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# The Voyager Mission: Encounters With Saturn

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The following reports summarize a number of post-Jupiter aspects of the first phase of the Voyager Mission, a major element in NASA's program of exploration of the outer planets. The objectives of this phase included comparative studies of the Jovian and Saturnian systems and studies of the interplanetary medium at increasing distances from the sun. Scientific reports on the mission through the Jupiter encounters may be found in the *Journal of Geophysical Research* (*86*, 8123–8841, 1981). With the completion of the mission through Saturn and with both spacecraft continuing to function well, a second mission phase was added with the objectives of exploring Uranus and investigating the interplanetary medium to beyond 20 AU. The Uranus flyby has been chosen so that a third phase can include the exploration of Neptune and extend the investigation of the interplanetary medium to distances beyond 40 AU and at distances of more than 20 AU above the ecliptic.

Because even during the first mission phase the round trip light time of ~3 hours delayed earth-based reaction to anomalies and restricted real time control of the instruments, the Voyager spacecraft incorporates a number of features that permit autonomous correction for hardware failures and onboard control and execution of complex sequences [*Draper et al.*, 1975]. One computer provides software control of spacecraft attitude and pointing of the scan platform. A second computer controls the scientific instruments and compresses and formats the data for a variety of telemetry modes, while a third computer controls the sequence of scientific and engineering activities.

Among the other important attributes of the spacecraft design is three-axis stabilization, providing long exposure times for imaging of low-contrast objects and long integration times for high-resolution spectrometry. An $X$ band transmitter permitted the return of 44.8 kbit/s from Saturn, and with an $S$ band transmitter, provided dual frequency occultation studies of Saturn's rings and of the atmospheres of Saturn and Titan. The spacecraft is powered by radioisotope thermoelectric generators providing ~400 W of electrical power. An outline of the spacecraft is shown in Figure 1.

In order to address the wide range of scientific objectives of the mission, NASA selected the eleven scientific investigations listed in Table 1. The locations of the instruments are shown in Figure 1, with their nominal characteristics indicated in Table 2. Five of the instruments (the narrow and wide angle cameras, the infrared and ultraviolet spectrometers, and the photopolarimeter) are mounted on the articulated scan platform and are boresighted. More detailed descriptions of the investigations can be found in *Space Science Reviews* (*21*, 75–376, 1977), as can a detailed description of the mission design and the selection of the trajectories at Jupiter and Saturn.



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Voyager 2 was launched from Cape Canaveral, Florida, on August 20, 1977, followed by the launch of Voyager 1 on September 5, 1977. Since Voyager 1 was on a faster trajectory, it encountered Jupiter on March 5, 1979, about four months ahead of Voyager 2, which encountered Jupiter on July 9, 1979. Using the gravity assist of the Jovian flybys, Voyager 1 and Voyager 2 continued their journeys toward Saturn as shown in Figure 2. Voyager 1 swung by Saturn on November 12, 1980, heading up out of the plane of the ecliptic. Voyager 2 followed nine months later, swinging by on August 26, 1981, heading toward an encounter with Uranus in January 1986.

The trajectories of Voyager 1 and Voyager 2 through the Saturnian system were chosen to provide complementary observations. The Voyager 1 trajectory provided a close encounter with Titan, permitting atmospheric occultations, a search for an intrinsic Titanian magnetic field, and studies of the interaction of Titan with either the solar wind or the Saturnian magnetosphere (see Figures 3 and 4). The trajectory was also designed to provide an optimum geometry for the transmission of $S$ and $X$ band radio waves from the spacecraft through the rings, so that the attenuation and scattering of 3.6- and 13-cm waves by the ring particles could be observed. In addition, Voyager 1 provided radio and ultraviolet occultation studies of Saturn's atmosphere as well as close ap-

