The Solar System

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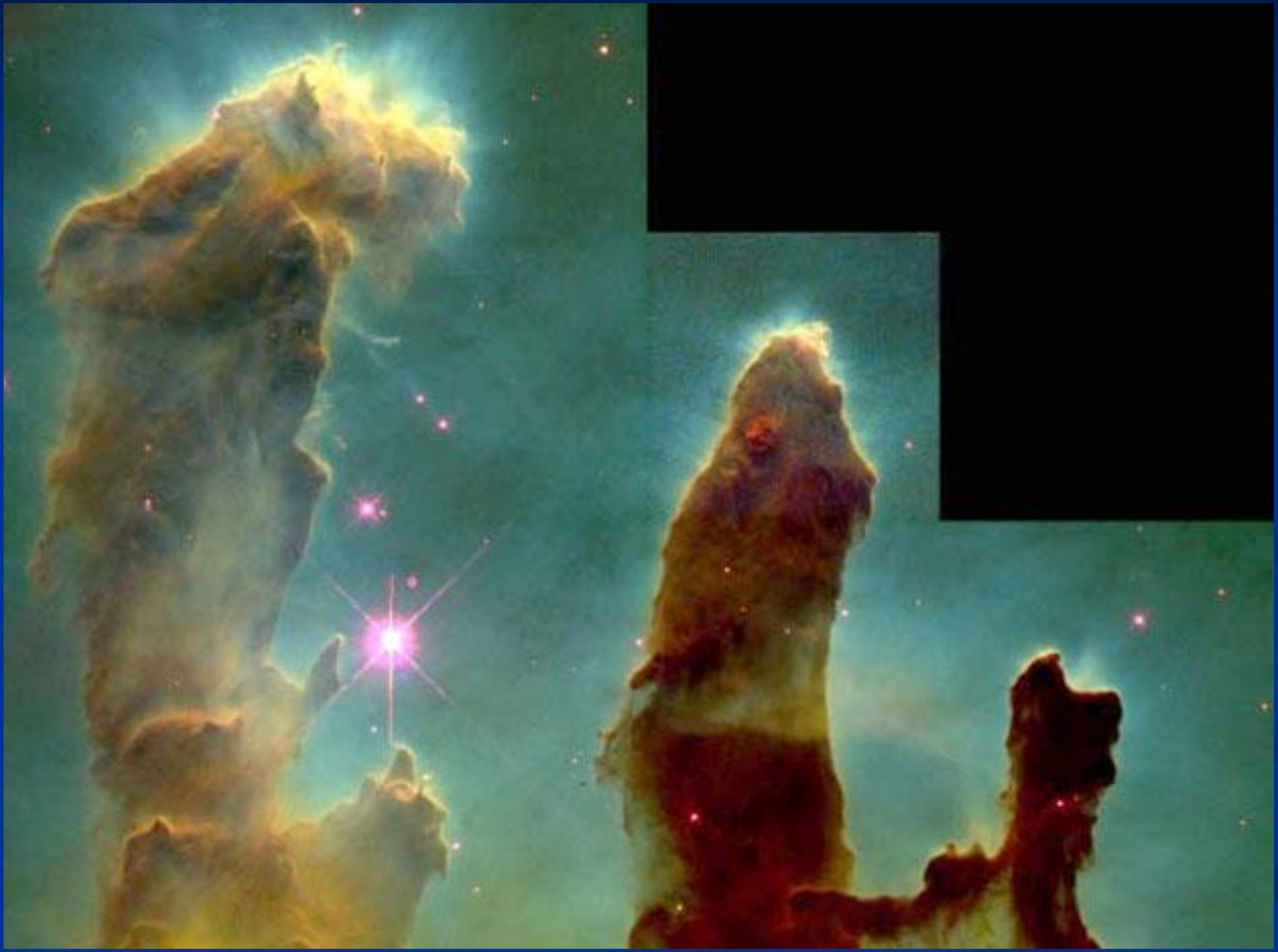
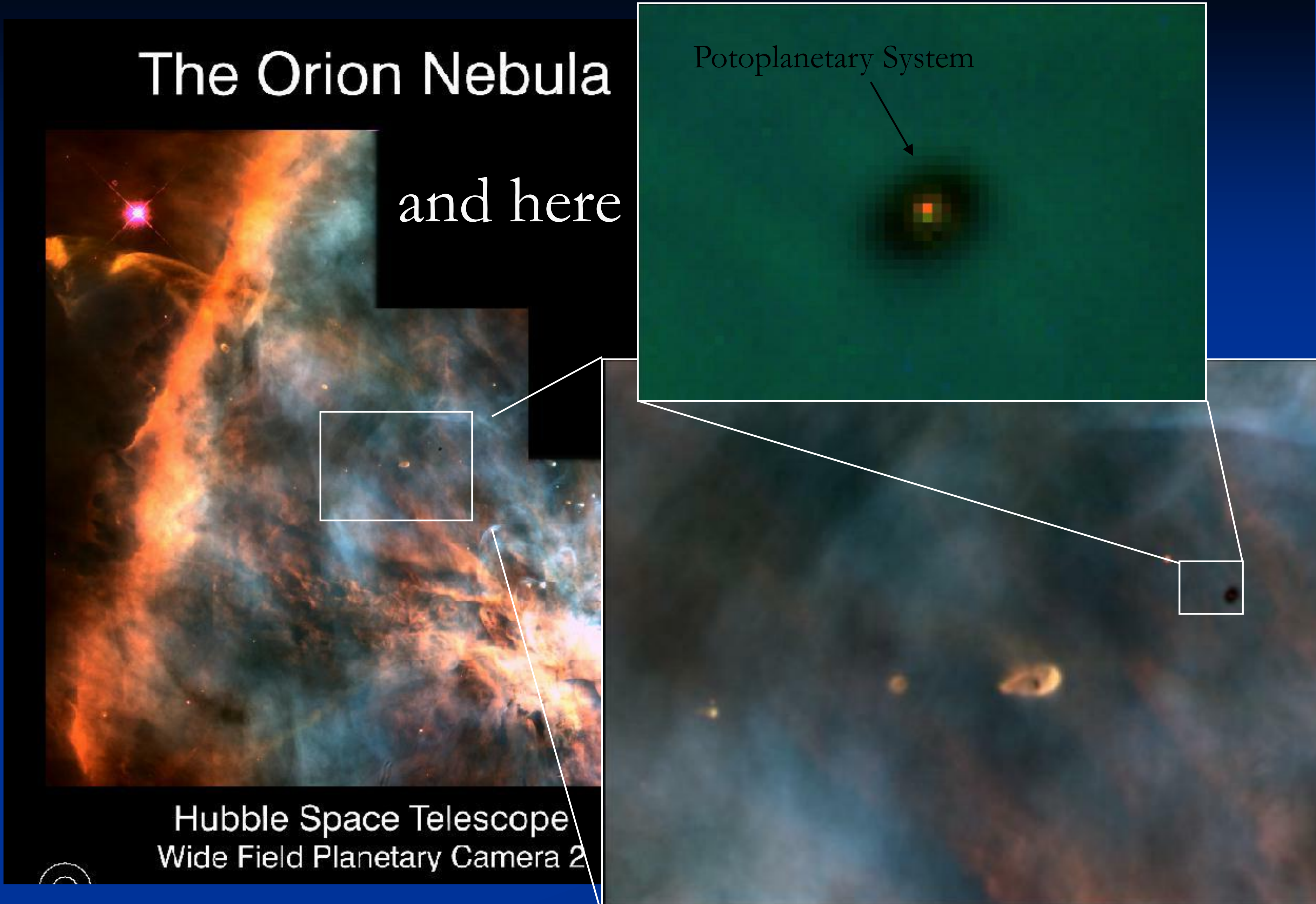
Here is where stars are born



Messier 16, Pillars of creation.
Credit: Hubble Space Telescope


The Orion Nebula
and here
Potoplanetary System
Hubble Space Telescope
Wide Field Planetary Camera 2

The planets in the past: the naked eyes visibles

Mercury
Venus
Mars
Jupiter
Saturne

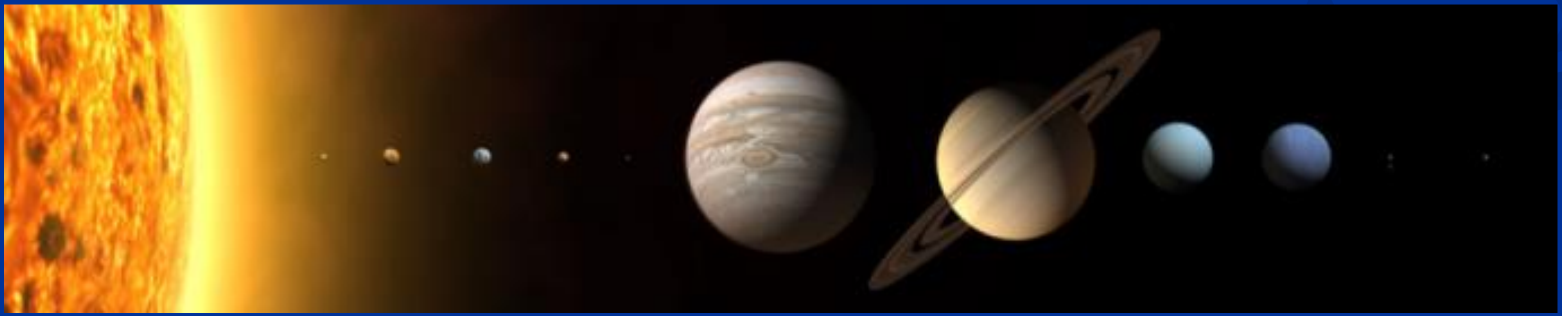
Visible at sunset or surise

Planetary alignement, May- 2002

The Solar System today

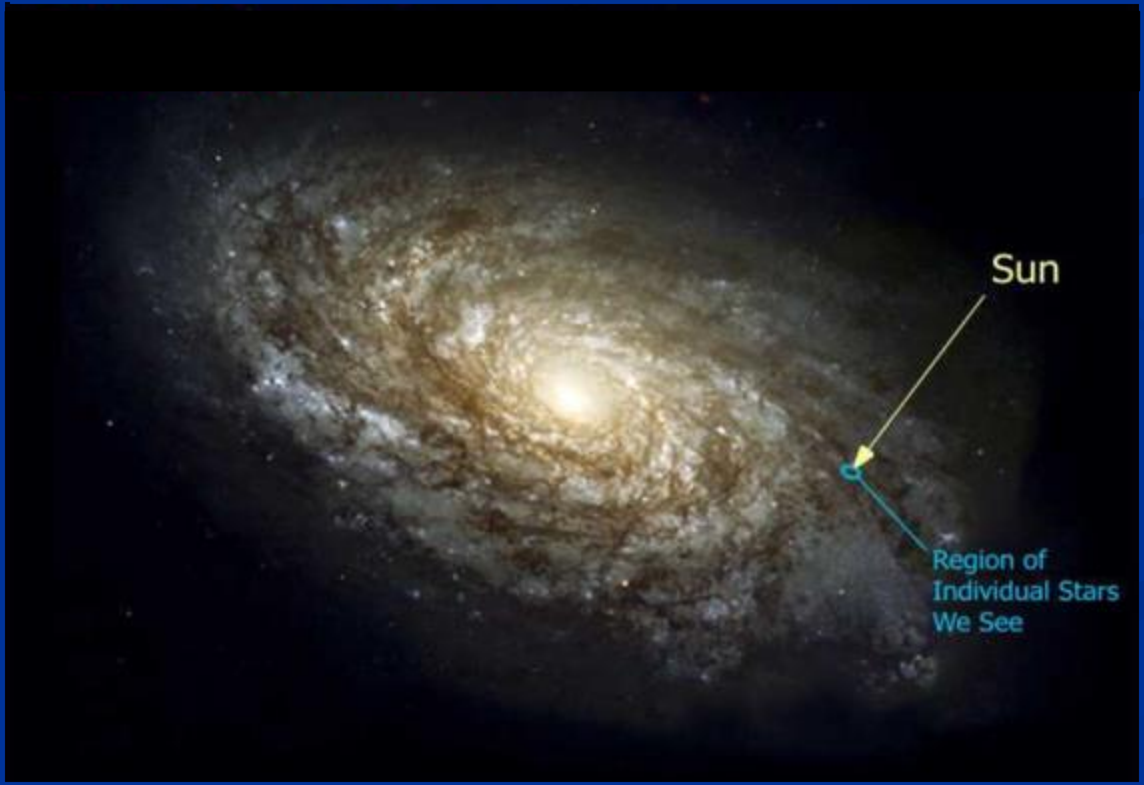
It is constituted by the Sun and all the bodies that revolve around it, under the action of gravity:

- 8 planets
- Hundred of natural satellites of planets
- Tenths of dwarf planets (between them Ceres, Pluto, Haumea, Makemake and Eris)
- An unknown number of minor bodies: asteroids, comets and transneptunians (debris of the processes of the planet formation).



Where is the Solar System?

It is in Orion arm, one of the Milky Way arms.



The Milky Way has about 200,000 millions of stars and its diameters is about 100,000 l.y.

The Solar System is located at a distance of ~25,000 light years from the center of the Galaxy (~ half the radius), and takes 250 millions years to complete a rotation around the center. The speed is 220 km/s (800.000 km/h)

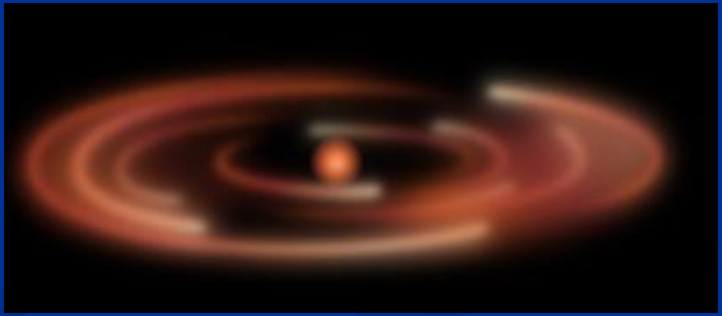
Model of the Milky Way, from the infrared observations by Spitzer (2005); our Galaxy is a barred spiral.

Solar System formation

- According to the standard theory, about 4.6 billion years ago the solar system was formed from the gravitational contraction of an interstellar gas and dust cloud. The collapse of the cloud started from a strong perturbation (possibly a supernova burst), which caused the gravitational force to overcome the pressure of the gases.
- The conservation of the angular momentum caused the nebula to turn faster and faster, to flatten out, and to give rise to a protosol at its center, and to a protoplanetary disk of gas and dust around it.

Solar System formation

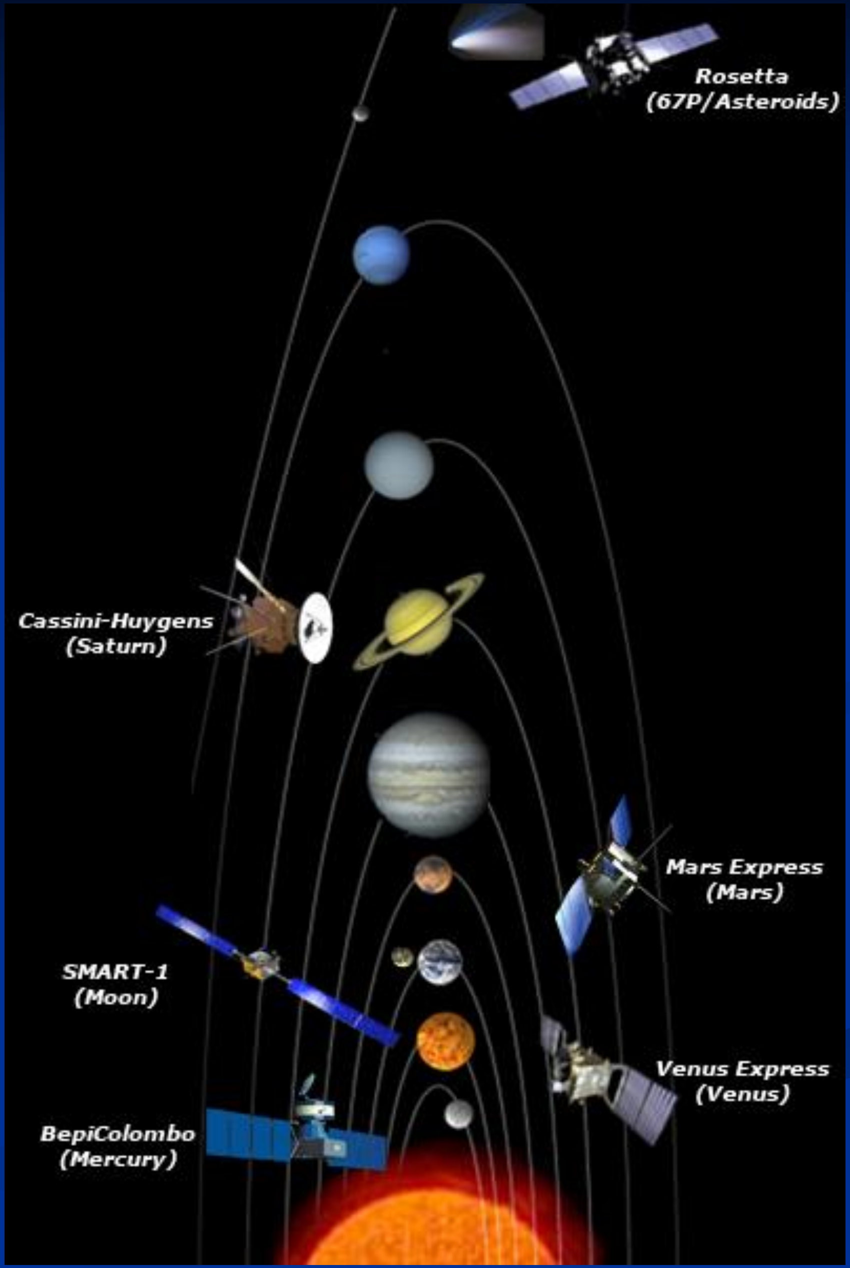
- **In the protoplanetary disk condensed small solid nuclei (planetesimals), which then were accumulated by an accretion process to form the planets.**
- The standard theory described above is accepted for having found, through high resolution radio images, protoplanetary systems around many young stars and due to the possibility of explaining the formation of planets within those systems.



Solar System Studies

The Sun concentrates more than 99.8% of the mass of the SS, while 98% of the angular momentum is found in the orbital movements of the planets.

Currently, the study of solar system bodies is done from Earth, but also through space telescopes, sending missions to space and even descending on its surface.



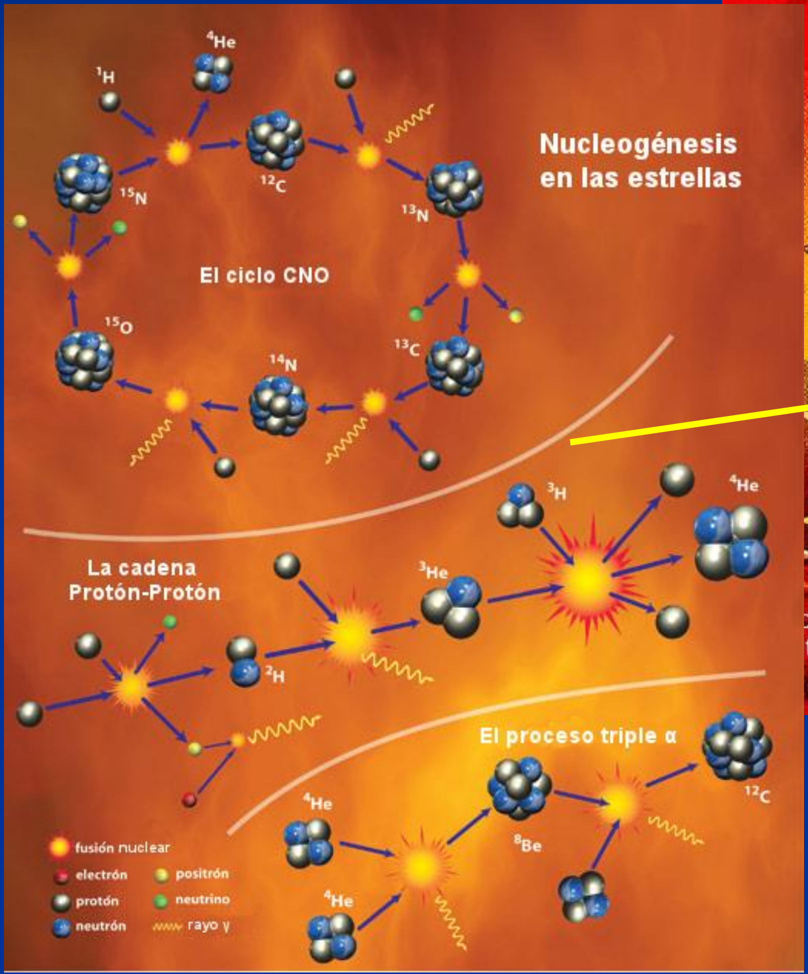
Credit: NASA

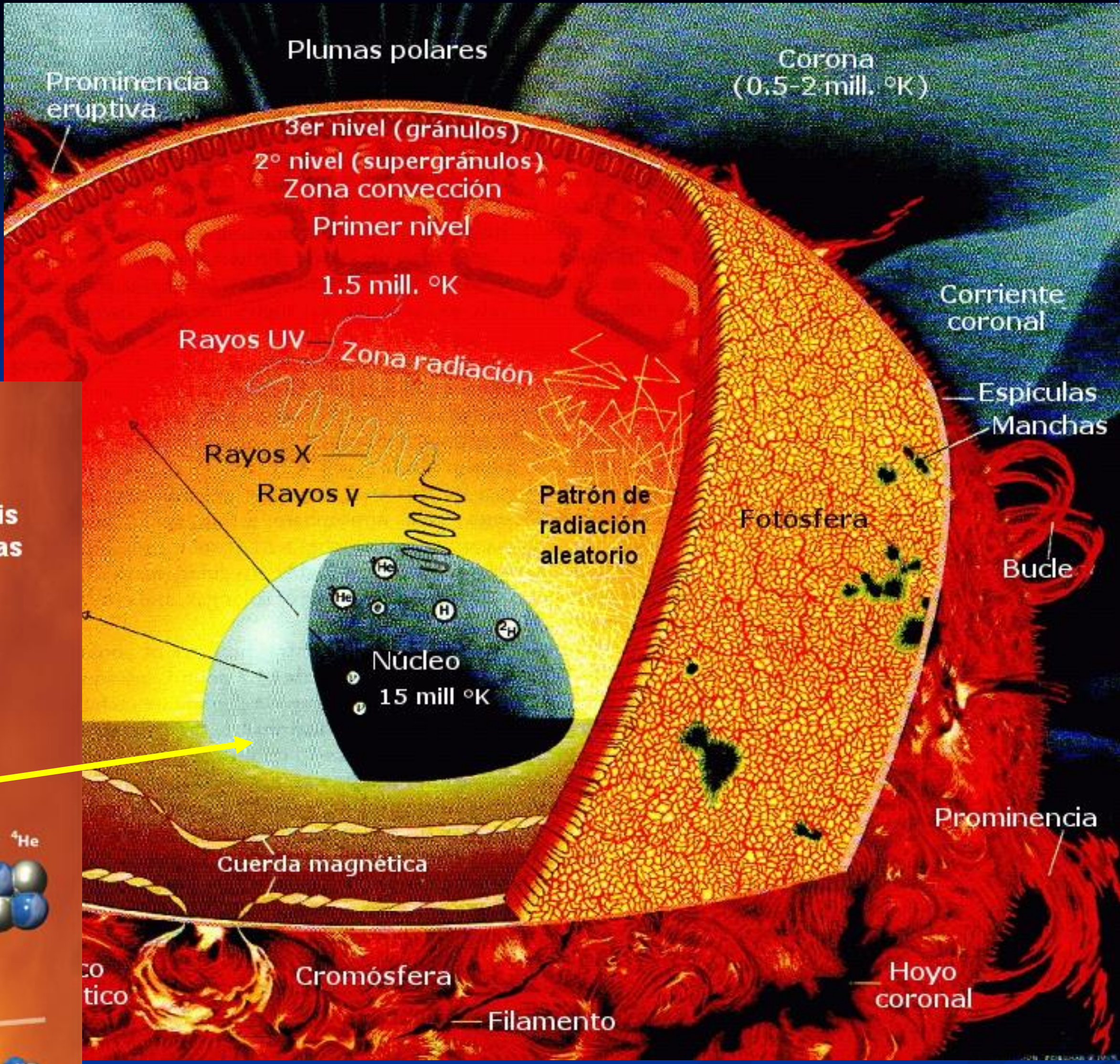
Our star: The Sun

- With an age of 4,600 million years, the Sun is approximately in the middle of its life cycle.
- Every second, in the Sun's core, 4 million tons of matter are converted into energy, generating a large number of neutrinos, positrons and radiation.

