

# Spacecraft Missions to Saturn

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## Chapter- 1

# Pioneer 11

### Pioneer 11



Pioneer 11 at Saturn (artist's impression)

<b>Operator</b>	ARC / NASA
<b>Major contractors</b>	TRW
<b>Mission type</b>	Flyby
<b>Flyby of</b>	Jupiter, Saturn
<b>Launch date</b>	1973-04-06 02:11:00 UTC (37 years, 10 months, and 18 days ago)
<b>Launch vehicle</b>	Atlas/Centaur/TE364-4
<b>Launch site</b>	Space Launch Complex 36A Cape Canaveral Air Force Station
<b>Mission duration</b>	Apr 6, 1973 - Sep 30, 1995 (22 years, 5 months, 25 days) (lost communication) Jupiter flyby (completed 1975-01-01) Saturn flyby

*(completed 1979-10-05)*

Interstellar mission

*(completed 1995-09-30)*

<b>COSPAR ID</b>	1973-019A
<b>Homepage</b>	Pioneer Project website <sup>(archived)</sup> NASA Archive
<b>Mass</b>	259 kg (571 lb)
<b>Power</b>	165.0 W (4 SNAP-19 RTGs)

*Pioneer 11* (also known as *Pioneer G*) was a 259-kilogram (569 lb) robotic space probe launched by NASA on April 6, 1973 to study the asteroid belt, the environment around Jupiter and Saturn, solar wind, cosmic rays, and eventually the far reaches of the solar system and heliosphere. It was the first probe to encounter Saturn and the second to fly through the asteroid belt and by Jupiter. Due to power constraints and the vast distance of the probe, communication has been lost since November 30, 1995.

## Mission background

### History

Approved in February 1969, *Pioneer 11* and twin probe *Pioneer 10*, were the first to be designed for exploring the outer solar system. Yielding to multiple proposals throughout the 1960s, early mission objectives were defined as:

- Explore the interplanetary medium beyond the orbit of Mars
- Investigate the nature of the asteroid belt from the scientific standpoint and assess the belt's possible hazard to missions to the outer planets.
- Explore the environment of Jupiter.

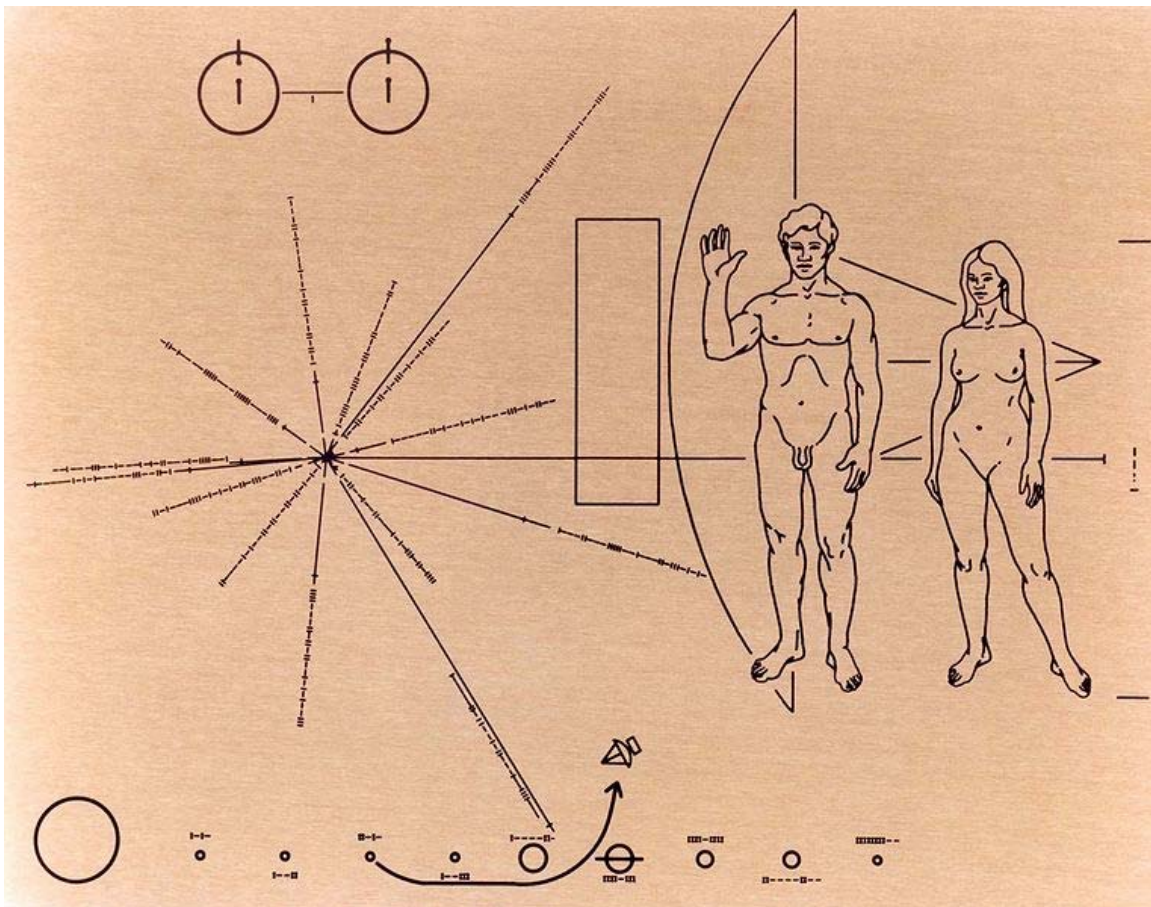
Subsequent planning for an encounter with Saturn added many more goals:

- Map the magnetic field of Saturn and determine its intensity, direction, and structure.
- Determine how many electrons and protons of various energies are distributed along the trajectory of the spacecraft through the Saturn system.
- Map the interaction of the Saturn system with the solar wind.
- Measure the temperature of Saturn's atmosphere and that of Titan, the large satellite of Saturn.
- Determine the structure of the upper atmosphere of Saturn where molecules are expected to be electrically charged and form an ionosphere.

- Map the thermal structure of Saturn's atmosphere by infrared observations coupled with radio occultation data.
- Obtain spin-scan images of the Saturnian system in two colors during the encounter sequence and polarimetry measurements of the planet.
- Probe the ring system and the atmosphere of Saturn with S-band radio waves at occultation.
- Determine more precisely the masses of Saturn and its larger satellites by accurate observations of the effects of their gravitational fields on the motion of the spacecraft.
- As a precursor to the Mariner Jupiter/Saturn mission, verify the environment of the ring plane to find out where it may be safely crossed by the Mariner spacecraft without serious damage.

*Pioneer 11* was built by TRW and managed as part of the Pioneer program by NASA Ames Research Center. A backup unit, Pioneer H, is currently on display in the "Milestones of Flight" exhibit at the National Air and Space Museum in Washington, D.C.. Many elements of the mission proved to be critical in the planning of the Voyager Program<sup>266-8</sup>.

### Pioneer plaque

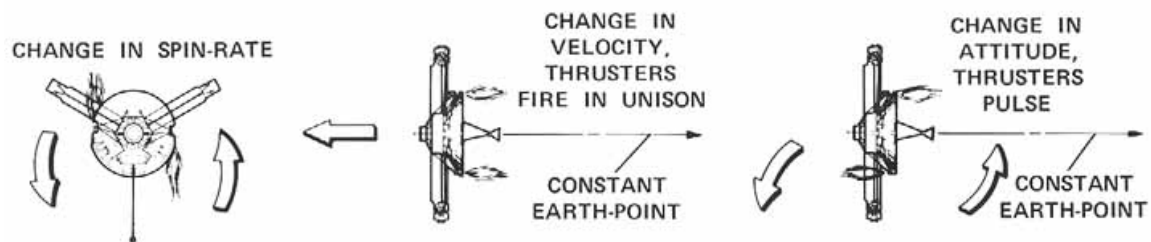


Pioneer 10 and Pioneer 11 carry a gold-anodized aluminium plaque in the event that either spacecraft is ever found by intelligent life-forms from other planetary systems. The plaques feature the nude figures of a human male and female along with several symbols that are designed to provide information about the origin of the spacecraft.

## Spacecraft design

The *Pioneer 11* bus measures 36-centimeters deep and with six 76-centimeters long panels forming the hexagonal structure. The bus houses propellant to control the orientation of the probe and eight of the eleven scientific instruments. The spacecraft had a mass of 260-kilograms.<sup>:42</sup>

## Attitude control and propulsion

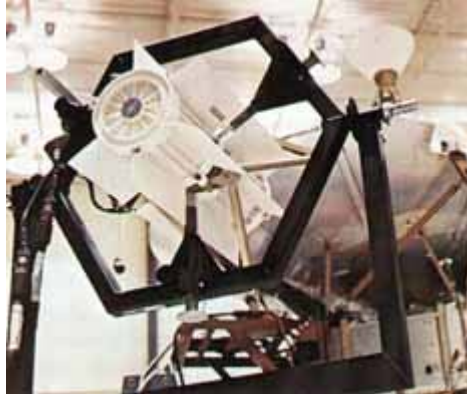


Orientation of the spacecraft was maintained with six 4.5 N, hydrazine monopropellant thrusters: pair one maintained a constant spin-rate of 4.8-rpm, pair two controlled the forward thrust, pair three controlled attitude. Information for the orientation was provided by a star sensor able to reference Canopus, and two sun sensors.<sup>:42-43</sup>

## Communications

The space probe included a redundant system of transceivers, one attached to the high-gain antenna, the other to an omni-antenna and medium-gain antenna. Each transceiver is 8 watts and transmits data across the S-band using 2110 MHz for the uplink from Earth and 2292 MHz for the downlink to Earth with the Deep Space Network tracking the signal. Prior to transmitting data, used a convolutional encoder, a form of error correction, to avoid sending corrupted data.<sup>:43</sup>

## Power



*Pioneer 10* used 4 SNAP-19 radioisotope thermoelectric generators (RTG) (*diagram*). They were positioned on 2 three-rod trusses, each 3 meters (10 feet) in length and 120 degrees apart. This was expected to be a safe distance from the sensitive scientific experiments carried on board. Combined, the RTGs provided 155 watts at launch, and decayed to 140w in transit to Jupiter. The spacecraft required 100w to power all systems.<sup>:44-45</sup>

## Computer

Much of the computation for the mission was performed on Earth and transmitted to the probe, where it was able to retain in memory, up to five commands of the 222 possible entries by ground controllers. The spacecraft included two command decoders and a command distribution unit, a very limited form of processor, to direct operations on the spacecraft. This system required that mission operators prepare commands long in advance of transmitting them to the probe. A data storage unit was included to record up to 6,144-bytes of information gathered by the instruments. The digital telemetry unit would then be used to prepare the collected data in one of the thirteen possible formats before transmitting it back to Earth.<sup>:38</sup>

## Scientific instruments

### Helium Vector Magnetometer (HVM)



Measures the fine structure of the interplanetary magnetic field, maps the Jovian magnetic field, and provides magnetic field measurements to evaluate solar wind interaction with Jupiter.

- **Principal investigator:** Edward Smith / JPL
- **Data:** PDS/PPI data catalog, NSSDC data archive

### Quadrispherical Plasma Analyzer



Peers through a hole in the large dish-shaped antenna to detect particles of the solar wind originating from the Sun.

- **Principal investigator:** Aaron Barnes / NASA Ames Research Center (archived website)
- **Data:** PDS/PPI data catalog, NSSDC data archive

### Charged Particle Instrument (CPI)



Detects cosmic rays in the Solar System.

- **Principal investigator:** John Simpson / University of Chicago
- **Data:** NSSDC data archive

### Cosmic Ray Telescope (CRT)



Collects data on the composition of the cosmic ray particles and their energy ranges.

- **Principal investigator:** Frank McDonald / NASA Goddard Space Flight Center
- **Data:** PDS/PPI data catalog, NSSDC data archive

### Geiger Tube Telescope (GTT)



Surveys the intensities, energy spectra, and angular distributions of electrons and protons along the spacecraft's path through the radiation belts of Jupiter.

- **Principal investigator:** James Van Allen / University of Iowa (website)
- **Data:** PDS/PPI data catalog, NSSDC data archive, NSSDC Jupiter data archive

### Trapped Radiation Detector (TRD)



Includes an *unfocused Cerenkov counter* that detects the light emitted in a particular direction as particles pass through it recording electrons of energy, 0.5 to 12 MeV, an *electron scatter detector* for electrons of energy, 100 to 400 keV, and a *minimum ionizing detector* consisting of a solid-state diode that measures minimum ionizing particles (<3 MeV) and protons in the range of 50 to 350 MeV.

- **Principal investigator:** R. Fillius / University of California San Diego
- **Data:** NSSDC hourly data archive, NSSDC Saturn data archive

### Meteoroid Detectors



Twelve panels of pressurized cell detectors mounted on the back of the main dish antenna record penetrating impacts of small meteoroids.

- **Principal investigator:** William Kinard / NASA Langley Research Center

- **Data:** NSSDC data archive list

### Asteroid/Meteoroid Detector (AMD)



Meteoroid-asteroid detector looks into space with four non-imaging telescopes to track particles ranging from close-by bits of dust to distant large asteroids.

- **Principal investigator:** Robert Soberman / General Electric Company
- **Data:** NSSDC data archive list

### Ultraviolet Photometer



Ultraviolet light is sensed to determine the quantities of hydrogen and helium in space and on Jupiter.

- **Principal investigator:** Darrell Judge / University of Southern California
- **Data:** PDS/PPI data catalog, NSSDC data archive

### Imaging Photopolarimeter (IPP)



The imaging experiment relies upon the spin of the spacecraft to sweep a small telescope across the planet in narrow strips only 0.03 degrees wide, looking at the planet in red and blue light. These strips were then processed to build up a visual image of the planet.

- **Principal investigator:** Tom Gehrels / University of Arizona
- **Data:** NSSDC data archive list

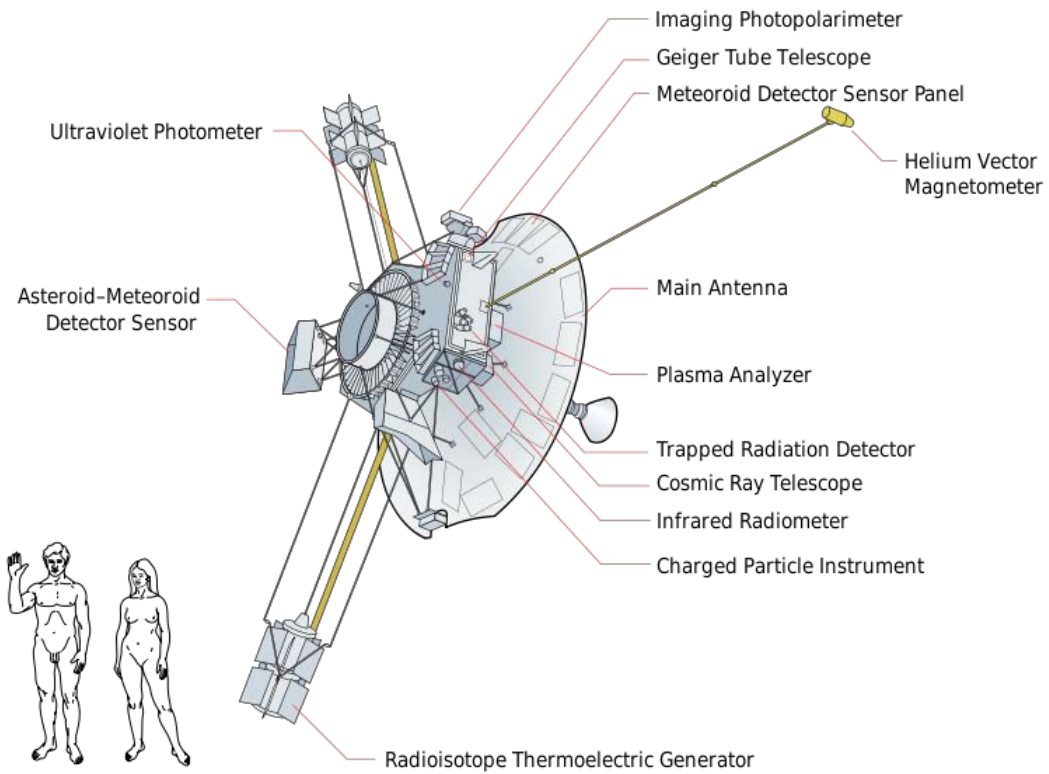
### Infrared Radiometer



Provides information on cloud temperature and the output of heat from Jupiter.

- **Principal investigator:** Andrew Ingersoll / California Institute of Technology

## Images of the spacecraft



*Pioneer 11* spacecraft design.



*Pioneer 11* spin stabilization testing.



The Pioneer plaque fixed to the space probe.



*Pioneer 11* being encapsulated for launch.

## **Mission profile**

### **Launch and trajectory**

The *Pioneer 11* probe was launched on April 6, 1973 at 02:11:00 UTC, by the National Aeronautics and Space Administration from Space Launch Complex 36A at Cape Canaveral, Florida aboard an Atlas/Centaur launch vehicle. Twin probe, Pioneer 10, had previously launched a year before on March 3, 1972.



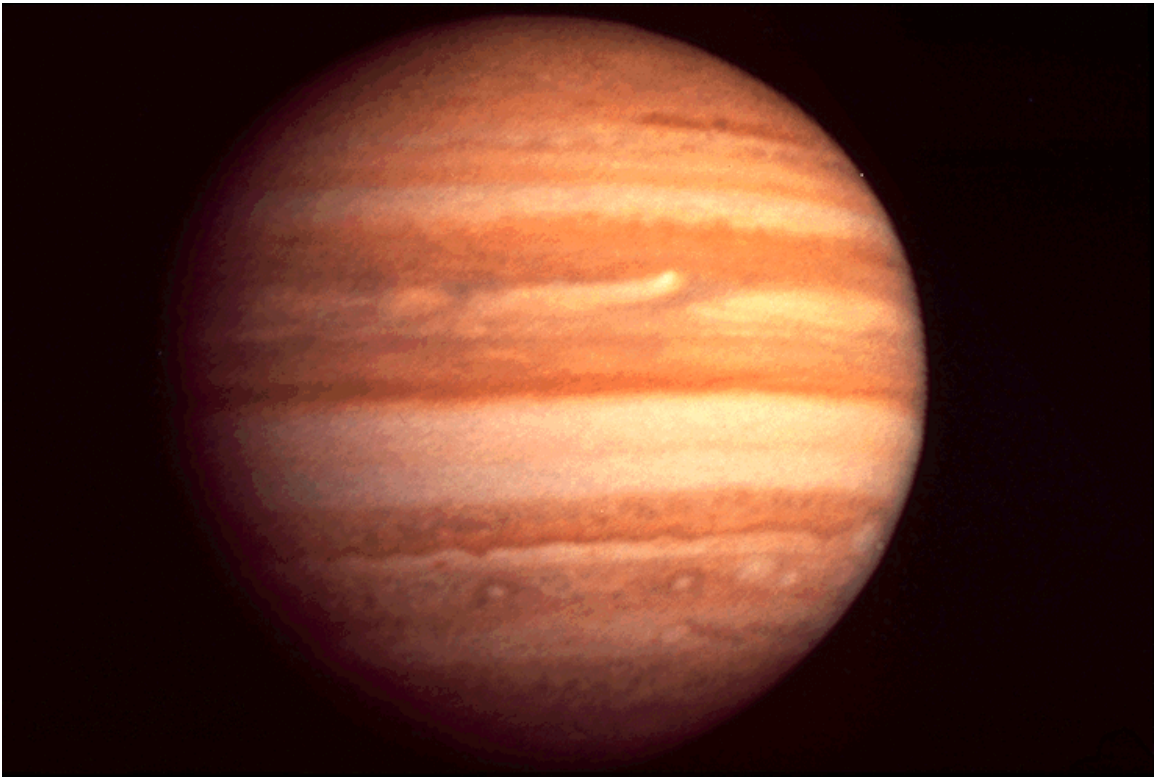
Pioneer 11 launching from Space Launch Complex 36A.

### **Encounter with Jupiter**

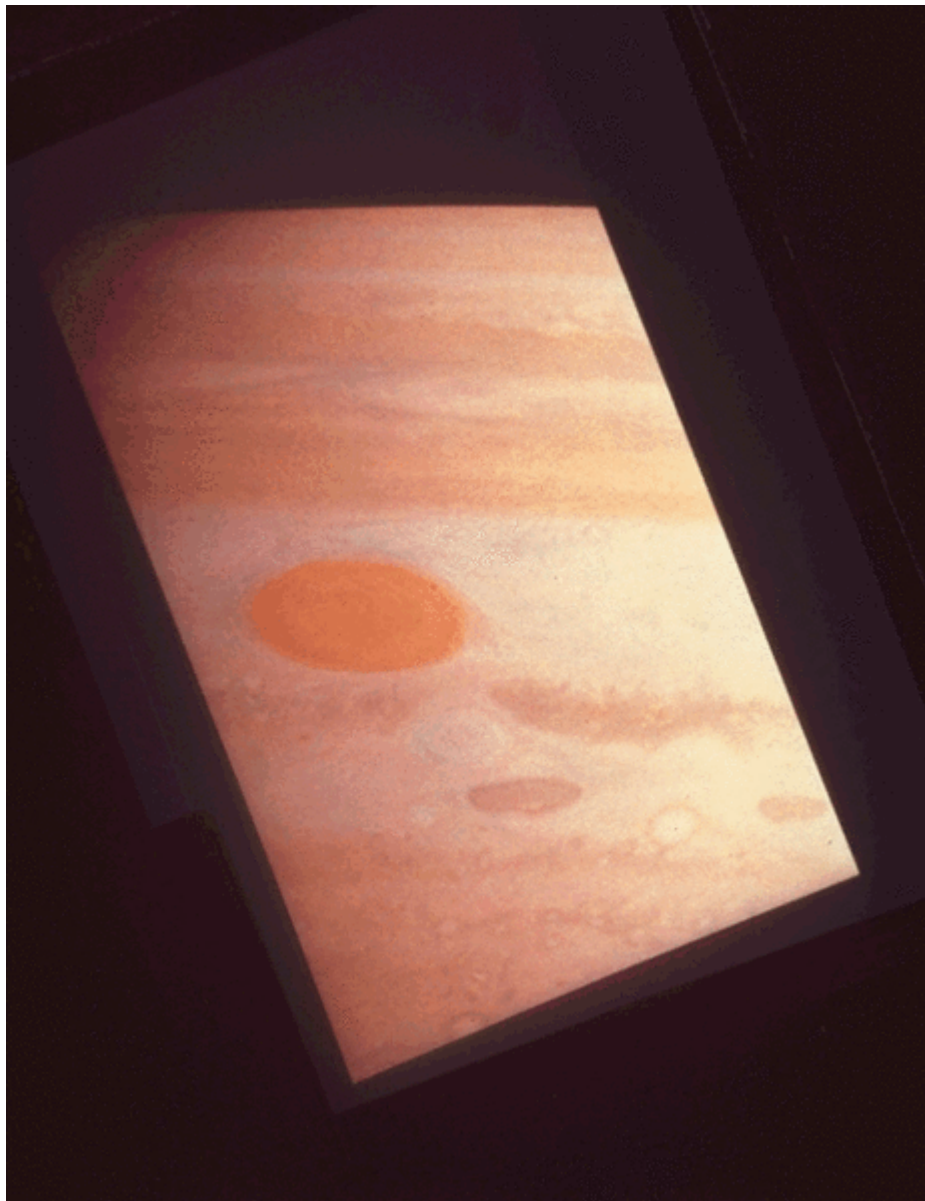
In November and December 1974, During its closest approach, December 2, 1974, *Pioneer 11* reached closest approach to Jupiter, passing 42,828 kilometers (26,612 miles) above the cloud tops. The probe obtained detailed images of the Great Red Spot, transmitted the first images of the immense polar regions, and determined the mass of Jupiter's moon Callisto. Utilizing the gravitational pull of Jupiter, a gravity assist was used to alter the trajectory of the probe, towards Saturn.



*Pioneer 11* Jupiter encounter.



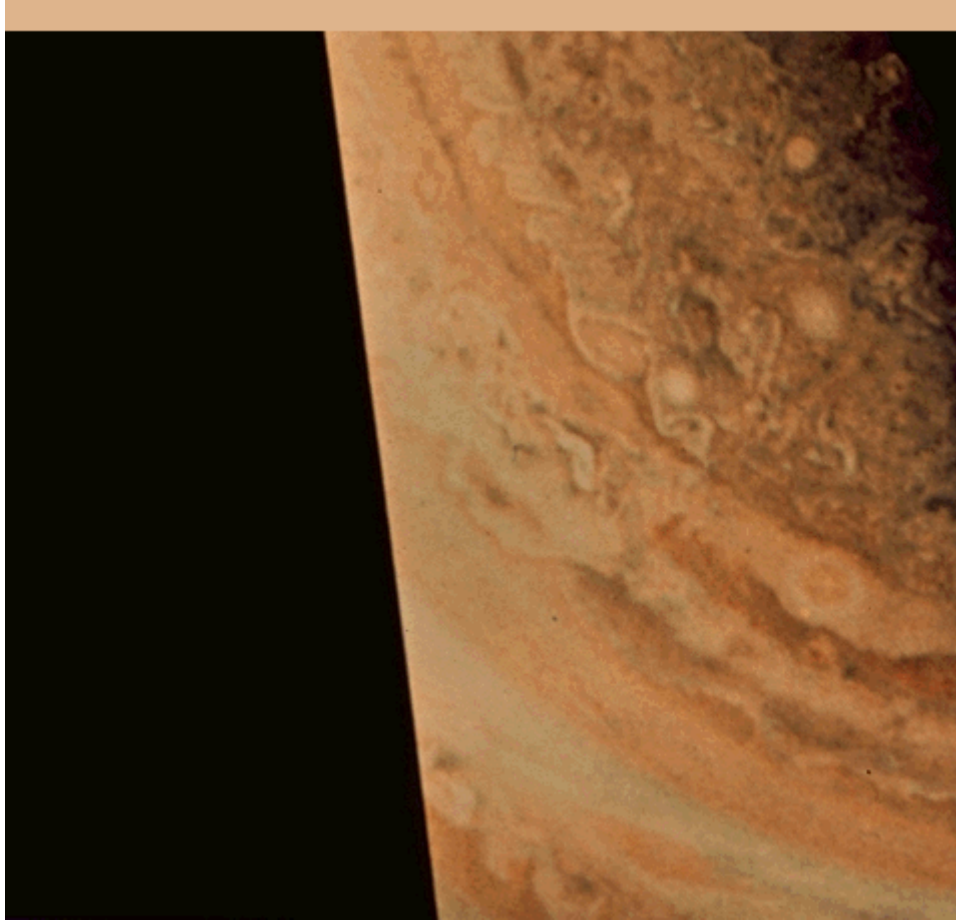
Approach on Jupiter.



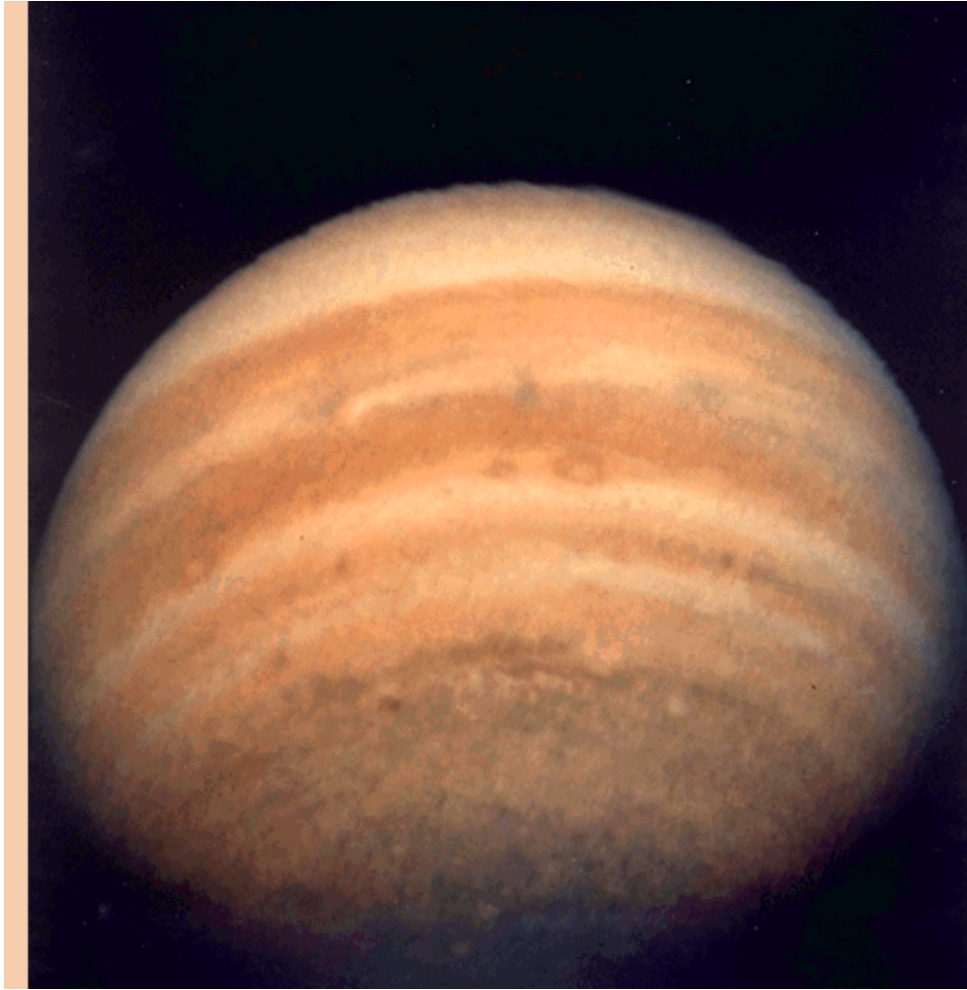
The Great Red Spot imaged by *Pioneer 11*.



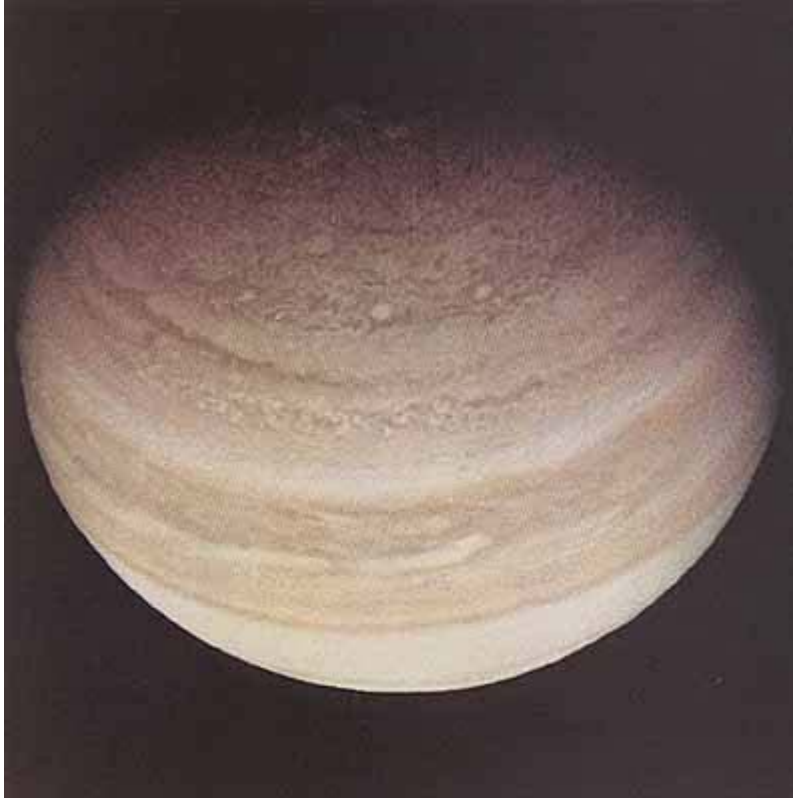
The Great Red Spot prior to closest approach.



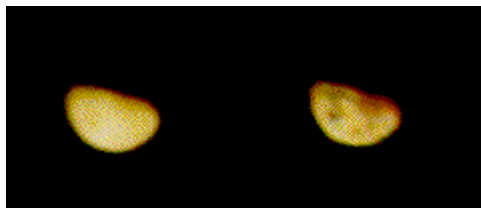
Cloud bands along the edge of Jupiter.



Beginning polar gravity assist



Jupiter polar region from 1,079,000 km.



Io imaged from 756,000 km.

## Saturn encounter



Pioneer 11 and Saturn rings on September 1, 1979 (artist's impression)

Pioneer 11 passed by Saturn on September 1, 1979, at a distance of 21,000 km from Saturn's cloud tops.

By this time Voyager 1 and Voyager 2 had already passed Jupiter and were also en route to Saturn, so it was decided to target Pioneer 11 to pass through the Saturn ring plane at the same position that the soon-to-come Voyager probe would use in order to test the route before Voyager arrived. If there were faint ring particles that could damage a probe in that area, mission planners felt it was better to learn about it via Pioneer. Thus, Pioneer 11 was acting as a "pioneer" in a true sense of the word; if danger was detected, then the Voyager probes could be rerouted further away from the rings, but missing the opportunity to visit Uranus and Neptune in the process.

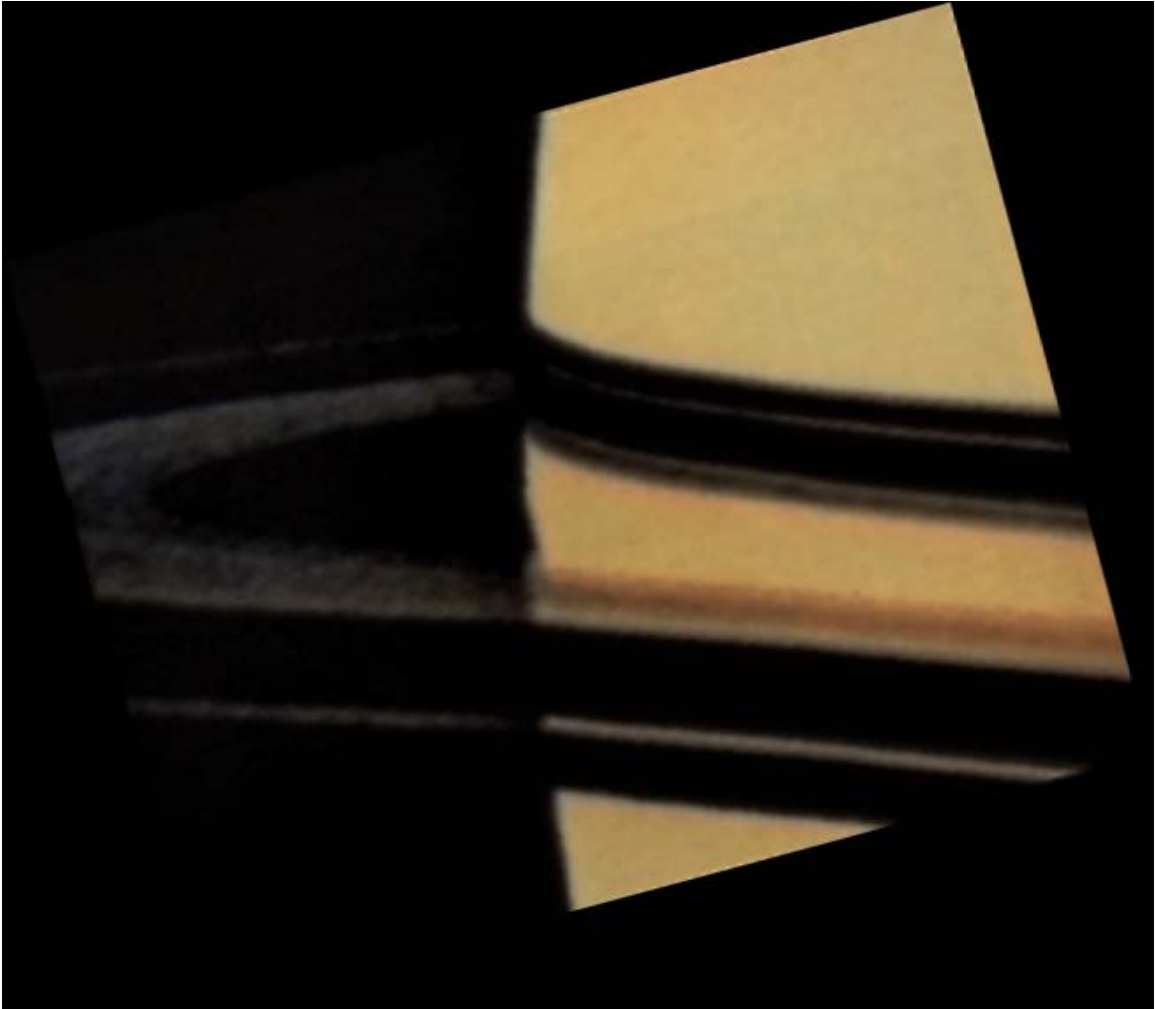
Pioneer 11 imaged and nearly collided with one of Saturn's small moons, passing at a distance of no more than 2500 miles. The object was tentatively identified as Epimetheus, a moon discovered the previous day from Pioneer's imaging, and suspected from earlier observations by Earth-based telescopes. After the Voyager flybys, it became known that there are two similarly-sized moons (Epimetheus and Janus) in the same orbit, so there is

some uncertainty about which one was the object of Pioneer's near-miss. Pioneer 11 encountered Janus on September 1, 1979 at 14:52 UTC at a distance of 2500 km and Mimas at 16:20 UTC the same day at 103000 km.

