The Jovian Satellites

- Satellites are common around Jovian planets
- Some are as large as Mercury, & thus are planets in their own right
- Some have atmospheres
- Discovery of the first Jovian satellites
  → In 1610, Galileo discovered the 4 Galilean satellites
  → Discoveries of new satellites continue to this day
Regular vs. Irregular Satellites

- **Regular**: Satellites having orbits of low eccentricity near the equatorial plane of their planet
  → Formed in the “sub-nebula” surrounding planet

- **Irregular**: Satellites having orbits of large eccentricity, high inclination, or both
  → Captured from elsewhere
Cratering

Source

- Inner solar system: 30% by comets & 70% by asteroids
- Outer solar system: long period comets

The impact rate on jovian satellites

- **Gravitational effect of planet**: cratering should occur at a higher rate with larger impacts for moons near planet
- **Synchronous rotation**: leading side of the moon receives more craters than the trailing side

Cratering studies of the jovian satellites confirm that there was a period ~ 4 billion years ago when the cratering rate was high
First Up: The Galilean Moons

- Io
- Europa
- Ganymede
- Callisto
Callisto

- **Density** = $1.9 \, \text{g cm}^{-3}$
  (½ water ice, ½ rock)
- **Reflectivity** = 18%
  (no resurfacing of fresh ice)
- **High crater impact rate** ~ 250 10 km craters per million km$^2$

Covered with craters
Callisto: Craters

- Sharpness of craters is more subdued than on the Moon
- I.e., the surface is ice, not rock
- Bottom line: the surface is very old.
Ganymede

- **Density** = 1.9 g cm\(^{-3}\) (\(\frac{1}{2}\) water ice, \(\frac{1}{2}\) rock)
- **Reflectivity** = 40% younger region, 25% old region
- **Younger region**
  → parallel mountains & valleys
  → **Origin**: lava of liquid water resulting from density & structural changes in the ice as the moon cooled

Darker cratered regions + lighter, less cratered regions
Mechanism for grooves on the surface of Ganymede?

**FIGURE 15.11** While we do not completely understand the processes that formed the grooved terrain on Ganymede, this diagram describes one possibility. (a) The original primitive crust is cracked by tensile stresses. (b) Subsidence, flooding, and freezing produce a new surface. (c) Additional faulting and subsidence produce the ridges and valleys seen today.
Ganymede: Craters

• Cratering rate for younger region ~ 100 – 200 10 km craters per million km²

• I.e., still old
Europa

- **Density** = 3 g cm$^{-3}$
  (primarily rock, with 10% water ice)

- **Reflectivity** = 70% (water ice)

- Similar to Earth →
  surface covered mostly in water & ice
The Surface of Europa

- **Streaks & ridges** are cracks in icy surface
- Ridges may result from material being squeezed up from below
- Purity of surface → **resurfacing process**
- No evidence of impacts
- Source of energy for resurfacing: **Tidal Heating by Jupiter**
A close-up of the Europa’s surface

- **Model:** Ice floating on a sea of water
• **Density** = 3.3 g cm\(^{-3}\) (rock with little or no water)

• **Thin atmosphere** of sulfur dioxide (note again: sulfur & oxygen from Io are major contributors to charged particles in Jupiter’s atmosphere)

• **No impact craters** → surface is young

White surface: sulfur dioxide
Other regions: hydrogen sulfide, sulfur, sodium (??)
Why is Io’s surface so young?

- **1979**: Voyager 1 photographed 9 plumes
- Types of volcanoes:
  1) **Violent & short-lived**: dark red deposits with sulfur as primary ejecta ($T = 700$ K, $v_{\text{ejecta}} = 1000$ m s$^{-1}$)
  2) **Long-lived**: white deposits of sulfur dioxide

**Answer**: Volcanoes
Why Sulfur?

- 100,000 tons of material ejected each second
- Could cover entire surface to a depth of 10s of meters in 1 million years
- 10 tons per second escape Io ($\text{SO}_2 + \text{Sunlight} \rightarrow \text{S} + \text{O}$)

Volatile such as water & carbon dioxide have long been lost
Volcanic hot spots

- Some in the form of “Lava lakes”
- To the left: Loki Patera → lake of liquid sulfur with a raft of solid sulfur inside
Figure 6.16 Tidal bulges face toward and away from the moon

Not to scale! The real tidal bulge raises the oceans by only about 2 meters.

Figure 6.17 Spring and neap tides
Energy for Io via tidal forces

- **Gravitational pull** of Europa & Ganymede keep Io from achieving circular orbit
- Thus, Io experiences **tidal torques** as it approaches & recedes from Jupiter
- Jupiter is slowing down as a result of this interaction: Io, Europa, & Ganymede are being pushed outward
I.o  Europe  Ganymede  Callisto

- Tidal Stronger (Internal Heating)
- Warmer (Depletion of Water in Early Subnebula)
- Impact Rate Higher (cratering)
- Resurfacing Higher