Astronomy 330

This class (Lecture 14):

Origin of Life

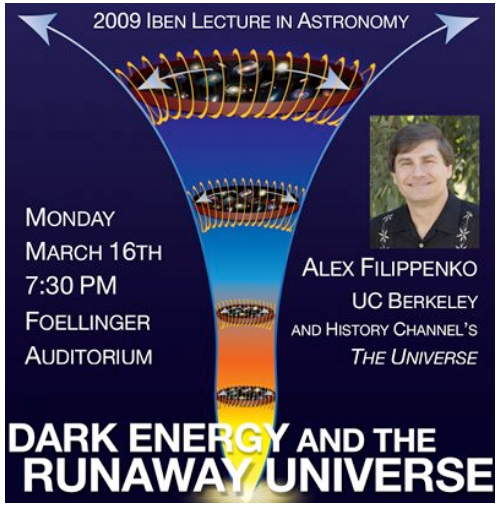
Next Class:

Life in the Solar System

Music: *For Science* – They Might Be Giants

Extra Credit?

0.5 % added to final grade for attending (and writing a short report) on Alex's talk on the 16th.



Outline

- Life on Earth
  - Transition to life.
- Life in our Solar System?

Drake Equation

That's 0.36 Life-liking systems/year

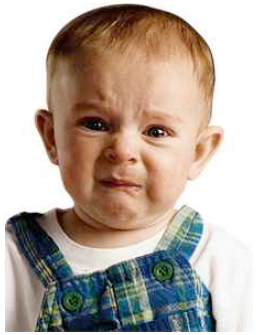
Frank Drake

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

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
	20 stars/ yr	0.12 systems/ star	1.25 x 0.12 = 0.15 planets/ system	life/ planet	intel./ life	comm./ intel.	yrs/ comm.

Life

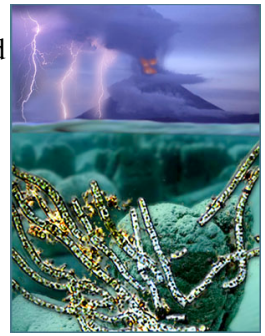
- Life is based on cells
  - Protective enclosures formed from lipids
- Cells contain nucleic acids and protein enzymes
  - Instructions and catalysts that allow replication of nucleic acids
- Methods for acquiring energy
  - **Most** organism now on Earth get energy from the Sun– either directly or indirectly. But that requires pigments (e.g. chlorophyll).
  - Not sure if pigments are a primary need or if chemical sources of energy were used for early life.



http://www.internetcash.com/en/images/baby-crying.jpg

Transition to Life

- **Two possibilities**
  - Primitive versions of proteins, nucleic acids, and protocells arose independently and combined to form a life form, called **primitive life**.
  - One of the components was dominant and the first "life" was based on only one polymer, then developed into life as we know it. We can call it **protolife**.
- The statistical argument would argue **against** primitive life and **for** protolife.



http://www.lbl.gov/Science-Articles/Archive/sb/July-2004/2_spinach.html

Transition to Life?

- Really the big question.
- How difficult is it for a collection of polymers to become life?
- The last step in chemical evolution is really biological evolution.

Protolife

If we assume that early life must have been protolife, then

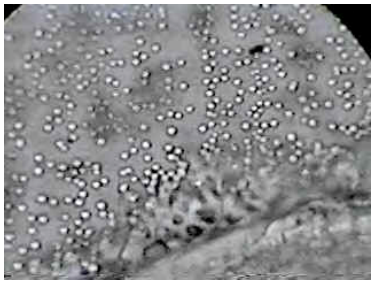
- Two protolife concepts based on nucleic acids or proteins.

