Astronomy 230
Section 1– MWF 1400-1450
106 B6 Eng Hall

<u>This Class (Lecture 9):</u>

Nature of the Solar System/

Habitable Planets

<u>Next Class:</u>

Nature of Life

Some Oral Presentation on Feb 16th and 18th!

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Chris Kramer
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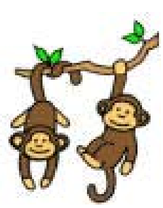
Adam Quinn
Chris Hall

Outline

- What's up with the oral presentations?
- 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.
- Have to keep intelligent life in a rather limited range of temperature.
- Planetary habitable zones.
- Life in 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.



Oral Presentation

1. How relevant is the topic to extraterrestrial life?
2. How interesting is the topic?
3. Rate the speaker's knowledge of the topic.
4. Rate the quality of the overall presentation.
5. Rate the scientific basis of the topic.

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

Back to f_p

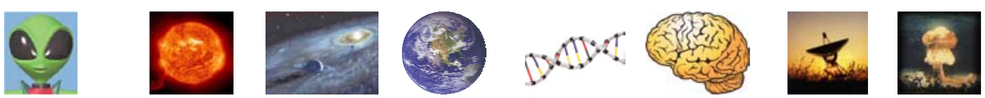
- About 2/3 of all stars are in multiple systems.
- But disks around stars are very common, even some of the binary systems have them.
- We know of many brown dwarves, so maybe some planets may not form around stars.
  - There might be free-floating planets, but…
- Extrasolar planet searches so far give about $f_p \sim 0.03$, but not sensitive to lower mass systems.
- Maximum is 1 and lower limit is probably around 0.02. What number do you prefer?

The Mob has Spoken

- The lowest estimate was 0.02 ← ***Pessimist***
- The highest estimate was 0.9 ← ***Optimist***
- The average was 0.34

Drake Equation

Frank Drake



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

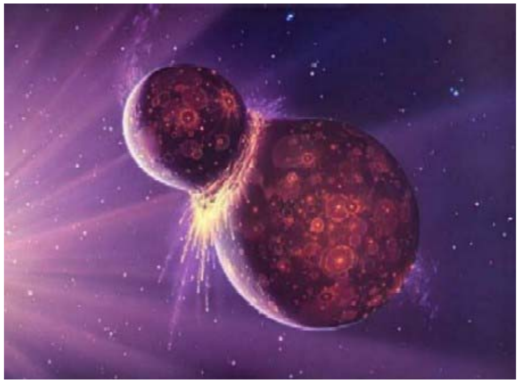
N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact	Rate of formation of Sun-like stars	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	10	**0.34**					
	Stars/year						

Formation of the Earth

- Focus on the formation of the Earth, including its atmosphere and oceans.
- The one peculiarity 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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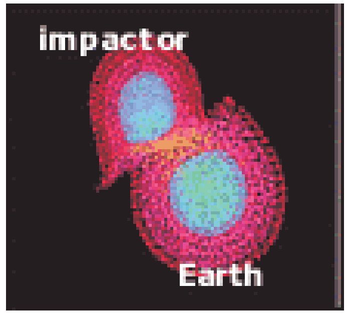
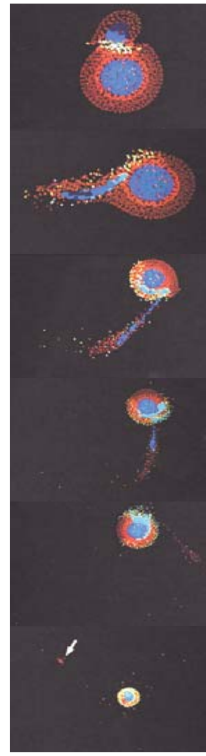


A.G.W. Cameron
Computer simulation

Large-Impact Hypothesis

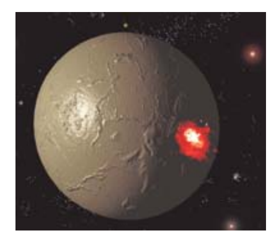


Why is this a good hypothesis?

- 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.

