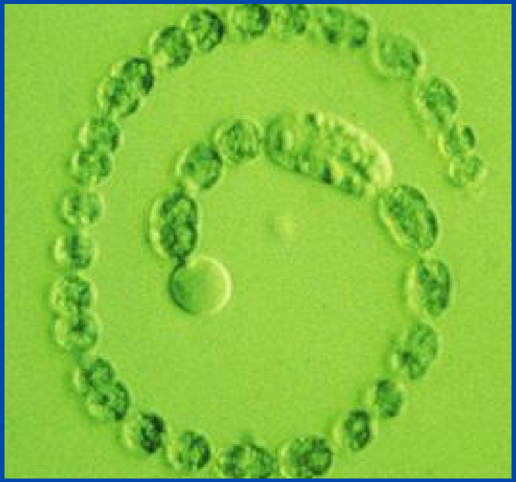
Lecture 16: Life in the Universe

Please remind me to take a break at 12:45 pm



Claire Max

May 29, 2014

Astro 18: Planets and Planetary Systems

UC Santa Cruz

Schedule for project presentations next Tues and Thurs

- If you have a big constraint on which day your group needs to meet (e.g. somebody will be out of town Tues or Thurs), let me know at the break.

- There will be signup sheets for Tues and Thurs during the break. If there is an imbalance between Tues and Thurs, I will move one or more groups to the other day

- Check website this evening to see which day your group will be speaking

Structure of each person's presentation (7 min/person)

- Intro (1 slide)
  - Your name
  - What question(s) are you addressing?
  - Brief outline of your section of the presentation
- Slides about what you learned
  - 5 minutes max, 1-2 min/slide depending on how complex the slide is
- Summary/Conclusion (1 slide)
  - Summarize progress you made on your question
  - Describe what new questions arose in the process

Plus an intro slide to start off each group

- **Title of your group project**
- **Names of each person in the group**
- **Topics that each person will talk about**

General suggestions about slides

- **No more than 3 or 4 bullet points per slide**
- **Intersperse graphics with text**
  - **Example: text on one side of slide, image on other side**
- **Try to have the slide title say what you want us to learn from that slide**

Practicalities: When to use quotes, citations, references

- **To avoid plagiarism, you must give credit whenever you use:**

  *** another person's idea, opinion, or theory;**

  *** any facts, statistics, graphs, drawings—any pieces of information—that are not common knowledge;**

  *** quotations of another person's actual spoken or written words; or**

  *** paraphrase of another person's spoken or written words.**

- **See handout, from http://www.indiana.edu/~wts/pamphlets/plagiarism.shtml**

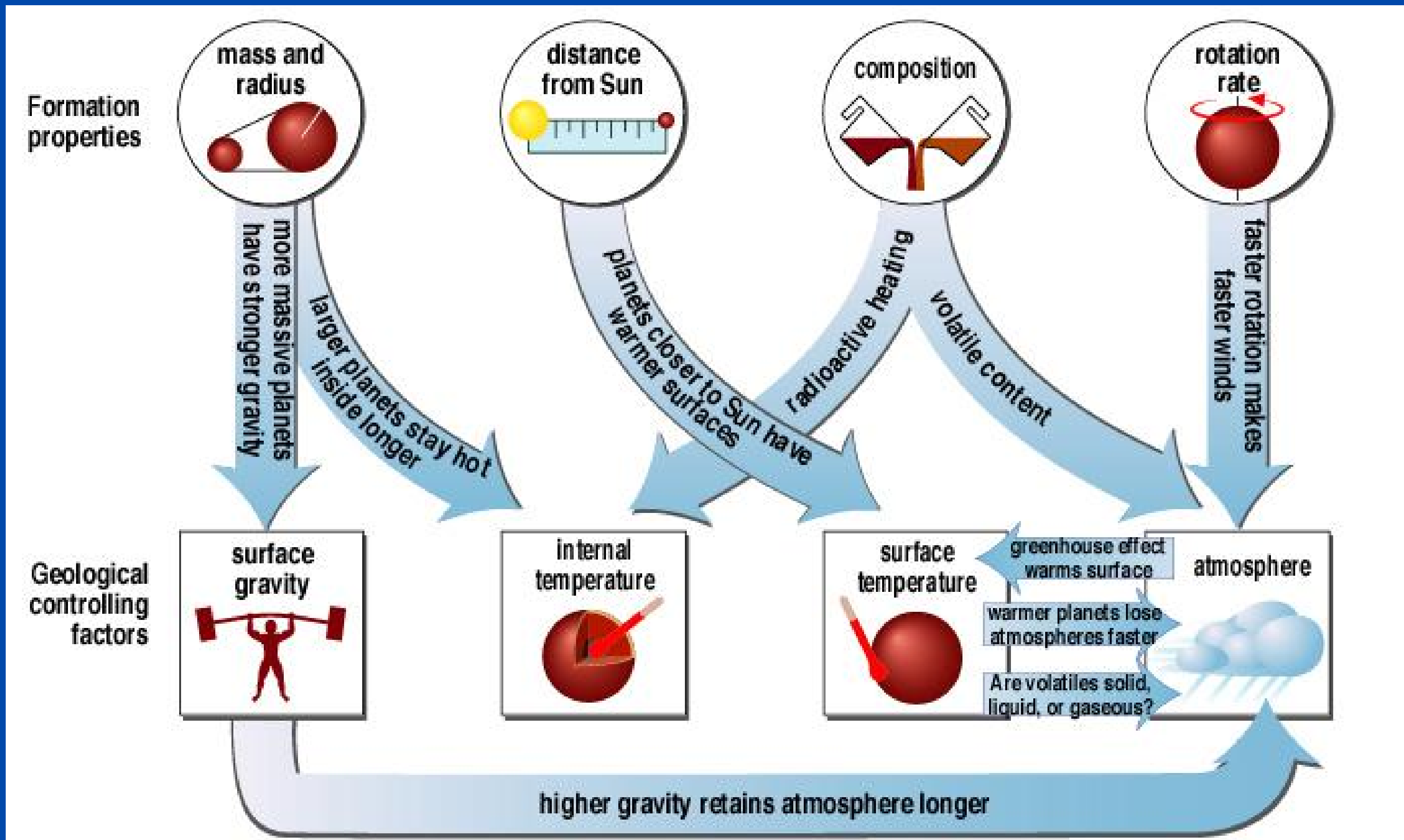
Paper: one per group, due Thurs June 5th

- **Same structure as talks**
- **Title page: overall title, name people in group**
- **Intro to paper (approx. 1 page): give general background, discuss how the sub-topics relate to each other**
- **Five to six pages of text per person (not counting space needed for figures)**
- **Each subsection should have its own bibliography with references**

Final exam question on concept maps: prepare ahead of time!

- **In class we looked at concept maps that describe factors influencing planetary surface geology.**
- **Draw your own concept map describing factors influencing planetary atmospheres. Indicate with arrows and text labels how these factors interact with each other to determine the most important characteristics of the atmosphere.**
- ***Hint*: Factors you might include:**
  - **Planetary mass, surface gravity, rotation rate, distance from Sun, chemical composition, surface temperature, internal temperature, volcanism, greenhouse gases, cratering rate, temperature compared with the boiling or freezing point of water, presence of life.**

Reminder: concept map for planetary geology



- **You can bring your concept map about planetary atmospheres with you to the exam**

A loose end: How to remember order of planets?

- Mercury Venus Earth Mars (Asteroids) Jupiter Saturn Uranus Neptune (not Pluto)
- Mnemonic: a sentence with same first letters of words. Helps remember a list.
- Example with Pluto: My very eager mother just sent us nine pizzas!
- Extra credit: Come up with a new mnemonic without Pluto.
  - Can start at either inside (Mercury) or outside (Neptune) of Solar System. (Starting at Neptune is worth a try….)
  - Nancy understood silly jokes after Mary explained very many
- Bring your candidates to the Final Exam

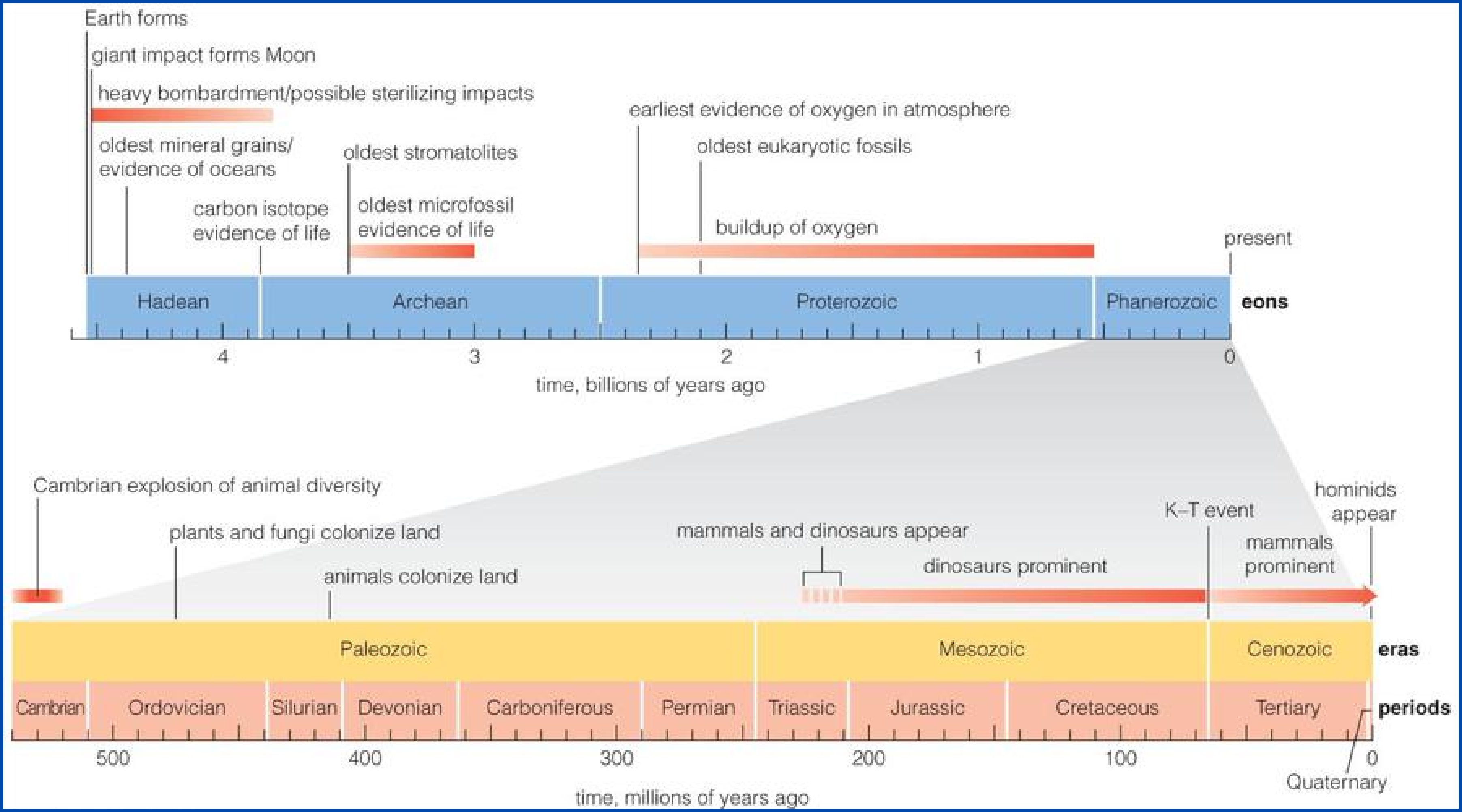
Outline of lecture

- Life on Earth
  - How did it begin?
  - How did it change over time?
- Life elsewhere in the Solar System
  - Mars? Venus? in past?
  - Jovian moons? now?
- Life in other solar systems
  - Concept of a Habitable Zone
- Search for Extra-Terrestrial Intelligence (SETI)

Life on Earth

- When did life arise on Earth?
- How did life arise on Earth?
- What are the necessities of life?

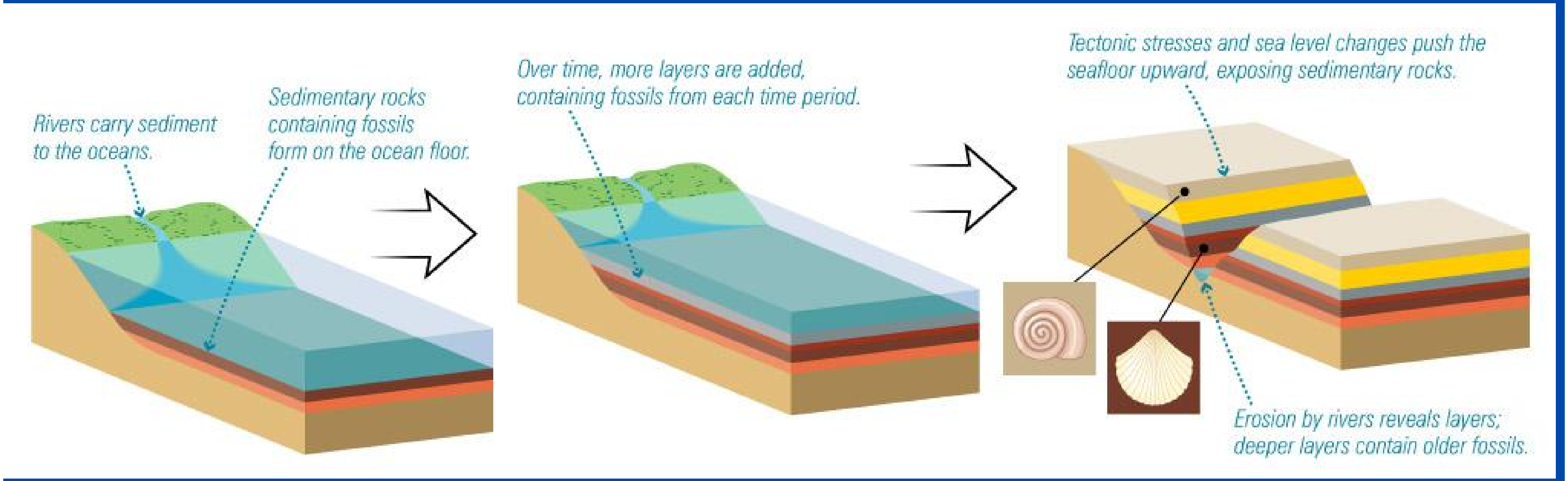
When did life arise on Earth?



