Astronomy 330

<u>This class (Lecture 13):</u>

Life in the Solar System

<u>Next Class:</u>

Origin of Life

Midterm due next Thursday.

Music: *Life on Mars*– David Bowie

Take Home Midterm

- Will email it to everyone after class today.
  - 50%: 4 short (few paragraphs) essays
  - 50%: 1 large (~1 page) essay (with definition terms)
- Must be typed, not handwritten.
- Will cover material up to and including today.
- It is a closed notes exam (honor system!).
- You can make 1 page of notes that you use during the exam.

HW 2

- **Marybeth Kram** http://www.unknowncountry.com/news/?id=1807
- **Christopher Moss** http://english.pravda.ru/science/19/94/378/14269_aliens.html

Outline

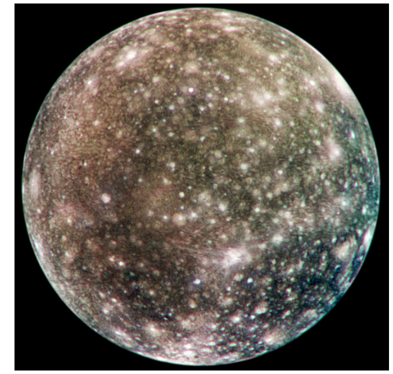
- What about Titan (Moon of Saturn)?
- Need to consider the Star too..
  - Too big?
  - Too small?
  - Too binary?
  - Too hairy?

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

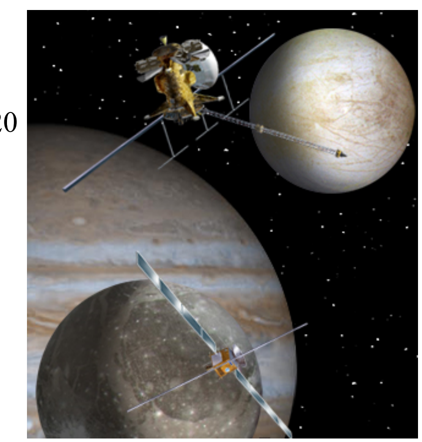


Finding JIMO

- Jupiter Icy Moon Orbiter
  - To launch in 2017 or later
- Study Callisto, Ganymede, and Europa
  - Investigate makeup
  - Histories
  - Potential for sustaining life

Europa Jupiter System Mission

- Early planning stages of NASA/ESA/JAXA mission.
- Two or three orbiters
  - Launch date around 2020

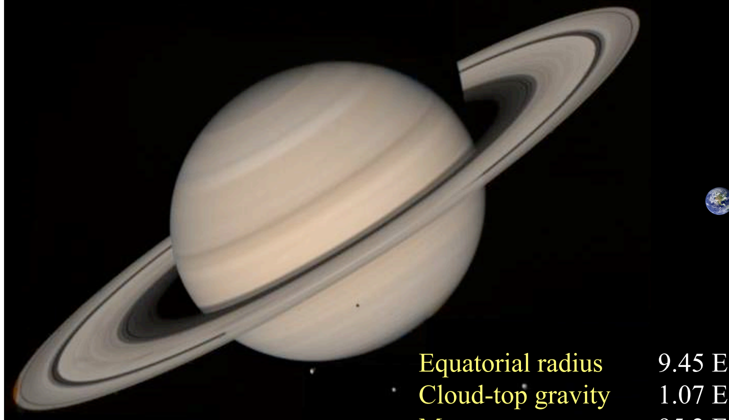


Question

The best place to look for life in the Jupiter system is

a) in the frozen oceans of Callisto.
b) in the frozen oceans of Ganymede.
c) in the upper atmospheres of Jupiter, floating life.
d) deep in the atmosphere of Jupiter, diamond bodied life to withstand the pressures.
e) under the ice on Europa.

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

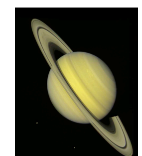
It floats. The least spherical planet.

Jupiter-Saturn Comparison

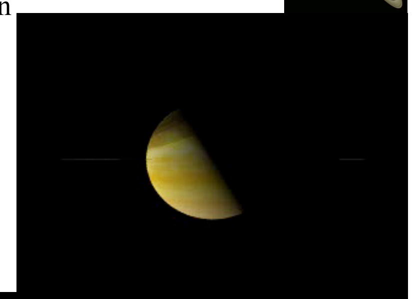
Equatorial radius	0.84 Jupiter
Mass	0.30 Jupiter
Density	0.52 Jupiter

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 60 moons
    - Most are small