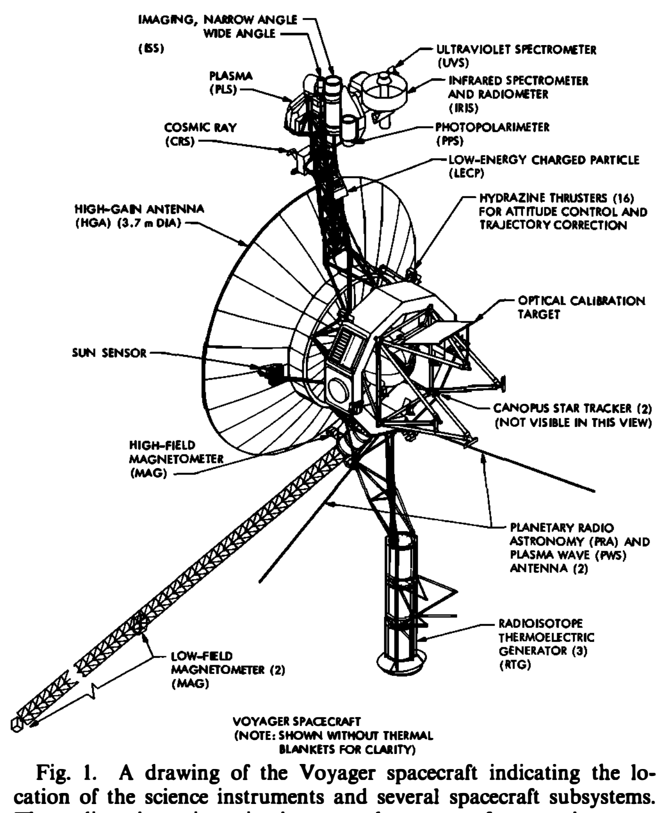


Fig. 1. A drawing of the Voyager spacecraft indicating the location of the science instruments and several spacecraft subsystems. The radio science investigation uses the spacecraft transmitters, an ultrastable oscillator, and the 3.7-m high gain antenna.

TABLE 1. Voyager Science Investigations

| Investigation Team | Principal Investigator/Institution |
|---|---|
| Imaging science (ISS) | Smith/Univ. of Arizona (Team Leader) |
| Infared spectroscopy and radiometry (IRIS) | Hanel/GSFC |
| Photopolarimetry (PPS) | Lane/JPL |
| Ultraviolet spectroscopy (UVS) | Broadfoot/Univ. of Southern Calif. |
| Radio science (RSS) | Tyler/Stanford Univ. (Team Leader) |
| Magnetic fields (MAG) | Ness/GSFC |
| Plasma (PLS) | Bridge/MIT |
| Plasma wave (PWS) | Scarf/TRW |
| Planetary radio astronomy (PRA) | Warwick/Radiophysics, Inc. |
| Low energy charged particles (LECP) | Krimigis/JHU/APL |
| Cosmic rays (CRS) | Vogt/Caltech |

proaches to three of the moderate-sized icy satellites (Mimas, Dione, and Rhea) and to a number of minor satellites.

The much later arrival of Voyager 2 and the Saturn flyby distance were chosen to permit a gravity-assisted continuation on to Uranus and Neptune. However, the exact time of arrival was chosen to provide close approaches to Enceladus and Tethys and closer observations of Hyperion, Iapetus, and Phoebe than achieved by Voyager 1. The Voyager 2 trajectory also provided closer viewing of the sunlit side of Saturn's rings and permitted measurements in a different region of Saturn's magnetosphere than did Voyager 1. An overview of the Voyager 2 trajectory through the Saturn system is shown in Figures 5 and 6. Table 3 summarizes selected encounter parameters for both spacecraft.

TABLE 2. Typical Instrument Characteristics

| Investigation | Nominal Characteristics |
|---|---|
| ISS | Two Se-S vidicon cameras ($f$ = 1500 mm and $f$ = 200 mm); Narrow angle camera; 19 μrad/line pair, 2900–6400 Å. |
| IRIS | Michelson interferometer (3.3–50 μm) and radiometer (0.33–2 μm); 51 cm telescope; 0/25° FOV. |
| PPS | Photomultiplier with 15-cm telescope; 2630–7500 Å; 3.5°, 1°, 1/4°, 1/10° FOV; 2 linear polarizer. |
| UVS | Grating spectrometer; 500–1700 Å with 10-Å resolution; airglow (1° × 0.1° FOV) and occultation (1° × 0.3° FOV). |
| RSS | S band (2.3 GHz) and X band (8.4 GHz); ultra stable oscillator ($<4 \times 10^{-12}$ short-term drift). |
| MAG | Two low-field ($<10^{-6}$ – 0.5 G) and two high-field ($5 \times 10^{-4}$ – 20 G) magnetometers; 13-m boom; 0–16.7 Hz. |
| PLS | Earth-pointing sensor (10-eV to 6-keV ions) and lateral sensor (10-eV to 6-keV ions, 4-eV to 6-keV electrons). |
| PWS | Sixteen channels (10 Hz–56.2 kHz); waveform analyzer (150 Hz–10 kHz); share PRA antennas. |
| PRA | Stepping receiver (1.2 kHz and 20.4 kHz–40.5 MHz); right and left circular polarization; orthogonal 10 m monopole antennas. |
| LECP | Two solid-state detector systems on rotating platform; 10 keV–10 MeV electrons; 10 keV/nucleon–150 MeV/nucleon ions. |
| CRS | Multiple solid-state detector telescopes; 3–110 MeV electrons; ~1–500 MeV/nucleon nuclei; three-dimensional anisotropies. |