Earliest Life Forms

- Life probably arose on Earth more than 3.85 billion years ago, shortly after the end of the late heavy bombardment
- Evidence comes from carbon isotopes
- There is still contraversy about age of earliest life on Earth
  - Hard to date the rock in which the carbon is embedded

Earliest Fossils in Sedimentary Rock are from ~3.5 billion years ago

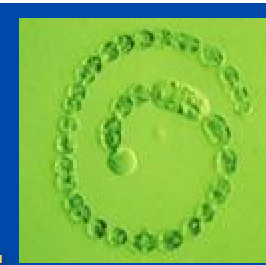


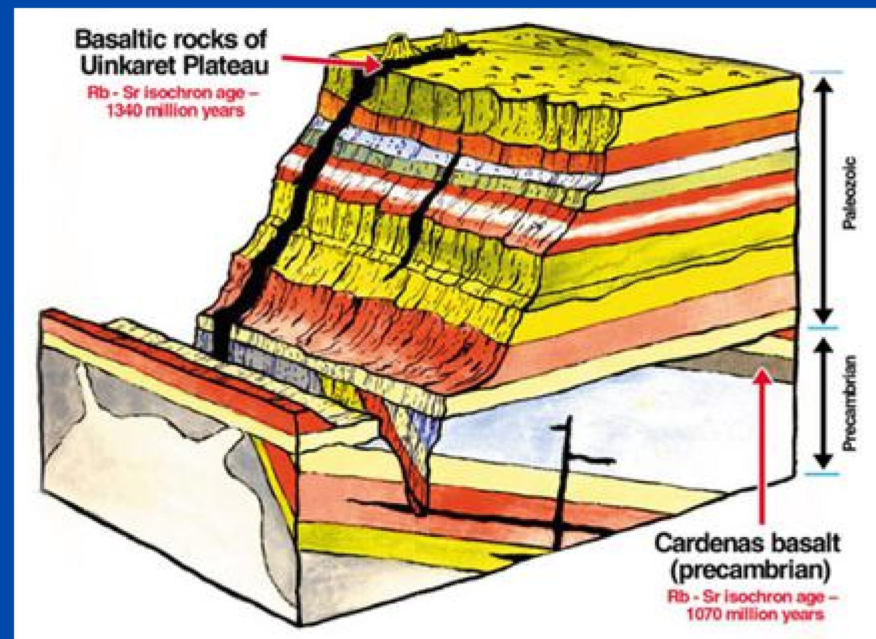
- Relative ages: deeper layers formed earlier.
- Absolute ages: radiometric dating (isotope ratios)

Use of Carbon isotope ratios to identify evidence of life in rocks

- Isotopes: Atoms with the same number of protons in the nucleus (the same element), but different numbers of neutrons.
- Normally, carbon-13 (C-13, with atomic weight 13), is much rarer than C-12.
- Biological processes concentrate C-12, so when organic debris falls to the ocean floor, the C-12 to C-13 ratio rises still further in the sedimentary rock that forms.
- That ratio is preserved even in rocks so old that their fossils have been ground up and destroyed.

Fossils in Sedimentary Rock

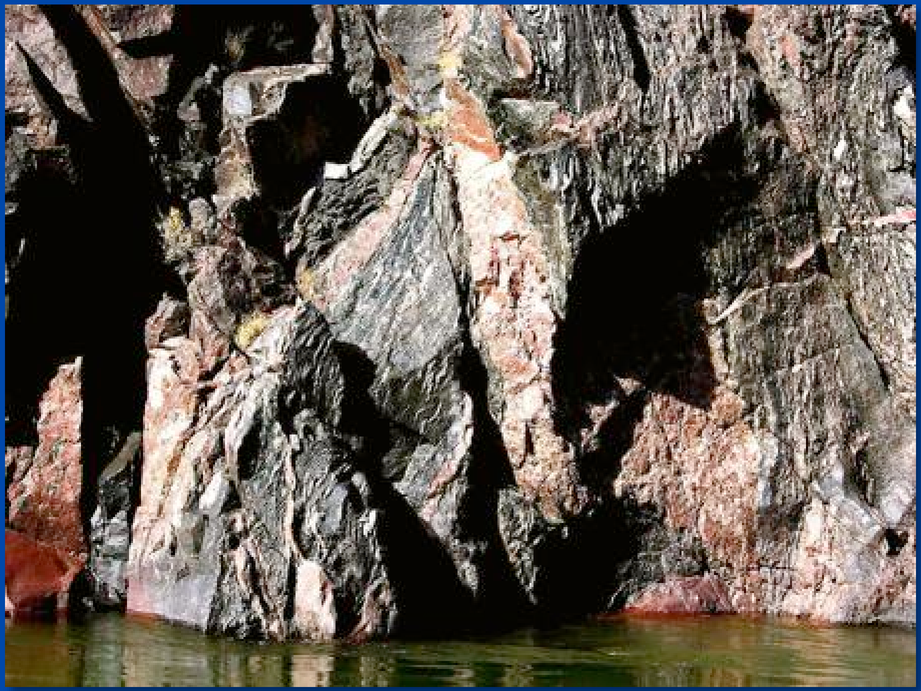




- **Rock layers of Grand Canyon record 2 billion years of Earth's history**

A Digression: Oldest Rocks in Grand Canyon

- **Vishnu Schist (about 2 billion years old)**



Vishnu Schist and Zoroaster Granite

Earliest Fossils

- Oldest fossils show that bacteria-like organisms were present over 3.5 billion years ago
- Living cyanobacteria agglomorated together in big blobs called stromatolites
- Fossil stromatolytes show first evidence of cyanobacteria

Origin of Life on Earth

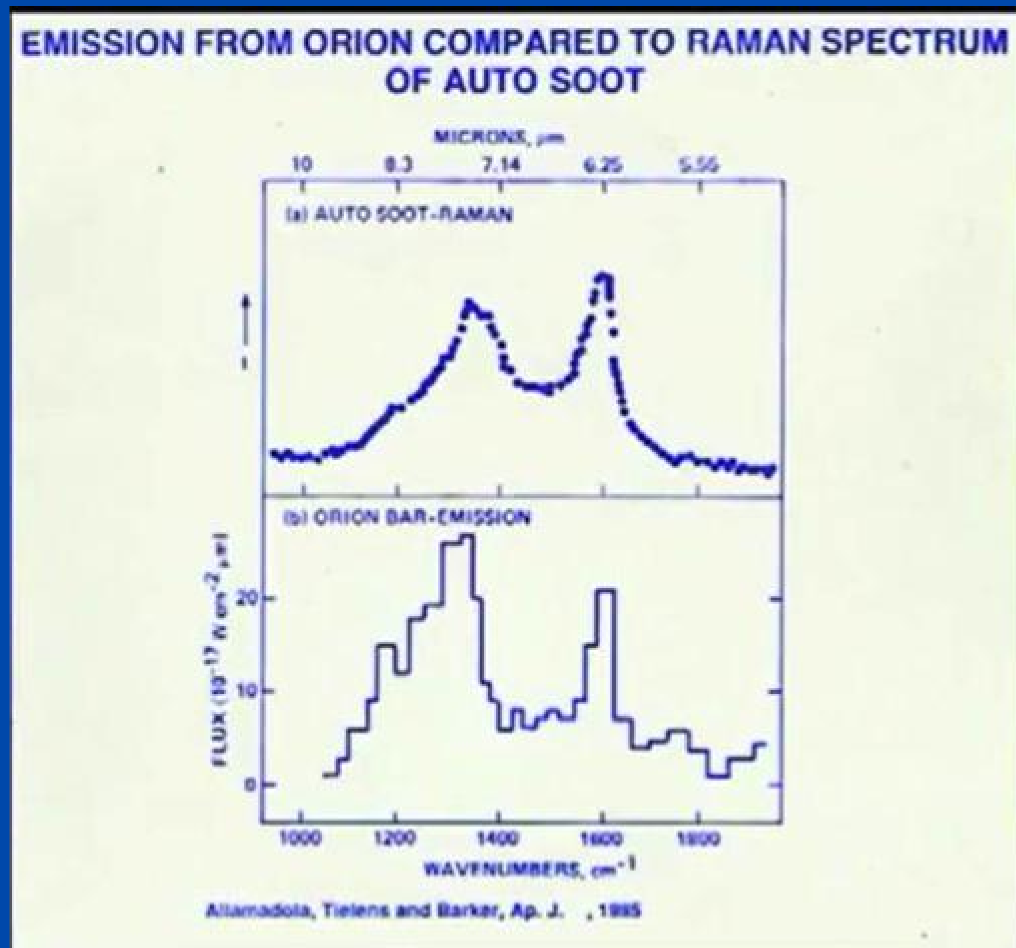
- **Did it come from somewhere else?**
  - **Panspermia**
- **Or did it form here on Earth**
  - **Chemical reactions to create building blocks of life**

Could life have migrated to Earth? Theory called Panspermia.

- **Venus, Earth, Mars have exchanged tons of rock (blasted into orbit by impacts)**
- **Some microbes can survive many years in space...**
- **Theory that life came from beyond Earth is called "Panspermia" - "life everywhere"**

Molecular clouds that host star formation contain organic molecules

Comparison of a spectrum taken from the Orion Nebula and one taken from diesel fumes



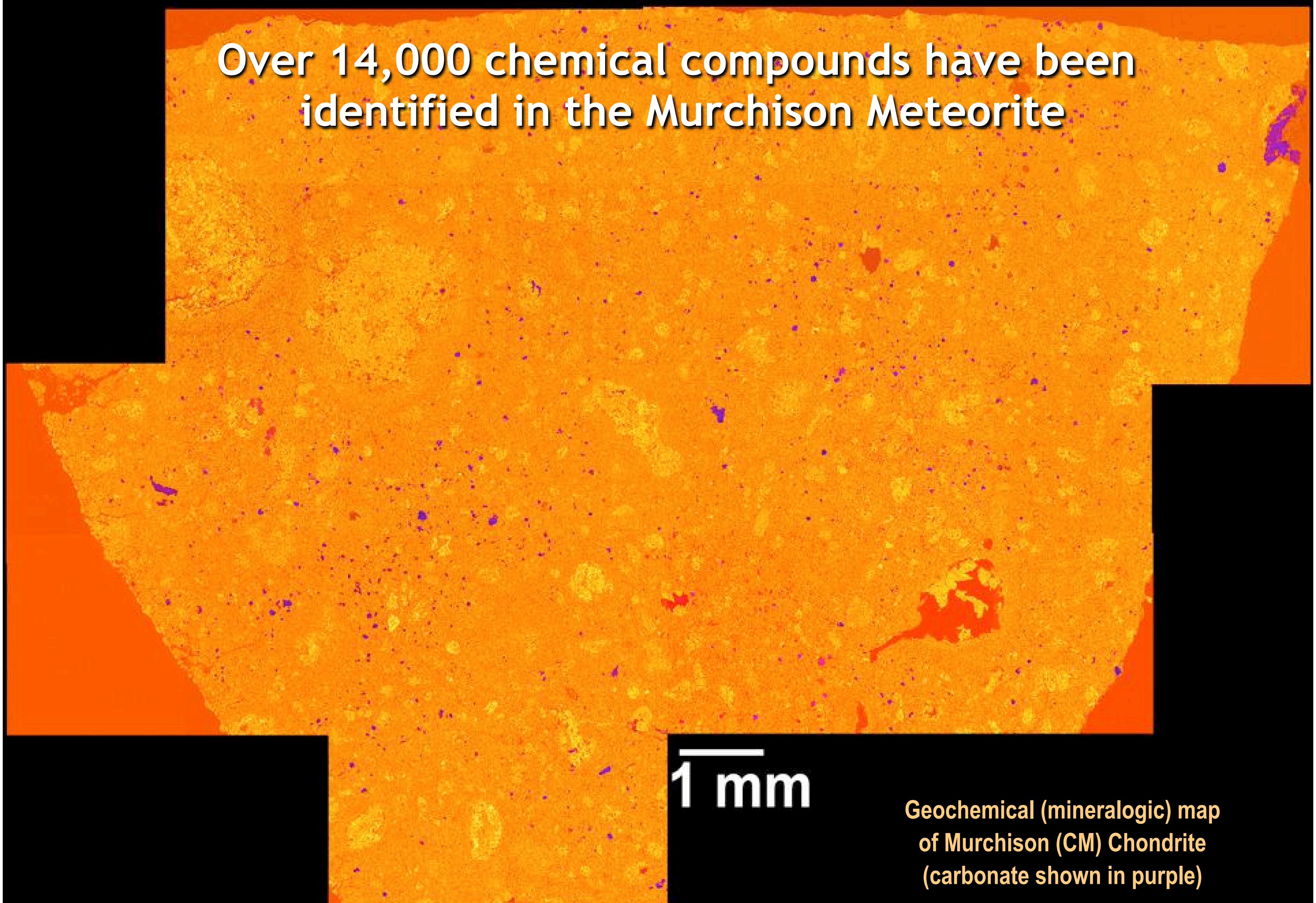
Credit: nnebbe.net/files/Astrochemistry_to_astrobiology.pptx

ORGANIC COMPOUNDS IN THE MURCHISON CHONDRITE

Class	Concentration (ppm)	Compounds Identified
Monocarboxylic Acids	>300	20
Polar Hydrocarbons	100-120	10+
Amino Acids	60	74
Amides	55-70	49+
Aliphatic Hydrocarbons	>35	140
Dicarboxylic Acids	>30	38
Aldehydes & Ketones	27	9
Aromatic Hydrocarbons	>15-28	87+
Hydroxy Acids	15	51
Alcohols	11	8
Amines	8	10
Basic N-Heterocycles	7	32
Purines and Pyrimidines	1	5
Sulfonic Acids	71	8
Phosphonic Acids	2	4

Credit:
Pawel Artymowicz

Over 14,000 chemical compounds have been identified in the Murchison Meteorite



Geochemical (mineralogic) map of Murchison (CM) Chondrite (carbonate shown in purple)

Credit: Arizona State Univ.

Comets: Dirty Snowballs with lots of organic compounds

- Not yet clear whether there would have been enough organic compounds to "seed" life on Earth

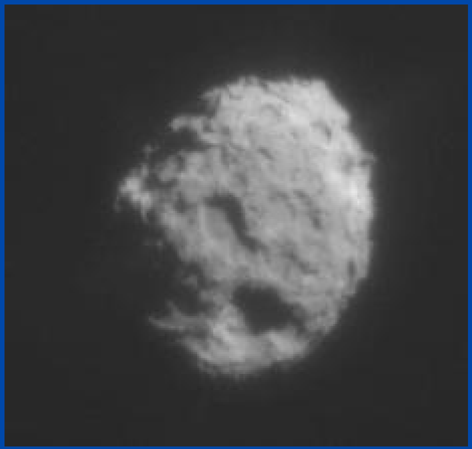
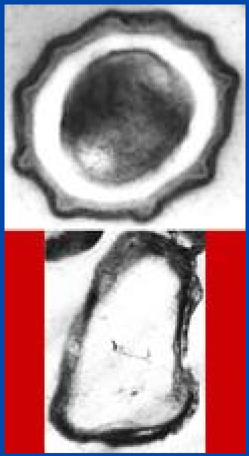


Table 1. Organic compounds in comets*

Molecule	Relative abundance
H_2O	100
CO	23
CO_2	6
CH_4	0.6
C_2H_2	0.1
C_2H_6	0.3
CH_3OH	2.4
H_2CO	1.1
HCOOH	0.1
CH_3CHO	0.02
$HCOOCH_3$	0.08
NH_2CHO	0.02
NH_3	0.7
HCN	0.25
HNC	0.04
HNCO	0.1
CH_3CN	0.02
HC_3N	0.02
H_2S	1.5
CS_2	0.2
CS	0.2
SO_2	0.2
SO	0.3
OCS	0.4
H_2CS	0.02
NS	0.02

Bacterial spores



A highly resistant, resting phase displayed by some types of bacteria.

