Extraterrestrial Life: Spring 2008

Jovian system
Massive, gas giant planet, ~0.001 Solar masses

Orbital radius: 5.2 AU - distance beyond snowline where rock and water ice dominates

4 large Galilean moons:
- Io (period 3.55 days)
- Europa
- Ganymede
- Callisto
  1:2:4 resonance between the orbital periods of the inner 3 satellites

Europa: radius 1560km
Gradient of mean density:
- Io: 3530 kg/m³
- Europa: 3018 kg/m³
- Ganymede: 1936 kg/m³
- Callisto: 1851 kg/m³
  density of rock (silicates)
  mixture of rock plus lower density ice (~920 kg/m³)

Surface of Europa is made of water ice
Mean density would be consistent with a 6% fraction of water by mass:
  e.g. 1450km rocky interior with a 110km thick layer of water (liquid or ice) at the surface

Evidence for an ocean on Europa
(1) Global surface appearance
  Europa surface has very few impact craters - only 3 with diameter > 3km
  Young surface
  Cratering rate in the outer Solar System is not well determined: models suggest an age between 10 million and 1 billion years
  Resurfacing must involve melting at least some of the ice

(2) Local surface features
  Galileo images of the surface show blocks of ice, km-10s km in size, separated by ridges
  Crust has been fractured and then refrozen in place
  Appearance resembles pack ice floating on the ocean at the North Pole and off the coast of Antarctica

(3) Magnetic field measurements
  Jupiter has a strong magnetic field, which Europa is orbiting through. Magnetic fields are generated by currents - flows of charged particles.

  If Europa’s interior does not conduct electricity, the moon cannot generate its own magnetic field and the field measured near the surface should be that of Jupiter alone

  If Europa’s interior conducts electricity, then the motion of the moon through Jupiter’s field induces a current, which distorts the Jovian field near the moon.
Extraterrestrial Life: Spring 2008

**Galileo measurements during a close flyby**

Prediction based on Jupiter’s magnetic field if Europa has no field of its own

Conclude that Europa does possess its own magnetic field, and hence that some part of the interior of the moon must be an electrical conductor…

Extraterrestrial Life: Spring 2008

**What could the conductor be?**

Rock and ice are both poor conductors

A salty ocean beneath the ice would be a good conductor: explains the Galileo magnetic field measurements quite well

An iron core would also be a good conductor: can’t exclude this possibility and if one exists, analysis is much more complicated…

Extraterrestrial Life: Spring 2008

**Heat source for Europa**

Internal heat of small bodies (Moon, Mars, Mercury) is not enough to sustain geological activity for the life of the Solar System

**Tidal heating**

Tides are raised on Europa by the different gravitational force from Jupiter on the near / far side of the moon

Stress and try to crack the surface

Dissipation of the tidal energy results in heat in the moon’s interior

Extraterrestrial Life: Spring 2008

**Possible oceans**

Current data provides little constraint on the thickness of the ice layer overlying the ocean. Two models:

1. Thin ice layer (~1km), fractured by tidal forces as Europa orbits Jupiter, or local heating from volcanic events at the silicate / water boundary
2. Thick ice layer (at least 20km) fractured by convection in the ice heated by tides

Extraterrestrial Life: Spring 2008

**Io: moon closest to Jupiter**

Very strong tides lead to volcanic activity on the surface

Moon is distorted (very slightly) by tidal gravitational force
As it rotates, tidal bulges don’t quite align with the axis between the Moon and Jupiter
Dissipation of the tides leads to heating

Extraterrestrial Life: Spring 2008
If Europa indeed has an ocean, are the basic conditions for life met?

- **Water**: yes
- **Carbon**: yes - surface of the other Galilean moons show abundant impact craters... meteors on Earth deliver organic material and the same must be true for Europa
- **Energy**: possibly... unknown whether hydrothermal vents or volcanic activity occurs at the bottom of the ocean

If energy is available, conditions in Europa’s ocean (T ~ 0°C, probably quite salty water) fall within the range for which extremophiles survive on Earth...

---

**Europa exploration**

No current spacecraft in the Jovian system, and no funded mission to return by NASA or ESA

High priority for “outer planets” science, but expensive and difficult to fly to Europa (distance, low Solar flux, radiation environment near Jupiter)

- **Europa orbiter** could definitively establish the presence or absence of an ocean, and measure the depth of the ice
- **Lander** could sample the ice near the surface, and conceivably drill through to the ocean