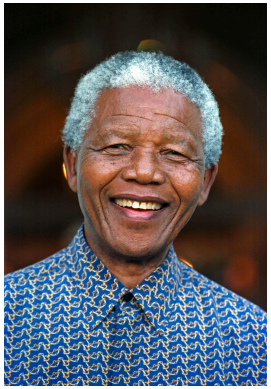
The amazing story of how life originated on Earth

Sudha Rajamani

28 April, 2019

IISER PUNE

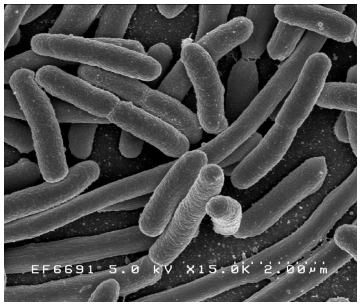
https://www.deviantart.com/kana-hebi/art/Tyrannosaurus-rex-544468282



https://www.thelantern.com/2013/12/ohio-state-students-react-nelson-mandelas-death/

http://www.yourarticlelibrary.com/fungi/the-importance-of-fungi-to-human-beings-744-words/7172/

CELLS!

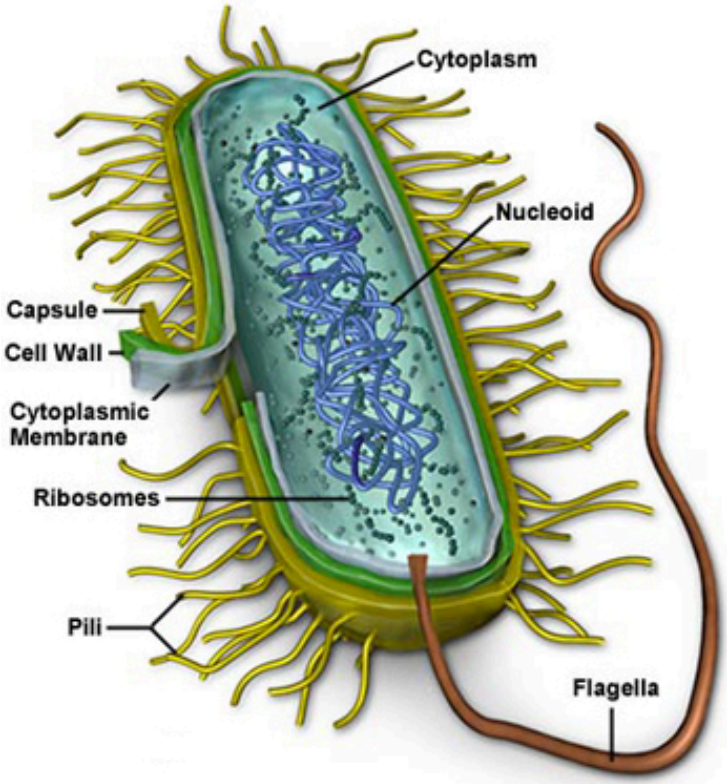


https://en.wikipedia.org/wiki/Proteobacteria#Gammaproteobacteria

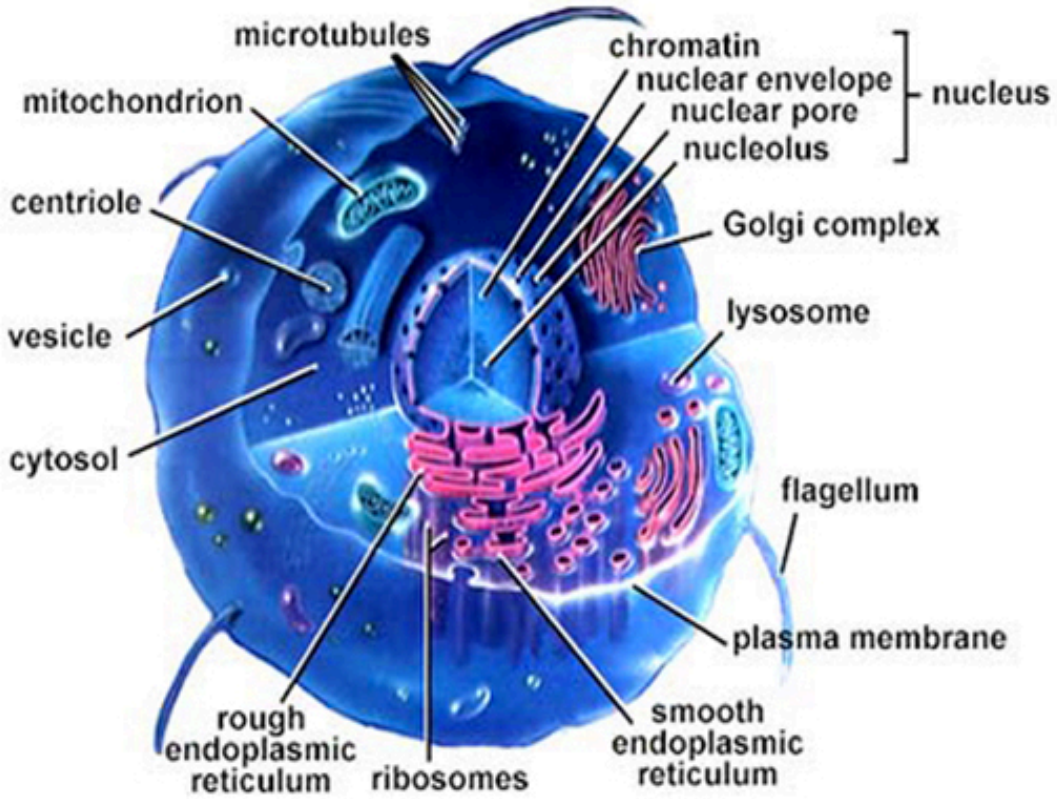
https://thequietbranches.com/2015/05/24/ian-sussex-and-plant-meristems/

http://internationalfishingnews.blogspot.com/2013/05/news-monster-size-wels-catfishes-landed.html

The fundamental unit of life



prokaryotic cell
(bacteria)

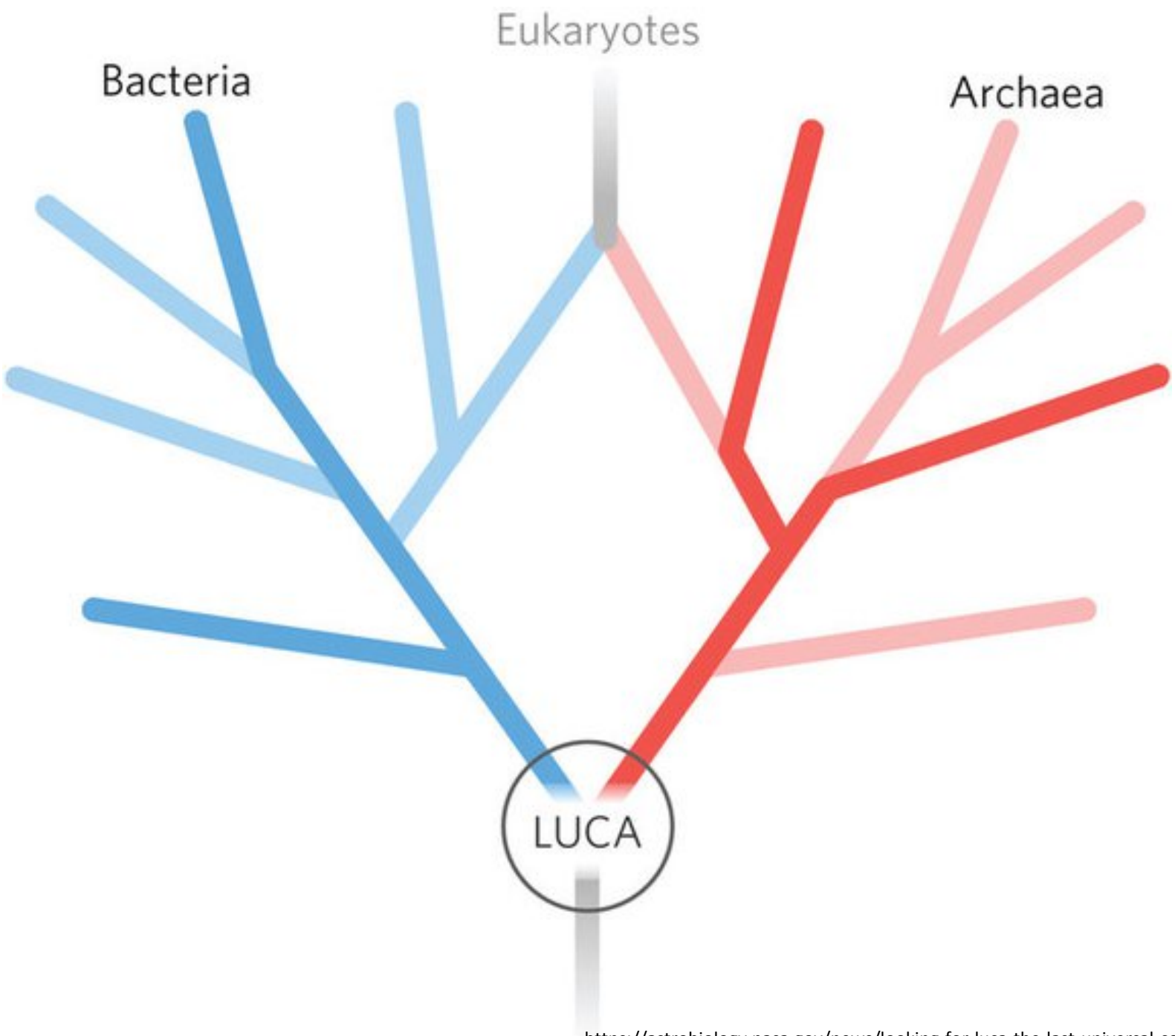


eukaryotic cell
(protists, fungi, animals, plants)

