Astronomy 330

This class (Lecture 15):

Life in the Solar System

Next Class:

Biological Evolution

Music: *The Universe Song*– Animaniacs

HW #3

- **Gretchen Bromann:** http://www.pararesearchers.org/
- **Kyla Bachtell:** http://www.nuforc.org

Outline

- Life in our Solar System?
  - Jupiter (Europa)
  - Saturn (Titan)

Drake Equation

That's 0.67 Life-liking systems/year

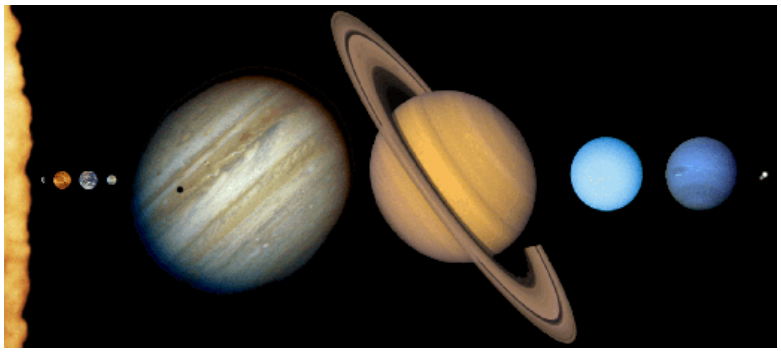
Frank Drake

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	19 stars/ yr	0.4 systems/ star	1.25 x 0.07 = 0.0875 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

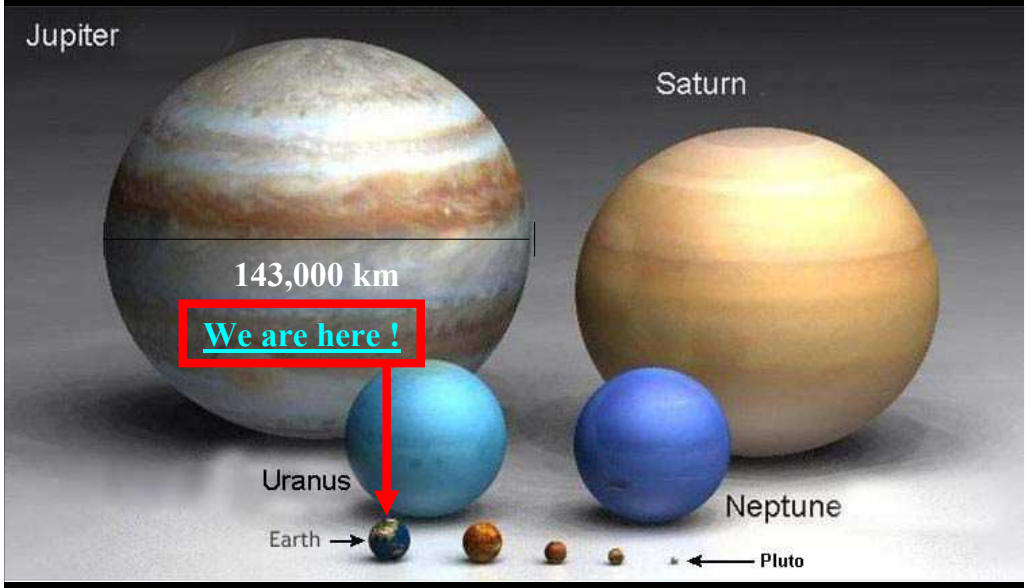
Life in the Solar System

- Venus may have life in the clouds.
- Mars might still have life under the soil.
- But what about the outer solar system?
- It isn't in our definition of the habitable zone, but it still is interesting.
- We will now focus on Jupiter, Io, Europa, and Titan.

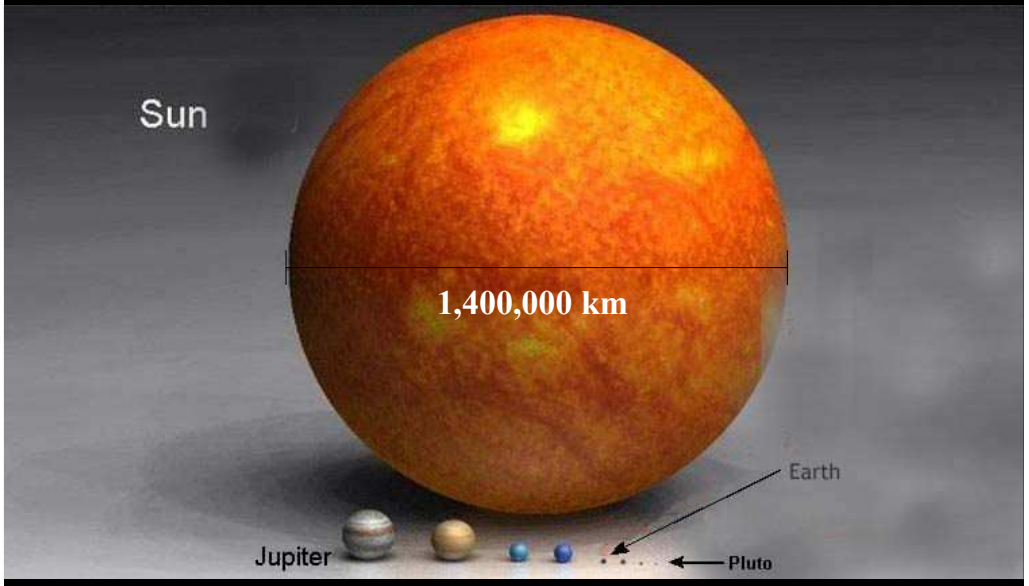


Mar 6, 2008

Big Boy?



Bigger Boy



Earth – Jupiter comparison

Biggest and most massive planet, has the largest gravity, has the largest number of moons (>63), yet has the shortest day in Solar System.
Radiates more energy than it absorbs.

Radius	11.2 Earth
Cloud-top gravity	2.5 Earth
Mass	318 Earth
(more than 2.5 times the rest combined)	
Distance from Sun	5.2 AU
Year	11.88 Earth years
Solar day	9 hours 55 minutes

Causes a bulge at the equator.

