# Astronomy 330

<u>This class (Lecture 10):</u>

Our Planet

<u>Next Class:</u>

Other Planets

**HW 4 is due Sunday!**

**Exam 1 on Thursday!**

Music: $3^{rd}$ *Planet* – Modest Mouse



# Exam 1

- 40 MC questions in this classroom next week.
- You can bring 1 sheet of paper with notes
- Will cover material up to and including today's lecture.
- Major resources are in-class questions and homework, the book and reading is supplemental (won't be directly on exam).

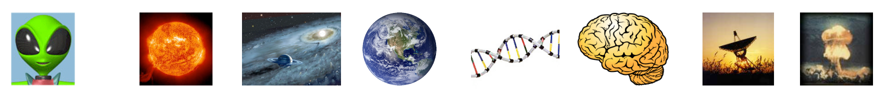
# Outline

- $n_e$
- What's up with the Earth?
- What do we need for a life-suitable planet?

# Drake Equation

Frank Drake

**That's 2.4 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 |
| | 20 stars/ yr | 0.12 systems/ star | planets/ system | life/ planet | intel./ life | comm./ intel. | yrs/ comm. |

## $n_e$

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

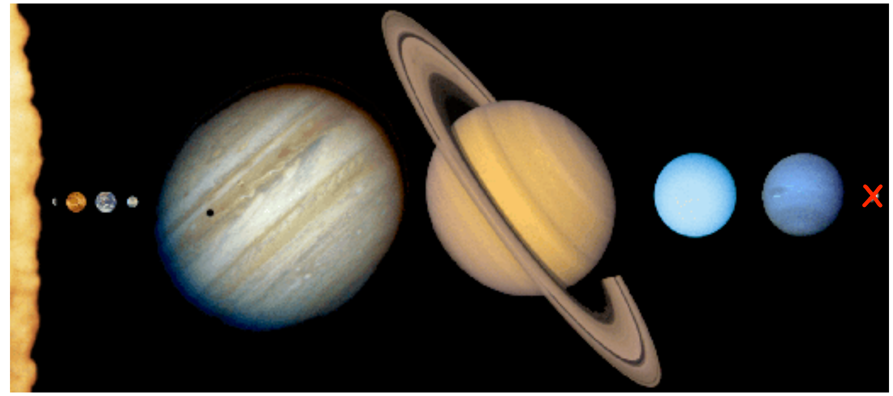
- $n_p$: number of planets suitable for life per planetary system
- $f_s$: fraction of stars whose properties are suitable for life to develop on one of its planets

$$n_e = n_p \times f_s$$

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

## Our Solar System

Terrestrial planets and Gas Giants… but how many are valid planets/moons for $n_p$?



## Earth-Moon Comparison

| | | | |
|---|---|---|---|
| Radius | 6378 km | Radius | 0.272 Earth |
| Surface gravity | 9.8 $m/s^2$ | Surface gravity | 0.17 Earth |
| Mass | $6.0 \times 10^{24}$ kg | Mass | 0.012 Earth |
| Distance to Sun | $1.5 \times 10^{8}$ 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 |

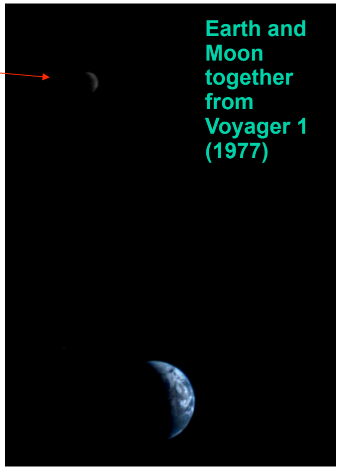
## Formation of the Earth

- Earth formed from planetesimals in 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



