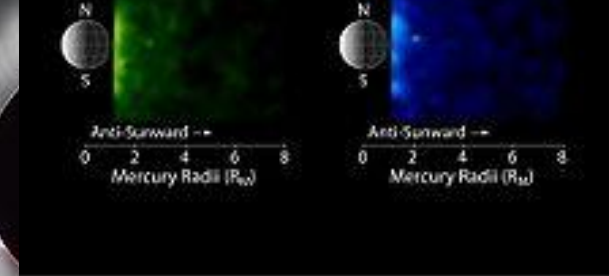
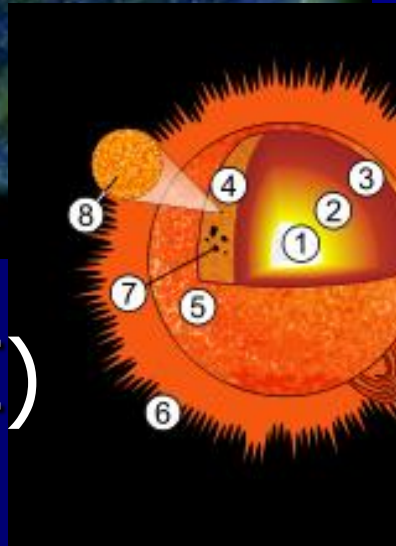
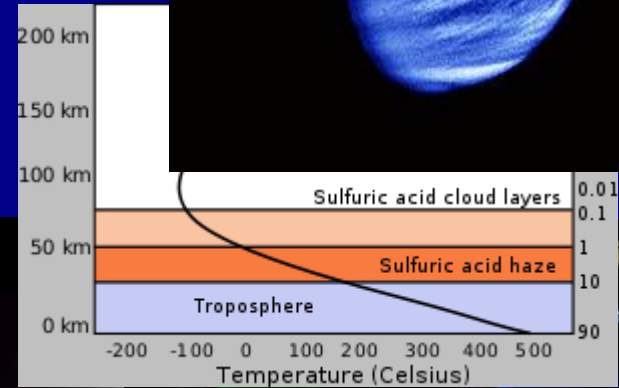
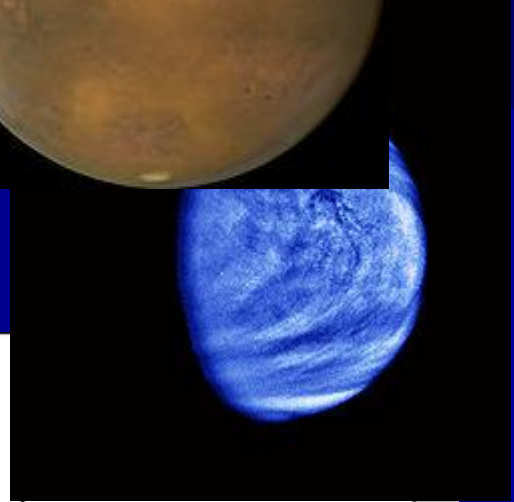
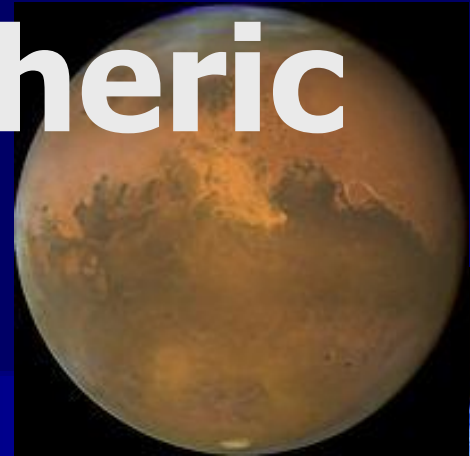
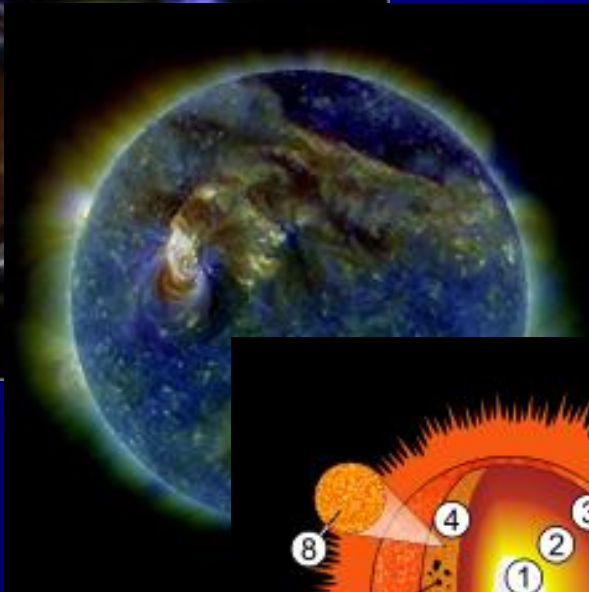
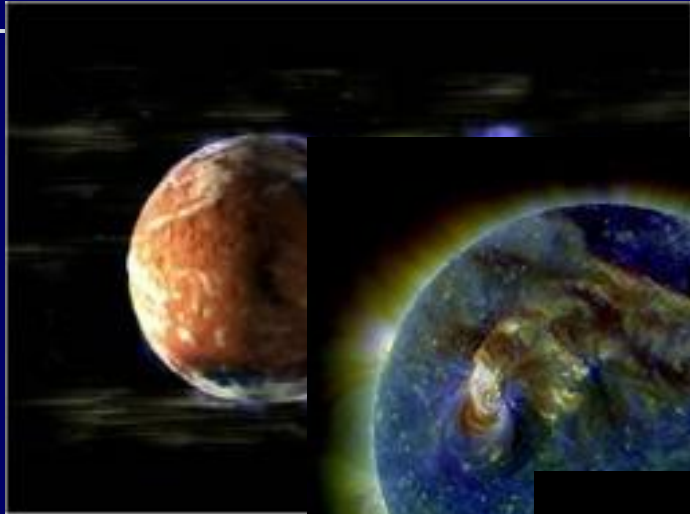


Space &  
Atmospheric  
Physics

# Space & Atmospheric Physics



Lecture - 04 (III)

# Asteroid Belt



Johann Elert Bode (this image is reversed; it was his right eye that was bad)

The Titius-Bode Law is rough rule that predicts the spacing of the planets in the Solar System. The relationship was first pointed out by Johann Titius in 1766 and was formulated as a mathematical expression by J.E. Bode in 1778. It lead Bode to predict the existence of another planet between Mars and Jupiter in what we now recognize as the **asteroid belt**.

The law relates the mean distances of the planets from the sun to a simple mathematic progression of numbers.

# Bode's law :

The **Titius–Bode law** (sometimes termed just **Bode's law**) is a hypothesis that the bodies in some orbital systems, including the Sun's, orbit at semi-major axes in a function of planetary sequence. The hypothesis correctly predicted the orbits of Mercury to Uranus and Pluto, but failed as a predictor of Neptune's orbit.

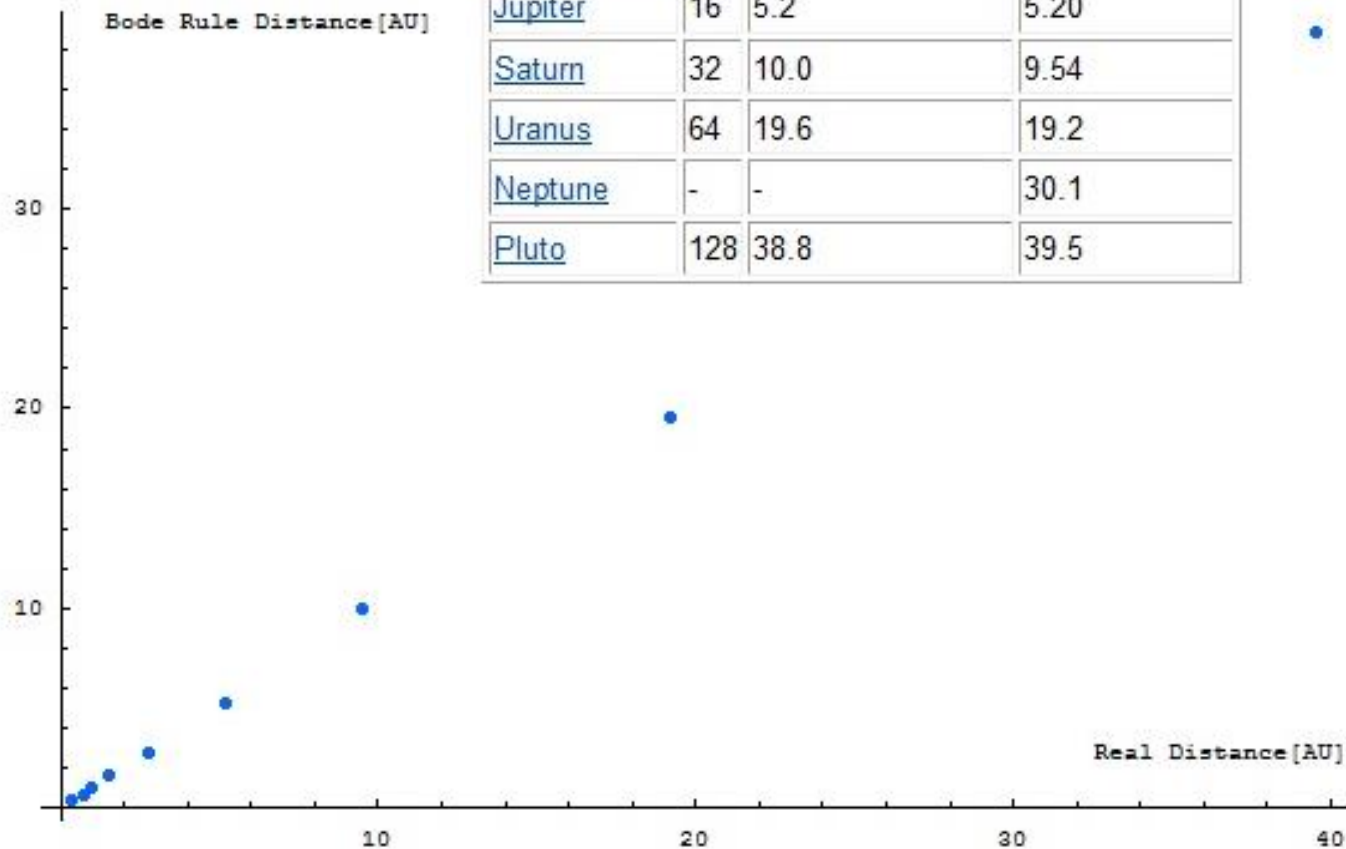
$$d_n = \begin{cases} 0.4 & ; n=1 \\ 0.4 + 0.3 \times 2^{n-2} & ; n \geq 2 \end{cases}$$

