Europa

And the Moons of Jupiter
\( N_H \) and \( F_\ell \)
Recap:
Comparative Planetology
Venus

- Near the inner edge of the Solar habitable zone
- Runaway greenhouse effect makes planet too hot to be inhabitable
Earth

- Outside the unmodified Solar habitable zone
- Habitable because of a mild greenhouse effect
- Only planet with liquid surface water
Mars

- Outside the unmodified Solar habitable zone

- Uninhabitable: too small to retain sufficient atmosphere for a greenhouse effect to operate

- May have subsurface water ice
The Jovian Planets
The Moons of Jupiter

Ganymede             Callisto                     Io                  Europa

The Galilean moons; there are 59 others
Discovery of the Galilean Satellites
• The size of Luna

• **Sulfur** surface produces the orange, yellow, and black colors.
Io

- The **most** volcanically-active body in the solar system
- Strong tidal stresses and internal heating.
- Density close to that of Earth's moon.
- Molten silicate interior; iron core
- No large craters ➔ surface <1 million years old.
Tides

• A tide is a differential gravitational force
• Gravity scales as $1/r^2$
• Tides scale as $1/r^3$
• Tidal forces generate friction, which dissipates as heat
Tides

• Tidal friction causes some objects to rotate in **synchrony** with their orbital period.
• Conservation of angular momentum affects orbits.
• Tidal heat dissipation can heat objects.
Tidal Heating

Io’s elliptical orbit means continual changes in the strength and direction of the tidal force from Jupiter . . . and the changing tides flex Io’s interior and cause tidal heating.

far from Jupiter: small tidal bulges

close to Jupiter: large tidal bulges
Tidal Heating on Io

Prometheus

Loki
Orbital Resonances

1 Ganymede orbit (7 days)

= 2 Europa orbits

= 4 Io orbits

Io

Jupiter

Europa

Ganymede
Ganymede

• 3rd of the Galilean satellites

• Bigger than Mercury

• Differentiated, iron core

• Complex surface
  • dark cratered regions
  • light grooved regions

• The grooved terrain:
  • 60% of the surface
  • Faulted
  • Few craters ➔ young
Callisto

• Most distant of the Galilean satellites

• Density $\rightarrow$ rock and ice

• Moment of inertia $\rightarrow$ undifferentiated

• Tidal forces have not heated its interior.

• Heavily cratered, very old surface
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• 2\textsuperscript{nd} of the Galilean satellites

• Smoothest surface in SS

• Surface appears to be water ice

• Surface looks like Arctic Ocean
  • Iceberg-like structures
  • Dark lines appear to be cracks in the ice

• No craters $\Rightarrow$ < 30 million year old surface

• Severe radiation environment
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- Smooth surface
- Few craters
- Compression ridges
- Stretch fractures
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Conamara Chaos - 70 x 30 km region
blue: young water ice (ejecta from crater Pwyll)
brown: mineral contaminants
Europa close-up

The surface at 1.6km resolution
Europa close-up

The surface at 26 m resolution
Europa Interior Models
Life in Europa

Ingredients:

• Liquid water
• The precursors of organic chemistry
• An energy source
Internal Structures
Other Types of Habitable Zones

Water requires heat and pressure to remain stable as a liquid.
Extended Habitable Zones

• You **do** need liquid water
• You **do** need an energy source.
• You do **not** need sunlight.

• Examples:
  – Black smokers
  – Europan ocean?
Revisiting $N_h$

- $N_h = 1$ (Earth)
- $N_h = 3$ (Venus, Earth, Mars)
- $N_h > 4$ (Places with liquid water)

$$N = N_* f_s f_p N_h f_l = 3.2 \times 10^{11} \left(\frac{N_h}{4}\right)$$
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_All these worlds are yours ... Except Europa. Attempt no landings there._

Arthur C. Clarke, 2010: Odyssey Two