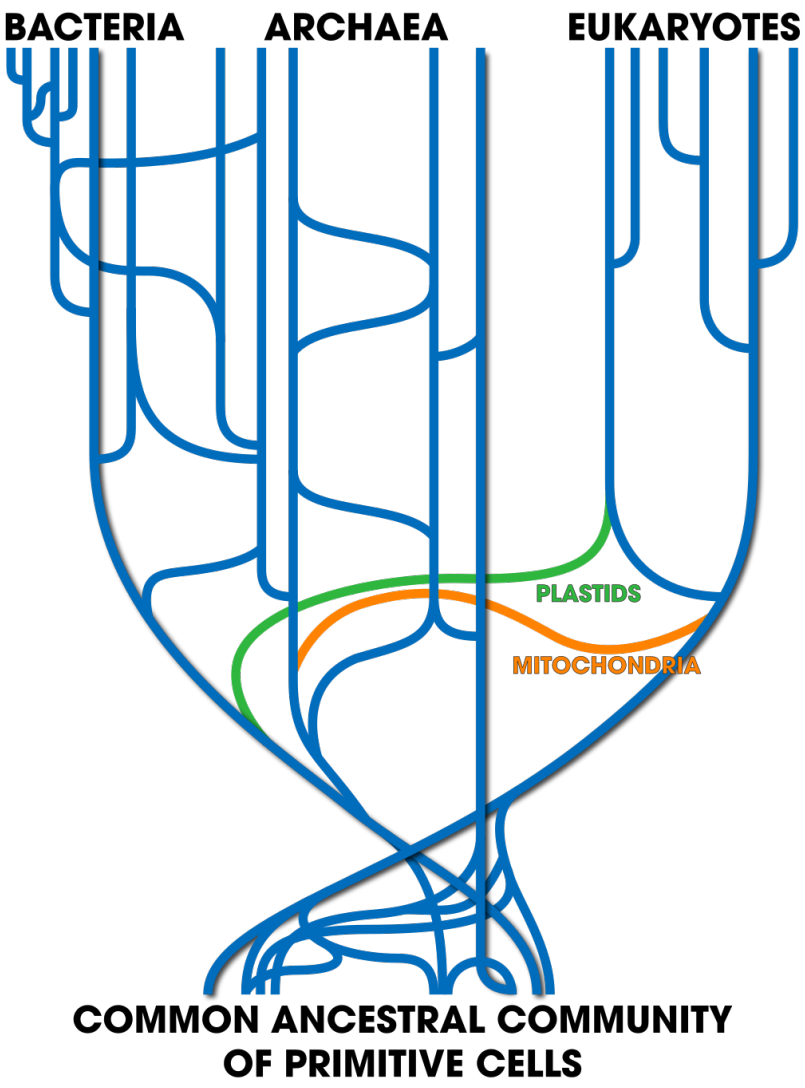
https://www.thinglink.com/scene/565728773106827265

Extreme life!

Courtesy: Siddharth Pandey

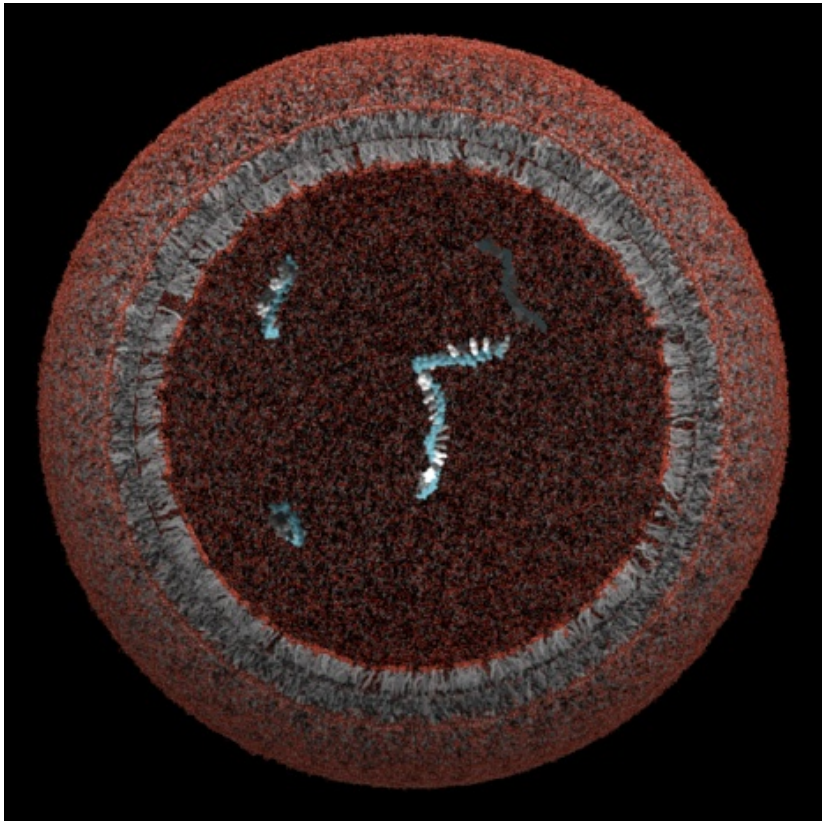


https://astrobiology.nasa.gov/news/looking-for-luca-the-last-universal-common-ancesto

