Reports

Pioneer Saturn

Abstract. *After leaving the neighborhood of Jupiter in December 1974, the Pioneer 11 spacecraft headed toward Saturn; it encountered Saturn on 1 September 1979. Its trajectory and general features are described in this report.*

On 1 September 1979, the Pioneer Saturn spacecraft provided man's first close exploration of Saturn. Called Pioneer 11 from its April 1973 launch until its encounter with Jupiter (*1*), the space probe discovered and penetrated the magnetosphere of Saturn. Its trajectory brought the spacecraft to 21,000 km from the planet's clouds and only 2,000 to 10,000 km below the visible rings. Pioneer's instruments defined the planet's magnetic field, the characteristics of its trapped radiation belts, and the magnetic field and charged particle interactions with the solar wind and ring material. All 11 of the spacecraft's instruments that had been operational at Jupiter continued to perform as well at Saturn. The asteroid-meteoroid detector had been turned off before Jupiter encounter because of an electrical malfunction.

The 550-pound Pioneer Saturn spacecraft is spin-stabilized at 7.8 rev/min, and its 8-foot-diameter parabolic dish antenna is pointed toward Earth by periodic precession maneuvers. Eight watts of radiated radio-frequency power communicated data at a rate of 512 binary bits per second to the Deep Space Network (DSN) from the environment of Saturn. Four radioisotope thermoelectric generators, after 6½ years of continuing service, provided 117 watts of electrical power. The spacecraft is shown and its scientific instruments and some major components are identified in Fig. 1.

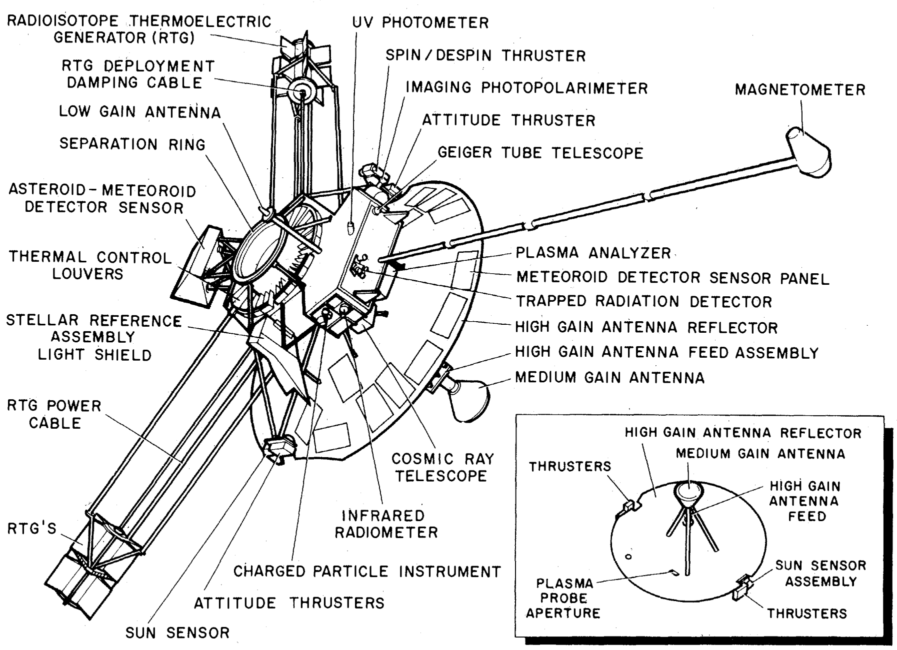
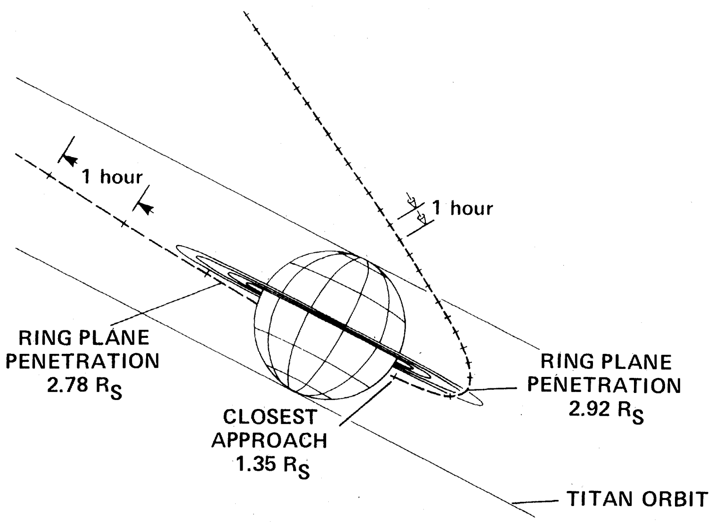


