

# Modern Astronomy: Voyage to the Planets

## Lecture 8

# The outer planets: Uranus, Neptune and Pluto

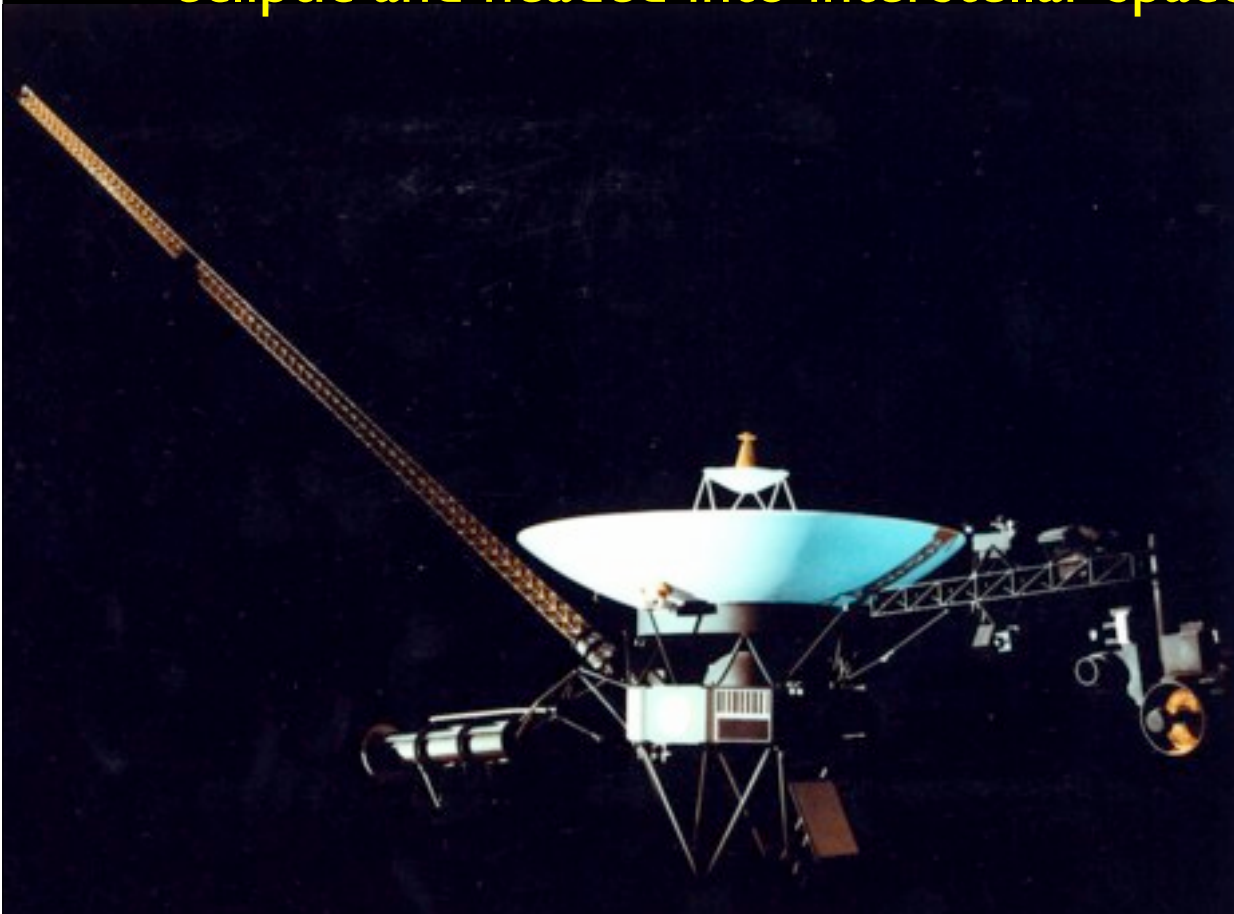
University of Sydney  
Centre for Continuing Education  
Autumn 2005

Tonight:

- Uranus
- Neptune
- Pluto and Chiron
- The Voyager missions continue (or not?)



The only mission to fly to the outer planets was Voyager 2. After leaving Saturn in August 1981, Voyager arrived at Uranus in January 1986, then flew on past Neptune in August 1989. It then swung down below the ecliptic and headed into interstellar space.



# Uranus



Uranus was discovered in 1781 by William Herschel, musician and amateur astronomer. Herschel became the first person in recorded history to discover a new



planet, at a stroke doubling the size of the known Solar System. In fact, Uranus had been detected, mistaken for a star, on 22 occasions during the preceding century, including by John Flamsteed, the first Astronomer Royal, who called it 34 Tauri.

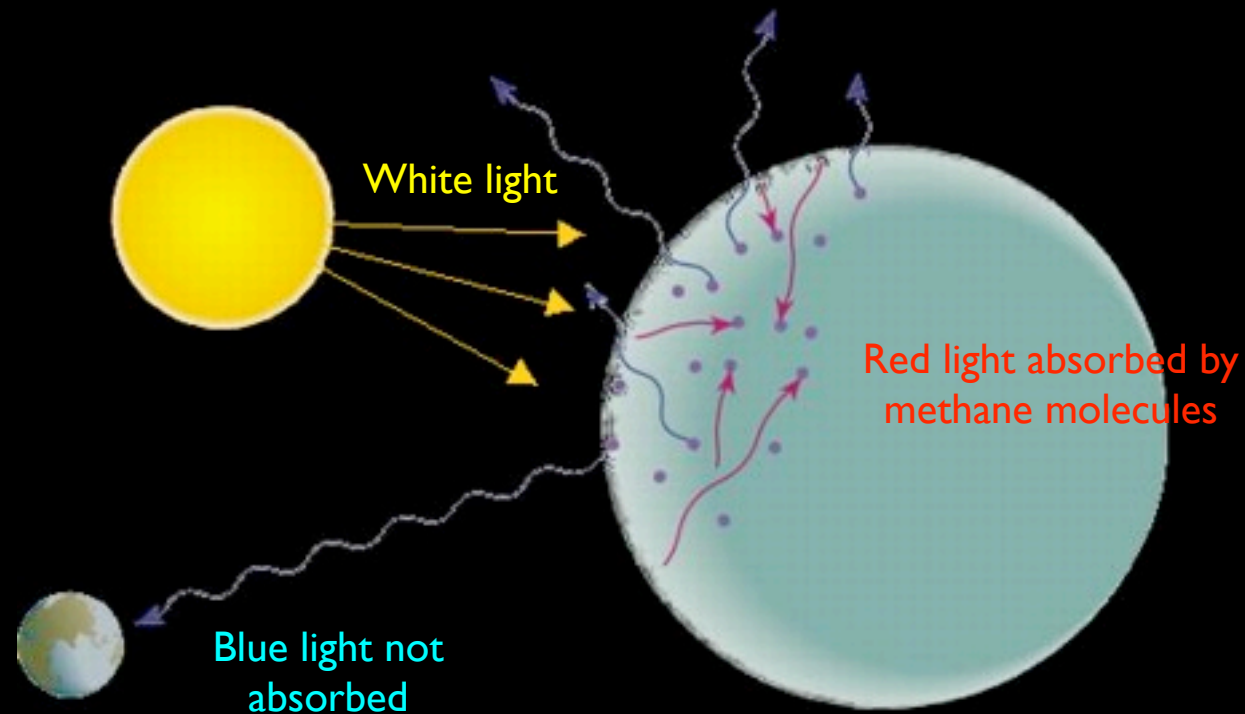
# Basic facts

	Uranus	Uranus/Earth
Mass	$86.83 \times 10^{24} \text{ kg}$	14.536
Radius	25,559 km	4.007
Mean density	$1.270 \text{ g/cm}^3$	0.230
Gravity (eq., 1 bar)	$8.87 \text{ m/s}^2$	0.905
Semi-major axis	$2872 \times 10^6 \text{ km}$	19.20
Period	30 685.4 d	84.011
Orbital inclination	$0.772^\circ$	-
Orbital eccentricity	0.0457	2.737
Axial tilt	$97.8^\circ$	4.173
Rotation period	-17.24 h	0.720
Length of day	17.24 h	0.718

Uranus shows an almost totally featureless disk. Even Voyager 2 at a distance of 80,000 km saw few distinguishable features.



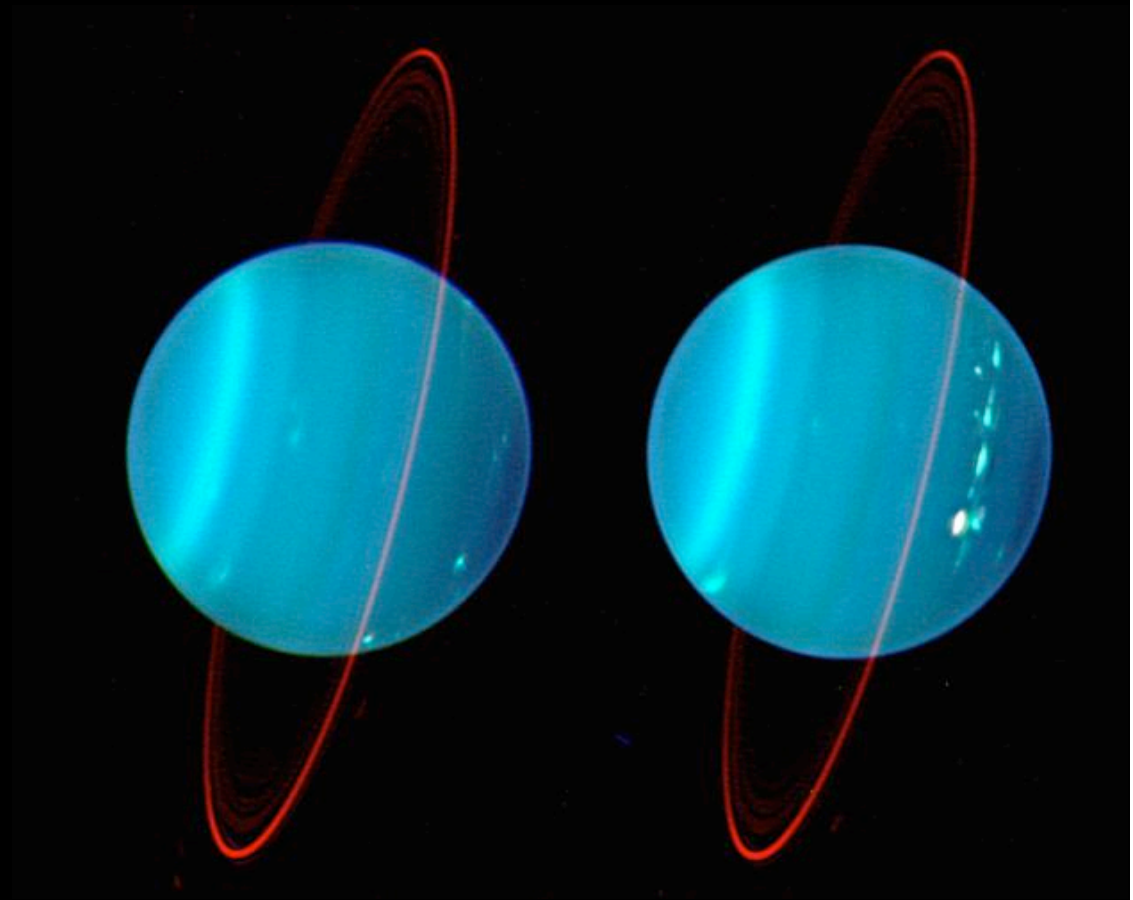
Uranus' atmosphere is made up of 83% hydrogen, 15% helium, 2% methane and small amounts of acetylene and other hydrocarbons. Methane in the upper atmosphere absorbs the red light and gives Uranus its blue-greenish colour.



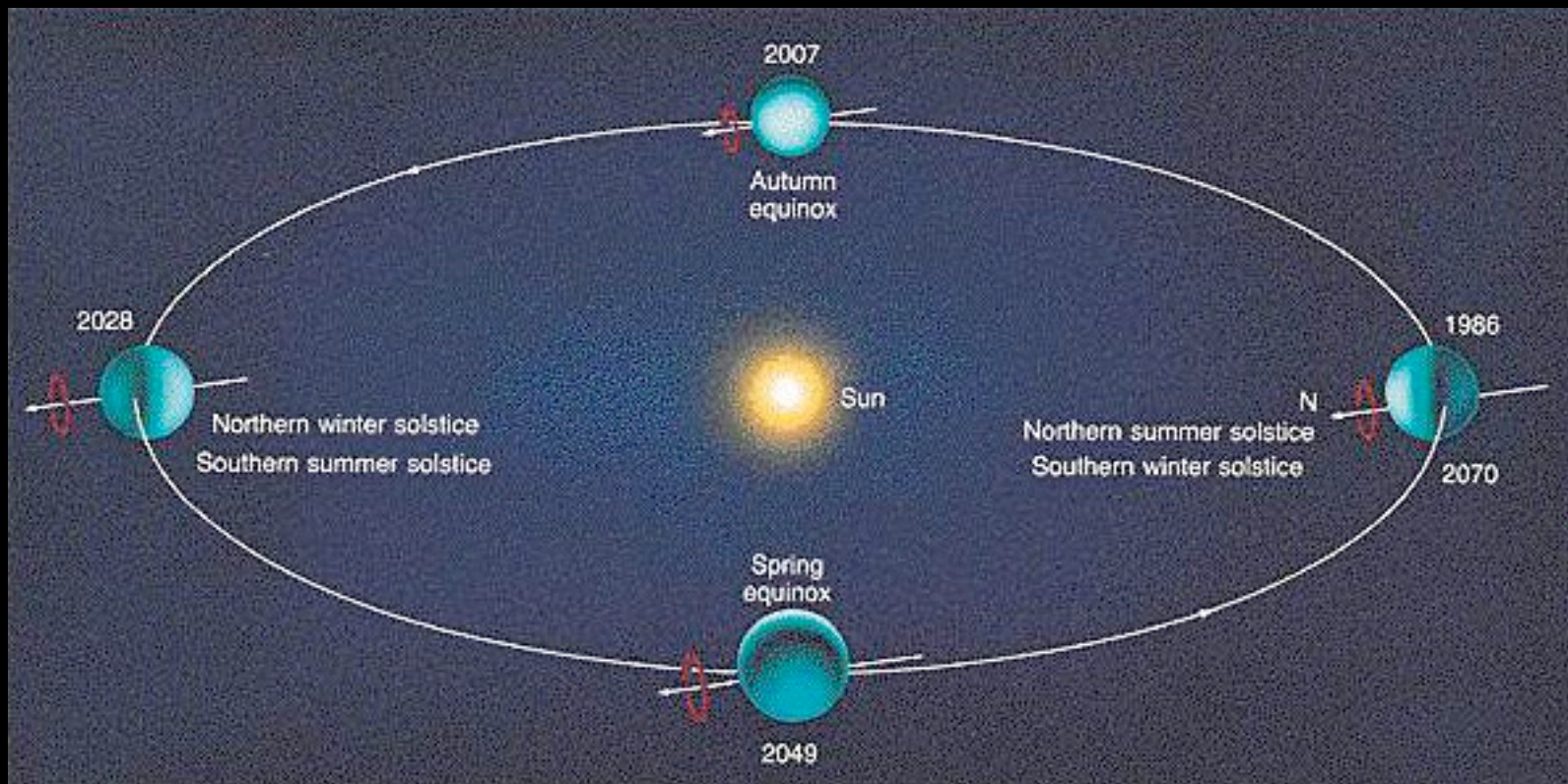


Unlike all the other planets, the rotation axis of Uranus is tilted to lie almost in the plane of its orbit. The equatorial plane is inclined  $98^\circ$ , so it spins *backwards* compared to other planets.

Infrared image taken by the Keck Telescope, showing layers in the atmosphere.

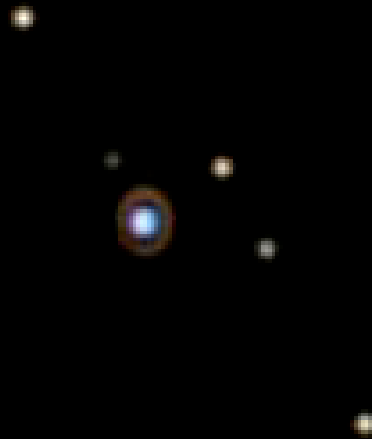


As a result of this tilt, Uranus has very bizarre seasons, with each pole being sunlit for 42 (Earth) years. During this time, the pole receives more light than the equator, before being plunged into darkness for the next 42 years.