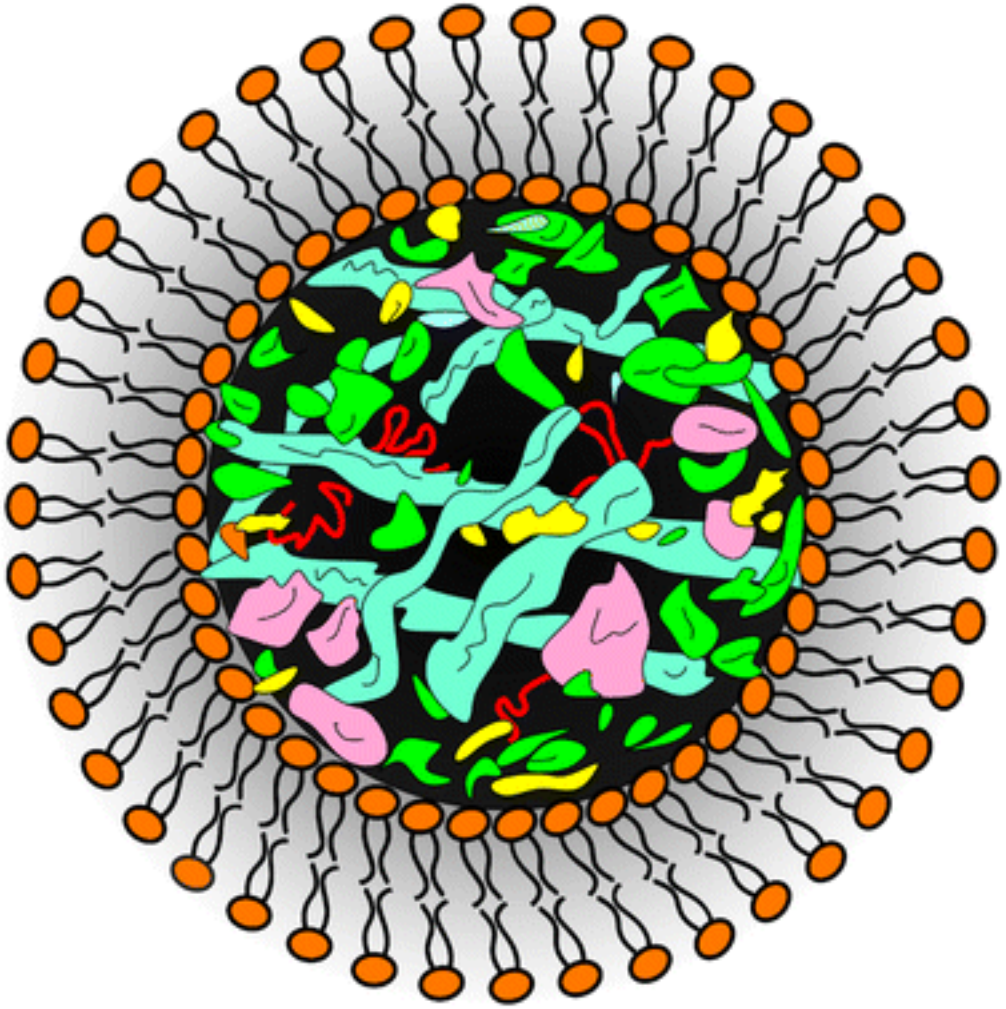


Protocells

Lipid membranes with nucleic acids

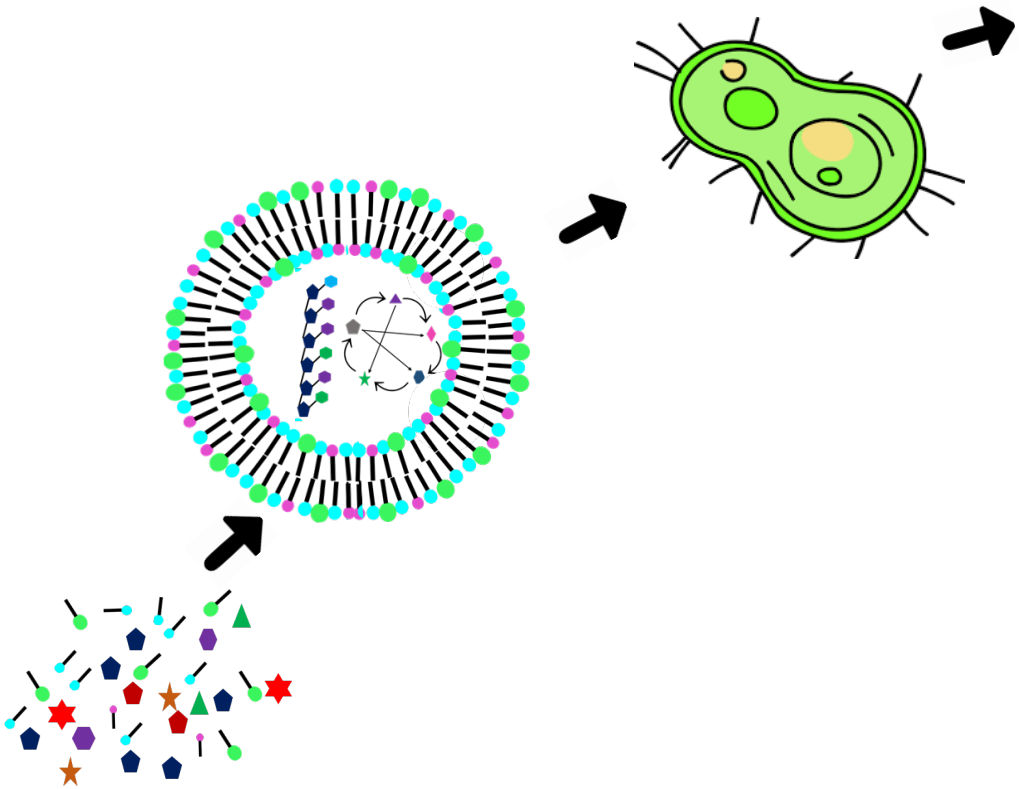


http://molbio.mgh.harvard.edu/szostakweb/exploringOriginsDownloads/protocell.jpg



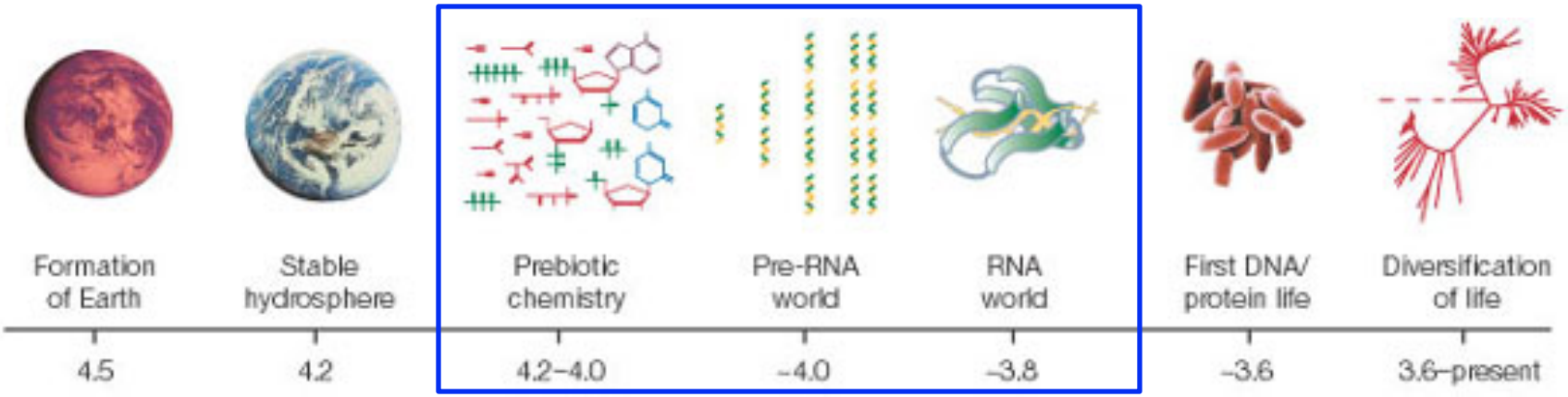
“The best we can ever do is to draw up a story that is consistent with all the evidence: with experiments in chemistry, with what we know about the early Earth, and with what biology reveals about the oldest forms of life. Finally, after a century of fractious effort, that story is coming into view.”

Saha R., Pohorille A. and Chen I.A., *OLEB*, 2014



COOL lab

Early history of life on Earth



Joyce,G. *Nature,* 2002, 418, 214.

RNA world hypothesis: RNA performed the dual role of replicating information and catalyzing important functions.

Our Universe

Cosmology
The astrophysical study of the history, structure, and dynamics of the universe.

Universe
Everything that exists, including the Earth, planets, stars, galaxies, and all that they contain; the entire cosmos.

Galaxy
A component of our universe made up of gas and a large number (usually more than a million) of stars held together by gravity.

Mankind's deepest-ever view of the universe

http://www.nasa.gov/images/content/690958main_p1237a1.jpg

The Andromeda galaxy

Robert Gendler/NASA

http://imagine.gsfc.nasa.gov/docs/dictionary.html#S, http://starchild.gsfc.nasa.gov/docs/StarChild/solar_system_level1/planets.html#

A TIMELINE of **LIFE'S EVOLUTION**

Drag the red marker to learn about important events in the history of life on Earth

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

BILLIONS of YEARS AGO

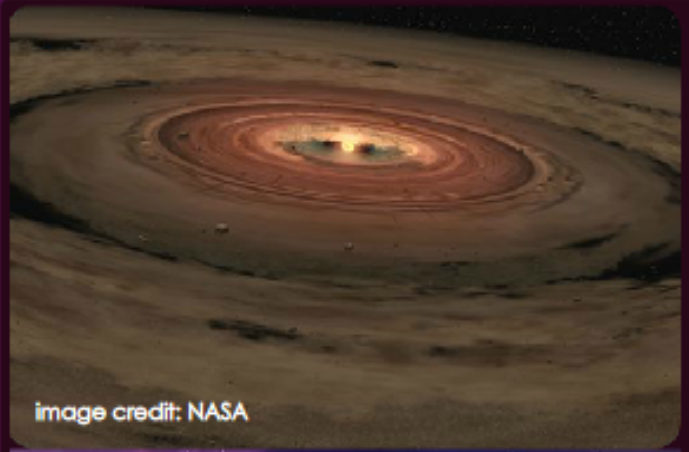


image credit: NASA

FORMATION OF THE SOLAR SYSTEM

circa 4.57 billion years ago

Our Solar System is thought to have formed from a giant rotating cloud of gas and dust, known as a protoplanetary disc. The Sun formed at the center of the disc, and the planets gradually formed around the Sun in a process known as accretion. The image on the left shows an artist's version of an accretion disc.

image credit: Joe Tucciarone

FORMATION OF THE MOON

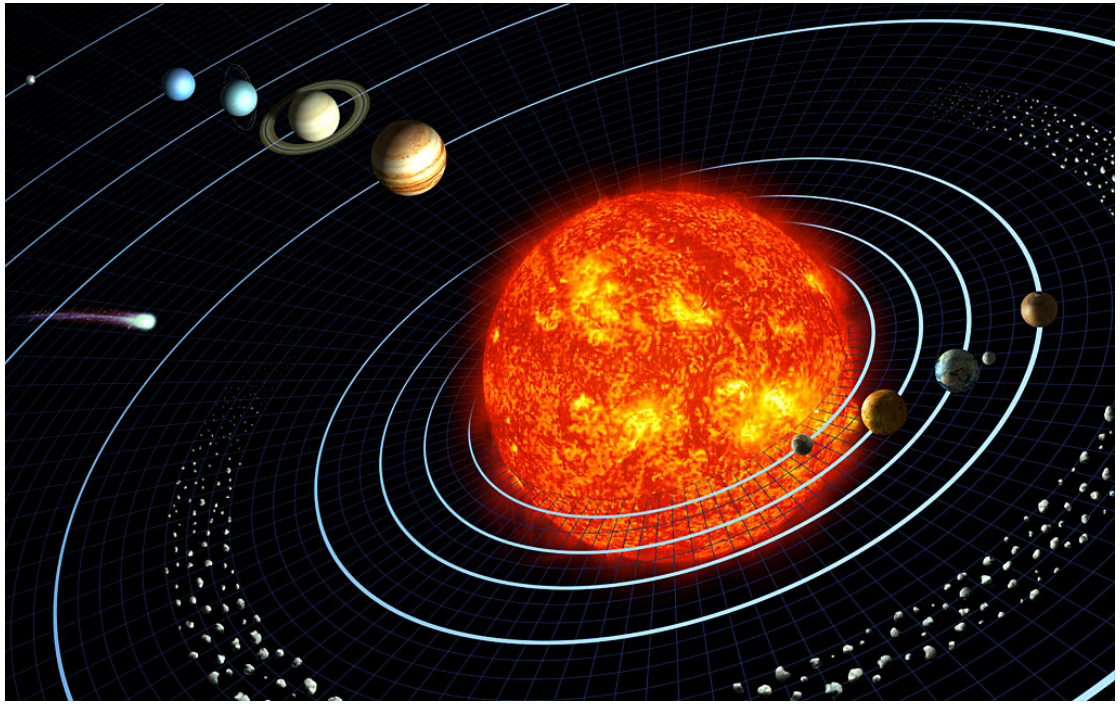
circa 4.53 billion years ago

According to the "Giant Impact" hypothesis, the Moon formed as a result of a collision between Earth and a Mars-sized body called Theia. The impact caused a portion of the combined mantle of Earth and Theia to be expelled into space, eventually forming the Moon.

http://exploringorigins.org/timeline.html

Star

A large ball of gas that creates and emits its own radiation.



Star forming pillars in the Eagle Nebula, as seen by the Hubble Space Telescope

Planet

A planet is a large space object which revolves around a star. It also reflects that star's light. Eight planets have been discovered in our solar system. Mercury, Venus, Earth, and Mars are the planets closest to the Sun. They are called the inner planets. The inner planets are made up mostly of rock. The outer planets are Jupiter, Saturn, Uranus, and Neptune. They are large balls of gases with rings around them. All eight planets travel around the Sun in a different orbit.

A TIMELINE of **LIFE'S EVOLUTION**

Drag the red marker to learn about important events in the history of life on Earth

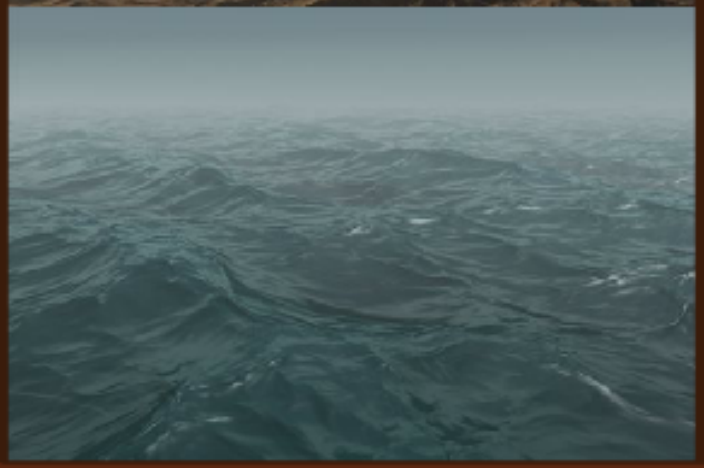
4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
BILLIONS of YEARS AGO

LATE HEAVY BOMBARDMENT

circa 4.1 - 3.8 billion years ago

Based on observations of impact craters on the Moon, many astronomers believe that the Earth endured a violent period of near-constant collisions with large asteroids and comets.

