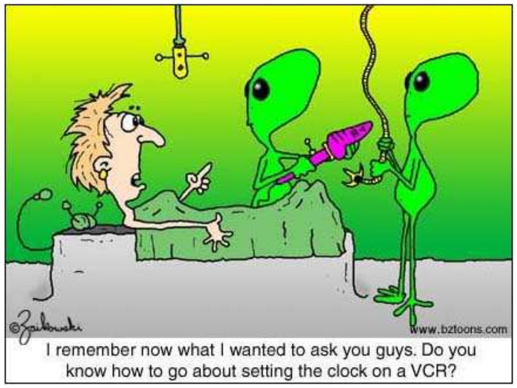
Astronomy 230

TR 1300-1420

134 Astronomy Building



This class (Lecture 8):

Nature of Solar Systems
Edward Espiritu &
Aylin Selcukoglu

Next Class:

Habitable Planets
Natalya Sholomyansky &
Rebecca Wright

HW 3 is due next class.

Sept 21:
Octavio Mendoza &
Shing-Chiang Huang

Music: *Sonne* – Rammstein

Presentations

- Edward Espiritu – String Theory
- Aylin Selcukoglu – Home Away from Home: The Kepler Mission

Outline

- Maybe some reasons the Earth is good for life.
- The importance of water.
- Requirements for life on Earth.
- What about other objects in our solar system?
- The effects of the star on life.

Drake Equation

Frank Drake

That's 7.5 planetary systems/year

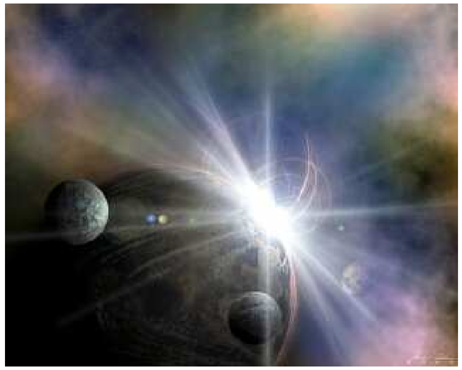
$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

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
	15 stars/ yr	0.5 systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

$$n_e = n_p \times f_s$$

n_p: number of planets suitable for life per planetary system (an average per planteary 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

Geologically Active Surface

- The young rocks on the Earth's surface indicate it is geologically active
- Where do these rocks come from?
  - Volcanoes
  - Rift valleys
  - Oceanic ridges
- Air, water erode rocks
- **The surface is constantly changing**

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 favored scenario is that impacted comets released – 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 ($CaCO_3$).

http://www.fli-cam.com/images/comet-liner.jpg

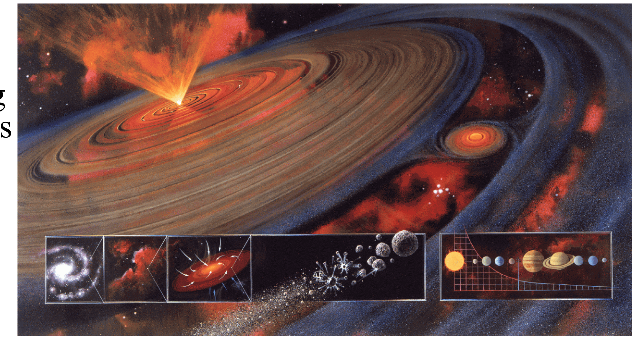
Our Atmosphere

- 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 (more comets?).

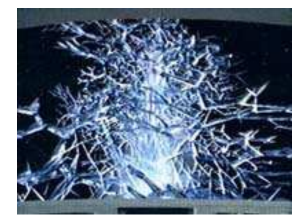


http://www.agnld.uni-potsdam.de/~frank/Images/painting.gif

This New Planet

- 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.

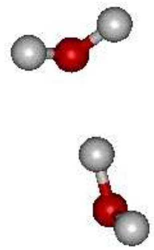
Water



- 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.

