ET: Astronomy 230

This Class (Lecture 24):

Life in the Solar System

Next Class:

MIDTERM

Midterm on Friday!

Presentations Monday Oct 24th

Jonathan Dellinger
Nathan Louer
Amit Behal

Presentations Wednesday Oct 26th

Jim Kestler
Melanie Kang
Brian Krutsch

Presentations Friday Oct 28th

Drew Sultan
Kurt Peterson
Jim Vorel

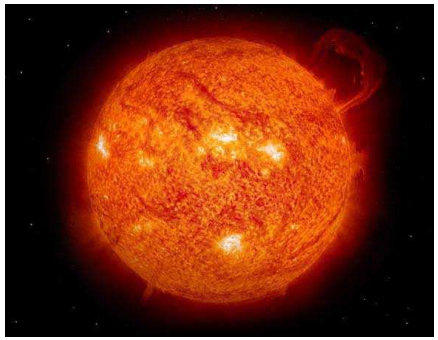
Music: *Vincent* – Dan Mclean

Midterm

- 1 hour exam in this classroom.
- It will cover material up to, but not including, "Life in the Solar System"
- Will consist of 17 multiple choice/ true-false questions (worth 2 points each) and 3 essay questions (6, 25, and 40 points each) .
- A total of 105 points, so 5 extra credit points.
- You can bring a normal-sized sheet of paper with notes on both sides.

Our Sun

- Is a fairly typical star
  - Has lived for 5 billion years
  - Will probably live another 5 billion

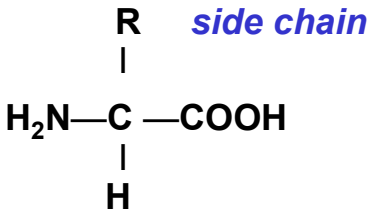


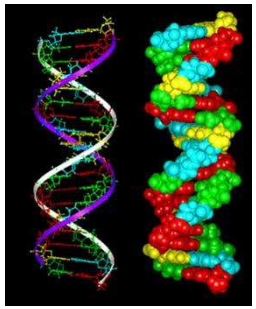
Proto-Earth

- The hot proto-Earth heated up the ices on dust grains– mostly water, carbon dioxide, and nitrogen– the Earth's first atmosphere.
- The water condensed to form oceans and much of the CO_2 was dissolved in the oceans, unlike Venus and Mars.
- No oxygen, no ozone layer.
- UV light, lightning, radioactivity, and geothermal heat, provided energy for chemical reactions.
- Perfect place for carbon chemistry.

Life on Earth

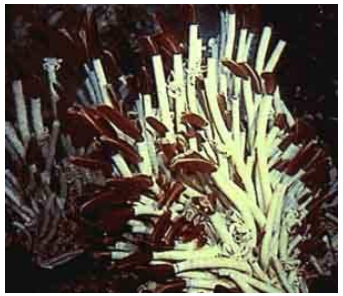
- Most important components are
  - Proteins or enzymes
    - Polymers made of amino acids strung together.
  - Nucleic Acids (DNA or RNA)
    - Polymers made of sugars (deoxyribose or ribose), a phosphate, and nitrogenous bases.
- In life on Earth, they are so closely linked that it is hard to figure out which came first.
- We do know that life began about 3.8 billion years ago, soon after the large bombardment.

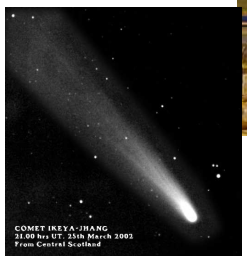




Synthesis of Monomers

- Miller-Urey experiment? Could be, but atmosphere probably not a heavily reducing atmosphere.
- Area around undersea hot vents might work.
- Interstellar space?



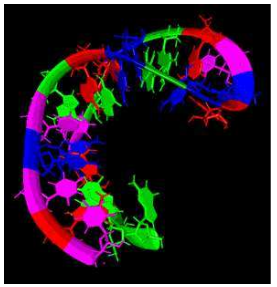


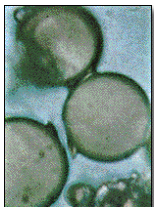
Synthesis of Polymers

- With monomers around, then you have to make the polymers.
- Maybe easier if the primordial soup quickly evaporates into a condensed soup.
- Polymerization in clay soils?
- An evaporating pool with geothermal energy?
- Polymerization of amino acids on the early Earth is plausible.
- Synthesis of nucleic acids seems to be much harder.

