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ATLAS OF THE SOLAR SYSTEM
TOPOGRAPHIC SERIES
MAPPING THE SOLAR SYSTEM
I-2447

MAPPING THE SOLAR SYSTEM

1994

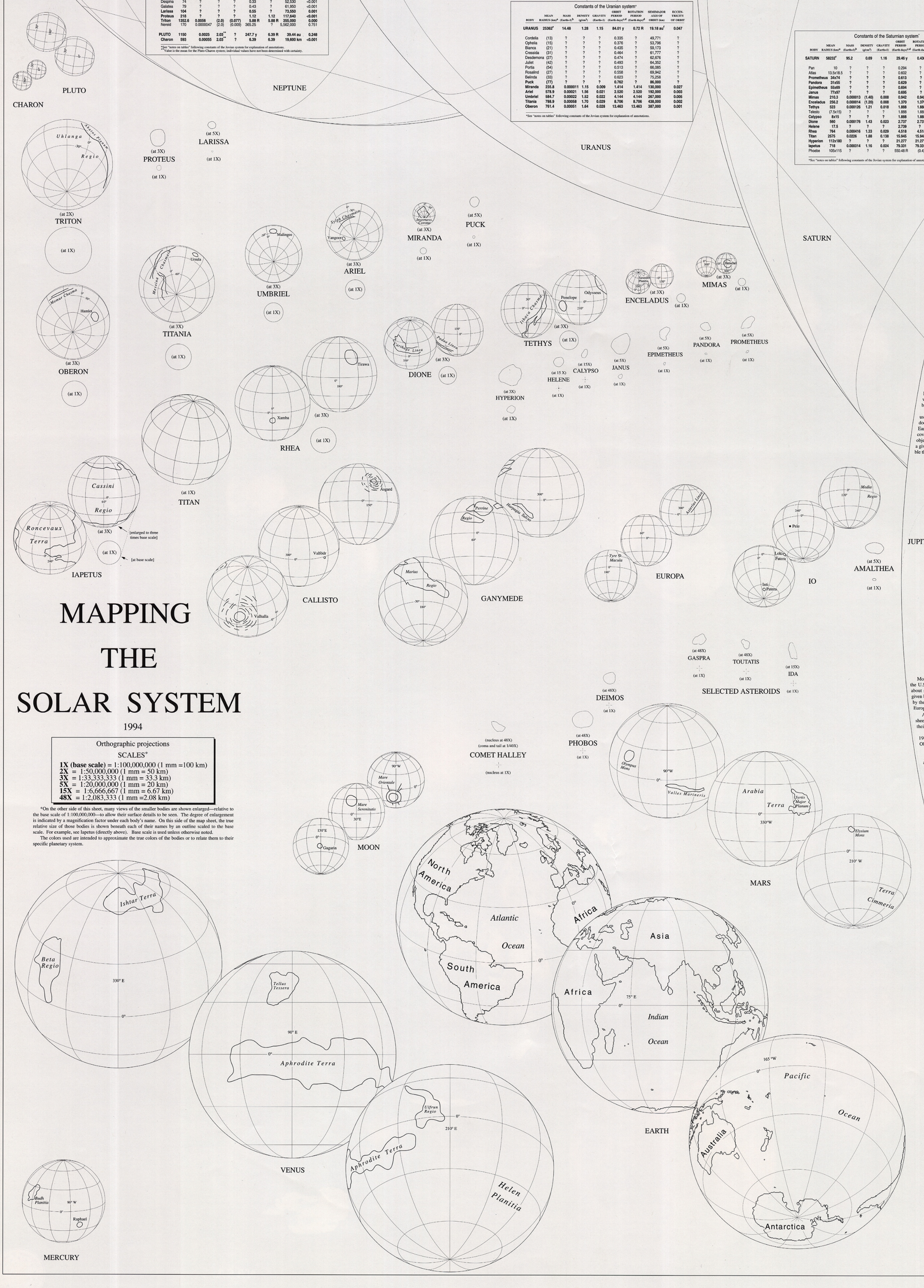
Orthographic projections

SCALES*

1X (base scale) = 1:100,000,000 (1 mm =100 km)
2X = 1:50,000,000 (1 mm = 50 km)
3X = 1:33,333,333 (1 mm = 33.3 km)
5X = 1:20,000,000 (1 mm = 20 km)
15X = 1:6,666,667 (1 mm = 6.67 km)
48X = 1:2,083,333 (1 mm =2.08 km)

