PLANÉTOLOGIE COMPARÉE & FORMATION PLANÉTAIRE

MASTER I.M.A.G.2.E — Départements Physique & Terre Environnement Espace • Université Nice Sophia-Antipolis

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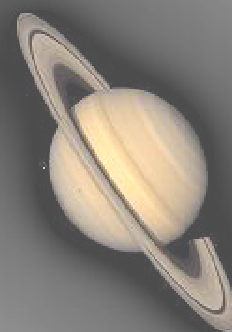
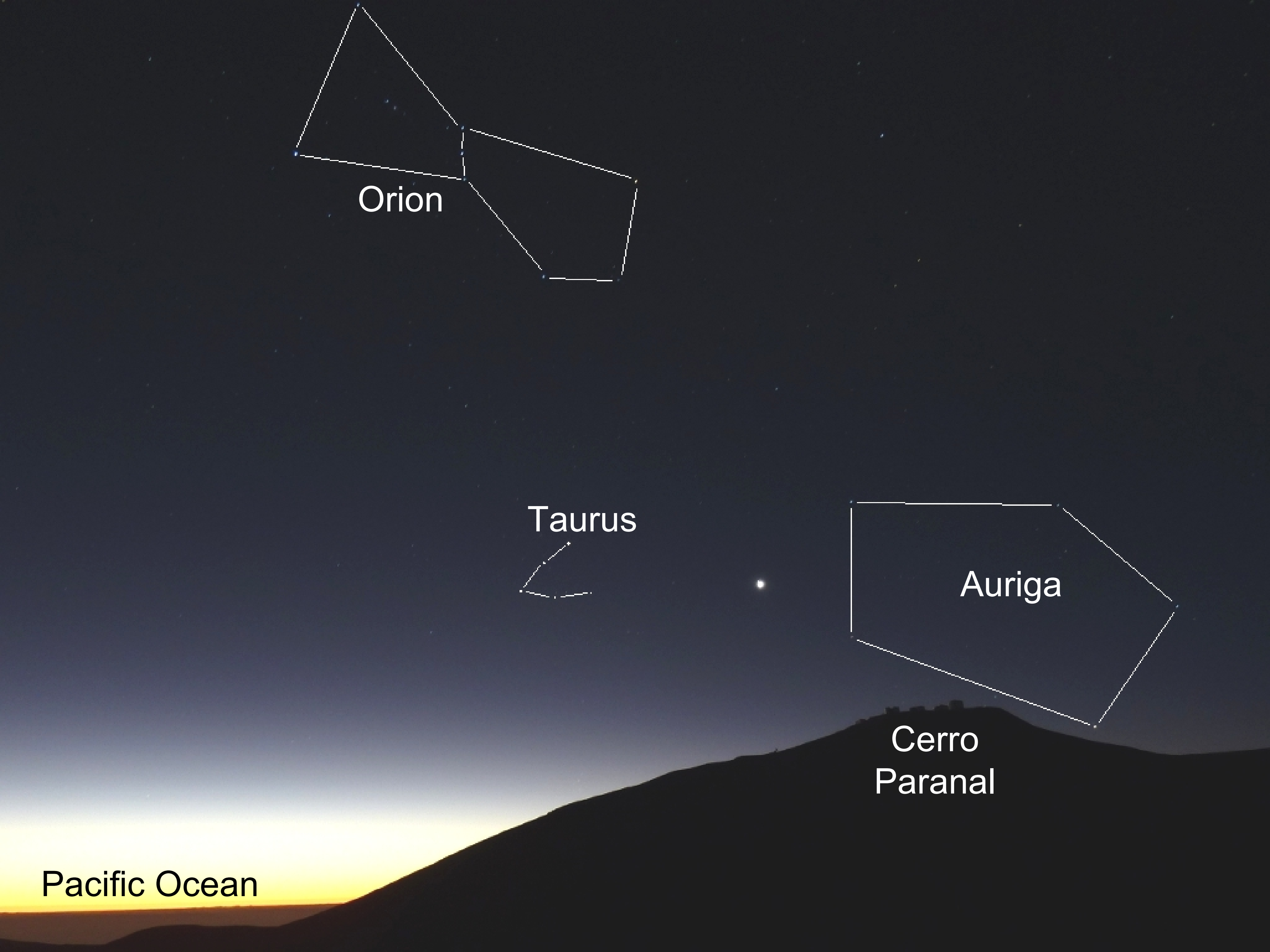


Aurélien CRIDA


Orion
Taurus
Auriga
Cerro
Paranal
Pacific Ocean

7 anomalies in the sphere of the fixed stars
→ 7 days of the week :

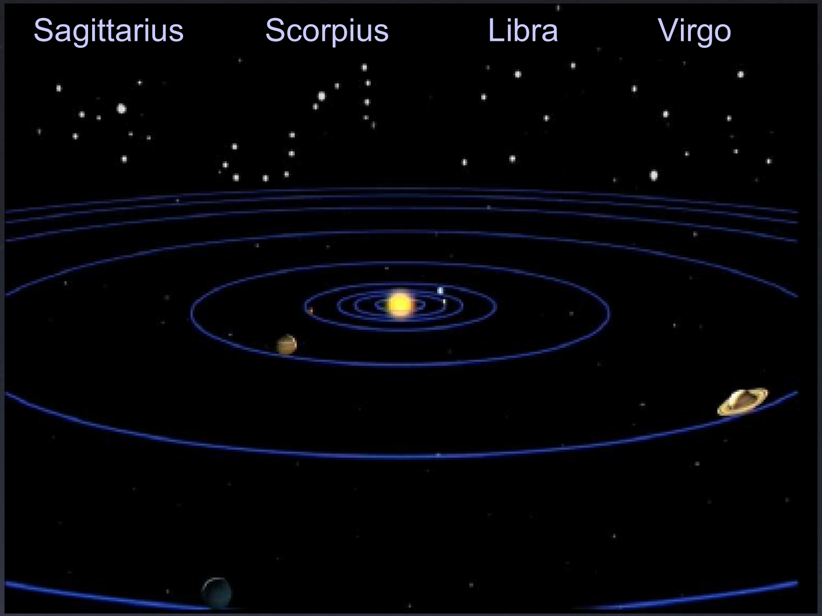
Moon, Mars, Mercury, Jupiter, Venus, Saturn, Sun
Lune, Mars, Mercure, Jupiter, Vénus, Saturne, Soleil.
Lundi, **Mar**di, **Mercre**di, **J**eudi, **Ven**dredi, **Satur**day, **Sun**day

Moving astres, called in greek πλανητηζ , planets.

These celestial bodies move, but not anywhere...
One has never seen a planet in the Big Bear :

Planets belong to the ecliptic plane, whose intersection with the celestial sphere marks the Zodiac.

The sky in May 2007



The Solar System is flat.

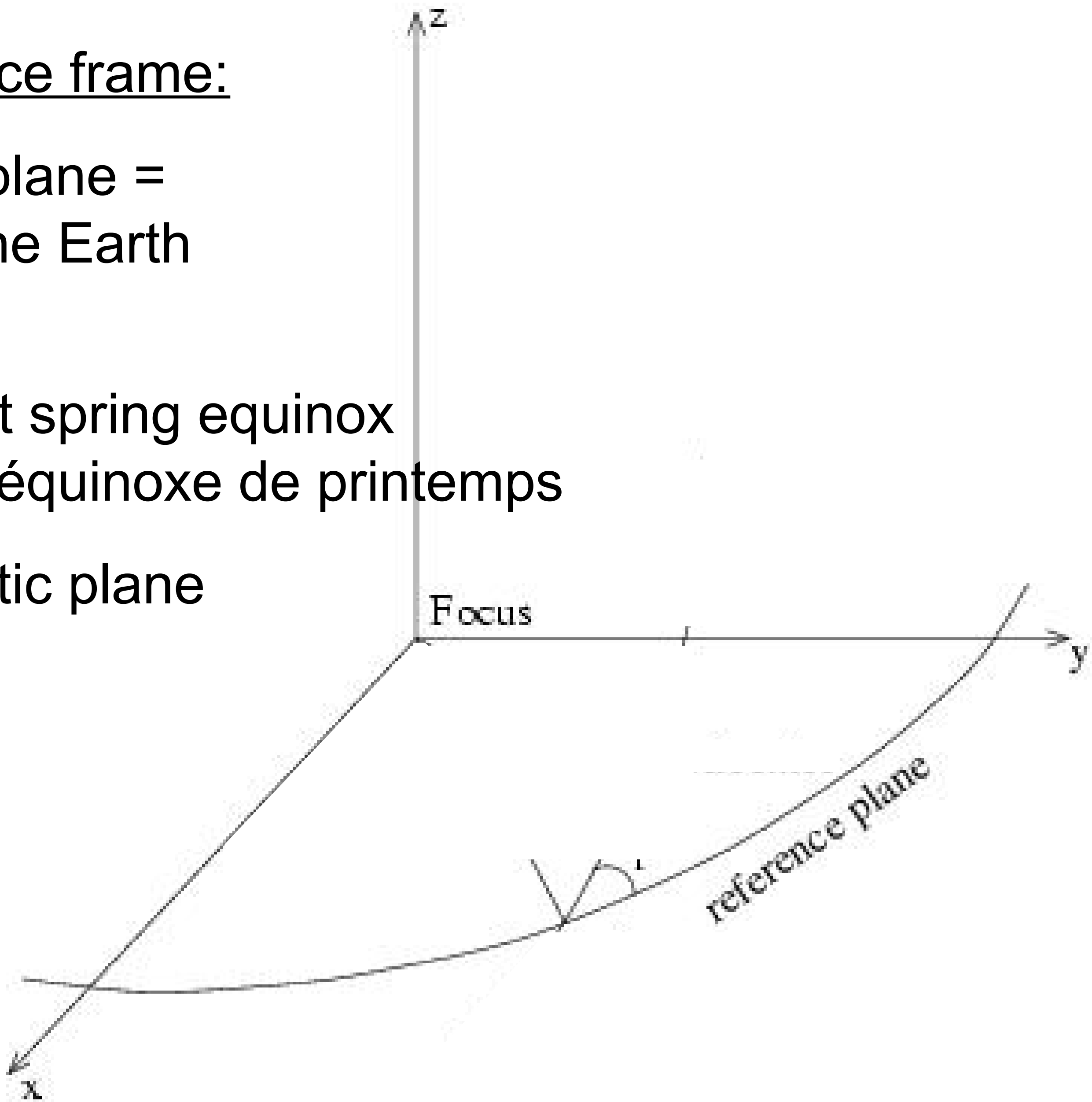
REFERENCE FRAME

Solar System reference frame:

(x,y) plane = ecliptic plane =
plane of the orbit of the Earth

x = vernal point =
direction of the Sun at spring equinox
direction du Soleil à l'équinoxe de printemps

= intersection of ecliptic plane
and equatorial plane



ORBITAL ELEMENTS

i = inclination / inclinaison

Ω = longitude of the (ascending) node
longitude du noeud (ascendant)

ω = argument of the pericenter
argument du péricentre

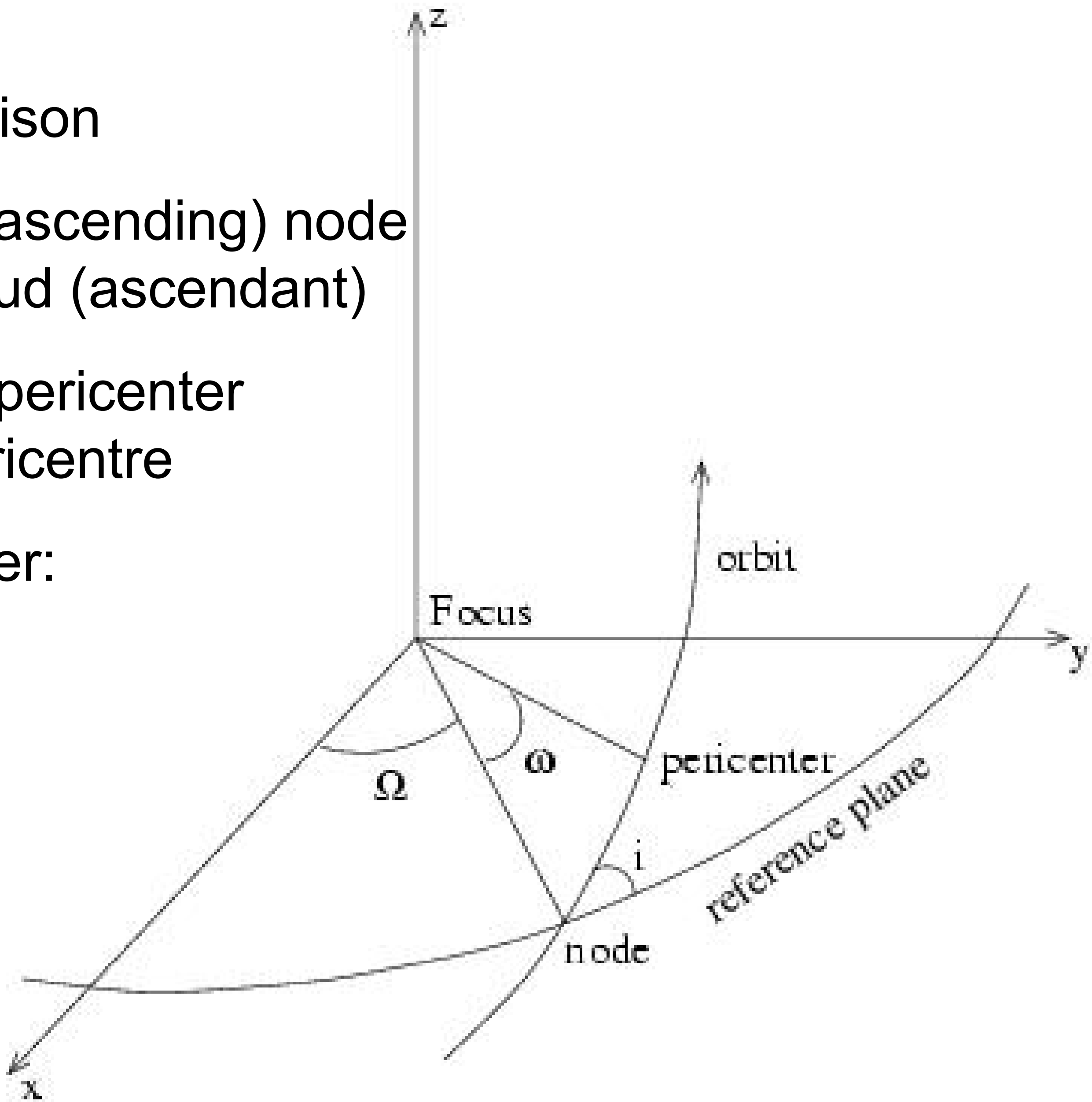
Longitude of pericenter:

$\varpi = \omega + \Omega$

Mean longitude:

$\lambda = M + \varpi$

Longitude :
angle / frame



ORBITAL ELEMENTS

a = semi major axis / demi grand axe

e = eccentricity / excentricité

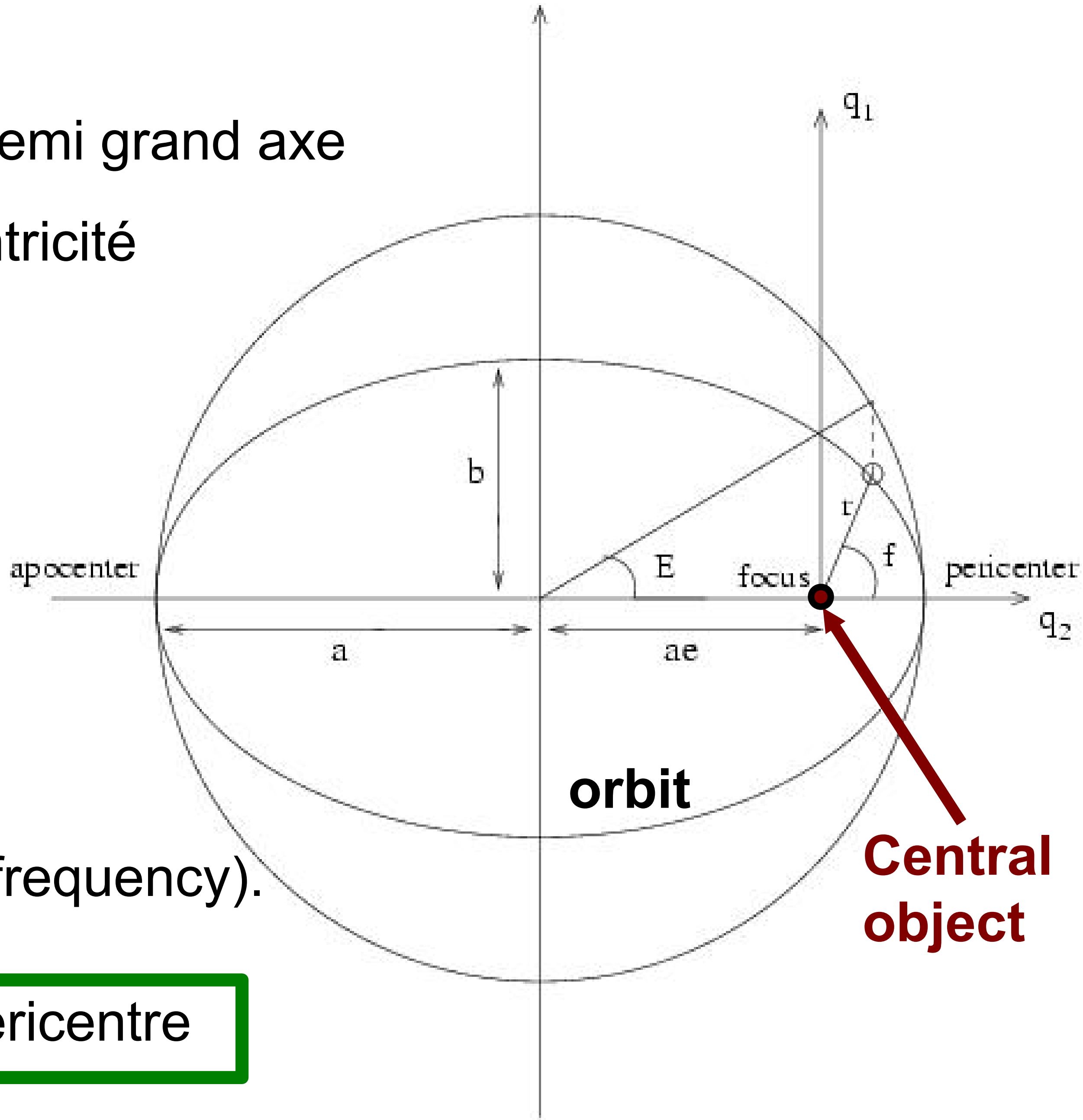
f = true anomaly / anomalie vrai

E = eccentric anomaly anomalie excentrique

Mean anomaly / Anomalie moyenne :

$M = E - e \sin E = n\,t$

$n = (GM_*)^{1/2}/a^{3/2}$ (orbital frequency).