Could early forms of life have survived the Late Heavy Bombardment, or was it only after this tumultuous time that the first cells formed?



FORMATION OF THE EARTH'S CRUST & OCEANS

circa 4 billion years ago?

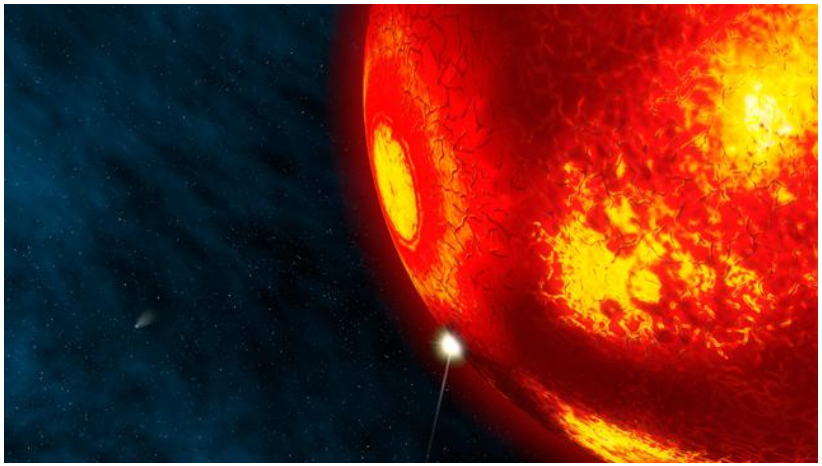
The cooling of the Earth allowed for crust formation and the condensation of water present in the atmosphere, forming the Earth's oceans.

The atmospheric composition of the early Earth and the timing of crust and ocean formation have been topics of controversy within the scientific community. Resolving these questions is crucial to understanding the early steps in life's evolution.

http://exploringorigins.org/timeline.html

Our Planet - Earth

3.8 - 4.1 billion years ago (4000000000 years)!!!



Artwork showing the early Earth by Walter Myers/SPL

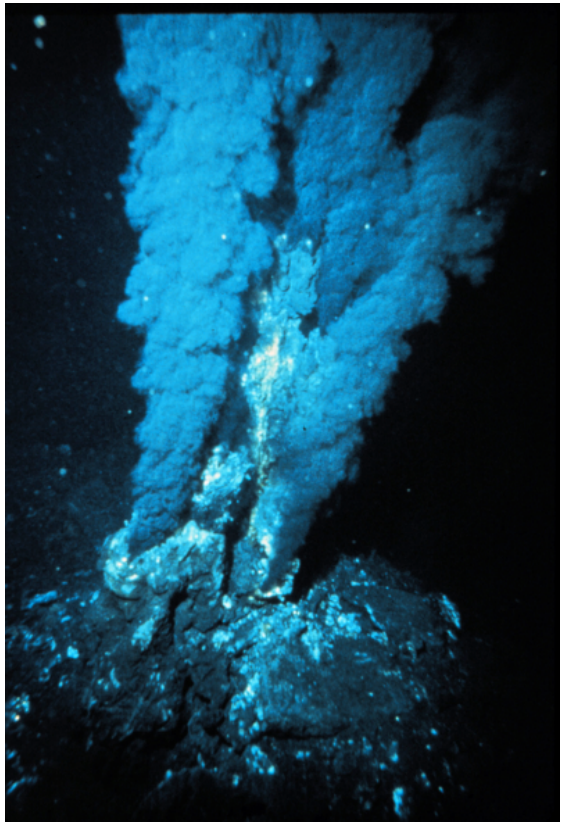
Illustration by Peter Sawyer © Smithsonian Institution

Today

http://eoimages.gsfc.nasa.gov/images/imagerecords/57000/57723/globe_east_2048.jpg

http://www.bbc.com/news/science-environment-25598050

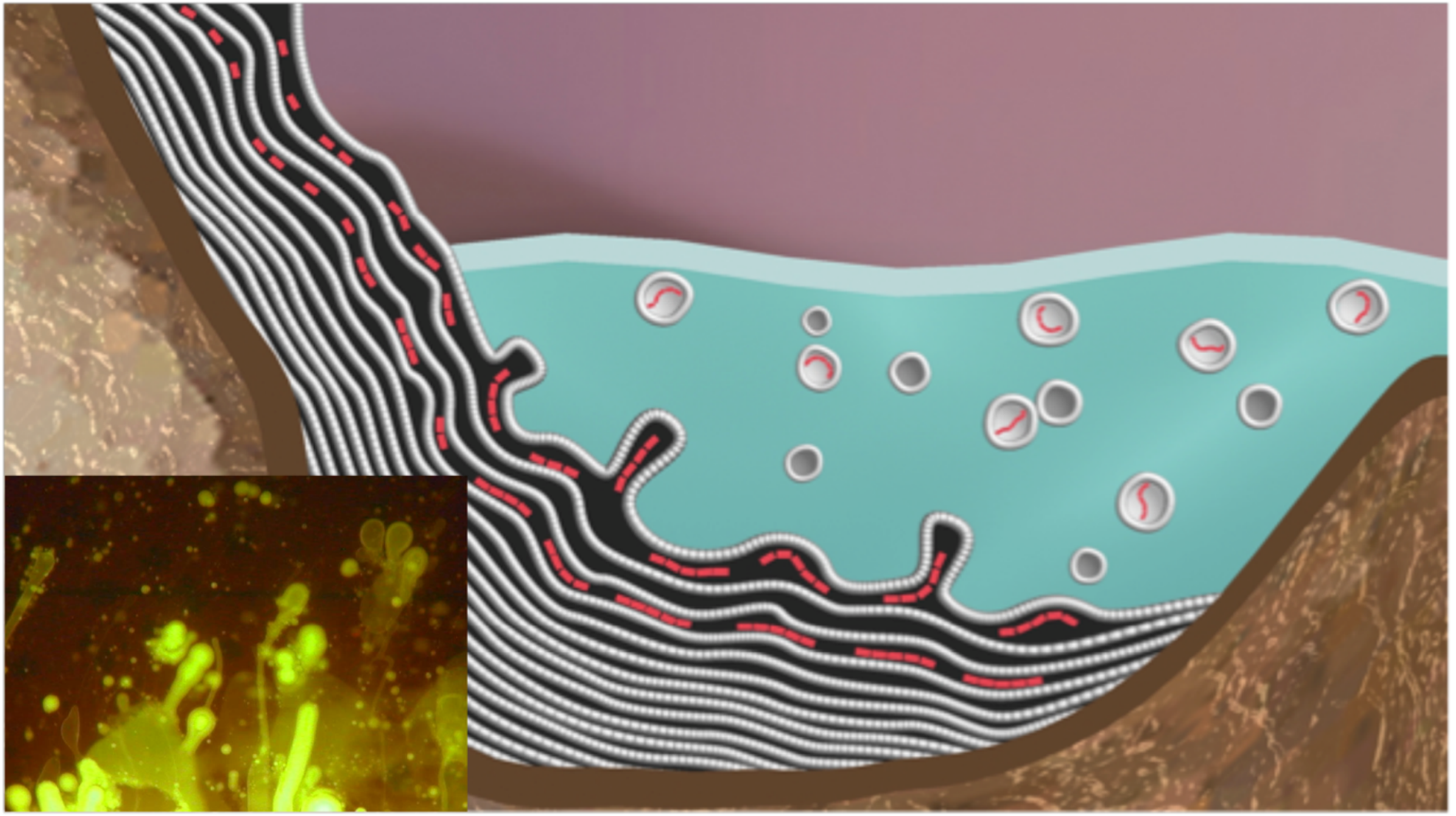
Environments that would have supported life-producing chemical reactions



http://www.photolib.noaa.gov/htmls/nur04506.htm

David Deamer, Bumpass Hell, Mount Lassen, CA, USA

Damer and Deamer, http://www.mdpi.com/2075-1729/5/1/872



Damer and Deamer, http://www.mdpi.com/2075-1729/5/1/872

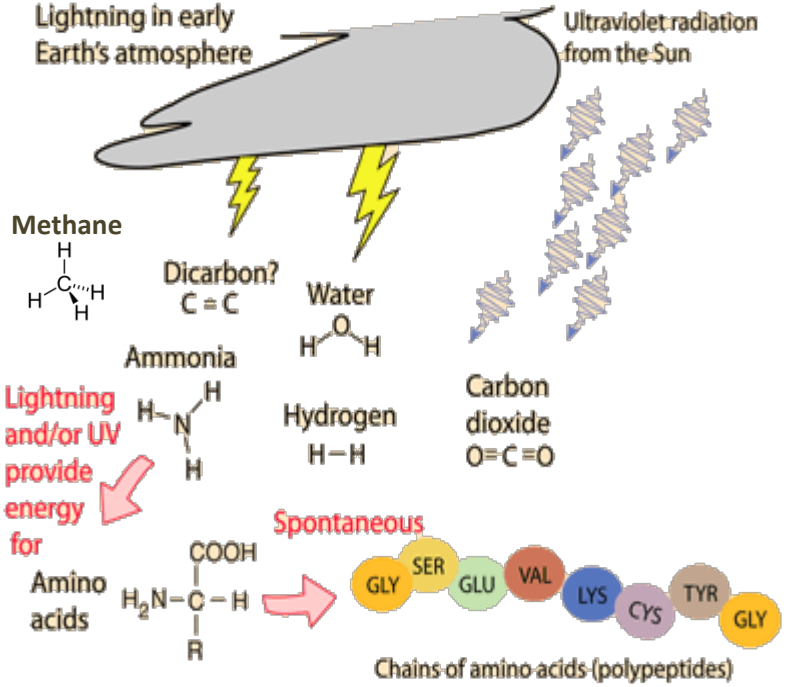
Oparin-Haldane Theory

The ideas of these two men were simple, elegant, and almost identical!