74% of the Sun is H, 25% is He, the rest are heaviest elements.

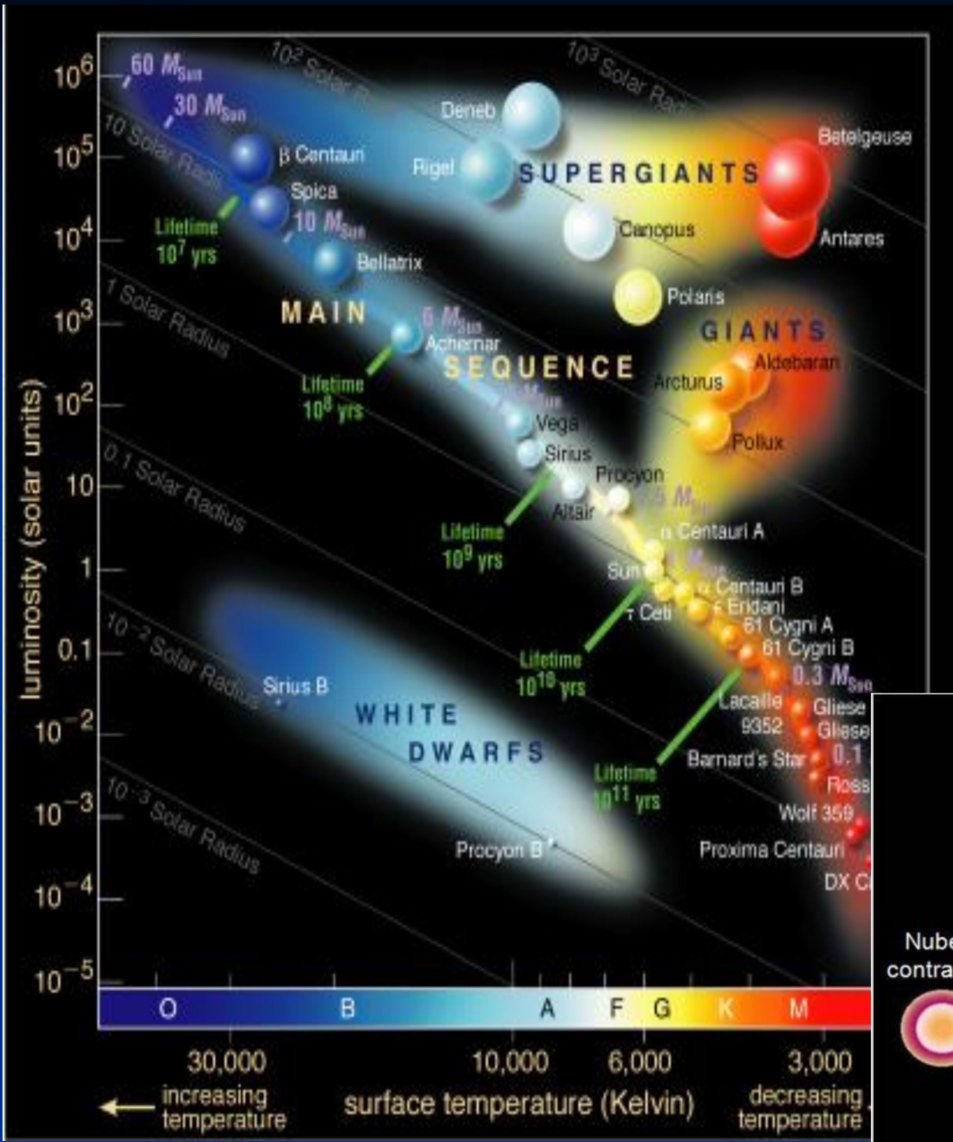
Sun structure

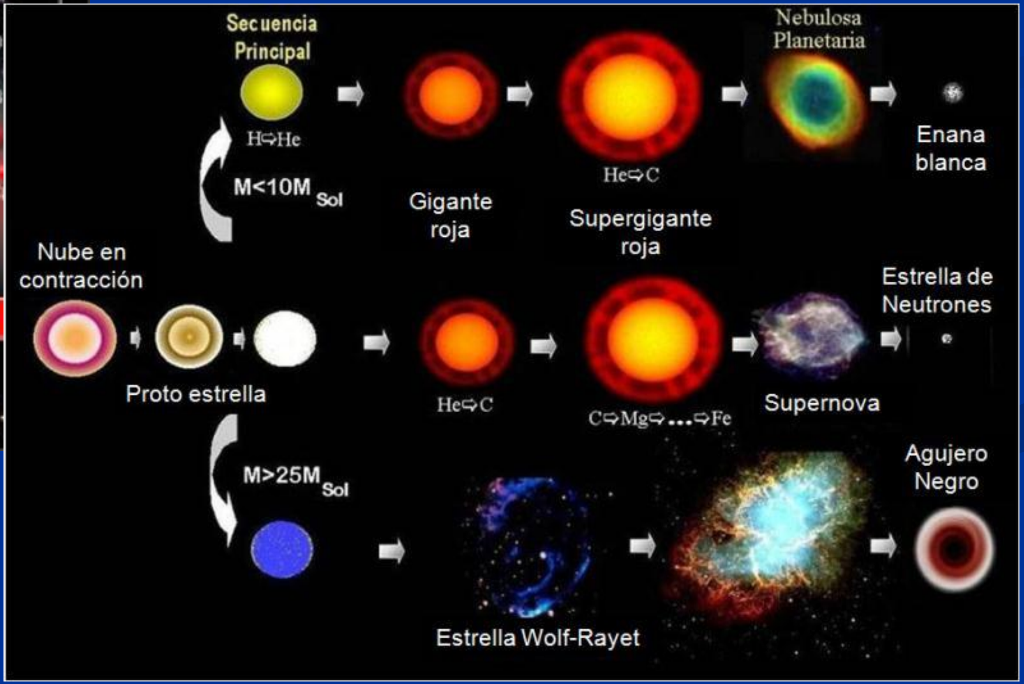




Energy production: fusion in the core.

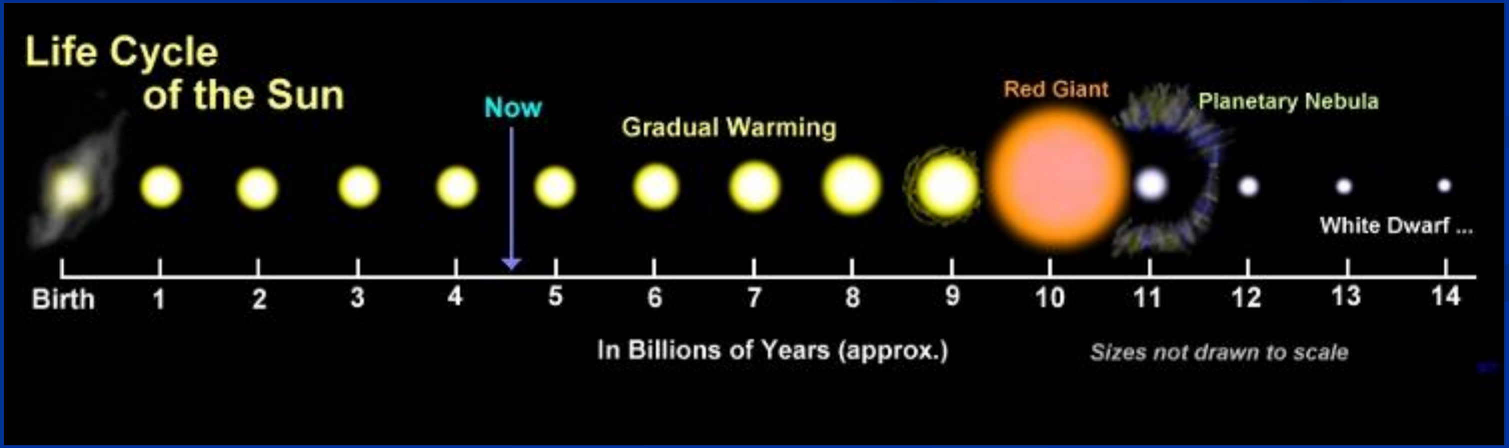
The life of the stars depens on their masses





Life cycle of the Sun

Within 5,000 million years, the Sun will swell and become a red giant. Then it will expel the outer layers, creating a planetary nebula, and in the center there will be a small star called white dwarf, which will slowly cool down.



The Planets

XXVI IAU-AG Resolution, Praha, 2006:

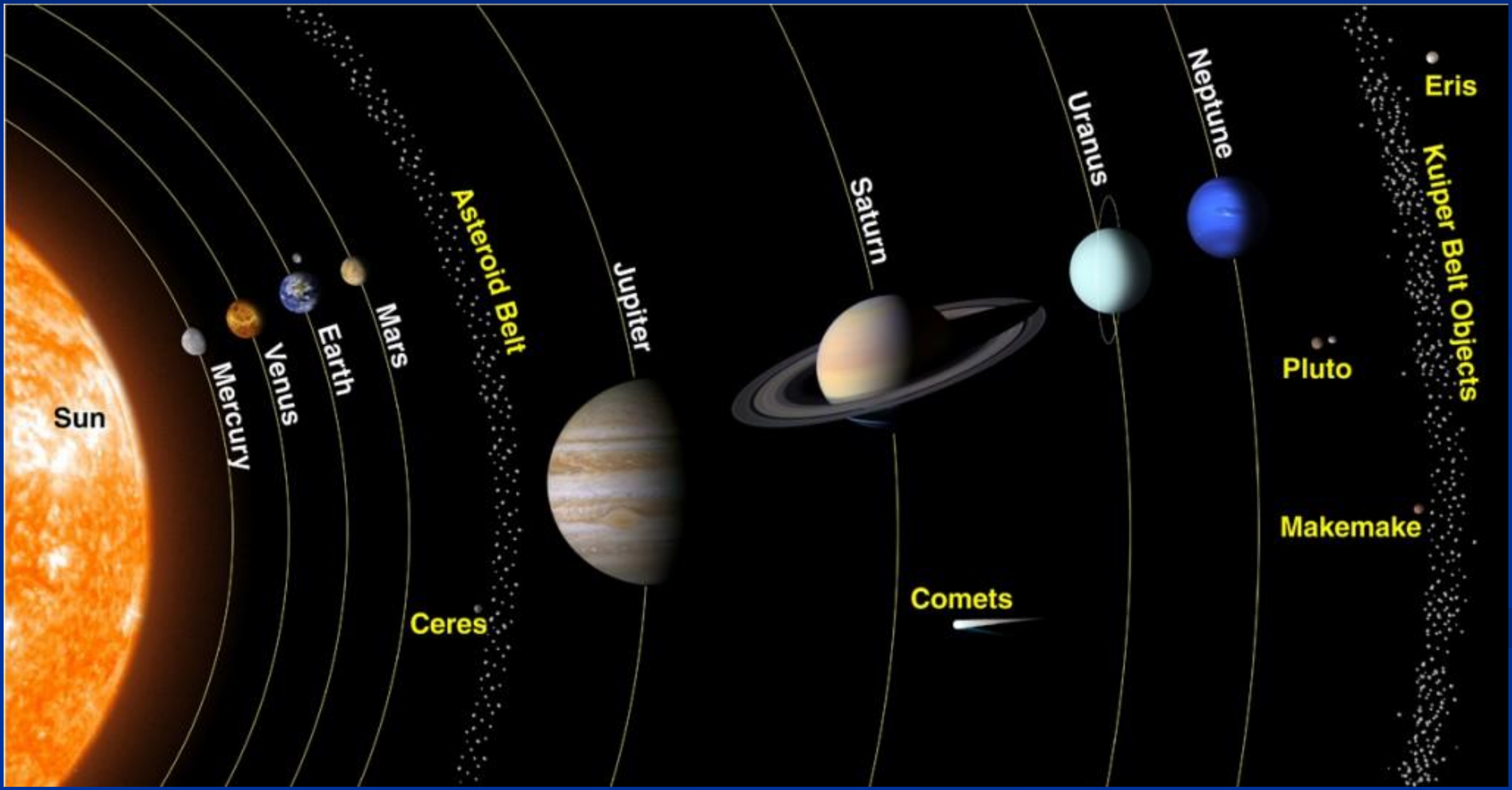
In the SS, a "planet" It is a celestial body that:

- It is in orbit around the Sun.
- It has enough mass for its self-gravity (which is a central force) to impose itself on the cohesive forces of a rigid body so that it assumes a form in hydrostatic (quasi-spherical) equilibrium.
- It has cleared other objects the neighborhood along its orbit.

A body that meets only the first two criteria, and that is not a satellite, is classified as a "dwarf planet".

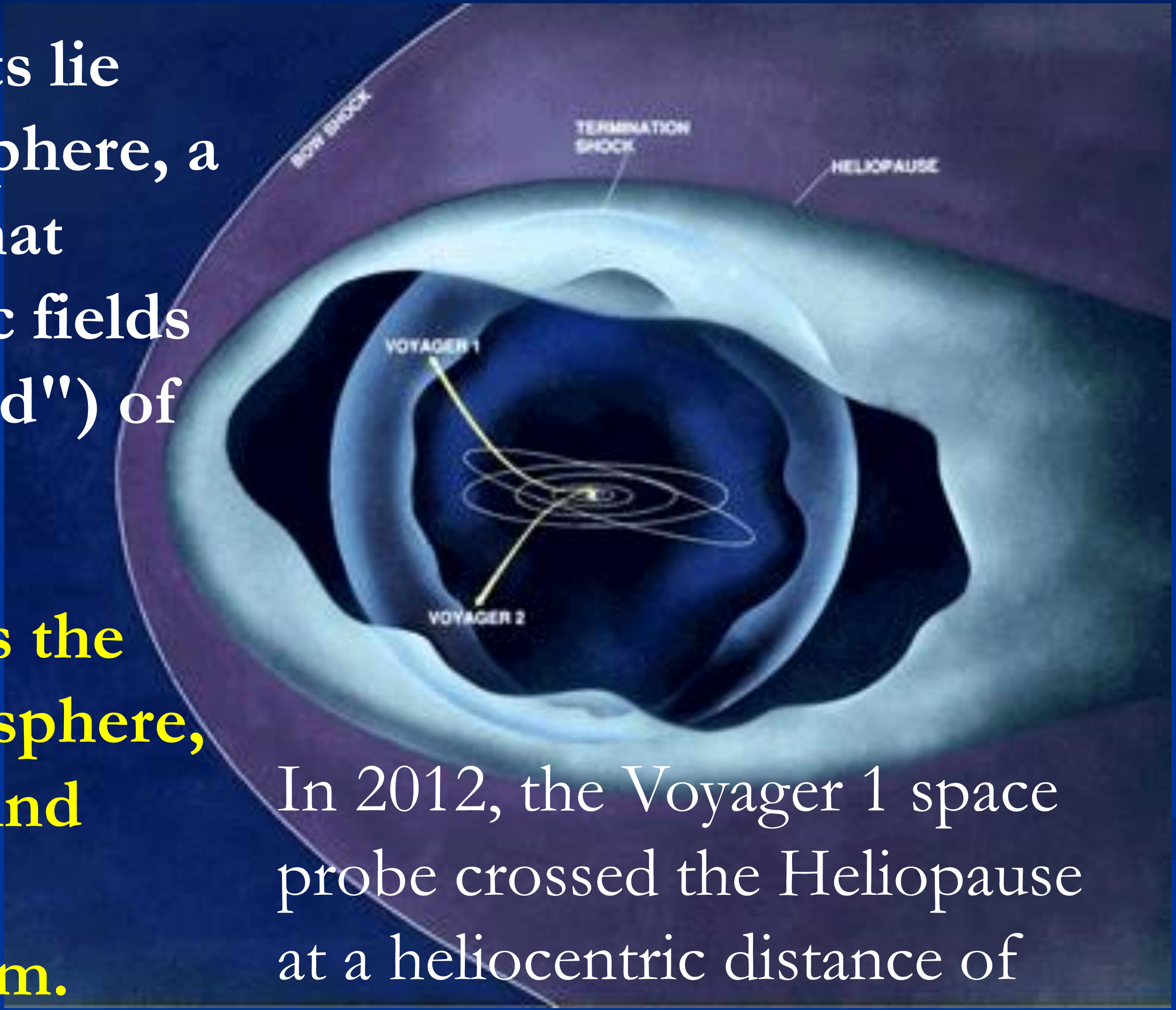
A body that meets only the first criteria, and that is not a satellite, is called "small body (or minor body) of the SS.

The Solar System today
(bodies in size scale)



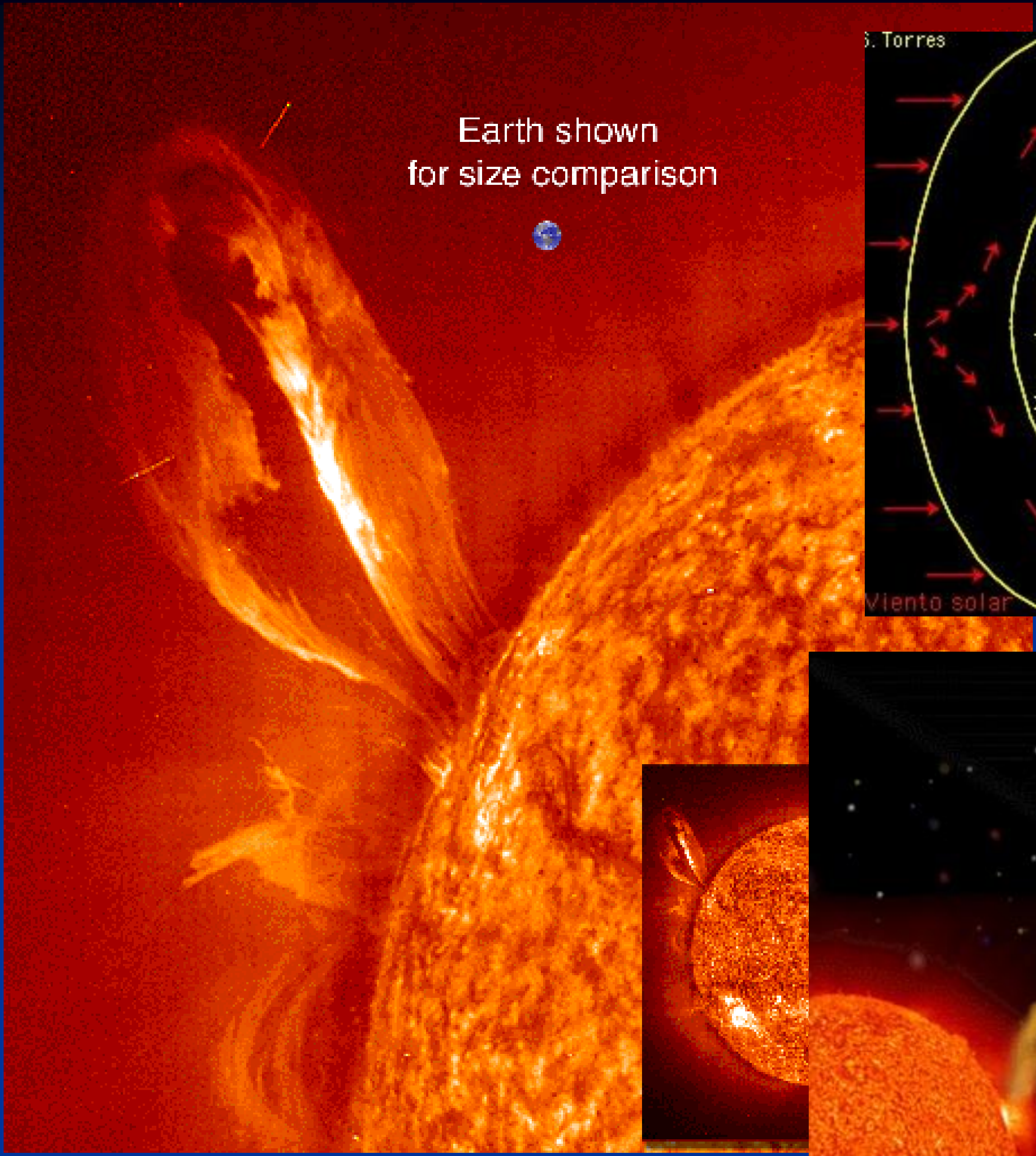
The limit of the Solar System

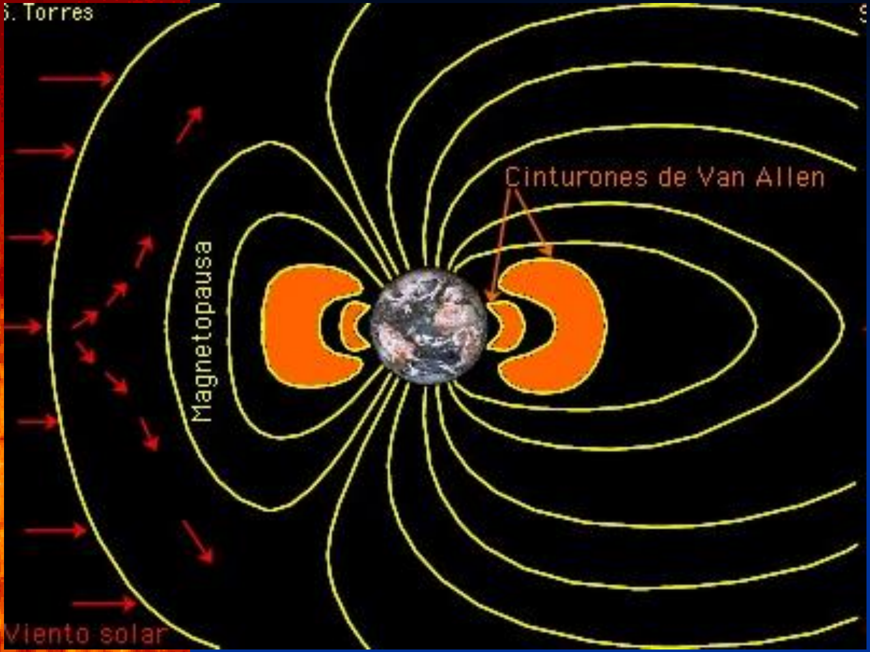
All planetary orbits lie within the Heliosphere, a region of space that contains magnetic fields and plasma ("wind") of solar origin.