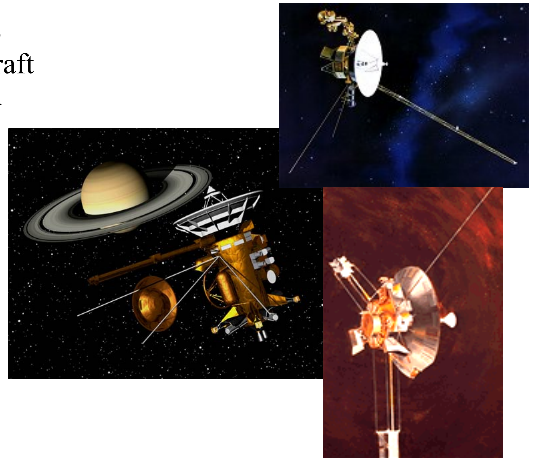


http://www.solarviews.com/cap/sat/saturn.htm

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

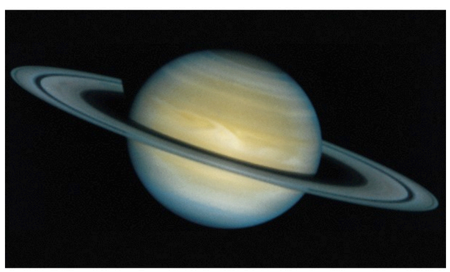


The Cassini Mission

- Launched on October 15th, 1997
- Arrived at Saturn on July 1st, 2004
- Orbiting Saturn, 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?

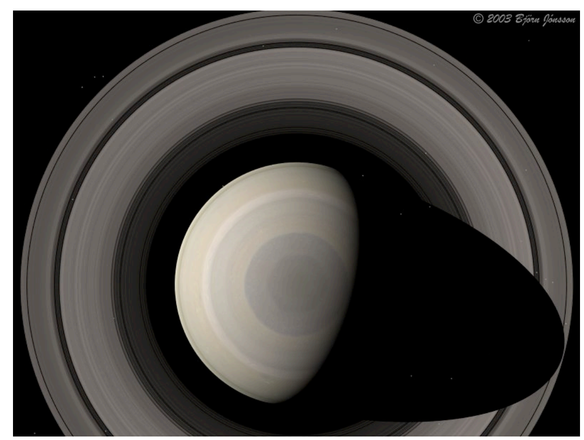
Saturn's Atmosphere

- 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!



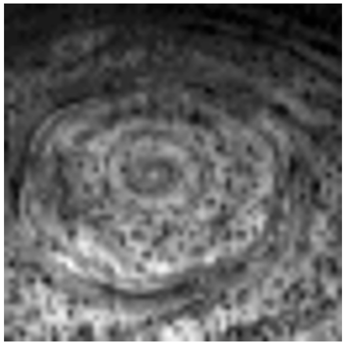
Driving Saturn's Weather

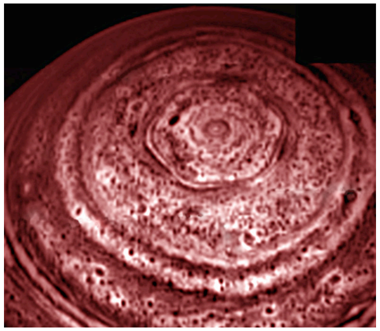
- As on Jupiter, Saturn's internal heat drives weather
  - Saturn radiates 80% more heat than it receives from the Sun
  - Like Jupiter, Saturn is still contracting!
  - As is contracts, heat is produced



Driving Saturn's Weather

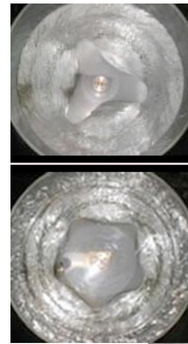
- As on Jupiter, storms are produced between cloud bands
  - No long lasting storm like the Great Red Spot, but hexagon cloud at pole has been stable for 20+ years.

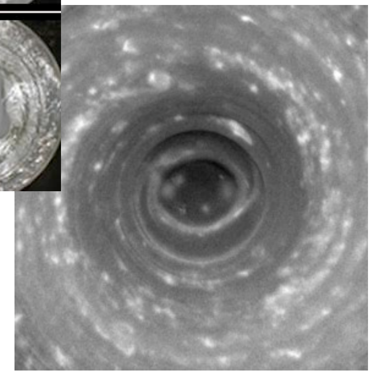




Driving Saturn's Weather

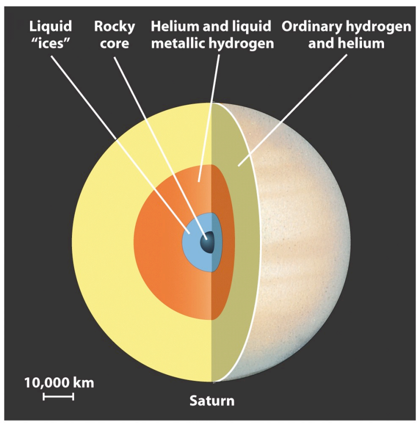
- Spinning water bucket experiments show similar features.
- Pseudoscience posit sound wave reflections.
- Saturn's South Pole also has an unusual structure.



