The Tree of Life

The Earth is at least 4.5 billion years old. Although the oldest rocks on Earth that can be aged date to 3.9 billion years, other objects in our solar system (the Moon and asteroids) date to 4.5 billion years.

Early Earth was likely very hot and didn’t cool sufficiently for rocks to form until about 3.9 bya.

The oldest organic deposits in rocks date to about 3.8 bya.

The oldest rocks with apparent cellular fossils date to 3.5 bya.

Life got started early in Earth’s history.
Living stromatolites

Fossil stromatolites
3.5 bya

Fossilized cellular life
The fossil record of life shows gradual progression from simple cellular beginnings.

Where did the first living things come from?

It is possible that the first living things on Earth came here from another planet in our solar system or from elsewhere in our Galaxy. This is the **Panspermia Hypothesis**. A spore could have arrived here on a meteorite or comet.

Our ability to look for evidence for or against the Panspermia Hypothesis is limited.
All life on Earth is associated with water. The search for life beyond Earth begins with a search for water.

Exploration of Mars has revealed water and suggested that large amounts of water may have been present in the past.

Moons of Jupiter and Saturn have large amounts of water.

Living things use energy and perform chemical reactions that should be detectable via probes, or remotely.
Life may have originated from chemical building blocks and basic physical process on Earth.
If life organized itself according to physical laws it can be investigated scientifically.
If it can be shown that one of the properties of life, or one of the basic building blocks of living systems, could not have become organized on its own under conditions that existed in the past, then we would have to reject the hypothesis.

Early Earth was likely very hot and it may have cooled to 49 to 88 C by the time of the first microbes. Thus, early living things lived in an environment very different than most places on Earth today.
The atmosphere of earth Earth probably lacked oxygen. It was a reducing atmosphere.

Gases in the atmosphere of early Earth probably included CO$_2$, H$_2$O, N$_2$, H$_2$, H$_2$S, NH$_3$, and CH$_4$. Other planets in our solar system have similar atmospheres today.

Oxygen did not become common until about 2.5 bya.

A reducing atmosphere may have fostered the formation of organic molecules.
In 1953, Stanley Miller and Harold Urey created a system to simulate conditions that may have existed on early Earth.

They used the gases they expected to have been in the atmosphere of early Earth in a system with a heating chamber, a cooling chamber and exposed the gases to electrical discharges.
After a few days they found their mix had changed and included many organic molecules, such as formaldehyde (CH₂O), hydrogen cyanide (HCN), formic acid (HCOOH), and urea (NH₂CONH₂).

After a few more days they found simple amino acids had formed.

Later experiments showed that many other organic building blocks can be formed similarly.
Research on the origins of life have continued and various experiments have showed that polypeptides and nucleic acids can form in nonliving systems. Simple biochemical pathways similar to glycolysis and the Krebs cycle can also originate in cell-free systems.

How cells became compartmentalized, separating organized chemical reactions from the surrounding environment with a membrane is an area of active research.

The hypothesis that life may have originated *de novo* on early Earth has not be rejected and many findings have shown how it might have originated from basic physical processes.
From the first living things, a tremendous diversity of living things have evolved.

To communicate about those things we need a system of organization and categorization - taxonomy is the science of classifying living things. Taxonomy is also known as systematics. Each kind, or group of organisms is a taxon (taxa).

Our current system of classifying organisms derives from a system originally developed by Carolus Linnaeus (Carl Linne).

Linnaeus recognized distinct kinds of organisms as species and grouped similar species into more general categories that he called genera (singular genus). Each species is named with a binomial name that includes both its general and specific name - Genus and species.

The genus name is a noun and the species name is an adjective.
The system of classification is **hierarchical**. Species are grouped into larger and more inclusive categories that Linnaeus saw as more and more general kinds of organisms - genera into families into orders into classes into phyla into kingdoms.

Subcategories - like subphylum and superclass are used to further subdivide the categories.

