." It somewhat resembles the debris of a terrestrial landslide, but nowhere on Earth do formations like this extend over such large regions.

The bright circular "desert" of Hellas (really

a misnomer, since all Mars is a desert) represents the third kind of topography of Mars. It is called featureless because in a large smooth basin, some 1,200 miles across, hardly any craters can be seen. Nothing on the moon looks like this, but it does somewhat resemble the great plains of Earth.

By contrast, the dark highland region to the west, Hellespontus, is heavily cratered. Geologists scratch their heads when you ask them to explain why. What could allow meteoroids to fall on Hellespontus but protect Hellas? Or what could erase the craters in one region and not in the other?

Professor Robert Sharp, of the Department of Geology at the California Institute of Technology, proposes the most interesting theory. He suggests that possibly Hellas is floored with some unusually light, porous material (which he dubs "micro-popcorn"). The Martian winds, perhaps occasionally reaching 100-mile-an-hour velocities, could easily move this material, and craters would quickly be filled in and lost.

PROFESSOR Bradford A. Smith, Director of the planet-photographing observatory at New Mexico State University (page 168), offers a plausible explanation for the evanescent lines called "canals."

"Now that we have seen the Mariner pictures, the idea of canals should cease to exist. Some of the classical lines are discovered to be chains of dark-floored craters, some are irregular alignments of dark patches. Most of the rest will be figments—illusory and misinterpreted."

Two scientists at the University of Massachusetts, Dr. William T. Plummer and Robert K. Carson, report that the reflection spectrum of Mars resembles that of an uncommon substance known as carbon suboxide, a foul-smelling compound with the formula C_3O_2. When ultraviolet radiation hits this substance, it forms polymers, or molecular chains, with an orange or reddish-brown color. Carbon suboxide, rather than iron minerals, could account for the color of Mars, the two scientists believe.

This report has aroused substantial controversy. However, a comment by Dr. Leighton becomes quite pertinent: "If you're planning to go to Mars, better take a clothespin for your nose. They tell me it smells like fermented sweat socks."

Asteroids

Time: Midsummer 1972. The Pioneer F spacecraft, which left Earth 140 days ago, has long since crossed the orbit of Mars. It is 125,000,000 miles from Earth, headed for Jupiter, largest of the planets. To us, as imaginary passengers, it appears as a mere point of light; its banded disk will not be clearly visible for many weeks.

Now we are running the gantlet of the asteroid belt. The moment of truth has arrived. Will we survive passage through the minor planets and millions of smaller objects that swirl in this celestial grinding machine between Mars and Jupiter? It will take us some 200 days to cross the 150,000,000-mile-wide belt.

A particle even the size of a pea moving at 12 miles a second could completely disable our spacecraft. What are the odds? Fortunately very low, according to the experts planning the Pioneer flights.

We scan the blackness, hoping to see one of the minor planets, but in vain. Calculations are that while traversing the belt we might be within viewing distance of no more than one object as large as 450 feet in diameter. Perhaps 20 bodies as large as 130 feet across will come close enough to be detected, but only if we are looking in the right direction at the right time.

On New Year's Day in 1801 an Italian, Giuseppe Piazzi, discovered a starlike body beyond the orbit of Mars, where a "missing planet" was supposed to be located. Named Ceres, it proved to be the first and largest of a group of objects called asteroids that circle the sun in a wide belt between the orbits of Mars and Jupiter.

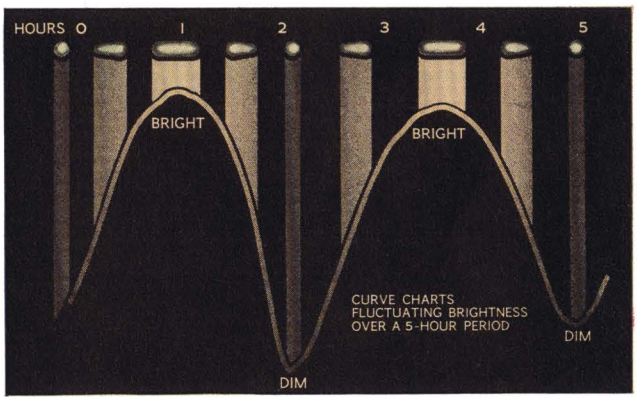
Ceres, an airless, lifeless ball 480 miles in diameter, is large enough to be termed a miniature planet, and so are a few others, such as Pallas, Juno, and Vesta. But the great majority are irregular chunks no more than a mile across, and countless numbers range down to the size of dust grains. Perhaps 100,000 could be detected with the 200-inch Hale telescope on Palomar Mountain, California. Only one, Vesta (page 195), is ever visible to the naked eye. If all were swept up together, they would be less than a thousandth the mass of Earth.

Nearly two thousand asteroids have been observed enough to be given numbers and names. Many bear mythological names. Others honor astronomers (Kepler and Hale), flowers

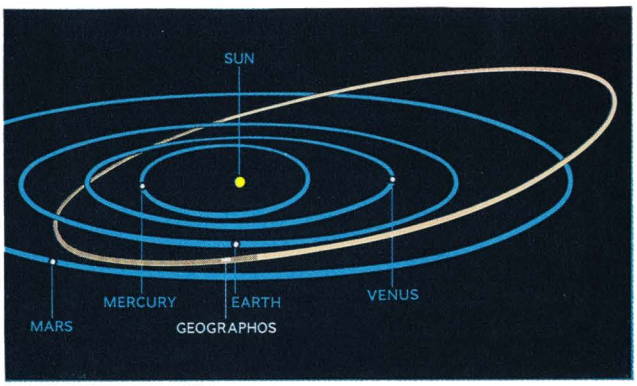
PAINTING BY DAVIS MEITZER (ABOVE); DIAGRAMS BY GEOGRAPHIC ART DIVISION © N.G.S.

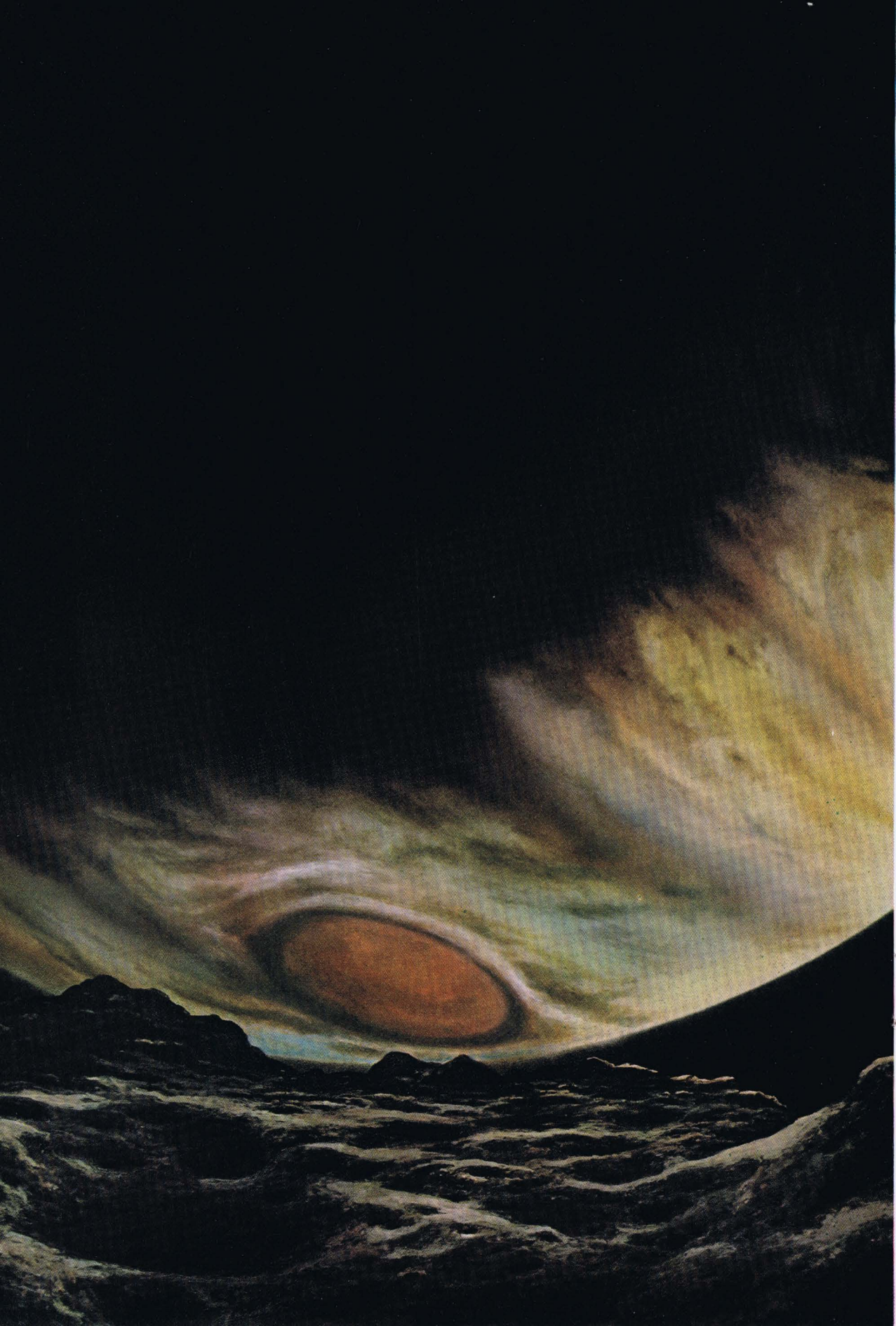
Celestial cigar, the asteroid Geographos makes its 1969 sweep to within 5.6 million miles of a tiny blue Earth, background. Recent recalculation by asteroid expert Dr. Tom Gehrels measures Geographos as 2½ miles long by half a mile wide. Discovered in the National Geographic-sponsored Palomar Observatory Sky Survey of 1949-58, the asteroid was named for your Society.