Spores are formed in response to adverse changes in the environment.

Original cell replicates its genetic material. One copy grows a tough coating. Outer cell disintegrates, releasing spore which is now protected against a variety of traumas, including extremes of heat and cold, and an absence of nutrients, water, or air.

Credit: Pawel Artymowicz

Panspermia, continued

The unmanned Surveyor 3 probe soft-landed on Moon in 1967.

Apollo12 astronauts brought the camera back to Earth 2.5 yrs later.

Insulation covering its circuit boards contained 50 to 100 viable specimens of Streptococcus mitis, a harmless bacterium .

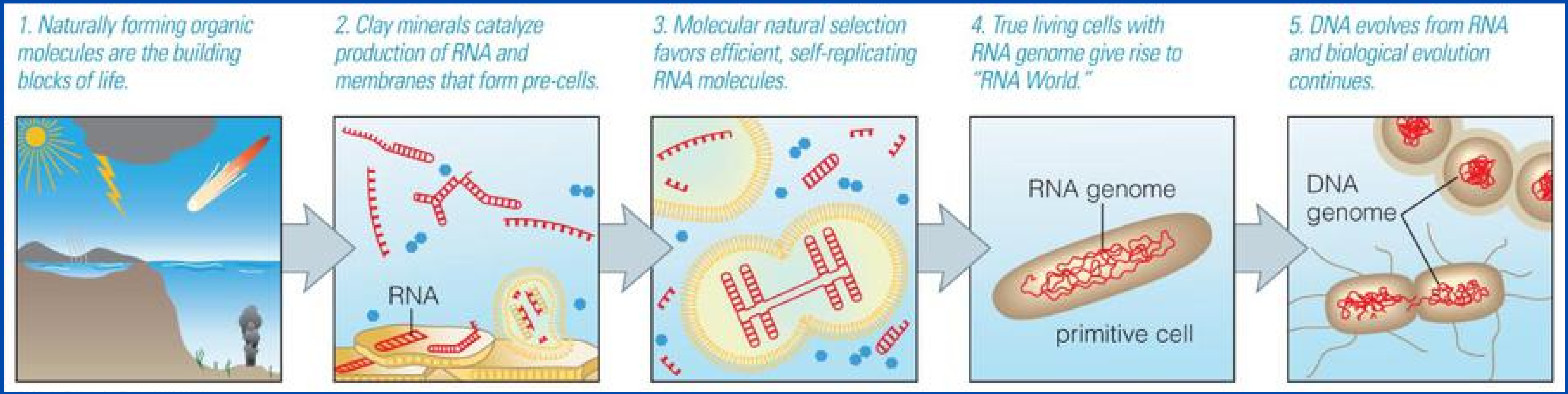
Astronaut Pete Conrad later commented:
the most significant thing that we ever found whole Moon was that little bacteria who came back and living and nobody ever said anything about it."

Credit: Pawel Artymowicz

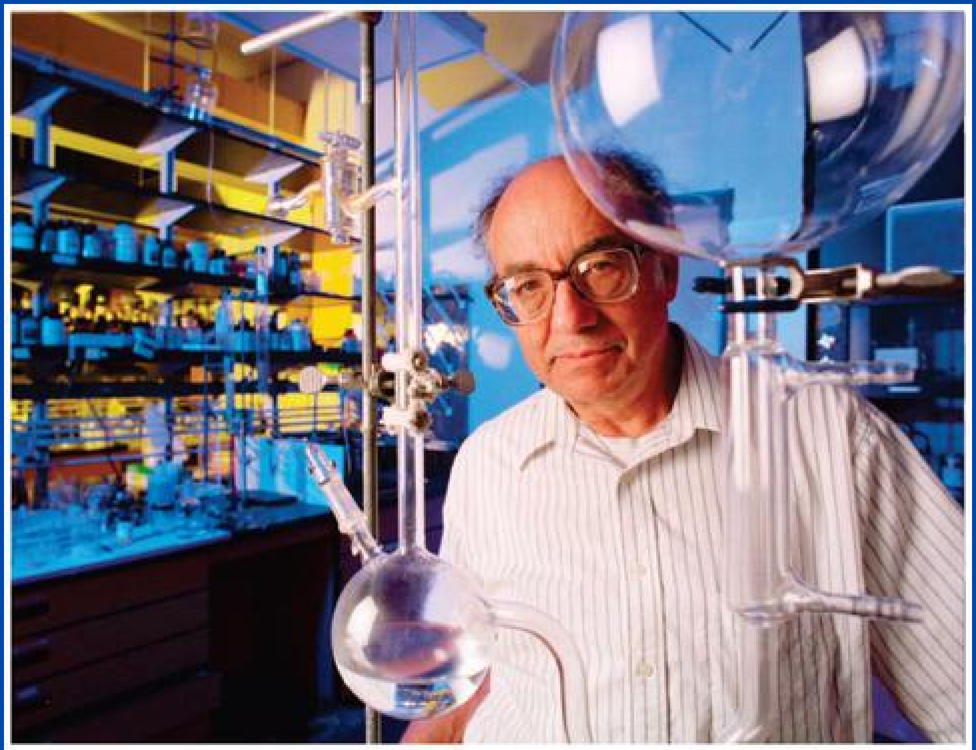
Alternative to Panspermia

- The in situ formation of life here on Earth
- Predominant theory, presently

Chemicals to Life?

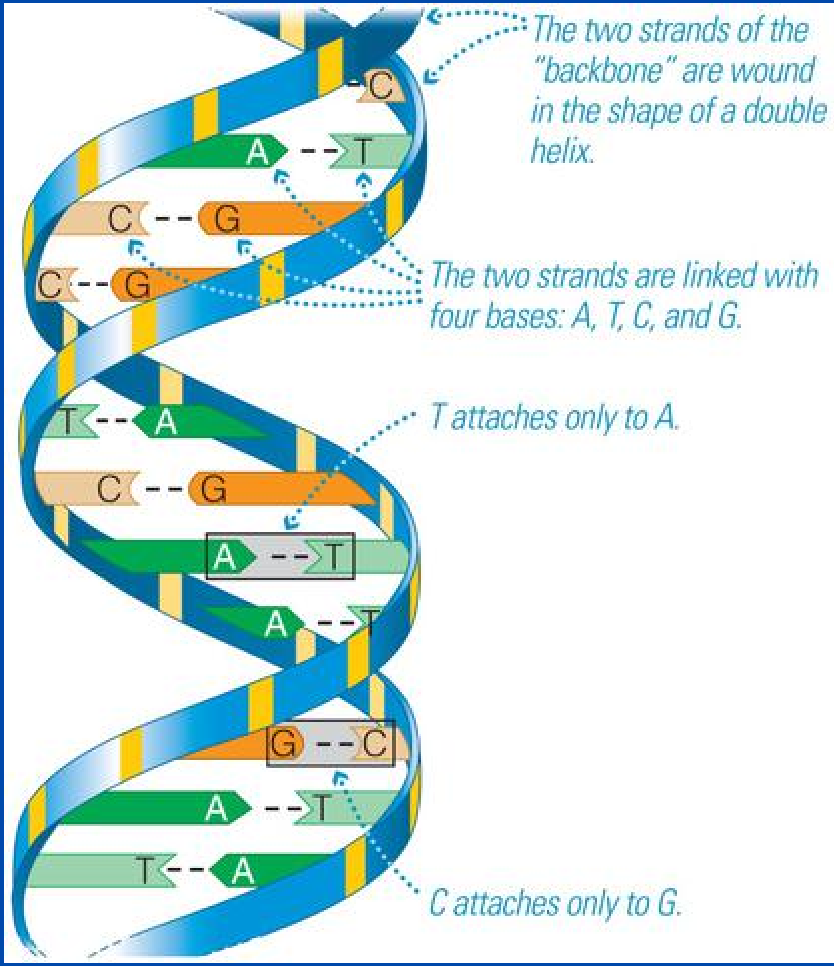


Laboratory Experiments



- The Miller-Urey experiment (and more recent experiments) show that the building blocks of life form spontaneously under the conditions of the early Earth.

The Theory of Evolution

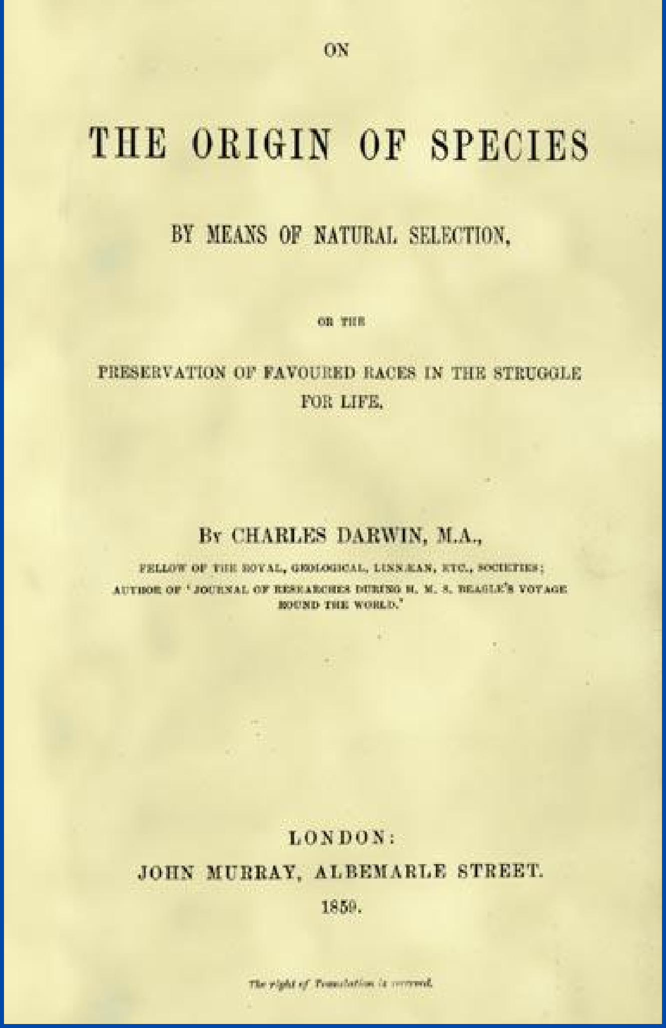


DNA encodes our genetics

- **Fossil record shows that changes in species have occurred through time.**
- **Darwin's theory tells us how evolution occurs: through natural selection.**
- **Theory strongly supported by discovery of DNA: present in each cell nucleus, encodes our genetics.**
- **Evolution proceeds through mutations of DNA.**
  - **Mutations induced by many factors: UV light, oxidants, ...**

Elements of Evolution: Definitions

- **Evolution: the change over time of genetic composition of populations**
- **Natural selection: populations of organisms can change over the generations if individuals having certain heritable traits leave more offspring than others**
- **Evolutionary adaptations: a prevalence of inherited characteristics that enhance organisms' survival and reproduction**



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

BY CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNÆAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

The right of Translation is reserved.

November 24, 1859

Natural Selection

- **Process itself is not random**
  - **Response to environmental conditions, especially if a species faces environmental threats**
- **Changes to DNA is random**
  - **Mutation: changes to DNA**
    - » **Occasionally cause beneficial changes in traits**
    - » **Increased reproductive success**
    - » **Trait endures through subsequent generations**

Credit: Amer. Association for the Advancement of Science

Other Evolutionary Mechanisms

- **Sexual selection**
  - Females prefer to mate with most impressive male

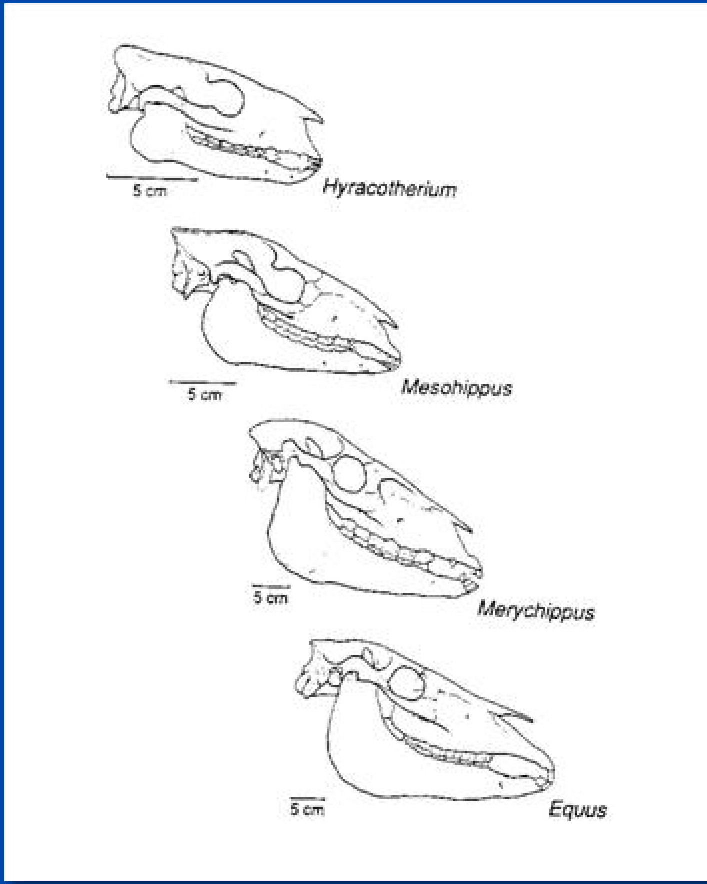
- **Genetic drift**
  - The genetic structure of a population changes randomly over time.