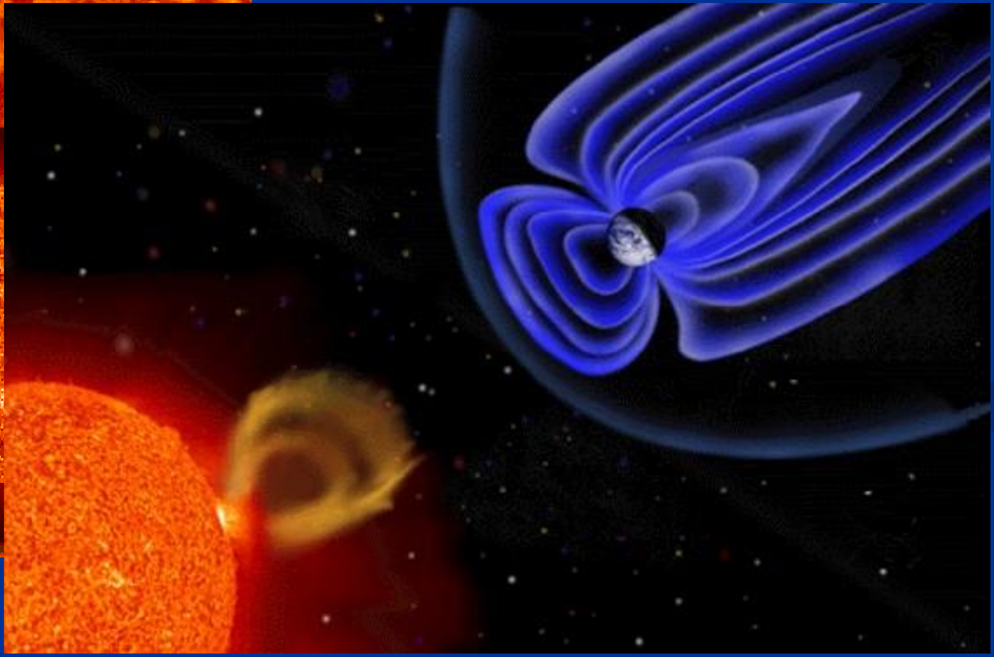


The Heliopause is the limit of the Heliosphere, where the solar wind merges with the interstellar medium.

In 2012, the Voyager 1 space probe crossed the Heliopause at a heliocentric distance of more than 100 A.U.



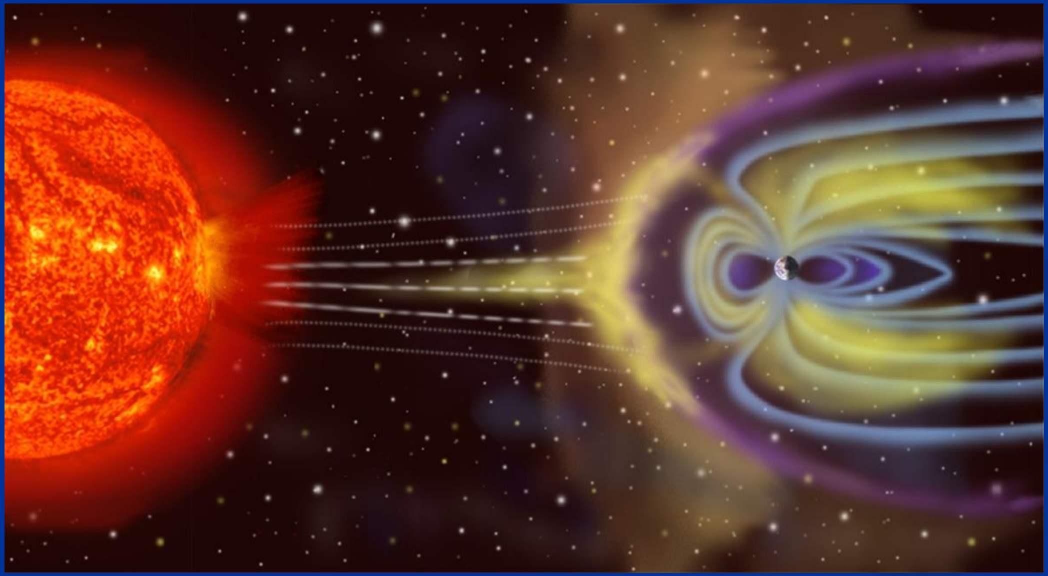




Sun-Earth environment

The Interplanetary Medium

The Sun emits electromagnetic radiation and solar wind (a continuous flow of charged particles, plasma).

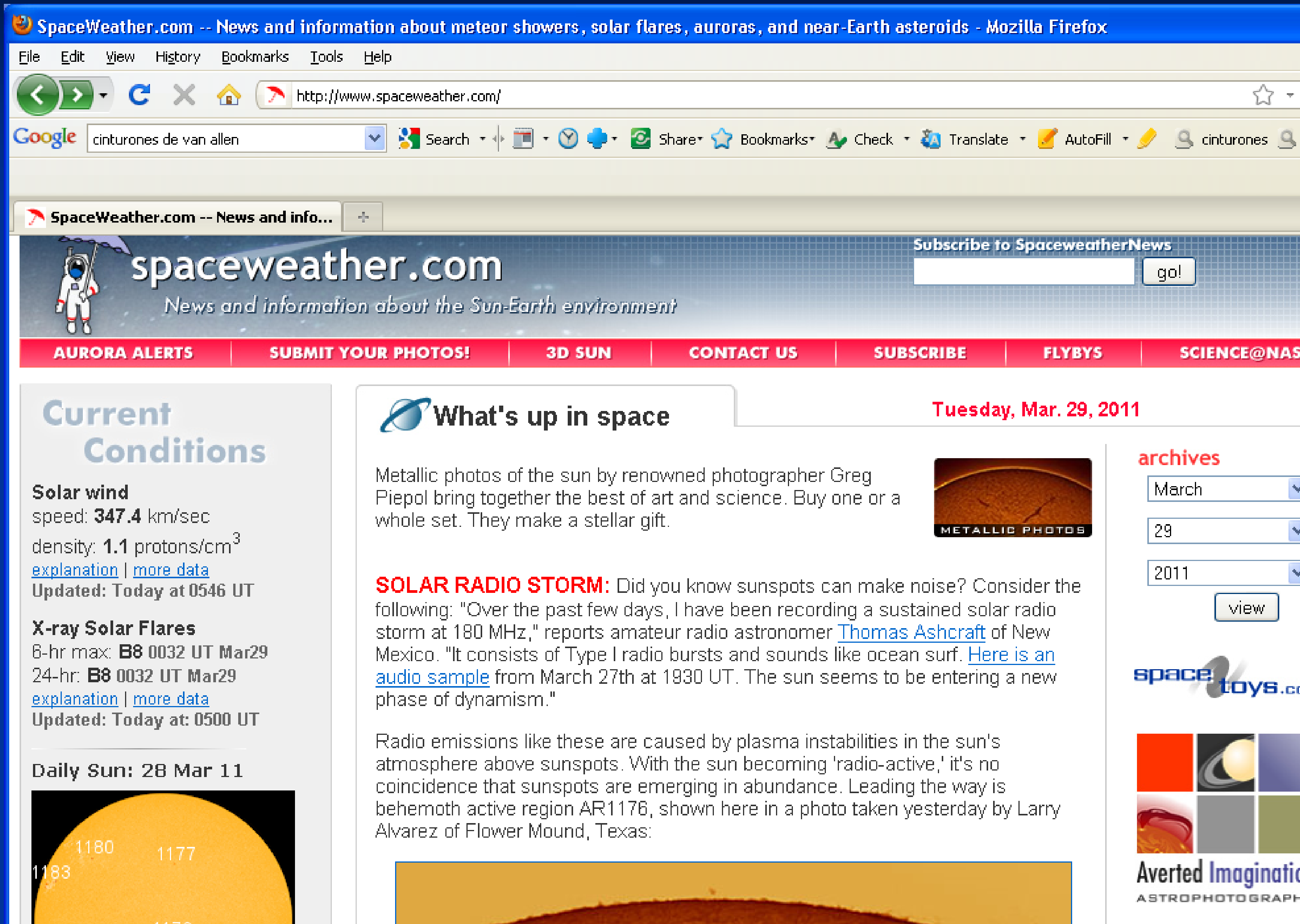


This dissipates at a speed of 1.5 million km / h, creating the heliosphere, a fine atmosphere that bathes the entire SS up to approx. 100 A.U., marking the heliopause.

The Earth's magnetic field protects the atmosphere from the solar wind and gives rise to the polar auroras (boreal and austral)

The heliosphere ensures a partial protection to the SS of the cosmic rays, protection that is stronger in the planets with magnetic field.

The “space weather” is monitoring 24 hs



The Planets

The 8 planets of our SS can be divided into:

- **4 Earth planets**, in the innermost region (Mercury, Venus, Earth and Mars). Rocky, with approximate densities between 4 and 5 g / cm3.
- **4 Giant planets**, in the outermost region, which in turn are divided into:
  - **Gaseous Giants**: Jupiter and Saturn. Richer in H and He, with a chemical composition similar to solar.
  - **Ice Giants**: Uranus and Neptune. Ice predominates with respect to gases. Its chemical composition differs a lot from solar.
- The giant planets are lighter than terrestrial ones, with densities between 0.7 g/cm^3 (Saturn) and 2 g/cm^3.

The giant planets had formed on time scales of the order of 10 million years (terrestrial planets did in about 100 million years).

They were not formed "in situ", there was a migration caused by the exchange of angular momentum between the giant planets in formation and the planetesimals that were swept to other regions of the SS or ejected from the SS

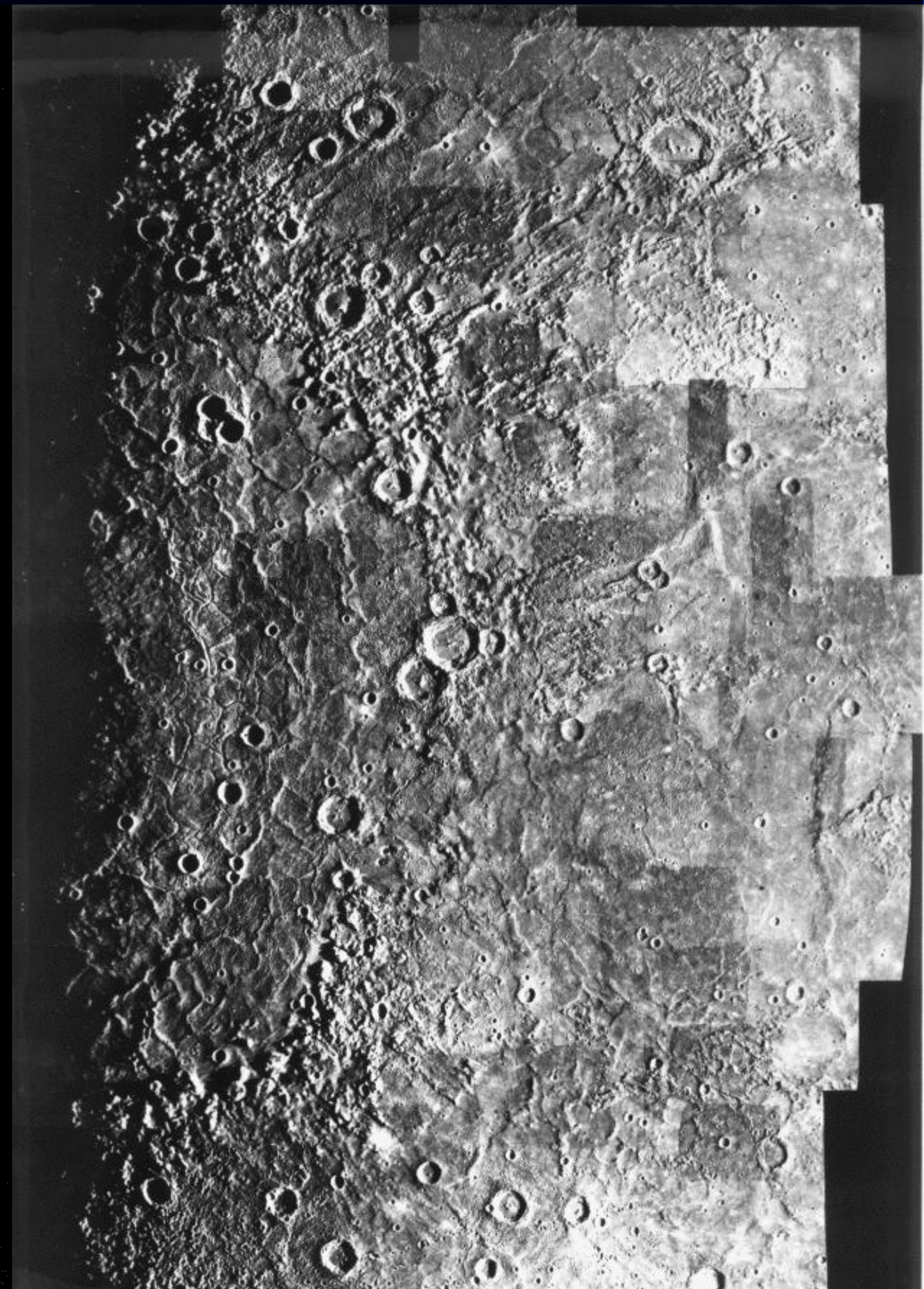
Earth

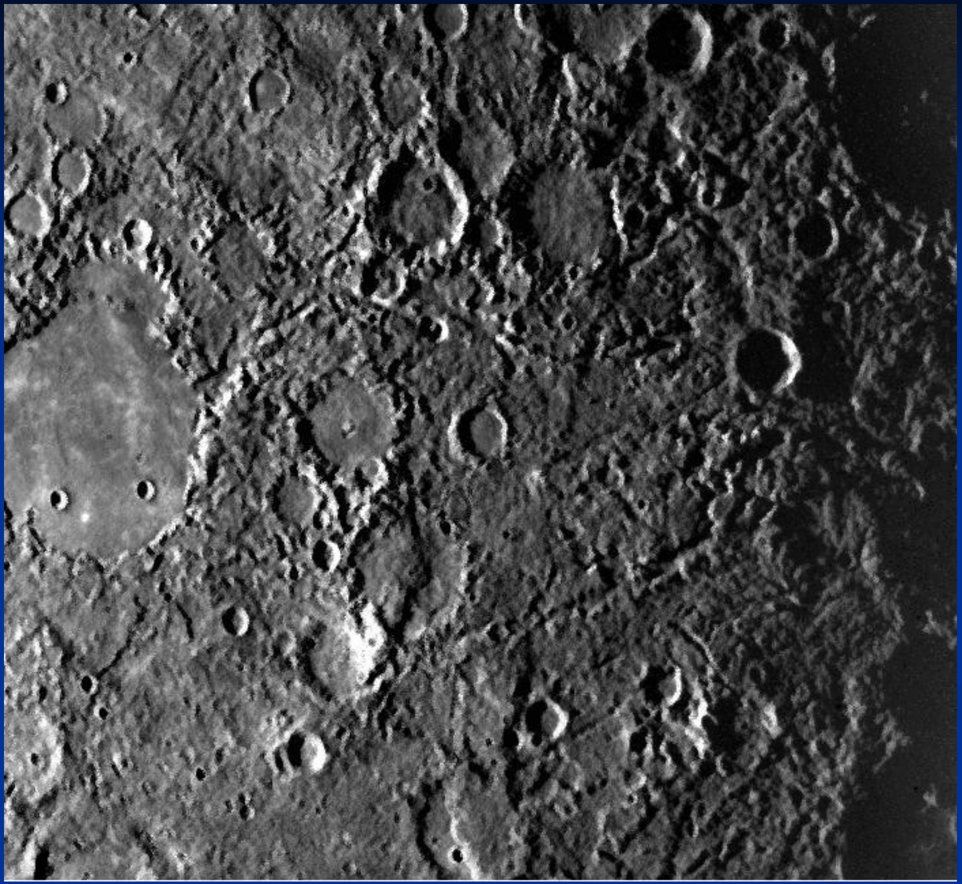
Earth-Moon system, photographed by the Galileo spacecraft, on its way to Jupiter (1998)

April 12, 1961
First circumnavigation flight to Earth by Yuri Gagarin

Mercury

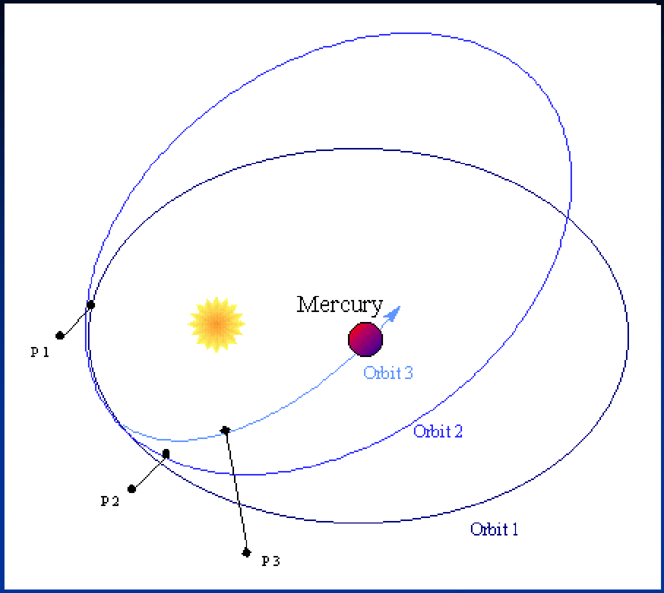
The one closest to the Sun, presents an impact surface





The most important crater is "Caloris Basin" (1,500 km in diameter): the impact that originated it produced waves that broke the surface at the antipodes (photo).

The precession of perihelion of Mercury



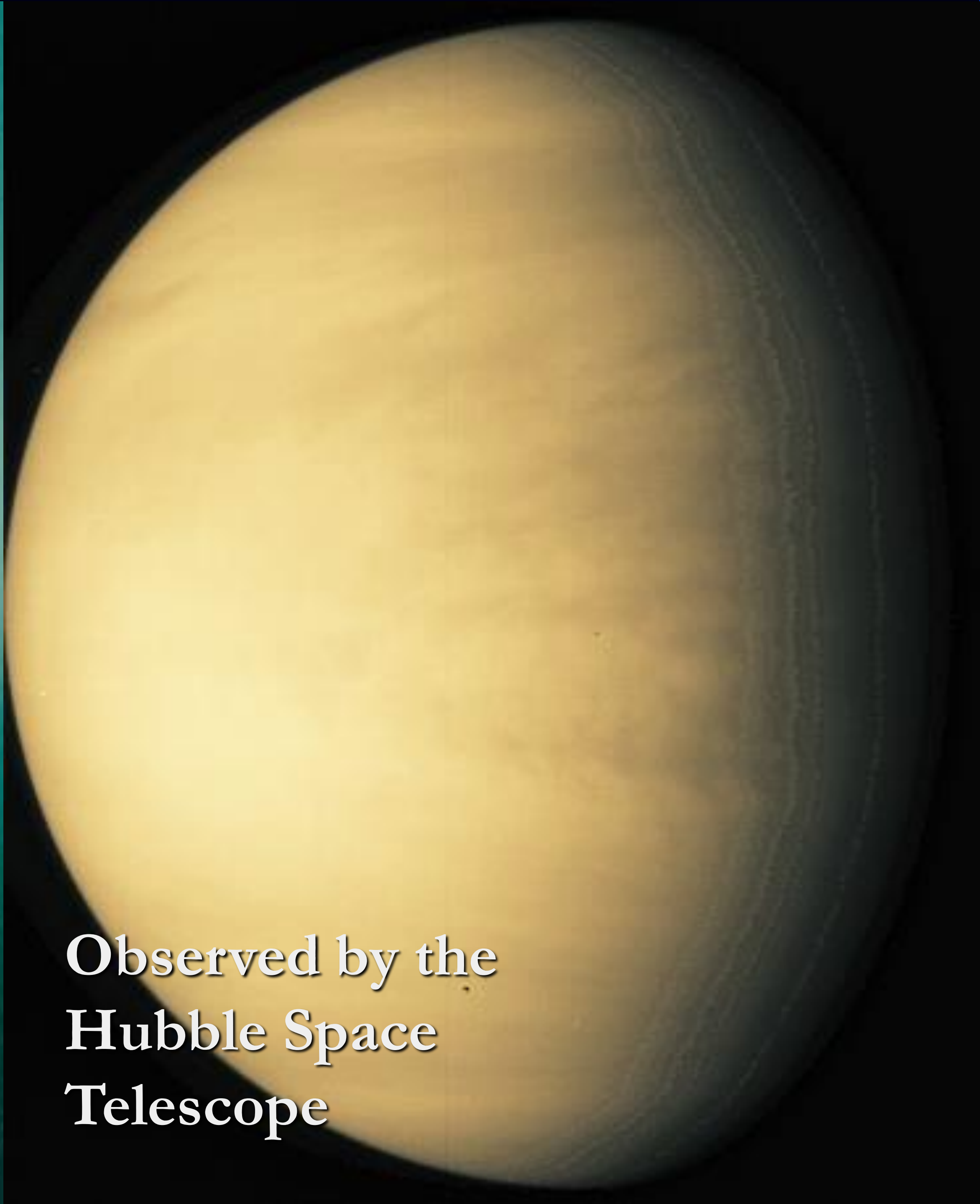
The precession of Mercury's perihelion is faster than the predictions of Newton's classical celestial mechanics.

That advance of perihelion was predicted by Einstein's General Theory of Relativity.

It is due to the curvature of the space caused by the Sun. It was a definitive proof of that Theory.