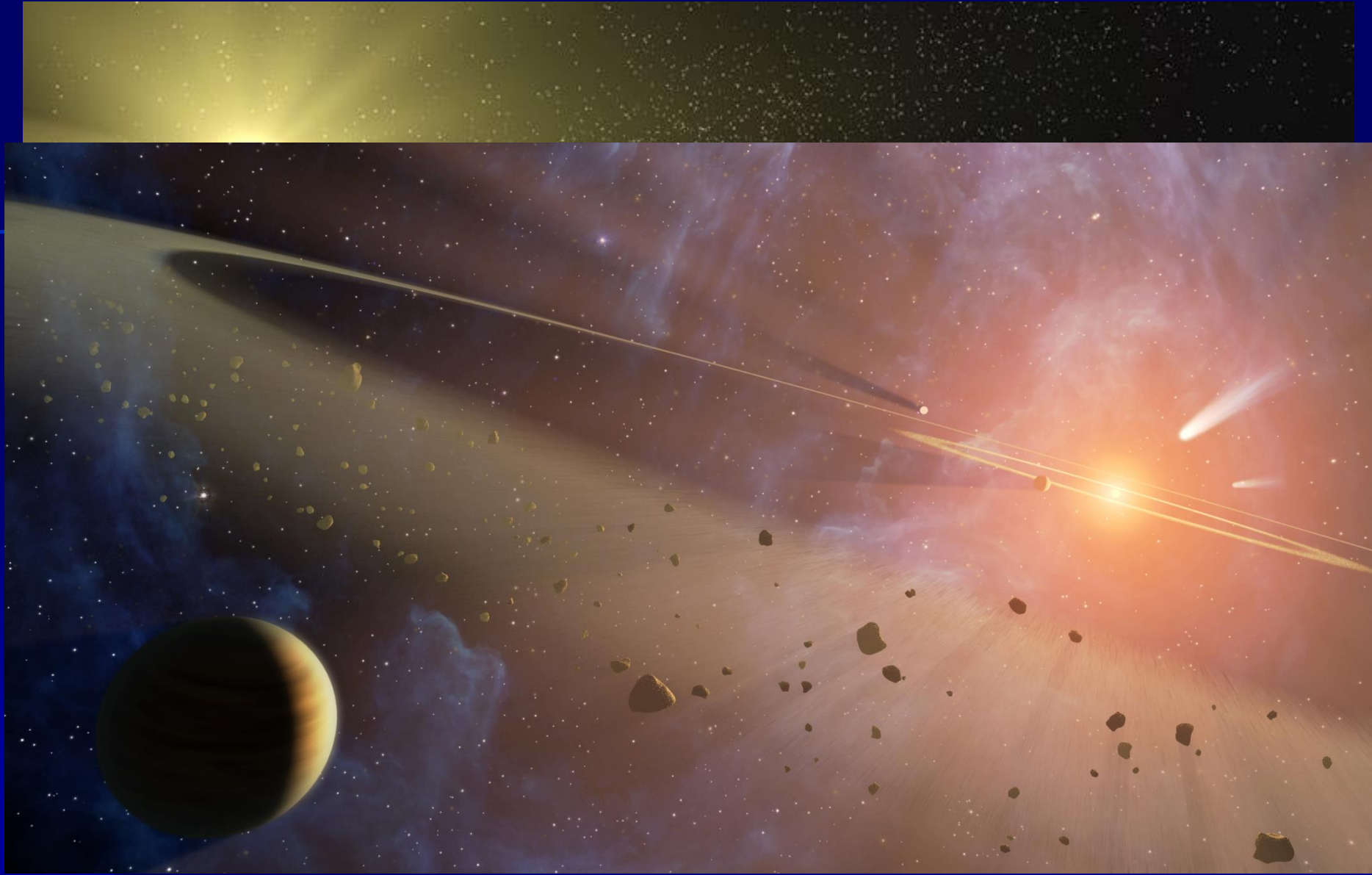
$d_n$  – Orbital distance (semi-major axis) of  $n^{\text{th}}$  planet, from the Sun in AU

$$1 \text{ AU} = 149\,597\,890 \text{ km}$$

Here are the distances of planets calculated from the original rule and compared with the real ones:

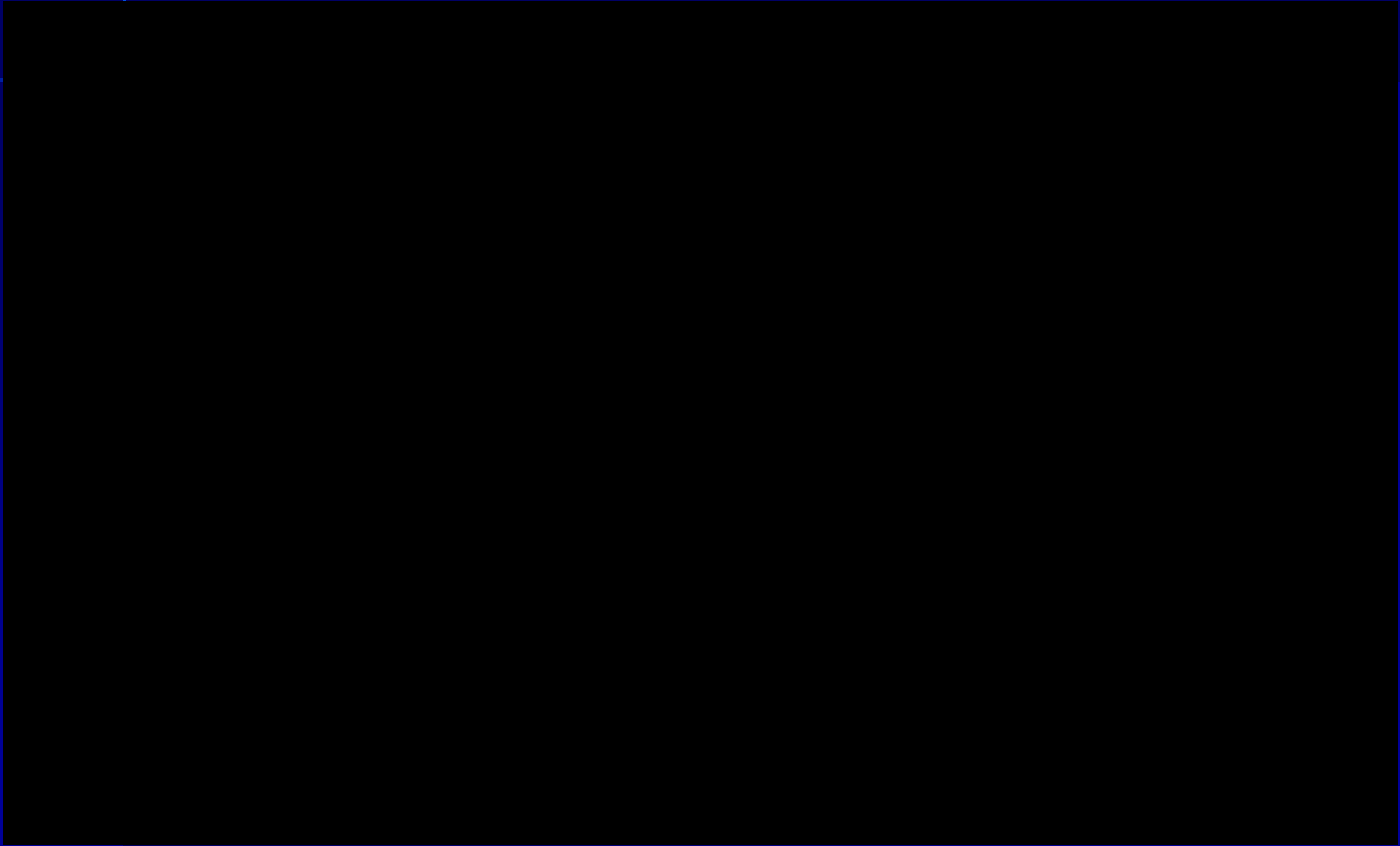
Planet	k	T-B rule distance	Real distance
<a href="#">Mercury</a>	0	0.4	0.39
<a href="#">Venus</a>	1	0.7	0.72
<a href="#">Earth</a>	2	1.0	1.00
<a href="#">Mars</a>	4	1.6	1.52
<a href="#">Asteroid Belt</a>	8	2.8	2.77
<a href="#">Jupiter</a>	16	5.2	5.20
<a href="#">Saturn</a>	32	10.0	9.54
<a href="#">Uranus</a>	64	19.6	19.2
<a href="#">Neptune</a>	-	-	30.1
<a href="#">Pluto</a>	128	38.8	39.5





