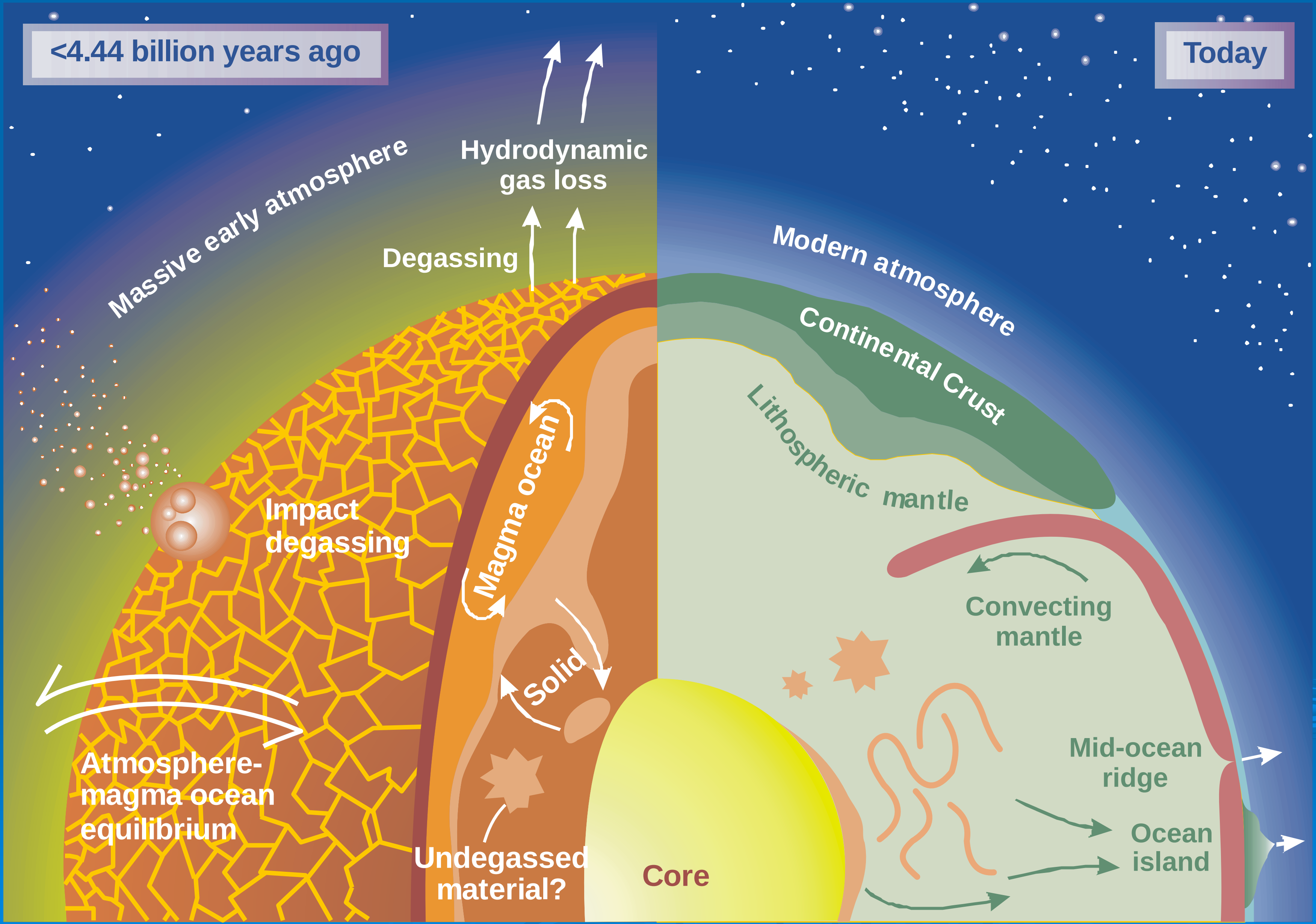
Origin and Evolution of Life

BI 201 Natural History of Guam

Class Presentation 23

- Origin of Life
  - Environmental conditions of primitive Earth
    - Earth was “born” about 4.5 Bybp
    - The planets probably formed from debris cast off from our Sun following its condensation from interstellar gas and dust of a nebula about 5–7 Bybp
    - At first, Earth was semi-molten, but gradually cooled enough to form a solid rock crust
      - The oldest rocks are 3.964 Bybp—from Canada

