ET: Astronomy 230
Section 1– MWF 1400-1450
134 Astronomy Building

This Class (Lecture 10):

Nature of Solar Systems

Next Class:

Habitable Planets

HW #2 is due today.

Presentations Sept 21
Carl Thomas
Hassan Bhayani
Aaron Bowling

Presentations Sept 26
Andrew Coughlin
Nicolas Jaramillo
Chris Fischetti

Music: *Parallel Universe* – Red Hot Chili Peppers

Outline

- Planet Searches: What to expect in the future.
- What is f_p?
- The formation of the Earth– atmosphere and oceans.

What Are We Looking For?
General Predictions of Solar Nebula Theory

☺ Are interstellar dust clouds common? ***Yes!***

☺ Do young stars have disks? ***Yes!***

? Are the smaller planets near the star?

Not the ones found so far! Haven't found smaller planets yet!

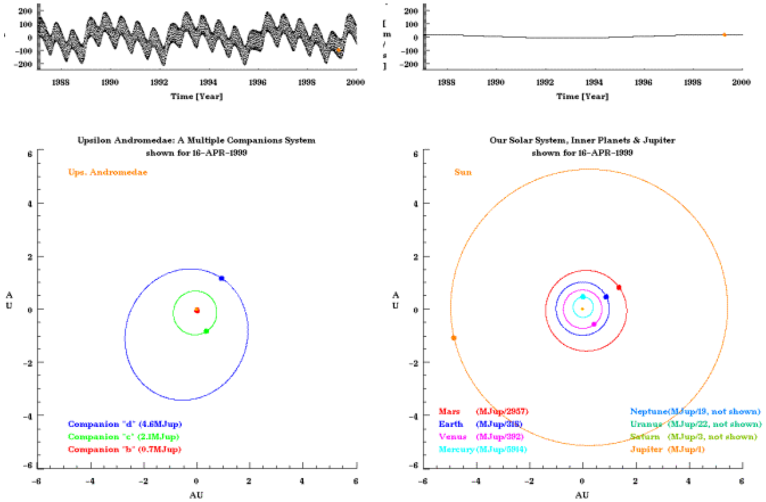
? Are massive planets farther away?

Not most of the ones found so far!

Important Caveat

- Our current observations of extrasolar planets do **not** exclude planetary systems like our solar system
- Current instruments are most sensitive to large planets close to their stars
  – Big planet - big wobble
  – Close planet - fast wobble
- We only have a little over 10 years of data – 1 orbit's worth for Jupiter
- To find solar-type systems, we need more sensitive equipment

Detecting the Solar System



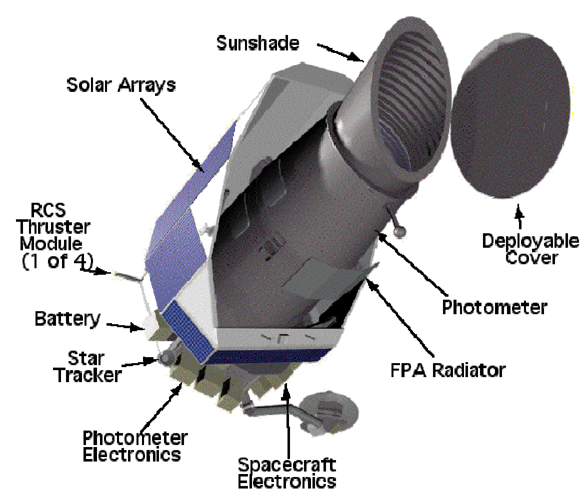
Future Projects

- Atacama Large Millimeter Array (ALMA): 2010
  - mm interferometer:
    direct detection of young gas giants
- Kepler: 2007
  - Planet Transits
- Next Generation Space Telescope
  James Webb Space Telescope (JWST): 2011
  - Direct imaging of forming gas giants?
- Space Interferometry Mission (SIM): 2009?
  - Astrometry
- Terrestrial Planet Finder (TPF): 2012?
  - Coronagraph
  - IR interferometer
- Terrestrial Planet Imager (TPI): 2015?
  - Either a visible band coronagraph or a large-baseline infrared interferometer. Imaging extrasolar Earths!!!!