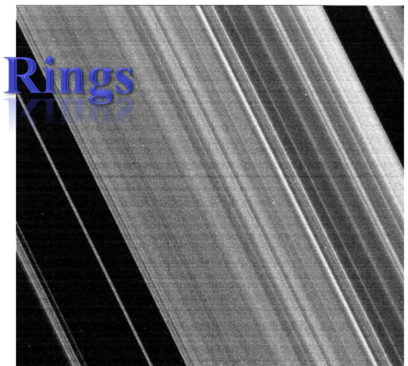


Saturn's Interior

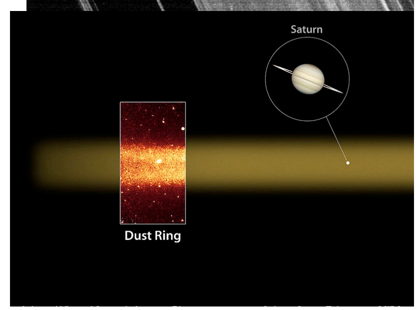
- Similar structure to Jupiter's
  - But Saturn is less massive
  - The interior is less compressed
- Liquid metallic hydrogen creates a magnetic field
  - 30% weaker than Earth's



Saturn's Rings

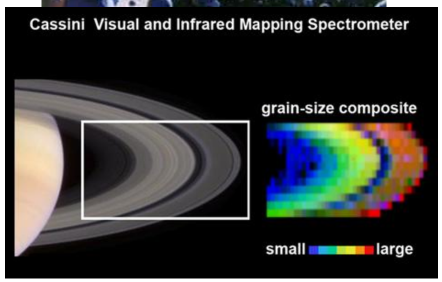


- Two main rings
  - Several fainter rings
  - Each ring is divided into *ringlets*
- The rings are **thin**
  - Only a few tens of meters thick– razor thin!



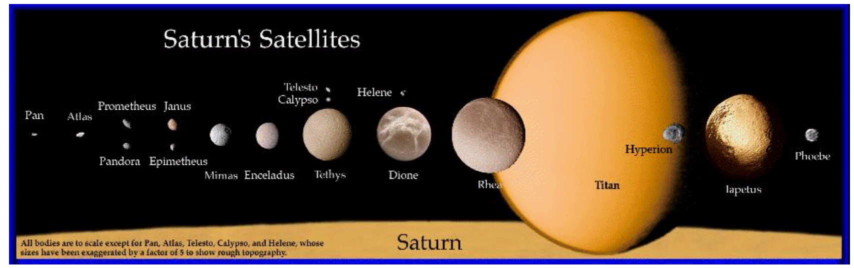
Makeup of the Rings

- 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



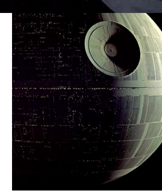
Saturn's Moons

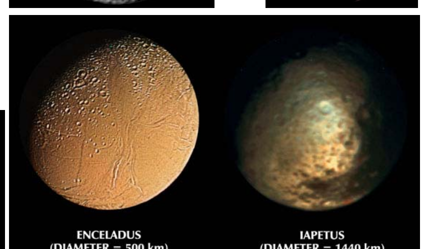
- Saturn has a large number of moons
  - At least 60
- Only Titan is comparable to Jupiter's Galilean moons
- Smaller moons are mostly ice, some rock

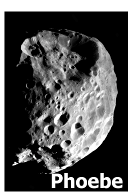


Saturn's Odd Moons

- **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

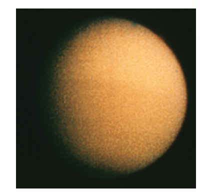




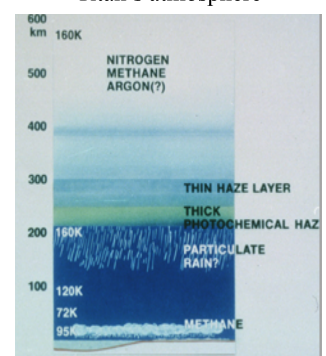


Titan

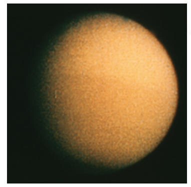
- Saturn's largest moon– bigger than Mercury.
- 2nd largest moon in the solar system after Ganymede.
- Discovered in 1655 by Christiaan Huygens
- Only moon to have a dense atmosphere
  - Dense nitrogen atmosphere
  - Small greenhouse effect
  - 98% nitrogen
    - –Only Earth is comparable
    - –Methane (something producing it)
  - Much like ancient Earth!