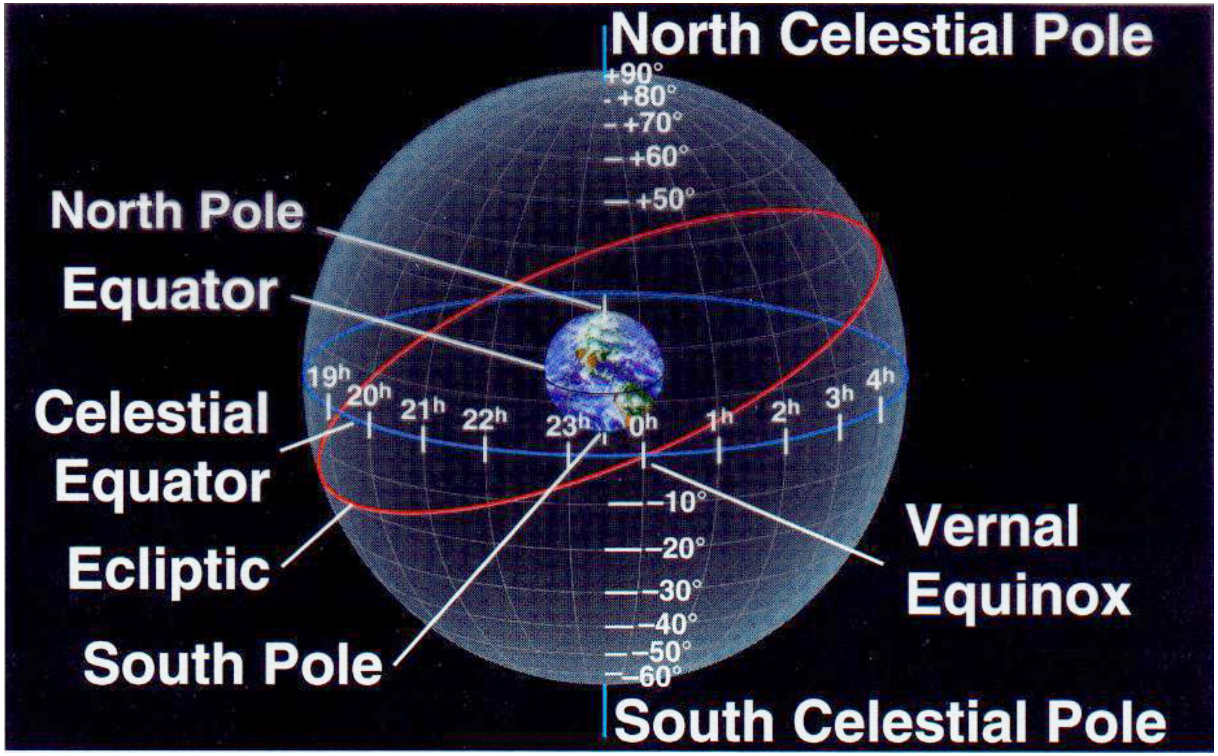
Anomaly : angle / pericentre

CELESTIAL COORDINATES

Sky coordinates :

latitude = declination / déclinaison, δ
from +90° above Earth's north pole.

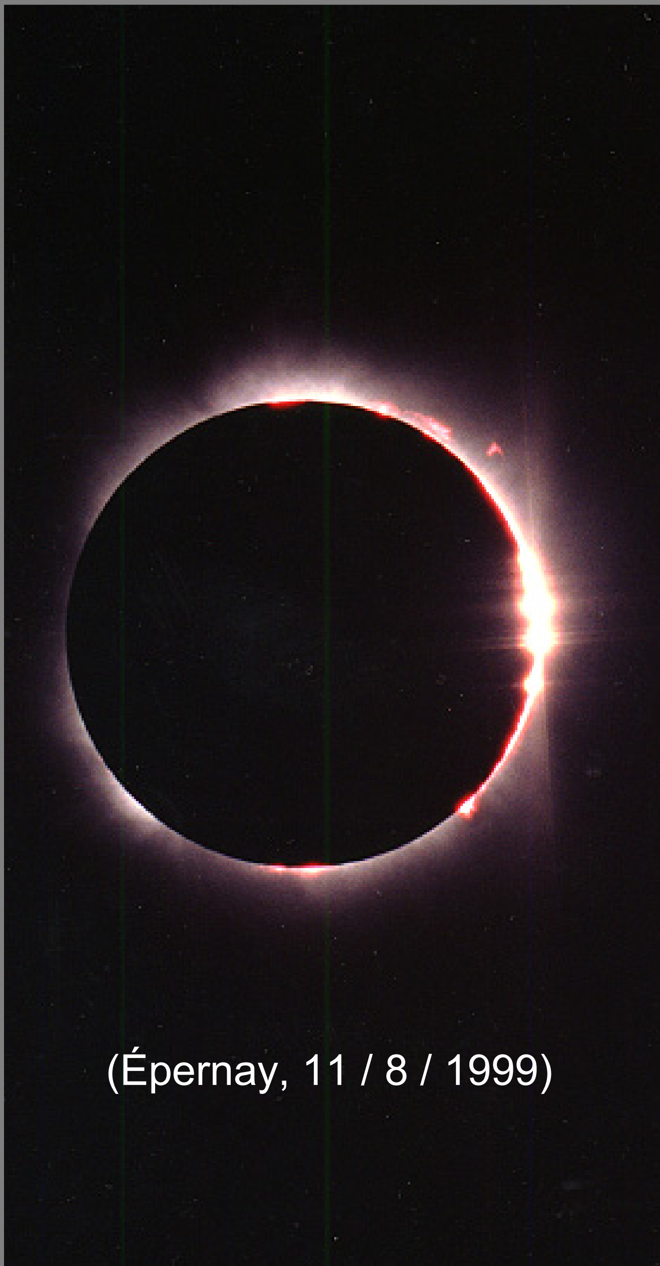
Longitude = right ascension / ascension droite, α
from vernal point.
Given in hours :
24h = 360°



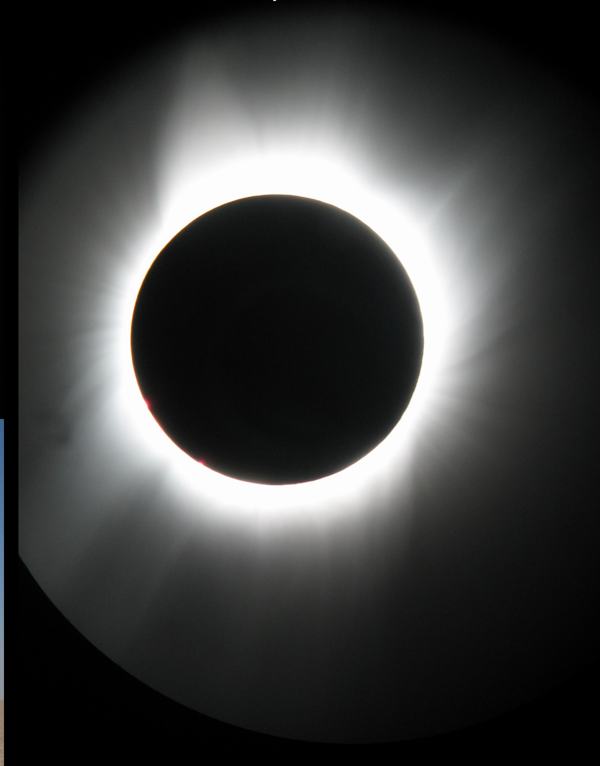
The Solar System is flat, and one can see it !

What else can we say from simple observations ?

The Sun has the same angular diameter as the Moon.



(Sahara Libya, 26 mars 2006)



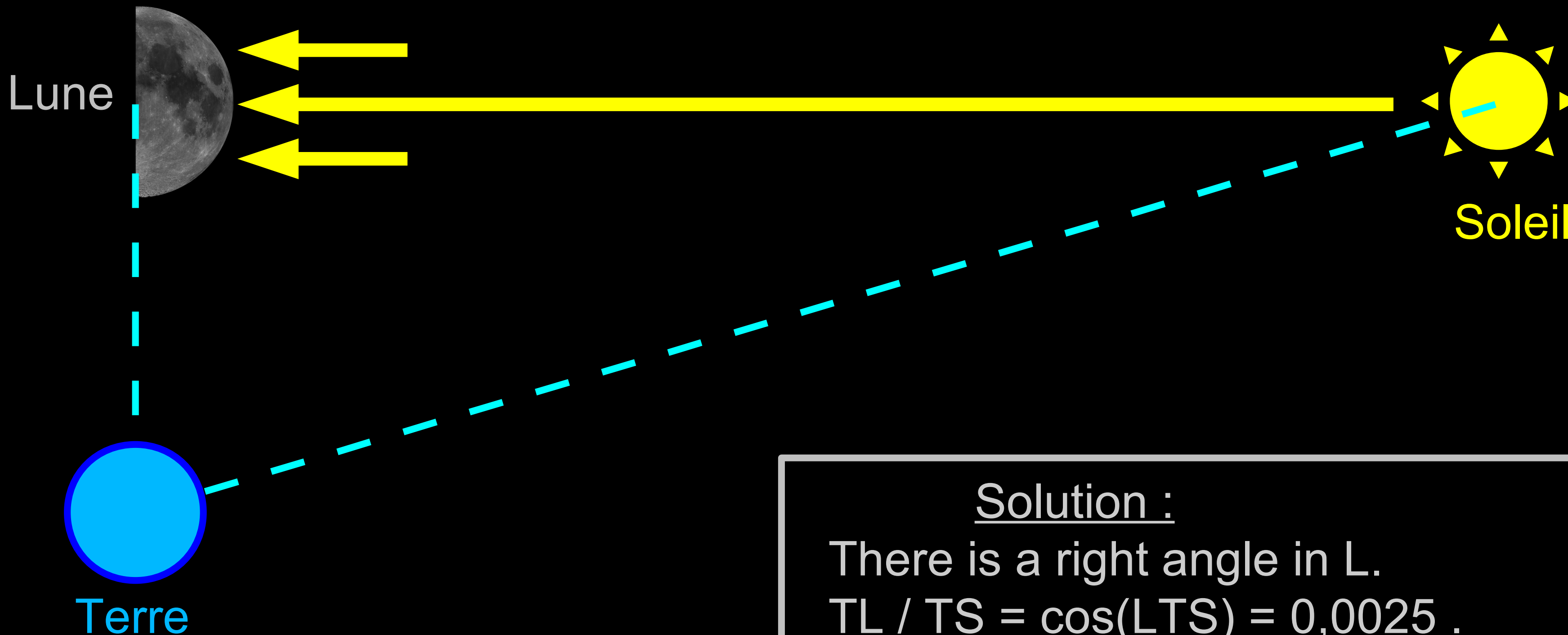
The Moon is about 4 times smaller than the Earth.

<u>Exercise :</u>

Draw the Earth, its shadow, the Moon, its shadow, respecting the relative sizes.

At first Quarter, what can we say about the triangle TLS ?

If the angle LTS is 89.85°, how far/big is the Sun ?



<u>Solution :</u>

There is a right angle in L.

TL / TS = cos(LTS) = 0,0025 .

Thus TS = 400 x TL.

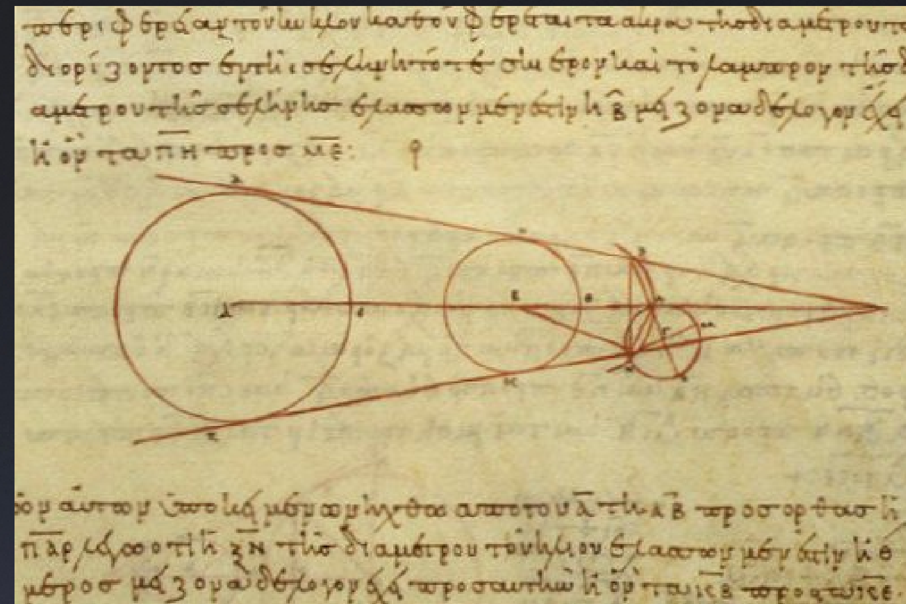
The Sun is 400 times further, thus larger than the Moon (as they have the same angular diameter).

Hence 100 times larger than the Earth.

The Sun is 100 times larger than the Earth,

so, the Earth should rotate around the Sun...

Alexandra Tavernier
(championne du monde junior)



Aristarchus of Samos
(-310 -230)

We have ratios only. How to close the system ?

We need 1 length.

- the size of the Earth, for instance... see Eratosthenes

- the measure of the AU... use Venus transit (XVIIIth century).

- the Earth-Moon distance, using the Laser-Lune at O.C.A. …

Then, using Kepler's law $P^2=(4\pi^2/GM_{sun})a^3$,
all the distances of the planets to the Sun can be known.

1781 : Discovery of Uranus, in the ecliptic plane.

1801: Discovery of Ceres → a new planet !

Then, discovery of other asteroids → asteroid belt.

1846 : Discouvery of Neptune.

1930 : Discouvery of Pluto → 9^{th} planet !

Then, discovery of other trans-neptunian objects, a few being even larger → Kuiper belt.

We need a clear definition of a planet.

Official definition (IAU, 2006) :

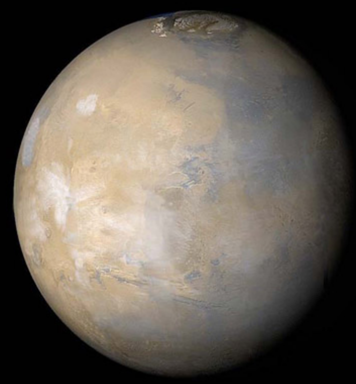
A planet is a celestial body that
- orbits around the Sun,
- has a large enough mass so that its own gravity gives it a spherical shape (hydrostatic equilibrium),
- dominates the local dynamics, has eliminated any other body on a nearby orbit.

There are 8 planets in the Solar System.