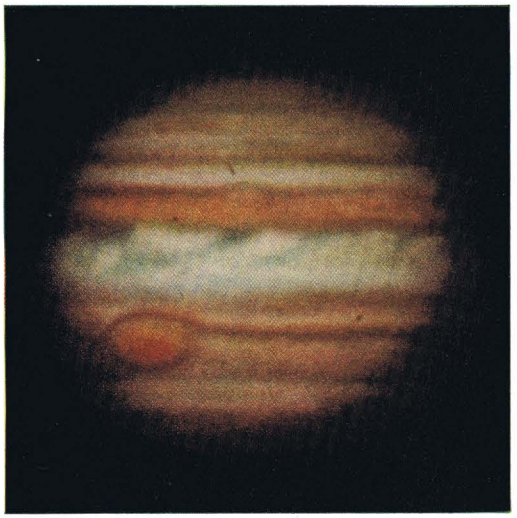
ASTEROIDS



Cavorting in space, Geographos rhythmically brightens and dims, defining a predictable light curve (upper diagram). This leads astronomers to deduce that the asteroid is an oblong body that constantly tumbles, reflecting brightest when broadside to Earth. Diagram of the 1969 sweep past Earth (lower) shows how the asteroid's orbit, tilted 13°, slices the ecliptic.







EKTACHROME (ABOVE) BY LUNAR AND PLANETARY LABORATORY, UNIVERSITY OF ARIZONA; PAINTING BY LUDEK PESEK © N.G.S.

Tumultuous cloud currents sweep Jupiter and eddy around the Great Red Spot in a revealing 1966 photograph. Bulging equator reflects the planet's rapid rotation, once every 9 hours and 55 minutes.

Jupiter's turbulent atmospheric bands, composed largely of frozen and liquid ammonia compounds, kaleidoscopically change shapes and colors; they swirl above a stormy interior of mounting pressure, perhaps crackling with lightning. Deep inside, at a level no instrument can detect from Earth, the planet's substance is crushed into a solid core of hydrogen.

Baring its woundlike brand, a crescent Jupiter overwhelms its snowy satellite Amalthea, foreground, only 70,000 miles away. The Great Red Spot, weirdly vivid in this portrayal, puzzlingly waxes and wanes, all the while drifting across the southern hemisphere.

Monstrous Jupiter, a quarter-million miles around, has one and a half times the volume of all the other planets combined. Its satellite Ganymede equals Mercury in size.

Jupiter seems in some ways to be less a planet than a star, or rather, a potential star whose nuclear furnace never lighted. Like the sun and other stars, it gives off more energy than it receives, while around it swirl a dozen satellites—its own planetary system.

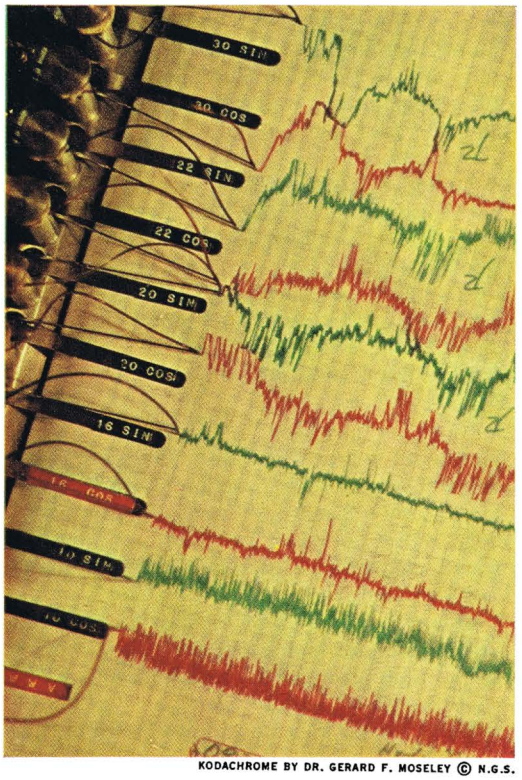
Jupiter's atmosphere contains ammonia and methane, gases that wrapped the primordial Earth billions of years ago, when life began. Thus Jupiter could offer a natural laboratory for viewing chemical reactions that might launch life.

(Crocus and Begonia), cities (Yalta and Chicago), and women (Sheba, Dulcinea, and Marlene—yes, Marlene Dietrich).

An easy assumption would be that the asteroids are the debris of a planet that exploded. But the reverse may well be true.

Dr. Tom Gehrels, a long-time student of these objects at the Lunar and Planetary Laboratory of the University of Arizona, regards them as building stones of the solar system. "The asteroids are probably part of the original record of the nebula, or dust cloud, from which we believe the sun and planets condensed some five billion years ago," he says. "Asteroids are dust that has been compacted—accretion products—or fragments from collisions of such bodies."

While most of these small bodies stay close to the asteroid belt, a few have eccentric orbits that invade the inner solar system, and some fly so close to our own planet that they might be called "Earth-grazers."



KODACHROME BY DR. GERARD F. MOSELEY © N.G.S.

The voice of Jupiter: Spasmodically and cryptically, restless Jupiter bursts forth with powerful radio noises—emissions once thought peculiar to the stars and galaxies. Apparently associated with the planet's magnetic field, the radiation is affected by the position of the satellite Io.

Here at a University of Texas radio telescope near Marfa, Jupiter symbols mark a Jovian radio storm. Other squiggles are noise and interference.

Icarus, for example, swings out 183 million miles from the sun, but every 409 days, at perihelion, it comes within 17 million miles of the sun's raging heat. At such close encounter its half-mile-thick bulk may become red hot. Appropriately, it bears the name of the lad in Greek mythology who came to grief when he tried to fly with wax-bound wings and approached too close to the sun.

In June 1968, Icarus missed Earth by only 4,000,000 miles. Another space rock, Hermes, only 1,000 feet across, came within half a million miles of us in 1937, barely twice the distance to the moon (painting, page 155).

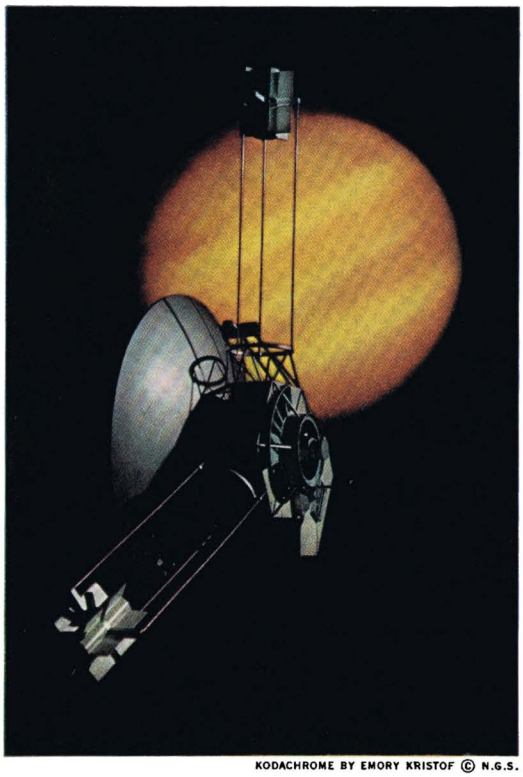
And just a year ago this month, astronomers took aim at a most unusual Earth-grazer, Geographos, which came within 5.6 million miles of their telescopes. Discovered in 1951 during the National Geographic Society-Palomar Observatory Sky Survey, this planetoid was named in honor of the Society. Its catalog number is 1620, which leads one astronomer to refer to it as "Plymouth Rock."

