# Satellites of the giant planets

Planets and Astrobiology (2018-2019)
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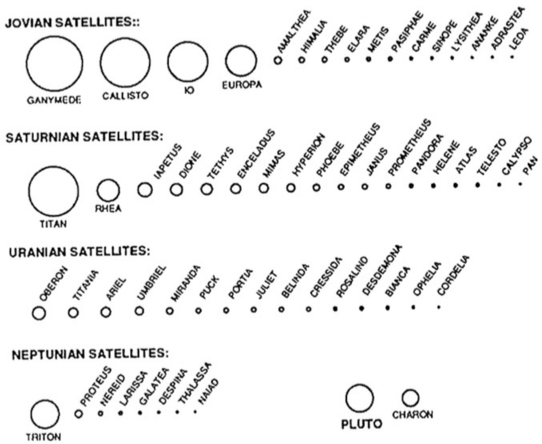
## Satellites of giant planets

Giant planets have a large number of satellites

The largest ones have sizes comparable to Mercury






## Satellites of giant planets

- Regular and irregular satellites
  - Regular satellites:

    The orbits around the planet have low eccentricity and are approximately coplanar with the equatorial plane of the planet
  - The dynamical characteristics of regular satellites suggest a common origin with the planet
  - Irregular satellites:

    Do not share the dynamical properties and are usually found at large distances from the planet
  - These facts suggest an independent origin, probably by gravitational capture, of bodies originated elsewhere



**Comparison of Satellite Systems**

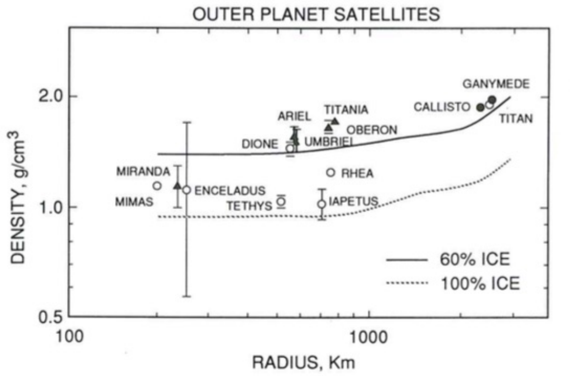
| Property[a] | Jupiter | Saturn | Uranus | Neptune |
|---|---|---|---|---|
| Regular Satellites | | | | |
| Number | 8 | 17 | 15 | (1)+6 |
| Location ($R_p$) | 1.8–27 | 2.3–59 | 2.0–23 | 1.9–4.7 and (15) |
| $M_{sat}/M_{pl}$ | $2.1\times10^{-4}$ | $2.4\times10^{-4}$ | $1.1\times10^{-4}$ | $2.9\times10^{-4}$ |
| $J_{sat}/J_{pl}$ | $6.5\times10^{-3}$ | $6.6\times10^{-3}$ | $6.5\times10^{-3}$ | $2.1\times10^{-2}$ |
| Irregular Satellites | | | | |
| Number | 8 | 1 | 0 | 1 |
| Location ($R_{pl}$) | 156–333 | 216 | | 227 |
| Rings | | | | |
| Location ($R_{pl}$) | 1.3–1.8 | 1.1–8[b] | 1.6–2 | 1.7–2.5 |
| $M_{ring}/M_{pl}$ | | $6\times10^{-8}$ | $6\times10^{-11}$ | |
| Max $\tau$ | $5\times10^{-5}$ | >1.5 | >1.5 | |

[a]The symbols $R$, $M$ and $J$ refer to radius, mass and angular momentum, respectively; subscripts sat, pl, and ring refer to satellite, planet and rings, respectively; and max $\tau$ is the maximum value of the normal optical depth at visible wavelengths.

[b]The major rings of Saturn, the A, B and C rings, are located between 1.2 and 2.3 $R_{pl}$.