1. Protein life
2. RNA life

http://www.perantivirus.com/sosvirus/graficos/bilgates.jpg

1. Protein Protolife

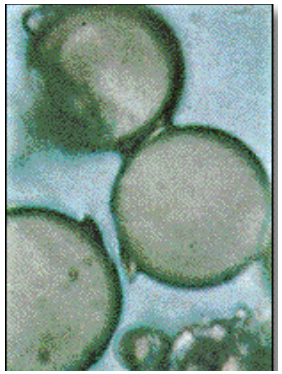
- Sydney Fox heated amino acids, droplets of protein formed when added to water– "proteinoids"
- Could have formed on the early Earth with tides.



http://leiwenwu.tripod.com/primordials.htm

1. Protein Protolife

- Sometimes they will grow and break into daughter spheres
- It is like cell reproduction, BUT there is no replication of nucleic acids, so not true reproduction.
- Nonetheless, they might be suitable for protocells.



http://www.biology.iupui.edu/biocourses/N100H/ch19life.html

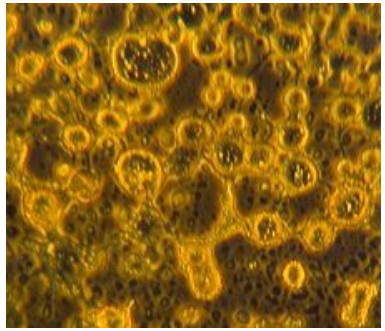
1. Protocells

- If so, how do nucleic acids come into play?
- Perhaps one proteinoid developed the capability to make its own protein from amino acids, then passed that on to its "offspring".
- Then, nucleic acids might have been used to store the amino acid information.

http://vcl.ctrl-c.liu.se/vcl/Artists/Juan-Crespo/Sydney-Fox-Lz.jpg

1. Protocells

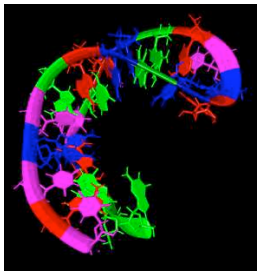
- And only later took over– revolt of the bookkeepers!
- Most biologist do not like the idea, as life without nucleic acid is hard to accept.



http://www.firstscience.com/home/articles/origins/genesis-by-comets-page-3-1_1383.html

2. The RNA World: Protolife

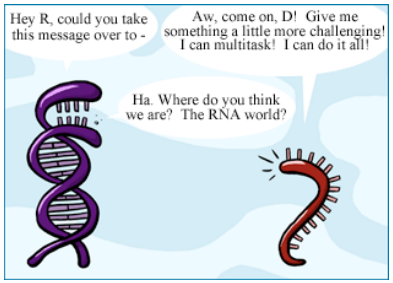
- The other camp believes that the transition to life was dominated by nucleic acids; the opposite problems of the Sydney Fox scenario.
- These genes are naked!
- A ecosystem of self-replicating RNA is nice, but without capability for protein synthesis, they could do little else.
- However, it's the most widely accepted concept due to numerous experiments.



http://www.bizspacebiotechnology.com/rna1.htm

2. The RNA World: Protolife

- The basic idea is that RNA did all the tasks.
- Both info storage and enzyme actions.
- Then, the DNA world evolved out of that.
- The rRNA encoding of proteins in today's world may be evolutionary left-overs.



http://evolution.berkeley.edu/evolibrary/images/interviews/rnaworld2.gif

2. RNA World

- RNA is mutating away– eventually one RNA develops an enzyme function.
- This evolves to fill many of the niches that today's enzymes perform.
- At some point, the RNA encode and produce proteins through amino acid encoding, using one of the RNA enzyme functions.
- This would make better enzymes, which would replace the RNA versions.
- Is this possible?

2. RNA World: Experiments

- Virus RNA is added to a test tube with replicase (an enzyme that catalyzes the synthesis of a complementary RNA molecule from an RNA template) and some activated nucleosides.
- The RNA was replicated without cell mechanisms.
- In one experiment, no RNA was added, and still RNA was produced.
- In fact, a number of variants were produced.
- The variant that replicated the fastest might win out.