Basic hypothesis: Early Earth's atmosphere was reducing. This means that the atmosphere had an excess of negative charge and could cause reducing reactions by adding electrons to compounds. Under these conditions, organic molecules could have formed from simple inorganic molecules.

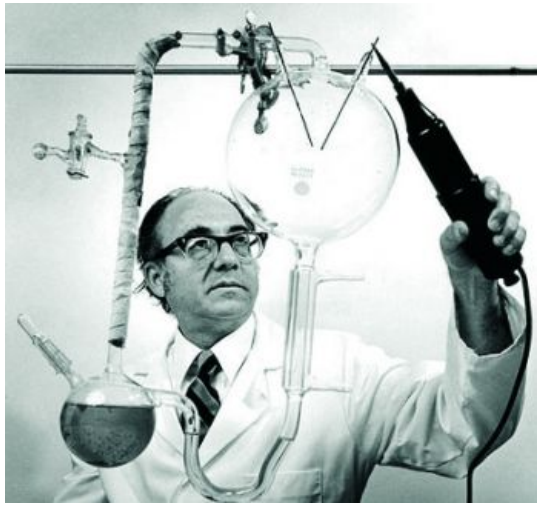
"Primordial Soup": Haldane proposed that the primordial sea served as a vast chemical laboratory powered by solar energy where the atmosphere was oxygen free. The host of organic compounds formed under these conditions became a 'hot dilute soup' containing large populations of organic monomers and polymers.

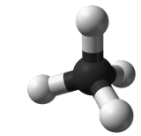
http://www.cbs.dtu.dk/staff/dave/roanoke/primsoup.jpg



http://hyperphysics.phy-astr.gsu.edu/nave-html/faithpathh/lifelab.html

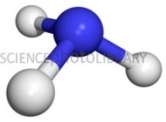
The Miller-Urey Experiment (1953)



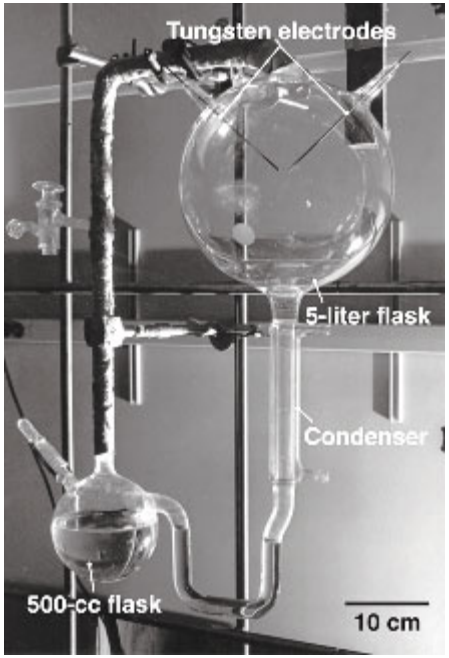


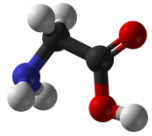
Methane

Water

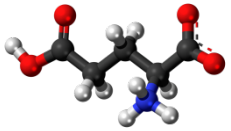


Ammonia

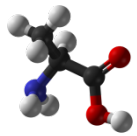




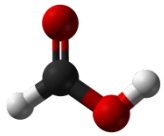
Glycine



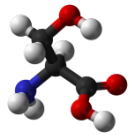
Glutamic acid



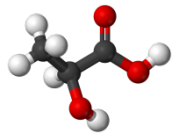
Alanine



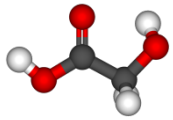
Formic acid



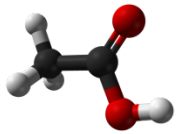
Serine



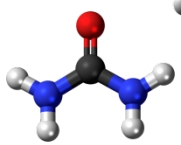
Lactic acid



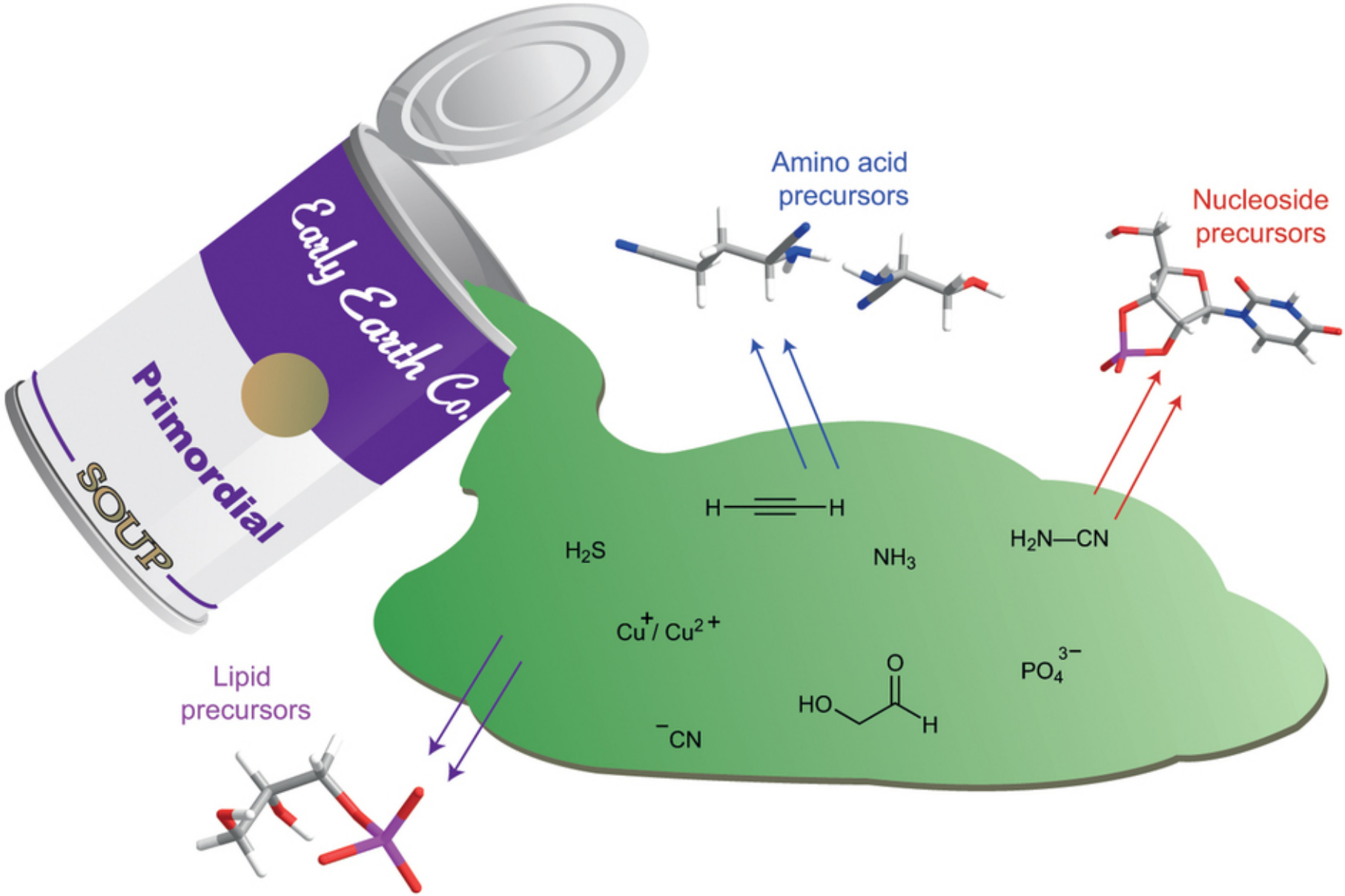
Glycolic acid



Acetic acid



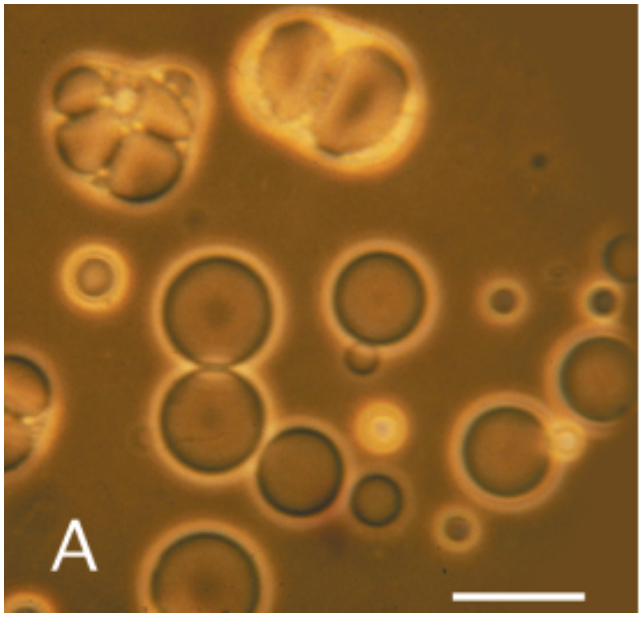
Urea



“A recipe for life itself? Precursors to amino acids, nucleosides and lipids can all be obtained from the same simple starting materials.” - Paul J. Bracher, in News and Views of Nature Chemistry , 7, 273–274 (2015)

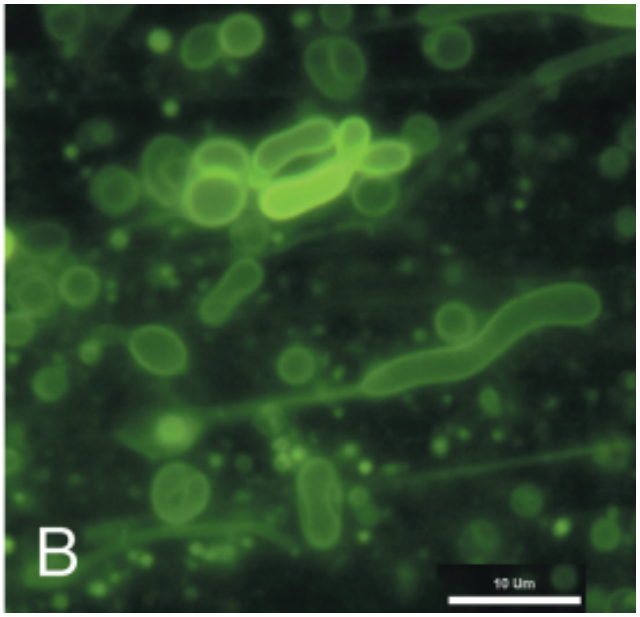
Primitive membrane structures visualized by light microscopy