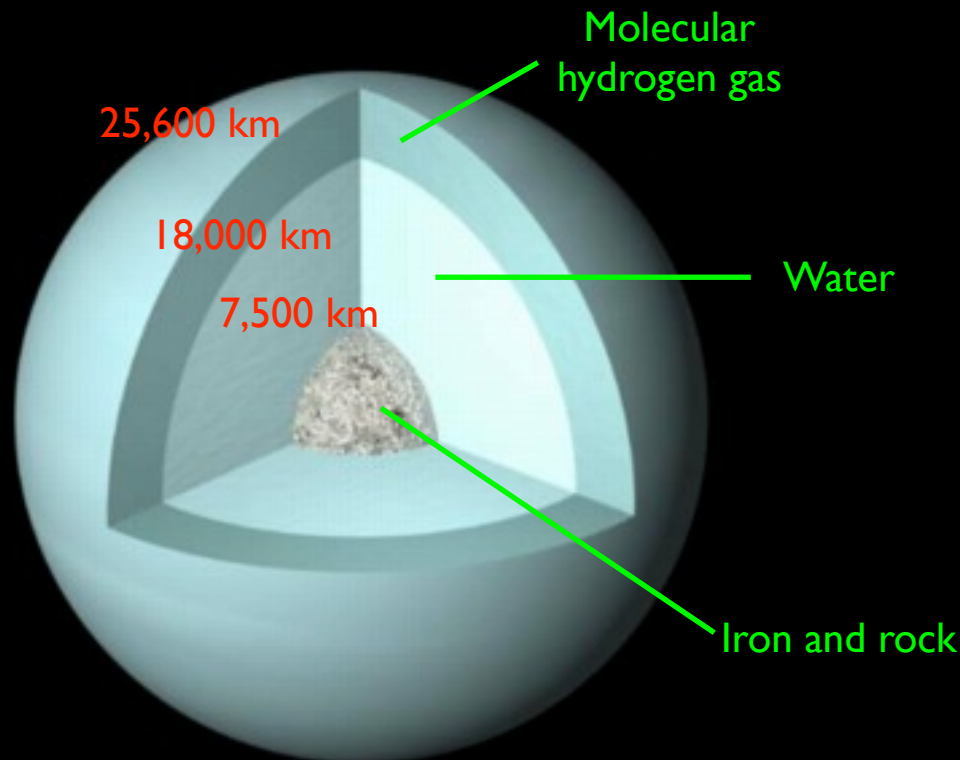
The Hubble Space Telescope saw enormous storms swirling around Uranus as the northern hemisphere came out of its 20-year winter.

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Like Jupiter and Saturn, Uranus has a rocky core. However, the pressure is high not enough to convert molecular hydrogen to metallic hydrogen in the interior. Instead, 80% of the mass of the planet consists of a

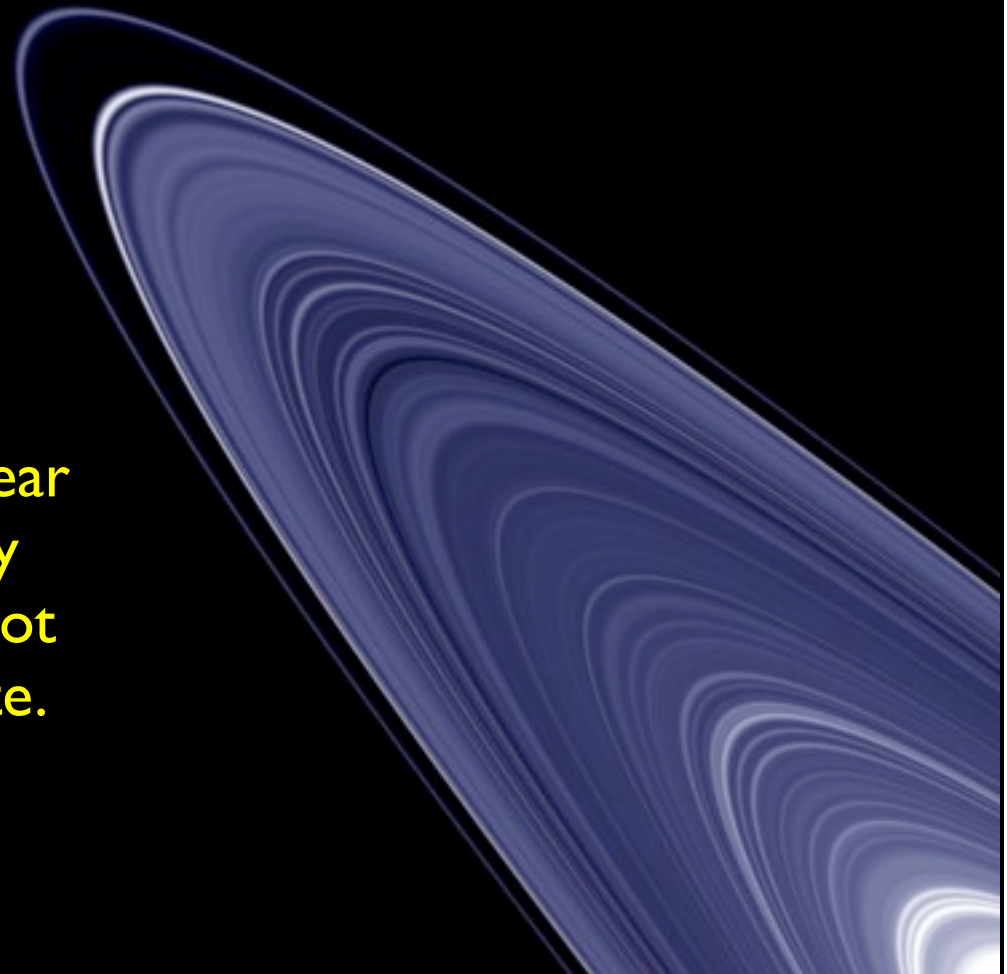
mantle made up mostly of water with some methane and ammonia. The inner core is about 1 Earth mass, and the outer layer is a hydrogen and helium-rich atmosphere.



Uranus has a magnetic field, about 50 times as strong as Earth's. However, the magnetic axis is not only tilted by about 60 degrees from the rotational axis, but is also offset from the centre of the planet by about 8000 km. This field probably arises as a result of electrical currents in the liquid mantle.

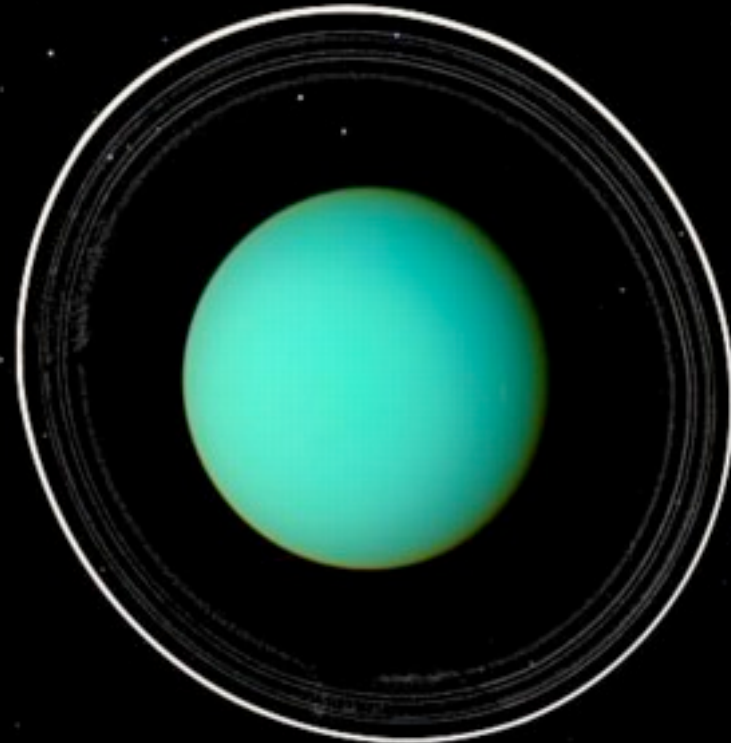


Uranus has rings which are narrow, widely separated, and eccentric, quite unlike those of Jupiter or Saturn. Most of them are less than 10 km in width. Unlike the icy rings of Saturn or the dusty rings of Jupiter, the particles in Uranus' rings are extremely dark, with albedos of only 2%, as dark as the blackest asteroids and meteorites known. The rings also appear to be clumpy, implying they are very young and have not yet reached their final state.

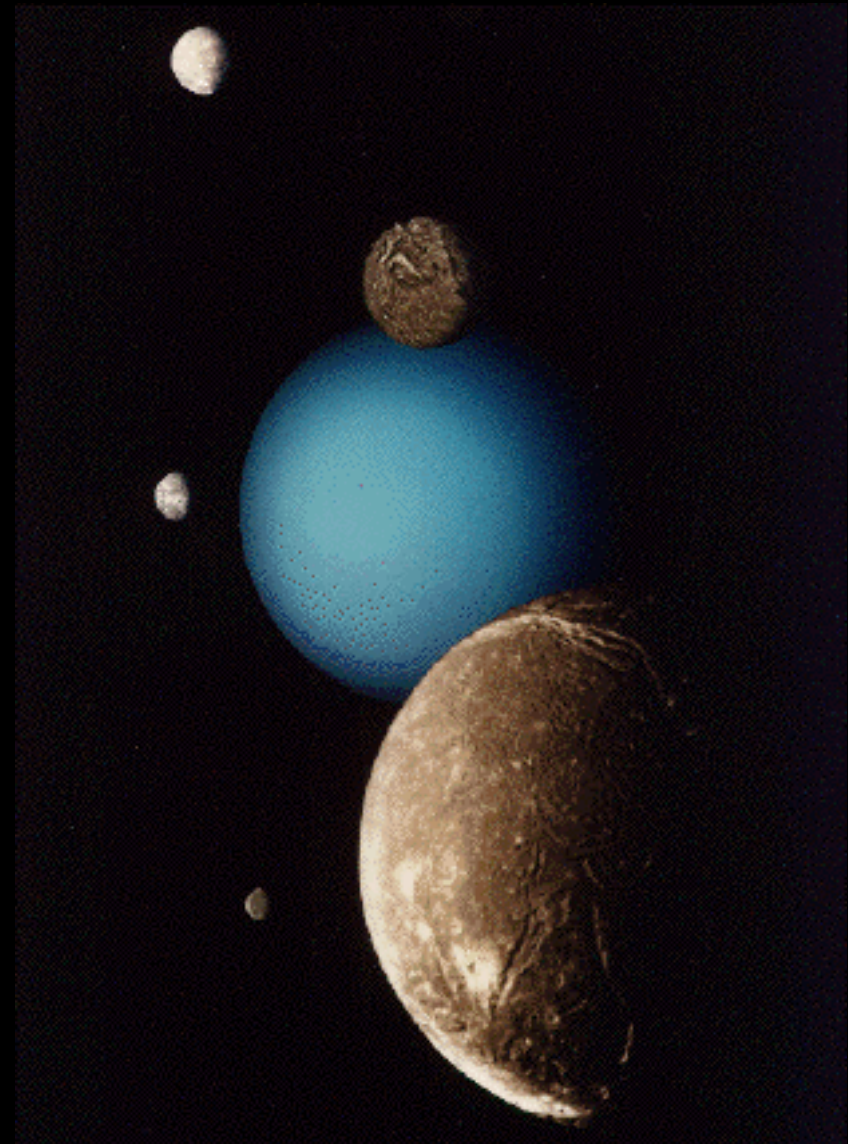




The brightest ring, Epsilon, orbits at a distance of just over twice Uranus' radius, or one radius above the surface. There are nine major rings: from the planet outwards, they are named 6, 5, 4, Alpha, Beta, Eta, Gamma, Delta, and Epsilon. Voyager detected a few additional rings and also showed that the nine major rings are surrounded by belts of fine dust.




Uranus has at least 21 moons. Five are large, known prior to the space age: Miranda, Ariel, Umbriel, Titania and Oberon. All are much smaller than the Earth's Moon, ranging from 1/6th the size of the Moon (Miranda) to about half (Titania and Oberon). Voyager discovered ten new moons, and Earth-based observations have added a few more. From their density, they appear to be mixtures of ice and rock, with some ammonia and methane.



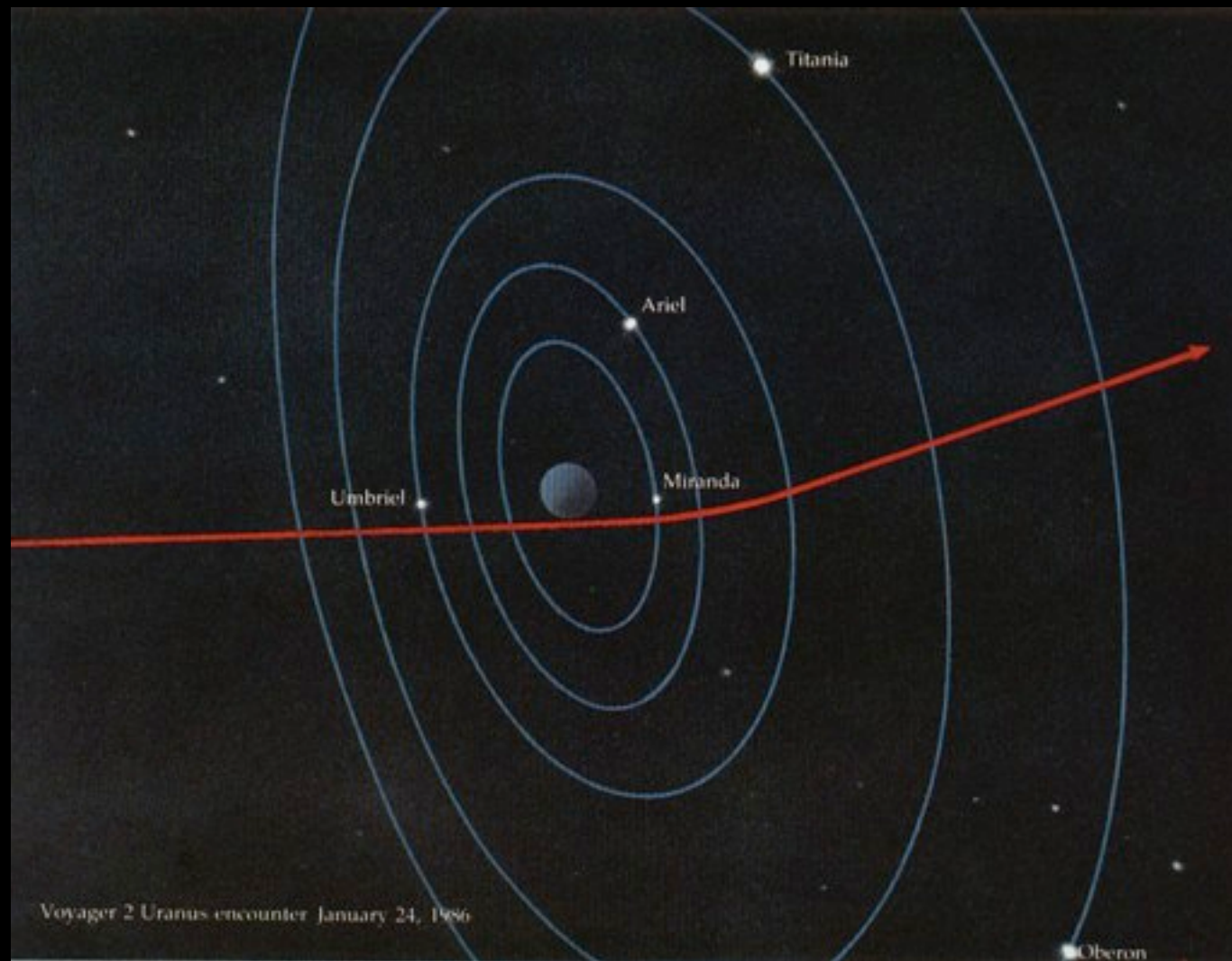


On the day of the encounter, Voyager's timetable was as follows:

