Astronomy 230

Section 1– MWF 1400-1450

106 B1 Eng Hall

This Class (Lecture 9):

Nature of the Solar System/

Habitable Planets

Next Class:

Nature of Life

First Oral Presentations on Sept 22 and 24!

David Sederquist
Pranay Patel
Doug Jones

Michael Chou
Eric Mazzone
Chris Varney

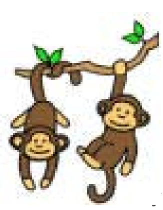
Music: *Parallel Universe* – Red Hot Chili Peppers

Outline

- What is f_p?
- Basically a whole lecture for estimating the number of Earth-like planets (read planets with life) per system.
- Formation of the Moon.
- Water plays a major role in life as a solvent.
- Is there a preferred zone for life around the Sun?
- Did life already pollute the Earth's atmosphere.

Presentations

- Will be treated like a real scientific talk at a meeting.
- I will keep you to 10 minutes with 5 minutes of questions.
- Any speculative claims *MUST* have a scientific reference source.
  - Can't just claim that monkeys live on the Moon.



Presentations

- Can give presentation in any format you want.
- Last semester:
  - 90% powerpoint
  - 6% talking with pics from webpages
  - 2% dedicated webpage
  - 2% overhead slides
- If presentation is electronic
  - Email me evening before
  - Or, on netfiles, send me location
  - Or, bring in burned CD

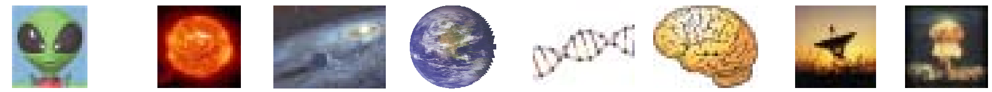
Oral Presentation

1. How relevant is the topic to the search for extraterrestrial life?
2. How interesting is the topic for the general class audience?
3. Rate the extent of the speakers knowledge on the topic?
4. Rate the quality of the overall presentation?
5. Does the research have a solid scientific basis?

These questions are rated 1-10 out of 10 scale.

Drake Equation

Frank Drake

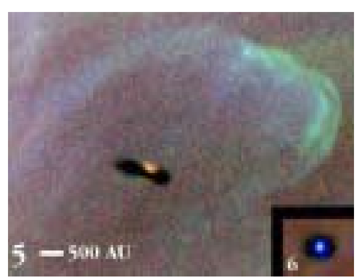


$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	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
	25						

Now, for f_p

- About 2/3 of all stars are in multiple systems.
  - Is this good or bad?
- Disks around stars are very common, even most binary systems have them.
- Hard to think of a formation scenario without a disk at some point– single or binary system.
- Disk formation matches our solar system parameters.
- We know of many brown dwarves, so maybe some planets do not form around stars.
  - There might be free-floating planets, but…

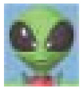
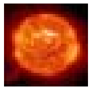
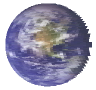
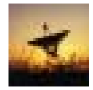
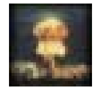


Now, for f_p

- Extrasolar planet searches so far give about $f_p \sim 0.03$, but not sensitive to lower mass systems.
- Maximum is 1 and lower limit is probably around 0.02.
- A high fraction assumes that the disks often form a planet or planets of some kind.
- A low fraction assumes that even if there are disks, planets do not form.
- This is not Earth-like planets, just a planet or many planets.

Drake Equation

Frank Drake

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# of advanced civilizations we can contact	Rate of star formation	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
	25	**?**					
	Stars/year						

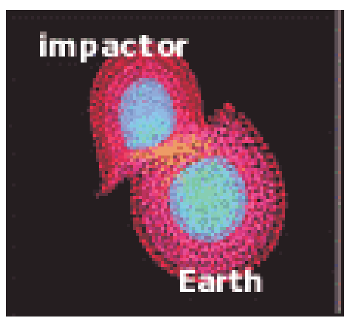
Formation of the Earth

- Focus on the formation of the Earth, including its atmosphere and oceans.
- The biggest peculiarity, compared to the other planets, is the large moon.