Jupiter, King of the Planets

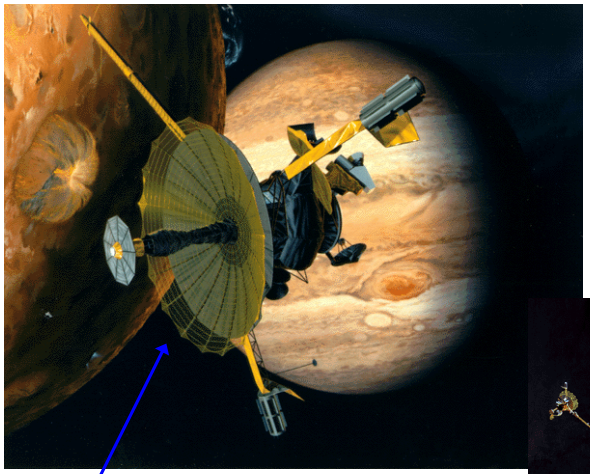
- Named for the king of the Roman gods
- A truly immense planet
  - Over 11 times the diameter of Earth
  - Over 300 times the mass of Earth
  - Over twice the mass of all the other planets combined!
  - Has over 63 moons, its own mini-solar system!
- Visited by 4 spacecraft
  - Pioneer 11 - Flyby in 1979
  - Voyagers 1 & 2 - Flybys in 1980 & 1981
  - Galileo - Went into orbit and dropped a probe into Jupiter's atmosphere, 1990-2003

Jupiter's Atmosphere

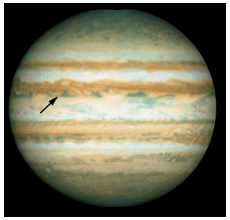
- Although mostly gas, by 20,000 km in, the pressure is 3 million atmospheres!
- Due to an internal heat source, the temperature rises as one penetrates the atmosphere.
- The outer atmosphere is made of freezing clouds of ammonia, methane, and ice.
- The swirling patterns are evidence of great storms.

Can you say Miller-Urey?

The Galileo Spacecraft (1989 – 2003)



How the main antenna *should* have looked



First atmospheric probe

Probing the Atmosphere

- The probe lasted for 57 minutes before it was destroyed by temperature and pressure.
- Found a lot of turbulence, strong winds (330 mph), very little water ice, and no lightning.

Probing the Atmosphere

- Did not encounter the layers of clouds that was expected.
- The probe entered the least cloudy region of Jupiter.
- Did not rule out life, but did not support it.
- Later, the spacecraft Galileo was crashed into Jupiter.

What Did Galileo Experience?

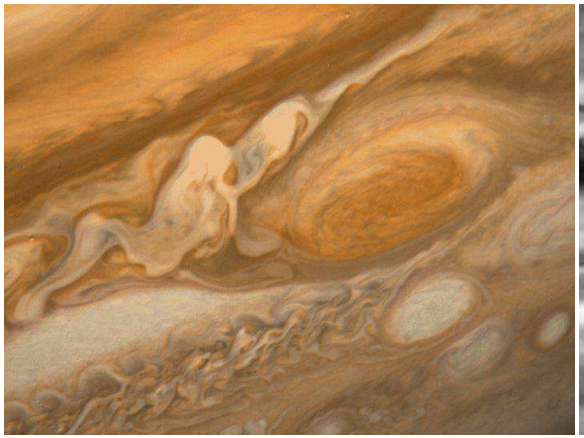
- An atmosphere unlike Earth's
  - 92% Hydrogen, 8% Helium, 0.1% other stuff
    - Very similar to the Sun's composition
    - Not too far from a binary star system
  - Rich chemistry
    - Ammonia, methane, other hydrocarbons, water, phosphine, etc..
- 400 mph winds
- Incredible pressures
- Increasing temperatures with depth

Driving Jupiter's Weather

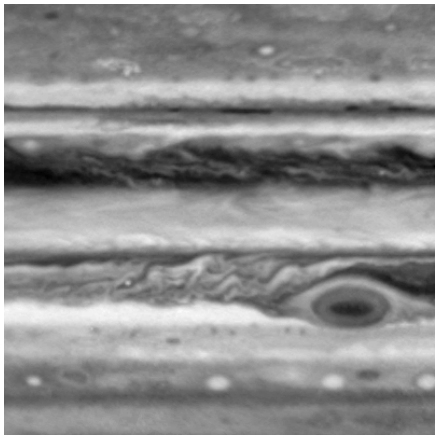
- On Earth, solar heating drives weather
- On Jupiter, internal heat drives weather
  - Winds maintain speeds to great depths
  - Jupiter radiates 70% more heat than it receives from the Sun
  - The heat is from Jupiter contracting under its own powerful gravity
  - As it contracts, the gas is squeezed, and the temperature increases

The Great Red Spot

- A huge storm 25,000 km across – twice size of the Earth!
- First observed > 300 years ago!

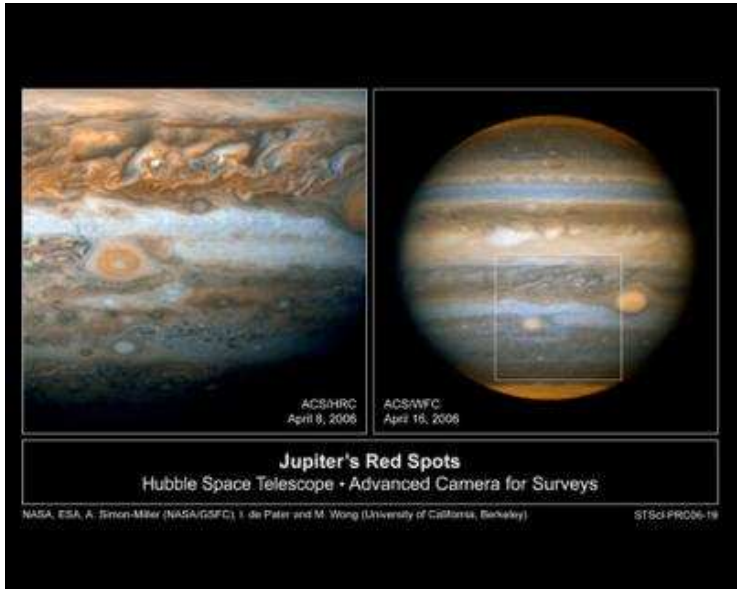


Voyager 1 image



Cassini images

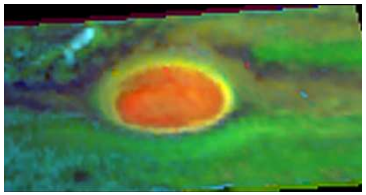
Little Red Spot



Jupiter's Atmosphere

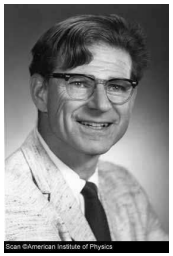
- The atmosphere resembles the conditions of the Miller-Urey experiment.
- The red bands and spots may be biological molecules.
  - The Miller-Urey experiment produces amino acids and **red polymers**.
  - Carl Sagan suggested that the atmosphere might be an optical photochemistry, like photosynthesis but more effective. Not much evidence for such a statement.
- But, constant churning of the atmosphere probably makes development of complex life nearly impossible.

Icy ammonia (light blue) discovered by Galileo



Life?