If the third condition is not met : *dwarf planet*

There are 3 dwarf planets in the Solar System :
Eris, Pluto, Ceres

What is the critical size to have a spherical shape ?



Exercice :

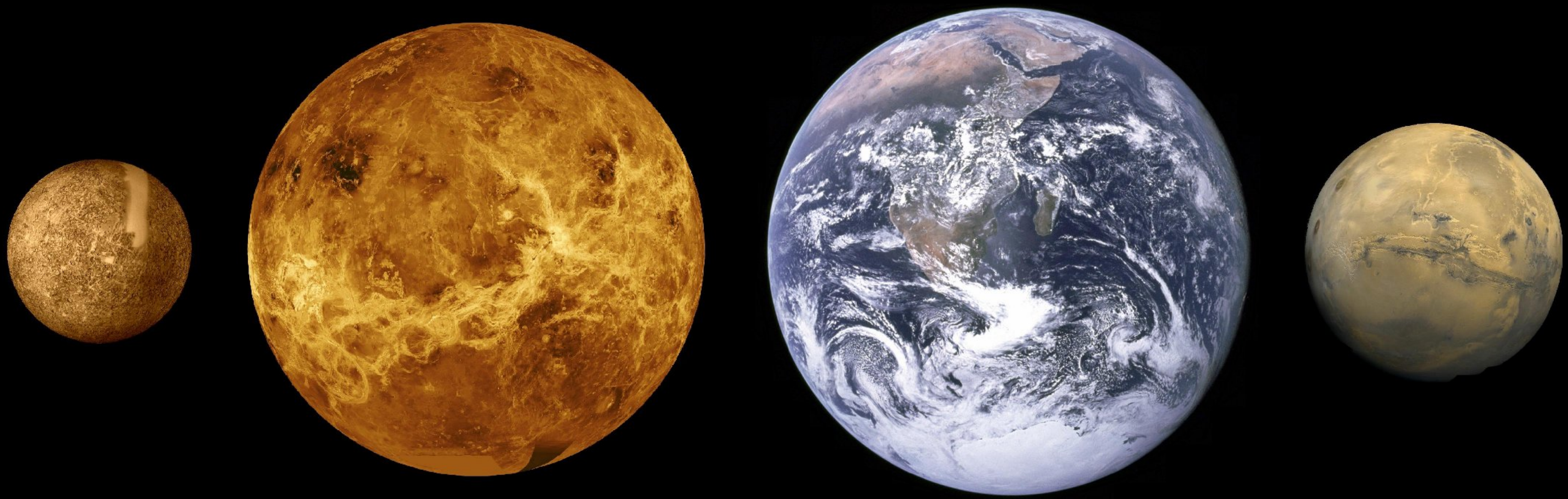
Compute the maximum height *h* of a mountain at the surface of a planet of radius *R*.

Data :

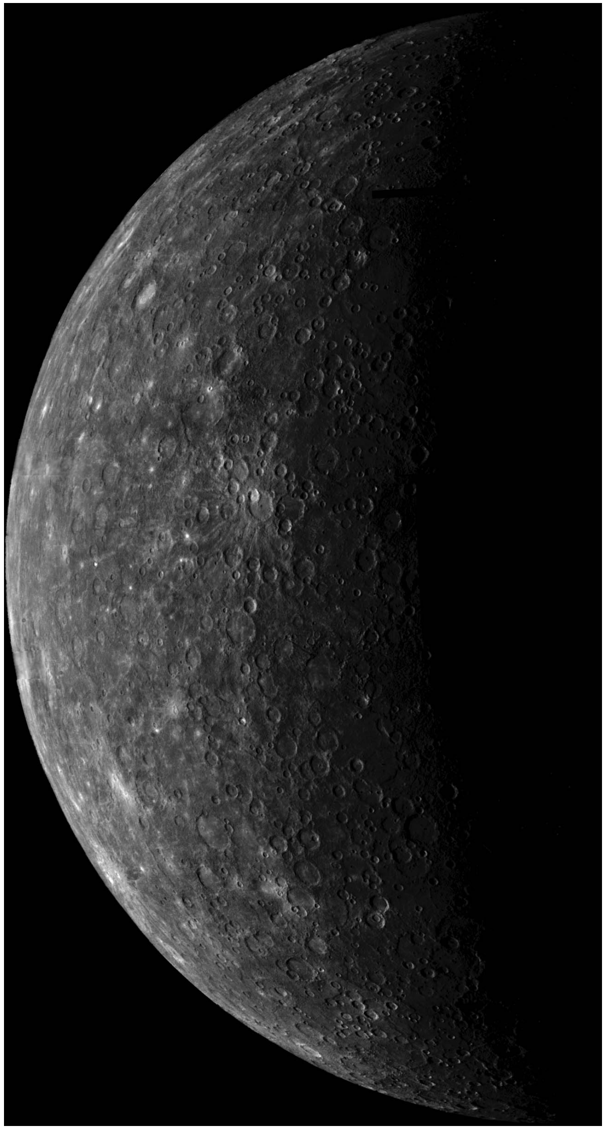
density $\rho = 5000$ kg.m^{-3}.

Latent heat of fusion $c_f = 120$ kJ/kg.

TERRESTRIAL PLANETS



MERCURY ☿



<u>Density :</u> 5 340 kg.m^{-3}.

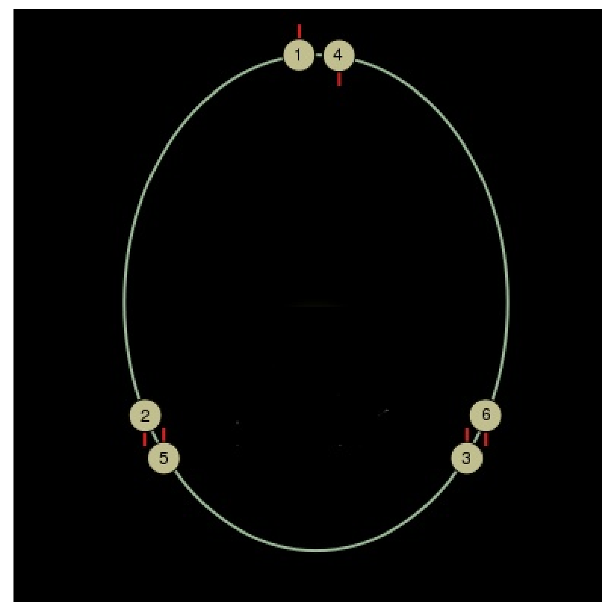
<u>Semi major axis :</u> 0.387 AU.

<u>Eccentricity :</u> 0,2

<u>Mass :</u> 1/20 of Earth

<u>Mag field :</u> ~Earth's field / 60.

<u>Rotation :</u>
spins 3 times
in 2 orbits
around the Sun.
(*resonance*)



MERCURY ☿

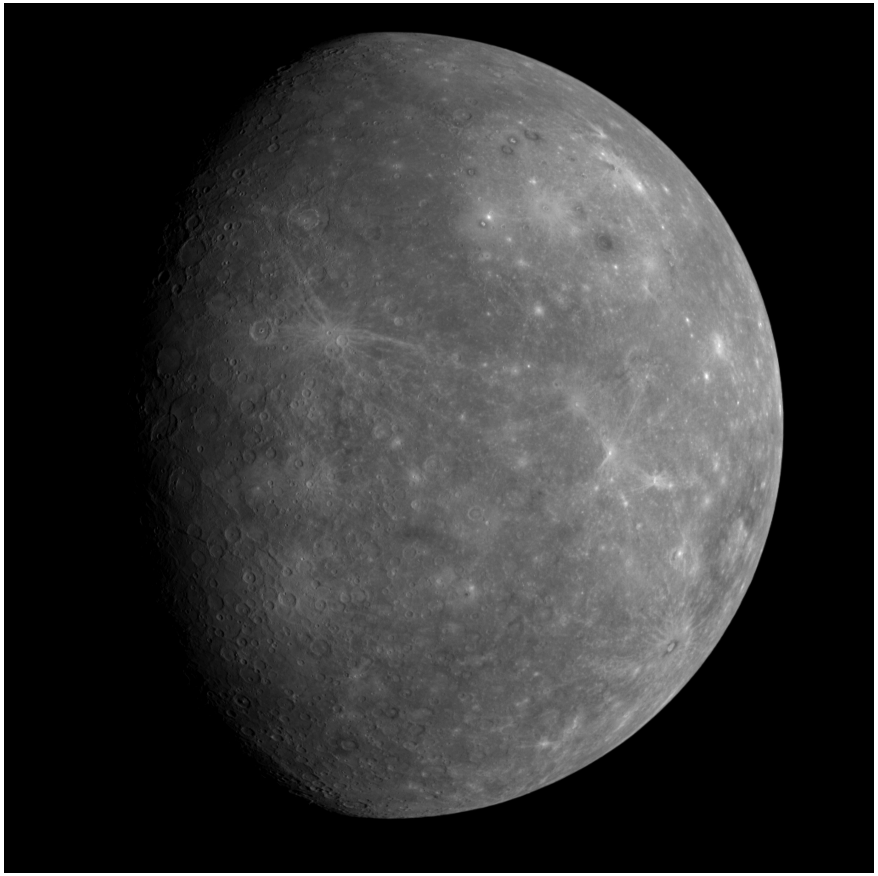
<u>Exploration and future :</u>

Messenger (NASA) since 2011.

Beppi-Colombo (ESA/JAXA) from 2020.

Where does the magnetic field come from ?

Is there a liquid core ?



VENUS ♀

Semi major axis: 0,72 AU.

Mass : 5/6 Earth.

Atmosphere: 95 Bar on the ground.

Density : 5270 $kg.m^{-3}$.

Rotation : Retrograde (or inclination = 177°).

VENUS ♀

Transit of Venus in front of the Sun observed on June, the 8th, 2004 with the « équatorial coudé » of the Nice observatory.

Historical importance :

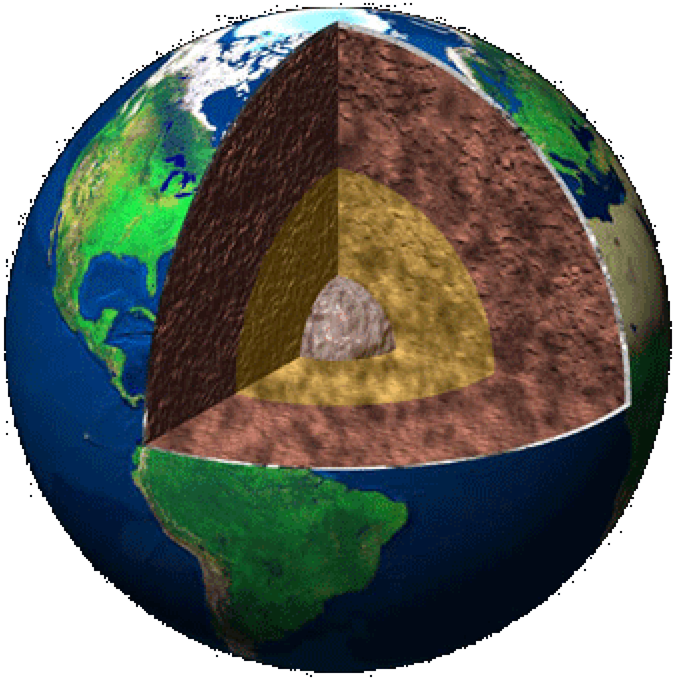
determination of the Astronomical Unit in 1761 and 1769.

EARTH

Semi major axis : 1 UA = 149 597 887 km.

Eccentricity : 0,016.

Rotation : periode = 23h56min, inclinaison = 23,4°.

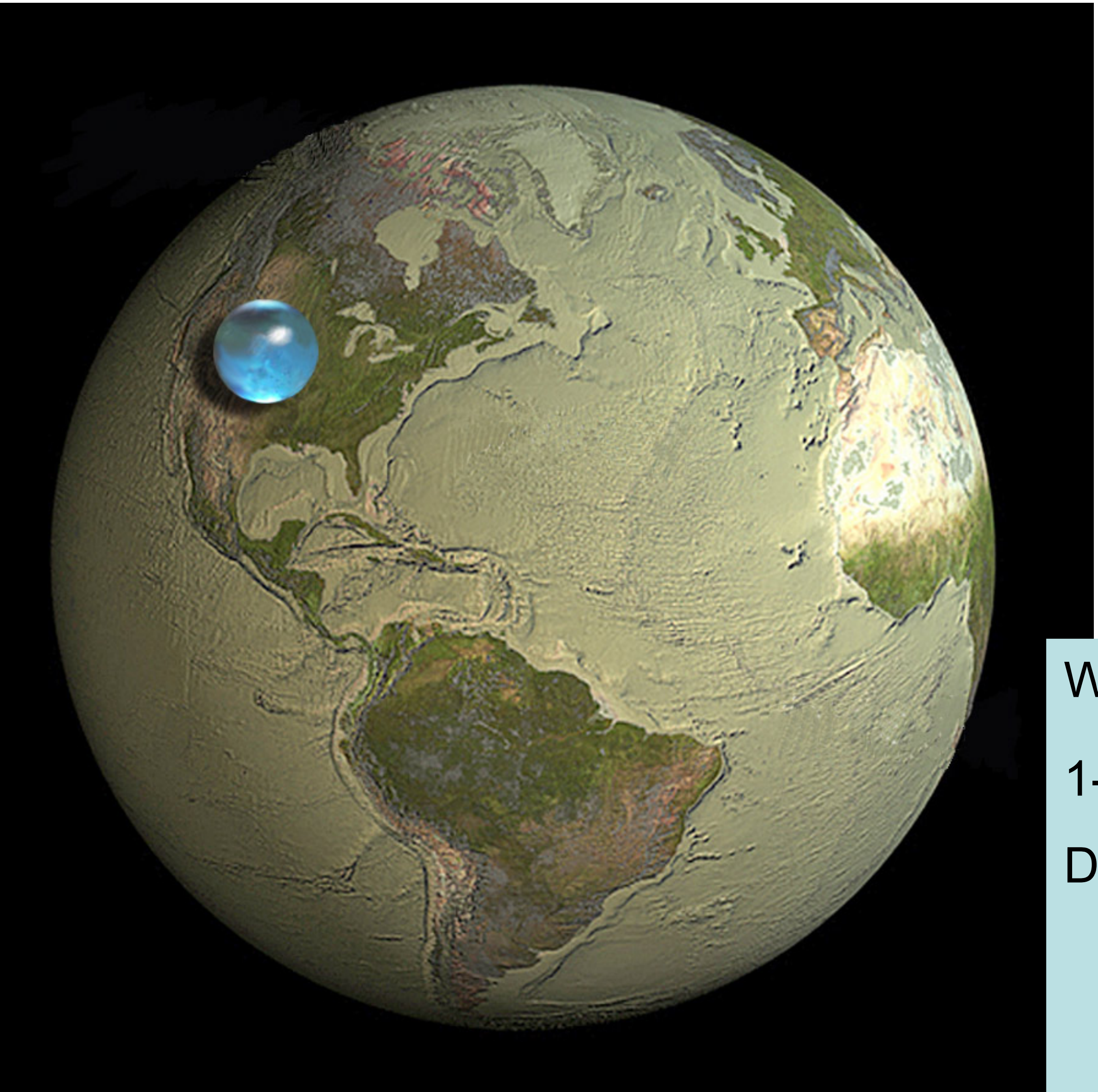


Mass : 6 x 10^{24} kg = 3 x 10^{-6} M_{sun}.

Density : 5 515 kg.m^{-3}.

EARTH

A dry planet !



