FOURTH EDITION

Exploring the Universe

PROTHEROE / CAPRIOTTI / NEWSOM

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W. M. PROTHEROE

E. R. CAPRIOTTI

G. H. NEWSOM

The Ohio State University

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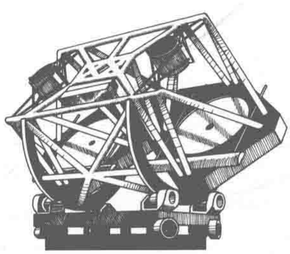
Cover Photo: Sombrero Galaxy, M104, a spiral galaxy seen edge-on. (National Optical Astronomy Observatories)

Back Cover Photo: The Milky Way from Australia. (Dennis di Cicco) For key, see page 665.

Title Page Photo: The Large Magellanic Cloud. The bright star at right is Supernova 1987A. (National Optical Astronomy Observatories)

Credits for color plates appear on p. 645.

The drawing below and on the opening of each chapter shows a model of the Columbus Project Telescope of the University of Arizona, Ohio State University, University of Chicago, and Osservatorio Astrofisico di Arcetri in Italy, which will consist of two 8-meter spin-cast mirrors in a common mount.



PREFACE

The study of astronomy is an excellent vehicle by which to introduce a student to the study of science. Being one of the oldest sciences, astronomy has a rich history, but with modern observational techniques now available, it carries with it the excitement of discovery and confrontation of the unknown. As a discipline, astronomy draws upon all other sciences, particularly the physical sciences.

Attempts to find answers to problems posed by astronomical observations have strongly influenced the intellectual development of the human race. The desire to understand and to predict the motions of the planets gave rise, in large part, to modern mechanics. The growth of mathematics was spurred by astronomical applications. Arguments over the heliocentric and geocentric models of the solar system had profound philosophical implications. Astronomy has supplied the testing grounds for new ideas, such as general relativity, or the impetus for others, such as thermonuclear reactions to explain the sun's energy source.

APPROACH

This text is designed to be used in an introductory course for nonscience majors, although such a course may well serve a unifying purpose for science majors. Because many students who take a course of this nature do not have an extensive background in science or mathematics, the course must supply the concepts of physics needed to interpret astronomical observations and forego a full mathematical development. Based upon our experience in teaching introductory astronomy to nonscience majors, we have incorporated the necessary background at a level that we feel is comprehensible to most college students. We have chosen to emphasize the historical development of astronomy—not as a historian would, but rather to aid the student in seeing how our understanding of the universe has evolved and is still developing. Our experience also indicates that this approach is the most effective one for students with backgrounds in the humanities or the social sciences. Furthermore, our approach does not do a disservice to those from the physical or biological sciences, who quite often have missed the historical development of a discipline because they are, of necessity, too concerned with the specifics of their particular fields.

We have emphasized the observed, how observations are interpreted, and how those interpretations have influenced our perceptions of the universe. To show that the study of astronomy is a human process, we have introduced each chapter by recounting a story or two appropriate to the material of the chapter. We feel that this will help to make the subject come alive to the students.

There is much to choose in developing a course in astronomy, but the nature and length of the course often require that there be some limitation in material. We have tried to center on what appear to be the most significant ideas and concepts in the development of astronomy. Our aim is to stimulate the imagination of students, to transfer some of the fascination of the subject with enough background and knowledge that they may follow new developments in the field long after they have completed the course.

ORGANIZATION

We have found it necessary to increase the size of this edition to do justice to recent developments in astronomy. The major additions concern the planets and satellites in the solar system, observations outside the visible spectrum possible from space, stellar evolution, interstellar matter, extragalactic bodies, and cosmology.

The material on the solar system has been extensively reorganized. We start with a chapter on the Earth-moon system to establish a familiar basis with which the other planets and their satellites can be compared. This is followed by a chapter on the terrestrial planets and one on the Jovian planets. Instead of reciting the facts about each planet, however, we introduce them in terms of physical processes in a comparative discourse, which we feel will lead to a better understanding of the planets. An entirely separate chapter is devoted to satellites and rings because of the explosion in our knowledge of them spurred by data collected by space vehicles that have visited their vicinities. Again a comparative approach makes what could have been an overwhelming assembly of facts into a structured presentation of the processes at work in the satellites.

The present knowledge and ideas about matter between the stars have induced us to prepare a chapter devoted to interstellar matter and how that matter interacts with and, in fact, creates stars. A chapter on the evolution of double star systems has been added because of their recognized importance in our understanding of some of the more exotic bodies discovered in the universe. A separate discussion of peculiar galaxies, quasars, and quasar-like systems has been introduced, again because of new data and their importance in understanding processes in action within the universe. Fortunately, the supernova of 1987 occurred in time for us to include the additional understanding of the supernova process that has resulted from it. The chapter on cosmology has been entirely rewritten to bring within the grasp of the student current thought on the structure and evolution of the universe.

FEATURES

Astronomy is a very visual subject, and some of the color pictures obtained by various observers are nothing short of spectacular. The 68 color plates are organized by 19 themes that can be read and studied as independent entities, thus removing the need to leaf back and forth between text and picture that so often diminishes the impact of these striking images. In addition, there are 255 black-and-white photographs and 216 drawings that we feel will bring a deeper appreciation of astronomy to the student.

An extensive set of review questions will be found at the end of each chapter. These can be used for self-testing because their answers are given at the end of the book. We have found the questions and answers to be an extremely helpful device for solidifying student understanding of the material presented.

Twenty-six special-feature boxes highlight various topics throughout the text. The boxes are designed to generate student interest and can be used either as primary material or as optional material. The boxes permit the introduction of additional material without disturbing the logical flow of the text.