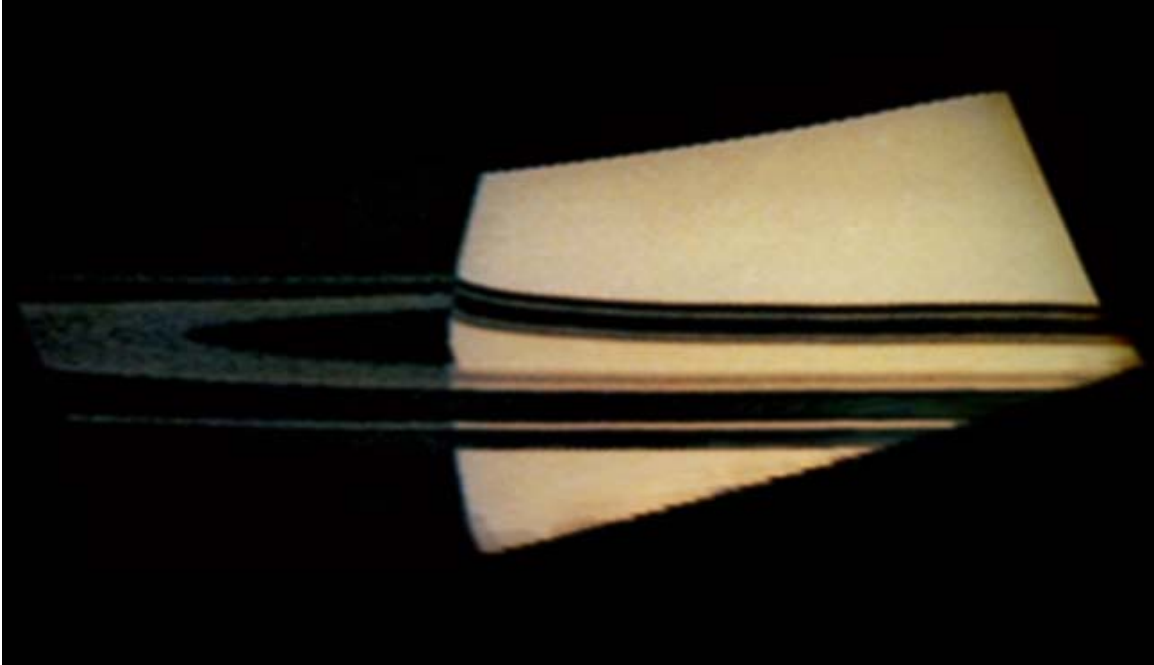
Besides Epimetheus, instruments located another previously undiscovered small moon and an additional ring, charted Saturn's magnetosphere and magnetic field and found its planet-size moon, Titan, to be too cold for life. Hurling underneath the ring plane, Pioneer 11 sent back amazing pictures of Saturn's rings. The rings, which normally seem bright when observed from Earth, appeared dark in the Pioneer pictures, and the dark gaps in the rings seen from Earth appeared as bright rings.



Pioneer 11 image of Saturn taken on 1979/08/26.



Pioneer 11 image of Saturn taken on 1979/09/01.



Pioneer 11 image of Saturn taken on 1979/09/01.



Outgoing Pioneer 11 image of Saturn taken on 1979/09/03.

## **Interstellar mission**

### **Pioneer anomaly**

Analysis of the radio tracking data from the Pioneer 10 and 11 spacecraft at distances between 20–70 AU from the Sun has consistently indicated the presence of an anomalous, small Doppler frequency drift. The drift can be interpreted as being due to a constant acceleration of  $(8.74 \pm 1.33) \times 10^{-10} \text{ m/s}^2$  directed towards the Sun. Although it is suspected that there is a systematic origin to the effect, none has been found. As a result, the nature of this anomaly has become of growing interest.

## Chapter- 2

# Voyager 1

### Voyager 1



*Voyager* spacecraft

<b>Operator</b>	NASA / JPL
<b>Mission type</b>	Flyby
<b>Flyby of</b>	Jupiter, Saturn
<b>Launch date</b>	1977-09-05 12:56:00 UTC (33 years, 5 months, and 19 days ago)
<b>Launch vehicle</b>	Titan IIIE / Centaur
<b>Launch site</b>	Space Launch Complex 41 Cape Canaveral Air Force Station
<b>Mission duration</b>	In progress (Interstellar mission)

(32 years, 1 month, and 20 days elapsed)

Jupiter encounter

*(completed 1979-04-13)*

Saturn encounter

*(completed 1980-12-14)*

<b>COSPAR ID</b>	1977-084A
<b>Homepage</b>	NASA <i>Voyager</i> website
<b>Mass</b>	721.9 kg (1,592 lb)
<b>Power</b>	420 W (3 RTGs)

The *Voyager 1* spacecraft is a 722-kilogram (1,592 lb) robotic American space probe launched by NASA on September 5, 1977 to study the outer Solar System and eventually interstellar space. Operating for 33 years, 5 months, and 19 days, the spacecraft receives routine commands and transmits data back to the Deep Space Network. It was the first probe to leave the Solar System and is the farthest human-made object from Earth.

Currently in extended mission, the spacecraft is tasked with locating and studying the boundaries of the Solar System, including the Kuiper belt, the heliosphere and interstellar space. The primary mission ended November 20, 1980, after encountering the Jovian system in 1979 and the Saturnian system in 1980. It was the first probe to provide detailed images of the two largest planets and their moons.

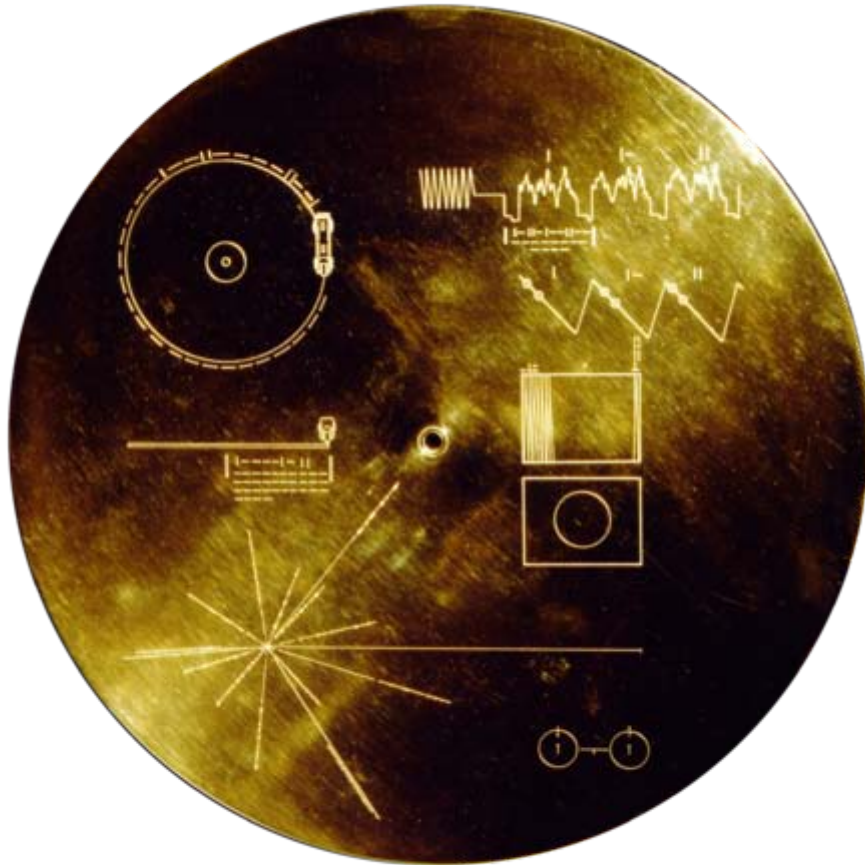
## Mission background

### History

Conceived in the 1960s, a Grand Tour proposal to study the outer planets, prompted NASA to begin work on a mission in the early 1970s. The development of the interplanetary probes coincided with an alignment of the planets, making possible a mission to the outer Solar System by taking advantage of the then-new technique, gravity assist.

Utilizing gravity assists would enable a single probe to visit the four gas giants (Jupiter, Saturn, Uranus, and Neptune) while requiring a minimal amount of propellant and a shorter transit duration between planets. Originally, *Voyager 1* was planned as *Mariner II* of the Mariner program however, due to congressional budget cuts, the mission was scaled back to be a flyby of Jupiter and Saturn, and renamed the Mariner Jupiter-Saturn probes. As the program progressed, the name was later changed to Voyager as the probe designs began to differ greatly from previous Mariner missions.

## Golden record



Each *Voyager* space probe carries a gold-plated audio-visual disc in the event that either spacecraft is ever found by intelligent life-forms from other planetary systems. The discs carry photos of the Earth and its lifeforms, a range of scientific information, spoken greetings from the people (e.g. the Secretary-General of the United Nations and the President of the United States, and the children of the Planet Earth) and a medley, "Sounds of Earth", that includes the sounds of whales, a baby crying, waves breaking on a shore, and a variety of music.

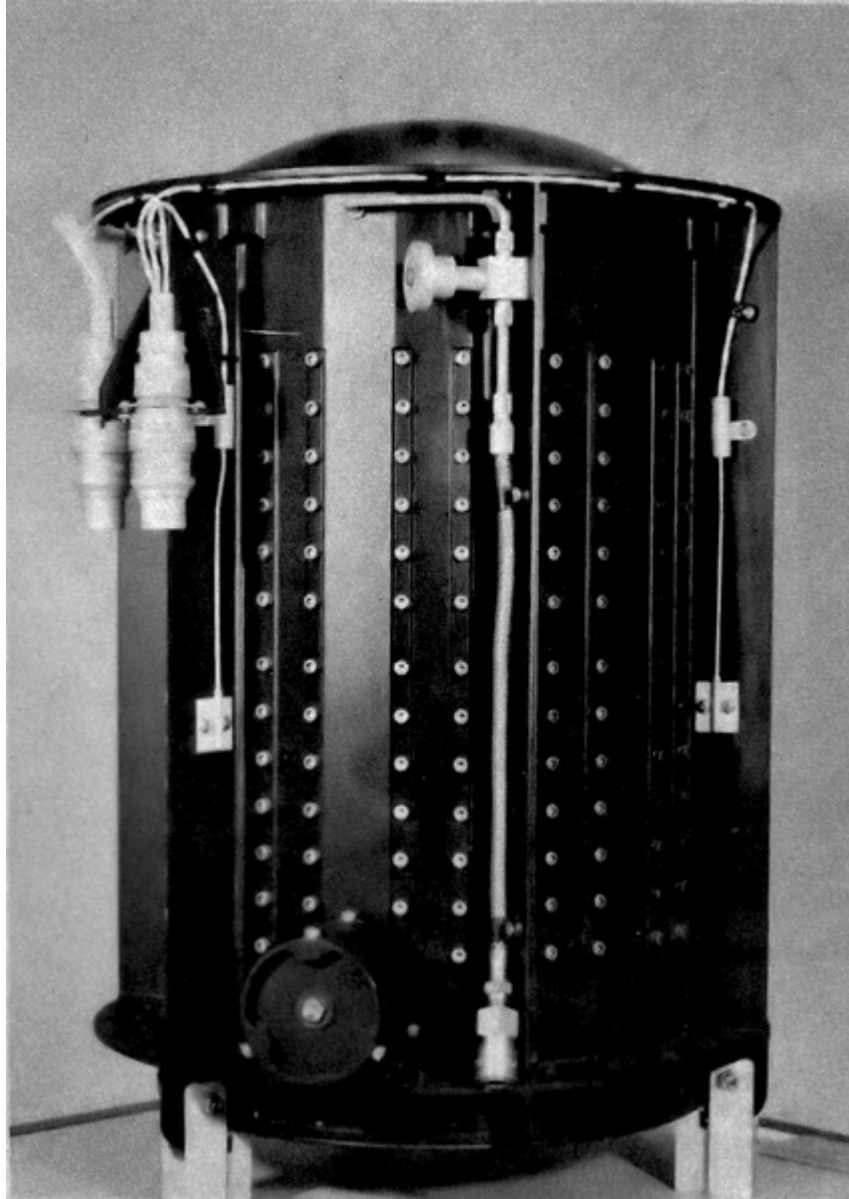
## Spacecraft design

Constructed by the Jet Propulsion Laboratory, *Voyager 1* included 16 hydrazine thrusters, three-axis stabilization, gyroscopes and celestial referencing instruments (sun sensor/Canopus Star Tracker) to maintain pointing of the high-gain antenna toward Earth. Collectively these instruments are part of the Attitude and Articulation Control Subsystem (**AACS**) along with redundant units of most instruments and 8 backup thrusters. The spacecraft also included 11 scientific instruments to study celestial objects as it traveled through space.

## Communications

Built with the intent for eventual interstellar travel, *Voyager 1* included a large, 3.7-meter parabolic, high-gain antenna (*see diagram*) to transceive data with the Deep Space Network on Earth. Communications are conducted over the S-band (13 cm wavelength) and X-band (3.6 cm wavelength) providing bandwidth as high as 115.2 kilobits per second. When the spacecraft is unable to communicate with Earth, the Digital Tape Recorder (**DTR**) is able to record up to 62,500-kilobytes of data to later transmit when communication is reestablished.

## Power



The spacecraft was built with 3 Multihundred-Watt radioisotope thermoelectric generators (**MHW RTG**). Each RTG includes 24 pressed plutonium oxide spheres and provide enough heat to generate approximately 157 Watts of power at launch. Collectively, the RTGs supply the spacecraft with 470 Watts at launch and will allow operations to continue until at least 2025. (*see diagram 1, 2*)

## Scientific instruments

### Expand

Instrument Name	Abr.	Description
Imaging Science System	(ISS)	Utilizes a two-camera system (narrow-angle/wide-angle) to provide imagery of Jupiter, Saturn and other objects along the trajectory.

### Filters

Narrow Angle Camera Filters				Wide Angle Camera Filters			
Name	Wavelength	Spectrum	Sensitivity	Name	Wavelength	Spectrum	Sensitivity
Clear	280 nm - 640 nm			Clear	280 nm - 640 nm		
UV	280 nm - 370 nm			Violet	350 nm - 450 nm		
Violet	350 nm - 450 nm			Blue	430 nm - 530 nm		
Blue	430 nm - 530 nm			CH <sub>4</sub> -U	536 nm - 546 nm		
				Green	530 nm - 640 nm		
Green	530 nm - 640 nm			Na-D	588 nm - 590 nm		
				Orange	590 nm - 640 nm		
Orange	590 nm - 640 nm			CH <sub>4</sub> -JST	614 nm - 624 nm		

- **Principal investigator:** Bradford Smith / University of Arizona (PDS/PRN website)
- **Data:** PDS/PDI data catalog, PDS/PRN data catalog

Utilized the telecommunications system of the Voyager spacecraft to determine the physical properties of planets and satellites (ionospheres, atmospheres, masses, gravity fields, densities) and the amount and size distribution of material in Saturn's rings and the ring dimensions.

Radio Science System (disabled)	(RSS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> G. Tyler / Stanford University PDS/PRN overview</li> <li>• <b>Data:</b> PDS/PPI data catalog, PDS/PRN data catalog (VG_2803), NSSDC data archive</li> </ul>
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Investigates both global and local energy balance and atmospheric composition. Vertical temperature profiles are also obtained from the planets and satellites as well as the composition, thermal properties, and size of particles in Saturn's rings.

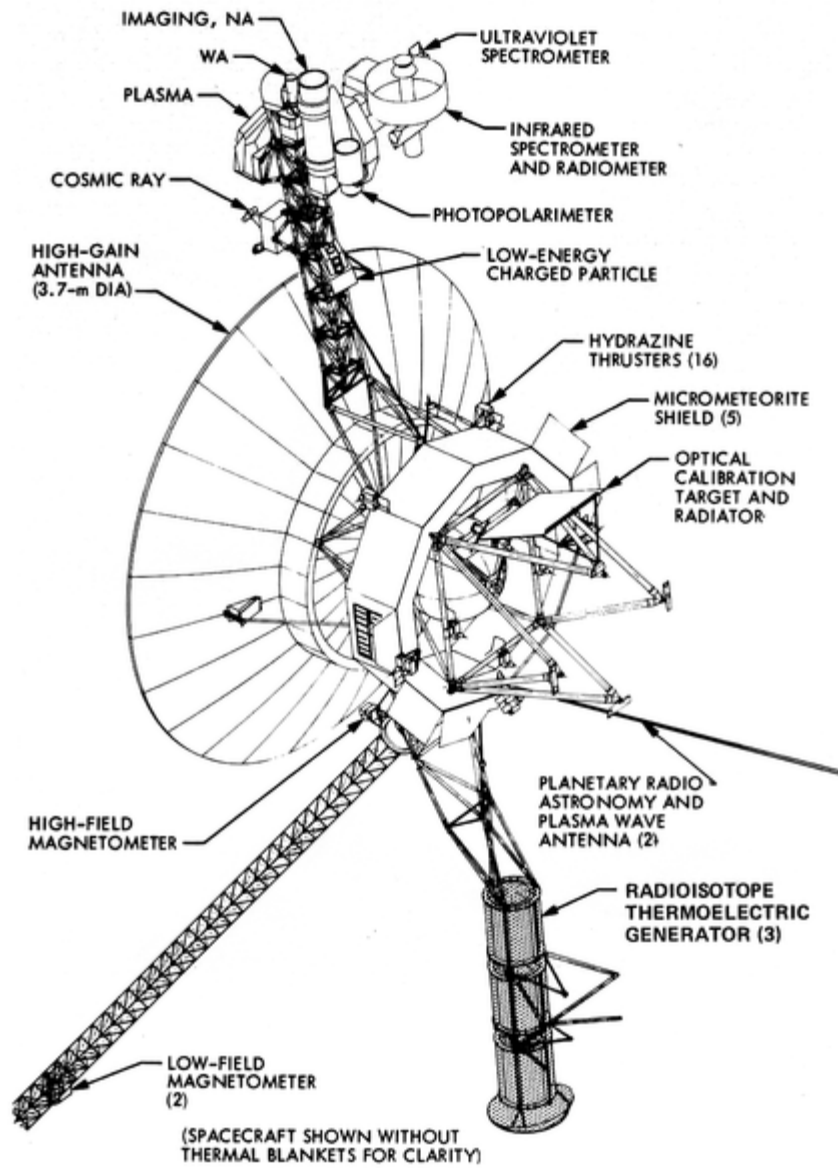
Infrared Interferometer Spectrometer (disabled)	(IRIS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> Rudolf Hanel / NASA Goddard Space Flight Center (PDS/PRN website)</li> <li>• <b>Data:</b> PDS/PRN data catalog, PDS/PRN expanded data catalog (VGIRIS_0001, VGIRIS_002), NSSDC Jupiter data archive</li> </ul>
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Designed to measure atmospheric properties, and to measure radiation.

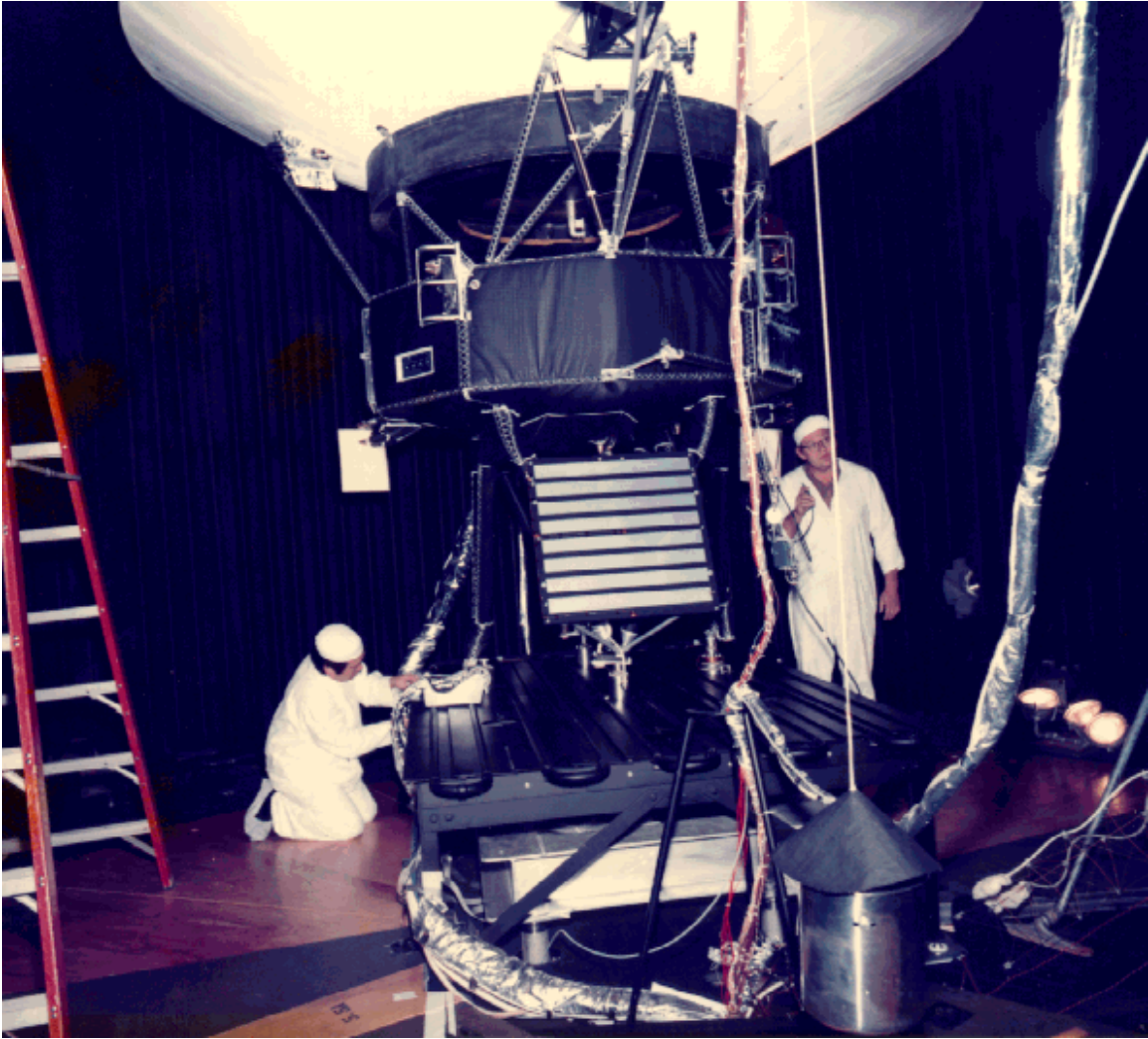
Ultraviolet Spectrometer (active)	(UVS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> A. Broadfoot / University of Southern California (PDS/PRN website)</li> <li>• <b>Data:</b> PDS/PRN data catalog</li> </ul>
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			Designed to investigate the magnetic fields of Jupiter and Saturn, the solar-wind interaction with the magnetospheres of these planets, and the interplanetary magnetic field out to the solar wind boundary with the interstellar magnetic field and beyond, if crossed.
Triaxial Fluxgate Magnetometer (active)	(MAG)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> Norman Ness / NASA Goddard Space Flight Center (website)</li> <li>• <b>Data:</b> PDS/PPI data catalog, NSSDC data archive</li> </ul>	
			Investigates the macroscopic properties of the plasma ions and measures electrons in the energy range from 5 eV to 1 keV.
Plasma Spectrometer (defective)	(PLS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> John Richardson / MIT (website)</li> <li>• <b>Data:</b> PDS/PPI data catalog, NSSDC data archive</li> </ul>	
			Measures the differential in energy fluxes and angular distributions of ions, electrons and the differential in energy ion composition.
Low Energy Charged Particle Instrument (active)	(LECP)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> Stamatios Krimigis / JHU/APL / University of Maryland (JHU/APL website / UMD website / KU website)</li> <li>• <b>Data:</b> UMD data plotting, PDS/PPI data catalog, NSSDC data archive</li> </ul>	
			Determines the origin and acceleration process, life history, and dynamic contribution of interstellar cosmic rays, the nucleosynthesis of elements in cosmic-ray sources, the behavior of cosmic rays in the interplanetary medium, and the trapped planetary energetic-particle environment.
Cosmic Ray System (active)	(CRS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> Edward Stone / CalTech / NASA Goddard Space Flight Center (website)</li> <li>• <b>Data:</b> PDS/PPI data catalog, NSSDC data archive</li> </ul>	
			Utilizes a sweep-frequency radio receiver to study the radio-emission signals from Jupiter and Saturn.
Planetary Radio Astronomy Investigation (disabled)	(PRA)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> James Warwick / University of Colorado</li> <li>• <b>Data:</b> PDS/PPI data catalog, NSSDC data archive</li> </ul>	
			Utilized a telescope with a polarizer to gather information on surface texture and composition of Jupiter and Saturn and information on atmospheric scattering properties and density for both planets.
Photopolarimeter System (defective)	(PPS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> Arthur Lane / JPL (PDS/PRN website)</li> <li>• <b>Data:</b> PDS/PRN data catalog</li> </ul>	
			Provides continuous, sheath-independent measurements of the electron-density profiles at Jupiter and Saturn as well as basic information on local wave-particle interaction, useful in studying the magnetospheres.
Plasma Wave System (partially disabled)	(PWS)	<ul style="list-style-type: none"> <li>• <b>Principal investigator:</b> Donald Gurnett / University of Iowa (website)</li> <li>• <b>Data:</b> PDS/PPI data catalog, NSSDC data archive</li> </ul>	

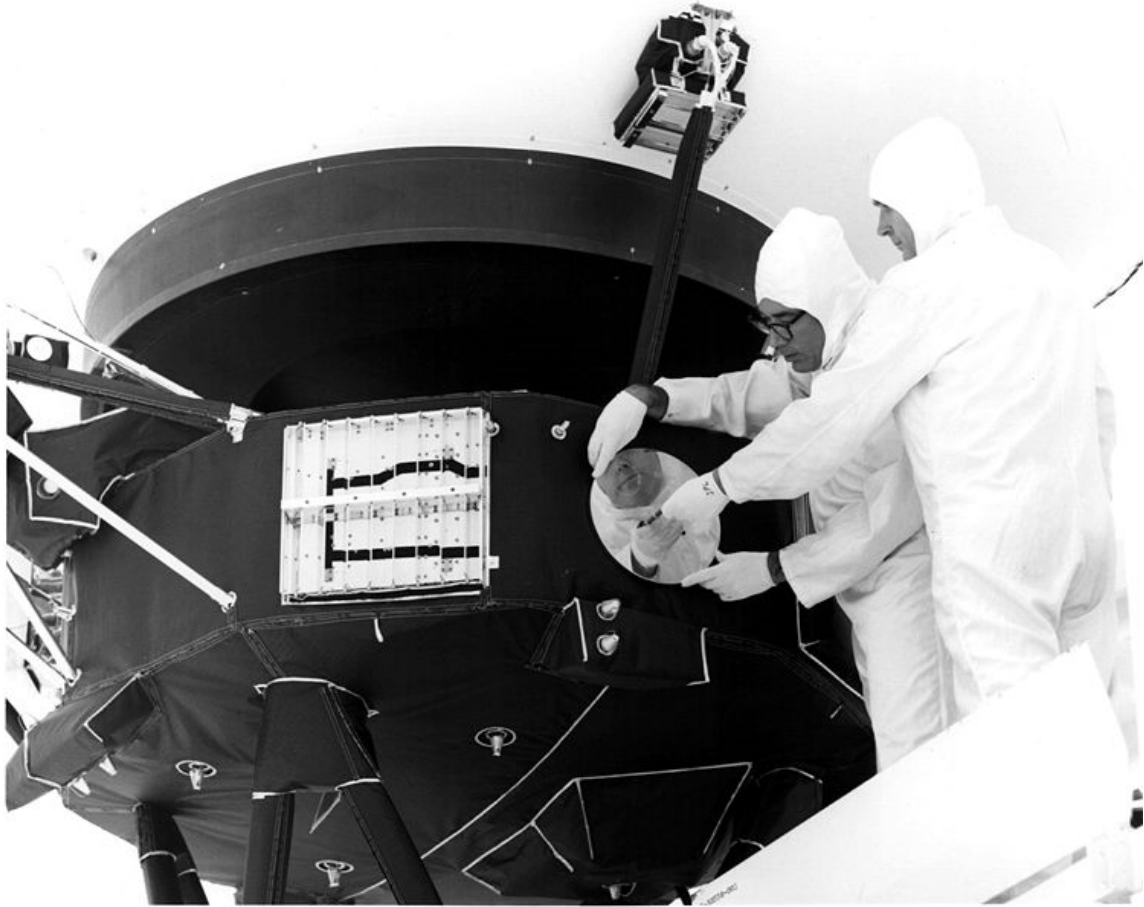
## Images of the spacecraft



*Voyager* spacecraft diagram.



*Voyager 1* in a space simulator chamber.



Gold-Plated Record is attached to *Voyager 1*.



*Voyager 1* awaiting payload entry into a Titan/Centaur-6 rocket.

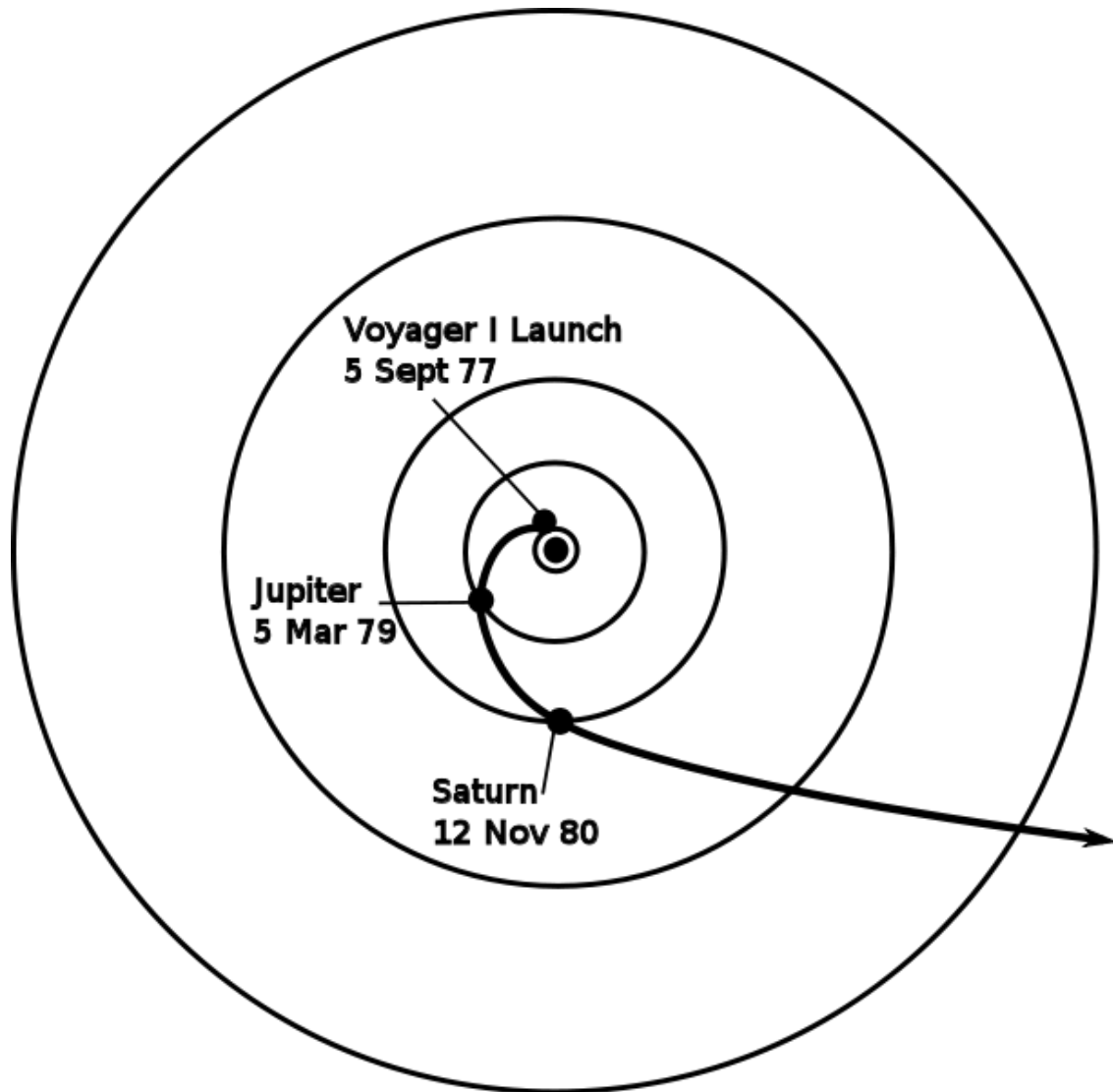
## **Mission profile**

### **Launch and trajectory**

The *Voyager 1* probe was launched on September 5, 1977, by the National Aeronautics and Space Administration from Space Launch Complex 41 at Cape Canaveral, Florida, aboard a Titan IIIE/Centaur launch vehicle. Two weeks prior, the twin *Voyager 2* probe had been launched on August 20, 1977. Despite being launched two weeks later, *Voyager 1* reached both Jupiter and Saturn sooner after being launched into a shorter trajectory.



*Voyager 1* lifted off with a Titan IIIE/Centaur

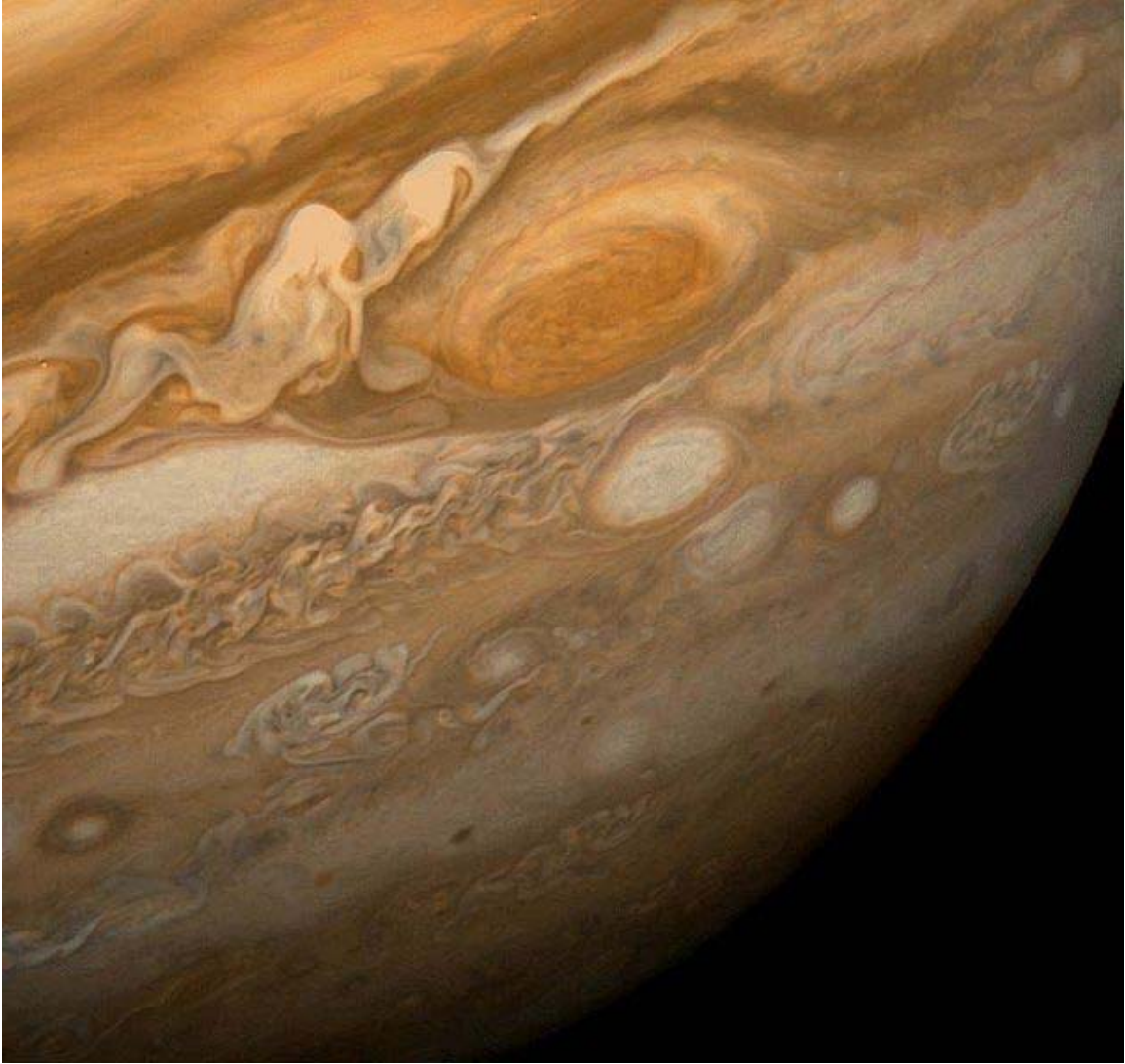


Trajectory of *Voyager 1* primary mission.

