Origin of Life:
Major Steps in Evolution
Origin of Life: Major Steps in Evolution
Big Bang Theory
- How did everything get started?

Evidence – distant galaxies are moving away from us rapidly (Hubble, red shift)
Expanding Universe – space itself is expanding

Every raisin in a rising loaf of raisin bread will see every other raisin expanding away from it.

$H = 71 \text{ km/s/Mpc}$
Big Bang – rapid expansion and cooling

- $10^{-32}$ second: Cosmic inflation ends
- $10^{-6}$ second: Protons form
- 100 seconds: Deuterium, helium and lithium are synthesized
- 100 million years: First stars form
- 500 million years: Current record holder for earliest known galaxy
- 4 billion years: Star formation peaks
Formation of the Solar System
4.6 billion years ago
Our solar system forms
Origin of the Moon

The Earth–Moon system formed as a result of a giant impact, where a Mars-sized body (named **Theia**) collided with the newly formed proto-Earth, blasting material into orbit around it that accreted to form the Moon.

The two hemispheres of the Moon are very different. While the near side is covered with large basaltic plains called maria, the far side is almost completely covered in craters.
Hadean Earth 4.5 BY Ago
Molten Earth – 4.5 BY
Hadean - Era of Large Impacts
Archean Eon, 4 – 2 BY
Archean Eon: 4-2 BYA
Origin of the Atmosphere

- Sun’s energy stripped away 1st atmosphere
- 2nd atmosphere formed from volcanic outgassing
- Primitive atmosphere: CO$_2$, water vapor, lesser amounts of CO, N$_2$, H$_2$, HCl, traces of NH$_3$ and CH$_4$
- Important for formation of life
Formation of Earth’s Oceans (4 by ago):

- Off gassing of water vapor from volcanos
- Condensation
- Rain

Water from Comets? Meteors?
Origin of Life

- Universe begins with Big Bang 16 billion years ago
- Solar System condenses from interstellar dust cloud
- Earth forms 4.5 billion years ago
- Oldest terrestrial rocks 4.3 billion years ago
- Heavy bombardment ends 4 billion years ago
- O$_2$ atmosphere 2.5 billion years ago

Time

- RNA World?
- DNA-based life
- Abundant cellular life 3.5 billion years ago
- Cambrian radiation 540 million years ago
- End-Permian extinction 250 million years ago
- Dinosaur extinction 65 million years ago
Chemical Evolution of Life on Earth

Necessary requirements:

1. Synthesis and accumulation of small organic molecules
2. Joining of monomers into polymers (protein, nucleic acids)
3. Aggregation of these molecules into protocells to form microenvironments
4. Origin of heredity molecules and reproduction
5. Origin of metabolism
Origin of Life – Possible Locations

Deep-sea vents
  conditions suitable for Archaea, Thermophilic (heat-loving)
Ocean’s edge
  bubble hypotheses
Within clay
  positively-charged clay polymerizing templates
Under frozen seas
  problematic due to necessary conditions
Deep in Earth’s crust
  byproduct of volcanic activity
In Ice?
  chemicals concentrate in bubbles
Organic precursors - Stanley Miller Experiments - 1953

- Mixed water, molecular hydrogen, methane, and ammonia in a flask.
- Passed mixture through electrical discharge as input energy to this mixture.
- Spark simulated the energy provided by lightning on the early Earth.
- 13 Amino acids formed, + adenine
Amino acids are monomers
- Monomers must form peptide bond to form proteins
- This requires an input of energy and removal of water
Polymer Formation - Proteins

• Sidney Fox (Univ. of Miami), 1950’s
• Cross-linked polymers formed when organic molecules dripped onto hot sand, clay, or rock
• Proteinoids, protein-enclosed droplets;
• Grow, reproduce by budding; a lot like living cells, but not alive
• Protein world first? Which came first?
Polymer Synthesis – Lipid Membranes

- Lipids in water form organized droplets (liposomes) with bilayer much like that of a plasma membrane.
Hereditary Material - DNA, RNA and Proteins?