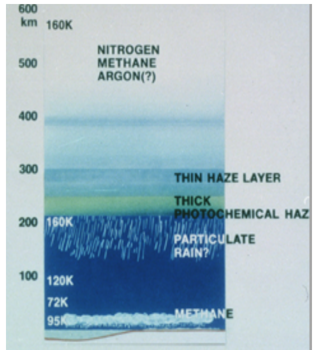
Titan's atmosphere



Titan



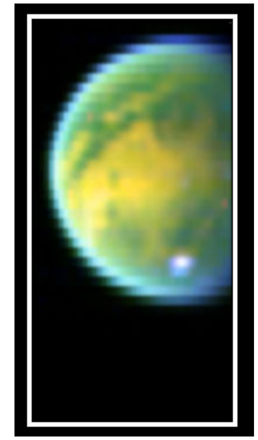
Titan’s atmosphere



- Atmospheric pressure is 1.5 times Earth’s
- Organic compounds – life?
  - Probably not – too cold: 95 K
  - May be a “deep freeze” of the chemical composition of ancient Earth

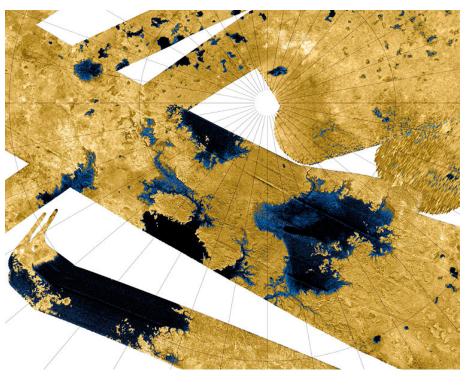
Piercing the Smog

- 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



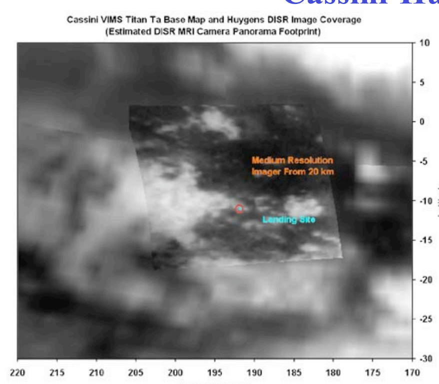
Surface Liquid

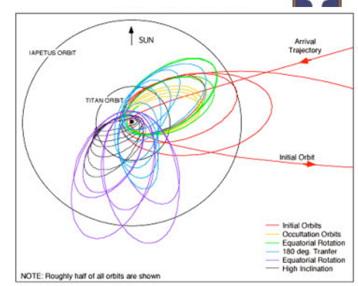
- Now confirmed to have liquid on surface.
- Only body besides the Earth.
- Too cold for water, so most likely filled with liquid ethane, methane, and dissolved nitrogen