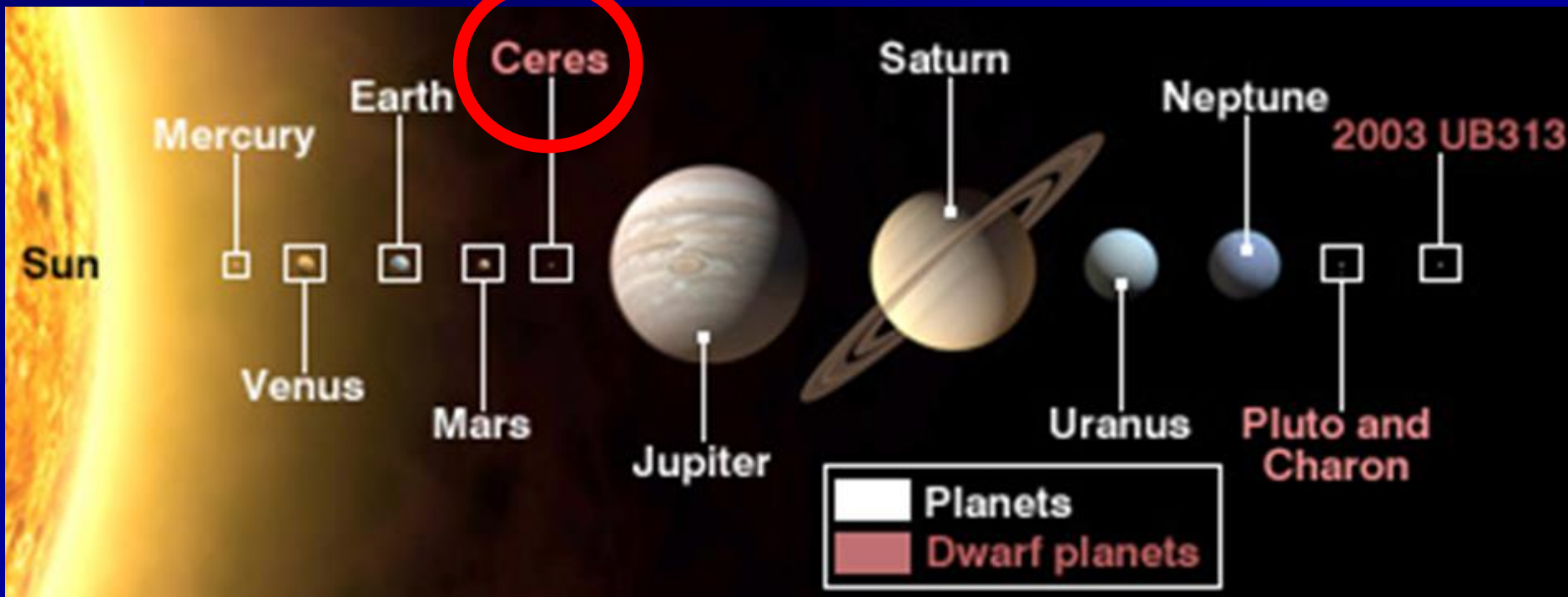
Atmosphere of Ceres

**The Asteroid Belt Between Mars and Jupiter**

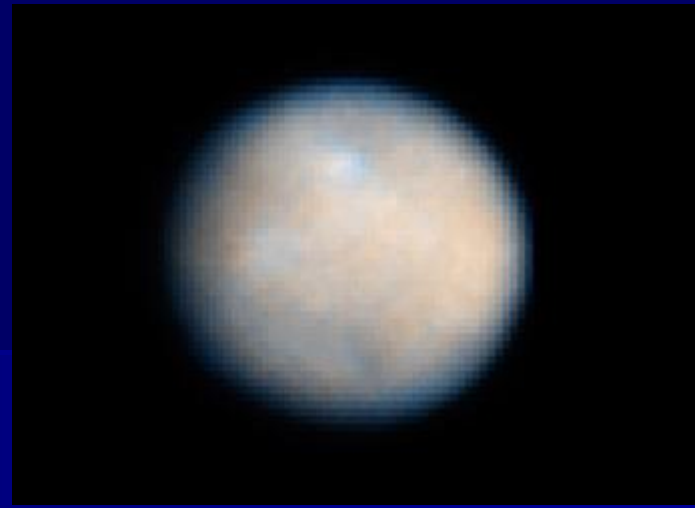




# Atmosphere of Ceres



# Atmosphere of Ceres



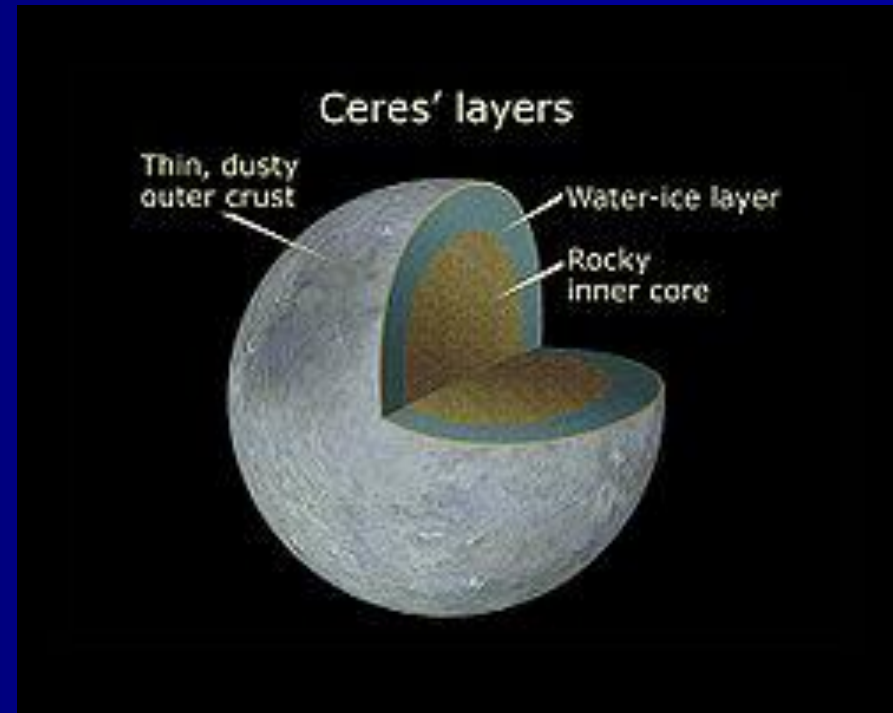
Ceres as seen by Hubble Space Telescope (ACS).

**Ceres**, is the only dwarf planet - and the largest asteroid - in the inner Solar System. It is a rock–ice body some 950 km (590 mi) in diameter, and though the smallest identified dwarf planet, it constitutes a third of the mass of the asteroid belt. **Discovered on 1 January 1801 by Giuseppe Piazzi.**

The Cererian surface is probably a mixture of water ice and various hydrated minerals such as carbonates and clays. It appears to be differentiated into a rocky core and icy mantle, and may harbor an ocean of liquid water under its surface.

# Atmosphere of Ceres

The classification of Ceres has changed more than once and has been the subject of some disagreement. Johann Elert Bode believed Ceres to be the "missing planet" he had proposed to exist between Mars and Jupiter, at a distance of 419 million km (2.8 AU) from the Sun.

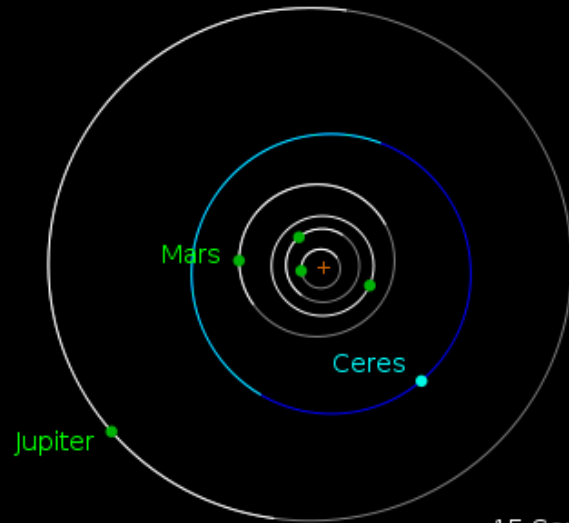


# Atmosphere of Ceres

## Atmosphere

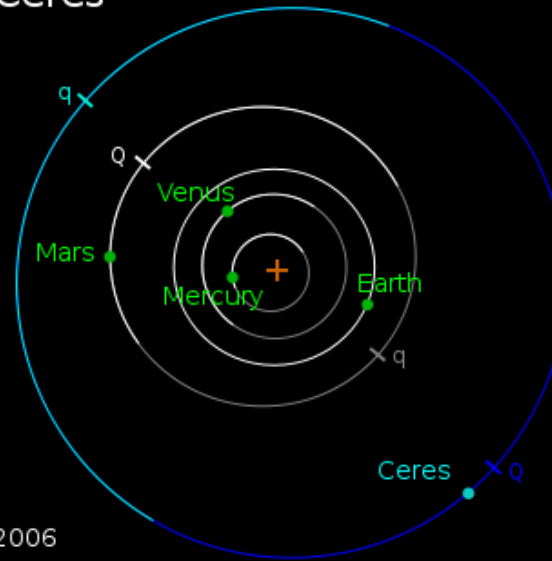
There are indications that Ceres may have a weak atmosphere and water frost on the surface.

Orbit of 1 Ceres

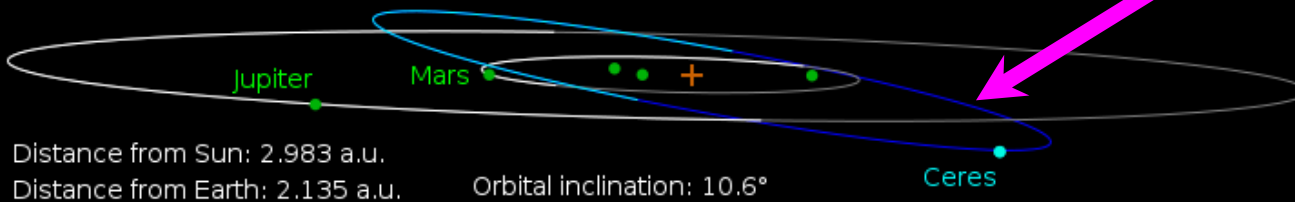


15 September 2006

Eccentricity: 0.080  
Orbital Period: 4.599 years



Perihelion (q): 2.544 a.u.  
Aphelion (Q): 2.987 a.u.

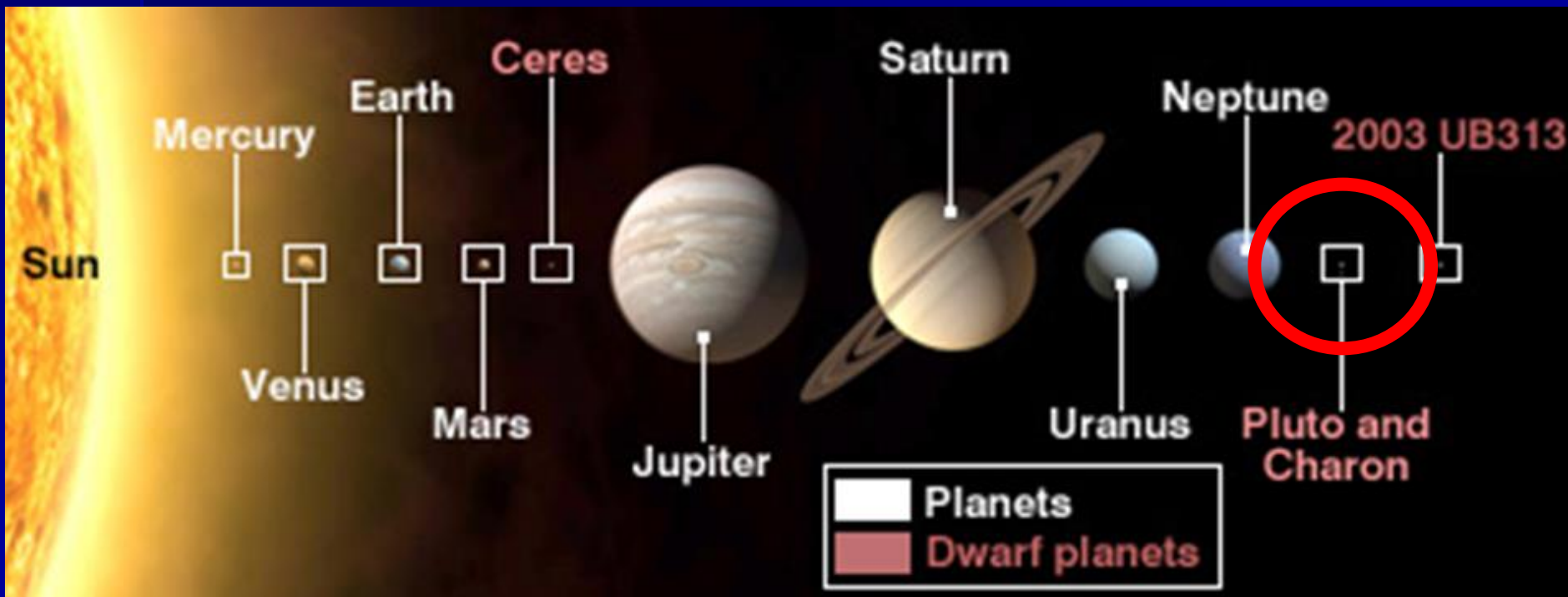


Distance from Sun: 2.983 a.u.  
Distance from Earth: 2.135 a.u.