## Density and radius of outer satellites

Consistent with the existence of a large fraction of ice






## Regular satellites of giant planets

- Main regular satellites of giant planets

  Here we discuss only some of them, those that are important from the astrobiological point of view

  – Jupiter

  Io, Europa, Ganymede, Callisto, Amaltea

  – Saturn

  Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion

  – Uran

  Ariel, Umbriel, Titania, Oberon

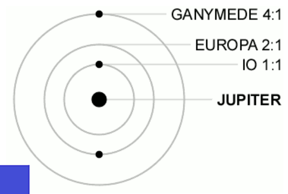
  – Neptun

  Triton, Nereid, Proteus



## Jupiter's satellites

- The four Galileian satellites are the most prominent ones
  - Discovered by Galileo in 1610
  - Extremely regular
  - The orbital periods are locked by tidal forces and resonances
- Observed with space probes
  - Particularly, *Voyager* and *Galileo*

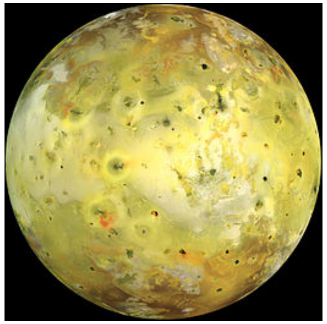


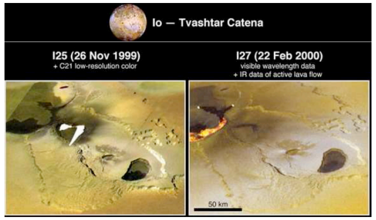

| Name | M [g] | R [km] | e | i [°] |
|---|---|---|---|---|
| Io | $8.9 \times 10^{25}$ | 1820 | 0.004 | 0.04 |
| Europa | $4.8 \times 10^{25}$ | 1565 | 0.009 | 0.47 |
| Ganymede | $1.5 \times 10^{26}$ | 2634 | 0.002 | 0.21 |
| Callistus | $1.1 \times 10^{26}$ | 2403 | 0.007 | 0.51 |



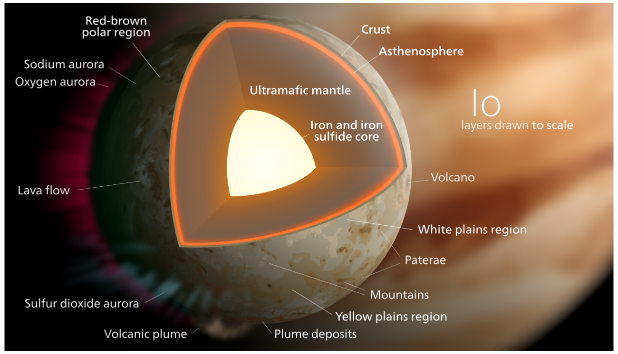
## Io

- The surface is characterized by a very intensive volcanic activity
  - The activity shows signatures of variability
  - The activity is induced by the tidal and magnetic interactions with Jupiter
  - Whitish and yellowish surface areas: volcanically deposited sulphur dioxide frost
- Surface temperature
  - T ~ 90 K – 130 K





- Io's mean density and interior
  - The mean density, 3.5 g/cm$^3$ , is the highest of any moon in the Solar System
  - Composed primarily of silicate rock and iron, closer in bulk composition to the terrestrial planets than to other satellites in the outer Solar System
  - The volatile compounds (such as $H_2O$ and $CO_2$) have been probably lost due to continuous recycling of internal material to the surface
  - The interior is believed to be melted and differentiated



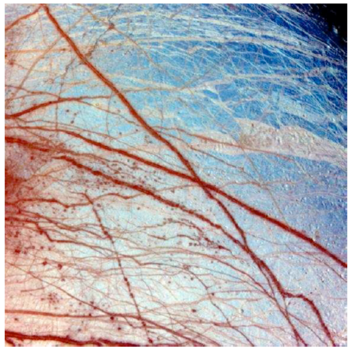



# Europa

A. Coradini (2010)

- The surface is composed of $H_2O$ ice
  - The gravimetric measurements indicate that the thickness of the ice layer might be of some tens of kilometeres

