The exploration of the solar system and the search for water

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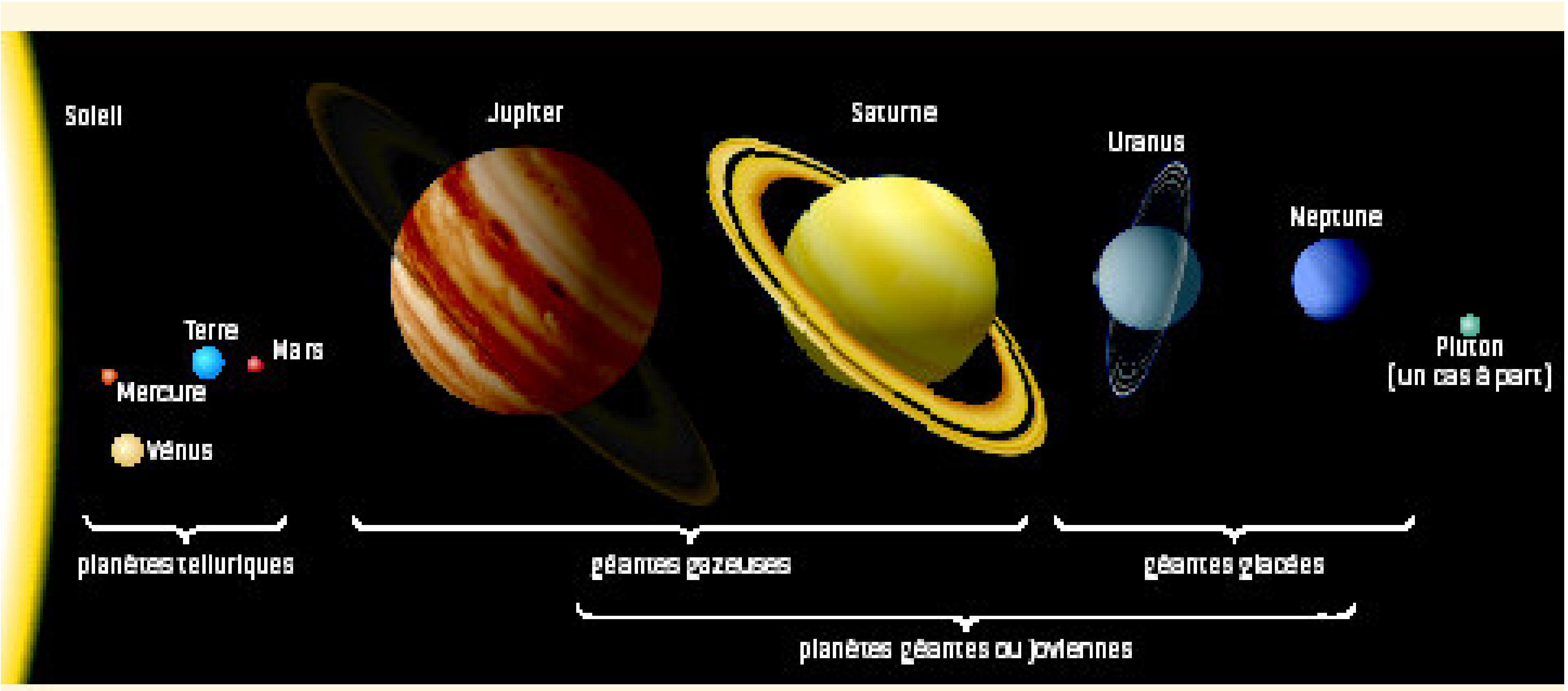
The exploration of the solar system and the search for water

- The exploration of solar system: the space era
- The birth of planets: the role of water
- Water in the outer solar system
- Water in the terrestrial planets
- The search for water in earth-like planets

What do we find in the solar system?

- Telluric planets: Mercury, Venus, Earth, Mars
  - Close to the Sun, small, dense
- Giant planets: Jupiter, Saturn, Uranus, Neptune
  - Far from the Sun, very big but less dense, surrounded with rings and many satellites
- Asteroids
  - Between the telluric and the giant planets
- Pluto and the trans-neptunian objects
  - Beyond the giant planets
- Comets
  - All through the solar system, close and far from the Sun

The solar system



<Telluric> planets   <   Giant planets   >   Trans-Neptunian objects

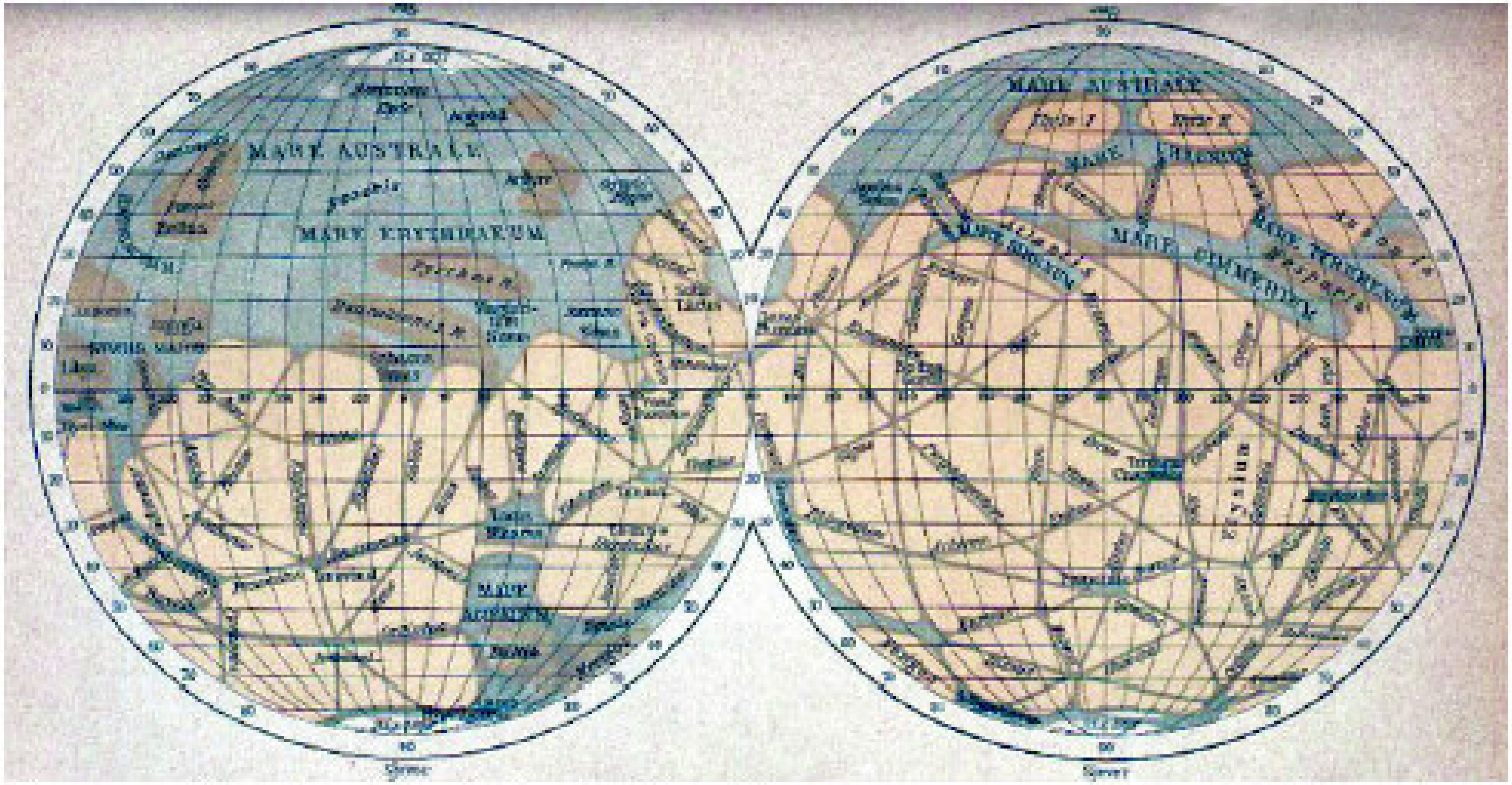
<Asteroids>

<   Comets   ->

The exploration of the solar system

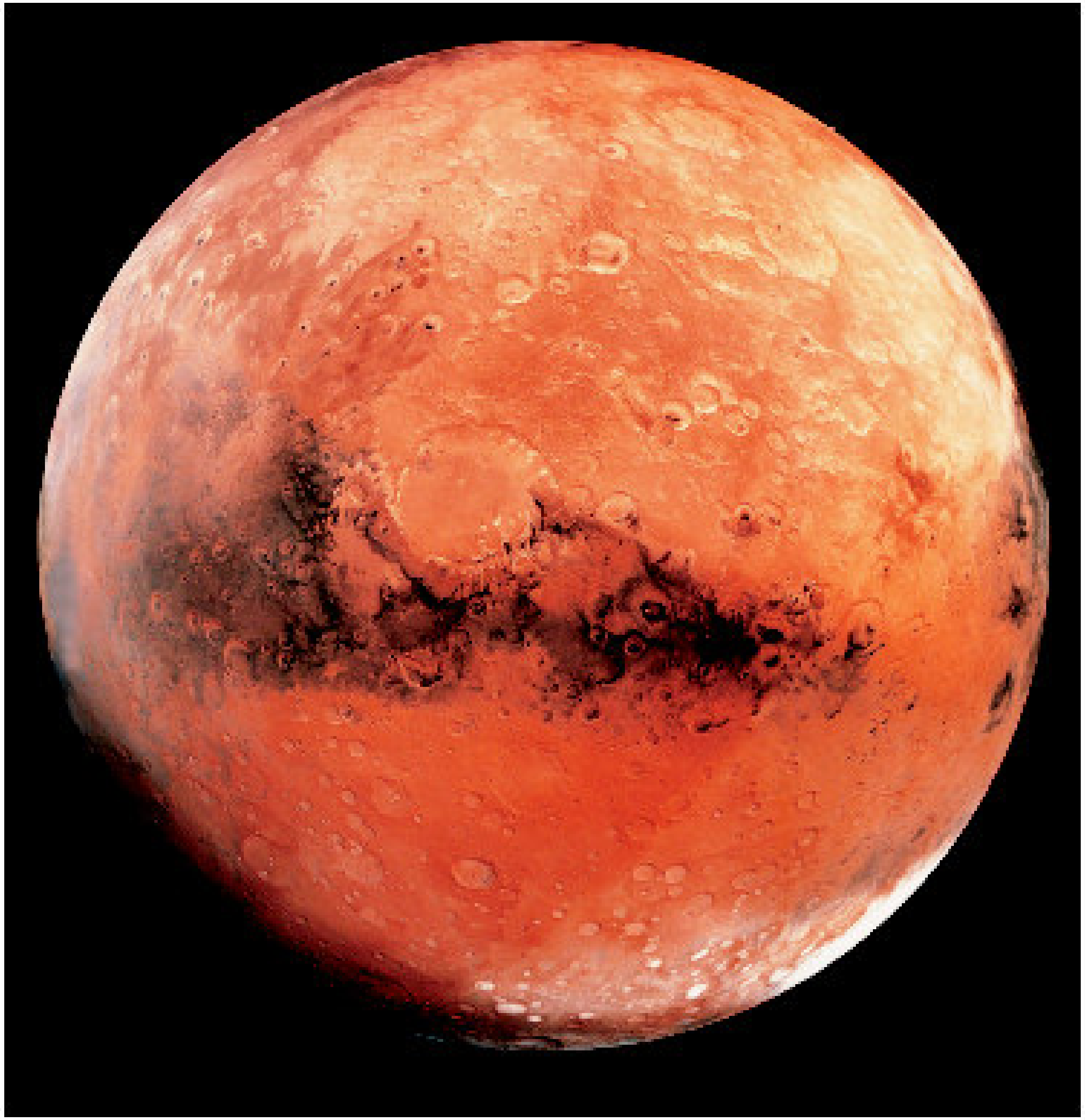
- Since Galileo (1610): refractors and telescopes
  - Visual observations
  - Photographic plates and cameras
  - Spectrographs (analysis of the radiation with wavelength -> physical and chemical properties
- Since the 1960: space exploration
  - Moon (human exploration) - 1960-70’
  - Mars, Venus (orbiters and landers) - 1970’ +
  - Giant planets (flybys), orbiters (Jupiter, Saturn), probe (Jupiter, 1995; Titan, 2005)
  - Comet Halley and others (flybys, 1986 +)

