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The Voyager 2 Encounter With Uranus

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The Voyager Uranus/Interstellar Mission is the continuation of the NASA program of exploration of the outer solar system. The first phase of the Voyager program included encounters with Jupiter and Saturn as summarized in the *Journal of Geophysical Research* (volume 86, pages 8123–8841, 1981, and volume 88, pages 8639–9018, 1983). With the successful completion of this first phase a second phase was undertaken with the objectives of exploring the Uranus system and investigating the interplanetary and interstellar media. Additional objectives included preserving the capability for extending the investigations to include an encounter with the Neptune system and a search for the heliopause. Summaries of results from the Uranus encounter are reported in the following papers.

All 11 scientific investigations listed in Table 1 made significant contributions to the exploration of Uranus. The characteristics of the corresponding instruments are summarized in Table 2, with more details available in *Space Science Reviews* (volume 21, pages 75–376, 1977). The five remote sensing instruments (the narrow and wide angle vidicon cameras, the infrared and ultraviolet spectrometers, and the photopolarimeter) are boresighted and mounted on a scan platform having two axes of articulation. The locations of the instruments on the spacecraft are shown in Figure 1.

Although the Voyager spacecraft were designed for 4-year missions to Jupiter and Saturn, the hardware proved to be quite robust, with both spacecraft nearly completely functional 10 years after launch. In addition, the spacecraft were designed for autonomous operation, with onboard computers controlling the attitude of the spacecraft, the pointing of the scan platform, the sequence of scientific and engineering events, the data formats and telemetry rates, and the operation of the scientific instruments [*Draper et al.*, 1975]. As a result, it was possible to optimize the operation of the spacecraft and instruments for lower light levels and greater communications distances at Uranus (see, for example, *Stone and Miner* [1986]). For example, partial compensation for the reduced telemetry rate was achieved by using a backup computer to compress the images so that on the average only three rather than eight bits per pixel were transmitted. The data return was further improved by electronically arraying several receiving antennas, including the 64-m Parkes radio telescope in Australia. Other changes to the spacecraft software made longer exposure times possible by significantly reducing the limit-cycle motion of the spacecraft and by providing a capability for maneuvering the entire spacecraft to compensate for image motion at closest approach.

The trajectories of the two Voyager spacecraft are shown in Figure 2. Voyager 2 was launched from Cape Canaveral, Florida, on August 20, 1977, followed on September 5, 1977, by Voyager 1, which was on a faster trajectory optimized for a close flyby of Io at Jupiter and of Titan at Saturn. The slower Voyager 2 trajectory was chosen to allow the option of using gravity assist at Saturn to continue on to Uranus and Neptune, although such a trajectory would have precluded a close Titan flyby and radio occultation by Saturn's rings. These and other Saturn objectives were achieved by the successful Voyager 1 encounter on November 12, 1980, and NASA subsequently approved the Uranus aimpoint option for Voyager 2, with a Saturn flyby on August 26, 1981, and a Uranus flyby on January 24, 1986.

The Voyager 2 trajectory at Uranus is shown in Figure 3, with selected encounter distances listed in Table 3. The closest approach distance to Uranus was chosen to allow a gravity-assisted continuation onto an encounter with Neptune. Fortunately, the aimpoint was near Miranda's orbit, permitting a close approach to that satellite with the proper choice of arrival time. Because of the unusual orientation of Uranus' rotational axis, the trajectory also provided for radio occultation studies of the rings. In addition, both radio and ultraviolet occultation studies of Uranus' atmosphere were possible.

The 11 scientific teams undertook a broad range of studies of the planet, the rings, the satellites, and the magnetosphere. Planning for these studies benefited greatly from the Earth-based observations and theoretical analyses which were summarized at a Uranus/Neptune workshop held in Pasadena, California, in February 1984 [*Bergstrahl*, 1984]. The initial reports of the Voyager 2 studies of Uranus, which were published in *Science* (volume 233, pages 1–132, 1986), have been followed by much more detailed studies, many of which are reported in the following papers. Studies of the Uranus data should continue for many years, since the Voyager 2 data are unlikely to be superceded for several decades.

The Voyager program is now in its third phase, the Voyager Neptune/Interstellar Mission. On August 25, 1989, Voyager 2 will encounter Neptune and its satellite Triton, while Voyager 1 will be exploring the interplanetary medium at a distance of ~ 39 AU from the Sun and ~ 20 AU above the ecliptic plane, moving outward at ~ 3.5 AU yr^{-1}. Following the encounter with Neptune the program will enter its fourth phase, the Voyager Interstellar Mission, with both spacecraft searching for the heliopause. If there are no catastrophic failures, they should continue returning data well into the next century from distances beyond 100 AU.