Kepler

1.4 meter mirror, measuring accurate brightness of stars.

A terrestrial-sized Earth-like planet would dim the star's light by 1/10,000th – comparable to watching a gnat fly across the beam of a searchlight.

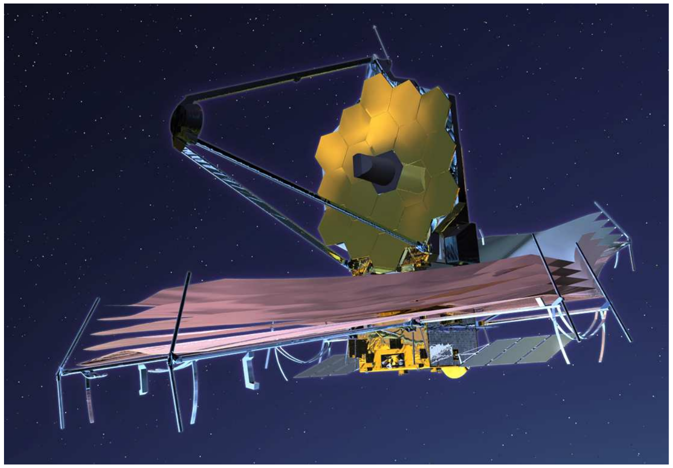


JWST

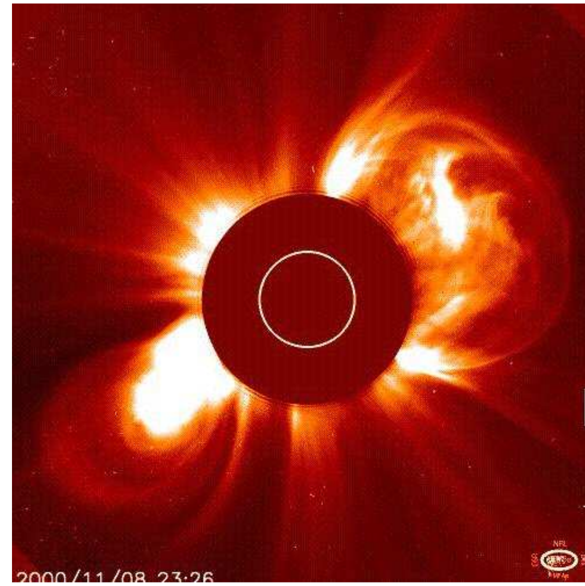
James Webb Space Telescope: Successor to HST

6.5 meter observatory

Working in the infrared with a coronagraph.



The Coronagraph Advantage



Space Interferometry Mission

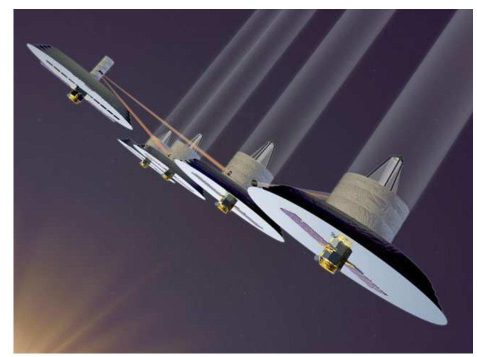
Accurately measure location of stars to micro-arcseconds.

