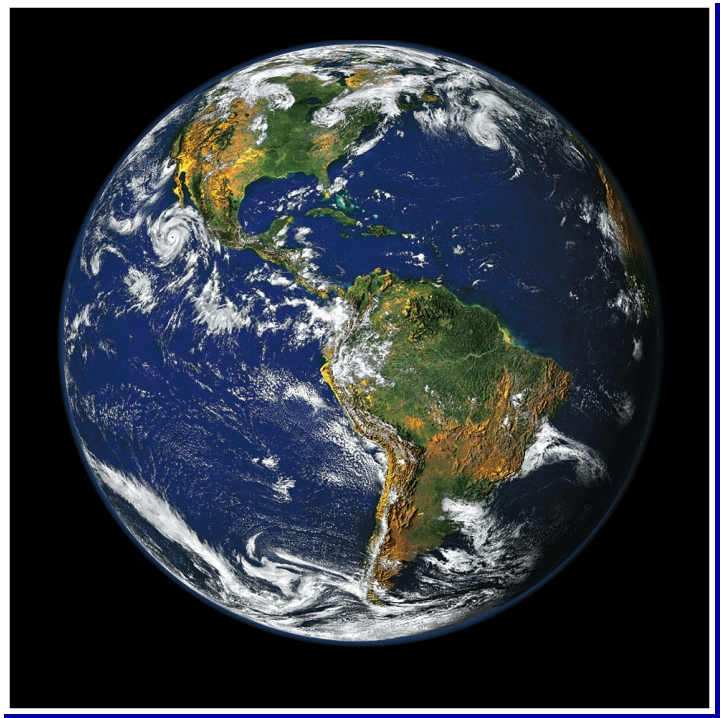


Our Biosphere: Past and Future

Music to gather by

Academy for Lifelong Learning

October 24 - November 14, 2017

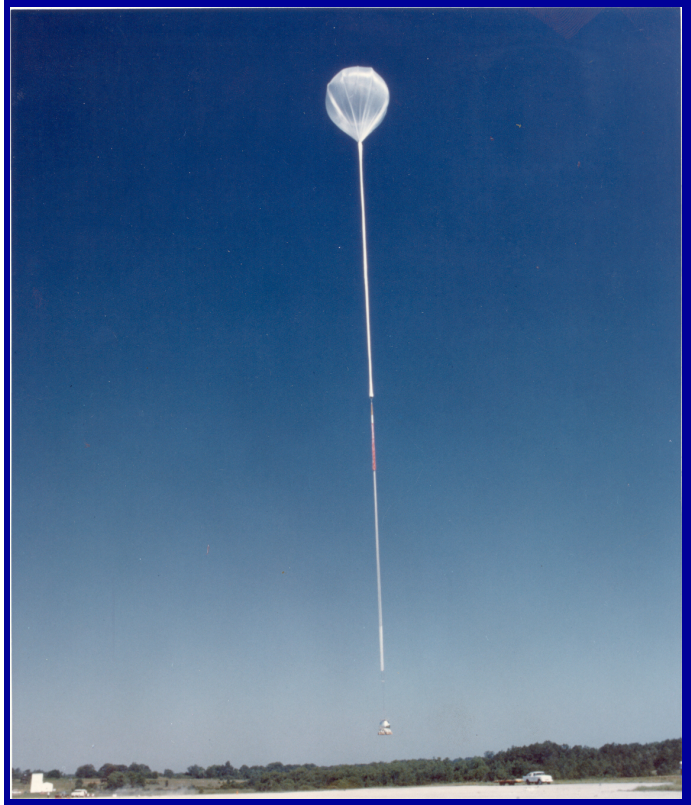
Jonathan F. Ormes

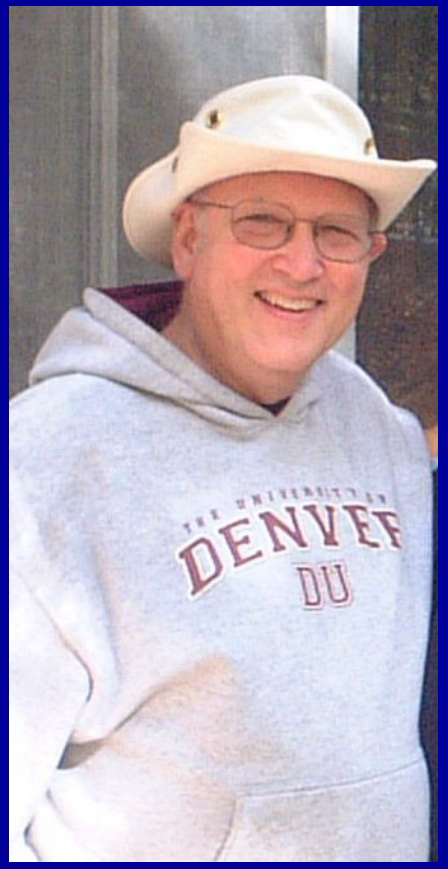
JFOrmes@comcast.net

Stanford University

UNIVERSITY OF MINNESOTA

Director of Space Sciences 2000-2004





Public Announcement

Presentation slides and handouts can be downloaded from either the link at the Academy's web site or directly from this Web site at DU:

http://portfolio.du.edu/OurClimate

The site is public.
You do not need to create an account.
Search for "OurClimate".

The Academy also has a link to my page there.
Click on **Courses** and then on the last item on the scroll down menu
Course Materials

http://www.academyll.org/course-materials/

Life might be called the "music of the spheres"

- Lithosphere
  - Rocky
- Atmosphere
  - Vapor
- Hydrosphere
  - Water
- Biosphere
  - Life

Play this

Boundaries are sometimes "fuzzy"

Hydro can include water in clouds and on land

Biota are found in all the other spheres, even deep underground extremophiles

Interesting things happen at the boundaries

Earth's biosphere temperature is controlled by a very thin layer of atmosphere!

The Greenhouse Effect keeps the planet warm and habitable.

Course outline

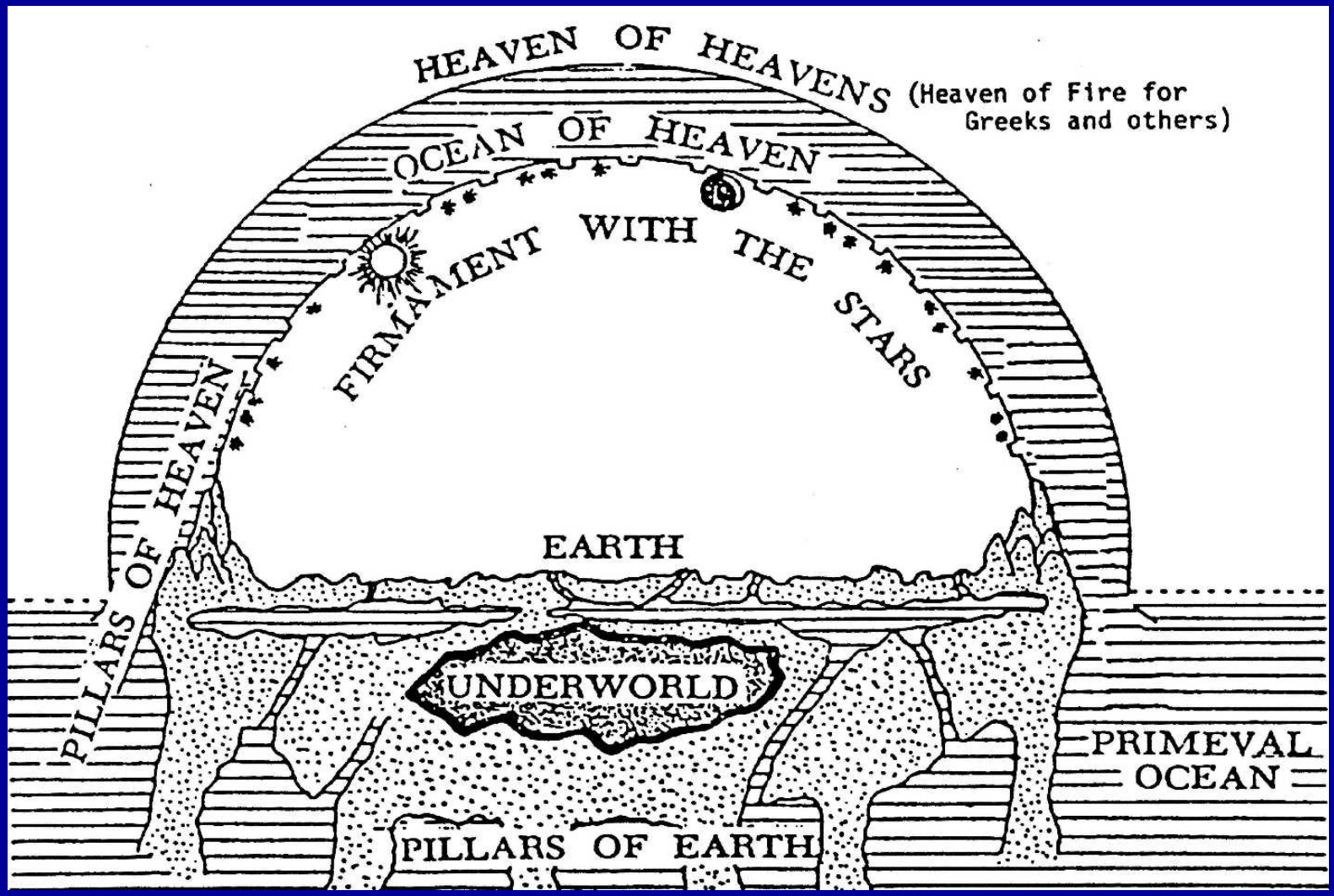
1. Origin of the Biosphere and Life
   - Planet Formation and the Origin of Life
   - Life on Earth: By Chance or By Law?
2. Guest speaker: Alexandra Jahn
   - Paleoclimate
   - Assistant Professor, Dept. for Atmospheric and Oceanic Sciences, CU-Boulder
3. Energy revolution and climate prospects
4. Predicting the future
   - Ethics and scarcity

Garden of Earthly Delights
by Hieronymus Bosch

How to describe the indescribable

“But I don’t want to go among mad people," Alice remarked.
"Oh, you can’t help that," said the Cat: "we’re all mad here. I’m mad. You’re mad."
"How do you know I’m mad?" said Alice.
"You must be," said the Cat, “or you wouldn’t have come here.”

