

# Moons of Giant Planets

## 1. Moons of Jupiter, especially Europa

Two things to note about Jupiter and Saturn:

1. They are *massive*, so they exert strong gravitational tides on their moons.
2. They are strong sources of *energetic charged particles* which irradiate the surfaces of their moons.



Io passing in front of Jupiter

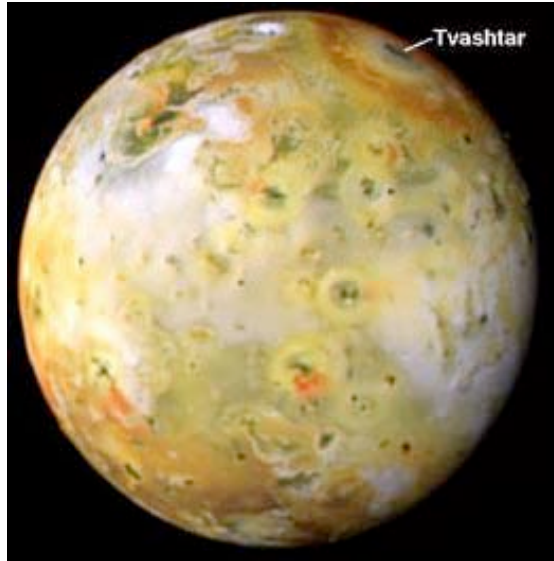
# Galilean moons of Jupiter

## Callisto



Most heavily cratered body in Solar System.  
Outermost of Jupiter's Moons

## Io



Innermost of Jupiter's moons.  
Most volcanic world in solar system, 100s of volcanoes, many active at any time, mostly sulfurous.  
Activity due to tidal heating.  
Maybe lakes of liquid sulfur.  
But no evidence for water, and extremely severe radiation environment (Jupiter's radiation belts).

## Ganymede

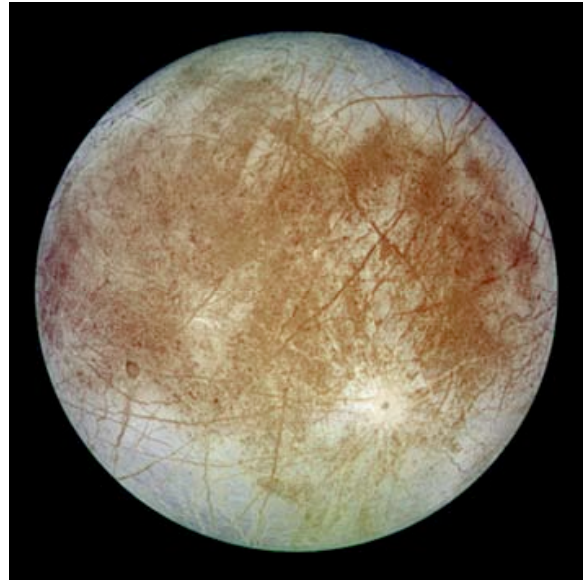


Largest moon in Solar System, has its own magnetic field, evidence for plate motions in crust, perhaps thin atmosphere containing oxygen.

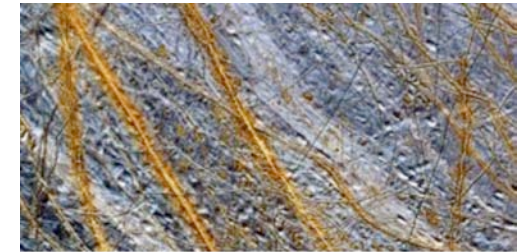
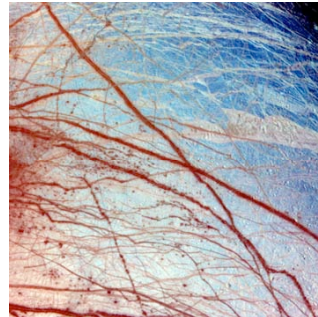
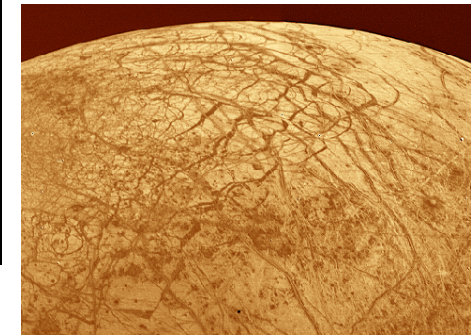
## Europa

### Why Europa?

- Several *Galileo* close flybys show the complex structures of the lines, the “spatter cones,” ice floes, and other structures that might be due to subsurface water.
- Lack of impact craters shows surface is geologically “young”.
- Dark, reddish coloration of cracks ⇒ bacteria (or some kind of organic gunk)??
- *Galileo* spacecraft’s near-infrared spectrometer indicated salts in this dark material, but *no* signature of organic compounds.
- Under the water: analogues of terrestrial hydrothermal vent organisms??