ACKNOWLEDGMENTS

We are particularly indebted to the following individuals for their careful and helpful review of chapters within their special interests: Peter H. Bodenheimer, University of California–Santa Cruz; Peter V. Foukal, Cambridge Research and Instrumentation, Inc.; John S. Gallagher, Lowell Observatory; Owen Gingrich, Center for Astrophysics; Paul W. Hodge, University of Washington; David M. Hunten, University of Arizona; Phillip C. Keenan, Ohio State University; Harold Masursky, Astrologic Studies Branch, U.S. Geological Survey; John S. Mathis, University of Wisconsin; Donald E. Osterbrock, University of California–Santa Cruz; Tobias C. Owen, State University of New York at Stoney Brook; Mirek J. Plavec, University of California–Los Angeles; Gary Steigman, Ohio State University; and Fred L. Whipple, Smithsonian Astrophysical Observatory.

We are no less indebted to the following individuals, who reviewed sections of the text and made many helpful suggestions with regard to both presentation and content: Phillip E. Barnhart, Otterbein College; Lee Bonneau, Foothill College; William Buscombe, Northwestern University; Martin L. Goodson, Delta College; Steven L. Kipp, Mankato State University; Phyllis Lugger, Indiana University; Terry Jay Jones, University of Minnesota; Gary Mechler, Pima Community College; James N. Pierce, Mankato State University; Yervant Terzian, Cornell University; David Theison, University of Maryland, College Park; Charles Tolbert, University of Virginia; Raymond E. White, University of Arizona; and John Wayne Wooten, Pensacola Junior College.

TELESCOPES THEN AND NOW

A

C

B

Telescopes have advanced from Galileo's crude instruments (C) to the Multiple Mirror Telescope (A) used at optical and infrared wavelengths and the Very Large Array (B) used at radio wavelengths. Galileo's tiny telescopes allowed him to see more detail and fainter objects than ever seen before.

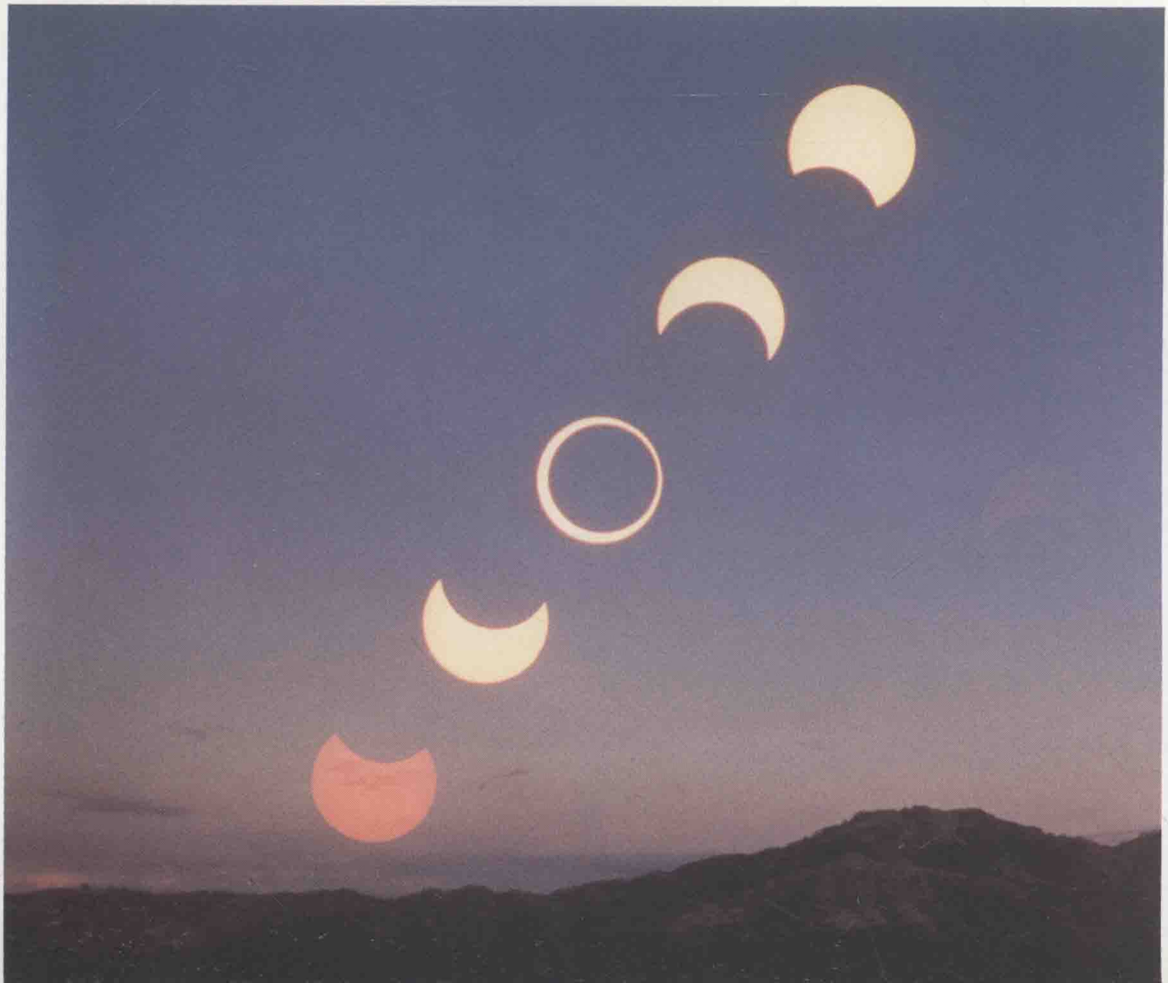
The MMT combines the light from six 1.8-meter mirrors and is equivalent to a single 4.5-meter mirror. It has paved the way for larger telescopes by proving that smaller, lighter mirrors can be effectively and economically combined to give the performance of a single, large mirror.