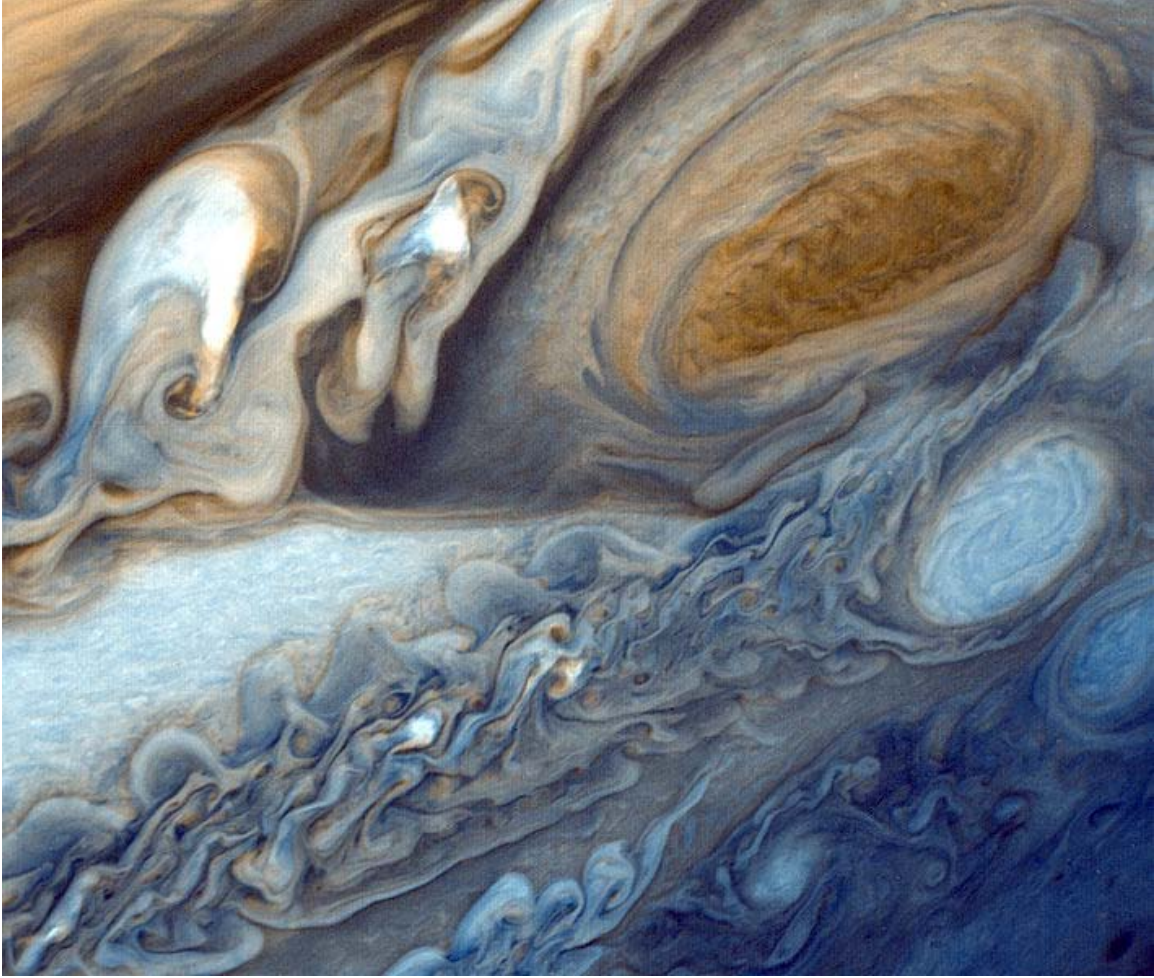
### **Encounter with Jupiter**

*Voyager 1* began photographing Jupiter in January 1979. Its closest approach to Jupiter was on March 5, 1979, at a distance of about 349,000 kilometres (217,000 miles) from the planet's center. Due to the greater photographic resolution allowed by a closer approach, most observations of the moons, rings, magnetic fields, and the radiation belt environment of the Jovian system were made during the 48-hour period that bracketed the closest approach. *Voyager 1* finished photographing the Jovian system in April 1979.

The two *Voyager* space probes made a number of important discoveries about Jupiter, its satellites, its radiation belts, and its never-before-seen planetary rings. The most surprising discovery in the Jovian system was the existence of volcanic activity on the moon Io, which had not been observed either from the ground, or by *Pioneer 10* or *11*.



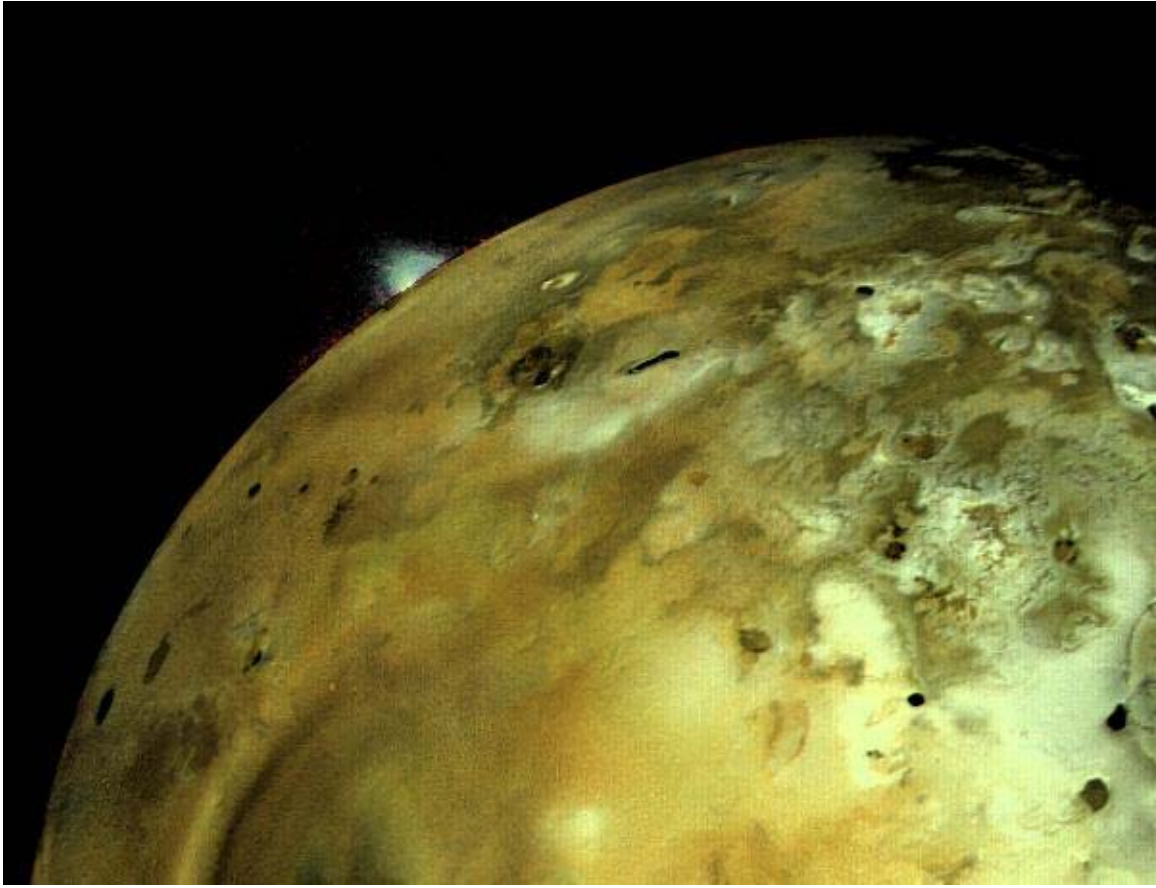
The Great Red Spot as seen from *Voyager 1*.



False color detail of Jupiter's atmosphere.



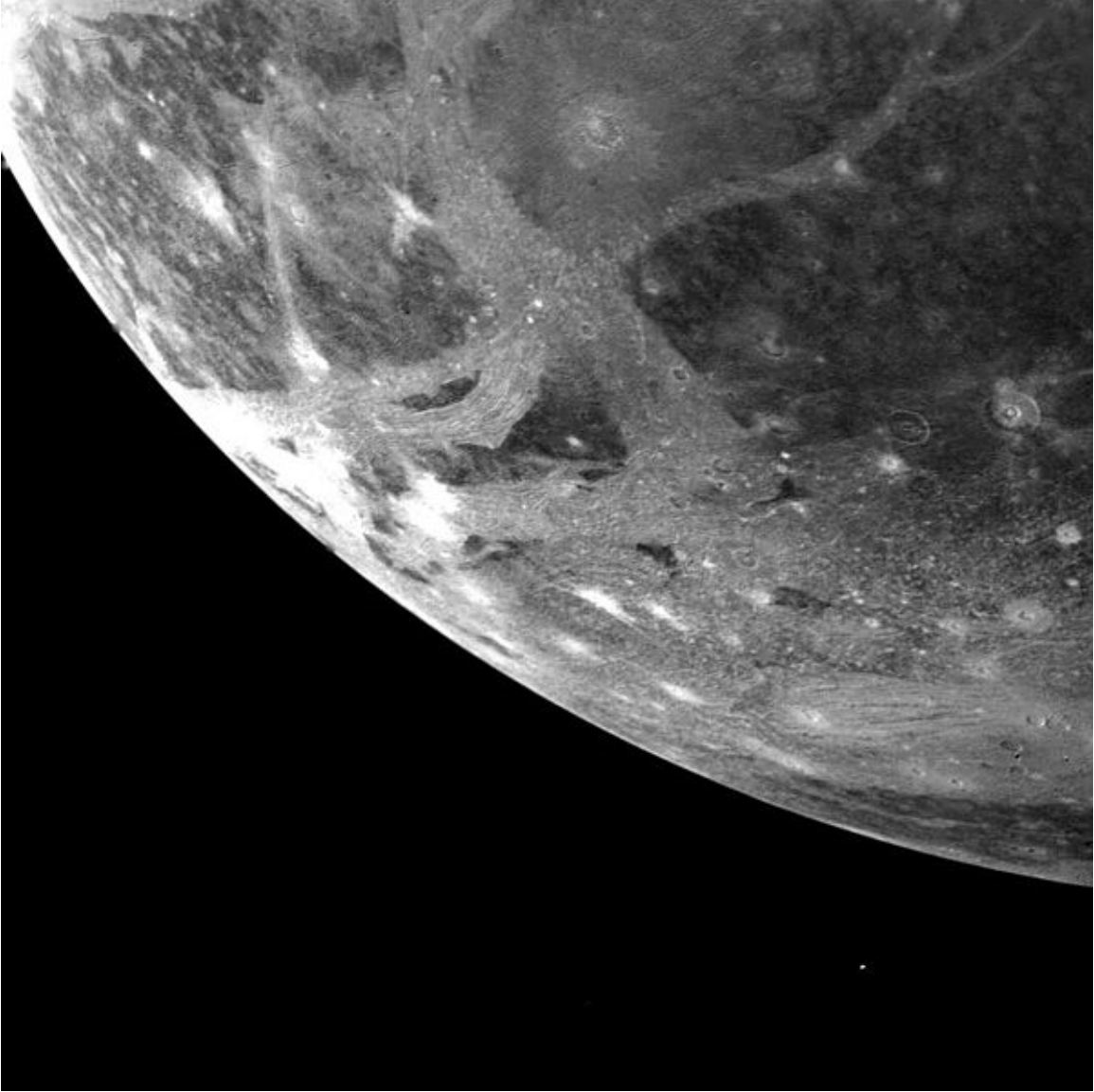
View of lava flows radiating from the volcano Ra Patera on Io.



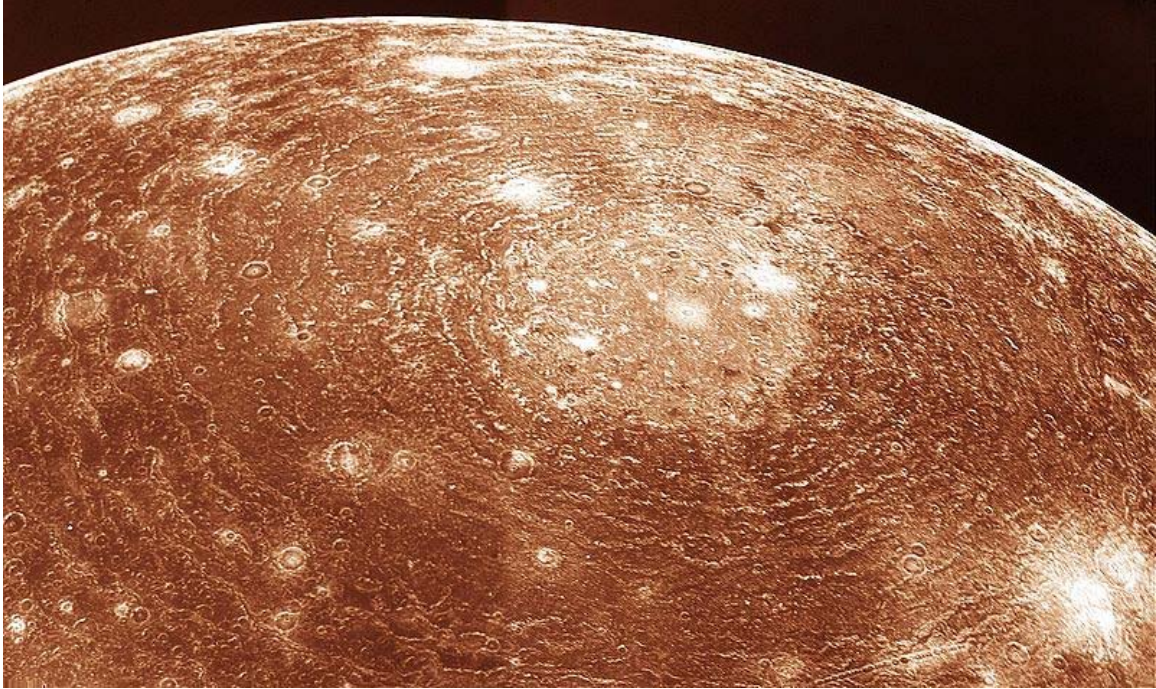
Volcanic eruption on Io photographed from *Voyager 1*.



Europa as seen from *Voyager 1* at a distance of 2.8 million km.



Icy surface of Ganymede as photographed from 253,000 km.



Valhalla crater on Callisto as imaged by *Voyager 1* in 1979.

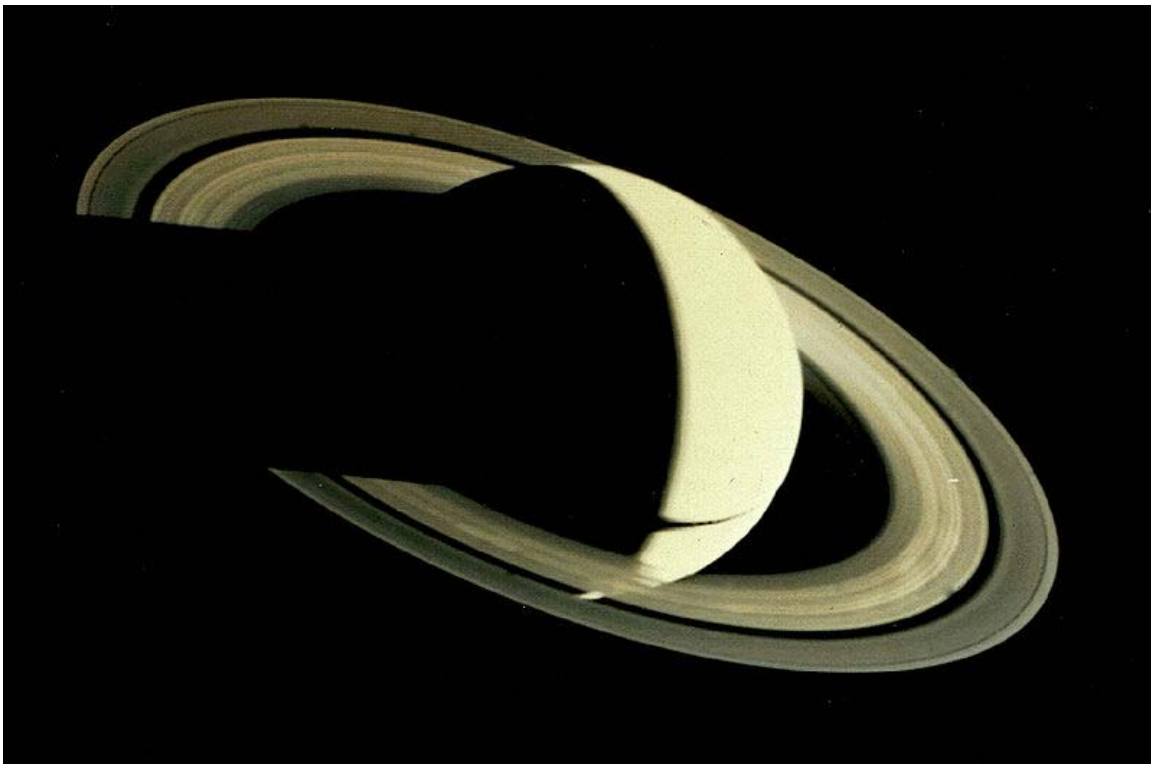


## Encounter with Saturn

The gravitational assist trajectories at Jupiter were successfully carried out by both *Voyagers*, and the two spacecraft went on to visit Saturn and its system of moons and rings. *Voyager 1*'s Saturnian flyby occurred in November 1980, with the closest approach on November 12, 1980, when the space probe came within 124,000 kilometers (77,000 mi) of Saturn's cloud-tops. The space probe's cameras detected complex structures in the rings of Saturn, and its remote sensing instruments studied the atmospheres of Saturn and its giant moon Titan.

Because Pioneer 11 had one year earlier detected a thick, gaseous atmosphere over Titan, the *Voyager* space probes' controllers at the Jet Propulsion Laboratory elected for *Voyager 1* to make a close approach of Titan, and of necessity end its Grand Tour there.

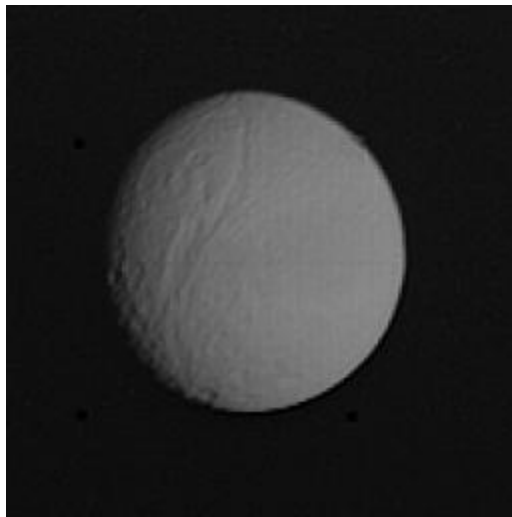
Its trajectory with a close fly-by of Titan caused an extra gravitational deflection that sent *Voyager 1* out of the plane of the Ecliptic, thus ending its planetary science mission. *Voyager 1* could have been commanded onto a different trajectory, whereby the gravitational slingshot effect of Saturn's mass would have steered and boosted *Voyager 1* out to a fly-by of Pluto. However, this plutonian option was not exercised, because the other trajectory that led to the close fly-by of Titan was decided to have more scientific value and less risk.



Saturn from 5.3 million km, four days after its closest approach.



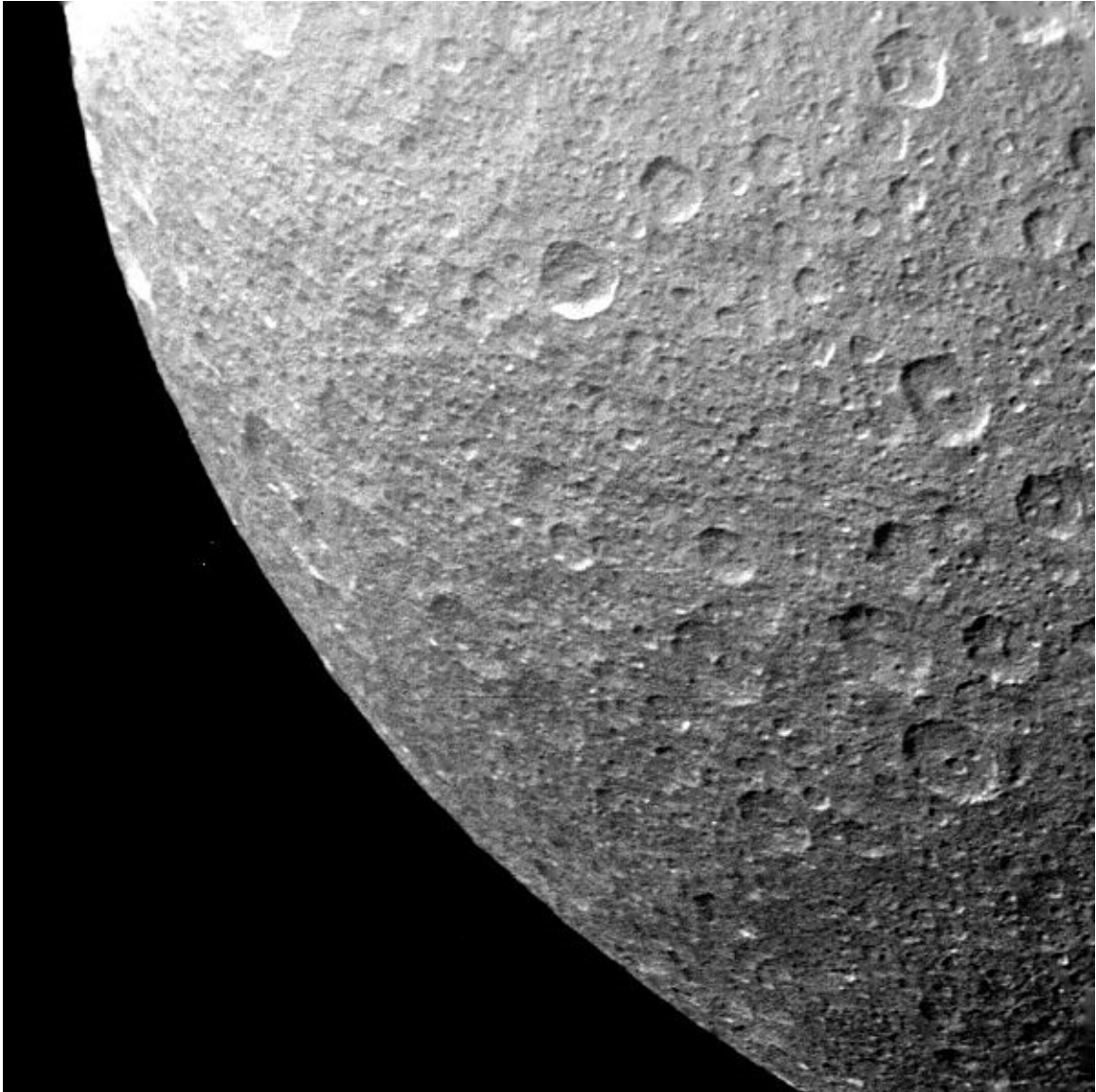
Mimas at a range of 425,000 km from *Voyager 1*.



Tethys photographed by *Voyager 1* from 1.2 million km.



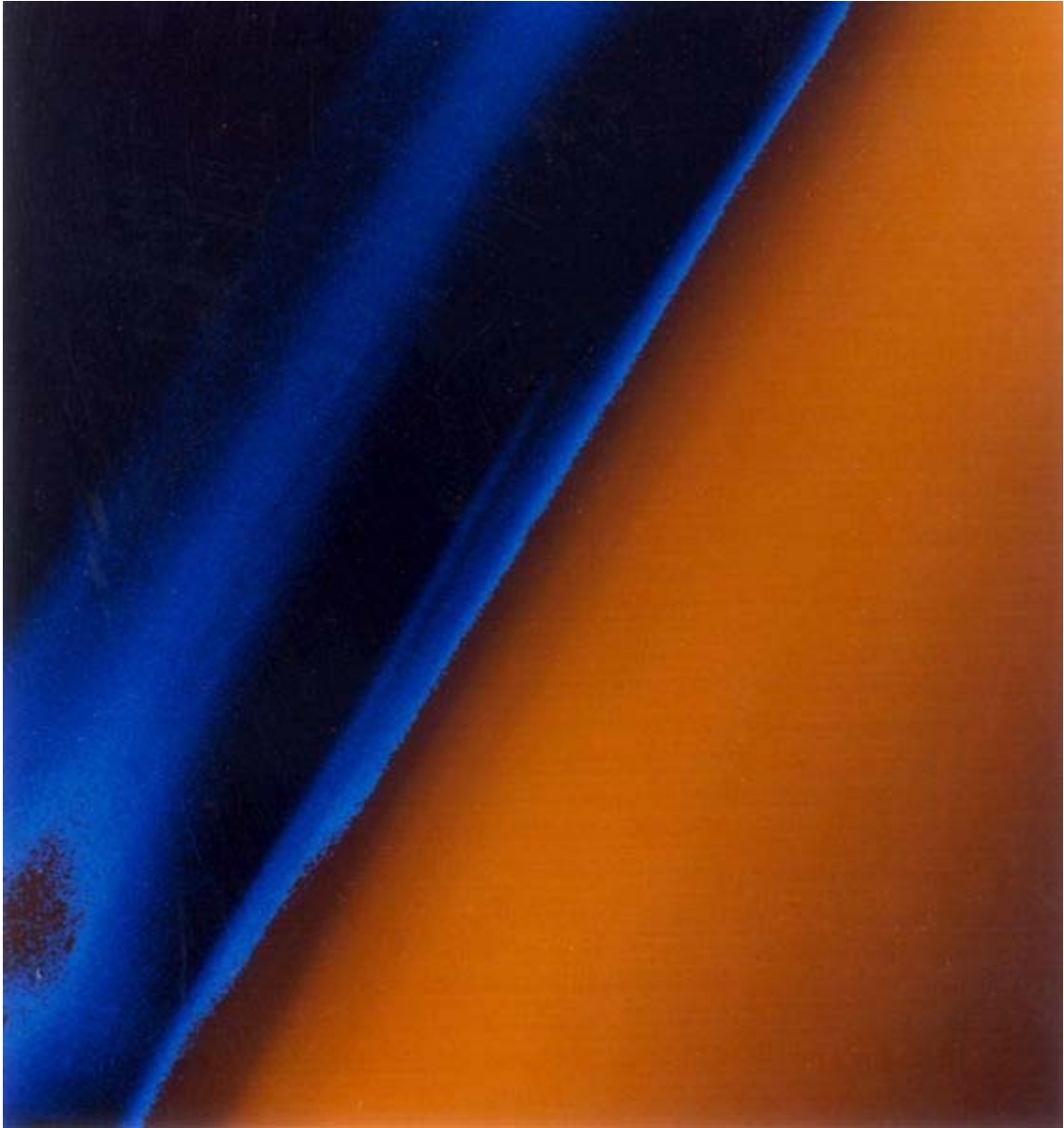
Fractured terrain on Dione.



Impact craters on the surface of Rhea appear similar to Mercury.



Titan's thick haze layer is shown in this enhanced *Voyager 1* image.

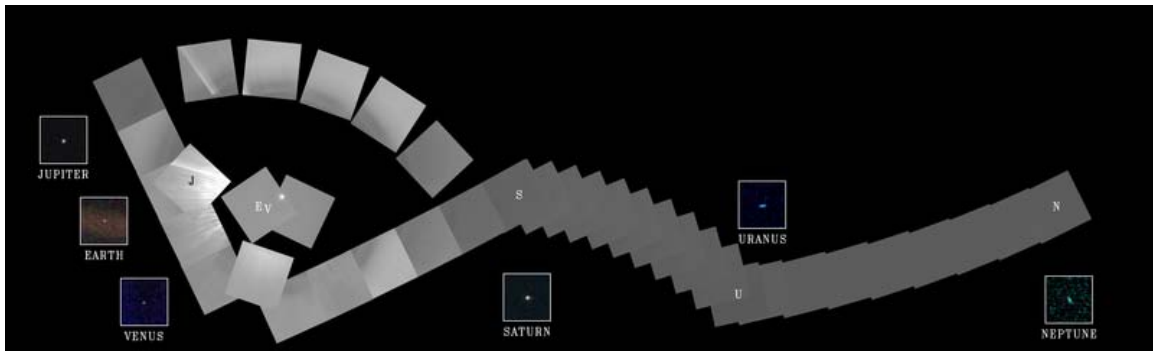


Layers of haze covering Saturn's satellite Titan.



*Voyager 1* image of Saturn's F Ring.

## Interstellar mission



The "family portrait" of the Solar system taken by *Voyager 1*

On February 14, 1990, *Voyager 1* took the first ever "family portrait" of our solar system as seen from outside, which includes the famous image known as "Pale blue dot". It is estimated that both *Voyager* craft have sufficient electrical power to operate their radio transmitters until at least 2025, which will be over 48 years after launch.

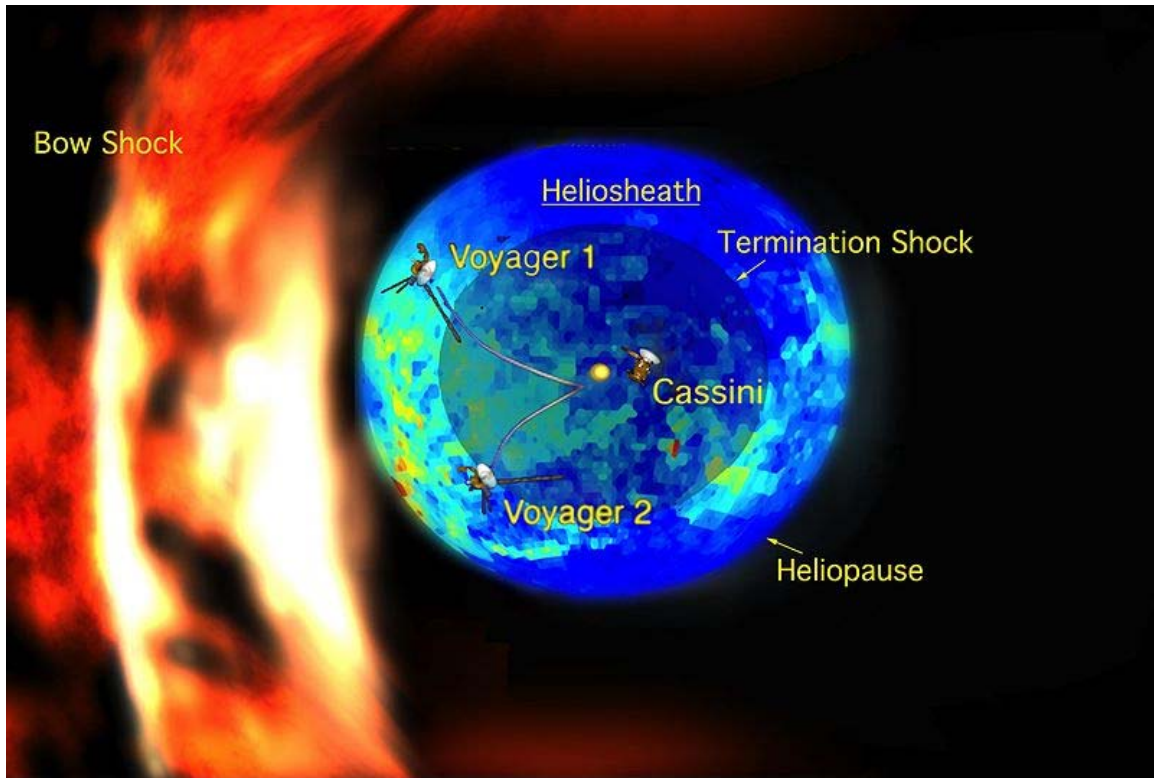
On November 17, 1998, *Voyager 1* overtook *Pioneer 10* as the most distant man-made object from Earth, at a distance of 69.419 AU. It is currently the most distant functioning

space probe to receive commands and transmit information to Earth. Provided *Voyager 1* does not collide with any stellar objects, the *New Horizons* space probe will never pass it, despite being launched from Earth at a faster speed than either *Voyager* spacecraft.

The current speed of *New Horizons* is slightly greater than *Voyager 1* but when *New Horizons* reaches the same distance from the sun as *Voyager 1* is now, its speed will be about 13 km/s (8 miles/sec) compared to *Voyager's* 17 km/s (10.5 miles/sec). The close flyby of Saturn and Titan gave *Voyager 1* a massive advantage with its extra gravity assist.

<b>Year</b>	<b>End of specific capabilities as a result of the available electrical power limitations</b>
2007	Termination of plasma subsystem (PLS)
2008	Power off Planetary Radio Astronomy Experiment (PRA)
2010	Terminate scan platform and Ultraviolet spectrometer (UVS) observations
2015	Termination of Data Tape Recorder (DTR) operations (limited by ability to capture 1.4 kbit/s data using a 70 m/34 m antenna array. This is the minimum rate at which the DTS can read-out data.)
2016 approx	Termination of gyroscopic operations
2020	Start shutdown of science instruments (as of 2008-03-18 the order is undecided but the Low-Energy Charged Particles, Cosmic Ray Subsystem, Magnetometer, and Plasma Wave Subsystem instruments are expected to still be operating)
2025 or after	Can no longer power any single instrument.

## Heliopause



*Voyager 1* is currently within the heliosheath and approaching interstellar space.

As *Voyager 1* heads for interstellar space, its instruments continue to study the solar system; Jet Propulsion Laboratory scientists are using the plasma wave experiments aboard *Voyager 1* and 2 to look for the heliopause, the boundary at which the solar wind transitions into the interstellar medium.

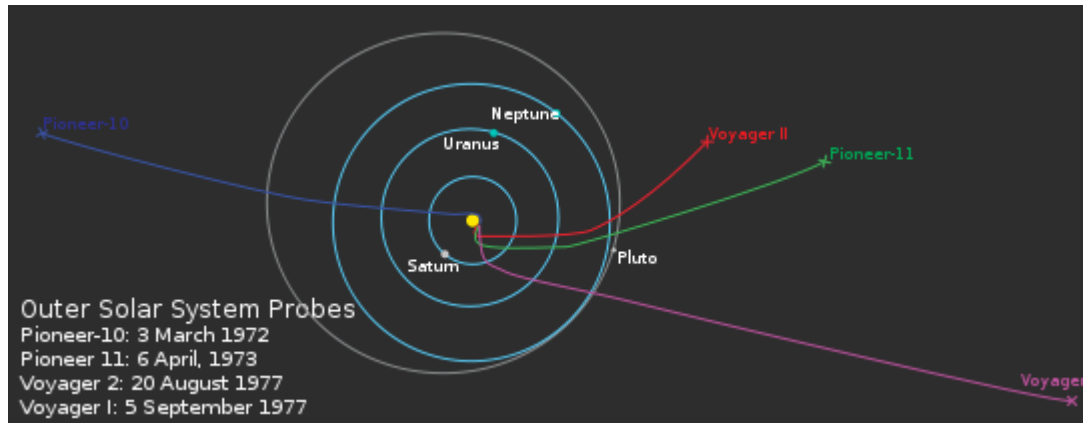
Scientists at the Johns Hopkins University Applied Physics Laboratory believe that *Voyager 1* entered the termination shock in February 2003. Some other scientists have expressed doubt, discussed in the journal *Nature* of November 6, 2003. In a scientific session at the American Geophysical Union meeting in New Orleans on the morning of May 25, 2005, Dr. Ed Stone presented evidence that *Voyager 1* crossed the termination shock in December 2004.

The issue will not be resolved until other data becomes available, since *Voyager 1*'s solar-wind detector ceased functioning in 1990. This failure has meant that termination shock detection must be inferred from the data from the other instruments on board.

However, in May 2005 a NASA press release said that consensus was that *Voyager 1* was now in the heliosheath. Scientists anticipate that the craft will reach the heliopause in 2015.

*Voyager 1* is the farthest human-made object from Earth, traveling away from both the Earth and the Sun at a relatively faster speed than any other probe.