Telescopic observations of Mars by Schiaparelli, 1879



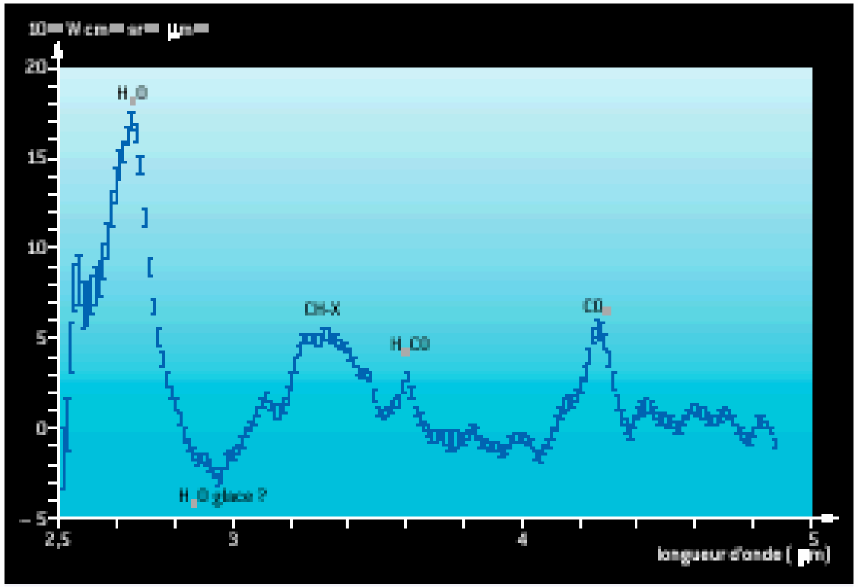
Halley’s comet as observed in 1910

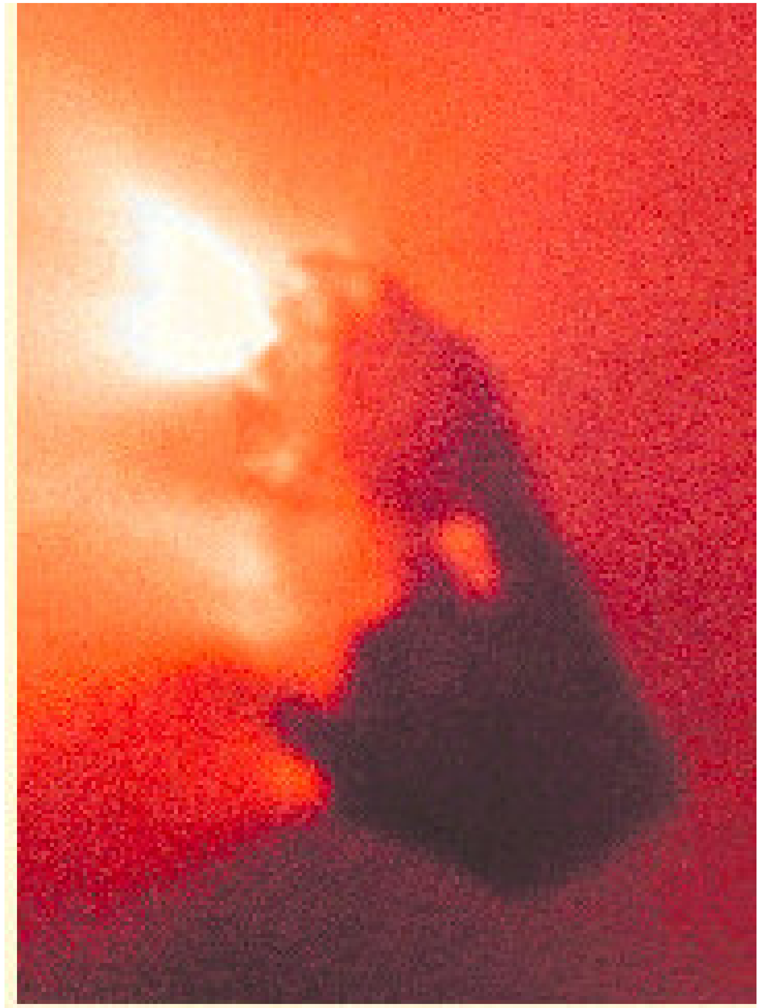
Mars as seen by space orbiters



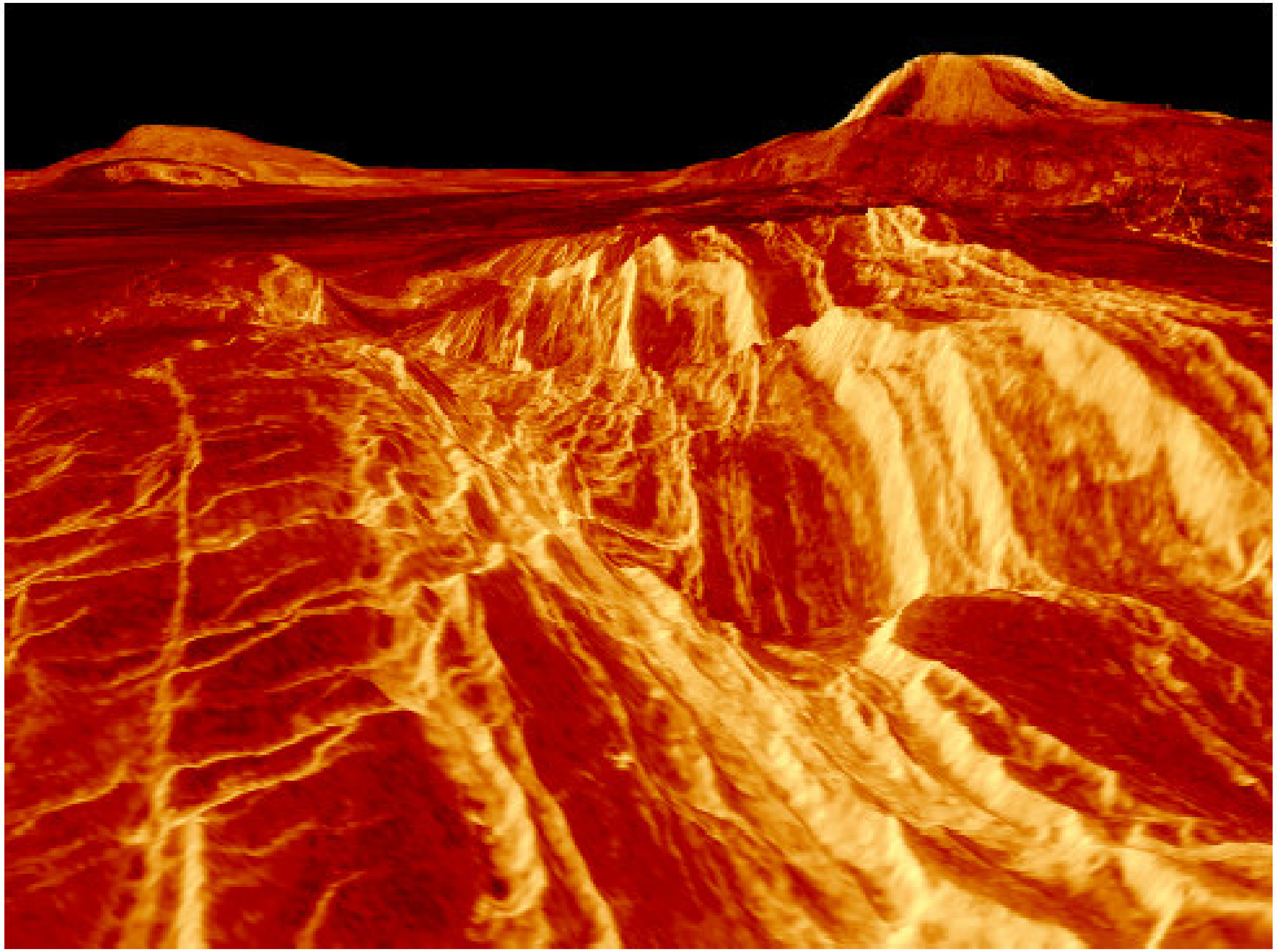
Halley 1986: an exploration with five spacecraft

- Giotto (ESA): observation of the nucleus (low albedo)
- Vega 1 and 2 (URSS-Europe): detection of water, CO_2 and complex hydrocarbons