http://photojournal.jpl.nasa.gov/catalog/?IDNumber=PIA10008

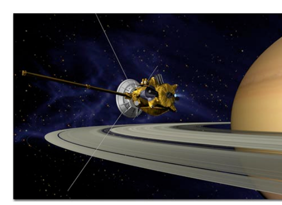
Cassini-Huygens





Arrival at Saturn
July 1, 2004

Huygens Probe
descent to Titan
Jan 14, 2005

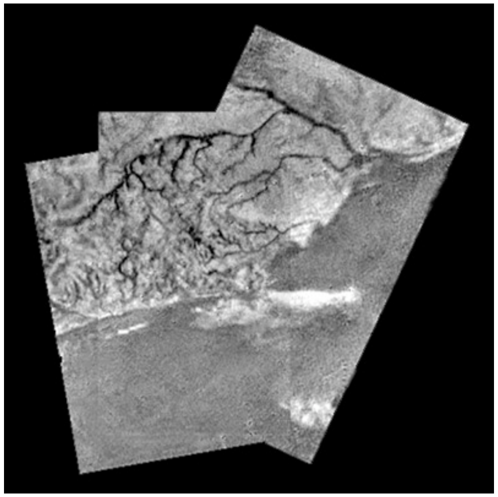


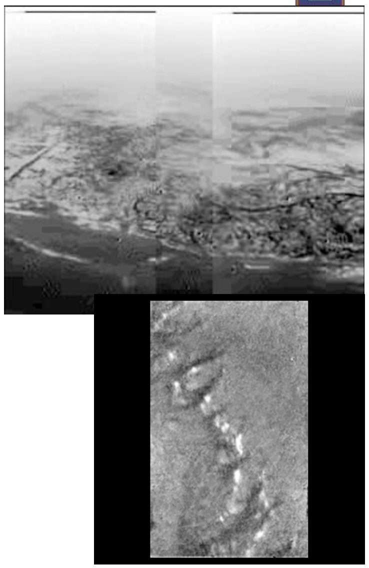
A Possible Landing

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

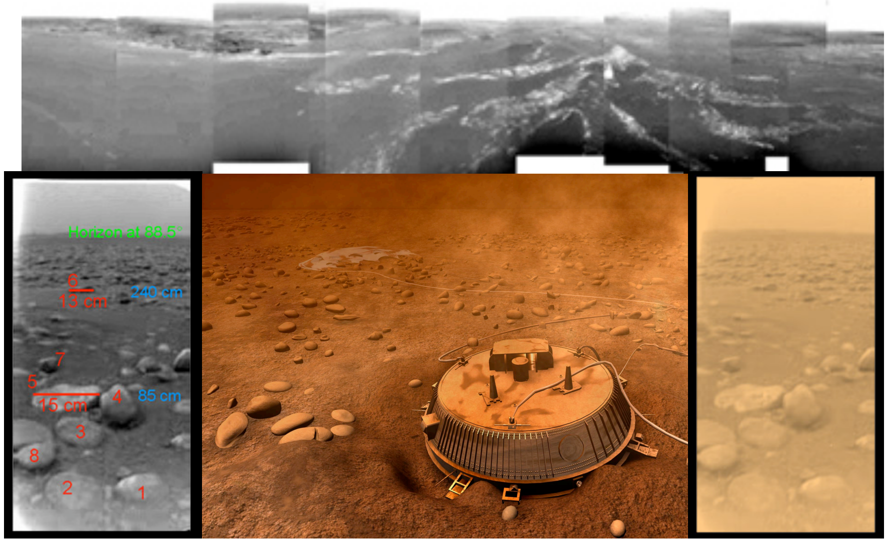
http://saturn.jpl.nasa.gov/cgibin/gs2.cgi?path=../multimedia/images/artwork/images/

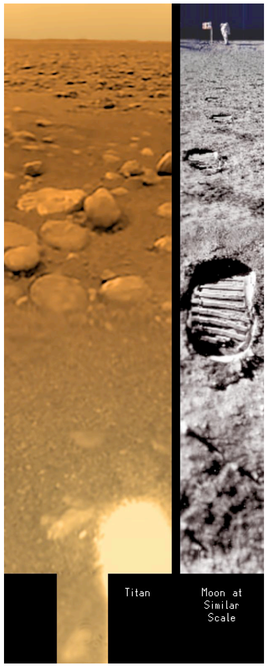
Mapping Titan



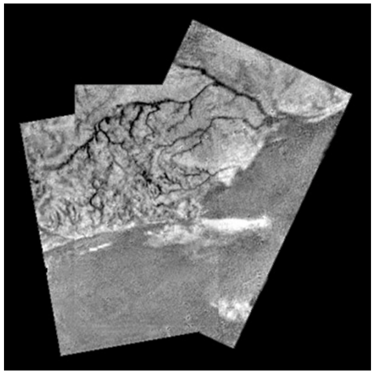


Mapping Titan





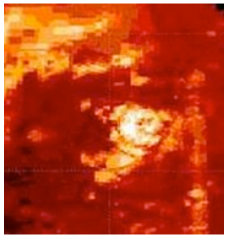
Mapping Titan



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

Cryovolcanoes

- Methane may come from volcanoes.
- Volcanoes heat up rock hard ice, spewing “lava” made up of water and ammonia.
- Two hot spots found in atmosphere, suggesting eruptions.
- Mountains found, suggesting some sort of plate tectonics.



Life on Titan

- Conditions much like the early Earth.
- Can organic chemistry work well in this environment?
- If found, would revolutionize our understanding of life.
- Some researchers suggest that panspermia from Earth is likely, so might find our cousins.
- Future missions will need to have biological component.

Conclusion

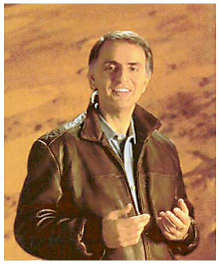
- ***No conclusive evidence exists for life in our solar system besides on Earth***
- But, possibilities exist for life
  - Venus’s clouds may have migrated life.
  - Mars may have some microbial history linked to water, and perhaps some subsurface life.
  - Jupiter’s reducing atmosphere may harbor sinkers.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

Question

Why is Titan an interesting place to look for life?

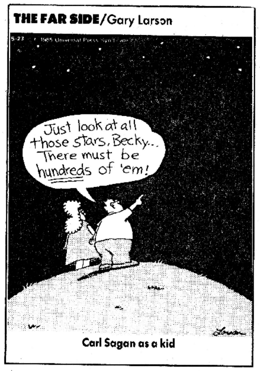
a) It will revolutionize how we think about ET life.
b) It will create new life hybrids.
c) There is no chance of life there.
d) The life is in early state if at all.
e) Black beans.

Optimism?



- Carl Sagan argues for $n_p > 3$.
  - If Venus had less clouds (less greenhouse) it could have been cool enough for life.
  - If Mars had a thicker atmosphere it could have been warm enough for life.
  - If solvents other than water were used, maybe the moons of the outer planets?
  - Giant Jupiter-like planets close in?
  - Non-Earth life?

http://www.uranos.eu.org/biogr/sagane.html
http://spider.ipac.caltech.edu/staff/jarrett/sagan/sagan.html



Carl Sagan as a kid

Pessimism?

