The Cosmos

Planets & Life

PHYS 214

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Please start all class related emails with "214:"

Admin

- Quizzes being marked - answers up though
- Assignment 2's here – pick up at end
- Assignment 3 back next Friday?
- USAT also today – will finish 10 minutes early

Today's Lecture

- Icy bodies in the solar system – Jupiter's icy moons as an example
  - Four assumptions for life
  - Jupiter's icy moons: Ganymede, Callisto & Europa
  - Europa in more detail
    - Tidal heating
    - Ice thickness
    - Life on Europa?
    - Missions to Europa

Fundamental assumptions about life on icy bodies

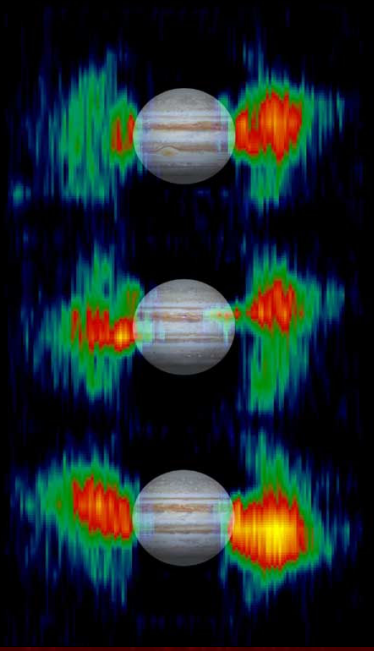
- We need to have water
  - All LAWKI has water as its principle solvent so "follow the water…"
- We need to have the right chemicals for life (C,H,O,N,P,S)
- We need some source of energy for life to draw from
  - On Earth we know this is primarily solar radiation, although hydrothermal vents are an alternative
  - In the outer Solar System we are going to be relying on something other than the Sun
    - Hydrothermal vents seem like the most likely candidate

- Before dismissing an object because the current environment seems bleak, life may have appeared if these conditions prevailed in the past..

Important points about Jovian environment

- Very large radiation field
  - Jupiter's magnetic field is very large and traps a lot of high speed charged particles
  - Io passes through some of the most intense regions of the radiation
- Mass attracts many comets & other bodies on collision courses (e.g. Shoemaker-Levy 9)
  - Means that organic material is probably being delivered quite regularly to moons in the system

Radiation fields



Jupiter's icy moons

Ganymede Callisto Io Europa

	Mean distance from Jupiter/ 10^3 km	Orbital period / days	Diameter / km
Europa	670.9	3.55	3130 (2/3 size of mercury)
Ganymede	1070	7.15	5268 (3/4 size of Mars)
Callisto	1883	16.7	4806 (~size of mercury)