Smack!

- Collision of Earth with Mars-size planetesimal early in history
- Core of planetesimal sank within Earth
- Earth rotation sped up
- Remaining ejecta thrown into orbit sufficient to coalesce into Moon

J. Tucciarone



A.G.W. Cameron
Computer simulation

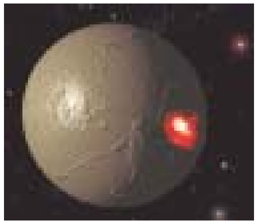
Why is this a good hypothesis?

- The Earth has a large iron core (differentiation), but the moon does not.
  - The debris blown out of collision came from the iron-depleted, rocky mantles. The iron core of the impactor melted on impact and merged with the iron core of Earth, according to computer models.
- Compare density of 5.5 g/cm^3 to 3.3 g/cm^3— the moon lacks iron.

http://www.flatrock.org.nz/topics/odds_and_oddities/assets/extreme_iron.jpg

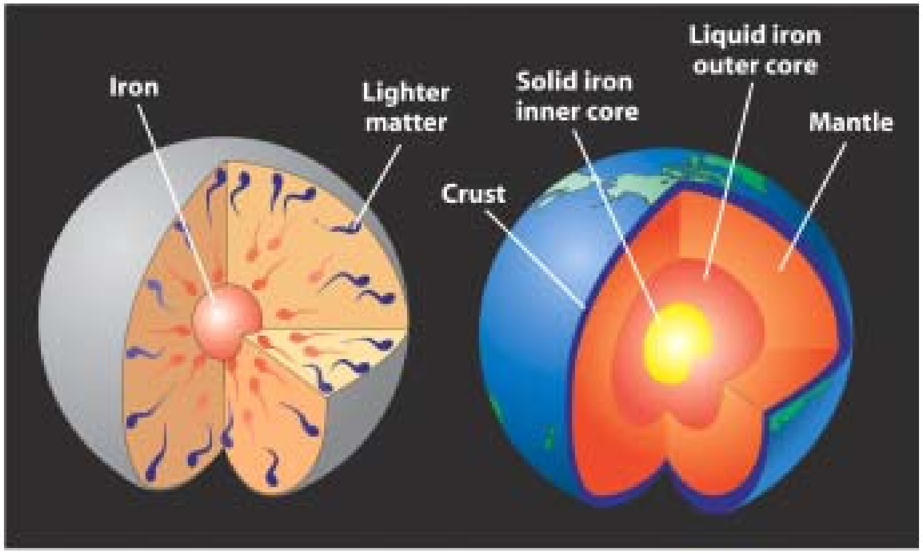
Implications

- **Hot, hot, hot.** Even if the moon theory is incorrect, other smaller bodies were playing havoc on the surface.
- When they impact, they release kinetic energy and gravitational potential.
- In addition, some of the decaying radioactive elements heated up the Earth– stored supernova energy!
- The planetesimals melt, and the Earth goes through a period of differentiation.



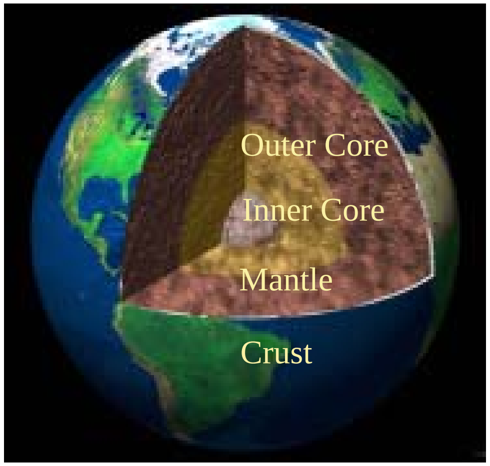
http://www.udel.edu/Biology/Wags/wagart/worldspage/impact.gif

Planetary Differentiation



Structure

- Luckily, not all of the iron sank to the center, else we would be still in the Stone Age.
- Core is made of 2 parts– inner core and the outer core.
- Temperature increases as you go deeper. From around 290 K on surface to nearly 5000 K at center.
- The deeper you go, more pressure from mass of Earth.