Orbital inclination: 10.6°

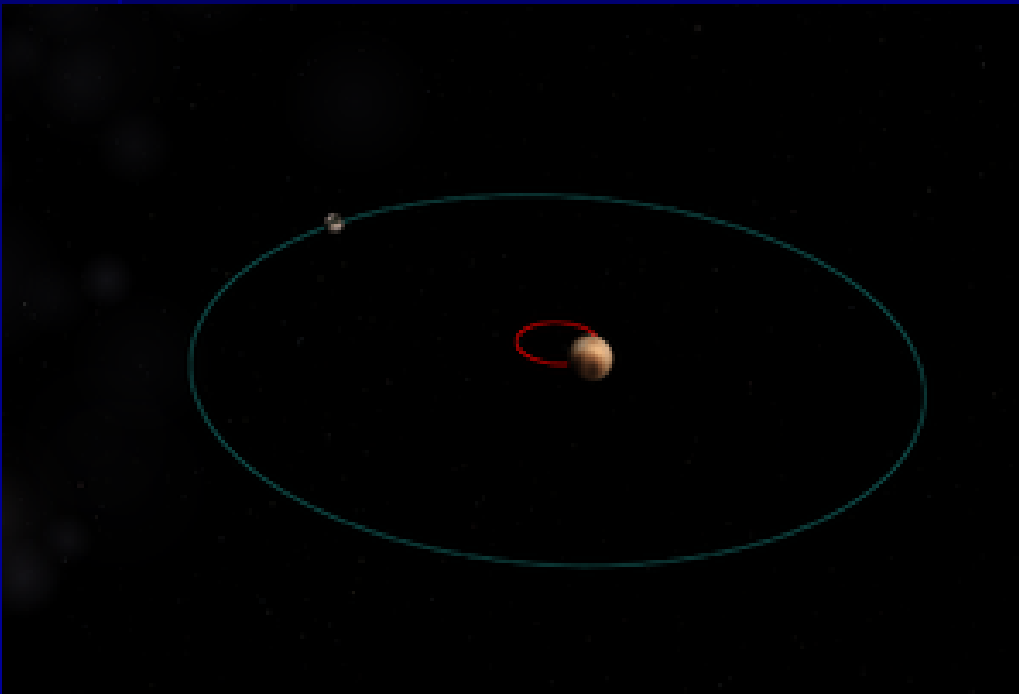
Orbit of  
Ceres

# Atmosphere of Charon



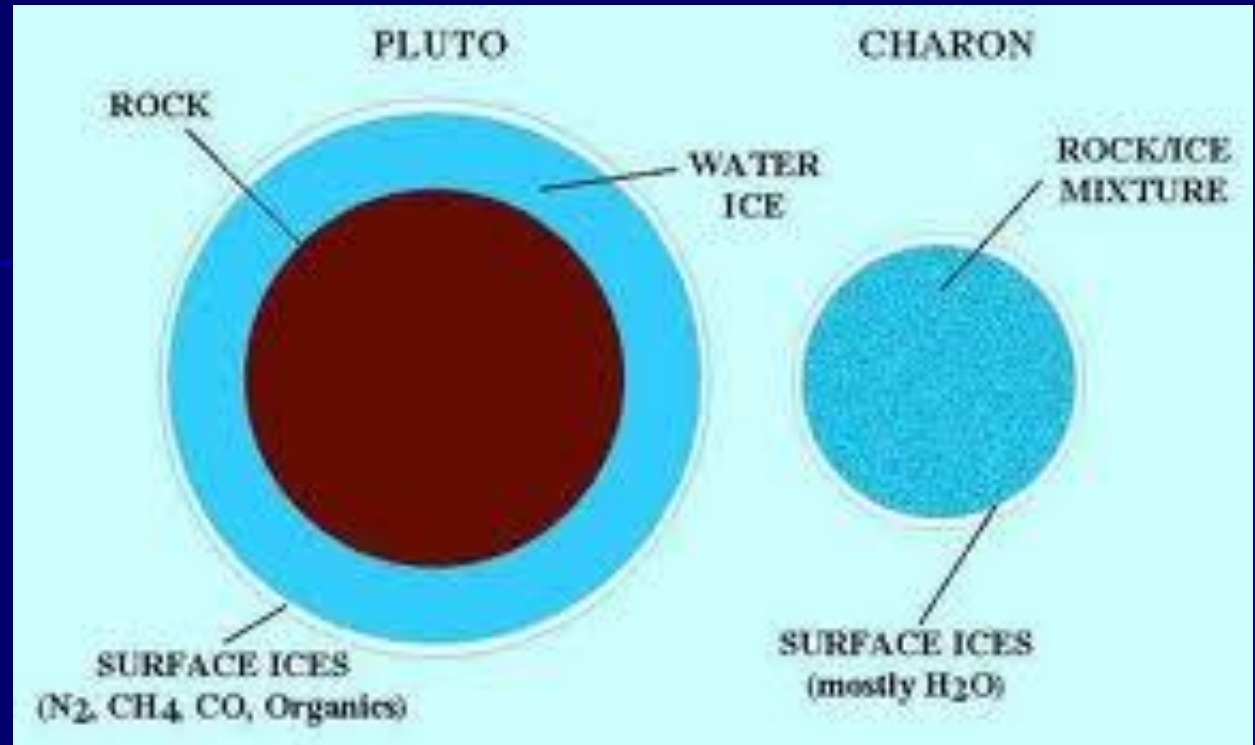
# Atmosphere of Charon

**Charon** is the largest satellite of the dwarf planet Pluto.(?????)



An oblique view of the Pluto–Charon system showing that Pluto orbits a point outside itself. **Pluto's orbit is shown in red and Charon's orbit is shown in green.**

# Atmosphere of Charon



It was discovered in 1978 at the United States Naval Observatory Flagstaff Station. Following the 2005 discovery of two other natural satellites of Pluto (Nix and Hydra), and in 2011, a fourth, S/2011 P 1, Charon may also be referred to as **(134340) Pluto I**. The New Horizons mission is scheduled to visit Charon and Pluto in July 2015

# Atmosphere of Charon

1990 photograph of Pluto and Charon.  
Taken by the Hubble Telescope.



Charon was discovered by astronomer James Christy on June 22, 1978, when he was examining highly magnified images of Pluto on photographic plates taken a couple of months earlier.

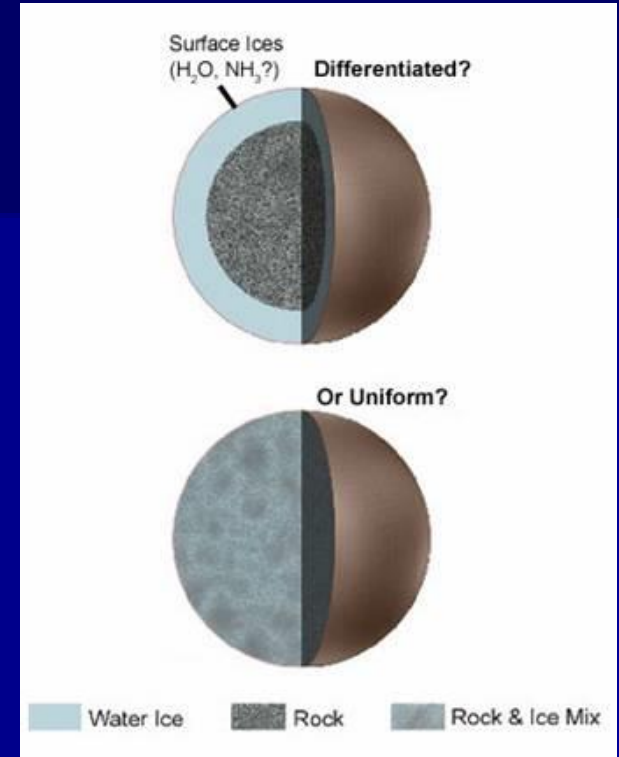
Charon's diameter is about 1,207 kilometres , just over half that of Pluto, with a surface area of 4,580,000 square kilometres . Unlike Pluto, which is covered with nitrogen and methane ices, the Charonian surface appears to be dominated by less volatile water ice, and also appears to have no atmosphere.



# Atmosphere of Charon

Charon's volume and mass allow calculation of its density from which it can be determined that Charon is largely an icy body and contains less rock by proportion than its partner Pluto. This supports the idea that Charon was created by a giant impact into Pluto's icy mantle.

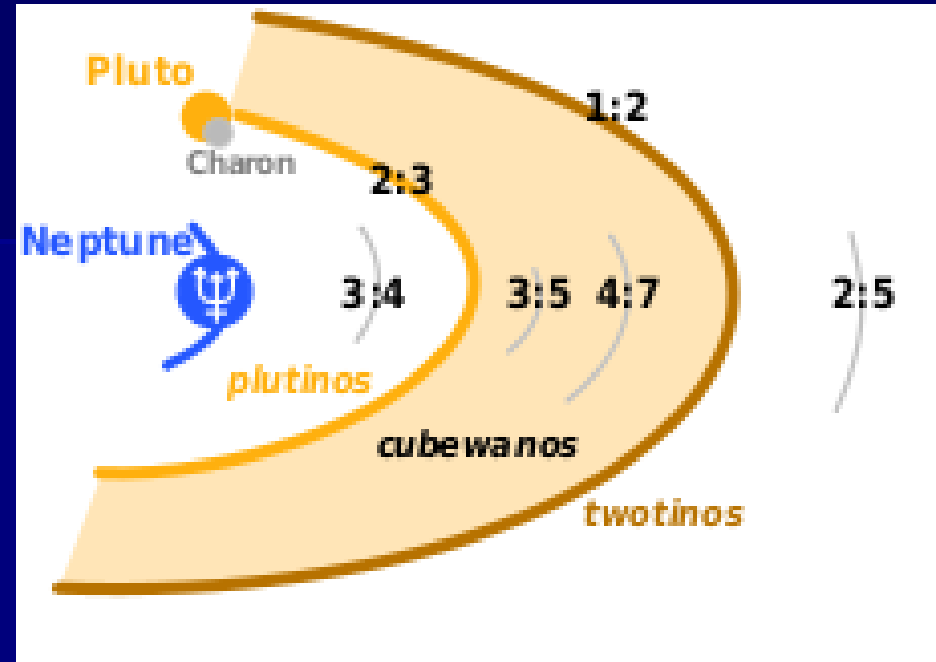
There are two conflicting theories about Charon's internal structure: some scientists believe it to be a differentiated body like Pluto with a rocky core and an icy mantle while others believe Charon to be of uniform composition throughout.



Evidence in support of the former position was found in 2007, when observations by the Gemini Observatory of patches of ammonia hydrates and water crystals on the surface of Charon suggested the presence of active cryo-geysers.

# Atmosphere of Charon

The Plutonian system contains 5 known bodies: Pluto and its four moons.

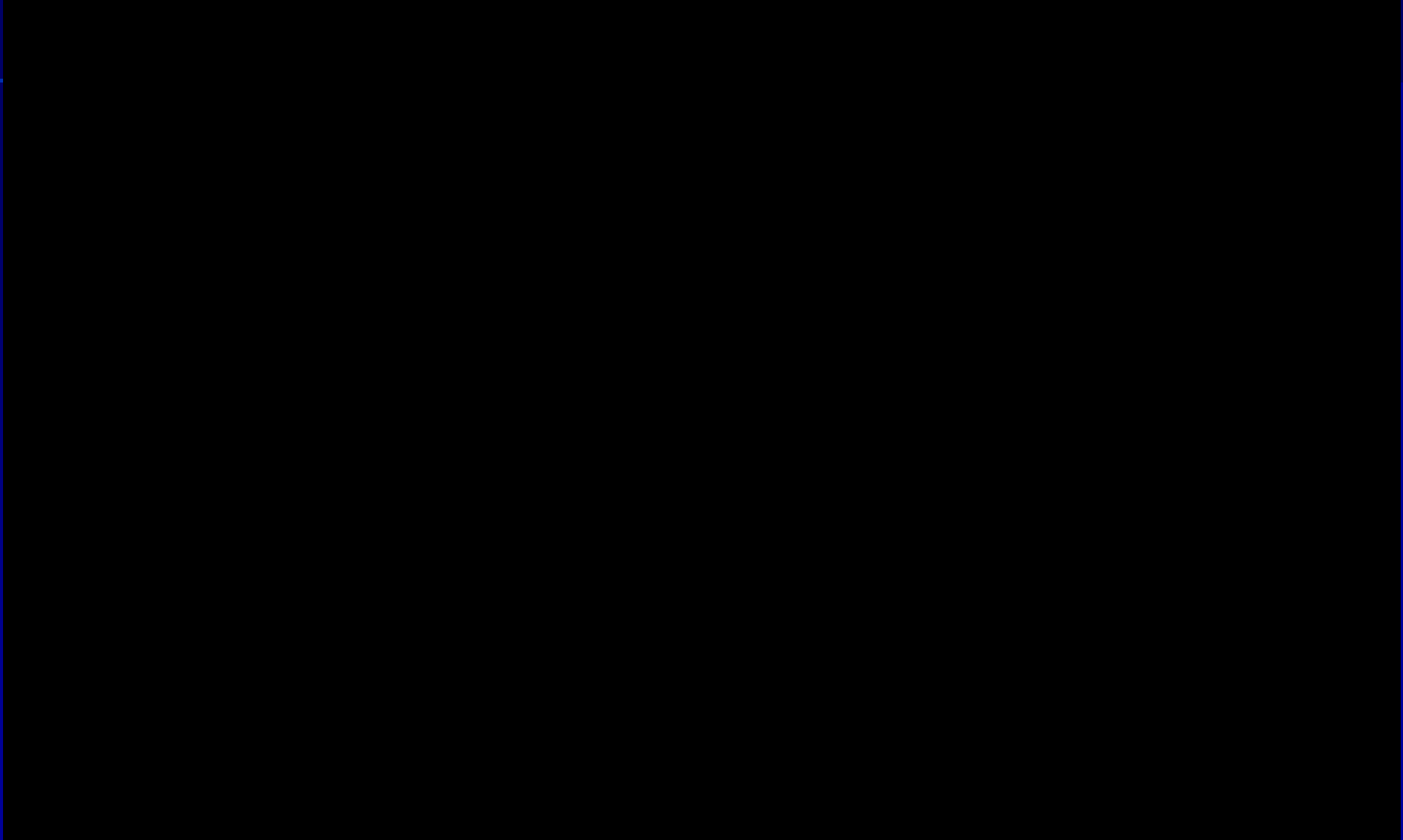


1994 image of Pluto and Charon (right) from ESA/Dornier FOC on the NASA Hubble.