When Geographos's light was measured with a photometer, it showed a peculiar rhythmic fluctuation in brightness. At periodic intervals, it seemed to be six times as bright as at other times. No other asteroid shows such extreme variation.

From this and other light measurements, Dr. Gehrels has recently determined that Geographos is a cigar-shaped body about 2½ miles long and half a mile wide. It tumbles end over end, so that part of the time we see reflection from its long side and part of the time only from an end. This explains the wide fluctuation in brightness (page 175).

HUGE CRATERS on the moon testify to what happens when the orbits of these flying mountains bring them into collision with other celestial bodies. Scientists generally accept the idea that some meteoroids are pieces from the asteroid belt, although others are the debris of comets.

Earth's atmosphere burns up the small meteoroids. And no one need worry about a large one striking Earth. Calculations suggest that it happens no more than once in 50,000 years in North America, even for a rock only 100 feet across, the size of the one that blasted out Arizona's Meteor Crater.



KODACHROME BY EMORY KRISTOF © N.G.S.

Spindly envoy to the king of planets, a Pioneer spacecraft model spreads wiry limbs before a photograph of its goal. Two unmanned Pioneers, built by TRW Inc., of Los Angeles, may embark in 1972 and 1973 on 600- to 900-day voyages to within 80,000 miles of Jupiter. Their instruments, powered by miniature radio-isotope generators on the outthrust struts, will study characteristics of the planet, and relay images back to Earth.

Jupiter

Time: Between December 7, 1973, and March 17, 1974. Safely through the asteroid belt, our buglike Pioneer F spacecraft approaches Jupiter, giant of the solar system. Earth, now a bluish point, lies more than 500 million miles behind. The sun, almost as far, shows a disk about a fifth its normal size.

Solar cells for energy would be of marginal use to us now: We receive only one twenty-seventh the solar radiation Earth receives. So, on two long booms stretching beyond our big antenna dish, we have generators using radioactive materials to produce power to operate our electronic equipment (above). Messages to Earth, carrying pictures and information on magnetic fields, ionized particles, temperature, and planet chemistry, now take 47 minutes to travel that great distance one way.

There seems no end to the enormous bulk below us. Although we are 80,000 miles away, this gargantuan hydrogen ball is so huge—enough to swallow up 1,300 Earths—that we cannot see an entire hemisphere. Only when we were farther out could we view it as a sphere and see how it is flattened at the poles because of its high rotation rate.

Irregular bands of alternate yellow and bluish or brownish gray cover the surface—and yet perhaps one should not say surface, for all we see are clouds. No man knows at what depth, perhaps thousands of miles down, Jupiter's enormous pressures have turned its hydrogen to a metallic solid.

Two striking phenomena catch the eye:

The Great Red Spot, one of the most curious objects of the entire solar system, stands out like a blemish on the southern hemisphere. Its elliptical area, seeming to "float" among the clouds, is larger than Earth's surface (pages 148, 176, and 177). The most likely theory yet proposed suggests that it is a kind of eddy in the atmosphere caused by a depression or a high spot far below.

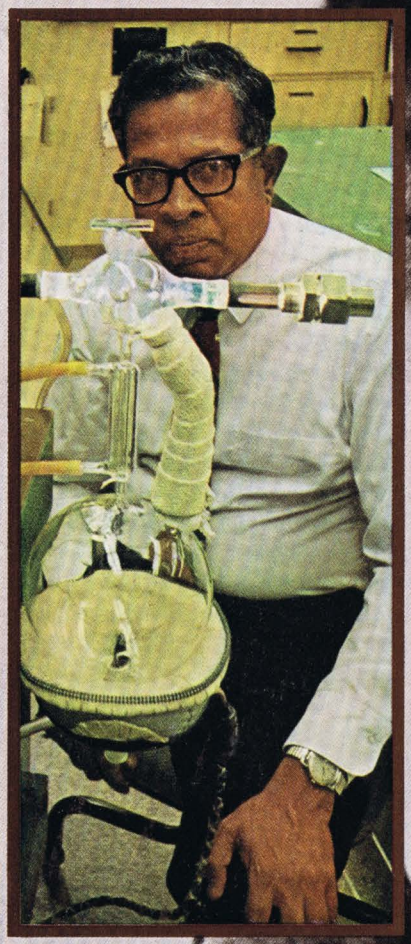
A crisp black circle marks the shadow of Io, one of Jupiter's 12 moons. Inexplicably, this shadow has been known to emit more radiant heat than the cloud layer around it.

Io itself has been easily visible to us as we approached, and so have the other three satellites Galileo first saw: Ganymede, larger than Mercury; Callisto, larger than Earth's one moon; and Europa, a fifth the size of Earth. Eight additional—and smaller—satellites give Jupiter a family larger than the sun's.

We know all too little about Jupiter; it is a series of perplexing questions and riddles. Yet what scientists do know and what they surmise make it in many ways the most exciting, the most provocative, body in the solar system.

"We regard this vast ball, so different from any of the rocky terrestrial planets, as a 'deep-freeze sample' of the original cloud of dust and gas from which the solar system condensed," says Dr. Tobias Owen, of the Illinois Institute of Technology Research Institute. Cold outer temperatures and high gravitational force (two and a third times that of Earth) have most likely prevented the primordial gases from escaping.

"Moreover," says Dr. Owen, "Jupiter may



be considered almost a star. If it were only a little more massive, gravitational contraction would release so much energy that it would turn into a nuclear furnace, like the sun or any other star, and become incandescent."

Though Jupiter is no more than a "near-star," something most unusual goes on within its deep, turbulent atmosphere: The giant planet gives off substantially more energy than it receives from the sun—two to three times as much. No one knows why, although gravitational contraction has been suggested as a cause. Scientists suspect that temperatures rise steadily from −200° F. at the cloud tops to as much as 20,000° at the core.

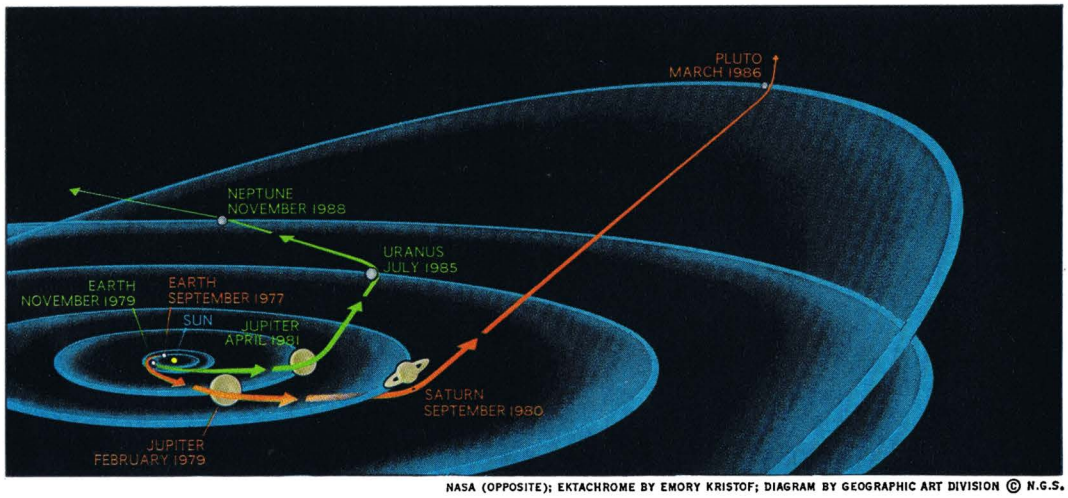
And through some mechanism not clearly understood, the Jovian planet emits random bursts of intense radio energy at long wavelengths (page 178). It is, as radio astronomers perceive it, the most powerful radio object in the sky except for the sun. Apparently these emissions are tied to the planet's powerful magnetic field and radiation belts (regions of charged particles above the atmosphere), something no other planet except Earth is known to have. To add to the puzzle, the radiocasts are affected by the position of Io, second closest of Jupiter's moons.

Astronomers analyzing Jupiter's upper atmosphere with spectrometers conclude that it consists largely of hydrogen and helium, a finding that explains why the planet's density is only a fourth that of Earth's.

Pioneer F—and Pioneer G, scheduled to go to Jupiter 13 months later—will seek to establish the all-important proportions of hydrogen and helium. These two gases, the lightest and simplest of all chemical elements, make up 99 percent of the universe, and their ratio will help indicate whether Jupiter truly is a living fossil of the solar system.