Only a portion of the VLA, an interferometer of 27 interconnected 25-meter radio telescopes, is shown. The VLA can attain a resolution equal to that of a 25-kilometer telescope, better than that of the largest optical telescope now available.

E C L I P S E S

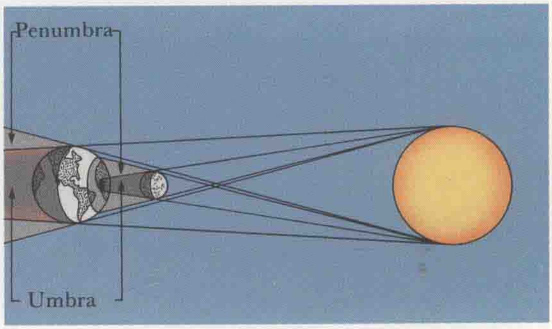

A

Eclipses form some of the most spectacular sights visible in the heavens. When the moon comes between the Earth and sun, one possible result is a *total eclipse* of the sun, with the moon blocking all direct light from the bright disk of the sun. Day turns to night as the tenuous, hot gases of the sun's corona appear. Sunlight reaching the Earth's atmosphere outside the eclipse gives the reddish glow seen in the distance in photograph C. As the total eclipse ends, the first part of the bright disk of the sun to reappear gives a beautiful "diamond ring" effect (A). In the more common *annular eclipse,* the moon appears slightly too small to completely cover the sun. In the series of exposures in B, even when the moon is directly in line with the sun, a bright ring, or annulus, of the sun remains visible.


B

C

D

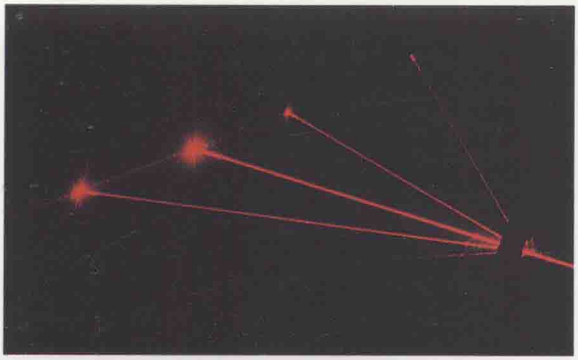


E

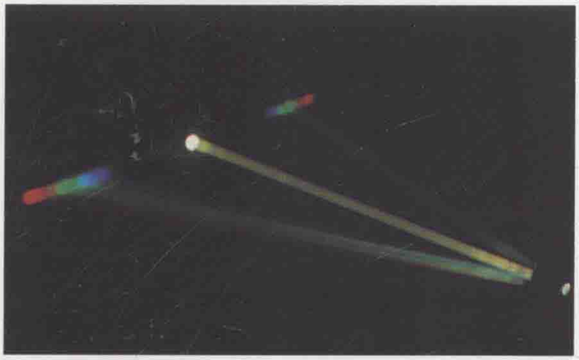
An eclipse of the moon occurs when the moon moves into the shadow of the Earth. However, the part of the Earth's shadow from which all direct sunlight is blocked (called the umbra) still contains a reddish glow, caused by sunlight refracted by the Earth's atmosphere. This coppery red glow can be seen on the part of the moon within the Earth's umbra (D). When the moon is partially within the umbra, a *partial eclipse* of the moon occurs. The small section of the moon at the lower left is in the penumbra, so it shows up much more brightly.

The circumstances of both solar and lunar eclipses are shown in E. As sunlight arrives from the left, a new moon may pass between the sun and Earth. If the umbra of the moon's shadow is directed toward an observer on Earth, that observer will see an annular solar eclipse when the umbra does not reach the Earth's surface, and a total solar eclipse when it does. If part of the full moon is in the Earth's umbra, a partial eclipse of the moon occurs. A total lunar eclipse takes place when all of the moon is within the Earth's umbra.

