Satellites of the giant planets

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Satellites of the giant planets

Giant planets have a large number of satellites. The largest ones have sizes comparable to Mercury.

\begin{itemize}
\item Regular and irregular satellites
  \begin{itemize}
  \item Regular satellites:
    \begin{itemize}
      \item The orbits around the planet have low eccentricity and are approximately coplanar with the equatorial plane of the planet
      \item The dynamical characteristics of regular satellites suggest a common origin with the planet
    \end{itemize}
  \item Irregular satellites:
    \begin{itemize}
      \item Do not share the dynamical properties and are usually found at large distances from the planet
      \item These facts suggest an independent origin, probably by gravitational capture, of bodies originated elsewhere
    \end{itemize}
  \end{itemize}
\end{itemize}
Density and radius of outer satellites

Consistent with the existence of a large fraction of ice

![Graph showing density and radius of outer satellites](image)

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 Galilean 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

<table>
<thead>
<tr>
<th>Name</th>
<th>M [g]</th>
<th>R [km]</th>
<th>e</th>
<th>i  [°]</th>
</tr>
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<tbody>
<tr>
<td>Io</td>
<td>8.9x10²⁵</td>
<td>1820</td>
<td>0.004</td>
<td>0.04</td>
</tr>
<tr>
<td>Europa</td>
<td>4.8x10²⁵</td>
<td>1565</td>
<td>0.009</td>
<td>0.47</td>
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<tr>
<td>Ganymede</td>
<td>1.5x10²⁶</td>
<td>2634</td>
<td>0.002</td>
<td>0.21</td>
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<tr>
<td>Callistus</td>
<td>1.1x10²⁶</td>
<td>2403</td>
<td>0.007</td>
<td>0.51</td>
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</tbody>
</table>

**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/cm³, 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 H₂O and CO₂) 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 variety of structures are visible on the surface, suggesting the presence of a remarkable activity

Europa

The surface is composed of H₂O 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 O₂
  – Surface pressure: 0.1 μPa

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 MgSO₄ 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

Europa’s interior

- Mean density
  - Mean density: 3.0 g/cm³

- 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

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 NH₃, may be interdispersed in the water

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

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

- 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 $CH_4$

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

<table>
<thead>
<tr>
<th></th>
<th>Titan</th>
<th>Earth</th>
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</thead>
<tbody>
<tr>
<td>$N_2$</td>
<td>82-99%</td>
<td>78%</td>
</tr>
<tr>
<td>$CH_4$</td>
<td>2-10%</td>
<td>2 ppm</td>
</tr>
<tr>
<td>$O_2$</td>
<td>-</td>
<td>21%</td>
</tr>
<tr>
<td>$CO_2$</td>
<td>0.01 ppm</td>
<td>350 ppm</td>
</tr>
<tr>
<td>$Ar$</td>
<td>&lt; 1-6%</td>
<td>0.9%</td>
</tr>
</tbody>
</table>

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 geothermal 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:

\[ d_{\text{Roche}} \sim 2.44 R_M \left( \frac{\rho_M}{\rho_m} \right)^{1/3} \]

- \( R_M \): radius of the main body
- \( \rho_M, \rho_m \): 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