Part III. Conserving biodiversity

I. How populations work

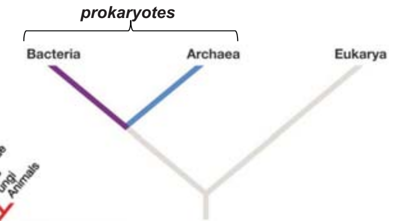
II. How communities & ecosystems work

III. Origins of biodiversity

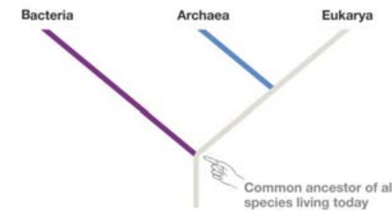
- How do species arise?
- How are phylogenies used to organize diversity?
- Surveys of biodiversity and evolutionary trends
  - Unit 8. Prokaryotes and Protists (single-celled organisms)
  - Unit 9. Green plants and Fungi
  - Unit 10. Animals

The Tree of Life

traditional phylogeny based on morphology



accepted phylogeny based on SSU-rRNA



Q: Are prokaryotes monophyletic or paraphyletic?

Some general characteristics of the three domains of life

Bacteria & Archaea

Unicellular

Prokaryotes (no membrane-bound nucleus)

Generally smaller than Eukaryotic cells

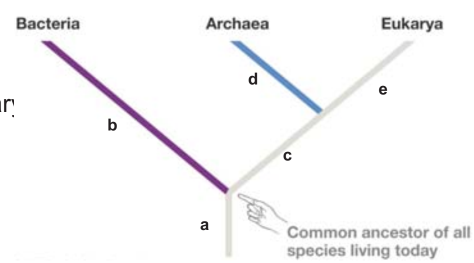
Domain Bacteria

Peptidoglycan cell walls

Plasma membrane similar to Eukar

Unique ribosomes

Unique RNA Polymerase



Domain Archaea

Polysaccharide cell walls similar to Eukarya

Unique plasma membrane

Ribosomes similar to Eukarya

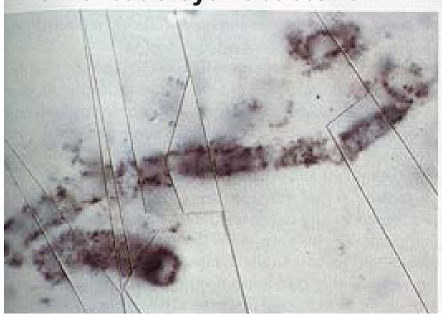
RNA polymerase similar to Eukarya

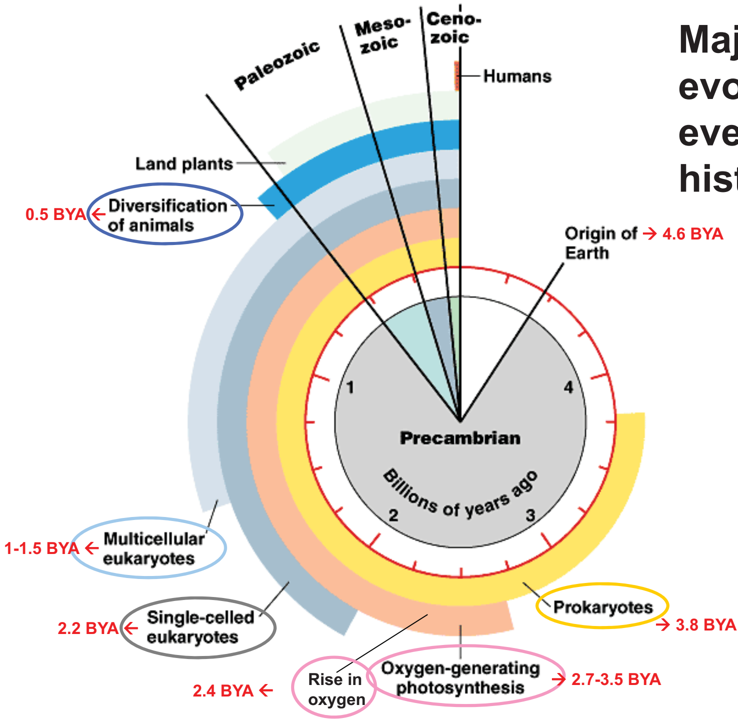
Q: Can you map the origin of these traits, using parsimony?

Earth's earliest organisms

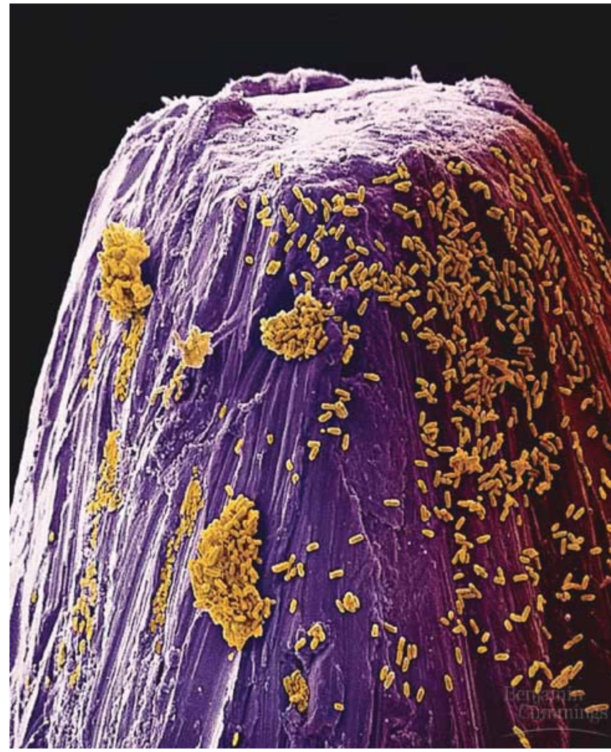
- **early atmosphere was anoxic, hostile to oxygen-based metabolism**
- **"oxygen revolution"**
  - **– cyanobacteria produce O_2 as byproduct of photosynthesis**

3.5 billion year old fossilized filamentous cyanobacterium





Major evolutionary events in the history of life

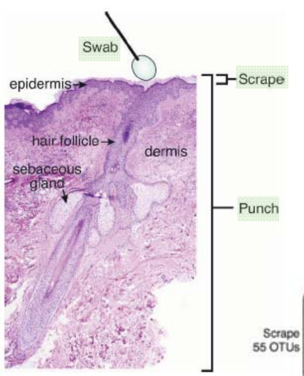


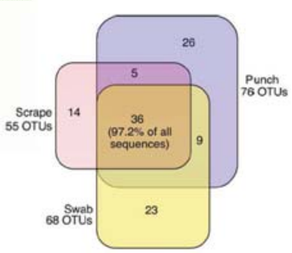
Prokaryotes are ubiquitous and diverse

- Among all organisms:
  50% of all carbon!
  90% of all nitrogen!
- Group I marine archaea most numerous organism on planet?