—Lewis Carroll, *Alice in Wonderland*



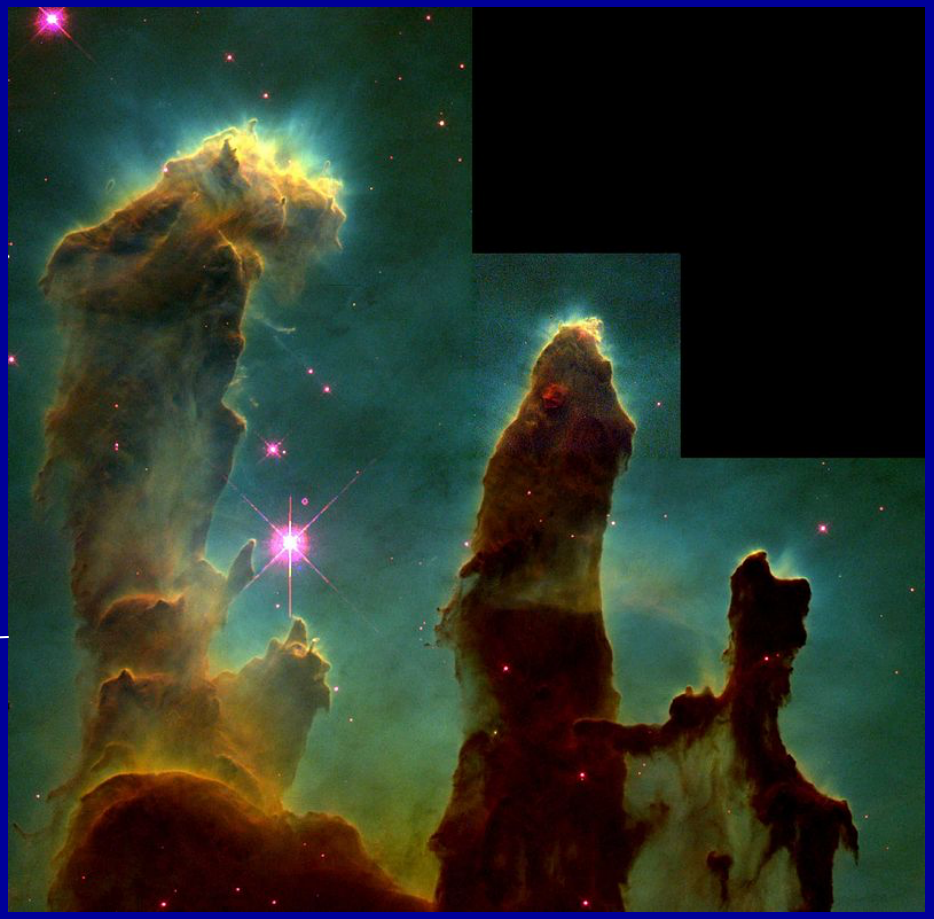
http://rosarubicondior.blogspot.com/2013/01/why-god-couldnt-have-written-bible.html

"I'll say one thing for the Bible: it's full of good laughs."
Rosa Rubicondior

The Flammarion engraving (1888), so called because it first appeared in his book *L'atmosphère: météorologie populaire* ("The Atmosphere: Popular Meteorology")

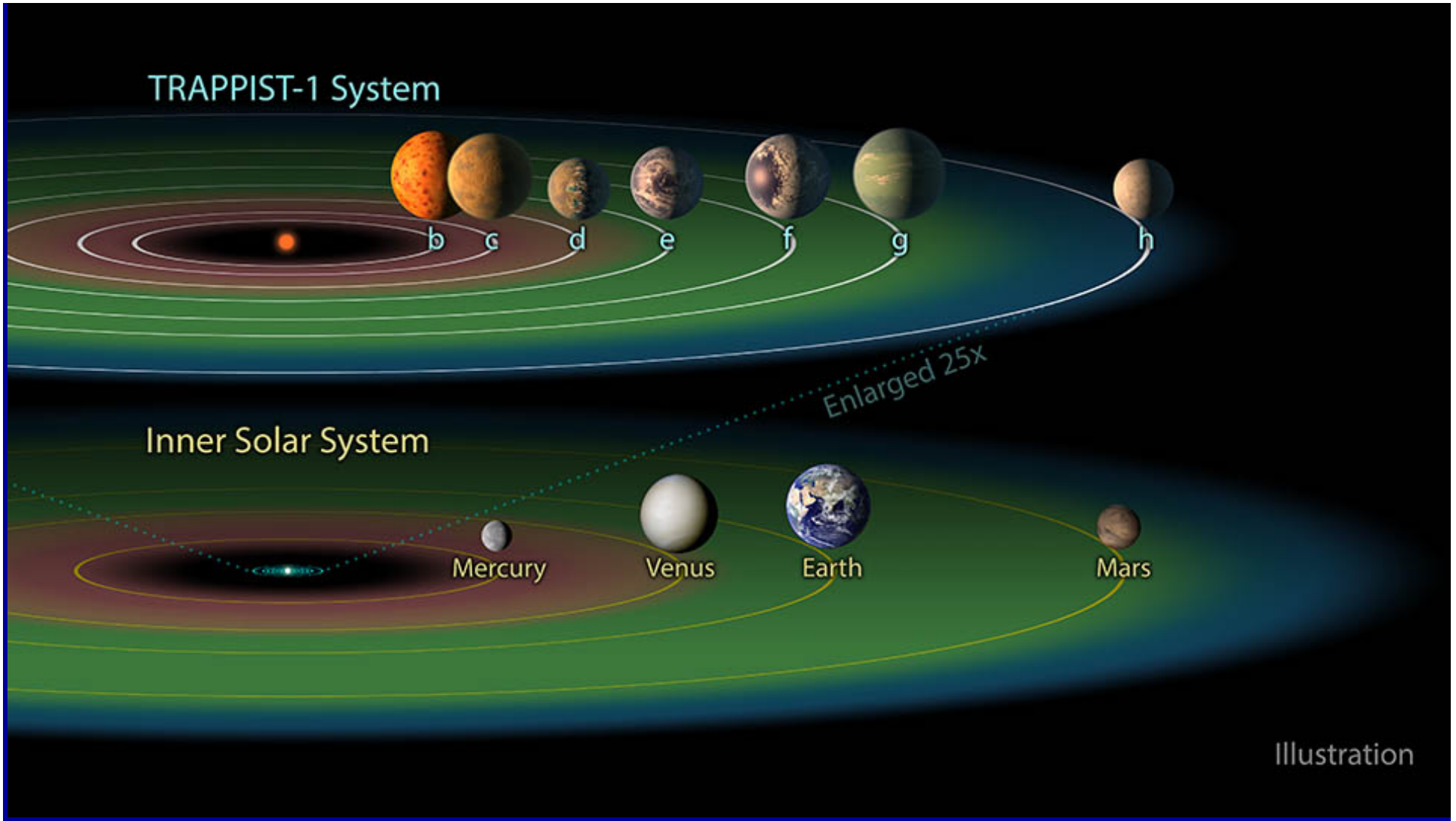
The engraving depicts a traveler who arrives at the edge of a flat Earth and sticks his head through the firmament.

Orion Nebula



Credit: Hubble Space Telescope

protostar

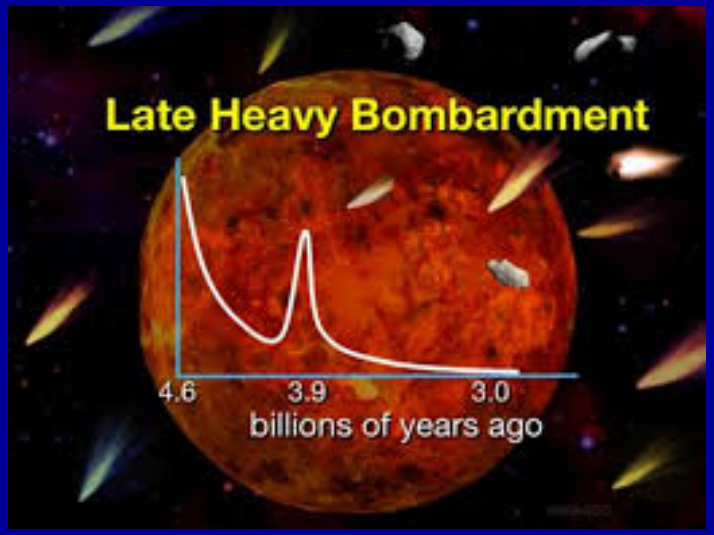


Kepler: 1200 planets =>
500 million planets orbiting stars like sun in our Milky Way galaxy

Collision with another fairly large "planet"

Formed the moon.

Data from the study of impact craters on the moon.