Transition to Life

- Most favored concept is the RNA world.
  - Dominance of the nucleic acids first.
  - An ecosystem of self-replicating RNA, but without capability for protein synthesis.
  - Naked genes.
  - Some RNA evolve enzyme ability, produce proteins
  - Eventually better protein enzymes are produced
  - Life.
- Or the proteins could have dominated– no info storage.
- Or life could have just happened with both nucleic acids and proteins together– primitive cells. Bloody unlikely.





Review

- What are the five biological attributes of life, and what do they mean?
- Compare the chemical composition of life to the chemical composition of: a) the crust of the Earth; b) Earth's oceans; and c) the Sun.
- What is the Drake Equation, and what do the terms mean?
- What is the origin and use of the four main biological elements H, O, N, and C?
- Describe the Early Universe. Why do we believe in the Big Bang?
- What are the properties of a first generation star? In particular, describe which heavy elements they made and how they did it.
- What are the properties of a second generation star? In particular, describe which heavy elements they made and how they did it.
- What does the presence of complex molecules in interstellar space tell us?
- Describe the techniques that astronomers use to search for planets around stars?

Review

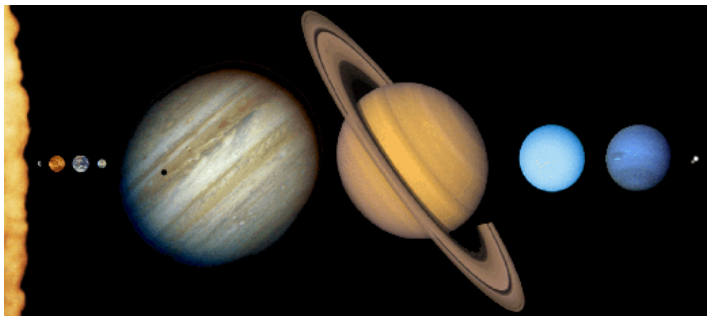
- Describe the processes for forming a star and its planets.
- The planets and the Sun formed from the same interstellar cloud. Discuss reasons why the chemical abundances of the inner planets are different than the outer planets.
- What determines if a planet is in the Habitable Zone?
- Discuss DNA and RNA. How do they function to assemble proteins that carry the genetic code?
- What was the Miller-Urey experiment and why is it thought to be important for life? Include the role of a reducing atmosphere in your discussion.
- What is one possible scenario for the synthesis of polymers on the early Earth? Include the probability of getting 200 of the 20 relevant amino acids in the correct order for constructing a protein.

Outline

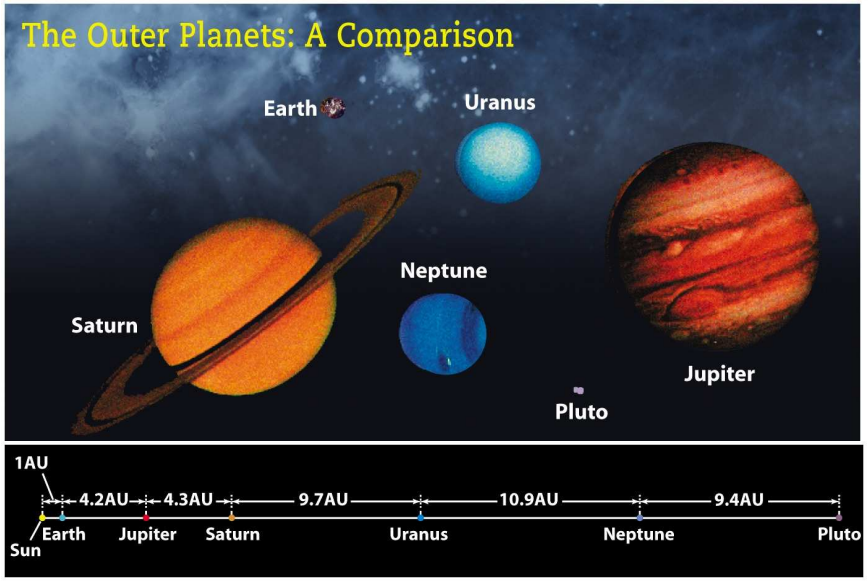
- Jupiter
  - Big planet with possibly interesting chemistry.
  - Floaters?
- IO
- Europa
  - Liquid water under a sheet of ice?
- Titan
  - Ethane or Methane oceans

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 focus on Jupiter, Io, Europa, and Titan in this class.