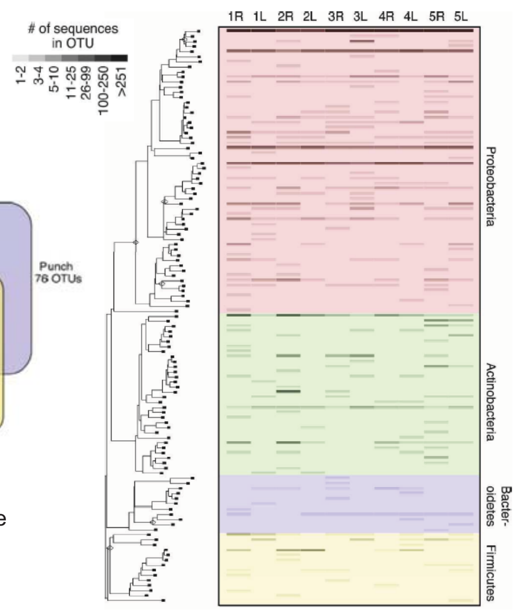
Human microbiome project

Grice et al. 2008. Genome Research





Prokaryotes are ubiquitous and diverse



Results of research

- 113 OTUs in inner elbow
- greater diversity in punches than on surface
- human:bacterial cell counts 1 : ?
- human:bacterial gene counts 1 : ?

1. Morphological diversity in prokaryotes

(a) Size varies

The sizes of bacteria and archaea vary. *Mycoplasma* cells (left) are about 0.5 μm in diameter, while *Thiomargarita namibiensis* cells (right) are about 150 μm in diameter.

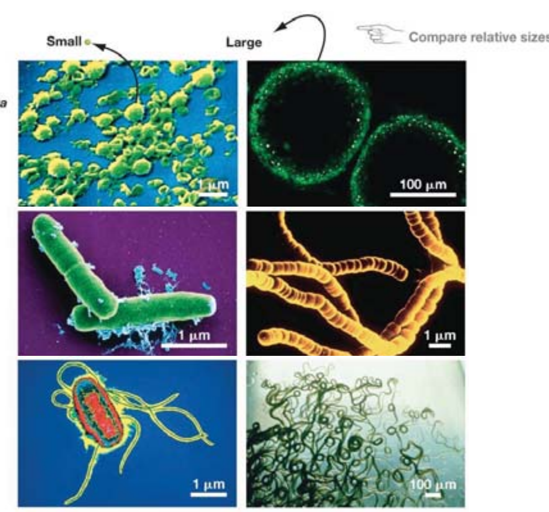
mouse to elephant!

(b) Shape varies

The shapes of bacteria and archaea vary from rods such as *Bacillus anthracis* (left) and spheres to filaments or spirals such as *Rhodospirillum*. In some species, such as *Streptococcus faecalis* (right), cells attach to one another and form chains.

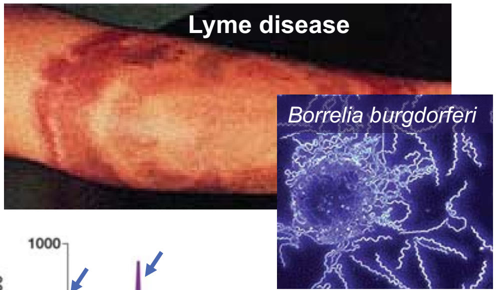
(c) Mobility varies

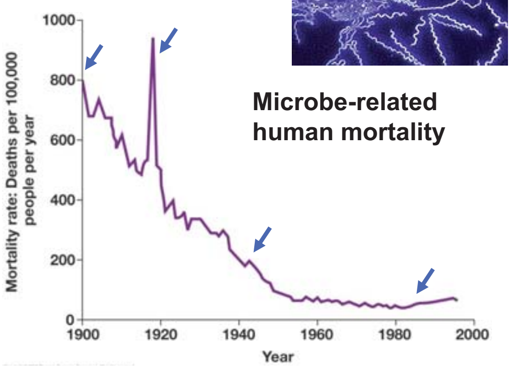
A wide variety of bacteria and archaea use flagella (left) to power swimming movements. These cyanobacterial cells (right) move by gliding across a substrate.



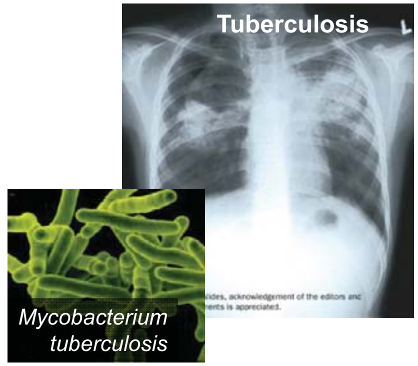
2. Ecological diversity in bacteria

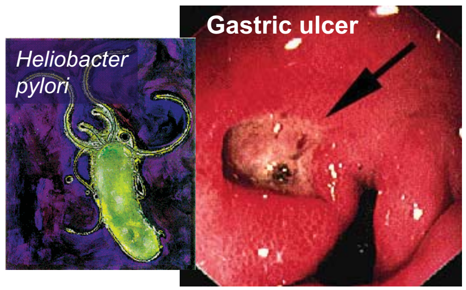
Some are pathogenic…





Microbe-related human mortality



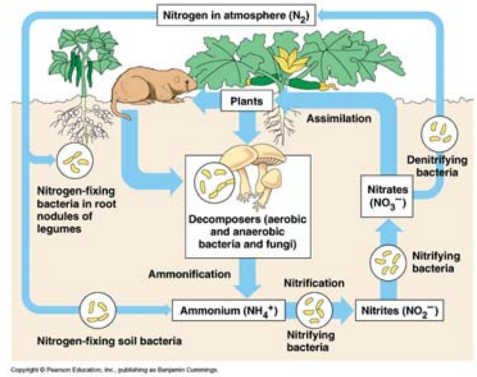


2. Ecological diversity in bacteria

Some provide services…

food production

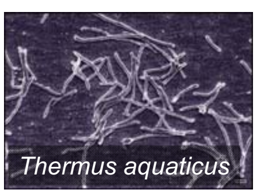
nutrient cycling



2. Ecological diversity in bacteria

Some are extremophiles…

- halophiles (e.g., salt flats)
- anaerobes (e.g. pluff mud)
- thermophiles (e.g., hydrothermal vents)



bacterium from Yellowstone hot spring

Taq polymerase for PCR (polymerase chain reaction)

revolutionized the study of genetics

Q: Why do astrobiologists study extremophiles?