Fig. 1. The Pioneer Saturn spacecraft.

The original objectives of the Pioneer 10–Pioneer 11 program had mostly been achieved by the time Pioneer 11 reached Jupiter. Specifically, the safety of flight through the asteroid belt had been proved by both spacecraft, Jupiter's radiation environment had been measured and mapped, and Pioneer 10 had been accelerated to escape the solar system carrying instruments to observe the far solar and cosmic environments. The practicality of extending this flight to Saturn was first proved in 1972, after the launch of Pioneer 10. An interim target at Jupiter was therefore selected for Pioneer 11 to conserve its propellant pending Pioneer 10's first exploration of Jupi-



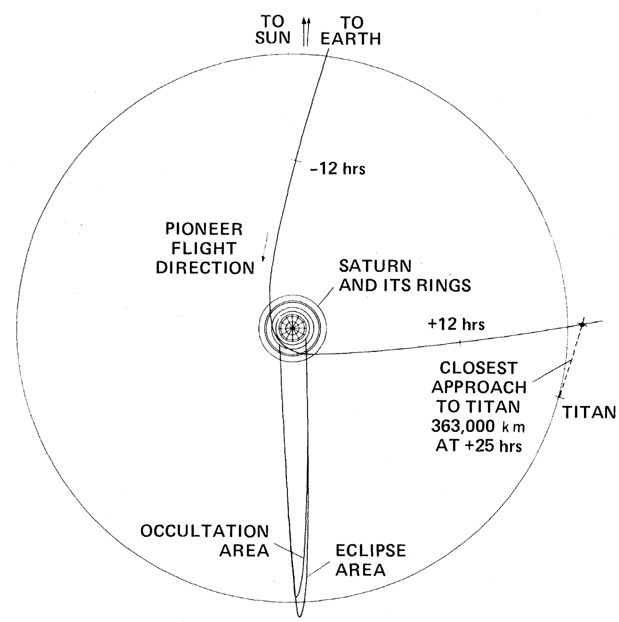


Fig. 2 (left). Pioneer Saturn encounter trajectory as viewed from Earth. The spacecraft crosses the ring plane in the foreground and curves leftward behind the planet. Fig. 3 (right). Pioneer Saturn encounter trajectory projected into Saturn's equatorial plane.

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ter. Commitment to a Saturn-bound trajectory was withheld until the complete success of Pioneer 10 eliminated the need for a repetition of the first flyby.

Pioneer 11 spiraled tightly around Jupiter, approaching from the south in front of Jupiter's orbital path and departing northward and back toward the sun. The trajectory across the solar system was inclined 15° above the ecliptic plane, with perihelion at 3.5 astronomical units.

The error projected at Saturn was about 2 million kilometers, little more than the predicted probable error. Time of projected arrival at Saturn was 3 September 1979, only 8 days before superior conjunction with Earth. The adjustment of the time of arrival to 1 September was designed to avoid solar interference at encounter as much as the available propellant would allow. The largest maneuvers, totaling 47 m/sec, were executed near perihelion in December 1975 and May 1976. The final maneuver to the target was completed in July 1978. The exact time of flyby was chosen to center the DSN's largest overlapping view, between the Canberra and Madrid Deep Space Stations, on Saturn.

Options for the spacecraft to fly by Saturn either inside or outside the visible rings were retained until late 1977. The outside was chosen because the expected scientific return at Saturn would be close to the optimum, the survival probability was very much greater, and penetration of the ring plane at the same radius necessary for the hoped-for continuation of Voyager 2 to Uranus could be directly tested. Pioneer Saturn penetrated Saturn's equatorial plane inbound at 2.82 Saturn radii (R_S) and outbound at 2.78 R_S without observable incident (Fig. 2).