2. RNA World: Variations

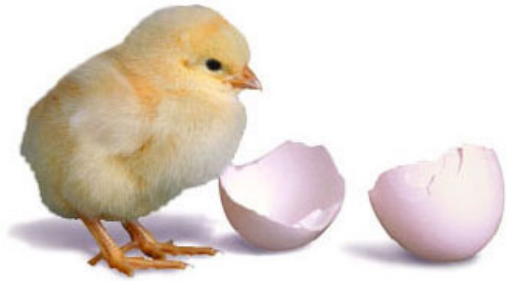
- Some think that RNA might not have been the first nucleic acid.
- On pre-biotic Earth maybe other nucleic acids were more easily formed at first.
- Some other nucleic acids include Peptide nucleic acid (PNA), Threose nucleic acid (TNA) or Glycerol nucleic acid (GNA).
- These would have been replaced with RNA later.

Genetic Code and Origin of Translation

- One of the essential aspects of life is the synergistic interaction between proteins and nucleic acids– still the Chicken and egg problem.
- If protein-like polymers of amino acids formed, they would have to polymerize (create) the nucleotides.
  - The resulting nucleic acid would have to direct the synthesis of more protein, leading to more of the nucleic acid. Etc.
- Or in some RNA world ribozymes (RNA enzymes) began to construct the proteins– the favored view.

Neither Chicken nor Egg?

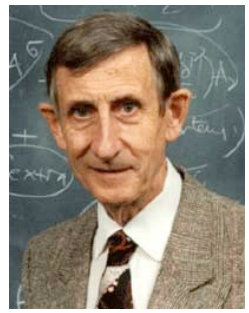
- While RNA world is favored, the difficulty is still in producing the nucleic acids on the early Earth.
- Freeman Dyson had argued that nucleic acid can not have been the first information carrying molecule.



http://www.antivegan.de/kochkurs/chicken-wings/chicken_egg2.jpg

Neither Chicken nor Egg?

- Transition between living and non-living requires a balance between order-preserving replication and error in replication.
- If too precise, nothing evolves.
- If too many errors, nothing consistent forms.
- He argues that RNA is not the easiest to start with, perhaps there were other polymers that preceded nucleic acids.



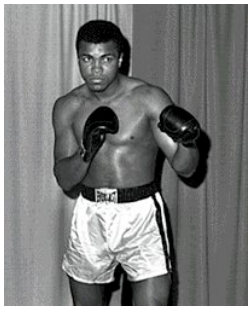
http://www.dartmouth.edu/~lhc/archive/sponsored/dyson.html

Alternatives: Clay

- Spontaneous life from non-living matter — abiogenesis
- Clay based genetic systems.
  - Layers of impurities in clay can produce patterns.
  - The layers can separate, settle elsewhere, and grow.
  - The patterns are not perfectly copied.
  - In 2007, researchers concluded that the crystals were not faithful enough to transmit info from one generation to the next.

Alternatives: Clay

- Would not have been a big deal, BUT clays can capture and help polymerize amino acids.
- Maybe there was clay based life?
- Eventually the proteins make nucleic acids, which then provides a parallel genetic system that disregards the clay.
- Bottom line is that the step from molecules to life is so great that we are far from understanding it.