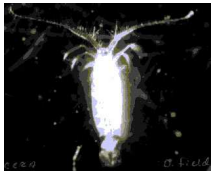
- Carl Sagan and Edwin Salpeter devised a scheme for life in the clouds of Jupiter.
- They argued that the atmosphere must be rich in organic chemistry, so why not expect Earth-like life?



http://tierra.rediris.es/merge/Carl_Sagan/192a.jpg
http://www.aip.org/history/esva/catalog/images/salpeter_edwin_a3.jpg

Floating Life

- The problem is that any life in the clouds that sank too far down would be destroyed by the temperature or pressure.
- They proposed a simple life form like oceanic plankton called "sinkers".
- Small (0.1 cm) life that grew and fell, but then replicated by "splitting-up" and getting circulated back into the upper atmosphere.



http://www.wackerbaits.com/sf/media/bellsinker.jpg
http://www.mantapacific.org/mantapacific/information/images/plankton.jpg

Floating Life

- The sinkers became the basis of a proposed ecology.
- They also posited "floaters"– large hydrogen balloon-like life that "swim" in the Jovian atmosphere.
- They could be huge creatures, as large as 1 to 2 km in diameter.

http://www.firaxis.com/smac/nativelife.cfm

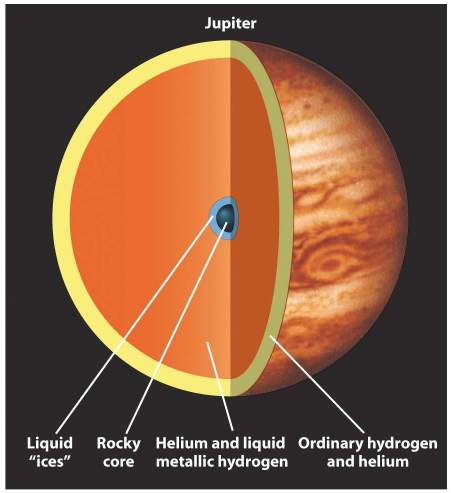
Floating Life

- Maybe similar to whales– mixture between jellyfish and birds?
- Big bags of hydrogen gas.
- Maybe there are also "hunters" that fed on the floaters?
- Of course, this is all speculative, and there is no way to detect such life.
- Science fiction from scientists really.

http://www.epilogue.net/cgi/database/art/list.pl?gallery=3126

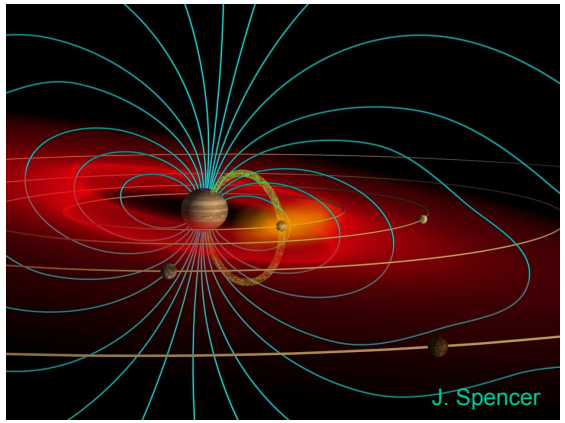
Jupiter's Interior

- Average density only 30% greater than water
- 25% that of the Earth's average density
- By 20,000 km, the pressure is 3 million times that on the Earth's surface!
  - Hydrogen becomes a liquid metal
- Core of rock & "ice" 10-12 Earth masses



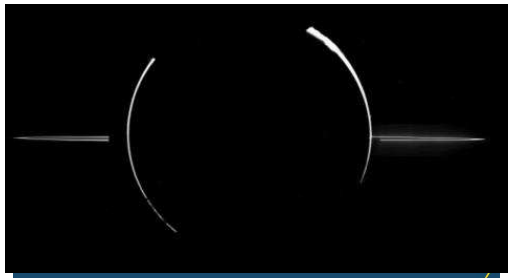
Jupiter's Magnetosphere

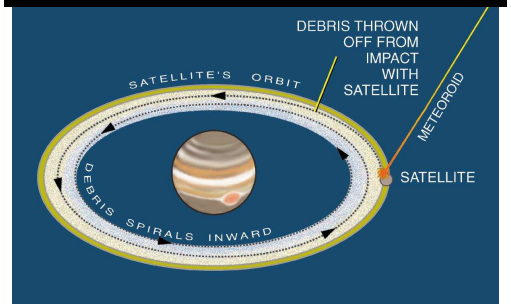
- Liquid metal hydrogen generates a magnetic field
  - 14x stronger than Earth's field
  - Over 4 million km across
- A ring of ionized particles surrounds Jupiter
  - Stripped from Jupiter's moon Io



Jupiter's Rings

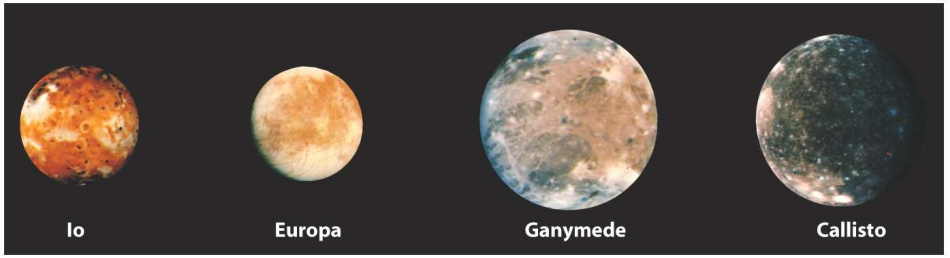
- Jupiter has rings!
- Discovered by the Voyagers
- Not prominent like Saturn's
- Dusty disk of debris, probably from meteoroid impacts with small moons





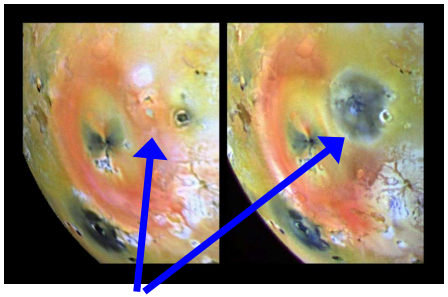
The Galilean Moons

- Io is active.
- Europa is now thought to be the best option for life.
- But, Ganymede and Callisto are contenders perhaps for ancient life.