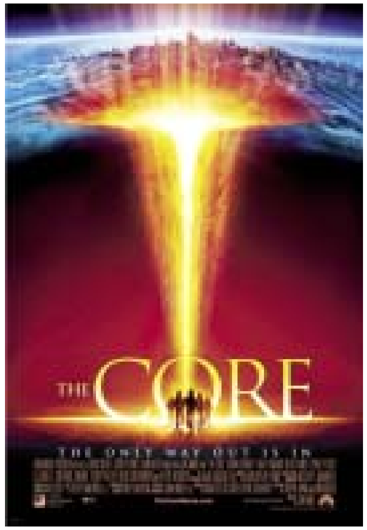


Inner Core

- With high pressures the inner core remains a solid
- Reaches very high temperatures– 5000 K (Close to the temperature at the surface of the Sun)!
- Mostly made of iron (Fe)
- Information about the inner core comes from the study of earthquakes, meteorites and the Earth's magnetic field.
- Might be rotating faster than the rest of the planet.

Outer Core

- The liquid layer of the Earth, high pressure but not enough to solidify
- Mostly Iron.
- Made of very hot molten liquid that floats and flows around the solid inner core– creates the Earth's magnetic field.



Mantle

- Largest layer of the Earth, source of magma and lava
- Distinct from the core
- Temperature increases the deeper you go into the mantle
- Heated from below, parts of the Mantle are hot enough to have an oozing, plastic flow (sort of like silly putty).

Crust

- Outside layer of the Earth (includes oceans) that floats on top of the mantle
- Much thinner and colder than any of the other layers
- Crust is rocky and broken into about 21 different pieces (like the shell of a cracked hard-boiled egg).
- Oxygen and Water are abundant

In Hawaii

Recycling Bio-elements

- From gravity and radioactivity, the core stays hot.
- This allows a persisting circulation of bioelements through continental drift— melting of the crust and re-release through volcanoes.
- Otherwise, certain elements might get locked into sediment layers– e.g. early sea life.
- Maybe planets being formed now, with less supernovae, would not have enough radioactivity to support continental drifts and volcanoes. (Idea of Peter Ward and Donald Brownlee.)

http://www.pahala-hawaii.com/j-page/image/activevolcanoe.jpg

The Earth's 1st Atmosphere

- The interior heat of the Earth helped with the Earth's early atmosphere.
- The inner disk had most gases blown away and the proto-Earth was not massive enough to capture these gases. And any impacts (e.g. the moon), would have blown the atmosphere away.
- Most likely the hot proto-Earth heated up the ices of the dust grains that made up the early Earth– water (H_2O), carbon dioxide (CO_2), and Nitrogen (N_2)– the first atmosphere.
- The water condensed to form the oceans and much of the CO_2 was dissolved in the oceans and incorporated into sediments– such as calcium carbonate ($CaCO_3$).

Our Atmosphere

- Rocks with ages greater than 2 million years show that there was little or probably no oxygen in the Earth's atmosphere.
- The current composition: 78% nitrogen, 21% oxygen, and trace amounts of water, carbon dioxide, etc.
- Where did the oxygen come from?
- Cyanobacteria made it.
  - Life on Earth modifies the Earth's atmosphere.

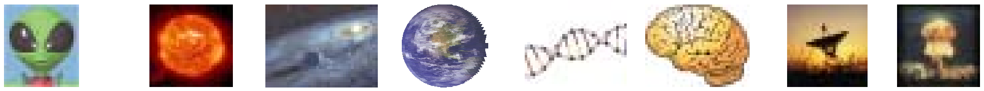
http://www.uweb.ucsb.edu/~rixfury/conclusion.htm

This New Planet

- Mostly oceans and some solid land (all volcanic).
- Frequent impacts of remaining planetesimals (ending about 3.8 billion years ago).
- Impacts would have sterilized the young Earth– Mass extinctions and maybe vaporized oceans.
- Impacts and volcanic activity created the continental landmasses.
- Little oxygen means no ozone layer– ultraviolet light on the surface.
- Along with lightning, radioactivity, and geothermal heat, provided energy for chemical reactions.

