
Diversity of Life

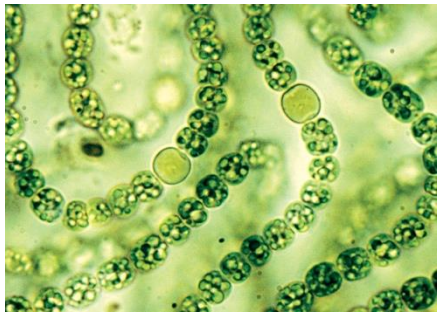
The Three Domains

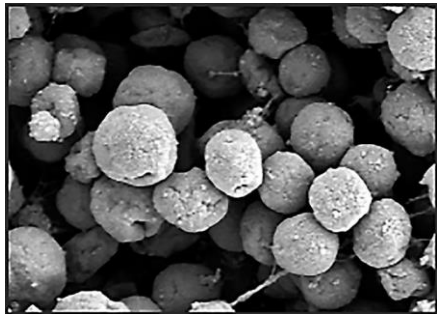
- Developed by Woese in 1978; based on sequences of nucleotides in rRNA

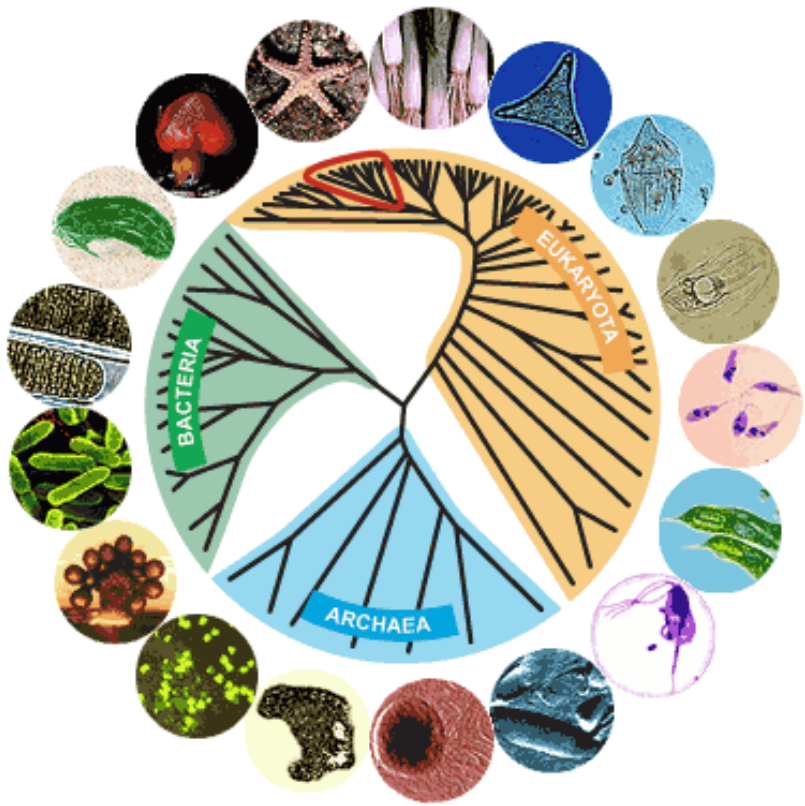
- **Eukarya**
  - Animals
  - Plants
  - Fungi
  - “Protists”
- **Bacteria**
  - Cyanobacteria
  - Pathogens
  - Beneficial gut microbes
  - Cheese/yogurt
- **Archaea**
  - Methanogens
  - Extreme halophiles
  - Hyperthermophiles









(Tenericutes)

Bacteria

Actinobacteria
Armatimonadetes
Chloroflexi
Firmicutes
Cyanobacteria

Zixibacteria
Cloacimonetes
Fibrobacteres
Gemmatimonadetes
WOR-3
TA06
Poribacteria
Latescibacteria
BRC1

Atribacteria
Aquificae
Calescamantes
Caldiserica
Dictyoglomi
Thermotogae
Deinococcus-Therm.
Synergistetes
Fusobacteria

Marinimicrobia
Bacteroidetes
Chlorobi
Ignavibacteria
Caldithrix

PVC superphylum
Planctomycetes
Chlamydiae,
Lentisphaerae,
Verrucomicrobia

Elusimicrobia
Omnitrophica
Aminicentantes
Rokubacteria
NC10
Acidobacteria
Tectomicrobia, Modulibacteria
Nitrospinae
Nitrospirae
Dadabacteria
Deltaproteobacteria
(Thermodesulfobacteria)
Chrysiogenetes
Deferribacteres
Hydrogenedentes NKB19
Spirochaetes
TM6
Epsilonproteobacteria
Alphaproteobacteria
Zetaproteo.
Acidithiobacillia
Betaproteobacteria
Gammaproteobacteria

0.4

Melainabacteria
RBX1
WOR1

Nomurabacteria
Kaiserbacteria
Adlerbacteria
Campbellbacteria
Giovannonibacteria
Wolfebacteria
Jorgensenbacteria
Azambacteria
Parcubacteria
Yanofskybacteria
Moranbacteria
Magasanikbacteria
Uhrbacteria
Falkowbacteria
Candidate Phyla Radiation
SM2F11
Peregrinibacteria
Gracilibacteria BD1-5, GN02
Absconditabacteria SR1
Saccharibacteria
Berkelbacteria

Wirthbacteria
Woesebacteria
Shapirobacteria
Amesbacteria
Collierbacteria
Pacebacteria
Beckwithbacteria
Roizmanbacteria
Gottesmanbacteria
Levybacteria
Daviesbacteria
Curtissbacteria
Microgenomates
Dojkabacteria WS6
CPR1
CPR3
Katanobacteria
WWE3

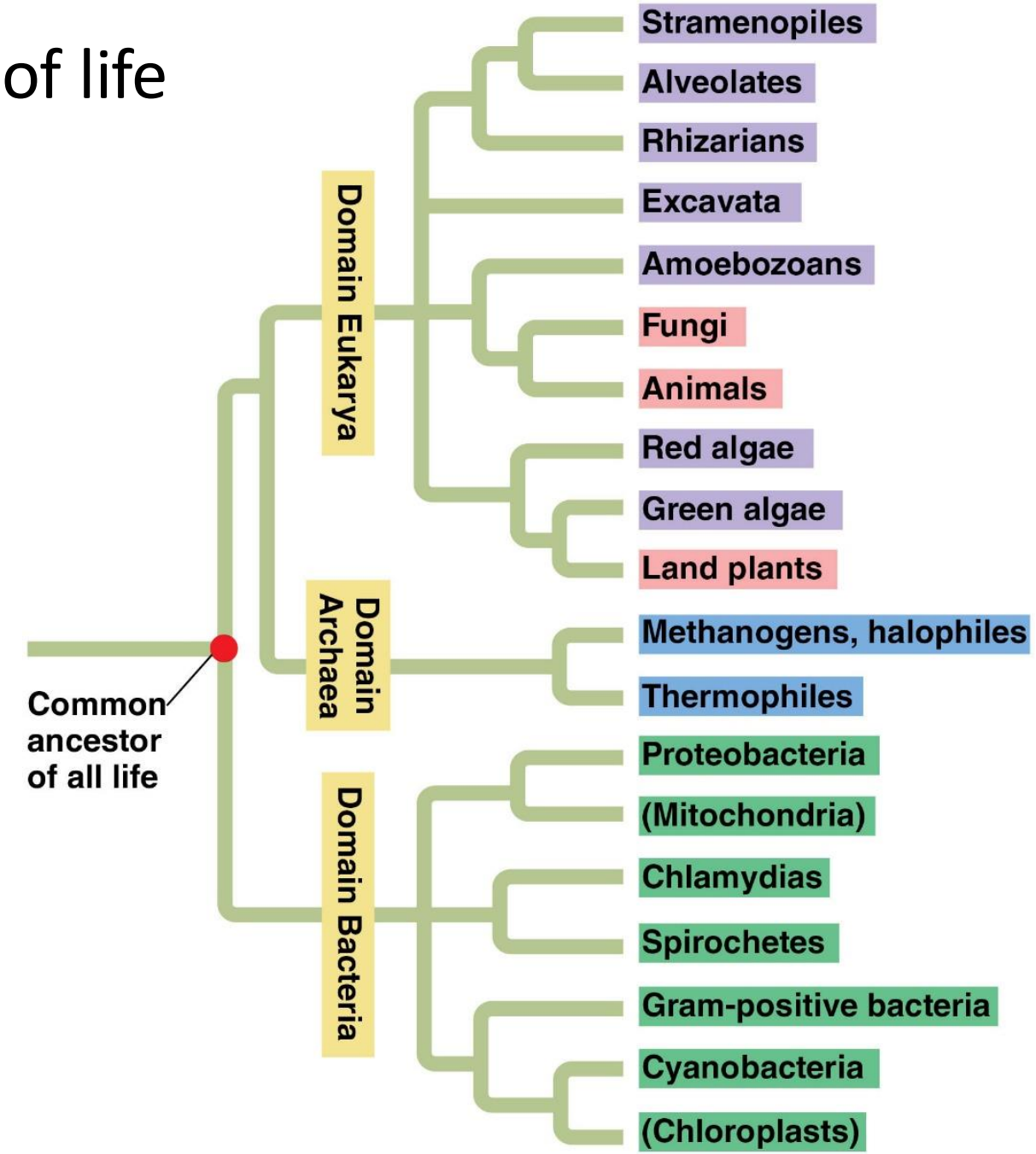
Major lineages with isolated representative: italics
Major lineage lacking isolated representative:

Micrarchaeota
Diapherotrites
Nanohaloarchaeota
Aenigmarchaeota
Parvarchaeota
DPANN
Pacearchaeota
Nanoarchaeota
Woesearchaeota
Altiarchaeales
Z7ME43
Methanopyri
Methanococci
Hadesarchaea
Thermococci
Methanobacteria
Thermoplasmata
Archaeoglobi
Methanomicrobia
Archaea

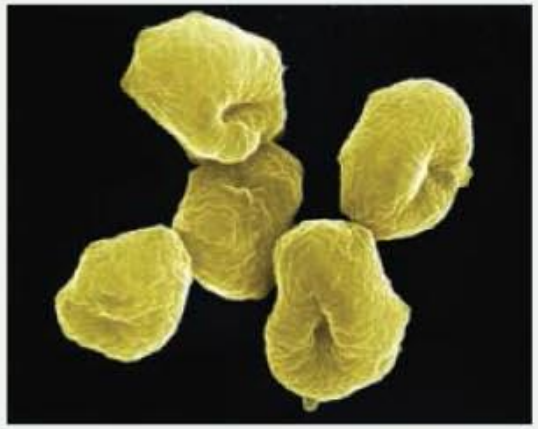
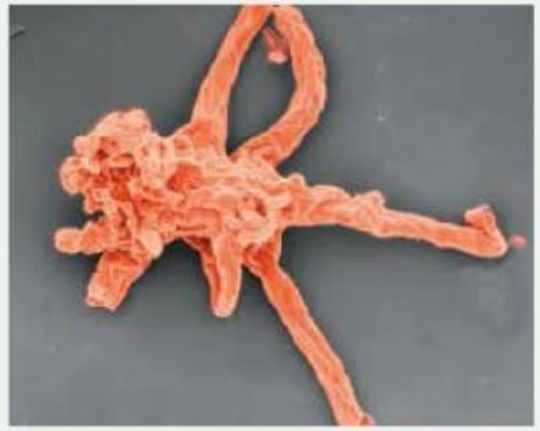
Korarch.
Crenarch.
Bathyarc.
YNPFFA
Aigarch.
Halobacteria
Loki.
Thor.
TACK
Thaumarchaeota