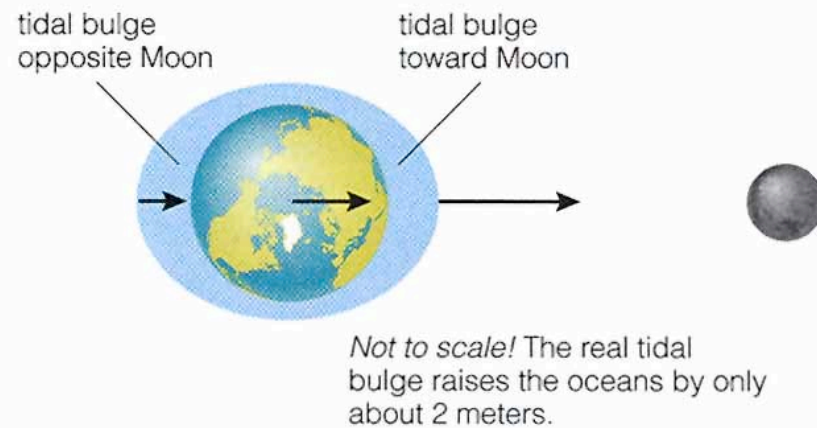
Surface dominated by long “lines,” many double and triple, appear to be fissures in An icy crust that may (or may not) cover a layer of *liquid water*.



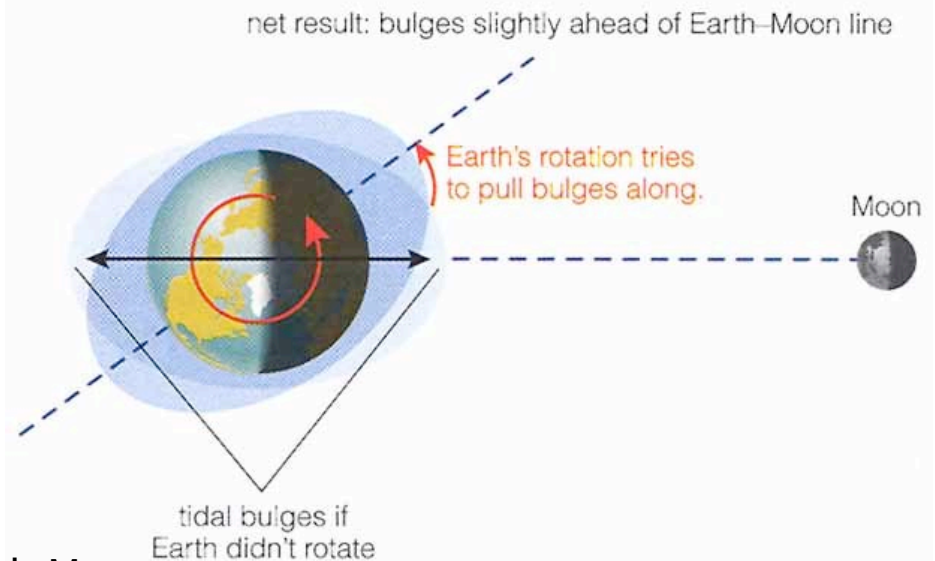
*None* of Jupiter’s satellites have atmospheres *today*, but could have earlier (they are more massive than Mars). So the interest is in subsurface liquids. Io’s volcanoes and Europa’s (possible) liquid water are due to the same effect: changing tidal forces due to interactions with Jupiter *and* with other satellites. We have to understand the physics of tidal heating to appreciate how this is possible--it could turn out to be a major source of heating for “habitable planets.”

# Tidal heating: First make sure you understand Earth-moon tides

Tidal bulges face toward and away from the Moon because of the difference in the strength of the gravitational attraction in parts of the Earth at different distances from the Moon. (Arrows represent the strength and direction of the gravitational attraction toward the Moon.) There are two daily high tides as any location on Earth rotates through the two tidal bulges.