L I G H T



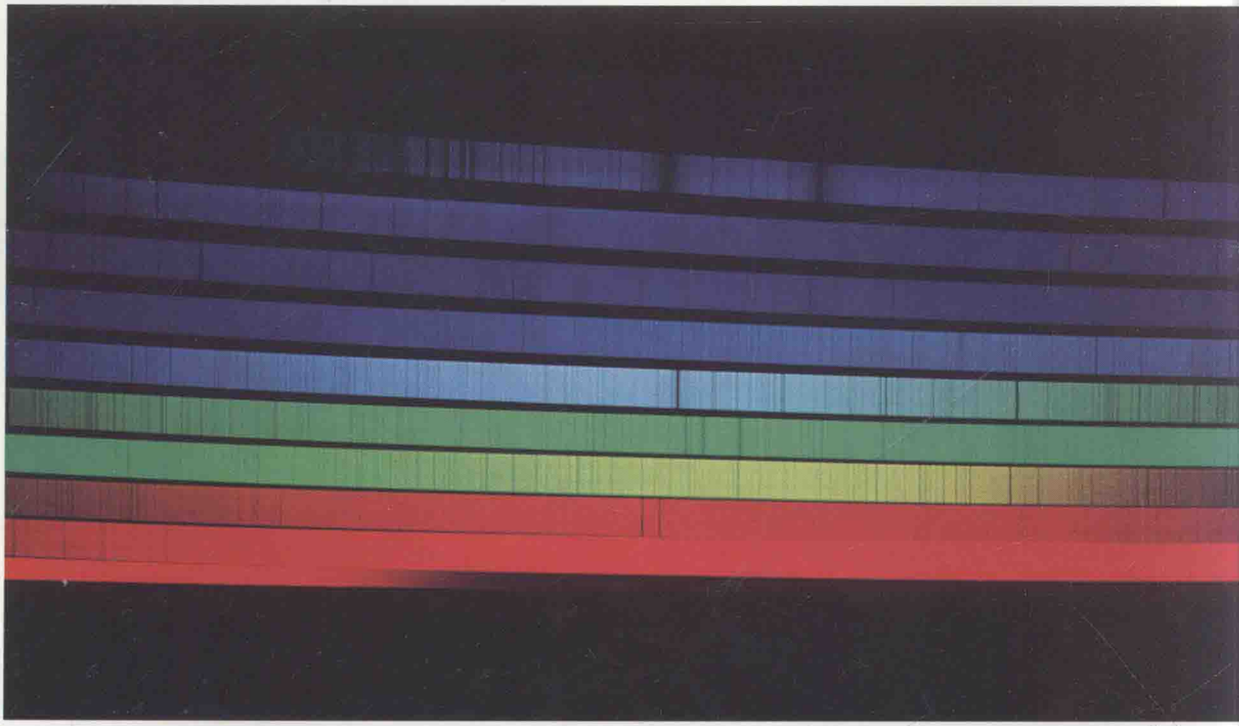
A



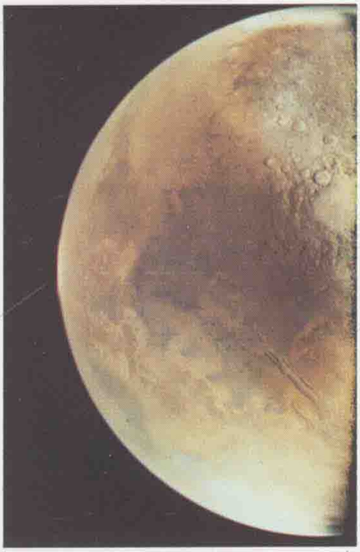
B

In A, a beam of laser light of only one color coming from the lower right falls on a diffraction grating. The light emerging from the grating travels in several discrete directions, forming beams. The result when light from an ordinary light bulb encounters a diffraction grating is shown in B. Beams still occur, but the diverted beams are spread into all colors of the rainbow. The central, or undiverted, beam contains all colors and remains white.

The band of dispersed light, or spectrum, of a light bulb is a *continuous spectrum,* where the colors gradually change with no sharp breaks between them. When sunlight passes through a grating, however, the continuous spectrum is crossed by a large number of dark lines (C). An *absorption spectrum* is caused by atoms of gas in the sun's atmosphere absorbing light at certain very well defined wavelengths. In addition to the sun's chemical composition, detailed study of these lines is used to find the temperature, pressure, and motions of the gases on the sun.