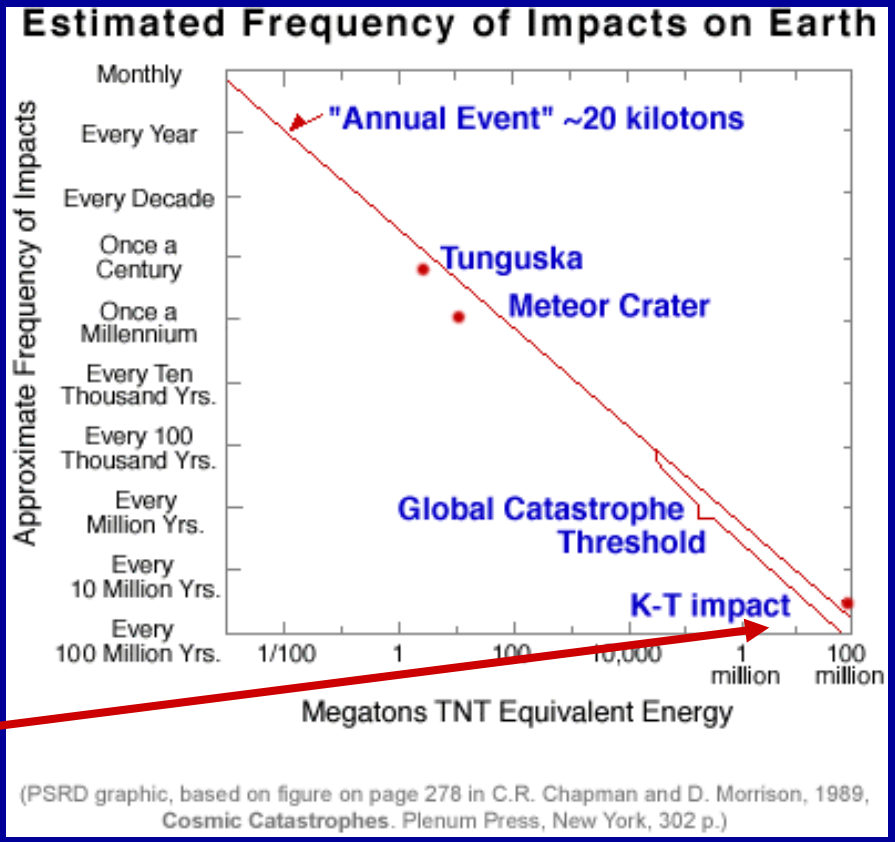



Source: NASA

Meteor Crater in Arizona

The biosphere is not disconnected from what comes in from above, so we might want to think of there being another sphere we might call the Ouranosphere after the Greek word (pre-Christian) for "sky, heaven".

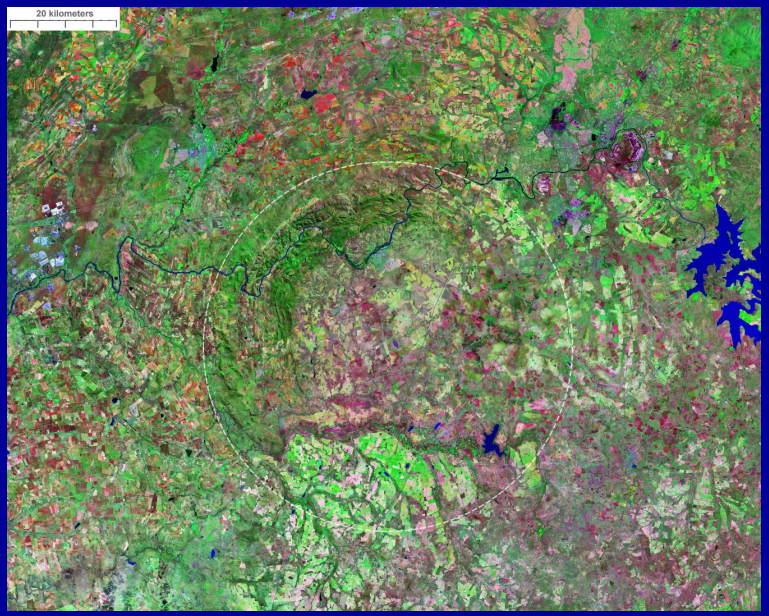
6-8 between 2-4 billion years ago



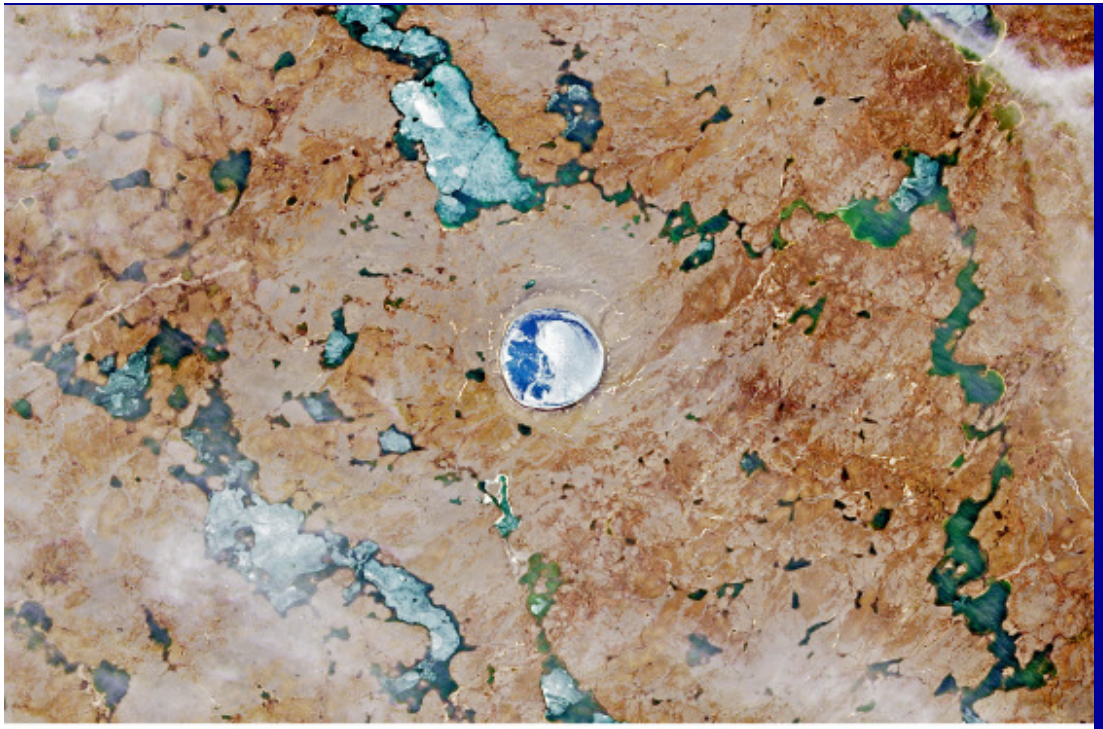
(PSRD graphic, based on figure on page 278 in C.R. Chapman and D. Morrison, 1989, **Cosmic Catastrophes**. Plenum Press, New York, 302 p.)

Sudbury Crater,
Ontario, Canada
1.85 Gya
155 miles diameter

Verdefort Crater,
South Africa, 2 Gya
112 miles diameter



Chicxulub, 6-9 miles diameter, 66 MYa
What about those that hit in the oceans? a giant tsunami

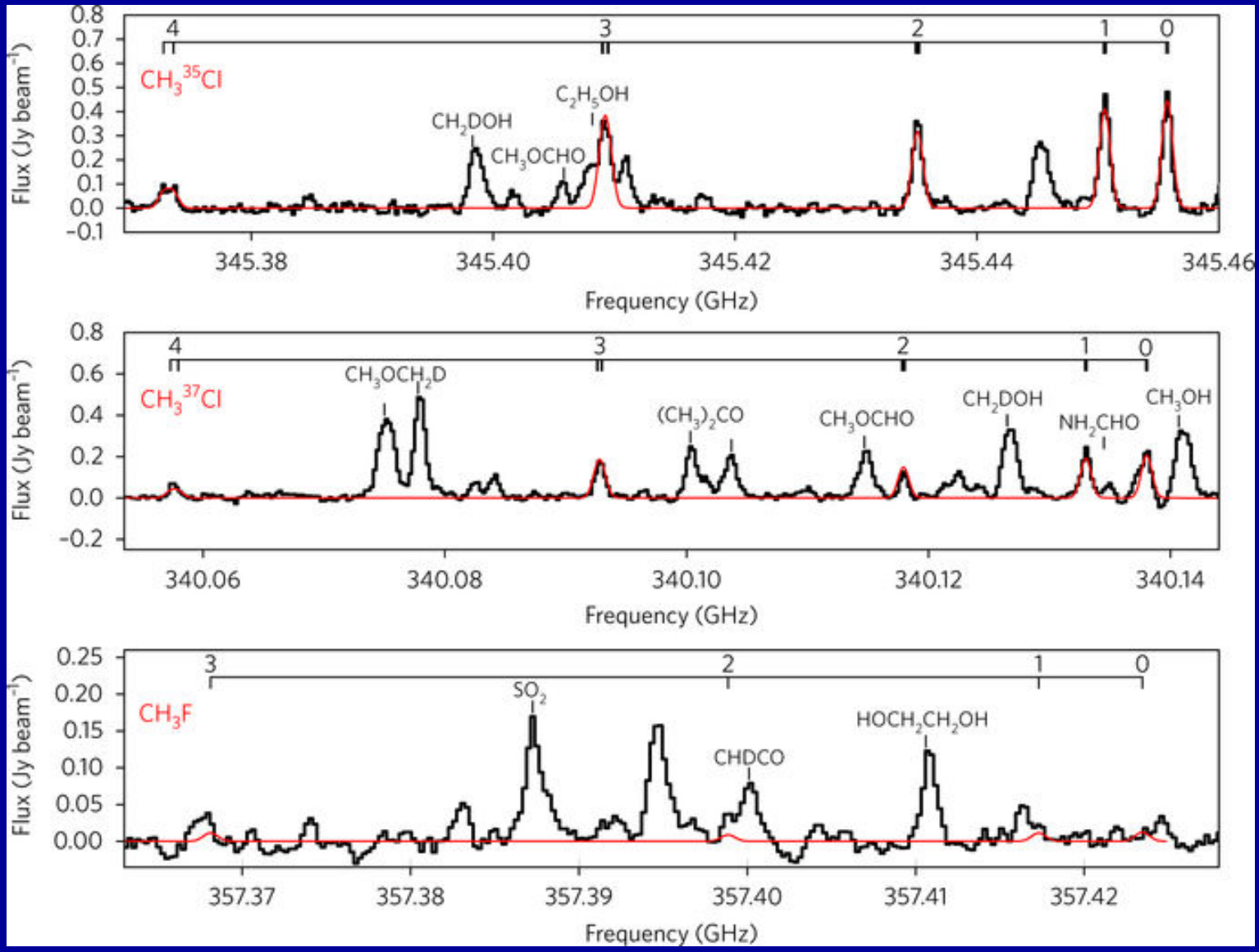


Crater Lakes are more common than thought.