Eukaryotes
Opisthokonta
Excavata
Archaeplastida
Chromalveolata
Amoebozoa

The three domains of life

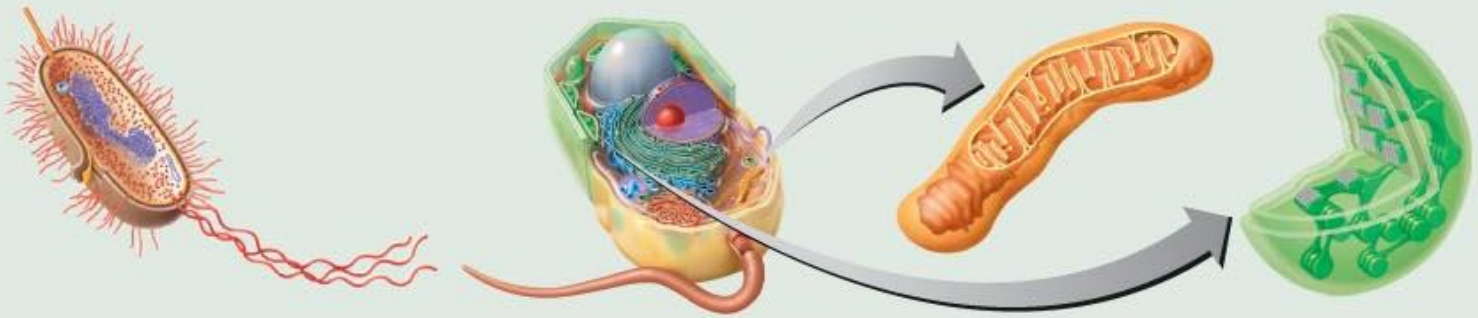


Characteristics of Archaea, Bacteria, and Eukarya domains

	Archaea	Bacteria	Eukarya
	 *Sulfolobus* sp. SEM 1 μm	 *E. coli* SEM 1 μm	 *Amoeba* sp. SEM 5 μm
Cell Type	Prokaryotic	Prokaryotic	Eukaryotic
Cell Wall	Varies in composition; contains no peptidoglycan	Contains peptidoglycan	Varies in composition; contains carbohydrates
Membrane Lipids	Composed of branched carbon chains attached to glycerol by ether linkage	Composed of straight carbon chains attached to glycerol by ester linkage	Composed of straight carbon chains attached to glycerol by ester linkage
First Amino Acid in Protein Synthesis	Methionine	Formylmethionine	Methionine

Prokaryotic cell and Eukaryotic organelles

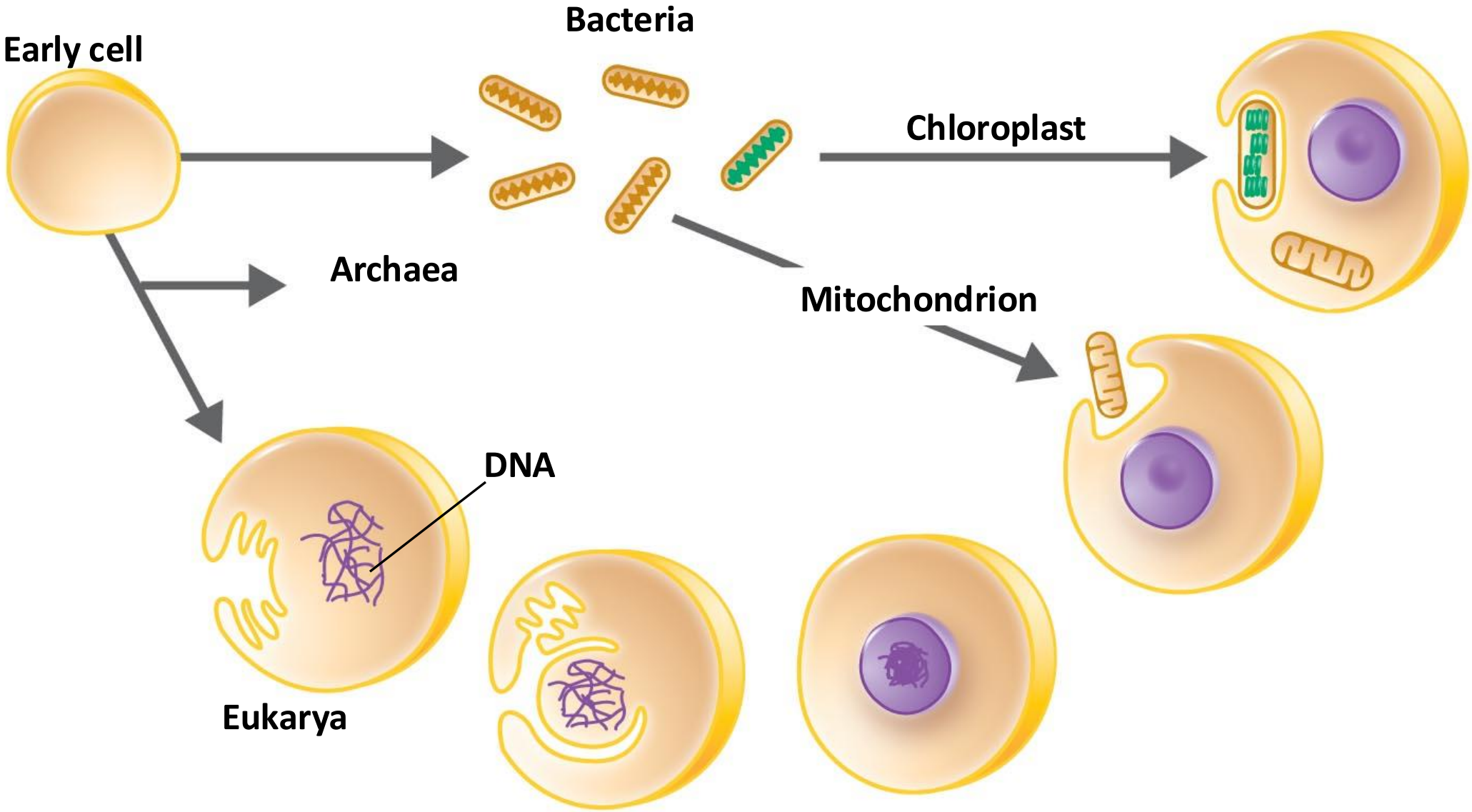
	Prokaryotic Cell	Eukaryotic Cell	Eukaryotic Organelles (Mitochondria and Chloroplasts)
DNA	One circular; some two circular; some linear	Linear	Circular
Histones	In archaea	Yes	No
First Amino Acid in Protein Synthesis	Formylmethionine (bacteria) Methionine (archaea)	Methionine	Formylmethionine
Ribosomes	70S	80S	70S
Growth	Binary fission	Mitosis	Binary fission

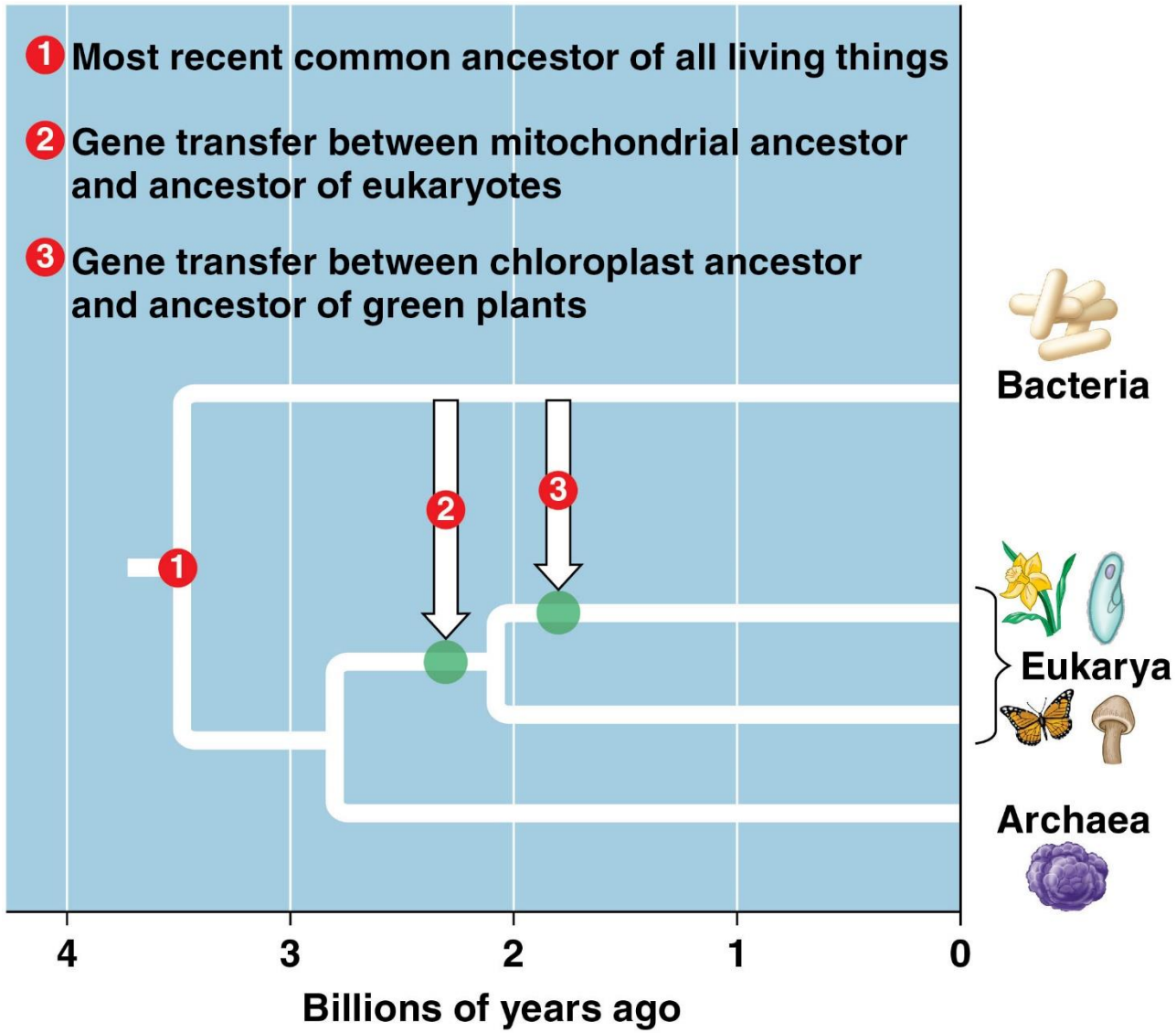


The Three Domains

- Eukaryotes originated from infoldings of prokaryotic plasma membranes
- Endosymbiotic bacteria developed into organelles