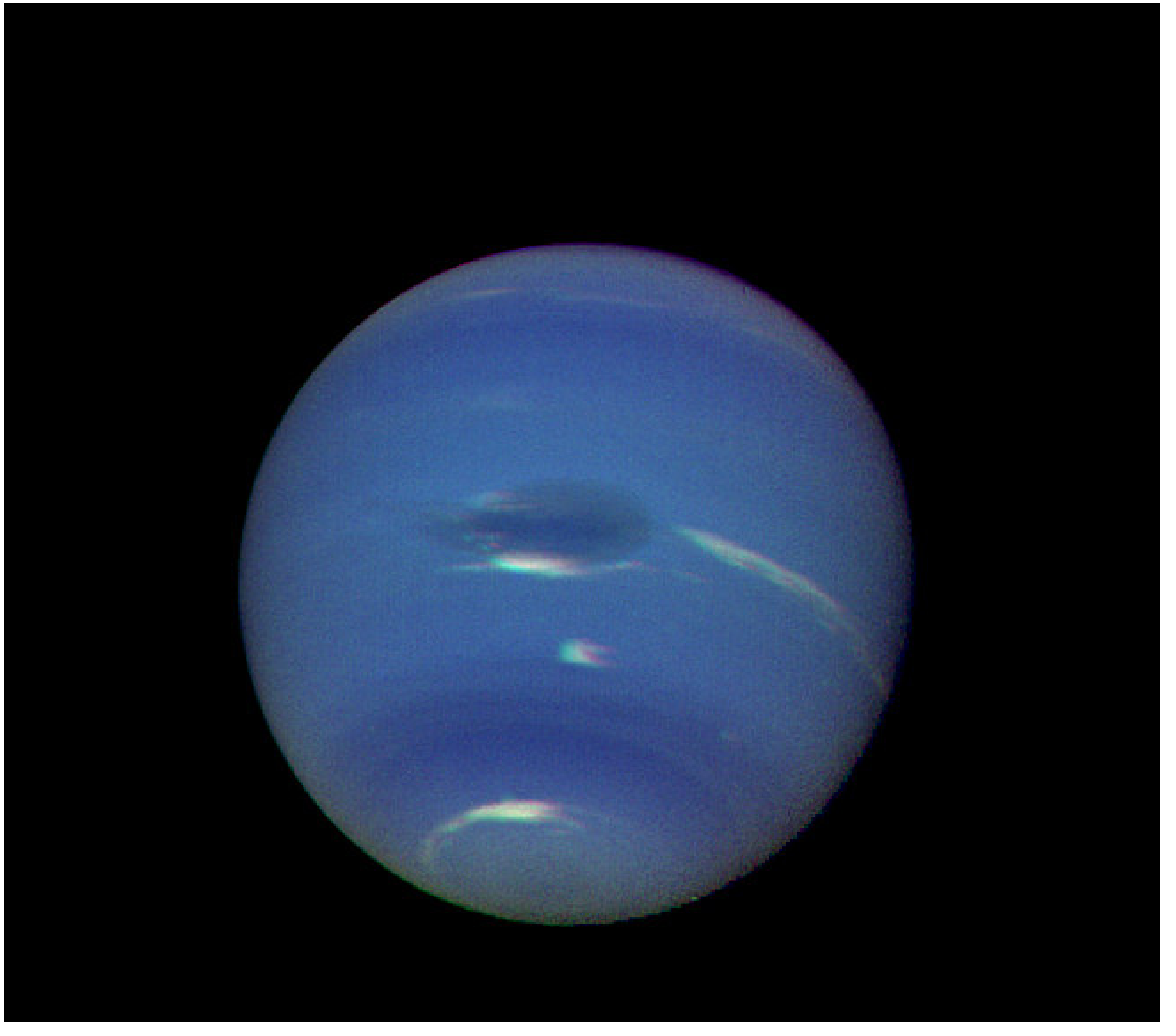




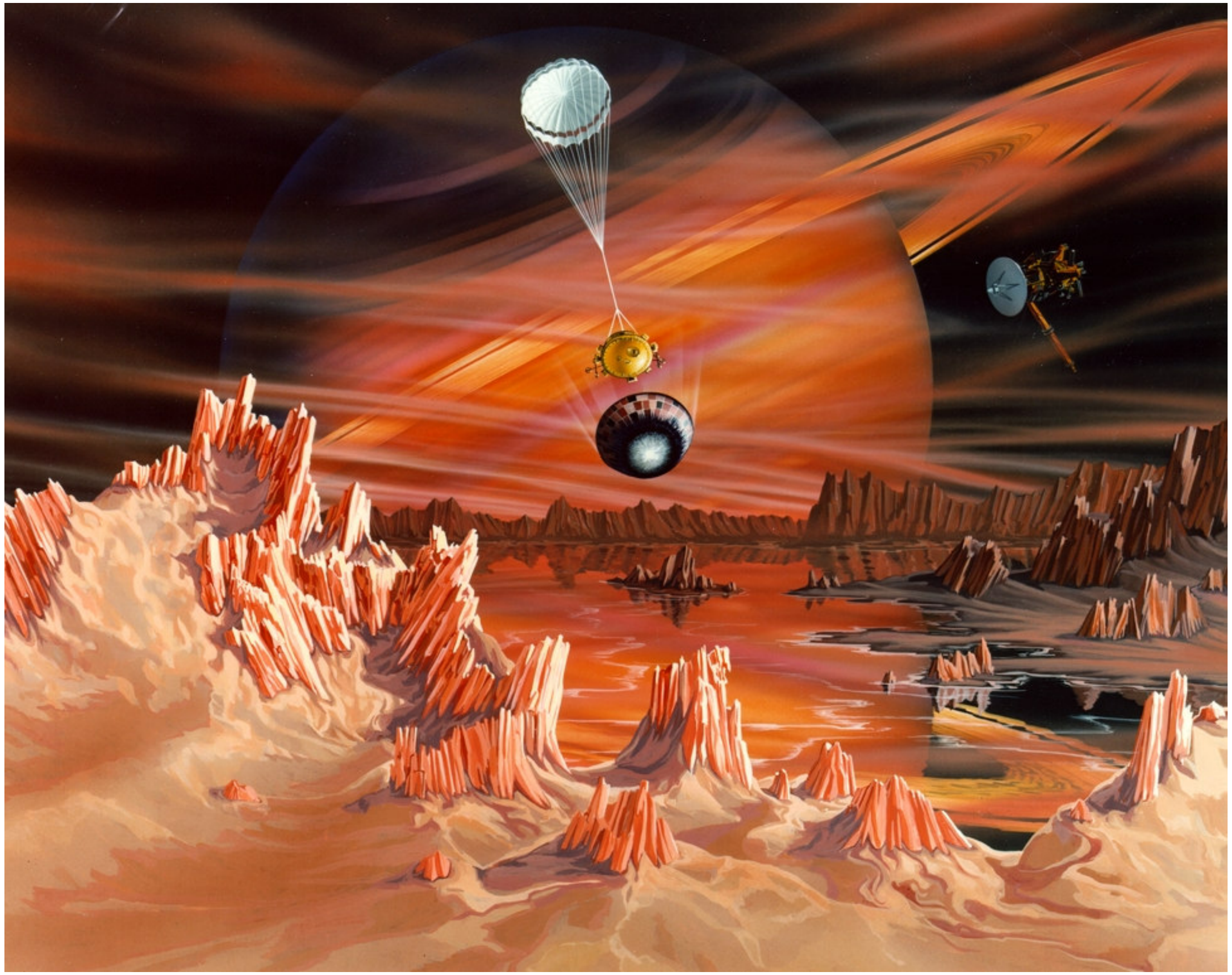
The surface of Venus as seen by
the radar orbiter Magellan (1991)



Neptune as seen by Voyager 2 (1989)

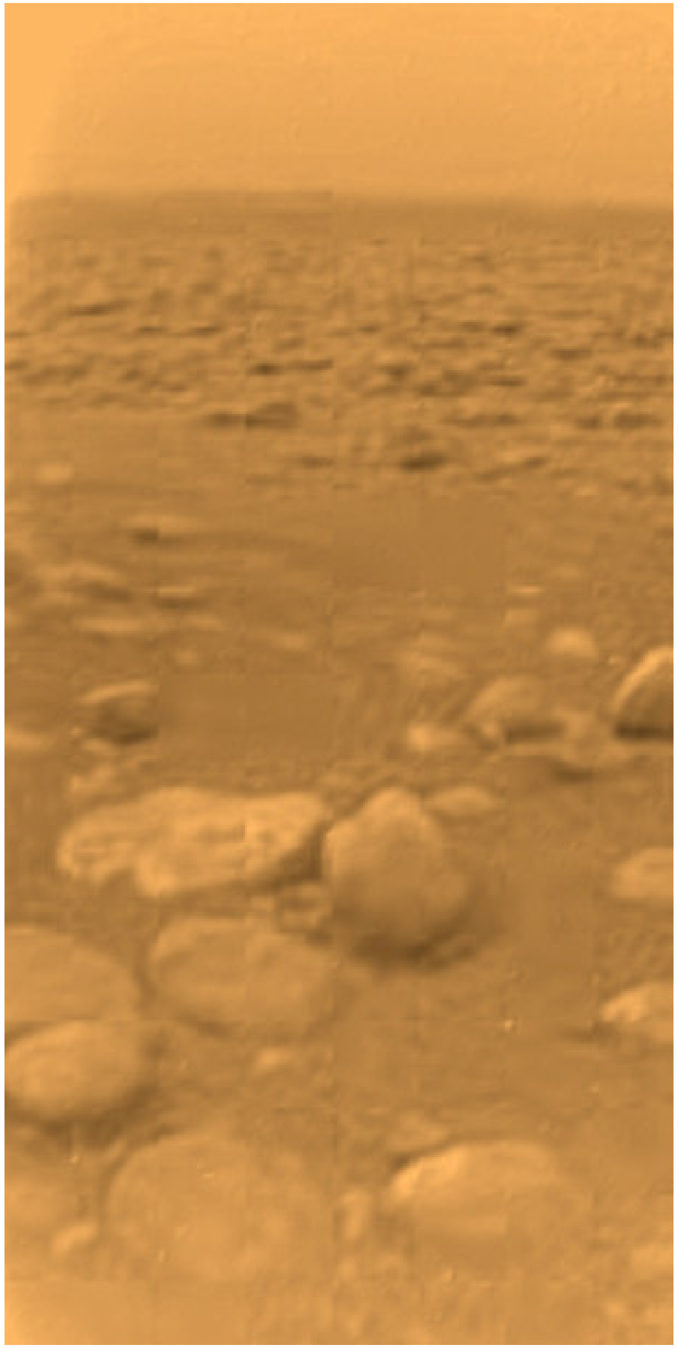


The exploration of Titan by Cassini-Huygens (2005): The surface of Titan as imagined before….