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TABLE 1. Voyager Science Investigations

Investigation Team	Principal Investigator/Institution
Imaging science (ISS)	B. A. Smith/University of Arizona (team leader)
Infrared spectroscopy and radiometry (IRIS)	R. Hanel/Goddard Space Flight Center
Photopolarimetry (PPS)	A. L. Lane/Jet Propulsion Laboratory
Ultraviolet spectroscopy (UVS)	A. L. Broadfoot/University of Arizona
Radio science (RSS)	G. L. Tyler/Stanford University (team leader)
Magnetic fields (MAG)	N. F. Ness/Goddard Space Flight Center
Plasma (PLS)	H. S. Bridge/Massachusetts Institute of Technology
Plasma wave (PWS)	F. L. Scarf/TRW
Planetary radio astronomy (PRA)	J. W. Warwick/Radiophysics, Inc.
Low-energy charged particles (LECP)	S. M. Krimigis/Johns Hopkins University Applied Physics Laboratory
Cosmic rays (CRS)	E. C. Stone/California Institute of Technology

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; two linear polarizers
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 (5×10^{-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 to 56.2 kHz); waveform analyzer (150 Hz to 10 kHz); share PRA antennas
PRA	stepping receiver (1.2 kHz and 20.4 kHz to 40.5 MHz); right and left circular polarization; orthogonal 10-m monopole antennas
LECP	two solid-state detector systems on rotating platform; 10-keV to 10-MeV electrons; 10-keV/nucleon to 150-MeV/nucleon ions
CRS	multiple solid-state detector telescopes; 3- to 110-MeV electrons; ~1- to 500-MeV/nucleon nuclei; three-dimensional anisotropies

TABLE 3. Selected Uranus Encounter Characteristics

Body	Closest Approach,* km
Uranus	107,100
Miranda	29,000
Ariel	127,000
Umbriel	325,000
Titania	365,200
Oberon	470,600

*Distance from center of body.