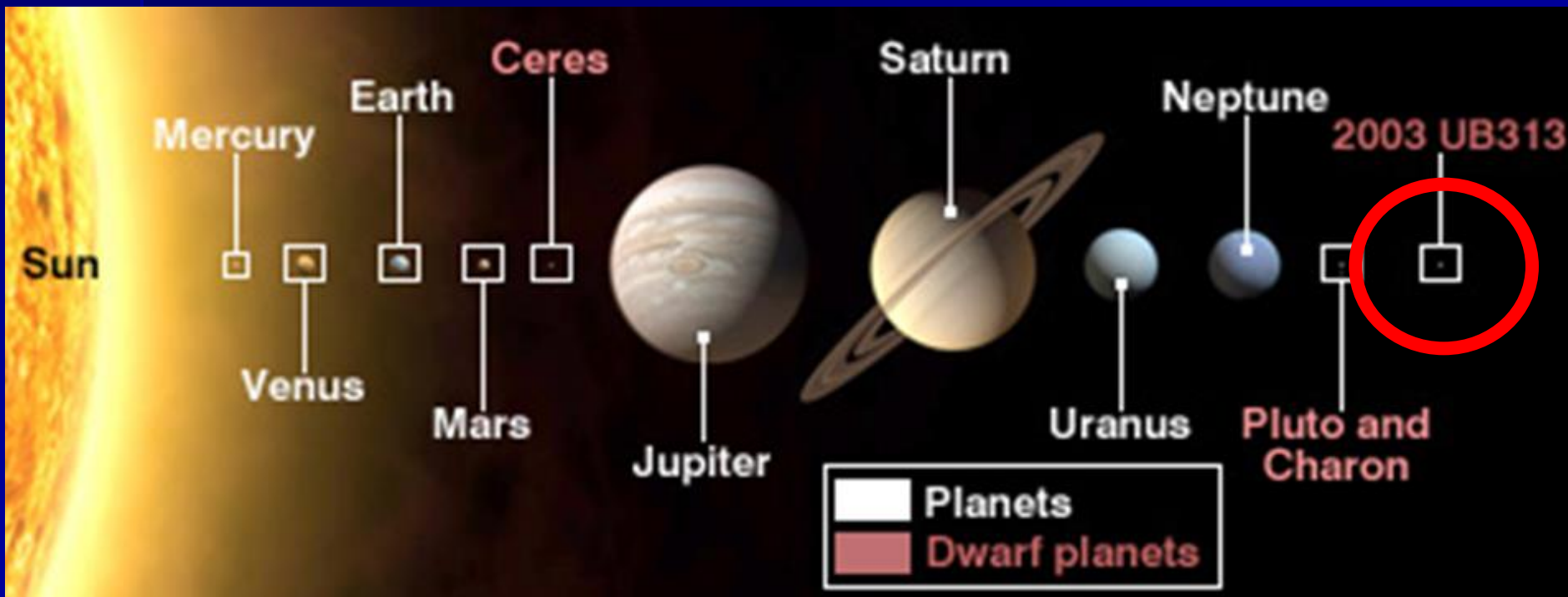


# Atmosphere of Charon

**Charon Helps Pluto Keep Its Atmosphere**



# Atmosphere of Eris



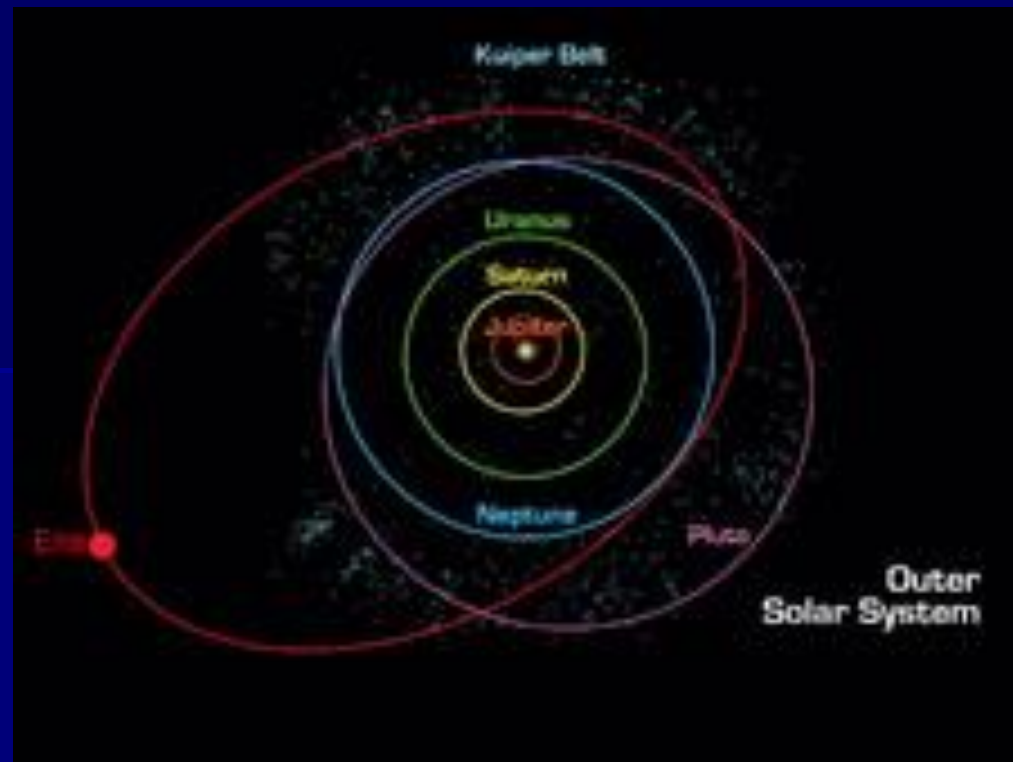
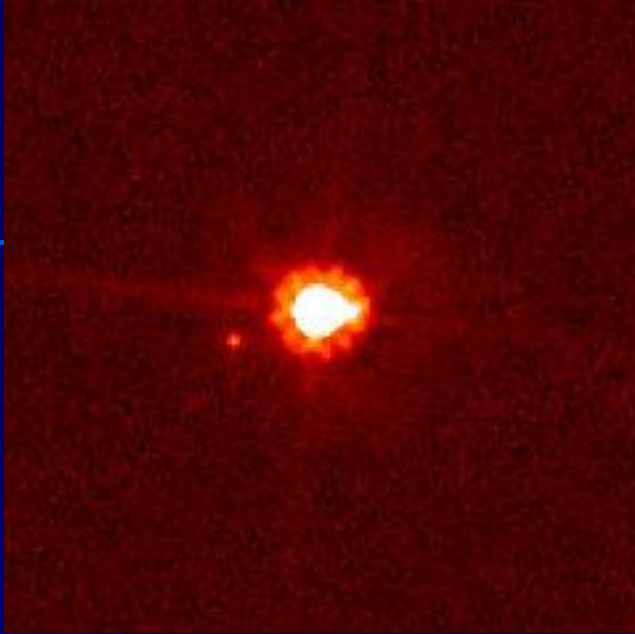
# Atmosphere of Eris



**Eris**, formal designation **136199 Eris**, is the most massive known dwarf planet in the solar system and the ninth most massive body known to orbit the Sun directly.

It is estimated to be approximately 2300–2400 km in diameter, and 27% more massive than Pluto or about 0.27% of the Earth's mass.

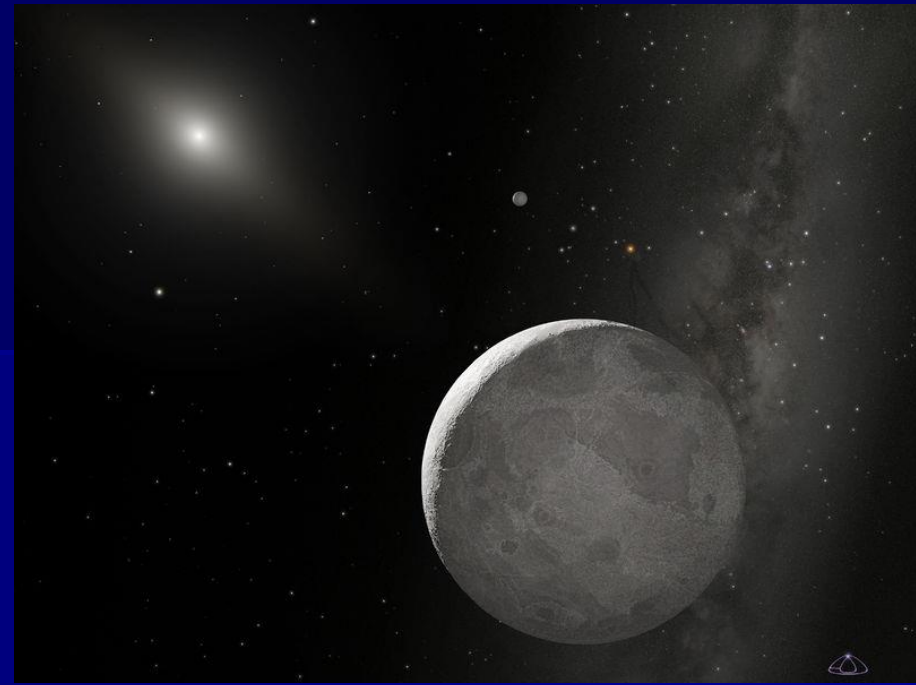
# Atmosphere of Eris



Eris was discovered in January 2005 by a Palomar Observatory - based team led by Mike Brown, and its identity was verified later that year.

Eris has an orbital period of 557 years, and as of 2011 lies at 96.6 AU from the Sun, almost its maximum possible distance (its aphelion (Distance from the Sun) is 97.5 AU).

# Atmosphere of Eris



The discovery team followed up their initial identification of Eris with spectroscopic observations made at the 8 m Gemini North Telescope in Hawaii on January 25, 2005.

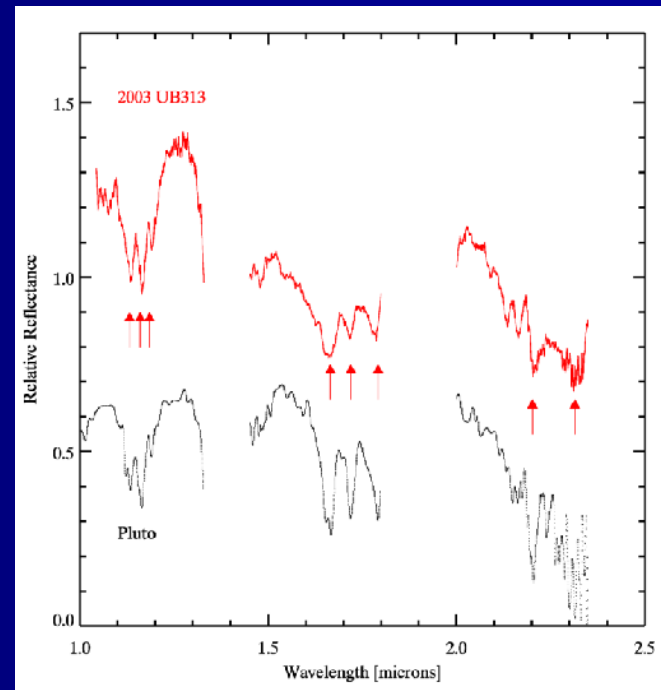
Infrared light from the object revealed the presence of methane ice, indicating that the surface may be similar to that of Pluto, which at the time was the only TNO known to have surface methane, and of Neptune's moon Triton, which also has methane on its surface.

# Atmosphere of Eris

Due to Eris's distant eccentric orbit, Eridian surface temperature is estimated to vary between about 30 and 56 kelvin (−243 and −217 degrees Celsius).

In contrast, Eris is far enough away from the Sun that methane can condense onto its surface even where the albedo is low. The condensation of methane uniformly over the surface reduces any albedo contrasts and would cover up any deposits of red tholins.