Water: $2,5 \times 10^{-4}$ M_{Earth} on top

1-10 times more in the mantle

D/H ratio: 6x the solar value

1/2x the comet value

~ meteorites' value

EARTH-MOON

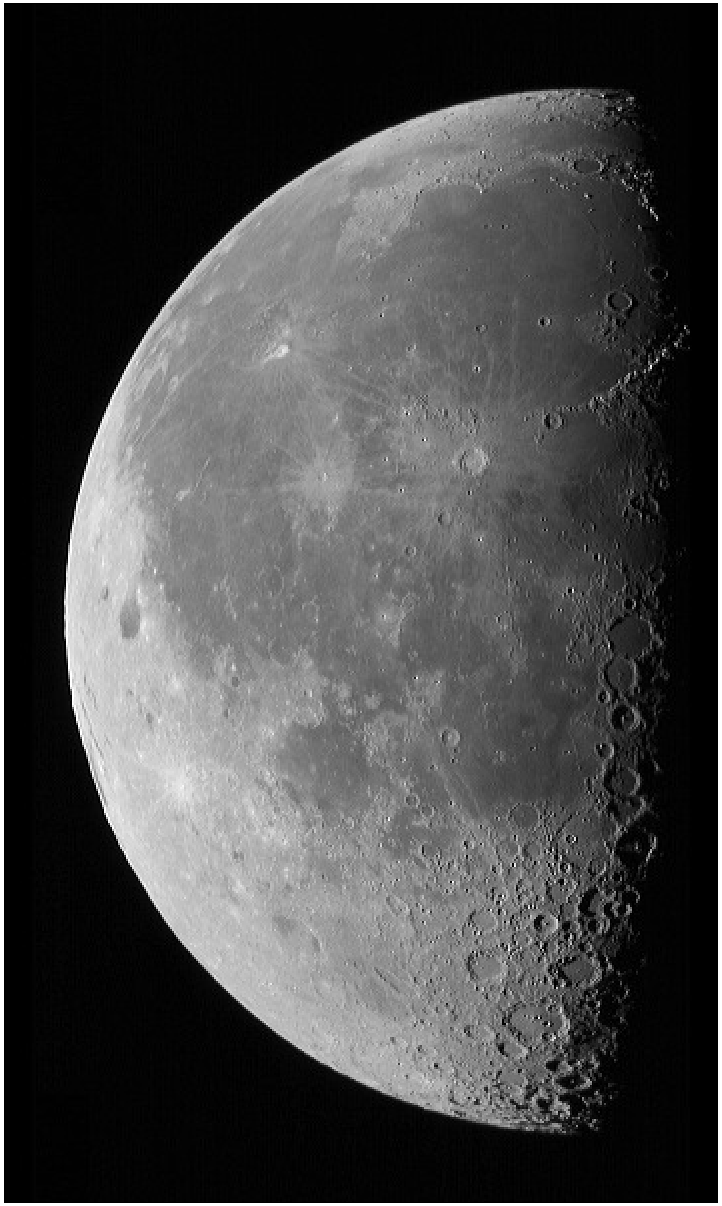
Seen from Saturn, by Cassini

<u>Exercice :</u>

The angular diameter of the Moon from Earth is ~(1/2) degree.

What is the Earth-Moon distance ? (in R_{Earth} and in km)

MOON

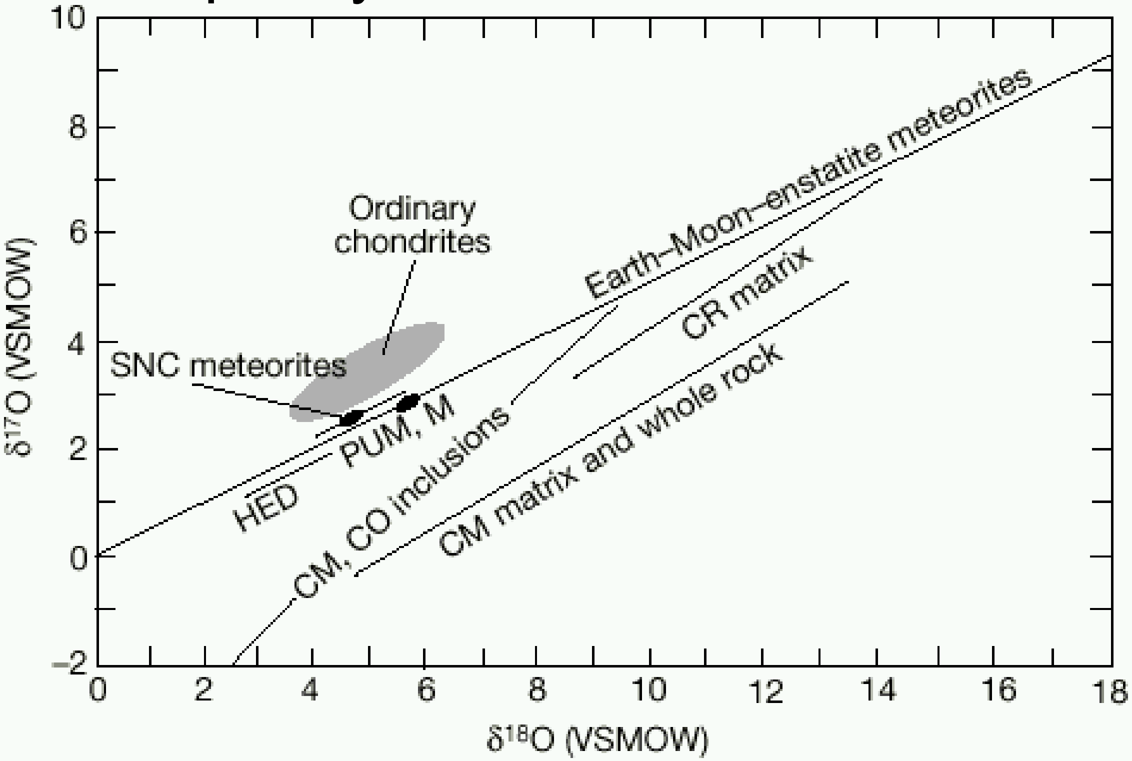


Mass : ~ 1/100 M_{Earth}

Very small core < 4% mass

Chemically very close to the Earth's mantle (drier).

Isotopically **identical** to the Earth.



MOON

Water : The spacecraft Lcross has detected hydrogen on the Moon,

(26 gallons, inside a hole of 60 to 100 feet, after an impact at 5600 miles/h)

Inside a crater of the south pole, permanently in the shadow.

(see Hergé, 1954)

WATER

Where does it come from ?

No ice closer than ~4 AU from the Sun in the primitive nebula (see next lectures).

Brought by comets (50% ice) ?
Not compatible with D/H = 300 for comets, 150 for Earth...

Chemical reactions between SiO_2 and $H_2 \rightarrow H_20$?

Brought by icy asteroids (10% ice, D/H compatible) ?

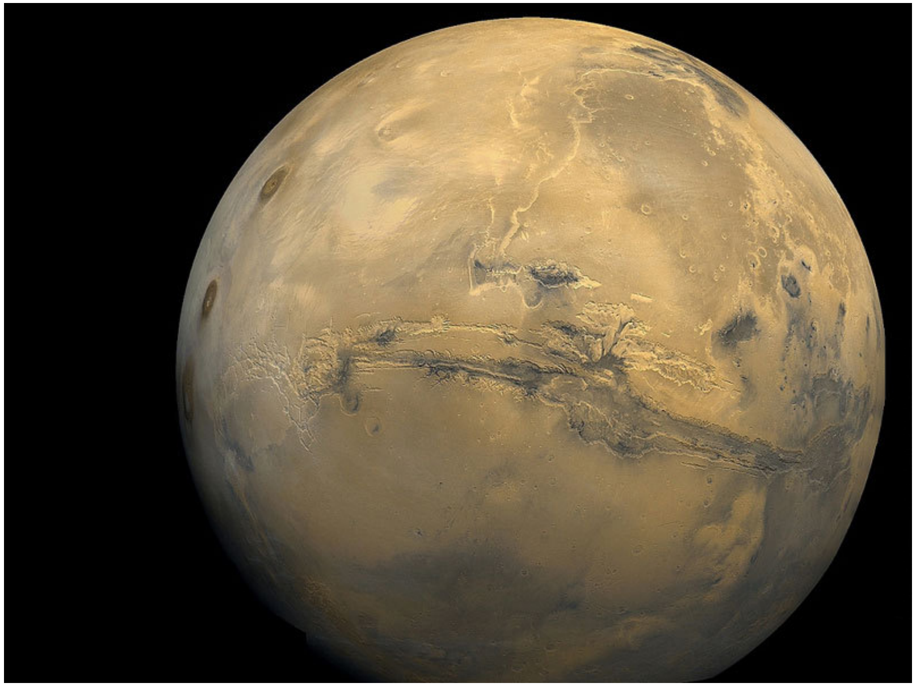
How does it leave ?

Thermal escape : $v_i = (2kT/m_i)^{1/2}$ $\rightarrow$ faster for H.

If $v_i > v_{echap}/2$, loss. Relative enrichment in Deuterium.

On Earth : loss ~ 1m water per Ga. On Venus : 1km/Ga.

MARS ♂



Semi major axis : 1,52 UA.

Eccentricity : 0,09.

Rotation : période = 24h37min
inclinaison = 25,2°.

Masse : 0,1 M_{Earth}.

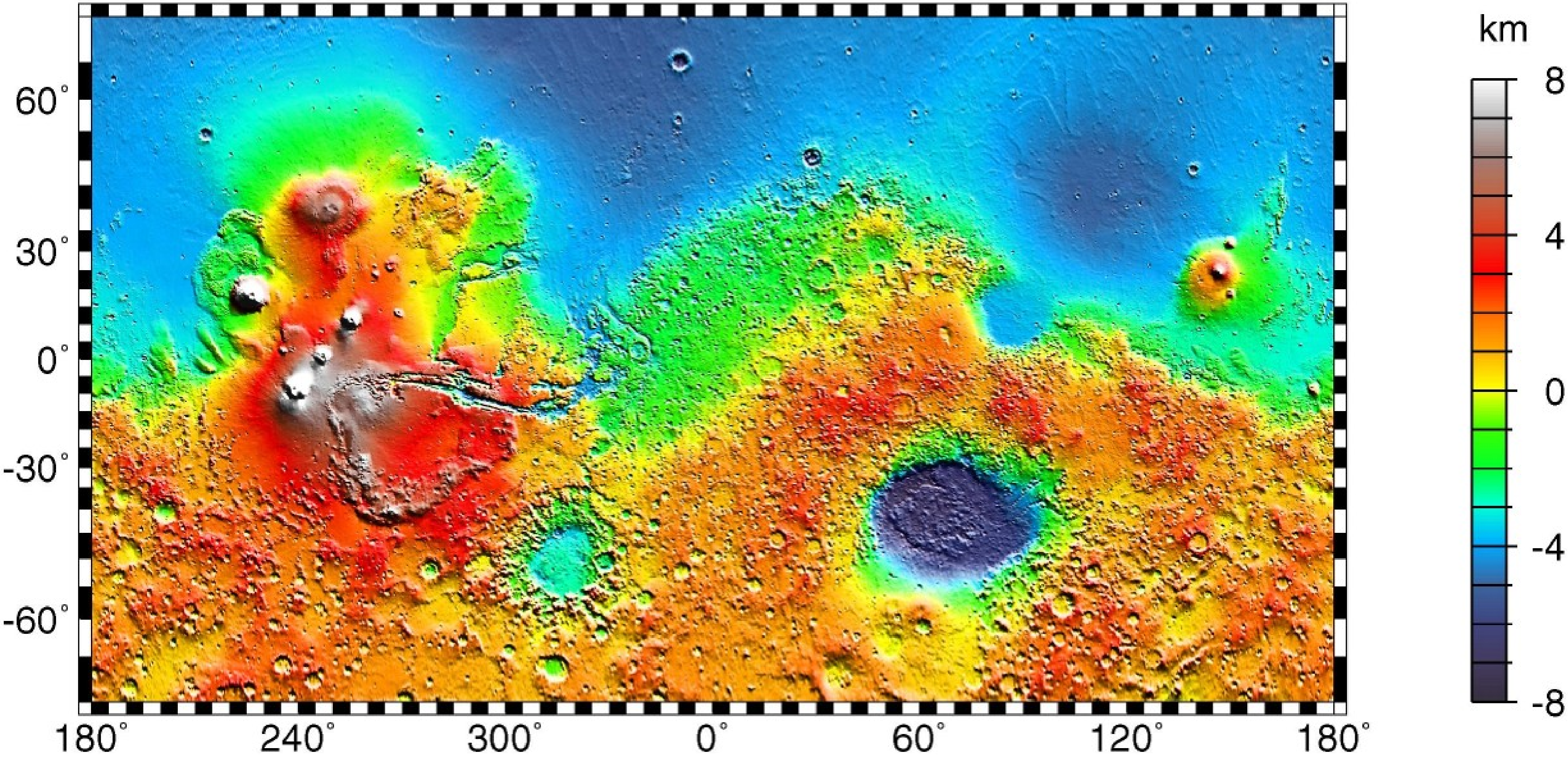
Density : 3 934 $kg.m^{-3}$.

Water : in the polar caps + ice in the ground (permafrost).

Proofs of past water presence : hydrated minerals, chenals...
Essentially lost with the atmosphere.

MARS

North-South dichotomy



COMMON PROPERTIES

<u>Similar average density.</u>

Mix of Fe, Mg, Si, O (95%) ; Ca, Al, Ni, S (4,99%).

$E_{pot} = 0,6\ GM^2/R$.

Temperature reached by accretion :

T prop. to E_{pot}/M, that is to R^2.

R>1000km => T>1000 K.

+ other heat sources (radioactivity)

Planets are born melted !

→ **Differenciation** , if R > ~1000 km.

INTERNAL STRUCTURE

Ex: the Earth.

Masses (in 10^{24}kg) :

Atmosphère = 0.0000051

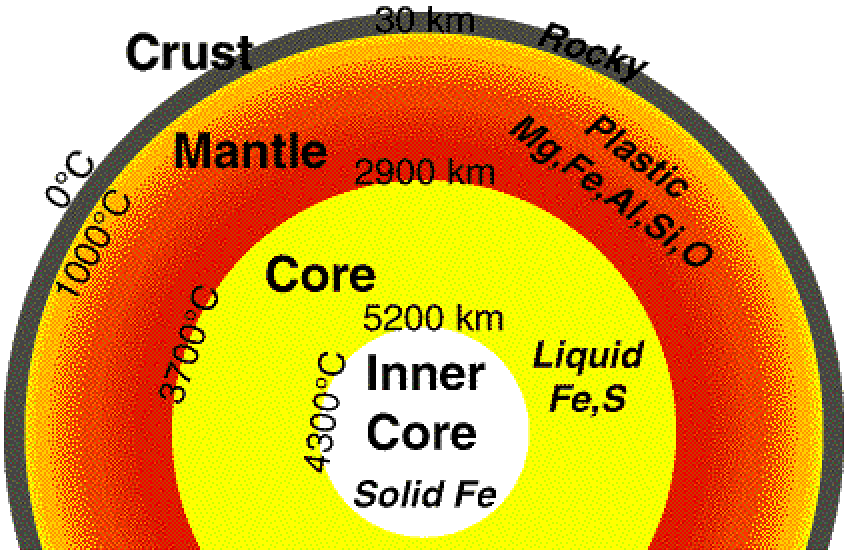
Oceans = 0.0014

crust = 0.026

Mantle = 4.043

Outer core = 1.835

Inner core = 0.09675

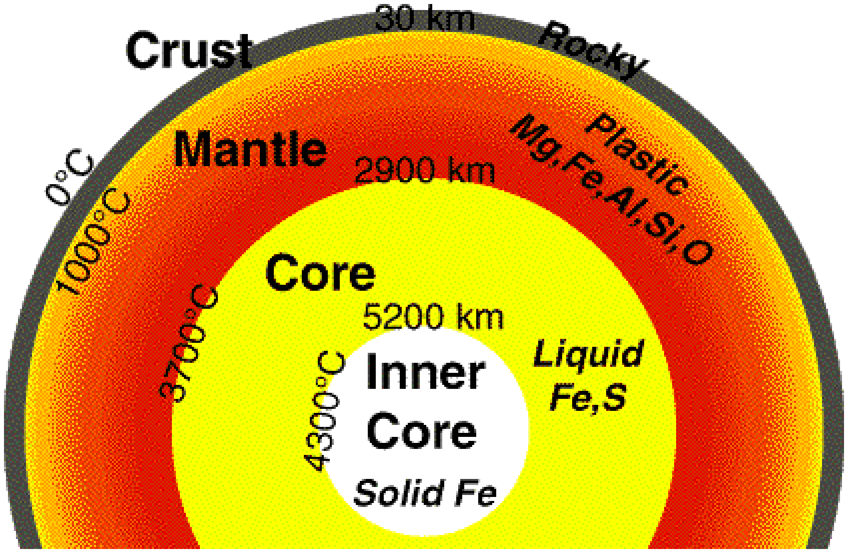


Presence of a solid graine ?
Depends on the Equation Of State, and of the size of the planet.

INTERNAL STRUCTURE

Heating by radioactivity :

Convection
→ plaque tectonics, volcanism → carbon cycle.



Liquid core → dynamo → magnetic field.

→ Stabilisation of the atmosphere.

INTERNAL STRUCTURE

Planet of radius R:

$$M(r) = 4\pi \int_0^r x^2 \rho(x)\, dx$$

$$P(r) = P_{surface} + \int_r^R \rho(x) g(x)\, dx$$

$$g(r) = \frac{GM(r)}{r^2}$$

$$M_p = M(R)$$

$$P(R) = P_{surface}$$

A.N. : Compute P at the center if P_{surf}=1Bar, R=6400km, ρ=5000 kg.m^{-3}=C^{te}.

Differenciated planet : $0<r<r_N$: $\rho=\rho_n$; $r_N<r<R$: $\rho=\rho_m$.

A.N. : $M_N=M_p/3$, ρ_n=9000 kg.m^{-3}, ρ_m=3000 kg.m^{-3}.

