

Satellites and rings of giant planets

Planets and Astrobiology (2017-2018)
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Satellites of giant planets

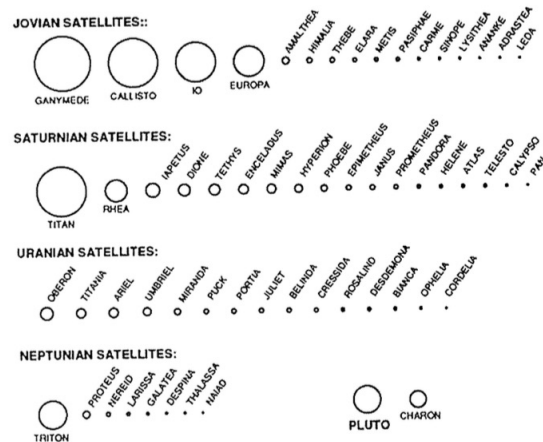
- Regular and irregular satellites
 - Regular satellites:
 - The orbits around the planet have low eccentricity and are approximately coplanar with the equatorial plane of the planet
 - The dynamical characteristics of regular satellites suggest a common origin with the planet
 - Irregular satellites: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

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Satellites of giant planets

Giant planets have a large number of satellites

The largest ones have sizes comparable to Mercury



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Comparison of Satellite Systems

Property*	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)
$M_{\text{sat}}/M_{\text{pl}}$	2.1×10^{-4}	2.4×10^{-4}	1.1×10^{-4}	2.9×10^{-4}
$J_{\text{sat}}/J_{\text{pl}}$	6.5×10^{-3}	6.6×10^{-3}	6.5×10^{-3}	2.1×10^{-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
$M_{\text{ring}}/M_{\text{pl}}$		6×10^{-8}	6×10^{-11}	
Max τ	5×10^{-5}	>1.5	>1.5	

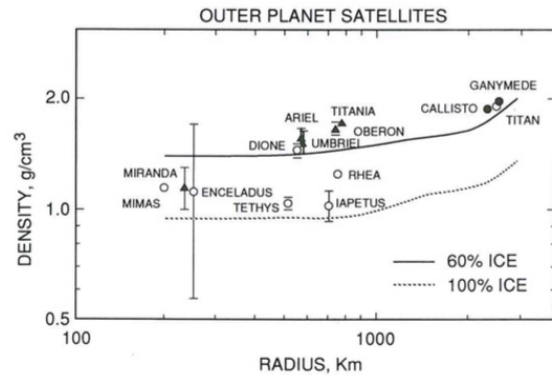
*The symbols R , M and J refer to radius, mass and angular momentum, respectively; subscripts sat, pl, and ring refer to satellite, planet and rings, respectively; and max τ is the maximum value of the normal optical depth at visible wavelengths.

^bThe major rings of Saturn, the A, B and C rings, are located between 1.2 and 2.3 R_{pl} .

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Density and radius of outer satellites

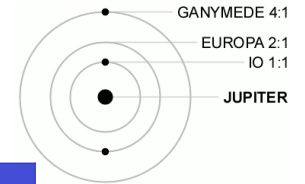
Consistent with the existence of a large fraction of ice



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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	8.9×10^{25}	1820	0.004	0.04
Europa	4.8×10^{25}	1565	0.009	0.47
Ganymede	1.5×10^{26}	2634	0.002	0.21
Callistus	1.1×10^{26}	2403	0.007	0.51

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Regular satellites of giant planets

- Main regular satellites of giant planets

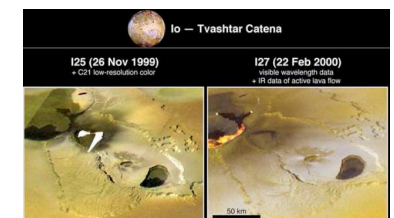
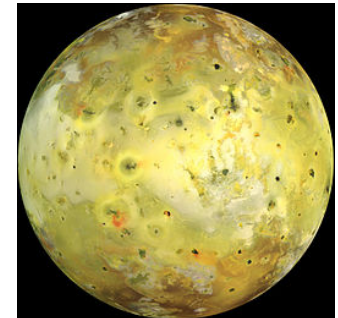
Here we discuss only some of them, those that are important from the astrobiological point of view

 - Jupiter
 - Io, Europa, Ganymede, Callisto, Amaltea
 - Saturn
 - Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Hyperion
 - Uran
 - Ariel, Umbriel, Titania, Oberon
 - Neptun
 - Triton, Nereid, Proteus