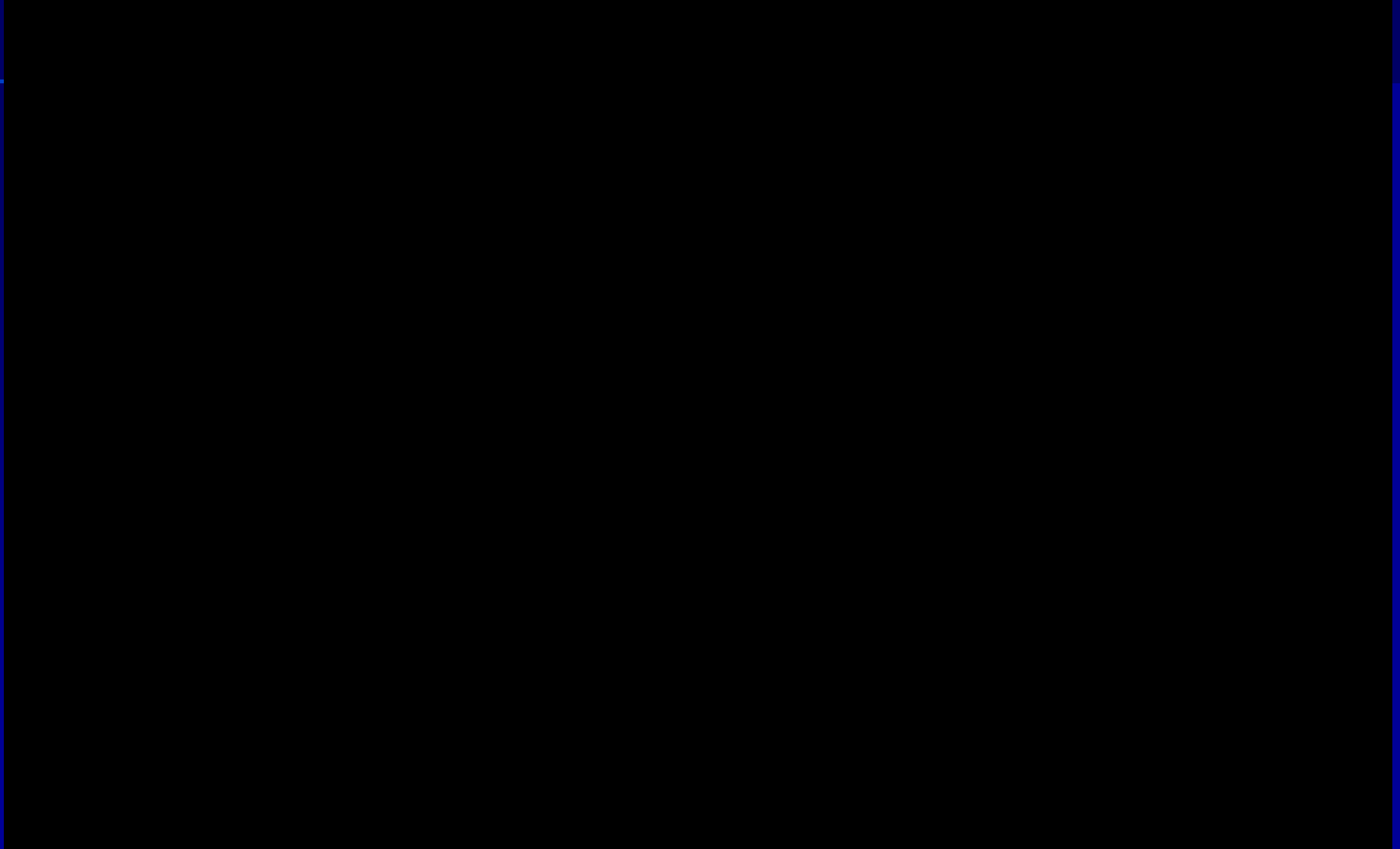
The infrared spectrum of Eris, compared to that of Pluto, shows the marked similarities between the two bodies. Arrows denote methane absorption lines.





# Atmosphere of Eris

**Dwarf Planet Eris**



# Atmospheres of Natural Satellites

# Jupiter's

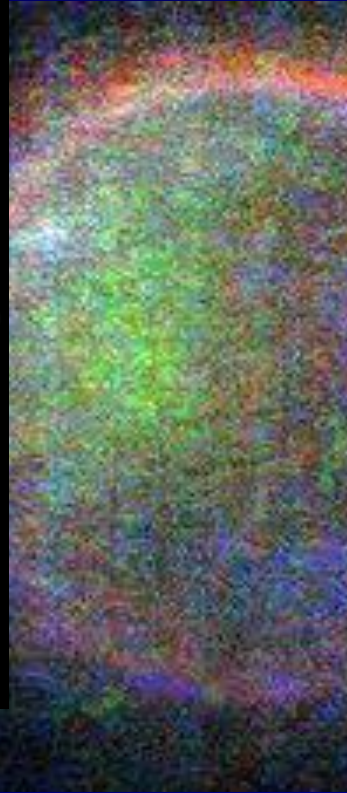
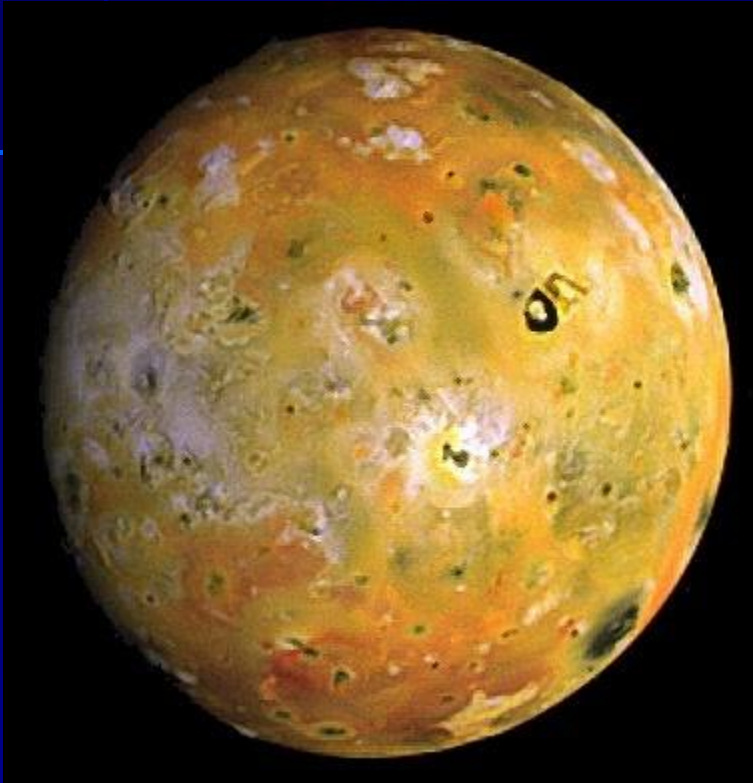
Io

Callisto

Europa

Ganymede

# Atmosphere of "Io" - Jupiter



Auroral glows in Io's upper atmosphere. Different colors represent emission from different components of the atmosphere (green comes from emitting sodium, red from emitting oxygen, and blue from emitting volcanic gases like sulfur dioxide). Image taken while Io was in eclipse.

# Atmosphere of "Io" - Jupiter

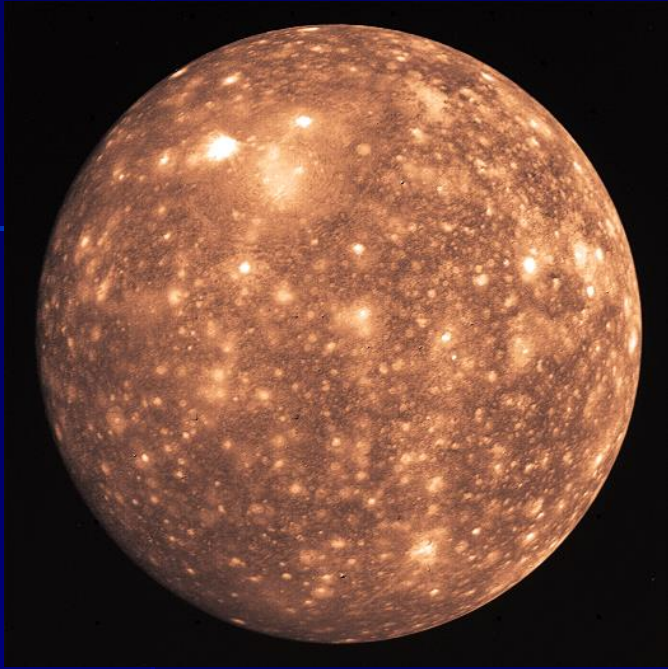
Io has an **extremely thin atmosphere consisting mainly** of sulfur dioxide (SO<sub>2</sub>), with minor constituents including sulfur monoxide (SO), sodium chloride (NaCl), and atomic sulfur and oxygen.

The maximum atmospheric pressure on Io ranges from  $0.33 \times 10^{-4}$  to  $3 \times 10^{-4}$  (Pa) or 0.3 to 3 nbar

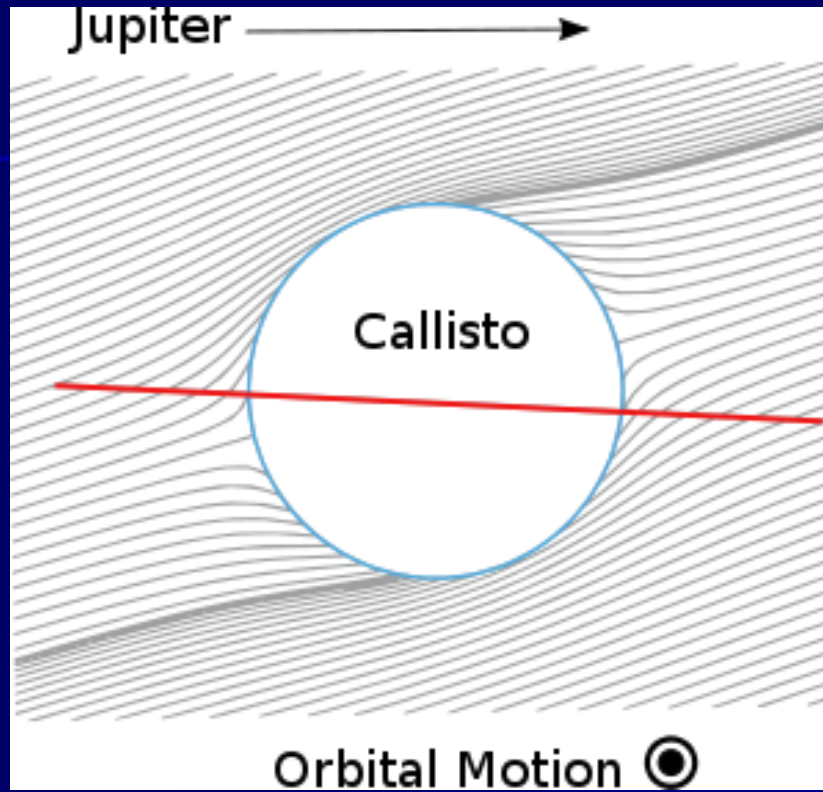
Io's **atmospheric temperature ranges from 273 K to 1800 K**

**Gas in Io's atmosphere is stripped by Jupiter's magnetosphere, escaping to either the neutral cloud that surrounds Io, or the Io plasma torus, a ring of ionized particles that shares Io's orbit but co-rotates with the magnetosphere of Jupiter. Approximately one ton of material is removed from the atmosphere every second through this process**

# Atmosphere of "Callisto" - Jupiter



# Atmosphere of "Callisto" - Jupiter



Induced magnetic field around Callisto

# Atmosphere of "Callisto" - Jupiter

## Atmosphere and ionosphere

Callisto has a very tenuous atmosphere **composed of carbon dioxide**.