Descent from above the ecliptic plane toward Saturn late in the morning quadrant gave Pioneer a view of the dark side of the rings. The approach asymptote was 6° above, while sunlight came from 2° below, the plane of the rings. Studies of the magnetosphere and its interaction with the solar wind, mapping of infrared radiation, and analyses of the radio signal for gravitational and atmospheric effects were well served by the chosen trajectory (Fig. 3). Only the ultraviolet radiometer was not in a position to observe Saturn satisfactorily, from a safe distance outside the anticipated trapped radiation. Therefore, to gather data in the ultraviolet, the spacecraft's spin axis was maneuvered as far as practical ($1^1/_4$°) away from Earth pointing for days 15 through 11 before encounter, and its data rate was temporarily reduced.

Solar noise became an important constraint at Saturn encounter. Plans to gather data for a few hours at 1024 bits per second from two of the tracking stations at their highest elevations had to be abandoned. Rapid reductions below 512 bits per second were forced by solar noise, beginning only 2 days after encounter.

The spacecraft departed from Saturn only slightly above the ring plane, and nearly along the morning terminator where polarimetry could be performed at a large solar phase angle. Titan's orbit was crossed 25 hours after Saturn flyby, affording a distant exposure (363,000 km) to the three remote sensing instruments.

Pioneer 11 became the second spacecraft to escape the solar system on its swing past Saturn. Departure asymptote from the sun is 251° celestial longitude and 12.6° above the ecliptic plane. Near the direction of the solar apex (that is, the direction of the sun's motion relative to its galactic neighbors), Pioneer 11's departure is roughly opposite Pioneer 10's trajectory.

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References

1. *Science* **183**, 301 (1974); *ibid.* **188**, 445 (1975).

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Scientific Results from the Pioneer Saturn Encounter: Summary

Abstract. *An overview of the Pioneer encounter with Saturn is presented, including a brief discussion of the characteristics of the planet and a summary of the scientific results, which are described in detail in the following reports.*

The objective of the Pioneer encounter with Saturn was to image the planet, its rings, and its satellites; to measure its particulate environment; and to measure the magnetic field and the photon and charged particle radiation associated with the Saturn system. Eleven operating scientific instruments were carried on Pioneer to meet these objectives. In addition, the 2.293-GHz telemetry carrier signal was used to study variations in the gravitational field of the Saturn system to better understand the distribution of matter in and around Saturn, and to understand the atmosphere and ionosphere by means of radio occultation

Table 1. Pioneer Saturn scientific instruments.

Instrument	Principal investigator	Experiment objective
Helium vector magnetometer	E. J. Smith, Jet Propulsion Laboratory	Magnetic fields
Fluxgate magnetometer	M. H. Acuna, Goddard Space Flight Center	Magnetic fields
Plasma analyzer	J. H. Wolfe, Ames Research Center	Solar plasma
Charged particle	J. A. Simpson, University of Chicago	Charged particle composition
Cosmic-ray telescope	F. B. McDonald, Goddard Space Flight Center	Cosmic-ray energy spectra
Geiger tube telescope	J. A. Van Allen, University of Iowa	Charged particles
Trapped radiation detector	W. Fillius, University of California, San Diego	Trapped radiation
Asteroid-meteoroid detector*	R. K. Soberman General Electric Co. and Drexel University	Asteroid-meteoroid astronomy
Meteoroid detector	W. H. Kinard Langley Research Center	Meteoroid detection
Radio transmitter and Deep Space Network	J. D. Anderson, Jet Propulsion Laboratory	Celestial mechanics
Ultraviolet photometer	D. L. Judge, University of Southern California, Los Angeles	Ultraviolet photometry
Imaging photopolarimeter	T. Gehrels, University of Arizona, Tucson	Photo imaging and polarimetry
Infrared radiometer	A. P. Ingersoll California Institute of Technology	Infrared thermal structure
Radio transmitter and Deep Space Network	A. J. Kliore, Jet Propulsion Laboratory	S-band occultation

*Not currently operational.