Pingualuit Impact Crater, Quebec, Canada

Far IR spectrum around protostar

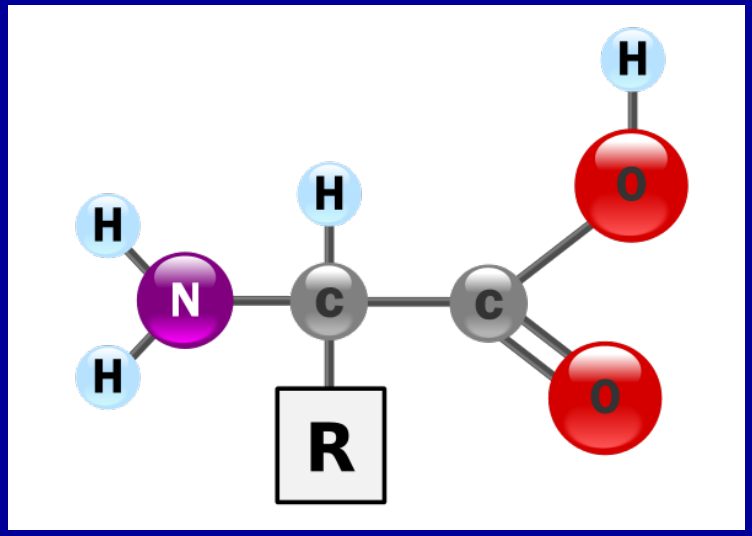
300 GHz ⇔ 1 milimeter



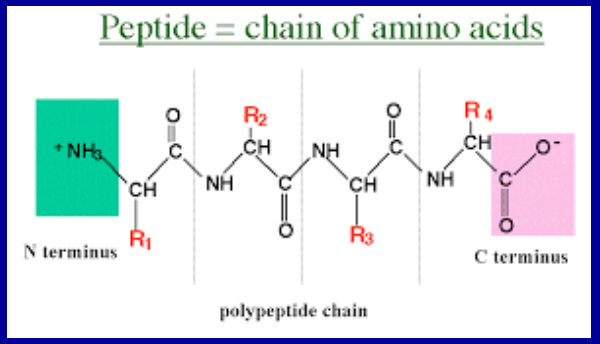
Meteors bring simple organic molecules
Amino acids, hydrogen cyanide, etc.

Collisional energy of "big guys"
Makes peptides

Amine: -NH_2 carboxyl: =COOH



Side group "R" of atoms specific to each acid



Life on planet Earth

- Easy or hard?
- Same here as on other planets, or fundamentally different?
  - Does life always require water?
- Chance vs. inevitable
- Extremophiles

Origin of Life

- When?
- Where?
- How?

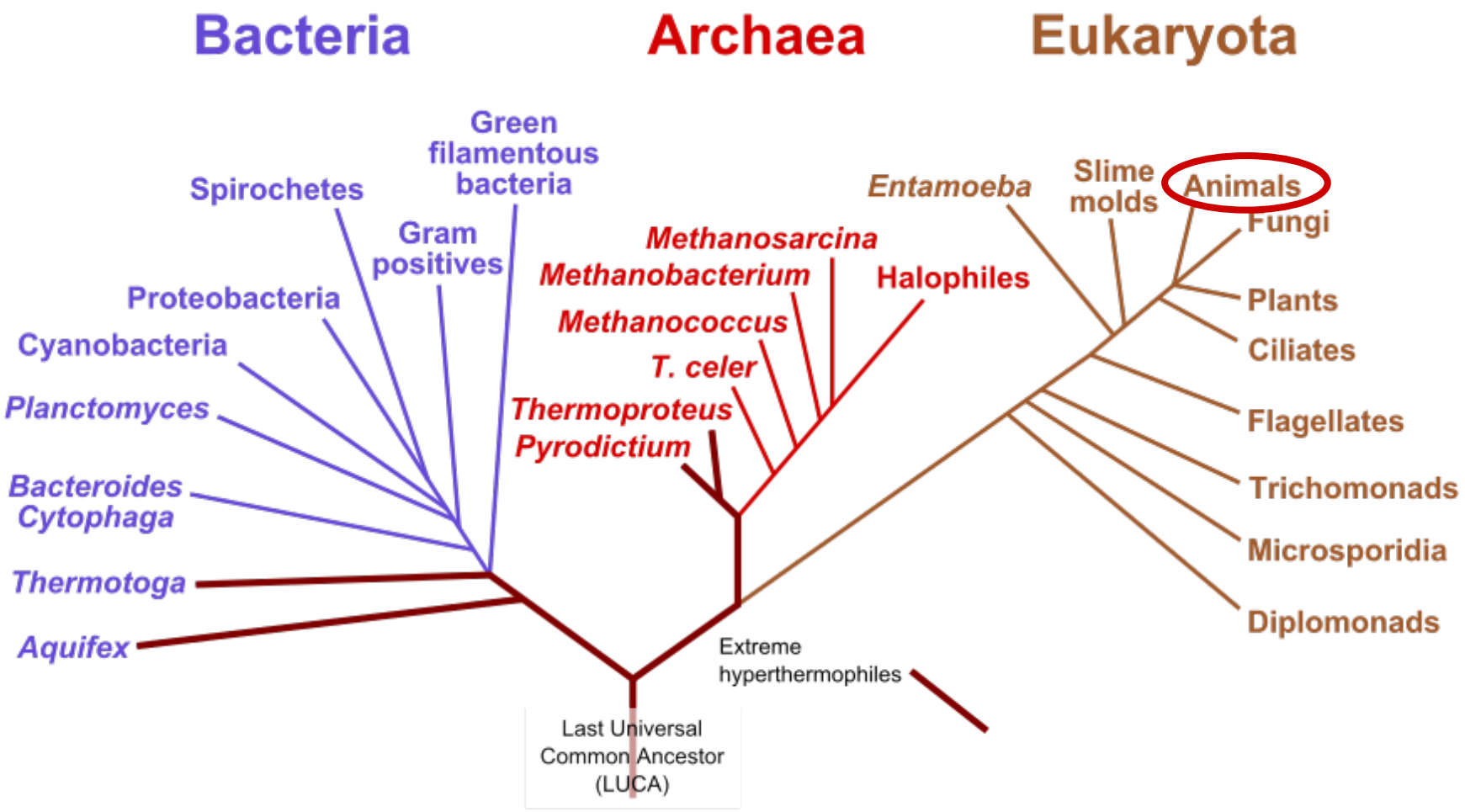
Number of events leading to life

$$\langle N_{abiogenesis}(t)\rangle = N_b \cdot \frac{1}{\langle n_0\rangle} \cdot f_c \cdot P_a \cdot t$$

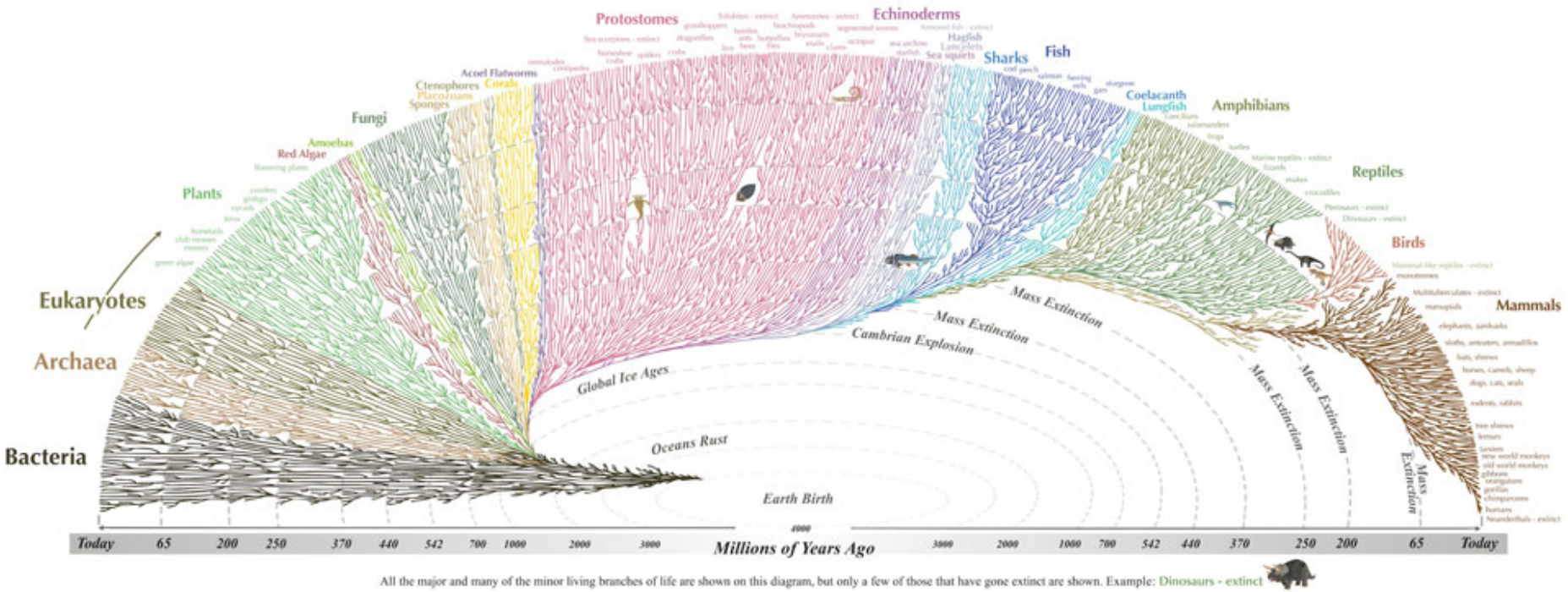
$N_{abiogenesis}$: the number of origin events
probably = 1 or at most a few for Earth

N_b : number of building blocks (must be a big number)
$\langle n_o \rangle$: number of building blocks required to get a living system
F_c : the fraction of the available building blocks
P_a : Probability of an origin event to occur (10^{-33}??) per unit time
assembly of the necessary molecules
t : time available (100 M yr)

Phylogenetic Tree of Life



Tree of Life



All the major and many of the minor living branches of life are shown on this diagram, but only a few of those that have gone extinct are shown. Example: Dinosaurs - extinct