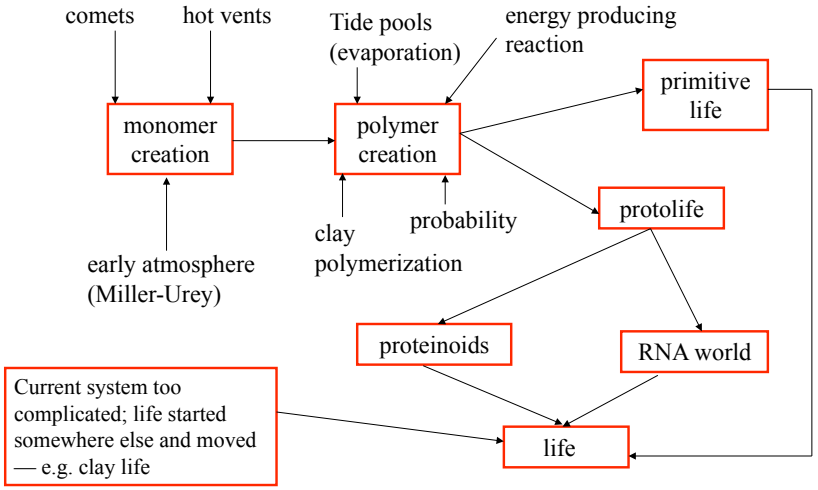


Question

We think the most likely path for life was

a) Life just arose with nucleic acid and proteins working together.
b) Life first started as a nucleic acid (RNA world).
c) Life first started as a nucleic acid (DNA world).
d) Life first started as a protein world.
e) Life first started as an amino acid world.

Pathways to Life on Earth



Exotic Life

- We have spent a long time with Earth Chauvinism, but ET life would be very different?
  Probably very alien!
- If other options are possible, then that gives a more optimistic value of f_l.
- As we just discussed, there are options for life based on other molecules than amino acids, some have been shown to sort of work in the lab.

http://www.itg.uiuc.edu/people/mcdowell/puppet-gallery/

Silicon Based Life?

- Silicon makes 4 bonds like Carbon
- It is 135 times more abundant than carbon on Earth.
- But there are 4 arguments against it:
  - C-C bonds are twice as strong as Si-Si
  - Si-O or Si-H is stronger than Si-Si, so harder to make long stands
  - Si does not usually make multiple Si bonds
  - C with O makes CO_2, but Si with O makes silicates (SiO_2), which are large solid crystals.
- Still it is a possibility that can not be ruled out.

http://www.decipher.com/startrek/cardlists/mirrormirror/images/horta.gif
http://soundwavs.trekkieguy.com/25.html

Other Solvents

Molecule	*Freezes (K)*	*Boils (K)*
Water (H_2O)	273	373
Ammonia (NH_3)	195	240
Methyl alcohol (CH_3OH)	179	338
Methane (CH_4)	91	109
Ethane (C_2H_6)	90	184

Water is about twice as good as ammonia or methyl alcohol. Water also has a high energy of vaporization, so it is very good at evaporative cooling (sweat).

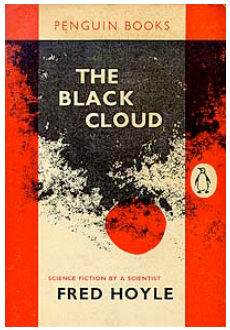
http://www.talisman-activities.co.uk/winter/images/ice%20climbing.jpg
http://web.media.mit.edu/~fletcher/tags/boiling.jpg

Non-Chemical Life

Life is based on chemical energy. Thinking is an electrochemical activity. What about a life form that uses electromagnetic energy instead, perhaps without a body.

The Black Cloud (1957) by Fred Hoyle

The story describes a small interstellar molecule cloud that is alive. The organism is half a billion years old, as big as the orbit of Venus, and as massive as Jupiter. The brain is a complex network of molecules. Once it discovers the Earth it communicates with us:



The Black Cloud Speaks

Paraphrased "badly"

- It is most unusual to find animals with technical skills inhabiting planets
- Living on a planet, greatly limits your size, thus the scope of your neurological activity.
- Living on a planet, forces you to possess muscular structures to promote movements.
- Your very largest animals have been mostly bone and muscle with very little brain.
- One only expects intelligent life to exist in a diffuse gaseous medium. At the moment, I myself am building basic chemicals at about 10,000,000,000 times the rate as your whole planet.

Cloud Problems

- How would such a cloud evolve?
- The most dense clouds are 10^{13} times less dense than our atmosphere, which makes molecule interactions very rare.
- In space, interstellar clouds are torn apart in about 10^{7} years. It took 10^{9} years for intelligent life to form on Earth.
- Still it is a cute idea.