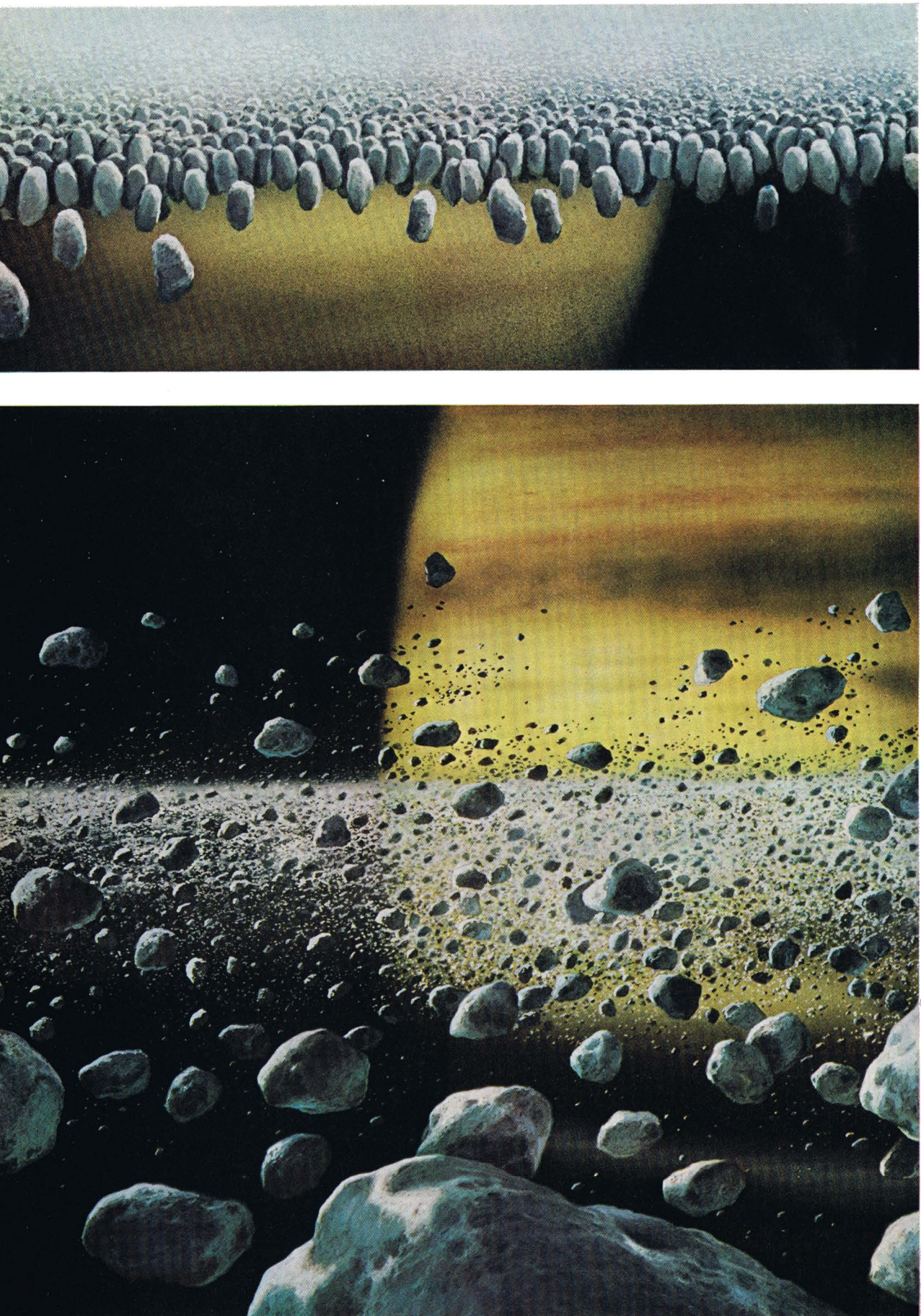
Methane and ammonia, simple compounds formed when hydrogen joins with carbon and nitrogen respectively, have also been detected. What lies deeper can only be conjectured; water has often been suggested.

Floating high in the Jovian atmosphere are the enormous bands of pastel-colored clouds, thought to be composed of frozen and liquid ammonia compounds. They rotate at



"Grand Tours": Two unmanned spacecraft may explore the remote outer planets in the late 1980's. Gravitational pulls will bend their courses and reduce flight times from decades to only 8½ years to Pluto, and 9 years to Neptune on a launch 26 months later.

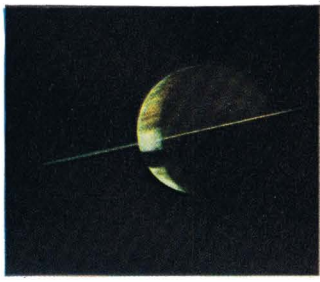
Might-be Martians, bacteria magnified 17,000 times, drift in a culture at NASA's Ames Research Center in Mountain View, California. A common soil microbe, rugged *Aerobacter aerogenes* thrives in a simulated Martian atmosphere of carbon dioxide and daily freezings and thawings, encouraging a belief that life could survive on other planets—provided they have water. Exploring the beginnings of life itself, Ames chemist Dr. Cyril Ponnamperuma (inset) bombards a flask of primordial planetary gases—ammonia, methane, and water vapor—with ultraviolet radiation. Result: He synthesizes complex organic compounds that form the basic building blocks of life.



PAINTINGS BY LUDEK PESEK © NATIONAL GEOGRAPHIC SOCIETY

Twirling like a top in space, Saturn intrigues astronomers with its delicate rings, here seen edge-on as they cast a shadow on the planet (right). Composed of countless minuscule moonlets and stretching outward some 50,000 miles, the rings have a thickness of at most a few thousand feet—and possibly only inches. So filmy are the rings that bright stars behind them sometimes shine through.

At left, Mr. Pesek illustrates two concepts of the rings' structure. Icy cylinders, worn by constantly rolling against each other, wheel around the planet in a thin-ring version (upper). Ice-coated rocks from pea- to piano-size hurtle around a thick-ringed Saturn (lower).



SATURN

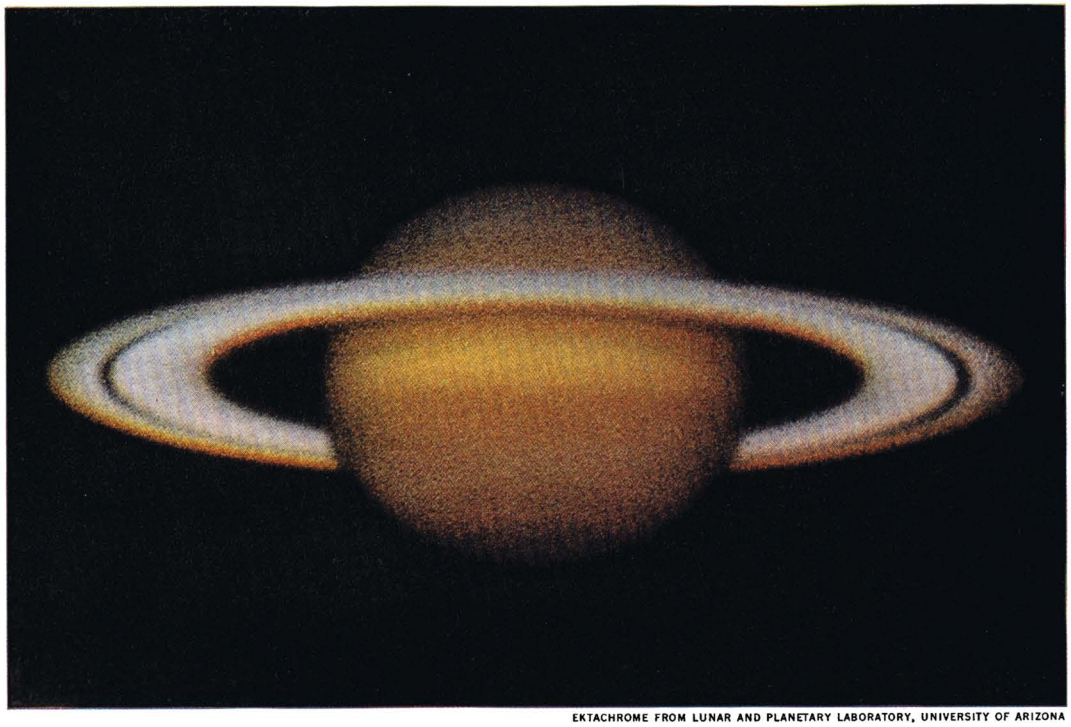
whirlwind speed; although Jupiter has eleven times the diameter of Earth, its rotation rate is more than twice as fast—one complete turn in less than ten hours! No wonder the planet bulges at the equator.

It may surprise those who are Earth-oriented to learn that Jupiter, rather than Earth, may now be the solar system's most hospitable environment for the beginning of life. Scientists concluded years ago that primitive life probably first appeared in an atmosphere of hydrogen, methane, ammonia, and water, such as Earth very likely had some $4\frac{1}{2}$ billion years ago. And that is thought to be the kind of atmosphere Jupiter has today.