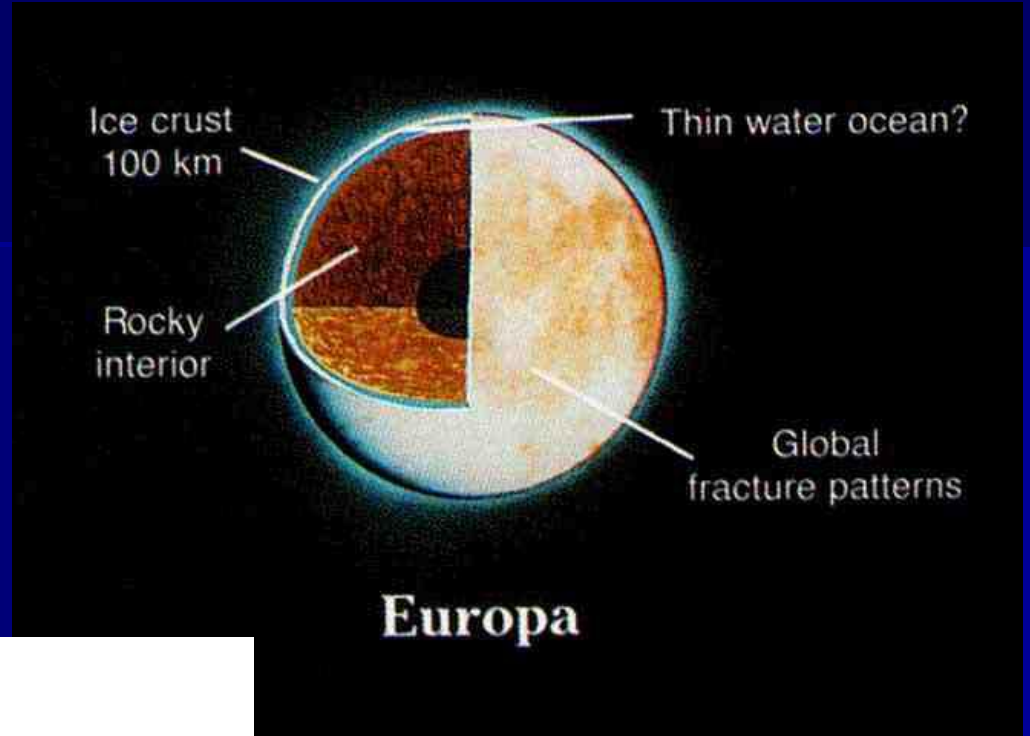
The surface pressure is estimated to be  $7.5 \times 10^{-12}$  bar (0.75  $\mu$ Pa) and particle density  $4 \times 10^8$   $\text{cm}^{-3}$ .

Callisto's ionosphere was detected - *Galileo* flybys; its **high electron density of  $7 - 17 \times 10^4$   $\text{cm}^{-3}$**

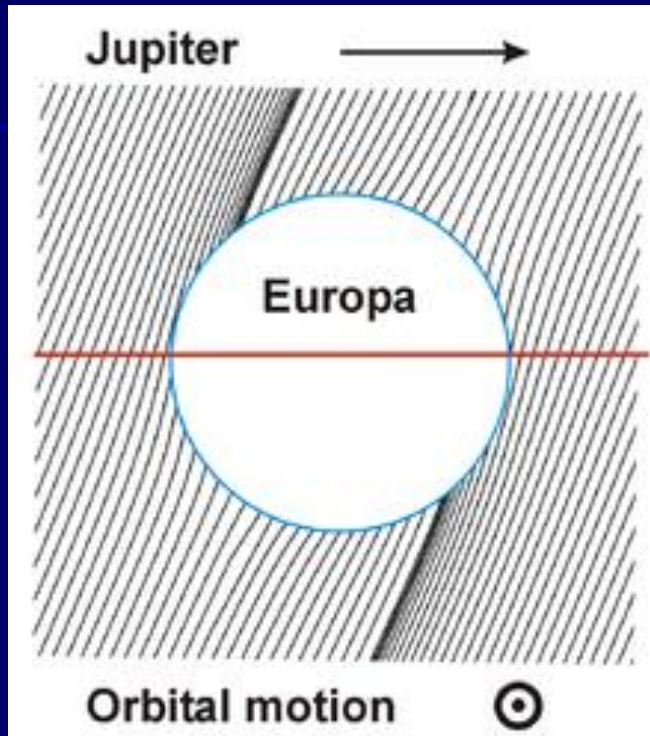
HST (Hubble Space Telescope) was able to detect condensed **oxygen trapped on the surface of Callisto**.



# Atmosphere of "Europa" - Jupiter



# Atmosphere of "Europa" - Jupiter



**Magnetic field around Europa.** The red line shows a trajectory of the *Galileo* spacecraft during a typical flyby

# Atmosphere of "Europa" - Jupiter

**Europa has a tenuous atmosphere composed mostly of molecular oxygen (O<sub>2</sub>).**

The surface pressure of Europa's atmosphere is 0.1 μPa, or 10<sup>-7</sup> times that of the Earth.

In 1997, the Galileo spacecraft **confirmed the presence of a tenuous ionosphere around Europa** created by solar radiation and energetic particles from Jupiter's magnetosphere, providing evidence of an atmosphere.

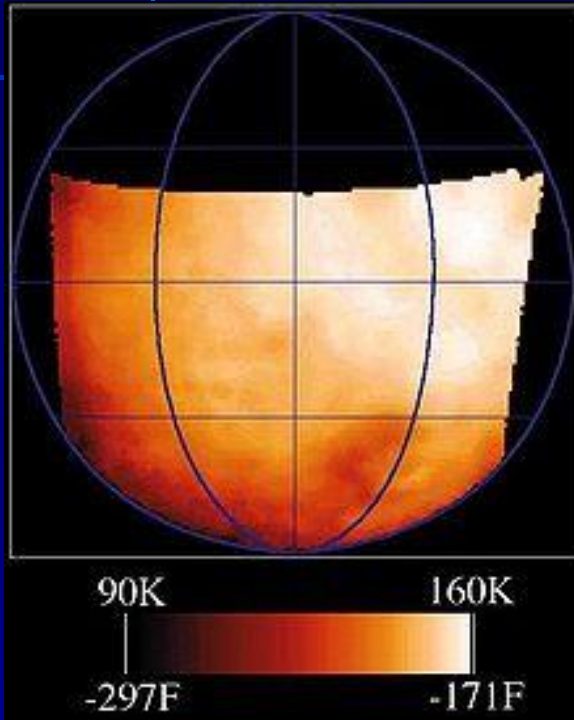
**Unlike the oxygen in Earth's atmosphere, Europa's is not of biological origin.**

# Atmosphere of "Ganymede" - Jupiter



# Atmosphere of "Ganymede" - Jupiter

## Atmosphere and ionosphere



False colour temperature map of Ganymede

In 1972, a team of Indian, British and American astronomers had detected a thin atmosphere

They estimated that the surface pressure was around 0.1 Pa.

The upper limit on the surface particle number density was found to be  $1.5 \times 10^9 \text{ cm}^{-3}$ , which corresponds to a surface pressure of less than 2.5  $\mu\text{Pa}$ .

# Atmosphere of "Ganymede" - Jupiter

## Atmosphere and ionosphere...

The existence of a neutral atmosphere implies that an ionosphere should exist, because oxygen molecules are ionized by the impacts of the energetic electrons coming from the magnetosphere and by solar EUV radiation.

The electron density near the surface is estimated by different sources to lie in the range  $400 - 2,500 \text{ cm}^{-3}$ . As of 2008, the parameters of the ionosphere of Ganymede are not well constrained.

**The detection of ozone ( $\text{O}_3$ ) bands was announced in 1996.**

Laboratory work has found that  $\text{O}_2$  would not cluster or bubble but dissolve in ice at Ganymede's relatively warm surface temperature of 100 K.

Saturn's

Titan

Enceladus

# Atmosphere of "Titan" - Saturn





# Atmosphere of "Titan" - Saturn



True-color image of layers of haze in Titan's atmosphere.

**The atmosphere of Titan is known as the only fully developed atmosphere** that exists on a natural satellite in our solar system.

## History

In 1981, Voyager 1 made the first detailed observations of **Titan's atmosphere, revealing that its surface pressure was in fact thicker than Earth's, at 1.5 bars.**

## Extent

Observations from the Voyager space probes have shown that the **Titanian atmosphere is denser than Earth's**, with a surface pressure about 1.45 times that of Earth's. Titan's atmosphere is about 1.19 times as massive as Earth's overall

# Atmosphere of "Titan" - Saturn



A cloud imaged in false color over Titan's north pole.

## Composition

The atmospheric composition in the stratosphere is 98.4% nitrogen the only dense, nitrogen-rich atmosphere in the Solar System aside from the Earth's - with the remaining 1.6% composed of mostly of methane (1.4%) and hydrogen (0.1–0.2%).

There are trace amounts of other hydrocarbons, such ethane, diacetylene, methylacetylene, acetylene and propane, and of other gases, such as cyanoacetylene, hydrogen cyanide, carbon dioxide, carbon monoxide, cyanogen, argon and helium.

# Atmosphere of "Titan" - Saturn



Layers of atmosphere, image from the Cassini - Huygens spacecraft

## Evolution

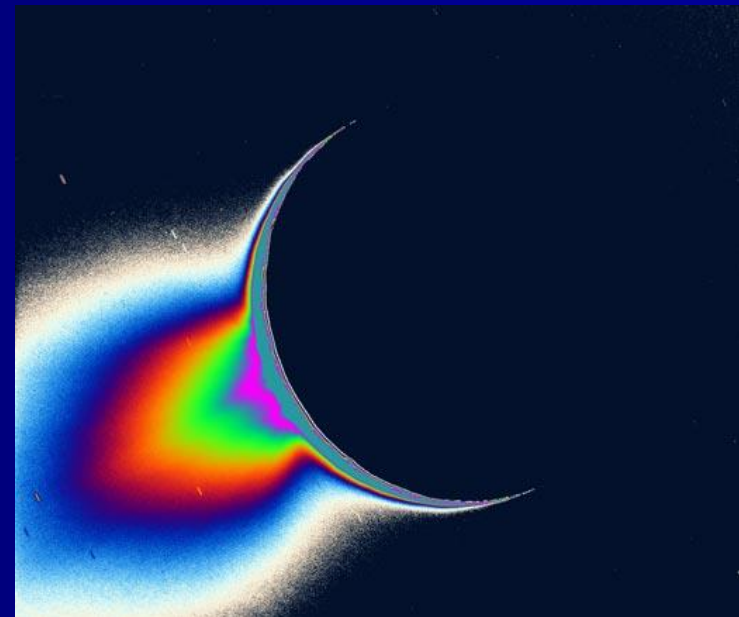
Titan's surface temperature is also quite low, about 90 K.

In fact, current interpretations suggest that only about 50% of Titan's mass is silicates, with the rest consisting primarily of various H<sub>2</sub>O (water) ices and NH<sub>3</sub>-H<sub>2</sub>O (ammonia hydrates).