Drake Equation

Frank Drake



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Earth Chauvinism?

n_e

- Complex term, so let's break it into two terms:
  - 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

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

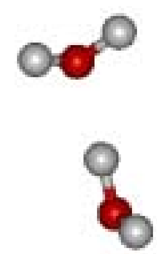
$$n_e = n_p \times f_s$$

Water

- Water is a key to life on Earth.
- Primary constituent of life– "Ugly bags of mostly water"
  - Life is about 90% water by mass.
- Primary role as a solvent
  - Dissolves molecules to bring nutrients and remove wastes. Allows molecules to "move" freely in solution.
  - Must be in liquid form, requiring adequate pressure and certain range of temperatures.
- This sets a requirement on planets, if we assume that all life requires water.

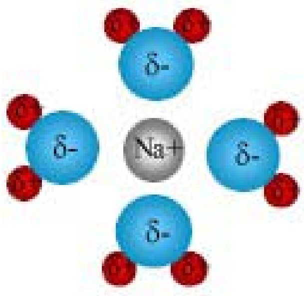
Water as a Solvent

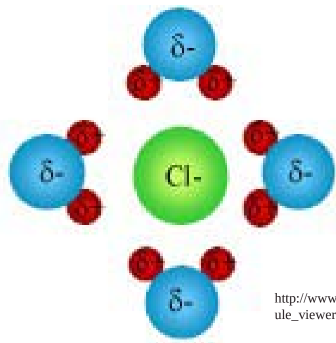
- The water molecule is "polar". The oxygen atoms have more build-up of negative charge than the hydrogen. This allows water molecules to link up, attracted to each other.
- In this way, water attracts other molecules, surrounds them and effectively dissolves them into solution.



Example: Dissolving Table Salt

The partial charges of the water molecule are attracted to the Na^+ and Cl^- ions. The water molecules work their way into the crystal structure and between the individual ions, surrounding them and slowly dissolving the salt.

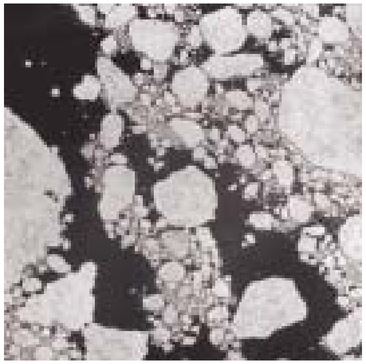




http://www.visionlearning.com/library/module_viewer.php?mid=57

Water

- A very good temperature buffer
  - Absorbs significant heat before its temperature changes
  - When it vaporizes, it takes heat with it, cooling down its original location
- It floats.
  - Good property for life in water.
  - Otherwise, a lake would freeze bottom up, killing life.
  - By floating to the surface, it can insulate the water somewhat.



Keeping it Useful

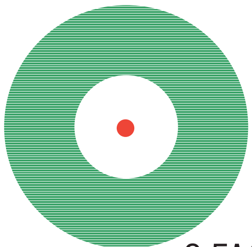
- Need to have enough pressure to keep water from boiling away at low temperature
  - Cooking at higher elevation requires more time. Boiling point lowered: water doesn't get as hot.
  - If pressure too low, water goes directly from ice to vapor (like dry ice CO_2)
- High pressure may make life more difficult to form.
- In addition, the range of temperature for Earth based complex life is less than 325K.

Keeping It Warm, but not too Warm

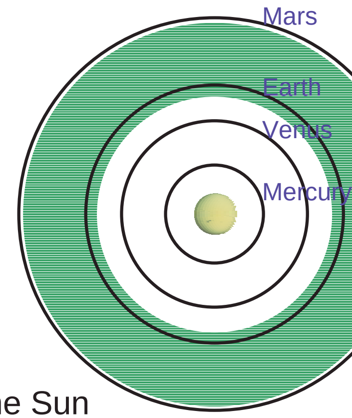
- What controls a planets temperature?
  - The amount of light received from its star.
  - The amount of energy the planet reflects back.
  - And any Greenhouse effects of the planet.
- Earth's effect raises its temperature by about 15%.
- Given a star's luminosity, a range of acceptable temperatures translates into a range of distances to the star.
- This range is called the star's habitable zone (HZ), as planets in this range have temperatures suited for life.
- Only a rough guideline.