All life is related:
anatomy of internal skeletal creatures is similar;
recall talk on "birds are dinosaurs"

Caveats on tree

1. From mammalian point of view
2. Bacteria hold more genetic diversity
3. Genetic diversity: more branches extinct than exist today
4. Single cell eukaryotes (aka protists) vastly underrepresented
5. Birds not a separate branch – they are a branch of theropod dinosaurs

Some new thinking

- Life is a basic planetary process
- Living systems have radically altered global planetary chemistry

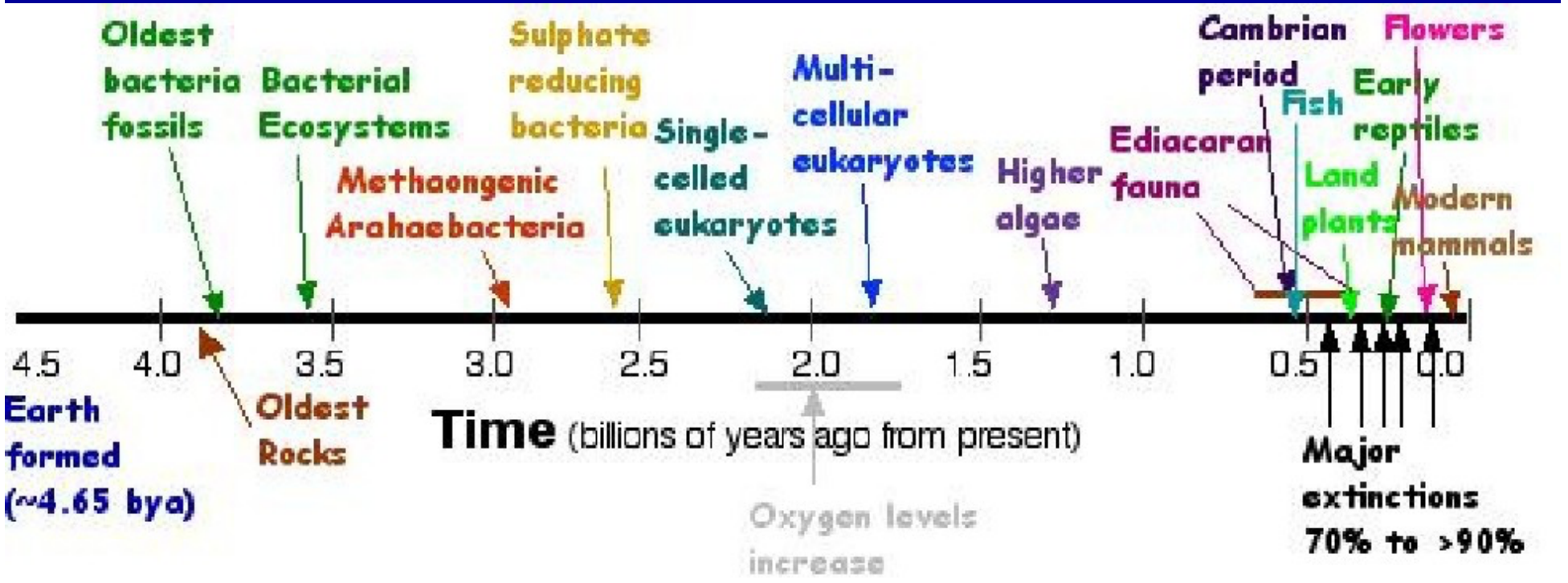
- Living systems are ordered – many ways and at many levels
  - Entropy; include environment
- Although living systems are diverse and heterogeneous, living order is highly selected
- A simple foundation underlies the unlimited complexity
- Durable feature of Earth

Interfaces between geospheres

- Chemicals can pass between geospheres; the interfaces can be concentrating centers for thermodynamic disequilibrium and the emergence of complexity.
- Examples:
  - Volcanic activity releases gases into water and air
  - Weathering removes chemicals from rock and transfers to water

Oldest sedimentary rock surface showing evidence of bacterial mats (3.48 Gya), Pilbara region of Australia.

Timeline

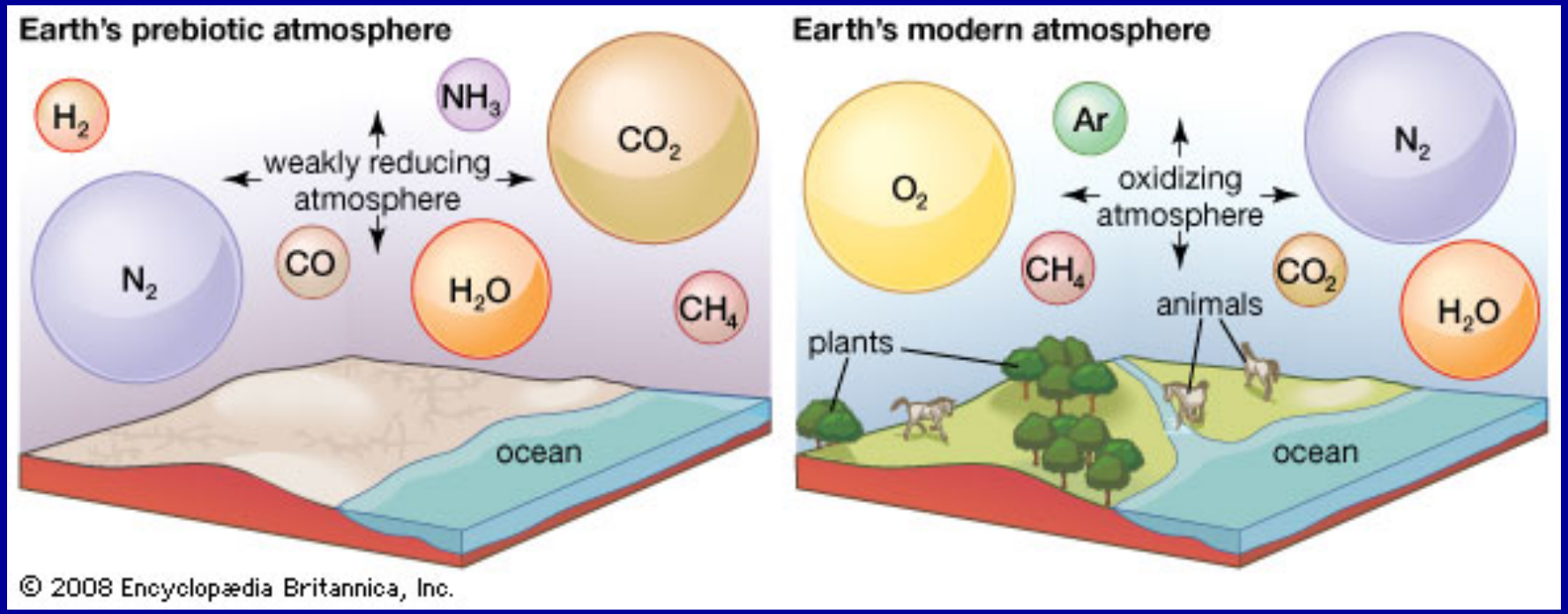


Methanogens still around today as extremophiles found deep in ice, underground and in hot desert environments. Some have a constant metabolism able to repair macromolecular damage, at temperatures of 145 to –40 ° C.

Biota have changed the atmosphere.

Oxygenation of the atmosphere by cyanobacteria, (anaerobic bacteria), the first to produce oxygen by photosynthesis.

began



Earth colored: early

- Red
  - iron
- Grey
  - igneous rocks - granite: quartz and feldspar like Yosemite
- Blue
  - water, brought by comets and asteroids
  - Probably enough water came with the original formation of the planet to provide for early forms of life

Colored Earth: late

- Cyan
  - Cyanobacteria
  - Prokaryote that use sunlight (first photosynthesis)
- Red
  - Rusty rocks
  - Iron oxide hematite
  - Corresponds to the appearance of oxygen
- Green
  - Evolution of plants

Mineral evolution

- Meteorites probably contain about 50
  - None with oxygen
- Gravity differentiated the elements
  - Liquid Earth
  - Iron fell to the center
  - Magnesium, aluminum, silicon etc. rose
  - As Earth cooled, more minerals formed
- We now have list of about 3500 minerals
  - Many with oxygen


Edu Science
Lab
8+
Color changing LED base!
¡Base LED que cambia de color!
Grow 6 crystal colors!
¡Haz crecer 6 cristales de distintos colores!
Grow crystal clusters!
¡Haz crecer racimos de cristales!
LAB GUIDE INCLUDED
GUÍA DE LABORATORIO INCLUIDA
Deluxe
Crystal Growing Kit
Kit de cultivo de cristales deluxe
WARNING:
CAUTION:
WARNING:
TOTAL NET WT. OF CONTENTS: 17.6 OZ (500 g)

Miller – Urey
University of Chicago, early 1950s

https://www.youtube.com/watch?v=xyhZcEY5PCQ

Start 18:33 end 21:35

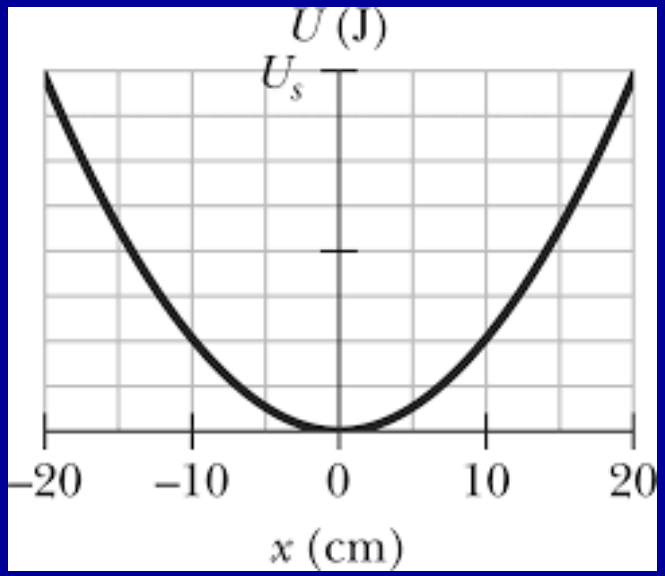
What is Life?