Need to know relative location of components to 50 pm.

http://planetquest.jpl.nasa.gov/SIM/sim_index.html

Terrestrial Planet Finder Mission

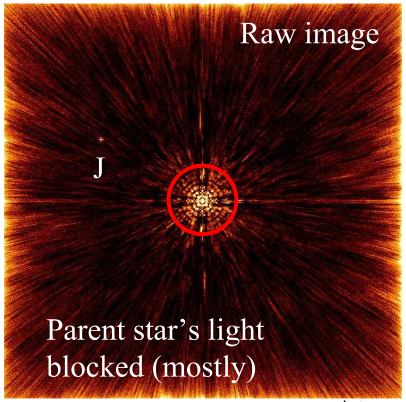
- Survey nearby stars looking for terrestrial-size planets in the "habitable zone”
- Follow up brightest candidates looking for atmospheric signatures, habitability, or life itself
- Launch is anticipated between 2012-2015

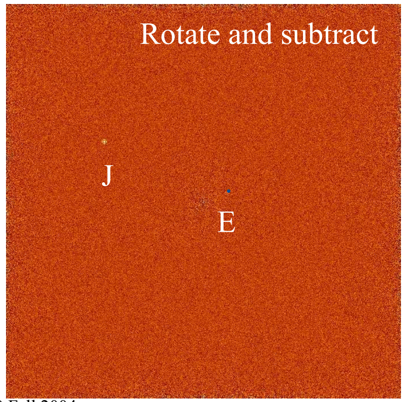


TPF

Visual wavelength `coronagraph'

- Find Earth-like planets
- Characterize their atmospheres, surfaces
- Search for bio-signatures of life (O_2, H_2O, etc)





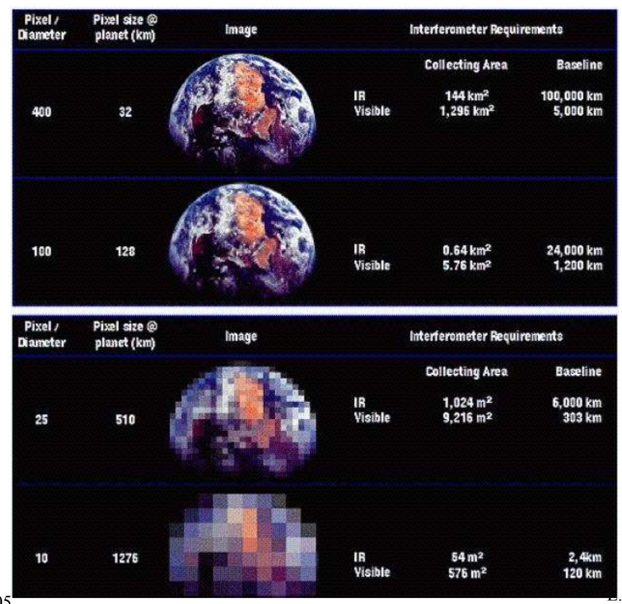
Terrestrial Planet Imager

The goal of imaging an Earth-like planet.

5 platforms of 4 eight meter interferometer in space.

http://spider.ipac.caltech.edu/staff/jarrett /talks/LiU/origins/openhouse30.html

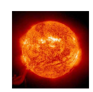
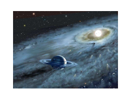
TPI -- Scales



Pixel / Diameter	Pixel size @ planet (km)	Image	Interferometer Requirements		
				Collecting Area	Baseline
400	32		IR Visible	144 km² 1,296 km²	100,000 km 5,000 km
100	128		IR Visible	0.64 km² 5.76 km²	24,000 km 1,200 km
Pixel / Diameter	**Pixel size @ planet (km)**	**Image**	**Interferometer Requirements**		
				Collecting Area	Baseline
25	510		IR Visible	1,024 m² 9,216 m²	6,000 km 303 km
10	1276		IR Visible	64 m² 576 m²	2,4km 120 km