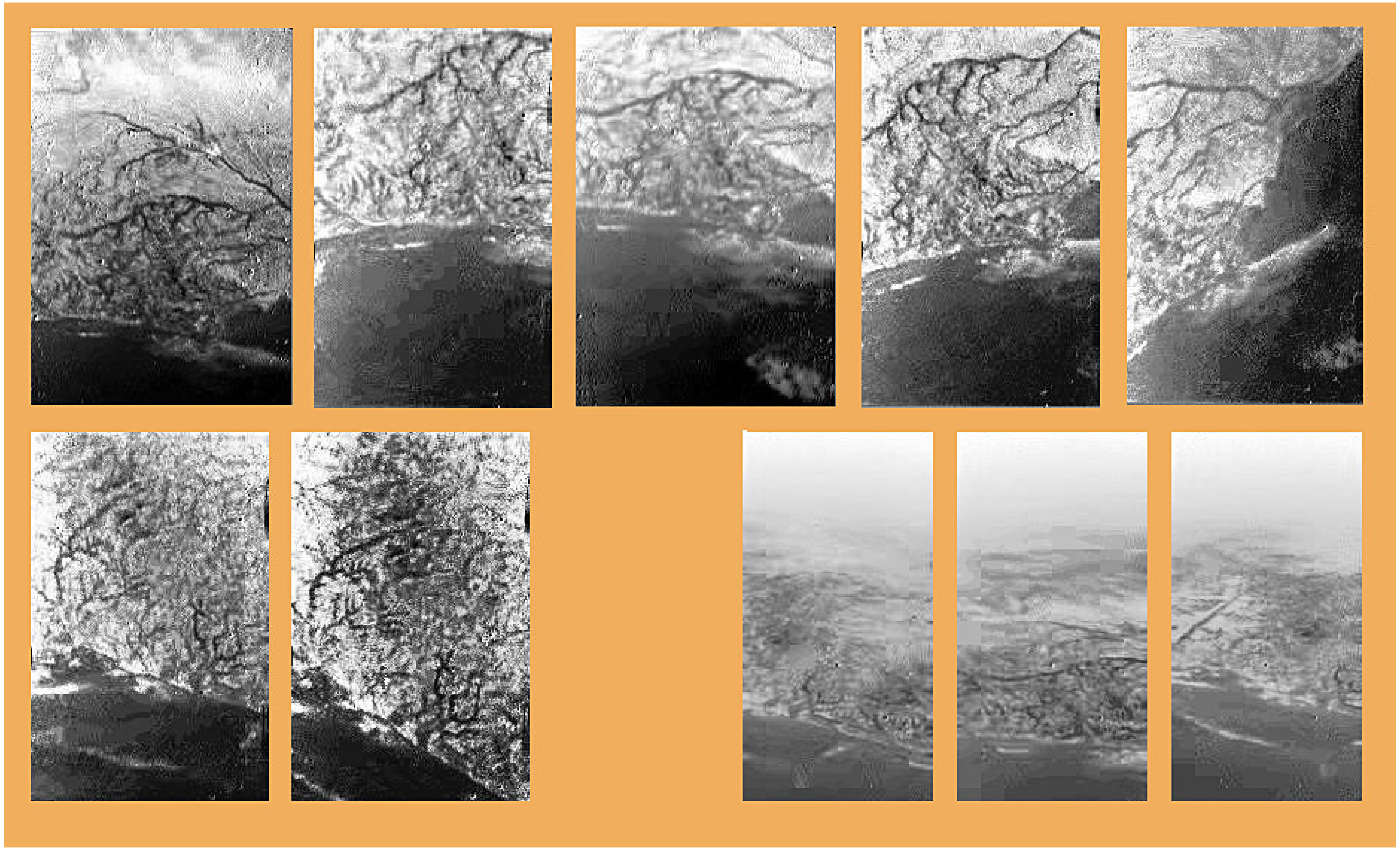


… and what has been seen:

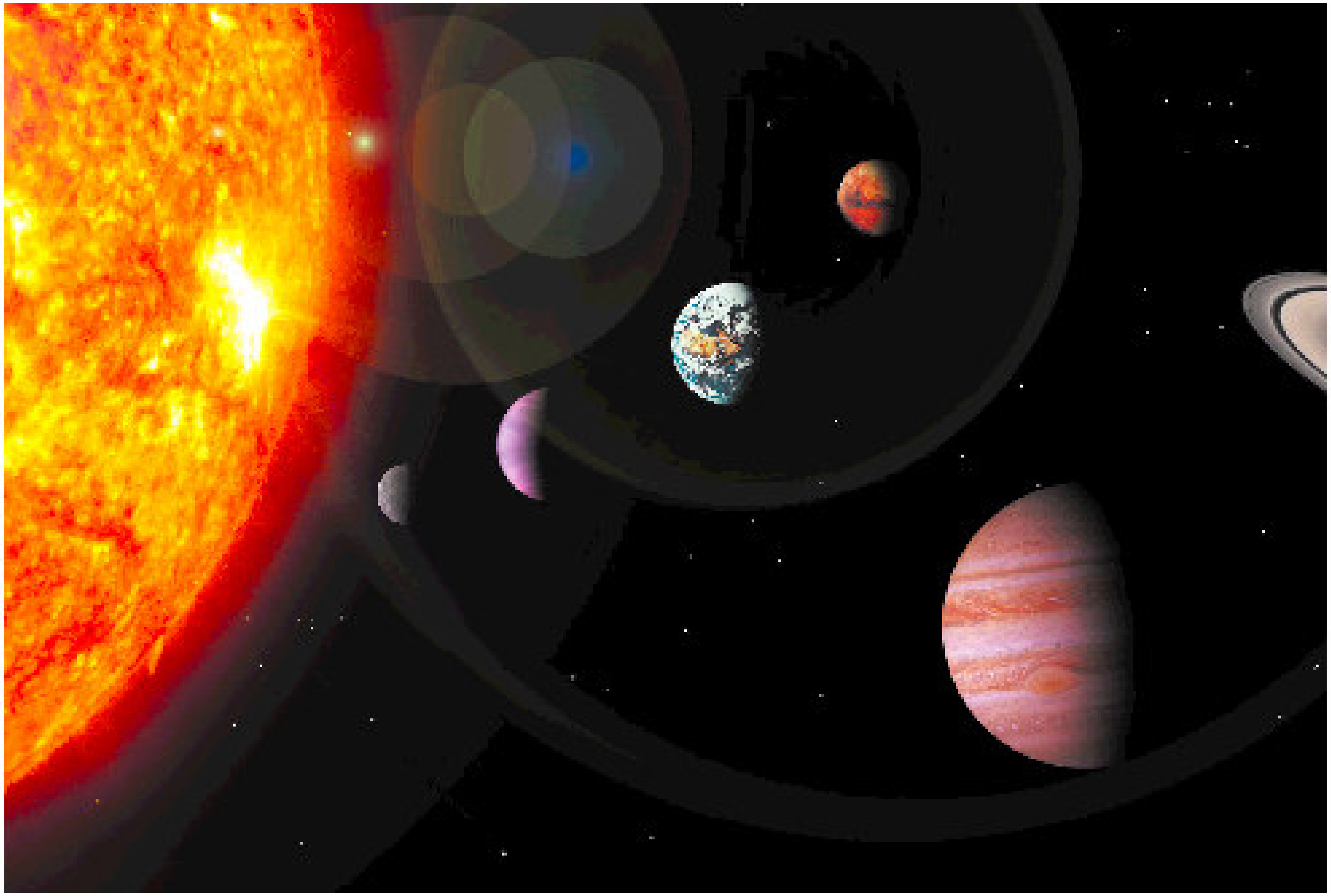
Boulders (most likely made of H_2O ice)
Strongly eroded by a visquous/ liquid flow (hydrocarbons)



Lanscape of Titan's surface, from an altitude of 8 km

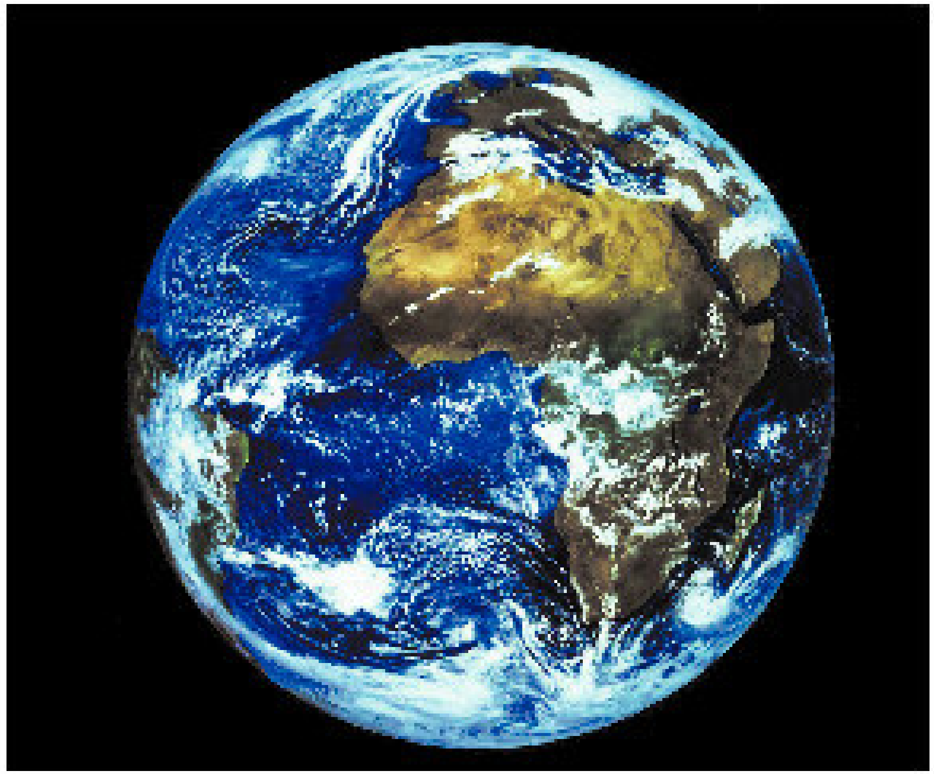


The birth of planets and the role of water



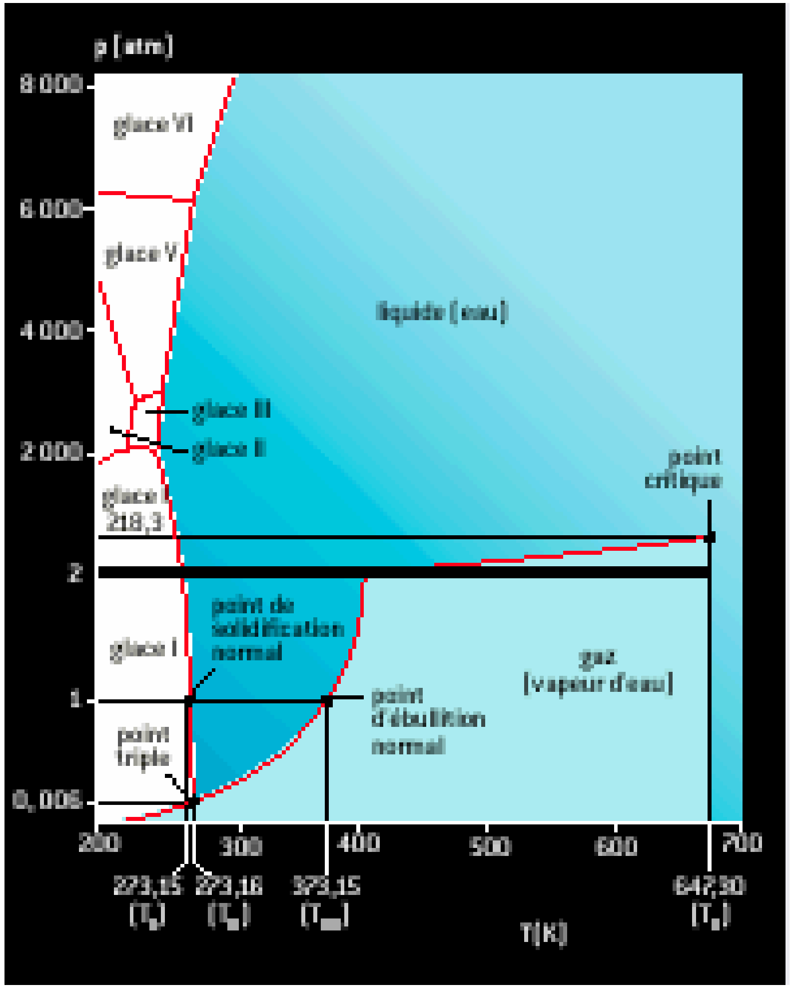
A very simple molecule: H_2O

- Present on Earth (and onlt there) in solid, liquid and vapor forms
- Very abundant in the Universe (O, H)
- Excellent solvent
- Essential in the development of life on Earth