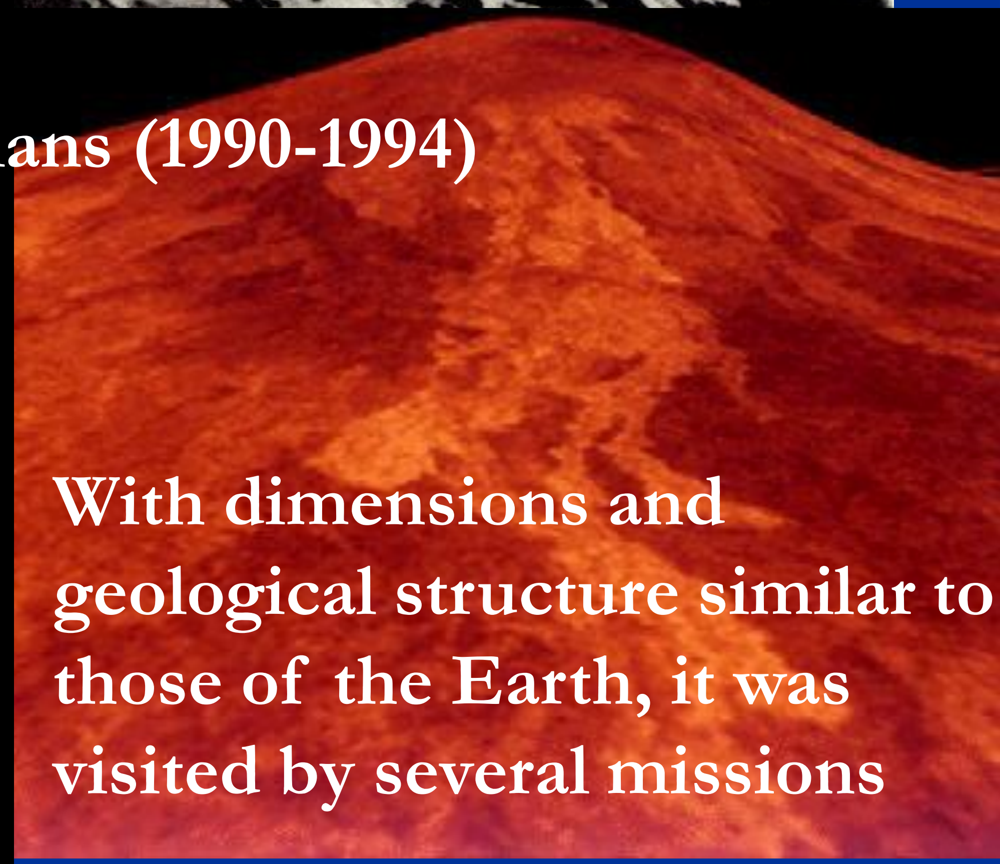
Venus

Observed on Earth with an small telescope



Observed by the Hubble Space Telescope

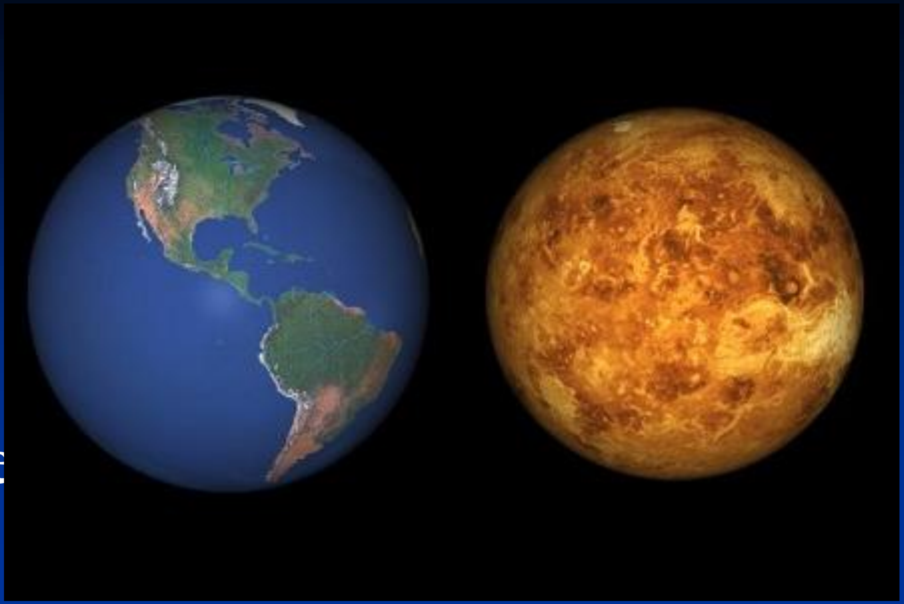
VENERA (1976)



Magellans (1990-1994)

With dimensions and geological structure similar to those of the Earth, it was visited by several missions

Venus and Uranus are the only planets with retrograde movement (they turn on themselves in the opposite direction to how they revolve around the Sun).



- Venusian year = 224 Earth days
- Venusian day = 243 Earth days.

The mixture of CO_2 and dense clouds of sulfur dioxide create the greatest greenhouse effect of the entire SS, with temperatures reaching 460º C, higher than that of Mercury.

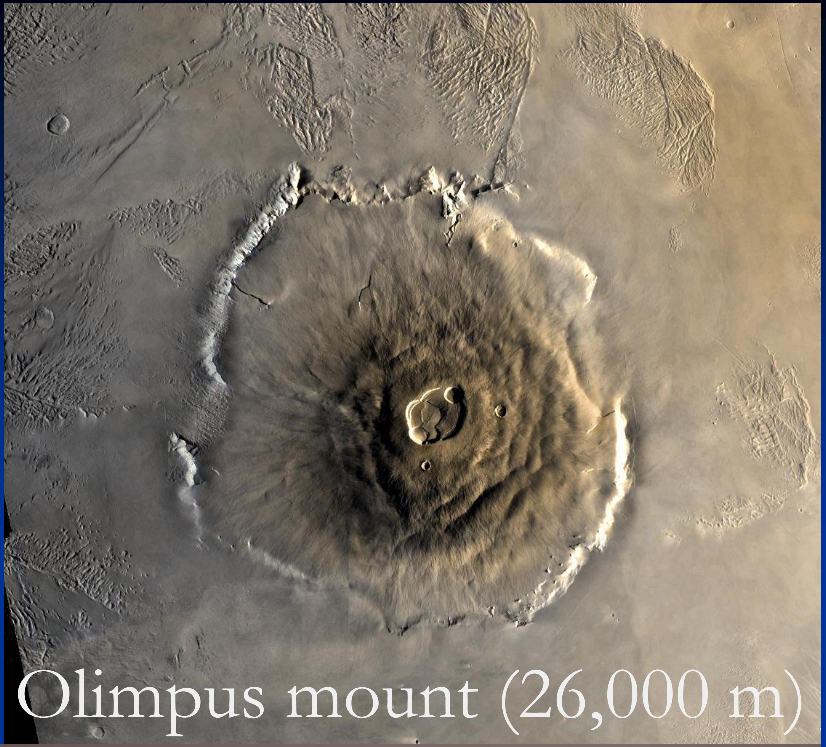
The atmospheric pressure is 100 times the Earth's pressure, there are clouds and perhaps rain of sulfuric acid.

Venus Transit

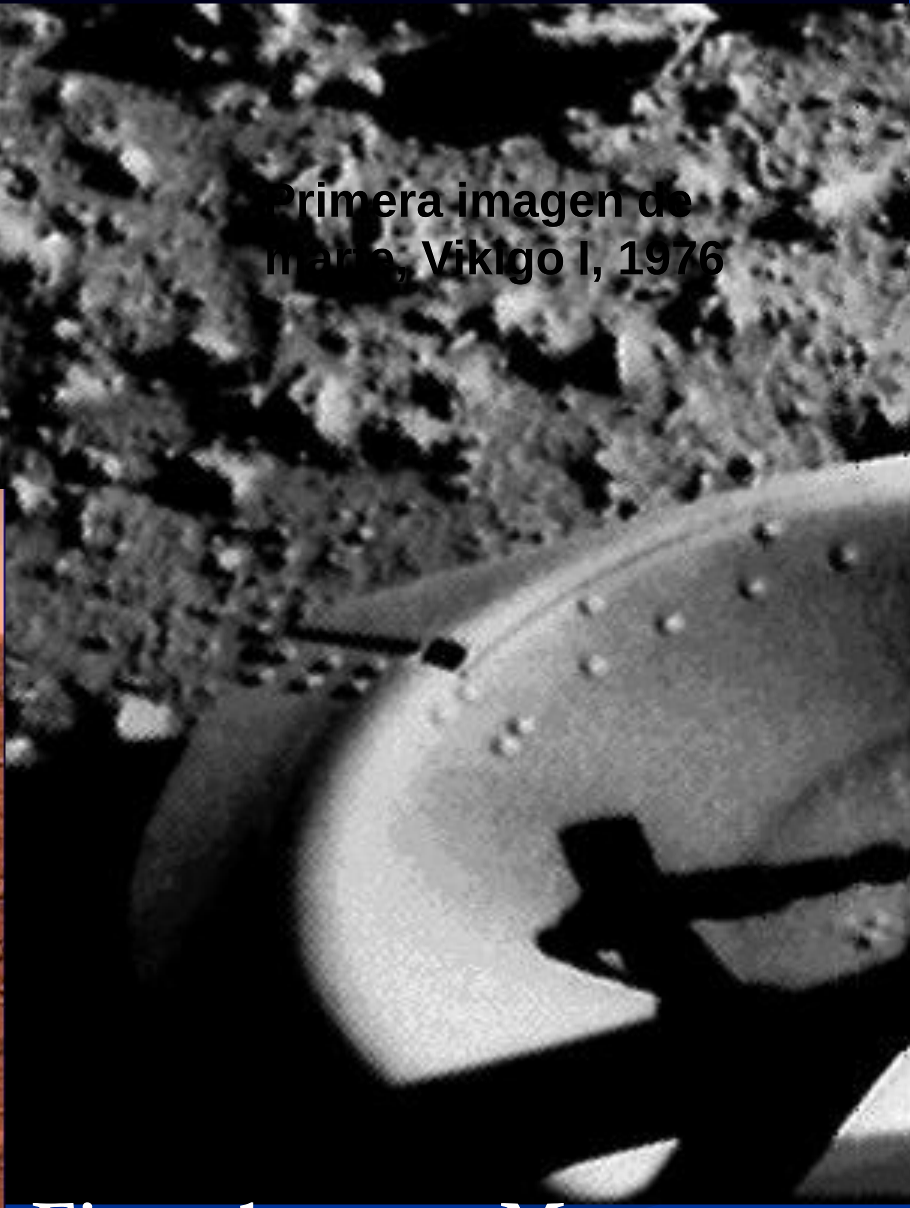
When Venus passes between the Earth and the Sun, its shadow crosses the solar disk.

Because the inclination of the orbit of Venus occurs twice in 8 years, and the next takes more than a century (105.5 or 121.5 years).

In June 2004 and June 2012 the last ones took place. There will not be another until December 11, 2117

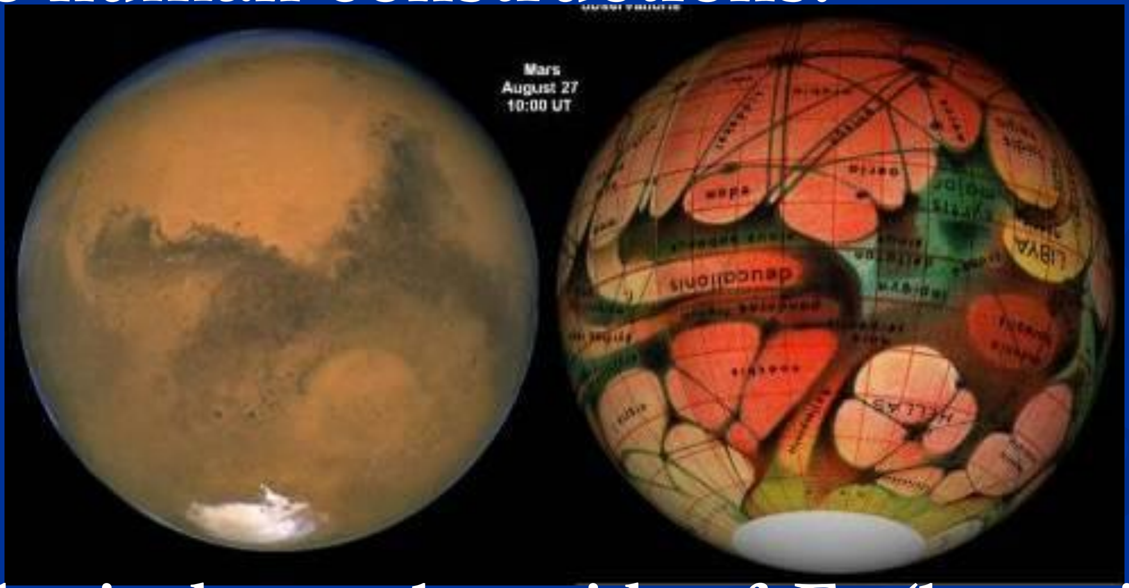


It has a fine atmosphere, composed mainly of CO_2. The atmospheric pressure is one hundredth of the Earth's.



First photo on Mars surface Viking I, 1976

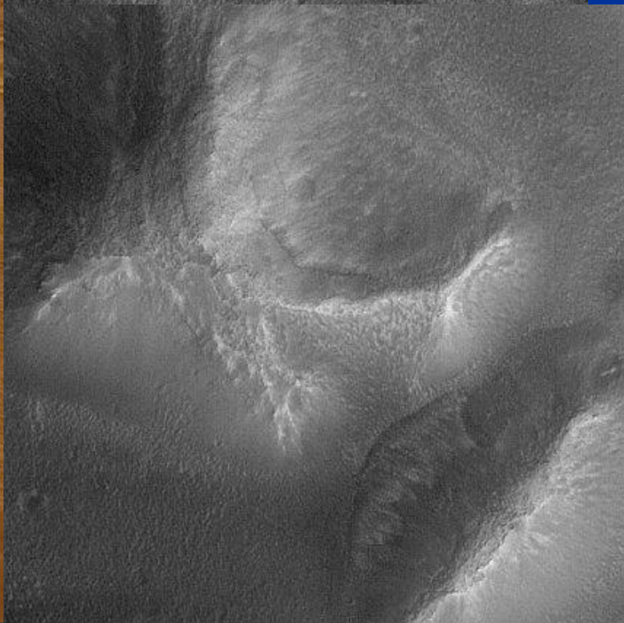
Source of inspiration for many science fiction authors ("extraterrestrial" = "Martian"), due to the famous "canali" observed by Giovanni Schiaparelli at the end of the 19th century: the term was translated into English as "canals" as if they were human constructions.

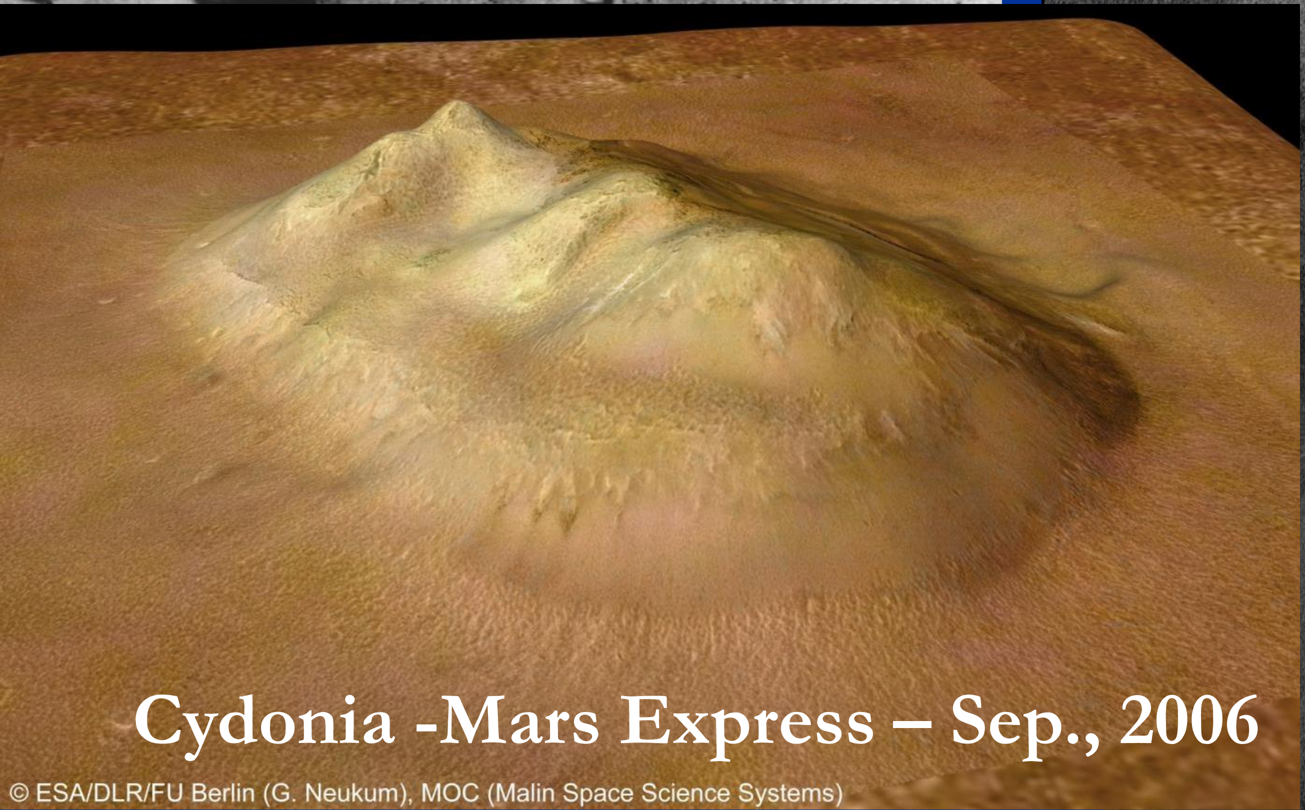


Its red color is due to the oxide of Fe (hematite), which is found in surface minerals


Cydonia – Viking I, 1976


Cydonia
Mars Global Surveyor 1998

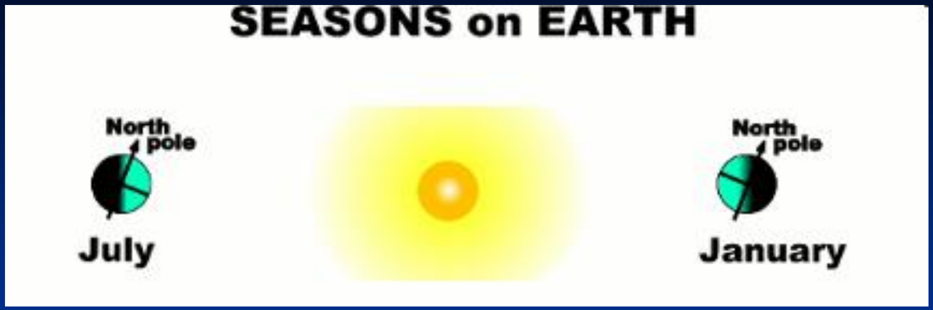


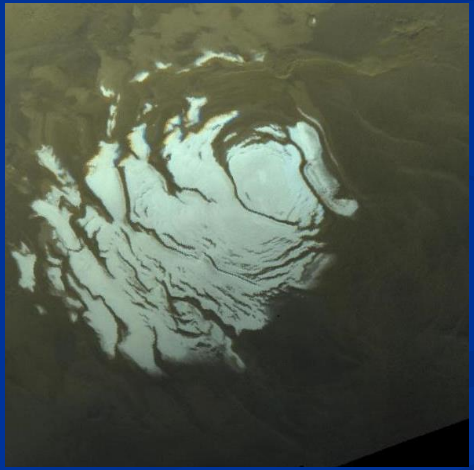

Cydonia -Mars Express – Sep., 2006
© ESA/DLR/FU Berlin (G. Neukum), MOC (Malin Space Science Systems)

There are traces that indicate that there was water on Mars.

The water may now be frozen in the subsoil.

As on Earth, there are stations on Mars because the axis of rotation is inclined with respect to the orbital plane, and because the planets move around the Sun keeping constant
the inclination of the axis.



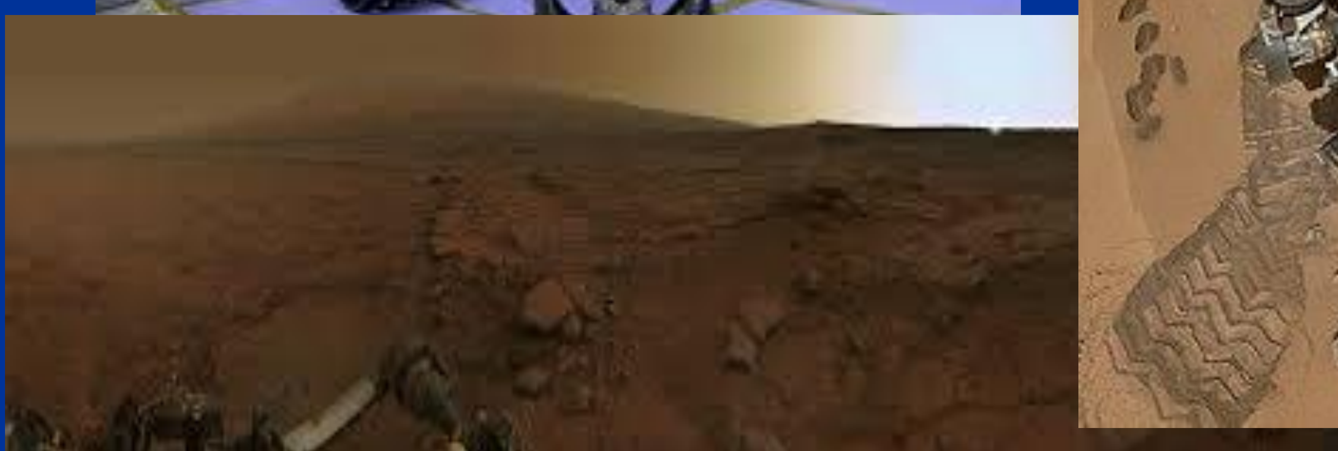


Martian Southern Pole

It has two ice caps, ice and CO_2 whose extension varies with the seasons.

Curiosity on Mars (2004-present): a successful history of science and technology: a microbiology laboratory

Selfportrait
Oct 21st,2012



Insight: arrives on Mars on Nov 28, 2018

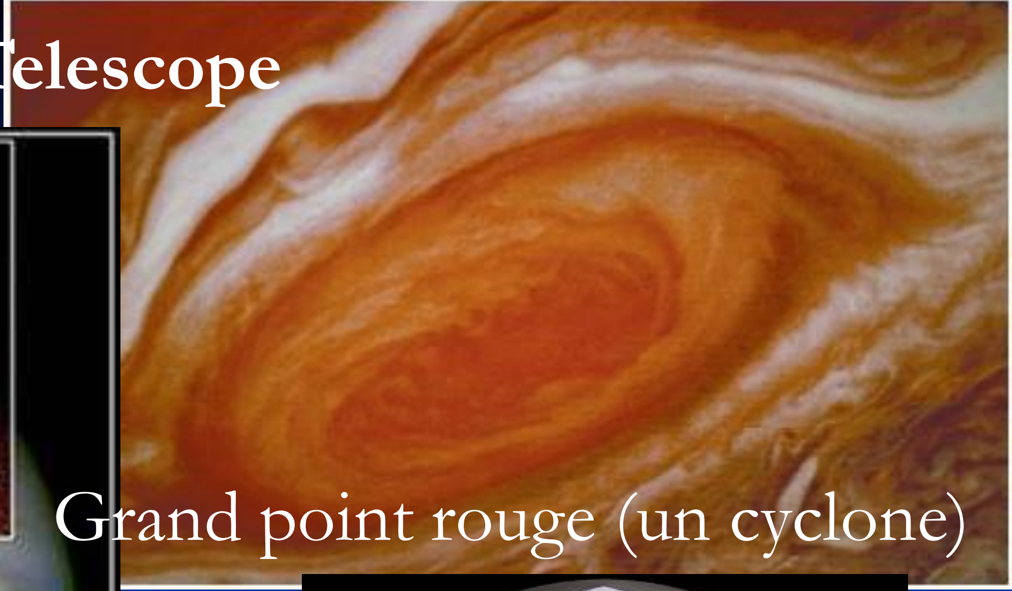
InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transpor,)

OBJECTIVE: to place a geophysical robot, equipped with high-tech instruments to study the interior, subsoil, heat transmission and movements of the Martian soil and analyze the early geological evolution of the planet.