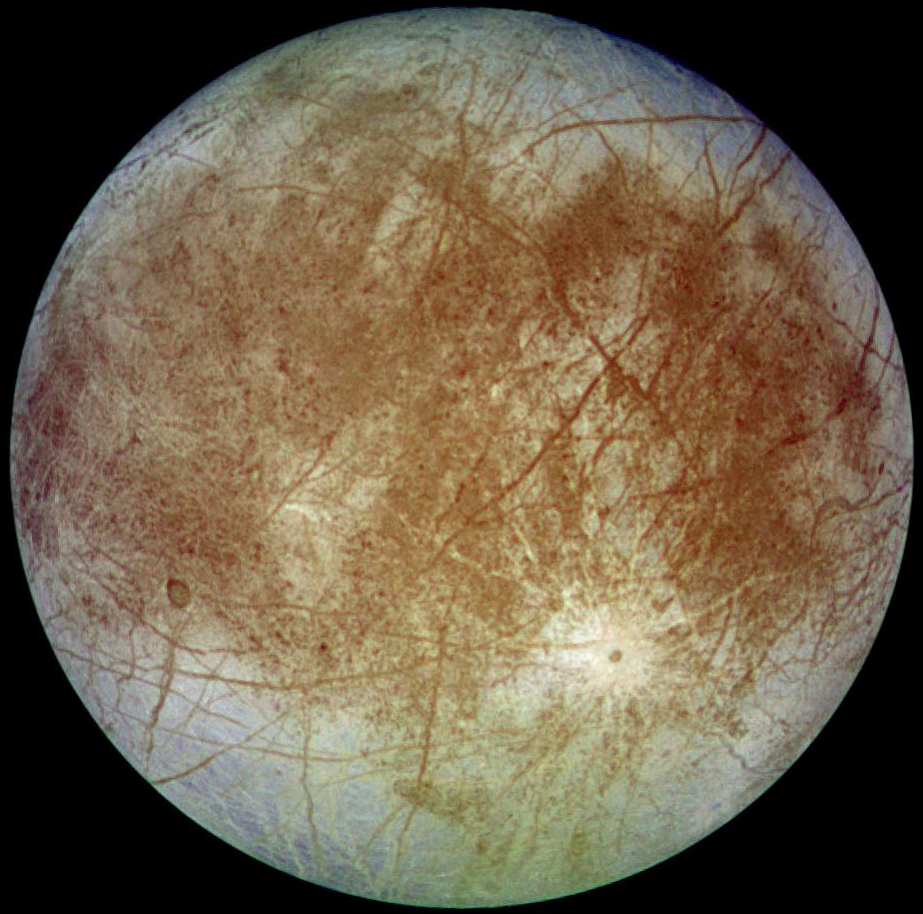
Temperature of the moons

- Naively applying the radiation balance model to these moons we find the estimate for their temperature is

$$T_p = \frac{278}{\sqrt{d_{p\,\text{in AU}}}}\,\text{K} = \frac{278}{\sqrt{5.2}}\,\text{K} \cong 120\,\text{K}$$

- Again, this value is fairly close to what has been found: Europa 103 K (mean) goes as low as 50 K, Ganymede 109 K, Callisto ~120 K
- The different values are caused by the different albedos. Europa is clearly more reflective than Ganymede & Callisto
  - No atmospheres to worry about in this case

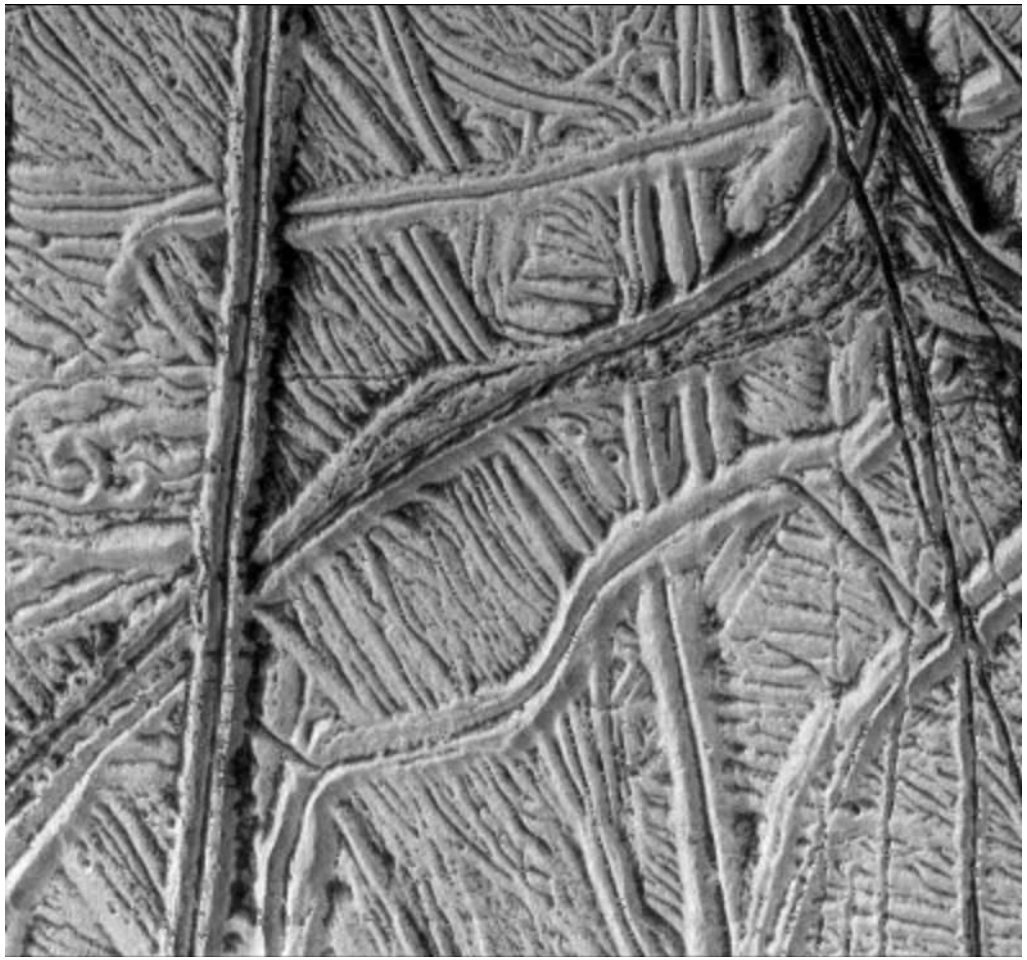
Focus on Europa



View from Galileo

- Very flat surface with little relief
  - Akin to a cue ball!
- Very few impact craters
  - Suggests surface is renewed regularly – perhaps every 10 Myr?
- Icy surface is covered with bands of different colours
  - Some dark, some very light
  - Light bands within dark bands also occur
  - Dark bands associated with sheets of ice moving apart
- Magnetic field data suggest that *somewhere* beneath the surface there is moving water