Credit: Amer. Association for the Advancement of Science

Evolution Evidence: The Fossil Record

The fossil record:

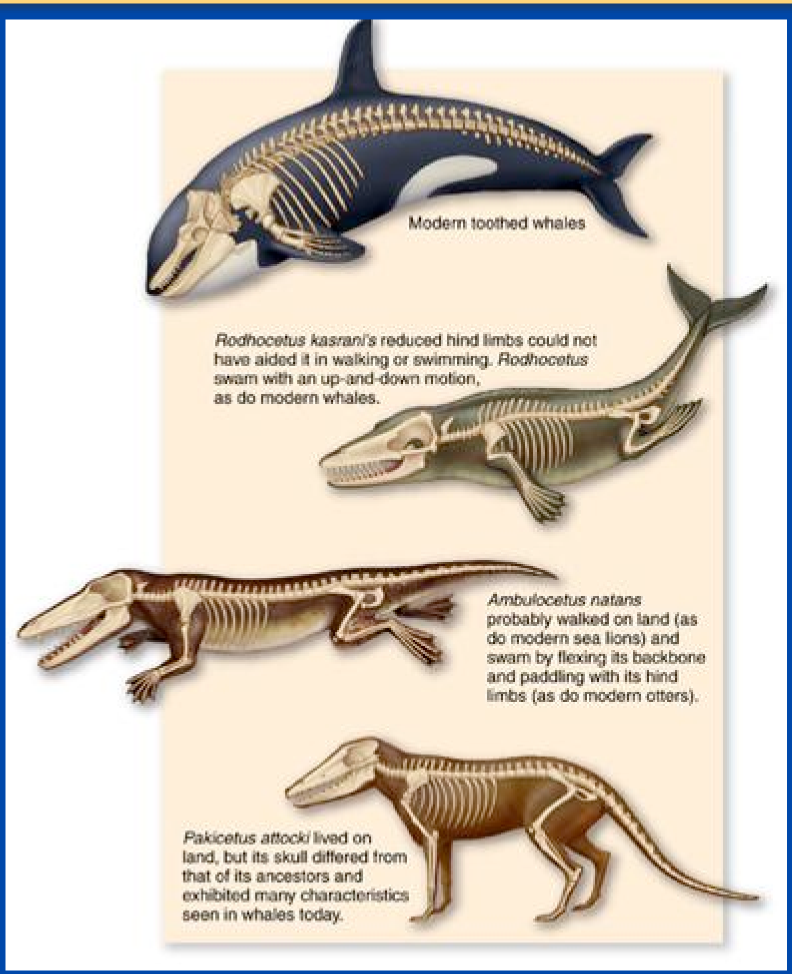
- **provides direct evidence of evolution**
- **shows that lineages change and diversify through time**
- **gives information about the *process* of evolution**
- **gives information on the *rate* of evolution**



Evolution of horse head from browsing (top) to grazing (bottom)

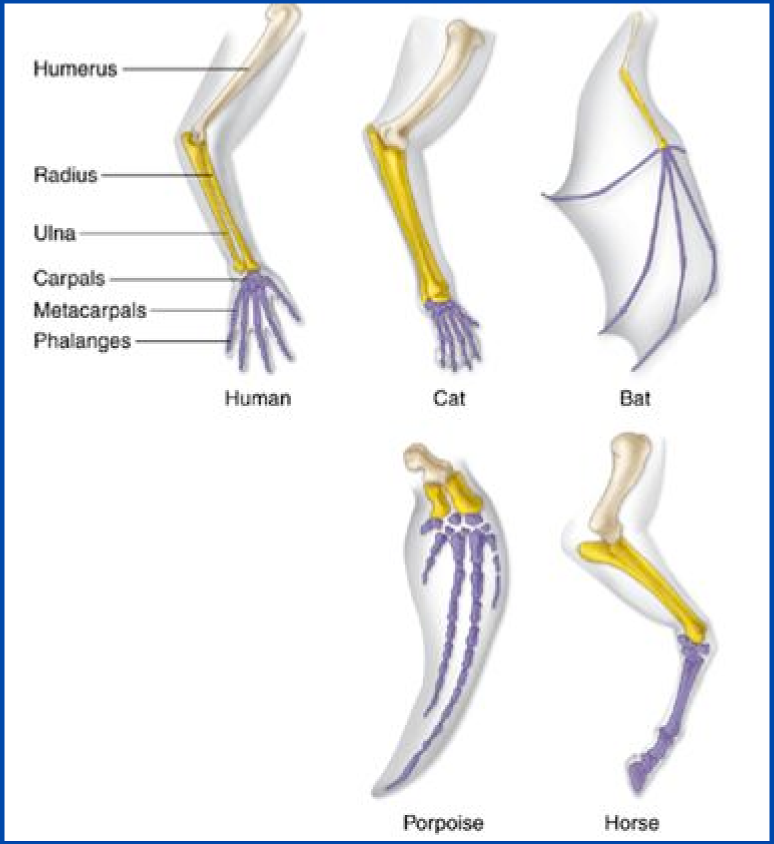
From MacFadden [1992] Cambridge Univ. Press

Fossil Evidence of Evolution: Whale "Missing Links"



Credit: Tom De Lany, Kilgore College

Anatomical Evidence for Evolution: Homologous Structures



Homology of the bones of the forelimb of mammals

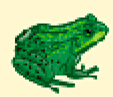
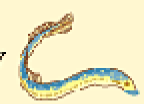
Homologous structures: structures with different appearances and functions that all derived from the same body part in a common ancestor

Credit: Tom De Lany, Kilgore College

Evolution Evidence: Molecular Biology

- Similarities in DNA, proteins, genes, and gene products between species
- Common genetic code
- Reconstruct sequence of slow genetic changes over time
- Extremely compelling evidence for evolution

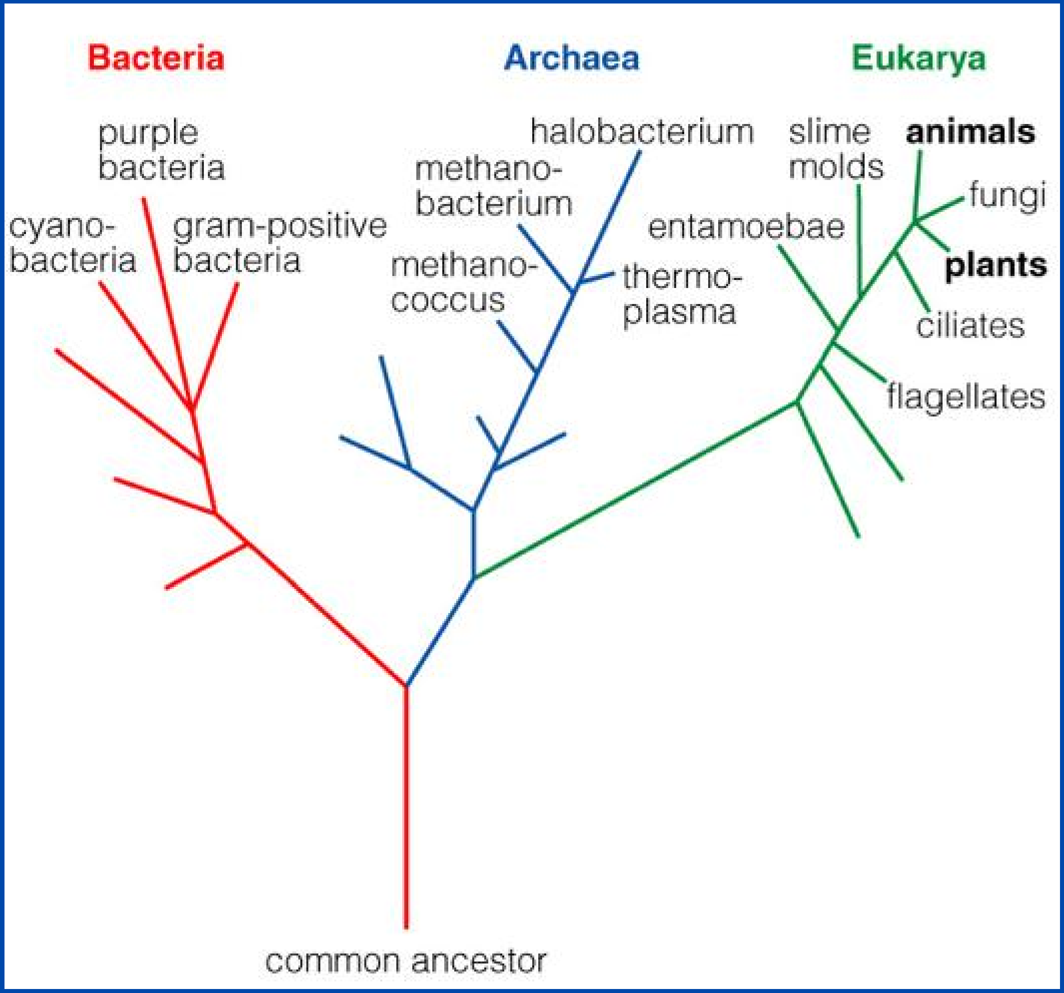
Table 22.1 Molecular Data and the Evolutionary Relationships of Vertebrates

Species	Number of Amino Acids That Differ from a Human Hemoglobin Polypeptide (Total Chain Length = 146 Amino Acids)
Human 	0
Rhesus monkey 	8
Mouse 	27
Chicken 	45
Frog 	67
Lamprey 	125

Brief History of Life

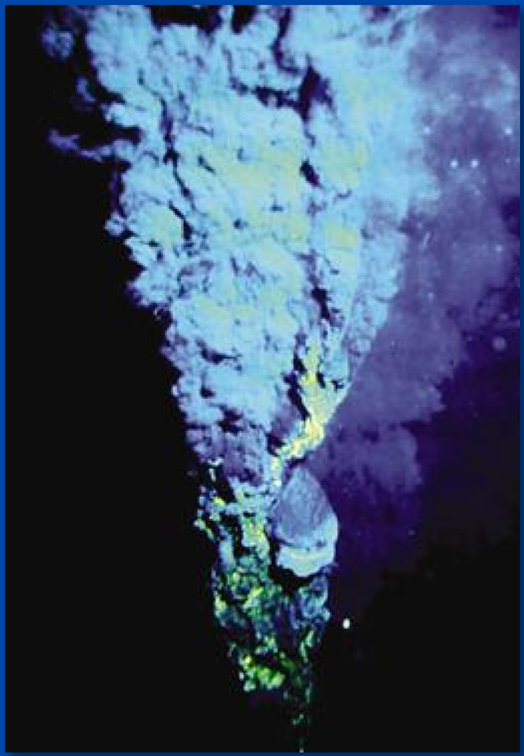
- 4.4 billion years - early oceans form (no free oxygen)
- First life 3.8 - 3.5 million yrs ago
- 3.5 billion years - cyanobacteria start releasing oxygen
  - Initially deposited on oxidized surfaces of rocks, not in the air
- 2.0 billion years - oxygen begins building up in atmosphere rather than on rocks
- 540-500 million years - Cambrian Explosion - many new species
- 225-65 million years - dinosaurs and small mammals (dinosaurs ruled)
- Few million years - earliest hominids

Tree of Life

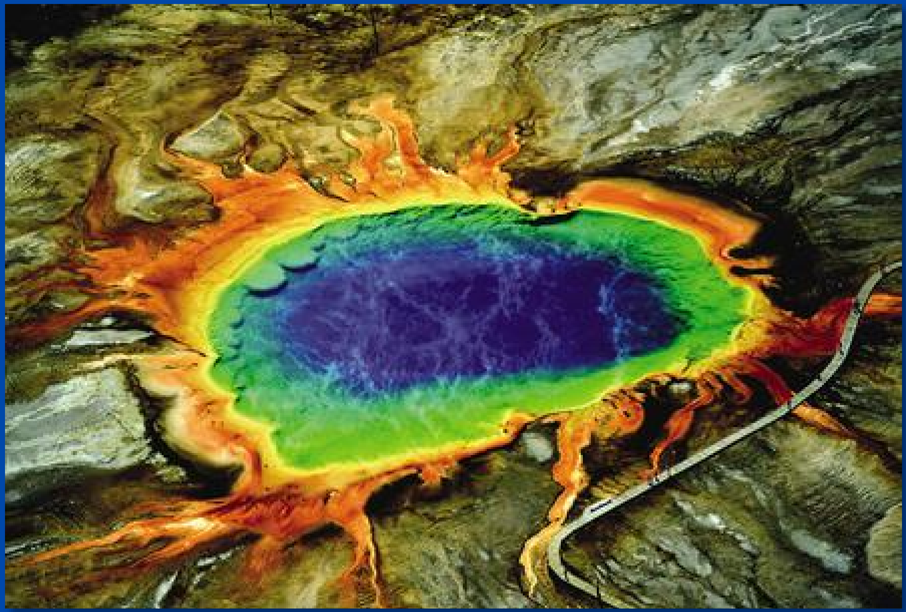


- Mapping genetic relationships has led biologists to discover this new "tree of life."
- Adjacent branches have very similar DNA
- Plants and animals are a small part of the tree.
- Suggests likely characteristics of common "ancestor".
- What was it?

- Genetic studies suggest that earliest life on Earth resembled bacteria today found near deep ocean volcanic vents (black smokers) and geothermal hot springs. Energy from chemicals, not photosynthesis.

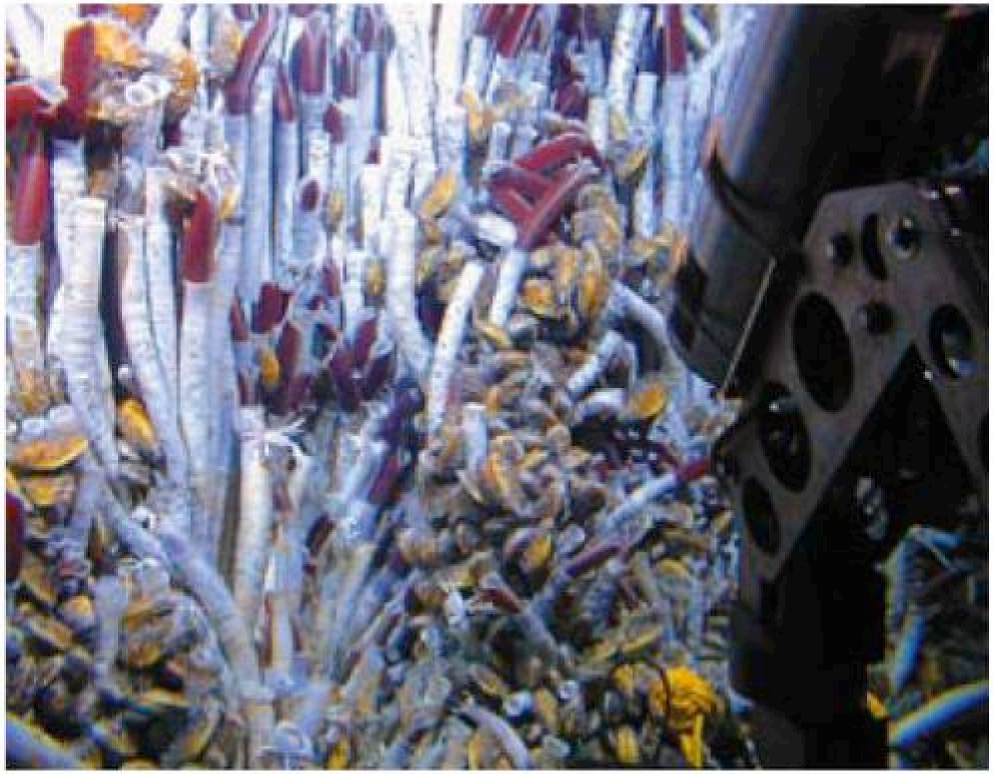


Deep-ocean vent



A hot-spring in Yellowstone. Different bacteria (colors) inhabit water at different temperatures.