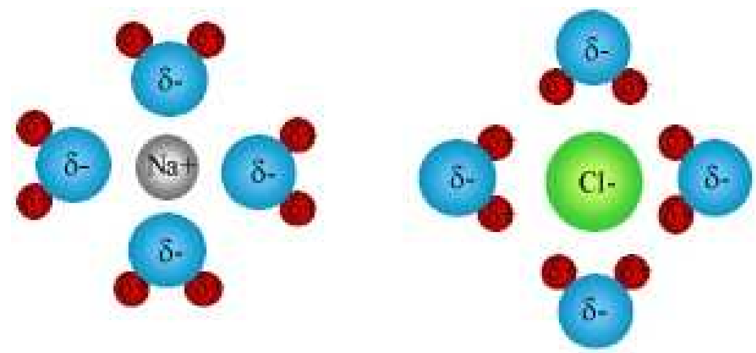
Water as a Solvent

- 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

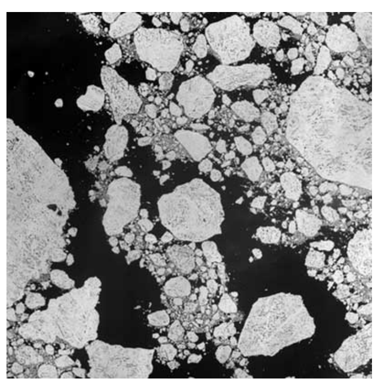
The partial charges of the water molecule are attracted to the Na^+ and Cl^- ions. The water molecules work their way into the crystal structure and between the individual ions, surrounding them and slowly dissolving the salt.



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

Water: Our Liquid Friend

- A very good temperature buffer
  - Absorbs significant heat before its temperature changes
  - When it vaporizes, it takes heat with it, cooling 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.



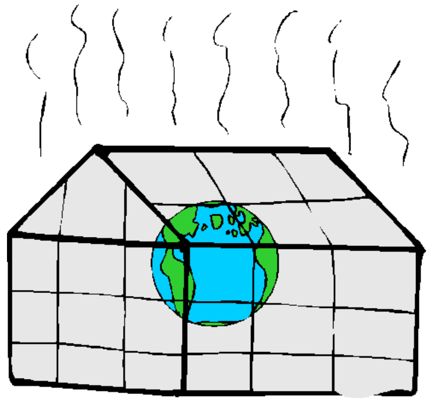
Keeping it Useful: Atmosphere

- 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)
- On the other hand, high pressure may make life more difficult to form.
- In addition, the range of temperature for Earth based complex life is less than 325K.

http://www.astro.su.se/~magnusg/large/Boiling_water.jpg

Keeping It Warm, but not too Warm

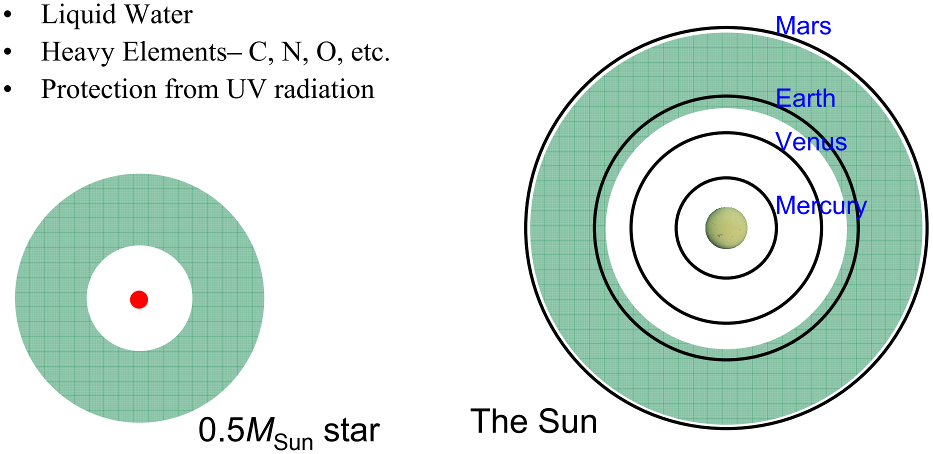
- What controls a planets temperature?
  - The amount of light received from its star.
  - The amount of energy the planet reflects back.
  - And any Greenhouse effects of the planet.
- Earth's greenhouse effect raises the temperature by about 15%.
- Given a star's luminosity, a range of acceptable temperatures 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.



http://www.solcomhouse.com/Greenhouse_Effect.gif

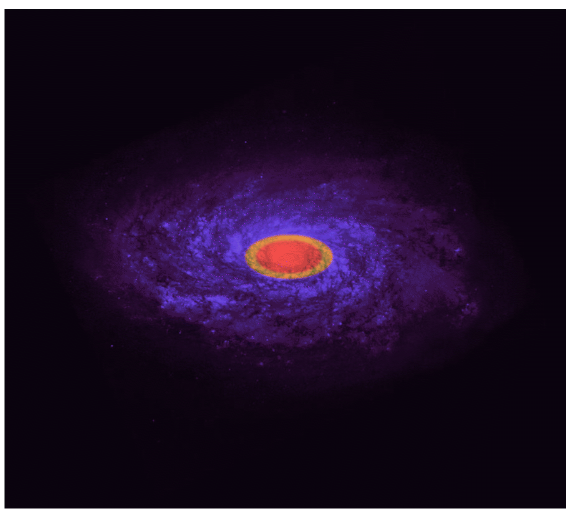
Habitable Zones– Are you in the Zone?