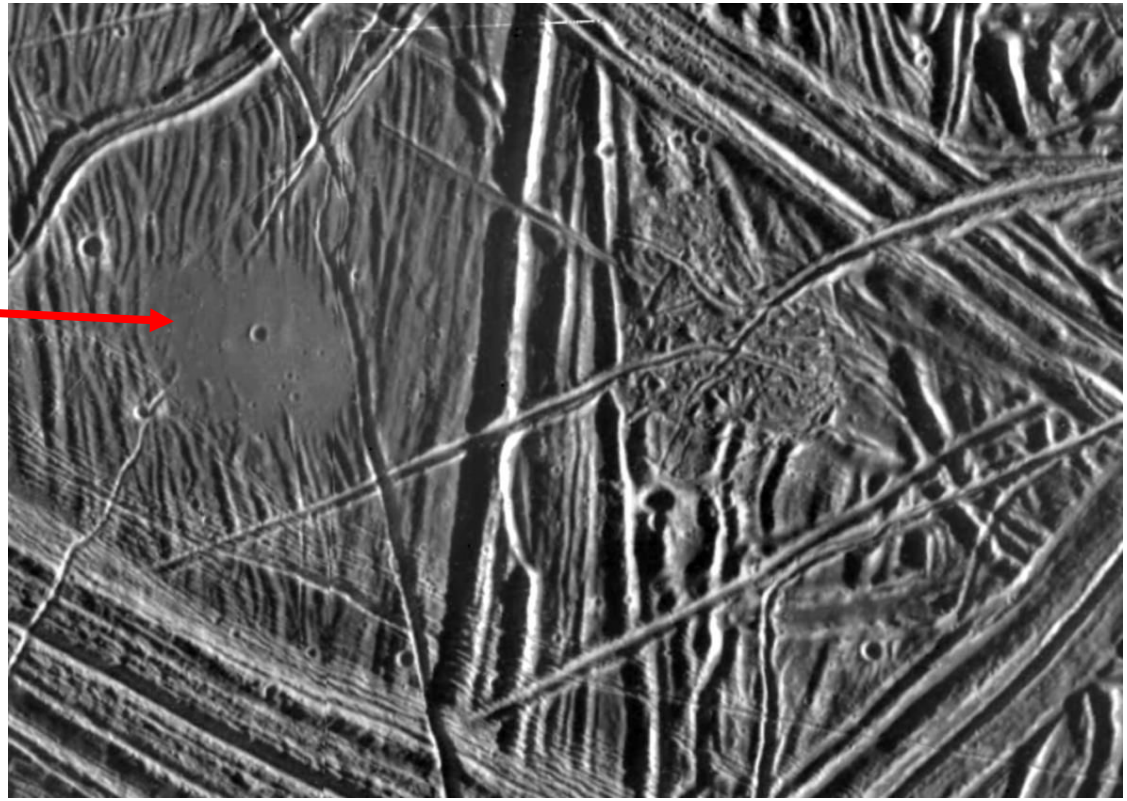
Surface Features



- Europa's major features are called **linea** and **maculae**.
- Vertical elevation is limited to a few hundred meters.
- The cross-cutting allows relative dating of features