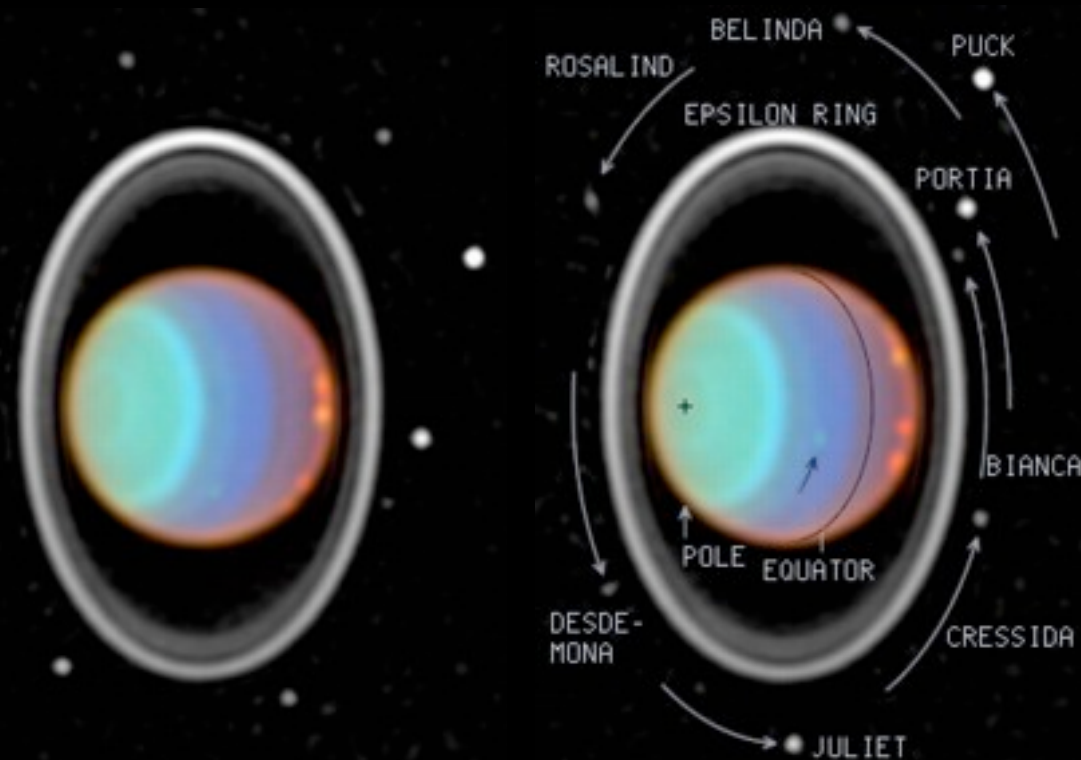


14:00	Voyager 230 000 km or 10 Uranian radii from Uranus
15:08	Closest to Titania (365 000 km)
16:12	Closest to Oberon (471 000 km)
16:20	Closest to Ariel (130 000 km)
17:03	Closest to Miranda (32 000 km)
17:16	Ring-plane crossing
17:59	Closest to Oberon (471 000 km)
20:38	Occultation of Voyager by Uranus (till 22:45)
20:45	Closest to Umbriel (325 000 km)
24:00	Voyager now 650 000 km from Uranus

Here's a picture of Voyager's trajectory during the fly-by:

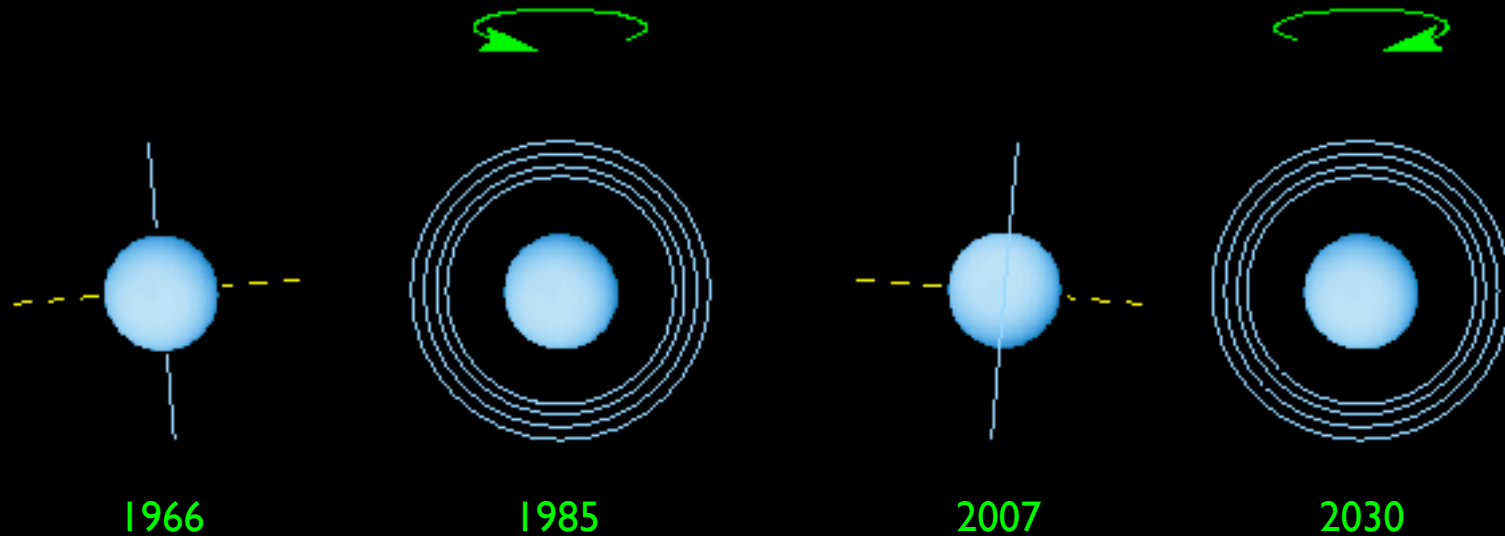


The moons are in Uranus' orbital plane, like other planets: so unlike Jupiter's moons, which appear always in a line to us, we have been able to see Uranus' moons (nearly) face on.



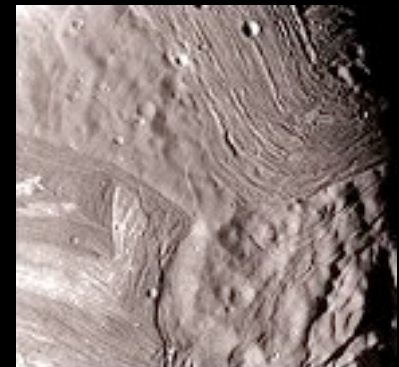
HST infrared images of Uranus, showing the rings and moons (which have moved over the 90 minutes between the two pictures).

However, this won't be true for much longer. Because Uranus' pole always points to the same direction in space, at some points in its orbit its pole is pointed towards us, and sometimes it appears side-on to us. By 2007 we will see Uranus' rings and moons side-on.



**Miranda**, the innermost of the five large moons, is only 470 km in diameter. Its surface looks as though it has been broken up and reassembled. It has huge fault canyons 20 km deep, layering and terraces, and old, pock-marked surfaces and young, bright regions. This suggests ice was melted and re-froze, though how this could

happen when the temperature is  $-187^{\circ}\text{C}$  is hard to understand. Possibly it was the result of the cataclysm which shattered the surface, and possibly the same one which tilted Uranus on its side.

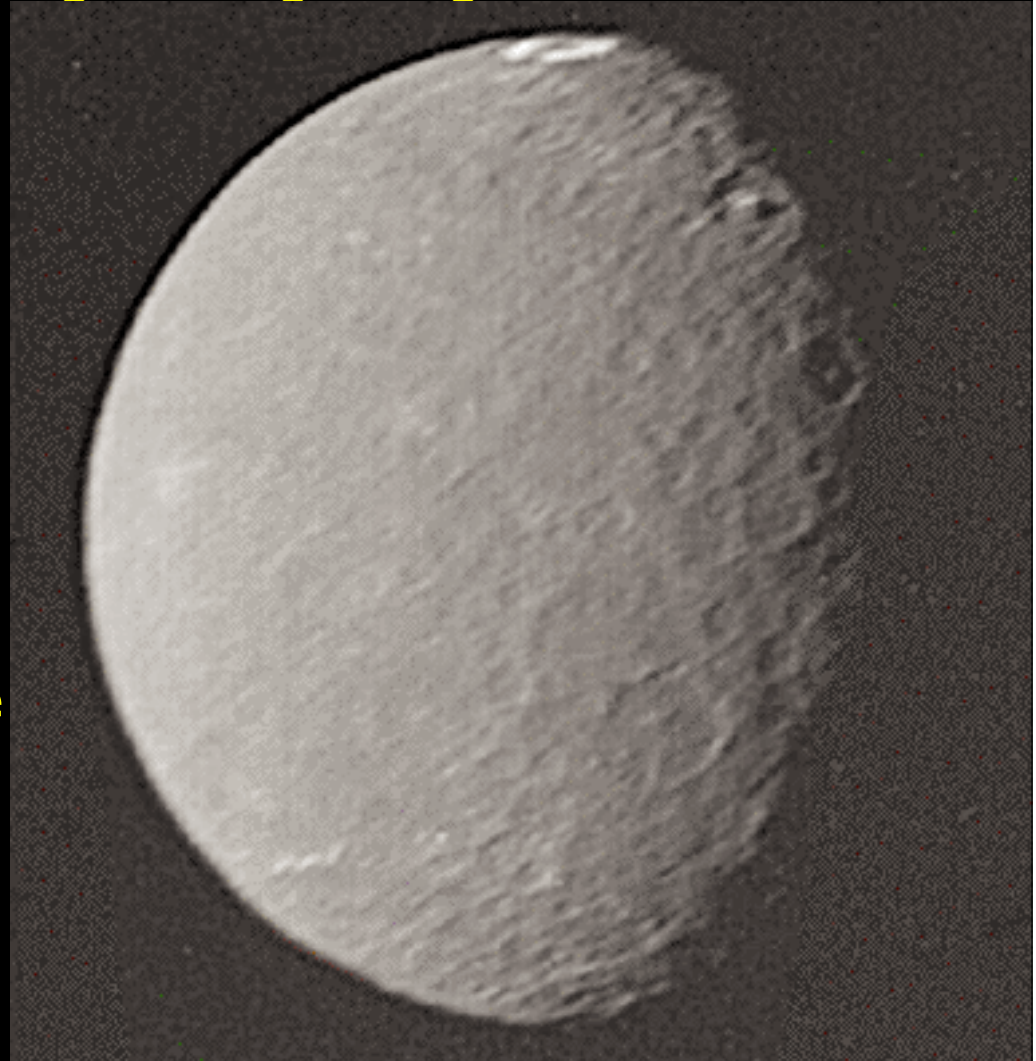


**Ariel** is covered with huge canyons, which look like faults produced by expansion and stretching of the crust. Some of the canyon floors appear to have been smoothed by liquid, presumably ammonia, methane or even carbon monoxide. Much of the surface is marked by small, young craters (from their bright ejecta blankets).

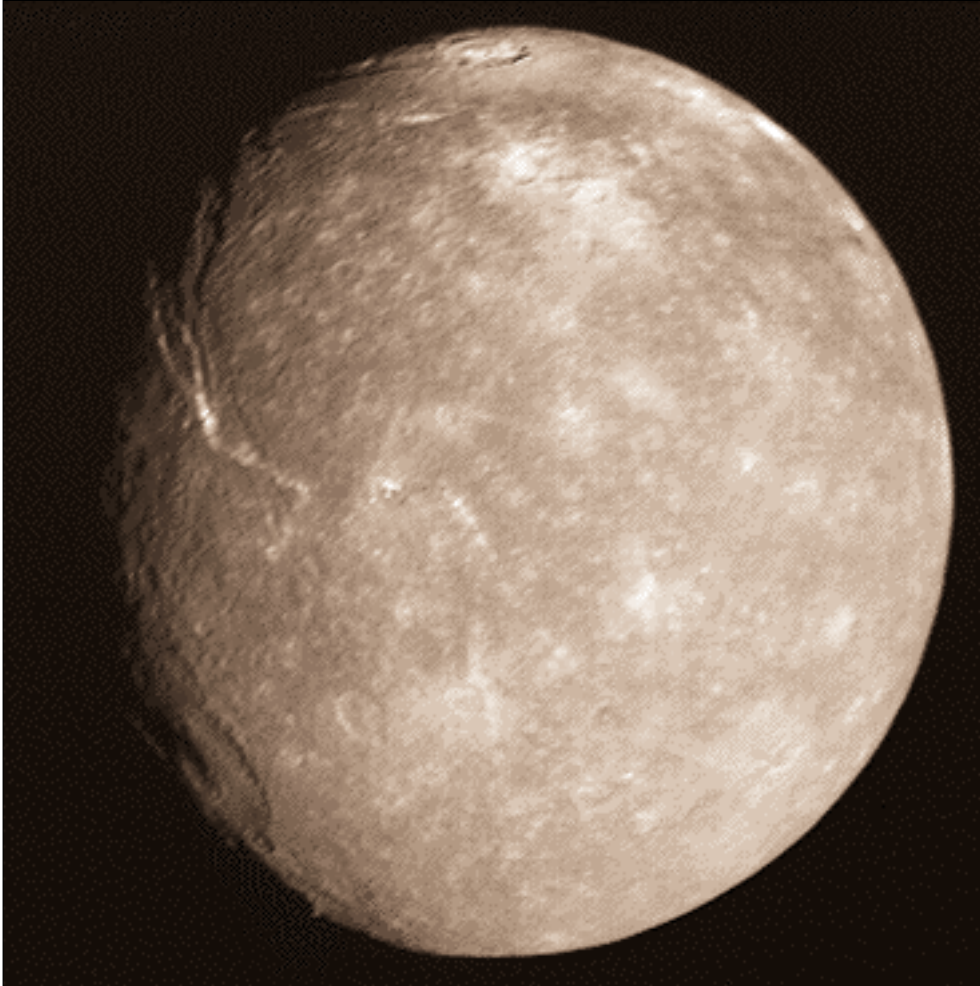




**Umbriel**, which is almost exactly the same size as Ariel, is darker, shows no major rift features, and is covered with craters of all sizes, including the bright ring at the top called the *fluorescent cheerio*, which is probably the floor of a crater. Possibly Ariel, but not its sibling Umbriel, was remelted by some process which led to cracking of the icy crust and the release of molten water.



**Titania**, the largest of Uranus' moons, has a few large impact basins, but is mostly covered with small craters and very rough rocks. It has huge fault systems and canyons that indicate that internal forces have been active in moulding its



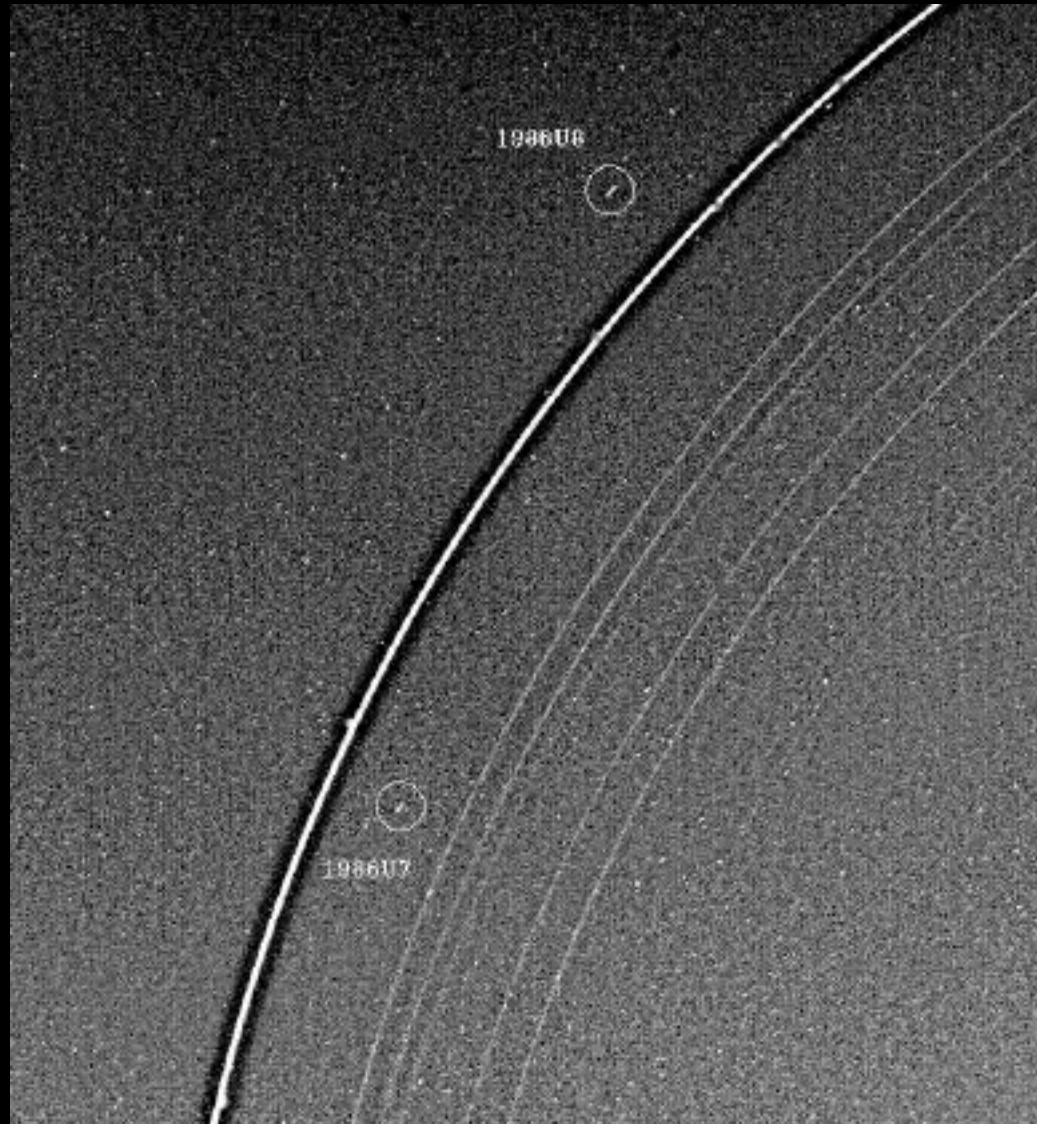
surface. A large double walled crater can be seen towards the top of the image. One theory is that it was once hot enough to be liquid. The surface cooled first, and when the interior froze it expanded, forcing the surface to crack.