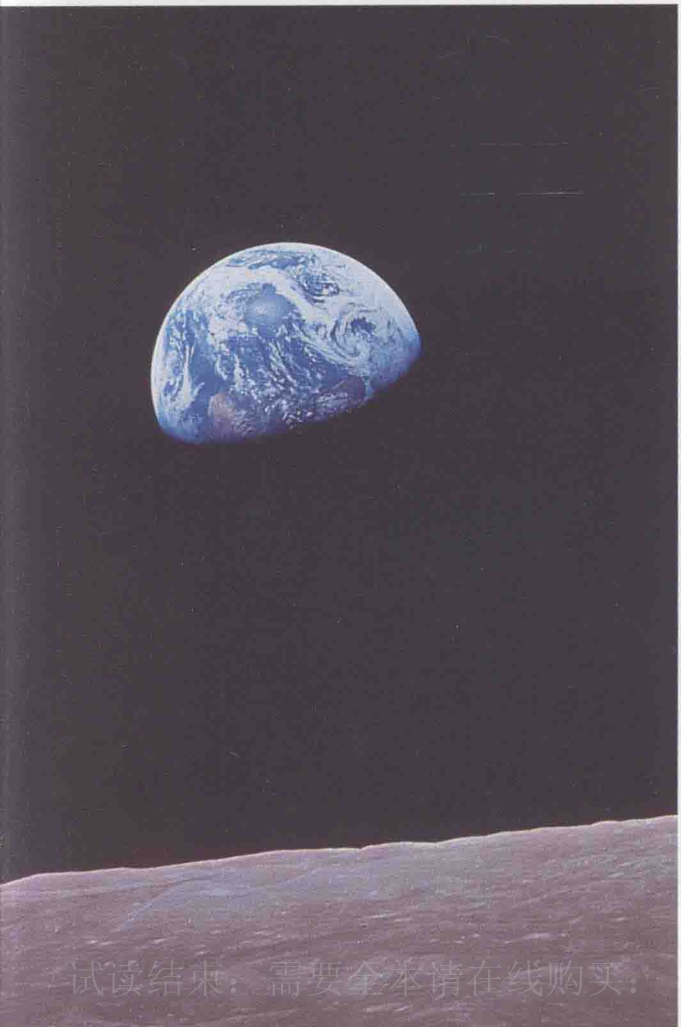


C



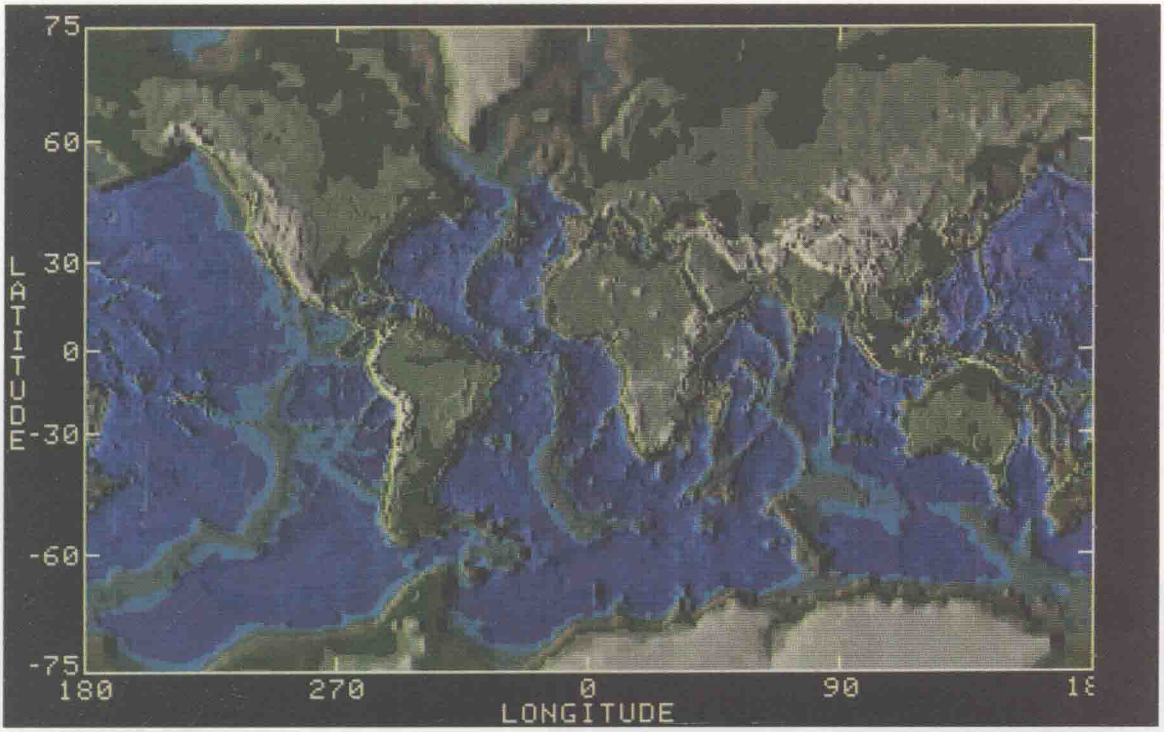
A

For centuries, other planets were best studied by telescope, while Earth itself could be studied close up. Spacecraft, however, have allowed other planets to be studied from close range and Earth to be seen from afar. From lunar orbit, Earth is a beautiful sight rising over the moon's limb. Since clouds reflect light so much better than the surface does, they appear bright white (B). Between the clouds, the blue oceans and brown continents are visible. Clouds are much rarer on Mars. The orange color of most of its surface can be seen in A. The darker markings slowly change from year to year, demonstrating that they are surface deposits of dark matter blown by the winds. The frozen carbon dioxide of Mars's south polar cap forms the white region at the top. Unlike Earth or Mars, Venus is continually covered with clouds. The brilliant white color of the crescent Venus is a beautiful sight through a telescope (C), but it means that the surface can be studied only by radar or instruments parachuted below the clouds from spacecraft.