Other Voices, Other Energies

- Life based on nuclear energy (put forward by Drake)
  - Life on the surface of a neutron star?
  - Gravity and temperature too high for normal life.
  - Life made of closely packed nuclear matter instead of molecules
  - They interact quickly 10^{-21} seconds, much faster than chemical reactions.
- It has been fictionalized by Robert Forward in *Dragon's Egg*
  - Talking to these beings would be difficult.
  - Their Biology uses the strong nuclear force.
  - A time difference of a million to one.
  - In the time it takes to say "Hello" - would be the equivalent of a week to a star creature. It would hear "He . . . " on Sunday and ". . . lo" on the following Saturday.

Or Too Big

- Life based on gravitational energy?
- In this creature, the gravity force would dominate– very large!
- The monomer of life would have to be a star.
- Perhaps individual stars play the role of individual atoms or molecules in Earth life.

Or Too Big

- Could galaxies be alive?
- Stars interact with one another on a time scale of many millions of years, so if life is to originate from such interactions it would take longer than the age of the Universe.
- If life is occurring, it is only at the stage where life was when the Earth was a few years old.

http://www.astro.cz/cz/wallpapers/index.php?id=15

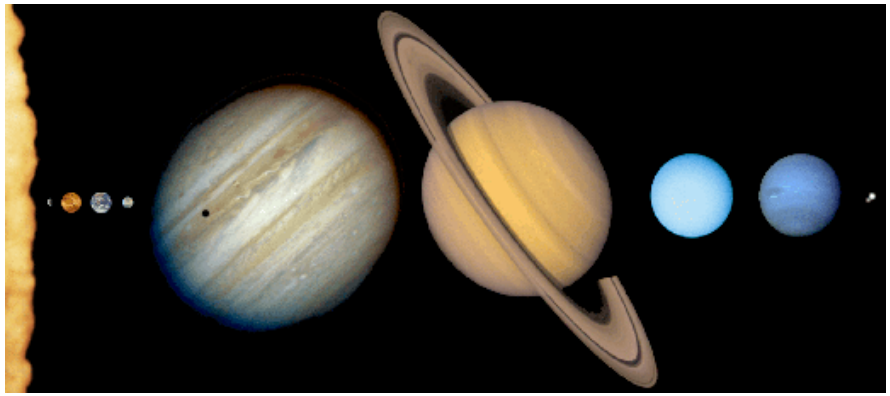
Question

Which is not a way that life's monomers might have formed on Earth?

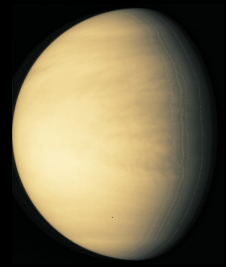
a) Hot vents at the bottom of the ocean.
b) In a clay substrate.
c) In the oceans, using energy sources and the early atmosphere of Earth (assuming reducing atmosphere).
d) From comets landing on Earth.
e) Debris from the early circumstellar disk (which had a reducing atmosphere).

Life in the Solar System?

- We want to examine in more detail the backyard of humans.
- What we find may change our estimates of f_l.



Earth – Venus comparison



Venus is the hottest planet, the closest in size to Earth, the closest in distance to Earth, and the planet with the longest day.

Radius	0.95 Earth
Surface gravity	0.91 Earth
Mass	0.81 Earth
Distance from Sun	0.72 AU
Average Temp	475 C
Year	224.7 Earth days
Length of Day	116.8 Earth d
Atmosphere	96% CO_2

What We Used to Think

Venus must be hotter, as it is closer the Sun, but the cloud cover must reflect back a large amount of the heat.

In 1918, a Swedish chemist and Nobel laureate concluded:

- Everything on Venus is dripping wet.
- Most of the surface is no doubt covered with swamps.
- The constantly uniform climatic conditions result in an entire absence of adaptation to changing exterior conditions.
- Only low forms of life are therefore represented, mostly no doubt, belonging to the vegetable kingdom; and the organisms are nearly of the same kind all over the planet.