- We only considered temperature. What about:
  - Gravity?
  - Atmospheric pressure?
  - Size of the moon or planet?
  - Does life need a Moon-like moon? Does life need the tides? Does the Moon protect the Earth's rotation? Is a Jupiter needed?
- If we impose Earth chauvinism, we can easily reduce to $n_p \sim 0.1$

http://sagiru.tripod.com/Travel/Lost_in_the_Sahara/lost_in_the_sahara

n_p: number of life planets per planetary system (average)

- Can range from 0.01 to >3.
  - Is seismic activity necessary to recycle bioelements?
  - How important is the first atmosphere? Ozone?
  - Is a moon needed? A large Jupiter-like planet?
  - Is liquid water a requirement? Other solvents okay?
    - Not too hot, not too cold; not too much pressure, not too little– Goldilocks requirement?
  - Habitable Zone around the star.
  - Galactic Habitable Zone
  - Does atmosphere need feedback mechanism?
  - But in our solar system, maybe 5 nearly possible life planets.

$$n_e = n_p \times f_s$$

n_p: number of planets suitable for life per planetary system

Class number is ?

http://nike.cecs.csulb.edu/~kjlivio/Wallpapers/Planets%2001.jpg

$$n_e = n_p \times f_s$$

n_p: number of planets suitable for life per planetary system

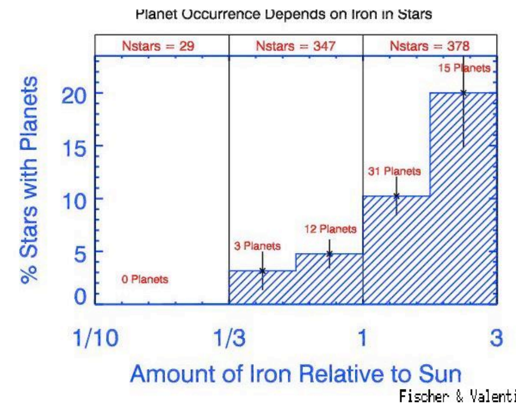
f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

We can list 5 situations that will have an effect on f_s.

http://nike.cecs.csulb.edu/~kjlivio/Wallpapers/Planets%2001.jpg

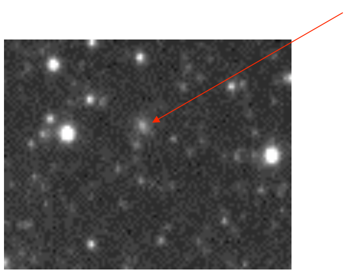
Differences of Stars to Life

1. **Metal rich stars**. Stars with heavy elements, probably more likely to have planets. Suggested in the current planet searches. About 90% of all stars have metals.



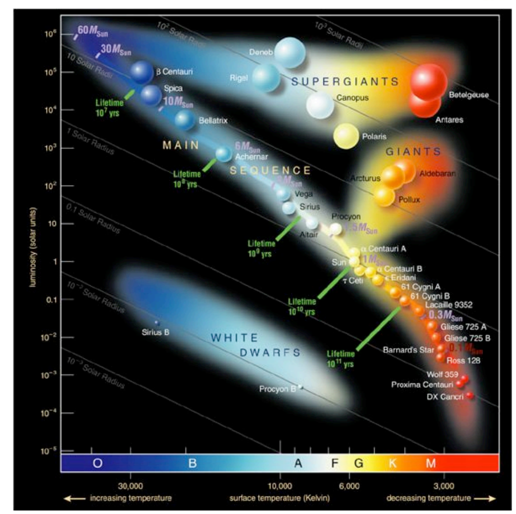
Differences of Stars to Life

2. **Main sequence stars**. Need the brightness to stay as constant as possible. Otherwise the temperature changes dramatically on the planets. This is 99% of all stars.



Differences of Stars to Life

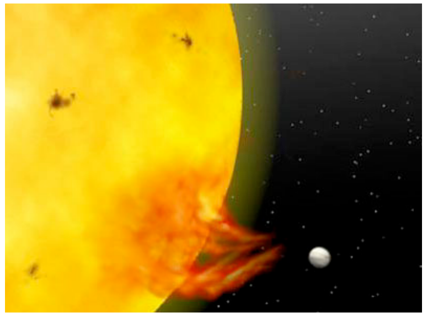
3. **Length of time on the main sequence**. We needed temperature stability for 5 billion years to get intelligence on Earth. This rules out stars more massive than 1.25 solar masses! 90% of all stars are less massive than that.



http://mjbs.org/hr.jpg

Differences of Stars to Life

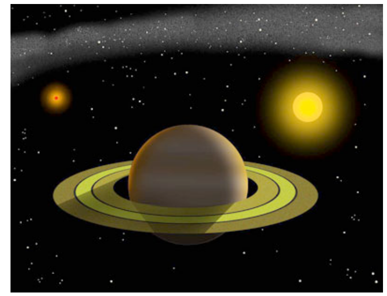
4. **Minimum mass of star**. If ice exists close to the star, that would imply the formation of Jupiter-like planets not Earth-like planets. And, any life bearing planet would have to be closer to the star– and closer to stellar effects (e.g. tidal locking and more flares from low mass stars). That limits us to a minimum of 0.5 solar masses. 25% of all stars are more massive than that.