Local melt

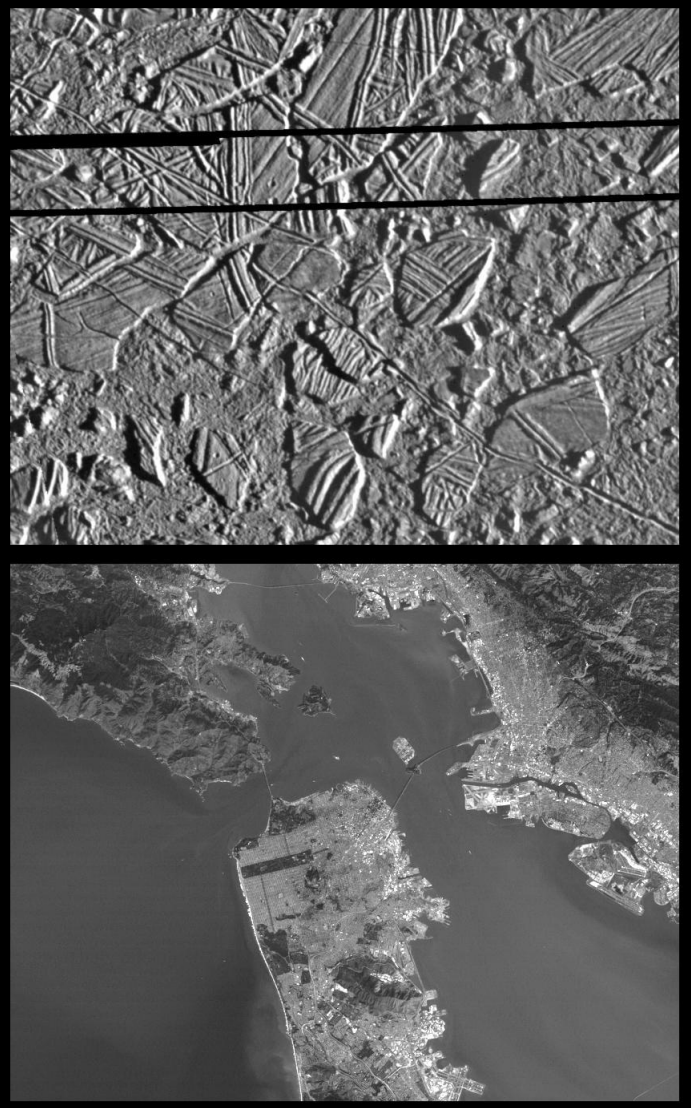
- The flat region on the left of the pictures looks like an example of recent local melting
  - Might this imply the top ice layer is thin?
  - Perhaps some form of local heating?



There is also evidence of broken icebergs….

Rafts

- These are regions where ice is presumed to have broken away from a liquid ocean surface
  - Long since refrozen though
- Believed to be analogous to pack-ice break-up
- This type of terrain is generally termed “chaos”
- The size of the shadows can be analyzed to estimate the heights of these objects



San Francisco bay area for size comparison

Ice thickness argument

- The pressure beneath a substance of density r of depth d in a gravitational field g is

$$P = \rho g d$$

- Pressure at water depth w must balance that from column of ice of height h+w

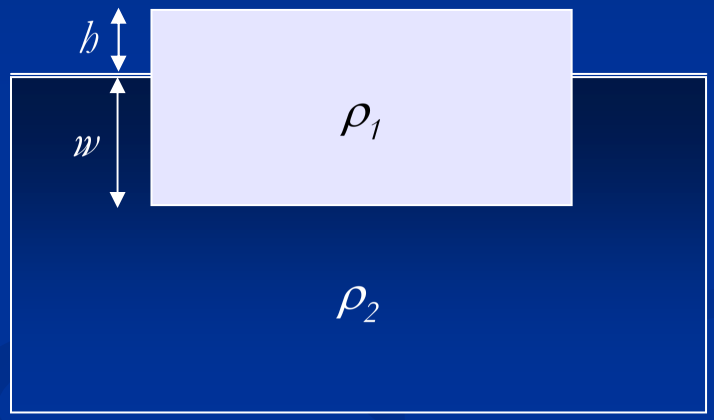
$$P = \rho_1 g(h+w) = \rho_2 g w$$

- Cancel g to give

$$\rho_1(h+w) = \rho_2 w \Rightarrow \rho_1 h + \rho_1 w = \rho_2 w$$

$$\therefore w = \frac{\rho_1 h}{\rho_2 - \rho_1}$$

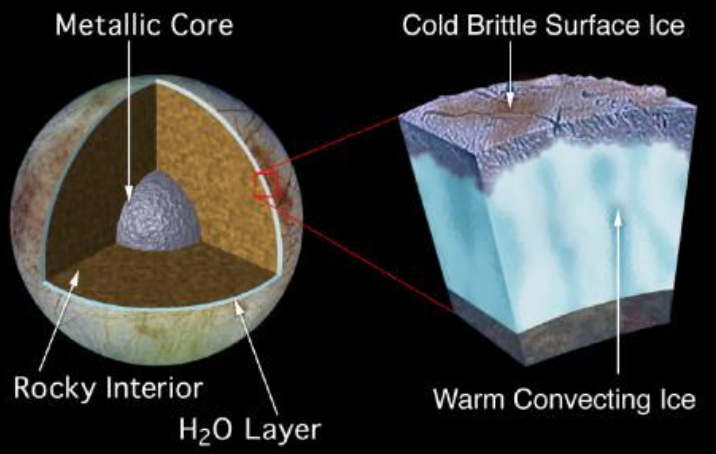
h=height above surface
w=depth of sheet in water