More recent understanding of living things has resulted in the addition of the category **domain** above kingdom.
Every since Darwin proposed that all living things are related, derived from a common ancestor through anagenesis and cladogenesis the goal of taxonomy is to classify organisms according to their degree of relatedness. Each level in the hierarchy should reflect the pattern of evolution.

A genus (or any other level in the hierarchy) should consist of a group of species that represent all of the descendants of their common ancestor. They should be monophyletic groups.
There are three monophyletic domains.

The bacteria and archaea are both prokaryotic.
Although bacteria and archaea are both prokaryotic, archaea share many characteristics with eukaryotes.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Archaea</th>
<th>Bacteria</th>
<th>Eukaryya</th>
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</thead>
<tbody>
<tr>
<td>Amino acid that initiates protein synthesis</td>
<td>Methionine</td>
<td>Formyl-methionine</td>
<td>Methionine</td>
</tr>
<tr>
<td>Introns</td>
<td>Present in some genes</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Membrane-bounded organelles</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
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<tr>
<td>Membrane lipid structure</td>
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<td>Unbranched</td>
<td>Unbranched</td>
</tr>
<tr>
<td>Nuclear envelope</td>
<td>Absent</td>
<td>Absent</td>
<td>Present</td>
</tr>
<tr>
<td>Number of different RNA polymerases</td>
<td>Several</td>
<td>One</td>
<td>Several</td>
</tr>
<tr>
<td>Peptidoglycan in cell wall</td>
<td>Absent</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>Response to the antibiotics streptomycin and chloramphenicol</td>
<td>Growth not inhibited</td>
<td>Growth inhibited</td>
<td>Growth not inhibited</td>
</tr>
</tbody>
</table>
The major differences between archaeans and bacteria were not appreciated until relatively recently. Since then much has been learned about the archaea.

Archaens often live in extreme environments. Many are extremophiles or exhibit uncommon metabolic abilities.

- Methanogens - obtain energy by using H₂ to reduce CO₂ to CH₄ - they live in anaerobic environments - the sediments of swamps and marshes, and the intestines of mammals.
- Thermophiles - live in high temperature habitats - 60 to 80 C.
- Cold-adapted - live in glacial ice or beneath ice in alpine lakes.
- pH extremists - live in highly acidic (pH = 0.7) or basic (pH = 11.0) environments.
- Pressure extremists - live in the deep sea at pressures greater than 300 atm.
Eukaryotes are the only group to have compartmentalized cells. The history of eukaryotes includes multiple instances of endosymbiosis.
Classically, the diversity of life has been divided into 6 kingdoms: 2 prokaryotic (Bacteria and Archaebacteria) and 4 eukaryotic (Protista, Plantae, Fungi, and Animalia).
The Kingdom Protista is highly diverse and has given rise to the other kingdoms of eukaryotes.

The Kingdom Protista is not monophyletic because it excludes many forms that are the descendants of the common ancestor of the rest of the protists.

Protists gave rise to the multicellular eukaryotes in three different events.
Land plants (classically the Kingdom Plantae) are a monophyletic group derived from green algae. One modern taxonomic arrangement puts all green algae and the land plants into a new kingdom - Viridiplantae - a larger monophyletic group that includes all the descendants of the first green alga.
The Kingdom Animalia is also derived from protists - the choanoflagellates. Sponges are the most primitive animals.

Molecular evidence suggests that segmentation evolved independently in three different lineages of animals.

<table>
<thead>
<tr>
<th>Lophotrochozoans</th>
<th>Ecdysozoans</th>
<th>Deuterostomes</th>
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<tbody>
<tr>
<td>Lophophorates</td>
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<td>Echinoderms</td>
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<td>Annelids</td>
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3. Map the gene duplication findings on a phylogeny based on ribosomal RNA.
Viruses are a special case - they are molecular parasites of both prokaryotes and eukaryotes. They may be derived from cellular life or they may have originated before cellular life or both.

Viruses are the subject of the next lecture.