3. Metabolic diversity: sources of energy and carbon

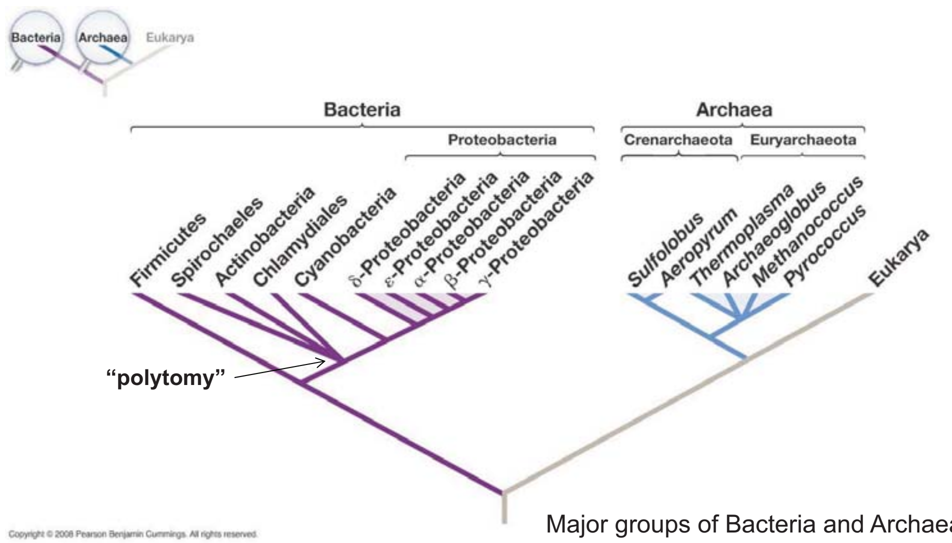
***sources of carbon** (→ organic compounds)*

sources of energy (→ ATP)

	Autotrophy *Synthesize own high potential energy organic compounds from CO2, CH4, other inorganic sources*	*Heterotrophs* *Use organic compounds with high potential energy produced by other organisms*
Light *(phototrophs)*	**Photoautotrophs** e.g. Cyanobacteria use photosynthesis to produce ATP, and fix CO2 through the Calvin cycle.	**Photoheterotrophs** e.g. Heliobacteria use photosynthesis to produce ATP, and absorb organic compounds from the environment.
↑nrg organic molecules *(organotrophs)*	**Chemoorganoautotrophs** e.g. *Clostridium* ferments glucose to produce ATP, and fixes CO2 through the acetyl-CoA pathway.	**Chemoorganoheterotrophs** e.g. *E. coli* uses fermentation or respiration of glucose to produce ATP, and absorbs organic compounds from the environment.
↑nrg inorganic molecules *(lithotrophs)*	**Chemolithotrophs** e.g. Nitrifying bacteria use respiration to produce ATP (using NH3 as electron donor), and fix CO2 through the Calvin cycle.	**Chemolithotrophic heterotrophs** e.g. *Beggiatoa* uses respiration to produce ATP (H2S as electron donor), and absorbs organic compounds from the environment.

metabolic diversity → ecological diversity

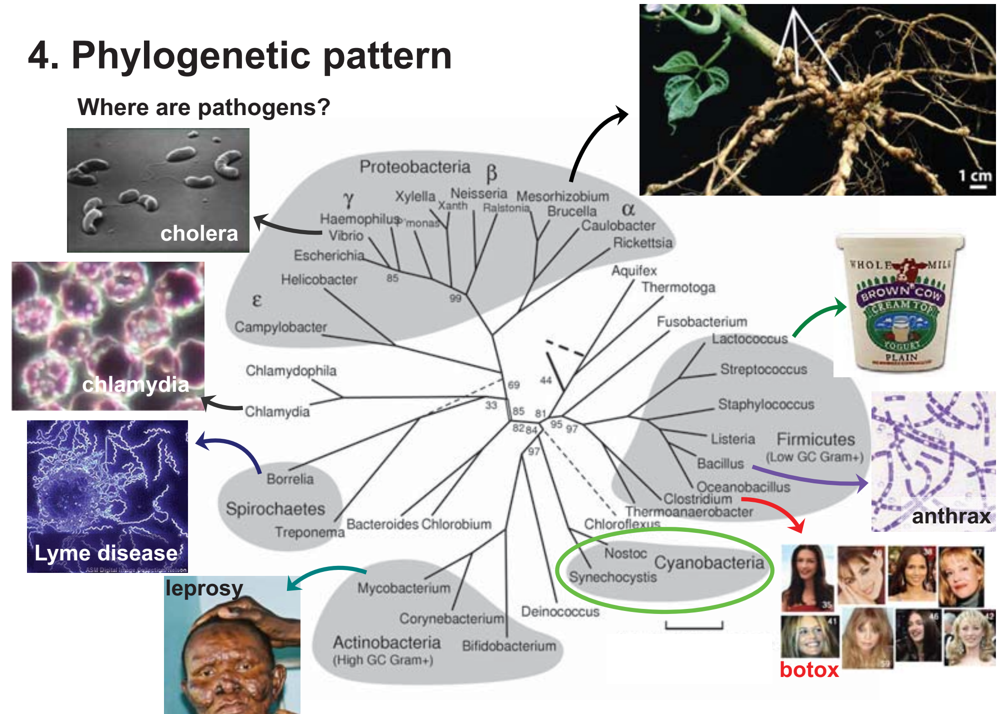
4. Does ecological diversity reflect phylogeny?



Major groups of Bacteria and Archaea
Some placement not fully resolved

4. Phylogenetic pattern

Where are pathogens?

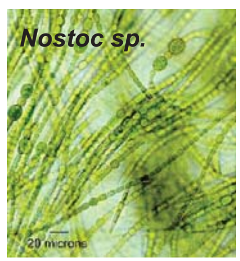


Q: Does ecological diversity reflect phylogenetic relationships?