## Current status



Location and trajectories of Pioneer and Voyager spacecraft, as of July 7, 2007. Note Voyager 2 is farther than Pioneer 11 and only appears closer here due to its -55 degree declination, and that Voyager 1's position is drawn too far away.

As of **February 22th, 2011**, *Voyager 1* was about 116.257AU (17.242 billion km, or 10.788 billion miles) or about 0.00183 of a light-year from the Sun. Radio signals traveling at the speed of light between Voyager 1 and Earth take 16.14 hours to cross the distance between the two. (To compare, Proxima Centauri, the closest star to our Sun, is about 4.2 light-years distant = 265 thousand AU) *Voyager 1*'s current relative velocity is 17.064 km/s, or 61,452 kilometres per hour (38,185 mph). This calculates as 3.599 AU per year, about 10% faster than *Voyager 2*. At this velocity, 73,600 years would pass before reaching the nearest star, Proxima Centauri, were the spacecraft traveling in the direction of that star.

*Voyager 1* is not heading towards any particular star, but in about 40,000 years it will pass within 1.6 light years of the star AC+79 3888 in the constellation Camelopardalis. That star is generally moving towards our Solar System at about 119 kilometers per second.

As of **February 22th 2011** the spacecraft is at 12.07° declination and 17.182 hours right ascension, placing it in the constellation Ophiuchus as observed from the Earth. NASA continues its daily tracking of *Voyager 1* with its Deep Space Network. This network measures both the elevation and azimuth angles of the incoming radio waves from *Voyager 1*, and it also measures the distance from the Earth to *Voyager 1*.

On **March 31, 2006**, the amateur radio operators from AMSAT in Germany tracked and received radio waves from *Voyager 1* using the 20-meter (66 ft) dish at Bochum with a long integration technique. Retrieved data was checked and verified against data from the

Deep Space Network station at Madrid, Spain. This is believed to be the first such tracking of *Voyager 1*.

On **December 13, 2010**, it was confirmed that *Voyager 1* passed the reach of the solar wind emanating from the Sun. It is suspected that solar wind at this distance turns sideways due to interstellar wind pushing against the heliosphere. Since June 2010, detection of solar wind has been consistently at zero, providing conclusive evidence of the event. The meridional (north-south) speed of the solar wind, which is suspected to have increased, cannot be inferred in *Voyager 1*'s current configuration. On this date, the spacecraft was approximately 17.3 billion km (10.8 billion miles) from the Sun

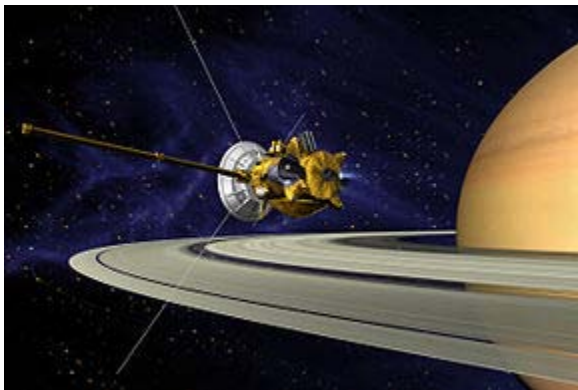
On **November 19, 2015**, *Voyager 1* is projected to be approximately 133.15 Astronomical Units from the Sun.

Information regarding updates about *Voyager 1* (as well as *Voyager 2*, *Pioneer 10*, *Pioneer 11* and *New Horizons*) are available online at [Spacecraft Escaping the Solar System](#) and [Weekly Mission Reports](#).

## Chapter- 3

# Cassini–Huygens

### Cassini–Huygens



Artist's concept of *Cassini's* Saturn Orbit Insertion  
maneuver

<b>Operator</b>	NASA / ESA / ASI
<b>Mission type</b>	Flyby, orbiter, lander
<b>Flyby of</b>	Venus, Moon, Earth, Masursky, Jupiter, Saturn's moons
<b>Satellite of</b>	Saturn
<b>Orbital insertion date</b>	2004-07-01 02:48:00 UTC
<b>Launch date</b>	1997-10-15 08:43:00 UTC (13 years, 4 months, and 9 days ago)
<b>Launch vehicle</b>	Titan IV-B / Centaur
<b>Launch site</b>	Space Launch Complex 40 Cape Canaveral Air Force Station

**In Progress** (Solstice)

(6 years, 7 months, and 23 days elapsed)

Venus<sup>1st</sup> flyby

(completed 1998-04-26)

Venus<sup>2nd</sup> flyby

(completed 1999-06-24)

Moon flyby

(completed 1999-08-18)

Earth flyby

(completed 1999-08-18)

**Mission duration**

Masursky flyby

(completed 2000-01-23)

Jupiter flyby

(completed 2000-12-30)

Huygens probe

(completed 2005-01-14)

Primary mission

(completed 2008-06-3-30)

Equinox mission

(completed 2010-09-27)

**COSPAR ID** 1997-061A

**Homepage** saturn.jpl.nasa.gov

**Mass** 2,523 kg (5,560 lb)

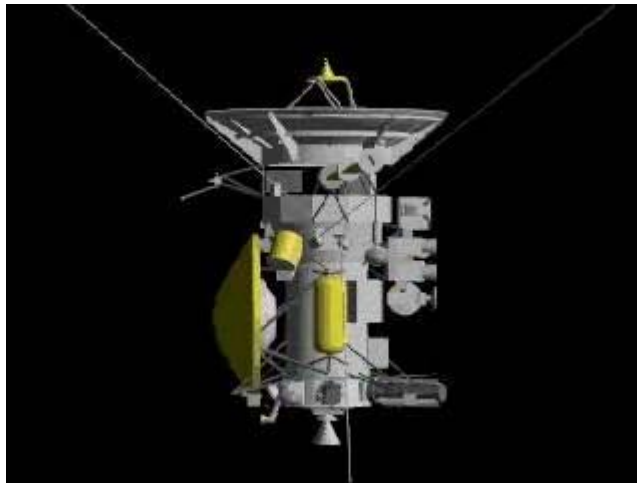
**Power** 640 W (3 RTGs)

***Cassini–Huygens*** is a joint NASA/ESA/ASI robotic spacecraft mission currently studying the planet Saturn and its many natural satellites. The spacecraft consists of two main elements: the NASA-designed and -constructed *Cassini* orbiter, named for the Italian-French astronomer Giovanni Domenico Cassini, and the ESA-developed *Huygens* probe, named for the Dutch astronomer, mathematician and physicist Christiaan Huygens. The complete *Cassini* space probe was launched on October 15, 1997, and after a long interplanetary voyage it entered into orbit around Saturn on July 1, 2004. On December 25, 2004, the *Huygens* probe was separated from the orbiter at approximately 02:00 UTC. It reached Saturn's moon Titan on January 14, 2005, when it descended into Titan's atmosphere, and downward to the surface, radioing scientific information back to the Earth by telemetry. This was the first landing ever accomplished in the outer solar system. On April 18, 2008, NASA announced a two-year extension of the funding for

ground operations of this mission, at which point it was renamed to **Cassini Equinox Mission**. This was again extended in February 2010 with the mission now continuing until 2017. *Cassini* is the fourth space probe to visit Saturn and the first to enter orbit.

16 European countries and the United States make up the team responsible for designing, building, flying and collecting data from the Cassini orbiter and Huygens probe. The mission is managed by NASA's Jet Propulsion Laboratory in the United States, where the orbiter was designed and assembled. Development of the Huygens Titan probe was managed by the European Space Research and Technology Centre, whose prime contractor for the probe was the Alcatel company in France. Equipment and instruments for the probe were supplied from many countries. The Italian Space Agency (ASI) provided the *Cassini* probe's high-gain radio antenna, and a compact and lightweight radar, which acts in multipurpose as a synthetic aperture radar, a radar altimeter, and a radiometer.

## Objectives



Satellite

*Cassini* has seven primary objectives:

1. Determine the three-dimensional structure and dynamic behavior of the rings of Saturn
2. Determine the composition of the satellite surfaces and the geological history of each object
3. Determine the nature and origin of the dark material on Iapetus's leading hemisphere
4. Measure the three-dimensional structure and dynamic behavior of the magnetosphere
5. Study the dynamic behavior of Saturn's atmosphere at cloud level
6. Study the time variability of Titan's clouds and hazes
7. Characterize Titan's surface on a regional scale

The *Cassini–Huygens* spacecraft was launched on October 15, 1997, from Cape Canaveral Air Force Station's Space Launch Complex 40 using a U.S. Air Force Titan IVB/Centaur rocket. The complete launcher was made up of a two-stage Titan IV booster rocket, two strap-on solid rocket motors, the Centaur upper stage, and a payload enclosure, or fairing.

The total cost of this scientific exploration mission is about US\$3.26 billion, including \$1.4 billion for pre-launch development, \$704 million for mission operations, \$54 million for tracking and \$422 million for the launch vehicle. The United States contributed \$2.6 billion (80%), the ESA \$500 million (15%), and the ASI \$160 million (5%).

The primary mission for *Cassini* ended on July 30, 2008. However, given the excellent condition of the orbiter, the mission was extended to the end of June 2010 (Cassini Equinox Mission). This studied the Saturn system in detail during Equinox, which happened in August 2009. On February 3, 2010, NASA announced another extension for Cassini, this one for 6½ years until 2017, the time of Summer Solstice in Saturn's Northern Hemisphere (Cassini Solstice Mission). The extension enables another 155 revolutions around the planet, 54 flybys of Titan and 11 flybys of Enceladus. In 2017, an encounter with Titan will change its orbit in such a way that, at closest approach to Saturn, it will be only 3,000km above the planet's cloudtops, below the inner edge of the D ring. This sequence of "proximal orbits" will end when another encounter with Titan sends the probe into Saturn's atmosphere.

## History



Launch occurred at 4:43 a.m. EDT (8:43 UTC) on October 15, 1997, from Space Launch Complex 40 at Cape Canaveral Air Force Station, Florida.

*Cassini-Huygens's* origins date to 1982, when the European Science Foundation and the American National Academy of Sciences formed a working group to investigate future cooperative missions. Two European scientists suggested a paired Saturn Orbiter and Titan Probe as a possible joint mission. In 1983, NASA's Solar System Exploration Committee recommended the same Orbiter and Probe pair as a core NASA project. NASA and the European Space Agency (ESA) performed a joint study of the potential mission from 1984 to 1985. ESA continued with its own study in 1986, while the

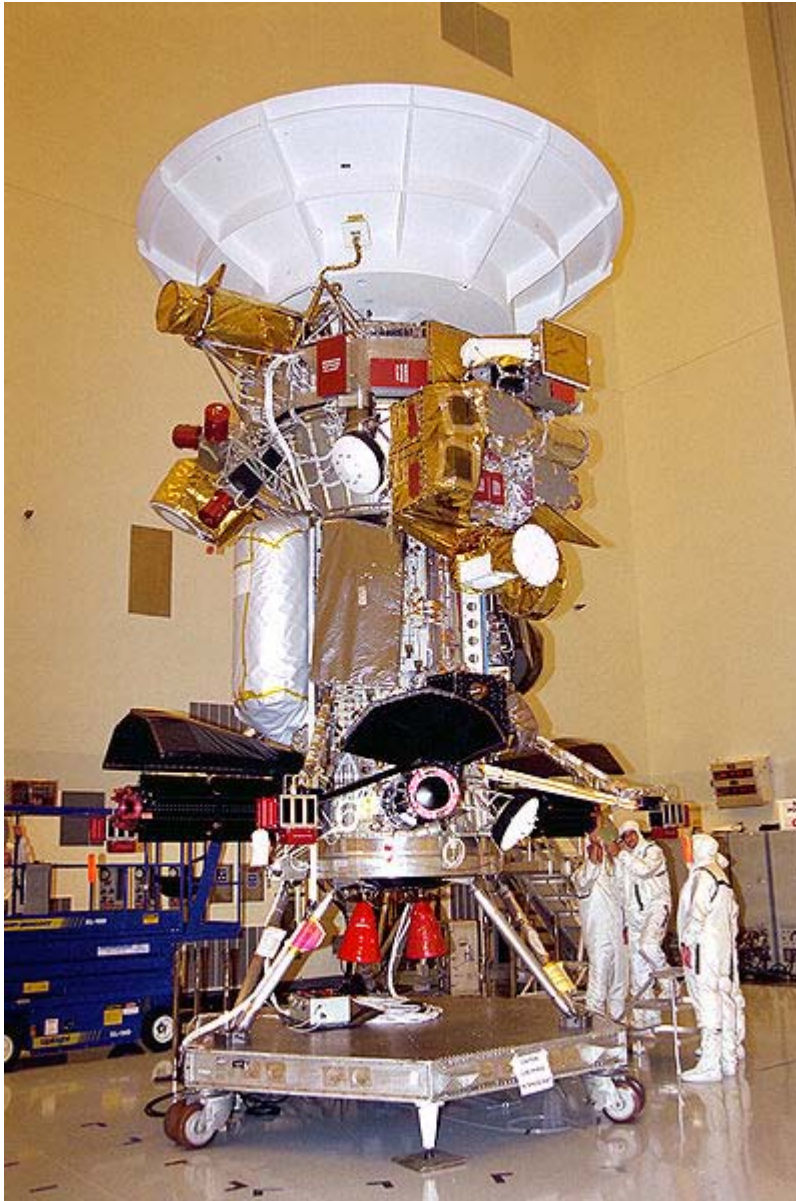
American astronaut Sally Ride, in her influential 1987 report "NASA Leadership and America's Future in Space", also examined and approved of the *Cassini* mission.

While Ride's report described the Saturn orbiter and probe as a NASA solo mission, in 1988 the Associate Administrator for Space Science and Applications of NASA Len Fisk returned to the idea of a joint NASA and ESA mission. He wrote to his counterpart at the ESA, Roger Bonnet, strongly suggesting that the ESA choose the *Cassini* mission from the three candidates at hand and promising that NASA would commit to the mission as soon as the ESA did.

At the time, NASA was becoming more sensitive to the strain that had developed between the American and European space programs as a result of European perceptions that NASA had not treated it like an equal during previous collaborations. NASA officials and advisers involved in promoting and planning *Cassini-Huygens* attempted to correct this trend by stressing their desire to evenly share any scientific and technology benefits resulting from the mission. In part, this newfound spirit of cooperation with Europe was driven by a sense of competition with the Soviet Union, which had begun to cooperate more closely with Europe as the ESA drew further away from NASA.

The collaboration not only improved relations between the two space programs but also helped *Cassini-Huygens* survive congressional budget cuts in the United States. *Cassini-Huygens* came under fire politically in both 1992 and 1994, but NASA successfully persuaded the U.S. Congress that it would be unwise to halt the project after the ESA had already poured funds into development because frustration on broken space exploration promises might spill over into other areas of foreign relations. The project proceeded politically smoothly after 1994, although citizens' groups concerned about its potential environmental impact attempted to derail it through protests and lawsuits until and past its 1997 launch.

## Spacecraft design



*Cassini* assembly

The spacecraft was originally planned to be the second three-axis stabilized, RTG-powered Mariner Mark II, a class of spacecraft developed for missions beyond the orbit of Mars. *Cassini* was being developed together with the *Comet Rendezvous Asteroid Flyby (CRAF)* spacecraft, but various budget cuts and rescopings of the project forced NASA to terminate *CRAF* development in order to save *Cassini*. As a result, the *Cassini* spacecraft became a more specialized design, canceling the implementation of the Mariner Mark II series.

The spacecraft, including the orbiter and the probe, is the largest and most complex interplanetary spacecraft built to date. The orbiter has a mass of 2,150 kg (4,700 lb), the probe 350 kg (770 lb). With the launch vehicle adapter and 3,132 kg (6,900 lb) of propellants at launch, the spacecraft had a mass of about 5,600 kg (12,000 lb). Only the two Phobos spacecraft sent to Mars by the Soviet Union were heavier. The *Cassini* spacecraft is more than 6.8 meters (22 ft) high and more than 4 meters (13 ft) wide. The complexity of the spacecraft is necessitated both by its trajectory (flight path) to Saturn, and by the ambitious program of scientific observations once the spacecraft reaches its destination. It functions with 1,630 interconnected electronic components, 22,000 wire connections, and over 14 kilometers (8.7 mi) of cabling.

Now that the *Cassini* probe is orbiting Saturn, it is between 8.2 and 10.2 astronomical units from the Earth. Because of this, it takes between 68 to 84 minutes for radio signals to travel from Earth to the spacecraft, and vice-versa. Thus, ground controllers cannot give "real-time" instructions to the spacecraft, either for day-to-day operations, or in cases of unexpected events. Even if they responded immediately after becoming aware of a problem, nearly three hours will have passed between the occurrence of the problem itself and the reception of the engineers' response by the satellite.

## **Instruments**

*Cassini's* instrumentation consists of: a synthetic aperture radar mapper, a charge-coupled device imaging system, a visible/infrared mapping spectrometer, a composite infrared spectrometer, a cosmic dust analyzer, a radio and plasma wave experiment, a plasma spectrometer, an ultraviolet imaging spectrograph, a magnetospheric imaging instrument, a magnetometer and an ion/neutral mass spectrometer. Telemetry from the communications antenna and other special transmitters (an S-band transmitter and a dual-frequency K<sub>a</sub>-band system) will also be used to make observations of the atmospheres of Titan and Saturn and to measure the gravity fields of the planet and its satellites.

### *Cassini* Plasma Spectrometer (CAPS)

The CAPS is a direct sensing instrument that measures the energy and electrical charge of particles that the instrument encounters, (the amount of electrons and protons in the particle). CAPS will measure the molecules originating from Saturn's ionosphere and also determine the configuration of Saturn's magnetic field. CAPS will also investigate plasma in these areas as well as the solar wind within Saturn's magnetosphere.

### Cosmic Dust Analyzer (CDA)

The CDA is a direct sensing instrument that measures the size, speed, and direction of tiny dust grains near Saturn. Some of these particles are orbiting Saturn, while others may come from other star systems. The CDA on the orbiter is designed to learn more about these mysterious particles, the materials in other celestial bodies and potentially about the origins of the universe.

### Composite Infrared Spectrometer (CIRS)

The CIRS is a remote sensing instrument that measures the infrared waves coming from objects to learn about their temperatures, thermal properties, and

compositions. Throughout the Cassini–Huygens mission, the CIRS will measure infrared emissions from atmospheres, rings and surfaces in the vast Saturn system. It will map the atmosphere of Saturn in three dimensions to determine temperature and pressure profiles with altitude, gas composition, and the distribution of aerosols and clouds. It will also measure thermal characteristics and the composition of satellite surfaces and rings.

#### Ion and Neutral Mass Spectrometer (INMS)

The INMS is a direct sensing instrument that analyzes charged particles (like protons and heavier ions) and neutral particles (like atoms) near Titan and Saturn to learn more about their atmospheres. INMS is intended also to measure the positive ion and neutral environments of Saturn's icy satellites and rings.

#### Imaging Science Subsystem (ISS)

The ISS is a remote sensing instrument that captures most images in visible light, and also some infrared images and ultraviolet images. The ISS has taken hundreds of thousands of images of Saturn, its rings, and its moons, for return to the Earth by radio telemetry. The ISS has a wide-angle camera (WAC) that takes pictures of large areas, and a narrow-angle camera (NAC) that takes pictures of small areas in fine detail. Each of these cameras uses a sensitive charge-coupled device (CCD) as its electromagnetic wave detector. Each CCD has a 1,024 square array of pixels, 12  $\mu\text{m}$  on a side. Both cameras allow for many data collection modes, including on-chip data compression. Both cameras are fitted with spectral filters that rotate on a wheel—to view different bands within the electromagnetic spectrum ranging from 0.2 to 1.1  $\mu\text{m}$ .

#### Dual Technique Magnetometer (MAG)

The MAG is a direct sensing instrument that measures the strength and direction of the magnetic field around Saturn. The magnetic fields are generated partly by the intensely hot molten core at Saturn's center. Measuring the magnetic field is one of the ways to probe the core, even though it is far too hot and deep to visit. MAG aims to develop a three-dimensional model of Saturn's magnetosphere, and determine the magnetic state of Titan and its atmosphere, and the icy satellites and their role in the magnetosphere of Saturn.

#### Magnetospheric Imaging Instrument (MIMI)

The MIMI is both a direct and remote sensing instrument that produces images and other data about the particles trapped in Saturn's huge magnetic field, or magnetosphere. This information will be used to study the overall configuration and dynamics of the magnetosphere and its interactions with the solar wind, Saturn's atmosphere, Titan, rings, and icy satellites.

#### Radar

The onboard radar is a remote active and remote passive sensing instrument that will produce maps of Titan's surface. It measures the height of surface objects (like mountains and canyons) by sending radio signals that bounce off Titan's surface and timing their return. Radio waves can penetrate the thick veil of haze surrounding Titan. The radar will listen for radio waves that Saturn or its moons may be producing.

#### Radio and Plasma Wave Science instrument (RPWS)

The RPWS is a direct and remote sensing instrument that receives and measures radio signals coming from Saturn, including the radio waves given off by the interaction of the solar wind with Saturn and Titan. RPWS is to measure the electric and magnetic wave fields in the interplanetary medium and planetary magnetospheres. It will also determine the electron density and temperature near Titan and in some regions of Saturn's magnetosphere. RPWS studies the configuration of Saturn's magnetic field and its relationship to Saturn Kilometric Radiation (SKR), as well as monitoring and mapping Saturn's ionosphere, plasma, and lightning from Saturn's (and possibly Titan's) atmosphere.

#### Radio Science Subsystem (RSS)

The RSS is a remote sensing instrument that uses radio antennas on Earth to observe the way radio signals from the spacecraft change as they are sent through objects, such as Titan's atmosphere or Saturn's rings, or even behind the Sun. The RSS also studies the compositions, pressures and temperatures of atmospheres and ionospheres, radial structure and particle size distribution within rings, body and system masses and gravitational waves. The instrument uses the spacecraft X-band communication link as well as S-band downlink and K<sub>a</sub>-band uplink and downlink.

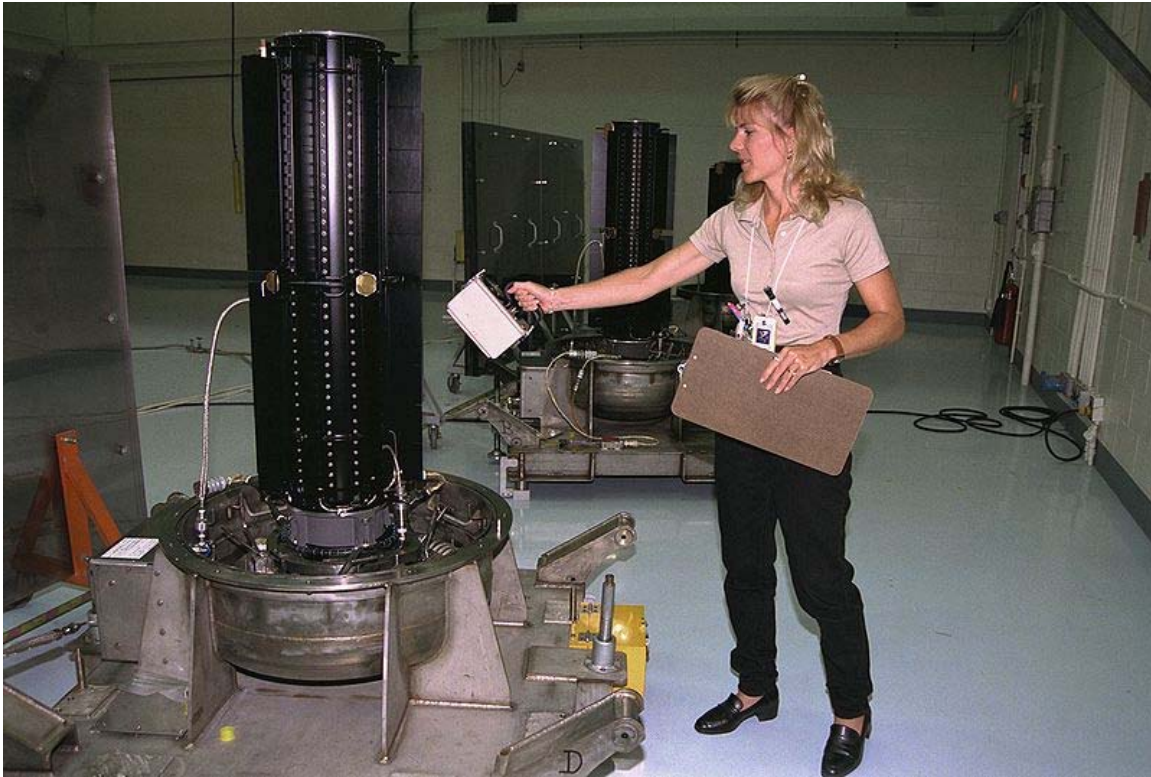
#### Ultraviolet Imaging Spectrograph (UVIS)

The UVIS is a remote sensing instrument that captures images of the ultraviolet light reflected off an object, such as the clouds of Saturn and/or its rings, to learn more about their structure and composition. Designed to measure ultraviolet light over wavelengths from 55.8 to 190 nm, this instrument is also a valuable tool to help determine the composition, distribution, aerosol particle content and temperatures of their atmospheres. Unlike other types of spectrometer, this sensitive instrument can take both spectral and spatial readings. It is particularly adept at determining the composition of gases. Spatial observations take a wide-by-narrow view, only one pixel tall and 64 pixels across. The spectral dimension is 1,024 pixels per spatial pixel. Also, it can take many images that create movies of the ways in which this material is moved around by other forces.

#### Visible and Infrared Mapping Spectrometer (VIMS)

The VIMS is a remote sensing instrument that captures images using visible and infrared light to learn more about the composition of moon surfaces, the rings, and the atmospheres of Saturn and Titan. It is made up of two cameras in one: one used to measure visible light, the other infrared. VIMS measures reflected and emitted radiation from atmospheres, rings and surfaces over wavelengths from 350 to 5100 nm, to help determine their compositions, temperatures and structures. It also observes the sunlight and starlight that passes through the rings to learn more about their structure. Scientists plan to use VIMS for long-term studies of cloud movement and morphology in the Saturn system, to determine Saturn's weather patterns.

## Plutonium power source



Inspection of *Cassini* spacecraft RTGs before launch

Because of Saturn's distance from the sun, solar arrays were not feasible as power sources for this space probe. To generate enough power, such arrays would have been too large and too heavy. Instead, the *Cassini* orbiter is powered by three radioisotope thermoelectric generators (RTGs), which use heat from the natural decay of plutonium-238 (in the form of plutonium dioxide) to generate direct current electricity via thermocouples. The RTGs on the *Cassini* mission have the same design as those used on the *New Horizons*, *Galileo* and *Ulysses* space probes, and they were designed to have very long operational lifetimes. At the end of the nominal 11-year *Cassini* mission, they will still be able to produce 600 to 700 watts of electrical power. (One of the spare RTGs for the *Cassini* mission was used to power the *New Horizons* mission to Pluto and the Kuiper belt, which was designed and launched later on.)

To gain interplanetary momentum while already in flight, the trajectory of the *Cassini* mission included several gravitational slingshot maneuvers: two fly-by passes of Venus, one more of the Earth, and then one of the planet Jupiter. The terrestrial fly-by was the final instance when the *Cassini* space probe posed any conceivable danger to human beings. This occurred successfully, with hundreds of miles to spare (the space probe passing 500 km above the Earth), on August 18, 1999. Had there been any malfunction that caused the *Cassini* space probe to collide with the Earth, NASA's complete

environmental impact study estimated that, in the worst case (with an acute angle of entry in which *Cassini* would gradually burn up), a significant fraction of the 32.7 kg of plutonium-238 inside the RTGs would have been dispersed into the Earth's atmosphere so that up to five billion people could have been exposed, causing an estimated 500,000 cancer deaths, but the odds against that happening were nearly ten million to one.

## ***Huygens* probe**

The *Huygens* probe, supplied by the European Space Agency (ESA) and named after the 17th century Dutch astronomer who first discovered Titan, Christiaan Huygens, scrutinized the clouds, atmosphere, and surface of Saturn's moon Titan in its descent on January 15, 2005. It was designed to enter and brake in Titan's atmosphere and parachute a fully instrumented robotic laboratory down to the surface.

The probe system consisted of the probe itself which descended to Titan, and the probe support equipment (PSE) which remained attached to the orbiting spacecraft. The PSE includes electronics that track the probe, recover the data gathered during its descent, and process and deliver the data to the orbiter that transmits it to Earth. The data was transmitted by a radio link between *Huygens* and *Cassini* provided by Probe Data Relay Subsystem (PDRS). As the probe's mission could not be telecommanded from Earth because of the great distance, it was automatically managed by the Command Data Management Subsystem (CDMS). The PDRS and CDMS were provided by the Italian Space Agency (ASI).

## Important events and discoveries

### Venus and Earth fly-bys and the cruise to Jupiter



Picture of the Moon during flyby

The *Cassini* space probe performed two gravitational-assist fly-bys of Venus on April 26, 1998, and June 24, 1999. These fly-bys provided the space probe with enough momentum to travel all the way out to the asteroid belt. At that point, the sun's gravity pulled the space probe back into the inner solar system, where it made a gravitational-assist fly-by of the Earth.

On August 18, 1999, at 03:28 UTC, the *Cassini* craft made a gravitational-assist flyby of the Earth. One hour and 20 minutes before closest approach, *Cassini* made the closest

approach to the Earth's Moon at 377,000 kilometers, and it took a series of calibration photos.

On Jan. 23, 2000, the *Cassini* space probe performed a fly-by of the asteroid 2685 Masursky at around 10:00 UTC. The *Cassini* craft took photos in the period five to seven hours before the fly-by at a distance of 1.6 million kilometers, and a diameter of 15 to 20 km was estimated for the asteroid.

### **Jupiter flyby**



Jupiter flyby picture

*Cassini* made its closest approach to Jupiter on December 30, 2000, and made many scientific measurements. About 26,000 images of Jupiter were taken during the months-long flyby. It produced the most detailed global color portrait of Jupiter yet, in which the smallest visible features are approximately 60 km (40 miles) across.

The *New Horizons* mission to Pluto captured more recent images of Jupiter, with a closest approach on February 28, 2007.

A major finding of the flyby, announced on March 6, 2003, was of Jupiter's atmospheric circulation. Dark "belts" alternate with light "zones" in the atmosphere, and scientists had long considered the zones, with their pale clouds, to be areas of upwelling air, partly because many clouds on Earth form where air is rising. But analysis of *Cassini* imagery showed that individual storm cells of upwelling bright-white clouds, too small to see from Earth, pop up almost without exception in the dark belts. According to Anthony Del Genio of NASA's Goddard Institute for Space Studies, "the belts must be the areas of net-rising atmospheric motion on Jupiter, [so] the net motion in the zones has to be sinking."

Other atmospheric observations included a swirling dark oval of high atmospheric-haze, about the size of the Great Red Spot, near Jupiter's north pole. Infrared imagery revealed aspects of circulation near the poles, with bands of globe-encircling winds, with adjacent bands moving in opposite directions.

The same announcement also discussed the nature of Jupiter's rings. Light scattering by particles in the rings showed the particles were irregularly shaped (rather than spherical) and likely originate as ejecta from micrometeorite impacts on Jupiter's moons, probably Metis and Adrastea.

## **Tests of Einstein's Theory of General Relativity**

On October 10, 2003, the *Cassini* science team announced the results of tests of Einstein's Theory of General Relativity, which were done by using radio waves that were transmitted from the *Cassini* space probe.

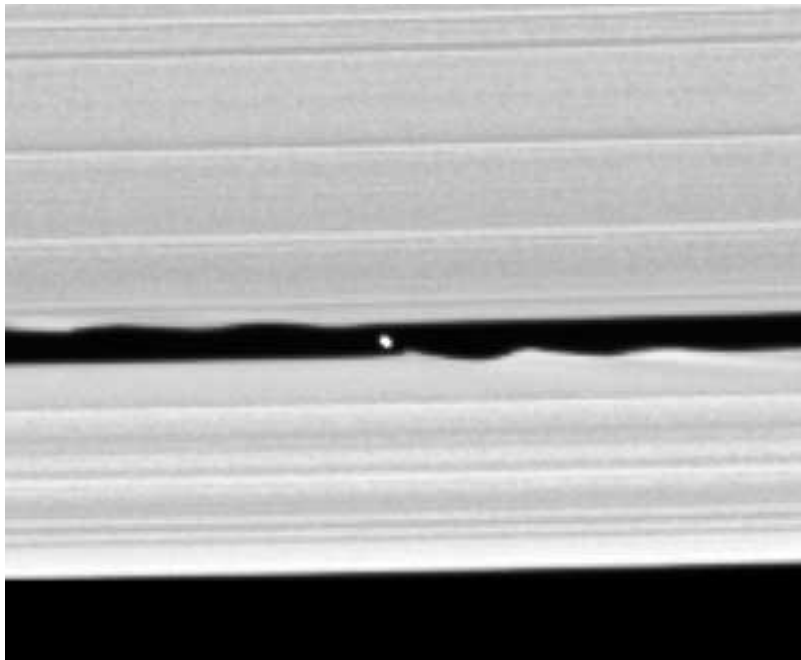
The radio scientists measured a frequency shift in the radio waves to and from the spacecraft, while those signals traveled close to the sun. According to the Theory of General Relativity, a massive object like the sun causes space-time to curve, and a beam of radio waves (or light, or any form of electromagnetic radiation) that passes by the sun has to travel farther because of the curvature.

The extra distance that the radio waves traveled from the *Cassini* craft, past the sun, to the Earth delays their arrival. The amount of this time delay provides a sensitive test of the calculated predictions of Einstein's Relativity Theory.

Although some measurable deviations from the values that are calculated using the General Theory of Relativity are predicted by some unusual cosmological models, none of these deviations were found by this experiment. Previous tests using radio waves that

were transmitted by the *Viking* and *Voyager* space probes were in agreement with the calculated values from General Relativity to within an accuracy of one part in one thousand. The more refined measurements from the *Cassini* space probe experiment improved this accuracy to about one part in 50,000, with the measured data firmly supporting Einstein's General Theory of Relativity.

### **New moons of Saturn**



Discovery photograph of moon Daphnis

Using images taken by *Cassini*, three new moons of Saturn were discovered in 2004. They are very small and were given the provisional names S/2004 S 1, S/2004 S 2 and S/2004 S 5 before being named Methone, Pallene and Polydeuces at the beginning of 2005.

On May 1, 2005, a new moon was discovered by *Cassini* in the Keeler gap. It was given the designation S/2005 S 1 before being named Daphnis. The only other known moon inside Saturn's ring system is Pan.



Image of Phoebe

A press release on February 3, 2009 shows yet a 6th new moon found by the Cassini Spacecraft. The moon is approximately 1/3 of a mile long in the G-ring of the ring system of Saturn, now named Aegaeon.

A press release on November 2, 2009 mentions the 7th new moon found by the Cassini Spacecraft on July 26, 2009. It is presently labeled S/2009 S 1 and is approximately 300 m (984 ft.) in diameter in the B-ring system.

## **Phoebe flyby**

On June 11, 2004, *Cassini* flew by the moon Phoebe. This was the first opportunity for close-up studies of this moon since the *Voyager 2* flyby. It also was *Cassini's* only possible flyby for Phoebe due to the mechanics of the available orbits around Saturn.

First close-up images were received on June 12, 2004, and mission scientists immediately realized that the surface of Phoebe looks different from asteroids visited by spacecraft. Parts of the heavily cratered surfaces look very bright in those pictures, and it is currently believed that a large amount of water ice exists under its immediate surface.