A number of intriguing experiments, begun in the laboratory of Dr. Stanley Miller at the University of Chicago as long ago as 1953, support this belief. When a simulated primitive Earth atmosphere of hydrogen, methane, ammonia, and water, similar to Jupiter's present atmosphere, is subjected to an electric discharge (comparable to a bolt of lightning) or ultraviolet radiation (such as that from the sun), something immensely important happens. Complex organic molecules appear, the building blocks of living cells (page 180). These include glycine, alanine, and other of the amino acids from which proteins are formed in living things.

LATE IN THE 1970's, if the present planning of NASA and the Jet Propulsion Laboratory is carried out, two unmanned missions called the "Grand Tours" will set forth on journeys to the outer reaches of the solar system. They will take advantage of an opportunity arising only once every 175 years, when the outer planets line up relatively close together along an arc, like pearls on a string.

The two 1,300-pound robot craft will aim first for Jupiter, whose enormous gravitational effect



EKTACHROME FROM LUNAR AND PLANETARY LABORATORY, UNIVERSITY OF ARIZONA

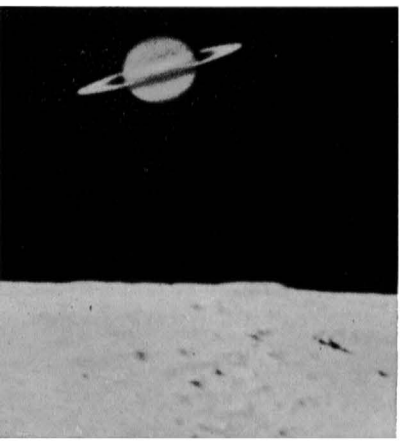
Resplendent with its halo, Saturn glows a characteristic yellow in the twilight nearly 900 million miles from the sun. In this exquisite 1968 photograph, two rings glimmer clearly, separated by a gap called the Cassini Division. Closer in, a filamentous third ring and a very faint fourth (observed in 1969 by the French astronomer Pierre Guérin) defy the camera's eye. Scientists believe the rings may be space matter that never condensed into a satellite.

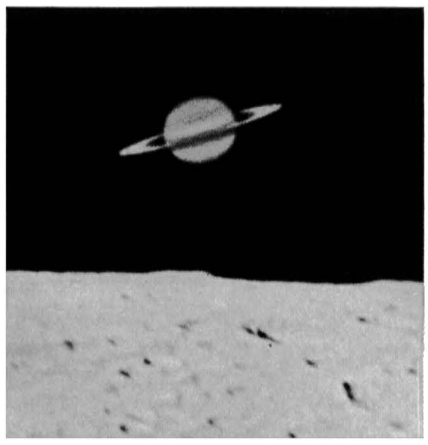
Like Jupiter, Saturn churns with a violent atmosphere that swirls in bands around its girth. Slowly changing color, the surface on rare occasions erupts with mammoth white spots.

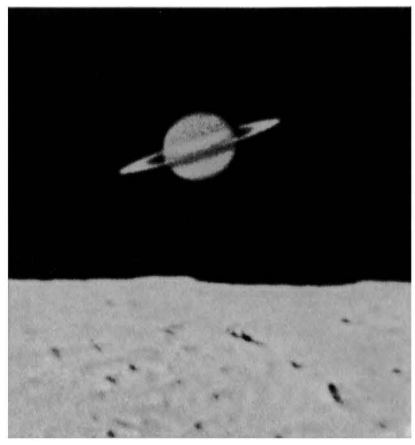
With far less mass, Saturn lacks the strong Jovian gravity needed to squeeze itself into a compact ball. Thus the bloated planet compares in density to an ordinary hardwood; it would float in water.

Swarming with ten satellites, Saturn claims one moon unlike all others known to the solar system: Titan, nearly 3,000 miles across, has an atmosphere.

Saturn rises beyond the rubble-strewn rim of Earth's moon (below, far right to left), in an unusual sequence filmed through a 24-inch telescope in New Mexico. As the moon moves, the planet seems to scoot like a flying saucer across the lunar surface.







will carom them off at greatly increased velocity to the next planet, where the process will be repeated. These might appropriately be called the "By Jove" missions.

One voyage, beginning in 1977, is planned to visit Jupiter, Saturn, and Pluto, making the trip in $8\frac{1}{2}$ years instead of the 40 it would take to go to Pluto alone if this game of celestial billiards were not played. The other Grand Tour, starting in 1979, aims for Jupiter, Uranus, and Neptune (diagram, page 181).

Saturn

Time: September 12, 1980. Since leaving Earth it has taken three years, even with Jupiter's powerful kick, for us to reach Saturn—sixth planet of our system. The sun lies nearly 900 million miles behind us, twice as far as from Jupiter. Its warmth and light are only a hundredth of what we are accustomed to; Saturn travels in eternal twilight. A message to Earth—at the speed of light—now requires nearly an hour and a half.

We are diving under Saturn, staying well clear of its hazardous rings and its ten moons. Our path will then turn up to throw us out of the ecliptic (the plane in which Earth orbits the sun) and toward Pluto, whose orbit is tilted 17° to the ecliptic (pages 152-3, lower).

Some 281,000 miles away, Saturn—the most extravagant sight in the family of the sun—glows with a dull yellowish hue. But the brilliant white of the rings suggests the glitter of countless diamonds.

I know something of what the space traveler will see when he looks down on Saturn. In the company of Dr. Tom Gehrels, I watched this remarkable planet, fascinated, through one of the University of Arizona telescopes. The half tilt of the rings presented a favorable view, and the seeing that winter night was exceptional. Even the faint bands on the planet itself were clearly discernible.

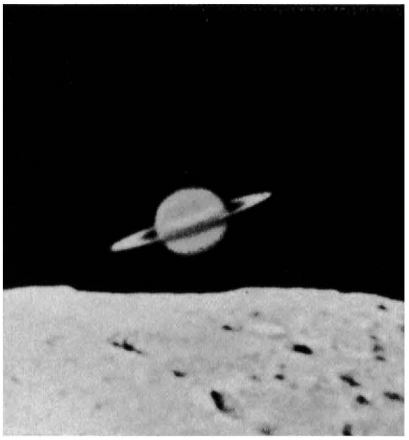
If I felt any disappointment, it was only that this exquisite spectacle, almost a billion miles away, presented the static quality of a carving in ice. Somehow I expected the rings in my eyepiece to whirl like a spinning top.

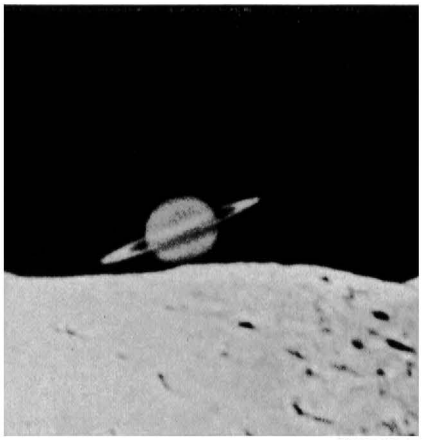
Controversy surrounds the rings. Most specialists, however, would agree that they represent particles that never did accrete into a satellite (or just possibly a satellite that swung too close to Saturn and broke up in its gravitational grip); and that they consist of chunks of water ice, or ice-coated bits of rock, each in its own orbit (paintings, pages 182-3).

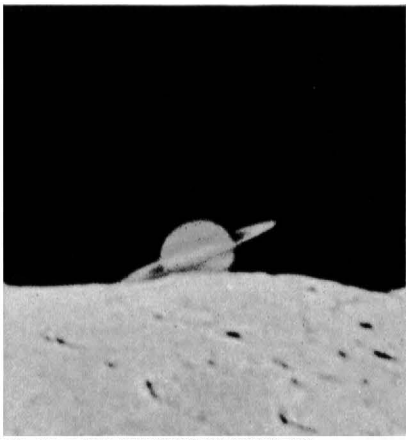
Spectral traveler near the limit of man's normal vision, chill Uranus (following pages) roamed its enormous orbit undetected until betrayed by the prying telescope in 1781. Here the planet hulks like a great domed head behind the rock and snow of satellite Umbriel, 150,000 miles distant. Two closer moons, Ariel, center, and fleet Miranda, ply their lower orbits. Some observers have reported atmospheric bands vaguely striping the planet.

PAINTING (FOLLOWING PAGES) BY LUDEK PESEK © N.G.S.