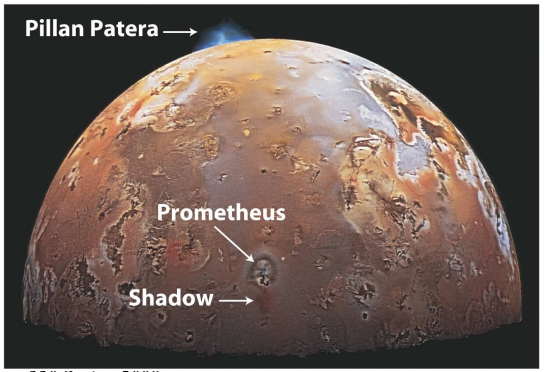


Io

- Innermost Galilean moon – the "pizza moon"
- The most volcanically active body in the solar system.
- Voyager 1 discovered presence of volcanoes
- Internal heating by Jupiter's tides
- Atmospheric gases ripped off by Jupiter's magnetic field – ion torus

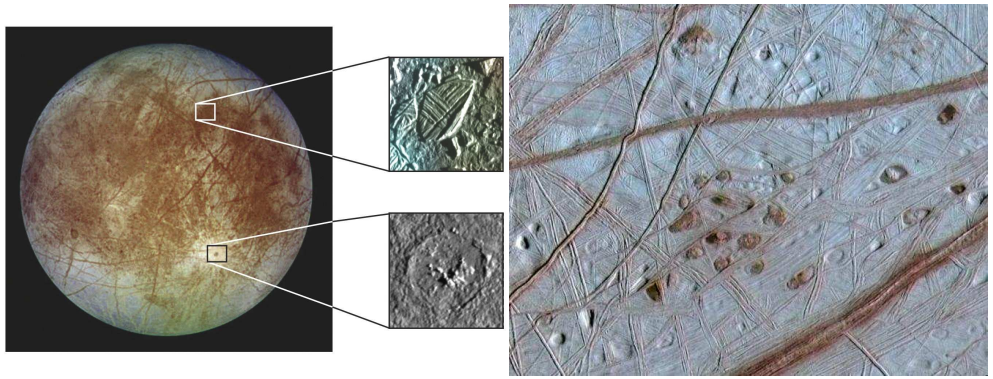


Pillan Patera eruption
Before & after



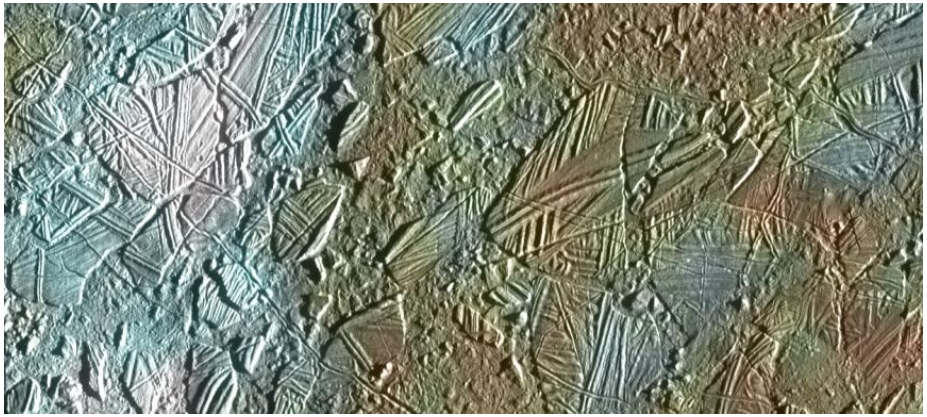
Europa

- Slightly smaller than our Moon.
- Icy crust 5 km thick. Can protect life against magnetic fields.
- Evidence for deep (50 km!) liquid water ocean beneath crust– remains liquid from tidal forces from Jupiter
- Cracks and fissures on surface – upwelling?



Galileo

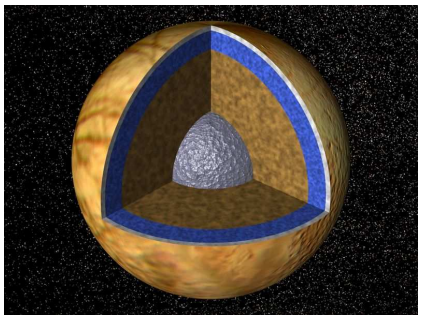
Europa



- Young surface – few craters
- Tidal forces pull and push the ice
  - Like Io, it probably has strong tidal forces.

Europa

- Life would have to be below the surface, around hydrothermal vents.
- Very encouraging, as early life on Earth, might have been formed around such vents.
- We don't how thick the ice is yet.
- Future missions, will have to employ smash and dive spacecraft.



Ganymede

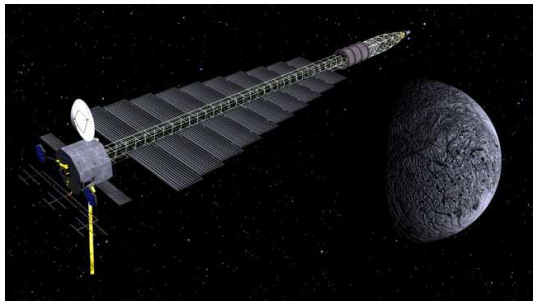
- Largest of the Galilean Moons
- Partly ancient surface, partly younger surface
  - Younger surfaces about the age of the Moon's maria
- Compared to our Moon:
  - 50% larger
  - 100% more massive
  - 40% less dense
- Interior more differentiated than Callisto, probably has an iron core
- May have a water ocean under surface.

Callisto

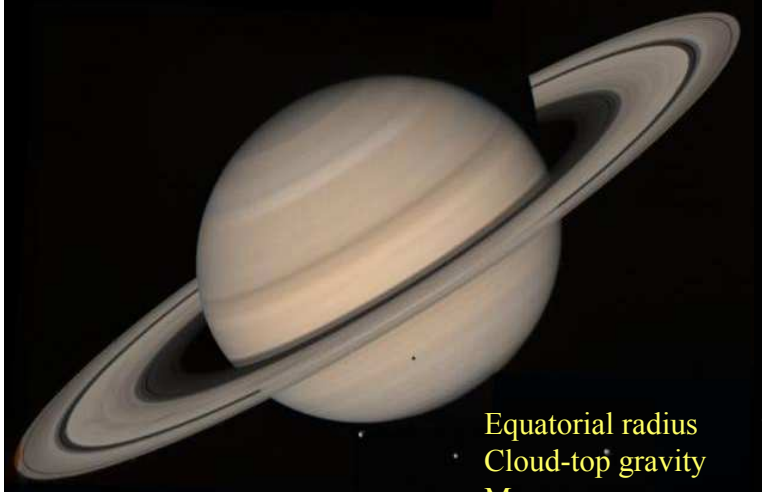
- Furthest of the Galilean Moons from Jupiter
- Ancient surface, covered with craters
- Compared to our Moon:
  - 40% larger
  - 50% more massive
  - 45% less dense
- Surface is made of "dirty ice"
- Interior is rocky, mixed with ice

Finding JIMO

- Jupiter Icy Moon Orbiter
  - To launch in 2015 or later
- Study Callisto, Ganymede, and Europa
  - Investigate makeup
  - Histories
  - Potential for sustaining life



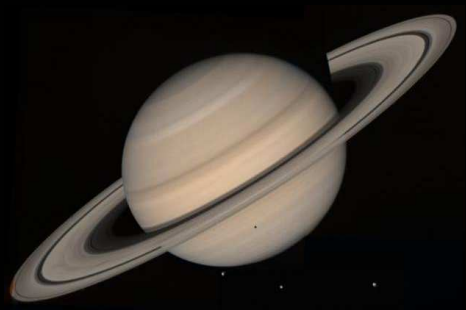
Earth – Saturn comparison



It floats. The least spherical planet.