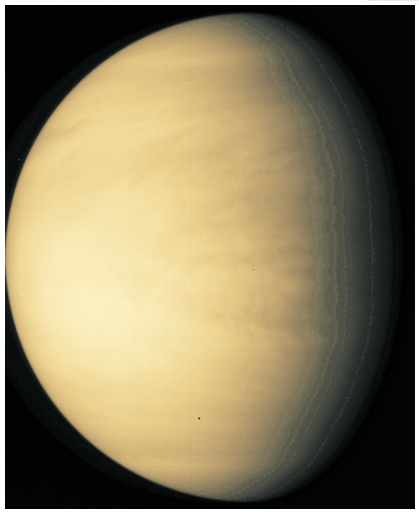
http://www.daviddarling.info/encyclopedia/V/Venuslife.html

Turns Out that Venus is Hell

- The surface is hot enough to melt lead
- There is a runaway greenhouse effect
- There is almost no water
- There is sulfuric acid rain
- Not a place to visit for Spring Break.

Our "Twin"

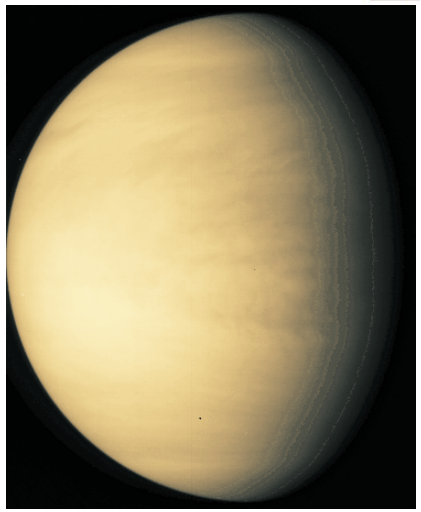
- Always covered in thick clouds of CO_2, which make it the hottest planet in the Solar System.
- Pressure on surface is 90 times that on Earth– like 1 km under the sea



http://antwrp.gsfc.nasa.gov/apod/ap960923.html

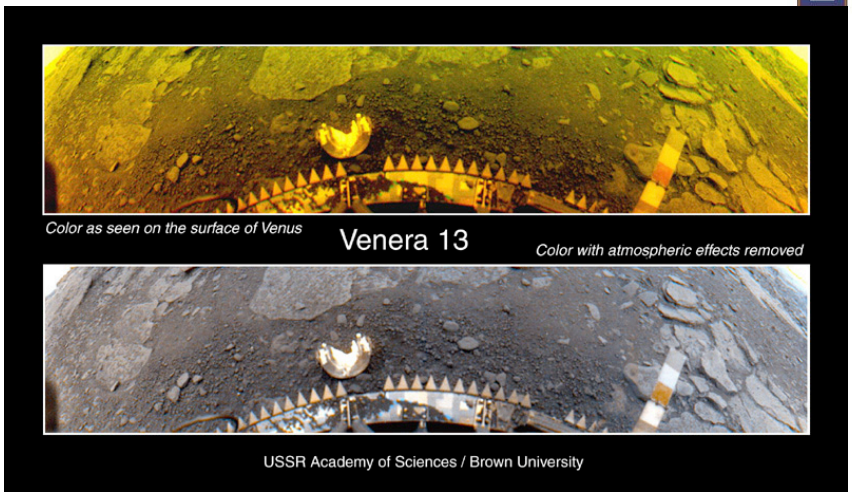
Our "Twin"