*On the other side of this sheet, many views of the smaller bodies are shown enlarged—relative to the base scale of 1:100,000,000—to allow their surface details to be seen. The degree of enlargement is indicated by a magnification factor under each body's name. On this side of the map sheet, the true relative size of those bodies is shown beneath each of their names by an outline scaled to the base scale. For example, see Iapetus (directly above). Base scale is used unless otherwise noted.

The colors used are intended to approximate the true colors of the bodies or to relate them to their specific planetary system.



Constants of the Neptunian and Plutonian systems*

BODY	MEAN RADIUS (km)[a]	MASS (Earth=1)[b]	DENSITY (g/cm³)	GRAVITY (Earth=1)	ORBIT PERIOD (Earth days)[c,d]	ROTATION PERIOD (Earth days)[d]	SEMIMAJOR AXIS OF ORBIT (km)	ECCEN-TRICITY OF ORBIT
NEPTUNE	**24622[e]**	**17.2**	**1.66**	**1.19**	**164.79 y**	**0.67**	**30.058 au[f]**	**0.009**
Naiad	29	?	?	?	0.30	?	48,230	<0.001
Thalassa	40	?	?	?	0.31	?	50,070	<0.001
Despina	74	?	?	?	0.33	?	52,530	<0.001
Galatea	79	?	?	?	0.43	?	61,950	<0.001
Larissa	**104**	**?**	**?**	**?**	**0.55**	**?**	**73,550**	**0.001**
Proteus	**218**	**?**	**?**	**?**	**1.12**	**1.12**	**117,640**	**<0.001**
Triton	**1352.6**	**0.0056**	**(2.0)**	**(0.077)**	**5.88 R**	**5.88 R**	**355,000**	**0.000**
Nereid	170	0.0000047	(2.0)	(0.009)	365.25	?	5,562,000	0.751
PLUTO	**1150**	**0.0025**	**2.03****	**?**	**247.7 y**	**6.39 R**	**39.44 au**	**0.248**
Charon	**593**	**0.00055**	**2.03****	**?**	**6.39**	**6.39**	**19,600 km**	**<0.001**

*See "notes on tables" following constants of the Jovian system for explanation of annotations.
**Value is the mean for the Pluto-Charon system; individual values have not been determined with certainty.

Constants of the Uranian system*

BODY	MEAN RADIUS (km)[a]	MASS (Earth=1)[b]	DENSITY (g/cm³)	GRAVITY (Earth=1)	ORBIT PERIOD (Earth days)[c,d]	ROTATION PERIOD (Earth days)[d]	SEMIMAJOR AXIS OF ORBIT (km)	ECCEN-TRICITY OF ORBIT
URANUS	**25362[e]**	**14.48**	**1.28**	**1.15**	**84.01 y**	**0.72 R**	**19.18 au[f]**	**0.047**
Cordelia	(13)	?	?	?	0.335	?	49,771	?
Ophelia	(15)	?	?	?	0.376	?	53,796	?
Bianca	(21)	?	?	?	0.435	?	59,173	?
Cressida	(31)	?	?	?	0.464	?	61,777	?
Desdemona	(27)	?	?	?	0.474	?	62,676	?
Juliet	(42)	?	?	?	0.493	?	64,352	?
Portia	(54)	?	?	?	0.513	?	66,085	?
Rosalind	(27)	?	?	?	0.558	?	69,942	?
Belinda	(33)	?	?	?	0.623	?	75,258	?
Puck	**(77)**	**?**	**?**	**?**	**0.762**	**?**	**86,000**	**?**
Miranda	**235.8**	**0.000011**	**1.15**	**0.009**	**1.414**	**1.414**	**130,000**	**0.027**
Ariel	**578.9**	**0.00021**	**1.56**	**0.021**	**2.520**	**2.520**	**192,000**	**0.003**
Umbriel	**584.7**	**0.00022**	**1.52**	**0.022**	**4.144**	**4.144**	**267,000**	**0.005**
Titania	**788.9**	**0.00058**	**1.70**	**0.029**	**8.706**	**8.706**	**438,000**	**0.002**
Oberon	**761.4**	**0.00051**	**1.64**	**0.028**	**13.463**	**13.463**	**387,000**	**0.001**