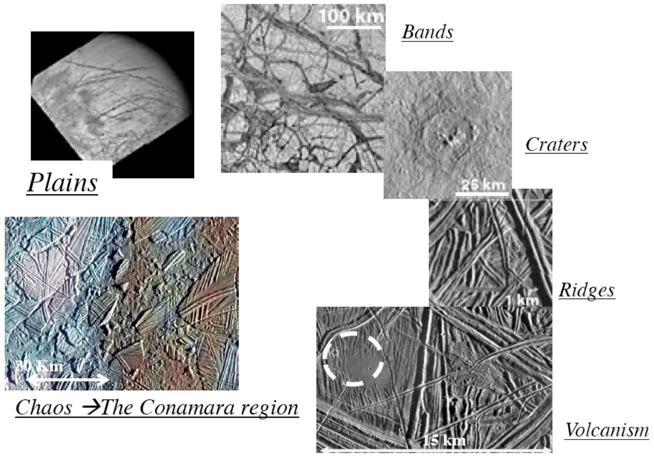
    The surface ice is "contaminated" by coloured compounds, probably salts that may have an endogenous origin
- Extremely rarified atmosphere
  - Composed mostly of $O_2$
  - Surface pressure: 0.1 μPa





# Europa

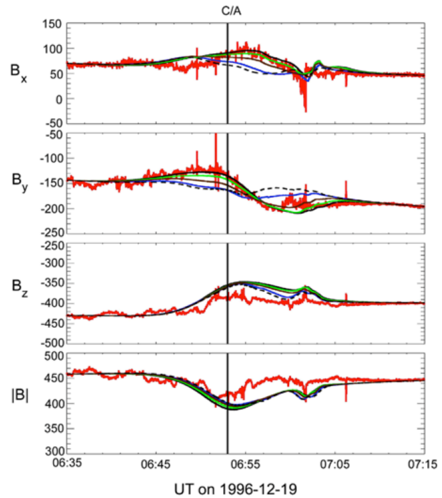
A variety of structures are visible on the surface, suggesting the presence of a remarkable activity






# A liquid water ocean below the surface of Europa

- Experimental evidence (1)
  - Magnetometric measurements indicate the presence in the interior of a compound with conductivity typical of a salty ocean
  - The experimental data are better fitted by $MgSO_4$ salt, rather than NaCl
  - Europa's magnetic field is induced by Jupiter's field (there is no intrinsic dynamo)



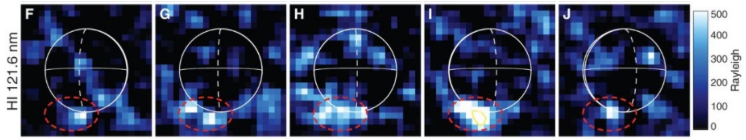
## A liquid water ocean below the surface of Europa

- Observational evidence (tentative)
  - Water vapour jets from the surface

    Detected from the analysis of HST ultraviolet data after subtraction of the disk reflectance

    Roth et al. 2014, Science

    The jets show evidence of variability with the orbital period





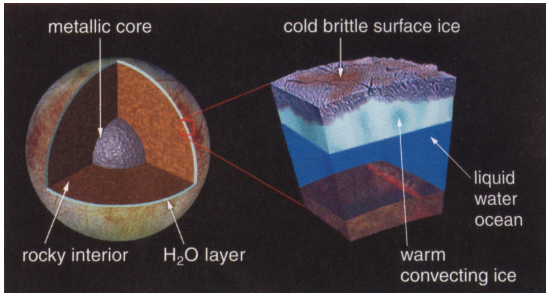

## A liquid water ocean below the surface of Europa

- The water ocean is expected to be present below the surface ice, given a suitable heating mechanism in the interior of Europa
- The example of Io indicates that tidal heating may provide internal heating
- Jupiter may keep Europa's oceans warm by generating large planetary tidal waves on Europa because of its small but non-zero obliquity. This generates so-called Rossby waves that travel quite slowly, at just a few kilometers per day, but can generate significant kinetic energy
- Dissipation of this kinetic energy could be the principal heat source of Europa's ocean
- To help water to be in liquid phase, other volatile compounds with lower melting point, such as $NH_3$, may be interdispersed in the water