Water: liquid on Earth, but only solid or vapor outside

-Interstellar medium (cold):
H_2O solid (mostly amorphous)
ou vapor in very dilute medium
-Stellar environments:
(high T, low pressure):
H_2O vapor
-Where to find liquid water?
-At low pressure: T= 0-100°C
(atmospheres of terrestrial planets)
-At high pressure and T > 0°C
(interiors of satellites)

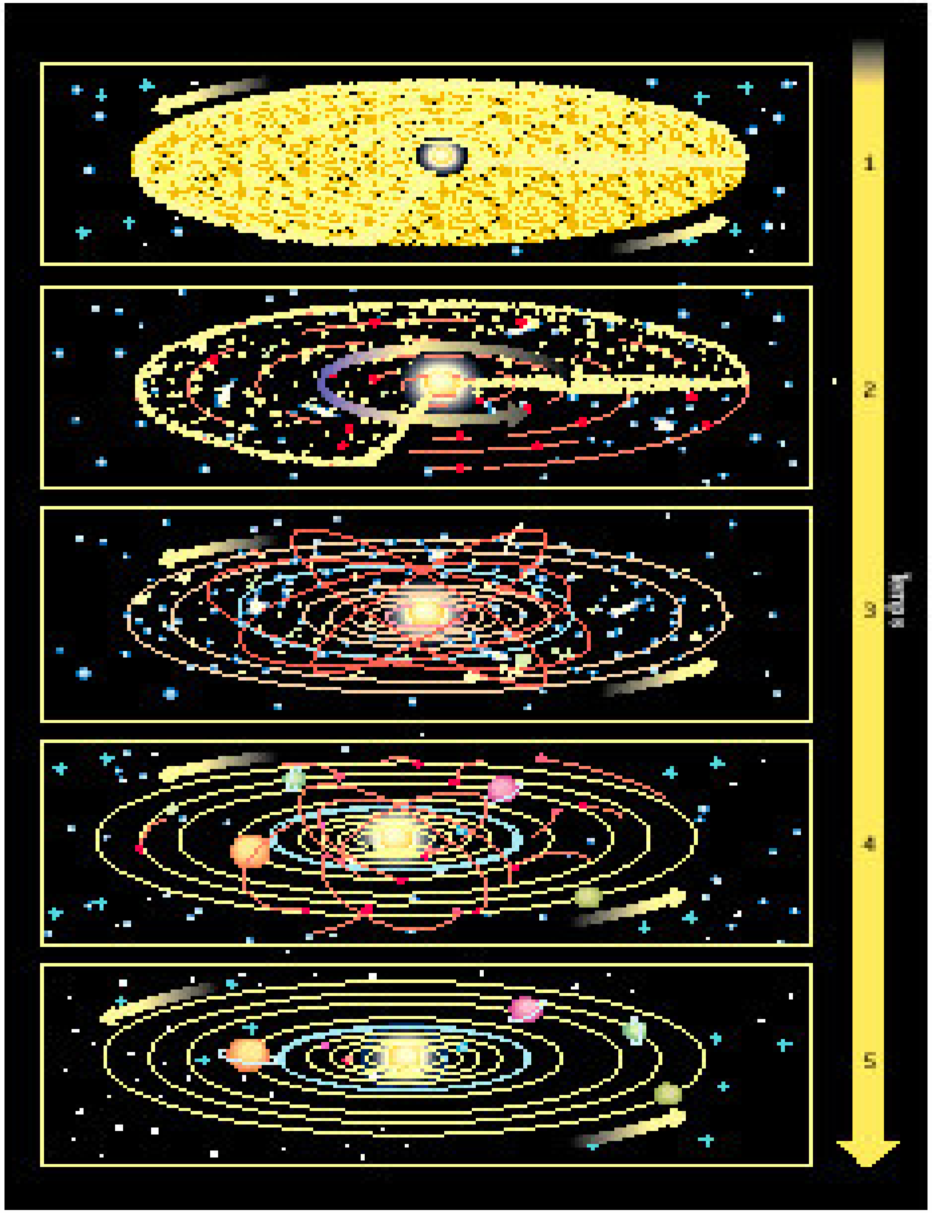


The main observations

- Orbits are almost coplanar, circular and concentric; planets rotate counter-clockwise, as the Sun
- This strongly suggests the formation of planets within a disk, product of a gravitational collapse of a rotating nebula
- This scenario is supported by the observation of protoplanetary disks around nearby stars

The main steps of the collapse model

- Contraction of a rotating cloud
- Collapse in a disk, perpendicular to the rotation axis
- Accretion of solid particles within the disk, following instabilities
- Growth of aggregates through collisions
- Further growth of biggest objects through gravity
- Dissipation of smallest particles by the stellar wind (T-Tauri phase)

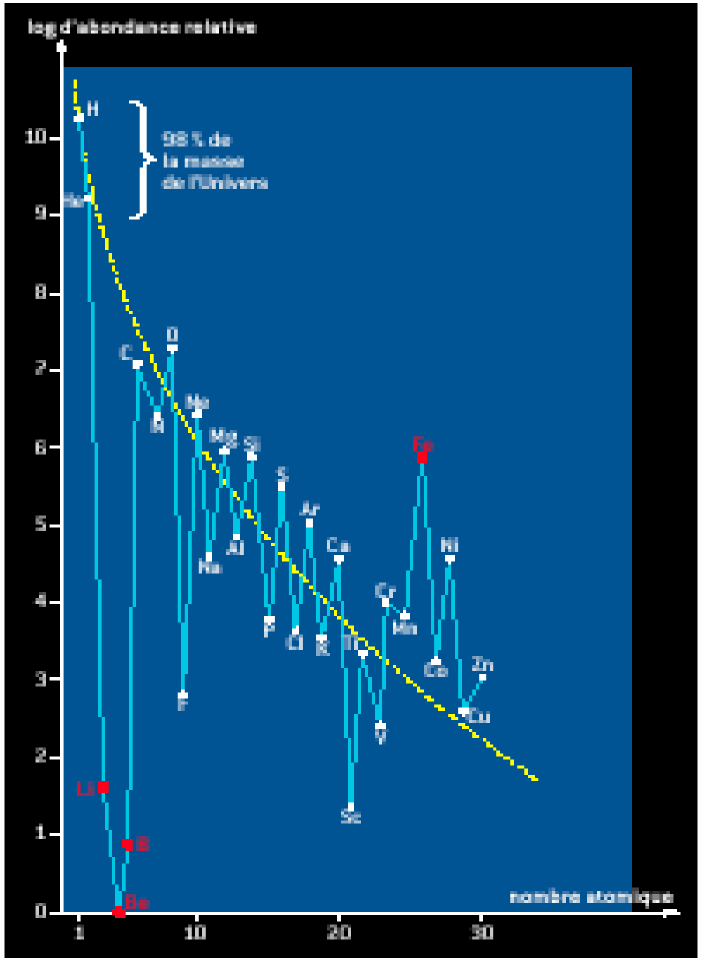


Formation of planets:

Accretion of
<u>solid particles</u>
+
Multiples collisions

Water, a very abundant molecule in the Universe

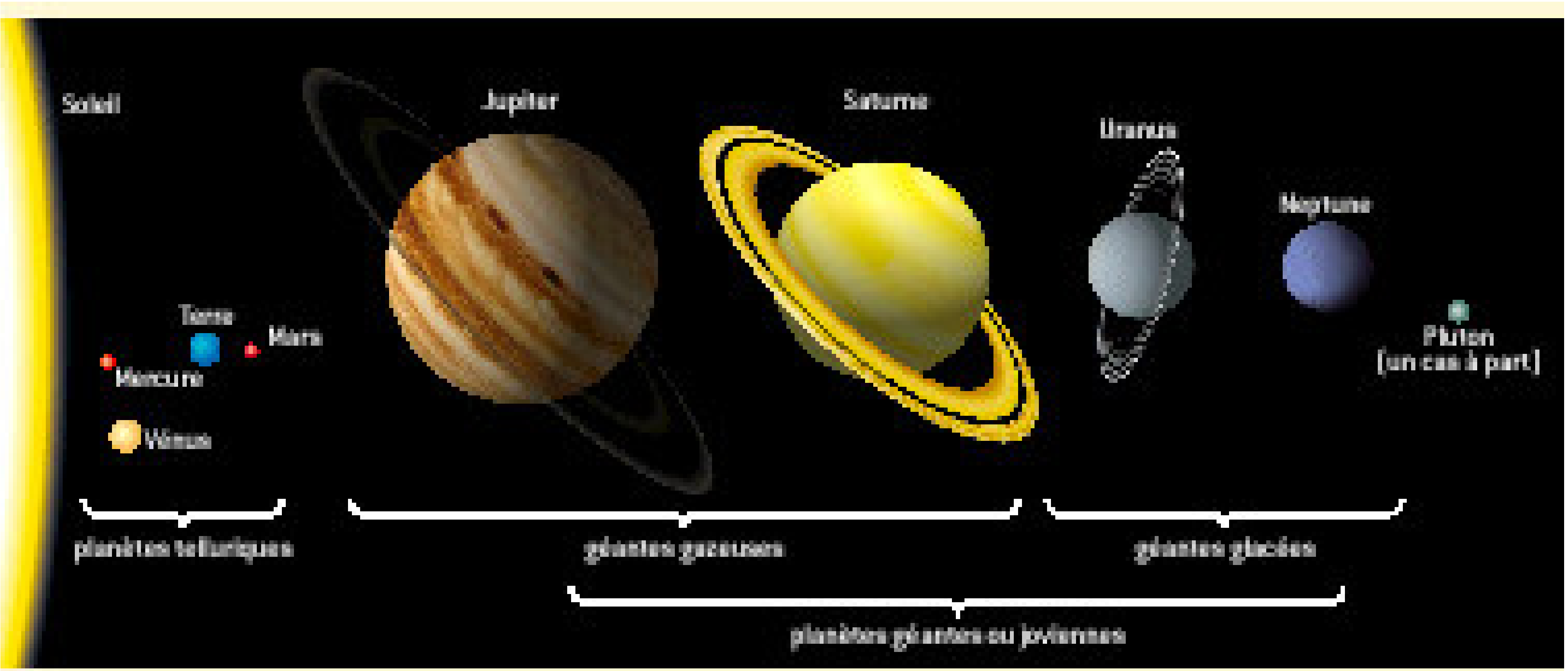
- Most abundant elements in the Universe: H, He
- Then: O, C, N (synthetized in stars), then heavier elements
- Formation of H_2O from H and O: reaction strongly exothermic -> possible in the interstellar medium (at low temperature)