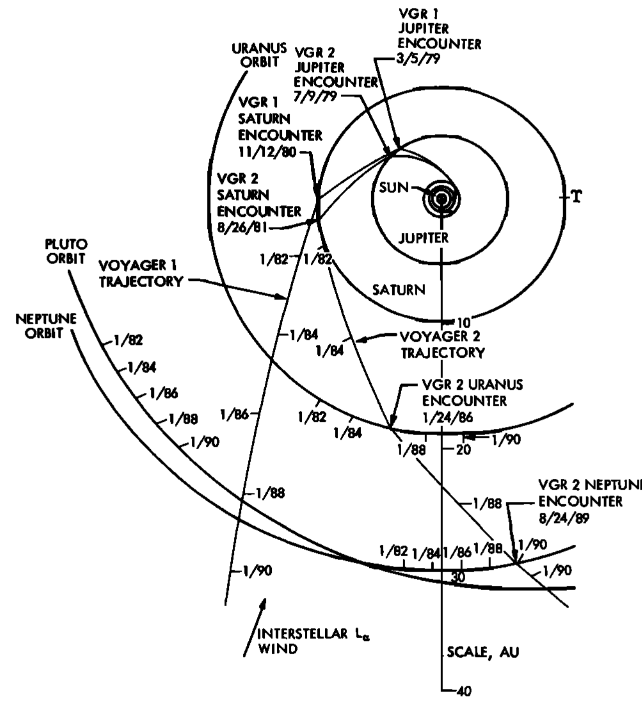


Fig. 2. A view normal to the ecliptic plane of the Voyager 1 and 2 trajectories.

The eleven science teams undertook a wide range of studies of the Saturnian system, including studies of the planet, the rings, the satellites, the magnetosphere, and the interplanetary medium between Jupiter and Saturn. Planning for these studies benefited significantly from continuing earth-based studies and from the Pioneer 11 flyby studies as reported in *Science* (*207*, 400–453, 1980) and in the *Journal of Geophysical Re-*

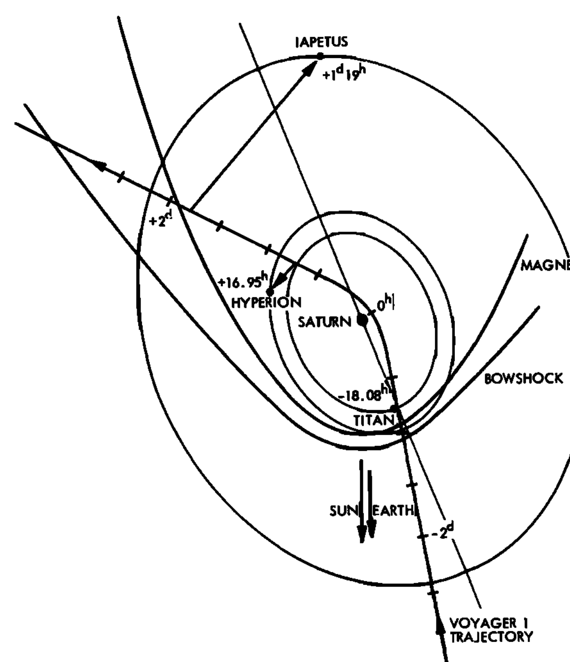


Fig. 3. A view normal to the trajectory plane of the Voyager 2 path through the Saturn system. The projected orbits of three outer satellites are shown with Iapetus orbiting Saturn at a distance of ~59 $R_S$. An arrow connects the location of the spacecraft and each satellite at the time of closest approach to that satellite by Voyager 1. Time ticks along the trajectory indicate 12-hour intervals.