*See "notes on tables" following constants of the Jovian system for explanation of annotations.

Constants of the Saturnian system*

BODY	MEAN RADIUS (km)[a]	MASS (Earth=1)[b]	DENSITY (g/cm³)	GRAVITY (Earth=1)	ORBIT PERIOD (Earth days)[c,d]	ROTATION PERIOD (Earth days)[d]	SEMIMAJOR AXIS OF ORBIT (km)	ECCEN-TRICITY OF ORBIT
SATURN	**58232[e]**	**95.2**	**0.69**	**1.16**	**29.46 y**	**0.436**	**9.53 au[f]**	**0.056**
Pan	10	?	?	?	0.294	?	133,600	(0)
Atlas	13.5x18.5	?	?	?	0.602	?	137,670	0.002
Prometheus	**34x74**	**?**	**?**	**?**	**0.613**	**?**	**139,350**	**0.005**
Pandora	**31x55**	**?**	**?**	**?**	**0.629**	**?**	**141,700**	**0.004**
Epimetheus	**55x69**	**?**	**?**	**?**	**0.694**	**?**	**151,422**	**0.009**
Janus	**77x97**	**?**	**?**	**?**	**0.695**	**?**	**151,472**	**0.007**
Mimas	**210.3**	**0.000013**	**(1.40)**	**0.008**	**0.942**	**0.942**	**185,540**	**0.004**
Enceladus	**256.2**	**0.000014**	**(1.20)**	**0.008**	**1.370**	**1.370**	**238,040**	**0.000**
Tethys	**523**	**0.000126**	**1.21**	**0.018**	**1.888**	**1.888**	**294,670**	**(0)**
Telesto	(7.5x15)	?	?	?	1.888	1.888	294,670	(0)
Calypso	**8x15**	**?**	**?**	**?**	**1.888**	**1.888**	**294,670**	**(0)**
Dione	**560**	**0.000176**	**1.43**	**0.023**	**2.737**	**2.737**	**377,420**	**0.002**
Helene	**17.5**	**?**	**?**	**?**	**2.739**	**?**	**378,060**	**0.005**
Rhea	**764**	**0.000416**	**1.33**	**0.029**	**4.518**	**4.518**	**527,100**	**0.001**
Titan	**2575**	**0.0226**	**1.88**	**0.138**	**15.945**	**15.945**	**1,221,860**	**0.029**
Hyperion	**112x180**	**?**	**?**	**?**	**21.277**	**21.277**	**1,481,000**	**0.104**
Iapetus	**718**	**0.000314**	**1.16**	**0.024**	**79.331**	**79.331**	**3,560,800**	**0.028**
Phoebe	105x115	?	?	?	550.48 R	(0.4)	12,954,000	0.163

*See "notes on tables" following constants of the Jovian system for explanation of annotations.