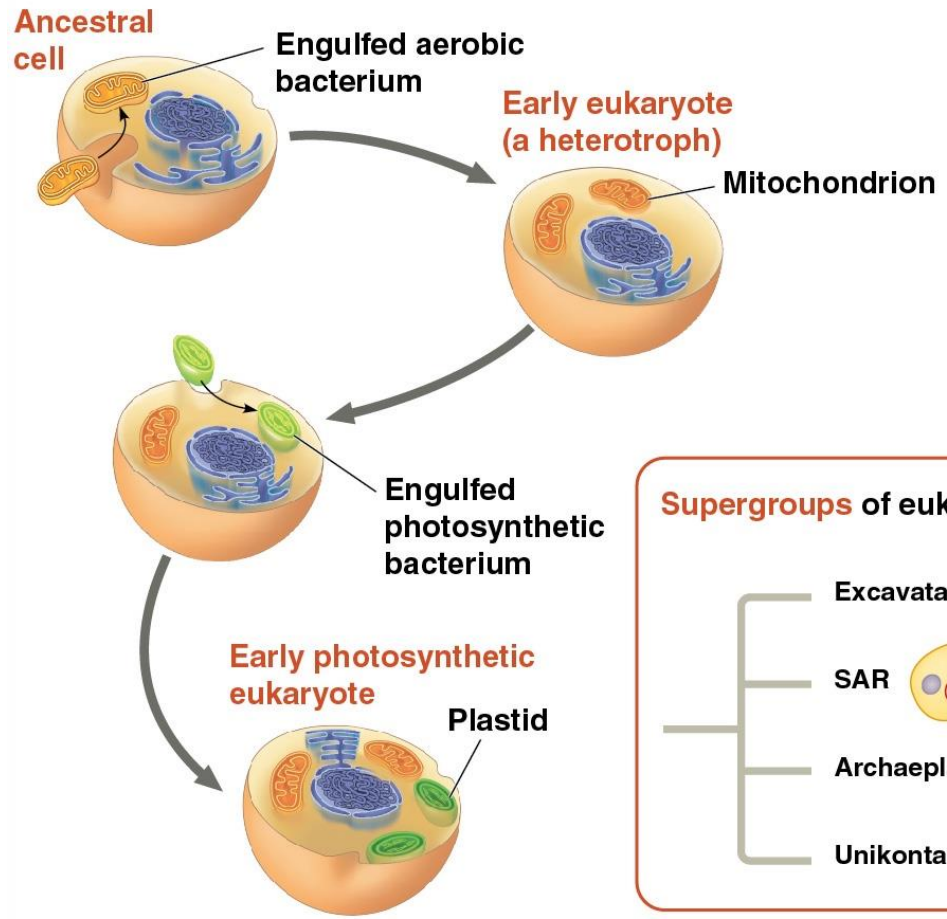
A model of the origin of Eukaryotes





What gave rise to the great diversity of protists, and how have their lineages diverged over time?

Much of protistan diversity can be traced to endosymbiosis:



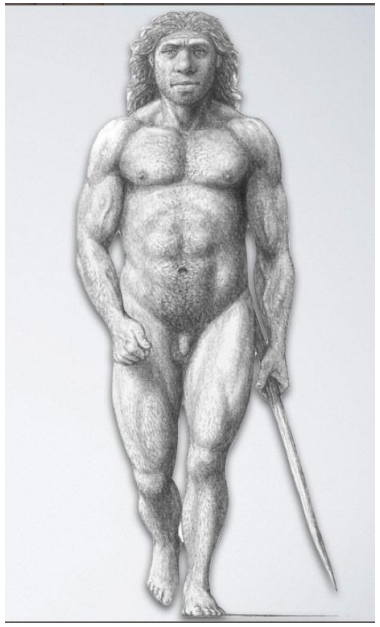
Scientific Nomenclature

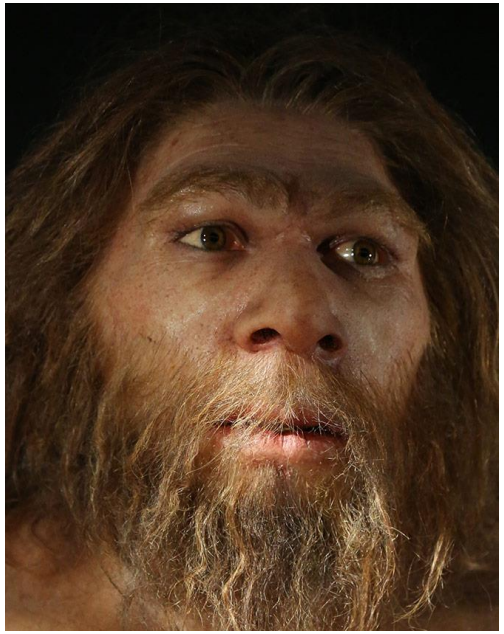
- Common names vary with languages and geography

- **Binomial nomenclature** is used worldwide to consistently and accurately name organisms
  - **Genus**
  - **Specific epithet (species)**

Vulpes vulpes

red fox, renard rouge, volpe rossa, Rotfuchs, *madra rua* ("red dog"), Lis rudy, sionnach, 붉은여우 , Rødrev, アカギツネ,



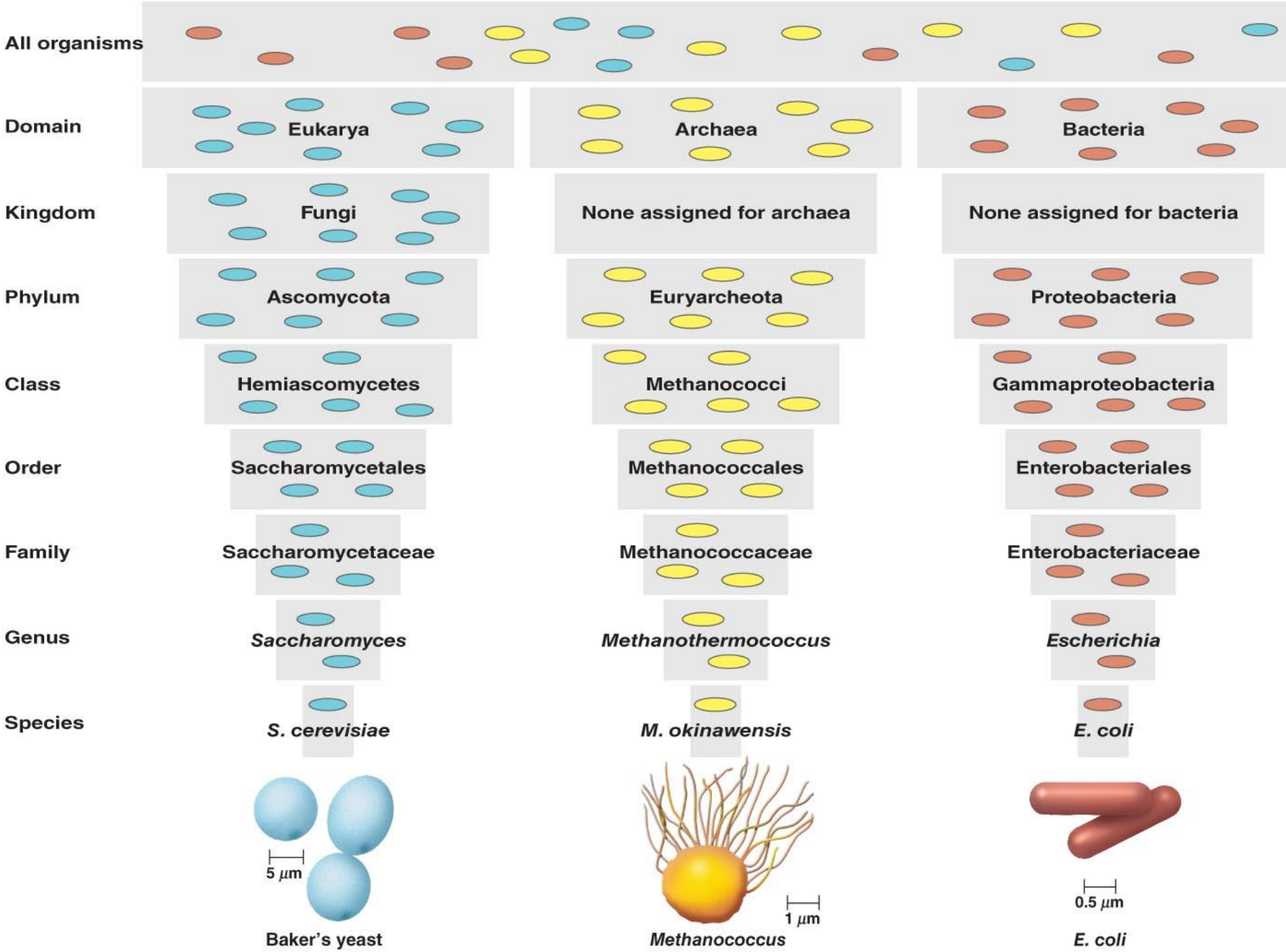


Homo neanderthalensis

The Taxonomic Hierarchy

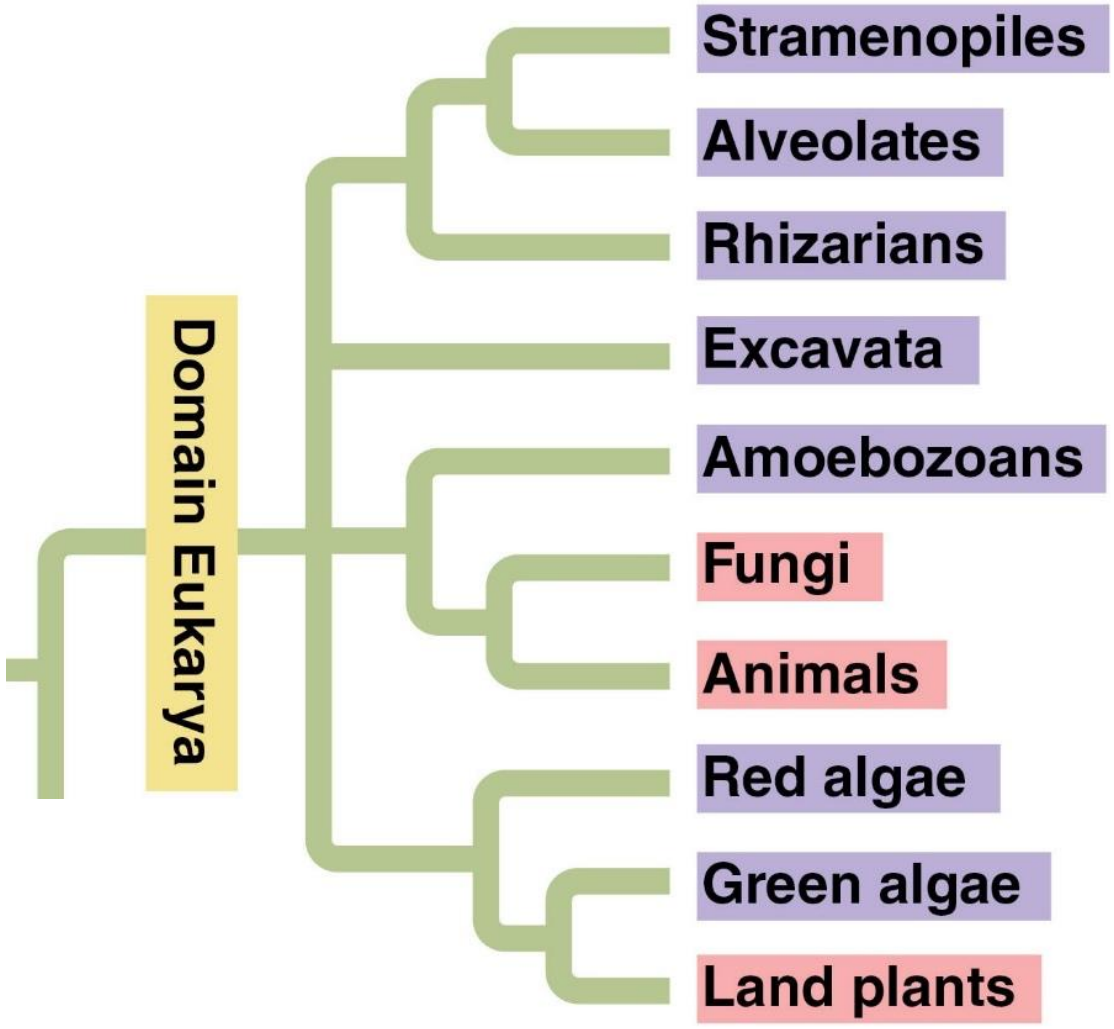
- A series of subdivisions developed by Linnaeus to classify plants and animals