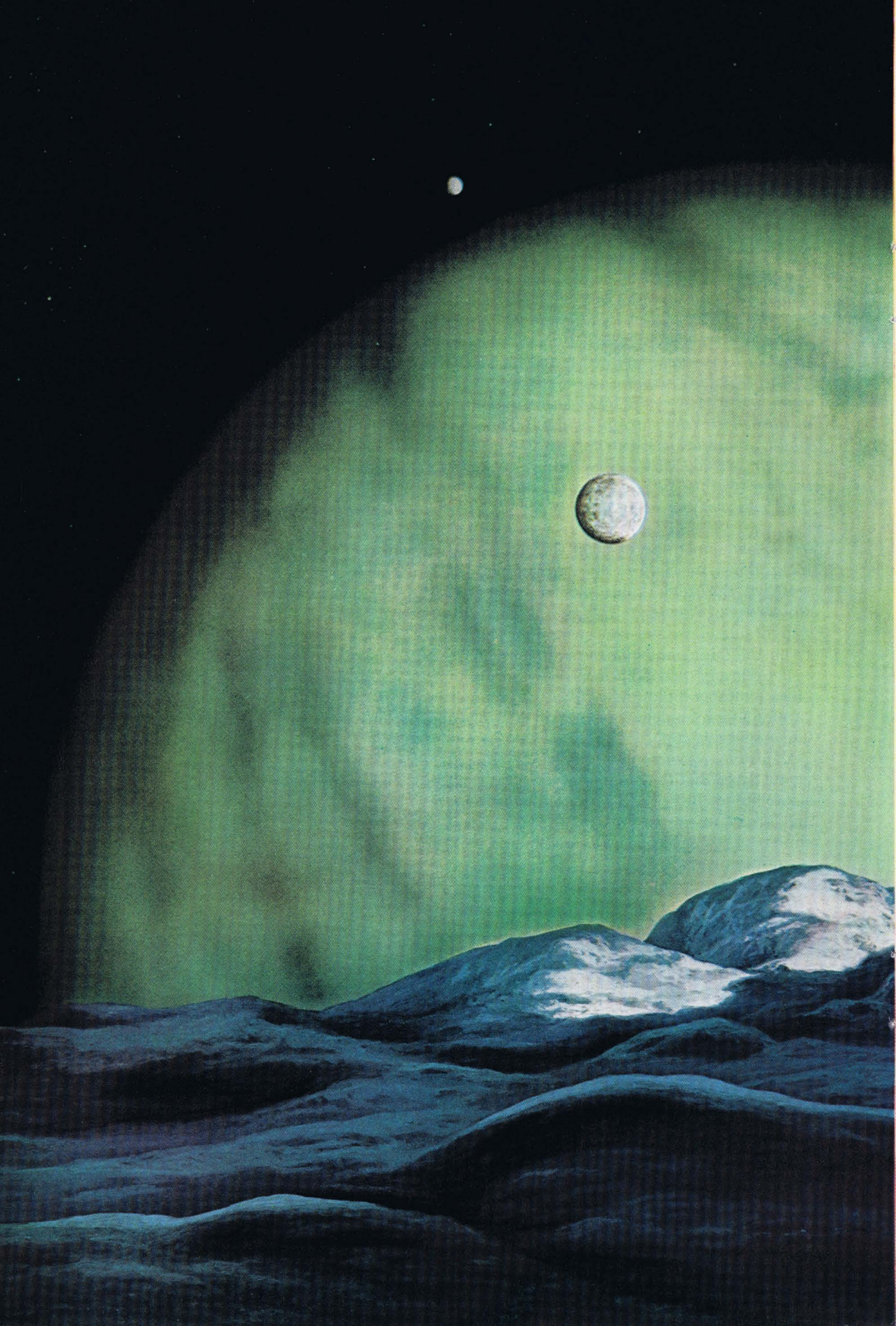
URANUS

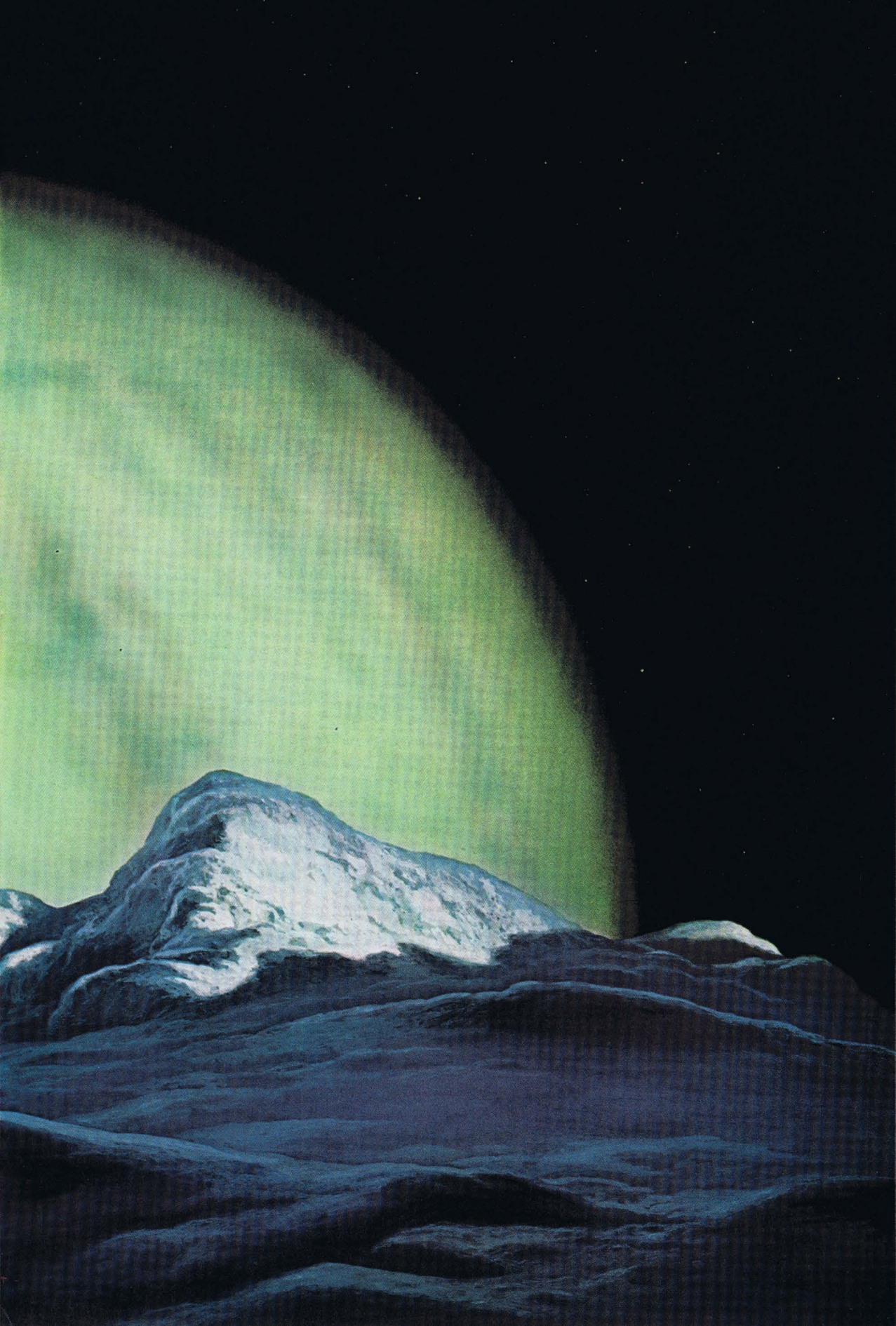


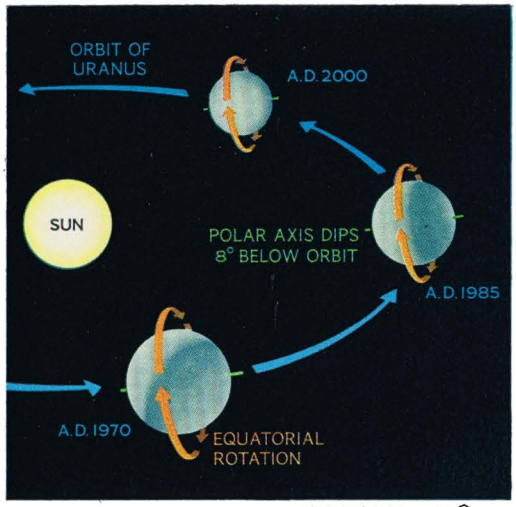




BRADFORD A. SMITH, NEW MEXICO STATE UNIVERSITY OBSERVATORY



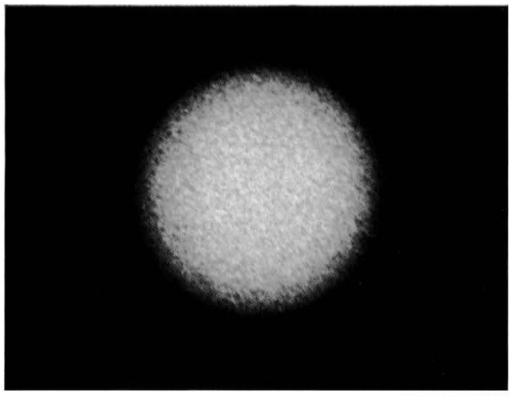




GEOGRAPHIC ART DIVISION © N.G.S.