The Outer Planets



Earth – Jupiter comparison

Biggest and most massive planet, has the largest gravity, has the largest number of moons (>61), 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.

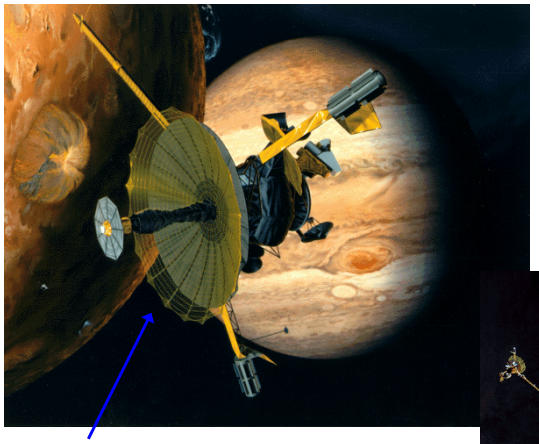
Jupiter, King of the Planets

- 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 60 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

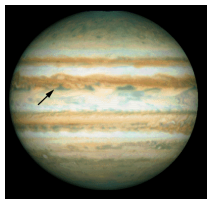
Jupiter's Atmosphere

- 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.

The Galileo Spacecraft (1989 – 2003)



How the main antenna *should* have looked



First atmospheric probe

Probing the Atmosphere

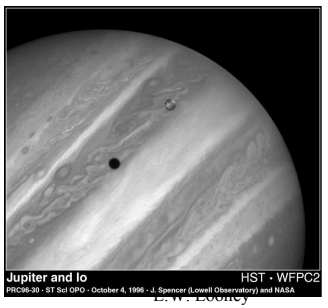
- The probe lasted for 57 minutes before it was destroyed by temperature and pressure.
- Found a lot of turbulence, strong winds (330 mph), very little water ice, and no lightning.
- Did not encounter the layers of clouds that was expected.
- The probe entered the least cloudy region of Jupiter.
- Did 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

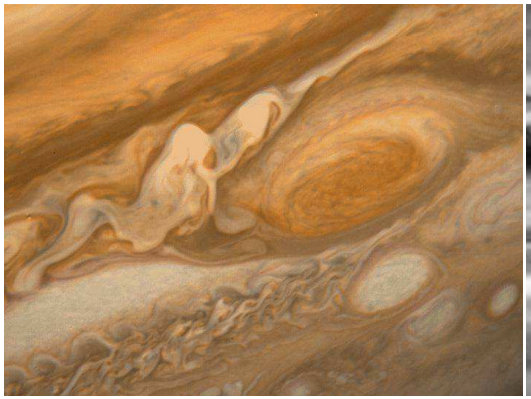
Driving Jupiter's Weather

- 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

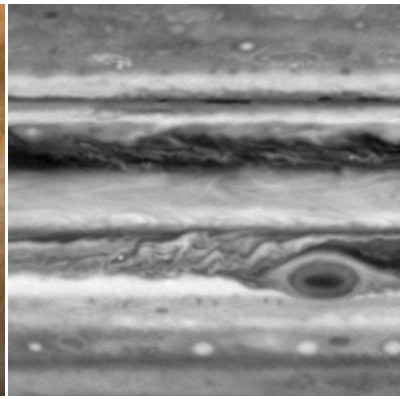


The Great Red Spot

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



Voyager 1 image

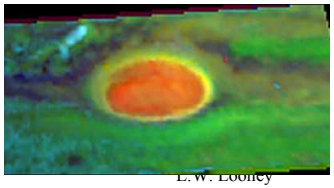


Cassini images

Jupiter's Atmosphere

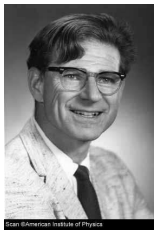
- The atmosphere resembles the conditions of the Miller-Urey experiment.
- The red bands and spots may be biological molecules.
  - The Miller-Urey experiment produces amino acids and **red polymers**.
  - Carl Sagan suggested that the atmosphere might be an optical photochemistry, like photosynthesis 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

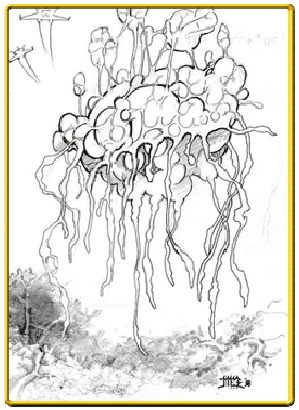
- The problem is that any life in the clouds that sank too far down would be destroyed by the temperature or pressure.
- They proposed a simple life form like oceanic plankton called "sinkers".
- Small (0.1 cm) life that grew and fell, but then replicated by "splitting-up" and getting circulated back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