INTRODUCTION

Prior to the advent of planetary space travel, we knew very little about the basic surface morphology of the solid bodies in the Solar System. Only in the last two decades have we seen most of these worlds close up—many we had not seen at all until spacecraft visited the outer reaches of the Solar System in the 1980's. (The two Voyager missions alone accounted for the discovery of 24 new satellites that range in size from mere rocks 10 km across to a small world 460 km in diameter). Of the planets and satellites whose existence we knew of 25 years ago, only the Moon and Mars have surface features that had been mapped with any degree of reliability; only the near side of the Moon and the vague albedo features of Mars could be mapped from Earth. Now, with the completion of the two Voyager missions in 1989 and the fortuitous mutual occultations of Pluto and Charon from 1984 to 1989, we have—for the first time in history—detailed maps of nearly all the larger solid-surfaced bodies in the Solar System.

THE MAPS

Map-making skills that previously were applied almost exclusively to Earth expanded outward following the discoveries brought about by planetary exploration. With a total solid surface area of 1.6 billion square kilometers, the Solar System has more than three times the mappable surface area of Earth alone. Charting this new frontier has resulted in the compilation of more than 1,600 detailed maps of the planets and their satellites since 1960. Most of these maps were made by the U.S. Geological Survey, but hundreds of additional maps of the Moon were made by the Defense Mapping Agency; all but a handful are based on data returned by spacecraft missions managed by the National Aeronautics and Space Administration. This poster is a summary compilation of many of those maps.

Four different types of maps are shown here: photomosaics, airbrush maps, radar mosaics, and brightness maps. Each is derived differently, and for different reasons. The *photomosaics* are compilations of "electronic photographs" obtained by spacecraft instruments that record visible or near-visible wavelength sunlight reflected from the planetary bodies. Photomosaics are used here for Earth, Mars, Titan, Rhea, Io, Triton, and all of the small irregular bodies (with the exceptions of Phobos, Deimos, and comet Halley, which are illustrated by airbrush maps).

Factors such as spacecraft trajectory, instrument problems, and lighting conditions often prevent consistent coverage, resolution, or other constant viewing conditions that are best for map making. *Airbrush maps* are a means of creating a view of the terrain with as many of these inconsistencies removed as possible. To make such a map, an airbrush artist looks at information from many different images and other data sources to draw a more consistent view of the surface, that is, one that is free of mosaic lines, atmospheric effects, image artifacts, and a variety of lighting or viewing conditions. (Airbrushers, however, cannot correct for missing data or create a globally consistent portrayal of detail where such detail was not obtained by the spacecraft.)

For cloud-covered bodies such as Venus or Titan, visible-light imaging of the surfaces is not possible, so a technique called *radar imaging* can be used. This technique involves an electronic "camera" with a "flash" that emits radar waves that penetrate the thick clouds and are reflected back from the surface. The map of Venus shown here is a radar image mosaic compiled from images obtained by the Magellan spacecraft in 1991-1992. Titan has not yet been visited by a spacecraft with an imaging radar system, so we have only photomosaics of its thick orange cloud cover. Radar images, incidentally, can look very different from visible-light images: because radar waves are so much longer than visible-light waves, they are more affected by the roughness of the reflecting surface at centimeter and larger scales than by molecular-scale characteristics (as is the case with visible-light reflections).

Pluto and its satellite, Charon, have not yet been visited by spacecraft, so another special technique was used to obtain information about their surface patterns: only twice in their 248-year orbit around the Sun does Charon's 6.4-day orbit around Pluto cause it to pass both in front of and behind Pluto as seen from Earth. One of these two periods lasted from 1984 to 1990 (beginning, luckily, only 6 years after Charon's discovery). Using telescopes on Earth, astronomers measured the changes in the combined *brightness* of the two objects as they eclipsed each other, thereby determining the brightness of the area hidden by the other body at a given time. Several years of observations—combined with a clever application of mathematics—made possible the images of Pluto and Charon shown here (Buie and others, 1992).