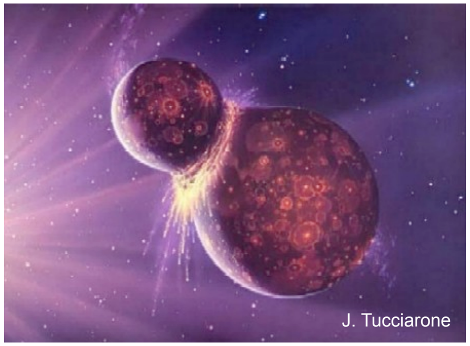

# The Moon

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

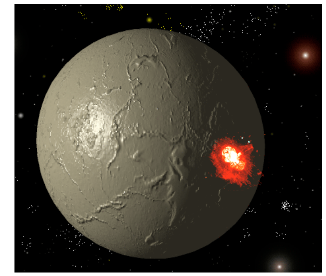
# Moon Life?

- Some think that our large Moon is very important for life on Earth.
  - Tides! Important to move water in and out of pools.
  - Stable Axial Tilt: 23.5 deg offset from the collision
  - Metals! Heavy elements at Earth's surface may be from core of impactor.

http://www.michaelbach.de/ot/sze_moon/index.html

# 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

# Early Earth

- No atmosphere
- No water
- High temp
- No life…….
- Big rocks keep falling on my head…

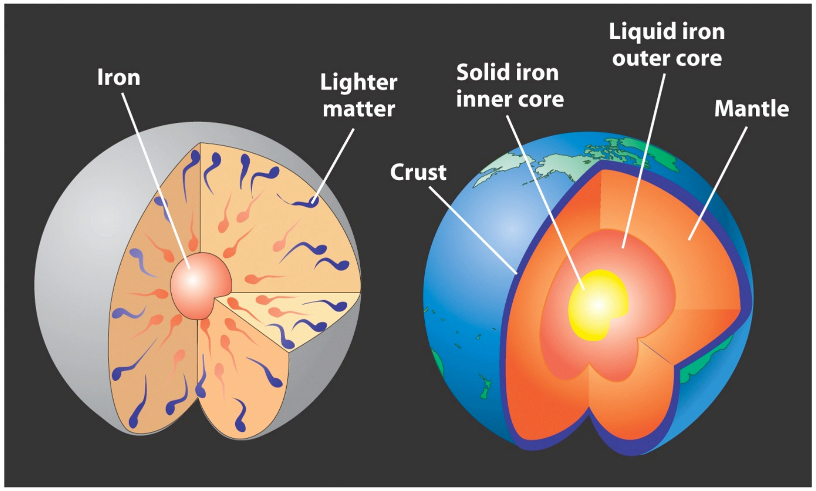
http://www.black-cat-studios.com/catalog/earth.html

# Question

Which of the following does NOT well describe the early Earth?

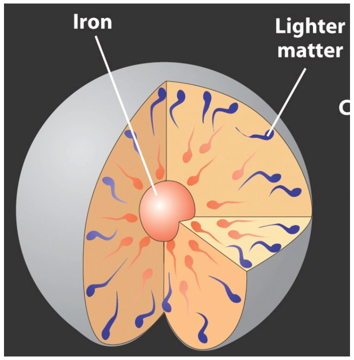
a) So hot that the surface had molten rock.
b) There was no water.
c) The surface kept getting hit by really, really big rocks.
d) The oxygen rich atmosphere caused quick oxidation (rusting) of iron-rich rocks
e) No chance of life at this stage.

## *Planetary Differentiation*



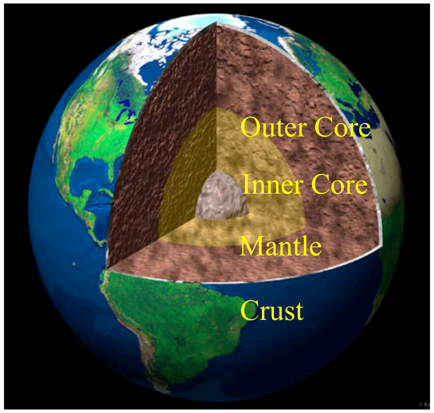

## Differentiation: Iron Catastrophe

- 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.
- Temperature increases as you go deeper underground. From around 290 K on surface to nearly 5000 K at center.
  - Heated by radioactive decay
  - Supernovae remnants
- Earth's magnetic field is established early on.. after the iron catastrophe… good for life.