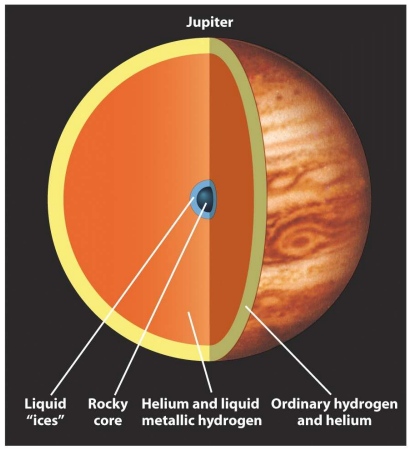
Floating Life

- 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

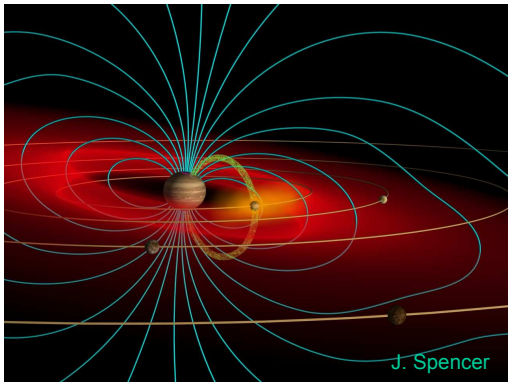
Jupiter's Interior

- 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



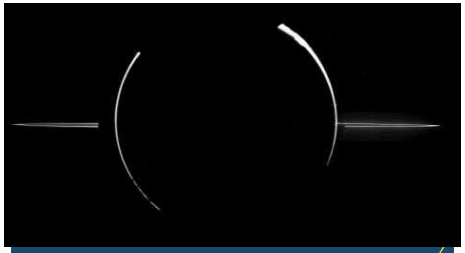
Jupiter's Magnetosphere

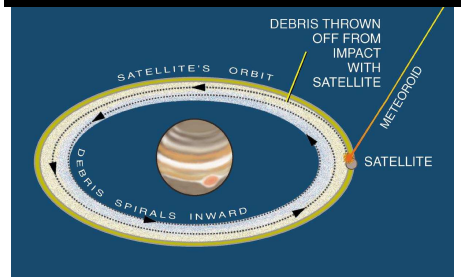
- Liquid metal hydrogen generates a magnetic field
  - 14x stronger than Earth's field
  - Over 4 million km across
- A ring of ionized particles surrounds Jupiter
  - Stripped from Jupiter's moon Io



Jupiter's Rings

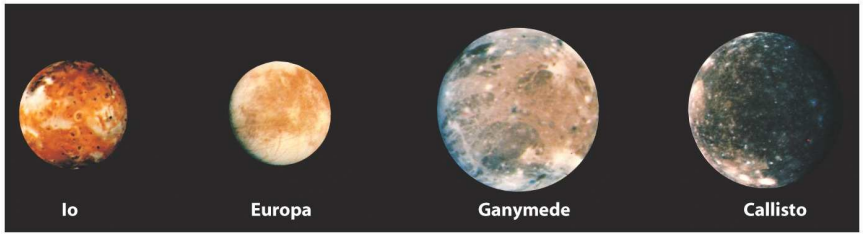
- Jupiter has rings!
- Discovered by the Voyagers
- Not prominent like Saturn's
- Dusty disk of debris, probably from meteoroid impacts with small moons





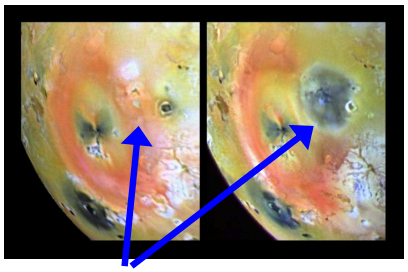
The Galilean Moons

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

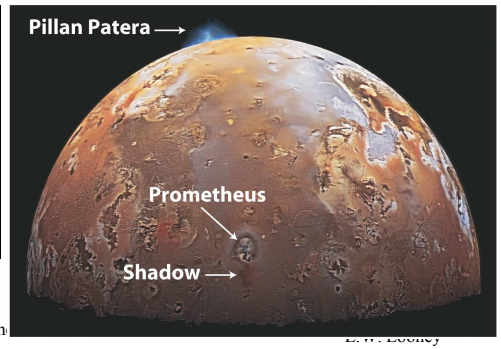


Io

- Innermost Galilean moon – the "pizza moon"
- The most volcanically active body in the solar system.
- Sulfur/sulfur dioxide on surface; silicate lava flows?
- Voyager 1 discovered presence of volcanoes
- Internal heating by Jupiter's tides
- Atmospheric gases ripped off by Jupiter's magnetic field – ion torus