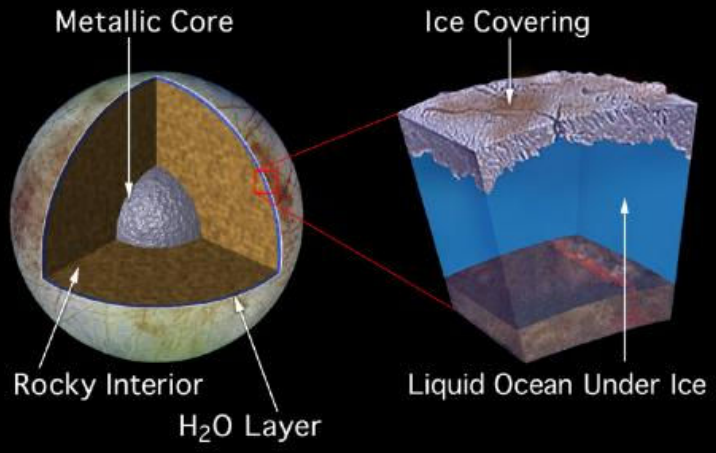


Estimates of the raft depth

- Rafts rise up to 100m above the surrounding material
- Upper and lower limits on the density of the frozen material depend upon the amount of dissolved metal ions (high density)
  - Pure(r) ice would be considerably lower in density
- Given limits on the ice density of 927 kg m^{-3} (lower) and 1126 kg m^{-3} (upper), and a water density of 1180 kg m^{-3} we find that
  - Maximum depth ≈ 2100 m (for highest density)
    - Raft depth being 2100+100=2200 m
  - Minimum depth ≈ 370 m (for lowest density)
    - Raft depth being 370+100=470 m

Internal Structure

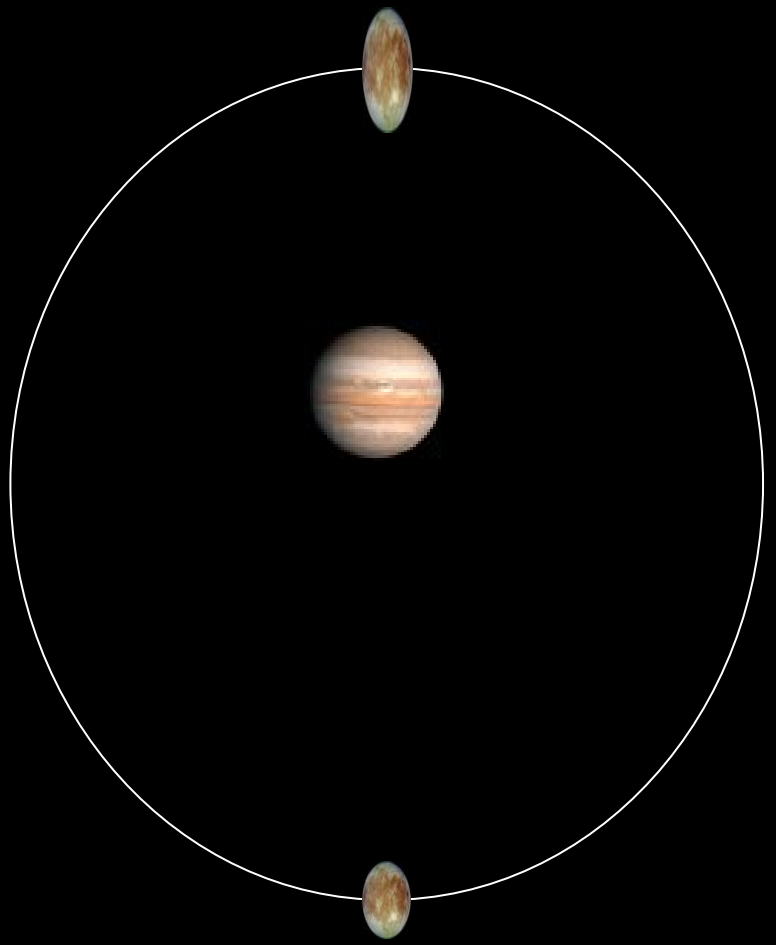




- We have no soundings from Europa, but very sensitive gravity measurements allow us to infer the interior structure
- Geophysical data suggest an "ice" layer 100 km thick, but it is not clear whether there is a global subsurface ocean or not
- Average density works out to be about 3 g cm^{-3}. The interior is mostly rocky (silicates) – not clear how well differentiated it is
  - Metallic core?
- Open questions:
  - Does Europa have a metallic core?
  - What is the thickness of the water layer?