Constants of the Jovian system*

BODY	MEAN RADIUS (km)[a]	MASS (Earth=1)[b]	DENSITY (g/cm³)	GRAVITY (Earth=1)	ORBIT PERIOD (Earth days)[c,d]	ROTATION PERIOD (Earth days)[d]	SEMIMAJOR AXIS OF ORBIT (km)	ECCEN-TRICITY OF ORBIT
JUPITER	**69911[e]**	**317.8**	**1.31**	**2.34**	**11.86 y**	**0.414**	**5.2 au[f]**	**0.004**
Metis	20	?	?	?	0.294	0.30	128,200	(0)
Adrastea	8x13	?	?	?	0.297	0.29	128,500	(0)
Amalthea	**67x131**	**?**	**?**	**?**	**0.498**	**0.498**	**181,300**	**0.003**
Thebe	45x55	?	?	?	0.675	0.675	222,000	0.015
Io	**1830**	**0.0149**	**3.55**	**0.138**	**1.769**	**1.769**	**422,600**	**0.004**
Europa	**1565**	**0.0081**	**3.04**	**0.135**	**3.551**	**3.551**	**670,900**	**0.009**
Ganymede	**2634**	**0.0175**	**1.93**	**0.145**	**7.155**	**7.155**	**1,070,000**	**0.002**
Callisto	**3404**	**0.0179**	**1.81**	**0.124**	**16.689**	**16.689**	**1,883,000**	**0.007**
Leda	5	?	?	?	240	240	11,094,000	0.148
Himalia	(85)	?	?	?	250.6	250.6	11,480,000	0.158
Lysithea	12	?	?	?	260	260	11,720,000	0.107
Elara	(40)	?	?	?	260.1	260.1	11,737,000	0.207
Ananke	10	?	?	?	617 R	617 R	21,200,000	0.169
Carme	15	?	?	?	692 R	692 R	22,600,000	0.207
Pasiphae	18	?	?	?	732 R	732 R	23,500,000	0.378
Sinope	14	?	?	?	758 R	758 R	23,700,000	0.275

*See "notes on tables," below, for explanation of annotations.

NOTES ON TABLES

a Polar and sub-primary equatorial radii are given for irregularly shaped bodies whose root-mean-square deviation from an ellipsoid is known to be greater than 1%
b Earth's mass=5.98×10^{24} kg
c Period is in Earth years where noted by a "y"
d R=retrograde
e Radius given for gaseous bodies corresponds to a 1-bar surface
f au=astronomical units (1 au=149,599,000 kilometers)
?=meaningful value cannot be determined from available data

Additional notes:
- Bold type indicates bodies portrayed on this sheet.
- Parentheses are used to indicate values with measurement error greater than 10%.

DATA SOURCES

Most of the airbrush portrayals of bodies on this sheet are derived from airbrush maps previously published by the U.S. Geological Survey at much larger scales. These earlier maps can be referred to for more information about sources of original data. A comprehensive index of published planetary maps, including other sources, is given by Inge and Batson (1992). The views of Earth are composed of NOAA weather satellite images mosaicked by the Geosphere Project*. The airbrush rendering of comet Halley's nucleus is based on images returned by the European Space Agency's Giotto spacecraft.

Although names for only one or two of the more conspicuous features are given on each view on this map sheet, more than 4,900 names have been assigned to geographic features on the planets other than Earth and their satellites (Masursky and others, 1986).

The planetary data tables are based on the most recent authoritative sources available (Anderson and others, 1987; Davies and others, 1992; Tholen and Buie, 1990; U.S. Naval Observatory and Royal Greenwich Observatory, 1992).

ACKNOWLEDGMENTS

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SELECTED BIBLIOGRAPHY

Suggested Reading

Alpha, Tau Rho, and Snyder, J. P., 1982, The properties and uses of selected map projections: U.S. Geological Survey Miscellaneous Investigations Series Map I-1402.

Greeley, Ronald, and Batson, R. M., 1990, Planetary mapping: Cambridge, England, Cambridge University Press, 296 p.