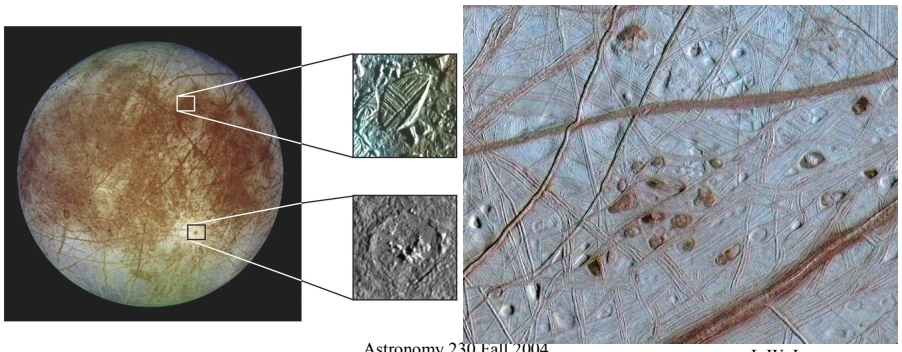


Pillan Patera eruption
Before & after



Europa

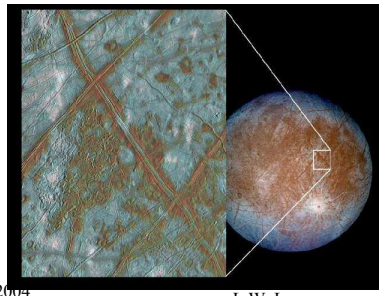
- Slightly smaller than our Moon.
- Icy crust 5 km thick. Can protect life against magnetic fields.
- Evidence for deep (50 km!) liquid water ocean beneath crust– remains liquid from tidal forces from Jupiter
- Cracks and fissures on surface – upwelling?



Galileo

Europa

- Few impact craters indicate recent resurfacing.
- Life would have to be below the surface, around hydrothermal vents.
- Like Io, it probably has strong tidal forces.
- Very encouraging, as early life on Earth, might have been formed around such vents.
- We don't how thick the ice is yet.
- To be continued.
- Future missions, will have to employ smash and dive spacecraft.



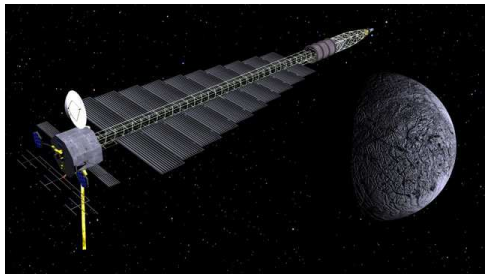
Ganymede

- 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

Callisto

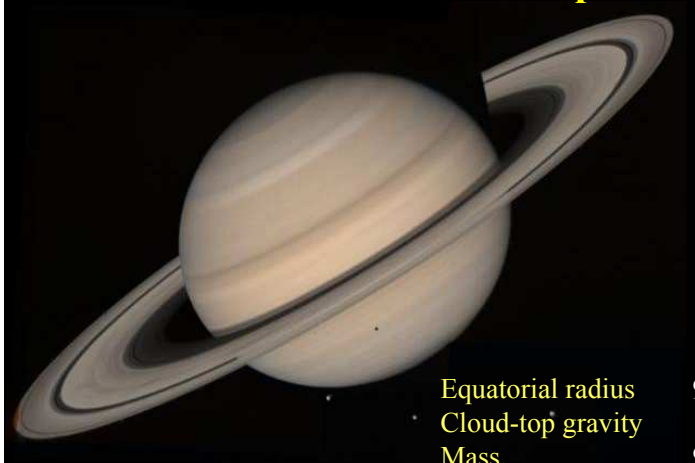
- Furthest of the Galilean Moons from Jupiter
- Ancient surface, covered with craters
- Compared to our Moon:
  - 40% larger
  - 50% more massive
  - 45% less dense
- Surface is made of "dirty ice"
- Interior is rocky, mixed with ice