- **Eukaryotic species:** a group of closely related organisms that breed among themselves


All organisms
Domain
Eukarya
Archaea
Bacteria
Kingdom
Fungi
None assigned for archaea
None assigned for bacteria
Phylum
Ascomycota
Euryarcheota
Proteobacteria
Class
Hemiascomycetes
Methanococci
Gammaproteobacteria
Order
Saccharomycetales
Methanococcales
Enterobacteriales
Family
Saccharomycetaceae
Methanococcaceae
Enterobacteriaceae
Genus
Saccharomyces
Methanothermococcus
Escherichia
Species
S. cerevisiae
M. okinawensis
E. coli
5 μm
1 μm
0.5 μm
Baker's yeast
Methanococcus
E. coli

Classification of Eukaryotes

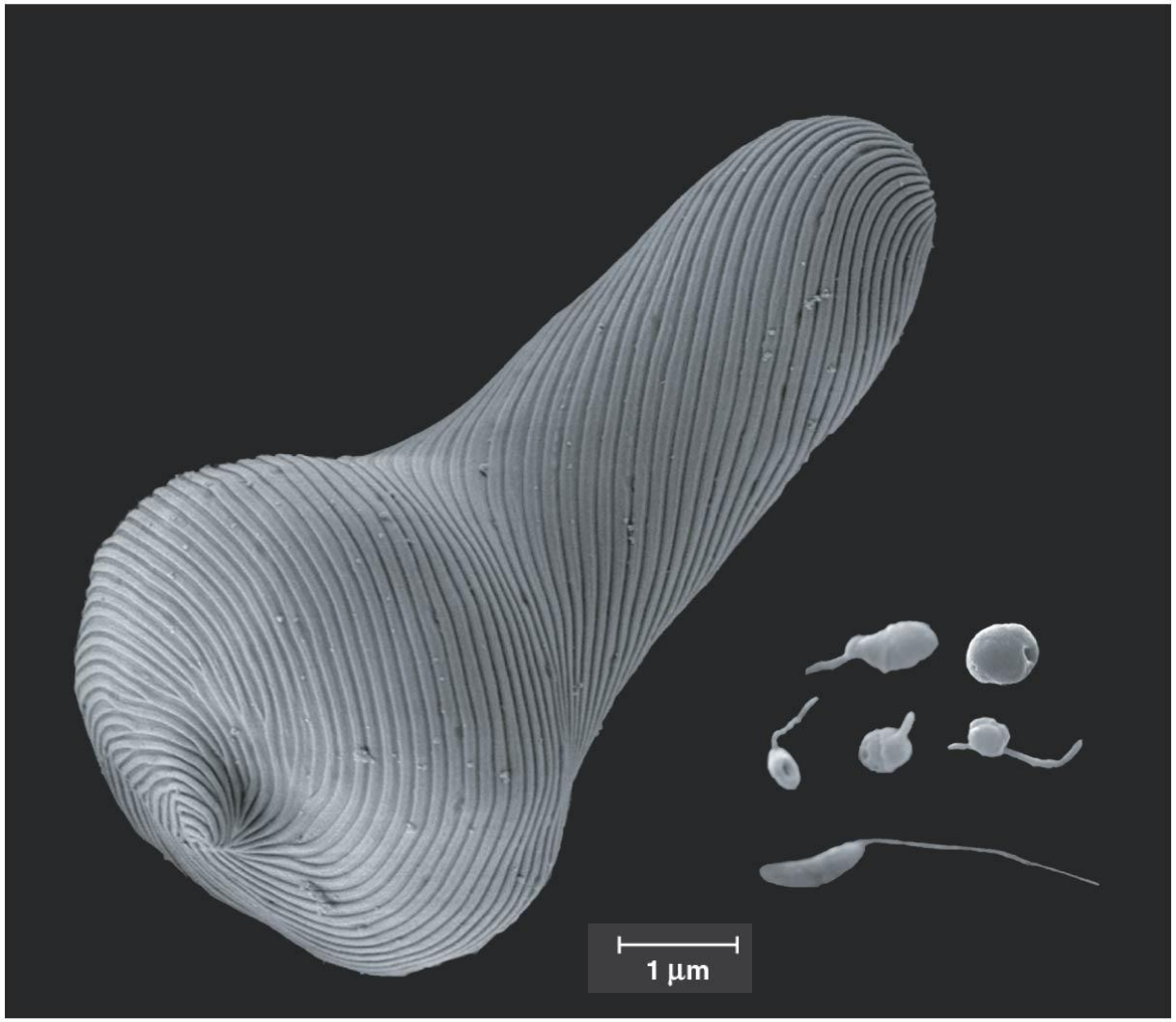
- **Protista:**
  - a “catchall kingdom” for a variety of organisms
  - unicellular or multicellular
  - autotrophic and heterotrophic
- **Fungi:**
  - unicellular or multicellular
  - cell walls of chitin
  - develop from spores or hyphal fragments
  - heterotrophs
- **Plantae:**
  - multicellular
  - cellulose cell walls
  - undergo photosynthesis (autotrophs)
- **Animalia:**
  - multicellular
  - no cell walls
  - heterotrophs



Most eukaryotes are single-celled organisms

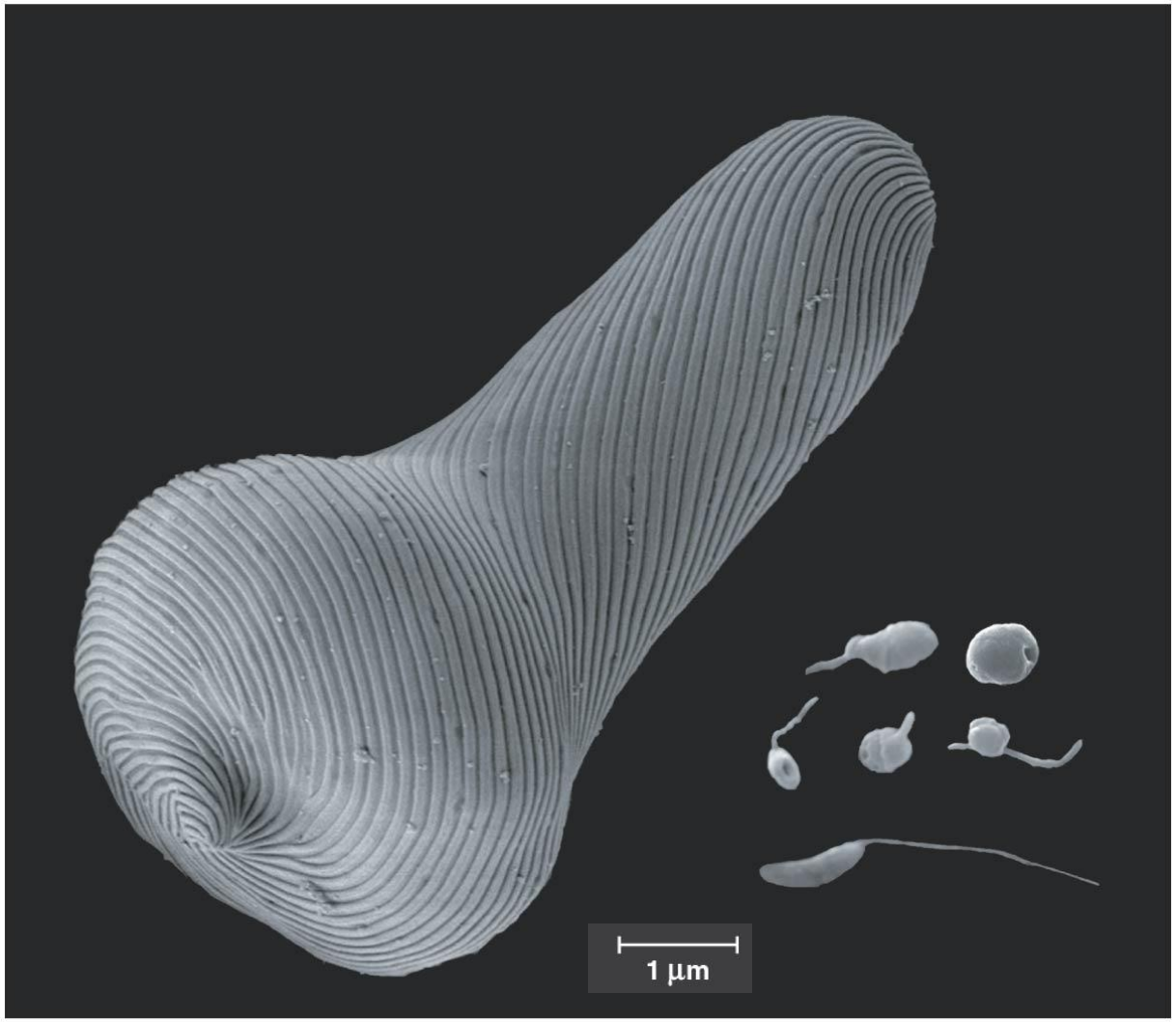
- **Protist** is an informal term used to refer to all eukaryotes that are not plants, animals, or fungi