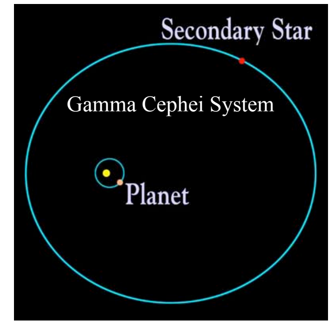
http://spaceflightnow.com/news/n0401/19planet/planet.jpg

Differences of Stars to Life

5. **Binarity**. Planets may form. But they may have odd orbits unless the 2 stars are far enough apart or the planet orbits the pair. Only 30% of all stars are single stars. 50% of all stars are single stars or wide binary stars.



http://spaceflightnow.com/news/n0210/11planet/



Adding it all up

Stellar Requirement	*Mass Limit*	*Fraction OK*	*Cumulative Fraction*
Heavy Elements	…	0.9	0.9
Main Sequence	…	0.99	0.891
Main Sequence Lifetime	$M < 1.25\ M_{sun}$	0.90	
Synchronous Rotation/ Flares	$M > 0.5\ M_{Sun}$	0.25	
Not a Binary	…	0.30	0.267
Wide Binary Separation	…	0.50	

Adding it all up

Stellar Requirement	*Mass Limit*	*Fraction OK*	*Cumulative Fraction*
Heavy Elements	…	0.9	
Main Sequence	…	0.99	
Main Sequence Lifetime	$M < 1.25\ M_{sun}$	0.90	
Synchronous Rotation/ Flares	$M > 0.5\ M_{Sun}$	0.25	
Not a Binary	…	0.30	
Wide Binary Separation	…	0.50	

Adding it all up

Stellar Requirement	*Mass Limit*	*Fraction OK*	*Cumulative Fraction*
Heavy Elements	…	0.9	
Main Sequence	…	0.99	
Main Sequence Lifetime	M < 1.25 M_{sun}	0.90	
Synchronous Rotation/ Flares	M > 0.5 M_{Sun}	0.25	
Not a Binary	…	0.30	
Wide Binary Separation	…	0.50	

f_s: fraction of stars that life can exist around

Stellar Requirement	*Mass Limit*	*Fraction OK*	*Cumulative Fraction*
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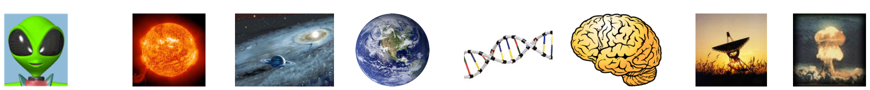
Wide Binary Separation	…	0.50	

Value can range from ~ 0.06 to ?

Drake Equation

Frank Drake

That's ? Life-liking systems/year



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

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
	20 stars/ yr	0.12 systems/ star	1.25x? planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Question

The best type of life sustaining stars are

a) Low mass stars (less than 0.5 solar masses), as life can exist nearer the star where more terrestrial planets are probably located.

b) Binary stars, as they double the chances of life.

c) Stars off the main sequence, as they have lived the longest, they are the best chance for finding intelligent life.

d) Middle mass stars (less than 1.25 and more than 0.5 solar masses), as they live longer and don't require the planets to be too close.

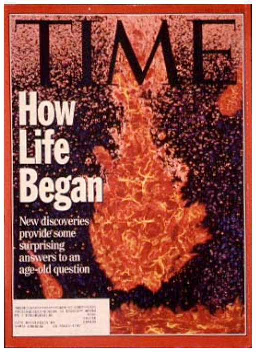
e) Massive stars (more than 2 solar masses), as they have more mass from which to form planets.

So Far, We have Studied

- The Universe
  - Big Bang
    - Creation of hydrogen, helium…
  - Galaxy formation
    - Swirls of elements embedded in self-gravitating cloud of dark matter
  - Star birth
    - Energy generation and element production in self-gravitating mass of gas
  - Planets
    - Ice, rock, gas surrounding stars form planetesimals, then planets

Life on Earth

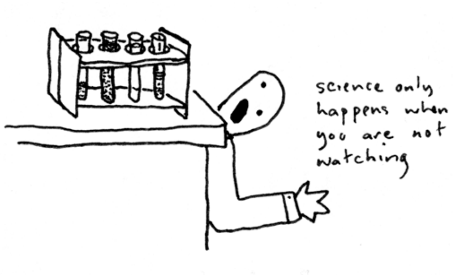
- Time to examine terrestrial evolution.
- Need to understand what is needed for life to arise.
- Again, some Earth chauvinism.
- Relies on chemical evolution
- Eventually life began?



http://www.accessexcellence.org/bioforum/bf02/awramik/bf02a1.html

Life on Earth

- In our scientific approach, we look at life as a result of chemical evolution of complexity.
- We will view the formation of "life" on planets as we did star formation
  - A natural consequence of natural laws
  - More specifically, as a consequence of the complex chemistry that is sometimes achieved.