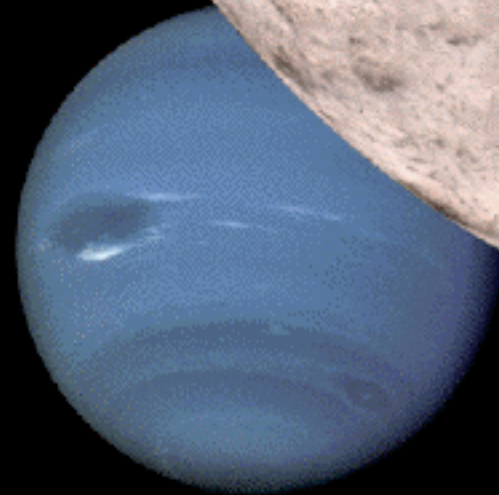
**Oberon** appears quite similar to Umbriel, though Oberon is 35% larger. Its surface is heavily cratered, showing more and larger craters than Ariel and Titania, some with bright rays of ejecta. Some of the crater floors are dark, perhaps covered with darker material that upwelled into the crater. Large faults cut across the entire southern hemisphere, which indicates some geologic activity early in Oberon's history. The large crater is called Hamlet (200 km in diameter). The mountain on the limb rises 6 km above its surrounds.



Of the ten small satellites which Voyager discovered, **Cordelia** and **Ophelia** appear to be the shepherding satellites for the bright Epsilon ring. Interestingly, both are within the Roche limit, where tidal forces pull solid bodies apart. Will they eventually be destroyed?

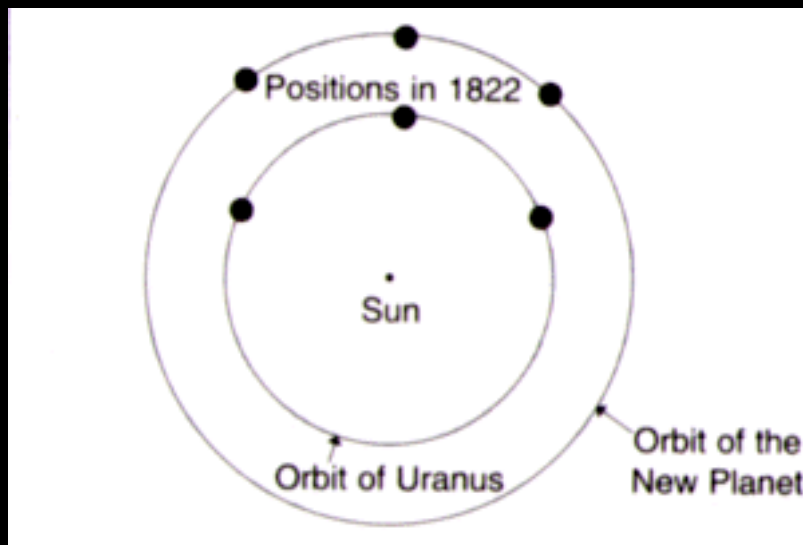


Neptune






Neptune was the first planet to be discovered due to a mathematical prediction. After Herschel's discovery, Uranus was not moving as predicted. Until 1822, it seemed to accelerate in its orbit, and to slow after that. Two young mathematicians independently set out to solve the mystery.



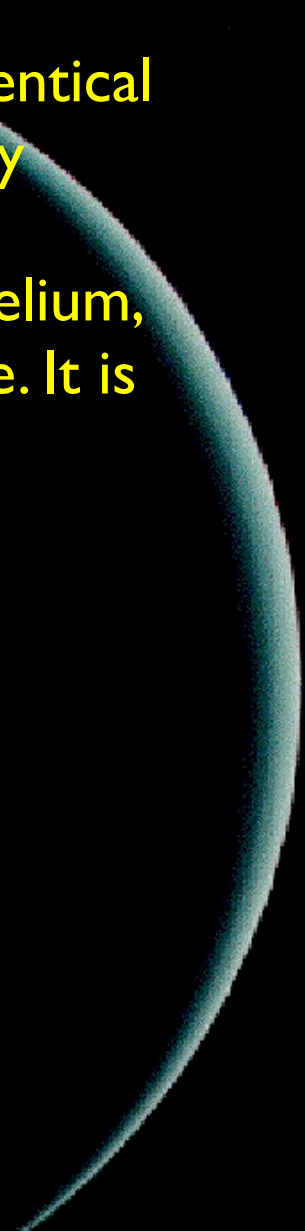
John Couch Adams predicted the position of the planet, as did Urbain Leverrier, whose solution led to the discovery of the planet by Johann Galle at the Berlin Observatory in 1846.

# Basic facts

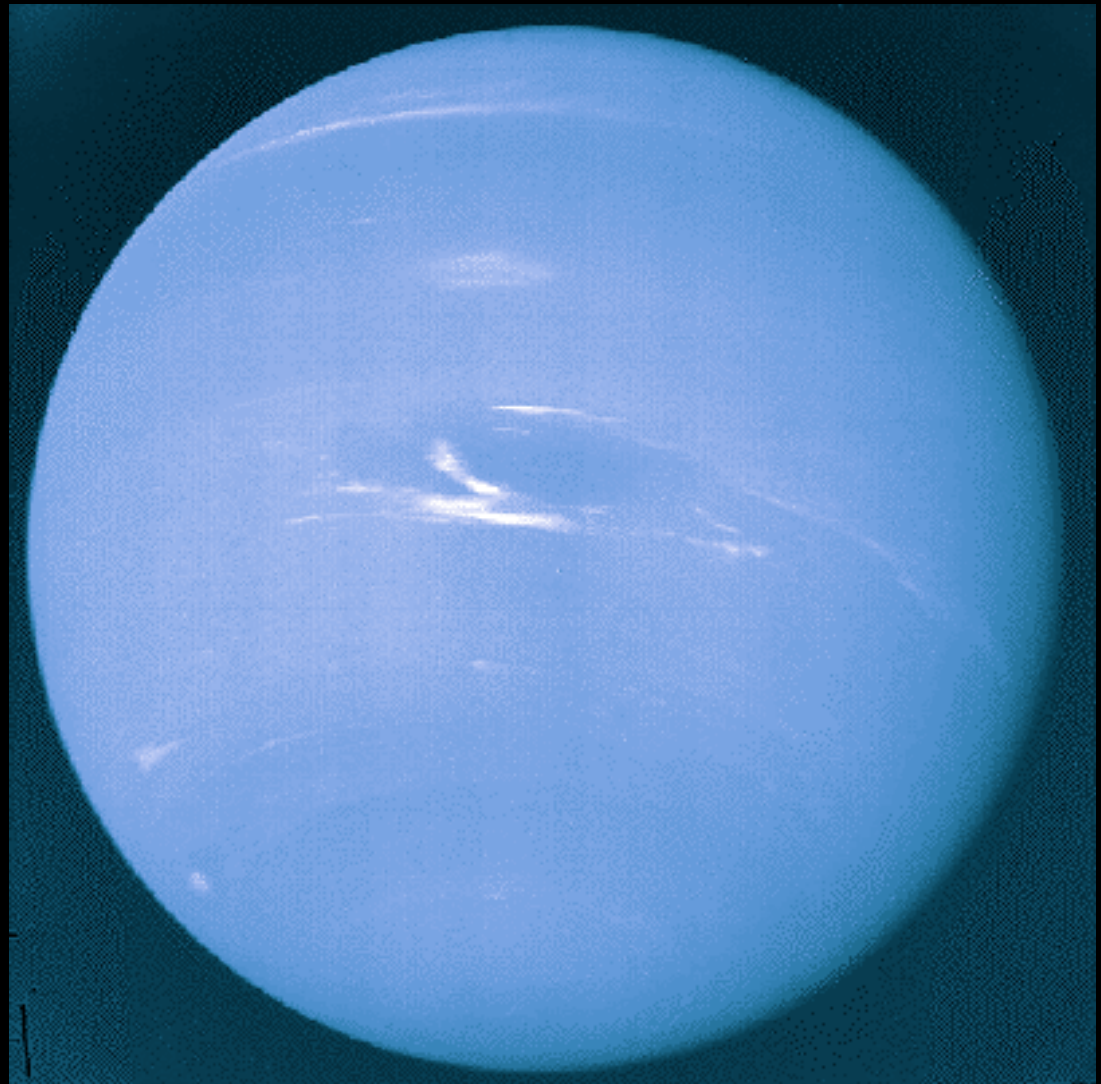


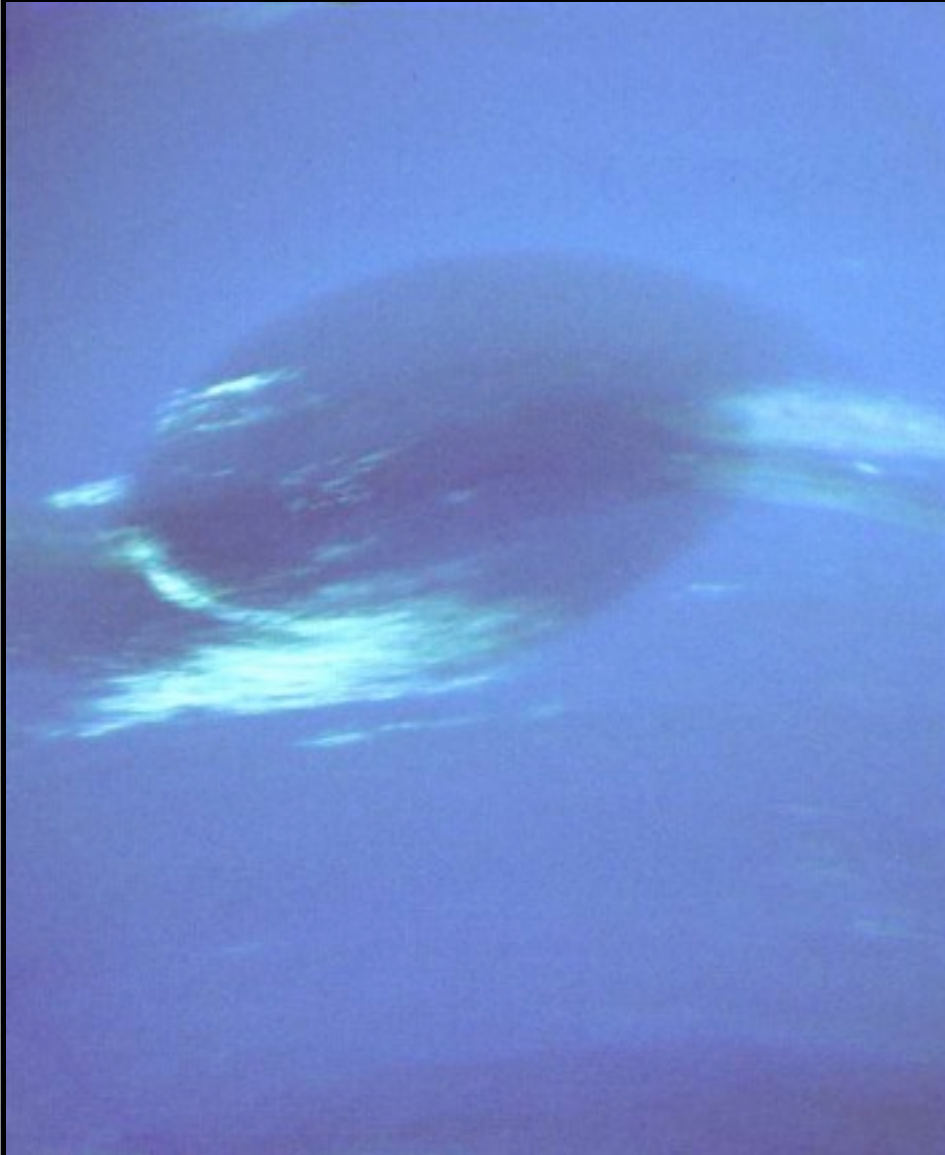
	Neptune	Neptune/Earth
Mass	$102.43 \times 10^{24} \text{ kg}$	17.147
Radius	24,764 km	3.883
Mean density	$1.638 \text{ g/cm}^3$	0.297
Gravity (eq., 1 bar)	$11.15 \text{ m/s}^2$	1.14
Semi-major axis	$4495 \times 10^6 \text{ km}$	30.047
Period	60 189 d	164.79
Orbital inclination	$1.769^\circ$	-
Orbital eccentricity	0.0113	0.677
Axial tilt	$28.3^\circ$	1.208
Rotation period	16.11 h	0.673
Length of day	16.11 h	0.671

Neptune is almost a twin to Uranus. Almost identical in size, Neptune is slightly denser, and so slightly more massive than Uranus. Like Uranus, its atmosphere consists mostly of hydrogen and helium, with small amounts of other gases like methane. It is bluer than Uranus, with 3% methane in its atmosphere instead of 2% for Uranus.



Neptune's outer surface is far more interesting than Uranus'. Its upper atmosphere is cold enough for methane (and possibly nitrogen) to condense, which form high clouds. These show up vividly in photos and reveal the rapid winds and huge storms on the planet.

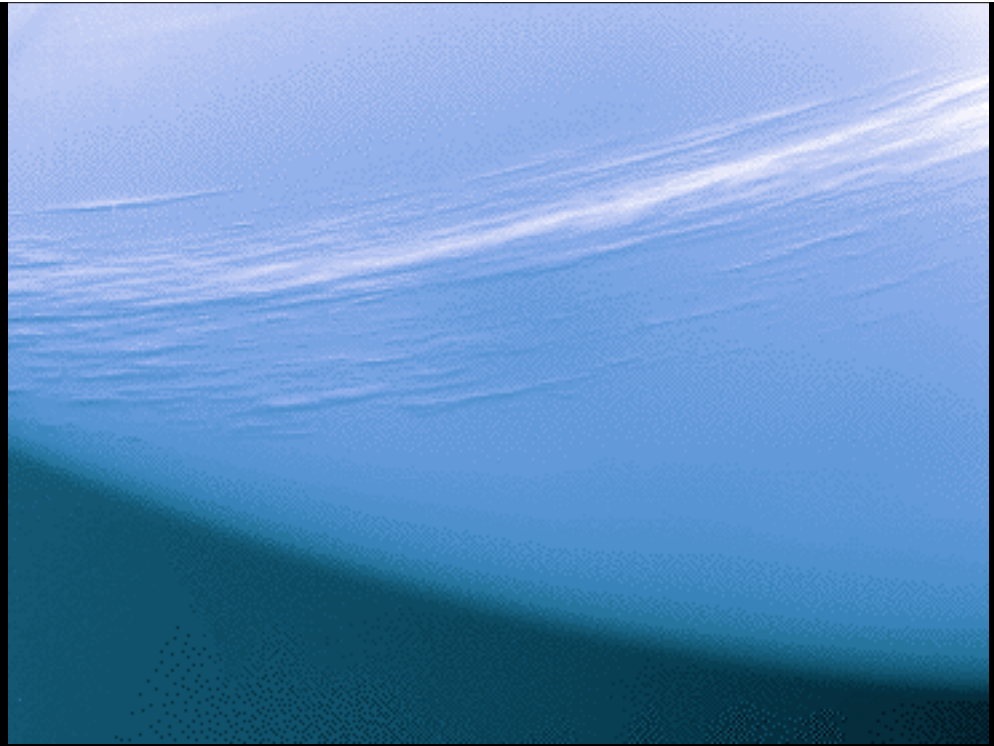




Voyager found a storm as large as the Earth, called the Great Dark Spot, about half the size of Jupiter's Great Red Spot. However, by the time Hubble imaged Neptune in 1994, the Dark Spot had vanished, so it was not nearly as long-lived as its Jovian cousin.