Tidal heating

- Europa experiences a small, but significant, amount of tidal heating due to its non-circular orbit
  - Io is an extreme example – it is constantly deformed by both Jupiter and the other Jovian satellites
- Tidal forces are proportional to $1/r^3$ so Ganymede and Callisto feel significantly less tidal heating
- Europa's surface is estimated to distort by ~50 meters per orbital period from tidal interactions. This is one explanation for Europa's cracked ice surface.



Physics of tidal heating

- Rather complicated – depends upon the relative rigidity, the stresses & strains created, as well as size of a body and it orbital characteristics
  - We won't look at the derivation in this course!
- For Europa the energy input* supplied by tidal heating is estimated to be 8.1×10^{12} W
  - Compare to Io which is 8900×10^{12} W!
- A very crude estimate puts the effective (average) energy input per surface area as 0.26 W m^{-2}
  - Two orders of magnitude lower than the net flux reaching the surface of the Earth
  - Local energy input around geological active regions could be much higher

**These numbers may actually be quite inaccurate, do not take them as absolutes.*

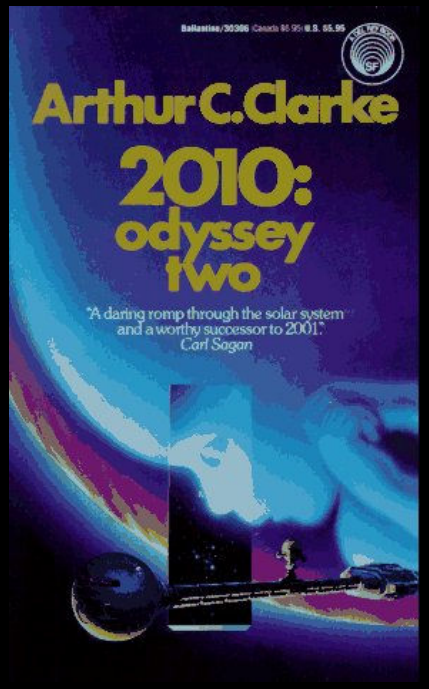
Life on Europa

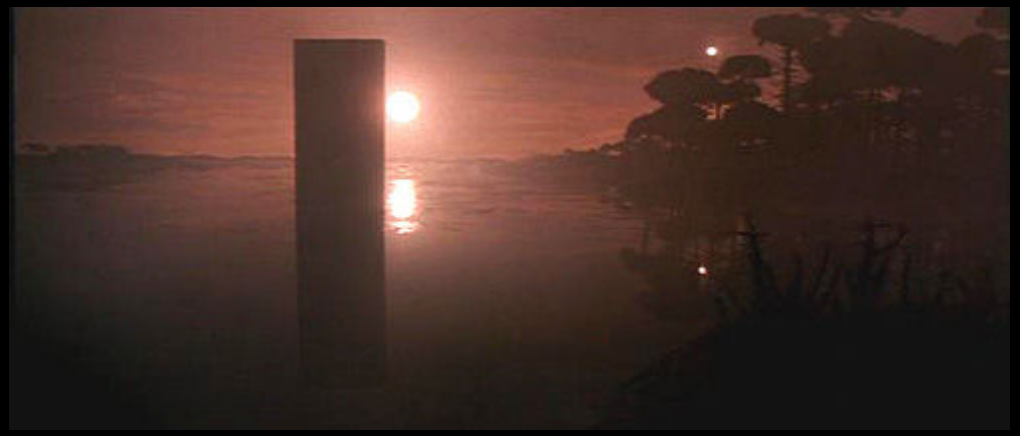
- Exactly how much of the tidal heating goes into the core of the planet versus the surface ice is unknown
  - If it all went into the ice then there would be no geothermal vents
- Ultimately, everything hinges on the geothermal vent issue!
  - Note RNA evidence suggests that life on Earth has a common ancestor of thermophylic microbes dependent on chemosynthesis rather than photosynthesis
- It is also unclear precisely what chemical reactions biota near Europan vents would use
  - The methanogensis pathway (see G&S 160) is ruled out for example
- Bottomline – sadly even life on Europa is highly questionable at best, but we should *definitely* take a look!