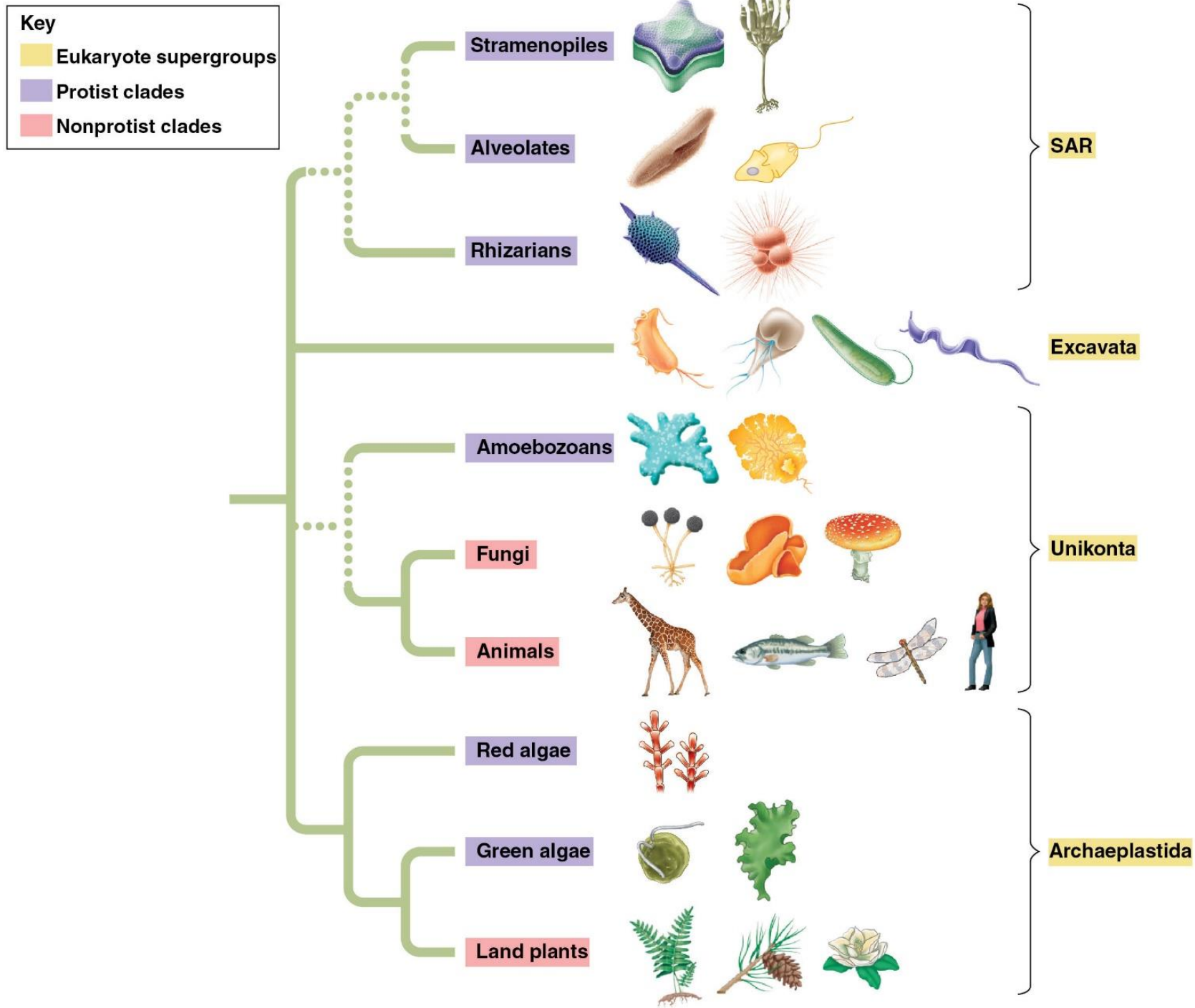
- This group is no longer considered a kingdom because some protists are more closely related to plants, fungi, or animals than other protists



Most eukaryotes are single-celled organisms

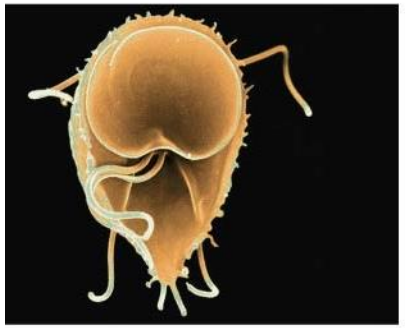
- Advances in eukaryotic systematics have caused the classification of protists to change significantly
- Protists constitute a polyphyletic group, and Protista is no longer a kingdom

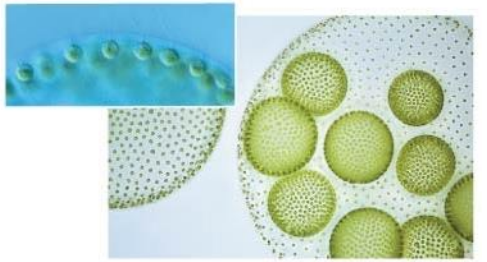


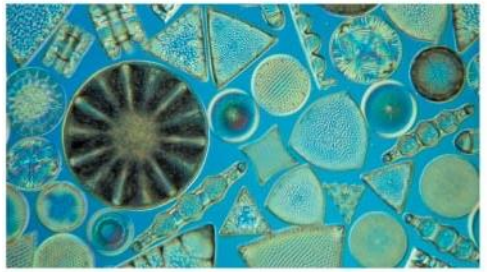

Key
Eukaryote supergroups
Protist clades
Nonprotist clades
Stramenopiles
Alveolates
Rhizarians
Amoebozoans
Fungi
Animals
Red algae
Green algae
Land plants
SAR
Excavata
Unikonta
Archaeplastida

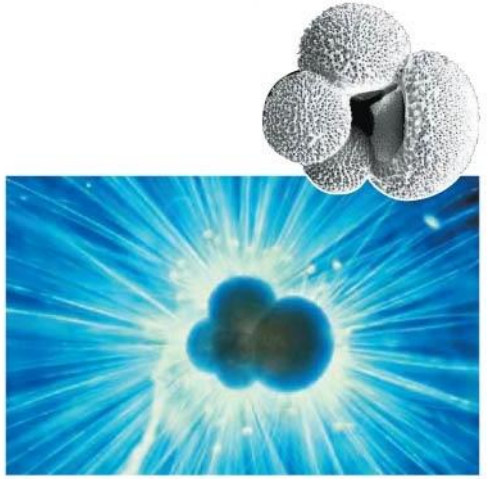
Structural and Functional Diversity in Protists

- Protists exhibit more structural and functional diversity than any other group of eukaryotes
- Though most protists are unicellular, there are some colonial and multicellular species
- Single-celled protists can be very complex, as all biological functions are carried out by organelles in each individual cell



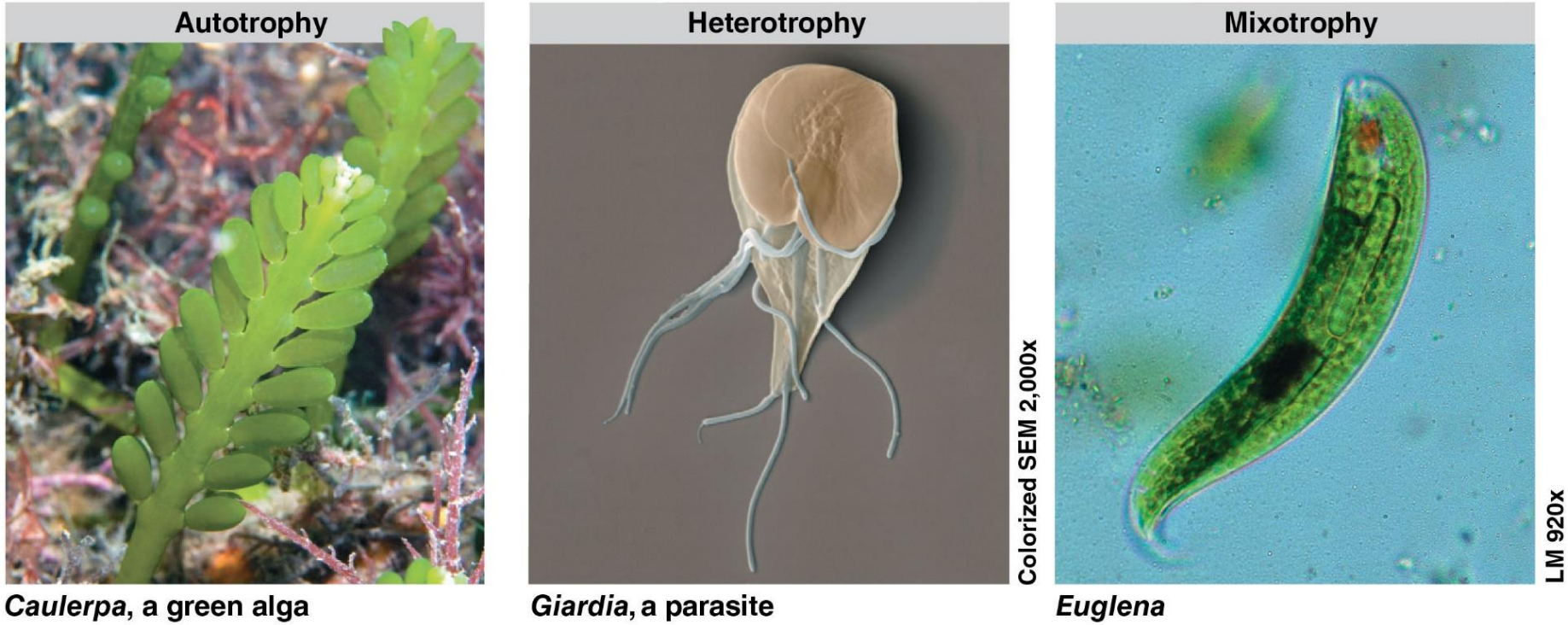






- Protists, the most nutritionally diverse of all eukaryotes, include
  - **Photoautotrophs**, which contain chloroplasts
  - **Heterotrophs**, which absorb organic molecules or ingest larger food particles
  - **Mixotrophs**, which combine photosynthesis and heterotrophic nutrition

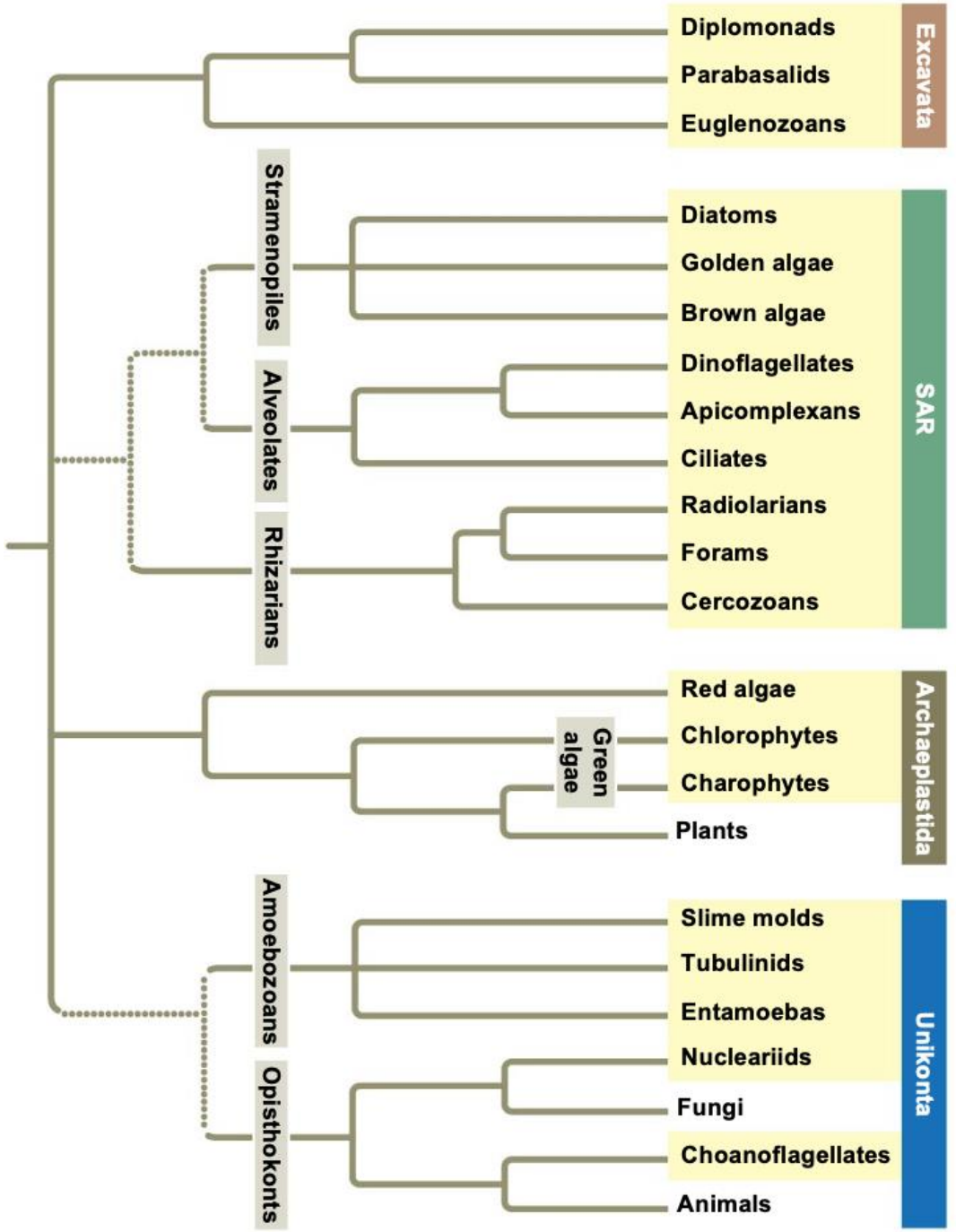
- Some protists reproduce asexually, while others reproduce sexually