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Io

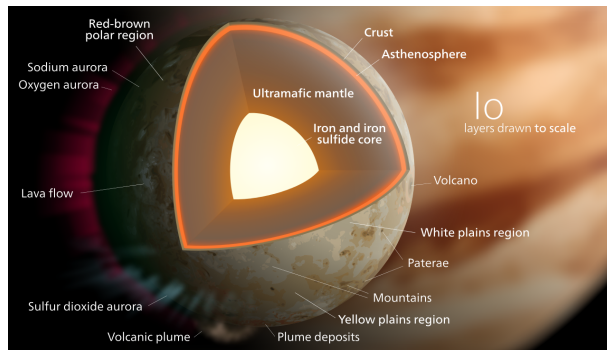
- The surface is characterized by a very intensive volcanic activity
 - The activity shows signatures of variability
 - The activity is induced by the tidal and magnetic interactions with Jupiter
 - Whitish and yellowish surface areas: volcanically deposited sulphur dioxide frost
- Surface temperature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



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- **Io's mean density and interior**

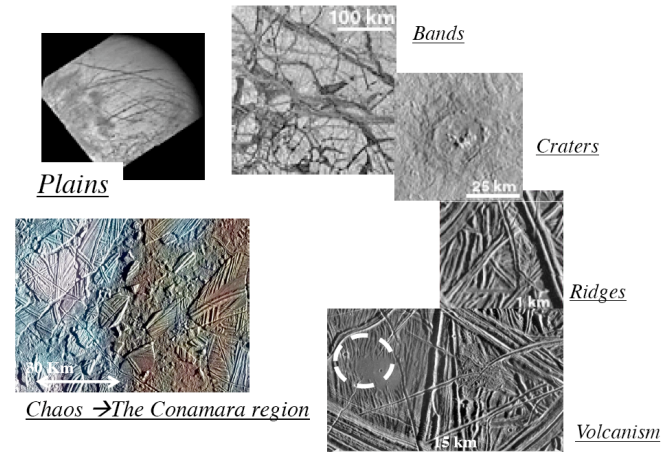
- The mean density, 3.5 g/cm^3 , is the highest of any moon in the Solar System
- Composed primarily of silicate rock and iron, closer in bulk composition to the terrestrial planets than to other satellites in the outer Solar System
- The volatile compounds (such as H_2O and CO_2) have been probably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



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Europa

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

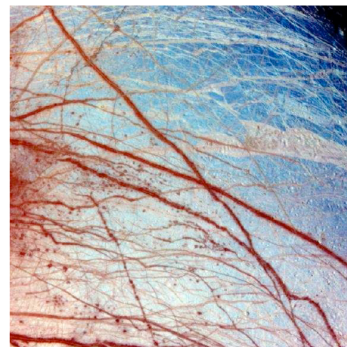


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Europa

A. Coradini (2010)

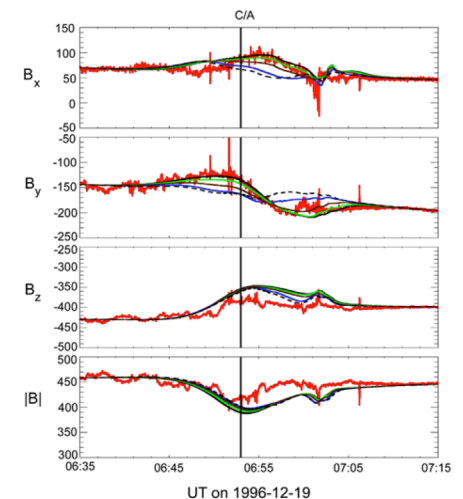
- **The surface is composed of H_2O ice**
 - The gravimetric measurements indicate that the thickness of the ice layer might be of some tens of kilometers
 - The surface ice is “contaminated” by coloured compounds, probably salts that may have an endogenous origin
- **Extremely rarified atmosphere**
 - Composed mostly of O_2
 - Surface pressure: $0.1 \mu\text{Pa}$



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A liquid water ocean below the surface of Europa

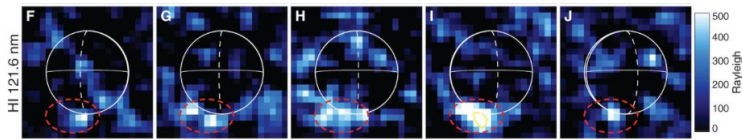
- **Experimental evidence (1)**
 - Magnetometric measurements indicate the presence in the interior of a compound with conductivity typical of a salty ocean
 - The experimental data are better fitted by MgSO_4 salt, rather than NaCl
 - Europa's magnetic field is induced by Jupiter's field (there is no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



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A liquid water ocean below the surface of Europa

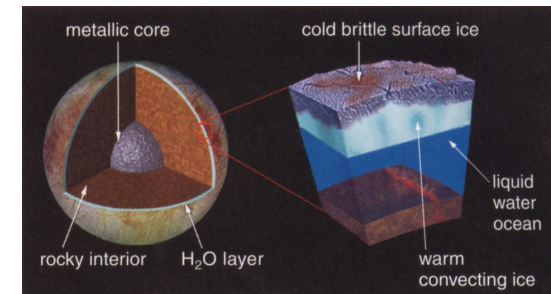
- **Experimental evidence (2)**
 - Water vapour jets from the surface
Detected from the analysis of HST ultraviolet data after subtraction of the disk reflectance
Roth et al. 2014, Science
 - The jets show evidence of variability with the orbital period