Amphiphilic compounds extracted from the Murchison meteorite



Monocarboxylic acids ranging from 8 to 11 carbons together with admixtures of PAH derivatives, which form vesicles when exposed to dilute aqueous salt solutions at pH 7.0

Vesicles formed from pure monocarboxylic acids

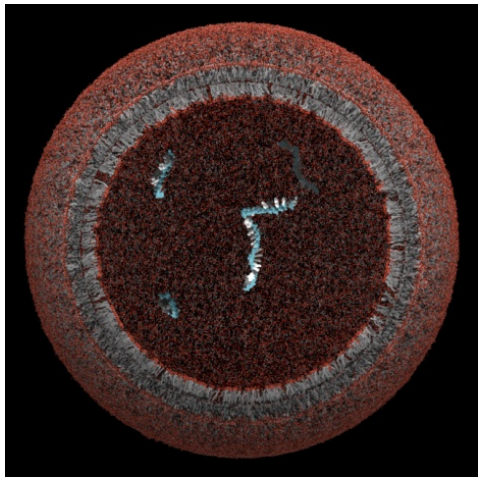


Decanoic acid:decanol (37mM: 3mM, C10, pH 7.4)

Monnard and Deamer, *The Anatomical Record,* 2002

What might have the earliest possible life forms looked like?

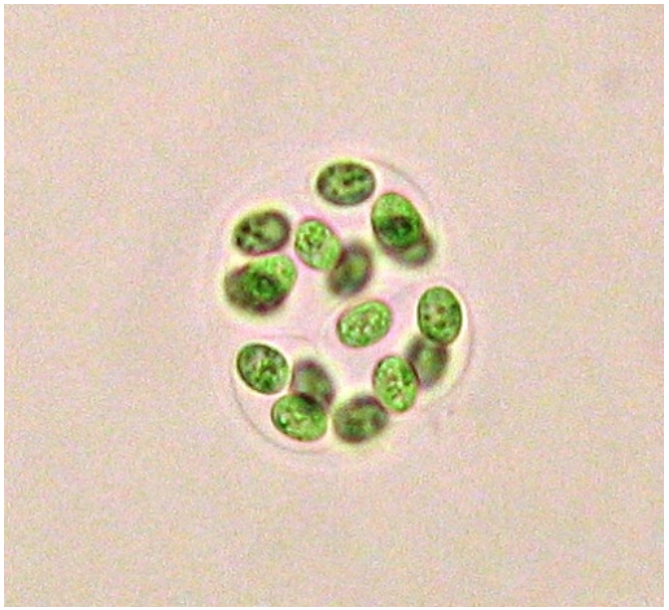
Protocells:
Lipid membranes with nucleic acids



http://molbio.mgh.harvard.edu/szostakweb/exploringOriginsDownloads/protocell.jpg

LUCA (Last Universal Common Ancestor)

***Gloeocapsa* (Cyanobacteria)**

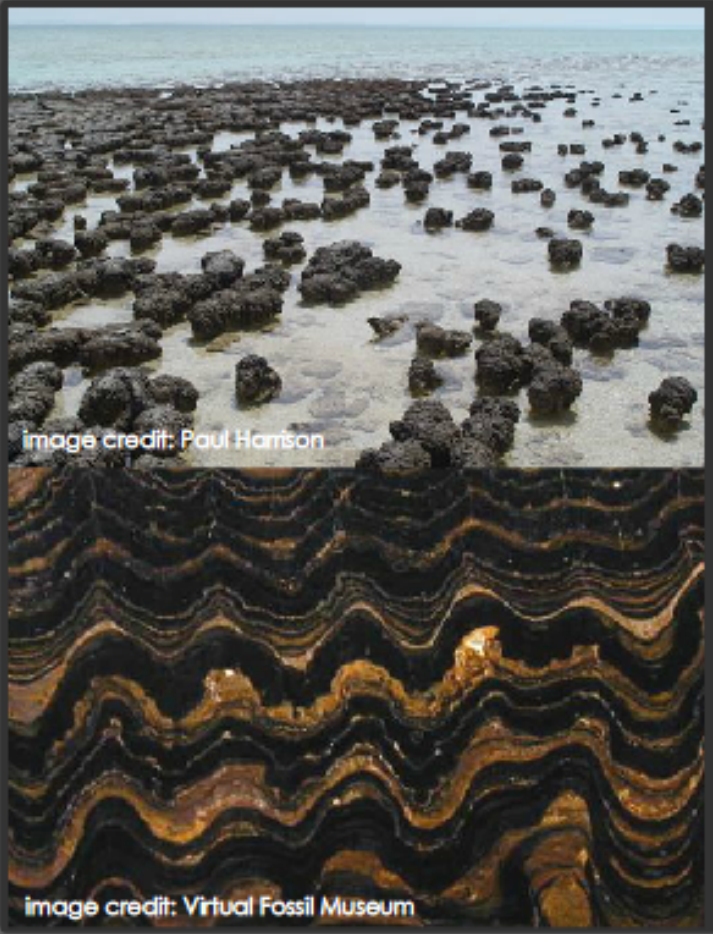


A TIMELINE of **LIFE'S EVOLUTION**

Drag the red marker to learn about important events in the history of life on Earth

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

BILLIONS of YEARS AGO



OLDEST GEOLOGICAL EVIDENCE OF LIFE

circa 3.5 billion years ago

The pillow-like rock formations shown in the image on the left, called stromatolites, are formed as a byproduct of microbial life. During the formation of stromatolites, sheets of microbes, such as cyanobacteria, capture sedimentary particles. Successive layers of microbes and sediment result in the striated pattern of growth as seen in the lower image on the left.

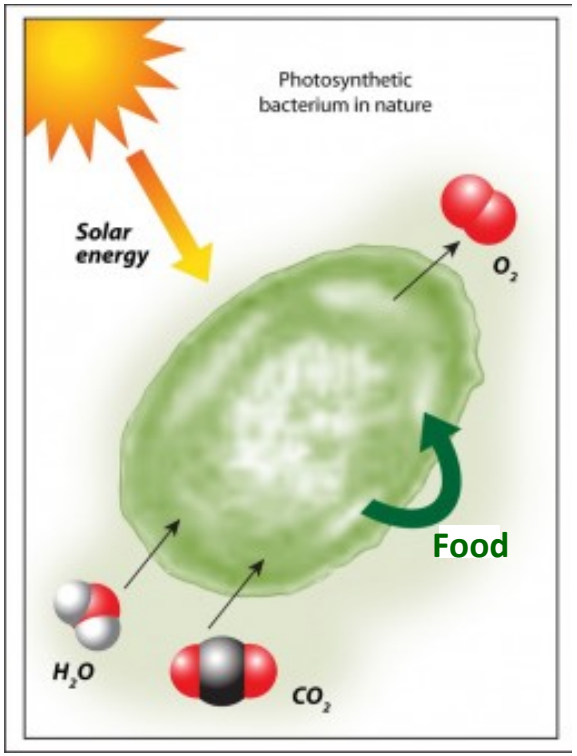
Recent studies on stromatolite samples suggest that microbes may have existed on Earth as early as 3.5 billion years ago. Additional stromatolite samples that have clear evidence of microbial life have been dated to 2.7 billion years ago.

From this evidence, it appears that life evolved within a short billion years after Earth's formation.

http://exploringorigins.org/timeline.html

Oxygenation of the earth's atmosphere – How did bacteria do it?

http://www.cambridgecarbonates.com/downloads/small2/large2/StromatolitesWeb.jpg



Adapted from http://bioenergy.asu.edu/faculty/jones/research.html

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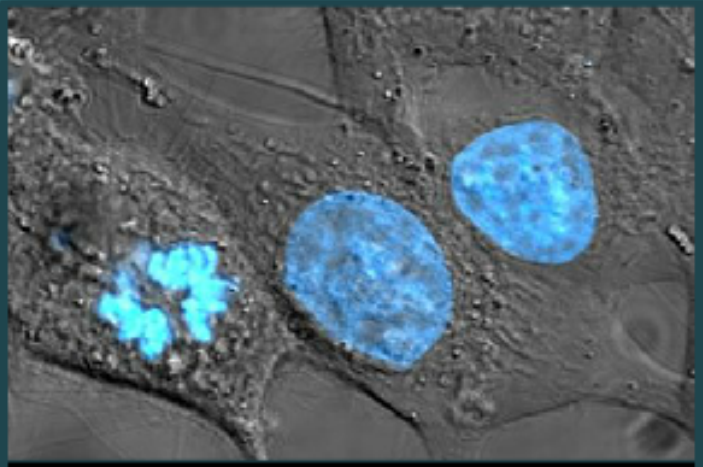
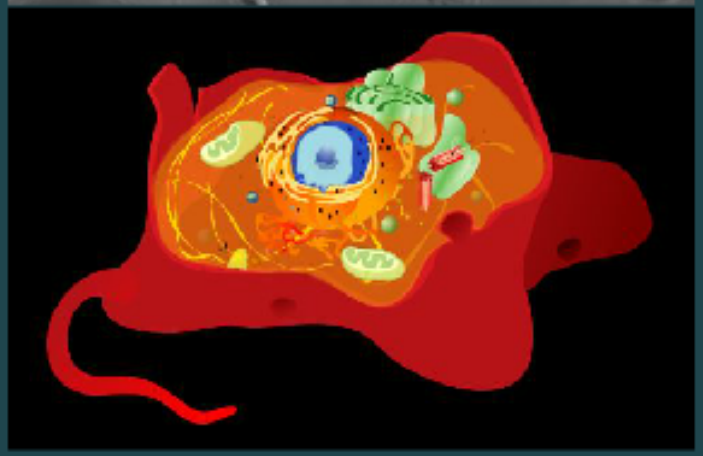
BILLIONS of YEARS AGO





EVOLUTION OF CELLS WITH NUCLEI (EUKARYOTES)