Four Supergroups of Eukaryotes

- Our understanding of the evolutionary relationships among protist groups continues to change rapidly

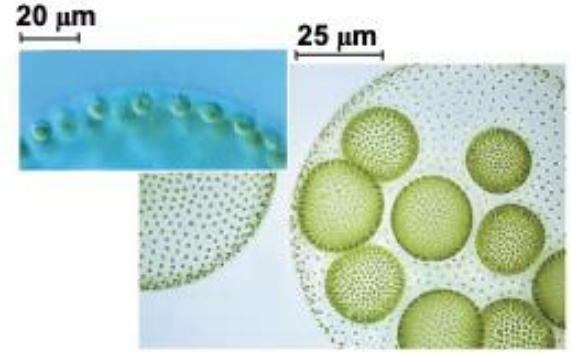
- One current hypothesis divides all eukaryotes (including protists) into four supergroups



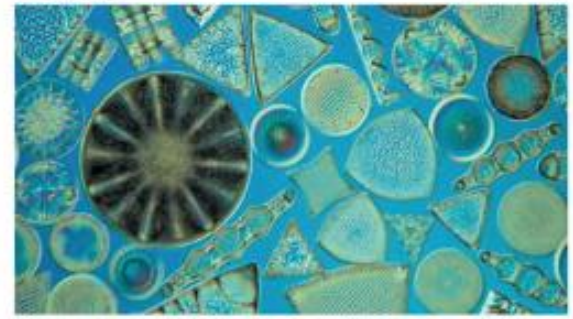
Diplomonads
Parabasalids
Euglenozoans
Excavata
Stramenopiles
Diatoms
Golden algae
Brown algae
Alveolates
Dinoflagellates
Apicomplexans
Ciliates
Rhizarians
Radiolarians
Forams
Cercozoans
SAR
Red algae
Green algae
Chlorophytes
Charophytes
Plants
Archaeplastida
Amoebozoans
Slime molds
Tubulinids
Entamoebas
Opisthokonts
Nucleariids
Fungi
Choanoflagellates
Animals
Unikonta

Excavata

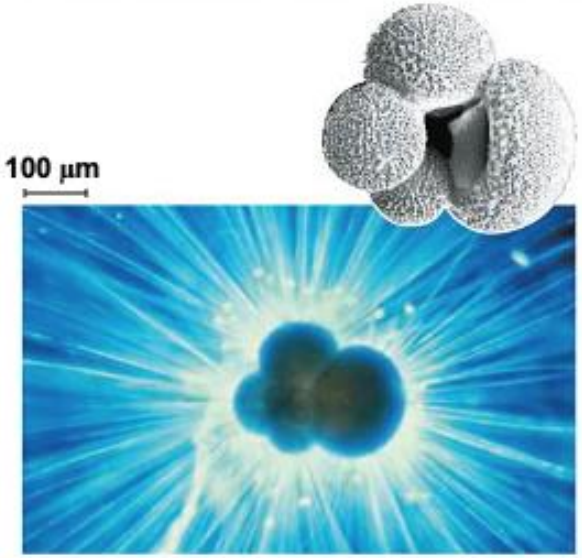
Archaeplastida



SAR



Unikonta

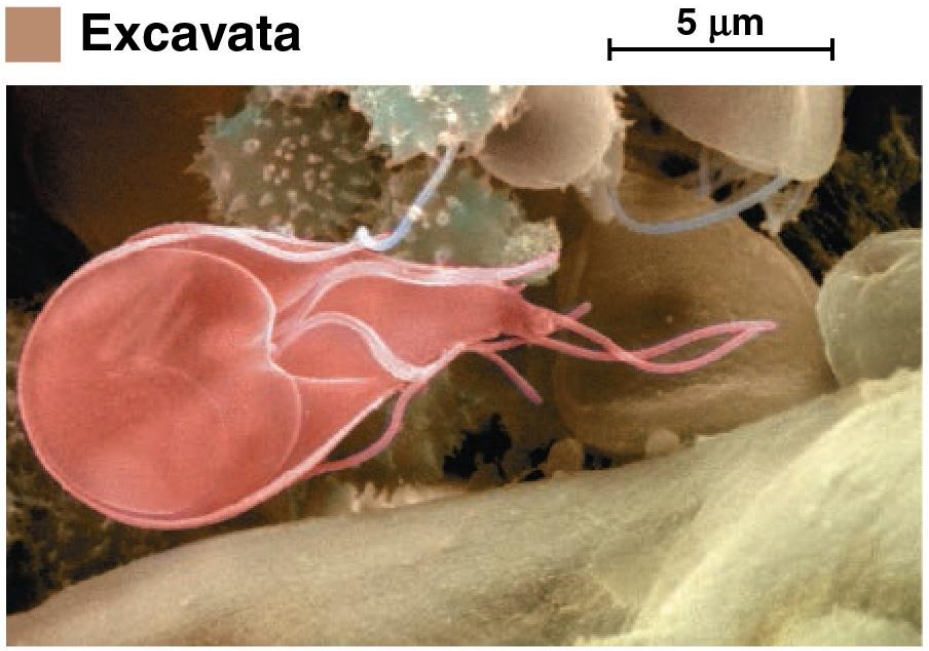


Exploring protistan diversity

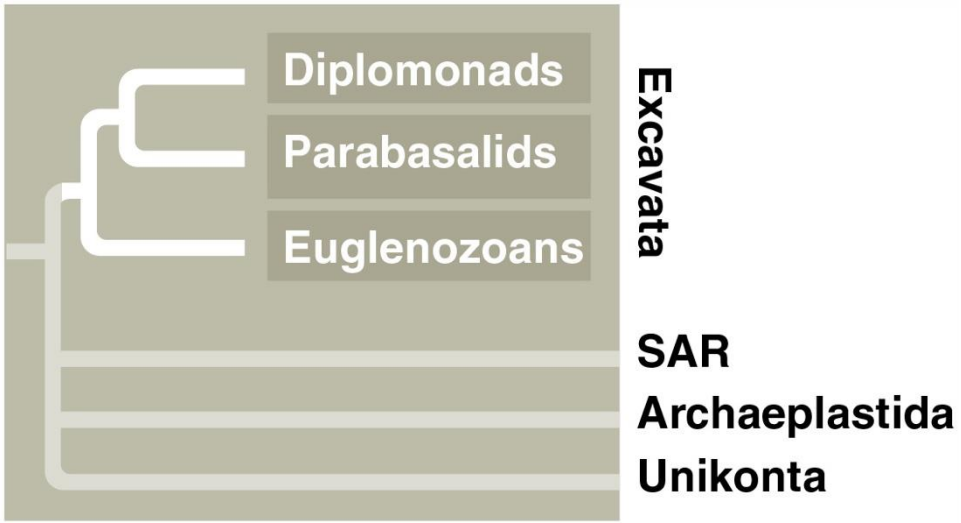
Excavata

- This supergroup includes three clades: parabasalids, diplomonads, and euglenozoans
  - For example, *Giardia intestinalis* is a parasite that causes intestinal infections in mammals

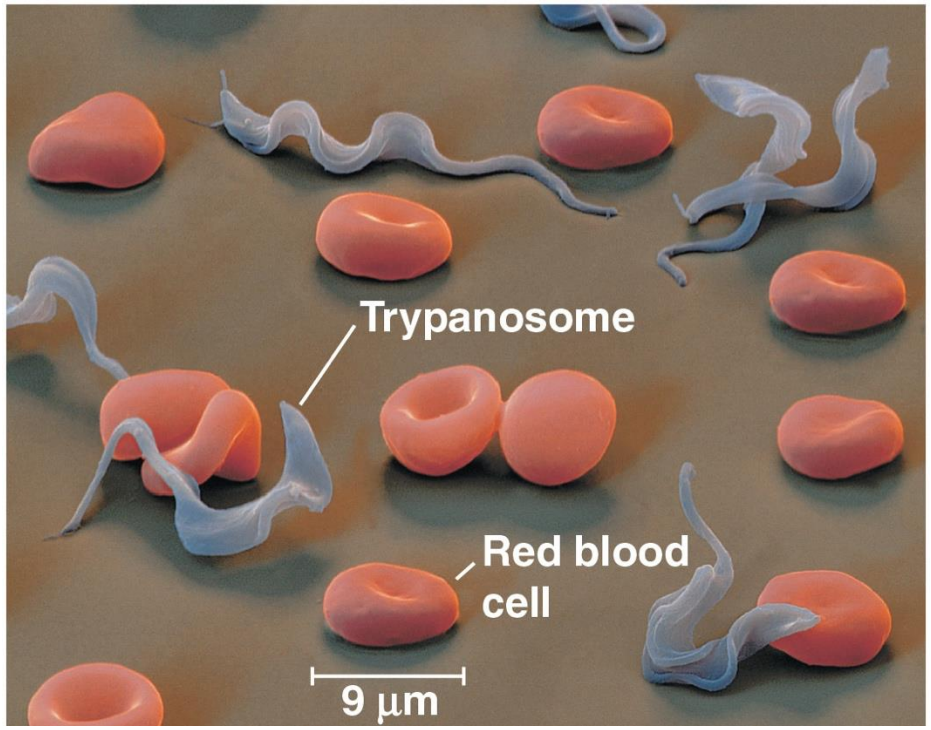
- Some members have an "excavated" feeding groove on one side of the body