Equatorial radius	9.45 Earth
Cloud-top gravity	1.07 Earth
Mass	95.2 Earth
Distance from Sun	9.53 AU
Year	29.5 Earth years
Solar day (equator)	10 hours 14 minutes

Jupiter-Saturn Comparison



Equatorial radius	0.84 Jupiter
Mass	0.30 Jupiter
Density	0.52 Jupiter

Almost as big as Jupiter, but Much less massive!

Saturn

- Named for the father of the Roman gods
- Saturn is very similar to Jupiter
  - Large planet
    - Mostly liquid hydrogen
  - Has a mini-solar system
    - At least 60 moons
    - Most are small

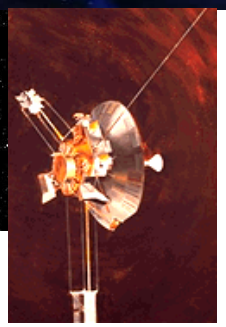
http://www.solarviews.com/cap/sat/saturn.htm

http://saturn.jpl.nasa.gov/cgibin/gs2.cgi?path=../multimedia/images/saturn/images/PIA05380.jpg&type=image

Missions to Saturn

- There have been 4 unmanned spacecraft missions to Saturn
- Pioneer 11
  - Flyby 1979
- Voyager 1
  - Flyby 1980
- Voyager 2
  - Flyby 1981
- Cassini-Huygens
  - Arrived 2004



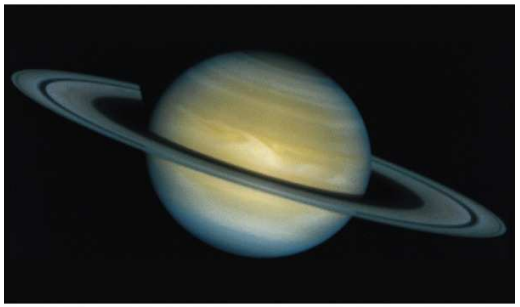


The Cassini Mission

- Launched on October 15th, 1997
- Arrived at Saturn on July 1st, 2004
- Will orbit Saturn for 4 years, making flybys of the planet, its rings, and some of its moons
- Contains 12 scientific instruments
- Also carries the Huygens probe, which was dropped onto Titan, Saturn's largest moon on Jan 2005. Remember?

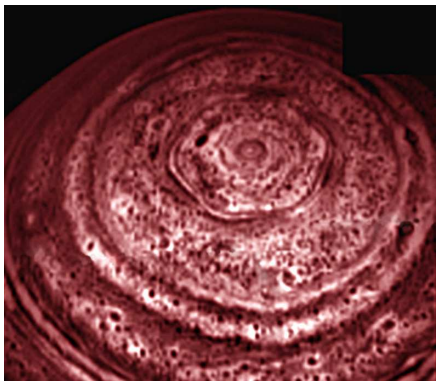
Saturn's Atmosphere

- Composition similar to Jupiter
  - Mostly hydrogen and helium
- Atmosphere more "spread out"
  - Less gravity
  - Contrast of cloud bands reduced
- Wind speeds fastest at the equator
  - 1000 km per hour!



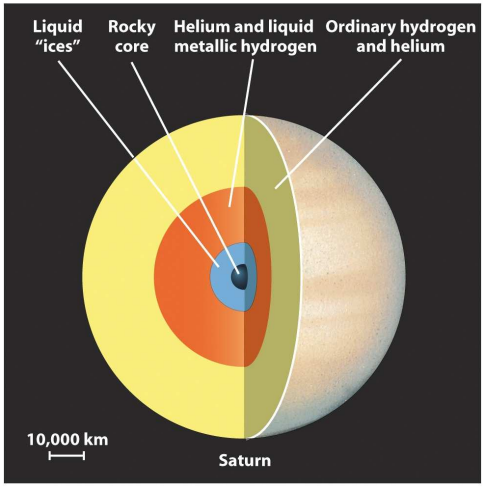
Driving Saturn's Weather

- As on Jupiter, Saturn's internal heat drives weather
  - Saturn radiates 80% more heat than it receives from the Sun
  - Like Jupiter, Saturn is still contracting!
  - As is contracts, heat is produced
- As on Jupiter, storms are produced between cloud bands
  - No long lasting storm like the Great Red Spot, but hexagon cloud at pole has been stable for 20+ years.



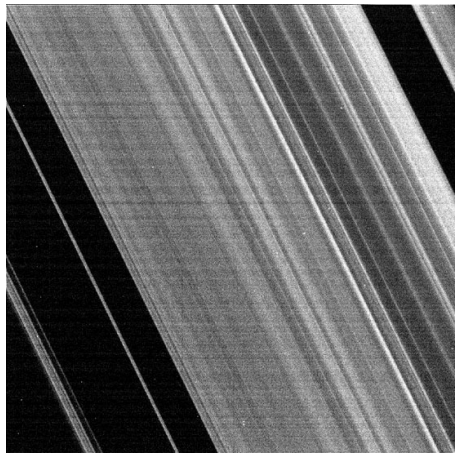
Saturn's Interior

- Similar structure to Jupiter's
  - But Saturn is less massive
  - The interior is less compressed
- Liquid metallic hydrogen creates a magnetic field
  - 30% weaker than Earth's



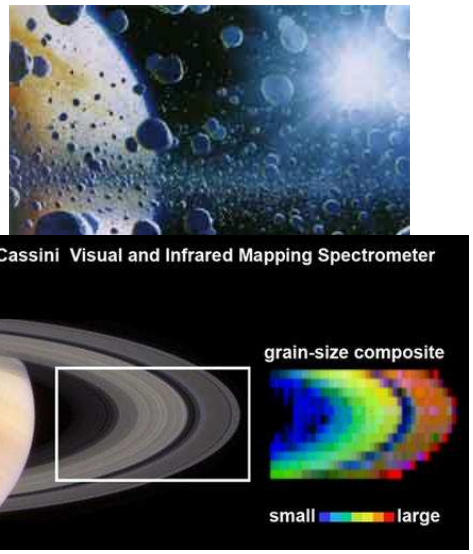
Saturn's Rings

- Two main rings
  - Several fainter rings
  - Each ring is divided into *ringlets*
- The rings are **thin**
  - Only a few tens of meters thick– razor thin!