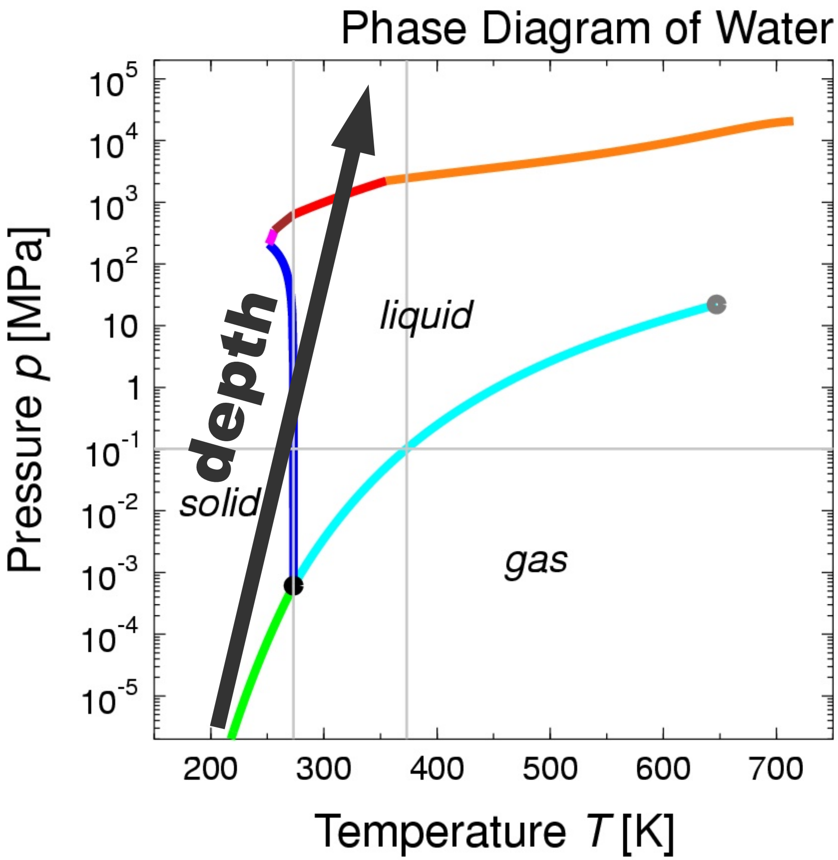
INTERNAL STRUCTURE

Solid or liquid ?

Depends on the Equation Of State...

ex1: Iron ; core – graine.

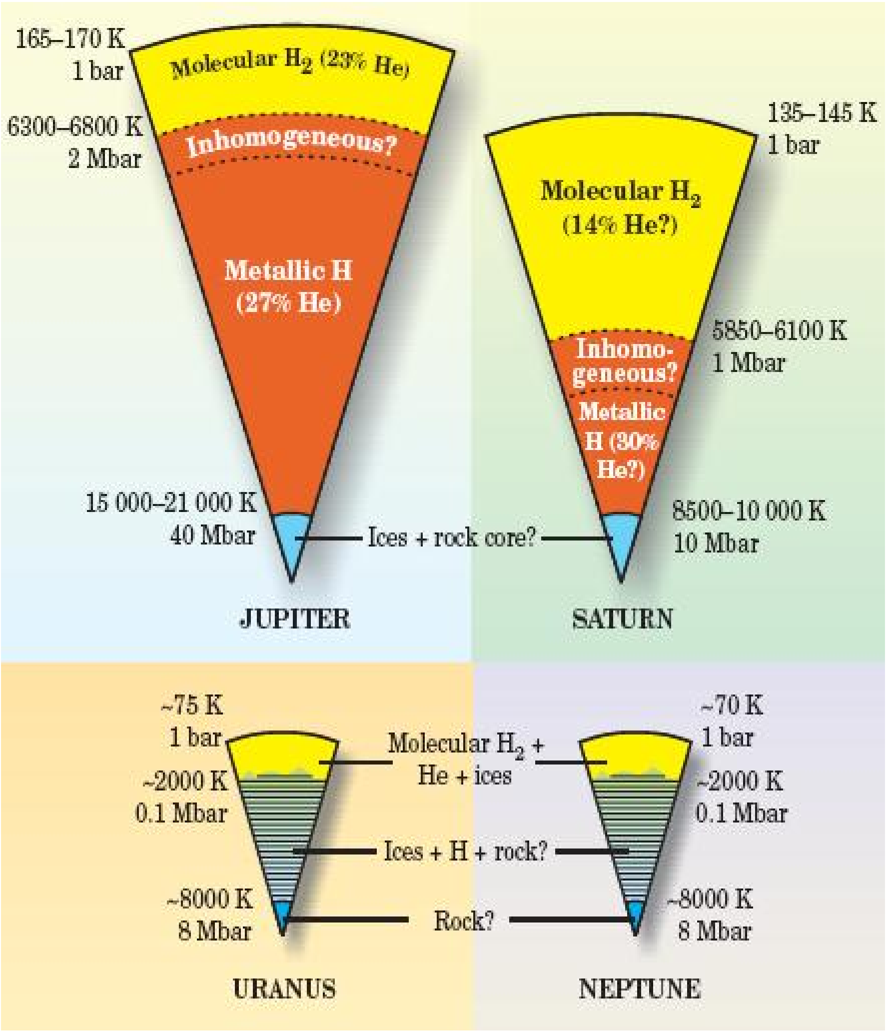
ex2: Water ;
Europa, Ganymede, Callisto, Titan...
have an ocean between two ice layers.



PLANÉTOLOGIE COMPARÉE
&
FORMATION PLANÉTAIRE

Aurélien CRIDA

GIANT PLANETS



Jupiter:

Mass: ~300 x M_{Earth}.

Density: 1.3 g/cm^3 = 1300 kg/m^3

Core mass: ~ 0-12 M_{Earth}.

Mass of heavy elts: 10-40 M_{Earth} .

Saturn:

Mass: ~100 x M_{Earth}

Density: 0,7 g/cm^3 = 700 kg/m^3

Core mass: ~ 10-25 M_{Earth}.

Mass of heavy elts: 20-30 M_{Earth}.

Uranus-Neptune:

Mass:~15 x M_{Earth} (14 et 17 resp.)

Mass atmosphere: ~ 1-4 M_{Earth}.

GEANTES GAZEUSES

Jupiter & Saturne,
les 2 plus grosses planètes:

Diamètre Jupiter = 140 000 km

Diamètre Saturne = 120 000 km.

$\mathbf{M_{Jupiter} = 300\ M_{Terre} = 0{,}001\ M_{Soleil}}$

$\mathbf{M_{Saturne} = 100\ M_{Terre}}$

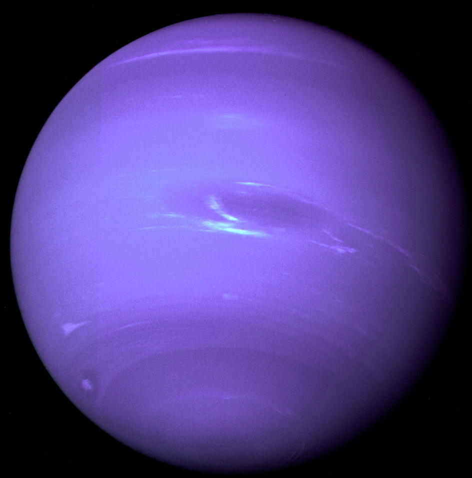
Essentiellement H et He, composition semblable au Soleil.

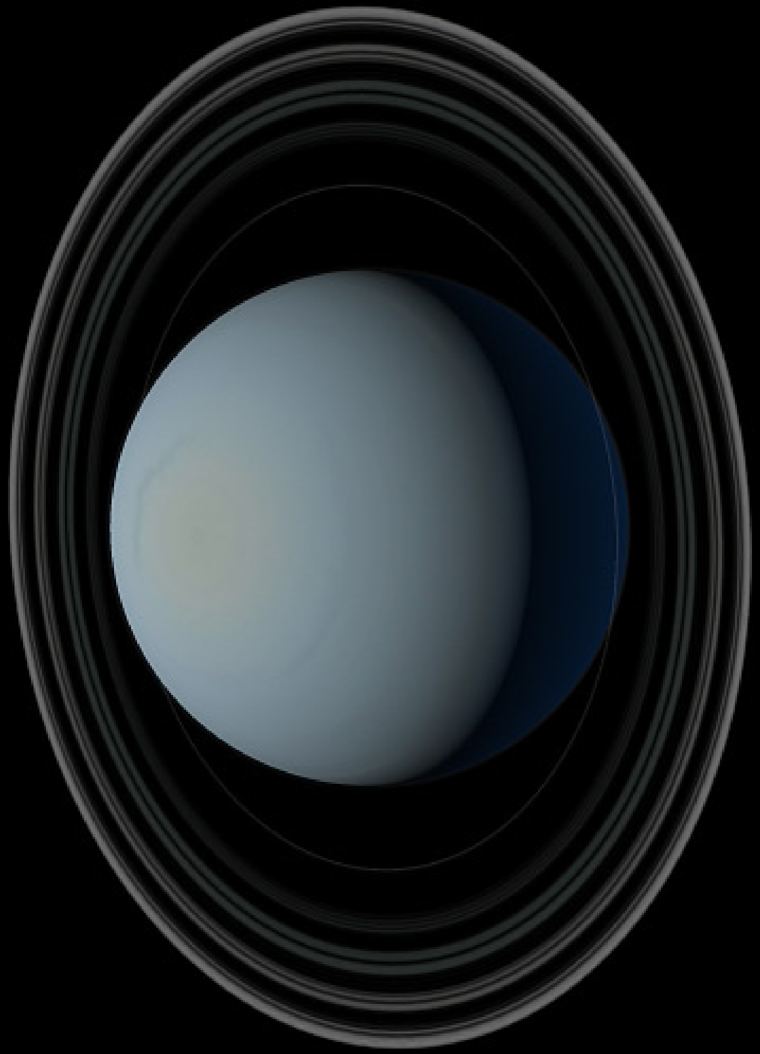
Coeur solide de $\sim 10\ M_{Terre}$.

GEANTES DE GLACE

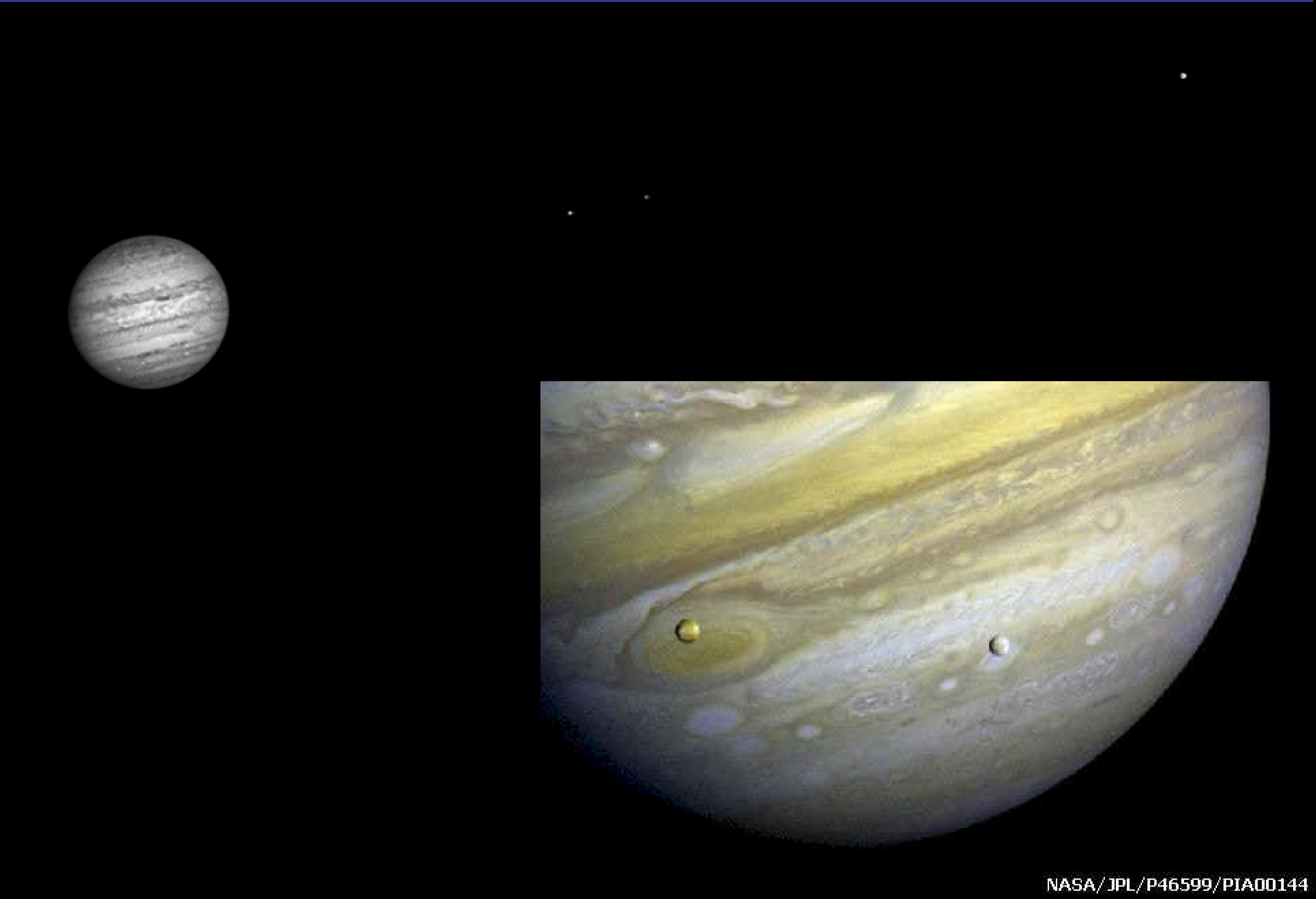
Uranus et Neptune, planètes les plus externes

Beaucoup plus petites que les gazeuses, ~ 15 M_{Terre}.

