The Origin of Life

- What is life?
- History of the Earth: The Big Bang
  - Earliest evidence of life
- Requirements for the Evolution of Life from Non-Life
  - Abiotic Synthesis of Monomers
    - A Hypothesis by Oparin and Haldane
    - The Miller and Urey Experiment
  - Anabolic Synthesis of Polymers
  - Formation of Protobionts: Chemical Isolation
  - Evolution of a Genetic Template
    - 3 Steps Toward the Evolution of the Central Dogma
- The Evolution of Complex Cells and Multicellularity
  - Autogenesis, Compartmentation, and Symbiogenesis
- The Five Kingdoms
Reconstructing the history of life:

- The fossil record
- Experimental models and simulations
- Deductions based on existing organisms
15 Billion Years of History in 90 seconds:

- The Big Bang (15 bya)
- Condensation of Solar System (5 bya)
- The Third Planet (4.6 bya)
  - Earth and Primitive Atmosphere
  - Crust Solidifies (4 bya)
  - Oceans and land masses
    (solid, liquid and gas states)
The scale of geological time and fossil evidence:

- **Cenozoic**
  - First humans
  - Extinction of dinosaurs

- **Mesozoic**
  - Plants and symbiotic fungi colonize land
  - Oldest animal fossils

- **Paleozoic**
  - Origin of multicellular eukaryotes
  - Oldest eukaryotic fossils
  - Oxygen produced by cyanobacteria begins to appear in atmosphere

- **Proterozoic**
  - Oldest prokaryotic fossils
  - Oldest chemical evidence of life
  - Origin of life
  - Earth cool enough for crust to solidify

- Origin of Earth

**Eukaryotes**
- Bacteria
- Archaea
- "Protists"
- Plants
- Fungi
- Animals
Compressing Geological Time: If 4.5 billion years = a single year

- Jan 1 - formation of earth
- Feb 17 - Meteor bombardment ends
- Mar 20 - Simple cells appear
- Nov 17 - Simplest animals (750 mya)
- Nov 20 - Cambrian Explosion and the Burgess Fauna (520 mya)
- Nov 28 - first land plants
- Dec 13 - Permian extinction
- Dec 21-27 - Dinosaurs present and gone
- Dec 31 8:45pm - Last ice age begins
- Dec 31 9:07pm - Early man (Homo)
- Dec 31 11:45pm - Man (Homo sapiens)
Fossil Evidence for the Origin of Life
3.5 billion years ago:
Requirements for Chemical and Cellular Evolution:

- A. Abiotic synthesis and accumulation of monomers
- B. Condensation of monomers into polymers (molecules → macromolecules)
- C. Formation of protobionts: chemically isolated systems
- D. Origin of genetic material: directive, continuity and changeable (mutable)
Experimental Evidence for Abiotic Synthesis:

- A. Oparin and Haldane’s Hypothesis (1920’s):
  - Elemental requirements: CHNOPS
  - Reducing atmosphere
  - Energy sources

- B. Miller and Urey: Testing Hypothesis with Primitive Earth apparatus
  - $H_2O, H_2, CH_4, NH_3$
  - $CO_2, CO, N_2$
The Miller-Urey Experiment: Brewing-up some “prebiotic soup”…
Evidence for the production of organic polymers:

- Polymerization = dehydration synthesis

- Proteinoids formed on hot sand or clay

- The importance of clay and zinc to concentration

\[ \text{H} + \text{OH} \rightarrow \text{H}_2\text{O} \]
Chemical Isolation: Protobionts

- David Deamer: The spontaneous formation of liposomes from phospholipids
Evolution of Genetic Material

A. Three functional requirements reviewed

B. The Central Dogma: DNA → RNA → Protein

C. Stepwise evolution of a complex process
   - RNA-based genome and catalysis
   - RNA-directed protein synthesis
   - DNA-RNA-protein
Kingdom Monera

- Kingdom Monera includes the bacteria and cyanobacteria.
- Very simple cells.
- Called prokaryotes or prokaryotic.
- Have no nucleus or complex organelles.
- Most closely resemble the earliest ancestral cells from 3.7 BYA.
- Ecologically and clinically important.

E. coli
Ecological Importance Bacteria and Cyanobacteria

- **Nutrient Cycling:**
  - Decomposers
  - Carbon fixation
  - Nitrogen fixation
  - Others

- **Symbioses:**
  - Mutualistic: +/-
  - Commensalistic: +/o
  - Parasitic: +/-

- **How is natural selection driving evolutionary change among these early prokaryotes?**
  - NS acting on genes
  - Mutations
  - Free exchange genes b/w individuals
The Evolution of Structural and Genomic Complexity: Eukaryotes and Compartmentalized Cell Structure

- Part 1 - The Autogenesis Theory
  - 1. Compartmentalization with regional specialization
  - 2. Increased membrane surface area
Evolution of Eukaryotes and Compartmentalized Cell Structure: Part 2 - The Endosymbiotic Theory

1. Parasites or prey are internalized
2. Mutualistic relationship develops
Evidence for Endosymbiotic Theory:

- 1. size
- 2. homology to prokaryotic plasma membranes
- 3. replication: binary fission, not de novo synthesis
- 4. DNA structure: circular loop and packing
- 5. complete “intracellular” protein synthesizing machinery
- 6. ribosomal structure, sequence and Abx sensitivity
Traditional hypothesis for how the three domains of life are related

Bacteria

Archaea

Eukaryotes

Plastids

Mitochondria

“LUCA”

Last universal common ancestor

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An alternative hypothesis for how the three domains of life are related

Consider the concepts of “Horizontal evolution” and “symbiogenesis”.
Sexual Reproduction: A rapid and continuous source of genetic variation that accelerates adaptability and change.