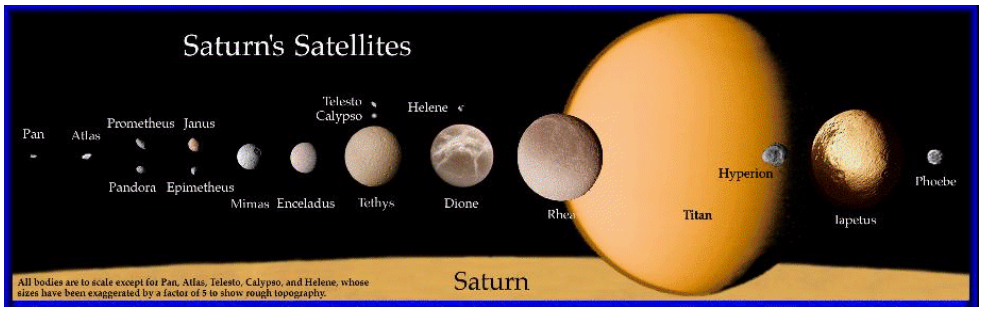
Makeup of the Rings

- The rings of Saturn are **not** solid rings
  - Made of icy rocks
  - 1cm to 10m across
- New Cassini data shows ring particle size varies with distance from Saturn
  - Note the gap is filled with small particles



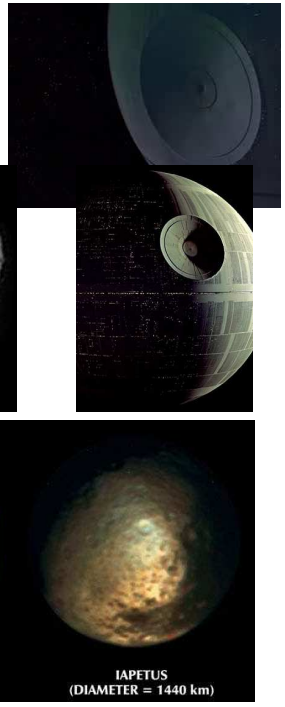
Saturn's Moons

- Saturn has a large number of moons
  - At least 60
- Only Titan is comparable to Jupiter's Galilean moons
- Smaller moons are mostly ice, some rock



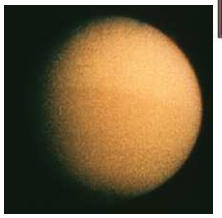
Saturn's Odd Moons

- **Mimas** - Crater two-thirds its own radius
- **Enceladus** - Fresh ice surface, water volcanoes?
- **Hyperion** – Irregularly shaped
- **Iapetus** - Half its surface is 10x darker than the other half
- **Phoebe** - Orbits Saturn backwards

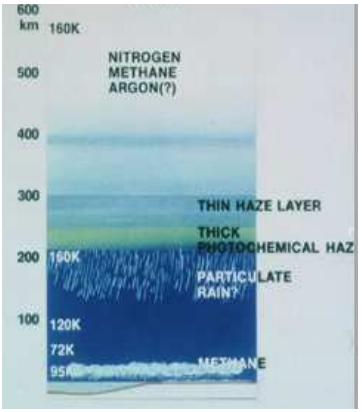


Titan

- Saturn's largest moon– bigger than Mercury.
- 2nd largest moon in the solar system after Ganymede.
- Discovered in 1655 by Christiaan Huygens
- Only moon to have a dense atmosphere
  - Dense nitrogen/methane atmosphere
  - Small greenhouse effect
  - 85% nitrogen
  - Much like ancient Earth!

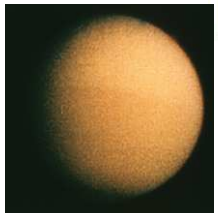


Titan's atmosphere

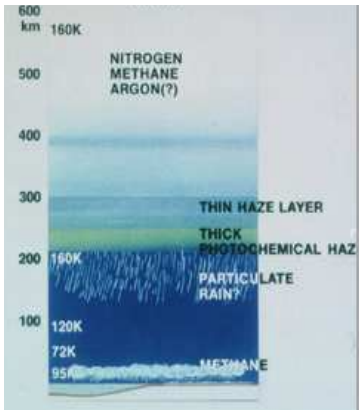


Titan

- Atmospheric pressure is 1.5 times Earth's
- Liquid/ice hydrocarbons?
- Organic compounds – life?
  - Probably not – too cold: 95 K
  - May be a "deep freeze" of the chemical composition of ancient Earth

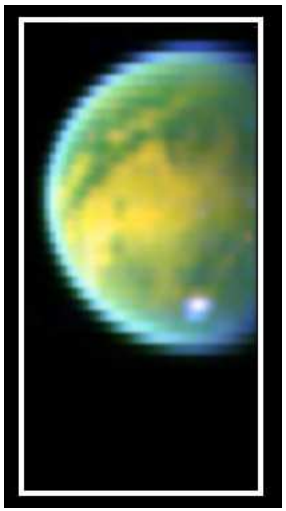


Titan's atmosphere

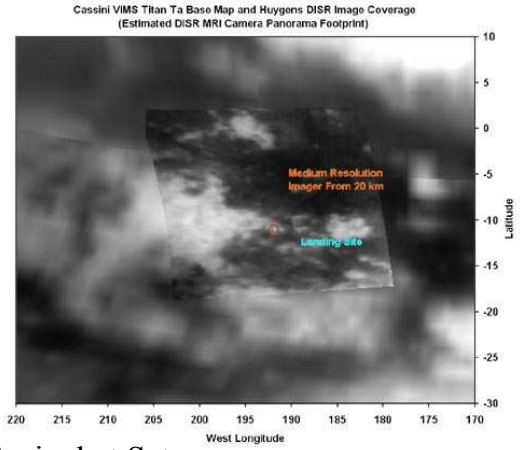


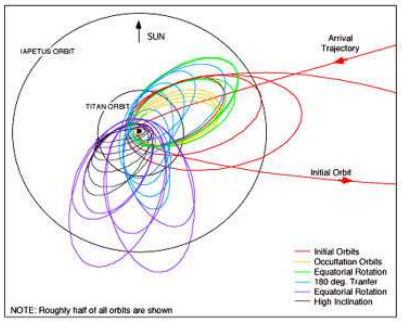
Piercing the Smog

- Cassini has special infrared cameras to see through Titan's smog
- Green areas are water ice
- Yellow-orange areas are hydrocarbon ice
- White area is a methane cloud over the south pole