- Decay of radioactive elements of Earth caused partial melting of the planet’s interior, with denser materials making up the core
- Differential temperatures of the core and crust set *convection currents* in motion in the mantle



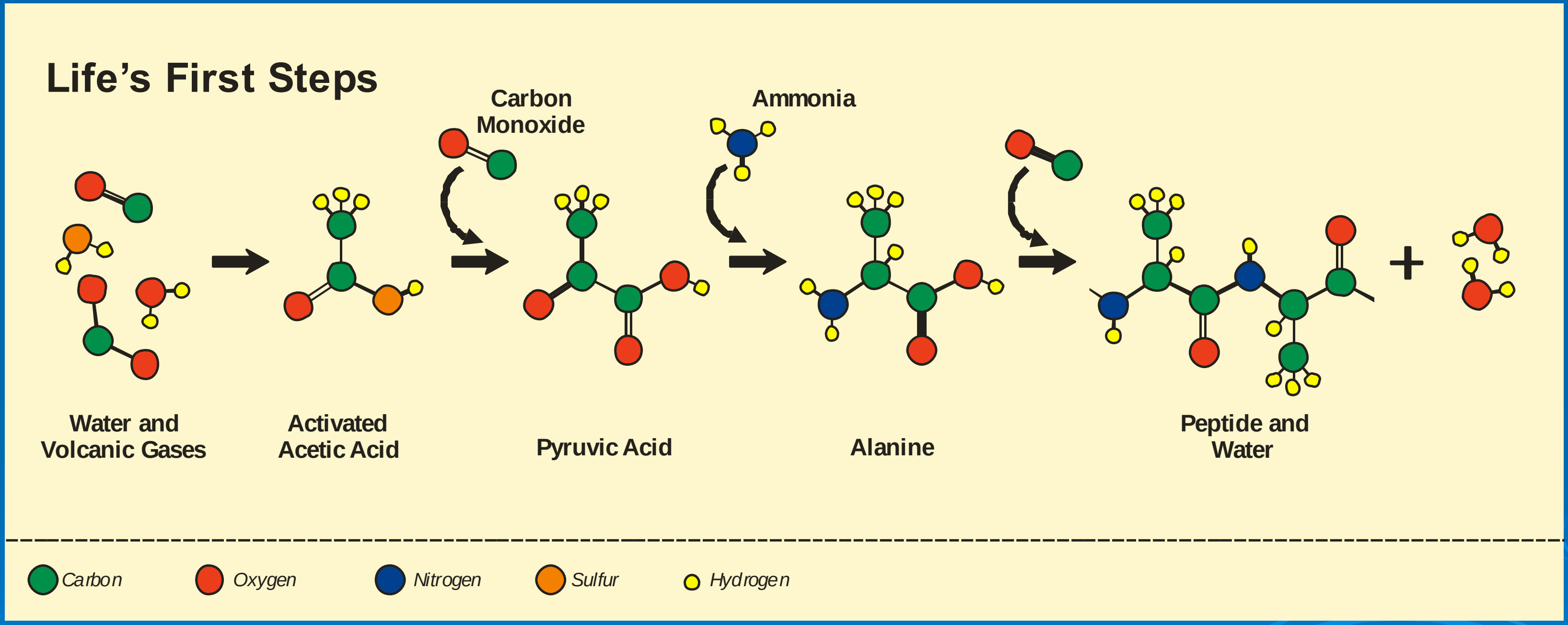
<4.44 billion years ago
Today
Massive early atmosphere
Hydrodynamic gas loss
Degassing
Impact degassing
Magma ocean
Solid
Atmosphere-magma ocean equilibrium
Undegassed material?
Core
Modern atmosphere
Continental Crust
Lithospheric mantle
Convecting mantle
Mid-ocean ridge
Ocean island

- As Earth cooled, there was a period of intense volcanic activity that released gases into the primitive atmosphere, primarily
  - **ammonia** = NH_3
  - **carbon monoxide** = CO
  - **hydrogen sulfide** = H_2S
  - **methane** = CH_4
  - **nitrogen** = N_2
  - **water vapor** = H_2O

- As the rate of radioactive decay slowed, water vapor condensed and fell through the atmosphere, dissolving gases and forming a “poisonous” rain
- Run-off of rainwater from the land carried dissolved minerals into a shallow proto-ocean
- The collective materials in the proto-ocean formed a “hot, thin primordial soup”