## **Saturn rotation**

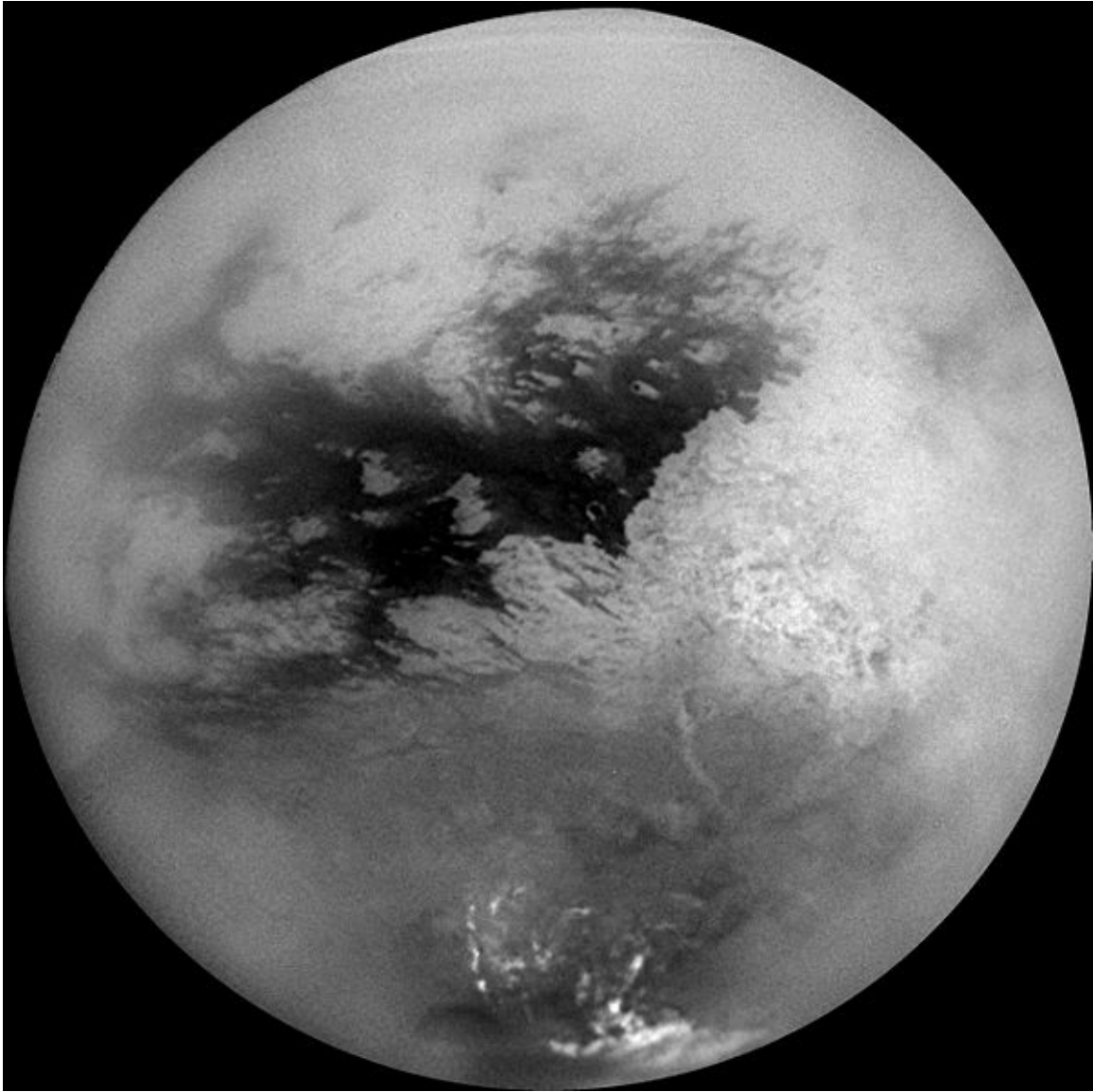
In an announcement on June 28, 2004, *Cassini* program scientists described the measurement of the rotational period of Saturn. Since there are no fixed features on the surface that can be used to obtain this period, the repetition of radio emissions was used. These new data agree with the latest values measured from Earth, and constitute a puzzle to the scientists. It turns out that the radio rotational period has changed since it was first measured in 1980 by *Voyager*, and that it is now 6 minutes longer. This does not indicate a change in the overall spin of the planet, but is thought to be due to movement of the source of the radio emissions to a different latitude, at which the rotation rate is different.

## **Orbiting Saturn**

On July 1, 2004, the spacecraft flew through the gap between the F and G rings and achieved orbit, after a seven year voyage. It is the first spacecraft to ever orbit Saturn.

The Saturn Orbital Insertion (SOI) maneuver performed by *Cassini* was complex, requiring the craft to orient its High-Gain Antenna away from Earth and along its flight path, to shield its instruments from particles in Saturn's rings. Once the craft crossed the ring plane, it had to rotate again to point its engine along its flight path, and then the engine fired to decelerate the craft by 622 meters per second to allow Saturn to capture it. *Cassini* was captured by Saturn's gravity at around 8:54 p.m. Pacific Daylight Time on June 30, 2004. During the maneuver *Cassini* passed within 20,000 km (13,000 miles) of Saturn's cloud tops.

## Titan flybys

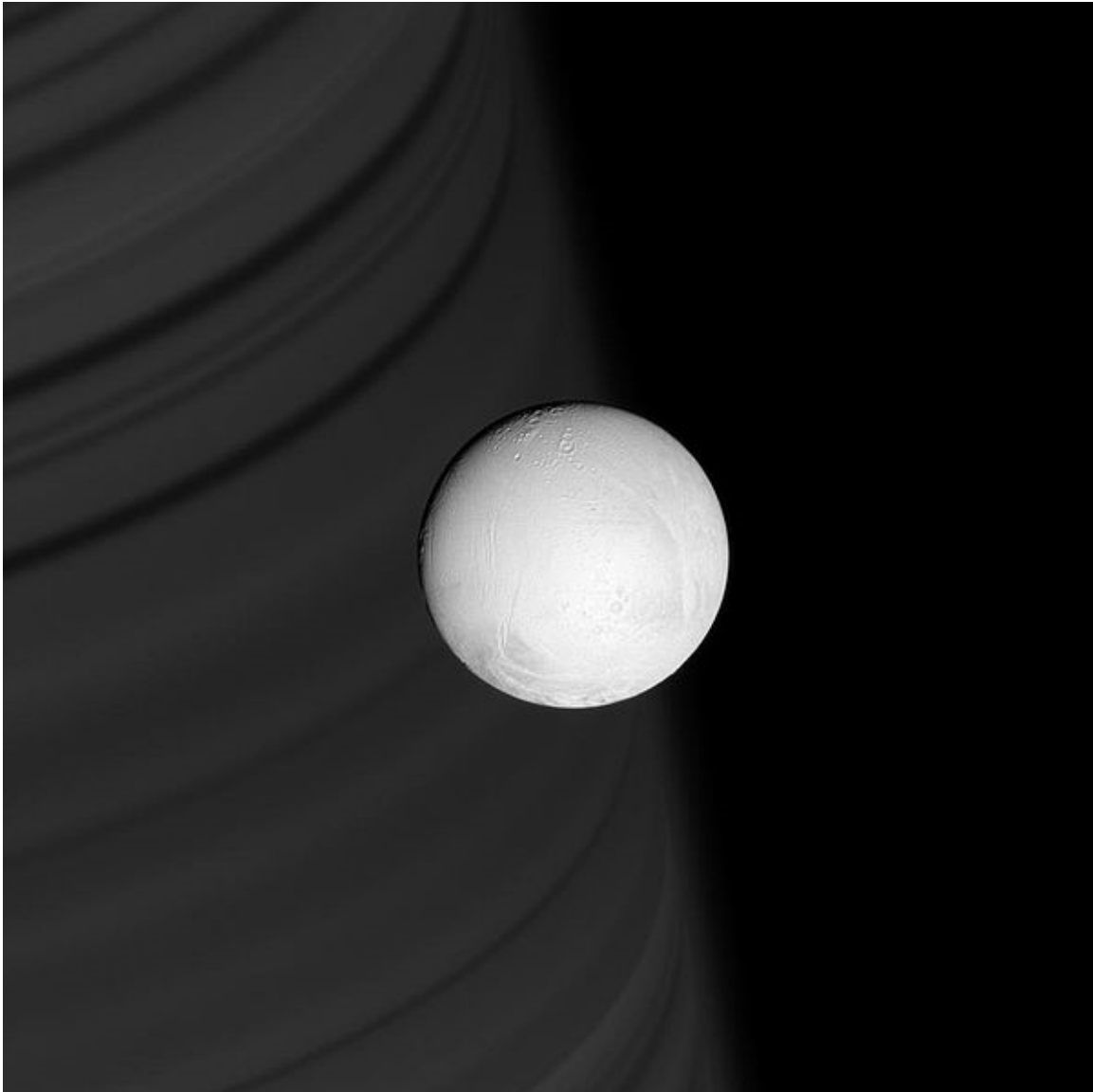


Titan's surface

*Cassini* had its first distant flyby of Saturn's largest moon, Titan, on July 2, 2004, only a day after orbit insertion, when it approached to within 339,000 km (211,000 mi) of Titan and provided the best look at the moon's surface to date. Images taken through special filters showed south polar clouds thought to be composed of methane and surface features with widely differing brightness. On October 27, 2004, the spacecraft executed the first of the 45 planned close flybys of Titan when it flew a mere 1,200 kilometers above the moon. Almost four gigabits of data were collected and transmitted to Earth, including the first radar images of the moon's haze-enshrouded surface. It revealed the surface of Titan (at least the area covered by radar) to be relatively level, with topography reaching no more than about 50 meters in altitude. The flyby provided a remarkable

increase in imaging resolution over previous coverage. Images with up to 100 times better "resolution" were taken and are typical of resolutions planned for subsequent Titan flybys. (Note that "resolution" refers to the clarity and precision of pictures, and that it has nothing to do with the overall size of the pictures in square centimeters, as is very commonly erroneously stated.)

### ***Huygens'* encounter with Titan**



Enceladus backdropped by Saturn's ring shadows

*Cassini* released the *Huygens* probe on December 25, 2004, by means of a spring. It entered the atmosphere of Titan on January 14, 2005, and after a two-and-a-half-hour descent landed on solid ground with no liquids in view. Although *Cassini* successfully relayed 350 of the pictures that it received from *Huygens* of its descent and landing site, a

software error failed to turn on one of the Cassini receivers and caused the loss of the other 350 pictures.

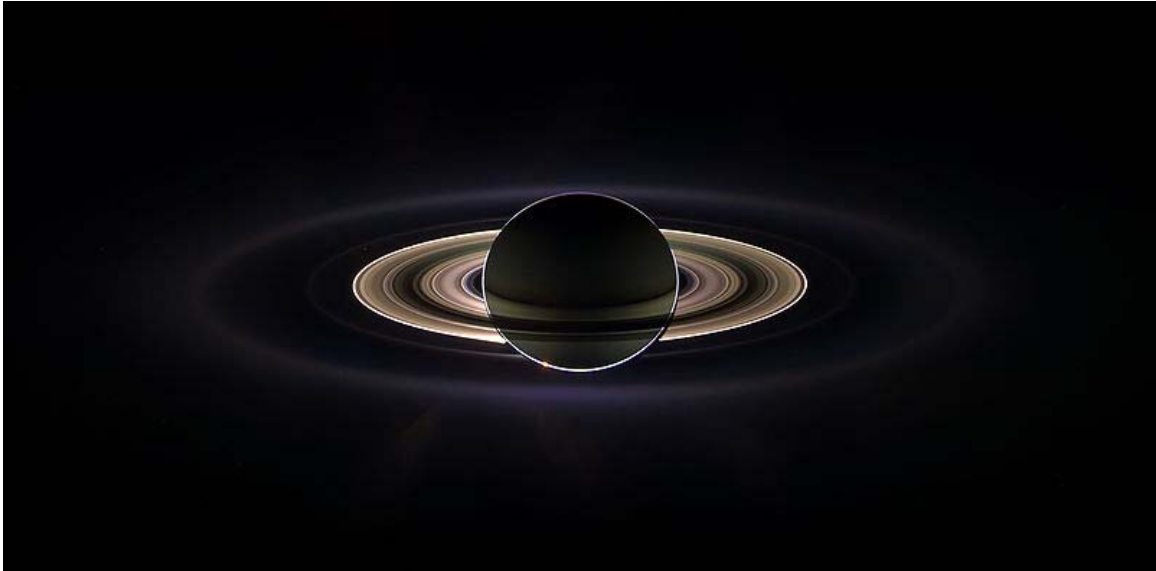
## **Enceladus flybys**

During the first two close flybys of the moon Enceladus in 2005, *Cassini* discovered a "deflection" in the local magnetic field that is characteristic for the existence of a thin but significant atmosphere. Other measurements obtained at that time point to ionized water vapor as being its main constituent. *Cassini* also observed water ice geysers erupting from the south pole of Enceladus, which gives more credibility to the idea that Enceladus is supplying the particles of Saturn's E ring. Mission scientists hypothesize that there may be pockets of liquid water near the surface of the moon that fuel the eruptions, making Enceladus one of the few bodies in our solar system to contain liquid water.

On March 12, 2008, *Cassini* made a close fly-by of Enceladus, getting within 50 km of the moon's surface. The spacecraft passed through the plumes extending from its southern geysers, detecting water, carbon dioxide and various hydrocarbons with its mass spectrometer, while also mapping surface features that are at much higher temperature than their surroundings with the infrared spectrometer. *Cassini* was unable to collect data with its cosmic dust analyzer due to an unknown software malfunction.

On November 21 Cassini again made a fly by of Enceladus, this time with a very different geometry, approaching within 1,600 kilometers (1000 miles) of the surface. The Composit Infrared Spectrograph (CIRS) instrument will make a map of thermal emissions from the tiger stripe Baghdad Sulcus. This is the eighth flyby of Enceladus and is also sometimes referred to as "E-8." The data and images returned will help to create the most-detailed-yet mosaic image of the southern part of the moon's Saturn-facing hemisphere and a contiguous thermal map of one of the intriguing "tiger stripe" features, with the highest resolution to date.

## Radio occultations of Saturn's rings



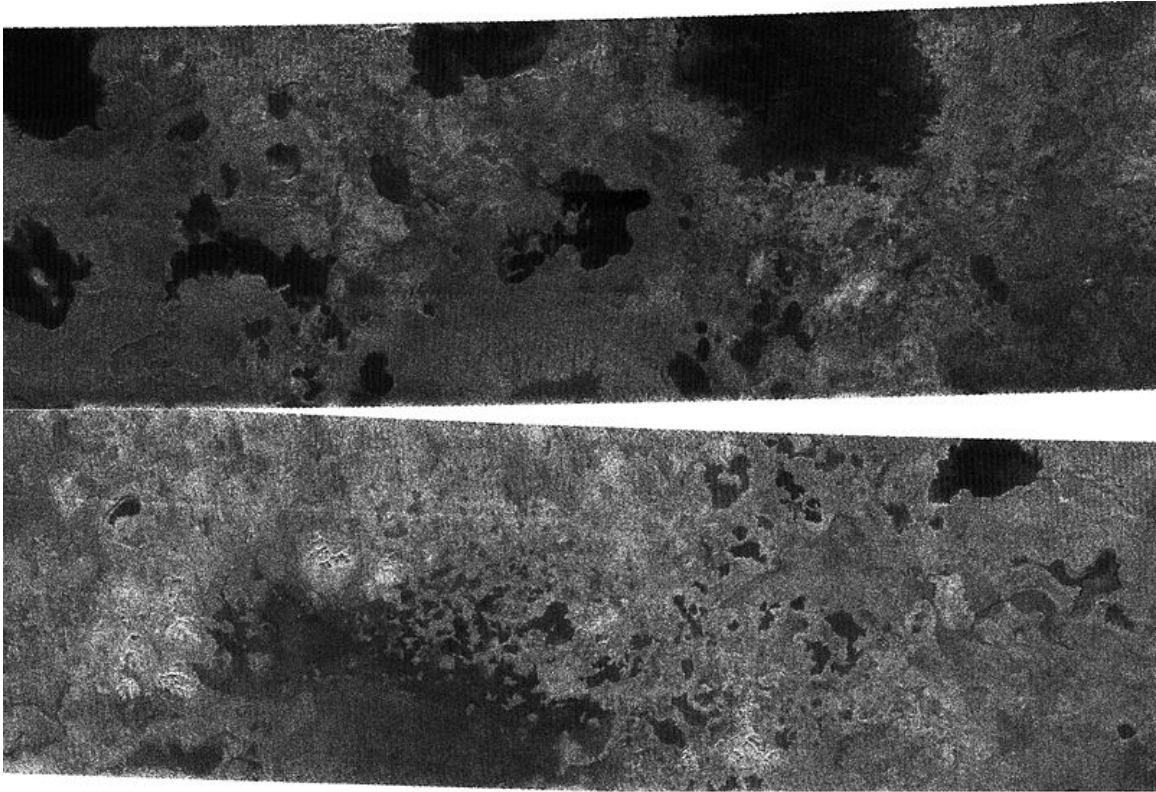
An eclipse of Saturn with the rings visible, taken in 2006

In May 2005, *Cassini* began a series of occultation experiments, to measure the size-distribution of particles in Saturn's rings, and measure the atmosphere of Saturn itself. For over 4 months, *Cassini* completed orbits designed for this purpose. During these experiments, *Cassini* flew behind the ring plane of Saturn, as seen from Earth, and transmitted radio waves through the particles. The radio signals were received on Earth, where the frequency, phase, and power of the signal was analyzed to help determine the structure of the rings.

### Spoke phenomenon verified

In images captured September 5, 2005, *Cassini* detected spokes in Saturn's rings, previously seen only by the visual observer Stephen James O'Meara in 1977 and then confirmed by the *Voyager* space probes in the early 1980s.

## Lakes of Titan



## Lakes of Titan

Radar images obtained on July 21, 2006 appear to show lakes of liquid hydrocarbon (such as methane and ethane) in Titan's northern latitudes. This is the first discovery of currently-existing lakes anywhere besides Earth. The lakes range in size from about a kilometer to one which is one hundred kilometers across.



Titan "sea" (left) compared at scale to Lake Superior (right)

On March 13, 2007, the Jet Propulsion Laboratory announced that it found strong evidence of seas of methane and ethane in the northern hemisphere of Titan. At least one of these is larger than any of the Great Lakes in North America.

### **Saturn hurricane**

In November 2006, scientists discovered a storm at the south pole of Saturn with a distinct eyewall. This is characteristic of a hurricane on Earth and had never been seen on another planet before. Unlike a terran hurricane, the storm appears to be stationary at the pole. The storm is 8,000 kilometers (5,000 mi) across, and 70 kilometres (43 mi) high, with winds blowing at 560 kilometers per hour (350 mph).

### **Iapetus flyby**

On September 10, 2007, *Cassini* completed its flyby of the strange, two-toned, walnut-shaped moon, Iapetus. Images were taken from 1,000 miles (1,600 km) above the surface. As it was sending the images back to Earth, it was hit by a cosmic ray which forced it to temporarily enter safe mode. All of the data from the flyby was recovered.

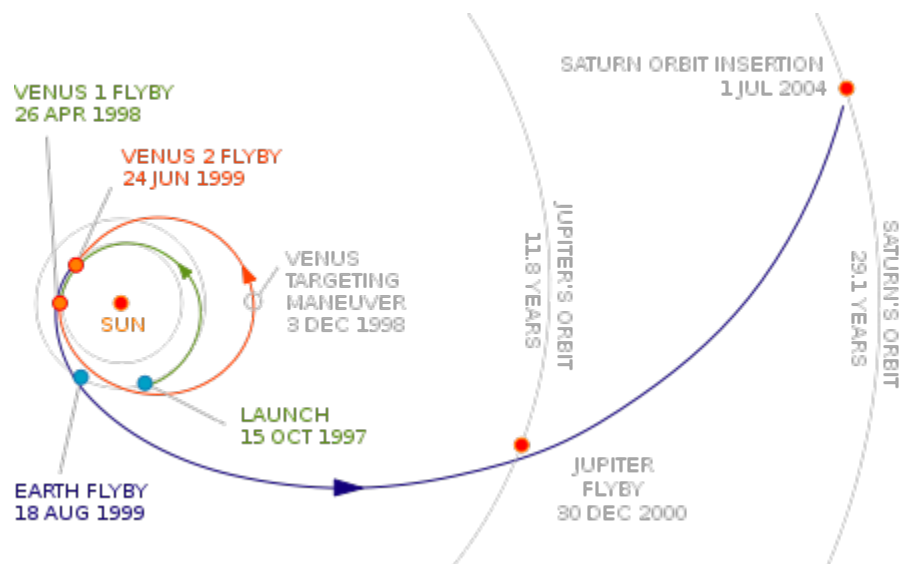
### **Mission extension**

On April 15, 2008, Cassini received funding for a two-year extended mission. It consists of 60 more orbits of Saturn, and includes 21 more Titan flybys, seven of Enceladus, six of Mimas, eight of Tethys, and one targeted flyby each of Dione, Rhea, and Helene. The

extended mission began on July 1, 2008, and has since been renamed the Cassini Equinox Mission as the mission coincides with Saturn's equinox. A proposal was submitted to NASA for a second mission extension, provisionally named the extended-extended mission or XXM. This was subsequently approved and renamed the Cassini Solstice Mission. It will see Cassini orbiting Saturn 155 more times, conducting 54 additional flybys of Titan and 11 more of Enceladus. The mission will end with a fiery plunge into the Saturn atmosphere around its 2017 northern summer solstice, safely disposing of the spacecraft without risk of biocontamination to the Saturnian moons.

On November 2, 2010, Cassini was triggered into a protective standby mode, or "safe mode", after a bit flip caused it to miss an important instruction. NASA announced the interruption in scientific processes on November 8. However, by November 8 some of the craft's functionality had already been partly restored. Nominal scientific instrument sequencing events were successfully started on November 10. Cassini was reactivated as scheduled on November 24 and has returned to perfect working order, in time for two scheduled close fly-bys with Enceladus. At this point there has been no public disclosure as to the data loss impact of the November 11 (T-73) flyby. However, no images were acquired at the 11 November polar flyby.

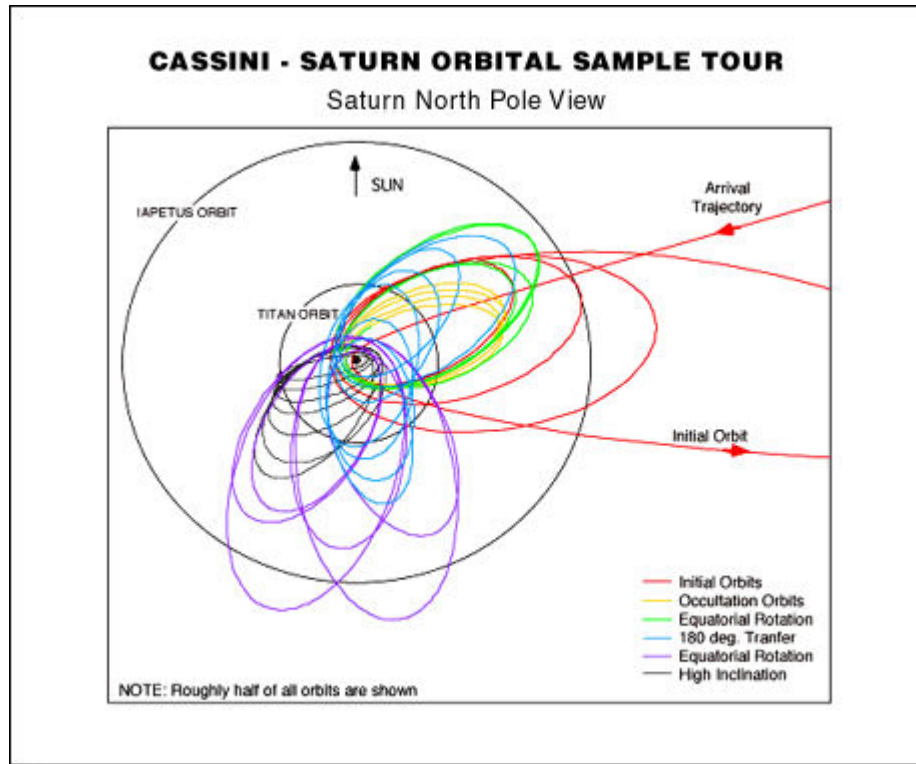
## Trajectory



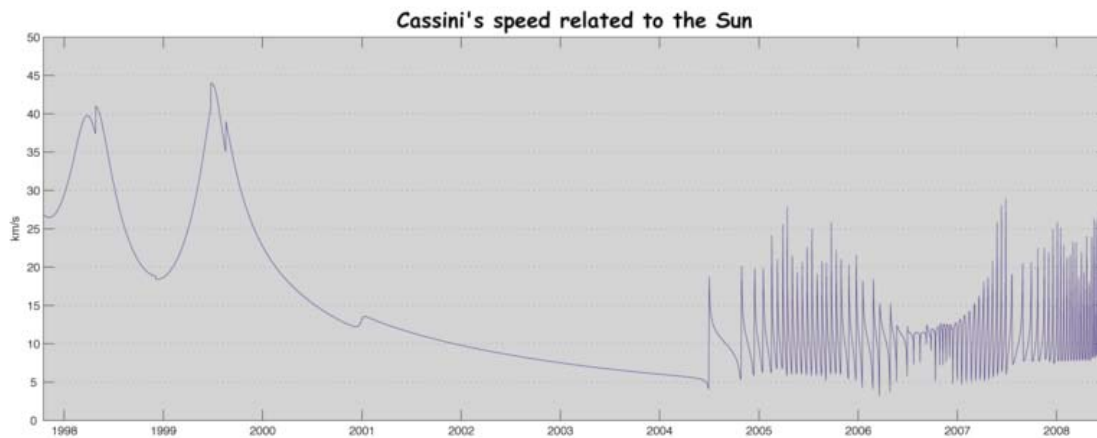
The initial gravitational-assist trajectory of *Cassini-Huygens*

The initial gravitational-assist trajectory of *Cassini-Huygens* is the process whereby an insignificant mass approaches a significant mass "from behind" and "steals" some of its orbital momentum. The significant mass, usually a planet, loses a very small proportion of its orbital momentum to the insignificant mass, the space probe in this case. However, due to the space probe's small mass, this momentum transfer gives it a relatively large momentum increase in proportion to its initial momentum, speeding up its travel through outer space.

The *Cassini–Huygens* space probe performed two gravitational assist fly-bys at Venus, one more fly-by at the Earth, and a final fly-by at Jupiter.



Simplified diagram which shows, in two dimensions, the orbital motion of *Cassini–Huygens* on and after arrival at Saturn



The *Cassini* craft's speed relative to the Sun. The various gravitational slingshots form visible peaks on the left, while the periodic variation on the right is caused by the

spacecraft's orbit around Saturn. The data came from the JPL Horizons Ephemeris System in 2005. The speed above is instantaneous velocity in kilometers per second. The date/time is UTC in Spacecraft Event Time, which is from 1997-Oct-16 00:00:01 to 2008-Jul-06 23:59:59 UTC, with two leap seconds during this period. Note also that the minimum velocity achieved during its Saturnian orbit is more or less equal to Saturn's own orbital velocity, which is the ~5.0 km/sec. velocity which the *Cassini* craft matched to enter orbit!

## Chapter- 4

# Voyager 2

### Voyager 2



*Voyager* spacecraft

<b>Operator</b>	NASA / JPL
<b>Mission type</b>	Flyby
<b>Flyby of</b>	Jupiter, Saturn, Uranus, Neptune
<b>Launch date</b>	1977-08-20 14:29:00 UTC (33 years, 6 months, and 4 days ago)
<b>Launch vehicle</b>	Titan IIIE / Centaur
<b>Launch site</b>	Space Launch Complex 41 Cape Canaveral Air Force Station
<b>Mission duration</b>	In Progress (Interstellar mission)

(31 years, 7 months, and 15 days elapsed)

Jupiter flyby

*(completed 1979-08-05)*

Saturn flyby

*(completed 1981-09-25)*

Uranus flyby

*(completed 1986-02-25)*

Neptune flyby

*(completed 1989-10-02)*

<b>COSPAR ID</b>	1977-076A
<b>Homepage</b>	NASA <i>Voyager</i> website
<b>Mass</b>	721.9 kg (1,592 lb)
<b>Power</b>	420 W (3 RTGs)

The *Voyager 2* spacecraft is a 722-kilogram (1,592 lb) robotic space probe launched by NASA on August 20, 1977 to study the outer Solar System and eventually interstellar space. Operating for 33 years, 6 months, and 4 days as of today's date (24 February 2011), the spacecraft receives routine commands and transmits data back to the Deep Space Network. Currently in extended mission, the spacecraft is tasked with locating and studying the boundaries of the Solar System, including the Kuiper belt, the heliosphere and interstellar space. The primary mission ended December 31, 1989 after encountering the Jovian system in 1979, Saturnian system in 1980, Uranian system in 1986, and the Neptunian system in 1989. It was the first probe to provide detailed images of the outer ice giants.

## Mission background

### History

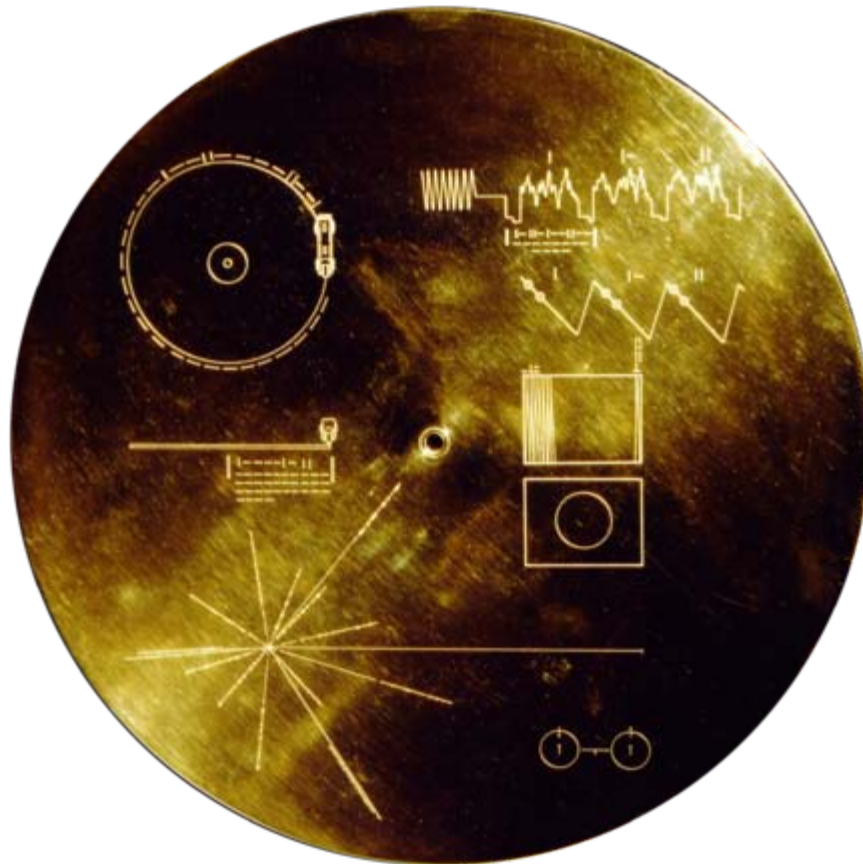
Conceived in the 1960s, a Grand Tour proposal to study the outer planets, prompted NASA to begin work on a mission in the early 1970s. The development of the interplanetary probes coincided with an alignment of the planets, making possible a mission to the outer Solar System by taking advantage of the then-new technique of gravity assist.

It was determined that utilizing gravity assists would enable a single probe to visit the four gas giants (Jupiter, Saturn, Uranus, and Neptune) while requiring a minimal amount of propellant and a shorter transit duration between planets. Originally, *Voyager 2* was

planned as *Mariner 12* of the Mariner program however, due to congressional budget cuts, the mission was scaled back to be a flyby of Jupiter and Saturn, and renamed the Mariner Jupiter-Saturn probes. As the program progressed, the name was later changed to Voyager as the probe designs began to differ greatly from previous Mariner missions.

Upon a successful flyby of the Saturnian moon Titan, by Voyager 1, *Voyager 2* would get a mission extension to send the probe on towards Uranus and Neptune.

### **Golden record**



Each *Voyager* space probe carries a gold-plated audio-visual disc in the event that either spacecraft is ever found by intelligent life-forms from other planetary systems. The discs carry photos of the Earth and its lifeforms, a range of scientific information, spoken

greetings from the people (e.g. the Secretary-General of the United Nations and the President of the United States, and the children of the Planet Earth) and a medley, "Sounds of Earth", that includes the sounds of whales, a baby crying, waves breaking on a shore, and a variety of music.

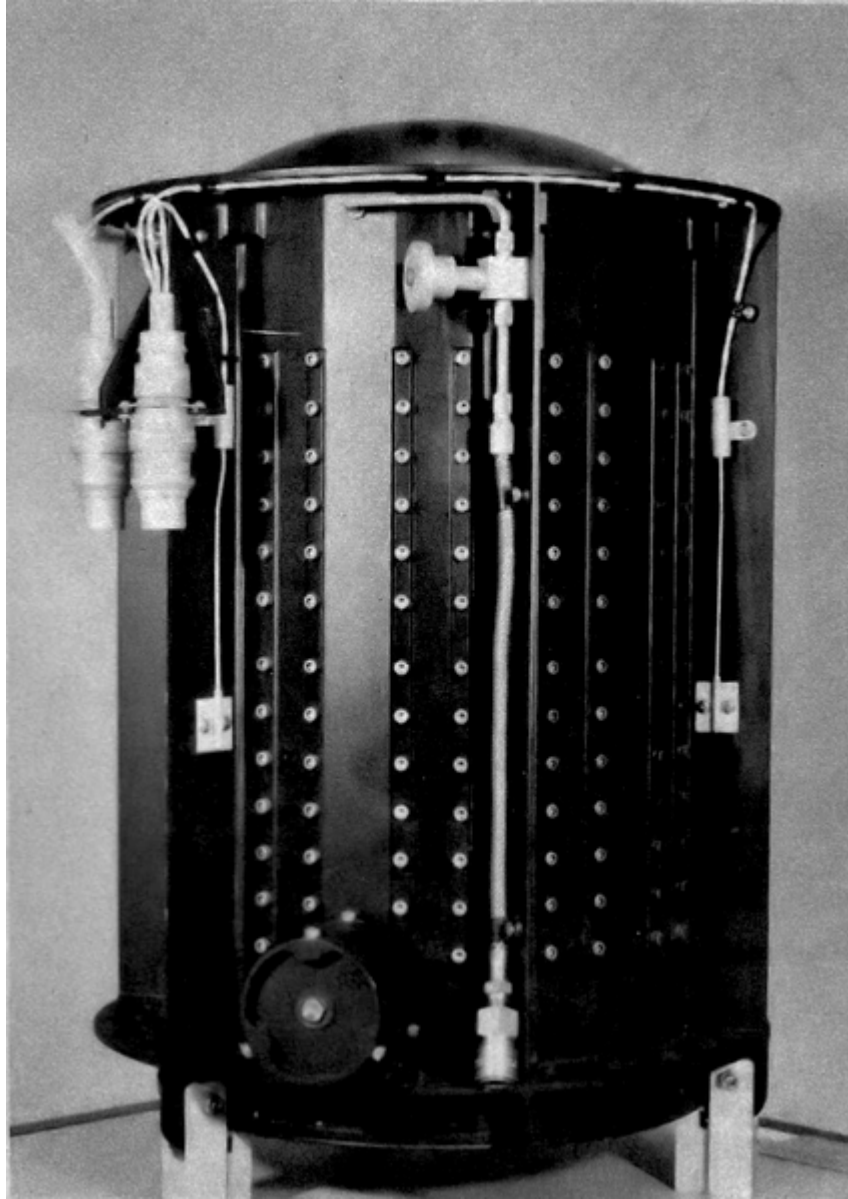
## **Spacecraft design**

Constructed by the Jet Propulsion Laboratory, *Voyager 2* included 16 hydrazine thrusters, three-axis stabilization, gyroscopes and celestial referencing instruments (sun sensor/Canopus Star Tracker) to maintain pointing of the high-gain antenna toward Earth. Collectively these instruments are part of the Attitude and Articulation Control Subsystem (**AACS**) along with redundant units of most instruments and 8 backup thrusters. The spacecraft also included 11 scientific instruments to study celestial objects as it traveled through space.

## **Communications**

Built with the intent for eventual interstellar travel, *Voyager 2* included a large, 3.7-meter parabolic, high-gain antenna (*see diagram*) to transceive data with the Deep Space Network on Earth. Communications are conducted over the S-band (13 cm wavelength) and X-band (3.6 cm wavelength) providing bandwidth as high as 115.2 kilobits per second. When the spacecraft is unable to communicate with Earth, the Digital Tape Recorder (**DTR**) is able to record up to 62,500-kilobytes of data to later transmit when communication is reestablished.

## Power



The spacecraft was built with 3 Multihundred-Watt radioisotope thermoelectric generators (**MHW RTG**). Each RTG includes 24 pressed plutonium oxide spheres and provide enough heat to generate approximately 157 Watts of power at launch. Collectively, the RTGs supply the spacecraft with 470 Watts at launch and will allow operations to continue until at least 2025. (*see diagram 1, 2*)

## Scientific instruments

Expand

Instrument Name	Abr.	Description
Imaging Science	(ISS)	Utilizes a two-camera system (narrow-angle/wide-angle) to provide imagery of Jupiter, Saturn

System and other objects along the trajectory.