Jupiter

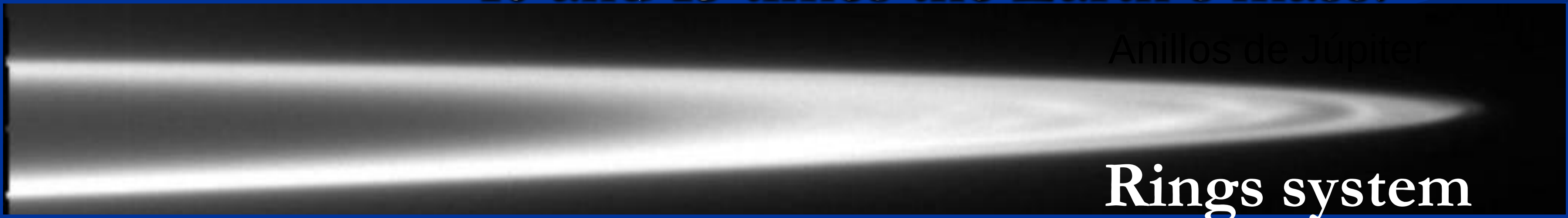
The most massive planet of the SS, has more than 60 moons. In 1610 Galileo observed for the first time 4 of them that he called "Mediceas". That same year Simon Marius baptized them as Io, Europa, Ganymede and Callisto.

Auroras, Photo by Hubble Telescope



Grand point rouge (un cyclone)

Probably has a small solid core, between 10 and 15 times the Earth's mass.



Rings system

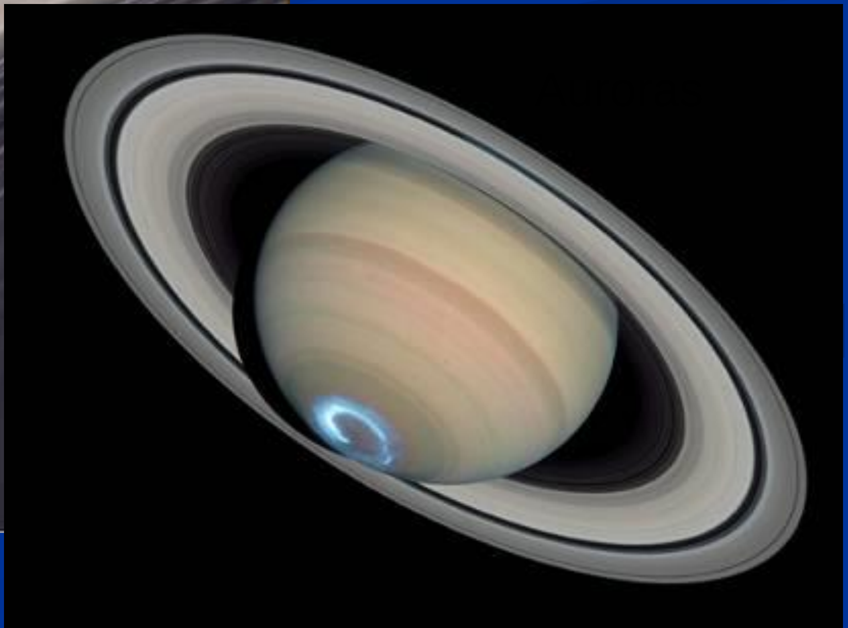
Saturn

The less dense planet of the SS.

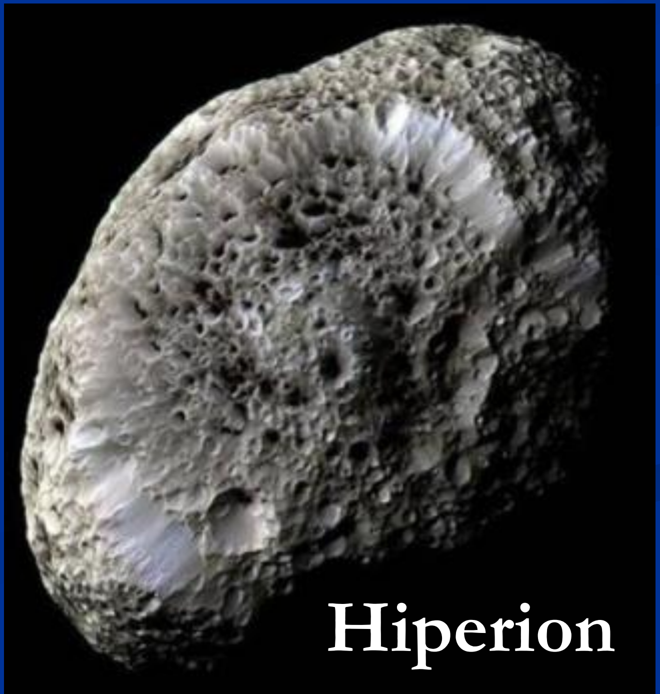
It has more than 60 moons and some of them are between the rings, dynamically organizing the system, they are called "shepherd satellites"

System of Rings, formed by dust and very small pieces of ice.

Aurora in Saturn, photo by the Hubble Space Telescope

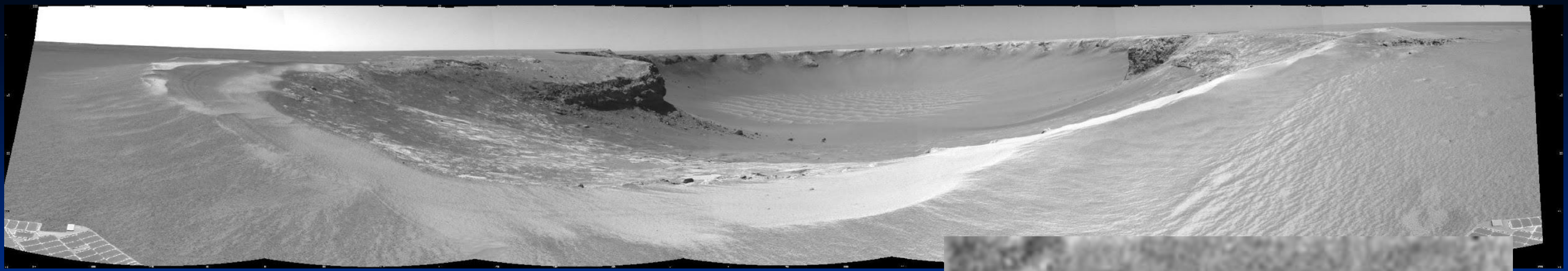


- Saturne has more than 60 satellites but 7 are large enough to take a spherical shape.
- Titan is the largest (larger than Mercury and Pluto) and the only one in the SS with a dense atmosphere.



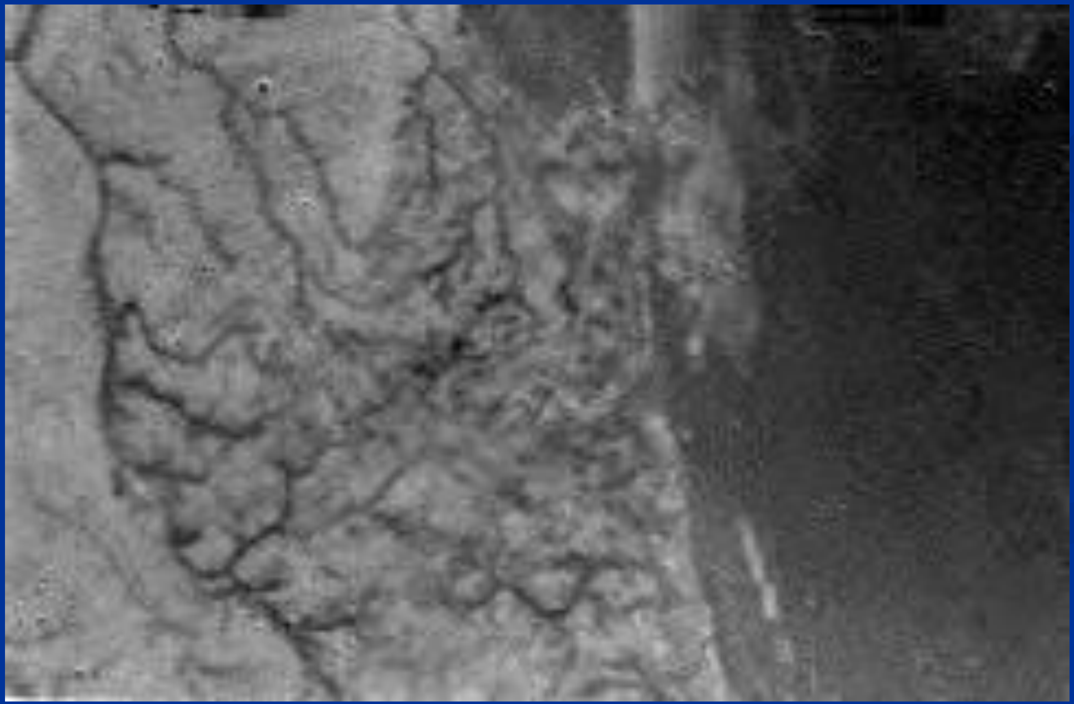
Cassini-Huygens Mission

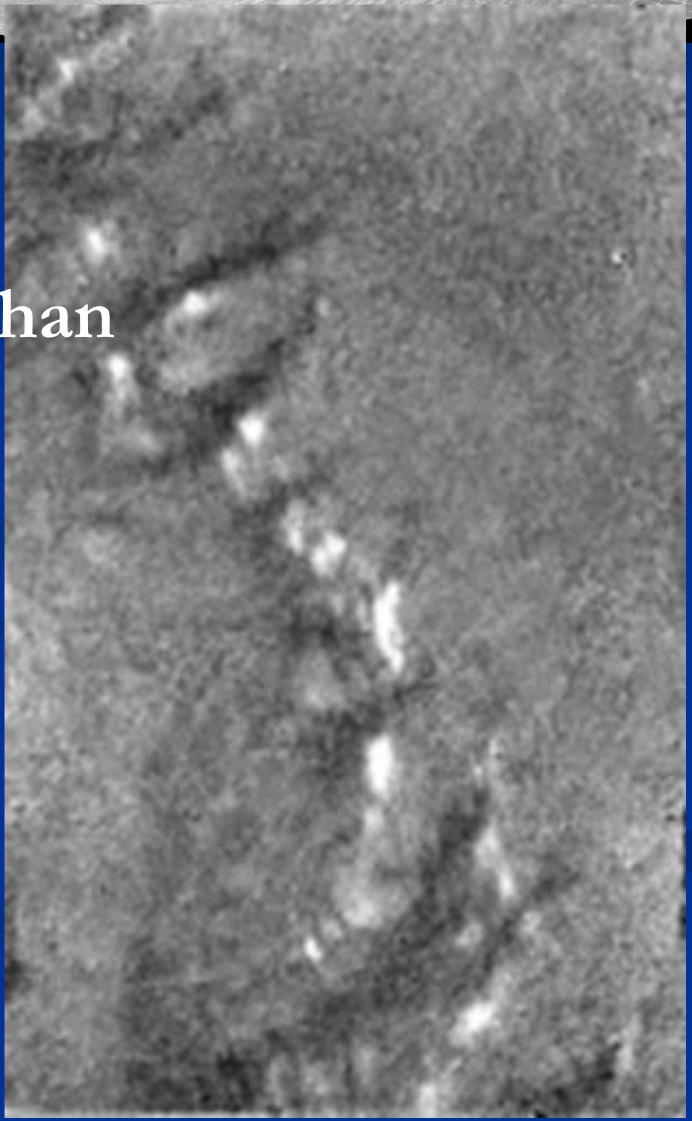
Huygens probe
descending on Titan
(artistic vision)



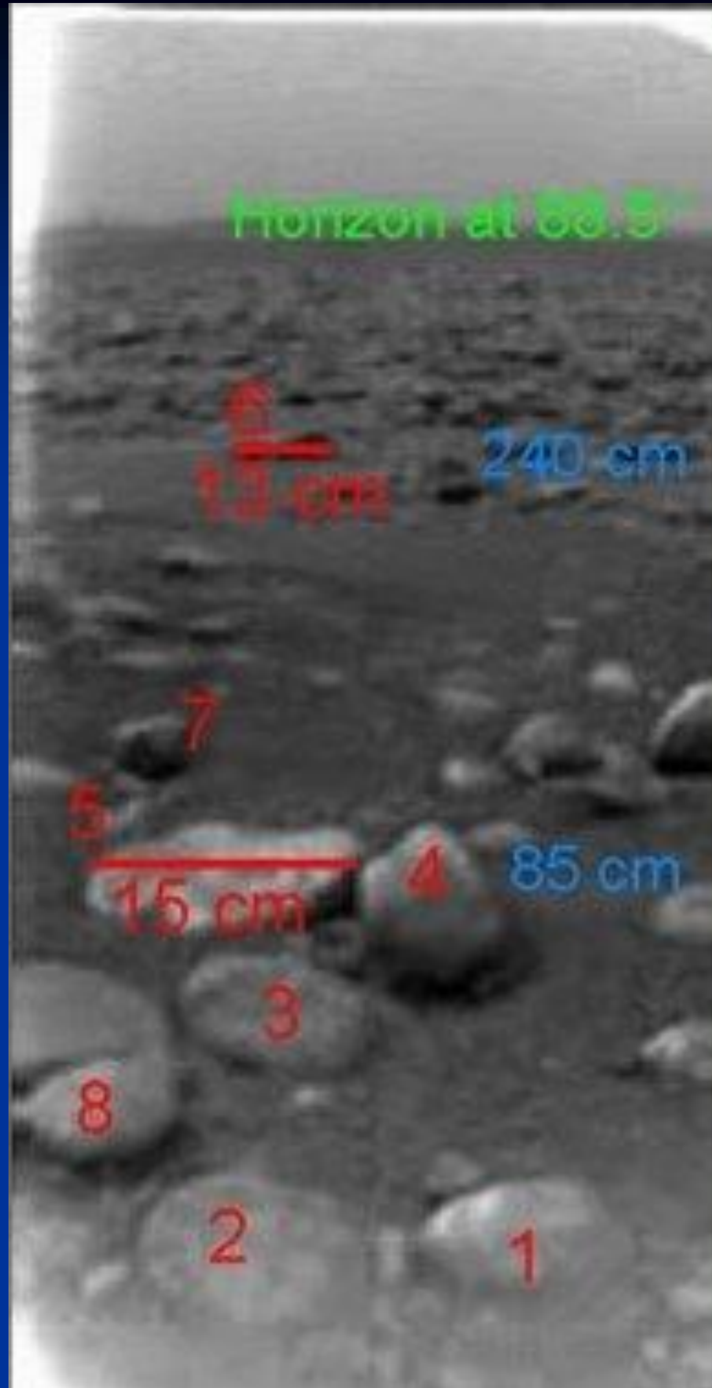
Sonda Huygens on Titan
(first panoramic photo, 2004)

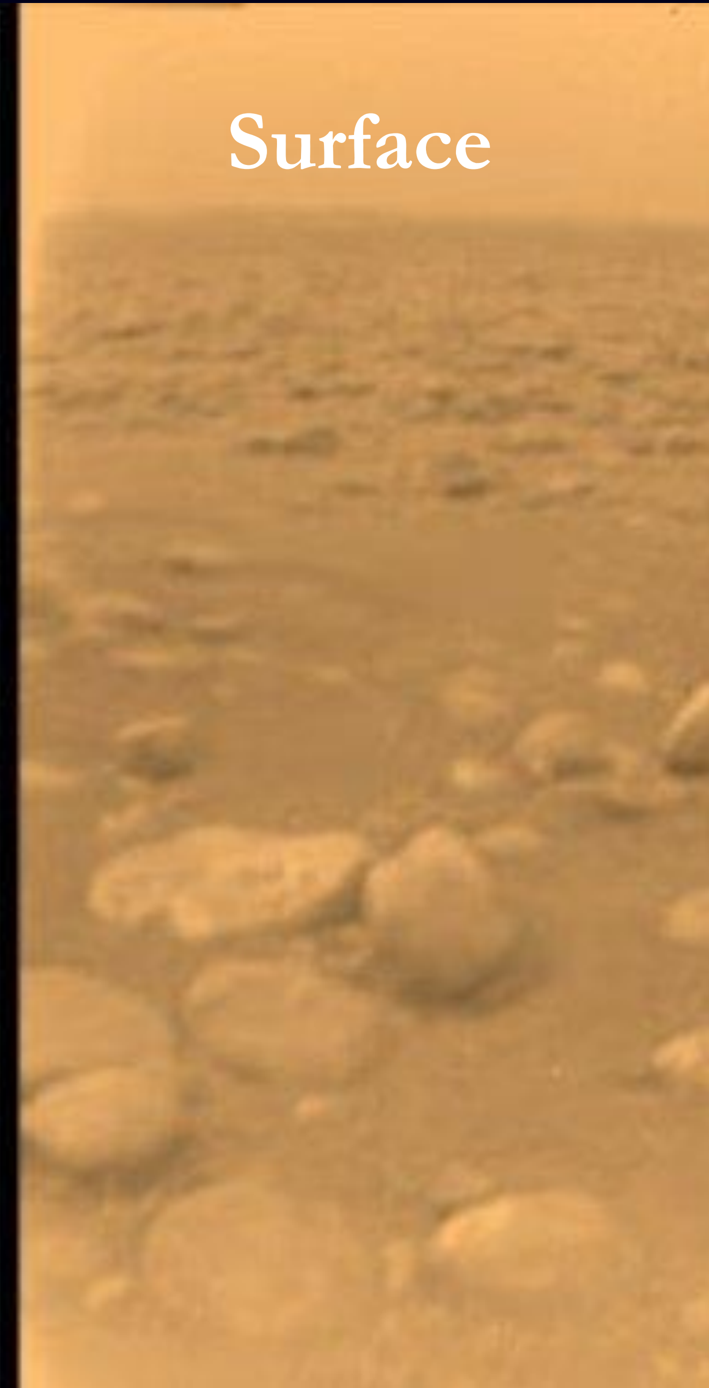
Titan: seas, rivers and lakes of methan





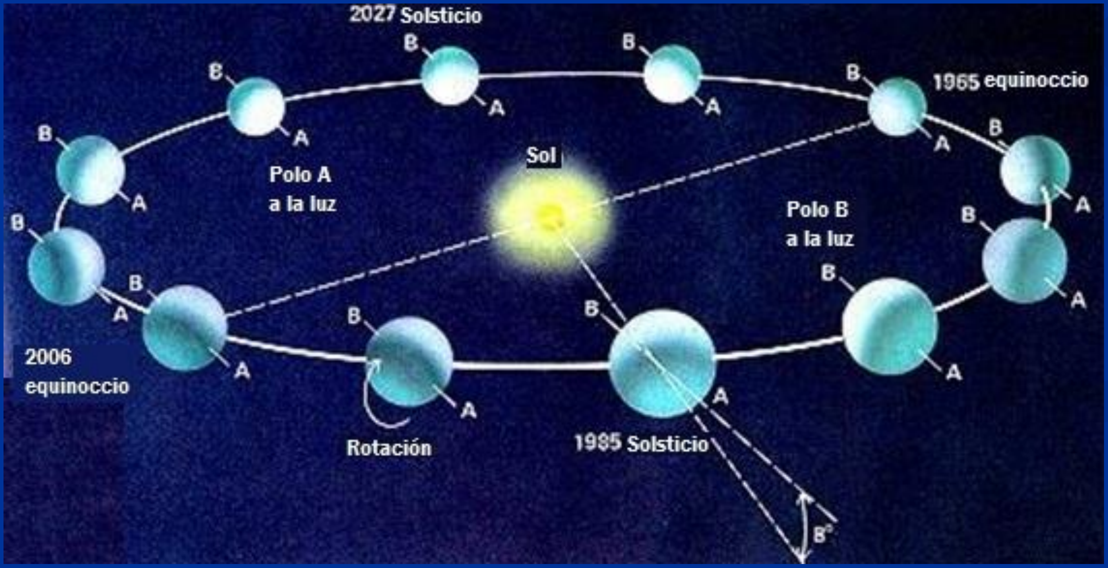
Last photo on Titan surface, Huygens probe

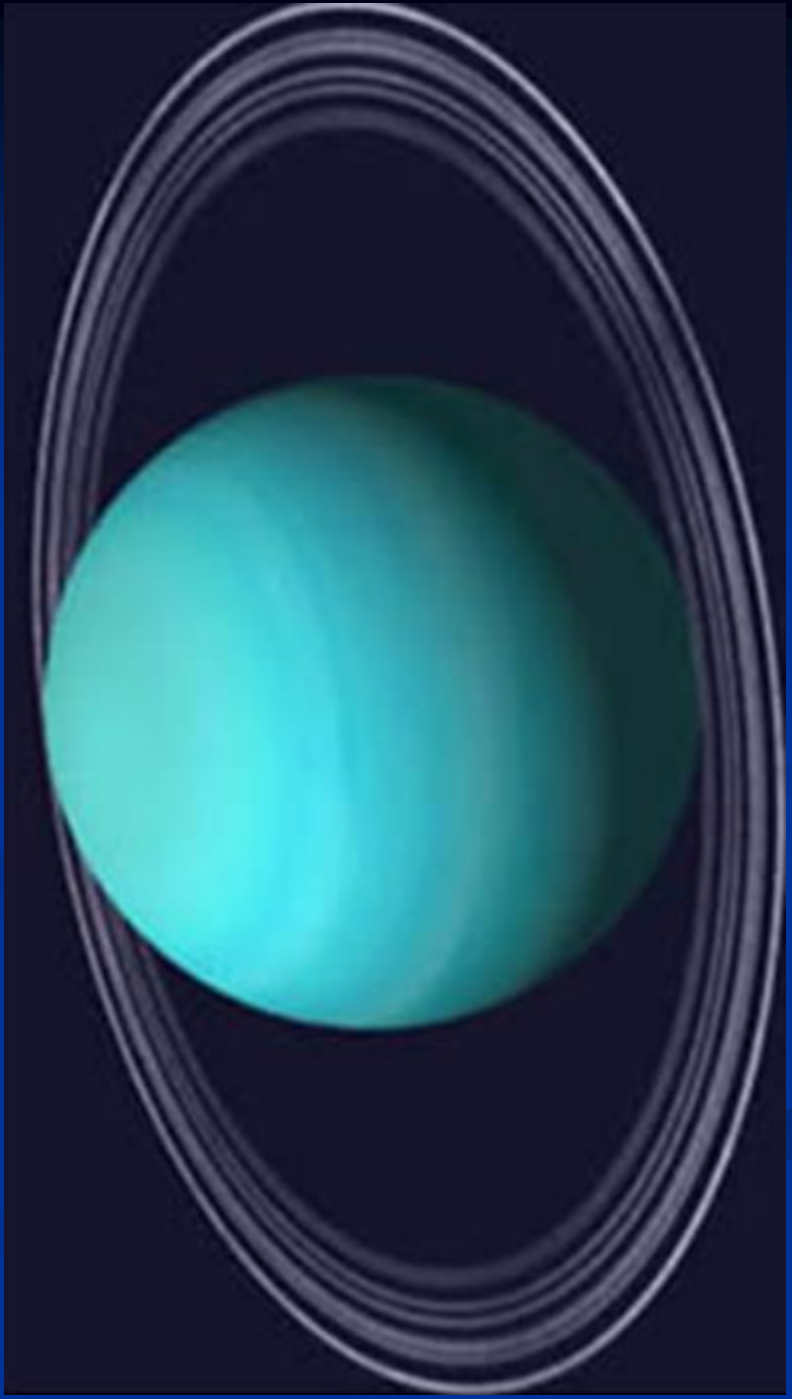




Uranus

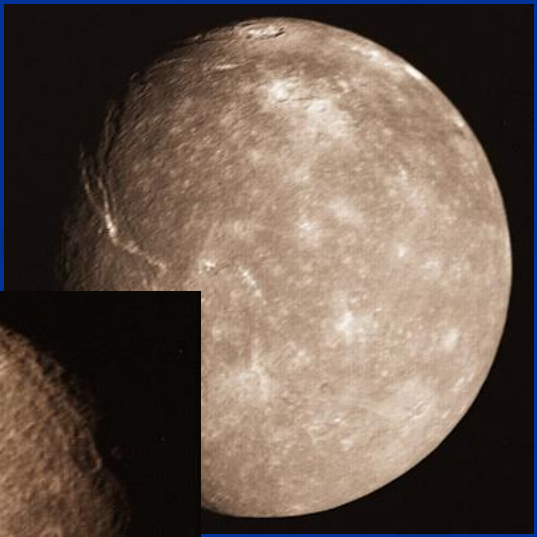
Its axis of rotation is practically in its plane of translation