Three fundamental classes of molecules are associated with modern life:

• DNA – Replication
• RNA - Transcription
• Protein – Translation

Which came first?

Today DNA replicates and information is transferred from DNA to RNA to protein
Short polymers of ribonucleotides can be synthesized abiotically in the laboratory.

- If polymers are added to a solution of ribonucleotide monomers, sequences up to 10 based long are copied from the template according to base-pairing rules.

Clay might have acted as the first template.
Ribozymes
RNA that catalyzes reactions

Has genotype and phenotype

Self-splicing RNA
RNA World?
- RNA acts as both information storage and as catalyst
- DNA comes later, more stable for information storage
Proto-cells and Metabolism

(a) Simple reproduction
(b) Simple metabolism

Glucose-phosphate
Phosphorylase
Starch
Amylase
Phosphate
Maltose
Maltose
Timeline

- Formation of Earth: 4.5 billion years ago
- Stable hydrosphere: 4.2 billion years ago
- Prebiotic chemistry: ~4.0 billion years ago
- Origin of life: ~3.5 billion years ago
- Apex formation microstructures: 3.4 billion years ago
- Oxygen-rich atmosphere: ~2.8-2.5 billion years ago

Sulfate reducers, anoxygenic phototrophs, and methanogens (?)

Modified from Becerra et al. (2007)
Oldest definite fossils 3.4 BY
Older fossil evidence questionable

- Found in a remote part of Western Australia
- Well preserved between the quartz sand grains of the oldest beach known on Earth, in some of the oldest sedimentary rocks that can be found anywhere.
Characteristics of living organisms:

1. Have one or more cells with DNA.
2. Capable of reproducing, growing, and developing.
3. Capable of capturing and using energy and raw materials.
4. Able to sense and respond to the environment.
5. Capable of evolving over generations.
Archean Eon: 4-2 BYA
Carl Woese and the rRNA Tree of Life

3 Domains

Carl Woese
1980s
ssRNA Sequences
Phylogenetic Tree of Life

Bacteria
- Spirochetes
- Proteobacteria
- Cyanobacteria
- Planctomyces
- Bacteroides
- Cytophaga
- Thermotoga
- Aquifex
- Green filamentous bacteria
- Gram positives

Archaea
- Methanosarcina
- Methanobacterium
- Methanococcus
- T. celer
- Thermoproteus
- Pyrobdictium
- Halophiles

Eukaryota
- Entamoeba
- Slime molds
- Animals
- Fungi
  - Plants
  - Ciliates
  - Flagellates
  - Trichomonads
  - Microsporidia
  - Diplomonads

Last Universal Common Ancestor (LUCA)
Archaea (Archaebacteria)

- Cell walls lack peptidoglycan which Bacteria cell walls have
- Ribosomal RNA different
- Membrane lipids with branched hydrocarbons which Bacteria do not have
- Archaea has more in common with Eukarya than with Bacteria

Some live in **extreme conditions**
- methanogens
- extreme halophiles
- extreme thermophiles
Bacteria (Eubacteria)

- Major group of prokaryotes
- Strong cell walls (peptidoglycan)
- Simple gene structure
- Contains most modern prokaryotes
- Includes photosynthetic bacteria (cyanobacteria)
Eukarya

- Arose about 1.5 BYA.
- Origin of Nucleus? Infolding of plasma membrane
- Internal membrane-bound structures such as mitochondria and chloroplasts are thought to have evolved via endosymbiosis.
Eukarya is more closely related to domain Archaea than to domain Bacteria. Analysis of rRNAs and other highly conserved genes and proteins provide the strongest evidence
End
JUST MOMENTS BEFORE THE BIG BANG
13.8 BILLION YEARS AGO, A FEW SECONDS BEFORE THE CREATION OF OUR UNIVERSE...

All set. Let's fire up this Large Hadron Particle Collider and see what happens!
How life on Earth really got its start.