**Filters**

Narrow Angle Camera Filters				Wide Angle Camera Filters			
Name	Wavelength	Spectrum	Sensitivity	Name	Wavelength	Spectrum	Sensitivity
Clear	280nm - 640nm			Clear	280nm - 640nm		
UV	280nm - 370nm			,	,		,
Violet	350nm - 450nm			Violet	350nm - 450nm		
Blue	430nm - 530nm			Blue	430nm - 530nm		
,	,		,	CH <sub>4</sub> -U	536nm - 546nm		
Green	530nm - 640nm			Green	530nm - 640nm		
,	,		,	Na-D	588nm - 590nm		
Orange	590nm - 640nm			Orange	590nm - 640nm		
,	,		,	CH <sub>4</sub> -JST	614nm - 624nm		

- **Principal investigator:** Bradford Smith / University of Arizona (PDS/PRN website)
- **Data:** PDS/PDI data catalog, PDS/PRN data catalog

Utilized the telecommunications system of the Voyager spacecraft to determine the physical properties of planets and satellites (ionospheres, atmospheres, masses, gravity fields, densities) and the amount and size distribution of material in Saturn's rings and the ring dimensions.

Radio Science System

(RSS)

- **Principal investigator:** G. Tyler / Stanford University PDS/PRN overview
- **Data:** PDS/PPI data catalog, PDS/PRN data catalog (VG\_2803), NSSDC Saturn data archive

Investigates both global and local energy balance and atmospheric composition. Vertical temperature profiles are also obtained from the planets and satellites as well as the composition, thermal properties, and size of particles in Saturn's rings.

Infrared Interferometer Spectrometer (disabled)

(IRIS)

- **Principal investigator:** Rudolf Hanel / NASA Goddard Space Flight Center (PDS/PRN website)
- **Data:** PDS/PRN data catalog, PDS/PRN expanded data catalog (VGIRIS\_0001, VGIRIS\_002)

Designed to measure atmospheric properties, and to measure radiation.

Ultraviolet Spectrometer (disabled)

(UVS)

- **Principal investigator:** A. Broadfoot / University of Southern California (PDS/PRN website)
- **Data:** PDS/PRN data catalog

Triaxial Fluxgate Magnetometer (active)

(MAG)

Designed to investigate the magnetic fields of Jupiter and Saturn, the solar-wind interaction with the magnetospheres of these planets, and the interplanetary magnetic field out to the solar wind boundary with the interstellar magnetic field and beyond, if crossed.

- **Principal investigator:** Norman Ness / NASA Goddard Space Flight Center (website)

- **Data:** PDS/PPI data catalog, NSSDC data archive

Investigates the macroscopic properties of the plasma ions and measures electrons in the energy range from 5 eV to 1 keV.

Plasma Spectrometer  
(active) (PLS)

- **Principal investigator:** John Richardson / MIT (website)
- **Data:** PDS/PPI data catalog, NSSDC data archive

Measures the differential in energy fluxes and angular distributions of ions, electrons and the differential in energy ion composition.

Low Energy  
Charged Particle  
Instrument  
(active) (LECP)

- **Principal investigator:** Stamatios Krimigis / JHU/APL / University of Maryland (JHU/APL website / UMD website / KU website)
- **Data:** UMD data plotting, PDS/PPI data catalog, NSSDC data archive

Determines the origin and acceleration process, life history, and dynamic contribution of interstellar cosmic rays, the nucleosynthesis of elements in cosmic-ray sources, the behavior of cosmic rays in the interplanetary medium, and the trapped planetary energetic-particle environment.

Cosmic Ray System  
(active) (CRS)

- **Principal investigator:** Edward Stone / CalTech / NASA Goddard Space Flight Center (website)
- **Data:** NSSDC data archive

Utilizes a sweep-frequency radio receiver to study the radio-emission signals from Jupiter and Saturn.

Planetary Radio  
Astronomy  
Investigation  
(disabled) (PRA)

- **Principal investigator:** James Warwick / University of Colorado
- **Data:** PDS/PPI data catalog

Utilized a telescope with a polarizer to gather information on surface texture and composition of Jupiter and Saturn and information on atmospheric scattering properties and density for both planets.

Photopolarimeter  
System  
(disabled) (PPS)

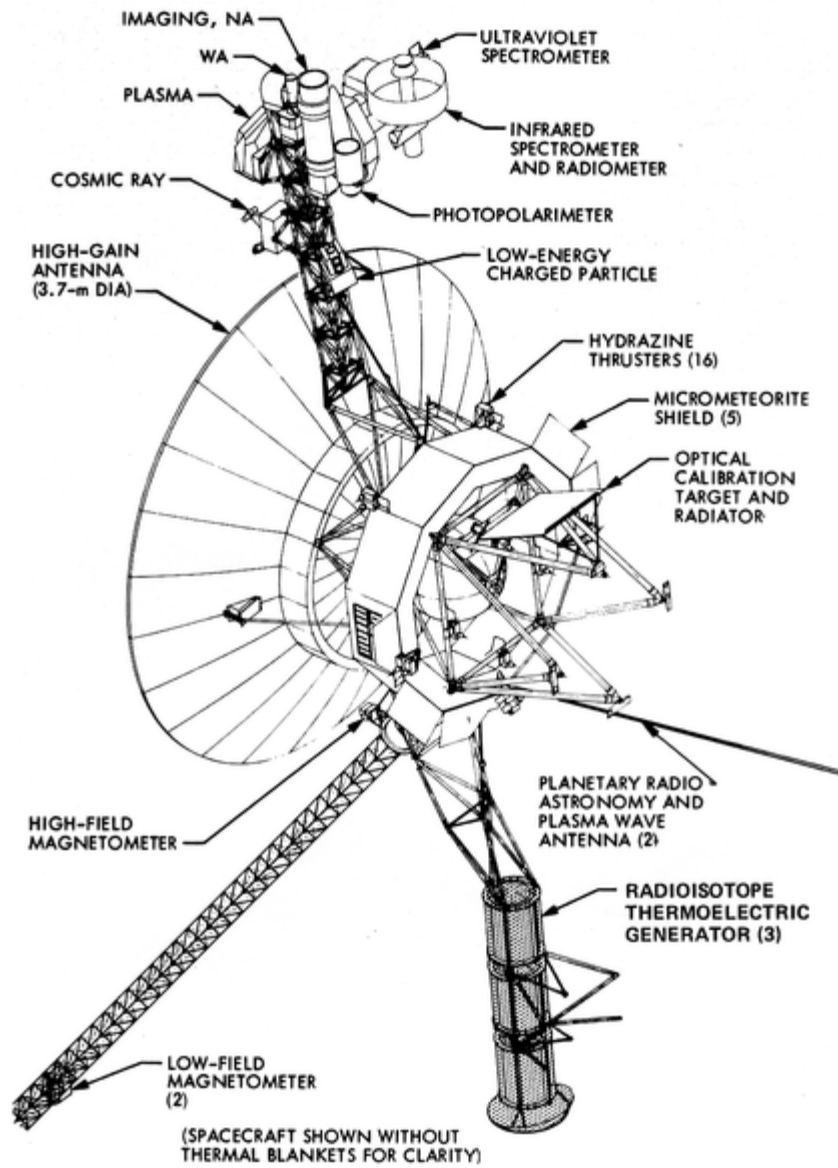
- **Principal investigator:** Arthur Lane / JPL (PDS/PRN website)
- **Data:** PDS/PRN data catalog

Provides continuous, sheath-independent measurements of the electron-density profiles at Jupiter and Saturn as well as basic information on local wave-particle interaction, useful in studying the magnetospheres.

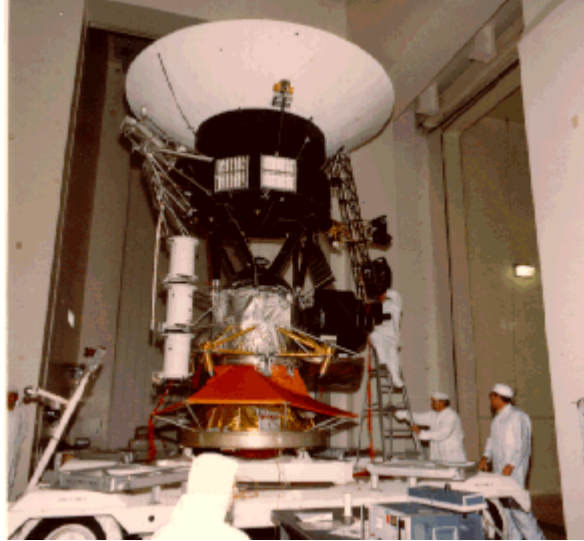
Plasma Wave  
System  
(partially disabled) (PWS)

- **Principal investigator:** Donald Gurnett / University of Iowa (website)
- **Data:** PDS/PPI data catalog, NSSDC data archive

## Images of the spacecraft



*Voyager* spacecraft diagram.



*Voyager* in transport to a solar thermal test chamber.



Gold-Plated Record is attached to *Voyager*.



*Voyager 2* awaiting payload entry into a Titan/Centaur-6 rocket.

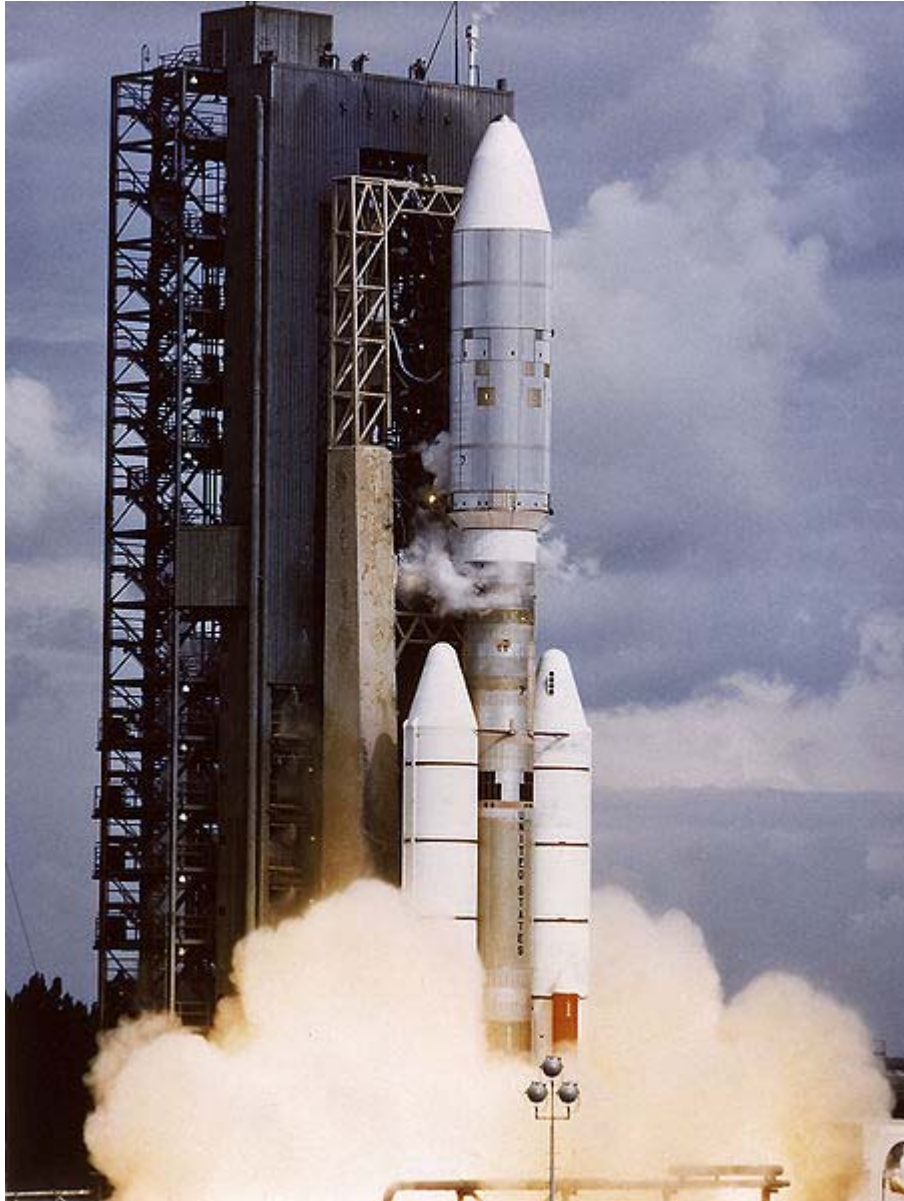
## **Mission profile**

### Timeline of travel

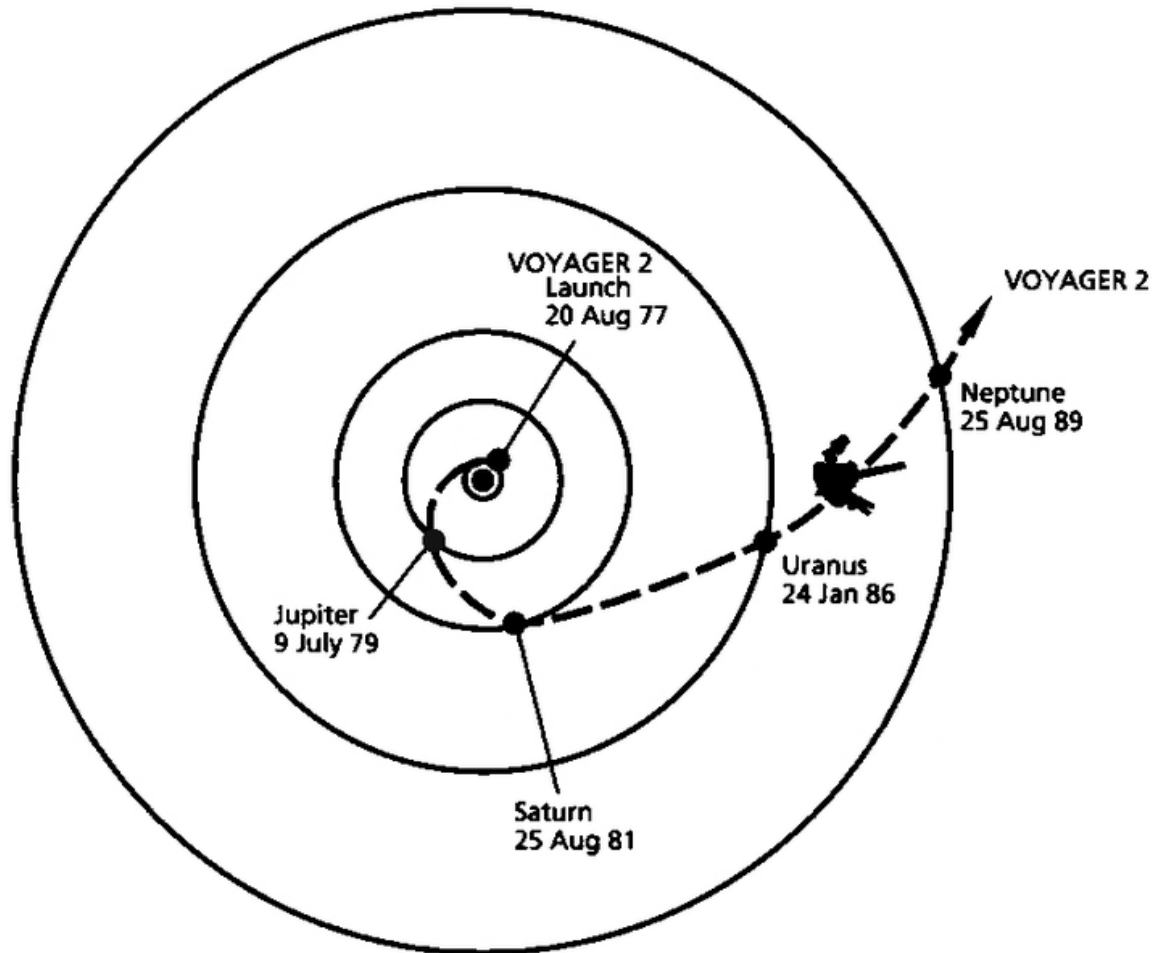
Date	Event
1977-08-20	Spacecraft launched at 14:29:00 UTC.
1977-12-10	Entered asteroid belt.
1977-12-19	Voyager 1 overtakes <i>Voyager 2</i> . ( <i>see diagram</i> )
1978-06-	Primary radio receiver fails. Remainder of mission flown using backup.
1978-10-21	Exited asteroid belt
1979-04-25	Start Jupiter observation phase
	<b>Time</b> <b>Event</b>
1981-06-05	Start Saturn observation phase.
	<b>Time</b> <b>Event</b>
1985-11-04	Start Uranus observation phase.
	<b>Time</b> <b>Event</b>
1985-11-04	Start Neptune observation phase.
	<b>Time</b> <b>Event</b>
1989-10-02	Begin Voyager Interstellar Mission.

### Launch and trajectory

The *Voyager 2* probe was launched on August 20, 1977, by the National Aeronautics and Space Administration from Space Launch Complex 41 at Cape Canaveral, Florida, aboard a Titan IIIE/Centaur launch vehicle. Two weeks later, the twin *Voyager 1* probe would be launched on September 5, 1977. However, *Voyager 1* would reach both Jupiter and Saturn sooner, as *Voyager 2* had been launched into a longer, more circular trajectory.



Voyager 2 launch on August 20, 1977 with a Titan IIIE/Centaur.



Trajectory of *Voyager 2* primary mission.

### **Encounter with Jupiter**

The closest approach to Jupiter occurred on July 9, 1979. It came within 570,000 km (350,000 miles) of the planet's cloud tops. It discovered a few rings around Jupiter, as well as volcanic activity on the moon Io.

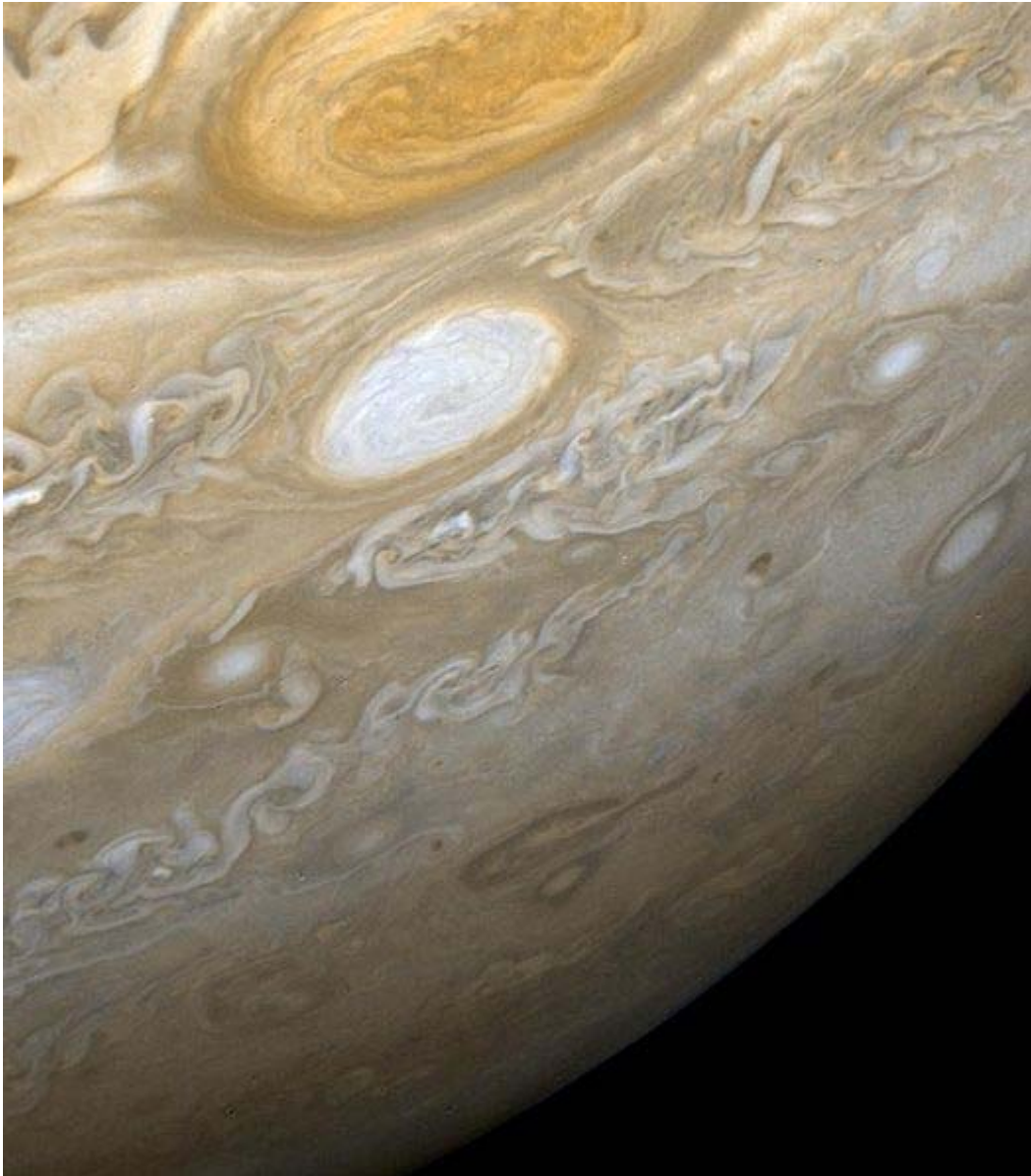
The Great Red Spot was revealed as a complex storm moving in a counterclockwise direction. An array of other smaller storms and eddies were found throughout the banded clouds.

Discovery of active volcanism on the moon Io was easily the greatest unexpected discovery at Jupiter. It was the first time active volcanoes had been seen on another body in the Solar System. Together, the Voyagers observed the eruption of nine volcanoes on Io, and there is evidence that other eruptions occurred between the two Voyager fly-bys.

The moon Europa displayed a large number of intersecting linear features in the low-resolution photos from *Voyager 1*. At first, scientists believed the features might be deep cracks, caused by crustal rifting or tectonic processes. The closer high-resolution photos

from *Voyager 2*, however, left scientists puzzled: The features were so lacking in topographic relief that as one scientist described them, they "might have been painted on with a felt marker." Europa is internally active due to tidal heating at a level about one-tenth that of Io. Europa is thought to have a thin crust (less than 30 kilometers or 18 miles thick) of water ice, possibly floating on a 50-kilometer-deep (30 mile) ocean.

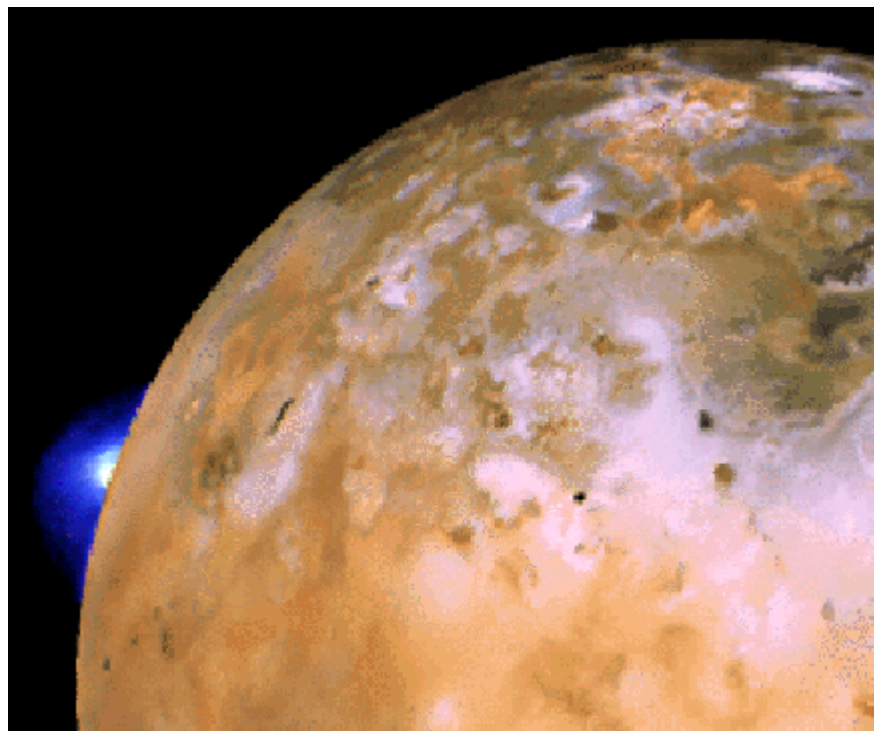
Two new, small satellites, Adrastea and Metis, were found orbiting just outside the ring. A third new satellite, Thebe, was discovered between the orbits of Amalthea and Io.



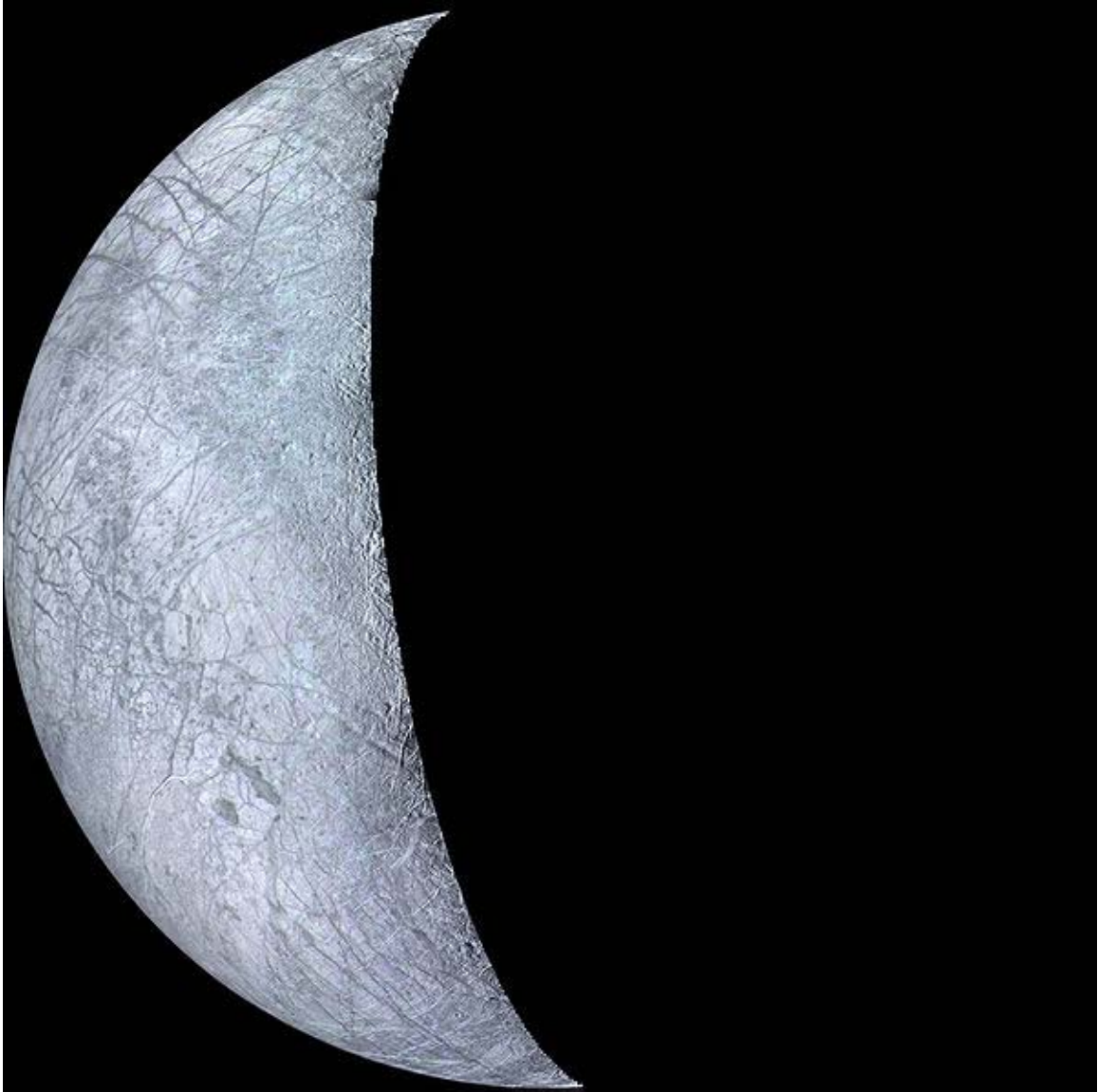
The Great Red Spot photographed during the *Voyager 2* flyby of Jupiter.



A transit of Io across Jupiter, July 9, 1979.



Eruption of a volcano on Io, photographed by Voyager 2.



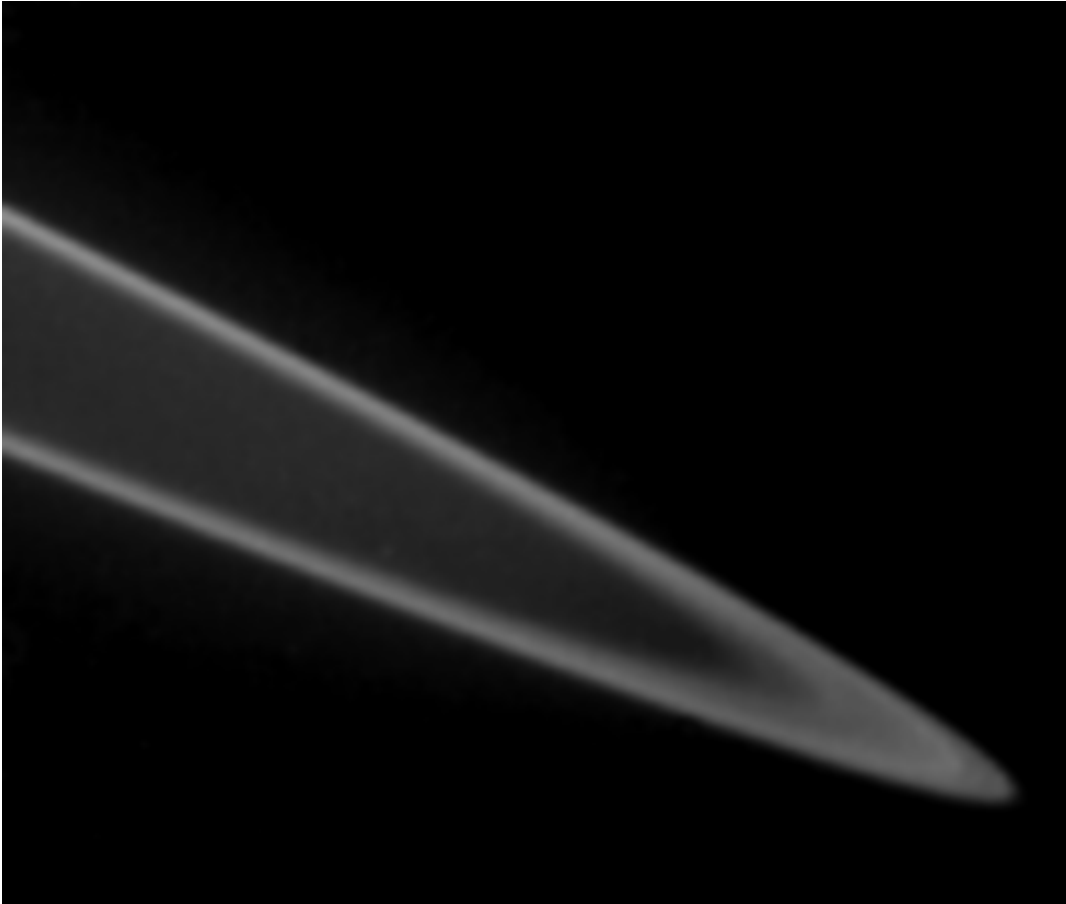
A color mosaic of Europa.



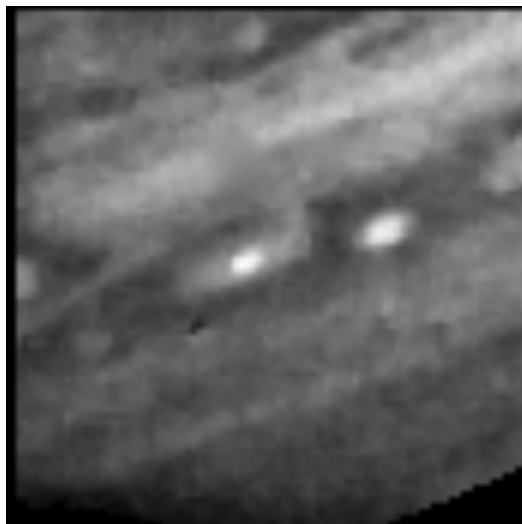
A color mosaic of Ganymede.



Callisto photographed at a distance of 1 million kilometers.



One faint ring of Jupiter photographed during the flyby.



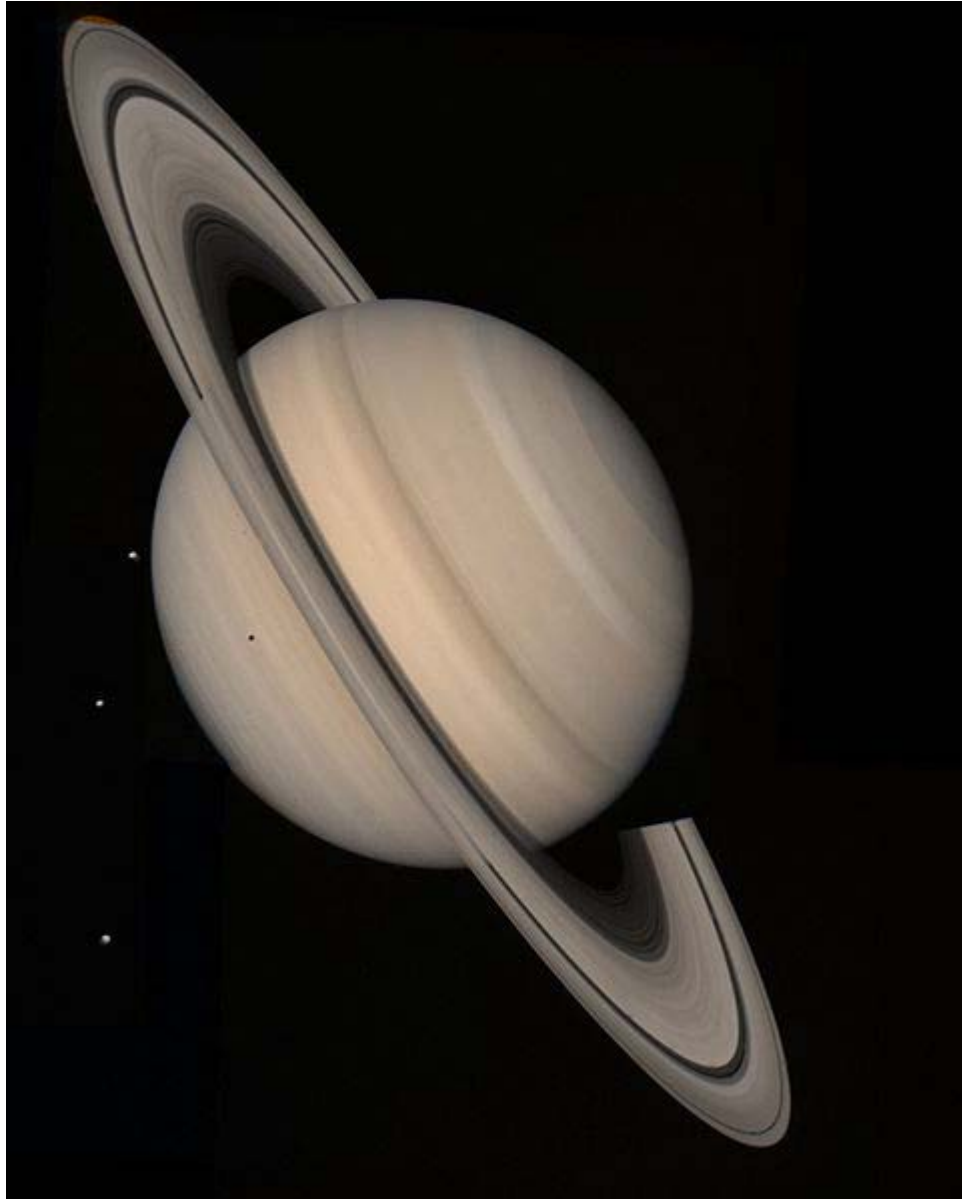
Atmospheric eruptive event on Jupiter.