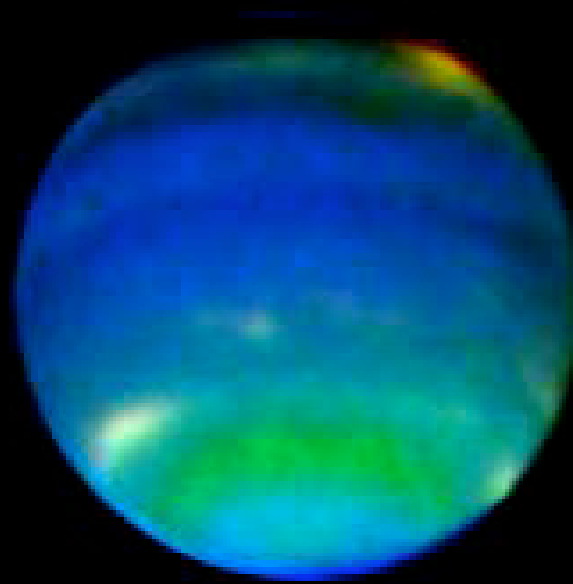


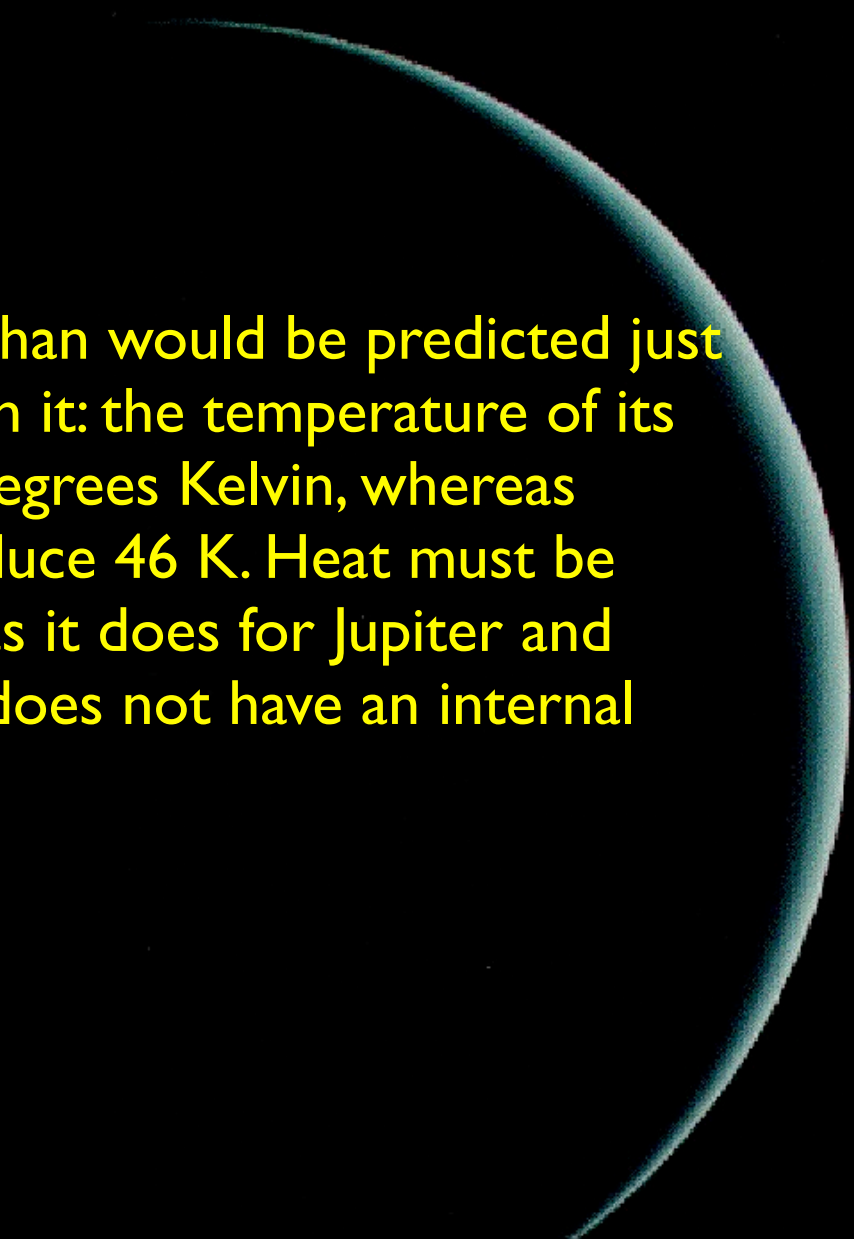
Long, bright clouds like cirrus were seen high in Neptune's atmosphere, casting shadows on the blue cloud deck 50 km below.



Neptune's winds are the fastest in the Solar System, reaching 2000 km/h. What drives these winds is not clear, given the relatively small amount of solar and internal heating to drive the circulation.

Here, images from HST over nine consecutive orbits have been assembled into a time-lapse movie showing a full 16-hour rotation of Neptune. These images show planet's powerful equatorial jet stream, immense storms, and dark spot in the Northern Hemisphere.



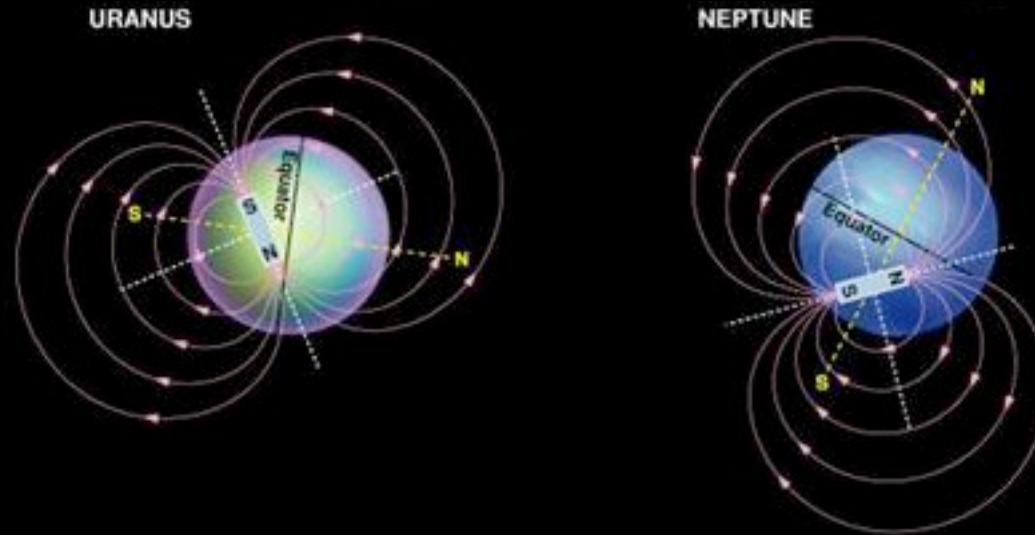
A thin, curved arc of a planet's limb, likely Neptune, is visible on the right side of the image. The arc is a pale, hazy blue-green color, contrasting with the solid black background. The curve starts from the top right and arcs downwards towards the bottom right.

Neptune is also warmer than would be predicted just from the sunlight falling on it: the temperature of its outer atmosphere is 60 degrees Kelvin, whereas sunlight alone would produce 46 K. Heat must be flowing from its interior, as it does for Jupiter and Saturn. Uranus, however, does not have an internal heat source: why not?

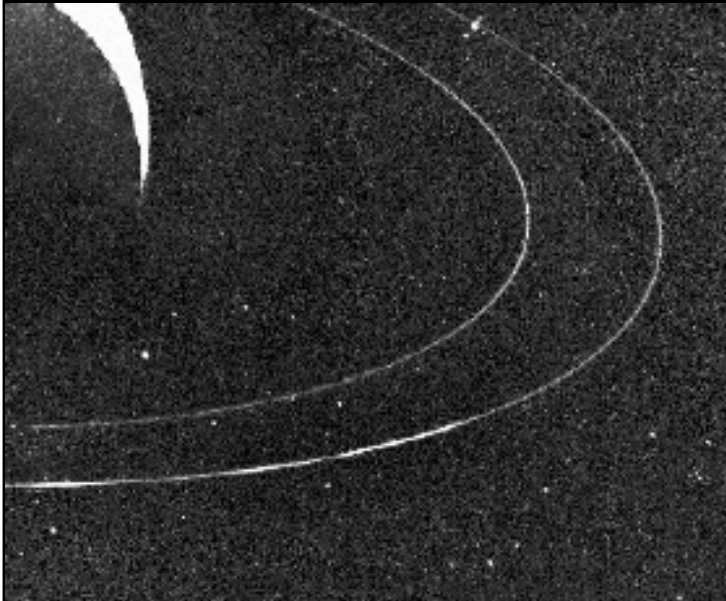
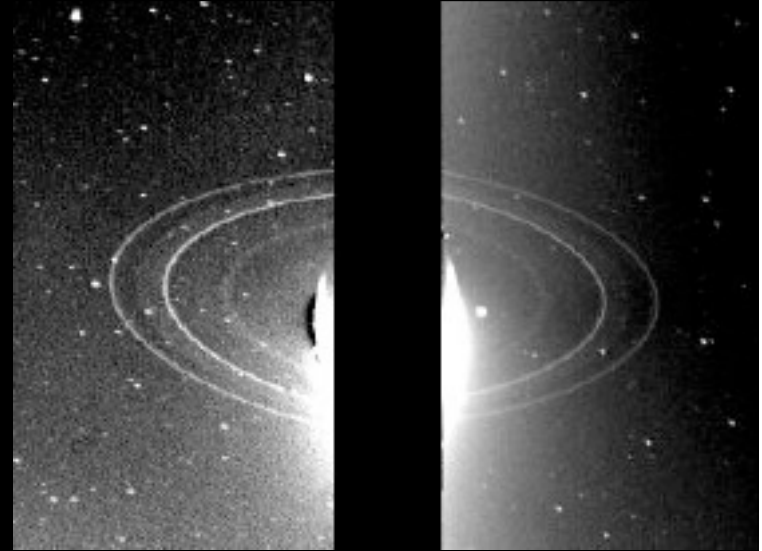
Like Uranus, Neptune might better be called an “ice giant” than a “gas giant” like Jupiter and Saturn, which contain 80-90% hydrogen and helium by mass. Uranus and Neptune contain between 5 and 20% hydrogen and helium. Like Uranus, underneath this atmosphere is a thick layer of water, methane and ammonia ices, with a small rocky core about the size of Earth.



Like Uranus, Neptune's magnetic field is tilted (about  $50^\circ$ ) and is displaced about halfway from the centre of the planet towards the edge. The field is much weaker than those of the other giant planets: about as strong as Earth's.

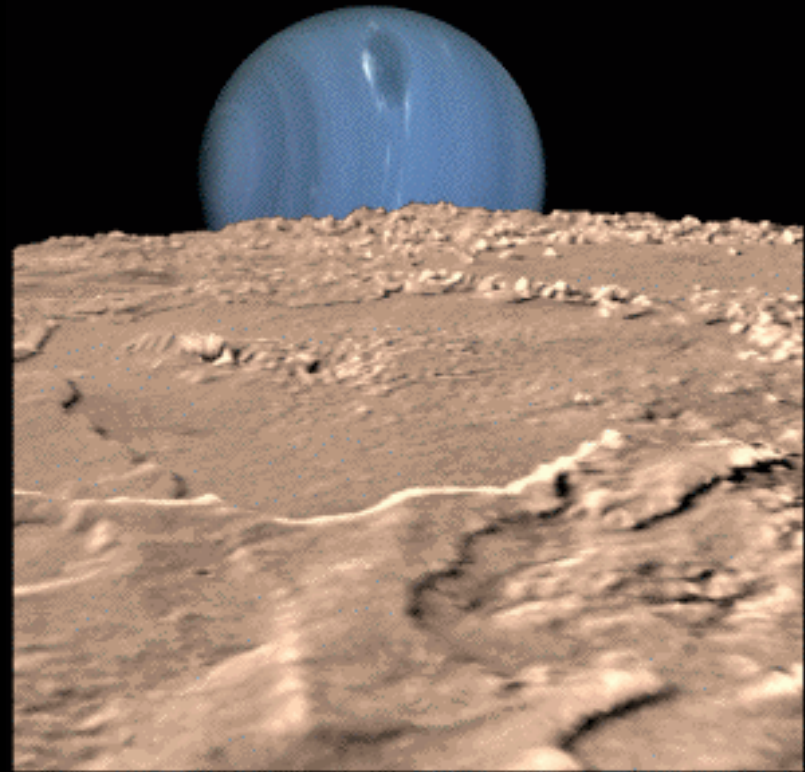


Neptune's rings are very faint and very dark. They contain large amounts of dust, and are probably rocky rather than icy.



The rings are clumpy, with short arcs of denser material. These appear to be due to gravitational interaction with the small inner moon Galatea.

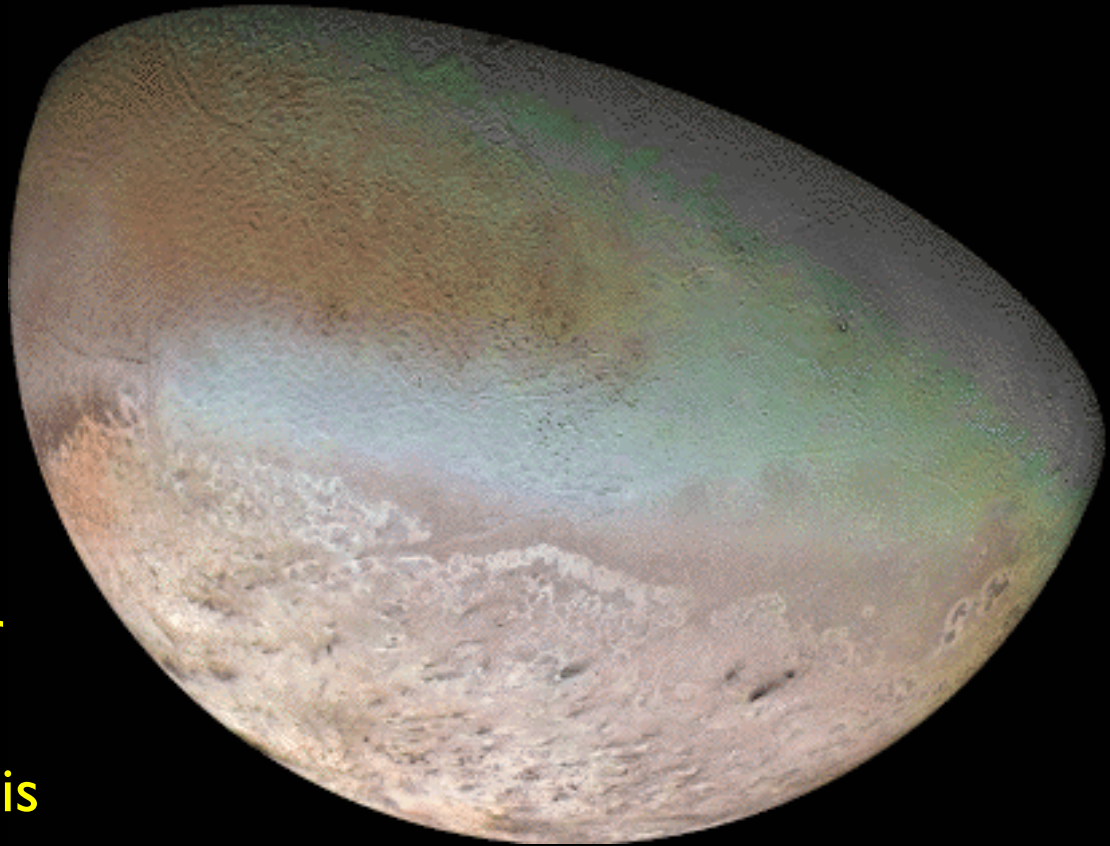
Neptune has eleven moons, six discovered by Voyager. The two moons visible from Earth, Triton and Nereid, both have peculiar orbits. Nereid has a highly eccentric orbit, and Triton is unique among large planetary satellites because it orbits backwards – opposite to the sense of the planet's rotation. The six moons discovered by Voyager mostly orbit closer to Neptune than the rings.