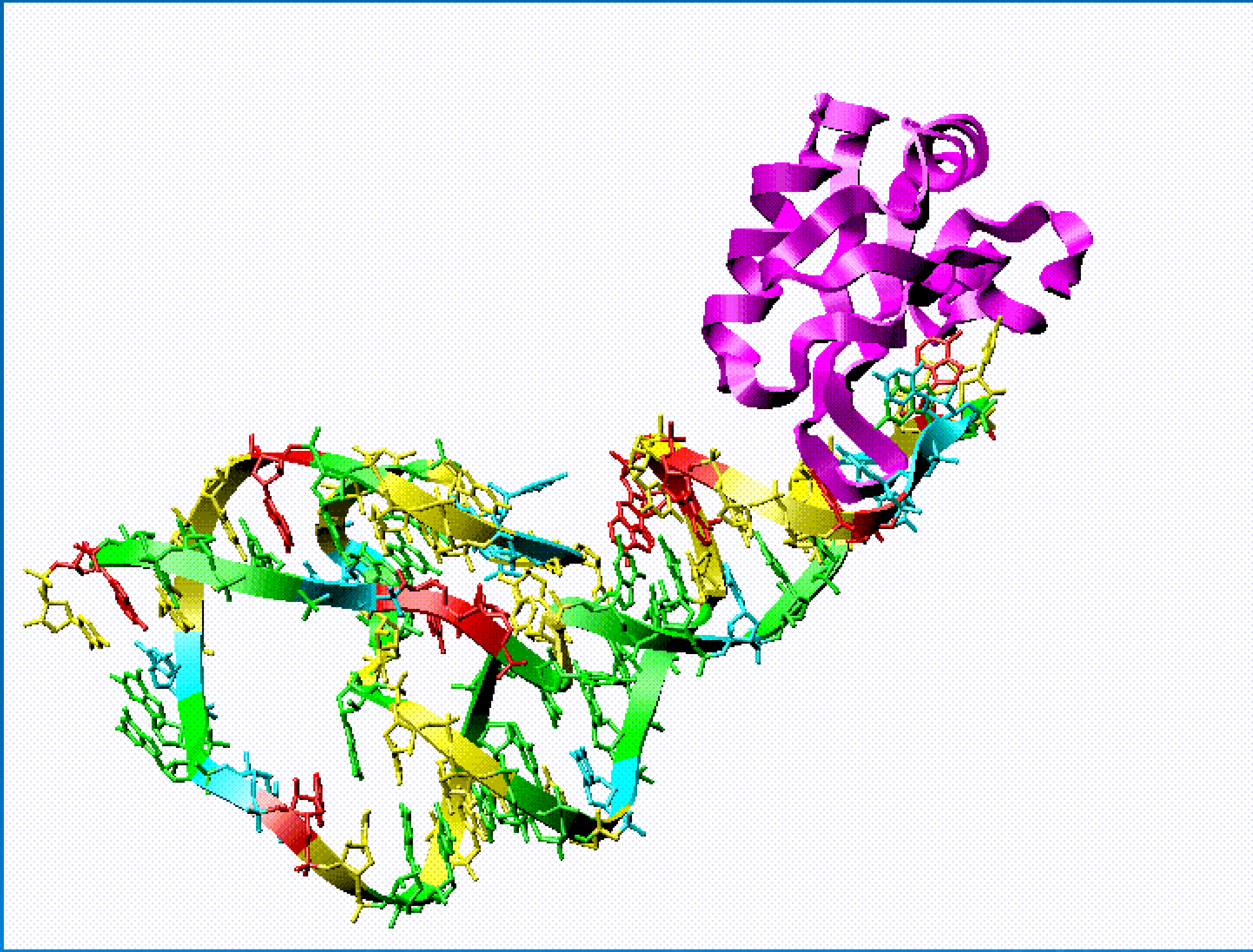
- Earth's surface was bombarded by solar energy, especially ultraviolet (UV) radiation (N.B., the ozone layer was not formed until ca. 600 Mybp)
- Intense electrical storms generated lightning that assaulted the surface
- Together, the UV and lightning provided energy necessary to arrange simple molecules of CH_4, NH_3, PO_4 salts, and H_2O into the basic building blocks of organic compounds, and then into complex macromolecules

- This chemical evolution of organic molecules is called **abiogenesis**



A blueprint describing how biomolecules may have evolved from inorganic chemicals spewing from the seafloor; with a jump-start from sulfide minerals (not shown), each step incorporates raw materials readily a vailable at hydrothermal vents to fashion a more complex molecule.