Life in hydrothermal vents sustained by chemosynthesis



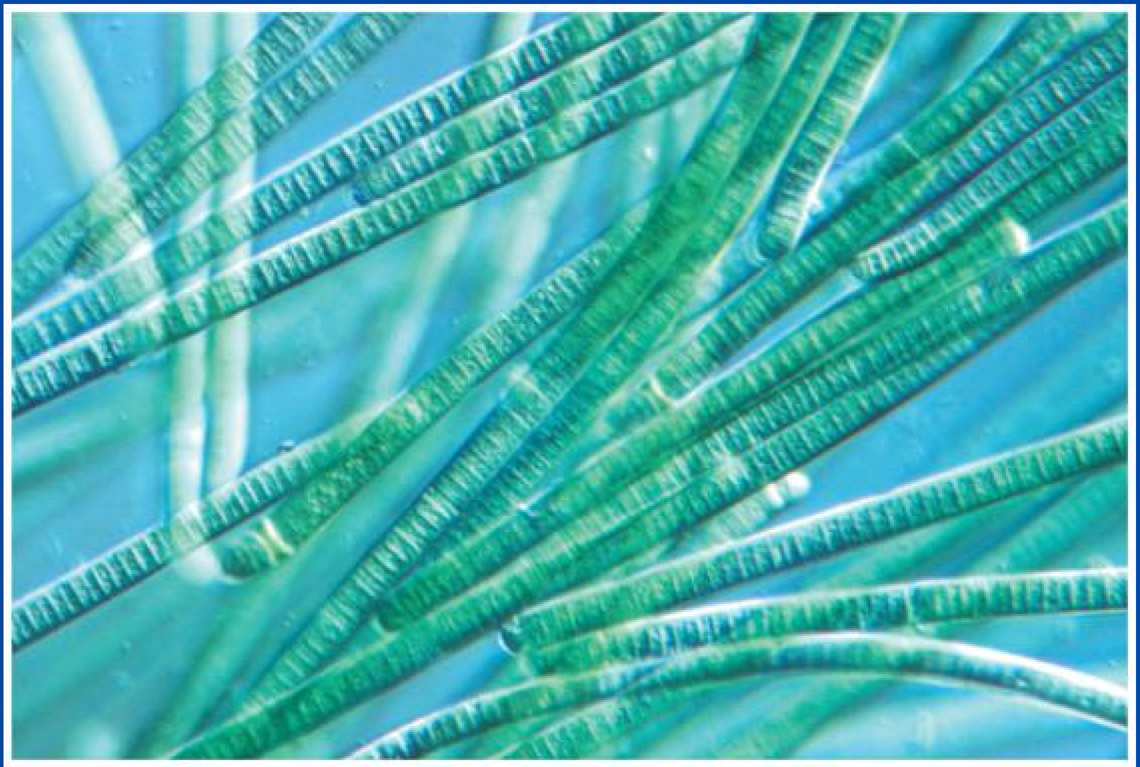
- Survival of *Riftia* (and other vent species) depends on a symbiotic relationship with the billions of bacteria that live inside these worms.

- These bacteria convert chemicals that shoot out of the hydrothermal vents into food for the worm.

- This chemical- based food-making process is chemosynthesis, $2\,H_2S + CO_2 \Rightarrow S_2 + CH_2O + H_2O$

Credit: David Webb, Univ. of Hawaii

Origin of Free Oxygen in Atmosphere

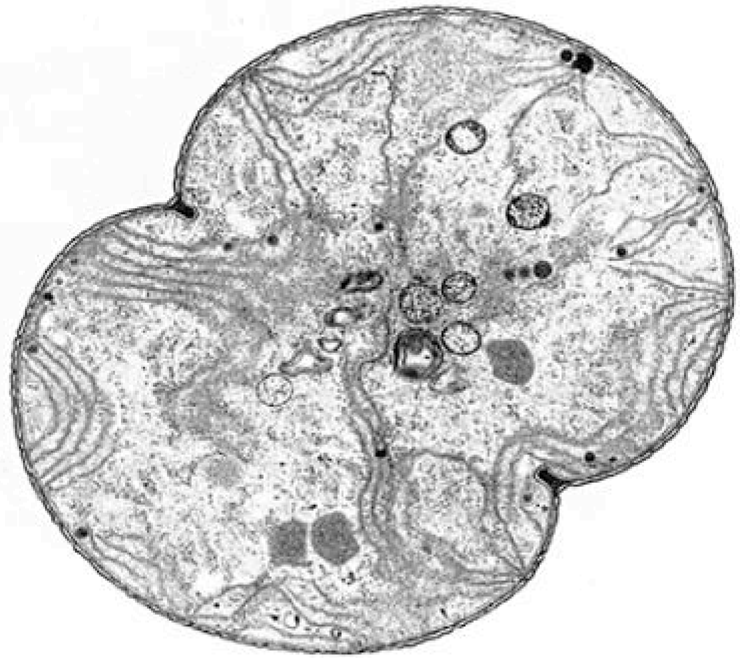


- Cyanobacteria paved the way for more complicated life forms by releasing oxygen into atmosphere via photosynthesis

Division Cyanophyta

Bacteria that are:

- Photosynthetic (convert light energy to food)
- Produce O_2 as a byproduct of photosynthesis
- Some produce toxins
- Some have capacity to fix N_2 into NH_4
- Some have formed millions of years old stromatolites as living structures



TEM of dividing cell

Cyanophytes have changed the path of evolution on earth

Credit: David Webb, Univ. of Hawaii

Necessities for Life (as we know it…)

- **Nutrient source**
- **Energy (sunlight, chemical reactions, internal heat)**
- **Liquid water (or possibly some other liquid)**

Hardest to find on other planets

Why is liquid water preferred, compared with other liquids?

- Water is liquid over a broader range of temperatures
  - Broader temperature range – water stays liquid through climate changes
  - Higher temperature range – water allows faster rates of chemical reactions, but not so hot that carbon chemical bonds break

- Other substances are liquid at temperatures that are problematic for biochemical reactions

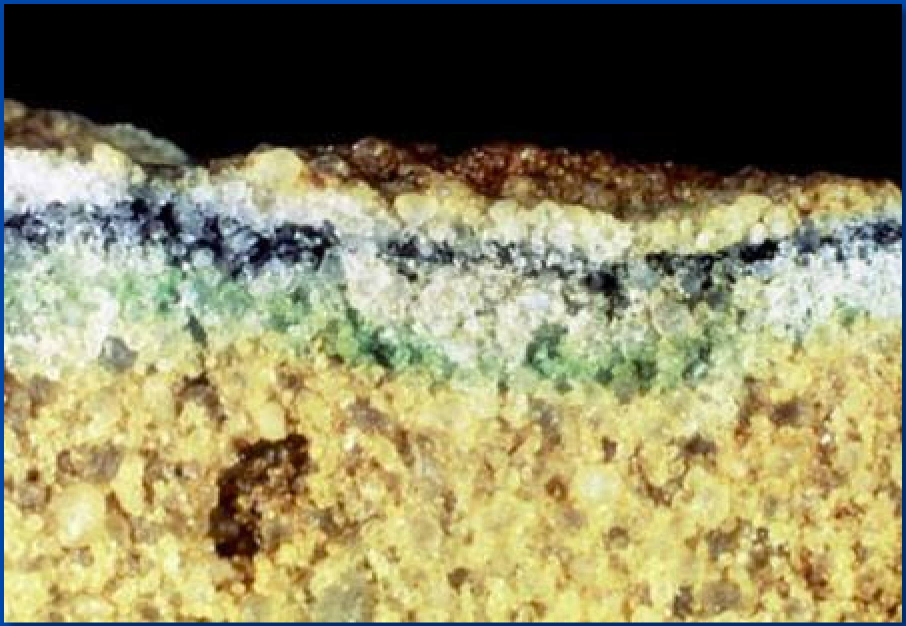
Credit: Lunar and Planetary Lab

In our Solar System, Mars is best candidate for finding life

Mars at 2001 opposition
Hubble Space Telescope image

- Exploration of Solar System has revealed…
  - no sign of large life forms
  - we must search for <u>microbial</u> life
- Mars is best candidate:
  - Mars was apparently warm & wet in its distant past
  - it had the chemical ingredients for life
  - it has significant amounts of water ice
  - pockets of underground liquid water *might* exist if there is still volcanic heat
- Will we find life underground?

Looking for life in rocks has good precedent on Earth



Outer few sixteenths of an inch of a rock in the cold desert of the McMurdo Dry Valleys create microclimates with just enough above-freezing days per year and just enough moisture that minute spaces between grains are home to organisms. Organisms are active enough to contribute to weathering of rock surface, but appear to be on the limit of their capability and are dormant most of the year.

(photo courtesy E. Imre Friedman, Florida State)

Possible Life on Jovian Moons

- Beneath its icy surface, Europa may have an ocean of liquid water.
  - tidal heating keeps it warm
  - possibly with volcanic vents
  - conditions may be similar to how Earth life arose
- Ganymede & Callisto may also have subsurface oceans, but tidal heating is weaker.

- Titan has a thick atmosphere and oceans of methane & ethane.
  - water is frozen; ethane is in liquid form
  - perhaps life can exist in liquids other than water (??)
- Pockets of liquid water might exist deep underground.

Are We Alone?

- Humans have speculated throughout history about life on other worlds
  - It was assumed by many thinkers of the 17th & 18th Centuries
  - Widely accepted by the public in the early 20th Century
  - Scientists became more skeptical once we began to explore the planets in our own Solar System

What is "life"?

- Surprisingly hard to define, if we want to avoid saying that all life must be like us
- Reasonable defining characteristics: (not unique set)
  - Ability to take energy from environment and change it from one form to another
  - Highly organized. Chemicals found within bodies are synthesized through metabolic processes into structures with defined purposes.
  - Regulate body and internal structures to certain normal parameters (e.g. temperature, acidity)
  - Respond to stimuli
  - Self-replicating by making copies of themselves
  - Grow and develop

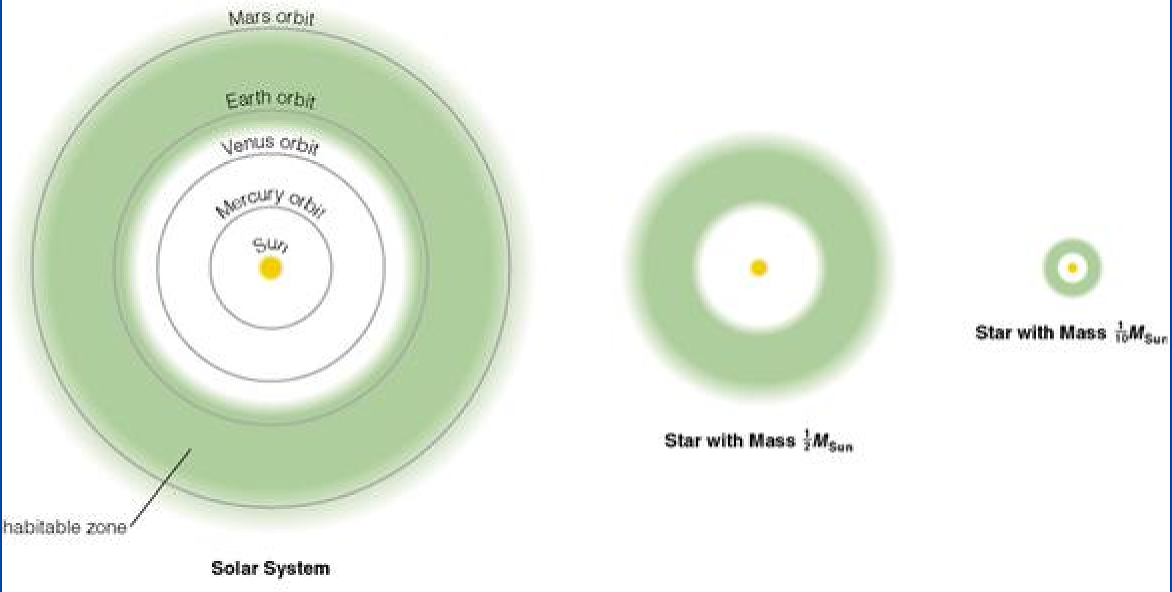
Where did "building blocks of life" come from?

- Building blocks of life
  - Amino acids, nucleic acid bases, sugars, phosphoric acid
- Origins of the building blocks?
  - Abiotic synthesis:
    - » Lab experiments in "reducing atmosphere" (little oxygen)
    - » Ingredients from volcanoes, sparked with electricity (as in lightning), rapidly formed amino acids and nucleic acids
  - Extraterrestrial origins:
    - » Carbonaceous chondrites (meteorites) carry amino acids
    - » Lab experiments: mixture of ices (water, carbon dioxide, carbon monoxide, methanol) was cooled to ten degrees above absolute zero. Ice mixture was then exposed to strong ultraviolet radiation. Formed amino acids and nucleic acids.


cvk'97

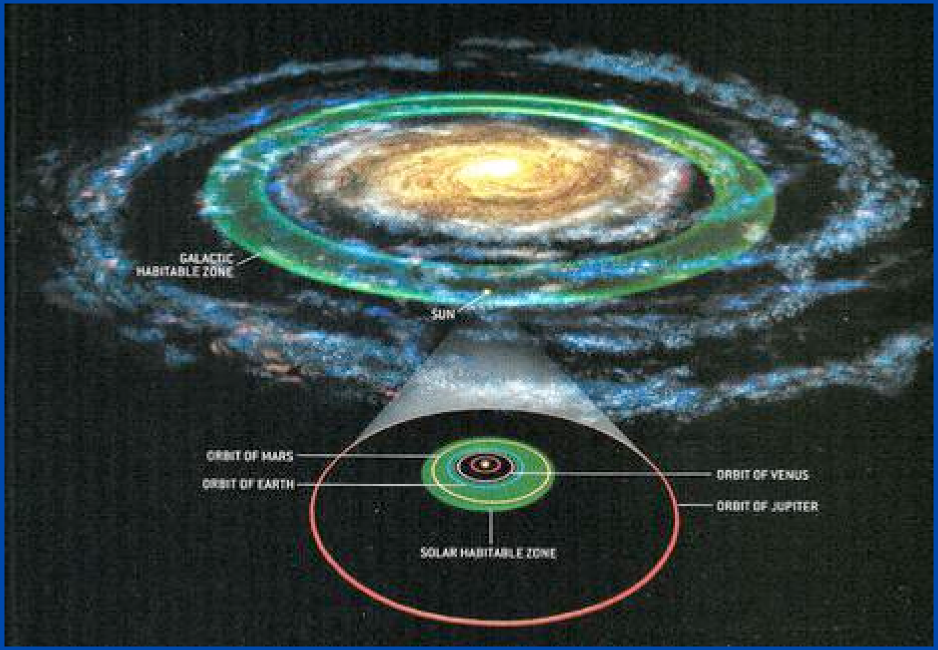
Which stars are most likely to have planets harboring life?