## The Crust

- Outside layer of the Earth (includes oceans) floats on top of still hot interior
  - 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!

# Today's Earth Surface

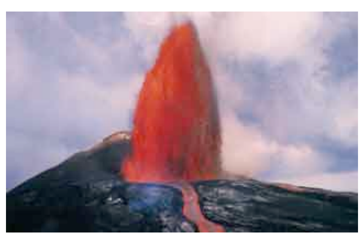
- 70% of the Earth's surface is covered with water
  - Ocean basins
  - Sea floors are young, none more than 200 million years old
- 30% is dry land – Continents
  - Mixture of young rocks and old rocks
  - Up to 4.2 billion years old

# 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*

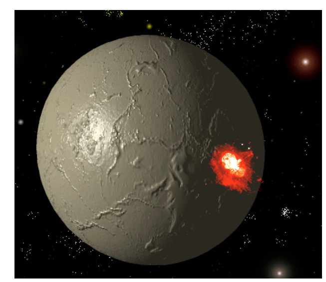
- From gravity and radioactivity, the core stays hot.
- This allows a persisting circulation of bioelements through continental drift— melting of the crust and re-release through volcanoes.
- Otherwise, certain elements might get locked into sediment layers– e.g. early sea life.
- Maybe planets being 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 inner disk had most gases blown away and the proto-Earth was not massive enough to capture these gases.
- Any impacts (e.g. the moon), would have blown any residual atmosphere away.
- The first atmosphere was probably H and He, which was lost quickly.



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

# *The Earth's 1st Atmosphere*

- The interior heat of the Earth helped with the Earth's early atmosphere.
- Volcanoes released gases (water vapor and $CO_2$)
- Another scenario is that impacted comets released – water ($H_2O$), carbon dioxide ($CO_2$), and Nitrogen ($N_2$) – the first true 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

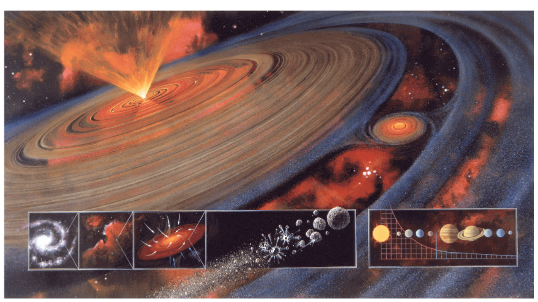
# *Our Atmosphere*

- Rocks with ages greater than **2 billion** years show that there was little or 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?).

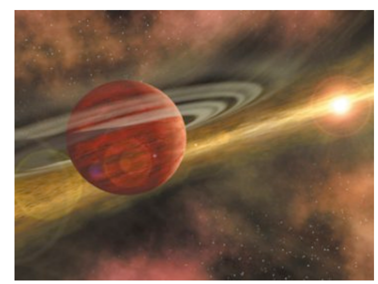


http://www.agnld.uni-potsdam.de/~frank/Images/painting.gif

# *This New Planet*

- Impacts and volcanic activity created the continental landmasses.
- Little oxygen means no ozone layer– flooded with ultraviolet light on surface.
- Along with lightning, radioactivity, and geothermal heat, provided energy for chemical reactions.

- **BUT, life on the surface not possible!**



# Question

The Earth's first atmosphere was

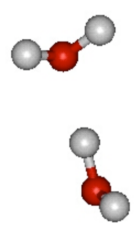
a) much like today's atmosphere, but older.
b) Trick Question. There was no atmosphere.
c) likely just H and He, and blown away quickly.
d) made from comets.
e) made from bacteria.