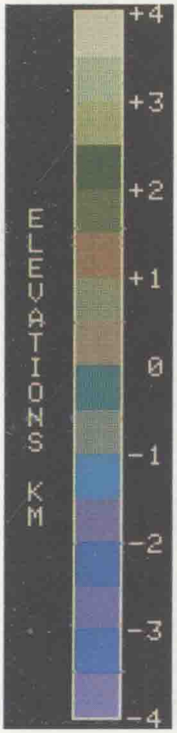


B

C



A

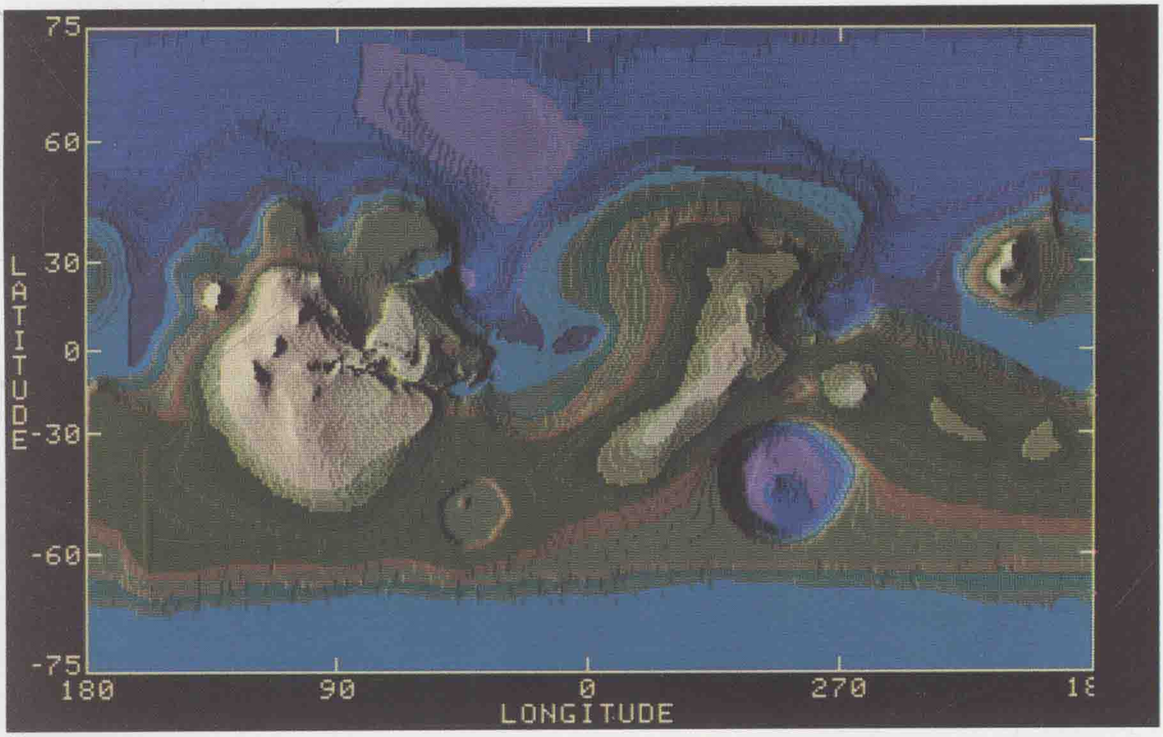


B

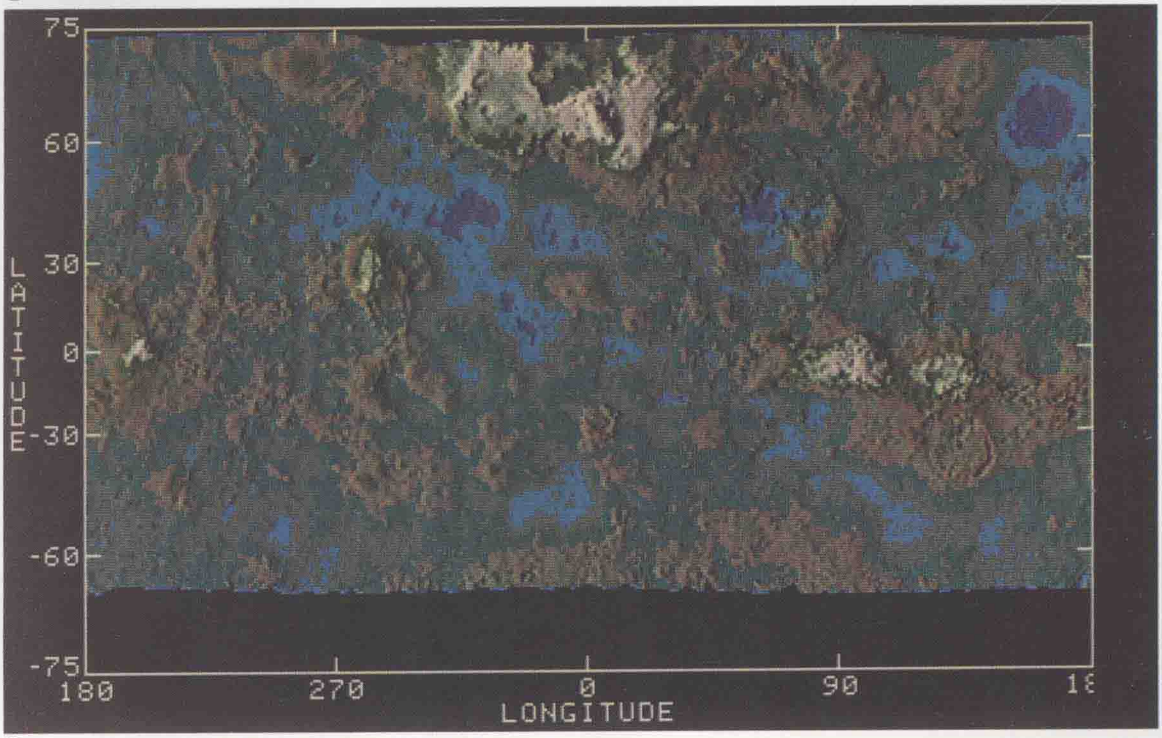
The familiar outlines of the Earth's continents are shown in the relief map above (A). The color coding of altitude on the surface is given at the left (B). This map and the ones for Mars (C) and Venus (D) are drawn to a resolution of 50 kilometers, about three times better than naked-eye views of the moon.

The Mars map (C) is made by combining results from radar ranging, photographs from Mars orbiters, and timings of when orbiters disappear and reappear from behind the planet. The Tharsis ridge dominates Mars's topography, crossing the equator near longitude 100° and crowned with three large volcanoes in a diagonal line. Olympus Mons is the isolated volcano just to the upper left of the Tharsis ridge. The two volcanoes at latitude 30° N to the far right are also on an elevated dome, a miniature version of the Tharsis region. Valles Marineris can be seen just south of the equator leading to the right from Tharsis ridge. Ancient impacts produced the two prominent circular depressions in the south; the larger one, at longitude 290°, is Hellas Planitia.

The radar map of Venus (D), while more complex than that of Mars, shows less large-scale structure than the Earth. The highest point is a presumed volcano, Maxwell Montes, at longitude 0° and latitude 65° N. The surface around Maxwell Montes is rough and irregular, presumably from volcanic eruptions and surface motion. This region and the smoother area to the left form the continent Ishtar. Although not as high or prominent as Ishtar, the continent Aphrodite covers considerably more area, mostly just south of the equator from longitude 60° all the way to 225°. The apparent volcanoes Rhea Mons and Theia Mons make up the Beta region, at latitude 30° N and longitude 285°.