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



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 changed 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 planet negative-feedback mechanism (like a thermostat).
- CO_2 cycles from atmosphere (greenhouse gas) and oceans (buried sedimentary especially carbonate rock).
- CO_2 in atmosphere: temporarily dissolved CO_2 in rainfall reacts with weathered rocks.
- Carbon is buried and can be released by volcanoes.
- Negative feedback process
  - Increase in temperature: evaporation of oceans, more rainfall, more weathering and CO_2 reduction, so decrease in temperature.
  - This negative feedback stabilizes the Earth's temperature.

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

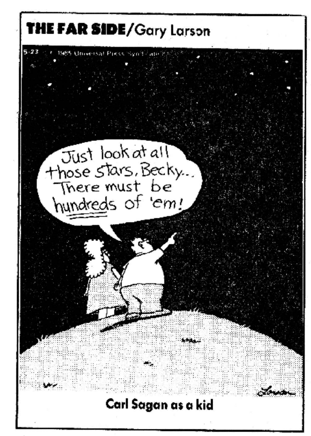
Life Adds to Feedback

- Life increases the weathering of rock.
- J.E. Lovelock has proposed that life also 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?



Carl Sagan as a kid

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

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.
  - 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

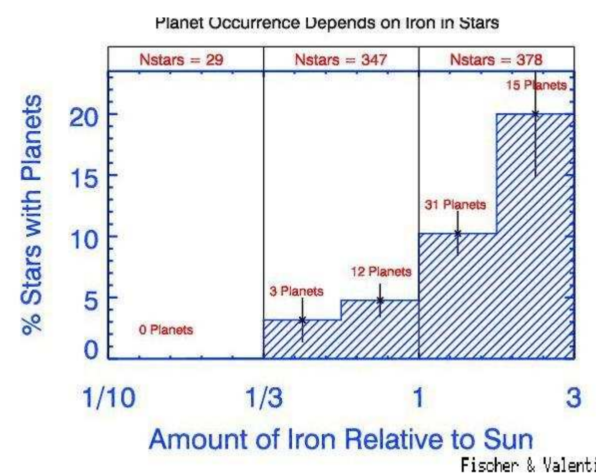
f_s: fraction of stars whose properties are suitable for life to develop on one of its planets

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

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

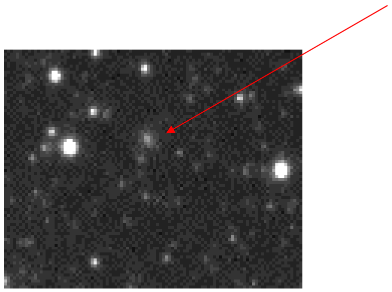
Differences of Stars to Life

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.

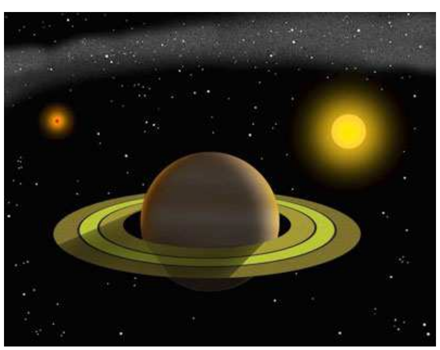


Differences of Stars to Life

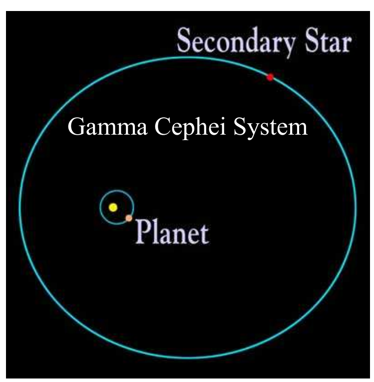
3. **Length of time on the main sequence**. We need temperature stability for 5 billion years to get intelligence on Earth. This rules out stars more massive than 1.25 solar masses! 90% of all stars are less massive than that.
4. **Minimum mass of star**. If ice exists close to the star, that would imply 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.

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

- 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

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

f_s: fraction of stars that life can exist around

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	

Value can range from ~ 0.06 to 0.2

Drake Equation

That's ? life liking systems/year

Frank Drake

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

N	R_*	f_p	n_e	f_l	f_i	f_c	L
# of advanced civilizations we can contact in our Galaxy today	Star formation rate	Fraction of stars with planets	# of Earthlike planets per system	Fraction on which life arises	Fraction that evolve intelligence	Fraction that commun-icate	Lifetime of advanced civilizations
	15 stars/ yr	0.5 systems/ star	planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.