***Giardia intestinalis*, a diplomonad parasite**

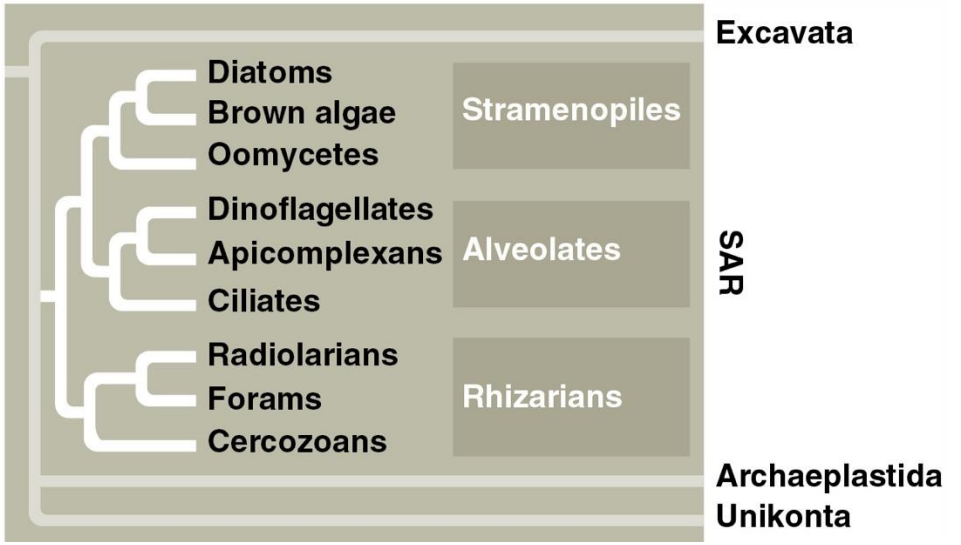


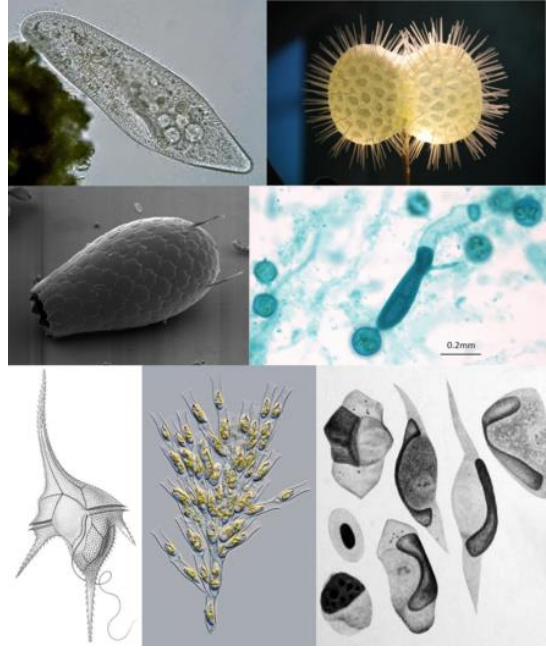
- Some species parasitize animals, plants, and other protists
  - For example, members of the genus *Trypanosoma* infect humans, causing sleeping sickness in about 10,000 people per year



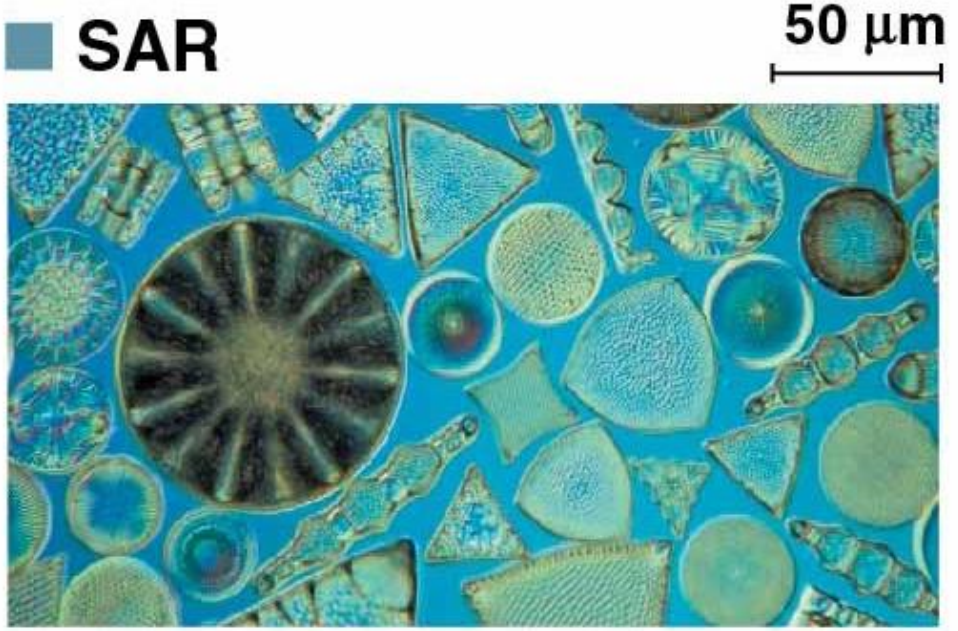
SAR

- This supergroup includes three large clades: Stramenopila, Alveolata, and Rhizaria





- **Stramenopiles** include some of the most important photosynthetic organisms on Earth
  - **Diatoms**, oomycetes, and brown algae are three important groups of stramenopiles



Diatoms

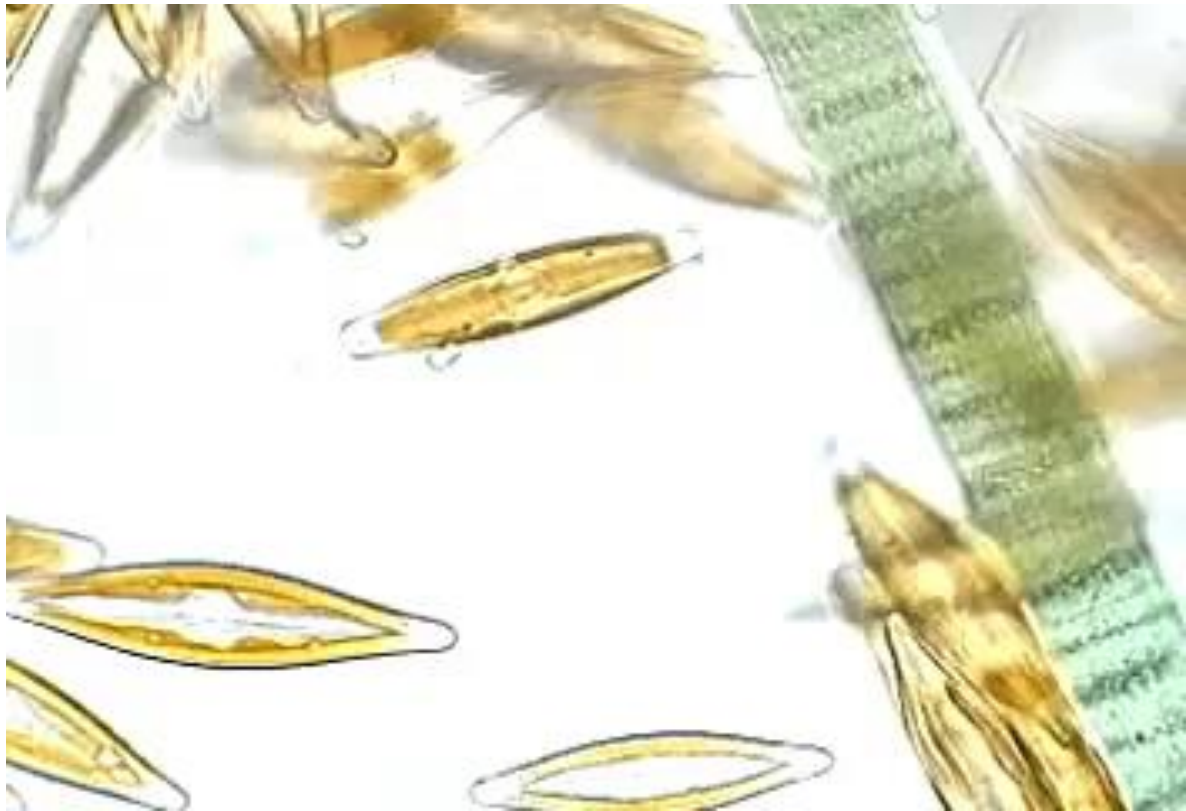
- **Diatoms** are unicellular algae with a unique two-part, glass-like wall of silicon dioxide

SiO_2

- The wall withstands pressure up to 1.4 million kg/m^2, protecting diatoms from the crushing jaws of predators

- Including about 100,000 species, diatoms compose much of the phytoplankton in the ocean and lakes

- Diatoms are so abundant and widespread that their photosynthetic activity affects global CO_2 levels

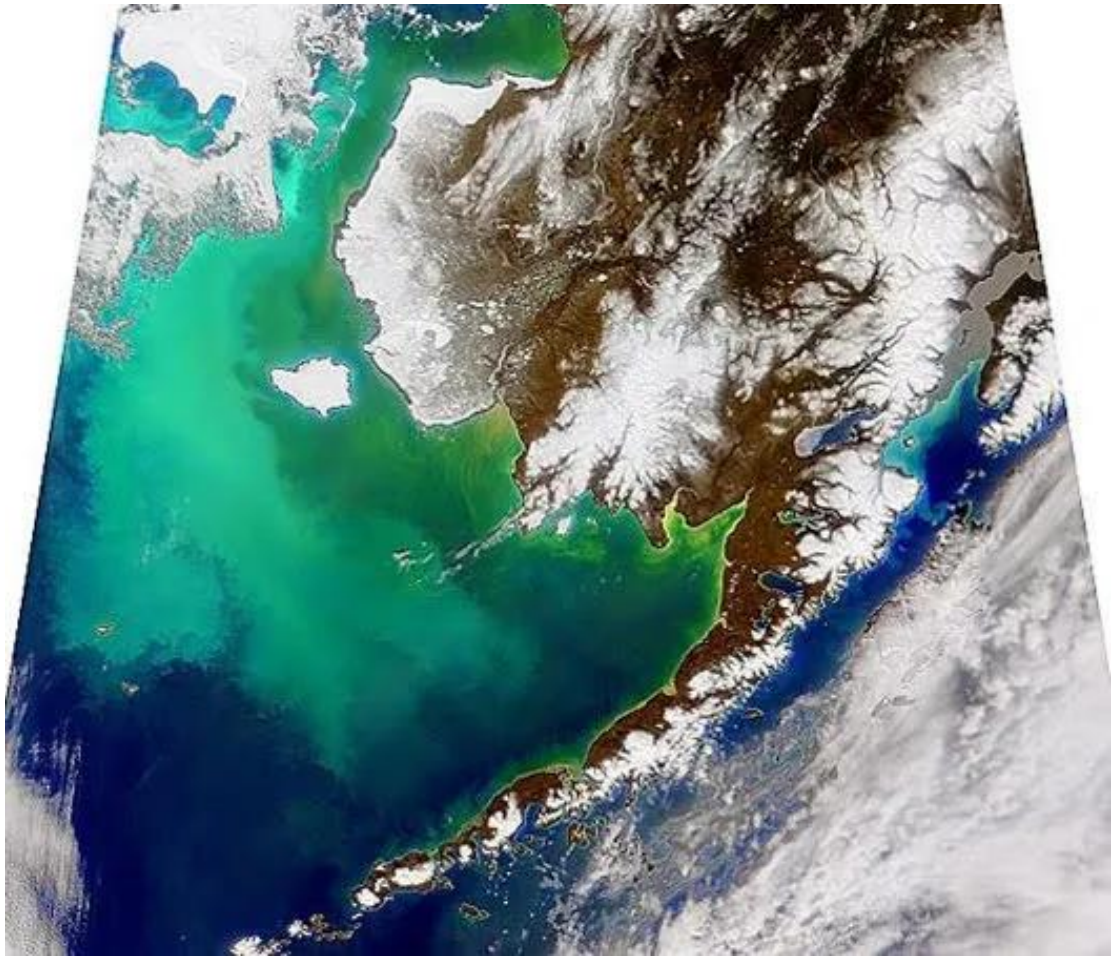


SAR

- After a diatom bloom, many dead individuals fall to the ocean floor, where decomposition is slow