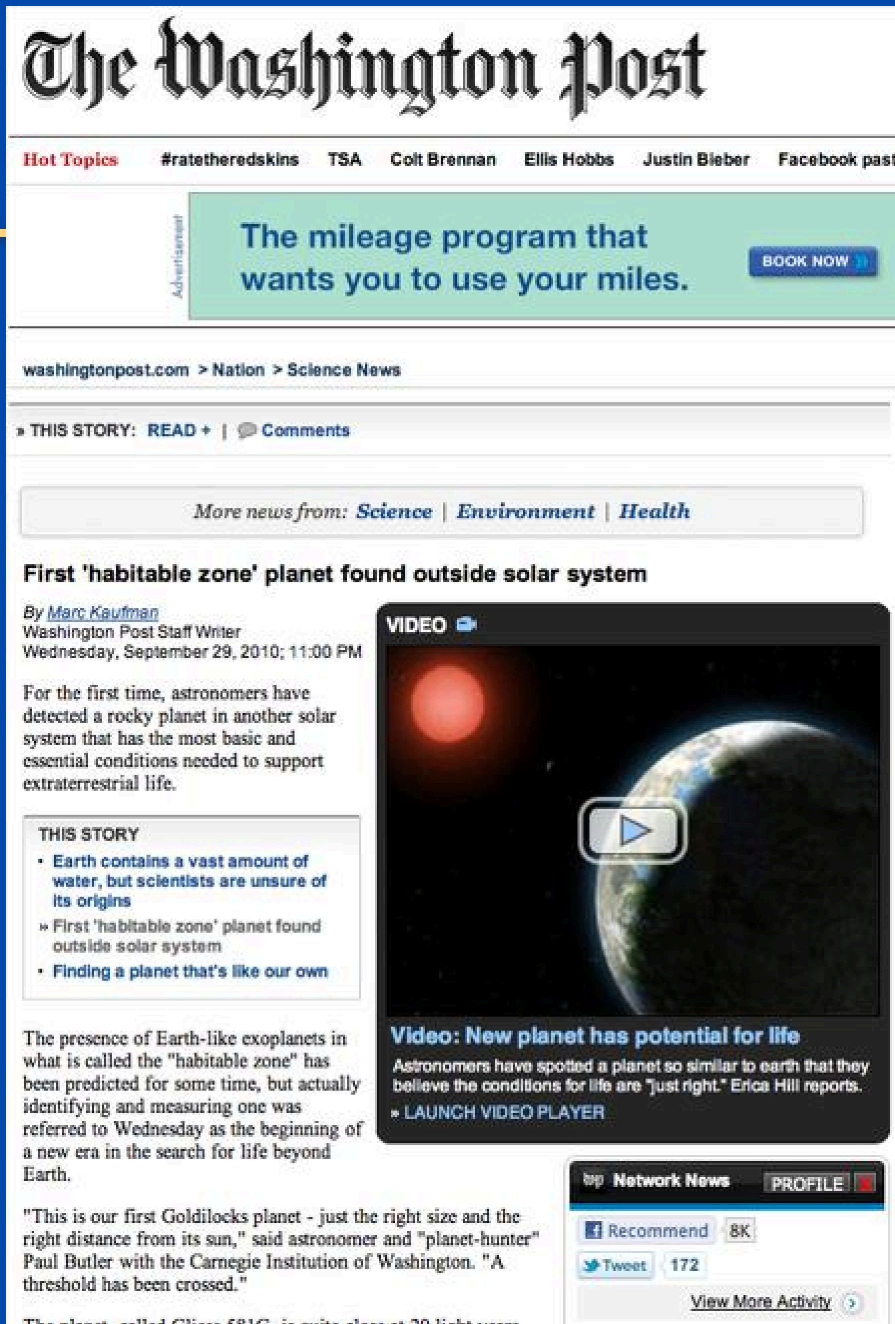
- Must be old enough that life could arise
  - More than a few x 10^8 years old, so not high-mass stars
- They must allow for stable planetary orbits
  - Probably rules out binary and multiple star systems
- They must have relatively large habitable zones
  - Surface temperature that allows water to exist as a liquid



There may be a Habitable Zone in our Galaxy as well

- Too far out in the Galaxy, not enough elements heavier than H and He.
- Too close to center, too high a density of stars & too many supernovae, dangerous to life.
- But this is not a settled question. For example if planet has atmosphere and B field, can protect against supernova radiation.





The Washington Post

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First 'habitable zone' planet found outside solar system

By Marc Kaufman
Washington Post Staff Writer
Wednesday, September 29, 2010; 11:00 PM

For the first time, astronomers have detected a rocky planet in another solar system that has the most basic and essential conditions needed to support extraterrestrial life.

THIS STORY
- Earth contains a vast amount of water, but scientists are unsure of its origins
- » First 'habitable zone' planet found outside solar system
- Finding a planet that's like our own

VIDEO

Video: New planet has potential for life

Astronomers have spotted a planet so similar to earth that they believe the conditions for life are "just right." Erica Hill reports.

» LAUNCH VIDEO PLAYER

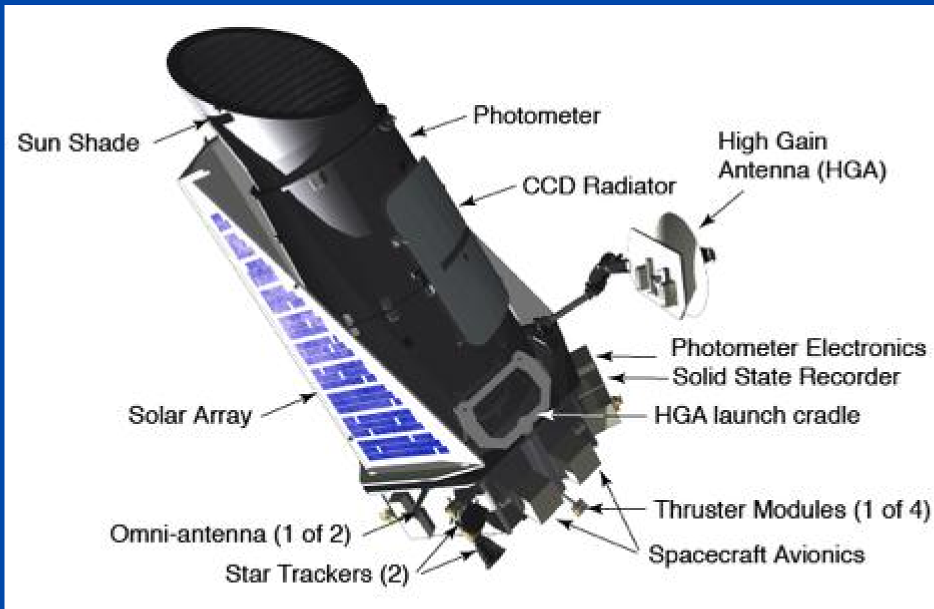
The presence of Earth-like exoplanets in what is called the "habitable zone" has been predicted for some time, but actually identifying and measuring one was referred to Wednesday as the beginning of a new era in the search for life beyond Earth.

"This is our first Goldilocks planet - just the right size and the right distance from its sun," said astronomer and "planet-hunter" Paul Butler with the Carnegie Institution of Washington. "A threshold has been crossed."

The planet, called Gliese 581G, is quite close at 20 light years

Kepler space mission has found many more!

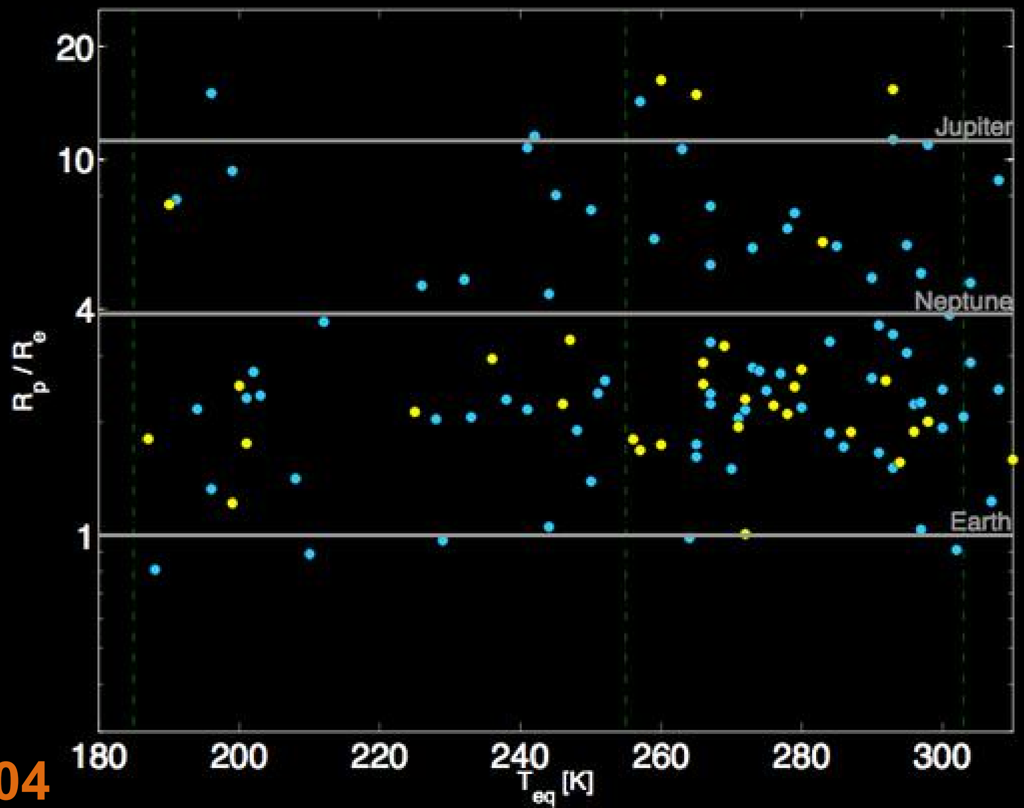
http://kepler.nasa.gov



- Searched for and monitor transits around 100,000 stars : frequency of Earth-size planets, semi-major axes of their orbits

Candidates in Habitable Zone

As of November 4, 2013

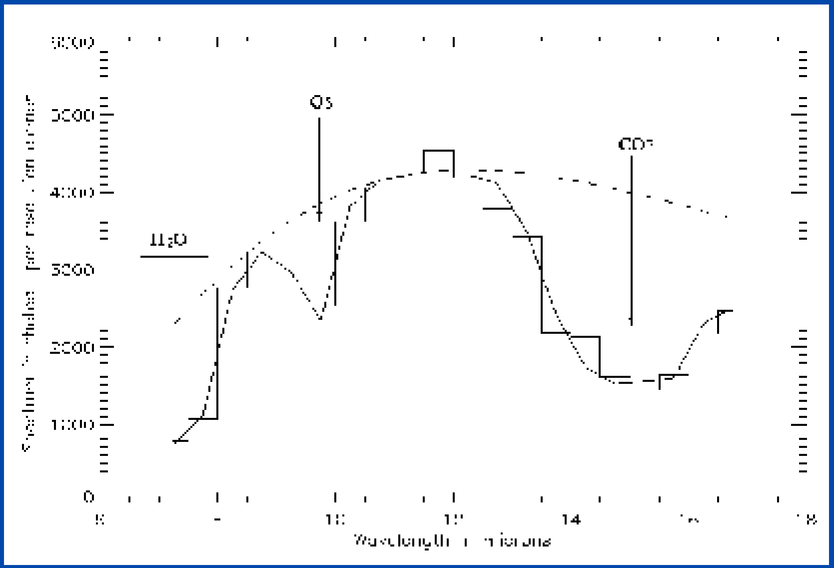


Total = 104

Signs of life

- **Oxygen is highly reactive**
  - **Not stable in Earth's atmosphere: maintained by plants**
  - **Earliest fossils were already photosynthesizing**
    - » **oxygen in atmosphere good indicator of life even in early stages**

- **Spectroscopic detection possible**
  - **in infra-red to reduce background from star**
  - **good for 3-atom molecules**
  - **detect CO_2 (atmosphere), H_2O (oceans), O_3 (life)**