- Life began with the first self-replicating "organism"
  - The earliest organism may have been no more than a **ribozyme**
    - A ribozyme is an RNA molecule capable of enzymatic actions, e.g., the self-splicing introns of some RNAs, which can excise themselves from the molecule without the help of protein enzymes



- These first self-reproducing organisms appeared about 3.5 Bybp
- They were prokaryotes and anaerobic heterotrophs that fed on organic molecules in the primordial soup
  - [anaerobic, without oxygen]
  - [heterotrophs, consume organics from other sources]

- Early life forms were continuously bombarded by UV radiation, causing mutations that produced new life forms
- As new life forms evolved, the predatory mode appeared
  - Consumption of prey organisms required catabolism of their organics through the process of respiration

- Anaerobic respiration released CO_2 into the atmosphere

$$C_6H_{12}O_6 \rightarrow \text{energy} + C_2H_3OH + CO_2$$

glucose — ethanol — carbon dioxide

- In the atmosphere, UV radiation cleaved CO_2 to form ozone

- The ozone accumulated into the ozone layer in the stratosphere, and blocked most of the UV radiation from penetrating to surface
- Formation of the ozone layer enabled development of terrestrial life forms

- Other organisms developed the ability to utilize energy released from breaking chemical bonds to manufacture their own organic compounds in the process called *chemosynthesis*

- About 2.7 Bybp, still other organisms developed the ability to utilize energy from sunlight to manufacture their own organic compounds in the process called *photosynthesis*
- Photosynthesis released a new gas into the atmosphere, oxygen

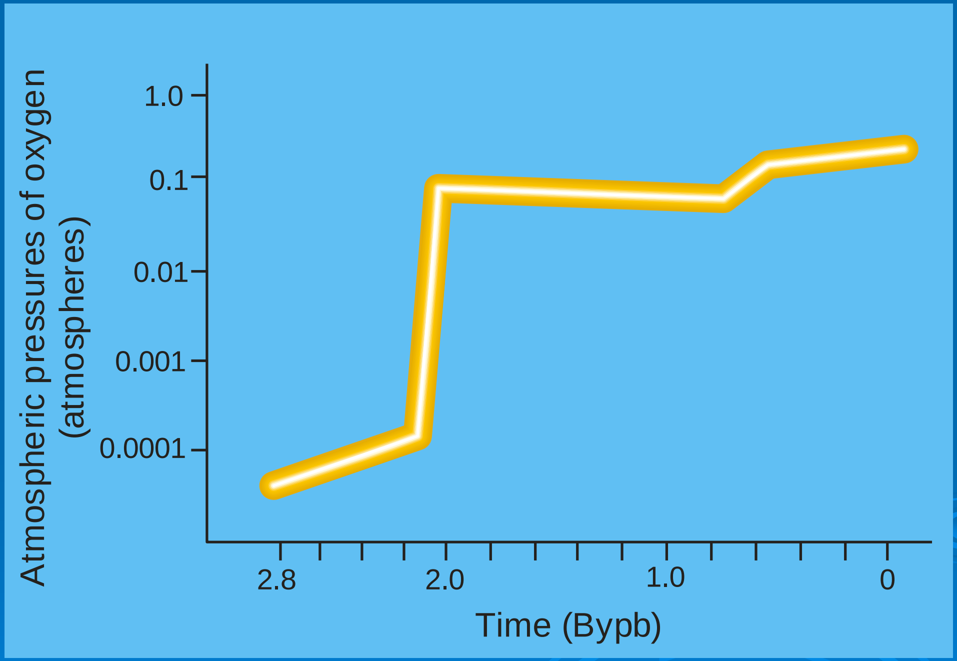
$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$$

carbon dioxide | water | glucose | oxygen

- At first, all of the oxygen released by photosynthesis reacted with iron in the lithosphere
- Gradually, free elements reached oxidized states, and O_2 began to accumulate in the atmosphere
- Because oxygen interferes with anaerobic respiration, another great change in life occurred, the development of aerobic respiration

$$C_6H_{12}O_6 + O_2 \longrightarrow \text{energy} + CO_2 + H_2O$$

- The oxygen-rich atmosphere and aerobic respiration are thought to have led to the evolution of eukaryotes