- Often called the morning star or the evening star. 3rd brightest object in the sky.
- Often mistaken for a UFO.
- Retrograde rotation – Sun rises in west
- No moons, no magnetic field



http://antwrp.gsfc.nasa.gov/apod/ap960923.html

Soviet Satellites on Venus

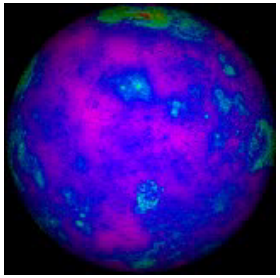


Mostly Basalts-like rocks, indicative of volcanoes

The Venusian Surface Revealed

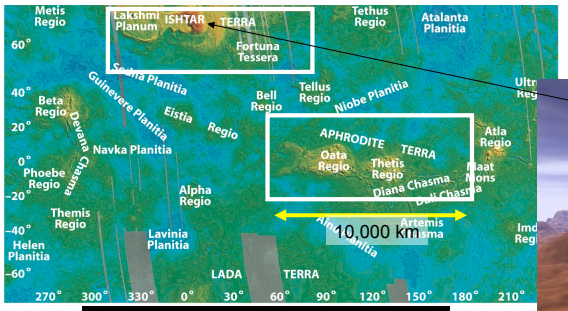
- We can't see Venus' surface in visible light, clouds block the view
- Magellan's Radar showed the surface
- Most of surface is smooth lava flows
- Many large volcanoes
- Probable ongoing volcanism

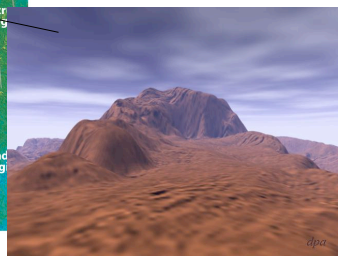
Surface of Venus: Radar

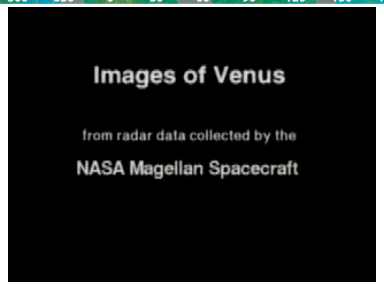


http://www.solarviews.com/raw/venus

Venus: surface features





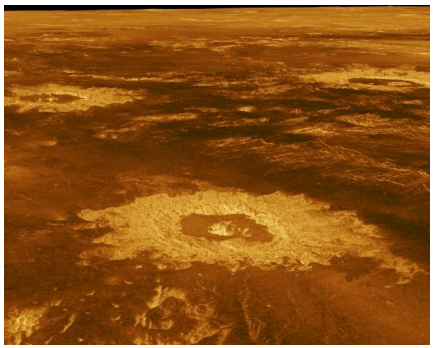


Maxwell Montes (65N 5E)
(Highest mountain range in the solar system
11km high– Everest is 8km)

http://www.geology.smu.edu/~dpa-www/venus.html

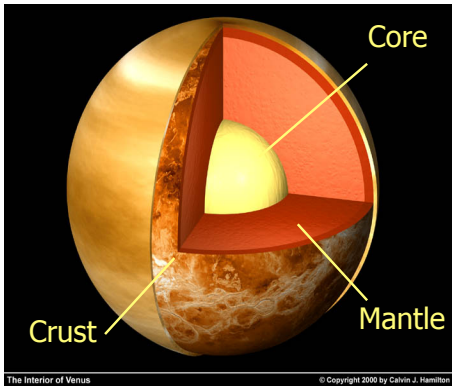
Impacts on Venus

- Venus has about 1,000 craters, often clustered
- No trace of heavy bombardment
- Cratering rate indicates Venus' surface about 500 million yrs old
- Why?
  - Possibility: Extreme temperatures soften rock, making the surface subject to catastrophic volcanic upheaval



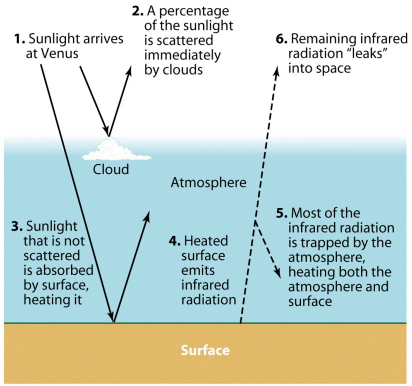
Venus' Interior

- Venus' size and density are roughly equal to Earth's
  - Indicates iron core of similar size
- No magnetic field
  - Very slow rotation - 243 Earth days