75
60
30
0
-30
-60
-75
LATITUDE
180
90
0
270
18
LONGITUDE

C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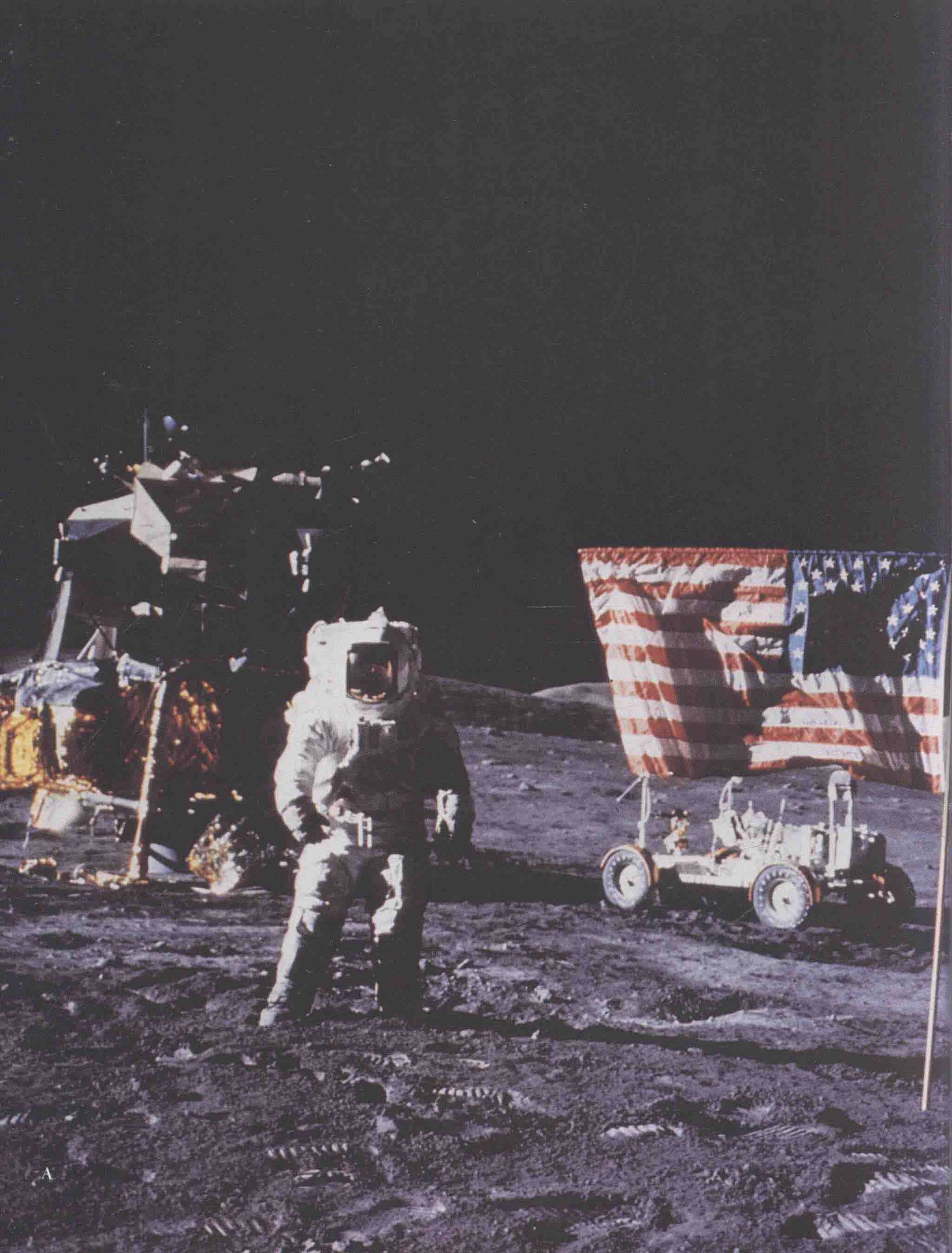
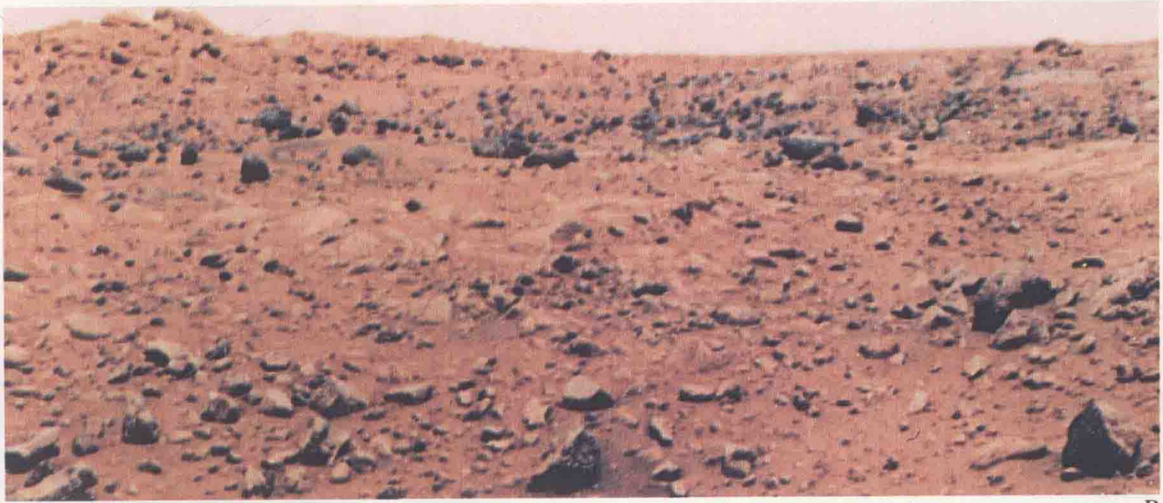
LONGITUDE