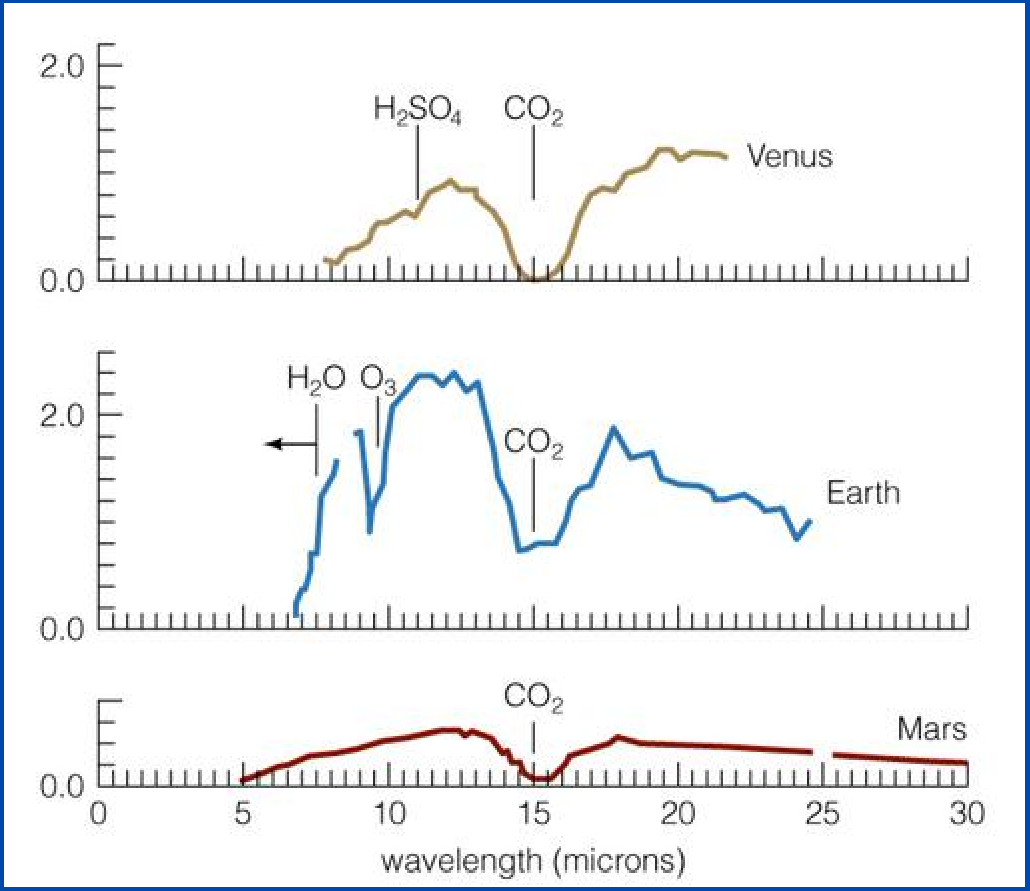
Simulated spectrum from DARWIN homepage

Specific Spectral Signatures of Life

Venus

Earth

Mars



oxygen/ozone

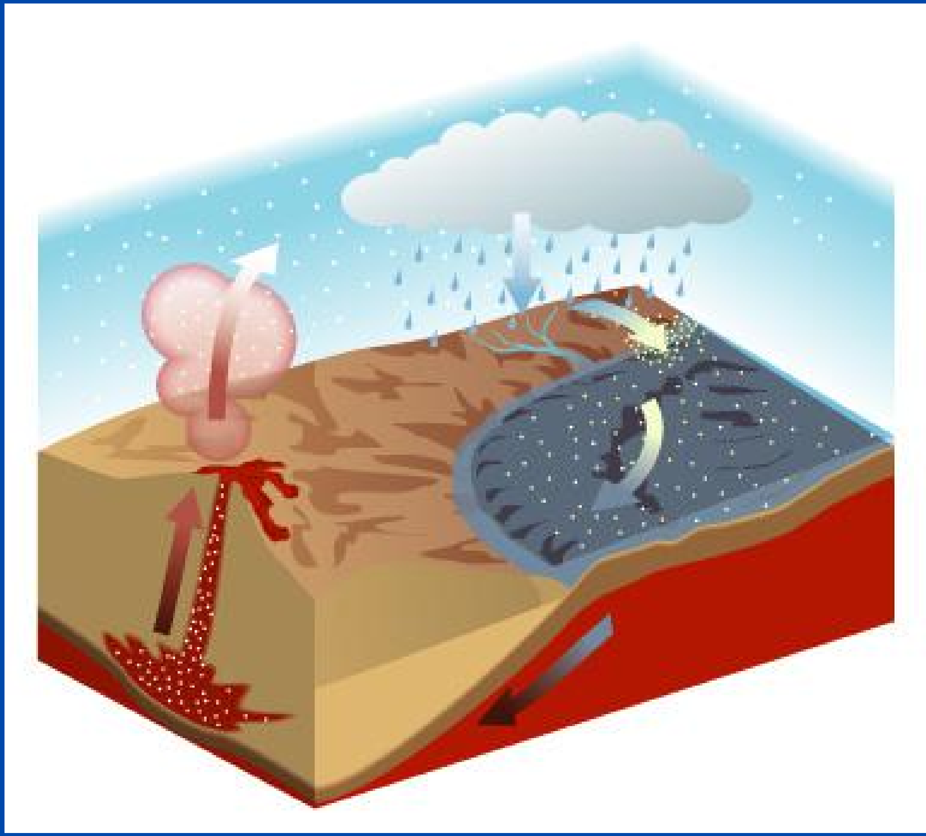
Renewed interest in “Astrobiology”

- **Reasons:**
  - **discovery of extrasolar planets indicate that planetary systems are common**
  - **organic molecules are found throughout the Solar System and Galaxy**
  - **geological evidence suggests life on Earth arose as soon as it was possible**
  - **discovery that living organisms can survive in the most extreme conditions on Earth**

Impacts and Habitability

- Some scientists argue that Jupiter-like planets are necessary to reduce rate of impacts on the terrestrial planets
- If so, then Earth-like planets may be restricted to star systems with Jupiter-like planets

Climate and Habitability



- Some scientists argue that plate tectonics and/or a large Moon are necessary to keep the climate of an Earth-like planet stable enough for life
- Would make habitable planets more rare

We don't yet know how important or negligible these concerns are.

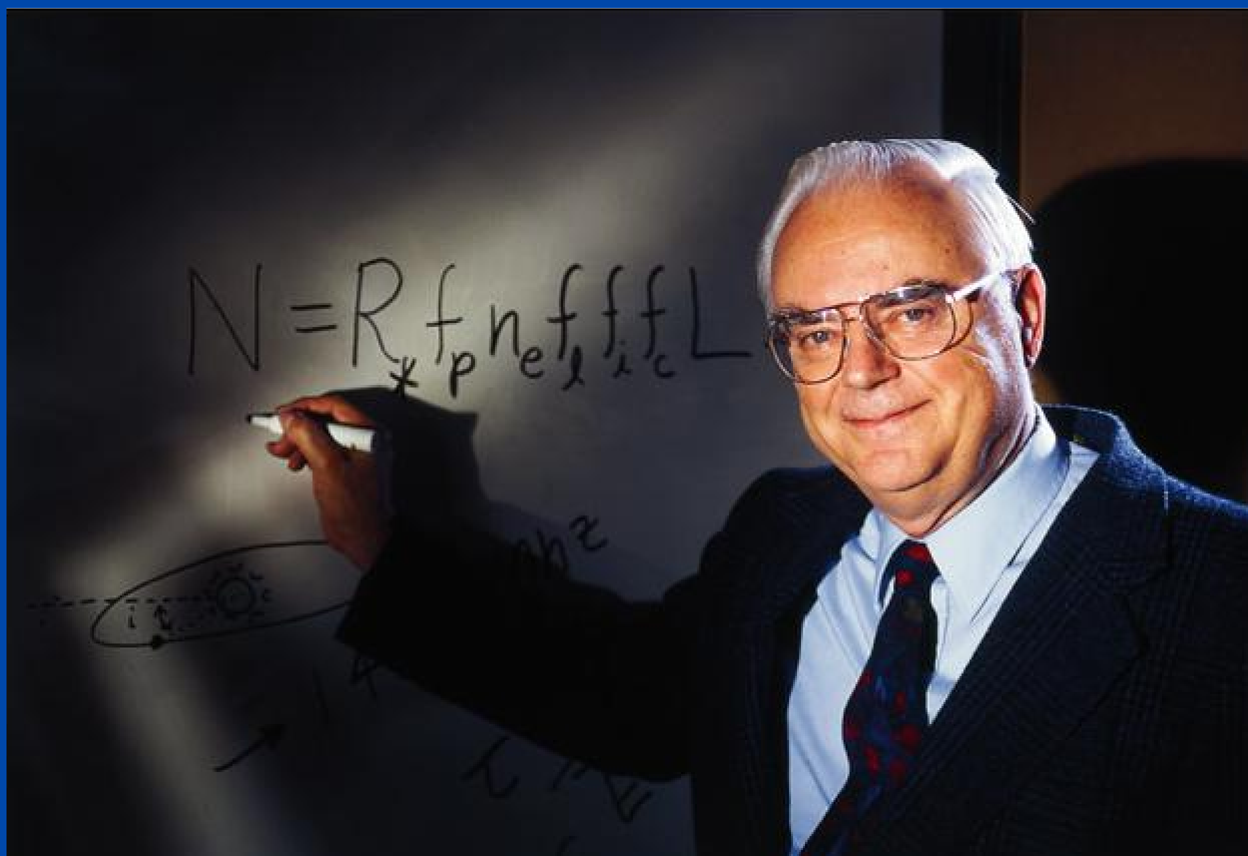
Life beyond microbes: Rare or Common?

- **Why animal life may be common:**
  - **billions of stars in Galaxy have medium-size habitable zones**
  - **planet formation theory: easy to form terrestrial planets**
  - **life on Earth began as soon as conditions allowed**
- **But some scientists propose "rare Earth hypothesis"**
  - **terrestrial planets may only form around stars with high abundances of heavy elements**
  - **the presence of our Jupiter deflects comets and asteroids from impacting Earth, so animal life can evolve from microbes**
  - **hence must have a Jupiter that did not migrate in towards the sun**
  - **Earth has plate tectonics which allows the CO_2 cycle to stabilize climate, so animal life can evolve**
  - **Moon, result of chance impact, keeps tilt of Earth's axis stable**

The Search for Extraterrestrial Intelligence

- **What is the Drake equation and how is it useful?**
- **What is SETI?**

How many civilizations are out there?



Professor Frank Drake, UCSC (retired)

How many civilizations exist in our Galaxy with whom we could make contact?

N_{HP} = number of habitable planets in the Galaxy

f_{life} = fraction of habitable planets which actually contain life

f_{civ} = fraction of life-bearing planets where a civilization has *at some time* arisen

f_{now} = fraction of civilizations which exist *now*

$$\text{Number of civilizations} = N_{HP} \times f_{life} \times f_{civ} \times f_{now}$$

- **This simple formula is a variation on an equation first expressed in 1961 astronomer Frank Drake (UCSC)**
- **It is known as the Drake equation.**

How many civilizations exist in our Galaxy with whom we could make contact?

- Values of the terms in Drake Equation are unknown
- The term we can best estimate is N_{HP}
  - including single stars whose mass < few $M_{\odot}$ AND…
  - assuming 1 habitable planet per star, N_{HP} ~ 100 billion
  - unless the “rare Earth” ideas are true
- Life arose rapidly on Earth, but it is our only example
  - f_{life} could be close to 1 or close to 0
- Life flourished on Earth for 4 billion yrs before civilization arose
  - value of f_{civ} depends on whether this was typical, fast, or slow
- We have been capable of interstellar communication for 50 years out of the 10 billion-year age of the Galaxy
  - f_{now} depends on whether civilizations survive longer than this

How does SETI work?

SETI experiments look for *deliberate* signals from E.T.

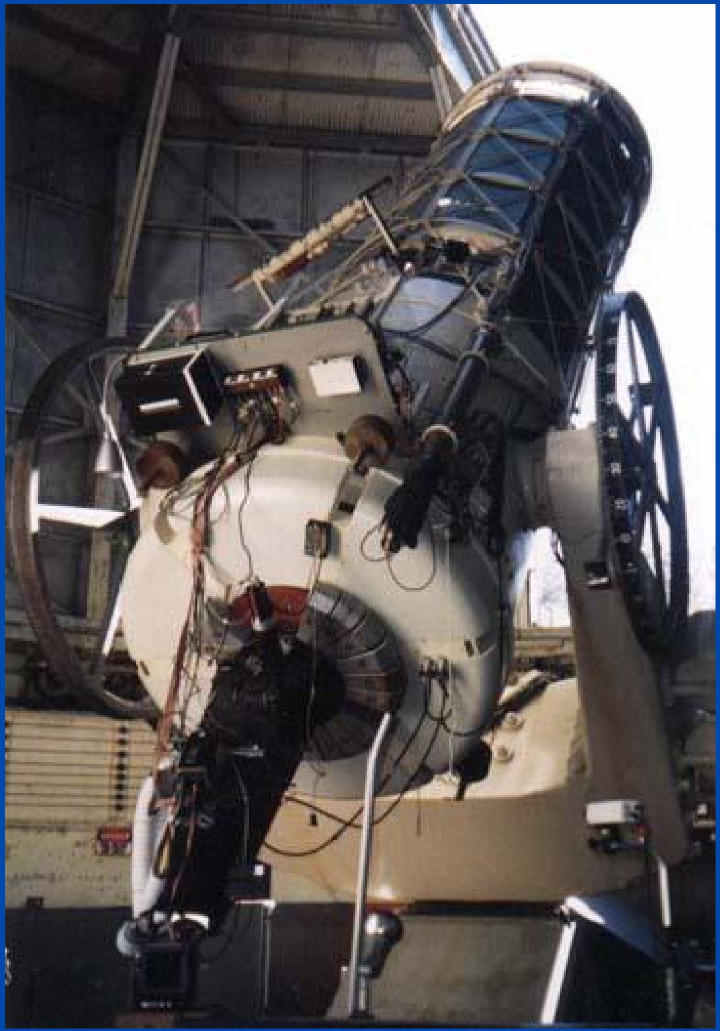
Search for ExtraTerrestrial Intelligence

- IF we are typical of intelligent species and…
- IF there are many intelligent species out there…
  - then some of them might also be interested in making contact!
- That is the idea behind the SETI program.