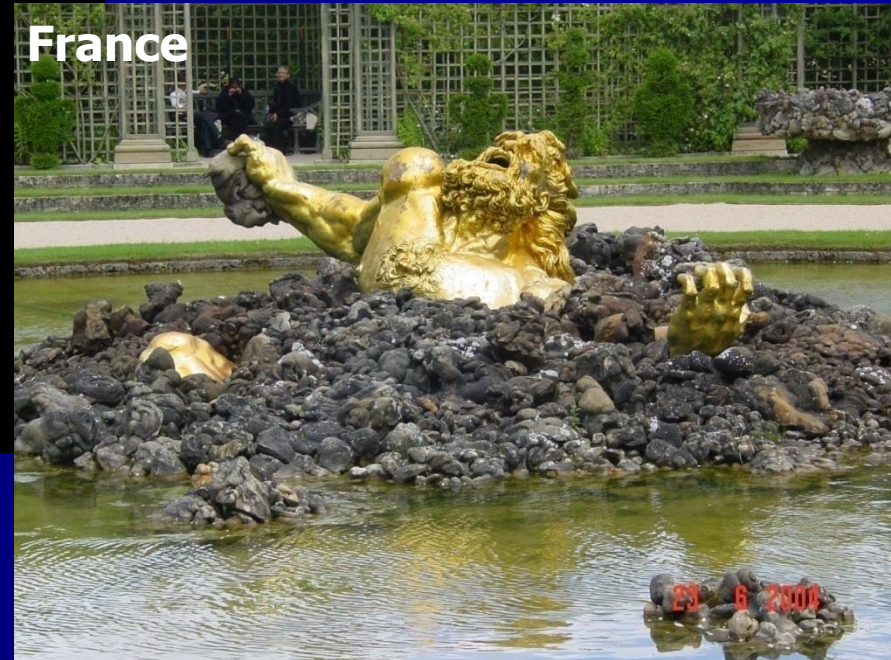
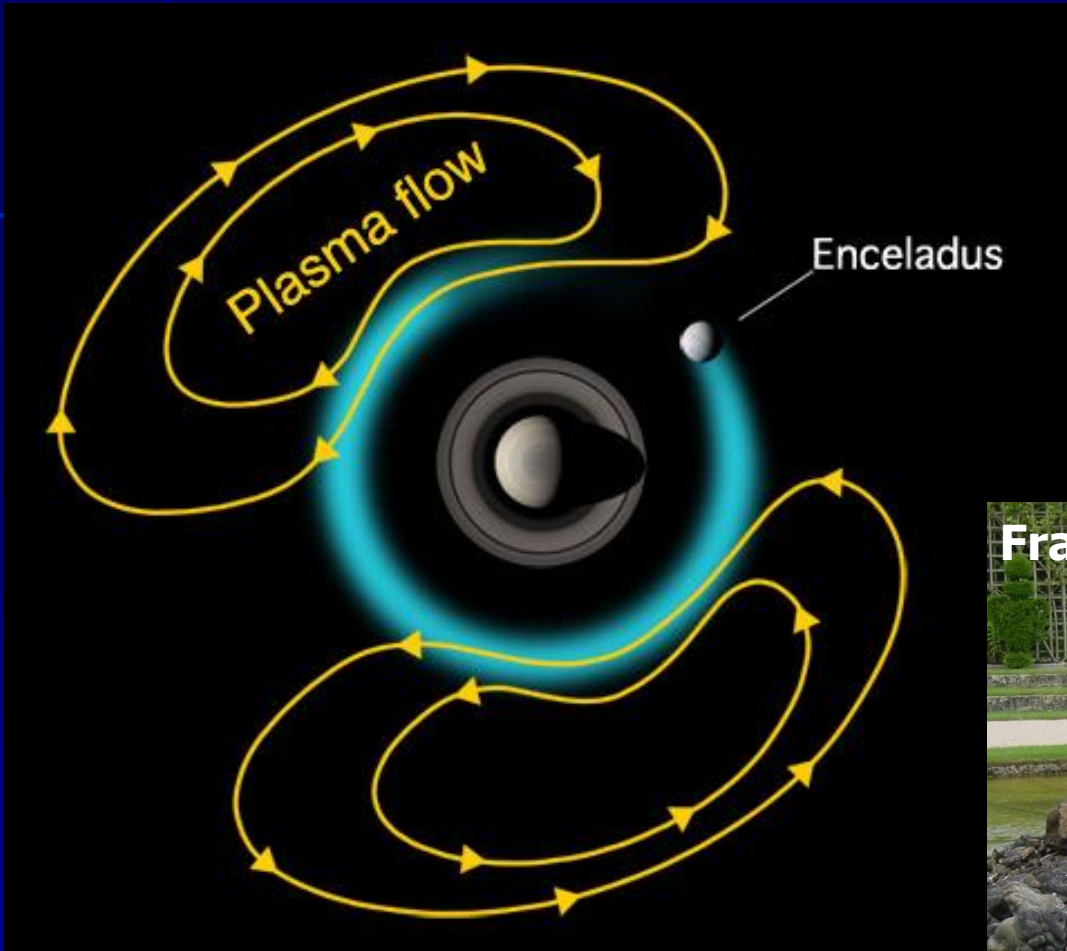
# Atmosphere of "Enceladus" - Saturn



Plumes above the limb of Enceladus feeding the E ring. These appear to emanate from the "tiger stripes" near the south pole. (View from Cassini spacecraft)

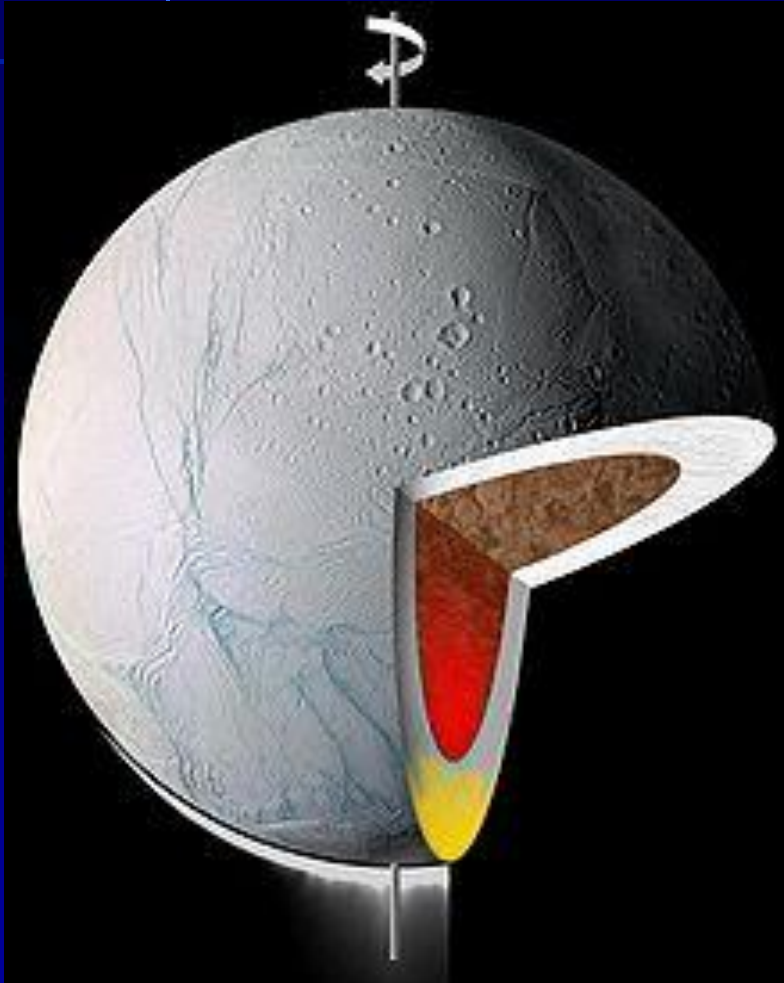


# Atmosphere of "Enceladus" - Saturn



# Atmosphere of "Enceladus" - Saturn

## Internal structure



Model of the interior of Enceladus based on recent *Cassini* findings. The inner, silicate core is represented in brown, while the outer, water-ice-rich mantle is represented in white. The yellow and red colours in the mantle and core respectively represent a proposed diaper under the south pole.

Mass estimates from the Voyager program missions suggested that **Enceladus was composed almost entirely of water ice.**

# Atmosphere of "Enceladus" - Saturn

Possible water ocean

**In late 2008, scientists observed water vapor spewing from Enceladus's surface. This could indicate the presence of liquid water, which might also make it possible for Enceladus to support life.**

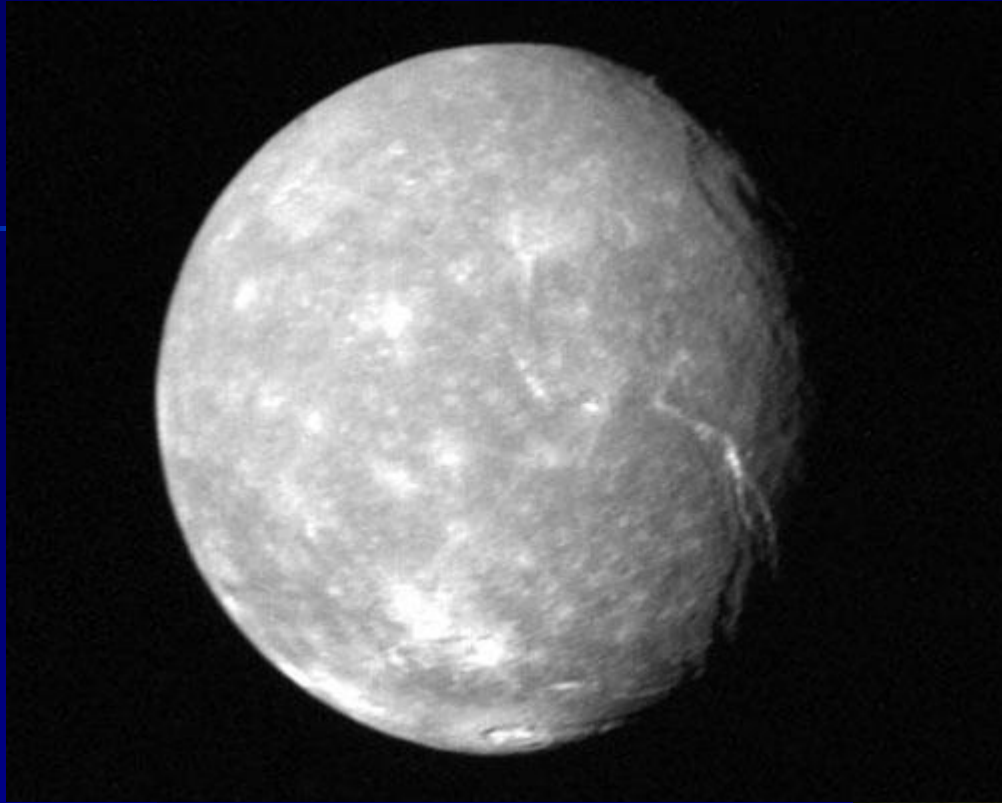
Particles of ice analysed by **Cassini revealed that the ice was of salt water** which could, it is surmised, only occur in a large liquid body of water; as such **Enceladus is a candidate for the harbouring of extra-terrestrial life.**

Uranus's

**Titania**



# Atmosphere of "Titania" - Uranus



# Atmosphere of "Titania" - Uranus

**The presence of carbon dioxide on the surface suggests that Titania** may have a tenuous seasonal atmosphere of CO<sub>2</sub>, much like that of the Jovian moon Callisto. **Other gases like nitrogen or methane are unlikely to be present**, because the moon's weak gravity could not prevent them escaping into the space. **At the maximum temperature attainable during Titania's summer solstice (89 K), the vapour pressure of carbon dioxide is about 3 nbar.**

During the summer, when the polar temperatures reach as high as 85–90 K, carbon dioxide sublimates and migrates to the opposite pole and to the equatorial regions, giving rise to a type of carbon cycle.

Neptune's

**Triton**

# Atmosphere of "Triton" - Neptune



# Atmosphere of "Triton" - Neptune

The atmosphere of Triton extends 800 kilometres above Triton's surface. **The atmosphere mainly is composed of nitrogen**, similar to Titan's atmosphere and Earth's atmosphere. The surface pressure is only 14 microbars, which is 1/70,000th of the surface pressure on Earth. **Originally, it was thought Triton had a thick atmosphere.**

## Composition

Nitrogen is the main gas in Triton's atmosphere. The two other known components are methane and carbon monoxide, which abundances are a few hundredths of a per cent of that of the nitrogen. **Carbon monoxide, which was discovered only in 2010** by the ground based observations, is slightly more abundant than methane.

Other possible components of the Triton's atmosphere include argon and neon.

# Atmosphere of "Triton" - Neptune

## Structure

Triton's atmosphere is well structured and global. The atmosphere extends up to 800 kilometres above the surface, where the exobase is located, and had a surface pressure of about 14 microbars as of 1989. This is only 1/70,000th of the surface pressure on Earth.

**The surface temperature was at least 35.6 K ( $-237.6\text{ }^{\circ}\text{C}$ )** because, transition between hexagonal and cubic nitrogen ice occurs at that temperature.

Convection near Triton's surface heated by the Sun creates a troposphere rising to an altitude of about 8 km. In it temperature decreases with height reaching a minimum of about 36 K at the tropopause.

Higher regions include the thermosphere (200–850 km) and exosphere (above 850 km). The thermosphere has a constant temperature of about 95 K.



Thank You !