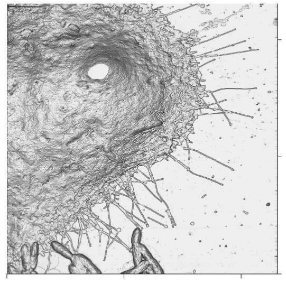
http://www.toothpastefordinner.com/052802/science-only-happens.gif

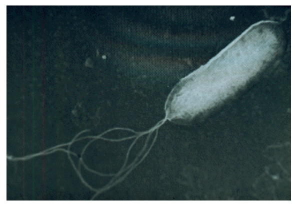
Cosmic Imperative?

- But is life a cosmic imperative?
- Just like gas forms galaxies, and in galaxies stars and planets form, do chemicals on some planets form molecules that lead to life?

All Made from the Same Stuff





Element Basis of Life

- About 95% of the mass of all terrestrial organisms is composed of only 4 out of 90 elements
  - **H**ydrogen (61% in humans)
  - **O**xygen (26% in humans)
  - **N**itrogen (2.4% in humans)
  - **C**arbon (10.5% in humans)
- **HONC** is essential to life, and it's common in space.

Question

Life on Earth is varied in how its made on the molecular level, i.e. elephants are made out of different stuff than bacteria.

a) True
b) False

Trace Elements

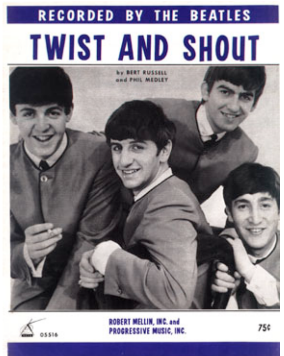
In addition to HONC, there are some other elements that are essential for life but in *smaller* amounts:

- Sulfur, magnesium, chlorine, potassium, sodium
  - These other elements make up about 1% of the mass of living organisms
  - Exist in roughly the same concentration in organisms as in ocean water
  - Highly suggestive that life began in oceans
  - Furthermore suggests that the evolutionary processes occurred on Earth. Panspermia problems?

http://www.maxxiweb.com/pics/wallpapers/paysages/oceans-006.jpg

Good News

- H,O,N,C is very common in universe; everywhere as far as we can tell
  - If life were based totally on rare elements, we might expect its occurrence to be extremely rare…
- So, we expect ET life to be based primarily on HONC.
  - The four primary chemical elements of life with some other simple components can produce staggering complexity.
- But, each planet will feature its own environment of trace elements giving each planet's life a unique **twist** to the standard HONC chemistry



http://www.rarebeatles.com/sheetmu/smtwist.jpg

Nature's Complexity

- The workings of biological molecules are an absolute marvel
  - How did this complexity develop?
  - How did it evolve?
- As complex and mysterious as life on Earth may be, we can begin to understand it
- Start with the basics:
  - Why are H,O,N,C the basis for living organisms?
  - How do the molecules formed by these (and other elements) work to make DNA, proteins, life?

http://europa.eu.int/comm/environment/life/toolbox/logo_life_high_resolution_2.jpg

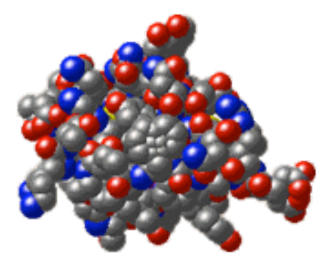
We Are Special Stuff?

- Why is Earth life based on H,O,N,C instead of the more abundant elements found on Earth?
  - Suggests that the formation of life is not able to be formed just out of anything lying around.
  - The selection of H,O,N,C seems to be a necessity of the chemistry of life.
  - In general, Earth life is a carbon based life. Carbon is the main backbone of the chemistry.
- Is this good news?

Why Carbon Based Life?

- Carbon's electronic structure allows it to form long chains
  - Chains of atoms and chains of molecules– complexity
  - Life needs bonds to be stable but breakable
- Good for us, at temperatures at which water is liquid, carbon bonds are stable but breakable
- Organic chemistry is the special branch devoted to carbon chemistry.

Insulin
$C_{254}H_{377}N_{65}O_{76}S_6$



http://www.biology.arizona.edu/biochemistry/tutorials/chemistry/page2.html