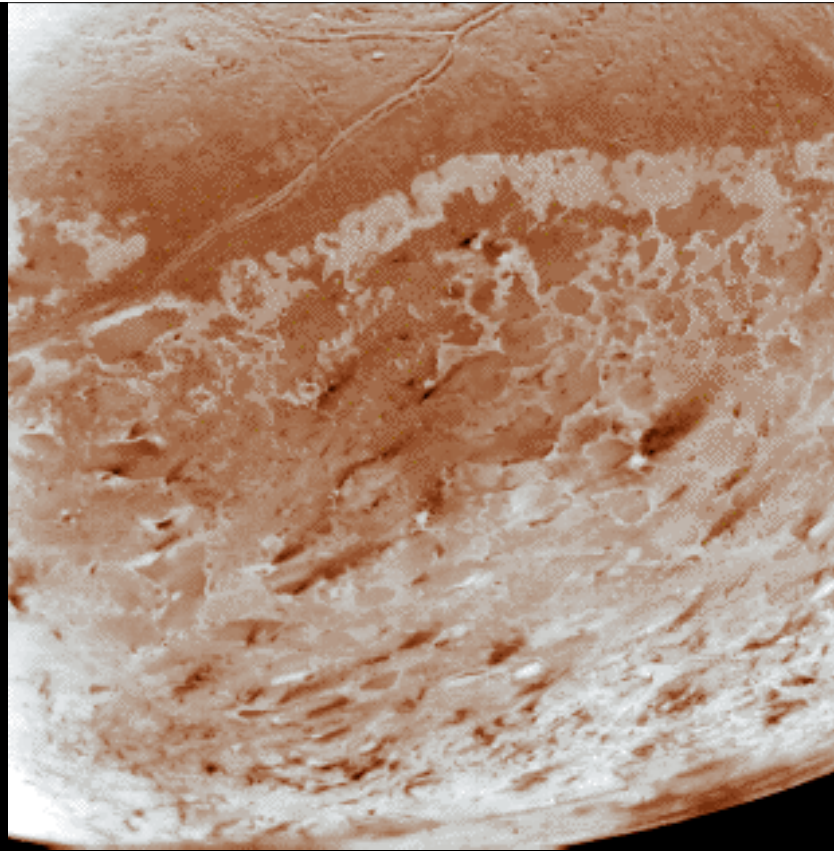
The orbits of Triton and Nereid



**Triton** is by far the largest of Neptune's satellites (diameter 2700 km, just 12% smaller than Earth's moon). It is very bright, with an albedo of 70%, which is due to a coating of frozen nitrogen. The surface temperature is  $-235^{\circ}\text{C}$ , the coldest temperature yet measured in the Solar System. Triton has a density of about  $2.1\text{ g/cc}^3$ , which means means it must be about 2/3 rock, much more than the icy satellites of Saturn and Uranus.



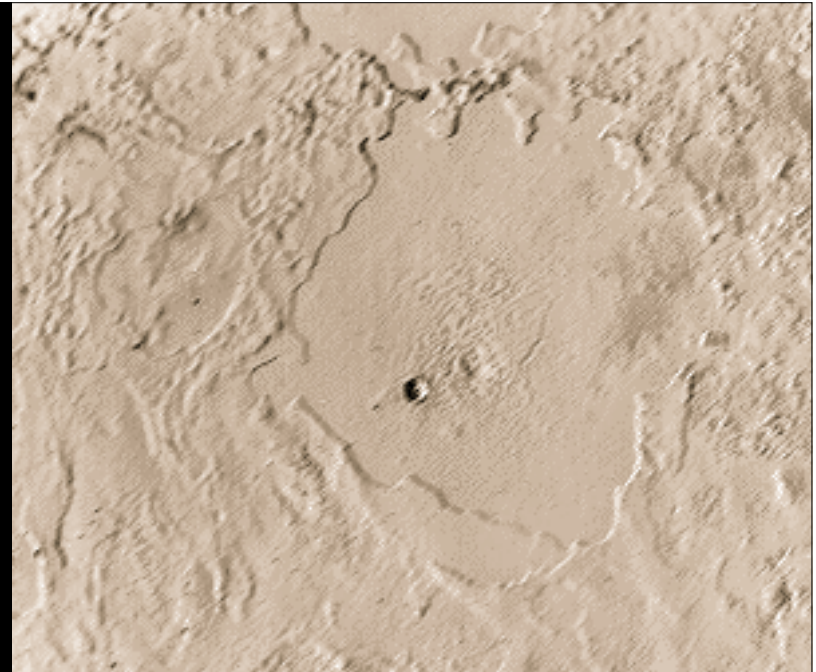




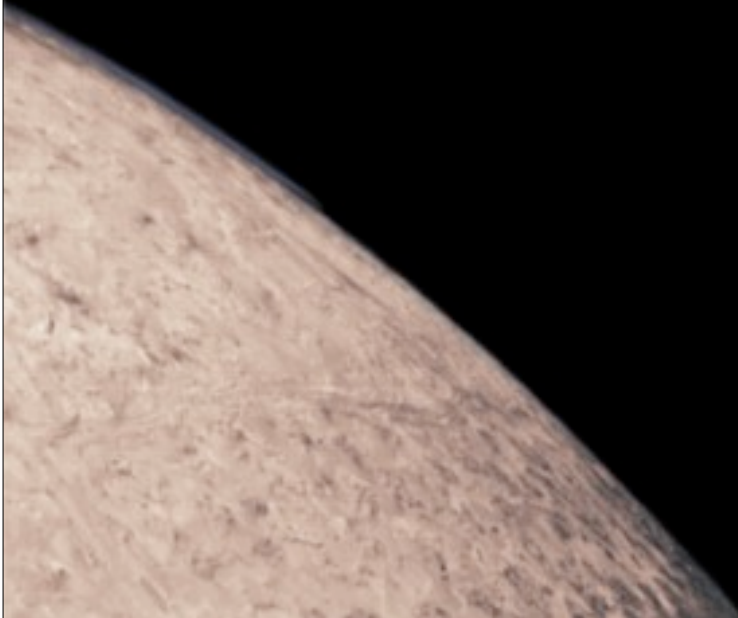
Voyager took this picture of Triton's south pole, revealing evidence of ice volcanoes. The dark streaks are material spread downwind from recent volcanic eruptions. The favoured mechanism for the volcanoes is that the Sun heats darkened methane ice on the surface, which heats underlying

nitrogen ice that vents through the surface as volcanoes. The fact that the streaks all point in the same direction suggest that the very thin atmosphere is able to blow material across the surface, and that there is a prevailing wind direction.

The surface shows a jumbled terrain, including smooth icy expanses filling what appear to be old impact basins. The few impact craters suggest a young surface.



Voyager photographed a thin layer of cloud along the limb of the moon, probably of nitrogen crystals.



Nereid is about 340 kilometres in diameter and takes 360 days to make one orbit. Nereid's orbit is the most eccentric in the solar system (eccentricity 0.75). Its distance to Neptune ranges from about 1.3 million kilometres to 9.6 million kilometres. Its orbit suggests it is probably a captured asteroid or Kuiper Belt object.



Of Neptune's other moons, six named moons were discovered by Voyager, and three more (as yet unnamed) were recently discovered from the ground. The six Voyager moons are mostly closer to Neptune than the rings, and are considered regular, since they orbit in the equatorial plane in the same direction as Neptune.

Three new moons were discovered in 2002, all small ( $< 40$  km), very distant from Neptune, and in highly eccentric and inclined orbits.

Artist's impression of the three new moons of Neptune.



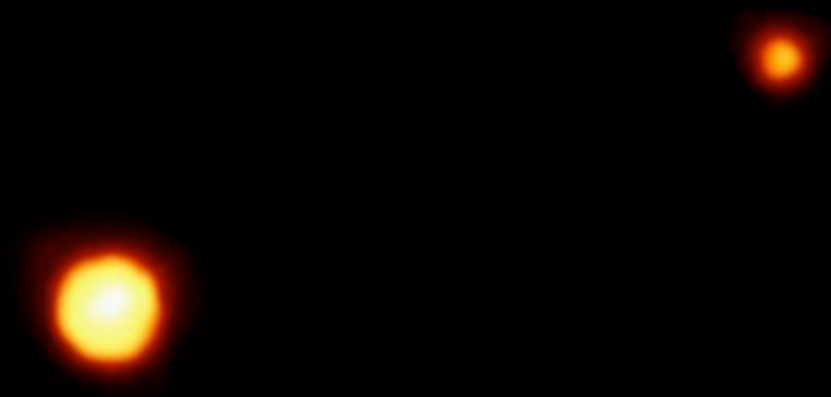


# Pluto & Charon



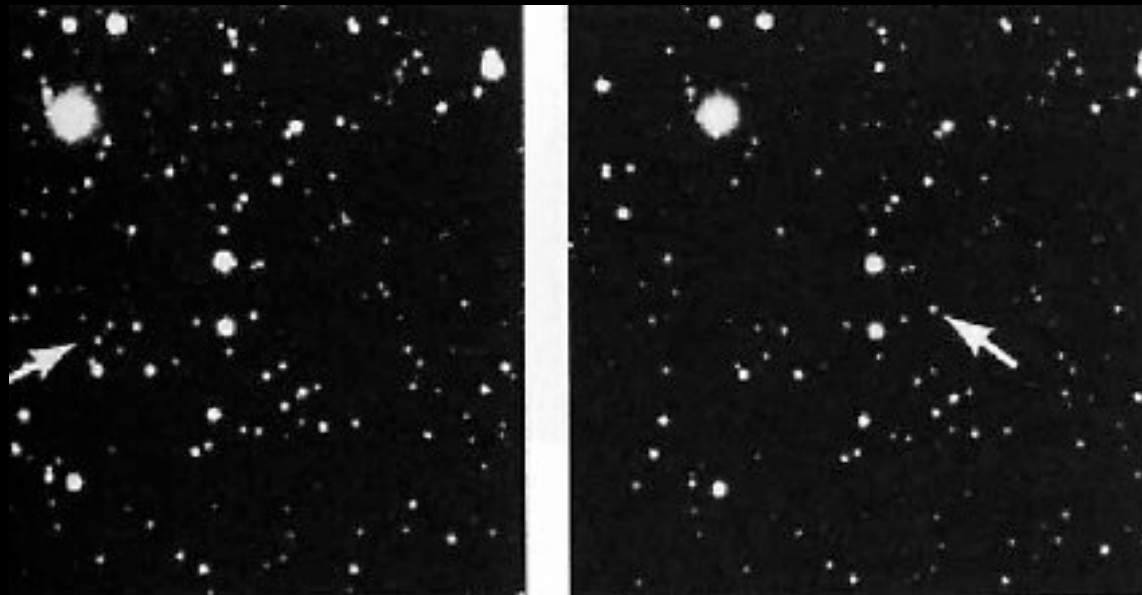


Pluto and Charon form an enigmatic double at the outer edge of the Solar System. They orbit each other once a week, in a highly eccentric orbit around the Sun which is tilted well out of the plane of the ecliptic. The combined mass of Pluto and Charon is less than one percent of Earth's, and so the status of Pluto as a planet is highly dubious.



HST image of Pluto and Charon taken in 1994

Pluto was discovered because of irregularities in Neptune's motion. Two different predictions had suggested the existence of a planet beyond Neptune, called Planet O (William Pickering) and Planet X (Percival Lowell). On February 19, 1930, Clyde Tombaugh at the Lowell Observatory found a faint, star-like image which was moving. Ironically, both calculations were wrong! but he found the planet anyway.

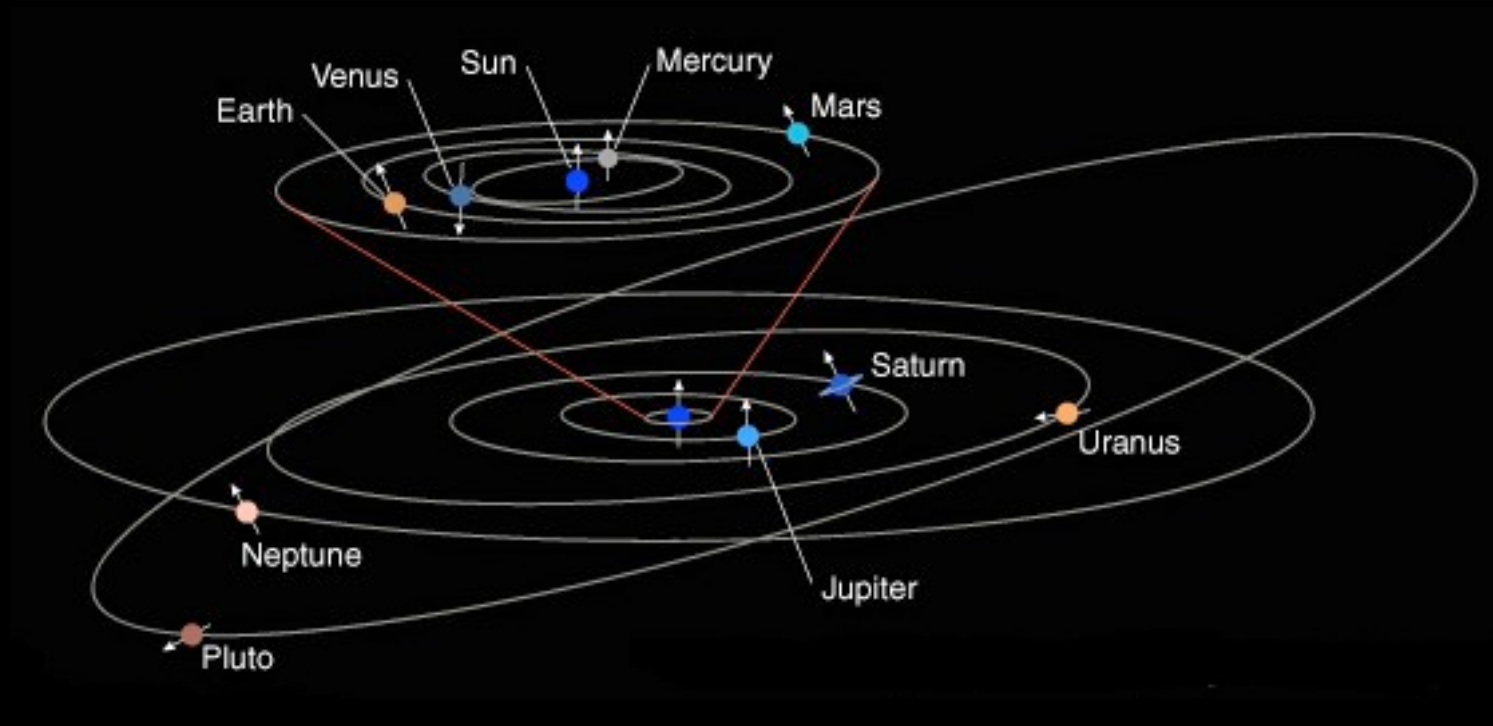


The discovery images for Pluto, showing the star moving between the two exposures, taken two weeks apart.