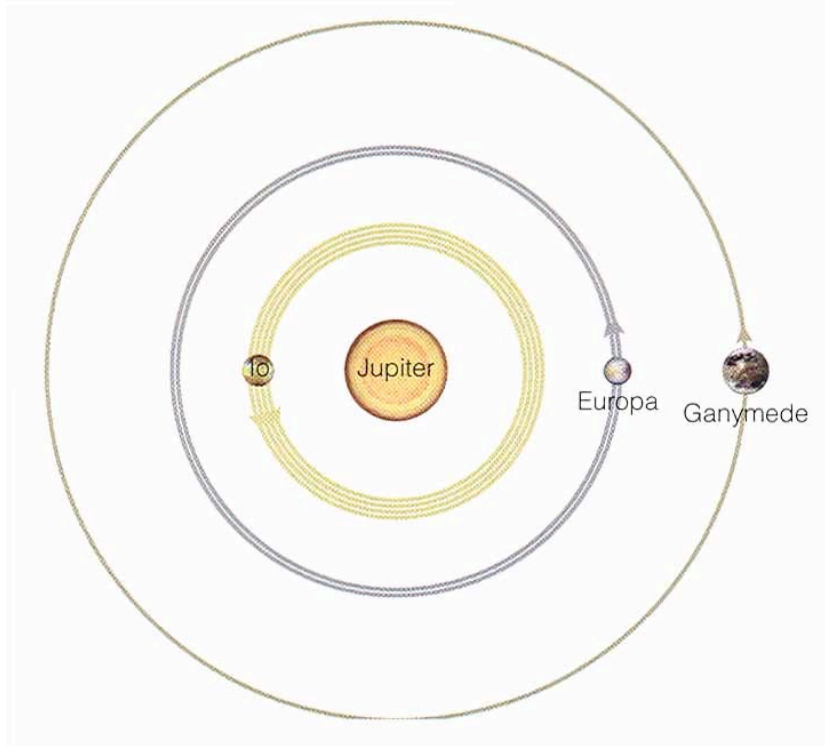
If the Earth always kept the same face to the Moon, the tidal bulges would stay fixed on the Earth–Moon line. But the Earth's rotation tries to pull the bulges along with it. The result is that the bulges stay nearly fixed relative to the Moon but in a position slightly ahead of the Earth–Moon line. (The effect is exaggerated here for clarity.)



- There is no significant tidal *heating* in the Earth-Moon system: the tidal bulge always has about the same size, because orbits of Earth and Moon are nearly circular. To get heating, the distance between Earth and Moon would have to be changing with time → **need more eccentric orbits**
- However the pull of Earth's bulge on the Moon slows the Earth and makes Moon move further from Earth. (Day was ~ 8 hours long ago, with Moon much nearer to Earth.)



## Jupiter-Io-Europa-Ganymede tidal system

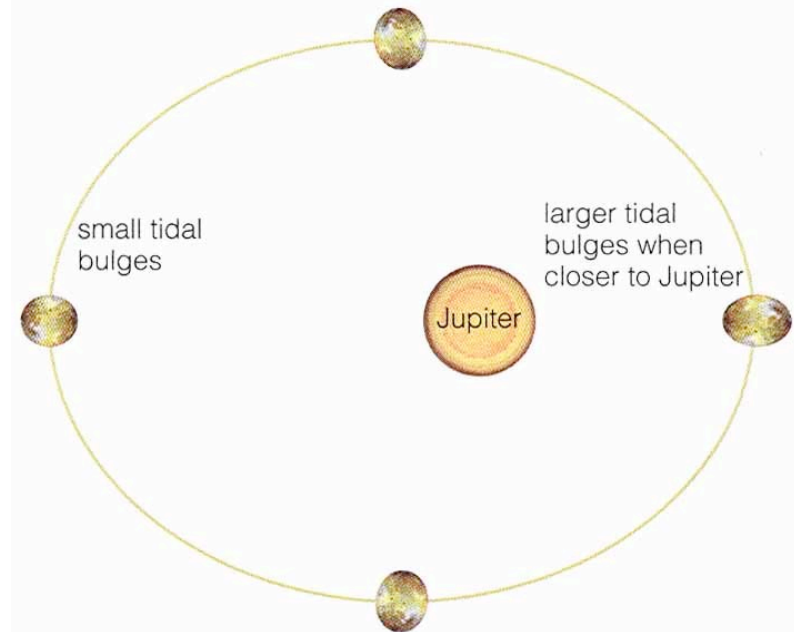


About every 7 earth days (one Ganymede orbit, two Europa orbits, and four Io orbits), the three moons line up as shown.