# *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.

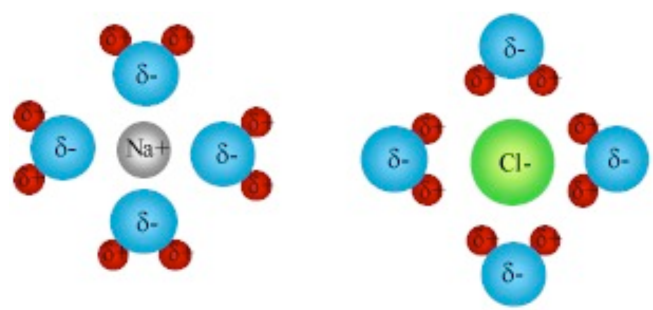
# *Water as a Solvent*

- 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*

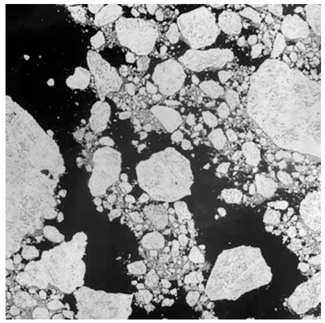
The partial charges of the water molecule are attracted to the $Na^{+}$ and $Cl^{-}$ ions. The water molecules work their way into the crystal structure and between the individual ions, surrounding them and slowly dissolving the salt.




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.



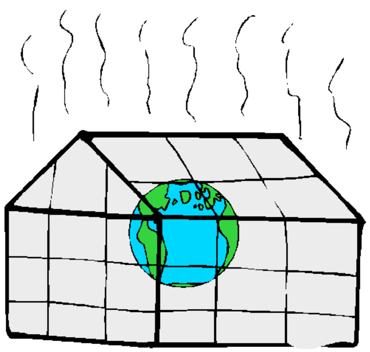
## *Keeping it Useful: Atmosphere*

- 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

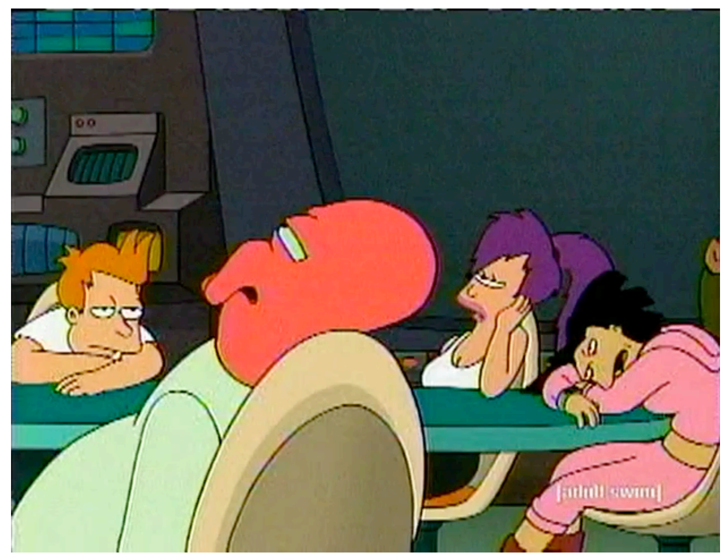
## *Keeping It Warm, but not too Warm*

- What controls a planet's temperature?
  - The amount of light received from its star.
  - The amount of energy the planet reflects back.
  - And any Greenhouse effects of the planet.