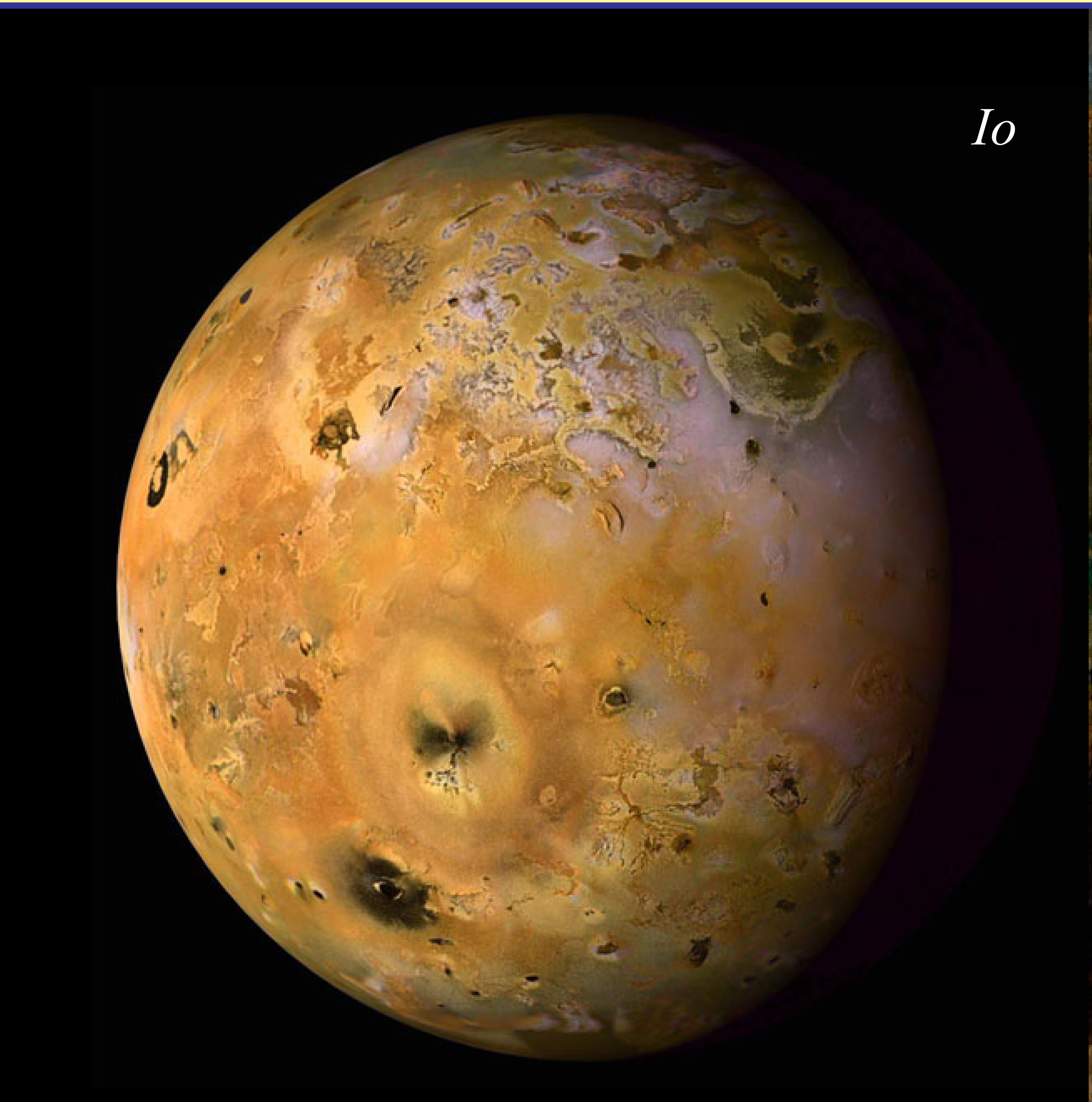




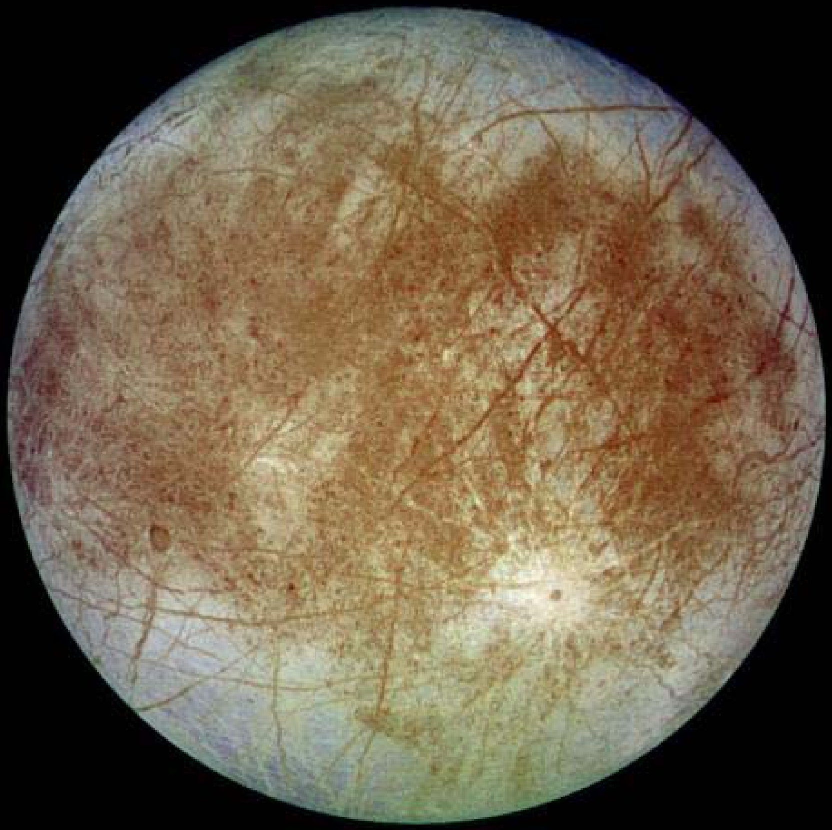
Le monde de JUPITER



Le monde de JUPITER



Le monde de JUPITER



Europe

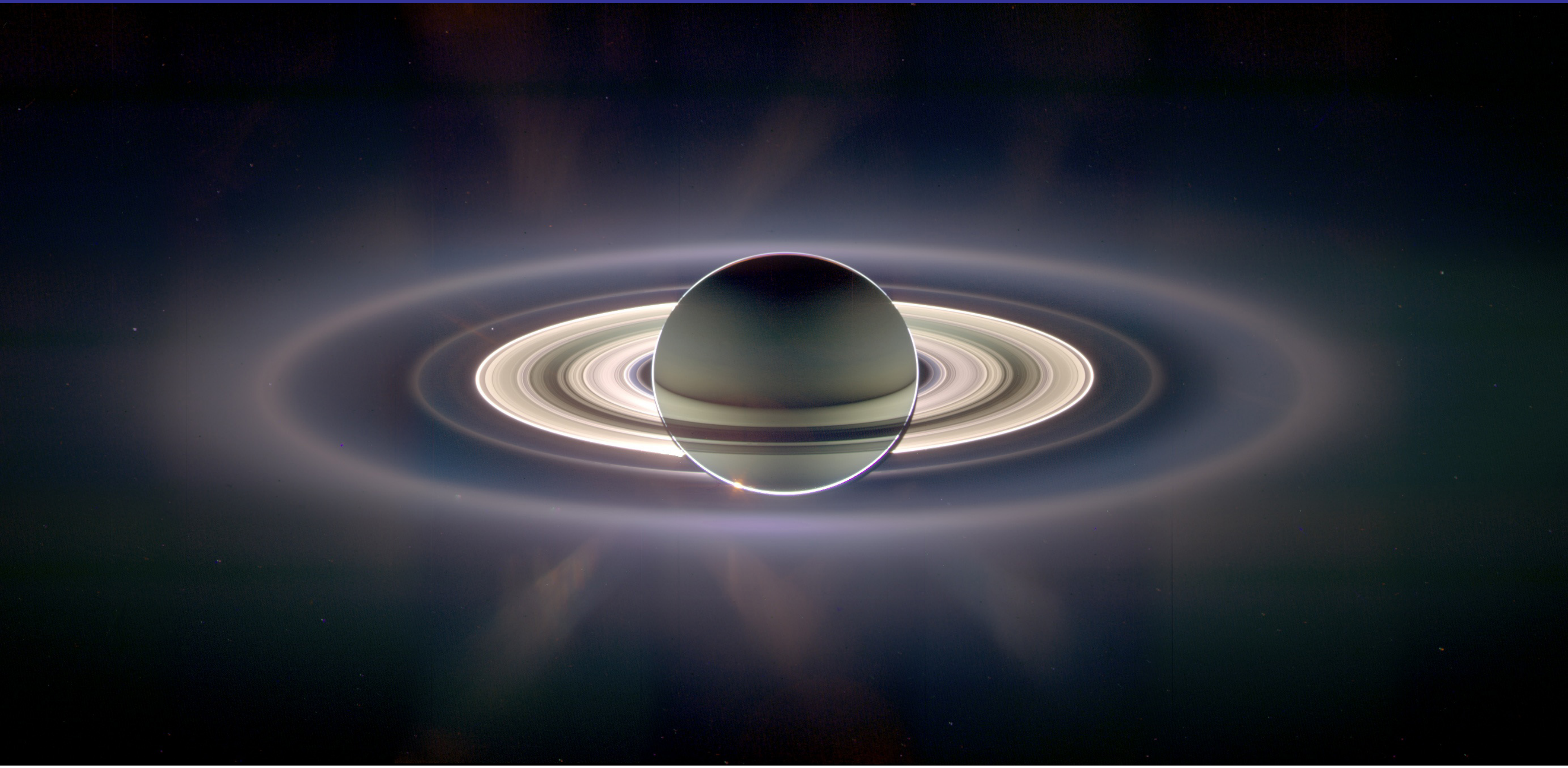
Le monde de JUPITER

Ganymède

Le monde de JUPITER

Callisto

SATURNE: Un système complexe



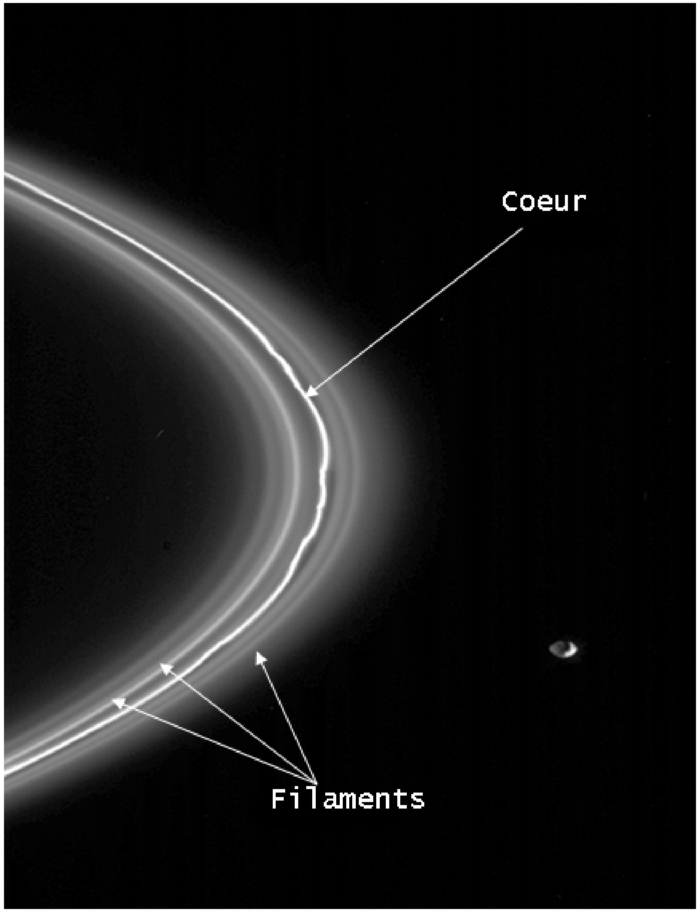
Principaux anneaux (A, B, C, D) entre la planète et la limite de Roche : accrétion impossible.

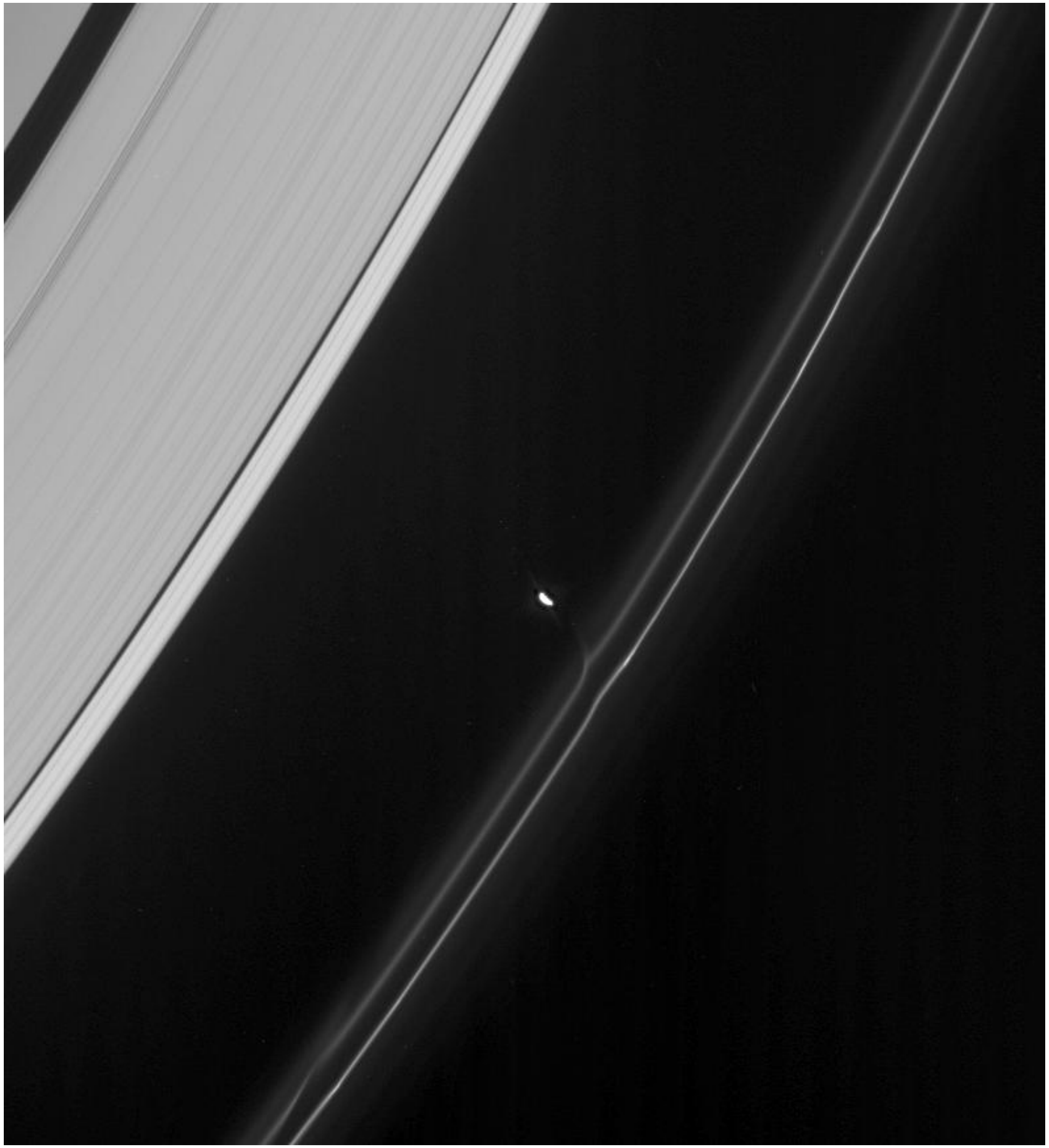
Anneau E : diffus et épais. D'où vient-il ?

SATURNE: Un système complexe

<u>Anneau F:</u>

Quasiment à la limite de Roche, confiné par 2 satellites.

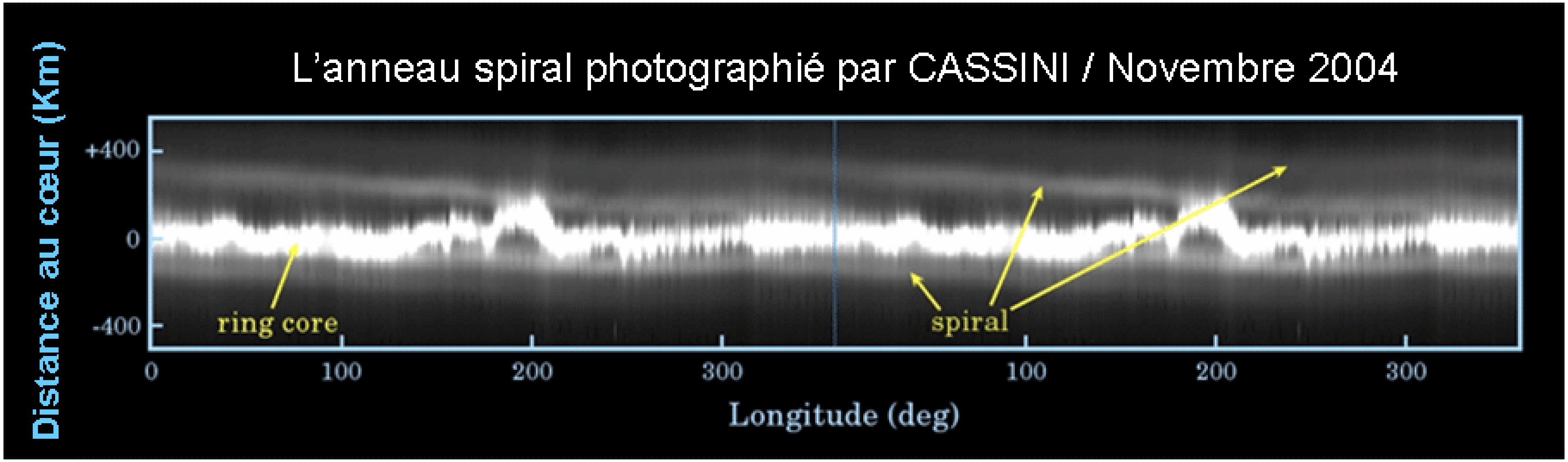




SATURNE: Un système complexe

Anneau F: Une spirale !