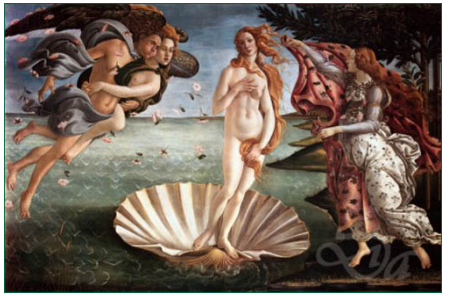
Runaway Greenhouse

- On Earth, greenhouse gasses insulate us
  - Keep Earth 35 K warmer than it would be otherwise
- On Venus, massive amounts of CO_2 keep it incredibly hot
  - Almost 300 K warmer!
  - The hottest planet in the Solar System



What Happened to Venus?

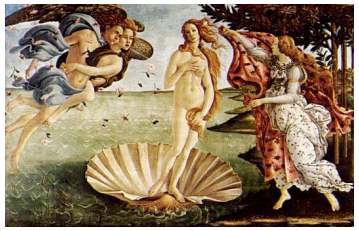
- It really should have been more like Earth, but the atmosphere is much different.
- Earth's atmosphere is mostly O_2 from life, but early Earth was N.
- Earth and Venus have similar amounts of carbon & nitrogen, but…



http://www.digitalart.ab.ca/art/ren/images/birth-of-venus.jpg

Why So Different?

- Earth's carbon is locked up
  - Dissolved in the oceans
  - Locked into rocks and life



- Venus' carbon is in its atmosphere
  - Too close to the Sun for liquid water
  - No oceans to trap the carbon dioxide
  - No life to process the carbon into sedimentary rocks

http://www.edgechaos.com/MECA/WALLART/VR89/venus.jpeg

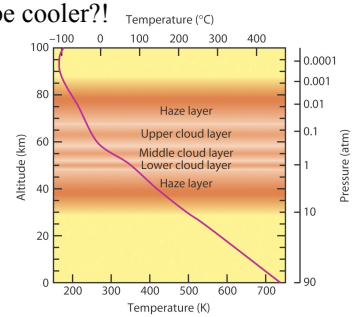
What Happened to Venus?

- Apparently Venus lost its H_2O– no oceans and no sediments.
- Probably the atmospheric temperature was hot enough for water to travel high enough to be broken apart by UV radiation, the H was lost and the O reacted with something else.
- Irreversible procedure!
- Which is why greenhouse effect is worrisome here too!
- The Earth traps water vapor in the cool tropopause at 14km.

http://photos1.blogger.com/blogger/4103/1148/1600/Venus%20Wimbeldon05.jpg

Life on Venus?

- Surface is far too hot
  - If lead is liquid, think of what heat would do to complex organic polymers
  - No cooler polar regions exist
    - Heat is uniform!
    - But, high in the clouds it should be cooler?!
- Maybe life can still exist in the clouds?
- At 50 km up, the temperature is not too hot and the pressure is 1 atmosphere.



Chemical Disequilibrium

- High clouds in the atmosphere contain chemicals that hint at the presence of some kind of biological activity.
- Hydrogen sulfide and sulfur dioxide - two gases that react with each other– exists in the clouds.
- Something is probably producing them.
- Hardly any carbon monoxide. So something is perhaps removing the gas.

http://www.manson-valley.de/fotogalerie/manson/images/acss/acss_32.jpg

Life on Venus?

- One possibility is that microbes living in the clouds could be combining sulfur dioxide with carbon monoxide and possibly hydrogen sulphide or carbonyl sulphide in a metabolism similar to that of some early terrestrial micro-organisms.
- Given that the temperature on Venus was once much cooler, there may once have been oceans on the planet. Life could have started there and retreated to stable niches once the runaway greenhouse effect began.
- Maybe a mission to scoop up some atmosphere?