The role of ices and the snow line

- In the disk, T decreases as Rh increases
- Near to the Sun (T>about 300K), only metals and silicates are in solid form -> the available solid mass is limited -> terrestrial planets
- Far from the Sun, the most abundant molecules (after H_2: H_2O, CH_4, NH_3…) are in the form of ice -> available for big nuclei -> for M_C>10 M_E: collapse of surrounding gas (H_2, He) -> giant planets
- Line of H_2O ice condensation: snow line (4 UA)

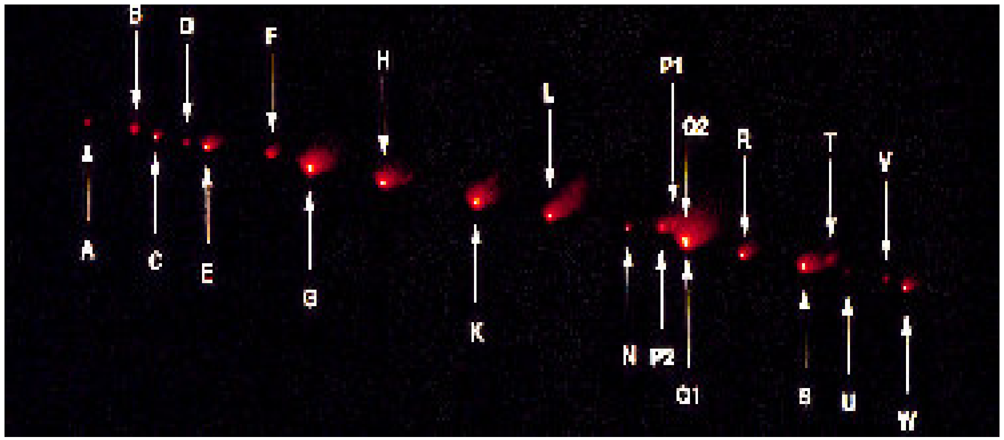
Giant planets



Jupiter and Saturn: gaseous giants (300 - 100 M_T)
Uranus et Neptune: icy giants (about 15 M_T)

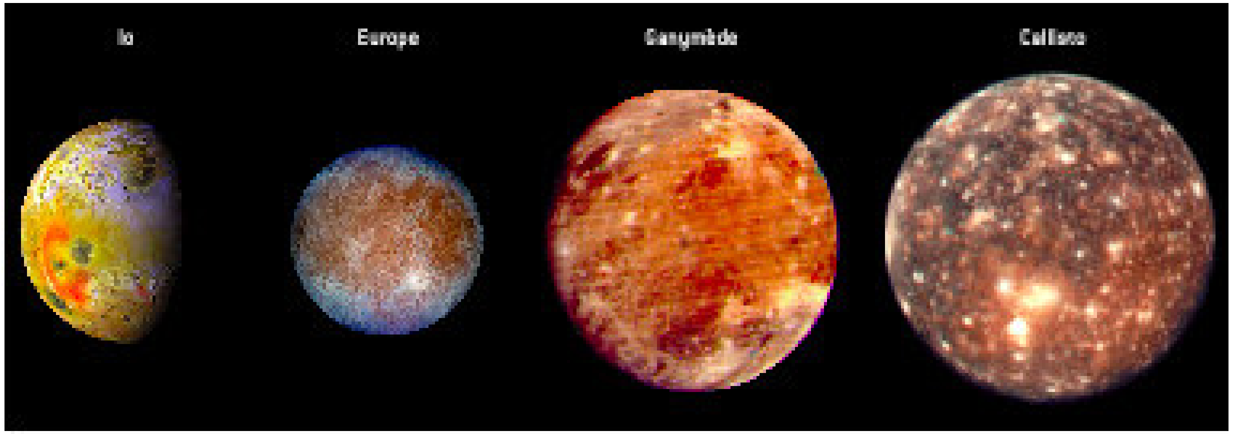
Water inside… and outside

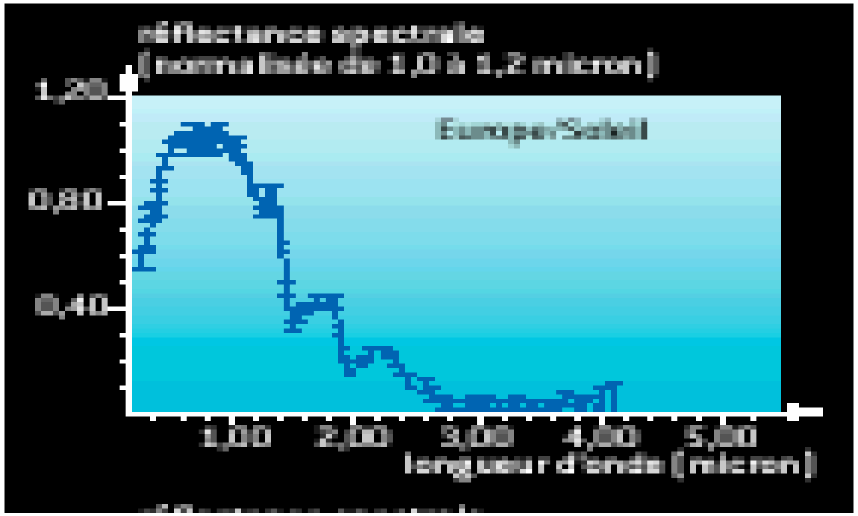
1994: Collision of comet Shoemaker-Levy 9 with Jupiter



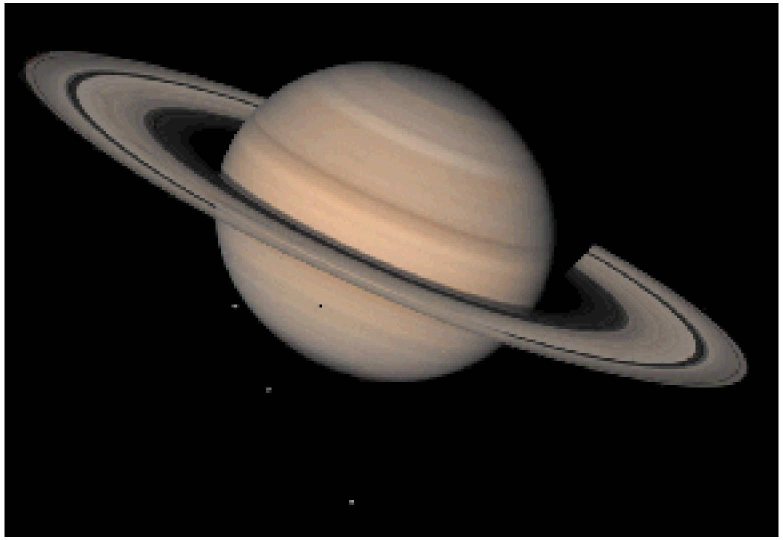
-> Injection of water in the upper atmosphere

Galilean satellites:
water ice at the surface…and possibly liquid water inside (except Io)