Habitable Zones– Are you in the Zone?

- Long living star
- Planets with stable orbits (thus stable temps)
- Liquid Water
- Heavy Elements– C, N, O, etc.
- Protection from UV radiation



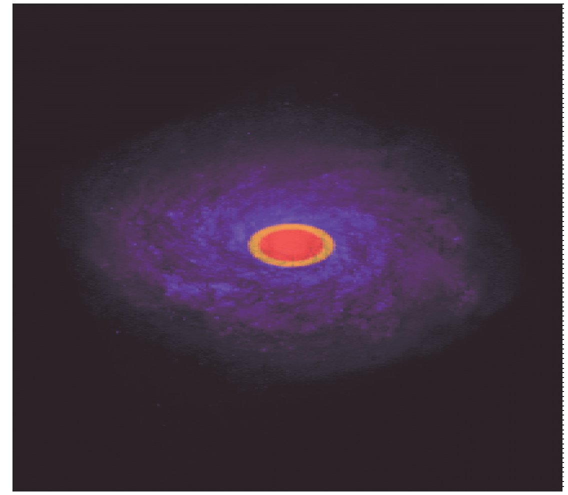
$0.5M_{Sun}$ star



The Sun

Galactic Habitable Zone

- Likewise the galaxy has regions that are better suited to life.
- In the inner regions of our galaxy, supernovae are too frequent.
- In the outer regions, there are too few metals.
- Simulation of Galaxy Zone from early stages to now.

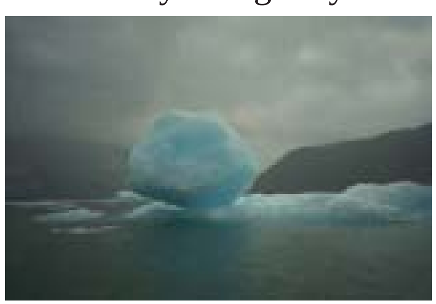


http://astronomy.swin.edu.au/GHZ/GHZmovie.html

The Sun's Variation

- As the Sun ages, it gets slightly brighter.
- When it was younger, its luminosity was 70% current values.
- A young Earth should have been 20K colder– iceball!
- During our ice ages, the temperature only changes by about 1%.

http://www.cherishclaire.com/iceball.htm



The Sun's Variation

- There is evidence that the Earth did nearly freeze over– 2.8 billion years ago and 700 million years ago.
- Probably changes in the Greenhouse gases.
- This implies that the habitable zone can vary with time, thus the real habitable zone is smaller than shown before.
- Some have postulated that real zone is only 0.95 to 1.01 AU! If the Earth were 1% farther away– Iceballed. And n_p would be very small ~ 0.1.

http://www.soest.hawaii.edu/gerard/GG108/images/bylot.jpg

Earth's Atmosphere

- Most recent studies suggest an efficient feedback mechanism.
- CO_2 cycles from atmosphere and oceans (buried sediments especially carbonate rock).
- Carbon is then released by volcanoes.
- Removing CO_2 from atmosphere by weathering rocks, allowing new reactions.
- Negative feedback process
  - Increase in temperature: evaporation of oceans, more rainfall, more weathering and CO_2 reduction, so decrease in temperature.

http://www.wildtech.org/images/feedback.gif

Life Adds to Feedback

- Life increases the weathering of rock.
- J.E. Lovelock has proposed that life stabilizes the planet temperature.
- Regardless, the negative feedback helps with the habitable zone, so we can estimate perhaps n_p is more around 1– more Earth chauvinism?

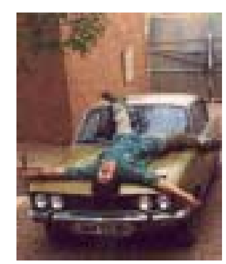
While testing out his new cereal mix on his horse, Dave gets some unexpected feed-back.

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?

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 reduce estimate to $n_p \sim 0.1$



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

n_p

- Can range from 0.01 to >3.
- Let's vote!
- In this class, let's assume a value n_p = ?