4. Phylogenetic pattern in Bacteria

Photosynthesizers

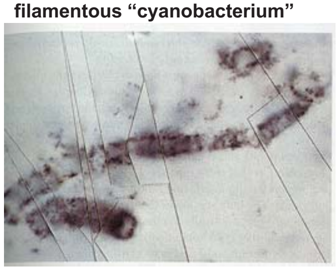
e.g. Cyanobacteria
(*Misnomer:* "blue-green algae")



- species-poor (~ 80) but <u>extremely</u> abundant
- <u>all photosynthetic</u>, some colonial

- early Earth's atmosphere was anoxic (CO_2, CO, H_2, H_20, N_2?)
- "oxygen revolution: cyanobacteria added O_2 to atmosphere

3.5 billion year old fossilized filamentous "cyanobacterium"



symbioses with fungi
(like lichens)

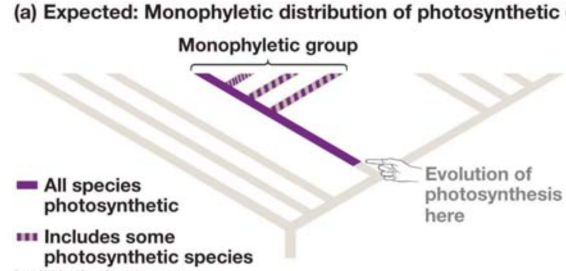
stromatolites: earliest communities
(cyanobacteria are the 1° producers)

4. Phylogenetic pattern in Bacteria

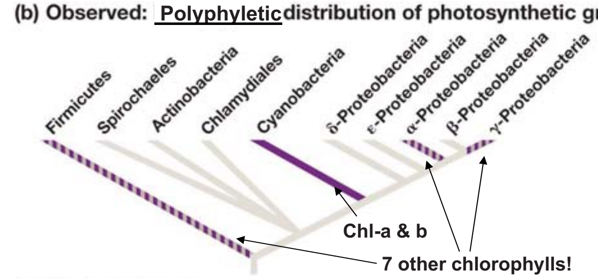
Where are photosynthesizers?

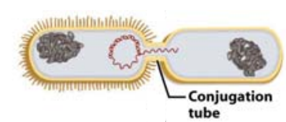
Q: Does metabolic diversity reflect phylogenetic pattern?

(a) Expected: Monophyletic distribution of photosynthetic groups



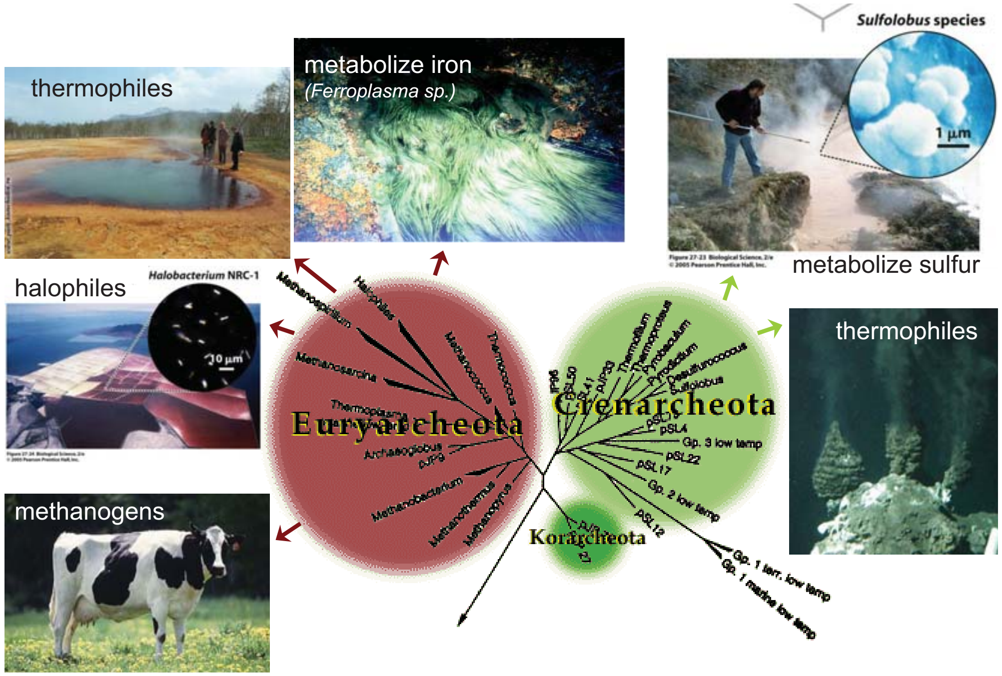
(b) Observed: <u>Polyphyletic</u> distribution of photosynthetic groups



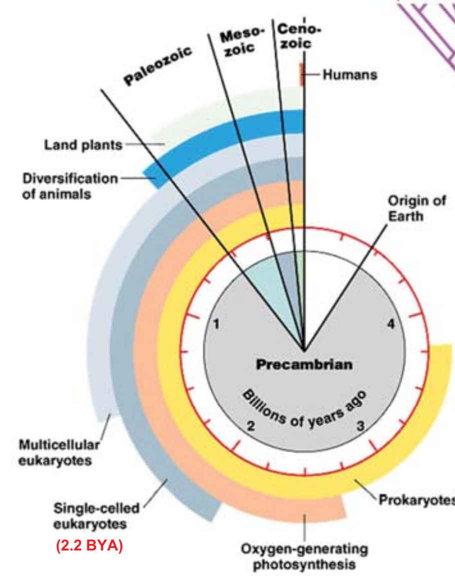


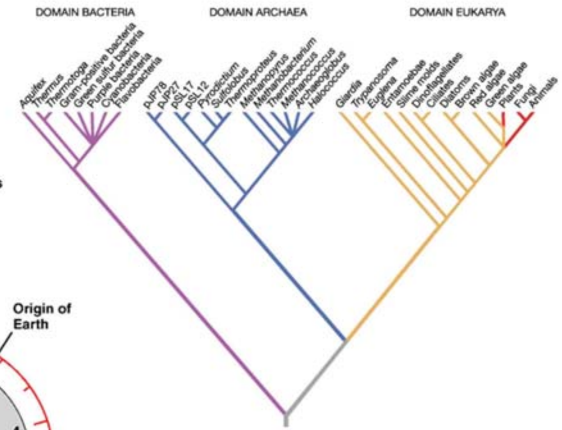
"Lateral gene transfer"