Finding JIMO



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

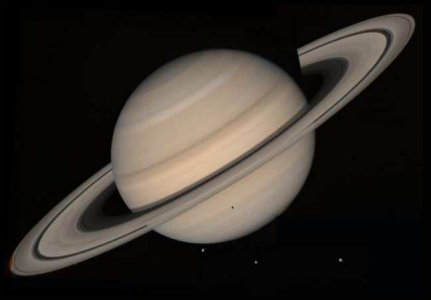
Earth – Saturn comparison



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

It floats. The least spherical planet.

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 30 moons
    - Most are small

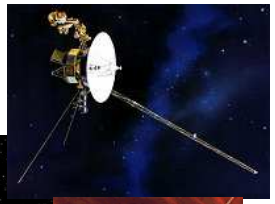
http://www.solarviews.com/cap/sat/saturn.htm

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

L.W. Looney

Missions to Saturn

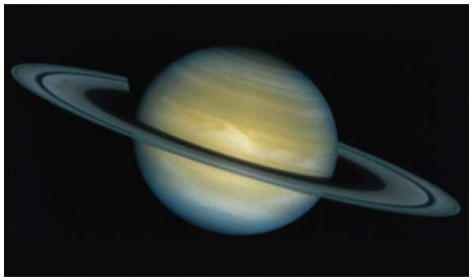
- There have been 4 unmanned spacecraft missions to Saturn
- Pioneer 11
  - Flyby 1979
- Voyager 1
  - Flyby 1980
- Voyager 2
  - Flyby 1981
- Cassini-Huygens
  - Arrived last year



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, at the beginning of last semester. Remember?

Saturn's Atmosphere



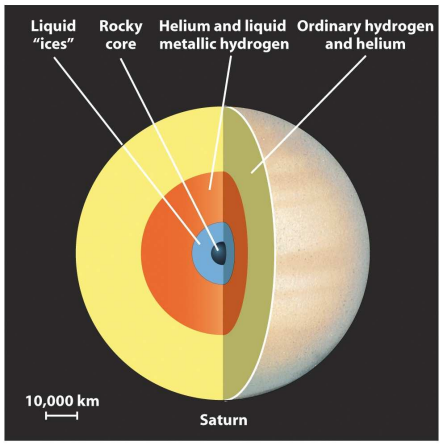
- Composition similar to Jupiter
  - Mostly hydrogen and helium
- Atmosphere more "spread out"
  - Less gravity
  - Contrast of cloud bands reduced
- Wind speeds fastest at the equator
  - 1000 km per hour!

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

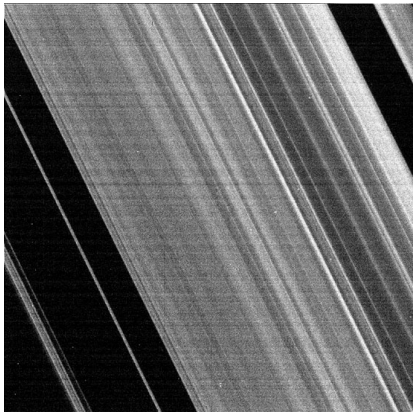
Saturn's Interior

- 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



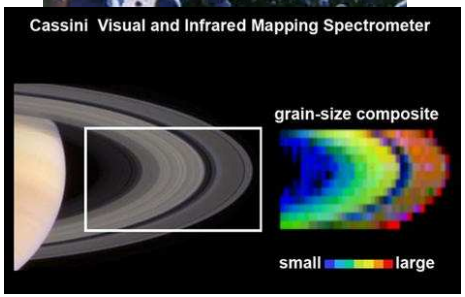
Saturn's Rings

- 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!