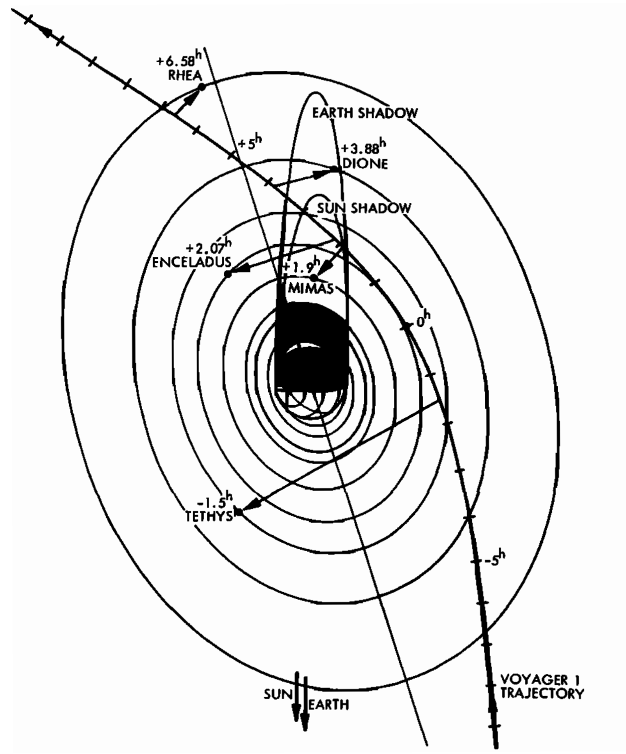


Fig. 4. A view similar to Figure 3 of the Voyager 1 path through the orbits of the inner satellites (Rhea orbits at ~8.7 $R_S$). Time ticks indicate 1-hour intervals.

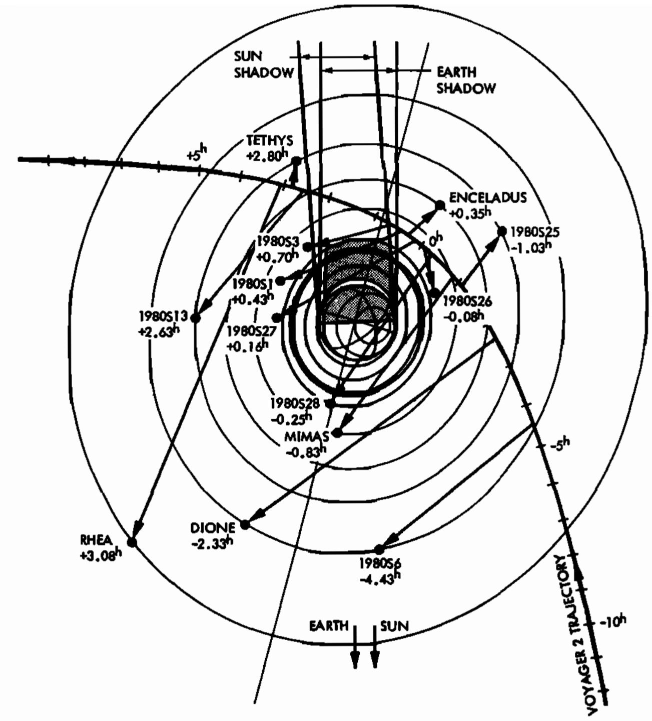


Fig. 6. A view similar to Figure 3 of the Voyager 2 path through the orbits of the inner satellites (Rhea orbits at ~8.7 $R_S$). Time ticks indicate 1-hour intervals.

*search* (*85*, 5651–5956, 1980). The initial reports of the Voyager 1 encounter results were published in *Science* (*212*, 159–243, 1981), and in *Nature* (*292*, 675–755, 1981), followed by the initial Voyager 2 reports in *Science* (*215*, 499–594, 1982). A number of more detailed reports have subsequently appeared, including papers in two special Saturn issues of *Icarus* (*53* 163–387, 1983, and *54*, 160–360, 1983) and a collection of papers on Titan in the *Journal of Geophysical Research* (*87*, 1351–1418, 1982).