## Europa’s interior

- Mean density
  - Mean density: 3.0 g/cm$^3$
- Internal structure
  - The water layers (ice plus ocean) are relatively thin compared to the radius of the satellite
  - The internal structure is believed to feature a metallic core surrounded by a rocky mantle






## Ganymede

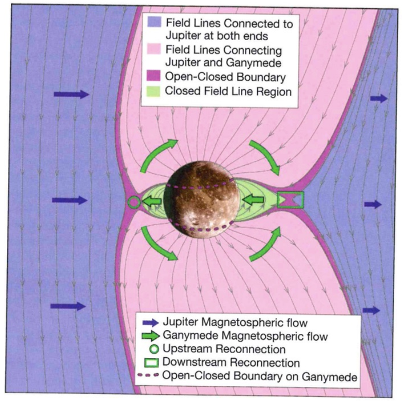
- Surface characteristics
  - Water ice seems to be ubiquitous on the surface, with a mass fraction of 50–90%
  - Two main types of terrain:

    dark regions, saturated with impact craters and dated to four billion years ago, cover about a third of the satellite

    lighter regions, crosscut by extensive grooves and ridges and slightly less ancient, cover the remainder two thirds
  - The heating mechanism required for the formation of the grooved terrain is an unsolved problem
  - Possibly the grooved terrain is due to tectonic processes

## Ganymede

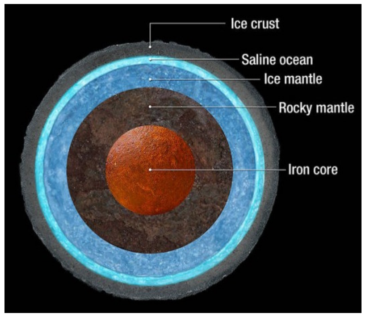
- Magnetic field
  - Ganymede is the only satellite with *endogenous* magnetic field suggestive of an internal dynamo mechanism (Europa and Callisto have *induced* magnetic fields)
  - The magnetic field of Ganymede interacts with Jupiter's magnetic field
  - The magnetometric measurements indicate the presence of a liquid and conductive internal layer
  - A liquid Fe core could be responsible for the magnetic field

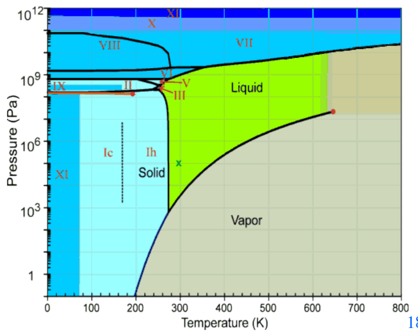





## Ganymede

- Interior
  - Density, gravity and magnetometric data suggest the presence of a liquid Fe core
  - The Fe core is surrounded by a rocky mantle
  - Interior models suggest that an internal ocean of liquid water may exist, sandwiched between the surface layer of Ice-I and the higher pressure phases of ice below





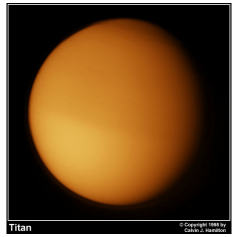

## Saturn satellites:
## Titan

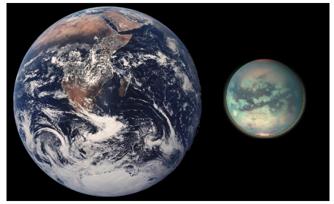
Largest among Saturn's regular satellites