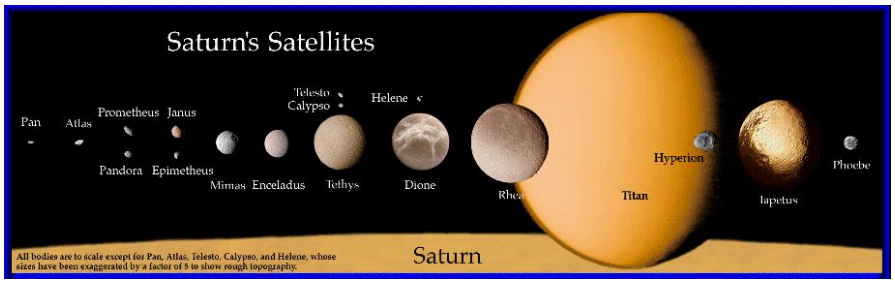
Makeup of the Rings

- 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 30
- Only Titan is comparable to Jupiter's Galilean moons
- Smaller moons are mostly ice, some rock

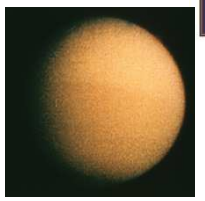


Saturn's Odd Moons

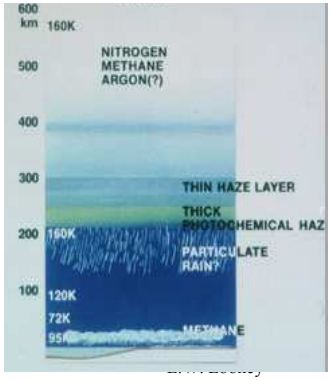
- **Mimas** - Crater two-thirds its own radius
- **Enceladus** - Fresh ice surface, water volcanoes?
- **Hyperion** – Irregularly shaped
- **Iapetus** - Half its surface is 10x darker than the other half
- **Phoebe** - Orbits Saturn backwards

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!