- Physics and chemistry
  - Matter, forces, energy, entropy, reactions
- Biology
  - Coding, signals, instructions, translation
- Information – anything that could be different
  - How does information come about

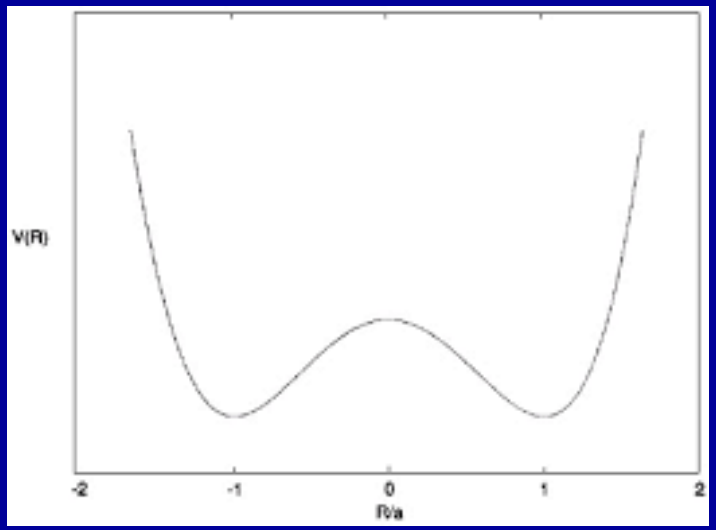
Stuff -> bits

Not to be confused with meaning, something given to information by us.

An example of information

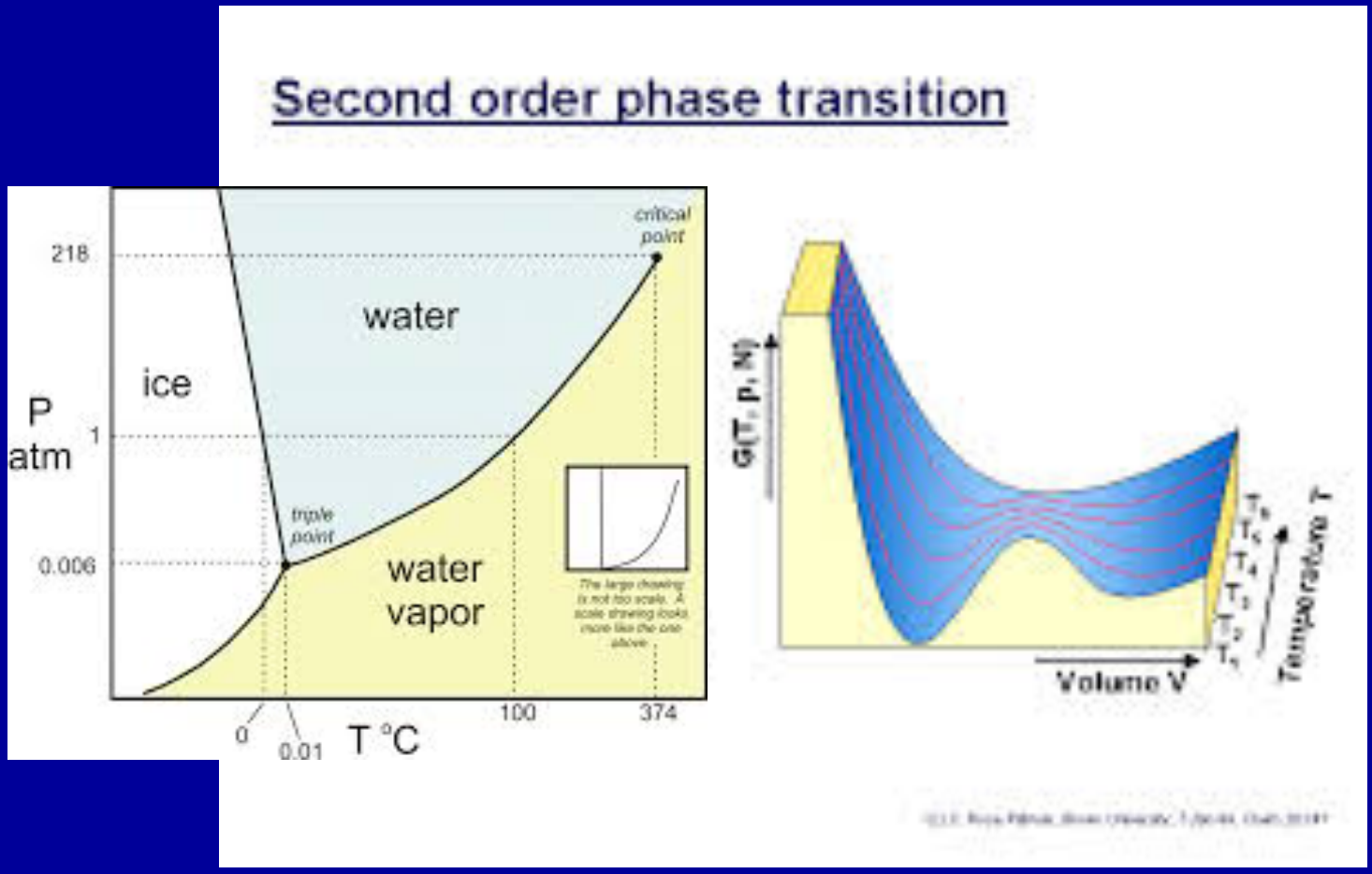


Stable potential



Bistable potential

Gibbs function (thermodynamics)



Phase transitions are probably key to understanding the origin of life

Let's get started

Did you get the email and assignment, and did you look at this short video?

https://www.youtube.com/watch?v=fgQLyqWaCbA

Life requires

- **Metabolic process**
- **Membrane (to make cell walls): lipids**
- **Genetic information: at least RNA, maybe DNA**

Most definitions include homeostasis: the ability to stay in equilibrium with environment

Ingredients to make life

- Carbon
  - Makes chain molecules - complexity
- Hydrogen
- Nitrogen
- Oxygen

All bond easily with carbon

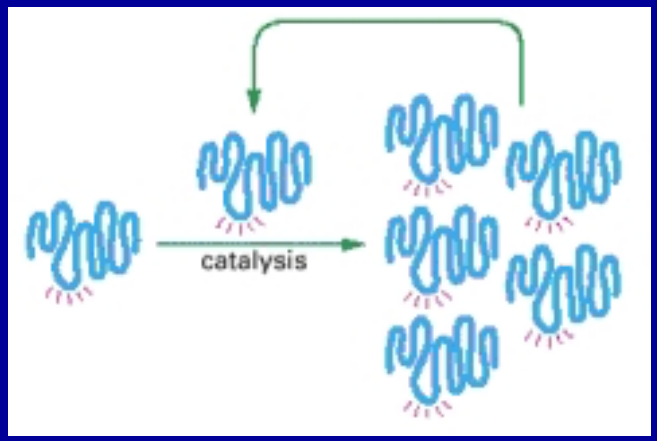
- Sulfur (sometimes selenium)
  - Electron shuffle
- Phosphorous (rarely arsenic)
  - Energy storage

Abiogenesis

- The evolution of life or living organisms from inorganic or inanimate substances
- Need the right environment
  - Concentrate chemicals
- Much work is going on to find the right environmental conditions and ingredients to make this happen

Life require self catalysis

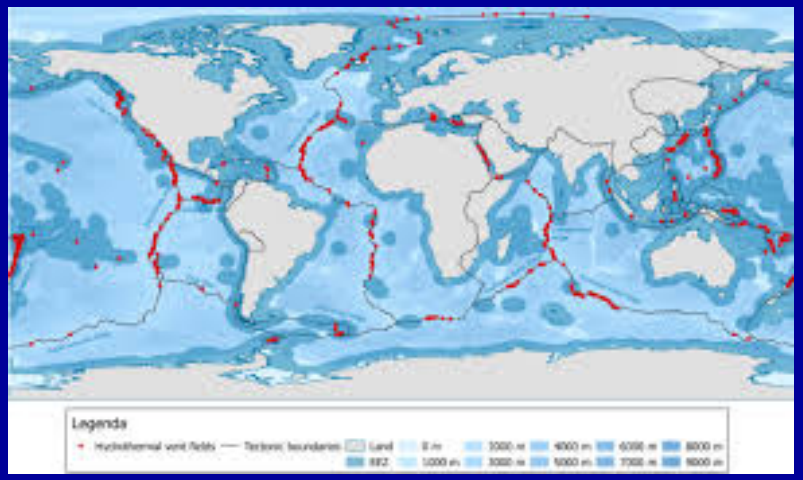
An hypothetical RNA molecule that can catalyze its own synthesis.