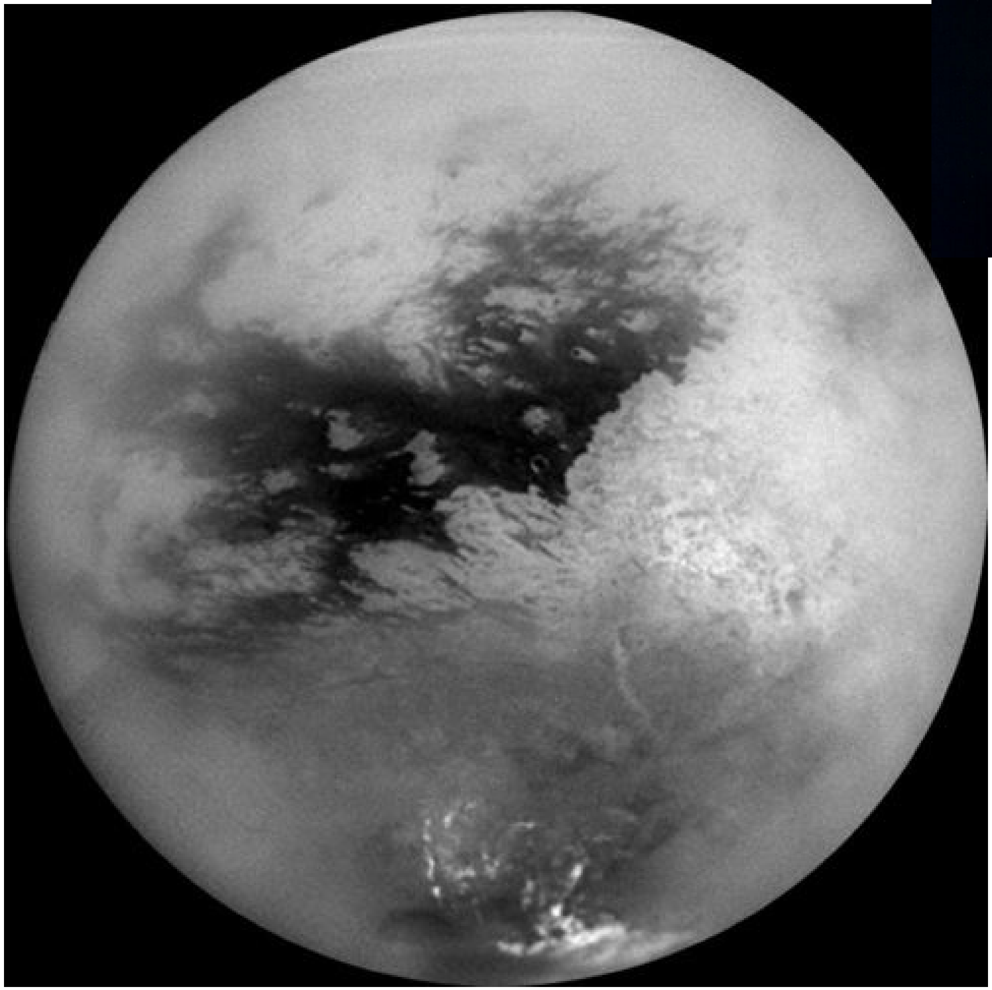
(Charnoz et al., 2007, Science)

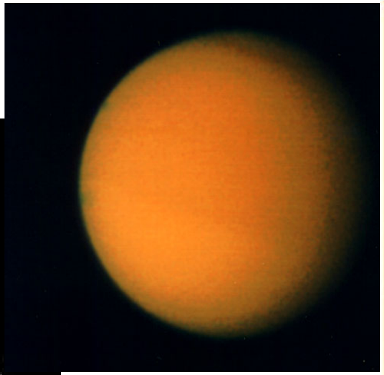


SATURNE: Un système complexe

<u>Titan:</u> Seul satellite avec une atmosphère, exploré par Huygens.

Lacs de méthane ?

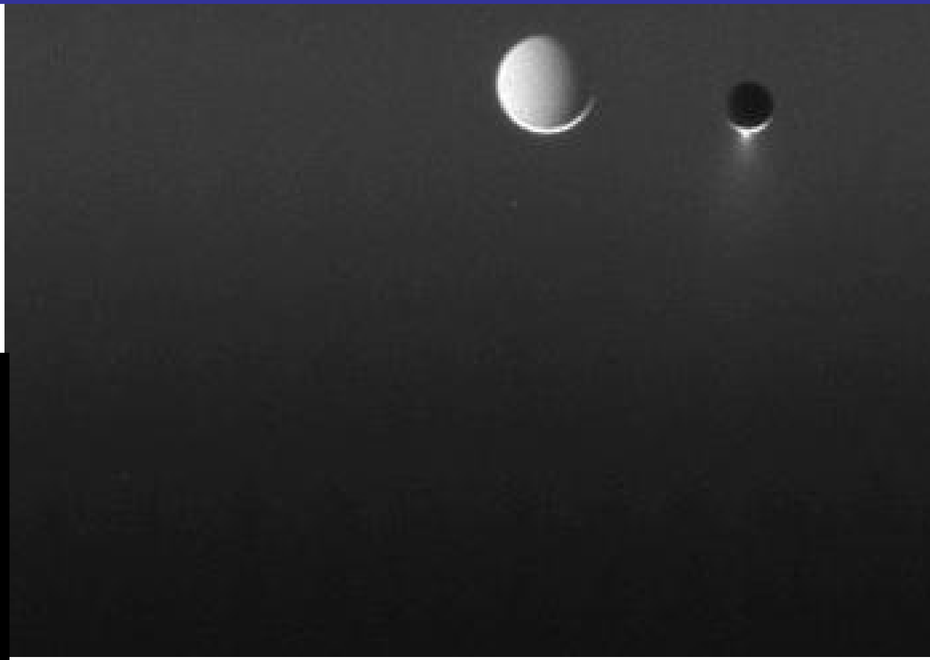


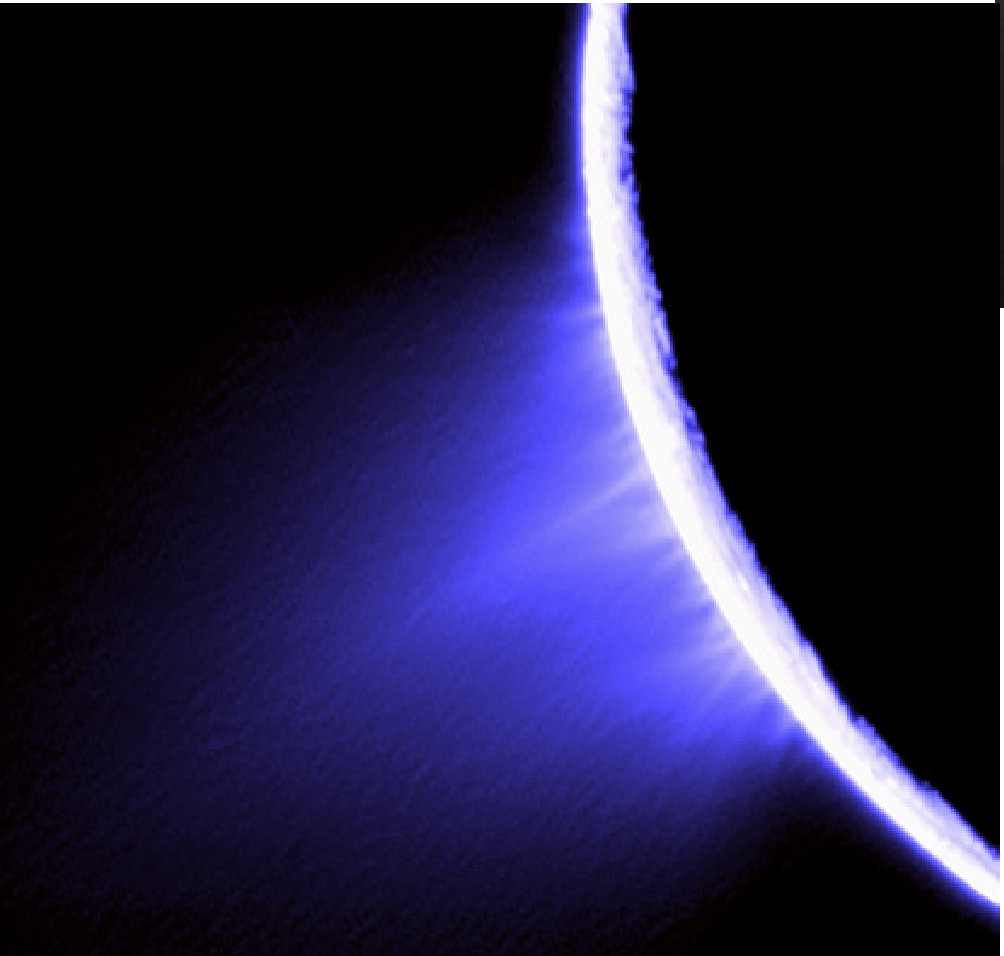


SATURNE: Un système complexe

<u>Encelade:</u>

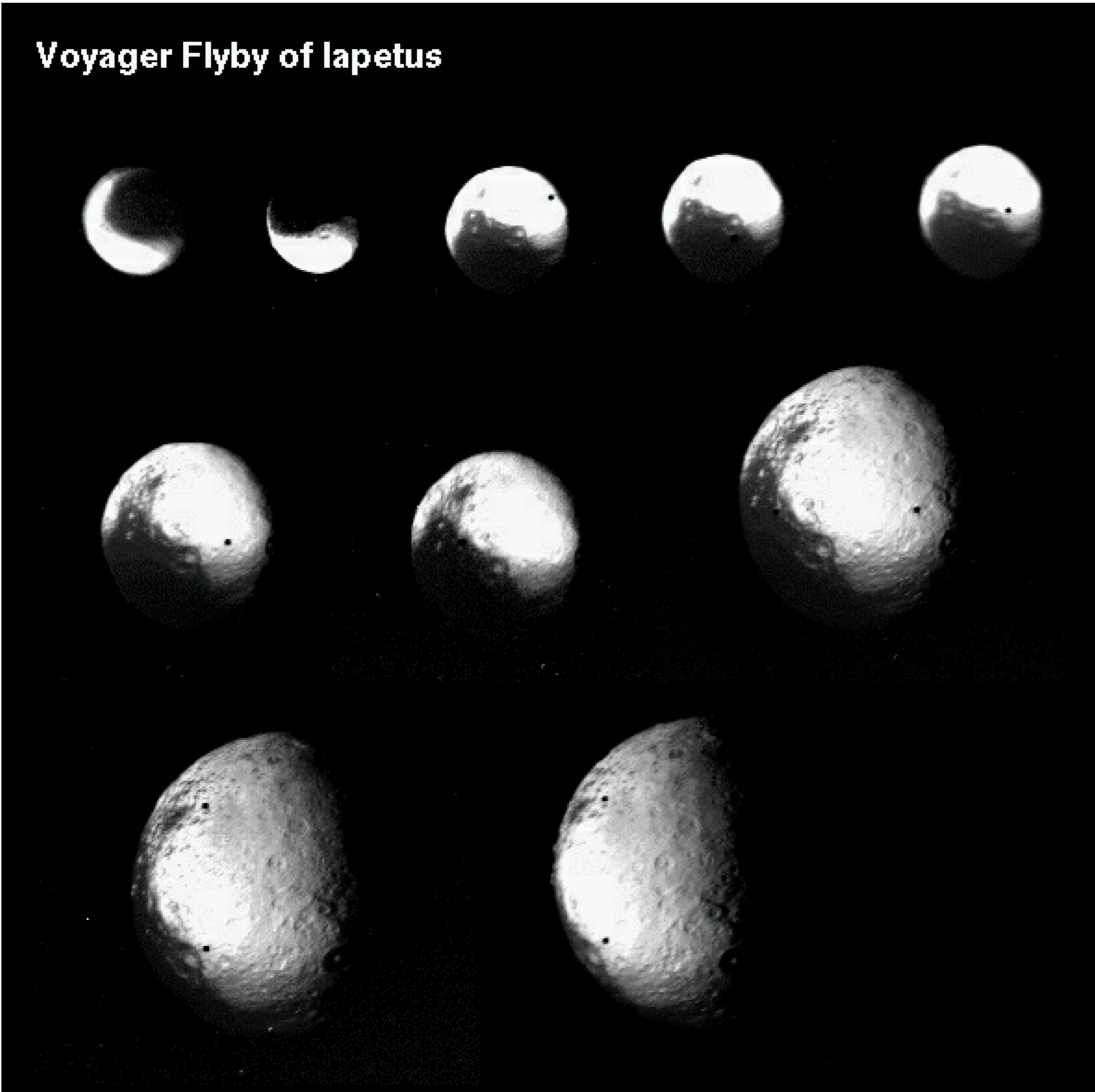
Satellite aux geysers de glace, alimentant l'anneau E.





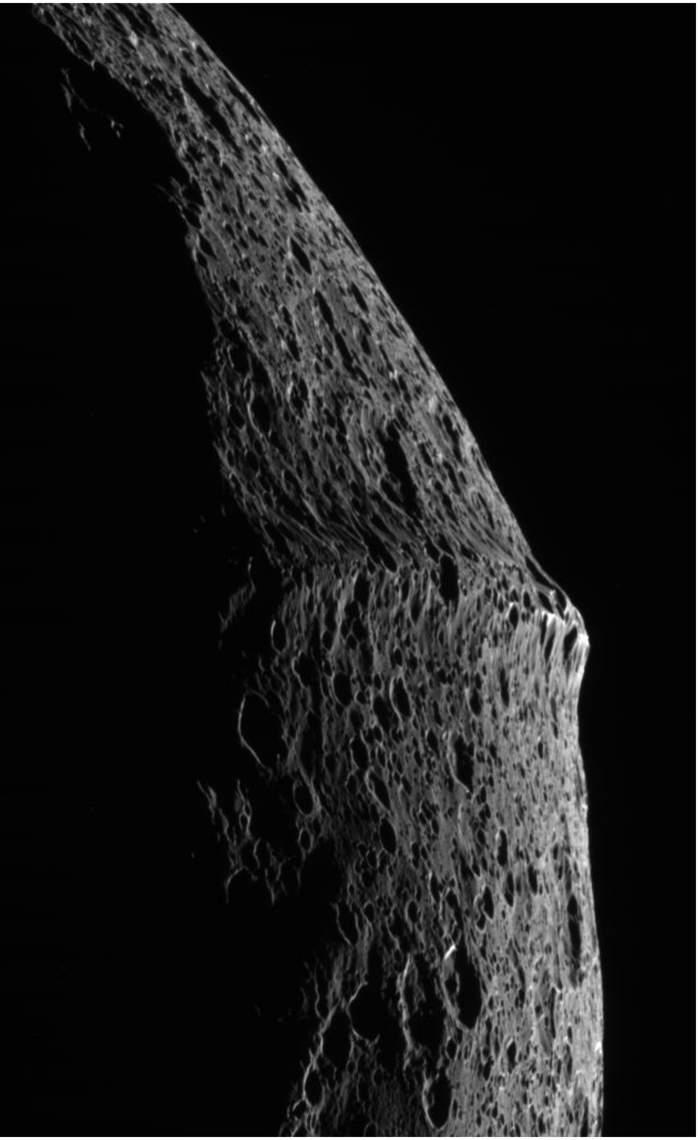
SATURNE: Un système complexe

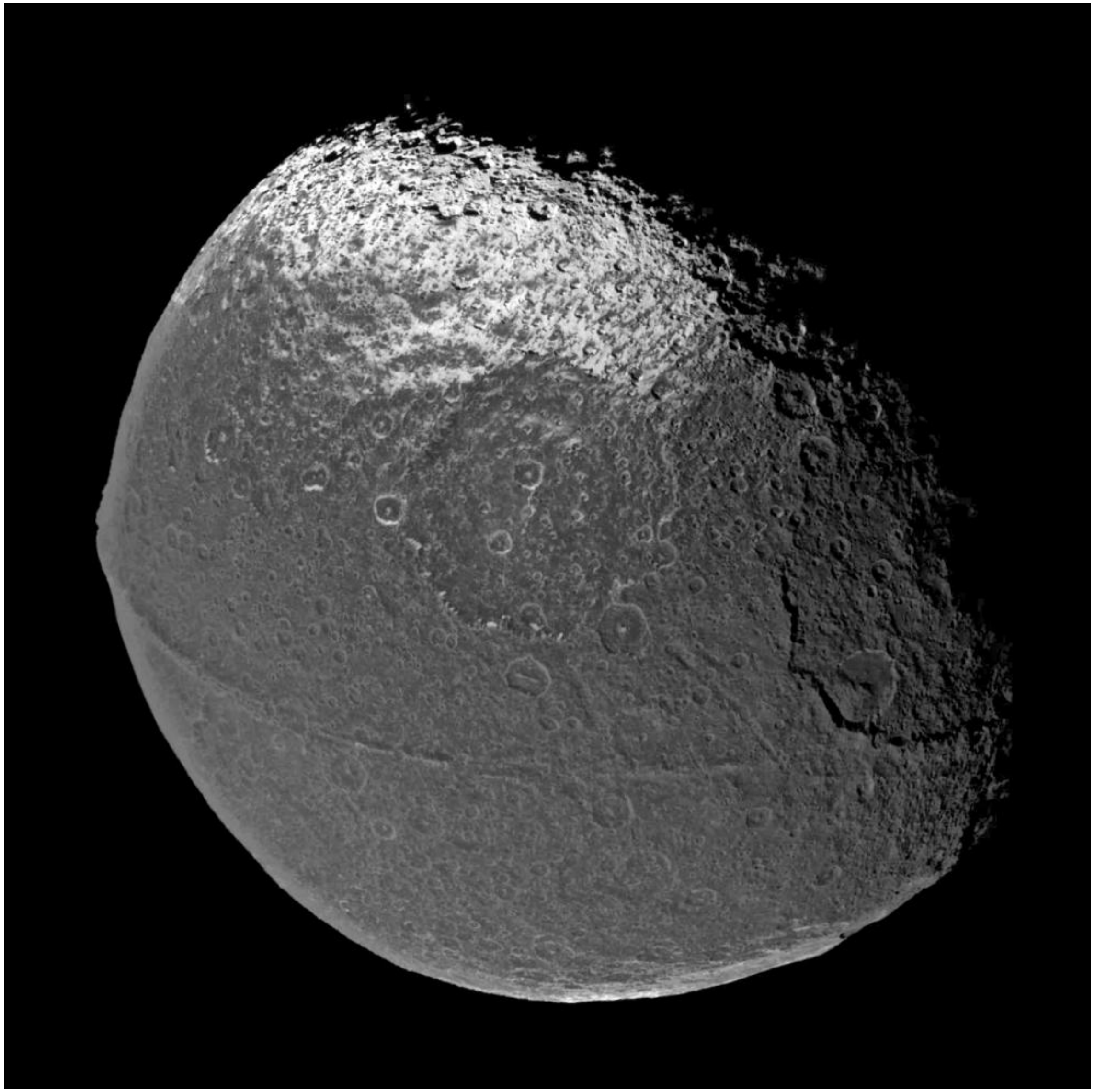
Japet: Satellite bicolore, découvert par Cassini en 1671.