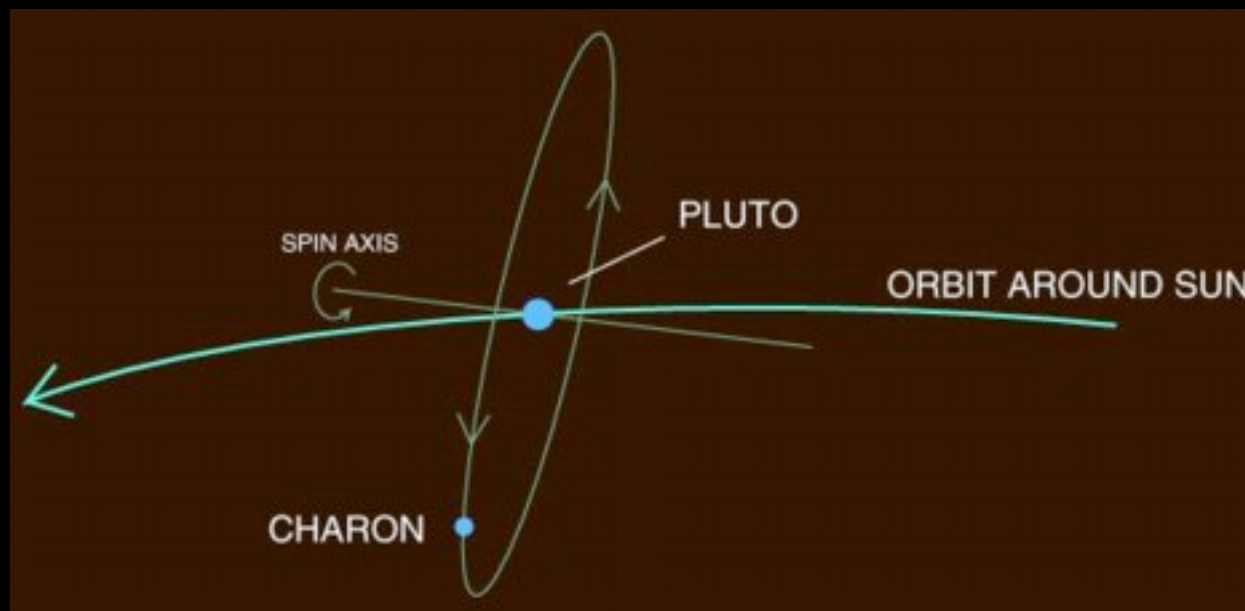
# Basic facts

	Pluto/Charon		Pluto/Charon / Earth	
Mass	$0.0125 \times 10^{24} \text{ kg}$	$0.0019 \times 10^{24} \text{ kg}$	0.0021	0.00032
Radius	1195 km	593 km	0.187	0.093
Mean density	$1.75 \text{ g/cm}^3$	$1.85 \text{ g/cm}^3$	0.317	0.335
Semi-major axis	$5870 \times 10^6 \text{ km}$		39.236	
Period	90 465 d		247.68	
Orbital inclination	$17.16^\circ$		-	
Orbital eccentricity	0.2444		14.6	
Tilt of axis	$122.53^\circ$		5.3	
Surface gravity	$0.58 \text{ m/s}^2$		0.059	
Rotation period	-153.2928 h		6.405	
Length of day	153.2820 h		6.387	

Pluto's highly elongated orbit takes it from 29.7 AU (within the orbit of Neptune) to 49.3 AU. It crossed back outside Neptune's orbit in March 1999, making it once more the most distant planet. Pluto's orbit is also inclined by  $17^\circ$  to the plane of the ecliptic. Pluto is locked in a 3:2 resonance with Neptune, so its orbital period is exactly 1.5 times longer than Neptune's.

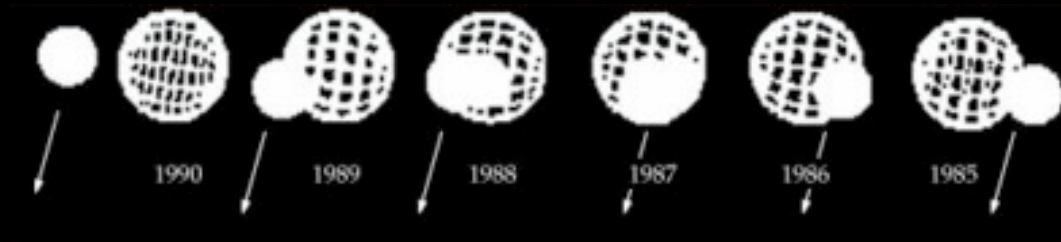


In 1978, Pluto was found to have a satellite with an orbital period of 6.4 days, which was named Charon. Like Neptune, Pluto orbits on its side, and Charon orbits in its equatorial plane. By good fortune, Charon was discovered just before its orbital plane became edge-on to us, so from 1985 to 1990 Charon passed in front and behind Pluto every 6.4 days.

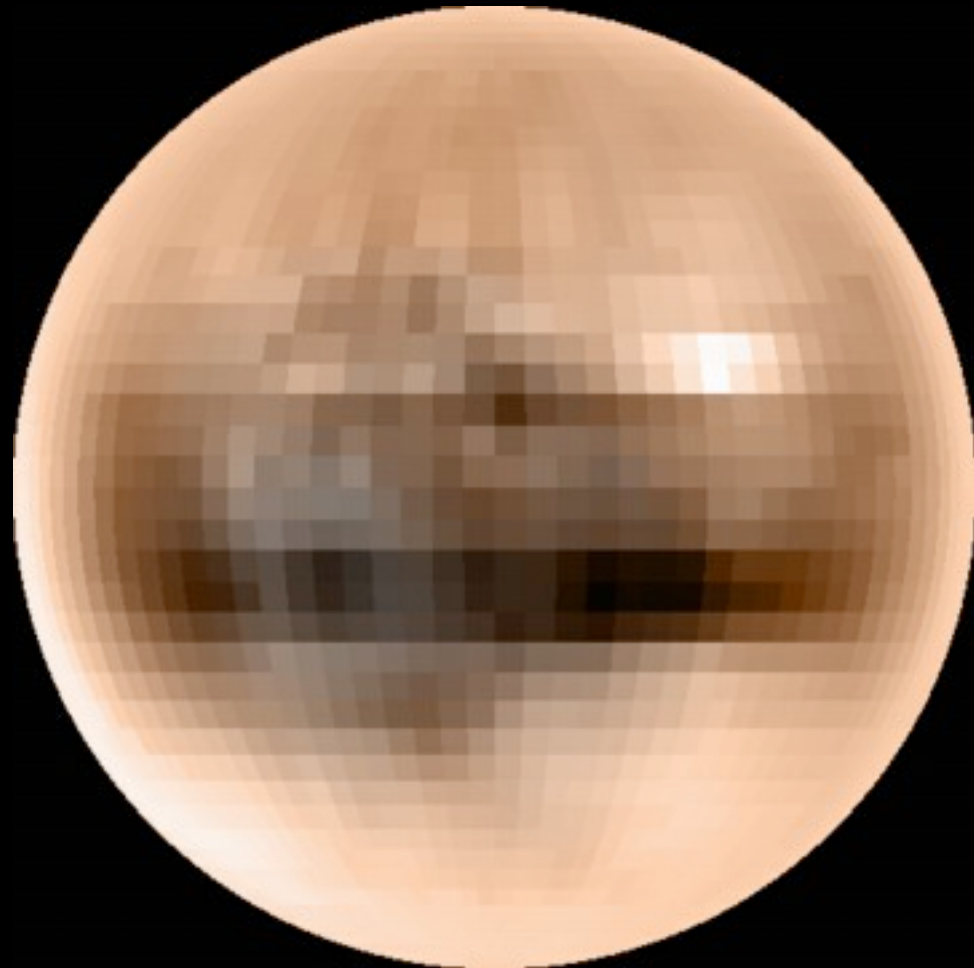




It was therefore possible to observe many transits of Pluto over Charon and vice versa. By keeping track of what part of Pluto was covered up and how dim the combined image of the planet and its moon became, astronomers could tell how bright the covered-up parts of Pluto must be. After watching many eclipses, they could piece together a mosaic of Pluto's surface (at least the half of Pluto that always faces Charon). By recording eclipses in several colours, they could even make a colour map of Pluto.



This map of Pluto was made from over 22 eclipse observations from 1985 to 1990. The brighter areas are mainly nitrogen frost. Most of Pluto has a red-brown tint, which is probably frozen methane deposits metamorphosed by faint but energetic sunlight (think condensed smog!).



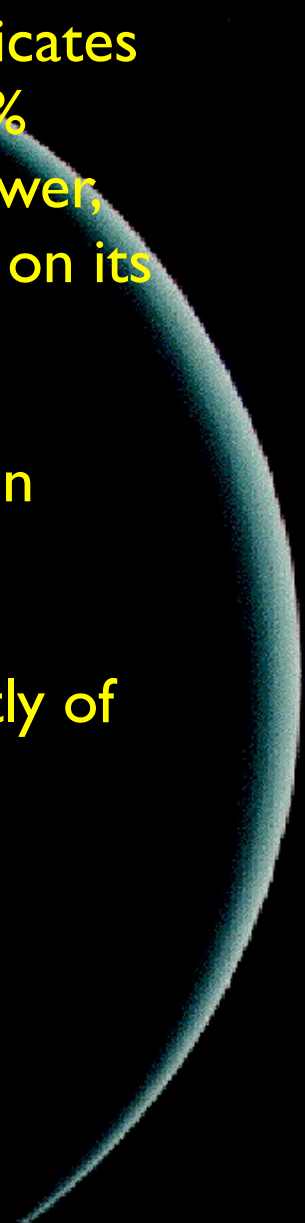
HST can resolve Pluto (barely), well enough to see contrast on its surface. The animation shows snapshots of nearly the entire surface of Pluto, taken as the planet rotated through a 6.4-day period. Pluto shows more large-scale contrast than any planet, except Earth. Topographic features such as basins, or fresh impact craters may cause some of the variations across Pluto's surface.



Pluto has a low density, about  $2 \text{ g/cm}^3$ , which indicates that it is probably a mixture of 70% rock and 30% water ice much like Triton. Charon's density is lower, about  $1.3 \text{ g/cm}^3$ , and it appears to have more ice on its surface.

The surface temperature on Pluto varies between about  $-235^\circ$  and  $-210^\circ \text{ C}$  (38 to 63 K).

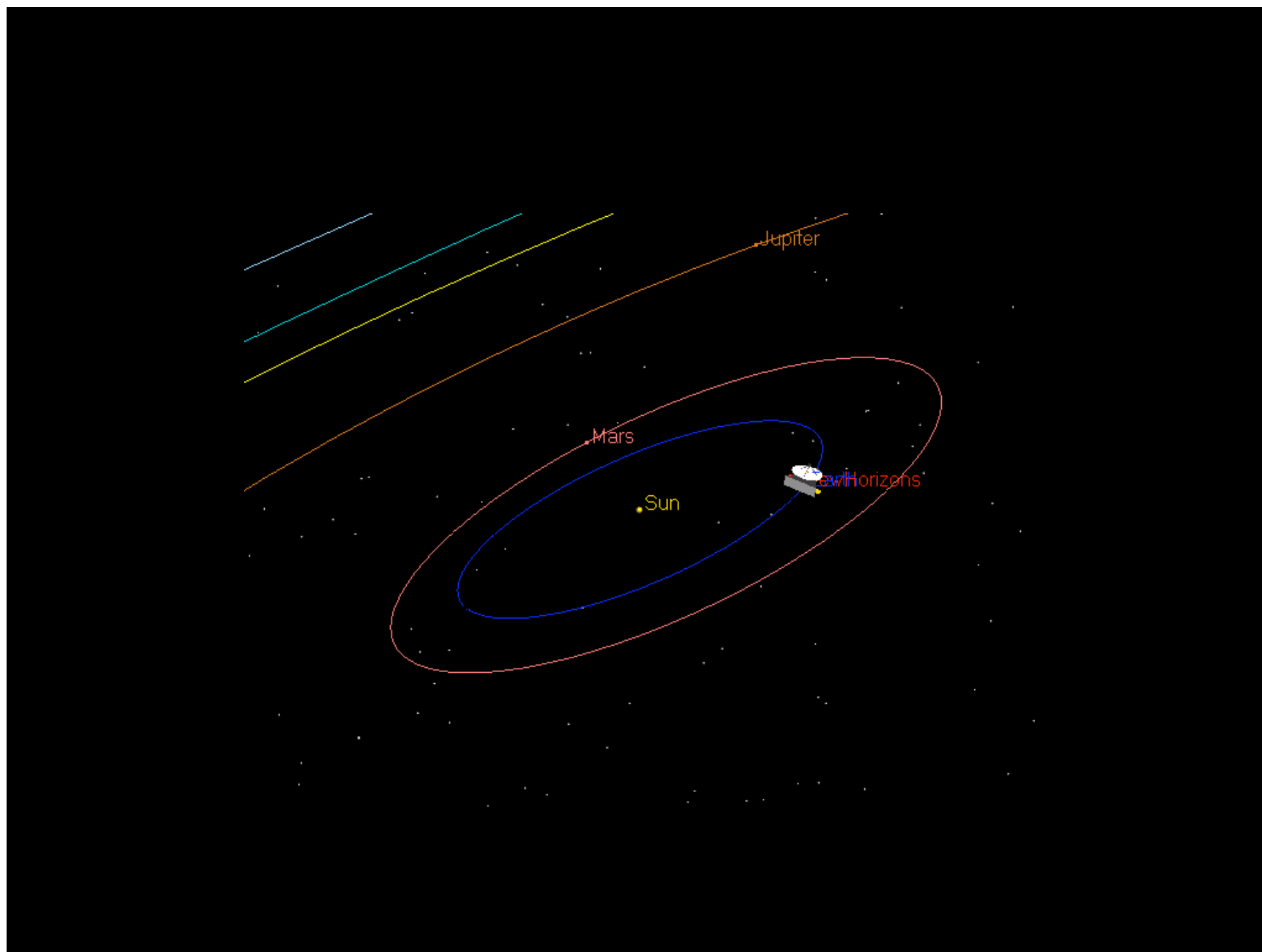
Pluto has a tenuous atmosphere, consisting mostly of nitrogen, with trace amounts of methane.



Pluto has so far not been visited by any mission. Pluto Express was planned for launch in 2004, but in 2000 it was cancelled by NASA. However, at the beginning of 2003 a new mission to Pluto and Charon and beyond to the Kuiper belt was approved. This mission, called New Horizons, will launch in 2006, get a gravity assist from Jupiter in 2007, and fly by Pluto in 2015.