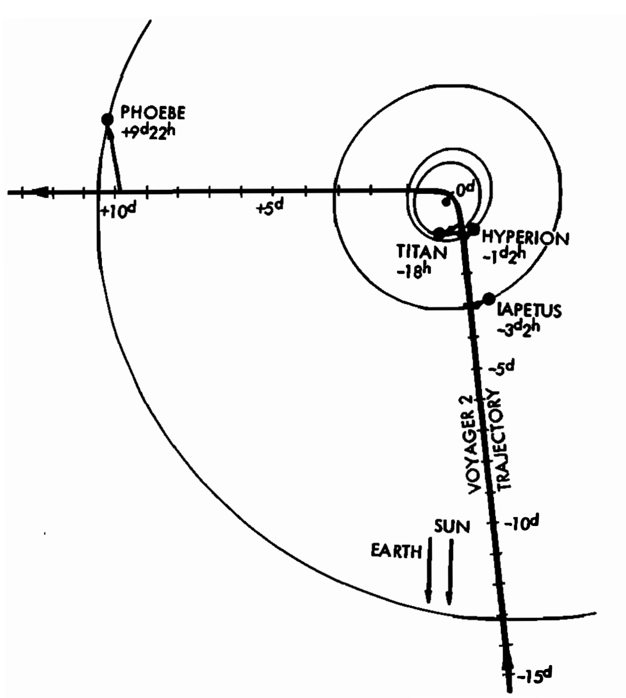


Fig. 5. A view similar to Figure 3 of the Voyager 2 path through the Saturn system. Phoebe orbits at ~215 $R_S$. Time ticks indicate 1-day intervals.

All of the data from the first mission phase will continue to be a significant resource in the detailed studies of the giant planets, their rings, satellites, and magnetospheres, and the intervening interplanetary medium. Both Voyagers, in conjunction with Pioneer 10 and 11 (see, for example, *Northrop et al.*, [1980]), will continue to explore new regions of the heliosphere, with the possibility of eventually observing the heliospheric boundary. In 1990, Voyager 1 will be at 40 AU, traveling outward at ~3.5 AU $yr^{-1}$. Even before reaching the boundary, the spacecraft may detect cosmic rays from nearby

TABLE 3. Selected Voyager Encounter Parameters

| | Distance, km | | |
|---|---|---|---|
| Satellite | Voyager 1 | Voyager 2 | Saturn* |
| Atlas | 219,000 | 287,000 | 137,670 |
| 1980S27 | 300,000 | 247,000 | 139,350 |
| 1980S26 | 270,000 | 107,000 | 141,700 |
| Epimetheus | 121,000 | 147,000 | 151,422 |
| Janus | 297,000 | 223,000 | 151,472 |
| Mimas | 88,440 | 309,930 | 185,540 |
| Enceladus | 202,040 | 87,010 | 238,040 |
| Tethys | 415,670 | 93,010 | 294,670 |
| 1980S6 | 230,000 | 270,000 | 378,060 |
| Dione | 161,520 | 502,310 | 377,420 |
| Rhea | 73,980 | 645,260 | 527,100 |
| Titan | 6,490 | 666,190 | 1,221,860 |
| Hyperion | 880,440 | 471,370 | 1,481,000 |
| Iapetus | 2,470,000 | 908,680 | 3,560,800 |
| Phoebe | 13,500,000 | 2,075,640 | 12,954,000 |

*Distance to center of planet. Saturn's equatorial radius is 60,330 km.

regions of our galaxy, which are of such low energy that the radially streaming solar wind limits their penetration to the outer fringes of the heliosphere.

During this same period, Voyager 2 will be encountering Uranus and Neptune about which much less is known than was known about Jupiter and Saturn prior to the Voyager encounters. Thus further discoveries await the continuing exploration of the outer solar system.