***The small gravitational tugs repeat and make all three orbits slightly elliptical.***

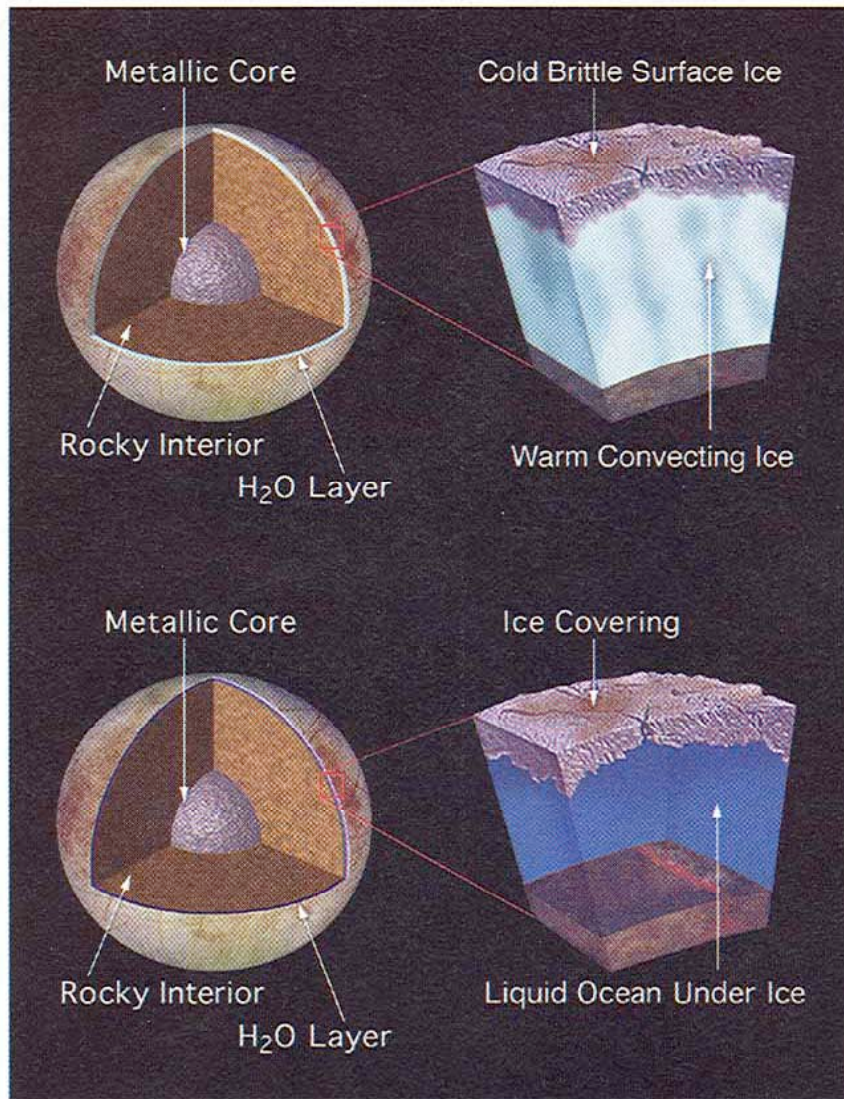
## Tidal Heating: Io

Because Io's orbit is slightly elliptical, the size and direction of Io's tidal bulges change. The bulges and orbital eccentricity are exaggerated.



Because Io's orbit is slightly elliptical, the size and direction of Io's tidal bulges change. ***This work done on the tidal bulges is the source of the tidal heating.*** Same occurs for Europa. The bulges and orbital eccentricity are exaggerated.