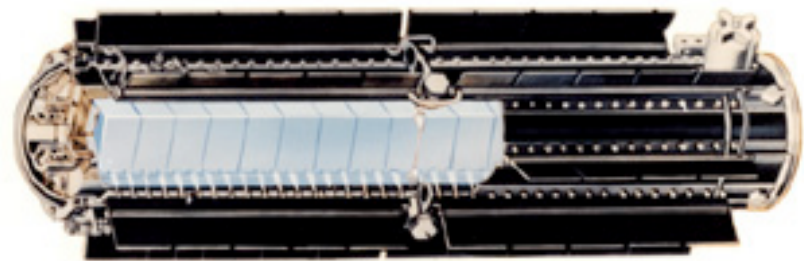






# Powering outer planet missions

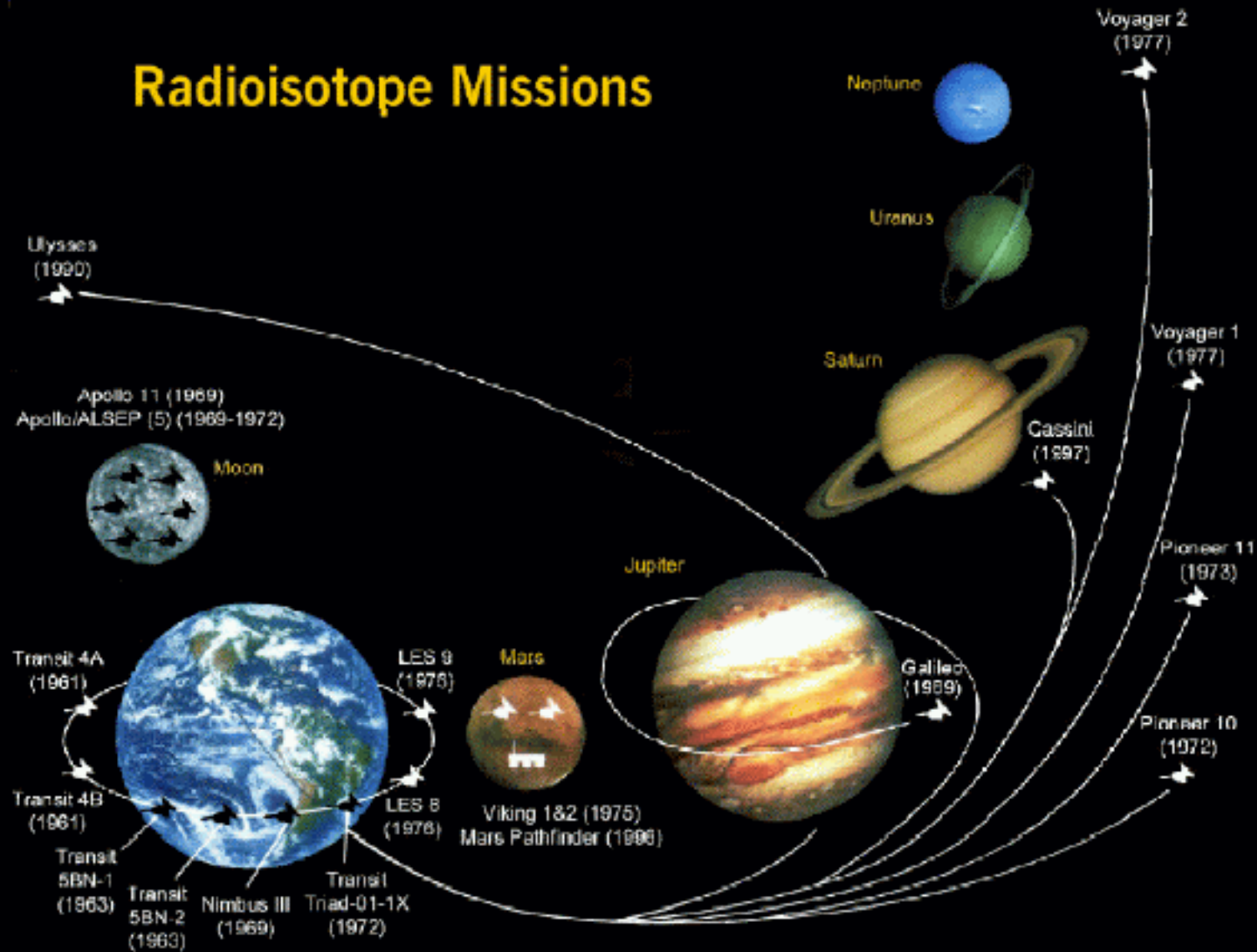
Spacecraft need electrical power to run their instruments, but there are no batteries which can last for the decades needed for missions to the outer planets. Such long-distance missions all use radioisotope thermoelectric generators (RTGs). These convert the heat produced by the natural decay of plutonium dioxide into electricity via solid-state thermocouples. A typical generator produces about 230 W of power, falling to about 200W after 16 years.



Radioisotope Thermoelectric Generator

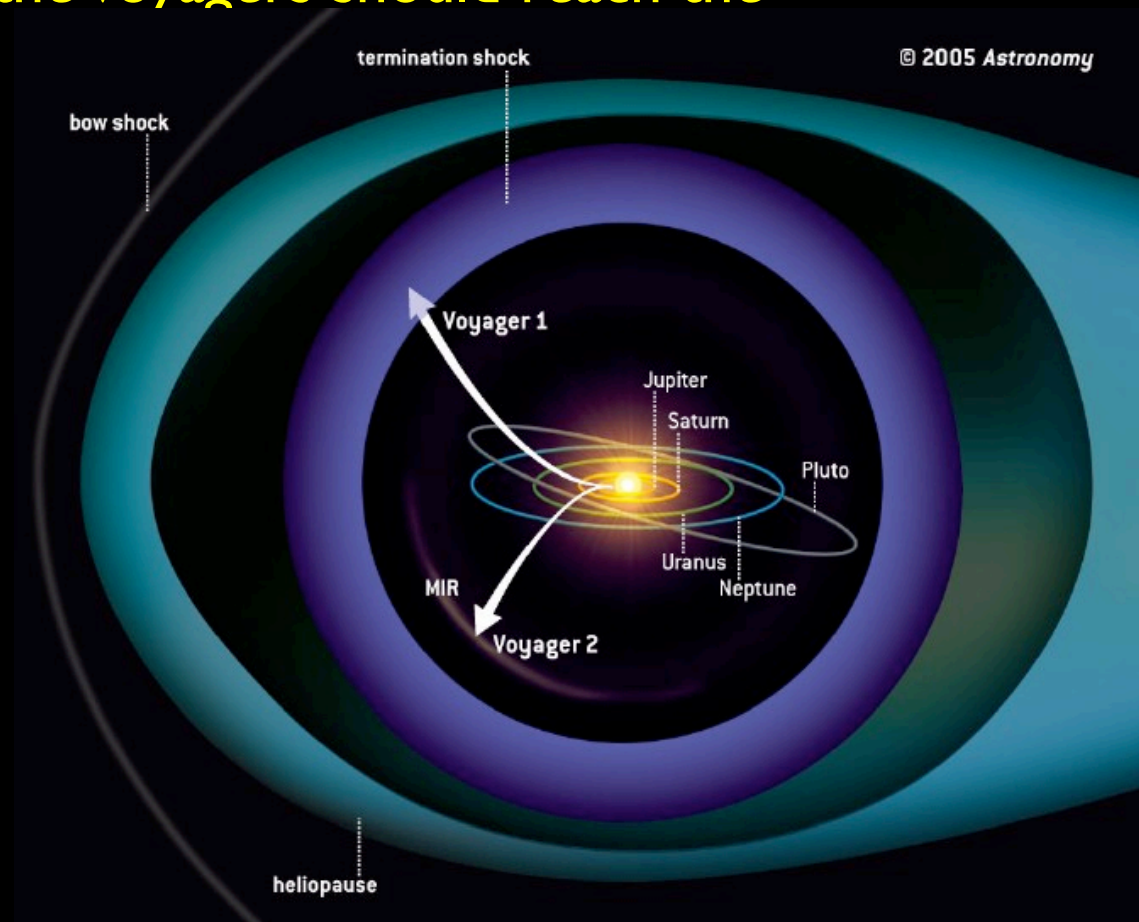
Most NASA missions have used RTGs.

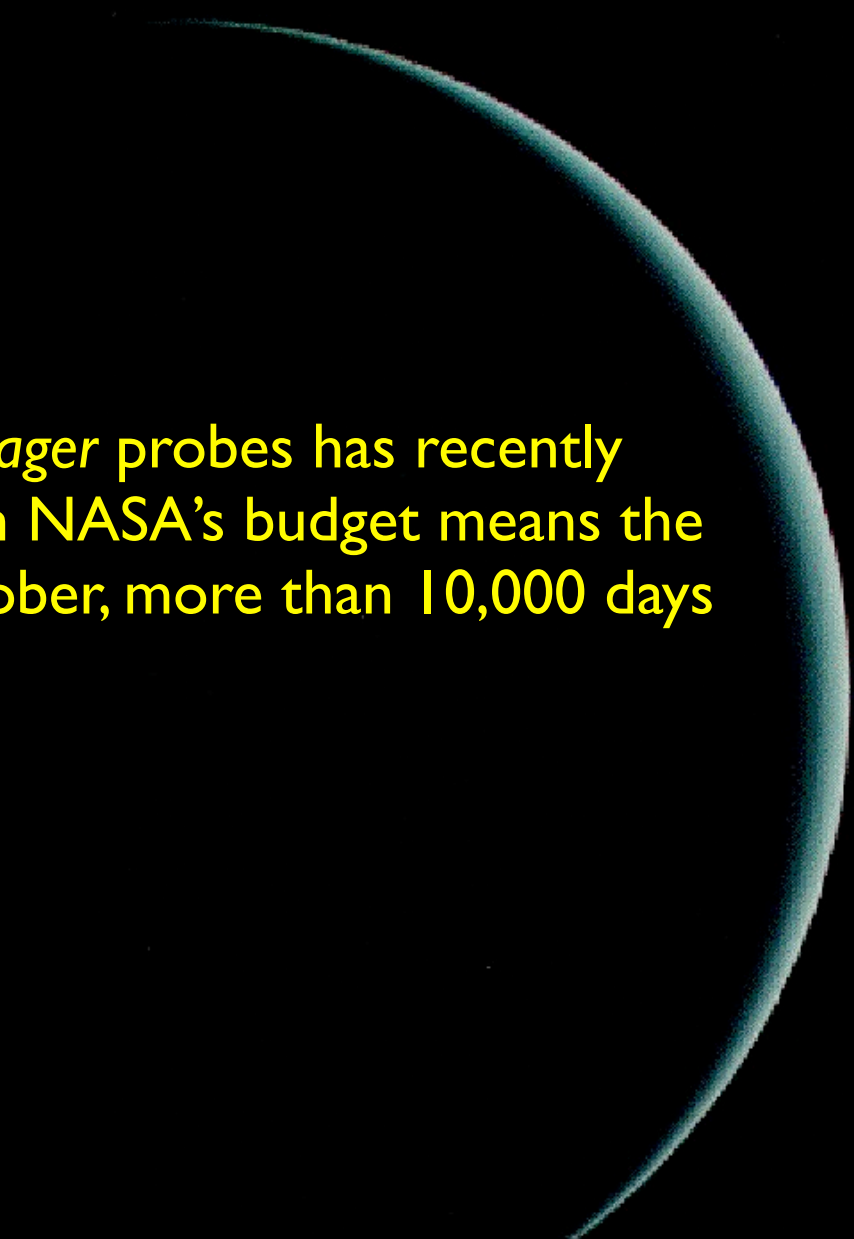
## Radioisotope Missions



Distances & Planets Are Not To Scale

The Voyager missions are currently leaving the Solar System. Voyager 1 is escaping at about 3.6 AU per year, 35° degrees north out of the ecliptic plane. Voyager 2 is escaping at about 3.3 AU per year, 48° south out of the ecliptic plane. Sometime in the next few years, the Voyagers should reach the termination shock, where the solar wind slows; then 5–10 years later they should reach the heliopause, where the Sun's influence ends and the interstellar wind begins.





NASA funding for the *Voyager* probes has recently been put in doubt. Cuts in NASA's budget means the project may cease in October, more than 10,000 days after it began.





# Next week...

... we'll tie the whole thing together by looking at theories for how the Solar System formed

# Further reading

I didn't find very many books particularly about the outer planets. A few interesting ones, in addition to the more general references I've given already:

- **“Atlas of Uranus”** by Garry Hunt and Patrick Moore (Cambridge, 1989) tells the story of Uranus after the Voyager 2 fly-by.
- **“Beyond Pluto: Exploring the outer limits of the solar system”** by John Davies (Cambridge 2001), though mainly about the Kuiper Belt and trans-Neptunian bodies, has a very interesting discussion on the status of Pluto as a planet.
- There was a very interesting article in the September 1999 issue of Scientific American called “Migrating Planets” by Renu Malhotra, on the idea that the outer planets may not have formed where we see them now.
- The home page for the “New Horizons” mission, which will fly by Pluto and Charon and on to the Kuiper Belt, is at <http://pluto.jhuapl.edu/>

## Sources for images used:

- Background image: parting image taken by Voyager 2, from "The Planetary Society: Voyager Celebrates 25th Anniversary", <http://www.planetary.org/voyager25/voyager-story.html>
- Voyager: from NSSDC Voyager Project Information <http://nssdc.gsfc.nasa.gov/planetary/voyager.html>
- Uranus: from NSSDC Photo Gallery: Uranus [http://nssdc.gsfc.nasa.gov/photo\\_gallery/photogallery-uranus.html](http://nssdc.gsfc.nasa.gov/photo_gallery/photogallery-uranus.html)
- Uranus/Earth comparison table: after "The Cambridge Photographic Guide to the Planets" by F.W.Taylor (Cambridge UP, 2001), p. 268.
- Herschel: from National Air and Space Museum, Exploring the Planets: Discovering New Planets [http://www.nasm.si.edu/ceps/etp/discovery/disc\\_planets.html](http://www.nasm.si.edu/ceps/etp/discovery/disc_planets.html)
- Why Uranus is blue: from "Explorations: An Introduction to Astronomy" by Thomas T. Arny, Fig. 9.18, <http://www.mhhe.com/physsci/astronomy/arny/instructor/graphics/ch09/0918.html>
- Atmosphere and rings: picture from the Keck Telescope, from Astronomy Picture of the Day 2004 November 18 <http://antwarp.gsfc.nasa.gov/apod/ap041118.html>
- Seasons: from Astronomy 121: The Solar System by Jim Brau [http://blueox.uoregon.edu/~courses/BrauImages/Chap13/FG13\\_006.jpg](http://blueox.uoregon.edu/~courses/BrauImages/Chap13/FG13_006.jpg)
- Interior: from Views of the Solar System by Calvin J. Hamilton <http://www.solarviews.com/browse/uranus/uranusint.jpg>
- Storms on Uranus: from Hubble Site News Release Archive, March 29 1999, "Huge Spring Storms Rouse Uranus from Winter Hibernation" <http://hubblesite.org/newscenter/archive/1999/11/>
- Uranus' magnetic field: from Astronomy 161, The Solar System, Lect 17 <http://csep10.phys.utk.edu/astr161/lect/uranus/surface.html>
- Rings: false colour image of a Voyager photo, from Views of the Solar System by Calvin J. Hamilton <http://www.solarviews.com/cap/uranus/u-ring.htm>

- Moon pictures: from Views of the Solar System by Calvin J. Hamilton <http://www.solarviews.com/eng/triton.htm>
- Montage of Uranus and moons: artist's impression based on Voyager images. From Smithsonian Institution: Exploring The Planets: Uranus  
[http://www.hrw.com/science/si-science/physical/astronomy/ss/uranus/uran\\_moons.html](http://www.hrw.com/science/si-science/physical/astronomy/ss/uranus/uran_moons.html)
- Uranus encounter times: from "Atlas of Uranus" by Garry Hunt and Patrick Moore (Cambridge UP, 1989), p. 53
- HST image of rings and moons: from Astronomy Picture of the Day 26 November 1997  
<http://antwarp.gsfc.nasa.gov/apod/ap971126.html>
- Changing position of the poles: re-drawn from "Atlas of Uranus" by Garry Hunt and Patrick Moore (Cambridge UP, 1989), p. 30
- Moon images: from Views of the Solar System by Calvin J. Hamilton <http://www.solarviews.com/eng/uranus.htm>
- Montage of Neptune and Triton: from Views of the Solar System by Calvin J. Hamilton  
<http://www.solarviews.com/cap/nep/trinep1.htm>
- Adams: from "John Couch Adams and the discovery of Neptune" by A. B. Ruth, The Eagle 1997  
<http://www.joh.cam.ac.uk/publications/eagle97/Eagle97-John.html>
- Full disk of Neptune: Voyager image, from Views of the Solar System by Calvin J. Hamilton  
<http://www.solarviews.com/cap/nep/neptunes.htm>
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- Time-lapse movie of Neptune's weather: from HST news release archive, "Hubble Makes Movie of Neptune's Rotation and Weather", October 24 1996, <http://hubblesite.org/newscenter/archive/1996/33/>
- Interiors and magnetic fields: from "Planets, Stars and Galaxies" by Todd Adams,  
[www.hep.fsu.edu/~tadams/courses/fall02/ast1002/lectures/Lecture092502.pdf](http://www.hep.fsu.edu/~tadams/courses/fall02/ast1002/lectures/Lecture092502.pdf)
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- New moons of Neptune: from CfA Press Release No.: 03-03, “New Moons Found Around Neptune”  
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- Artist’s conception of Pluto and Charon: from Astronomy Picture of the Day 2001 October 18  
<http://antwarp.gsfc.nasa.gov/apod/ap011018.html>
- HST image of P/C: from Astronomy Picture of the Day 13 February 1999  
<http://antwarp.gsfc.nasa.gov/apod/ap990213.html>
- Pluto discovery images: from Astronomy 110 by Gareth Wynn-Williams, Lecture 9: The small planetary bodies  
[http://www.ifa.hawaii.edu/~wynnwill/110/9\\_small\\_bodies.htm](http://www.ifa.hawaii.edu/~wynnwill/110/9_small_bodies.htm)
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- Colour image of Pluto: from “Mapping Pluto’s Surface” by Eliot Young  
<http://www.boulder.swri.edu/~efy/PMap01/PlutoMaps/PlutoMaps.html>
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- Radioisotope missions: from NASA Space Science Project Prometheus  
<http://spacescience.nasa.gov/missions/prometheus.htm>
- Voyager interstellar mission: from Voyager: Celebrating 25 Years of Discovery  
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