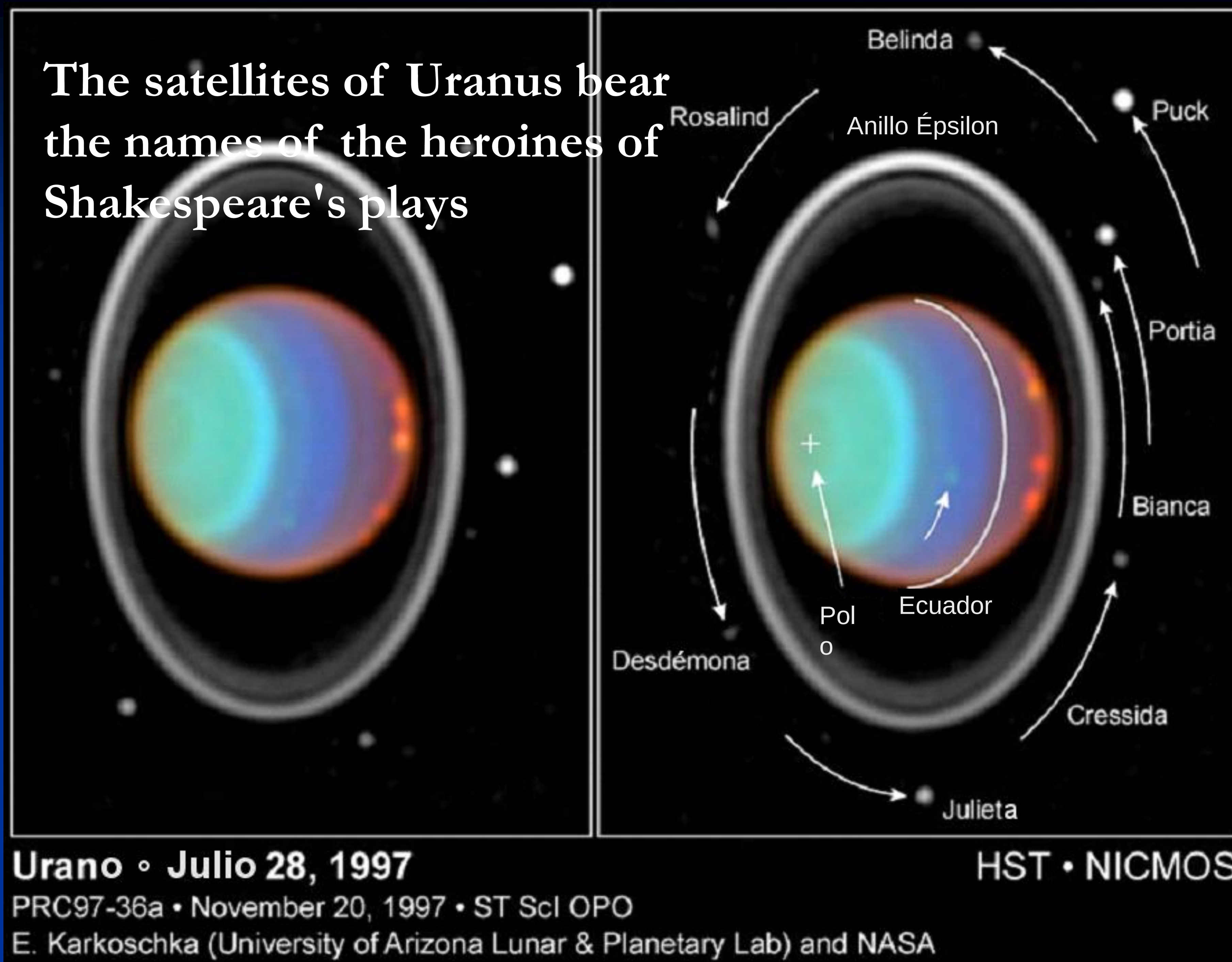


Rings system of Uranus

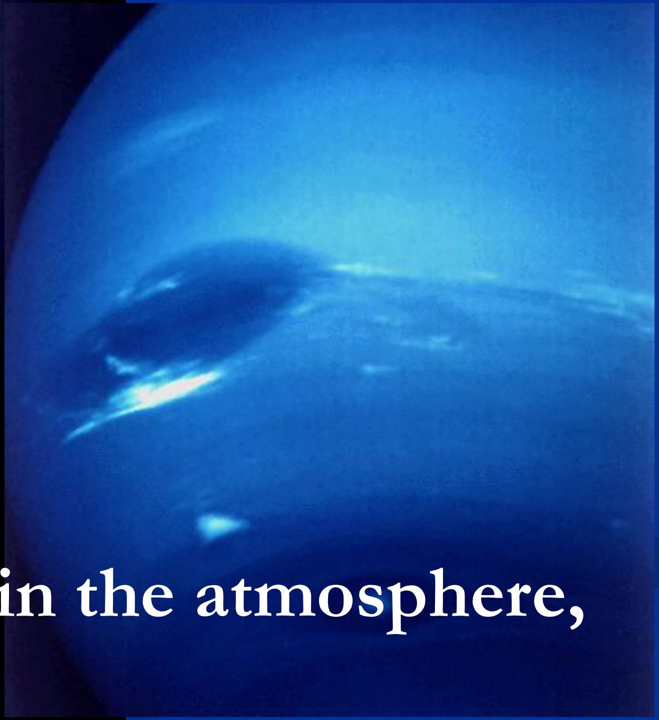
Uranus has at least 27 natural satellites.
The first two were discovered by William Herschel in 1787: Titania and Oberon.



The satellites of Uranus bear the names of the heroines of Shakespeare's plays

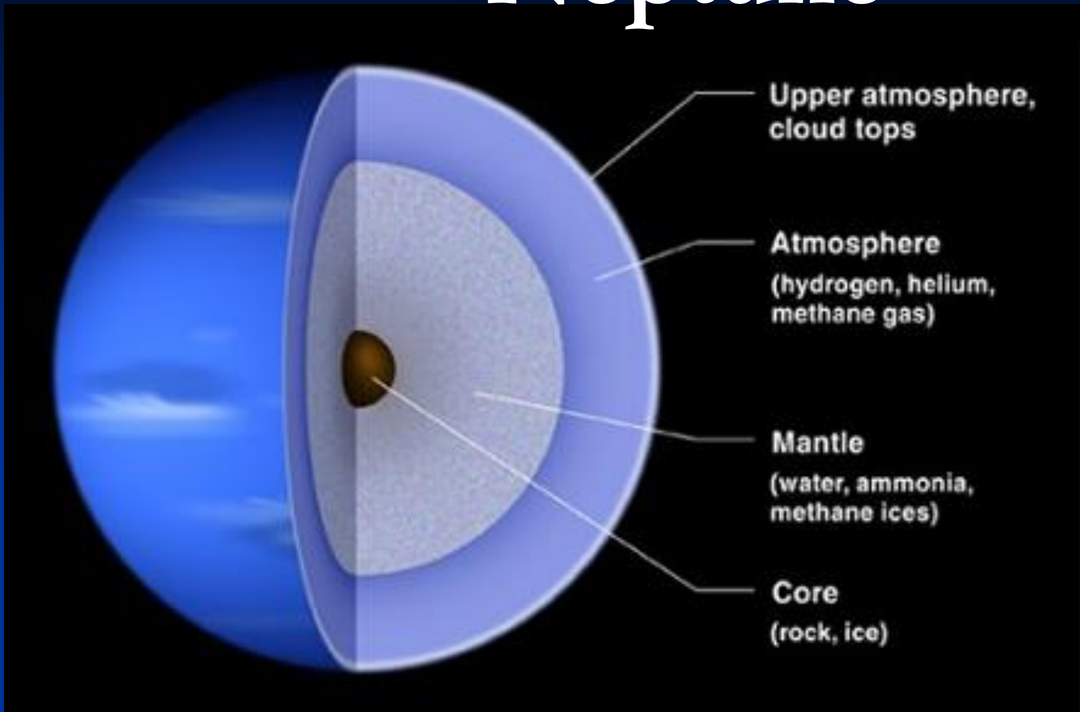


Neptune



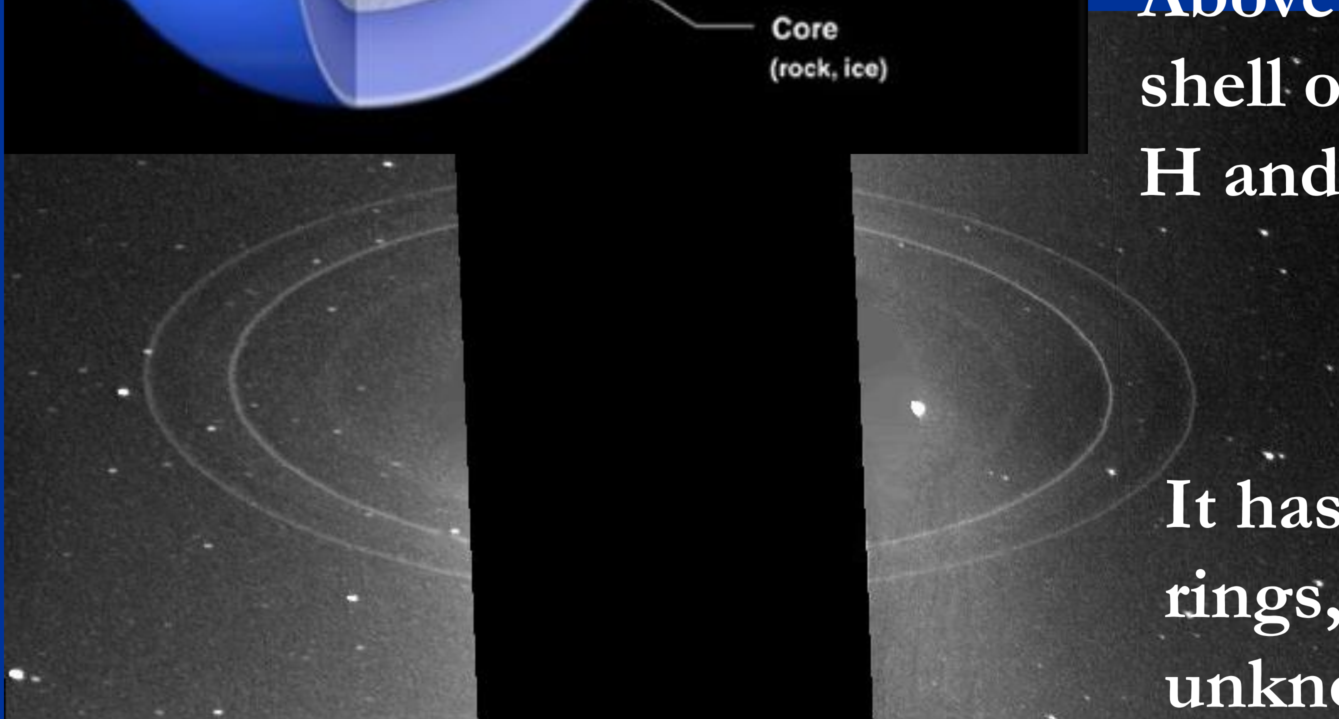
Its color to the presence of methane in the atmosphere, which absorbs red and infrared.

Neptune

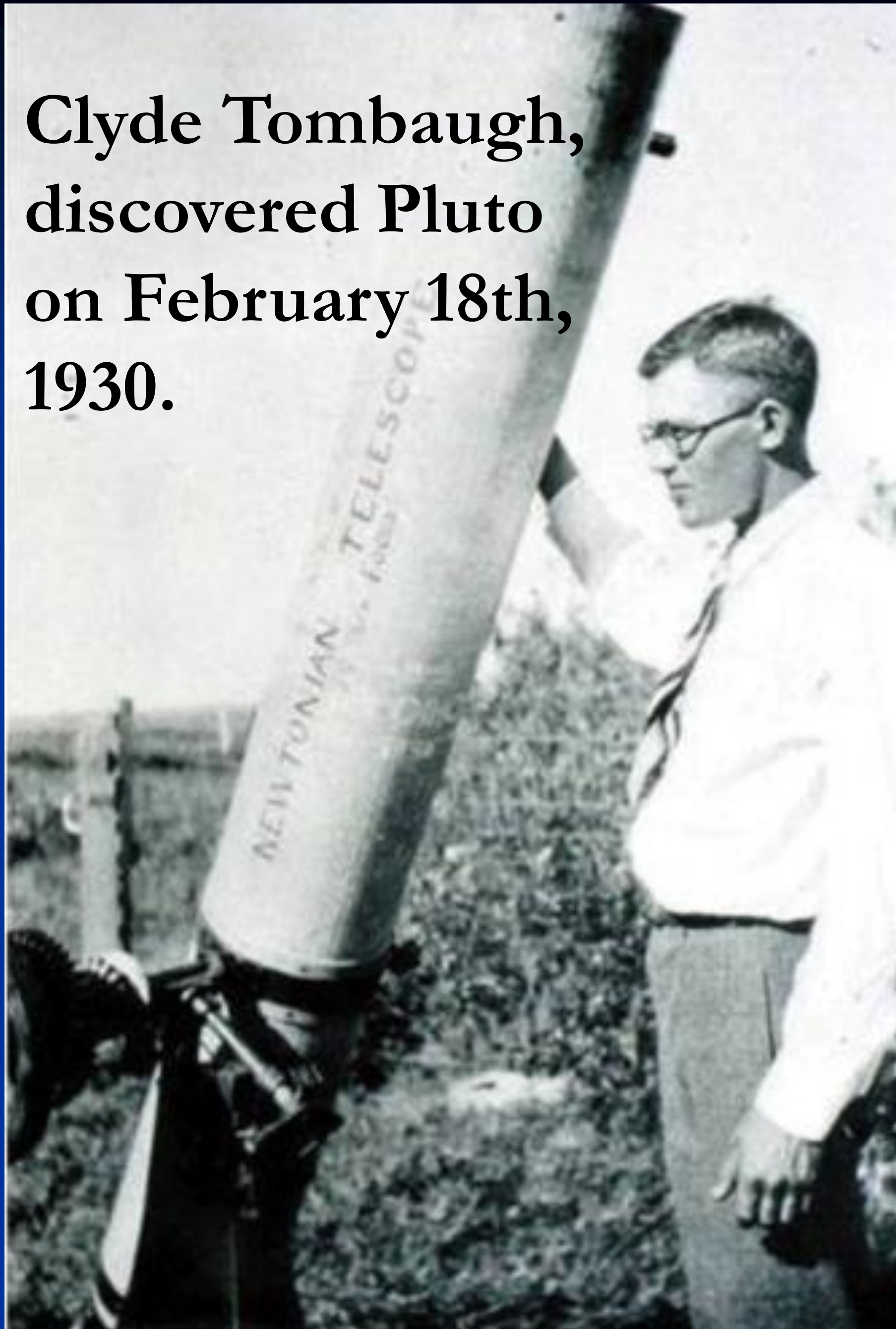


It is believed that it has a solid core of silicates and iron, almost as large as Earth.

Above the core is a shell of ice, methane, H and a little He



It has several dark rings, with origin unknown.



Clyde Tombaugh, discovered Pluto on February 18th, 1930.

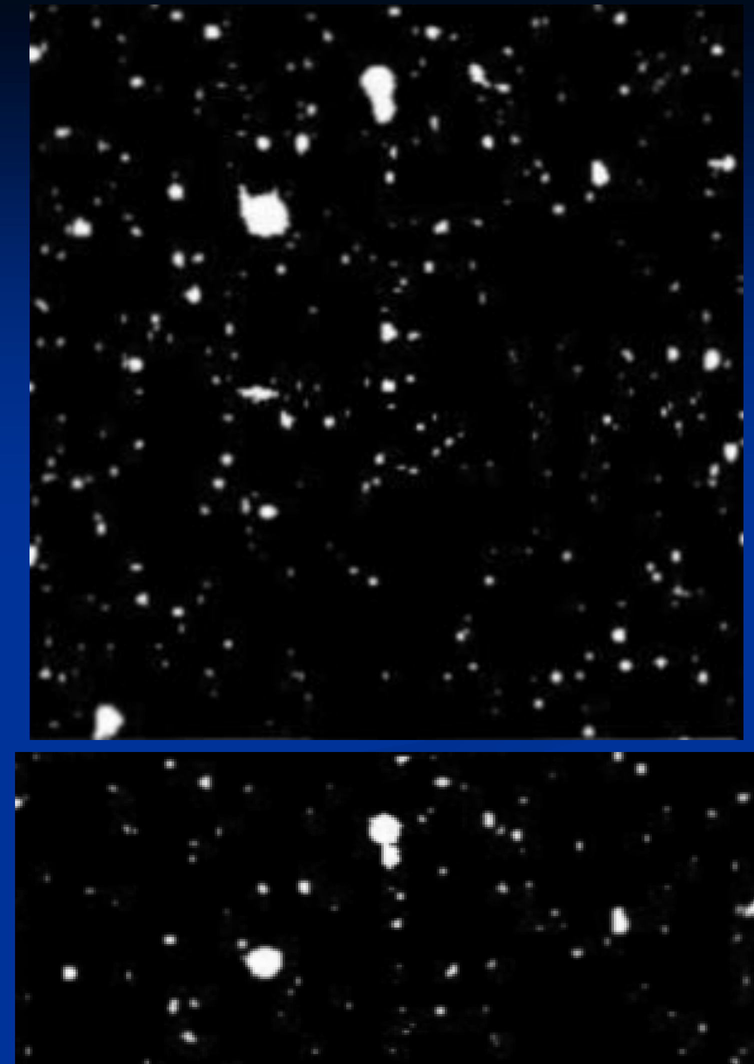
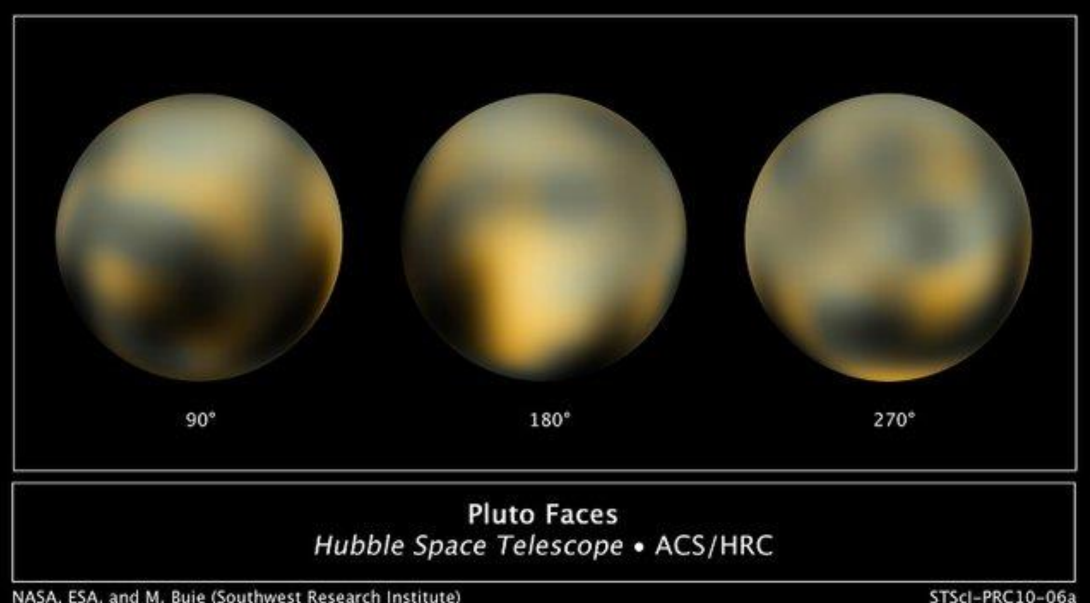