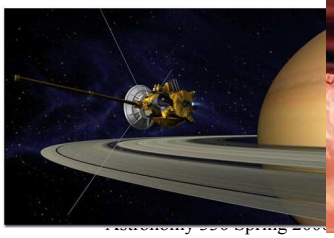
Cassini-Huygens



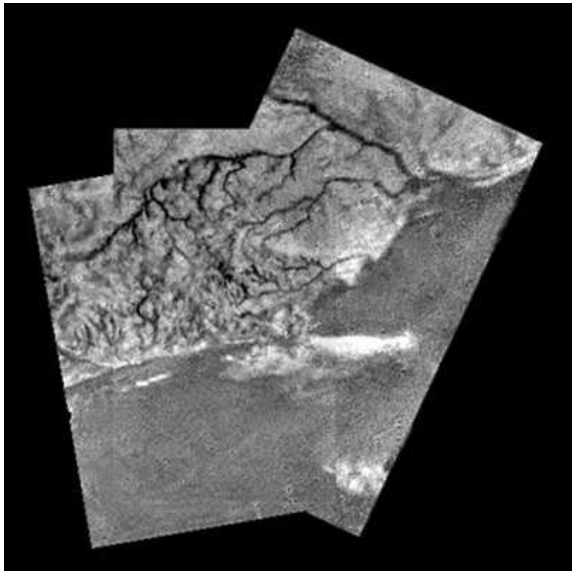


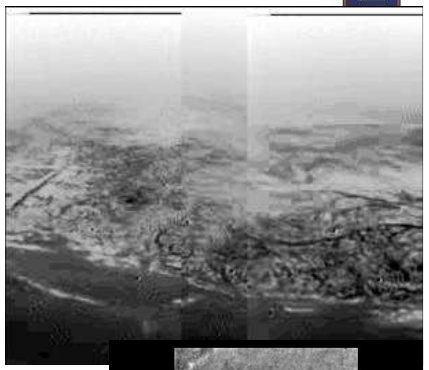
Arrival at Saturn
July 1, 2004

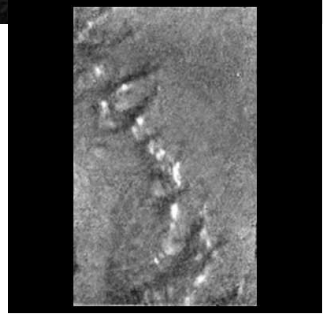
Huygens Probe descent to Titan
Jan 14, 2005



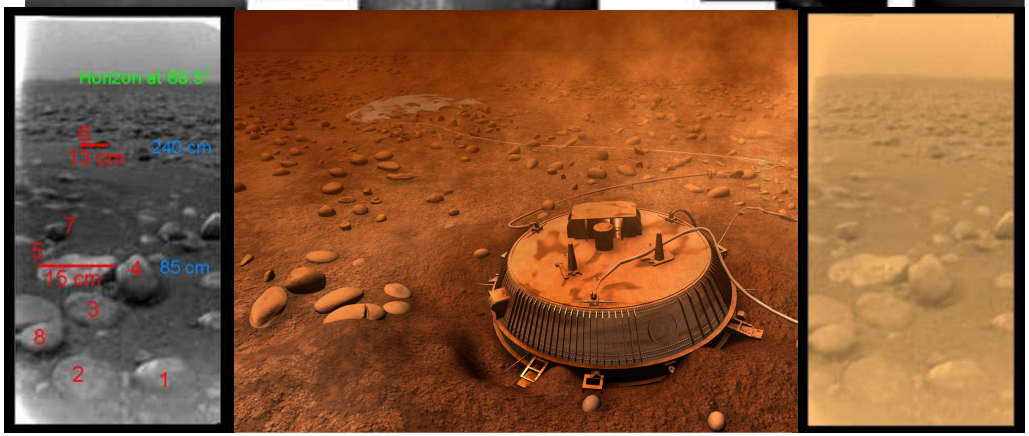
Mapping Titan

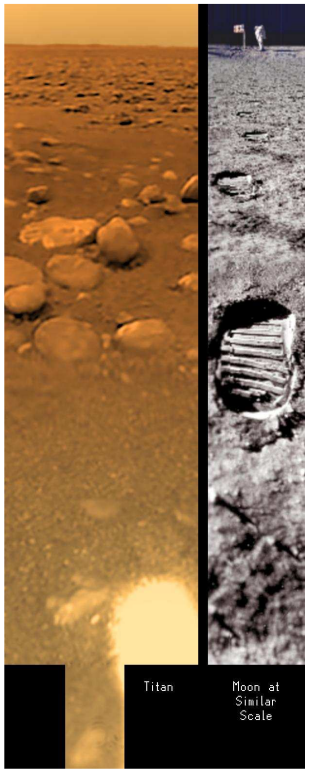




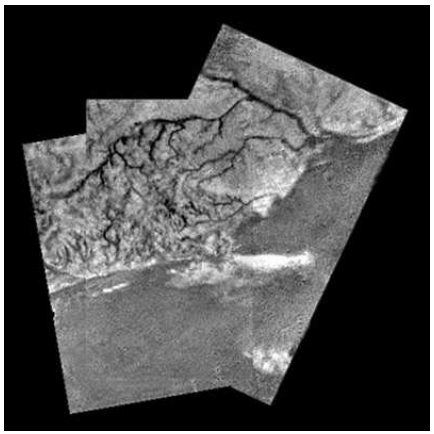


Mapping Titan



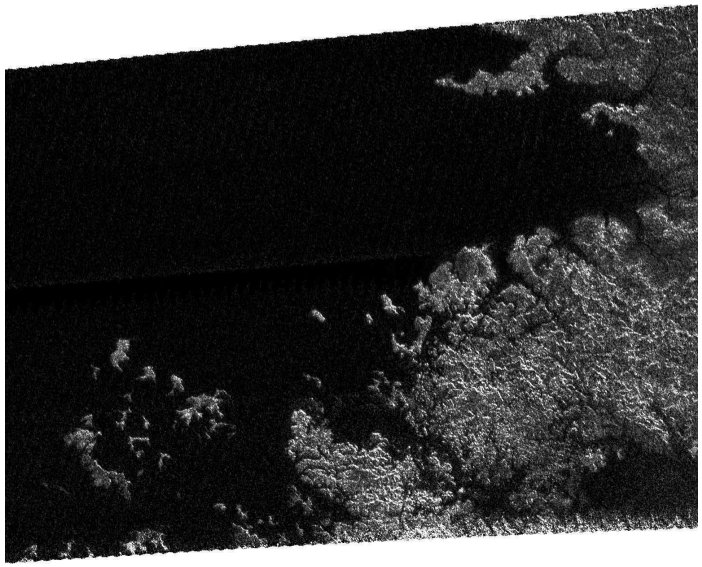


Mapping Titan



http://esamultimedia.esa.int/multimedia/esc/esaspacecast001.mp4

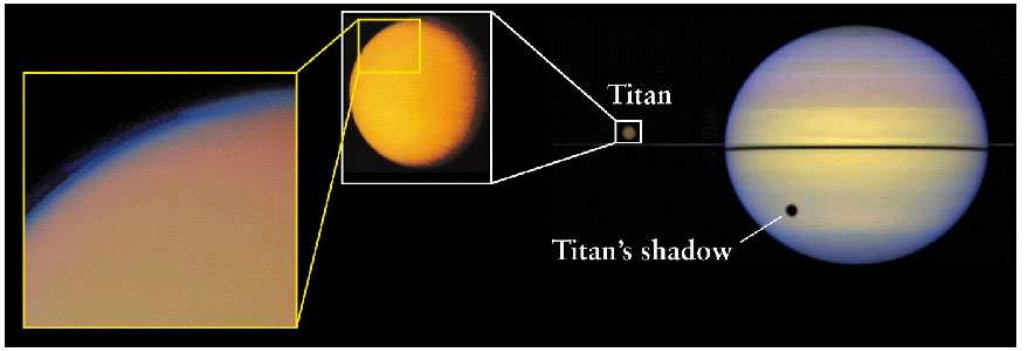
Liquid Sea?
Possible liquid methane



http://antwrp.gsfc.nasa.gov/apod/ap070530.html

Titan

- N_2 came from ammonia (NH_3) – common in outer solar system
- Second most abundant component is methane (natural gas)
  - One option is UV + methane → hydrocarbons (e.g., ethane)
  - Then, ethane condenses and rains down on Titan's surface