Contributions from science fiction…!

- Arthur C. Clarke was one of the first to ponder on the possibility of tidal heating of Europa reproducing hydrothermal vent environments
- The 2010 novel explores this idea in detail and has been a motivator for many people's interest in Europa…

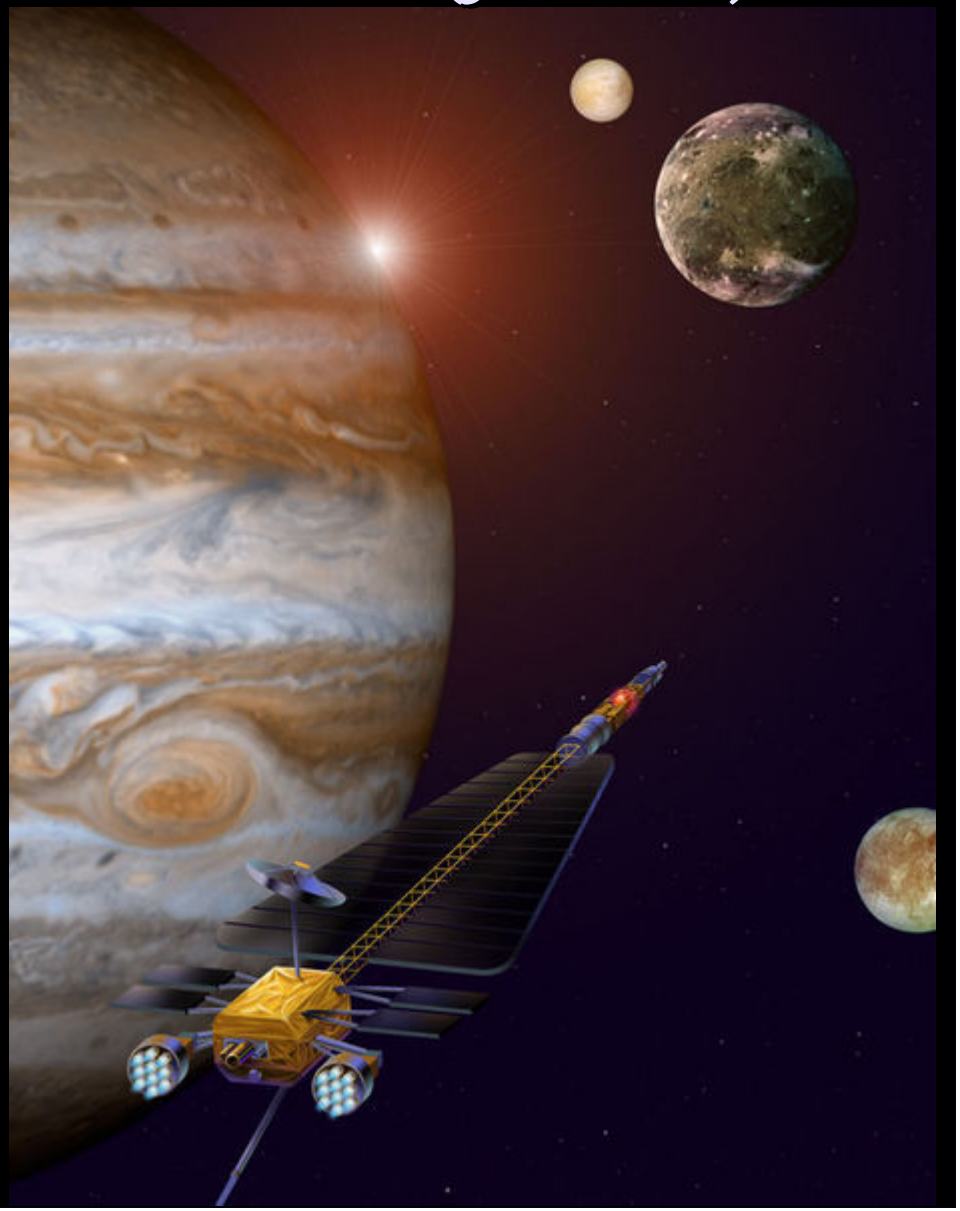
The book is better than the movie in my opinion!