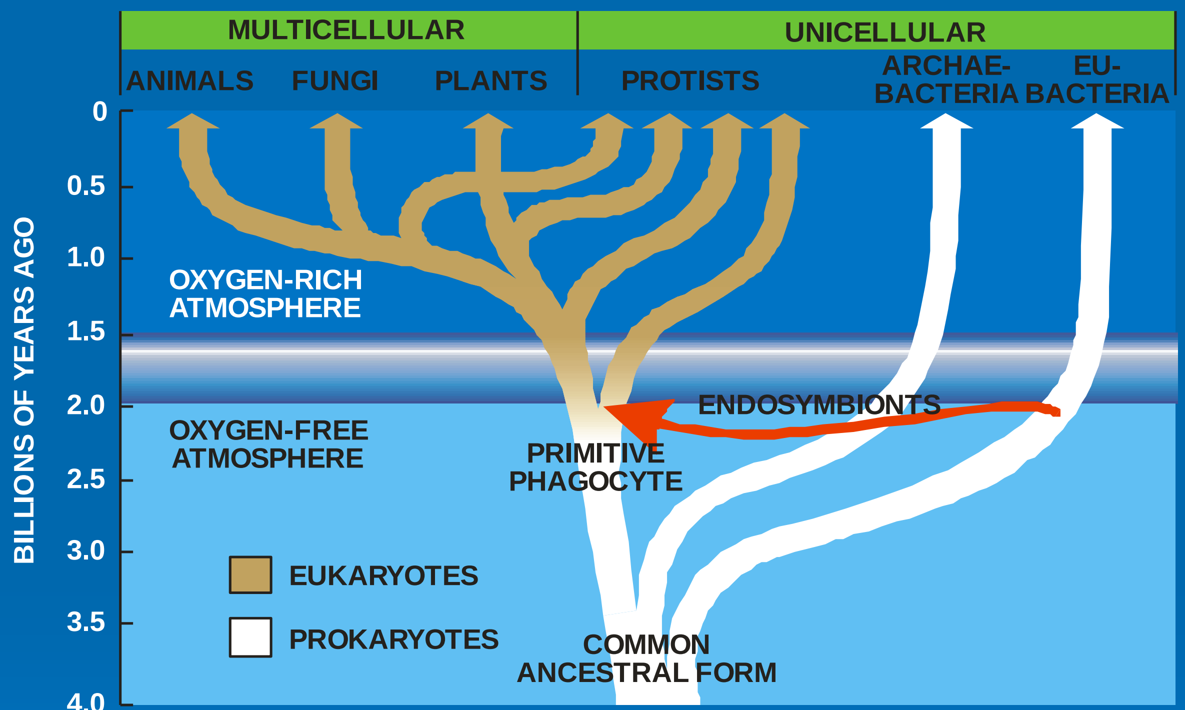


The first spike in oxygen levels was a toxic challenge to life and may have shattered a life-sustaining greenhouse. [Adapted from Kerr, 1999].

- Serial Endosymbiosis Theory
  - In the 1970s, scientists hypothesized that eukaryotes arose as free-living bacteria in symbiosis with some archaebacterial host that became the nucleus-containing cytoplasm of the resulting eukaryote
  - They further hypothesized that organelles were modified from prokaryotic endosymbionts during eukaryote evolution

- Evidence in support of SET
  - Some organelles possess their own DNA outside the nucleus of the cell
  - DNA in organelles is in the form of a convoluted loop

- For each organelle, there is an analog that that has been identified among living Eubacteria
  - Bacteria giving rise to **mitochondria** were aerobic respirers (and predatory?)
    - similar to modern α purple bacteria
  - Bacteria giving rise to **plastids** were oxygenic phototrophic bacteria
    - similar to cyanobacteria, and probably were ingested but not digested or digestible
  - Bacteria giving rise to **undulipodia** (e.g., cilia, sperm tail, etc., but NOT true flagella of bacteria)
    - similar to spirochetes



Evolutionary tree depicts major events in the history of life. Some scientists argue that the last common ancestor of all living beings existed a little more than two billion years ago. [Modified from de Duve, 1996].