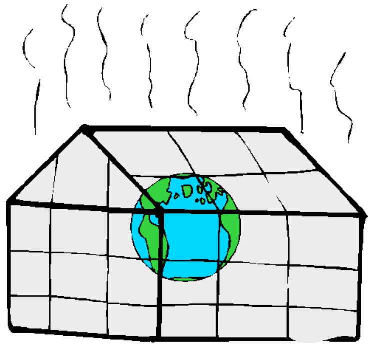


http://www.solcomhouse.com/Greenhouse_Effect.gif

## Greenhouse Explained



## *Keeping It Warm, but not too Warm*

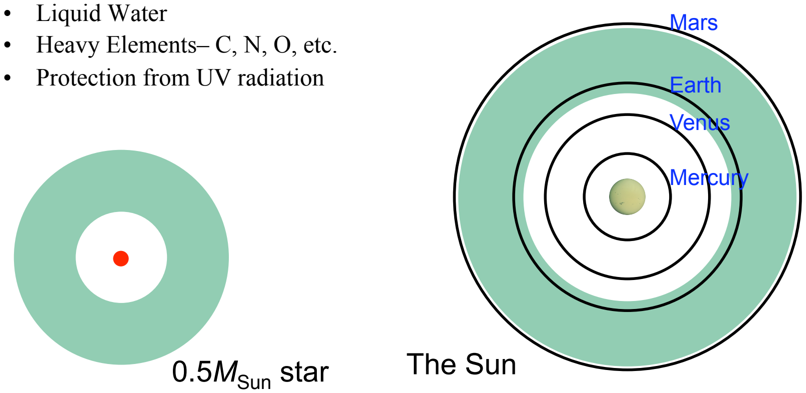


- Earth's greenhouse effect raises the temperature by about 15%.
- Given a star's luminosity, a range of acceptable temperatures translates into a range of distances to the star.
- This range is called the star's habitable zone (HZ), as planets in this range have temperatures suited for life.
- Only a rough guideline.

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

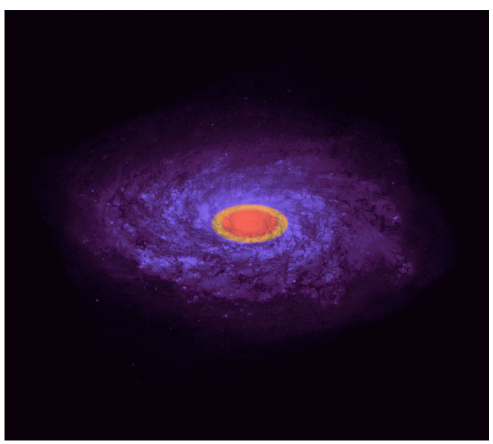
## *Habitable Zones– Are you in the Zone?*

- 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.



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

# Question

The Greenhouse effect

a) will destroy our planet.
b) will hopefully stop this crazy winter.
c) keeps the Earth warmer than it would be otherwise at its distance from the Sun.
d) is all Man-Made.
e) keeps the Earth colder than it would be otherwise at its distance from the Sun.

# 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:
## Trapping $CO_2$ for Fun and Profit

- Most recent studies suggest an efficient planet negative-feedback mechanism (like a thermostat).
  - $CO_2$ cycles from atmosphere (greenhouse gas) and oceans (buried sediment especially carbonate rock).
  - $CO_2$ in atmosphere: temporarily dissolved $CO_2$ in rainfall reacts with weathered rocks, trapping it.
- 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.

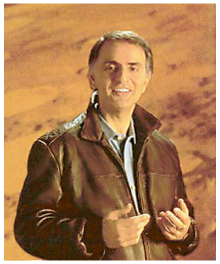

http://www.wildtech.org/images/feedback.gif

# 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?

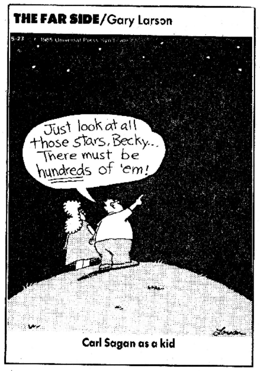

While testing out his new cereal mix on his horse, Dave gets some unexpected feed-back.

# 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?

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.