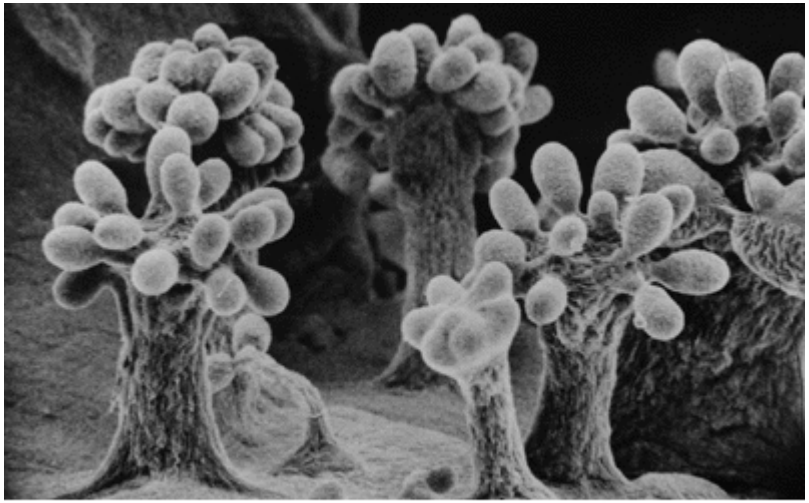
circa 2.0 billion years ago

Geological evidence suggests that life on Earth was limited to prokaryotic, bacteria-like life until around 2 billion years ago. Modern eukaryotes are characterized as having membrane-bound organelles, such as mitochondria and choloroplasts, as well as a membrane-bound nucleus. Some scientists suspect that the organelles and nucleus may have evolved as a result of an ancient symbiotic relationship between different bacteria. Eventually, the bacteria that went on to become organelles transferred the bulk of their genetic information to the host cell genome and lost their ability to survive independently.

http://exploringorigins.org/timeline.html

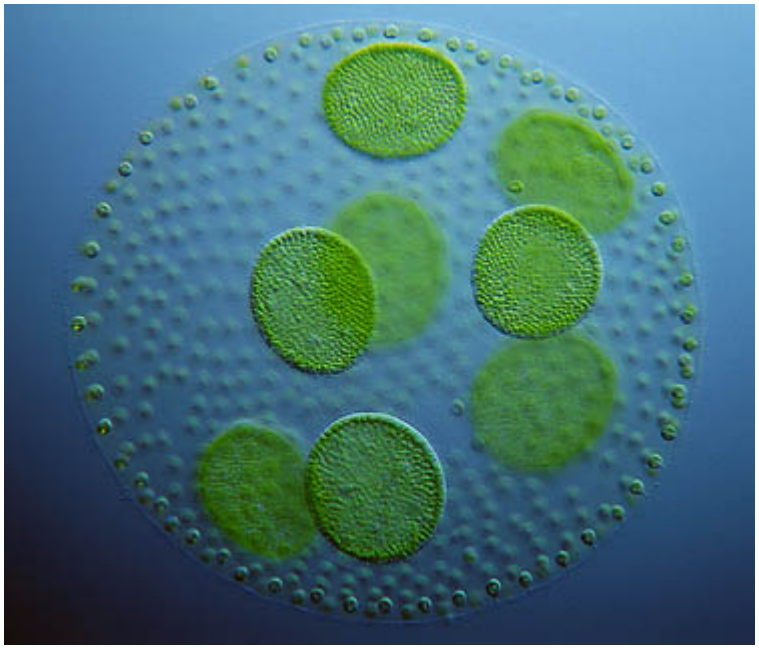
Evolution of multicellular organisms (1.2 billion years ago)

Fruiting bodies formed by a myxobacterium



P.L. Grilione and J. Pangborn, *J. Bacteriol.* 124:1558-1565, 1975.)

Volvox



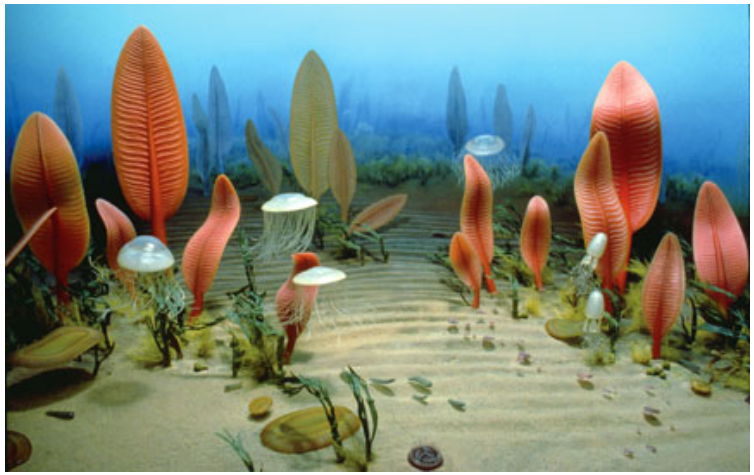
http://25.media.tumblr.com/tumblr_ltdt7pJauT1r3ajgyo2_400.jpg

The Ediacaran Period (~540 million years ago) was populated by some of the very first multi-cellular organisms.

http://www.bbc.co.uk/nature/history_of_the_earth/Ediacaran

Cambrian Explosion!

A menagerie of strange creatures emerged during the Cambrian explosion.



National Museum of Natural History, courtesy of the Smithsonian Institution

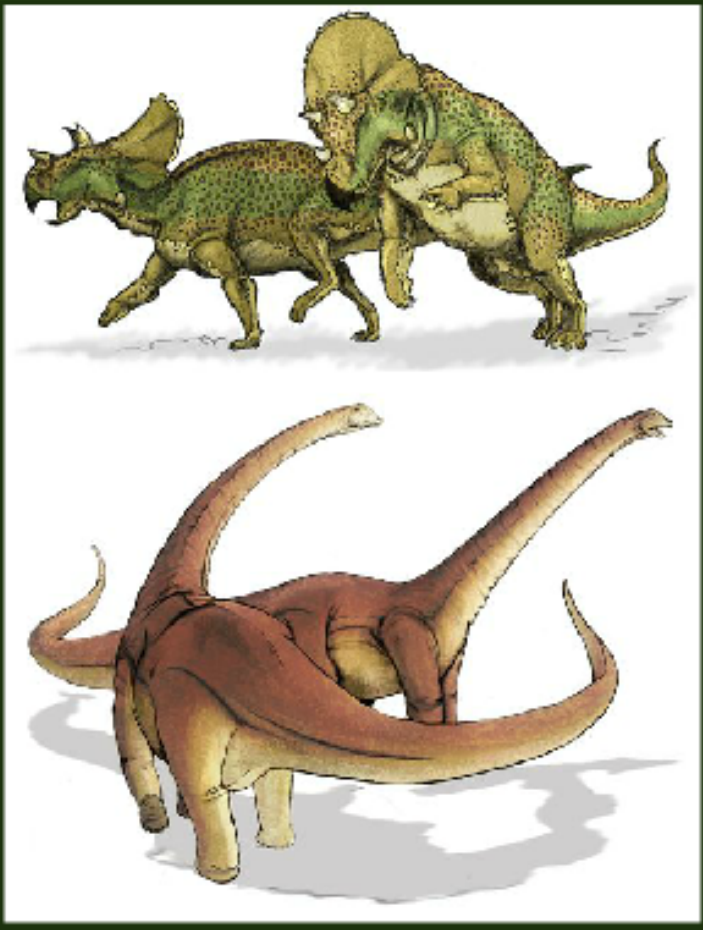
http://www.astrobio.net/albums/origins/agb.jpg, D.W. Miller

A TIMELINE of **LIFE'S EVOLUTION**

Drag the red marker to learn about important events in the history of life on Earth

4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

BILLIONS of YEARS AGO



REIGN OF THE DINOSAURS

circa 230 - 65 million years ago

For over 150 million years, dinosaurs populated the Earth, eventually reaching every continent on the planet. Their sudden mass extinction, known as the Cretaceous-Tertiary Extinction Event, is thought to have been caused by a large asteroid impact or an increase in volcanic activity.

http://exploringorigins.org/timeline.html

Cretaceous-Tertiary mass extinction

+ Intense volcanic activity

A TIMELINE of **LIFE'S EVOLUTION**

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4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0

BILLIONS of YEARS AGO

image credit: AMNH / wallyg / flickr

image credit: Luis Gerard

APPEARANCE OF MODERN HUMANS

circa 200 thousand years ago

Paleontological evidence suggests that modern humans, *Homo sapiens*, evolved from *Homo erectus* approximately 200 thousand years ago.

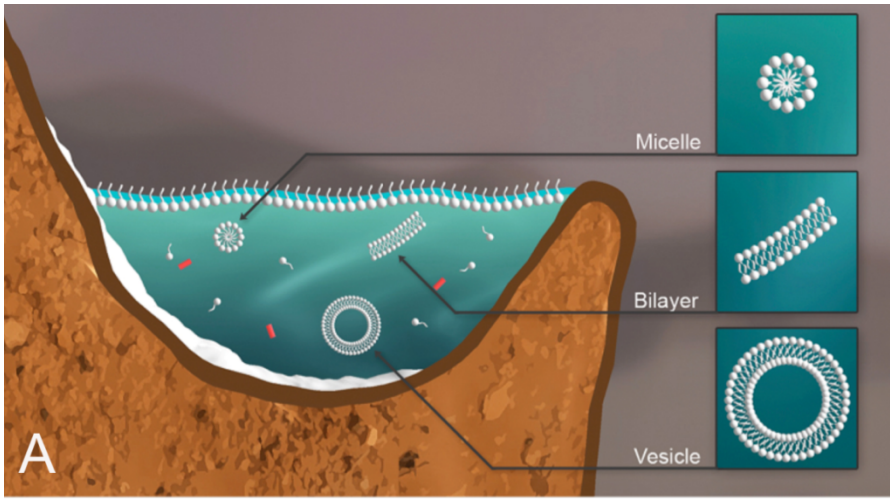
The current human population is estimated to be over 6.5 billion, with humans inhabiting every continent on the Earth.