## Encounter with Saturn

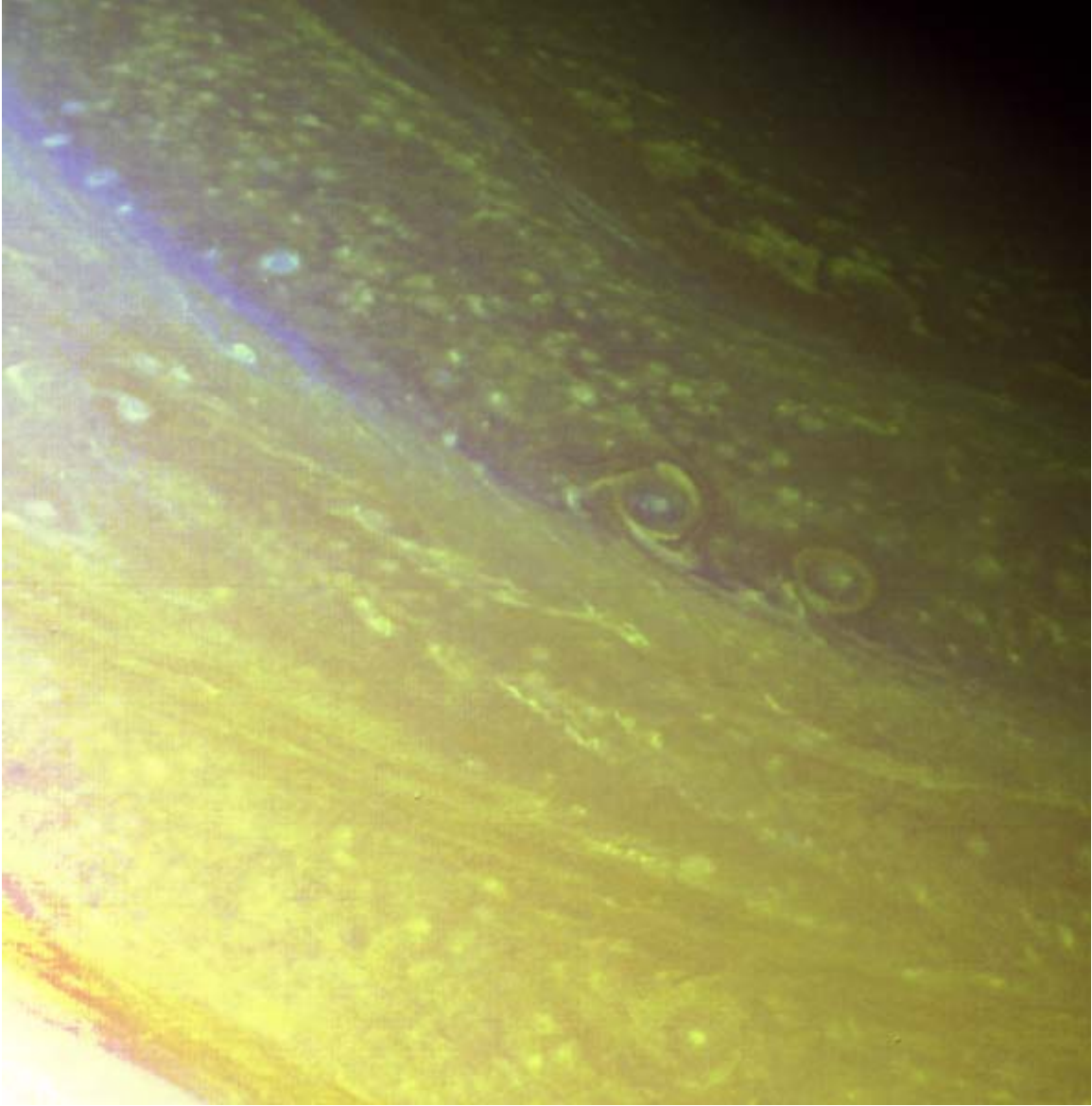
The closest approach to Saturn occurred on August 26, 1981.

While passing behind Saturn (as viewed from Earth), *Voyager 2* probed Saturn's upper atmosphere with its radio link to gather information on atmospheric temperature and density profiles. *Voyager 2* found that at the highest pressure levels (seven kilopascals of pressure), Saturn's temperature was 70 kelvins ( $-203\text{ }^{\circ}\text{C}$ ), while at the deepest levels measured (120 kilopascals) the temperature increased to 143 K ( $-130\text{ }^{\circ}\text{C}$ ). The north pole was found to be 10 kelvins cooler, although this may be seasonal.

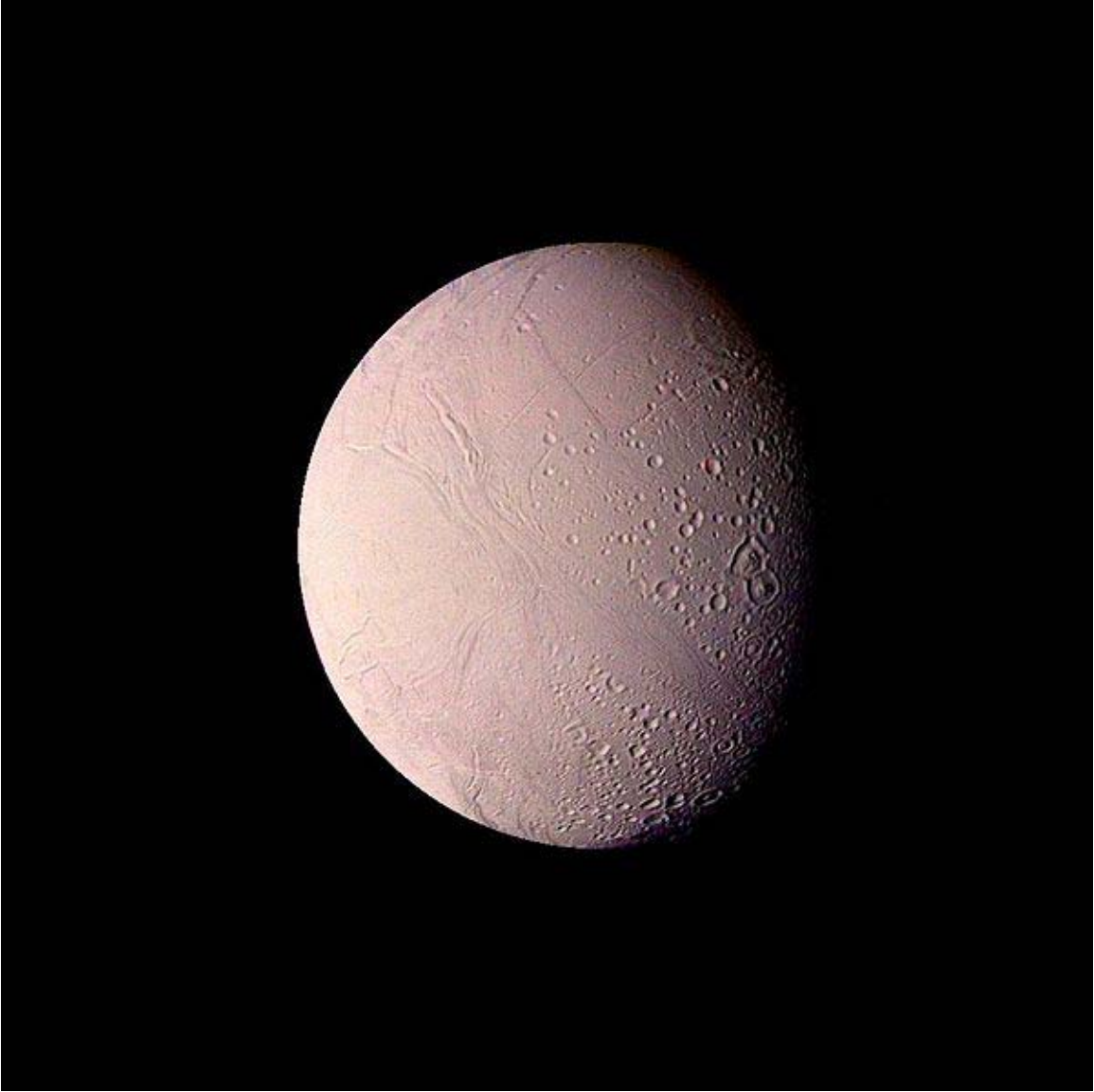
After the fly-by of Saturn, the camera platform of *Voyager 2* locked up briefly, putting plans to officially extend the mission to Uranus and Neptune in jeopardy. Fortunately, the mission's engineers were able to fix the problem (caused by an overuse that temporarily depleted its lubricant), and the *Voyager 2* probe was given the go-ahead to explore the Uranian system.



*Voyager 2* Saturn approach view.



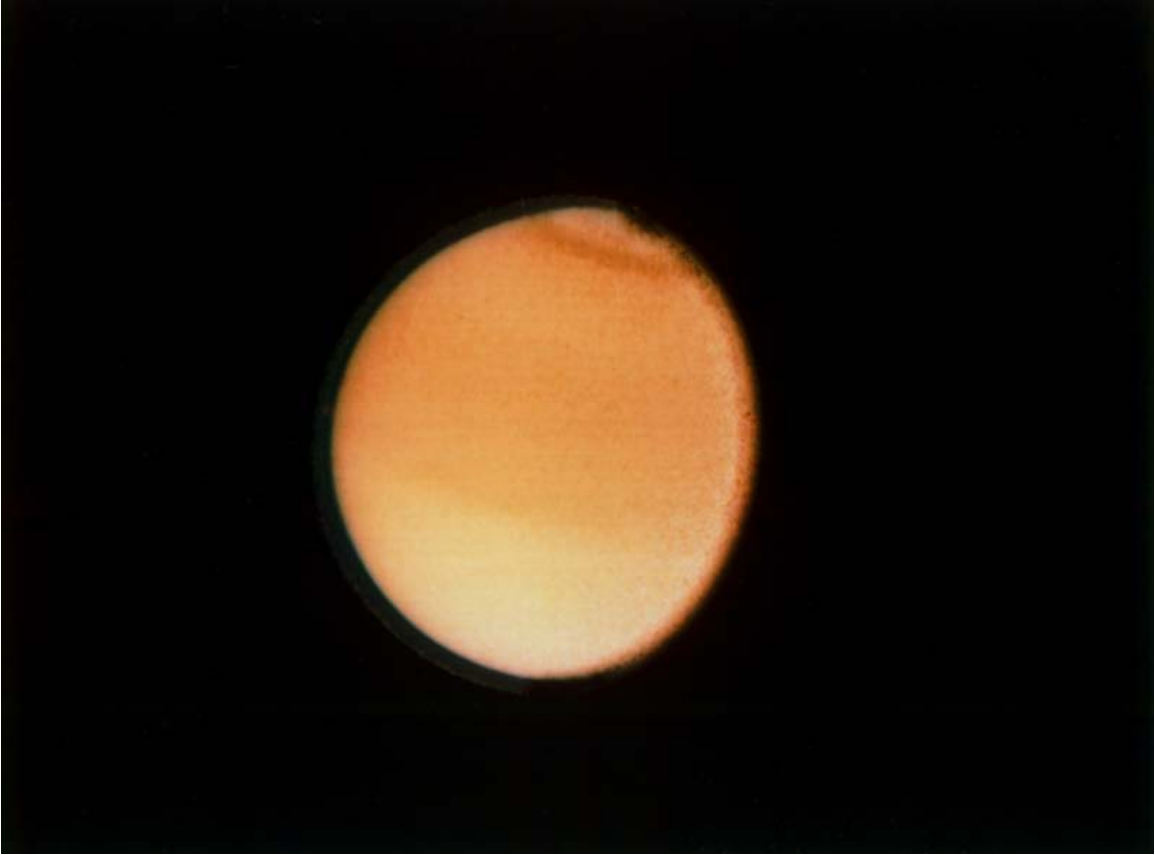
North, polar region of Saturn imaged in orange and UV filters.



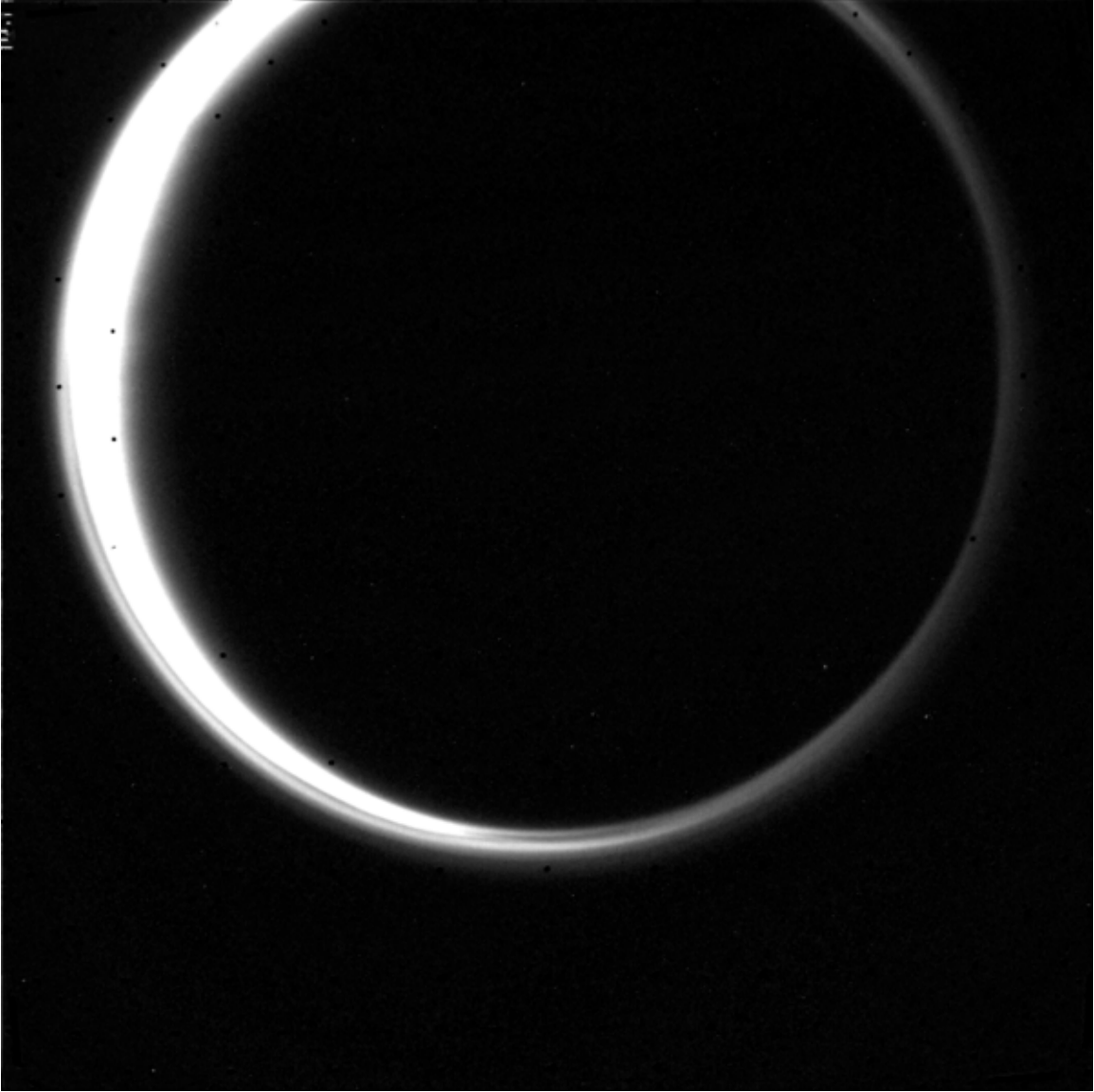
Color image of Enceladus showing terrain of widely varying ages.



Cratered surface of Tethys at 594,000 km.



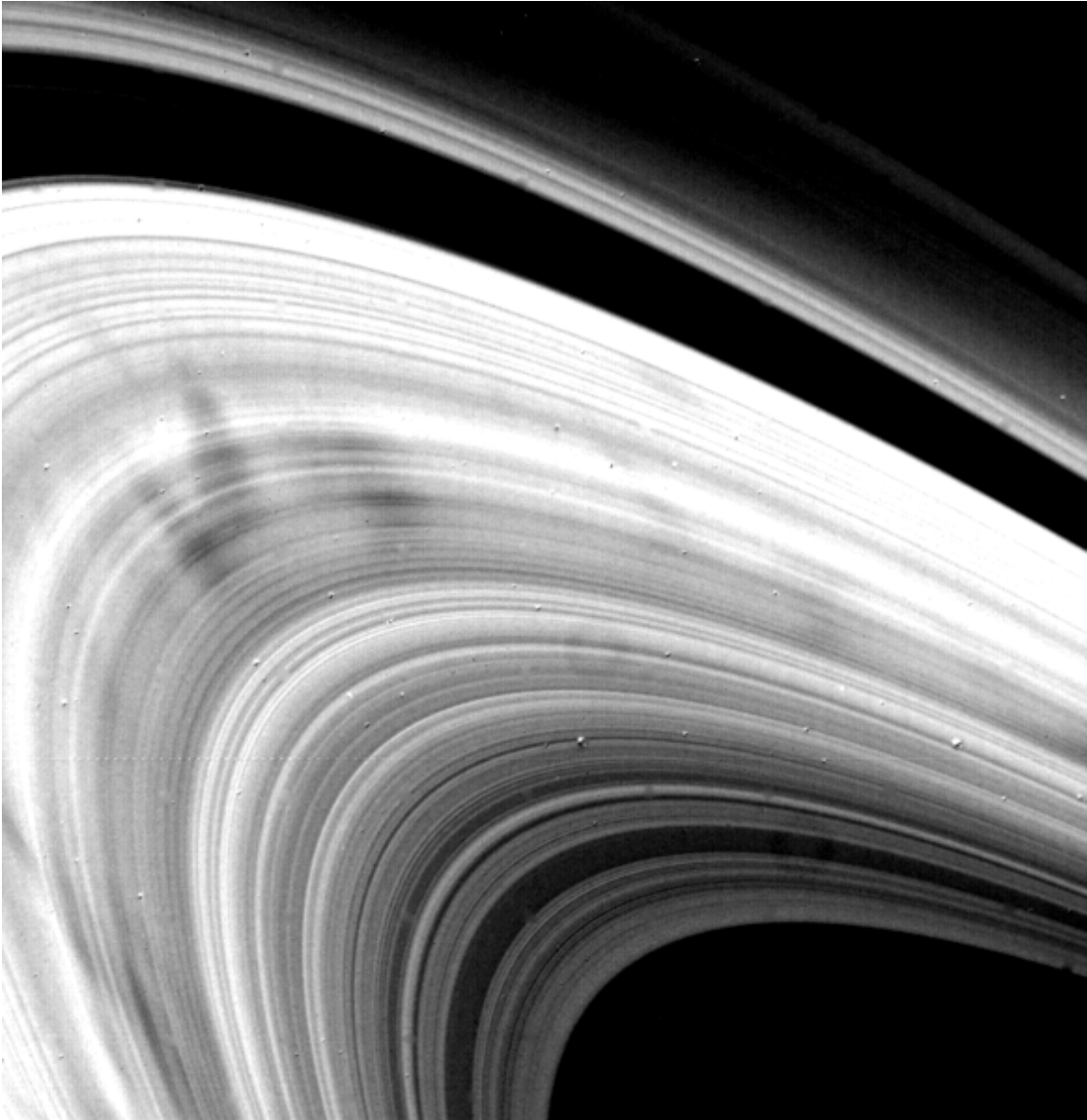
Atmosphere of Titan imaged from 2.3 million km.



Titan occultation of the Sun from 0.9 million km.



Two-toned Iapetus, August 22, 1981.



"Spoke" features observed in the rings of Saturn.

## **Encounter with Uranus**

The closest approach to Uranus occurred on January 24, 1986, when *Voyager 2* came within 81,500 kilometers (50,600 miles) of the planet's cloud tops. *Voyager 2* also discovered 10 previously unknown moons of Uranus; studied the planet's unique atmosphere, caused by its axial tilt of  $97.8^\circ$ ; and examined the Uranian ring system.

Uranus is the third largest (Neptune has a larger mass, but a smaller volume) planet in the Solar System. It orbits the Sun at a distance of about 2.8 billion kilometers (1.7 billion miles), and it completes one orbit every 84 years. The length of a day on Uranus as

measured by *Voyager 2* is 17 hours, 14 minutes. Uranus is unique among the planets in that its axial tilt is about 90°, meaning that its axis is roughly parallel, not perpendicular to the plane of the ecliptic. This extremely large tilt of its axis is thought to be the result of a collision between the accumulating planet Uranus with another planet-sized body early in the history of the Solar System. Given the unusual orientation of its axis, with the polar regions of Uranus exposed for periods of many years to either continuous sunlight or darkness, planetary scientists were not at all sure what to expect when observing Uranus.

*Voyager 2* found that one of the most striking effects of the sideways orientation of Uranus is the effect on the tail of the planetary magnetic field. This is itself tilted about 60 degrees from the Uranian axis of rotation. The planet's magneto tail was shown to be twisted by the rotation of Uranus into a long corkscrew shape following the planet. The presence of a significant magnetic field for Uranus was not at all known until *Voyager's 2* arrival.

The radiation belts of Uranus were found to be of an intensity similar to those of Saturn. The intensity of radiation within the Uranian belts is such that irradiation would "quickly" darken—within 100,000 years—any methane that is trapped in the icy surfaces of the inner moons and ring particles. This kind of darkening might have contributed to the darkened surfaces of the moons and the ring particles, which are almost uniformly dark gray in color.

A high layer of haze was detected around the sunlit pole of Uranus. This area was also found to radiate large amounts of ultraviolet light, a phenomenon that is called "dayglow." The average atmospheric temperature is about 60 K (−350 degrees Fahrenheit/−213 degrees Celsius). Surprisingly, the illuminated and dark poles, and most of the planet, exhibit nearly the same temperatures at the cloud tops.

The Uranian moon Miranda, the innermost of the five large moons, was discovered to be one of the strangest bodies yet seen in the Solar System. Detailed images from *Voyager 2's* flyby of Miranda showed huge canyons made from geological faults as deep as 20 kilometers (12 miles), terraced layers, and a mixture of old and young surfaces. One hypothesis suggests that Miranda might consist of a reaggregation of material following an earlier event when Miranda was shattered into pieces by a violent impact.

All nine of the previously known Uranian rings were studied by the instruments of *Voyager 2*. These measurements showed that the Uranian rings are distinctly different from those at Jupiter and Saturn. The Uranian ring system might be relatively young, and it did not form at the same time that Uranus did. The particles that make up the rings might be the remnants of a moon that was broken up by either a high-velocity impact or torn up by tidal effects.



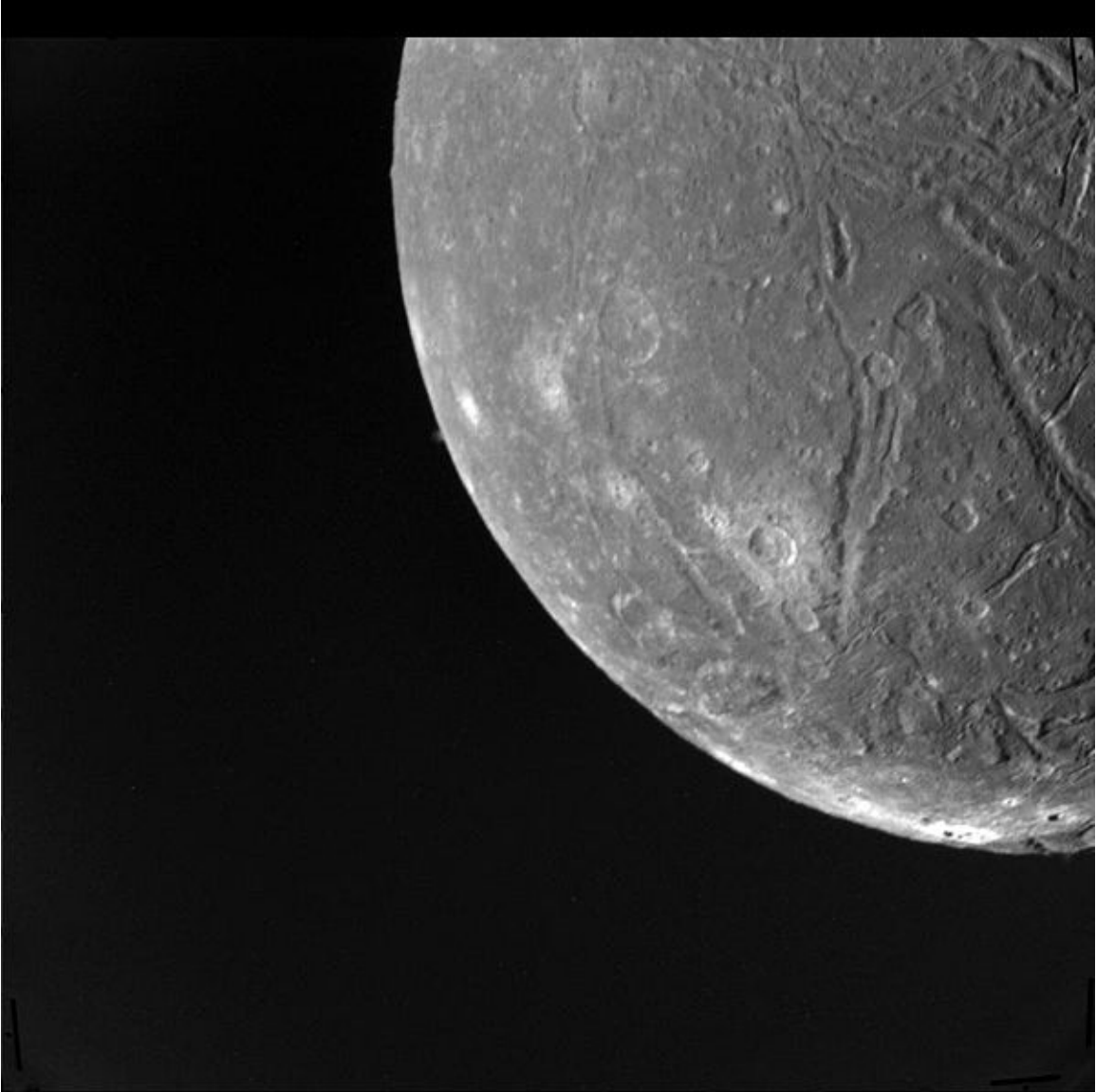
Uranus viewed from 18 million km.



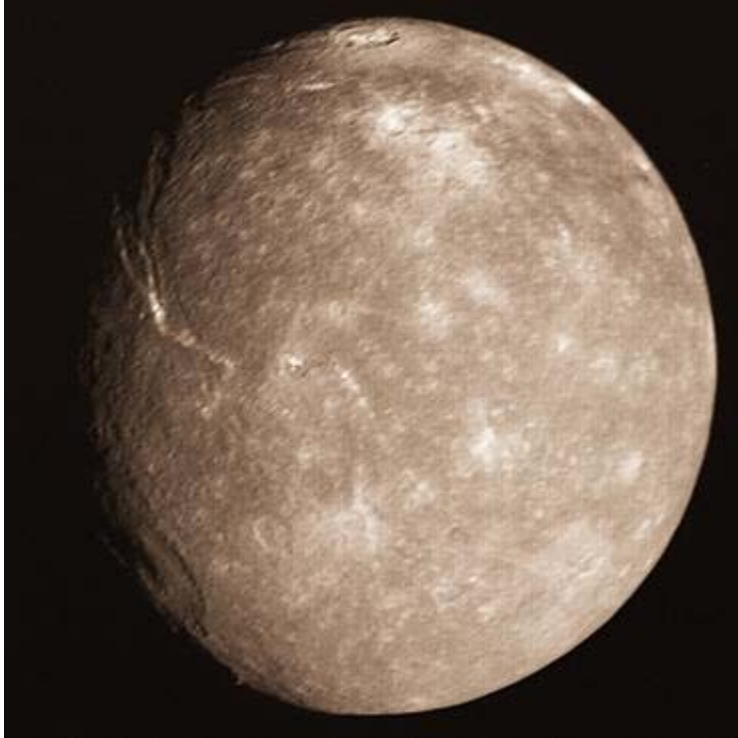
Departing image of crescent Uranus.



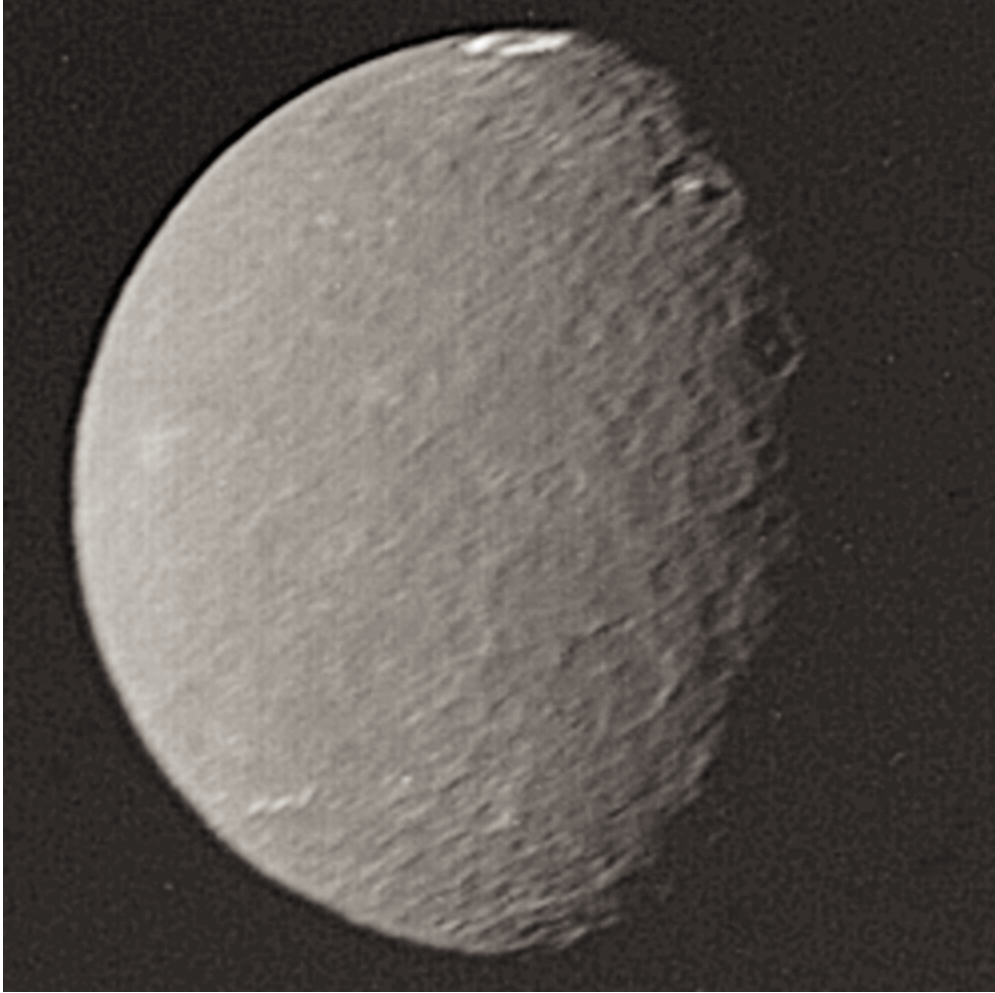
Fractured surface of Miranda.



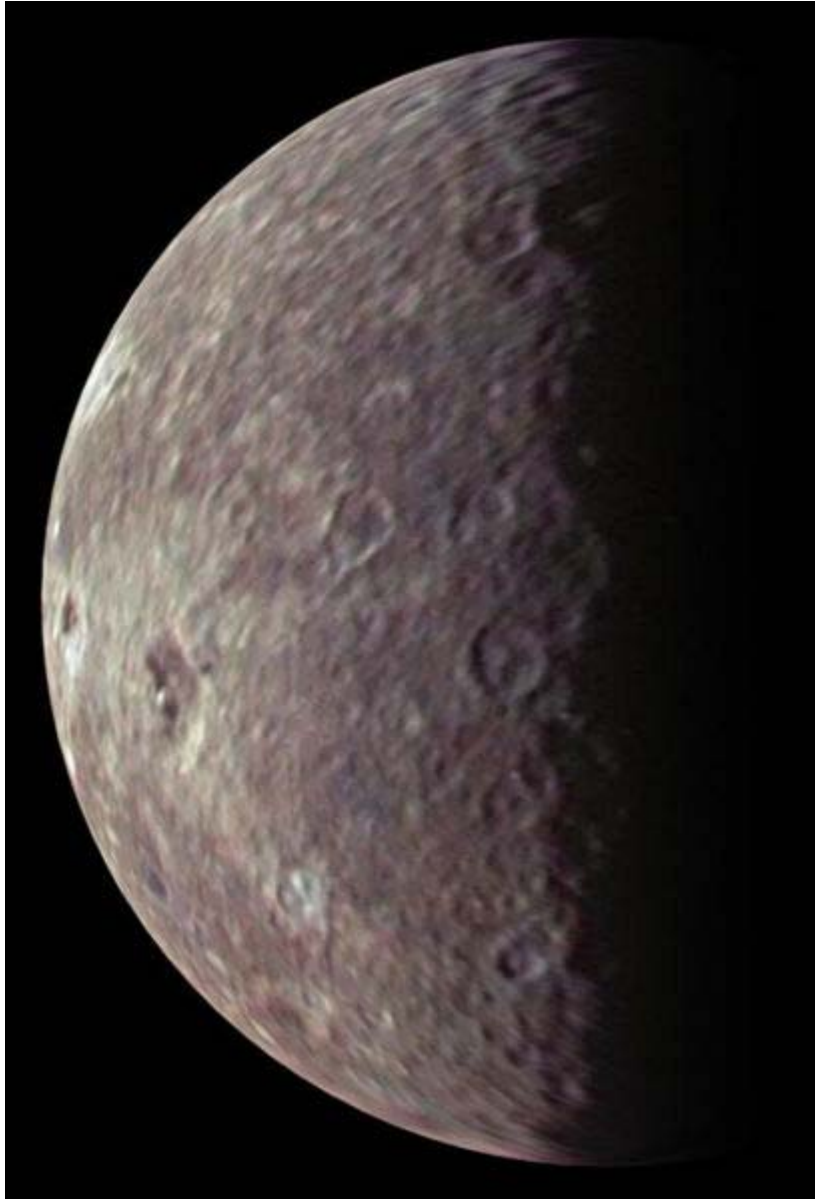
Ariel as imaged from 130,000 km.



Color composite of Titania from 500,000 km.



Umbriel (moon) imaged from 550,000 km.



Color composite of Oberon.



The Rings of Uranus imaged by *Voyager 2*.

## **Encounter with Neptune**

*Voyager 2's* closest approach to Neptune occurred on August 25, 1989. Since this was the last planet of our Solar System that *Voyager 2* could visit, the Chief Project Scientist, his staff members, and the flight controllers decided to also perform a close fly-by of Triton, the larger of Neptune's two originally known moons, so as to gather as much information on Neptune and Triton as possible, regardless of what angle at which *Voyager 2* would fly away from Neptune. This was just like the case of *Voyager 1's* encounters with Saturn and its massive moon Titan.

Through repeated computerized test simulations of trajectories through the Neptunian system conducted in advance, flight controllers determined the best way to route *Voyager*

2 through the Neptune-Triton system. Since the plane of the orbit of Triton is tilted significantly with respect to the plane of the ecliptic, through mid-course corrections, *Voyager 2* was directed into a path several thousand miles over the north pole of Neptune. At that time, Triton was behind and below (south of) Neptune (at an angle of about 25 degrees below the Ecliptic), close to the apoapsis of its elliptical orbit. The gravitational pull of Neptune bent the trajectory of *Voyager 2* down in the direction of Triton. In less than 24 hours, *Voyager 2* traversed the distance between Neptune and Triton, and then it observed the northern hemisphere of Triton as *Voyager 2* passed over the north pole of Triton.

The net and final effect on the trajectory of *Voyager 2* was to bend its trajectory south below the plane of the Ecliptic by about 30 degrees. *Voyager 2* is on this path permanently, and hence, it is exploring space south of the plane of the Ecliptic, measuring magnetic fields, charged particles, etc., there, and sending the measurements back to the Earth via telemetry.