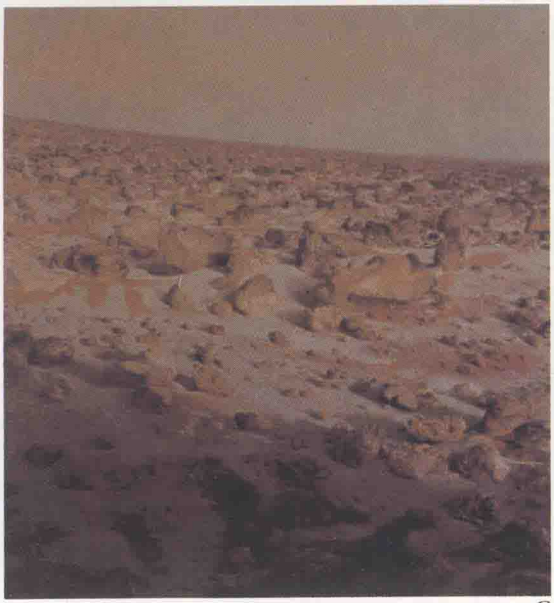
D



A



B



C

D

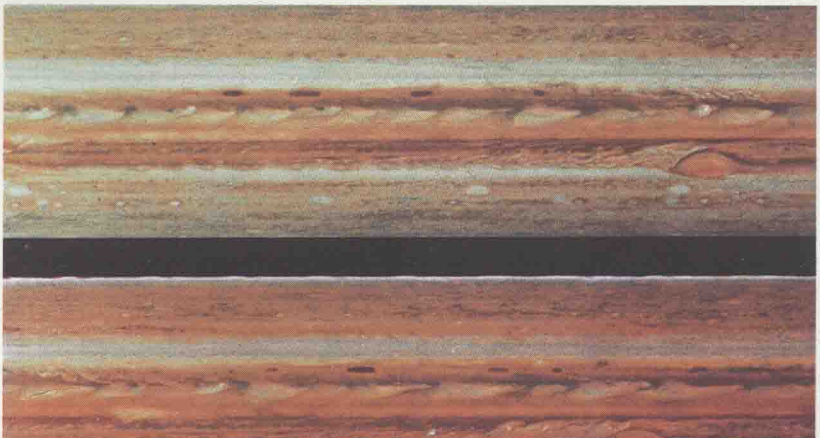
The telescope radically changed astronomy, which quickly became a science of interpreting what was seen through a telescope. Equally revolutionary has been the ability to travel to heavenly bodies, with manned or unmanned space probes. Never before or since have so many people around the world been united in watching (via television) such an event as an astronaut walking on the moon, collecting samples from our neighbor (A). The landings on Mars, all unmanned, have yielded dramatic views of the surface of that barren planet (B). Among details documented on Mars are interactions between its surface and atmosphere. During the bitter Martian winter, regions at high latitudes experience a carbon dioxide frost, as dry ice condenses on the surface (C). Water vapor often forms a frost overnight, and when it evaporates in the morning sun, a white fog can pervade the valleys (D).

JUPITER'S ATMOSPHERE

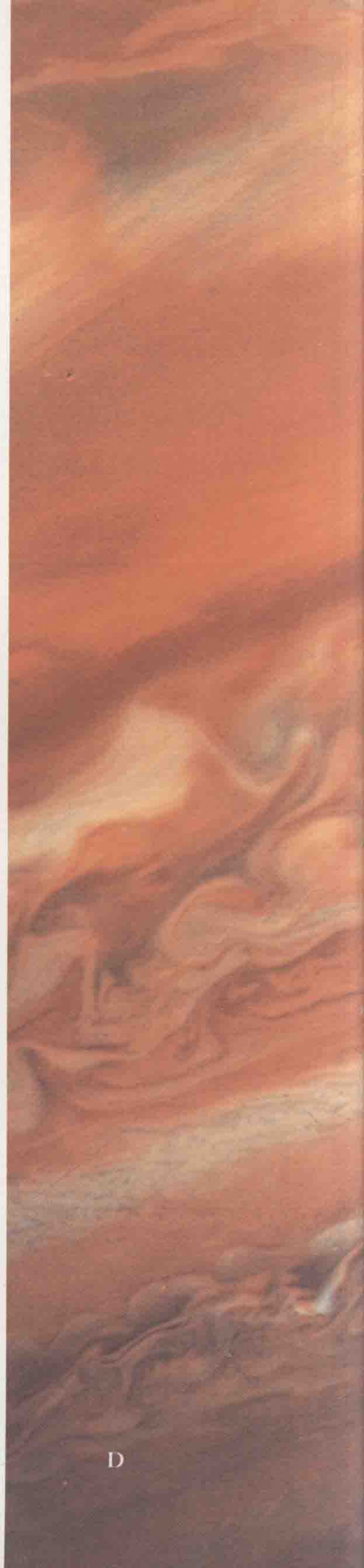
A picture of Jupiter taken by the *Voyager 1* spacecraft (A) is compared to a ground-based infrared image of Jupiter taken an hour earlier (B). The bright bands in infrared light mark warmer regions of the atmosphere; note how they correspond to darker clouds in the *Voyager* photo. Since the temperature increases with depth in the atmosphere, the darker, warmer clouds seen in visible light are at lower altitudes, while the white clouds are higher. The Red Spot is exceptional, being both dark and cool. The atmospheric temperature differences must help create winds on Jupiter, just as they do on Earth. *Voyager 2* mapped Jupiter's clouds four months after *Voyager 1*. The changes that occurred are obvious in C: the Red Spot had moved to the west (leftward), while the white ovals just to the south had moved to the east. The winds also produce striking patterns. As clouds just to the north of the Red Spot veer around it, the normally smooth flow becomes very turbulent, as seen to the left of the Red Spot (D).

A

B



C



D