As if it took a tumble, Uranus revolves around the sun with its axis lying only 8° from its orbital plane, instead of more nearly vertical like other planets. Thus, for half its 84-year orbit, one of its poles constantly sees the "midnight sun," while the opposite pole dwells in frigid darkness.

Dead-pan disk of Uranus peers from a high-resolution photograph taken last March at an altitude of 80,000 feet by Stratoscope II, a balloon-



PRINCETON UNIVERSITY

borne observatory launched at Palestine, Texas. Stratoscope scientists, astronomers at Princeton University, hope that computerized sharpening of such images will establish whether Uranus has faint surface markings.

Together with neighboring Jupiter, Saturn, and Neptune, Uranus belongs to a subfamily in the solar system called the Jovian planets. All rotate furiously, wear dense atmospheres, and consist of far lighter elements than the earthlike, or terrestrial, planets. Despite the bitter cold of its outer atmosphere, Jupiter at least may harbor life. Somewhere in its depths, where temperatures rise, life zones may support organisms.

Collisions among particles whose orbits crossed because they were elliptical or tilted have gradually forced all the particles into circular orbits in approximately the same flat plane, a plane thinner than a sheet of paper in proportion to its width.

Dr. Gerard Kuiper believes that the particles can be no more than about ten inches thick, and that the rings are probably not much thicker.

Bradford Smith and others contend that the rings are more likely half a mile thick, because they can still be photographed when they are edge-on to Earth, every 15 years. An analysis of light measurements made by Professor Smith may settle the matter by the end of this year. In any case, the rings are not completely opaque; stars have been seen through them.

Two bright rings are clearly visible, separated by the Cassini Division. A third, the Crape Ring, a dusky band, lies closer in. And inside these, reaching almost to Saturn, is a fourth ring, extremely faint, observed last year by Pierre Guérin of France.

Second planet in size, Saturn is another gas giant with a composition much like Jupiter's. If you could get it into a tub of water, it would float, for the density of Saturn is only 7/10 that of water.

Uranus

Time: July 28, 1985, six years since leaving Earth and four years from Jupiter. We are moving into the bitter cold and unrelieved darkness of the outer solar system, crossing the orbits of far-ranging comets. Uranus lies only 15,500 miles below, a pale greenish orb with faint markings. Five moons make up its retinue.

Earth glimmers nearly two billion miles away, a distance requiring 2 hours and 45 minutes for our radio signals to span.

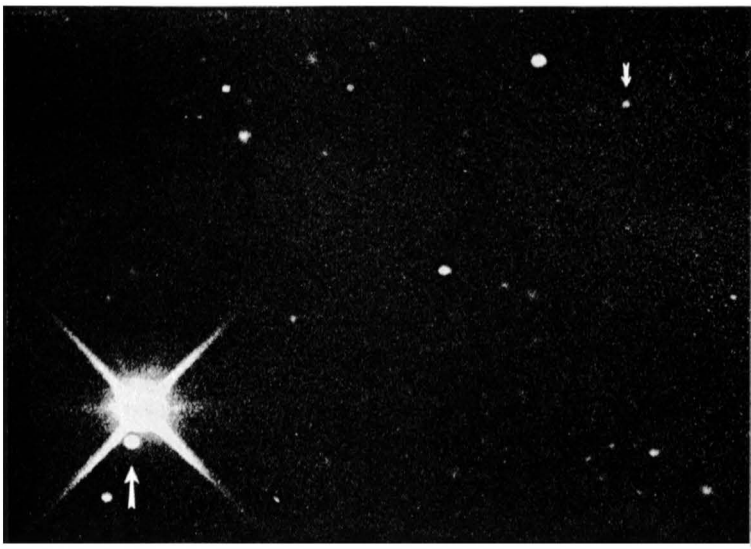
"From here on out," says Dr. Bruce Murray, "we know so little about the planets that we can hardly ask questions."

Even with the best telescopes, cameras rarely if ever record true surface features on Uranus. Its diameter and rotation period are imperfectly known, and its surface markings and atmosphere are still speculative.

Quite unlike its neighbors, Uranus lies on its side, so that at intervals in its orbit its poles point almost directly toward the sun (diagram, above). If you watched from one of the poles, you would see the sun for 42 years, and then live in darkness for another 42.

NEPTUNE

Neptune sparkles like a star in a 20-minute exposure, distorted by the telescope. Arrows mark the planet's moons: little Nereid, at upper right, and Triton, seemingly engulfed. Because of Triton's nearness to Neptune and its hugeness—larger than Earth's moon—Dr. Thomas McCord of MIT predicts that in 10 to 100 million years a decaying orbit will drop it into the planet's atmosphere.



YERKES OBSERVATORY, PHOTOGRAPHED BY DR. GERARD P. KUIPER

Like cotton candy, Neptune floats above the stark reaches of its satellite Triton, 200,000 miles away. As depicted by artist Pesek, the planet wears faint atmospheric bands—features suspected by observers but never actually photographed.

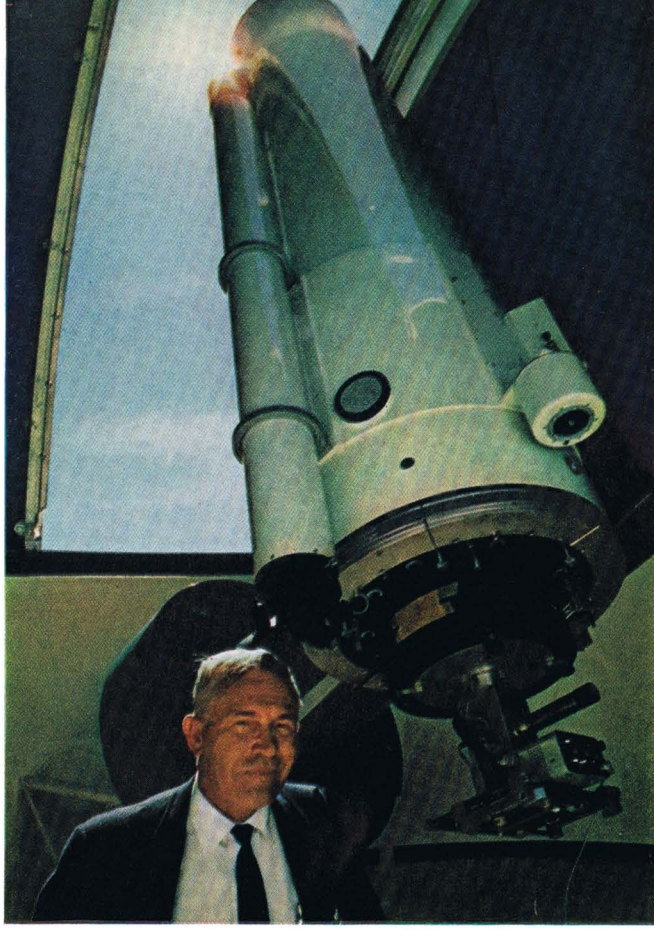
PAINTING BY LUDEK PESEK © N.G.S.

Neptune

Time: November 28, 1988. We see Neptune dead ahead, a bluish-green sphere whose features have never been photographed from Earth. Farthest out of the giant planets, this twin of Uranus now moves nearly three billion miles from the sun. So intense is the cold that our spacecraft would drop to 370° below zero F., except for the heat from our radio-isotope thermal generators.

Radio time to Earth: four hours, six minutes. The data our instruments are now recording, and the pictures being sent to Earth, will add immeasurably to our understanding of Neptune and its moons, for our knowledge is meager indeed.

Both Uranus and Neptune have densities greater than Jupiter and Saturn. This fact suggests that the two outer planets are not as rich in hydrogen and helium, but must contain a higher proportion of water and ammonia ices, as do comets.