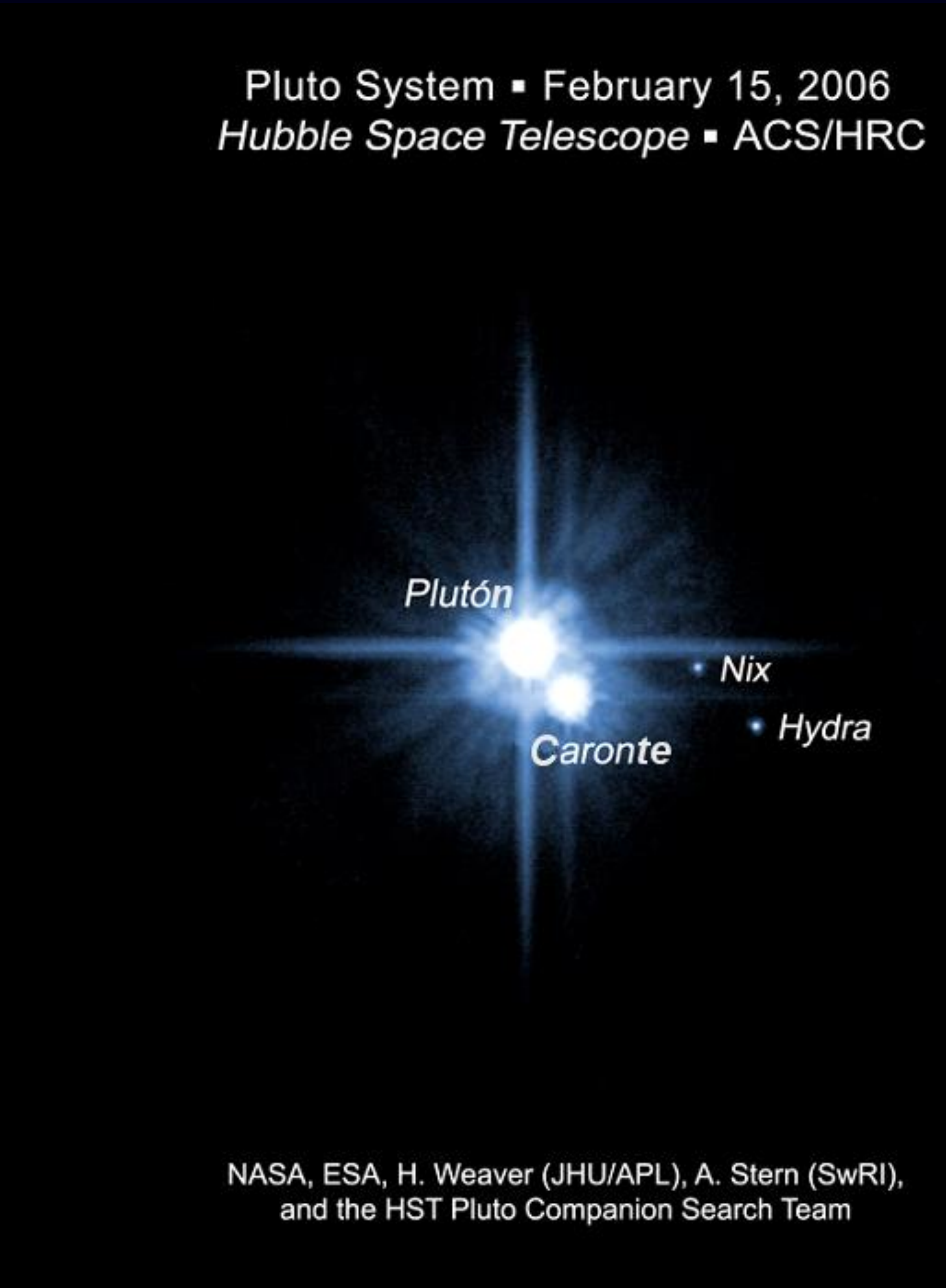
Image of the discovery. (1930)

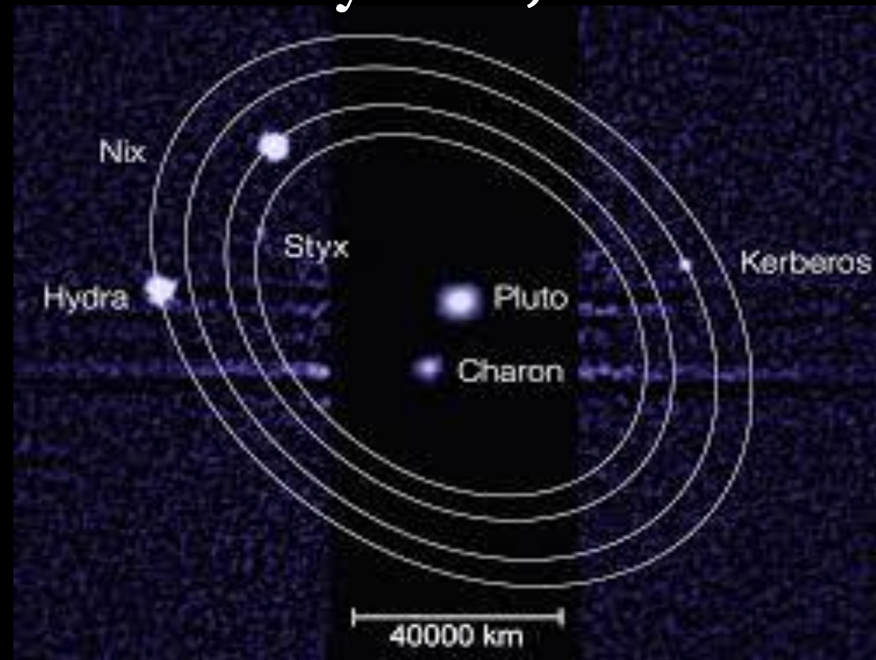
Pluto is too small to disturb Neptune's orbit long enough to betray its presence, however much Lowell has calculated to locate it. Clyde Tombaugh found Pluto (magnitude ~ 13.5) photographing in a systematic way the plane of the SS.

Pluto and Charon
Hubble Telescope
1999



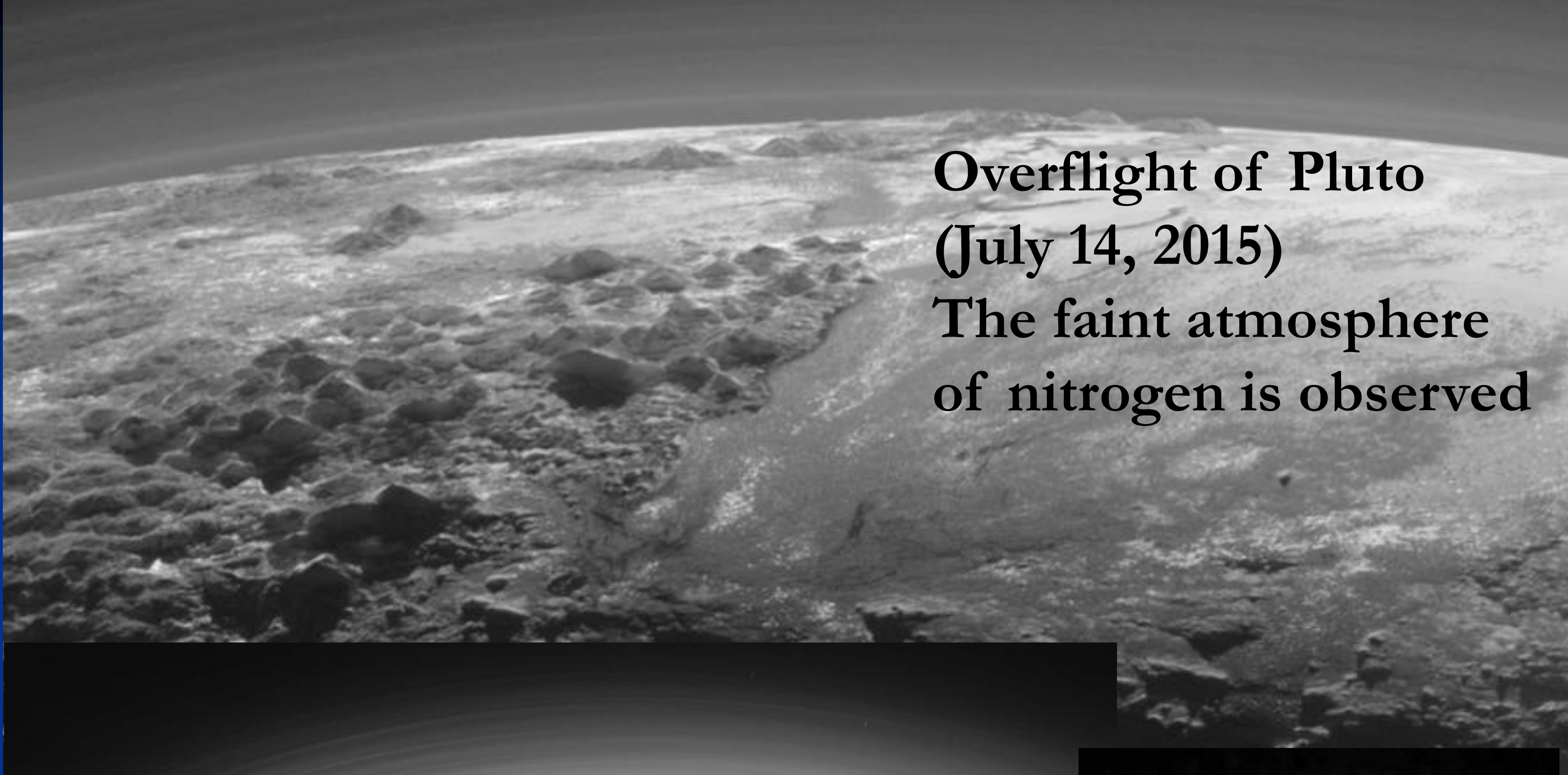
Pluto System, 2011-2012

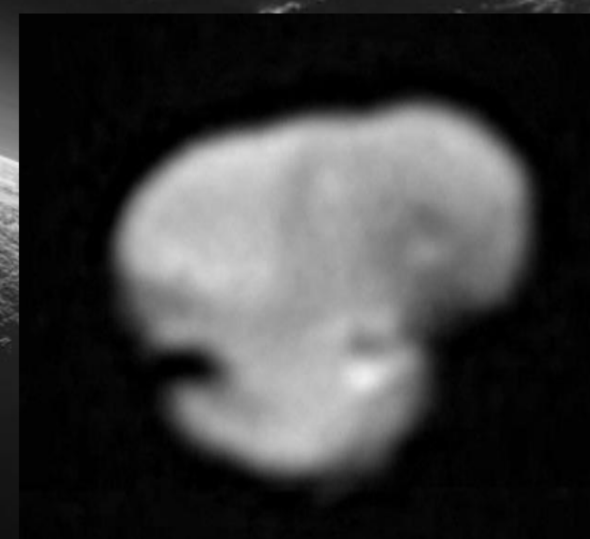




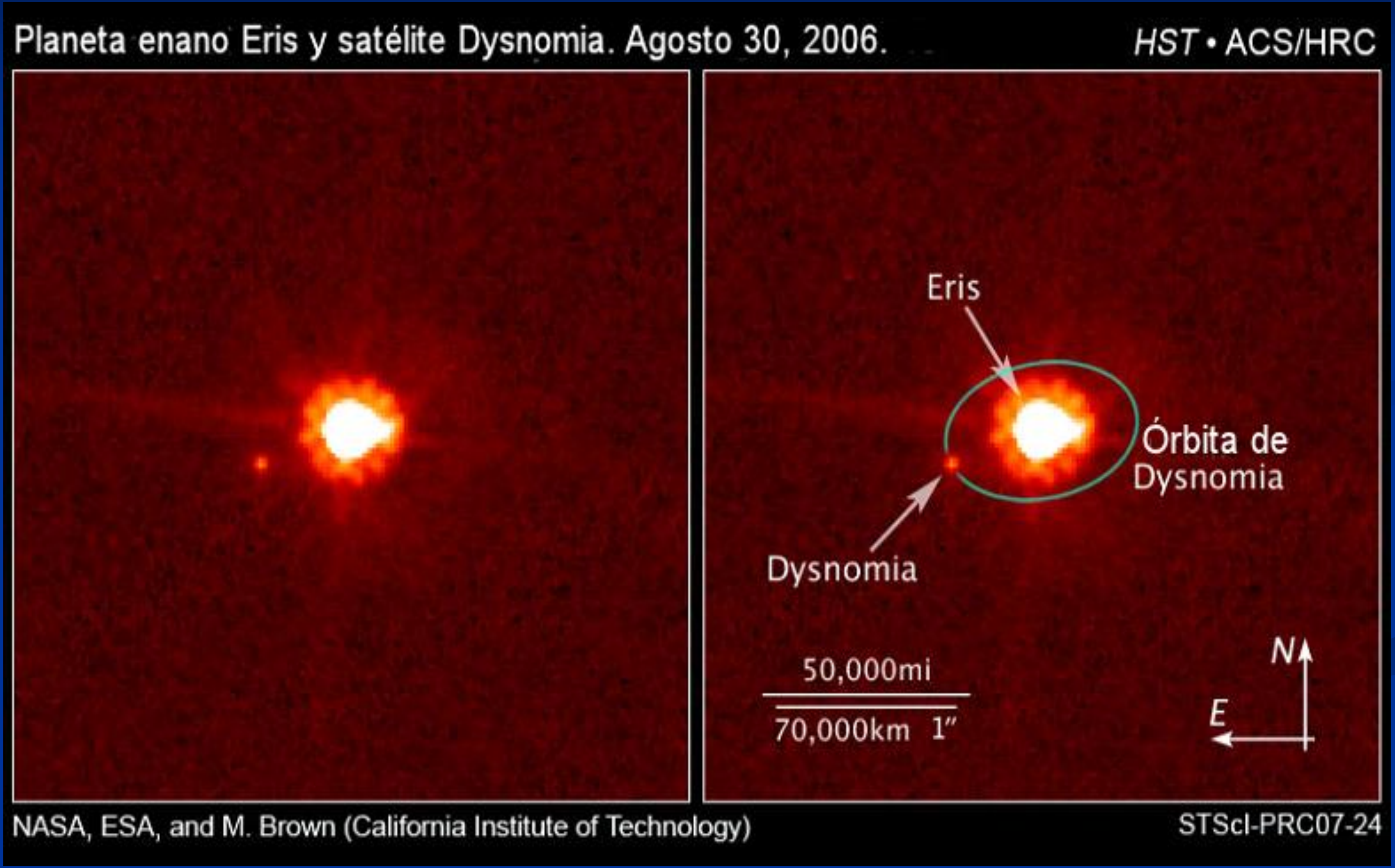
Pluto and Charon
New Horizonts, 2015

Overflight of Pluto (July 14, 2015)
The faint atmosphere of nitrogen is observed





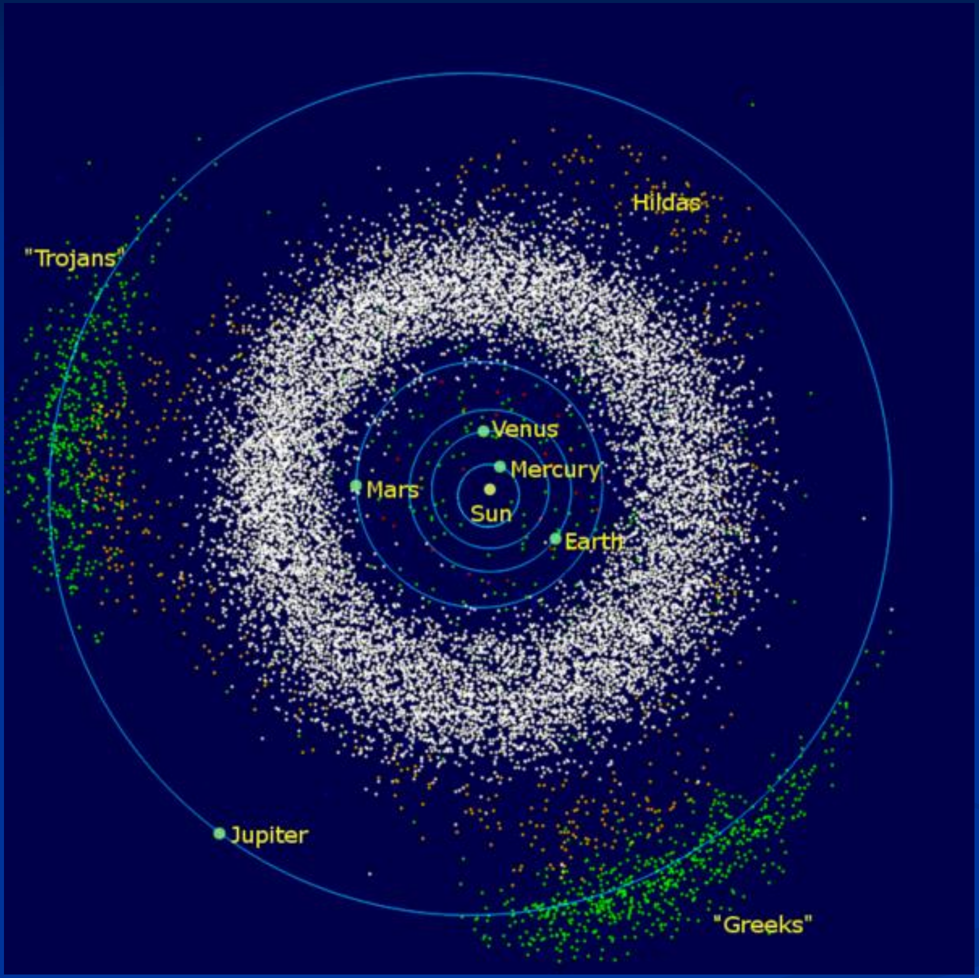
Eris Discovery



Minor bodies of the Solar System

- They are the remnants of the planetary accretion.
- They comprise diverse populations of asteroids, comets and transneptunian objects.
- The asteroids are essentially rocky and metallic, while the comets are more fragile and porous objects, formed basically by ice (predominantly water) and dust particles.
- The vast majority of asteroids lie in a region between the orbits of Mars and Jupiter, known as the "Asteroid Main Belt."
- Transneptunian objects will contain significant amounts of ice, and are located in a region beyond the orbit of Neptune, known as the "Transneptunian Belt" (or Kuiper Belt, in recognition of one of the first to predict its existence).

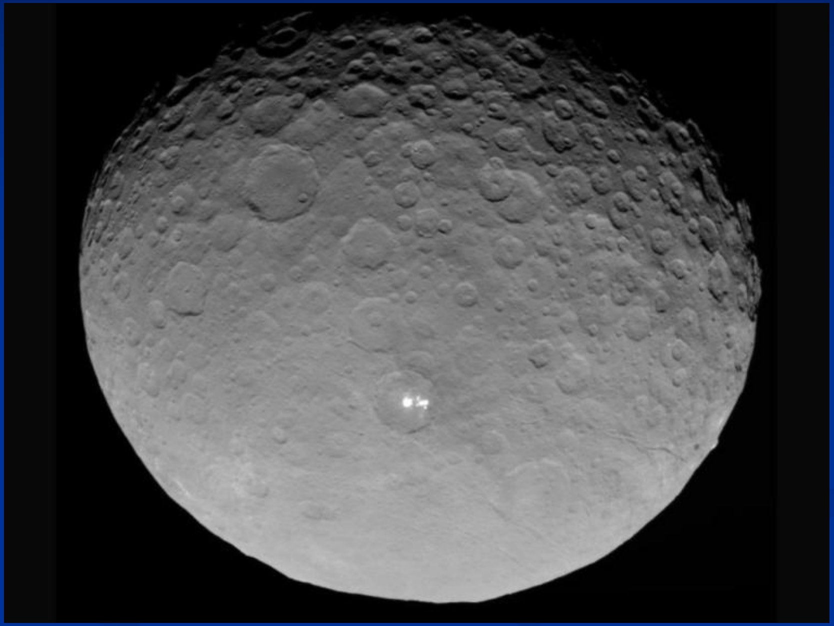
Asteroids Main Belt



There are hundreds of thousands or millions, and the total mass would not exceed one thousandth of the Earth.

The size of the asteroids ranges from several hundred km to meters and fractions of m.

Ceres

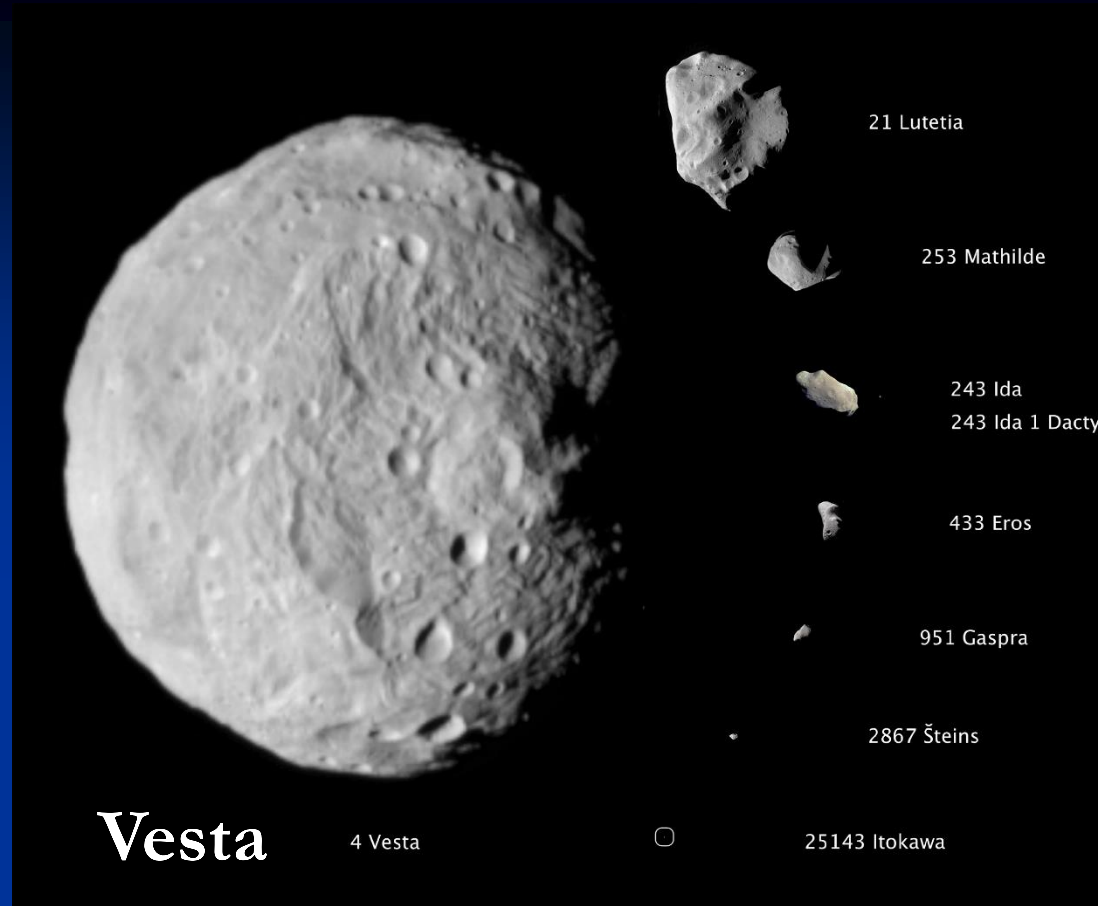


Discovered in 1801 by Giuseppe Piazzi, it was considered a planet until 1850 when many other similar objects were found.

It is the largest body of the asteroid belt, and the only one of them cataloged in 2006 as a dwarf planet.

With a diameter of almost 1,000 km, it is large enough for its gravity to give it a spherical shape.

All other asteroids are considered small, irregular bodies, although some of them like Pallas and Vesta could be classified as dwarf planets if they are shown to reach hydrostatic equilibrium



Pallas

Reservoirs of minor bodies in the SS

The reservoirs are relatively stable regions, where objects can remain for times comparable to the SS age, until some perturbative force changes their orbit.