# Two models for the interior of Europa



Both models heated by Jupiter's tides

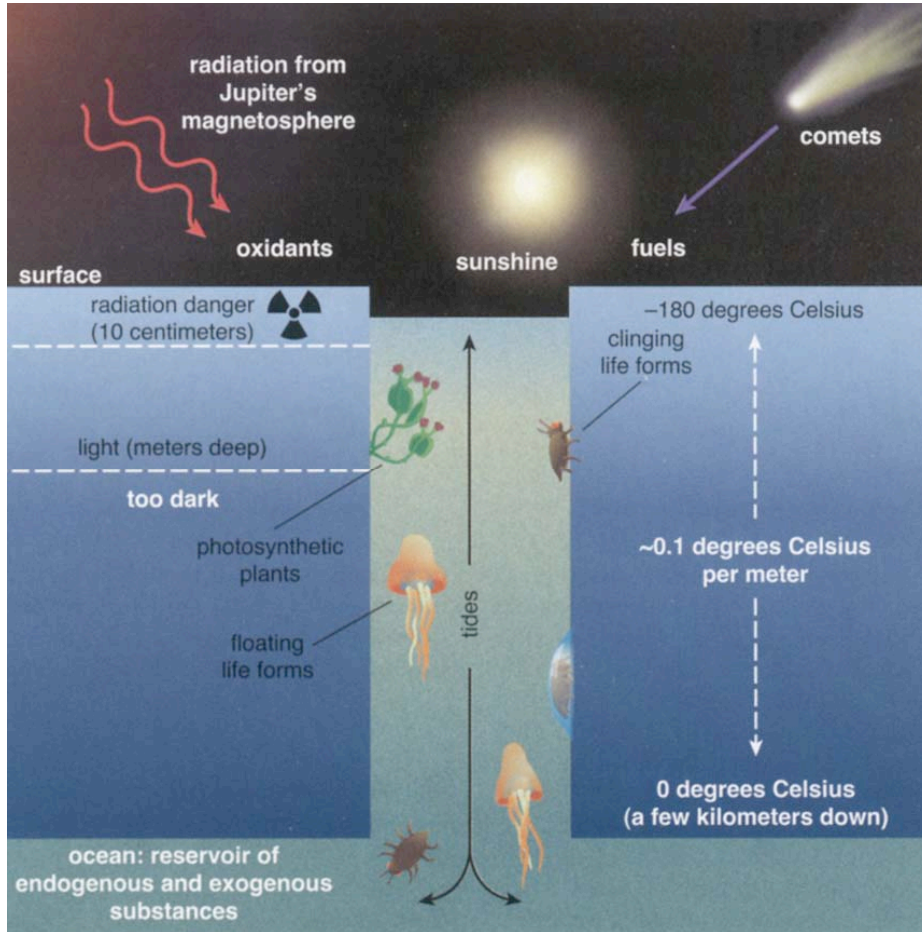
Top: Water layer consists of warm ice (which can flow and convect) and a brittle crust.

Bottom: Liquid water layer beneath the crust.

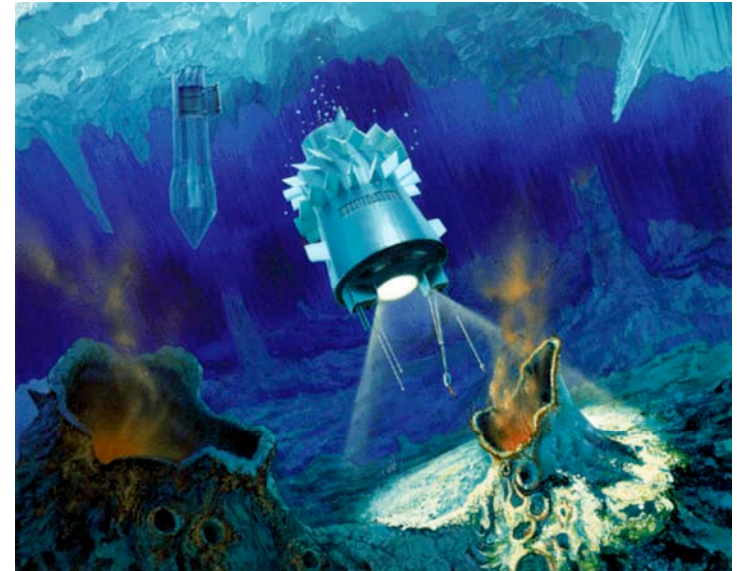
If liquid water, several speculative models for a subsurface oceanic ecology (see next slide for typical illustrative example)



# Speculative European subsurface ecology



In this model, chemistry is driven by energetic charged particles (from Jupiter) and decay of radioactive potassium-40 in the liquid layers. See next slide for details.



How deep is icy crust? If not too deep, could envision, for umpteen gazillion dollars, something like shown to right. However current estimates for thickness are at least 10 km. But remember Enceladus....theory is extremely uncertain. *No one has a technique for burrowing this deeply into an icy crust.*

# More details of Europa subsurface model (only examine if interested)