4. Phylogenetic pattern in Archaea

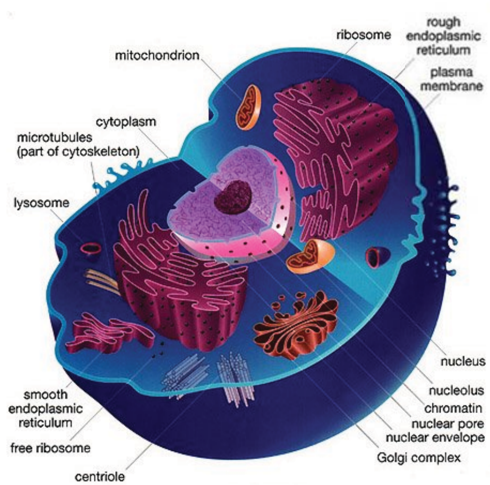


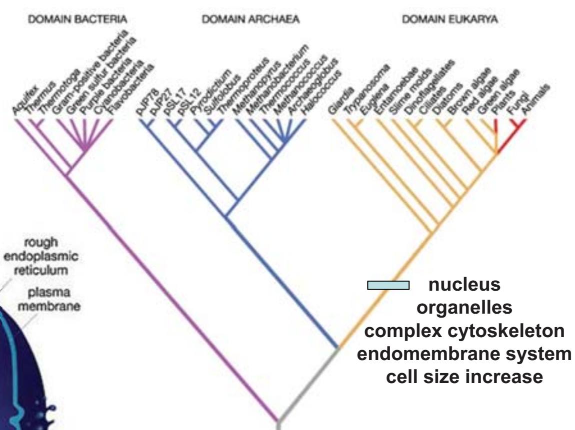
Domain Eukarya





Domain Eukarya



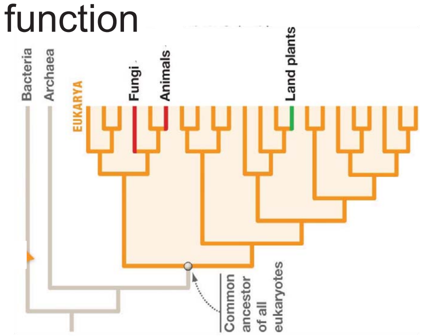


Q: Are eukaryotes monophyletic?

Q: How did they arise?

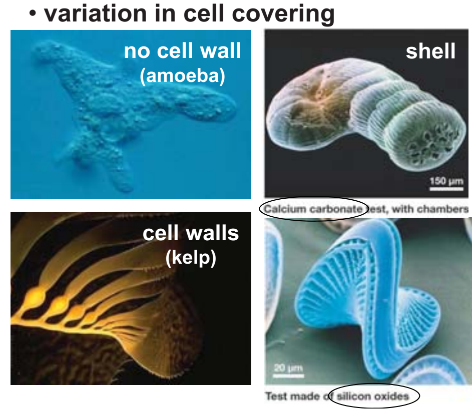
Protists – diverse in form and function

- unicellular or multicellular

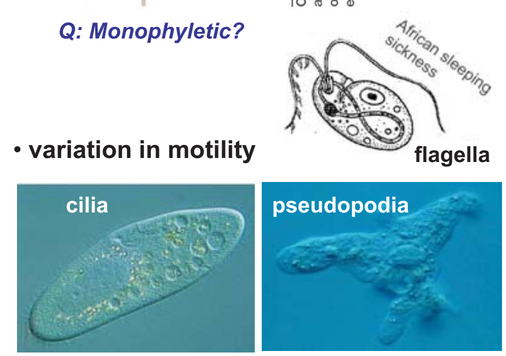


Q: Monophyletic?

- variation in cell covering



- variation in motility

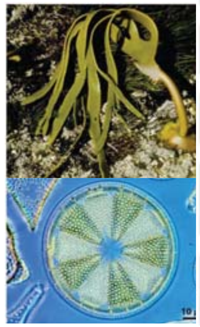


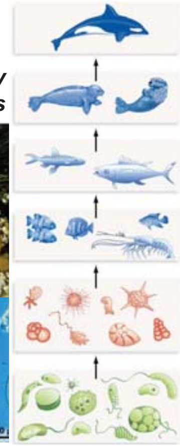
Protists – diverse and paraphyletic

- **unicellular or multicellular**
- **variation in cell covering**
- **variation in motility**
- **variation in nutritional mode**
  - photosynthesis
  - absorption
  - ingestion (*new!*)

filter feeders

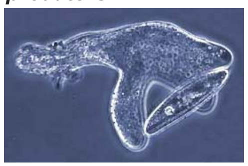
primary producers



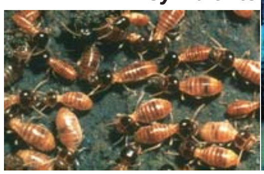


pathogens

predators



symbionts

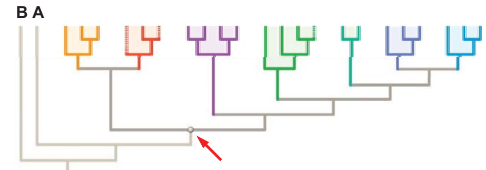


decomposers

1. How did eukaryotes arise? → Internal membranes

Inferred common ancestor of all modern eukaryotes:

- unicellular
- membrane-bound nucleus
- cytoskeleton
- no cell wall
- mitochondria



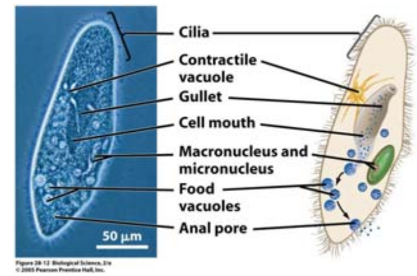
EVOLUTIONARY INNOVATION: *Endomembrane system*

↑ SA:V ratio

Allows cells to ↑ size

Allows for specialized compartments

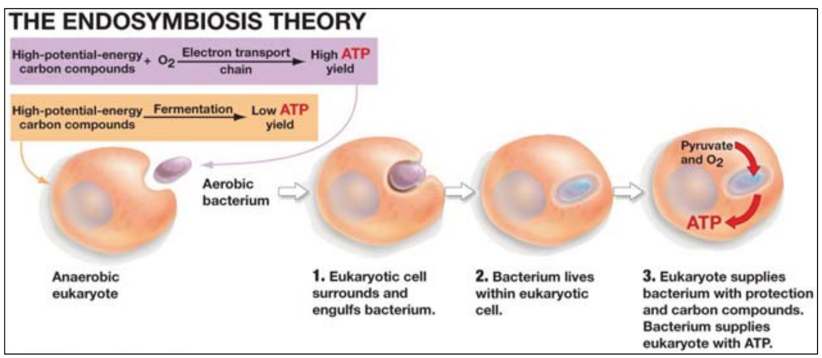
- Endoplasmic Reticulum
- Golgi Complex
- Vacuoles
- Nuclear Membrane