- Only Solar System satellite with a thick atmosphere
  - Surface pressure larger than on Earth: $P$=1.5 bar
- Factors that contribute to the existence of a thick atmosphere
  - Not too low escape velocity ($v_{esc}$=2.65 km/s)
  - Sufficiently low surface temperature ($T$= ~94 K)

    This temperature is sufficiently high to avoid solidification of the volatiles that are present in the atmosphere

*Voyager* image of Titan in the optical band





- Chemical composition of Titan's atmosphere
  - Main constituent: $N_2$, as on Earth

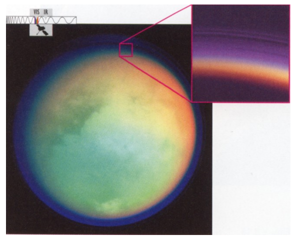
    However, $O_2$ is not present
  - Rich of hydrocarbons, mainly methane $CH_4$, but also ethane $C_2H_6$
  - The atmosphere is surrounded by a brownish-reddish haze
  - The haze is composed of "tholins":

    Nitrogen-rich organic molecules produced by the photo-dissociation of $CH_4$

| | Titan | Earth |
|---|---|---|
| $N_2$ | 82-99 % | 78% |
| $CH_4$ | 2-10 % | 2 ppm |
| $O_2$ | - | 21% |
| $CO_2$ | 0.01 ppm | 350 ppm |
| Ar | < 1-6 % ? | 0.9% |

- Surface
  - Lakes of methane $CH_4$ and ethane $C_2H_6$ discovered by the lander *Huygens*

False color image obtained by *Cassini*, evidentiating the haze layer



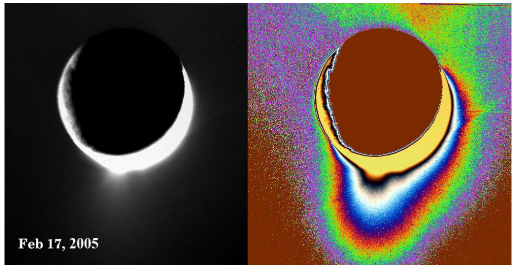
# Encelado

- Small satellite of Saturno
  - Jets of ice particles and water vapour have been found in the South pole of this satellite

    The jets suggest the presence of a geothermic energy source

    The water vapour in the jets exhibits simple organic compounds

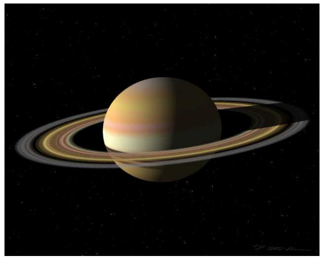
    McKay et al. (2008, AsBio, 8, 909)




# Rings of giant planets

- All giant planets of the Solar System have ring systems
  - Thin, complex structures that differ from planet to planet
  - Composed of solid debris with sizes ranging from a fraction of micron (dust) up to meter-size boulders
  - Interesting as a laboratory of physics

    A variety of dynamical processes are required to explain their characteristics, including resonances with satellites and limits of disruption of astronomical bodies under a gravitational field





# Roche limit

Distance within which a celestial body, held together only by its own gravity, will disintegrate due to a second celestial body's tidal forces

The Roche limit is obtained by equating gravitational and tidal forces inside the body

$$F_G = F_T$$

From this equality one obtains an expression of the type:

$$d_{Roche} \sim 2.44\, R_M\, (\varrho_M/\varrho_m)^{1/3}$$

$R_M$: radius of the main body

$\varrho_M$ , $\varrho_m$: mean density of the main and minor bodies, respectively

The value of the constant (2.44) depends on the assumptions used to derive the above equation



Ring-moon systems of the giant planets scaled to a common planetary radius (solid central circle)

Dotted line:

Roche radius for a satellite density 0.9 g/cm$^3$