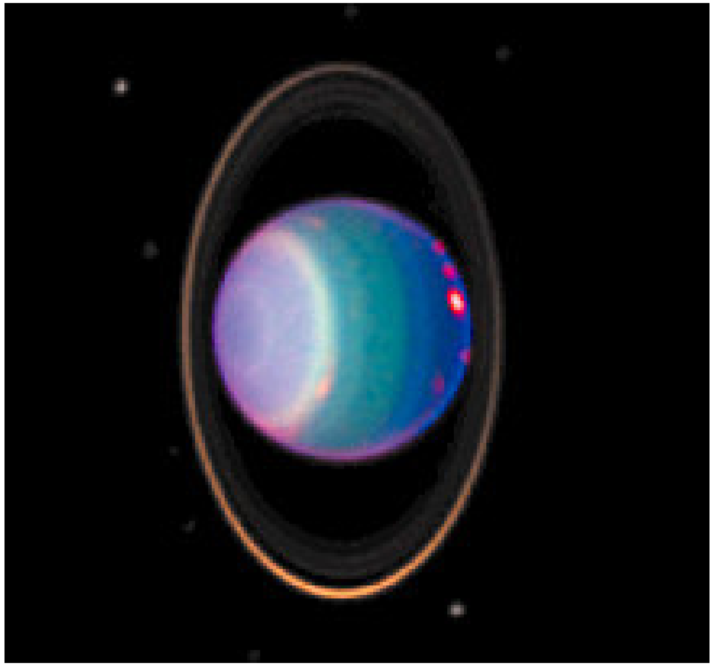


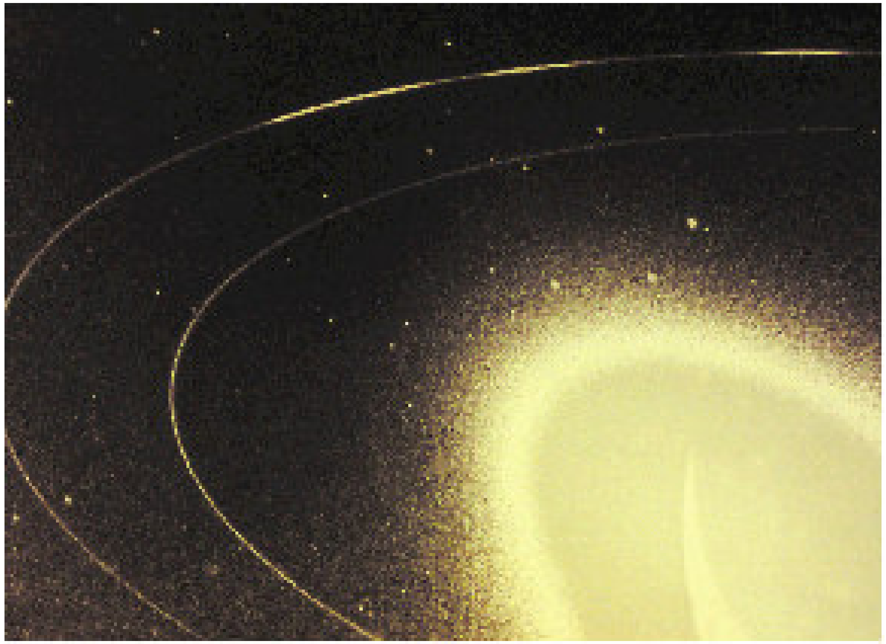
Saturn, the lord of the rings



Saturn’s rings, a myriad of icy grains of all sizes

Uranus and Neptune: very tenuous rings





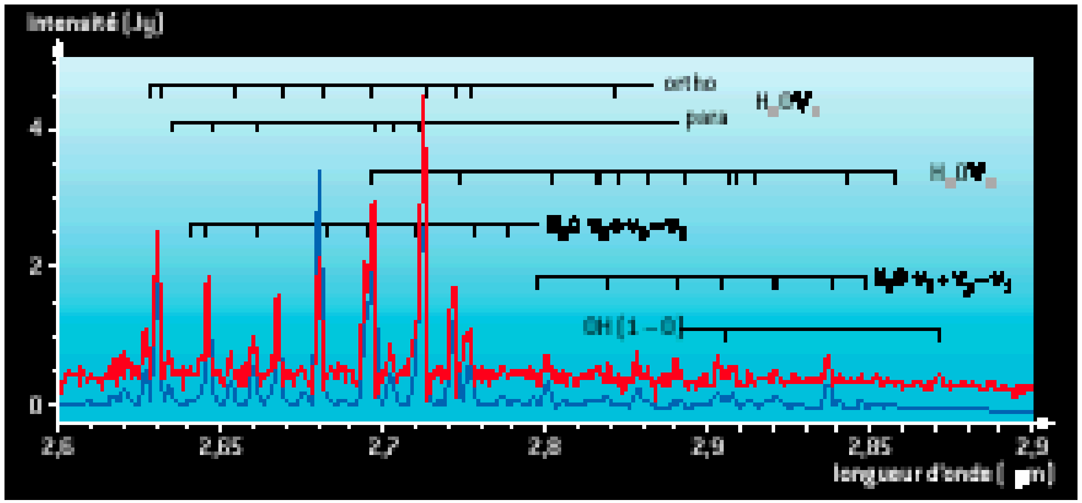
…composed of water ice and et refractory grains

Water in comets

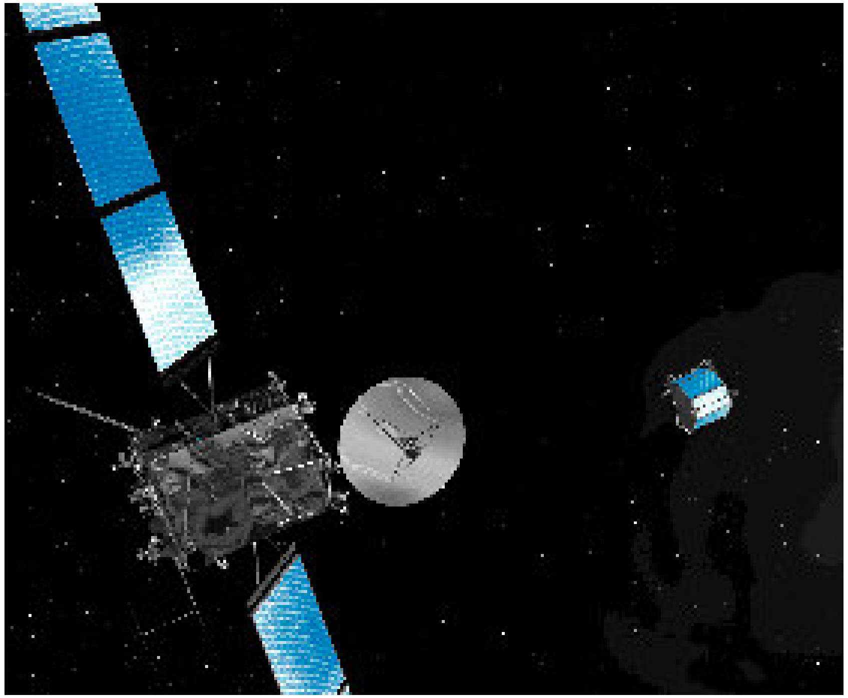
Halley's comet (1986):
une « dirty snowball »...

1997: Hale-Bopp, the giant comet

ISO spectrum
of water
(2.66 µm)



The future of cometary research: the Rosetta mission



Launch: February 2004 (ESA)
Encounter with comet Churyumov-Gerasimenko
End of mission: 2015

Telluric planets

Venus, Earth and Mars:
very differents destinies...

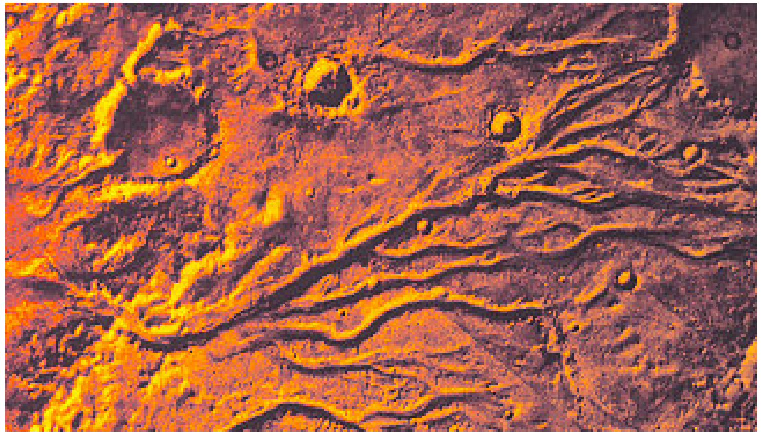
Four very different planets

- Mercury: too small and too hot to keep a stable atmosphere (gravity field is too weak)
- Venus: Ps = 90 bars, Ts = 460°C
  - 96% CO_2, 3% N_2, H_2SO_4 clouds
- Earth: Ps = 1 bar, Ts = 15°C
  - 77% N_2, 21% O_2, H_2O clouds
- Mars: Ps = 0.006 bar, Ts = -55°C
  - 95% CO_2, 3% N_2, H_2O and CO_2 clouds

The role of water and the greehouse effect

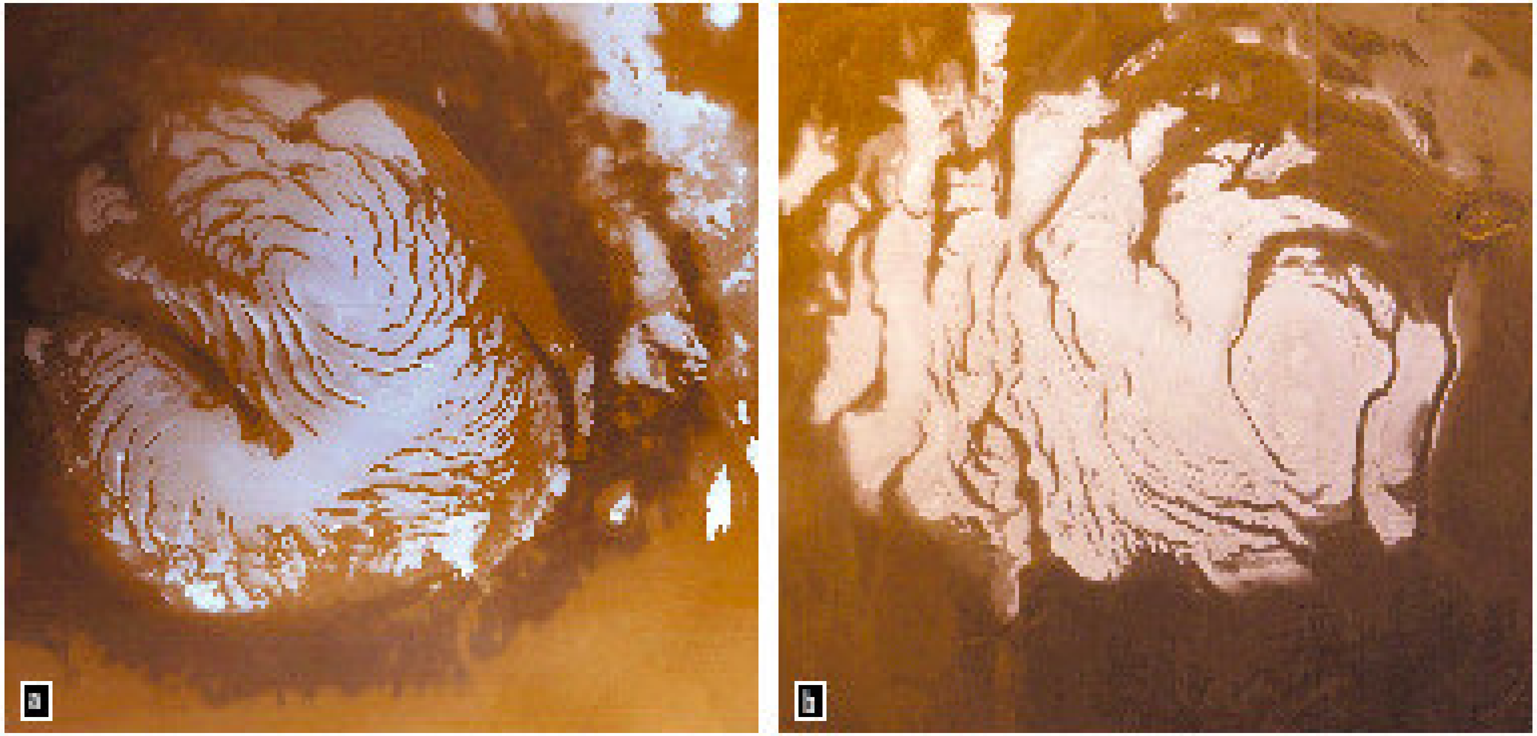
- At the beginning: atmospheres of comparable chemical composition (CO_2, N_2, H_2O, CO)
- On Vénus: H_2O gaseous-> strong greenhouse effects which amplifies -> Ts = 460°C!
- On Earth: H_2O liquid ->CO_2 trapped in the oceans-> effet de serre modéré, Ts=Cst.=20°C
- On Mars: H_2O solid et planet less massive -> low internal activity -> the greenhouse effect vanishes, Ts = -40°C

What happened to water on Mars?



Traces of valley networks and liquid flows:
-> liquid water must have been present
on the Martian surface in the past

The Martian polar caps



North: H_2O ice
South: CO_2 ice + H_2O ice below
(Mars Odyssey, Mars Express)

Mars: open questions…

- Where did the Martian water go? (under the surface, under the caps? Which volume?)
- Did Mars have a warmer and wetter climate in the past?
- If so, could liquid water stay and for how long?
- If so, could life have appeared and developed there?
- If so, could we hope to find fossil traces of life?