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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



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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

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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

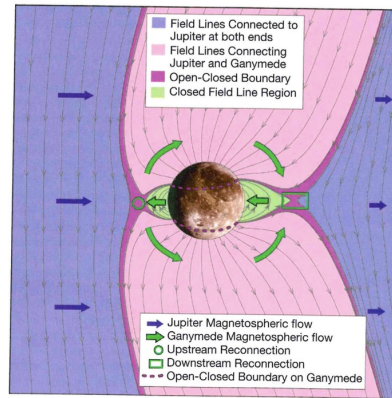


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Ganymede

- 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

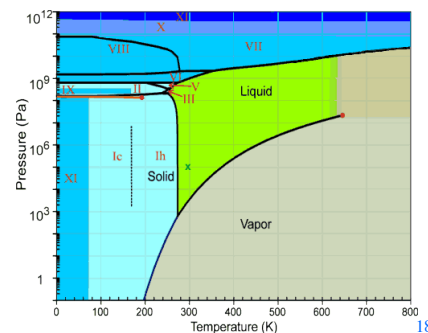
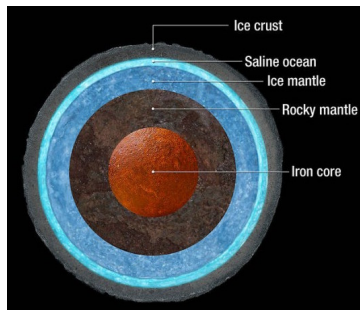


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Ganymede

- 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



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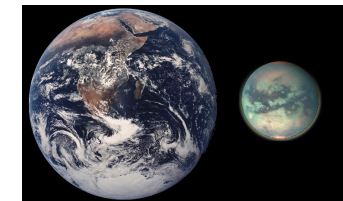
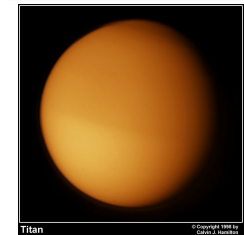
Saturn satellites: Titan

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 ($T= \sim 94$ 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



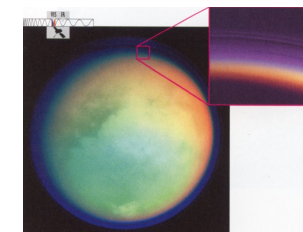
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- **Chemical composition of Titan's atmosphere**

- 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%

False color image obtained by Cassini, evidentiating the haze layer



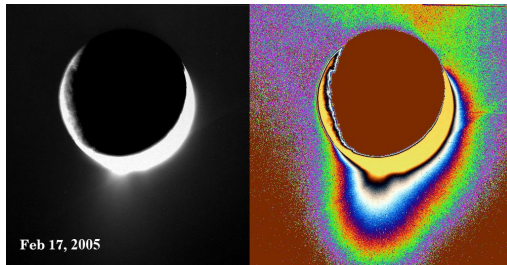
- **Surface**

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

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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)



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:

$$d_{\text{Roche}} \sim 2.44 R_M (Q_M/Q_m)^{1/3}$$

R_M : radius of the main body

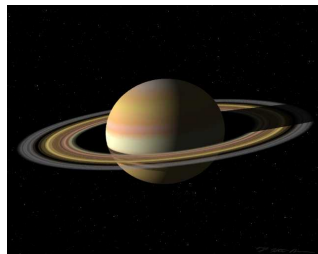
Q_M, Q_m : mean density of the main and minor bodies, respectively

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

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Rings of giant planets

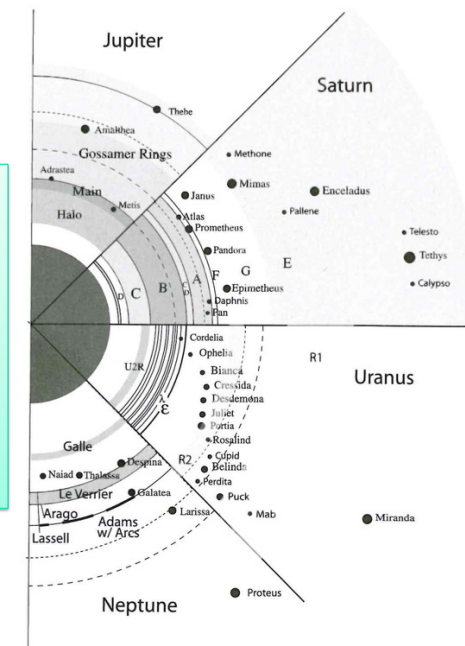
- **All giant planets of the Solar System have ring systems**
 - Thin, complex structures that differ from planet to planet
 - Composed of solid debris with sizes ranging from a fraction of micron (dust) up to meter-size boulders
 - Interesting as a laboratory of physics
- A variety of dynamical processes are required to explain their characteristics, including resonances with satellites and limits of disruption of astronomical bodies under a gravitational field



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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



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