Jupiter Icy Moons Orbiter (JIMO)

- Very ambitious (nuclear) powered rocket
  - Estimated budget cost $10 billion
- Originally planned for launch in 2017
- Designed to enter Jovian system and move from moon to moon (Ganymede, Callisto, Europa)



JIMO mission outline

Europa lander & probe concept (circa late 1990s)

Crybot Movie

Missions: post JIMO cancellation

- Scientists studying the outer Solar System are in broad agreement that Europa is the #1 target for a mission
- ESA, as part of its "Cosmic Vision" proposal is currently examining proposals for a JIM mission
- Following an uproar from planetary scientists, NASA is also reviewing (descoped) alternatives to the cancelled JIMO
  - JIMO was exceptionally ambitious in scope…
- Very unclear where things are going right now

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Major space missions move ahead

By Paul Rincon
Science reporter, BBC News, Houston

The European and US space agencies are moving ahead on their next major missions to explore the Solar System.

What should follow the great success of Cassini-Huygens?

Nasa has begun choosing a destination for a "flagship" robotic venture along the lines of Cassini-Huygens, which has been exploring Saturn and its moons.

It is considering four targets: the Jupiter system, Jupiter's moon Europa, and Saturn's moons Enceladus and Titan.

The European Space Agency has called for proposals for one flagship mission and another medium-sized mission.

Europa, Titan and Enceladus are also among the destinations expected to be proposed under the European Space Agency's (Esa) "Cosmic Visions" programme of exploration.

Other proposals likely to be submitted include a mission to return soil

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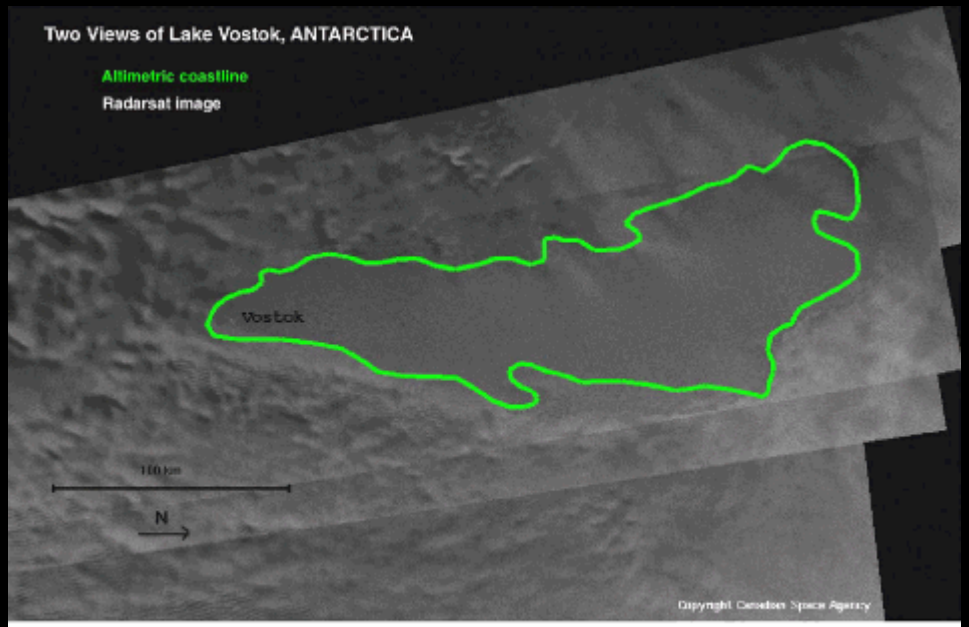
Lake Vostok – Europan analogue?

- Discovered in Antarctica in 1996 using ground penetrating radar
  - Lies under 4 km ice-cap
  - Average water temp -3° C
  - 250 km by 50 km wide
    - similar size to L. Ontario!
  - The (fresh) water is estimated to have been in the lake for 1 million years
    - L. Ontario water around for 6 years on average
- Russians began drilling in 1974 but didn't realize what they were drilling into
  - Ended up stopping 120 m above the estimated edge
  - 60 tons of aviation fuel and anti-freeze poured down bore hole to keep it open
    - Environmental disaster!



Radar Image of Lake

Ice cores taken from very close to the lake show the presence of microbial life.

Summary of lecture 26

- Europa is intriguing because it may well have the three necessary ingredients for life
  - Liquid water (at least somewhere)
  - Supply of organics
  - Energy source from tidal heating
- Many questions remain though, especially about the nature of the subsurface ocean and the thickness of the ice sheet
- Despite this interest, life on Europa seems unlikely, although we should view it as the #1 priority
- The remaining icy moons have less tidal heating, and seem less likely candidates for life

Next lecture

- Broadcasts & ETI