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.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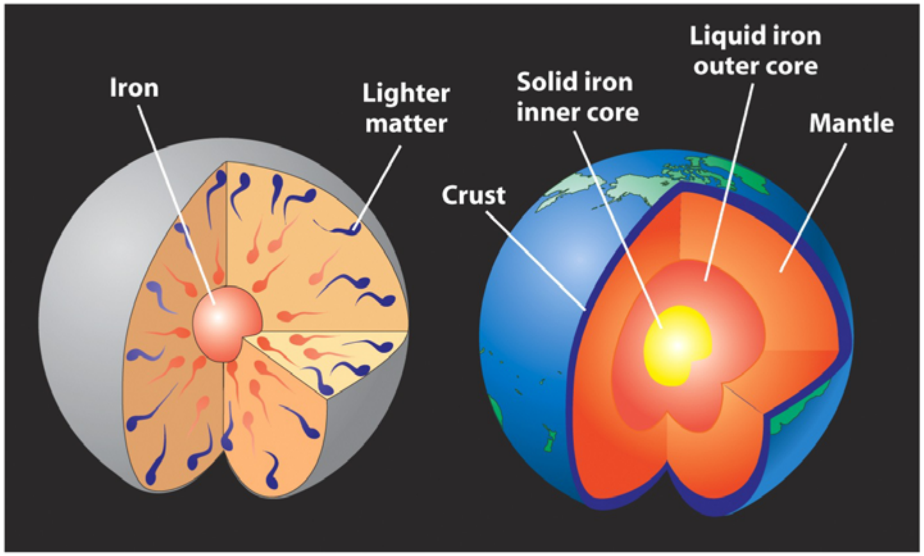
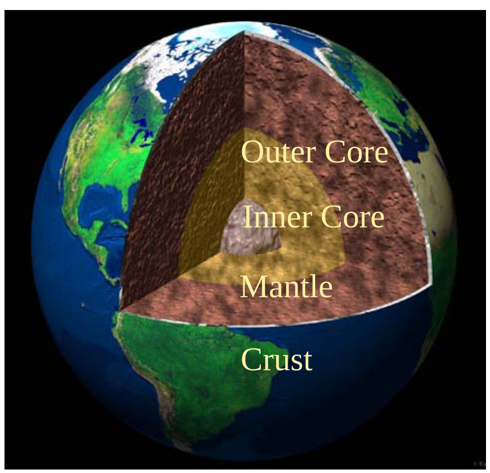
Planetary Differentiation



In Hawaii

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– heat convection plays major role
- This convection produces complicated circulation pattern of iron (electrical conductor)– creates a 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

Recycling Bio-elements

- From gravity and radioactivity, the core stays hot.
- This allows a persisting circulation of bioelements through continental drift.
- Otherwise, certain elements might get locked into 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.)

The Earth's 1st Atmosphere

- Also, the interior heat of the Earth may have 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 that may have formed the moon, would have blown the atmosphere away.
- Most likely the hot proto-Earth heated up the ices on the dust grains– water (H_2O), carbon dioxide (CO_2), and Nitrogen (N_2)– the Earth's 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

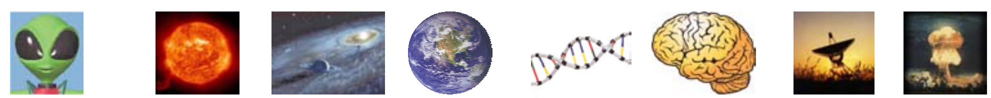
- Rocks with ages greater than 2 million years show that there was little or perhaps no oxygen in the Earth's atmosphere.
- The current composition: 78% nitrogen, 21% oxygen, and trace amounts of water, carbon dioxide, etc.
- Life on Earth modifies the Earth's atmosphere.

This Old 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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	10	**0.34**					

Earth Chauvinism?

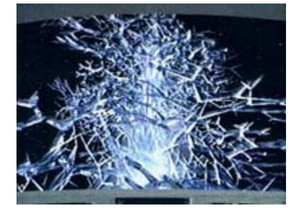
n_e

- 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

$$n_e = n_p \times f_s$$

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

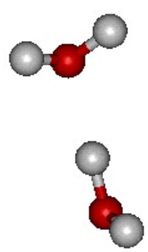
Water



- 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.