1. How did eukaryotes arise? → Organelles

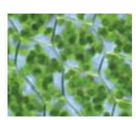
EVOLUTIONARY INNOVATION: *Mitochondria*

- site of respiration in <u>all</u> eukaryotic cells



EVOLUTIONARY INNOVATION: *Chloroplasts*

- site of photosynthesis in <u>some</u> eukaryotic cells



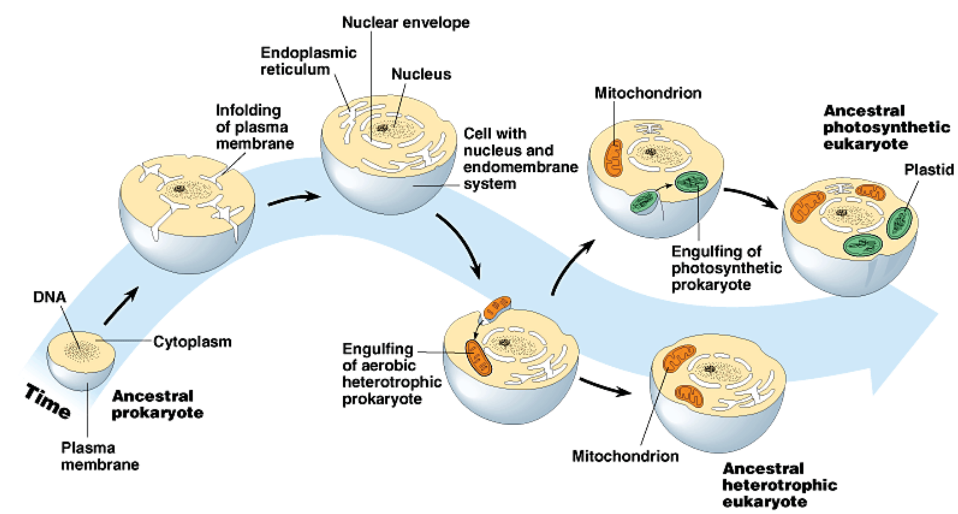
According to endosymbiotic theory:

Q: How many membranes should surround a mitochondrion? Chloroplast?

Q: What should mitochondrial or chloroplast DNA be most like?

1. How did eukaryotes arise?

➢ membrane infolding and acquisition of organelles

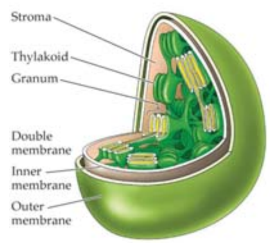


1. How did eukaryotes arise?

What is the evidence for Endosymbiosis Theory?

a. Traits shared by bacteria and mitochondria/chloroplasts:

- Circular DNA
- Divide by fission
- Small size
- Distinct ribosomes



b. Double membranes

c. Morphological similarity to cyanobacteria

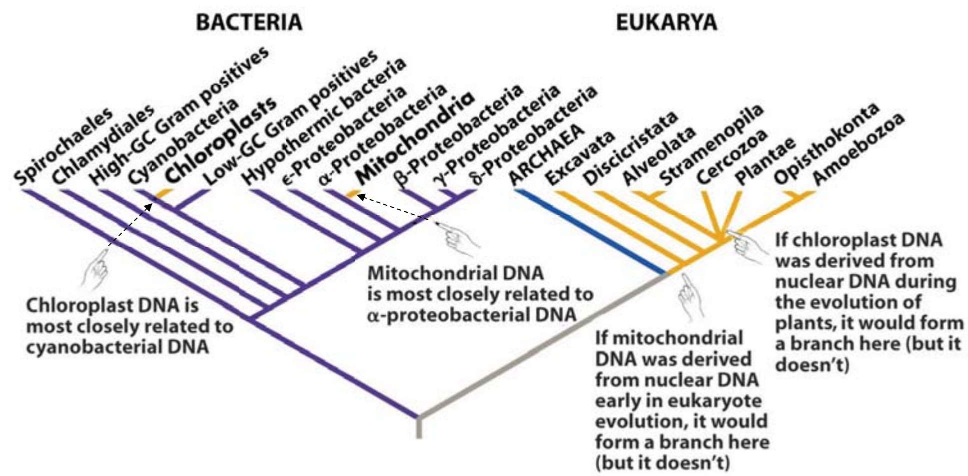
d. Analogous examples of protists with bacterial endosymbionts

e. Molecular phylogeny: where do organelles fit on the tree?

1. How did eukaryotes arise?

What is the evidence for Endosymbiosis Theory?

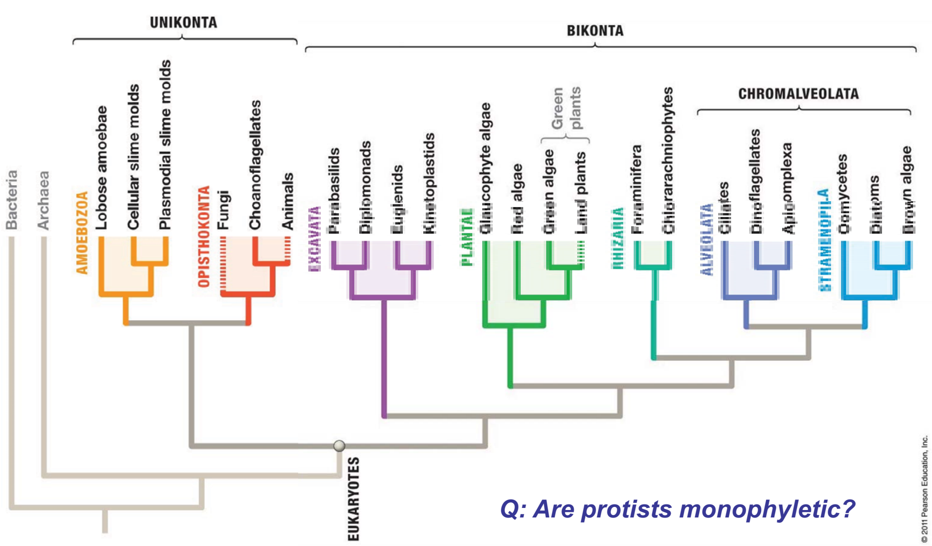
e. Molecular phylogeny: where do *organelles* fit on the tree?