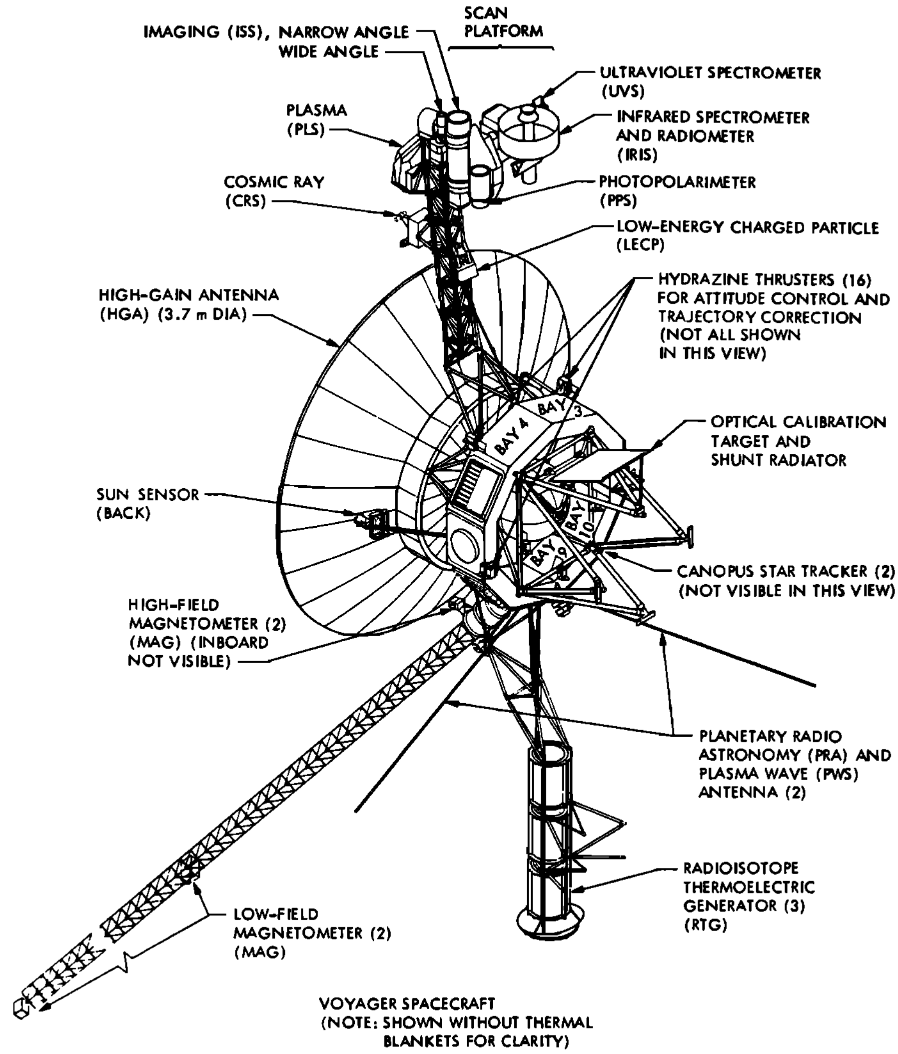

Fig. 1. A drawing of the Voyager spacecraft indicating the location of the science instruments and several spacecraft subsystems. The radio science investigation uses the spacecraft transmitters, an ultrastable oscillator, and the 3.7-m high gain antenna.

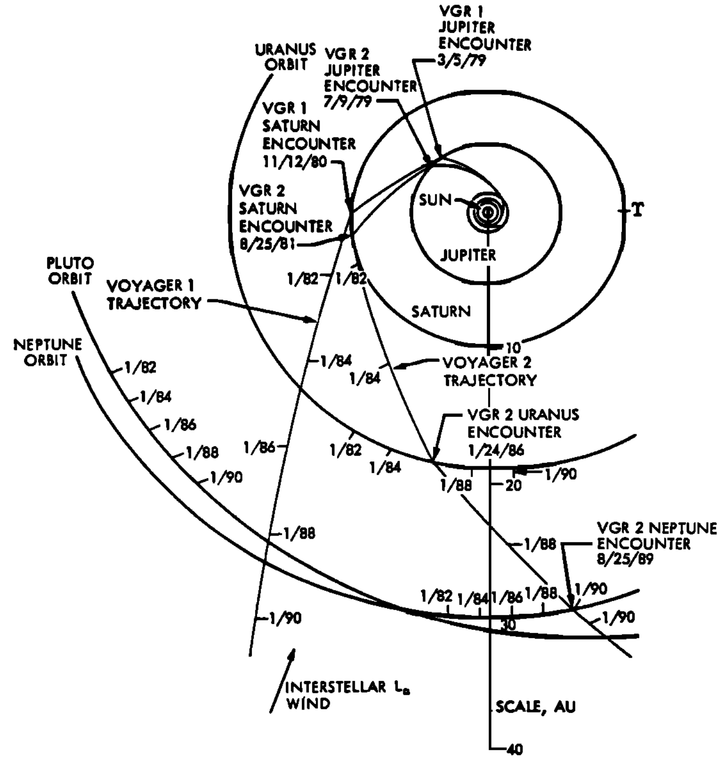

Fig. 2. Voyager 1 and 2 trajectories projected onto the ecliptic plane.

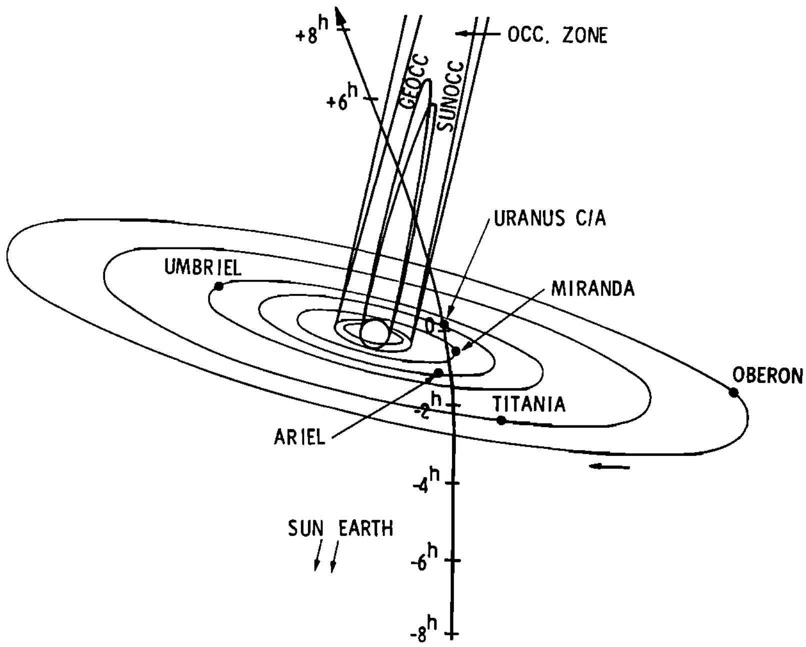

Fig. 3. A view normal to the trajectory plane of the Voyager 2 path through the Uranus system.

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