Drake Equation

Frank Drake



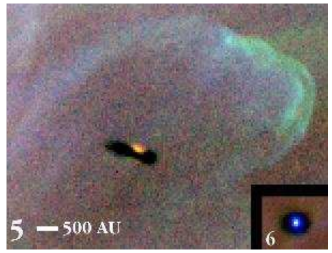

$$N = R_* \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

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

10

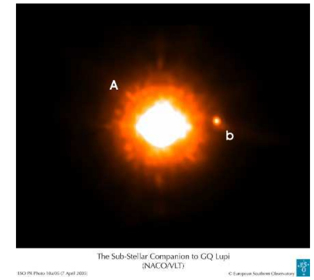
Now, for f_p

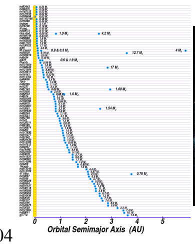
- About 2/3 of all stars are in multiple systems.
  - Is this good or bad?
- Disks around stars are very common, even most binary systems have them.
- Hard to think of a formation scenario without a disk at some point– single or binary system.
- Disk formation matches our solar system parameters.
- We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

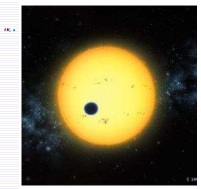


Now, for f_p

- 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 0.01.
- 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.
- <u>This is not Earth-like planets, just a planet or many planets.</u>







Earth-Moon Comparison

Radius	6378 km	Radius	0.272 Earth
Surface gravity	9.8 m/s^2	Surface gravity	0.17 Earth
Mass	6.0×10^{24} kg	Mass	0.012 Earth
Distance to Sun	1.5×10^8 km	Distance to Earth	384,000 km
Year	365.2422 days	Orbital Period	27.3 days
Solar day	1 day	Solar day	27.3 days

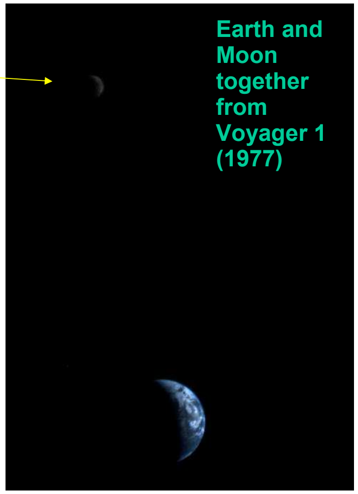
Formation of the Earth

- Focus on the formation of the Earth, including its atmosphere and oceans.
- Earth formed from planetesimals from the circumstellar disk.
- Was hot and melted together.
- The biggest peculiarity, compared to the other planets, is the large moon.

A Double World

Why a “double world”?

- Most moons are tiny compared to the planet
  - The Moon is over 25% the diameter of Earth
  - Jupiter's biggest moons are about 3% the size of the planet
- The Moon is comparable to the terrestrial planets
  - About 70% the size of Mercury
  - Nearly the same density as Mars



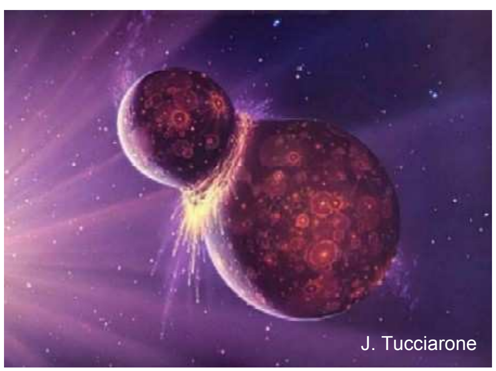
The Moon

The Moon's surface is barren and dead

- No water, no air
- No life!

Formation of the Moon: Smack

- Collision of Earth with a Mars-sized body early in the solar system’s history
- Iron-rich core of the impactor sank within Earth
- Earth’s rotation sped up
- Remaining ejecta thrown into orbit, coalesced into the Moon



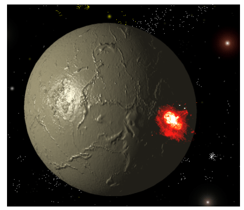
Why is this a good hypothesis?