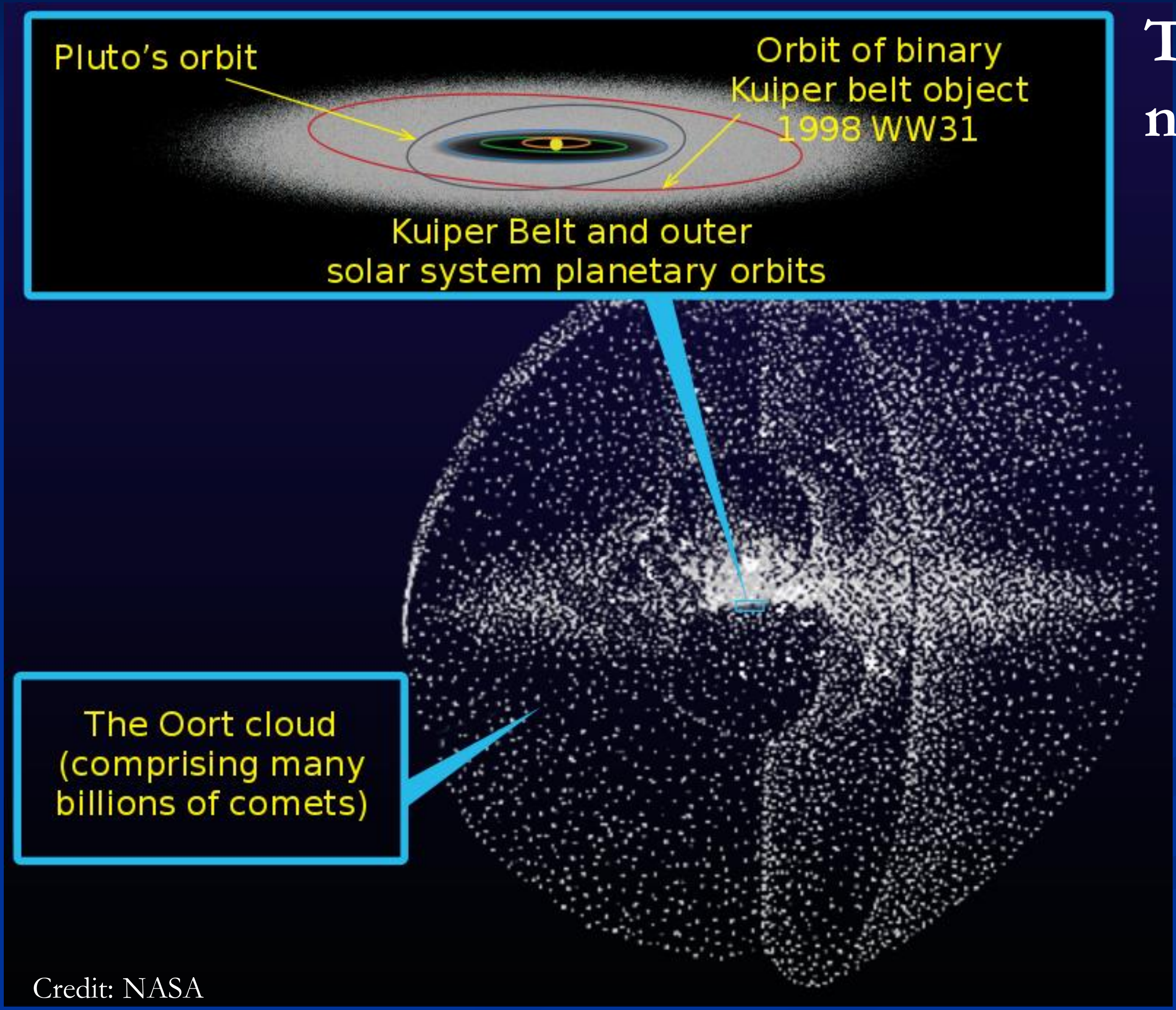
There are three large reservoirs in the SS:

- The **Main Asteroid Belt** Other populations would come from this region, such as the asteroids that approach Earth (known as NEAS by its acronym in English).
- The **Transneptunian Belt**. It is the region where short-period comets come from.
- The **Oort Cloud**. It has a spherical distribution and is formed by the frozen planetesimals swept out by giant planets during the formation of the SS. Thanks to perturbations due to the close passage of stars or giant molecular clouds, or to the galactic tides, the orbits of some of these objects can change deviating towards the interior of the SS, transforming into long-period comets.

Data at April 17, 2019.
Source: NASA/JPL https://ssd.jpl.nasa.gov)

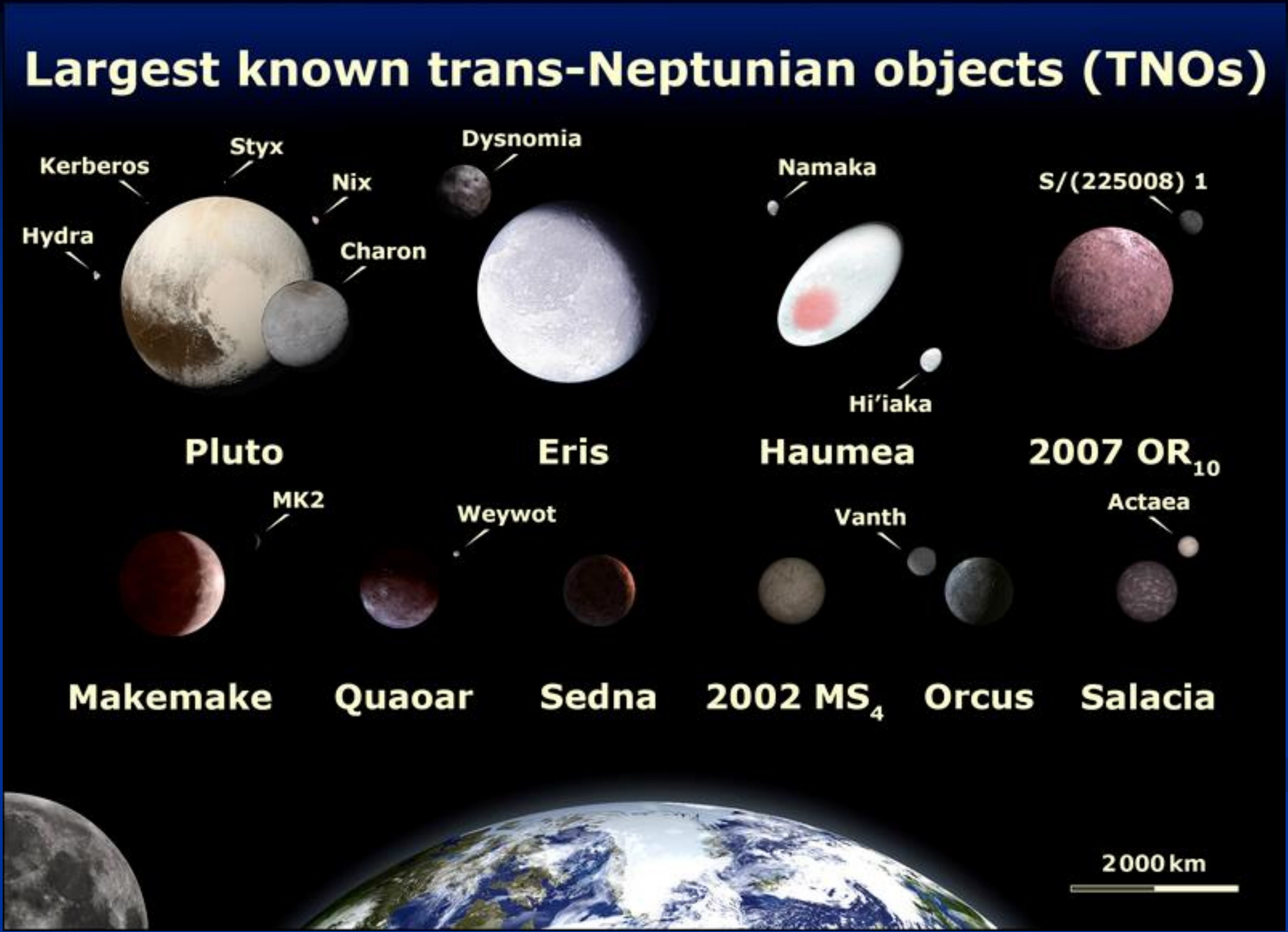
- Total of known Asteroids: 798,130. Including:
  - Main belt: 705,913
  - Troyans of Jupiter: 7,236
  - Asteroids with inner Mars orbits: 3,573
  - NEAs: 19,996
  - Partial dangereuses Asteroids (PHAs): 1,973
- Comets:
  - Elliptical: 420 long periodo (P>200 years) + 860 short periodo (P<200 years).
  - Parabolics: 1,837
  - Hyperbolic: 347 (extra-solar origen)
- Trans-neptunians (TNOs): 3,218

Transneptunian belt and Oort cloud



Trans neptunians

The biggest ones are dwarf planets


Largest known trans-Neptunian objects (TNOs)
Kerberos
Styx
Nix
Hydra
Charon
Dysnomia
Namaka
S/(225008) 1
Hi'iaka
Pluto
Eris
Haumea
2007 OR10
MK2
Weywot
Vanth
Actaea
Makemake
Quaoar
Sedna
2002 MS4
Orcus
Salacia
2000 km

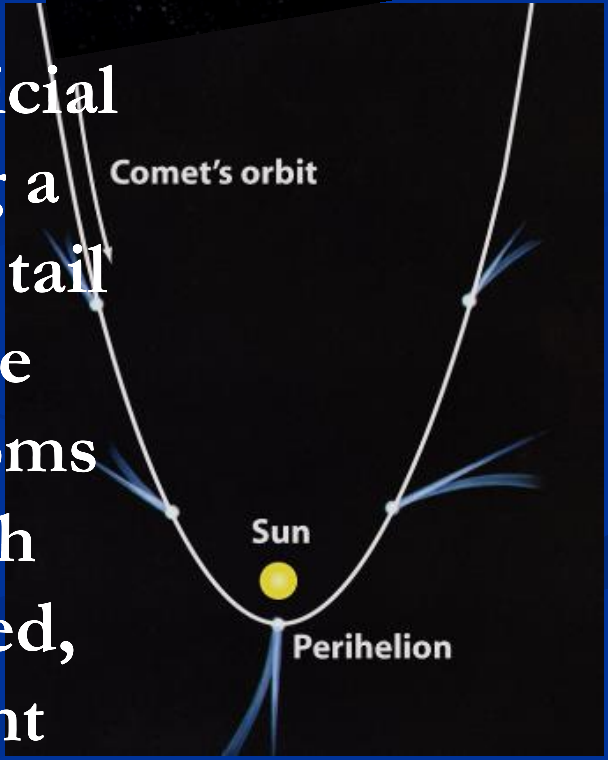
Credit: NASA

Comets

- Are small bodies of a few km, made mainly of volatile materials (water ice, carbon dioxide, methane, ammonia, etc.) and dust particles.
- When they approach the Sun they can be visible.
- It is thought that H_2O on Earth could come from them.

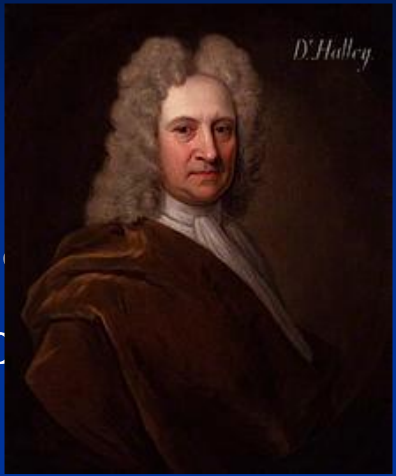
- In general comets have quite eccentric orbits. Those of long period have random inclinations and may have retrograde or direct orbits: those of short period have generally small inclinations and their orbits are direct.

- When approaching the Sun, the superficial ice of the comet is sublimated creating a coma or "hair", and the "tails": a dust tail formed by dust particles dragged by the gas, and an ionic tail formed by the atoms and ionized molecules that interact with the solar wind. The powder tail is curved, while the bluish ionic tail points straight and opposite the Sun



Halley: the most famous of the comets

It was named in honor of Edmond Halley, who predicted his approach to the Sun, applying the Law of Universal Gravitation an the calculation of disturbances. Halley did no see his prediction confirmed.

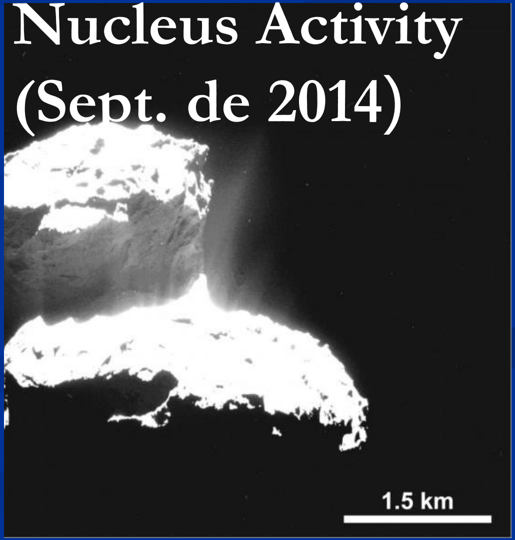


It returns every 76 years.

In 1986 was the first comet visited by a probe: the Giotto. It photographed the nucleus.

Rosetta Mission: close encounter with the comet 67P/Churyumov-Gerasimenko

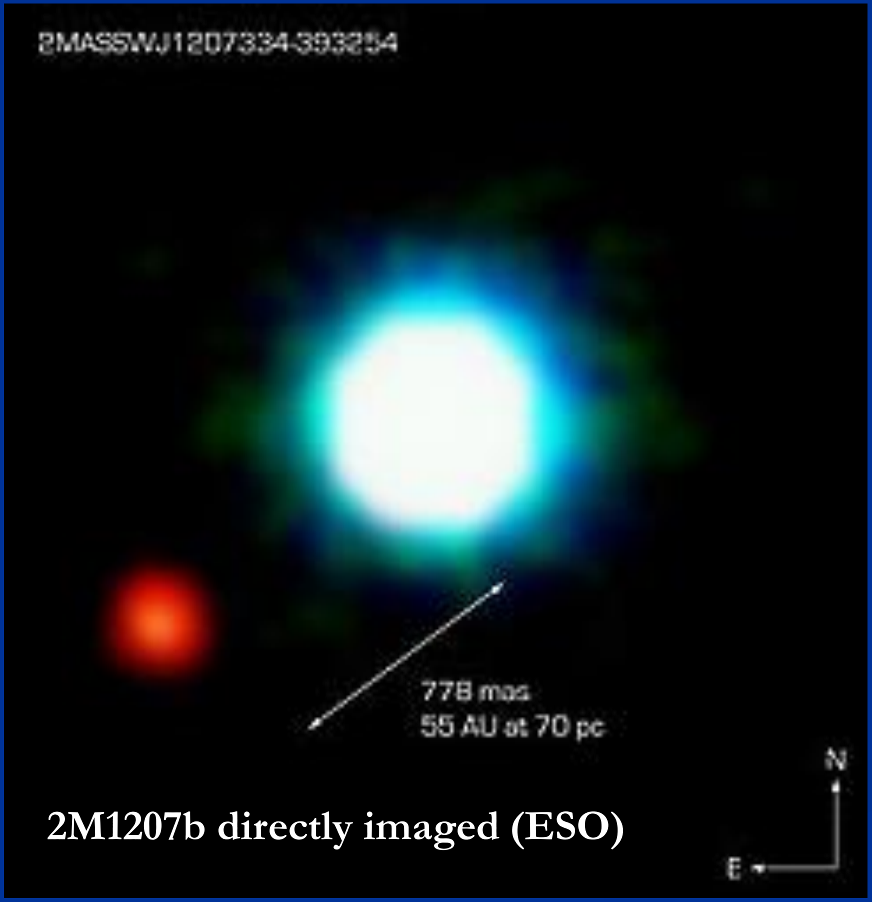
Philae descends on the comet on Nov 12, 2014



Camera OSIRIS/ESA

Other Planetary Systems

In 1995 the Swiss astronomers Michel Mayor and Didier Queloz announced the detection of an exoplanet orbiting 51 Pegasi.



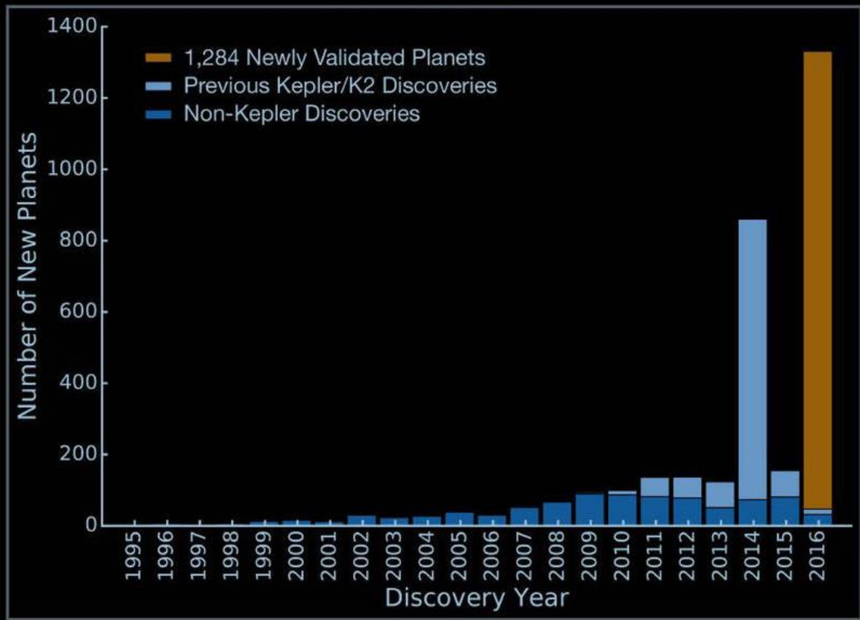
2M1207b directly imaged (ESO)

- This star and its planet were baptized as Helvetios and Dimidio in 2015, after a public vote promoted by the IAU.

1st photo of an extrasolar planet around a brown drwaf 2M1207. March 16, 2003

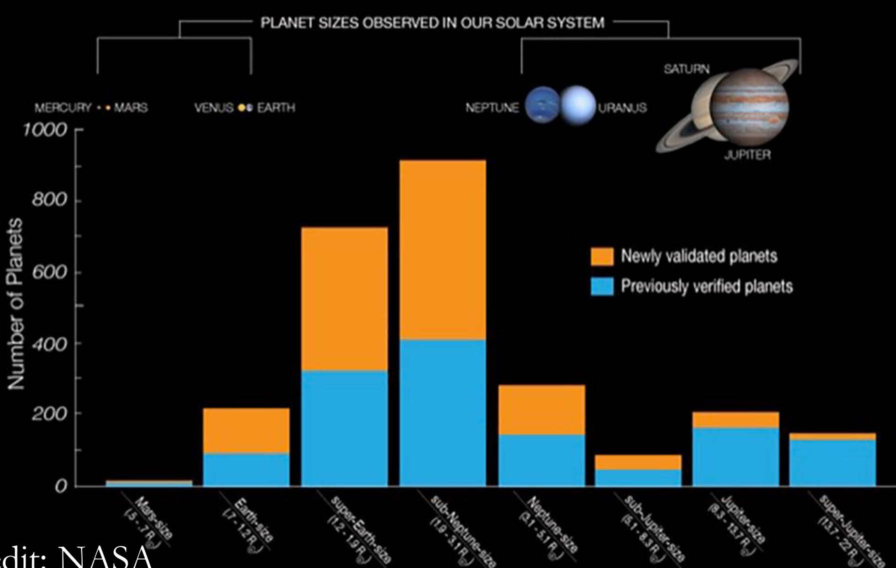
Exoplanet Discoveries Through the Years

As of May 10, 2016



Kepler's Planets by Size

As of May 10, 2016



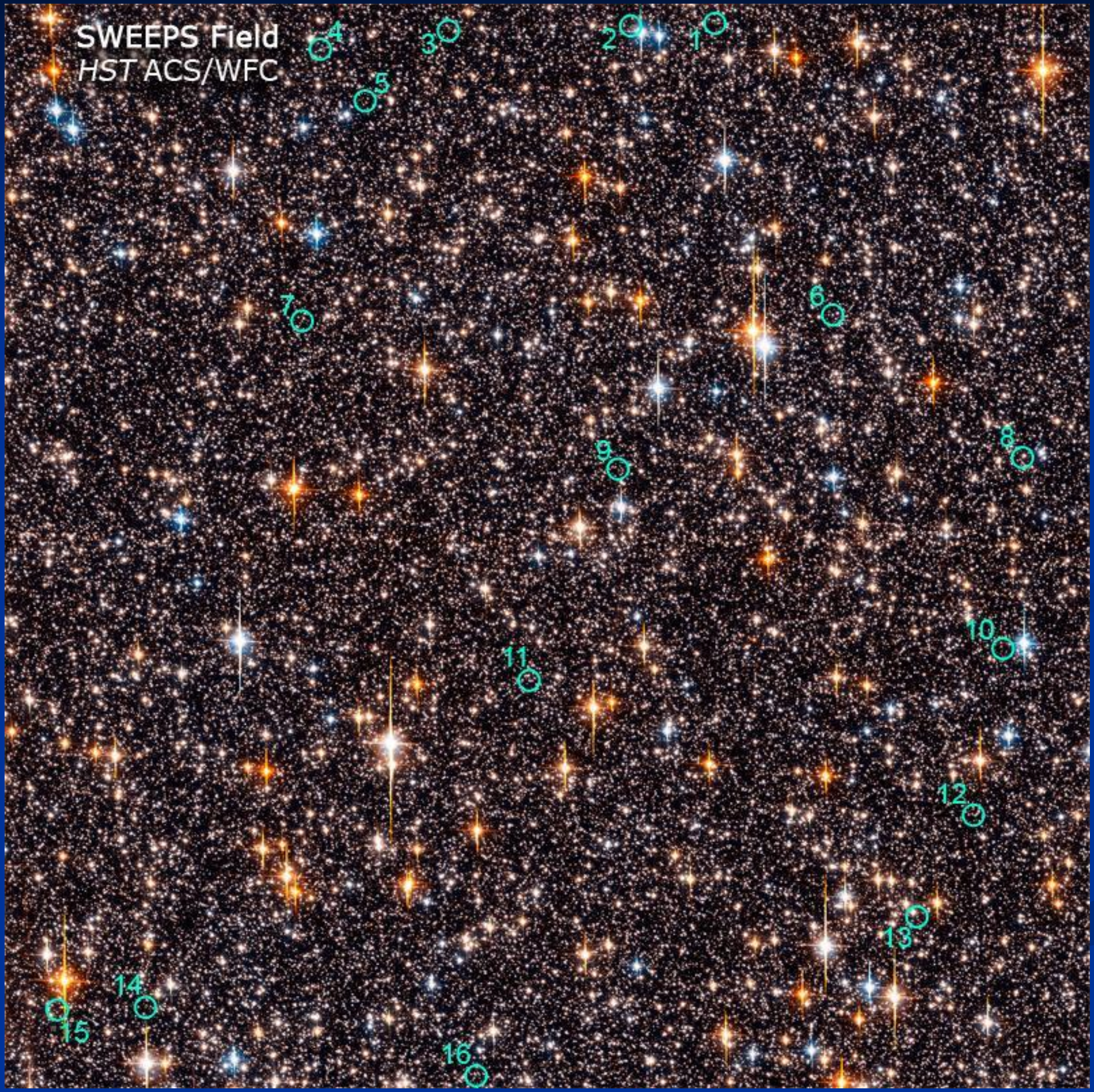
Credit: NASA

Kepler (March 2009), is NASA's first mission to find potentially habitable planets, the size of Earth.

On May 10, 2016, he announced the largest exoplanet collection for which news is available.

Out of a total of about 5,000 candidates, more than 3,200 have been verified, and 2,325 of these were discovered by the Kepler telescope.

Since 2018, the NASA satellite "Transiting Exoplanet Survey" will use the same method as the Kepler telescope to monitor 200,000 nearby bright stars and search for planets, especially the size of Earth or greater (the super Earths).



How many stars have planets?

How many of those planets are habitable?

In how many developed some form of life?

Questions that astronomy seeks to answer

Many Thanks
for your attention!