U.S. Geological Survey, 1991, Planetary maps: Maps to help you find your way around on the Moon and Mars and on some of Earth's neighboring planets and their satellites: U.S. Geological Survey brochure. Available on request from any U.S. Geological Survey Earth Science Information Center or by calling 1-800-USA-MAPS (1-800-872-6277).

Data Sources

Anderson, J.D., Campbell, J.K., Jacobson, R.A., Sweetnam, D.N., Taylor, A.H., Prentice, A.J.R., and Tyler, G.L., 1987, Radio science with Voyager 2 at Uranus: Results on masses and densities of the planet and five principal satellites: Journal of Geophysical Research, v. 92, p. 14,877-14,883.

Buie, M.W., Tholen, D.J., and Horne, Keith, 1992, Albedo maps of Pluto and Charon: Initial mutual event results: Icarus, v. 97, p. 211-227.

Davies, M.E., and eight others, 1992, Report of the IAU/IAG/COSPAR Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites: 1991: Celestial Mechanics and Dynamical Astronomy, v. 53, p. 377-397.

Inge, J.L., and Batson, R.M., 1992, Indexes of maps of the planets: National Aeronautics and Space Administration Technical Memorandum 4395, 180 p.

Masursky, Harold, and nine others, 1986, Annual gazetteer of planetary nomenclature: U.S. Geological Survey Open-File Report 84-692 [variously paged].

Tholen, D.J., and Buie, M.W., 1990, Further analysis of Pluto-Charon mutual event observations—1990 [abs.]: Bulletin of the American Astronomical Society, v. 22, no. 3, p. 1129.

U.S. Naval Observatory and Royal Greenwich Observatory, 1992, The astronomical almanac for the year 1993: Issued jointly by the Nautical Almanac Office, Washington, D.C., U.S. Government Printing Office, and Her Majesty's Almanac Office, London, Her Majesty's Stationery Office [variously paged].

Prepared on behalf of the Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration, under contract W-18,271.

Constants of the inner planets and minor bodies*

BODY	MEAN RADIUS (km)[a]	MASS (Earth=1)[b]	DENSITY (g/cm³)	GRAVITY (Earth=1)[c]	ORBIT PERIOD (Earth days)[c,d]	ROTATION PERIOD (Earth days)[d]	SEMIMAJOR AXIS OF ORBIT	ECCEN-TRICITY OF ORBIT
Mercury	**2439.7**	**0.055**	**5.43**	**0.376**	**87.97**	**58.65**	**0.387 au[f]**	**0.206**
Venus	**6051.9**	**0.814**	**5.24**	**0.903**	**224.7**	**243.0 R**	**0.723 au**	**0.007**
Earth	**6371.0**	**1.000**	**5.52**	**1.000**	**365.26**	**1.00**	**1.000 au**	**0.017**
Moon	**1737.4**	**0.012**	**3.34**	**0.165**	**27.32**	**27.32**	**384,400 km**	**0.055**
Mars	**3388.0**	**0.108**	**3.94**	**0.380**	**686.98**	**1.026**	**1.524 au**	**0.093**
Phobos	**9.2x13.4**	**1.6×10^{-9}**	**1.90**	**0.0007**	**0.319**	**0.319**	**9,378 km**	**0.018**
Deimos	**5.2x7.5**	**3.3×10^{-10}**	**2.10**	**0.0004**	**1.262**	**1.262**	**23,459 km**	**0.002**
Gaspra [1]	**5x5.5x9**	**?**	**?**	**?**	**3.28 y**	**?**	**2.21 au**	**0.173**
Toutatis[1]	**(4x6.5)**	**?**	**?**	**?**	**~4.0 y**	**?**	**chaotic**	**chaotic**
Ida[1]	**(11x26)**	**?**	**?**	**?**	**4.84 y**	**?**	**2.86 au**	**0.042**
Halley [2]	**(4x8)**	**?**	**?**	**?**	**76.6 y**	**?**	**17.8 au**	**0.967**

1 Asteroid
2 Comet
*See "notes on tables" following constants of the Jovian system for explanation of annotations.

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