Gametic Life Cycle

Zygotic Life Cycle

Sporic: The Alternation of Generations
“Kingdom Protista” (aka, K. Fruit Salad)

- Eukaryotic single celled and colonial organisms
- 100,000 living species, 35,000 fossilized members
- Autotrophic, heterotrophic mixotrophic
- Ancestors to metazoans: plants, fungi, animals
- Low specialization, high complexity
- The origins of Eukaryotic complexity: Two trends allowed the eukarya to arise from the eubacteria
  - Compartmentalized cell structure
  - Increased genomic size
- Nuclear lineage and symbiogenesis
Protistans are NOT monophyletic

Note: These groups only represent a sample of protist diversity; many other lineages are not shown on the tree.
The Evolution of “Multicellularity” Among Autotrophs and Heterotrophs:

- Cellular specialization
  - Somatic and gametic cells
- Division of labor
- Interdependence
- Intercellular coordination
Kingdom Plantae- Eukaryotic

- Eukaryotic and multicellular
- Photosynthetic autotrophs
- Cellulose cell walls
- Terrestrial and aquatic environments
- Base of food chain on land
Kingdom Fungi-

- Eukaryotic and multicellular
- Absorptive heterotrophs
- Cell walls of chitin
- Yeast, molds, lichens, mycorrhizae
- Heterotrophic, mainly terrestrial. Some microscopic.
- Cytoplasmic continuity, a different brand of multicellularity
- Important in decomposition
You want mushrooms on that veggie pizza?

- Cell wall composition?
- Free flowing cytoplasm?
- Autotrophic or heterotrophic?
- Flagella?
- Gametes?
- Males and females?
Evolutionary Origin of K. Fungi

- Heterotrophs with monophyletic origin
- Co-evolution with plants to terrestrial habitats
- Cell wall prohibits phagotrophic link with protozoans
- 3 patterns of metabolism:
  - 1/3 mutualists
  - 1/3 decomposers
  - 1/3 parasites
The Vegetative Structure of Fungi

- Hyphae: microscopic filaments
- High SA
- Septate or coenocytic
- Continuous cytoplasm
- Low complexity, no tissues
- High growth potential
- Grow together as mycelia
- Surface growth
Septate hyphae (above) and nonseptate hyphae (below)
Fungi vs. Bacteria: Comparing the adaptations and niches of two competitors

- Fungi prefer lower pH
- Most fungi are aerobic and grow on surfaces
- Both absorptive heterotrophs
- Most fungi are resistant to osmotic pressure
  - High salt or high sugar
- Fungi capable of growth on dry, low moisture environments
- Fungi can digest unique nutrient sources, metabolic specialists
- May be polymorphic: single- and multilcellular forms
- Role of antibiotics
Sexual Reproduction: A rapid and continuous source of genetic variation that accelerates adaptability and change.

- **Gametic Life Cycle**
  - Meiosis → Fertilization
  - 2n Diploid multicellular organism → n Zygote
  - (a) Animals

- **Zygotic Life Cycle**
  - Mitosis → Meiosis → Fertilization
  - n Haploid multicellular organism → 2n Zygote
  - (b) Most fungi and some algae

- **Sporic: The Alternation of Generations**
  - Meiosis → Mitosis → Fertilization
  - n Haploid multicellular organism (gametophyte) → 2n Zygote
  - (c) Plants and some algae

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The generalized fungal life cycle: reproductive hyphae (1n), fusion of mating types to form a heterokaryon (n+n), a transient zygote (2n)
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Mold

- Rapid growth form
  - Hyphae and mycelia
- Asexual reproduction
  - Sporangia or conidia
- Sexual reproduction
  - Fruiting bodies
Yeast

- Single celled stage
- Usually asexual
  - Budding
- Fermentation
- Cloning
- Opportunistic pathogens
Mycorrhizae

- Mutualistic association with roots
- Found on >95% of plants
- Permanent
Lichens

- Fungal/algal symbiosis
- Food or fixed $N_2$ exchanged for physical env’t
Kingdom Animalia - Eukaryotic

- Eukaryotic and multicellular
- Digestive heterotrophs
- Found in all environments
- Capable of movement
- Some microscopic
- Greatest diversity of form
Each kingdom is further subdivided according to this hierarchy:

- **Kingdom**
  - **Phylum (Division)**
    - **Class**
      - **Order**
        - **Family**
        - **Genus**
        - **Species**

(e.g., *Escherichia coli*, *Staphylococcus aureus*)