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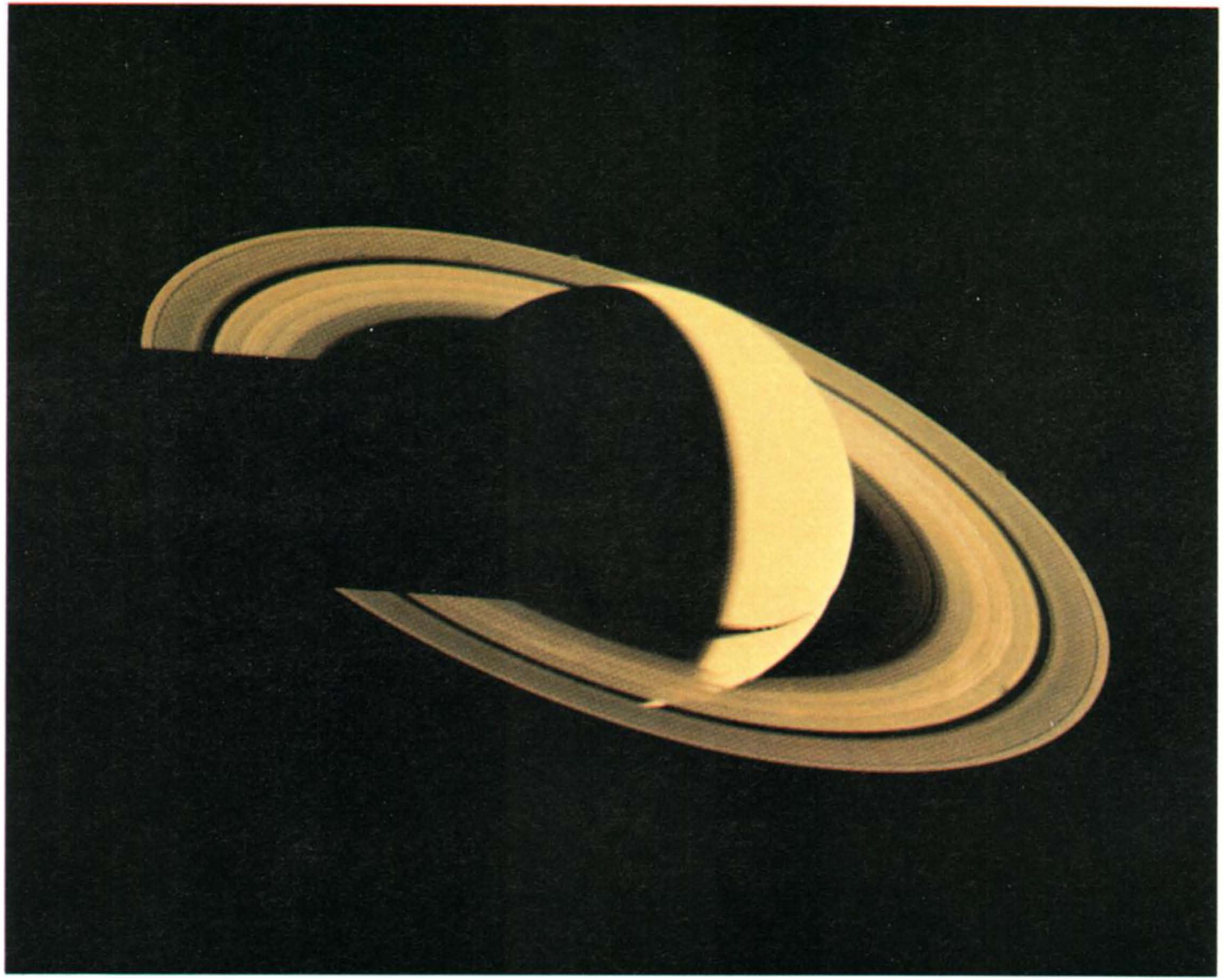

Voyager 1 looked back at Saturn on November 16, 1980, four days after the spacecraft flew past the planet, to observe the appearance of Saturn and its rings from this unique perspective. A few of the spokelike ring features discovered by Voyager appear in the rings as bright patches in this image, taken at a distance of 5.3 million kilometers (3.3 million miles) from the planet. Saturn's shadow falls upon the rings, and the bright Saturn crescent is seen through all but the densest portion of the rings. From Saturn, Voyager 1 is on a trajectory taking the spacecraft out of the ecliptic plane, away from the sun, and eventually out of the solar system (by about 1990). Although its mission to Jupiter and Saturn is over (the Saturn encounter ended December 18, 1980), Voyager 1 will be tracked by the Deep Space Network as far as possible in an effort to determine where the influence of the sun ends and interstellar space begins. Voyager 1's flight path through interstellar space is in the direction of the constellation Ophiuchus. Voyager 2 reached Saturn on August 25, 1981, and is targeted to encounter Uranus in 1986 and possibly Neptune in 1989. The Voyager Project is managed for NASA by the Jet Propulsion Laboratory, Pasadena, California.