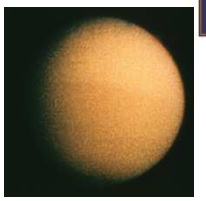


Titan's atmosphere

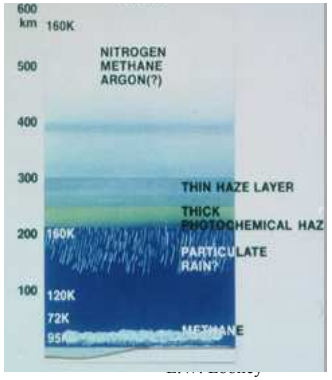


Titan

- 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

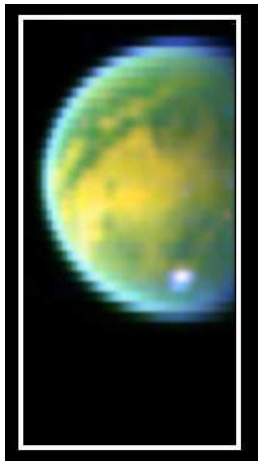


Titan's atmosphere

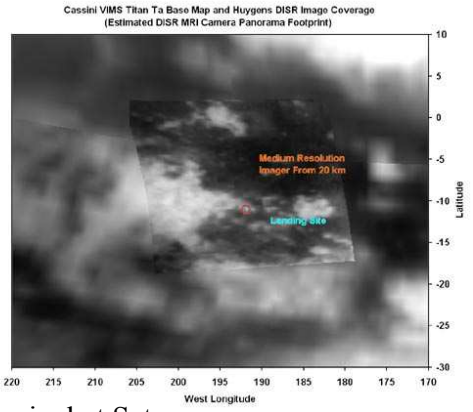


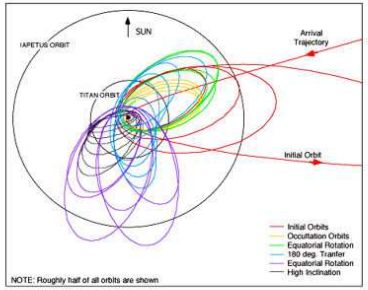
Piercing the Smog

- 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



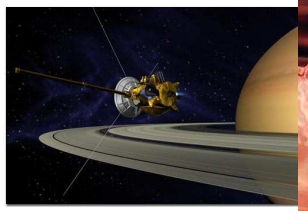
Cassini-Huygens



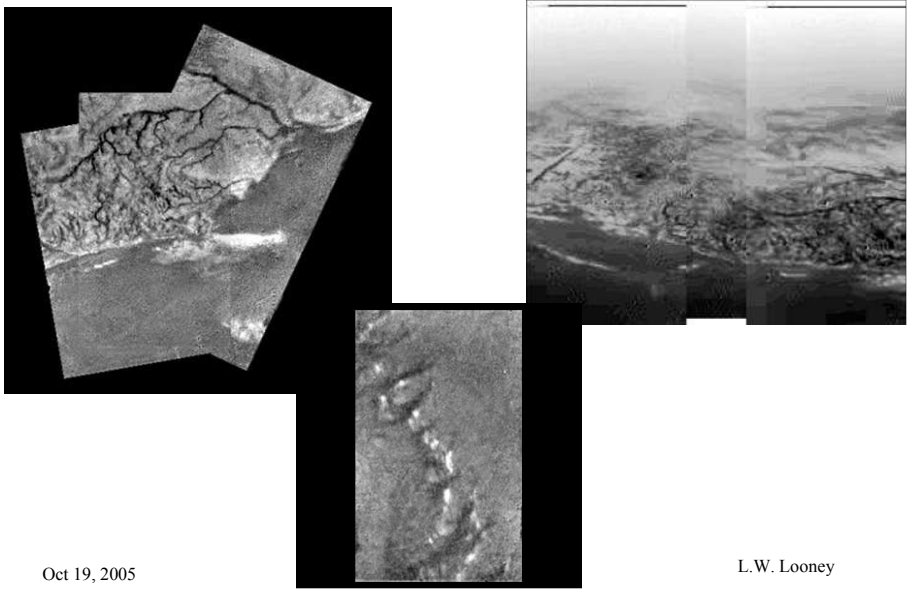


Arrival at Saturn
July 1, 2004

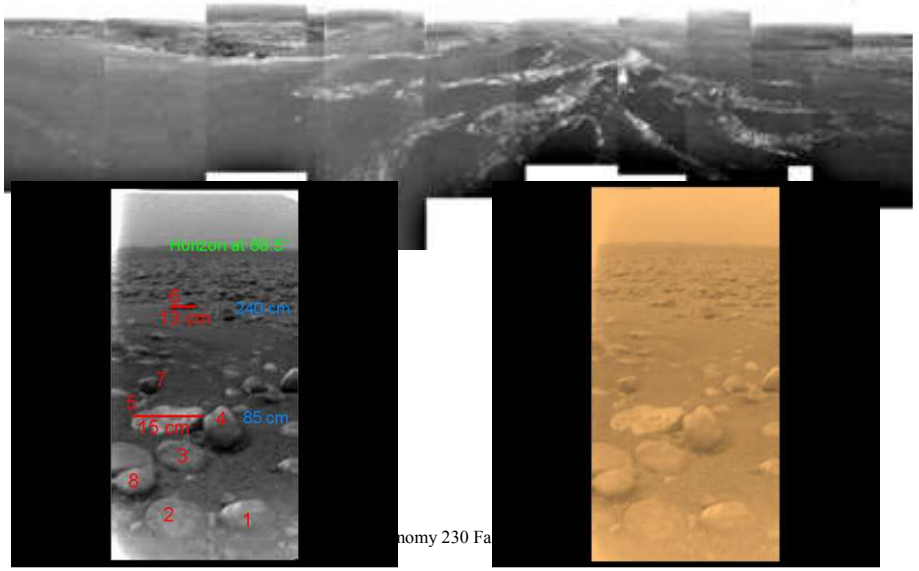
Huygens Probe descent to Titan
Jan 14, 2005



Mapping Titan

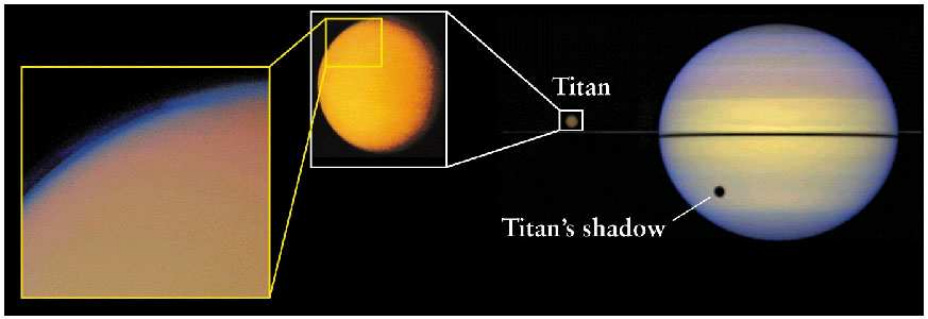


Mapping Titan



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
- So, it might have liquid ethane or methane lakes/oceans?
- Many organic compounds should be in atmosphere– reducing atmosphere.
- If life exists here, then it will change our water–chauvinistic ideas.



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
  - Mars may have some microbial history linked to water, and perhaps some subsurface life.
  - 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.

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.
- 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