A Possible Past

- The probe floating in the ethane sea of Titan.
- Mountains in the distance.

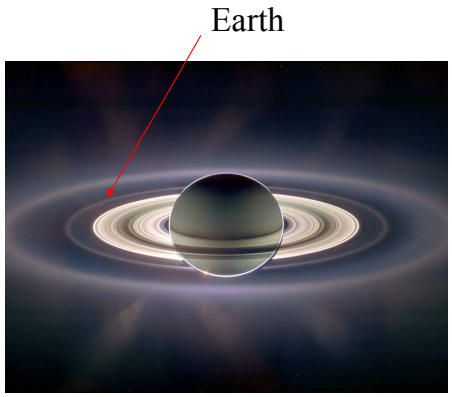
http://saturn.jpl.nasa.gov/cgibin/gs2.cgi?path=../multimedia/images/artwork/images/

Conclusion

- ***No conclusive evidence exists for life in our solar system besides on Earth***
- But, possibilities exist for life
  - Venus's clouds may have migrated life.
  - Mars may have some microbial history linked to water, and perhaps some subsurface life.
  - Jupiter's reducing atmosphere may harbor sinkers.
  - Europa's sub-crustal oceans may harbor life, even fish-like life.
  - Titan is still very interesting
    - Thick atmosphere
    - Reducing chemistry

No Intelligent Life

- We might find evidence of some sort of life in the next decade, but very unlikely to find complexity needed for intelligent and communicative life.
- Apparently in our system, Earth's conditions are necessary.
- Other planets may have microbial forms of life, and maybe complex fish-like organisms, but we don't expect communicative beings.



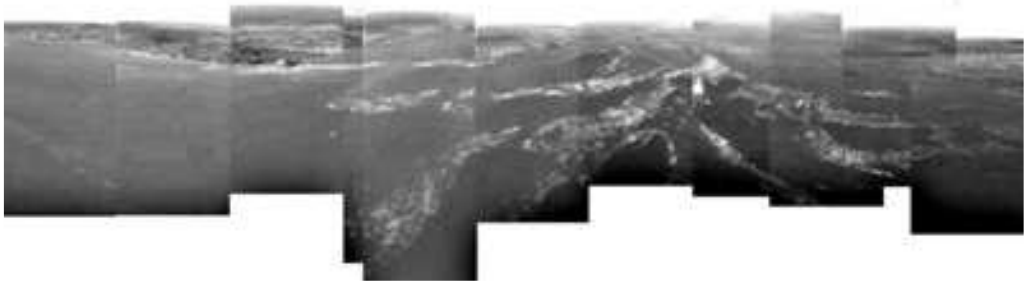
http://antwrp.gsfc.nasa.gov/apod/ap061016.html

How to search for life?

- How do we search for life in our Solar System and beyond?
- What test will indicate life exclusively?
- Remember the Viking problems on Mars.
  - Need flexibility to test interpretations.
- But, it is difficult to anticipate fully the planet conditions.

How to search for life?

- Is is apparent that future missions need to land as near as possible to sites of subsurface water or other solvents.
- On Titan, what are the important tests for determining biological signatures of non-water life?
- What if the life is still in the protolife stage? Can we detect that?
- The boundary between chemical and biological processes is difficult to distinguish.



Decision Trees– Search for Life

- Wait for it to come to us via meteorites or comets.
- Robotic one-way investigations– Mars rovers.
- Fetch and return with samples.

http://www.ibiblio.org/wm/paint/auth/friedrich/tree.jpg

Problems

- In the last 2 cases, we have the problem of contamination by Earth life.
- Organisms can live in Mars-like conditions on Earth.
- If some Earth life survives the space journey, it could colonize Mars, possibly destroy any Martian life. Think of Kudzu.
- Current missions must be sterilized.

http://www.hope.edu/academic/biology/faculty/evans/images/Angiosperms/CoreEudicots/EurosidsI/Fabaceae/Kudzu.JPG

Biomarkers: How to look for extrasolar life.

- We need to decide how to search for biomarkers or chemical signatures of life.
- On Earth, methane and oxygen are indicators. They normally react. Something is keeping it out of equilibrium. Sort of like Venus disequilibrium.
- The Galileo spacecraft on its way out to Jupiter, turned and looked at the Earth.
- Did it detect life?

Biomarkers: Looking at Earth.

- Strong "red edge" from reflected light. Absorption from photosynthesis.
- Strong O_2. Keeping oxygen rich atmosphere requires some process. It should slowly combine with rocks.
- Strong methane. Should oxidize. Replenished by life.
- Strange radio emissions that could be intelligent life.

http://epod.usra.edu/archive/epodviewer.php3?oid=56256

Biomarkers: Looking at Earth.

- Recently, researchers have looked at the Earthshine from the moon.
- They agree with Galileo result.
  There is life on Earth.
  - Water
  - Oxygen
  - Tentative detection of "red edge"

http://epod.usra.edu/archive/epodviewer.php3?oid=56256

Summing Up

- Existence of organic molecules in space implies that amino acid complexity is common.
- Fact: On Earth polymers arose and evolved to life.
- Life it seems evolves naturally through a number of intermediate steps if conditions are right and $\mathbf{f_l = 1}$
- But how often are the conditions right?
- Nonetheless, even with only a vague notion of how life on Earth evolved, it seems that there are possible pathways that take the mysterious polymerization to transition to life steps.
- Still a number of questions:

Summing for f_l

- Is life a natural occurring consequence of the laws of nature?
- Will each planet from n_e outgas and produce water?
- Will it have a reducing atmosphere?
- Will it have the right energy sources to produce life's monomers?
- Monomers from space?
- Will polymerization occur?
- Are tides necessary to wash polymers back into liquid water?
- Will basic life occur? Protolife or life?
- Alternative life?
- Maybe the conditions that produced life on Earth are unusual or maybe common.
- That means f_l can range from small numbers 0.0001 to 1.