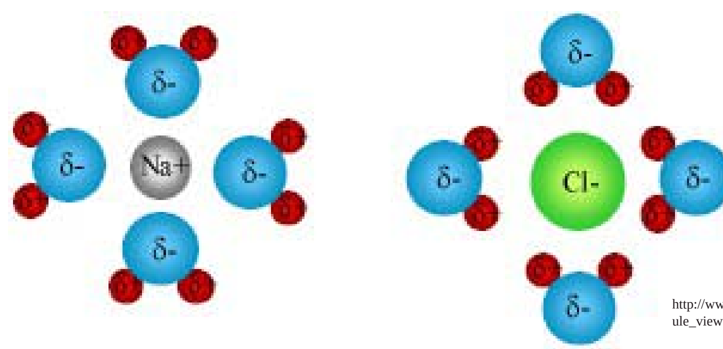
Water as a Solvent

- 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

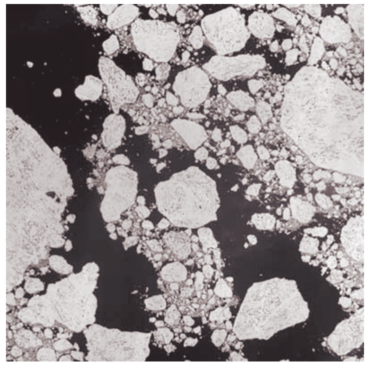
The partial charges of the water molecule are attracted to the Na^+ and Cl^- ions. The water molecules work their way into the crystal structure and between the individual ions, surrounding them and slowly dissolving the salt.



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 much 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

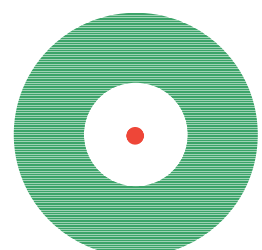
- Need to have enough pressure to keep water from boiling away at low temperature
  - Cooking at higher elevation requires more time. Boiling point lowered.
  - If pressure too low, water goes directly from ice to vapor (like dry ice CO_2)
- High pressure may make life more difficult to form.
- In addition, the range of temperature for Earth based complex life is less than 325K.

Keeping It Warm, but not too Warm

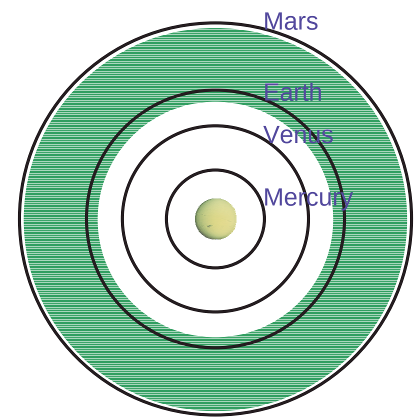
- What controls a planets temperature?
  - The amount of light received from its star.
  - The amount of energy the planet reflects back.
  - And any Greenhouse effects of the planet.
    - Earth's effect raises its temperature by about 15%.
- Given a star's luminosity, a range of acceptable temperatures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

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%.
- 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.

Earth's Atmosphere

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

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 around 1– more Earth chauvinism?

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 $n_p \sim 0.1$

n_p

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

- So what about this f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

Differences of Stars to Life

1. Metals. Stars with heavy elements, probably more likely to have planets. Suggested in the current planet searches.
2. Main sequence lifetime of star. Need the brightness to stay as constant as possible. Otherwise the temperature changes dramatically on the planets.
3. Time on the main sequence. Again, we need temperature stability for at least 5×10^9 years. This rules out stars more massive than 1.25 solar masses! Good news is that still leaves 90% of all stars.

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 about 0.5 solar masses, leaving about 25% to 50% of all stars.
5. Binarity. Planets may form. But they may have odd orbits unless the 2 stars are far apart or it orbits the binary.

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	0.890
Synchronous Rotation/ Flares	$M > 0.5\ M_{Sun}$	0.25	0.200
Not a Binary	…	0.30	0.060
Wide Binary Separation	…	0.50	0.1

f_s

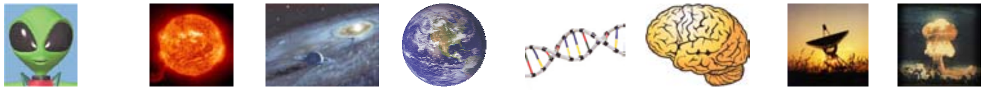
- Can range from 0.06 to 0.2.
- Let's vote!
- In this class, let's assume a value f_s = ?

Then, we can estimate n_e

$n_e = n_p \times f_s$ = ? X ? = ?

Drake Equation

Frank Drake



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