SATURNE: Un système complexe

<u>Japet:</u> Une ride équatoriale, découverte par Cassini en 2005.

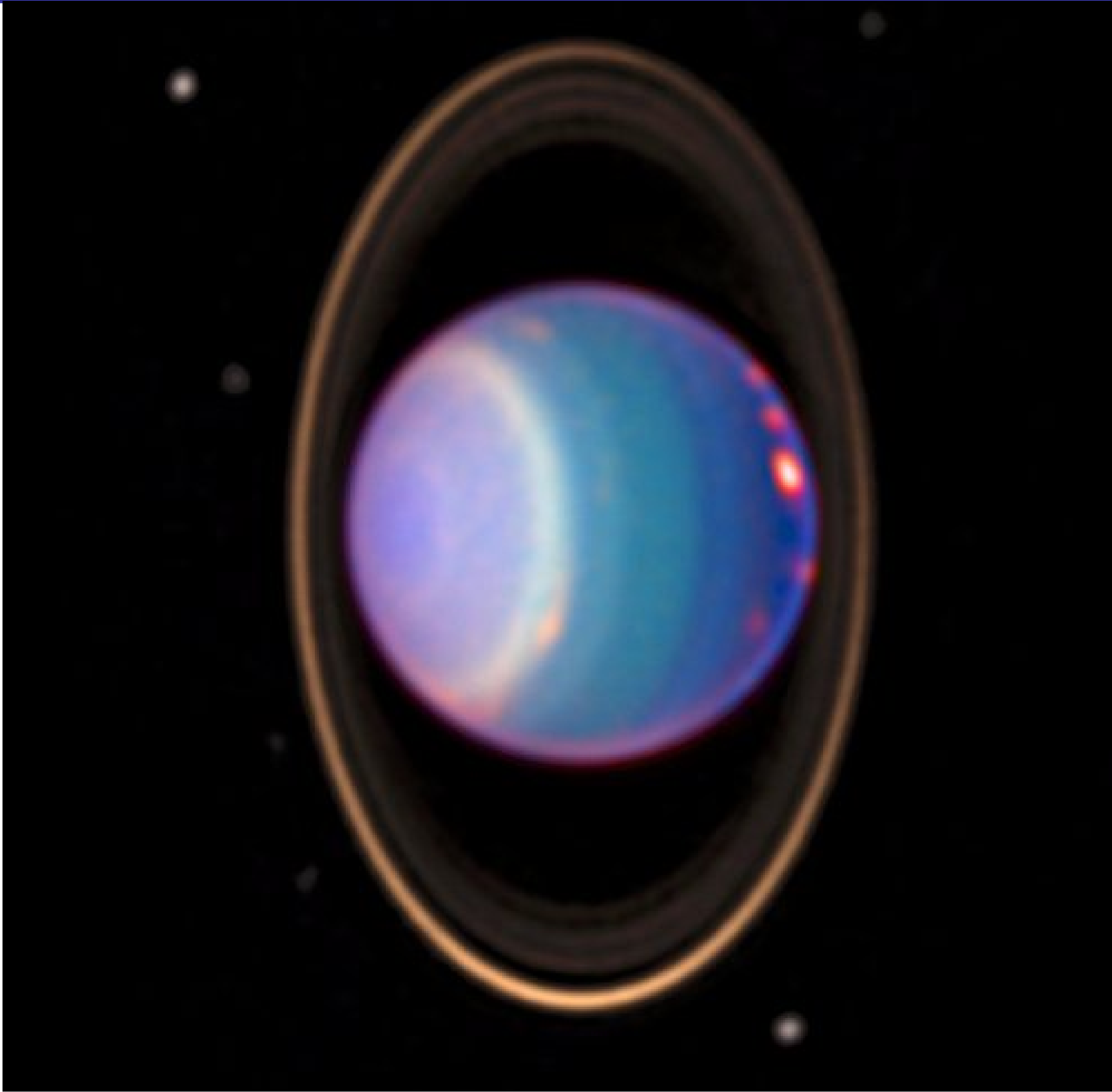




URANUS

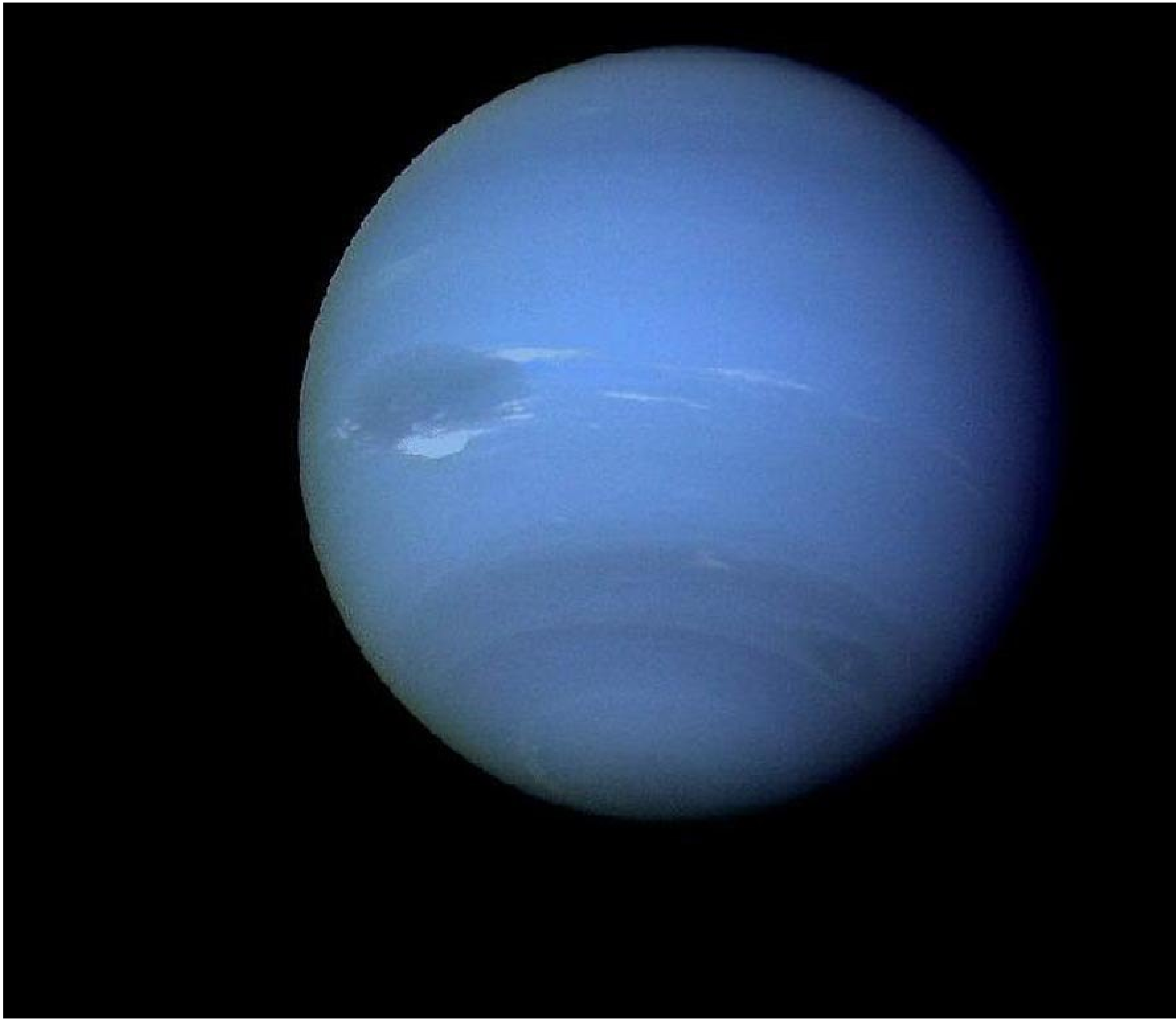
Discoverd by Herschel by chance in 1781.

Inclination of the spin axis : 98°.



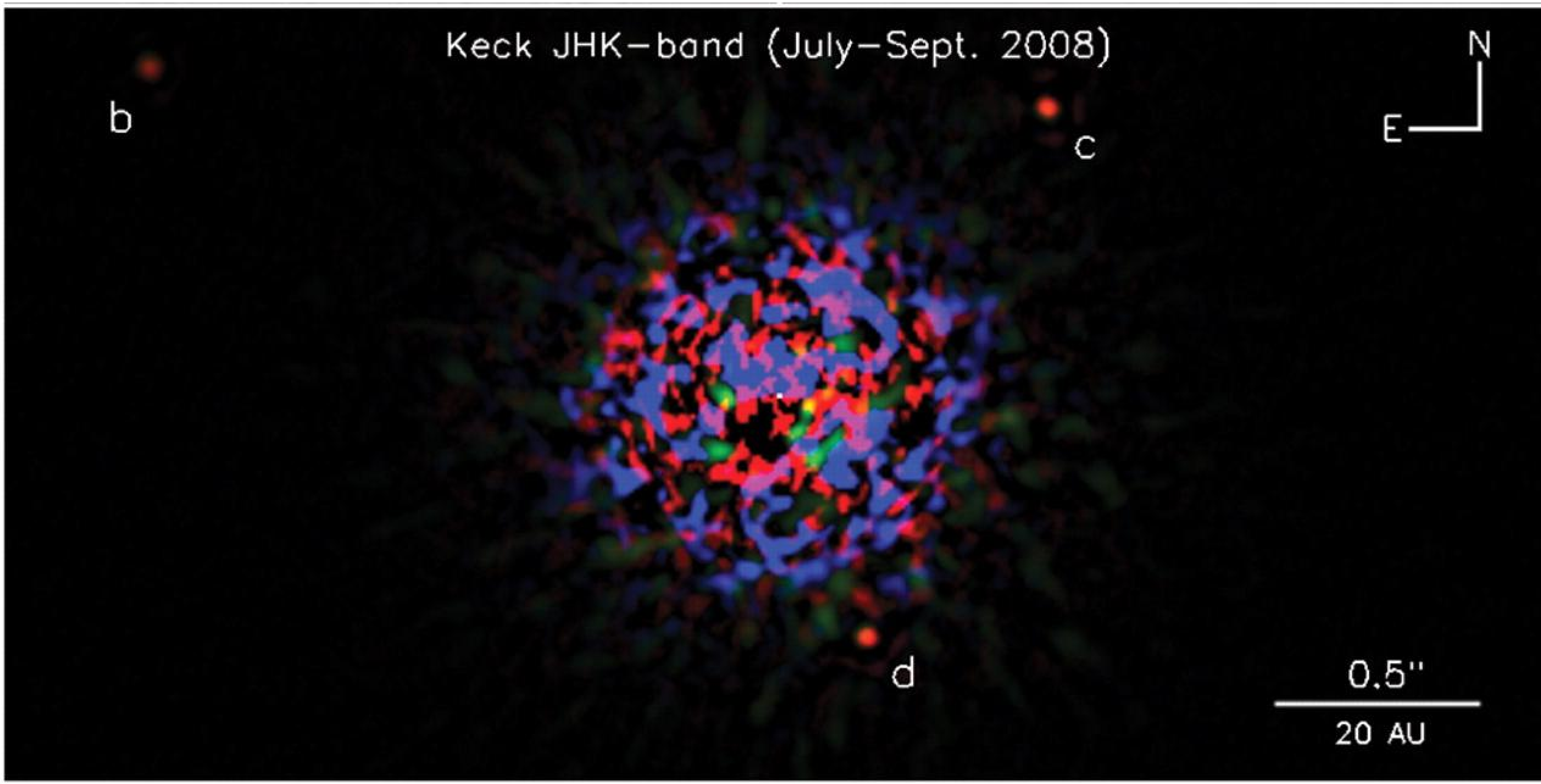
NEPTUNE

Discovered by Le Verrier and Galle in 1846, by computing !



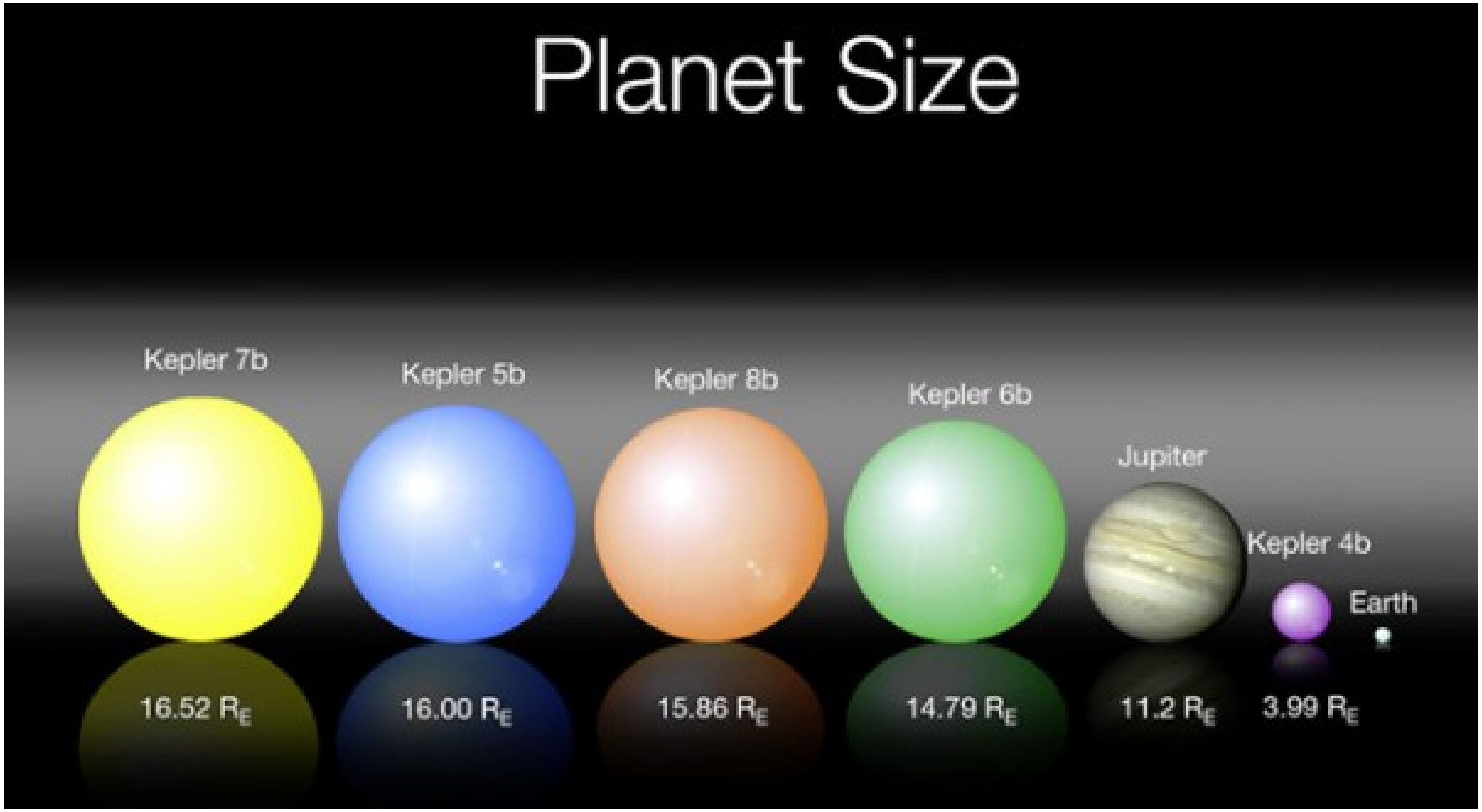
OTHER PLANETS

Since 1995, we know planets around other stars than the Sun: the *extra-solar planets*, or *exoplanets*.



OTHER PLANETS

Very variable sizes...



OTHER PLANETS

Masses very variable too !

Density ?
Composition ?
Formation ?