2. Phylogenetic and ecological diversity of protists

<u>Seven</u> major, morphologically distinct lineages ("protists" are solid lines)

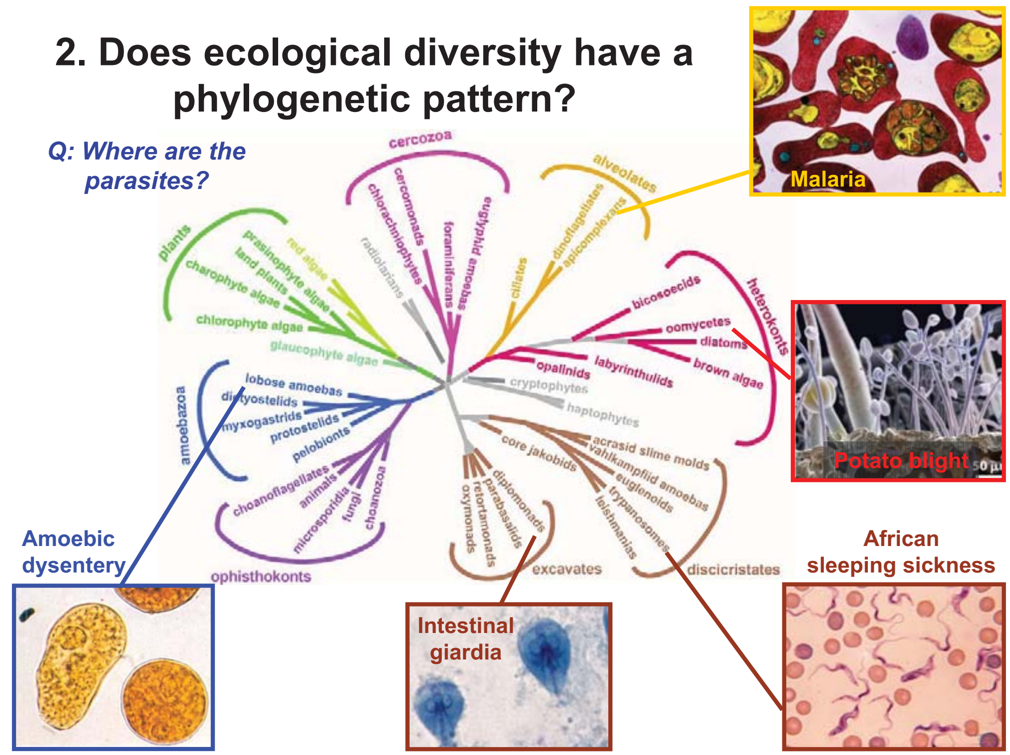
Relationships among groups not completely resolved



Q: Are protists monophyletic?

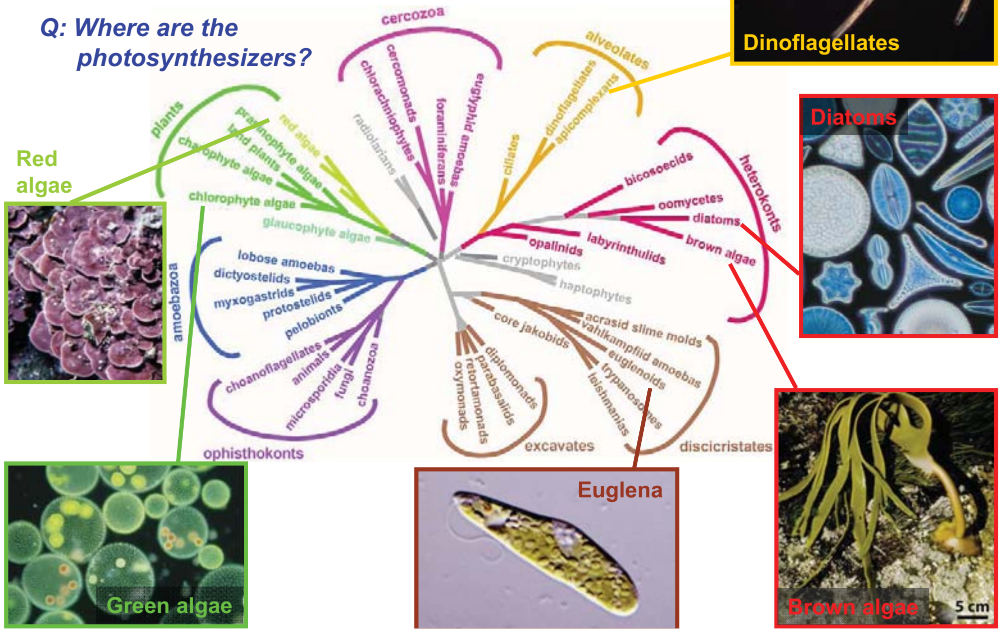
2. Does ecological diversity have a phylogenetic pattern?

Q: Where are the parasites?



2. Does ecological diversity have a phylogenetic pattern?

Q: Where are the photosynthesizers?



2. Does ecological diversity have a phylogenetic pattern?

Q: What are the photosynthetic "algae"?

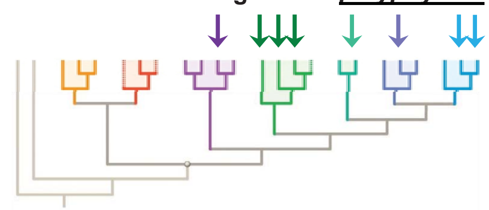
PLANTAE
Green Algae – unicellular, colonial, multicellular
Red Algae – most are multicellular
Glaucophyte Algae – unicellular or colonial

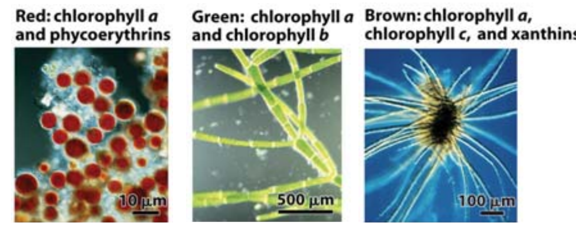
STRAMENOPILA
Brown Algae – multicellular
Diatoms – unicellular or chains

ALVEOLATA
Dinoflagellates – unicellular or colonial

EXCAVATA
Euglenids – unicellular, also ingest food

"Algae" are *polyphyletic*

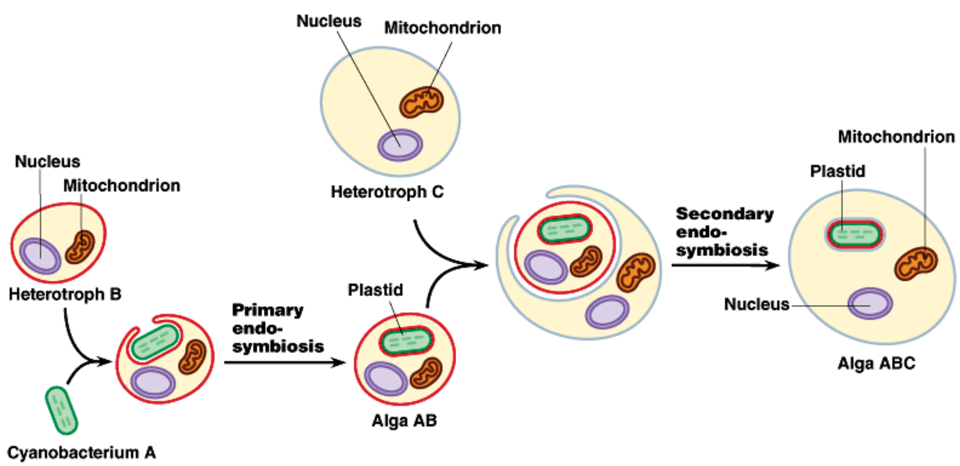




Recall:
mono-
para-

3. How did polyphyly in photosynthesis arise?

➢ **spread of photosynthesis through *secondary* endosymbiosis (!)**



According to *secondary* endosymbiosis:

Q: How many membranes should surround a 2° derived chloroplast?