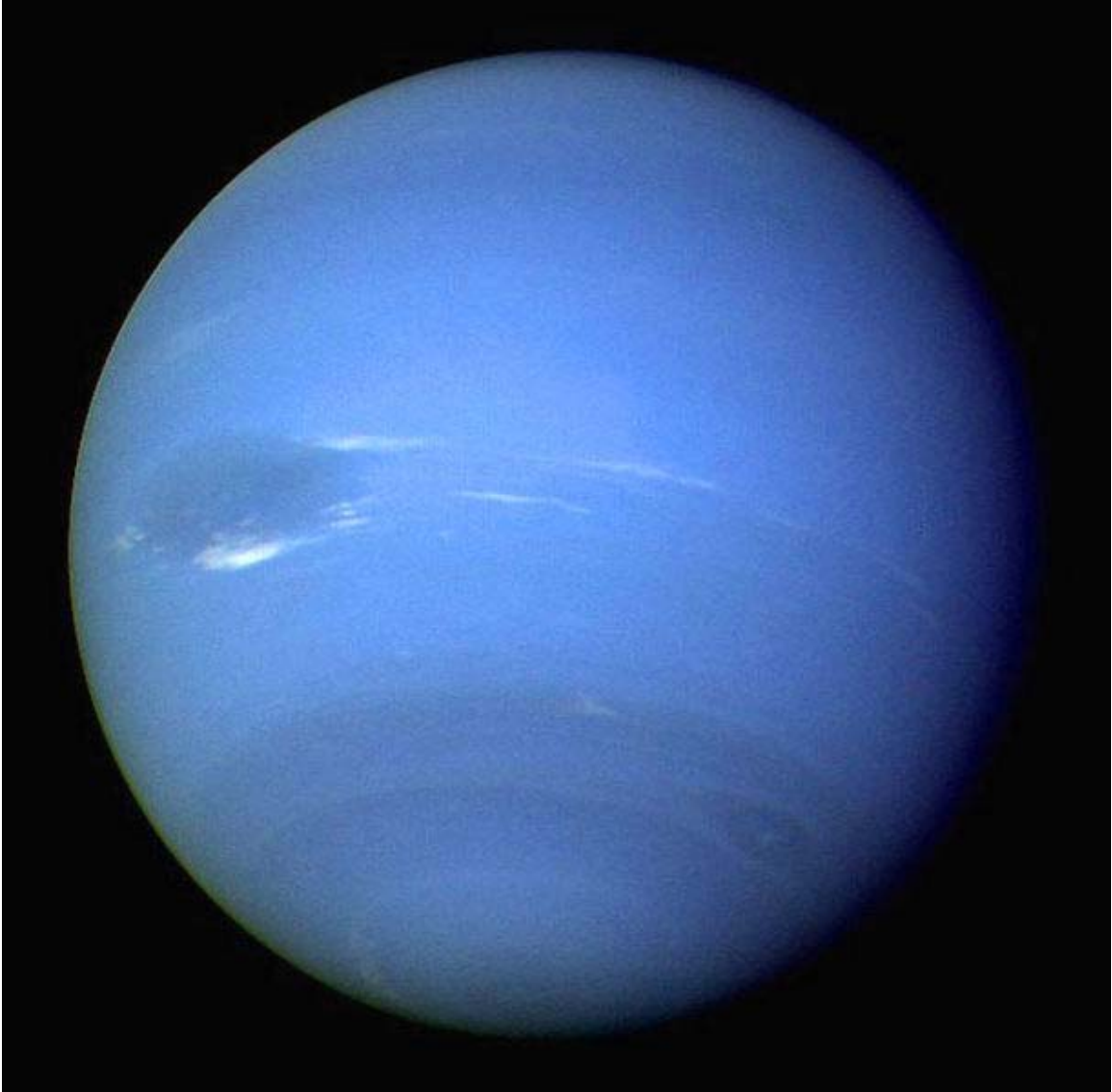
While in the neighborhood of Neptune, *Voyager 2* discovered the "Great Dark Spot", which has since disappeared, according to observations by the Hubble Space Telescope. Originally thought to be a large cloud itself, the "Great Dark Spot" was later hypothesized to be a hole in the visible cloud deck of Neptune.

Neptune's atmosphere consists of hydrogen, helium, and methane. The methane in Neptune's upper atmosphere absorbs the red light from the Sun, but it reflects the blue light from the sun back into space. This is why Neptune looks blue.

For decades, beginning in the late 19th century, it was widely thought that an unseen planet (dubbed "Planet X") was influencing the orbits of Uranus and Neptune, by perturbing them, since their observed positions differed somewhat from the positions predicted by calculations. This notion might have brought about the 1930 discovery of Pluto, but the actual discovery of Pluto by Clyde Tombaugh in 1930 was an accidental one that occurred while a few astronomers were scanning areas of the sky for "Planet X".

The notion of a "Planet X" has persisted, because over the decades since 1930, it became increasingly clear that Pluto has insufficient mass to account for the observational discrepancies. When *Voyager 2* flew-by Neptune, it took very precise measurements of Neptune's mass. Neptune was evaluated at about 0.5 percent less massive than previous estimates — a difference comparable to a planet with the mass of Mars. When the orbits of Uranus and Neptune orbits were recalculated using the more accurate mass figure, it was found that the imprecise number for Neptune — and not the gravity of an unseen planet — caused the orbital discrepancies that had long perplexed planetary astronomers.

With the decision of the International Astronomical Union to reclassify Pluto as a "plutoid" in 2008, the flyby of Neptune by *Voyager 2* in 1989 became the point when every known planet in the Solar System had been visited at least once by a space probe.



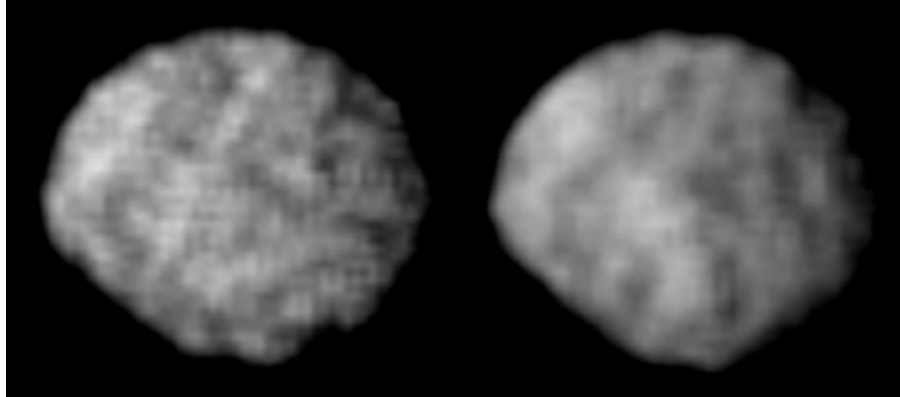
*Voyager 2* image of Neptune.



Neptune and Triton three days after *Voyager 2* flyby.



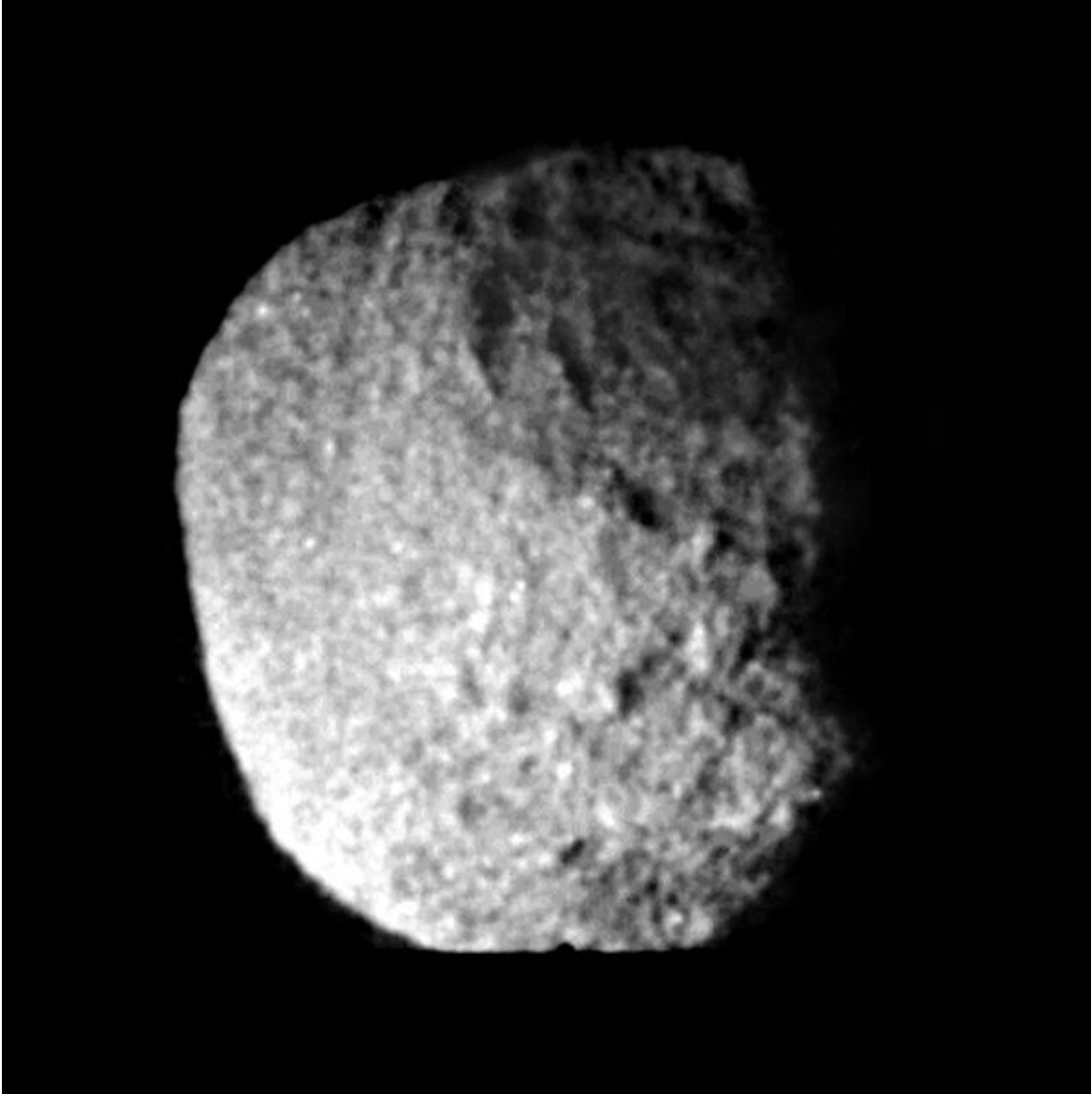
Despina as imaged from *Voyager 2*.



Cratered surface of Larissa.

## **Interstellar mission**

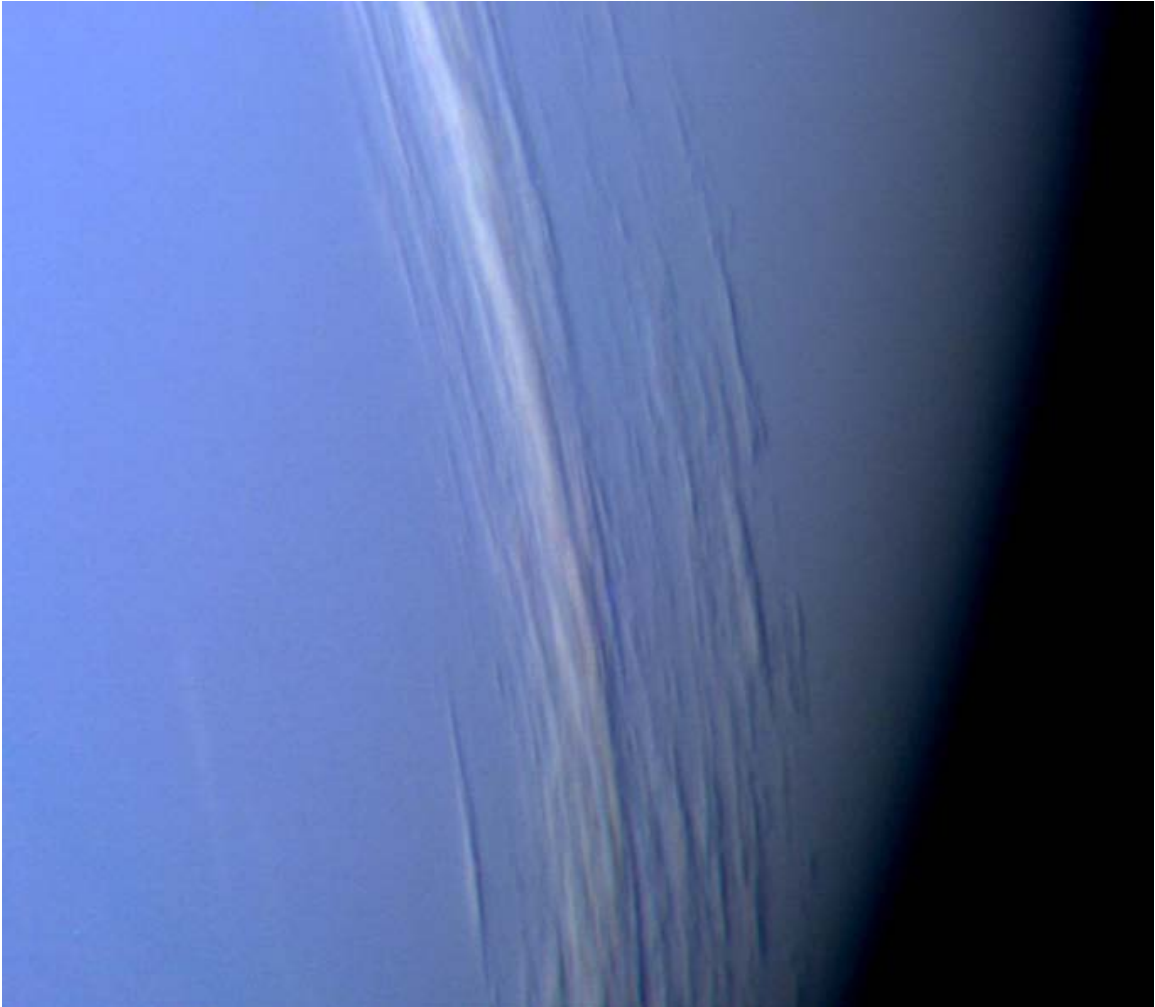
Since its planetary mission is over, *Voyager 2* is now described as working on an interstellar mission, which NASA is using to find out what the solar system is like beyond the heliosphere. On August 30, 2007, *Voyager 2* passed the termination shock into the heliosheath, approximately 1 billion miles (1.6 billion km) closer to the Sun than *Voyager 1* did. This is due to the local interstellar magnetic field of deep space. The southern hemisphere of the solar system's heliosphere is being pushed in.



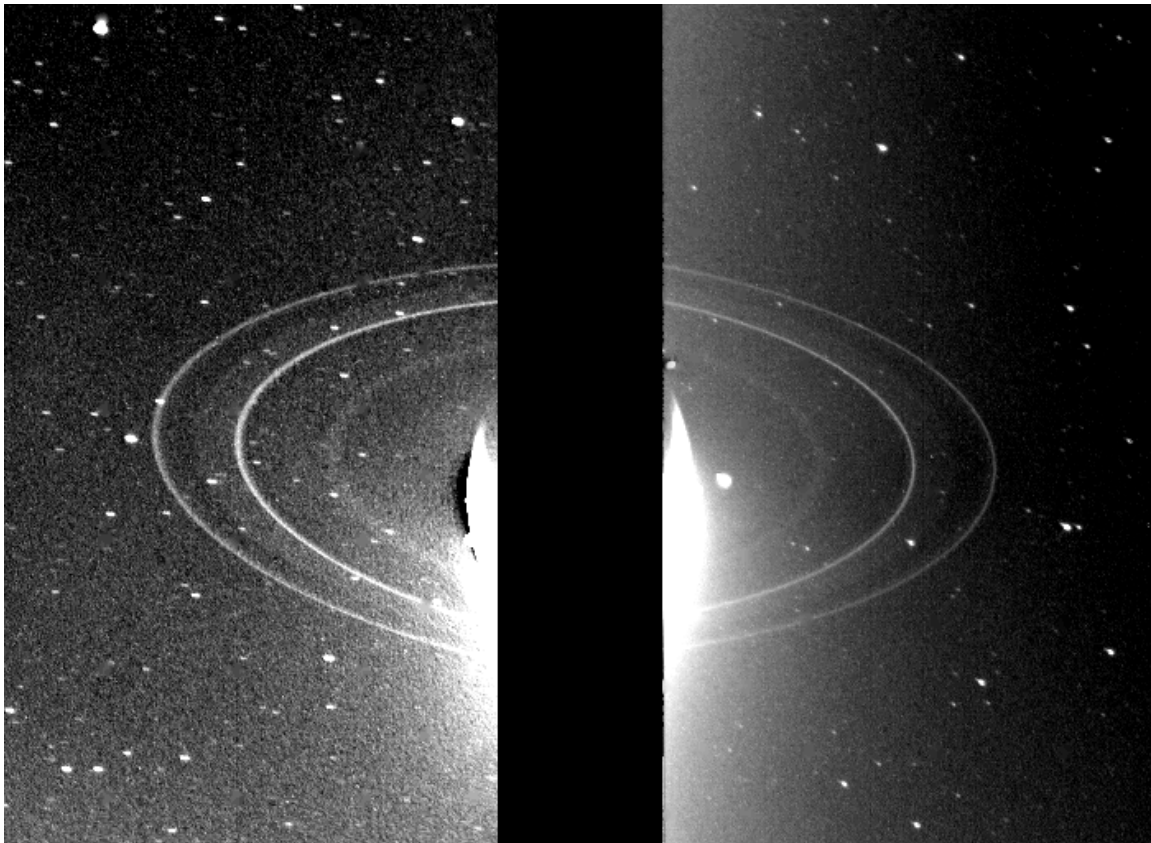
Dark surface of Proteus.



Color mosaic of *Voyager 2* Triton.



Cirrus clouds imaged above gaseous Neptune.



Rings of Neptune taken in occultation from 280,000 km.

As of April 13, 2010, *Voyager 2* was at a distance of around 91.898 AU (13.747 billion km, 8.542 billion miles or 0.001443 light years) from the Sun, deep in the scattered disc, and traveling outward at roughly 3.264 AU per year. It is more than twice as far from the Sun as Pluto, and far beyond the perihelion of 90377 Sedna, but not yet beyond the outer limits of the orbit of the dwarf planet Eris.

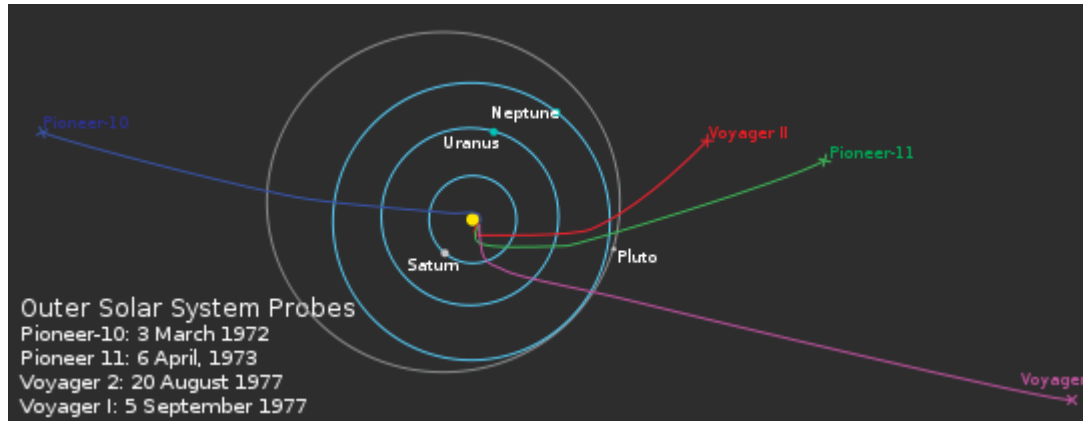
*Voyager 2* is not headed toward any particular star. If left alone, it should pass by star Sirius, which is currently about 2.6 parsecs from the Sun and moving diagonally towards the Sun, at a distance of 1.32 parsecs (4.3 ly, 25 trillion mi) in about 296,000 years.

*Voyager 2* is expected to keep transmitting weak radio messages until at least 2025, over 48 years since it was launched.

Year	End of specific capabilities as a result of the available electrical power limitations
1998	Terminate scan platform and UV observations
2007	Termination of <i>Digital Tape Recorder</i> (DTR) operations (It was no longer needed due to a failure on the <i>High Waveform Receiver</i> on the <i>Plasma Wave Subsystem</i> (PWS) on June 30, 2002. )
2008	Power off <i>Planetary Radio Astronomy Experiment</i> (PRA)

2015 approx Termination of gyroscopic operations  
 2020 approx Initiate instrument power sharing  
 2025 or slightly afterwards Can no longer power any single instrument

## Current status



Location and trajectories of Pioneer and Voyager spacecraft, as of July 7, 2007. Note Voyager 2 is further than Pioneer 11 and only appears closer here due to its -55 degree declination, and that Voyager 1's position is drawn too far away.

*Voyager 2* is currently transmitting scientific data at about 160 bits per second. Information about continuing telemetry exchanges with *Voyager 2* is available from Voyager Weekly Reports. Information on the current location of *Voyager 2* can be found at HeavensAbove.

As of **February 22nd 2011**, *Voyager 2* is 94.619AU from the Sun, at  $-54.88^\circ$  declination and 19.879 h right ascension, placing it in the constellation Telescopium as observed from Earth.

On November 30, 2006, a telemetered command to *Voyager 2* was incorrectly decoded by its on-board computer—in a random error—as a command to turn on the electrical heaters of the spacecraft's magnetometer. These heaters remained turned on until December 4, 2006, and during that time, there was a resulting high temperature above  $130^\circ\text{C}$  ( $266^\circ\text{F}$ ), significantly higher than the magnetometers were designed to endure, and a sensor rotated away from the correct orientation. It has not been possible to fully diagnose and correct for the damage caused to the *Voyager 2's* magnetometer, although efforts to do so are proceeding.

There are regular posts of the current distance of *Voyager 2* to Earth in light-travel time to Twitter.

On April 22, 2010, *Voyager 2* encountered scientific data format problems as reported by the Associated Press on May 7, 2010.

On May 17, 2010, JPL engineers revealed that a flipped bit in an on-board computer had caused the issue, and scheduled a bit reset for May 19.

On May 23, 2010, *Voyager 2* has resumed sending science data from deep space after engineers fixed the flipped bit.

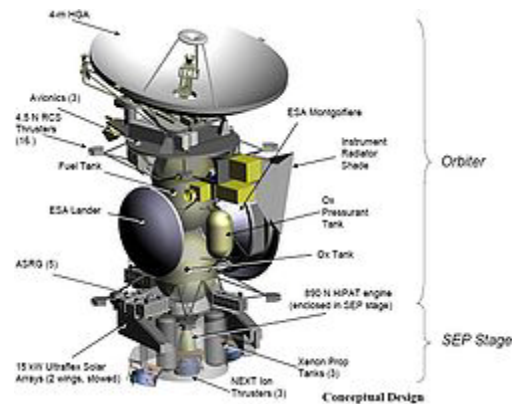
Currently research is being made into making the area of memory with the flipped bit off limits or disallowing its use.

The Low-Energy Charged Particle Instrument is currently operational and data from this instrument concerning charged particles is being transmitted to Earth. This data permits measurements of the heliosheath and termination shock.

## Chapter- 5

# Titan Saturn System Mission

### Titan Saturn System Mission / TandEM



<b>Operator</b>	NASA, ESA
<b>Mission type</b>	One orbiter, one montgolfière, one lander
<b>Orbital insertion date</b>	ca. nine years after launch
<b>Launch date</b>	after 2020
<b>Launch vehicle</b>	Delta IV-H, Ares or Atlas
<b>Mission duration</b>	2 years (orbiter)
<b>Homepage</b>	ESA Webpage on TandEM/TSSM
<b>Mass</b>	Orbiter: 1613 kg; Montgolfière: 600 kg; Lander: 190 kg
<b>Power</b>	Orbiter: RTG; Lander: ASRG

#### Orbital elements

**Semimajor axis**    1,500 km (Final orbit around Titan)

**Inclination**        85° (Final orbit around Titan)

**Orbital period**    ~ 4,8 h

**Titan Saturn System Mission (TSSM)** is a joint NASA/ESA proposal for an exploration of Saturn and its moons Titan and Enceladus, where many complex phenomena have been revealed by the recent Cassini–Huygens mission. With an estimated NASA cost of \$2.5 Billion (FY07), TSSM was originally proposed to launch in 2020, get gravity assists from Earth and Venus, and arrive at the Saturn system in 2029. The 4-year prime mission would include a two-year Saturn tour, a 2-month Titan aero-sampling phase, and a 20-month Titan orbit phase.

## **Origin and status**

The Titan Saturn System Mission (TSSM) was officially created in January 2009 by the merging of the ESA's **Titan and Enceladus Mission (TandEM)** with NASA's **Titan Explorer 2007** study, although plans to combine both concepts date at least back to early 2008. TSSM was competing against the Europa Jupiter System Mission (EJSM) proposal for funding since then, however in February 2009 it was announced that NASA/ESA had given EJSM priority ahead of TSSM, although TSSM will continue to be studied for a later launch date, probably sometime in the 2020s. Detailed assessment reports of the mission elements as well as a specific concept for a lake landing-module called Titan Mare Explorer (TiME) with the potential of becoming a part of the TSSM have been released in February and October 2009, respectively.

## Mission overview



Part of the mission proposal is a montgolfière planned to circumnavigate Titan.

The TSSM mission consists of an orbiter and two Titan exploration probes: a montgolfière (hot air balloon) that will float in Titan's clouds, and a lander that will splashdown on one of its methane seas.

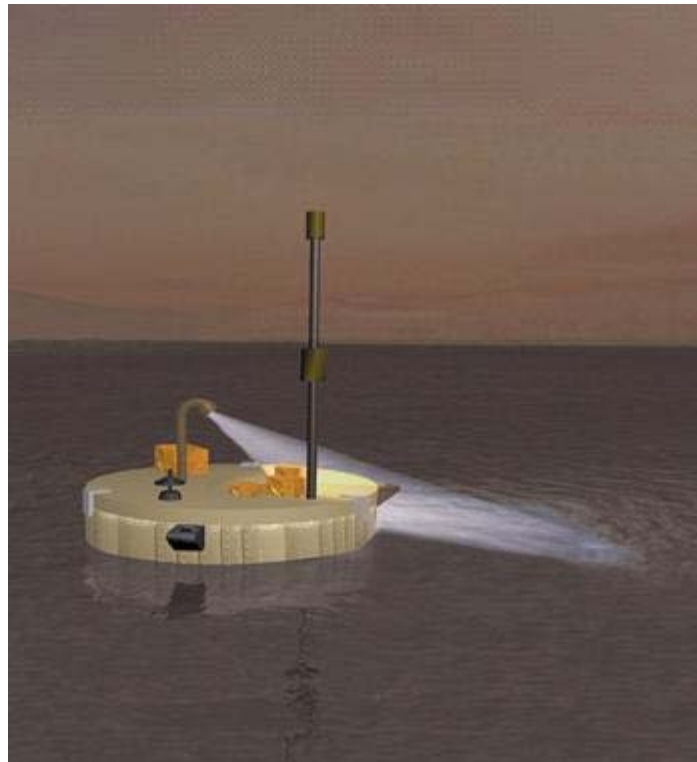
Both probes' data are to be relayed to a Titan orbiter. They will be equipped to study Titan's features with instruments for imaging, radar profiling, and surface as well as atmospheric sampling, much more complete than done by the Cassini–Huygens mission.

The spacecraft will use several gravity assist flybys of other planets to enable it to reach Saturn. The baseline design envisages a September 2020 launch, followed by four gravity assists (Earth-Venus-Earth-Earth), and arrival at Saturn 9 years later in October 2029. This is one of several available Earth-to-Saturn transfer options from the year 2018 through 2022.

Upon Saturn arrival, in October 2029, the orbiter's chemical propulsion system will place the flight system into orbit around Saturn, followed by a two year Saturn Tour Phase, characterized by the deployment of the *in situ* elements, and including a minimum of seven close Enceladus flybys and 16 Titan flybys. During this period, repeated satellite gravity assists and manoeuvres will reduce the energy needed to insert into Titan's orbit. As the craft completes its flyby by Enceladus, the orbiter will analyze the unusual cryovolcanic plumes at the moon's south pole.

The montgolfière, a hot air balloon, will be released on approach to the first Titan flyby for ballistic entry into Titan's atmosphere for its six Earth months' mission from April 2030 to October 2030. Based on Cassini-Huygens discoveries, the montgolfière should be able to circumnavigate Titan at least once during its nominal lifetime at its deployment latitude of about 20°N, 10 kilometers above Titan's surface.

### **The lake-lander**



The Titan Mare Explorer (TiME), which, if postponed sufficiently, could become the lake-lander of the TSSM.

Numerous proposals have been brought forward with respect to the lake-lander concept. One of the most detailed plans so far is the so called Titan Mare Explorer (TiME), which has originally been proposed as a separate scout mission, but might eventually be postponed and included in the TSSM. If approved, TiME would be released by the orbiter on its second Titan flyby. Due to Titan's haze layer and its distance to the Sun, the lander cannot be powered by solar panels and it will rely on the new Advanced Stirling Radioisotope Generator (ASRG), which is a prototype meant to provide availability of long-lived power supplies for landed networks and other planetary missions. The lander will be targeted to Ligeia Mare, a northern polar sea of liquid hydrocarbons at about 79°N. The probe will descend by parachute, like the Huygens probe of 2005. A few hours later, it will splashdown on the liquid surface; this would be the first floating exploration of an extraterrestrial sea. The plutonium-powered craft's principal function is to sample and analyze organics on the surface for a period of about 3 to 6 months, including 6 hours of atmospheric descent.

## Science goals and objectives

The major goals of the TSSM mission can be summarized under four categories:

- Explore Titan as a system
- Study Titan's organic inventory and astrobiological potential
- Constrain Titan's origin and evolution models
- Recover information on Enceladus and Saturn's magnetosphere



Comparison of Ligeia Mare's area with Lake Superior on Earth.

At Titan, the science goals would be to provide information on such aspects as the composition of the surface and the geographic distribution of the various organic constituents; on the methane cycle and the methane reservoirs; on the ages of the surface features, and in particular on whether cryovolcanism and tectonism are actively ongoing or are relics of a more active past; on the presence or absence of ammonia, of a magnetic field and of a sub-surface ocean; on the chemistry that drives complex ion formation in the upper atmosphere; and on a large altitude range in the atmosphere, from 400–900 km, which remains poorly explored after Cassini. In addition, much remains to be understood about seasonal changes of the atmosphere at all levels, and the long-term escape of constituents to space.

TiME lander would splashdown on Ligeia Mare, a methane sea on Titan's northern hemisphere. It is believed that Titan's methane cycle is analogous to Earth's hydrologic cycle, with meteorological working fluid existing in liquid and gas phase. TiME would directly discern the methane cycle of Titan and help understand its similarities and differences to the hydrologic cycle on Earth. However, questions about the sources of re-supply of methane to the atmosphere remain to be answered. This world is built by organic activities which still operate and Cassini/Huygens findings suggest a world with a balance of geologic and atmospheric processes that is the solar system's best analogue to Earth. Moreover, an interior ocean discovered by Cassini, deep underneath Titan's dense atmosphere and surface is thought to be largely composed of liquid water. TSSM would be the first mission in the 50 years of space exploration, where an extensive and interdisciplinary in situ survey of active organic chemistry and climate on the land, on the sea, and in the air of another world will take place.

## Chapter- 6

# Kronos (Spacecraft) & Titan Mare Explorer

## Kronos

**Kronos** is a proposed mission to Saturn. It is aimed at detailed study of the chemical composition of the Saturn's atmosphere, gravity and magnetic fields. The proposal consists of the solar powered carrier spacecraft, two atmospheric probes and (possibly) two small probes for the close-up imaging of the Saturnian rings. Kronos was proposed as a part of collaboration between NASA and ESA.

After the launch at some date after 2015 and several flybys of Venus, Earth and Jupiter, Kronos would arrive at Saturn. The cruise time depends on chosen trajectory and is from 6 to 17 years. In the vicinity of Saturn two atmospheric probes are to be released, entering the atmosphere of Saturn and obtaining information on chemical composition (including isotopic ratios), temperature, wind speeds and cloud structure to pressures down to 10 bar. Two rings probes, if implemented, would also be released in order to provide images of ring particles from a very close distance (a few kilometers). The carrier spacecraft is proposed to fly by Saturn at a close distance obtaining precision information on the gravitational and magnetic fields of Saturn as well as on the atmospheric circulation and deep composition of the atmosphere.

The carrier spacecraft design closely follows that of Juno including solar panels. The proposed design of the descend probes will be similar to that of the Galileo's atmospheric Entry Probe. The mission will be generally based on the existing technology.

# Titan Mare Explorer

## Titan Mare Explorer (TiME)



The lake lander probe TiME (artist's rendering)

<b>Operator</b>	Under evaluation by NASA
<b>Mission type</b>	Lake-lander
<b>Orbital insertion date</b>	June 2022
<b>Launch date</b>	January 17 - February 7, 2015 or 2016
<b>Launch vehicle</b>	Atlas 411
<b>Mission duration</b>	3 to 6 months
<b>Power</b>	ASRG

**Titan Mare Explorer (TiME)** is a proposed spacecraft lander that, if launched, would probe Titan, the largest moon of the planet Saturn, and would perform the first exploration of an extraterrestrial sea. TiME has been proposed to NASA by Proxemy Research as a scout-like pioneering mission, originally as part of NASA's Discovery & Scout Mission Capability Expansion (DSMCE) concept-study program. Currently, the mission is a possible proposal to be submitted for NASA's Discovery program. As such, TiME has not been funded and it is still in its conceptual phase; if selected, its intended launch window would be in January 2016. It has also been proposed to delay TiME enough so it can be incorporated into the flagship-Titan Saturn System Mission proposed for launch in the 2020s.

TiME is a low-cost, outer-planet mission that would directly measure the organic constituents on Titan and would perform the first nautical exploration of an extraterrestrial sea, analyze its nature and, if possible, its shoreline.

## **Background**

The discovery on 22 July 2006 of lakes and seas in Titan's northern hemisphere confirmed the expectation that liquid hydrocarbons exist on it. In addition, previous observations of southern polar storms and new observations of storms in the equatorial region provide evidence of active methane-generating processes, possibly cryovolcanic features from the interior of Titan.

It is believed that Titan's methane cycle is analogous to Earth's hydrologic cycle, with meteorological working fluid existing as rain, clouds, rivers and lakes. TiME would directly discern the methane cycle of Titan and help understand its similarities and differences to the hydrologic cycle on Earth. The Principal Investigator of the lander mission is Ellen Stofan, a member of the Cassini radar team; the spacecraft is being developed by Lockheed Martin and Proxemy Research Inc.

Stofan has already teamed up with the Applied Physics Lab at Johns Hopkins University to shepherd the lake lander through proposal phases. Now the researchers must await a possible year-end announcement of the final selections for NASA's Discovery missions. From the 40 proposals submitted to NASA's DSMCE Program, nine were selected for further study. Currently, NASA is soliciting for proposals for the next Discovery mission, of which TiME will likely be one such proposal.

## Target



Comparison of Ligeia's size (left) with Lake Superior on Earth (right)

TiME's launch would be with an Atlas 411 rocket during the 21-day launch window starting on 17 January 2015. The target lake is Ligeia Mare (78°N, 250°W). It is one of the largest lakes of Titan identified to date, with a surface area of about ~100,000 km<sup>2</sup>. The backup target is Kraken Mare.

## Science objectives

The Titan Mare Explorer would undergo a simple interplanetary cruise with no flyby science. Measurements and data transmissions would begin only after splashdown. The science objectives of the mission are:

1. Determine the chemistry of seas to constrain Titan's methane cycle, look for patterns in the abundance of constituents in the liquids and analyze noble gases. Instruments: Mass Spectrometer (MS), Meteorology and Physical Properties Package (MP3).
2. Determine the depth of the Titan sea to determine sea volumes, and thus, organic inventory. Instrument: Meteorology and Physical Properties Package (Sonar) (MP3).
3. Investigate Titan's lake-related processes by characterizing physical properties of its liquid seas, and how they vary with depth. Instrument: Meteorology and Physical Properties Package (MP3).

4. Determine how the local meteorology over the seas ties to the global cycling of methane on seasonal and longer timescales. Instrument: Meteorology and Physical Properties Package (MP3).
5. Analyze the nature of the sea surface and if possible, shorelines, to determine physical properties of sea liquids and better understand origin, evolution, and subsurface methane/ethane hydrology of Titan lakes and seas. Instrument: Descent and Surface Imagers (DI, SI).

## Power source

Titan's thick atmosphere rules out the use of solar panels like the ones that have kept the Mars rovers and landers functioning for years, while batteries would only provide some hours of power at most. If selected by NASA, the TiME lander would be the test flight of the new Advanced Stirling Radioisotope Generator (ASRG), which is a prototype meant to provide availability of long-lived power supplies for landed networks and other planetary missions. For this mission, it would be used in two environments: deep space and non-terrestrial atmosphere. The ASRG is a radioisotope power system using Stirling power conversion technology and is expected to generate 140–160 W of electrical power; that is four times more efficient than RTGs currently in use. Its mass is 20 kg and will have a nominal lifetime of 14 years.

### Specifications

- $\geq 14$  year lifetime
- Nominal power : 140 W
- Mass ~ 20 kg
- System efficiency: ~ 30 %
- 2 GPHS <sup>238</sup>Pu modules
- Uses 0.8 kg plutonium-238

The lake-lander would not be self-propelled and the wind will be expected to push this buoyant craft around the lake for months.

## Potential habitable zone

The chance to discover a form of life with a different chemical basis than life on Earth has led some researchers to consider Titan the most important world on which to search for extraterrestrial life. A few scientists hypothesize that if the hydrocarbon chemistry on Titan crossed the threshold from inanimate matter to some form of life, it would be difficult to detect. This is because there is no way that terrestrial life could have originated or could prosper on Titan because of the fundamentally different chemistry of Titan's surface. Moreover, because Titan is so cold, the amount of energy available for building complex biochemical structures is limited, and any water-based life would freeze without a heat source.