Molecular Biology of the Cell. 4th edition.
Alberts B, Johnson A, Lewis J, et al.
New York: Garland Science; 2002.

https://www.ncbi.nlm.nih.gov/books/NBK26876/

Hydrothermal vents



Vent inorganic chemistry

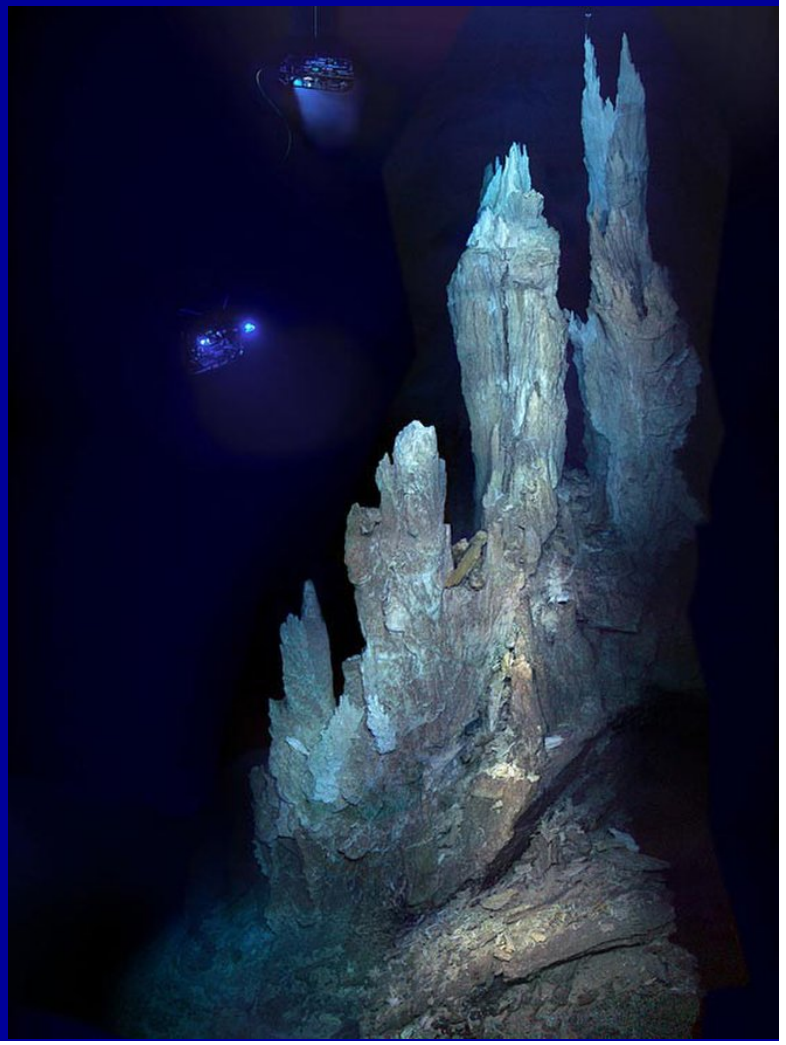
Cations (positive ions) from seawater (Mg^{+2}, Ca^{+2}, and Na^{+}) form hydroxyl (OH) bearing minerals in the volcanic rocks, altering the minerals and releasing hydrogen ions to solution. The hot, acidic altered-seawater releases metals (Fe, Mn, Zn, and Cu) and reduced sulfur (H_2S) from the volcanic rock; these are transported by hydrothermal solutions to the seafloor and form metallic mineral deposits.

Organic compounds can use the ions to catalyze chemical reactions. Hydroxyl-bearing alteration minerals are created.

Source of dissolved simple organic molecules

High temperatures suddenly cooled by contact with seawater leads to a big change in the equilibrium concentration known as organic quenching. This creates a high concentration and provides a chemical potential energy that allows more complex molecules in the presence of the minerals in the rocks around the geothermal vents.

Called the *Iron-Sulfur World Theory*



Chemosynthesis

Chemosynthesis uses inorganic molecules (such as hydrogen sulfide) or methane and combines them with an oxygen source (in this case seawater) to create simple sugars.

Issues:

- How is a supply of "chemical food" for reactions concentrated?
- How do the more complex molecules survive at such high temperatures?

Photosynthesis vs. chemosynthesis

All photosynthetic organisms use solar energy to turn carbon dioxide and water into sugar and oxygen. There is only one photosynthetic formula: $CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Photosynthesis occurs in plants and some bacteria, wherever there is sufficient sunlight - on land, in shallow water, even inside and below clear ice.

All chemosynthetic organisms use the energy released by chemical reactions to make a sugar, but different species use different pathways. Some vent bacteria oxidize hydrogen sulfide, add carbon dioxide and oxygen, and produce sugar, sulfur, and water:

$$CO_2 + 4H_2S + O_2 \rightarrow CH_2O + 4S + 3H_2O$$

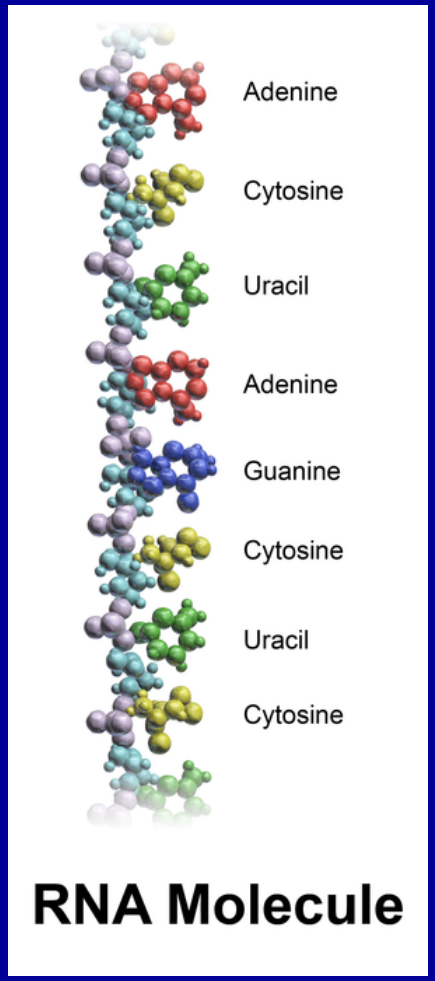
Minerals may play a big role

- It has been proposed that the first "biological" molecules on Earth were formed by metal-based catalysis on the crystalline surfaces of minerals. An elaborate system of molecular synthesis and breakdown (metabolism) could have existed before the first cells arose.
- Life requires molecules that possess the ability to catalyze reactions that lead, directly or indirectly, to the production of more molecules like themselves.
- Catalysts with this special self-promoting property can use raw materials to reproduce themselves and thereby divert these same materials from the production of other substances.

Autocatalytic molecules

- In 1982, it was discovered that RNA molecules themselves can act as catalysts and also carry the information required to make proteins.
- This forms the basis of the RNA world hypothesis.
- Although RNA seems well suited to form the basis for a self-replicating set of biochemical catalysts, it is unlikely that RNA was the first kind of molecule to do so. (Difficulties exist!)
- The first molecules to possess both catalytic activity and information storage capabilities may have been polymers that resemble RNA but are chemically simpler.

Laboratory synthesis of RNA



Short chains of RNA have been synthesized in the laboratory but it seems to be hard to get sufficiently long chains.

Bridging the prebiotic and RNA worlds: prebiotic RNA synthesis on clay. Ertem et al. (2000)

- Montmorillonite - a primitive clay
- Have to "feed it" the monomers (A, C, G, and U)

How to concentrate the building blocks

- Ocean geothermal vents – problem dissipation by ocean currents
- New proposal hot-dry geothermal pools
  - Scientific American, Aug. 2017, p28

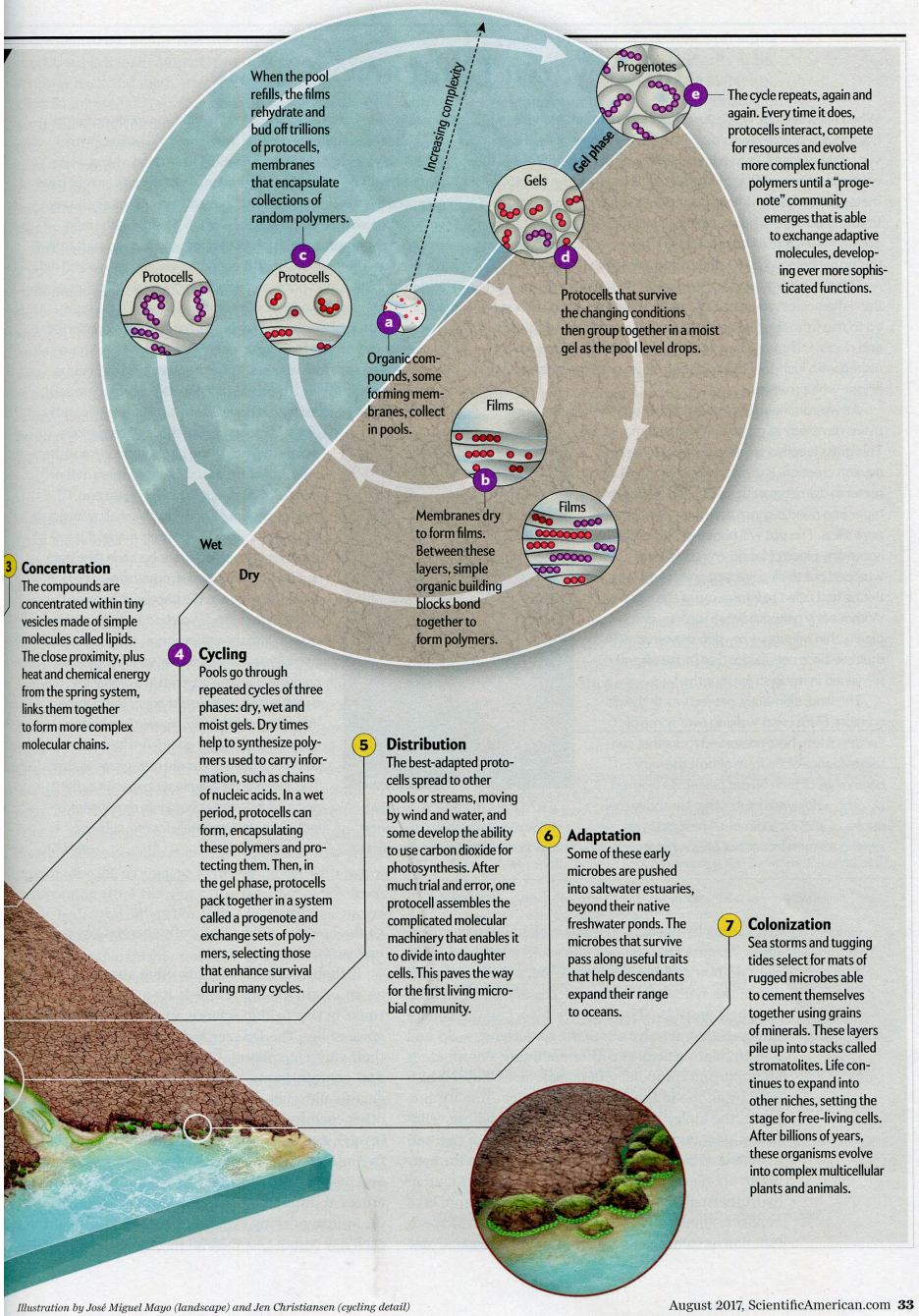
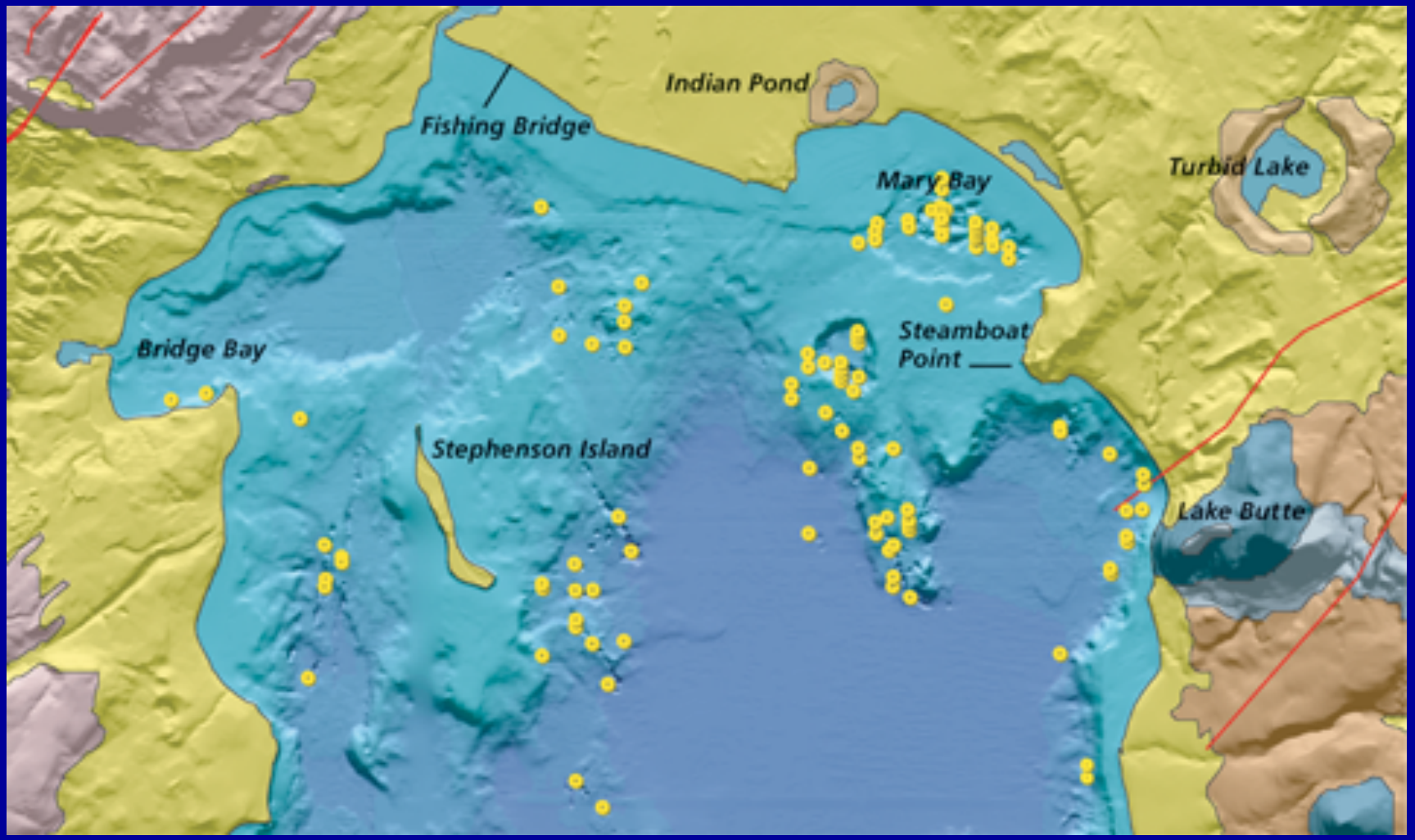