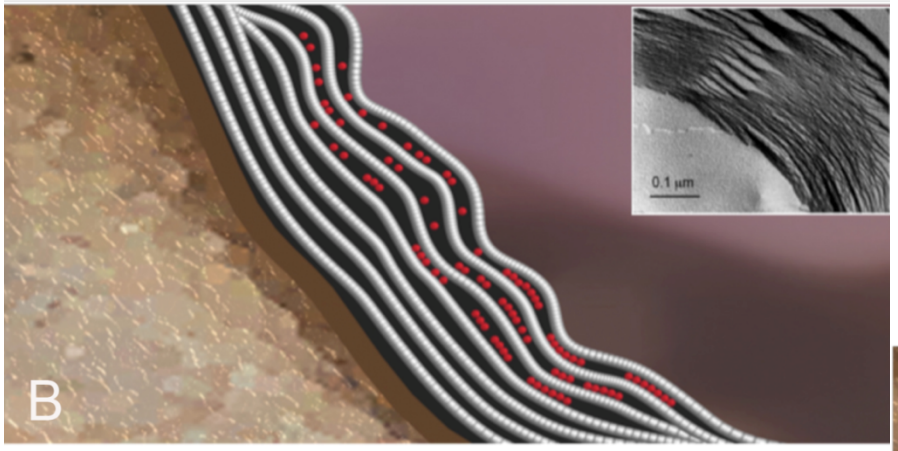
http://exploringorigins.org/timeline.html

Chemical Origins of Life

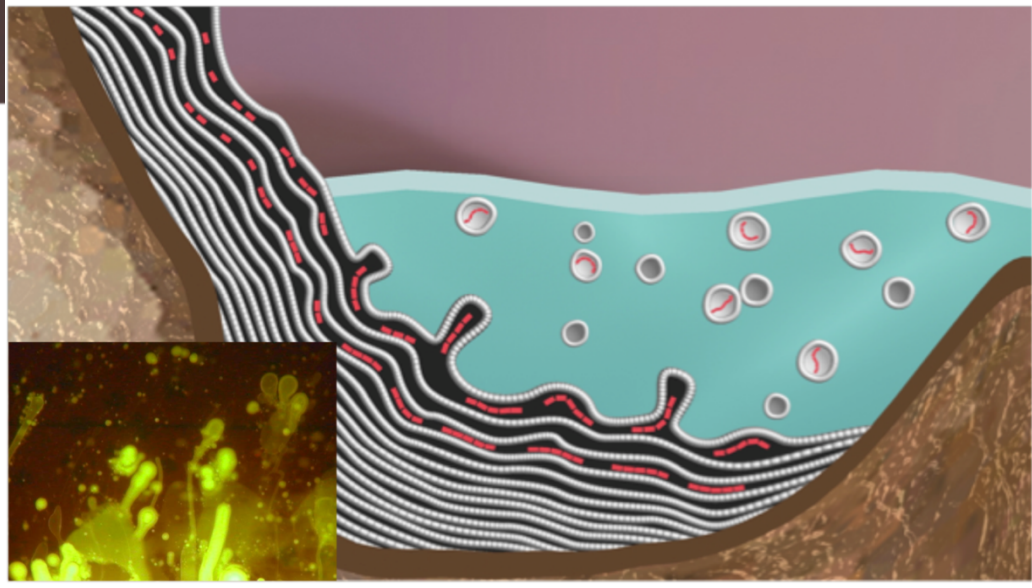
the New Yorker
Sep 18, 2006
pg 77

"Are you my mommy?"



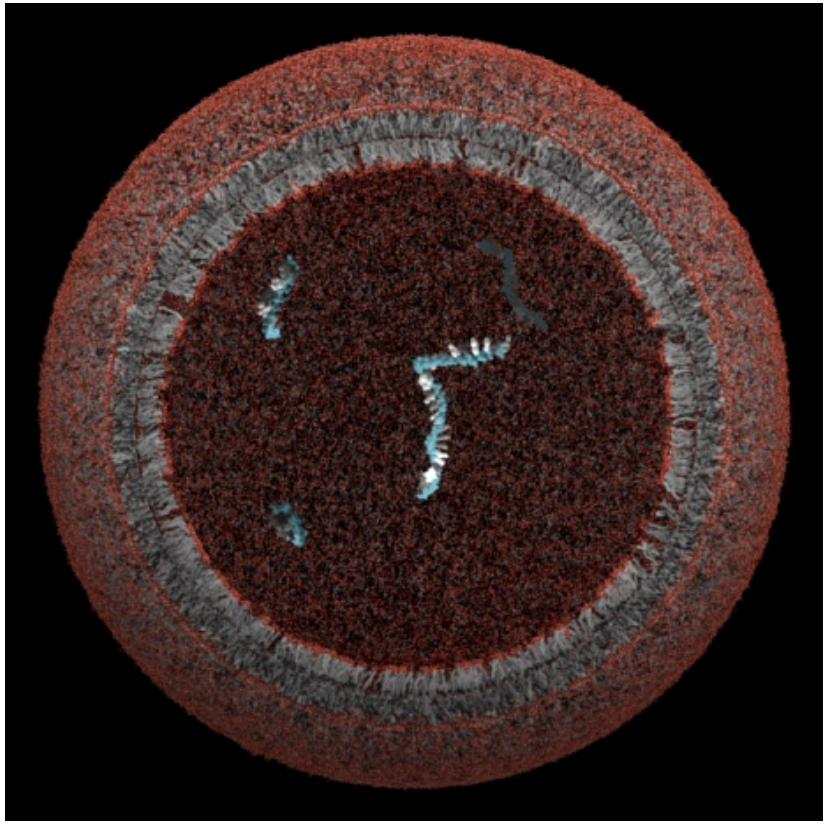


Prebiotic processes facilitated in terrestrial geothermal pools or intertidal pools

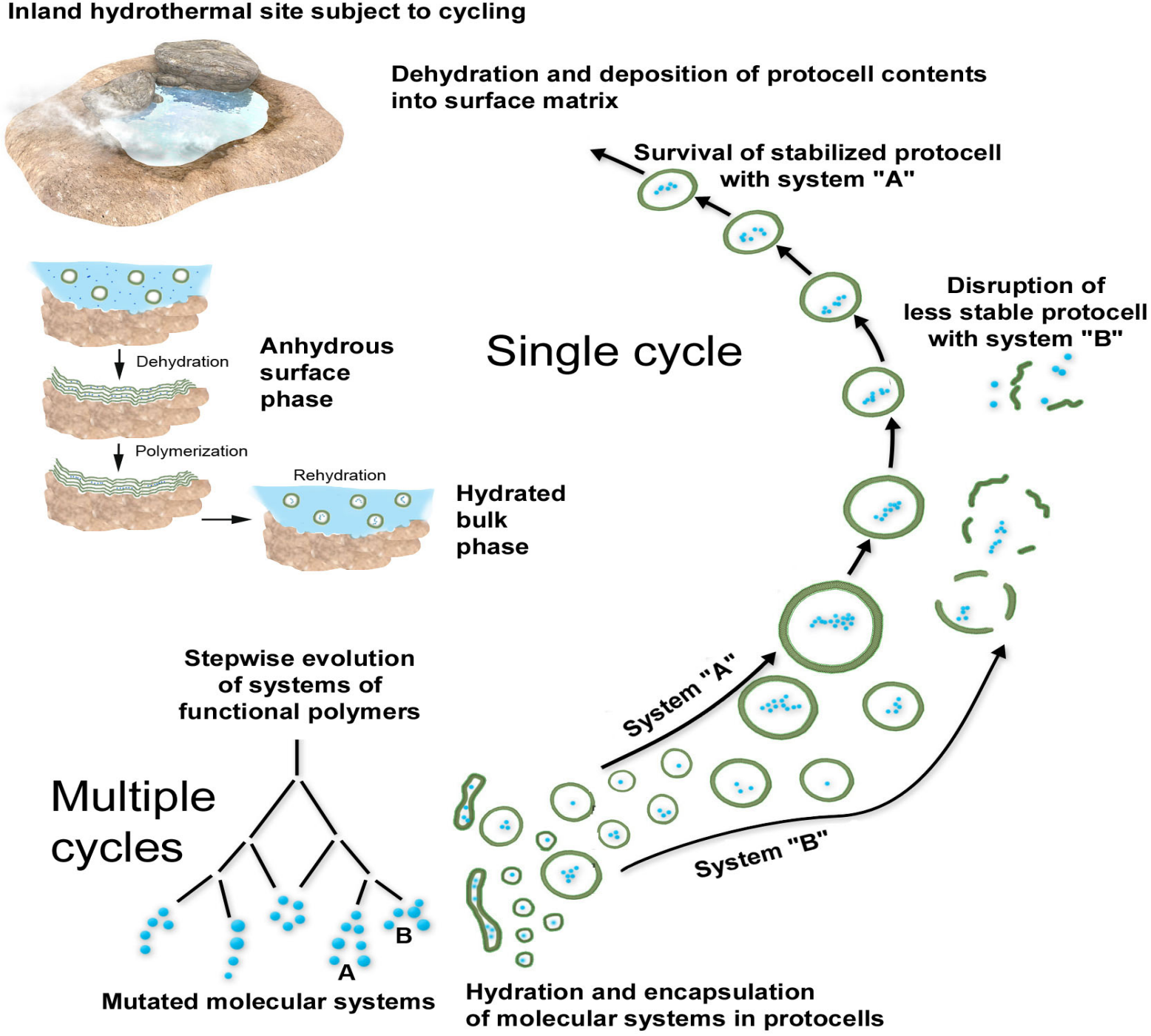


Damer and Deamer, http://www.mdpi.com/2075-1729/5/1/872

Protocells:
Lipid membranes with nucleic acids



http://molbio.mgh.harvard.edu/
szostakweb/exploringOriginsDownloads/
protocell.jpg


Inland hydrothermal site subject to cycling
Dehydration and deposition of protocell contents into surface matrix
Survival of stabilized protocell with system "A"
Disruption of less stable protocell with system "B"
Single cycle
Dehydration
Polymerization
Rehydration
Anhydrous surface phase
Hydrated bulk phase
Stepwise evolution of systems of functional polymers
Multiple cycles
B
A
Mutated molecular systems
System "A"
System "B"
Hydration and encapsulation of molecular systems in protocells