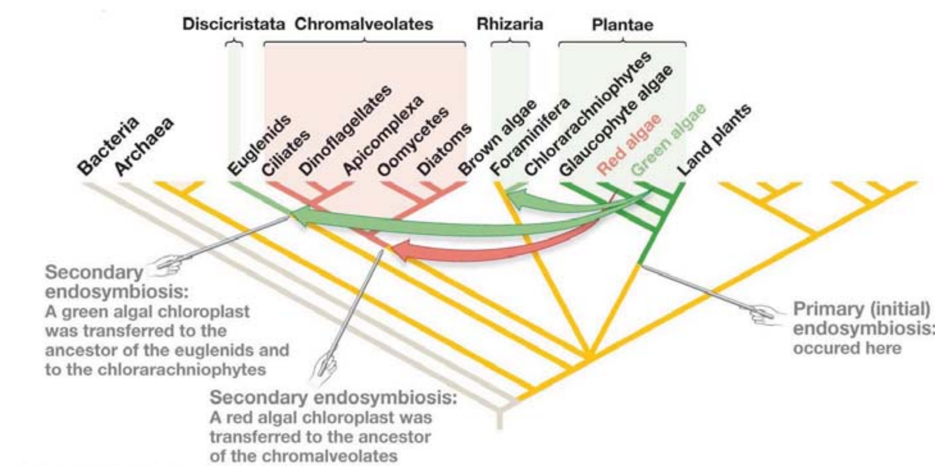
Q: What should the chloroplast DNA be most like?

3. How did polyphyly in photosynthesis arise?

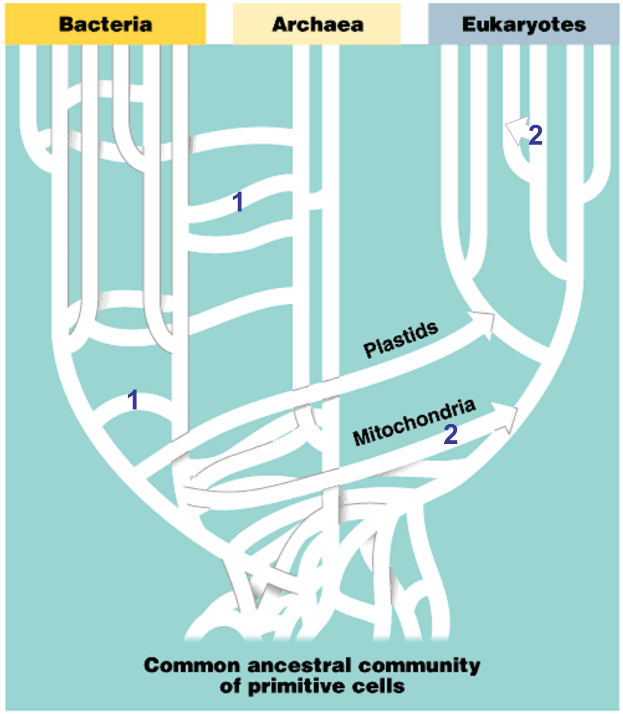
Multiple independent origins?

chloroplasts with >2 membranes in some protist groups

→ secondary endosymbiosis – lateral transmission of chloroplasts



Tree of life or web of life?



Q: What two processes contribute to these cross-taxon bridges?

4. How did large, complex eukaryotes arise?

EVOLUTIONARY INNOVATION: *Multicellularity*

- cells become differentiated (▶division of labor)
- cells become interdependent

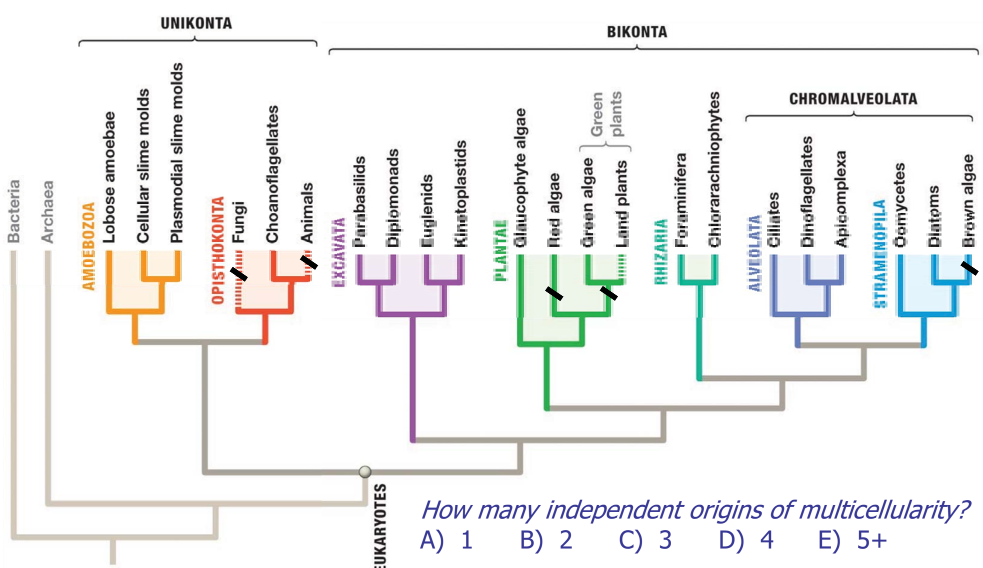
Rare examples of cell specialization within bacterial colonies (δ-proteobacteria)

More common examples of cell specialization in protist colonies

Chlamydomonas **is unicellular.** → ***Gonium*** **forms small colonies.** → ***Pandorina*** **forms large colonies.** → ***Volvox*** **is multicellular.**

4. How did large, complex eukaryotes arise?

EVOLUTIONARY INNOVATION: *Multicellularity*



How many independent origins of multicellularity?

A) 1 B) 2 C) 3 D) 4 E) 5+

4. How did sexual reproduction evolve?

EVOLUTIONARY INNOVATION: Meiosis

- haploidy prepares a cell genome for recombination with another genome

haploid —*fertilization*→ **diploid** —*meiosis*→ **haploid**

- dominant stage(s) in life cycle could be haploid *or* diploid *or* both

alternation of generations (some eukaryotes) – prominent multicellular haploid *and* diploid stages