- The Earth has a large iron core (differentiation), but the moon does not.
  - The debris blown out of collision came from the rocky mantles
  - The iron core of the impactor merged with the iron core of Earth
- 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

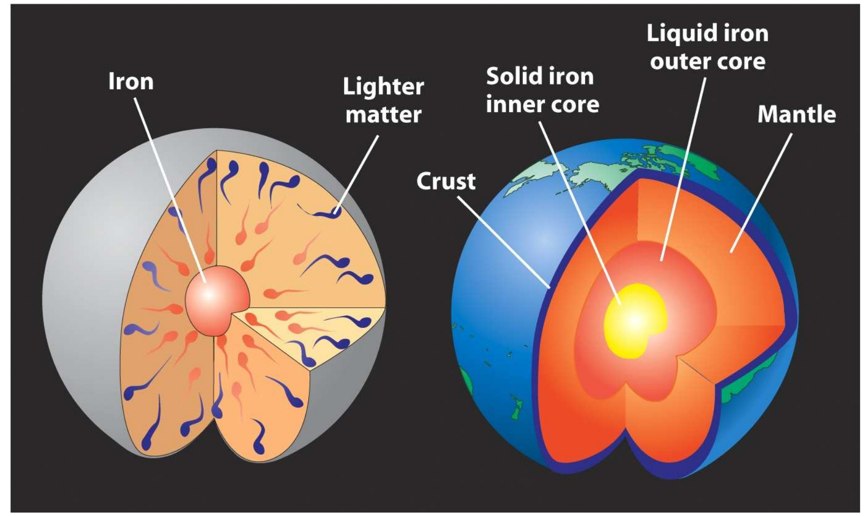
Implications

- **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 went through a period of differentiation.



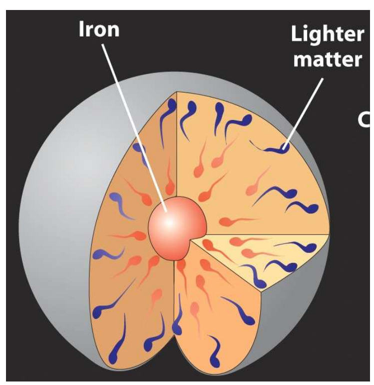
http://www.udel.edu/Biology/Wags/wagart/worldspage/impact.gif

Planetary Differentiation



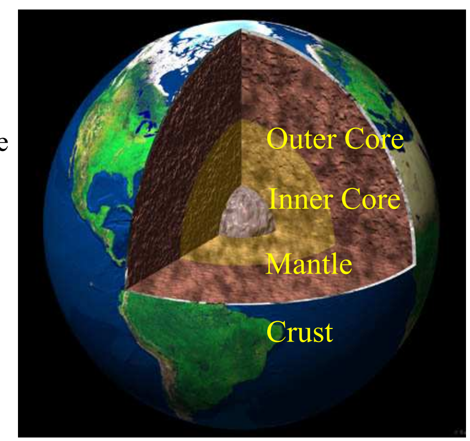
Differentiation

- Average density of Earth is 5.5 g/cm^3
- Average density on the surface is 3 g/cm^3
- So, something heavy must be inside
- When the Earth formed it was molten
  - Heavy materials (e.g. iron, nickel, gold) sank
  - Lighter materials (e.g. silicon, oxygen) floated to the top



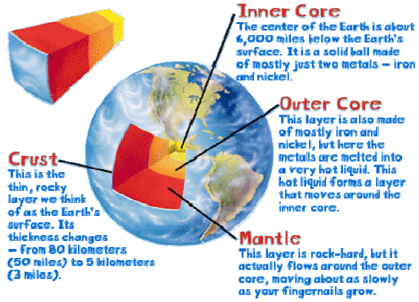
Structure

- 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.
  - Heated by radioactive decay
  - Supernovae remnants