Illustration by José Miguel Mayo (landscape) and Jen Christiansen (cycling detail)

Wet-Dry cycle for the origin of life

- Stable crust of Earth peppered with volcanic landmasses (Yellowstone-like environments common)
- Each with 100 geothermal springs, varying chemical and environmental conditions, energy
- -> millions of combinations of chemicals per year
- 10 millions years – lots of experiments to make life

Geothermal vents: Lake Yellowstone (hot/cool)



Wet-dry pools Yellowstone

Throw in some geysers

To help produce wet dry cycling, and (some say) bingo – the potential to make a self-replicating molecule.

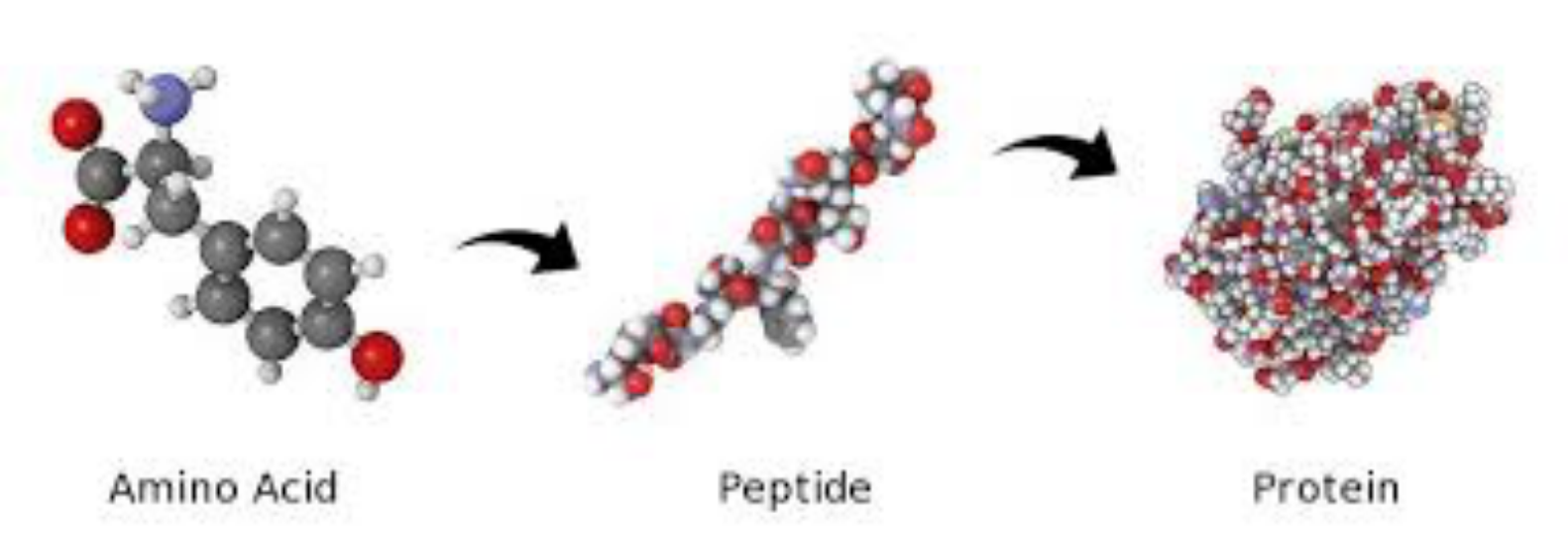
Seven ideas being explored

1. Lightening in a reducing atmosphere
   - Early Earth atmosphere wasn't reducing, but maybe around volcanos
2. Molecular meetup on clay
   - Maybe as part of a hot-dry model
3. Deep sea vents – concentration in cavities of the rocks
4. Ice protected complex molecules from ultraviolet light.

Seven ideas

5. DNA formed from RNA, but how did we get RNA? Known as the gene-first hypothesis.
6. Simple molecules did the reaction but were replaced by more complex but more efficient processes by more complex molecules – metabolism first
7. Panspermia – life came here from somewhere else.

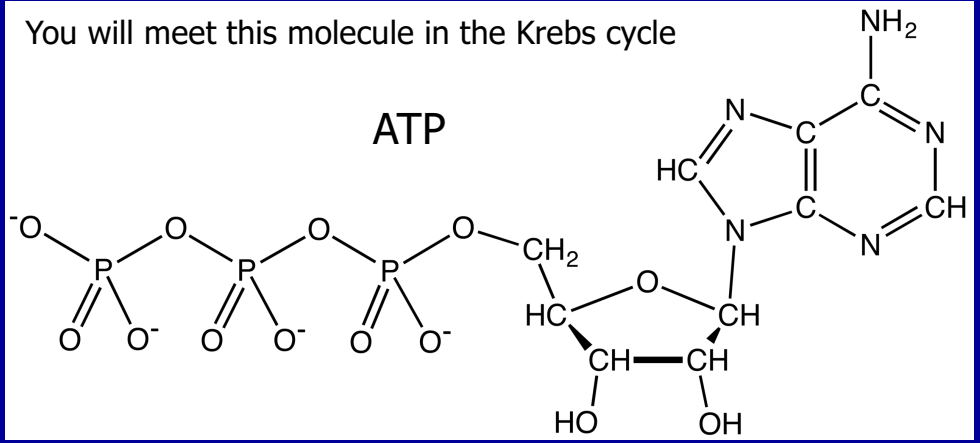
How to get long chains of peptides that might form RNA?



Key is adenosine triphosphate aka ATP

You will meet this molecule in the Krebs cycle

ATP



Stromatolites

Live stromatolites in western Australia

cyanobacteria

Fossilized stromatolites found with oldest rock on Earth in Australia

Blue-green algae that learned how to photosynthesize sunlight and produce oxygen as a byproduct, eventually building up oxygen in the atmosphere.

Reacted with abundant iron in oceans to produce red rocks (rusted the planet).

Christian de Duve 1917 - 2013

"If you equate the probability of the birth of a bacteria cell to chance assembly of its atoms, eternity will not suffice to produce one… Faced with the enormous sum of lucky draws behind the success of the evolutionary game, one may legitimately wonder to what extent this success is actually written into the fabric of the universe".

de Duve lecturing on the origin of the eukaryotic cell in October 2012

How Life Began Origins Nova Neil Degrasse Tyson

https://www.youtube.com/watch?v=NJQ4r81DZtY

Start 4:47 End 50:49