Pluto

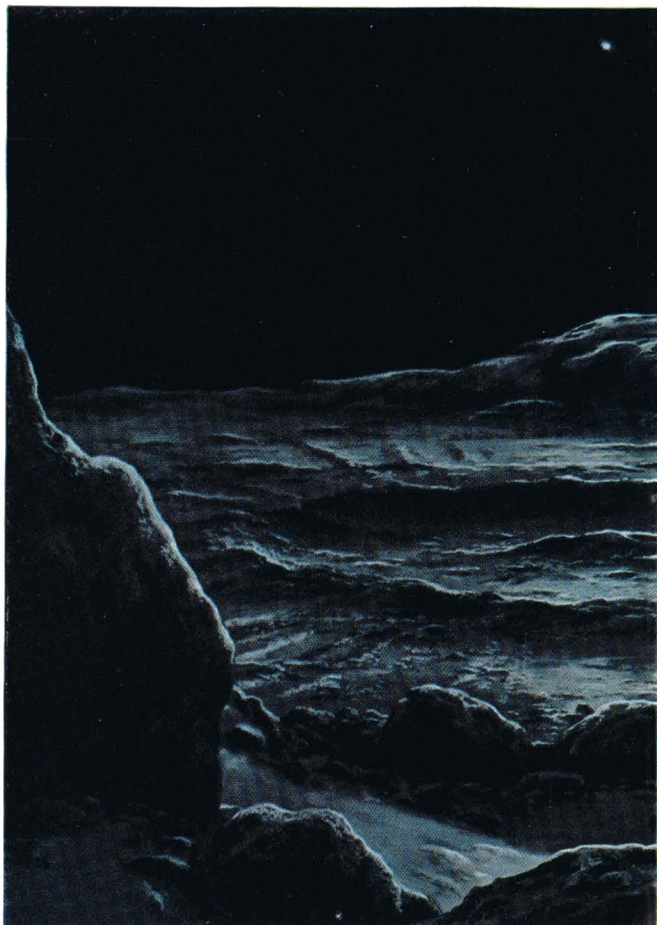
In the 1840's, a Frenchman and an Englishman, working separately, concluded that the gravitational tug of an unknown planet was forcing Uranus to wander from its predicted orbit. The location where the missing planet should be was calculated, and Neptune was found within an hour's search.

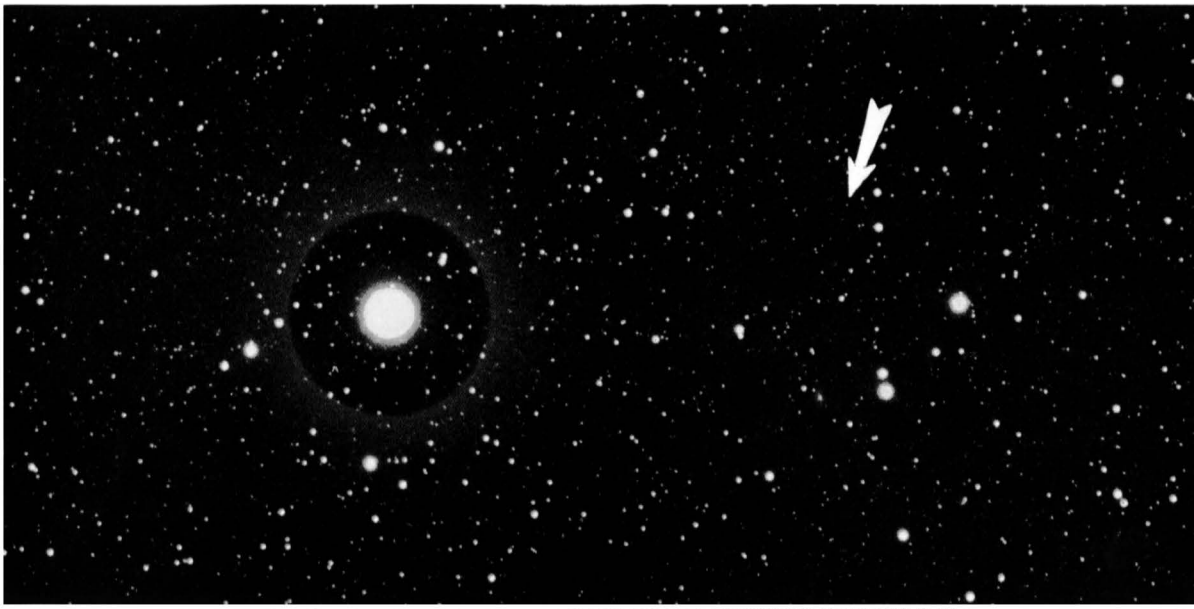
But Neptune's pull seemingly did not fully account for the observed wanderings of Uranus. Two Americans, Percival Lowell and W. H. Pickering, insisted that still another planet would be found, and predicted its path around the sun.

In 1929, Clyde W. Tombaugh, a young astronomer at the Lowell Observatory in Flagstaff, Arizona, undertook to look for "Planet X." I well remember the excitement stirred by his discovery of Pluto in 1930. So I felt more than ordinary pleasure a few months ago when I talked to Professor Tombaugh, now at New Mexico State University, and heard his own account of the search.

Tombaugh's technique was to make two photographs of a section of the sky a few nights apart, then compare the images. He showed me one of his glass-plate negatives that had recorded a million stars in an area of 14 by 17 inches. It looked as if it had been spattered with soot.

Under a viewing device known as a blink comparator, he examined first one plate, then the other, in rapid succession, studying





LOWELL OBSERVATORY (ABOVE); PAINTING BY LUDEK PESEK; KODACHROME BY EMORY KRISTOF © N.G.S.

Elusively roaming the solar system's frozen frontiers, Pluto evaded discovery until 1930. Then, in one of astronomy's great triumphs, it fell captive to the patient eye of Clyde W. Tombaugh (left), here standing beside a 24-inch planetary telescope of New Mexico State University at Las Cruces.

Tombaugh's original photographic plate (above), exposed for an hour, preserves man's first glimpse of Pluto, arrow. Bright body is Delta Geminorum, the only star on the plate visible to the naked eye.

Arid, frigid, and dark, Pluto numbs the mind with its remoteness and hostility. Icy hummocks and a sprawling crater (below) glimmer in wan light of a tiny sun (bright star) nearly four billion miles away.

Steppingstone to the planets: A space station, left, orbits 280 miles above Earth, in a scene combining a number of actions that normally would occur over several days. Planned for the late 1970's, the station will provide a laboratory for studying Earth and the planets and help reveal the demands of sustained space travel on men and equipment.

Tall as a four-story house, the station houses a crew of 12 for shifts as long as six months. Men on the station's lower level control a mechanical arm that unloads a supply module from a streamlined 200-foot-long space shuttle parked alongside, right. The module will dock at a port beneath the winglike solar panel that supplies the station's power.

Other crew members exercise, dine in the wardroom, and perform chores in the weightlessness of zero gravity. Beneath an outthrust radio antenna, a technican replaces a data package in an astronomy module, attached to the station for servicing. Released with solar panels outstretched, the unmanned observatory will study the heavens free of the

distortions of Earth's atmosphere.

After delivering its load, the space shuttle will descend to land on a conventional runway. Launched from Cape Kennedy, another shuttle separates from a re-usable booster that carried it into space. To include the maneuver in this panorama, artist Meltzer portrays it at nearly the altitude of the station. Actually the booster will separate at only 47 miles up.

one small area at a time. If any object had moved against the star background in that interval of several nights, it would seem to jump.

Asteroids and spurious images complicated this tedious work. But on February 18, 1930, after seven months' painstaking inspection of some six million star images, Professor Tombaugh found his quarry—a yellowish body with a magnitude of about 15, only 1/4000 as bright as the faintest star you can see with the naked eye. It was named Pluto, and the first two letters of the name, which also are Percival Lowell's initials, became its symbol.

The outermost planet is so small and so remote that it is exceedingly difficult to measure accurately. Thus we know almost nothing about it, except that it orbits the sun in 247 earth years, rotates in 6.4 days (known from fluctuation of its light), and appears to be no larger than Mars. It is thought to be solid and not made of gases. Its eccentric orbit brings it inside Neptune's orbit near perihelion; in fact, it comes closer to the sun than Neptune ever does. For this and other reasons, some astronomers think Pluto is actually an escaped satellite of Neptune.

Following his discovery, Tombaugh continued searching for other planets. Fourteen years of work on 338 pairs of plates with 90 million star images left him exhausted but convinced: "If anyone wants to go out and look for more planets, O.K., but he'd better look up what is involved," declares the man who found Pluto.

Ironically, the calculations of Uranus's deviations on which Lowell's prediction was based have since been shown to be in error. So the discovery of the ninth planet, although the result of the most tedious systematic searching, was in reality a happy accident.

ON MARCH 9, 1986, *we encounter Pluto on our Grand Tour. At that time the little planet, probably a snow-covered rock, is thirty times as far from the sun as is Earth, and the solar energy falling on each square mile is a thousandth of that for Earth.*

Our long voyage to the planets is ended. The Grand Tour spacecraft moves on to an endless wandering beyond the solar system and into the mazes of the Milky Way. We have traveled farther than any man before us, and have seen such wonders as no eye has ever beheld.

With Immanuel Kant, the 18th-century philosopher, we may say: "I have . . . ventured on a dangerous journey, and I already behold the foothills of new lands. Those who have the courage to continue the search will set foot upon them. . . ." THE END