Inner Core

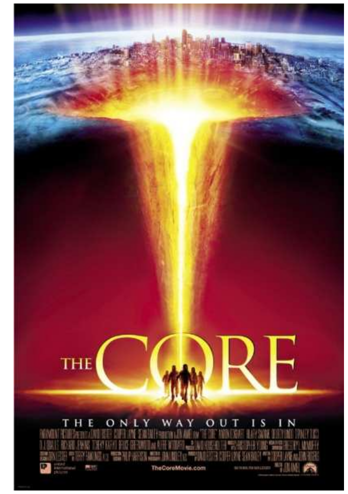
- Reaches very high temperatures– 5000 K (Close to the temperature at the surface of the Sun)!
- But still the high pressure makes the inner core a solid
  - Solid inner core – 1200 km radius
- Mostly made of iron (Fe) and nickel (Ni)



http://ology.amnh.org/earth/stufftodo/images/ediblelayers.gif

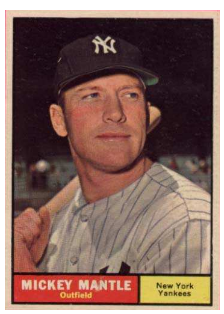
Outer Core

- The liquid layer of the Earth, high pressure but not enough to solidify
  - Liquid outer core – 2200 km radius
- Mostly Fe and Ni.
- Made of very hot molten liquid that floats and flows around the solid inner core– creates the Earth's magnetic field.



The Mantle

- Largest layer of the Earth
  - To a depth of 2900 km
  - Temperature increases with depth
  - Made of heavy silicates
- Parts of the mantle are hot enough to have an oozing, plastic flow
  - Sort of like Silly Putty
  - Currents in the mantle cause plate tectonics
  - Hot spots in the mantle can become plumes of magma (e.g., the Hawaiian Islands)



http://www.martyspsagradedcards.com/61mm.jpg

The Crust

- Outside layer of the Earth (includes oceans) that floats on top
  - About 50 km thick
  - Coldest layer – rocks are rigid
- Mostly silicate rocks
  - Made of lighter elements like silicon, oxygen, and aluminum
- Oxygen and water are abundant
- Excellent insulator
  - Keeps the Earth's geothermal heat inside!

Earth's Surface

- 70% of the Earth's surface is covered with water
  - Ocean basins
  - Sea floors are young, none more than 200 million years old
- 30% is dry land – Continents
  - Mixture of young rocks and old rocks
  - Up to 4.2 billion years old

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 comets impacted that 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 ($CaCO_3$).

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.

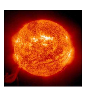
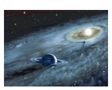
http://www.uweb.ucsb.edu/~rixfury/conclusion.htm

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?).
- 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

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

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	?					

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

$$n_e = n_p \times f_s$$

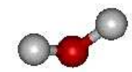
http://nike.cecs.csulb.edu/~kjlivio/Wallpapers/Planets%2001.jpg

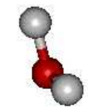
Water

- 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

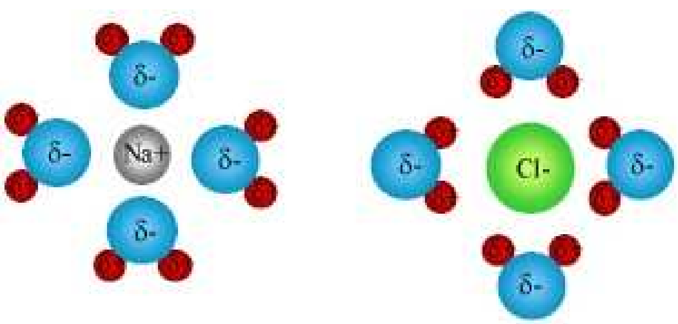
- The water molecule is “polar”. The oxygen atoms have more build-up of negative charge than the hydrogen. This allows water molecules to link up, attracted to each other.
- In this way, water attracts other molecules, surrounds them and effectively dissolves them into solution.





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 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.