The future of the Martian space exploration

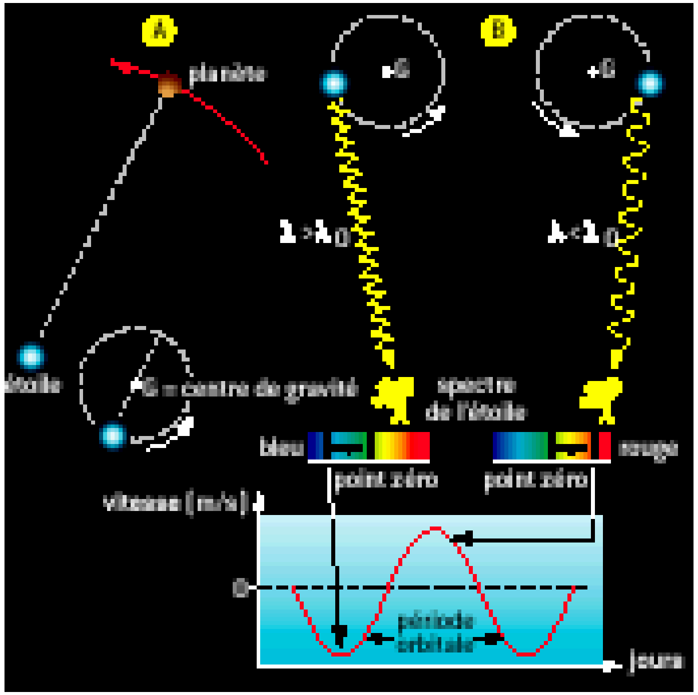
- In-orbit now: Mars Global Surveyor, Mars Odyssey (NASA); Mars Express (ESA)
- Ground Stations: Spirit, Opportunity (NASA)
- Future projects (NASA, ESA?): orbiters and landers
- First objective: « Follow the water! »

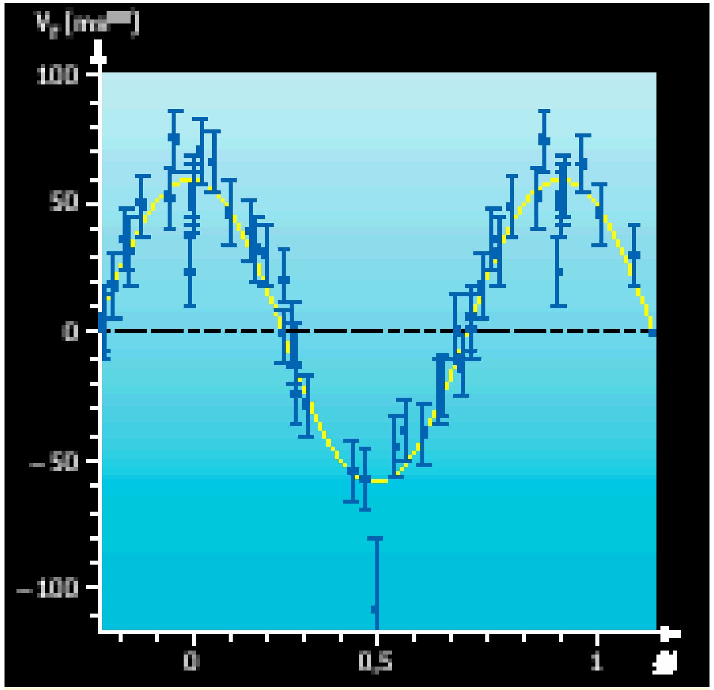
The search for water in extrasolar planets

- Since 1995: about 170 extrasolar planets, most of them giants (« exoplanets ») discovered around nearby stars (< 50 pc)
- Method: velocimetry (measurement of the doppler velocity of the star wrt the center of gravity of the system)

- Another complementary method: measurement of transits (variation of the stellar flux when the star is occulted by its planet))

The velocimetry method

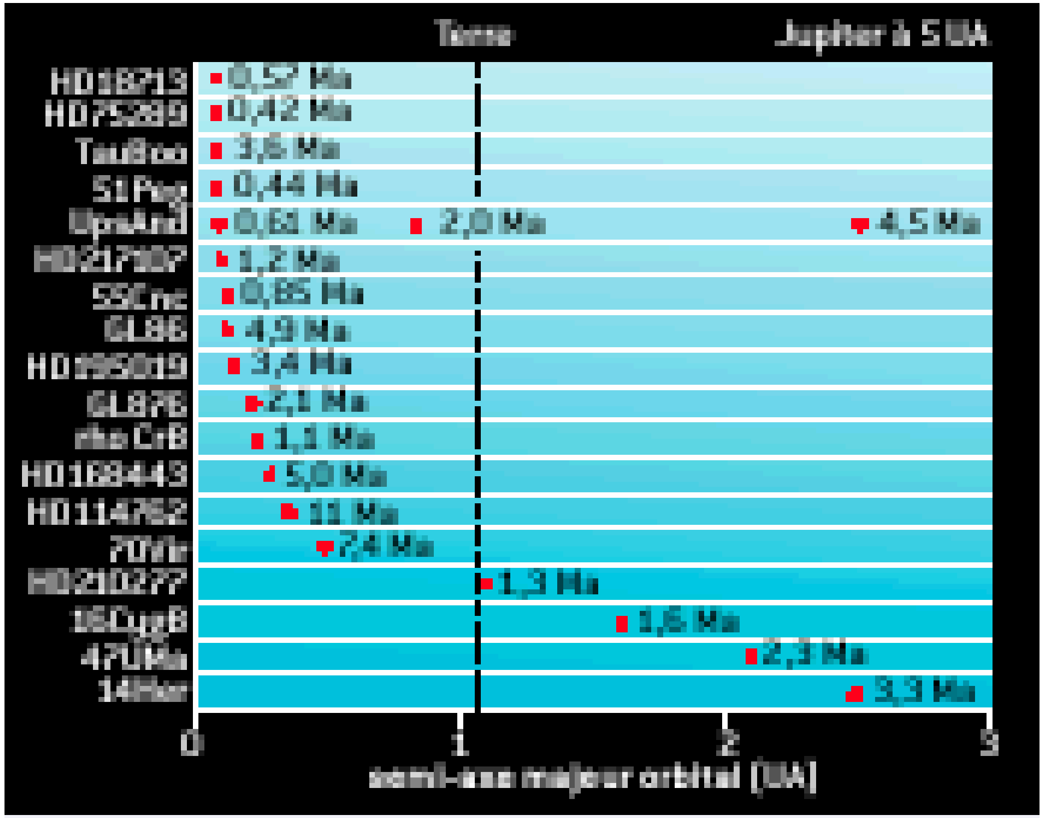




First detection: 51 Peg B (Mayor & Queloz, 1995)

The method is best suited for the detection of giant exoplanets

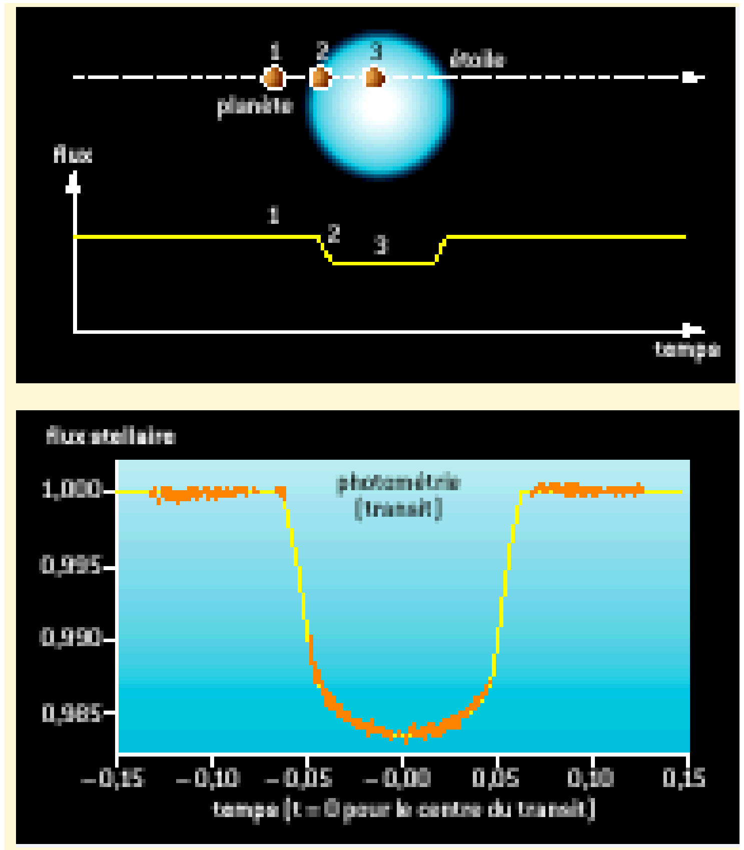
A big surprise: giant exoplanets are very close to their star!



The formation model of exoplanets is different from the solar systeme’s one

The method of transit

Transit of a planet in front of its star
-> decrease of the stellar flux
(Jupiter: 1%; Earth: 0.01%)
->
Possible detection of giant exoplanetes from the Earth,
of earth-like exoplanets
from space



Transit of HD209458B (HST)

The space mission COROT (CNES)

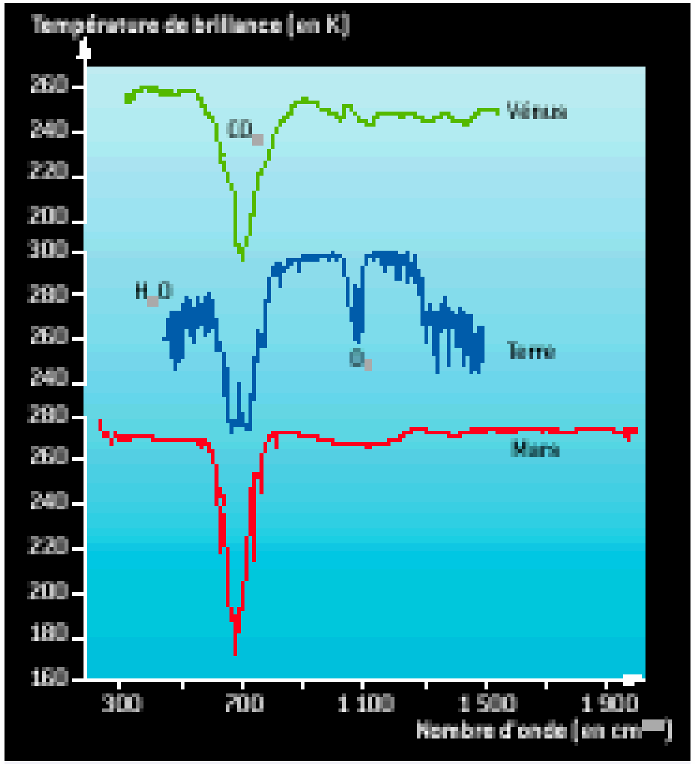
Objectif: recherche des exoterres par observation photométrique de champs stellaires

Lancement: 2006
Durée de vie: 2 ans

How to search for life in Earth-like exoplanets?

- A favorable element (if not mandatory): the presence of liquid water
- Definition of an « habitable zone » around each star, where water can be liquid (T around 0-100°C)
- Exploration of « habitable Earth-like exoplanets »
- Search for spectral signatures: H_2O, O_2, O_3, CH_4
- Advantage of the IR range: better contrast planet/star, stronger spectral signatures

The space mission Darwin-TPF (ESA/NASA)



maging terrestrial exoplanets by interferometry and
Measurement of their infrared spectrum
Launch: > 2015