- Radio telescopes listen for encoded signals.
  - strategies to decide which stars to observe
  - scan millions of frequencies at once
- We sent a powerful signal once in 1974 to the globular cluster M13
  - now we just listen
- SETI is privately funded
  – NASA dropped funding when a senator made fun of SETI

Also "Optical SETI" - search for spectral lines typical of common lasers

- A search for intense short laser pulses, transmitted deliberately in our direction by another civilization.
- Harvard
- Lick Observatory
- Princeton
- Columbus Ohio

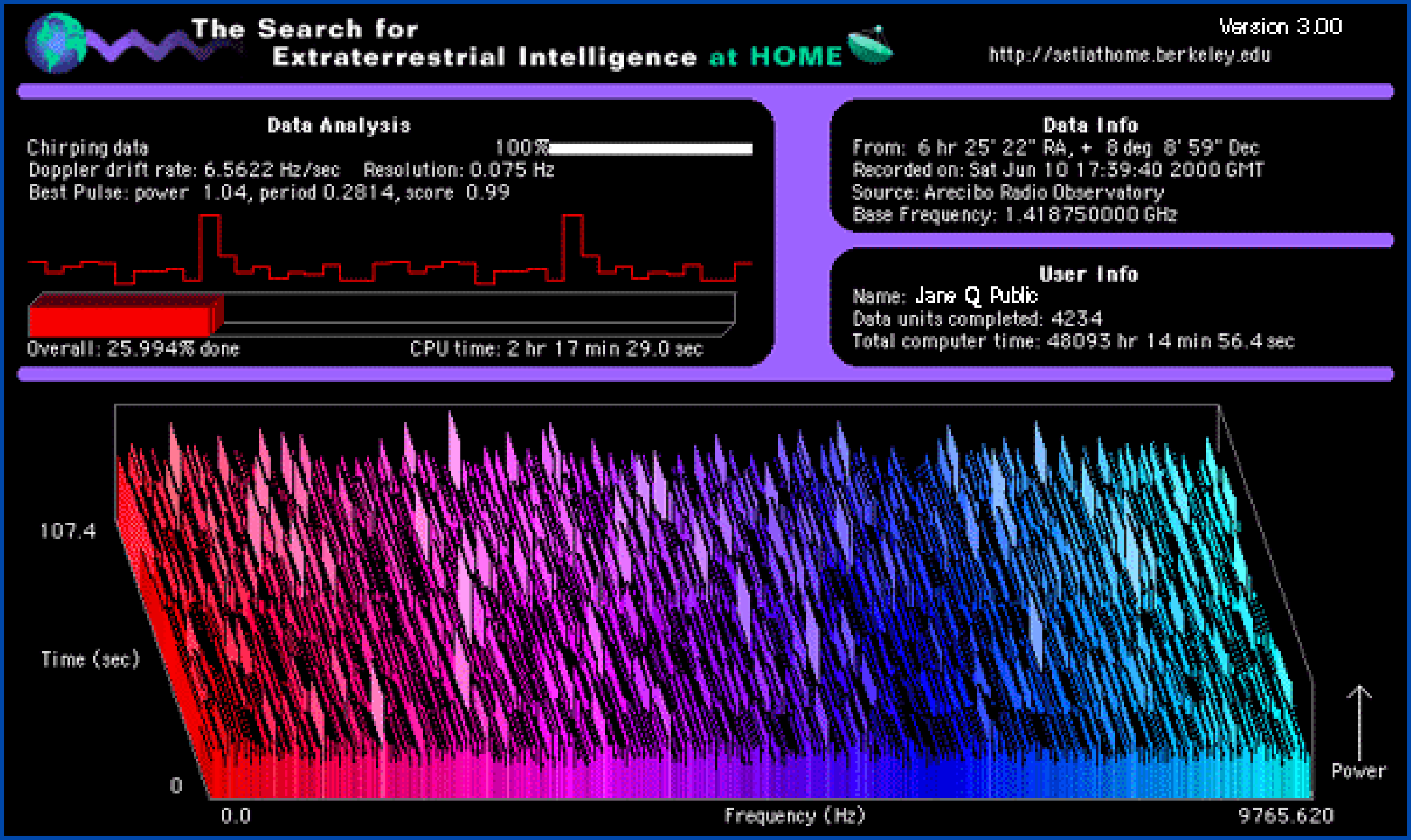


We've even sent a few signals ourselves…

Earth to globular cluster M13: Hoping we'll hear back in about 42,000 years!

You can participate in SETI@home

- **Screensaver that analyzes results from Arecibo radio telescope, sends back results to SETI**



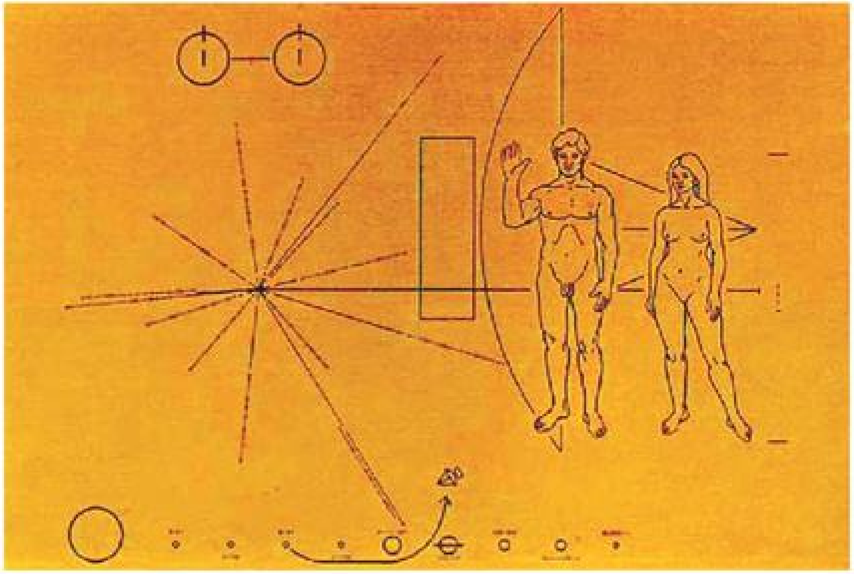
http://setiathome.ssl.berkeley.edu/

Interstellar Travel and Its Implications for our Civilization

- **How difficult is interstellar travel?**
- **Where are the aliens?**

Current Spacecraft are WAY too slow

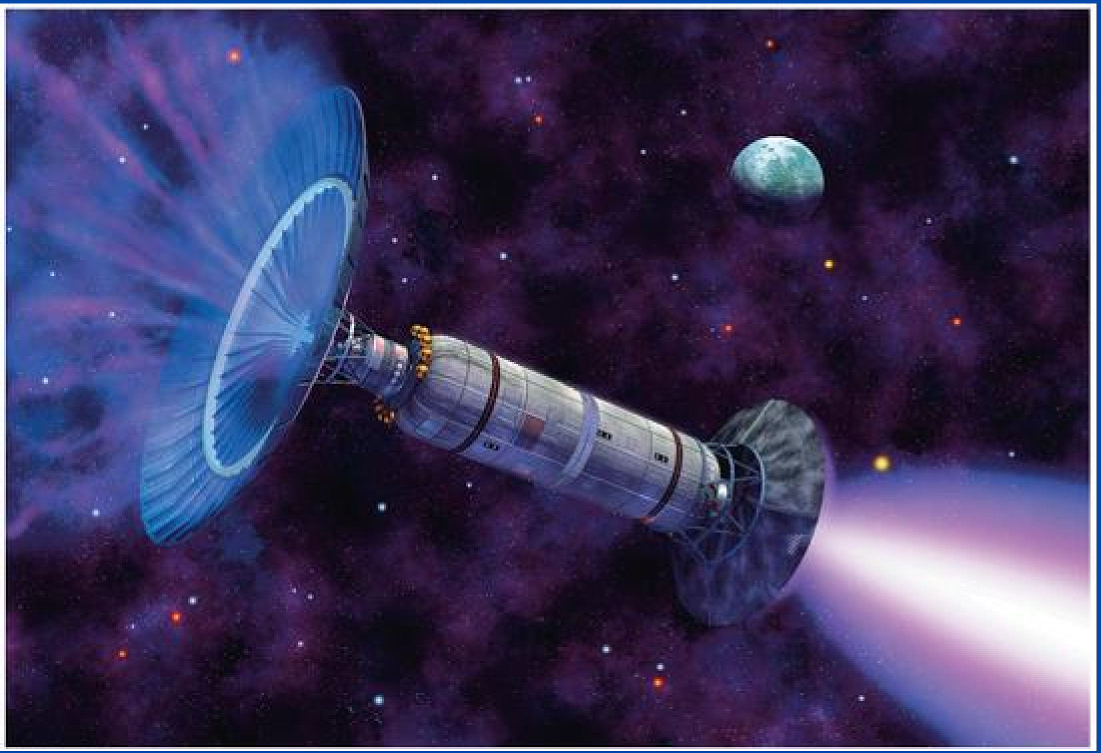
- **Current spacecraft travel at < 1/10,000 *c*; 100,000 years to the nearest stars**



Pioneer plaque

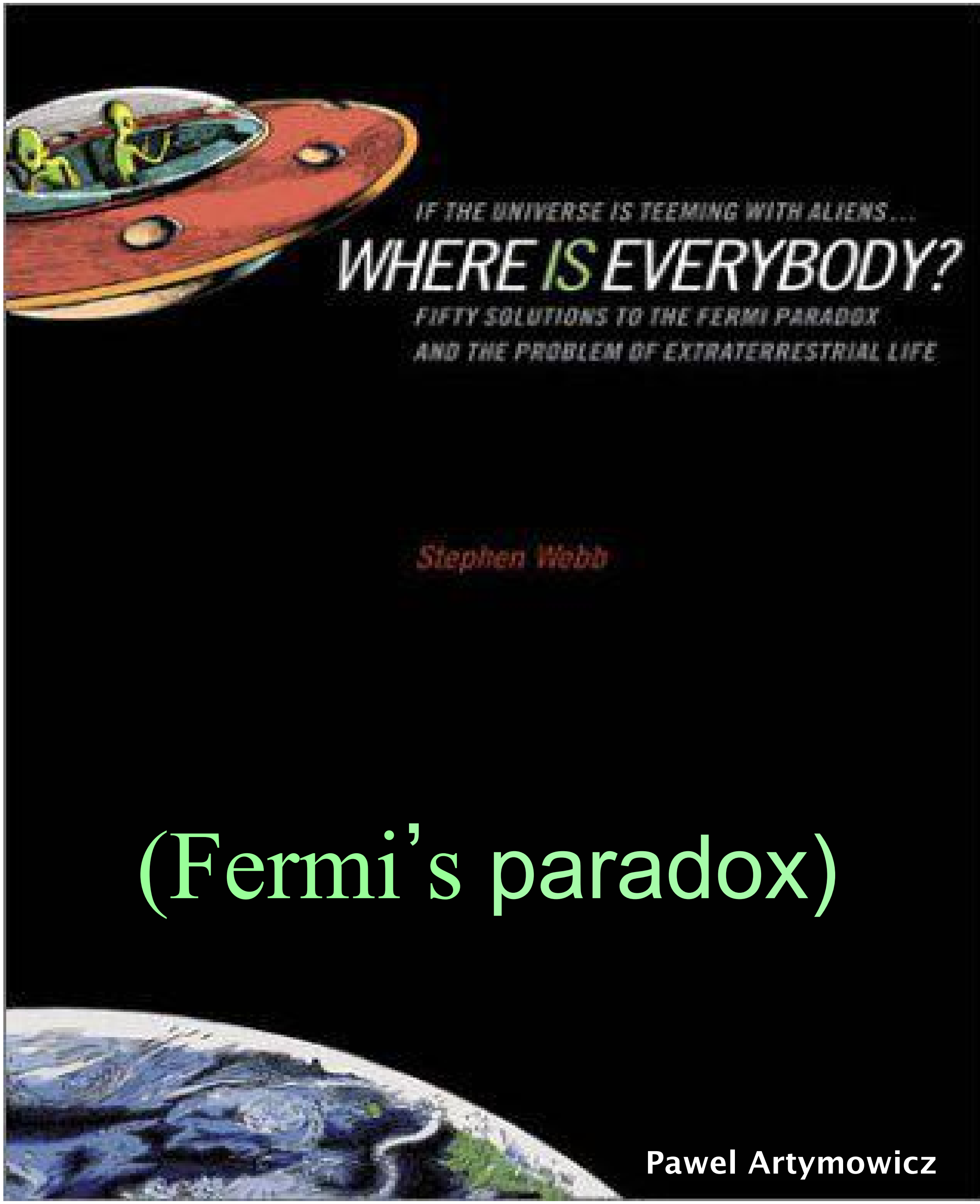
Voyager record

Difficulties of Interstellar Travel



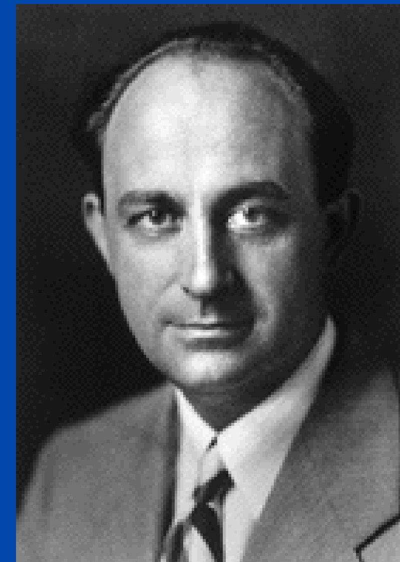
- Far more efficient engines are needed.
- Ordinary interstellar particles become like cosmic rays.
- Social complications of time dilation.

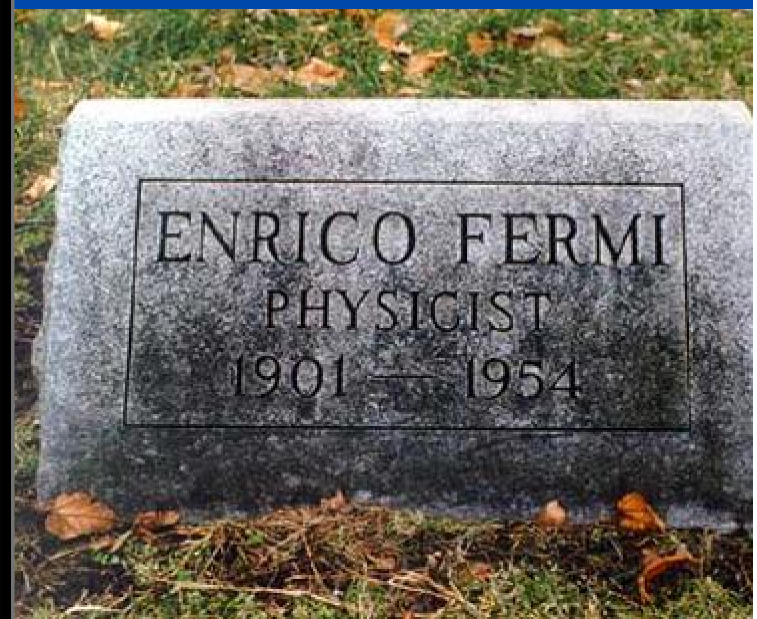
Energy: to accelerate a single spacecraft the size of Starship Enterprise to half the speed of light would require 2,000 times the total annual energy use of the whole world today



(Fermi's paradox)

Pawel Artymowicz





Where are the Aliens?
Fermi's paradox

- With current technology it is plausible that…
  - within a few centuries, we could colonize a few nearby stars
  - in 10,000 years, we could spread out to 100s of light years
  - in a few million years, human outposts throughout the Galaxy
- Assume most civilizations take 5 billion yrs to arise:
  - the Galaxy is 10 billion yrs old, 5 billion yrs older than Earth
  - IF there are other civilizations, the first could have arisen as early as 5 billion yrs ago
  - there should be many civilizations which are millions or billions of years ahead of us
  - they have had plenty of time to colonize the Galaxy
- So…where is everybody? Why haven't they visited us?

Possible Solutions to Fermi's Paradox

- We are really alone
  - civilizations are extremely rare and we are the first one to arise
  - then we are unique, the first part of the Universe to attain self-awareness
- Civilizations are common, but have not colonized
  - interstellar travel is even harder or costlier than we imagine
  - most civilizations have no desire to travel or colonize
  - most civilizations have destroyed themselves before they could
- There *is* a Galactic civilization
  – it has deliberately concealed itself from us
- We may know which solution is correct within your generation!

Main Points

- Life elsewhere in the universe:
  - None discovered yet
  - Building blocks seen throughout interstellar space
  - Microbial life seems VERY resilient here on Earth
  - Promising other sites for life in our Solar System
  - Kepler spacecraft is finding many Earth-like planets

- Big unknowns: are conditions for animal-type life common, or rare?