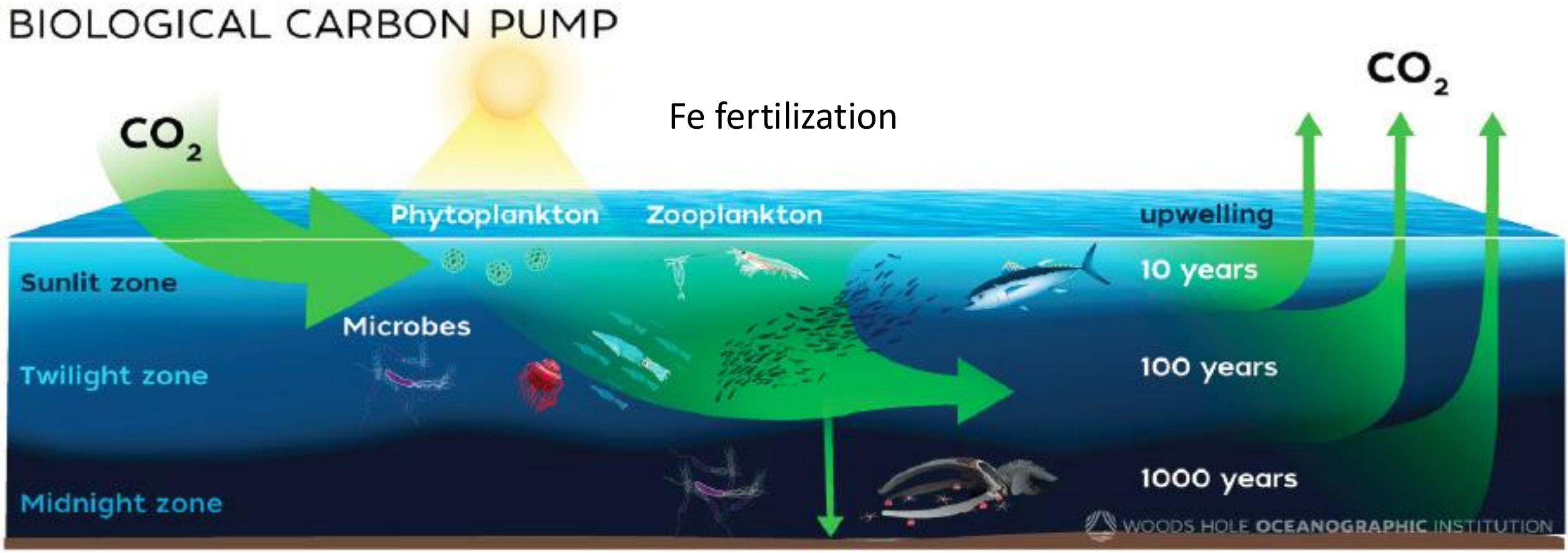
- The breakdown and release of carbon stored in the diatoms on the ocean floor can take centuries

- Promoting diatom blooms by fertilizing the ocean with essential nutrients is a proposed approach to reduce atmospheric CO_2 levels



Ocean-based carbon dioxide removal (ocean CDR)

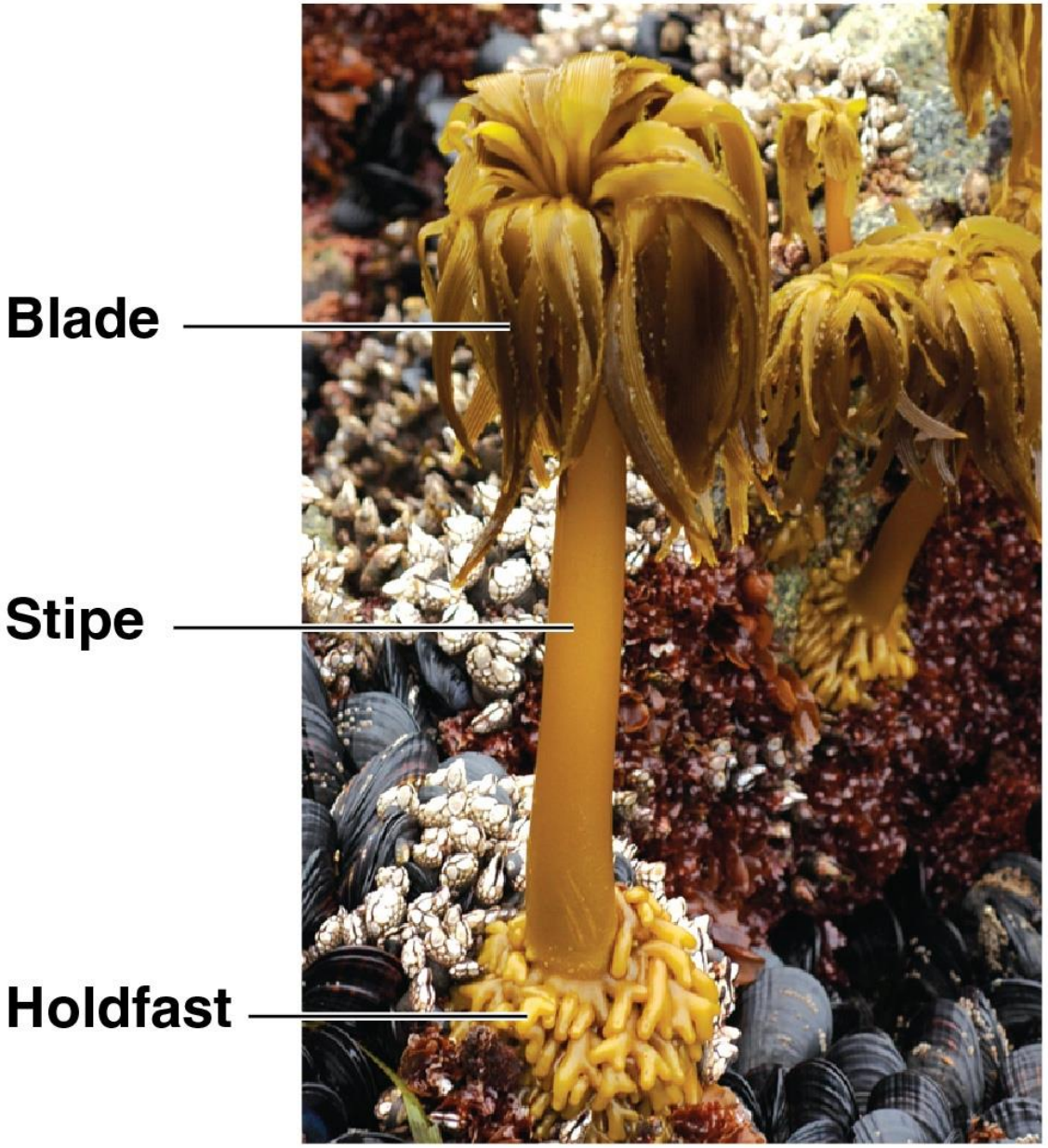
Fe fertilization



SAR

Brown Algae

- **Brown algae** are the largest and most complex multicellular algae
- Most are marine, including many species commonly called “seaweeds”
- Plantlike structures: the rootlike **holdfast**, which anchors the alga, and a stemlike **stipe**, which supports the leaflike **blades**
- Some have gas-filled, bubble-shaped floats to keep photosynthetic structures near the water surface
- Brown algae lack the true tissues and organs found in plants



- Brown algae are important commodities for humans
  - Some species are eaten (e.g. *Laminaria)*
  - Algin, a gel-forming substance found in the cell wall, is used as a thickener in many processed foods

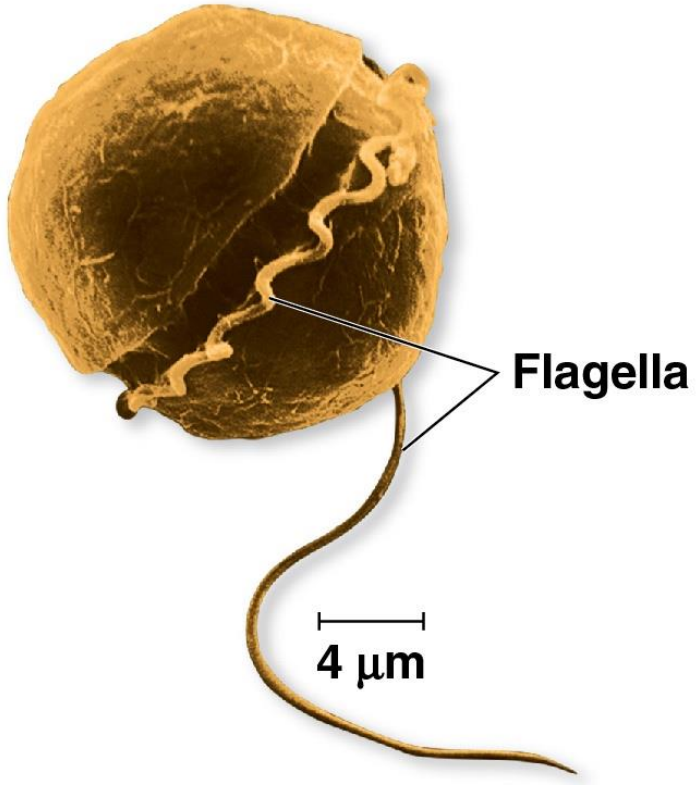
SAR

Dinoflagellates

- **Dinoflagellates** are abundant components of marine and freshwater phytoplankton

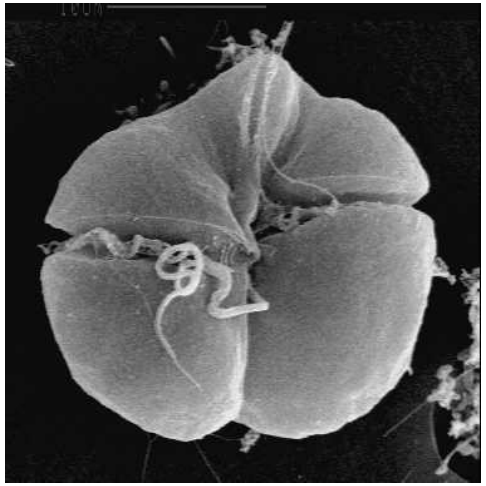
- They have two flagella housed in the grooves of armor-like cellulose plates that surround the cell

- Beating of the spiral flagella causes dinoflagellates to spin as they move through the water



- Dinoflagellate blooms cause “red tides” where the water appears brownish red or pink due

- Ocean warming caused by climate change is facilitating more frequent red tides



Karenia brevis

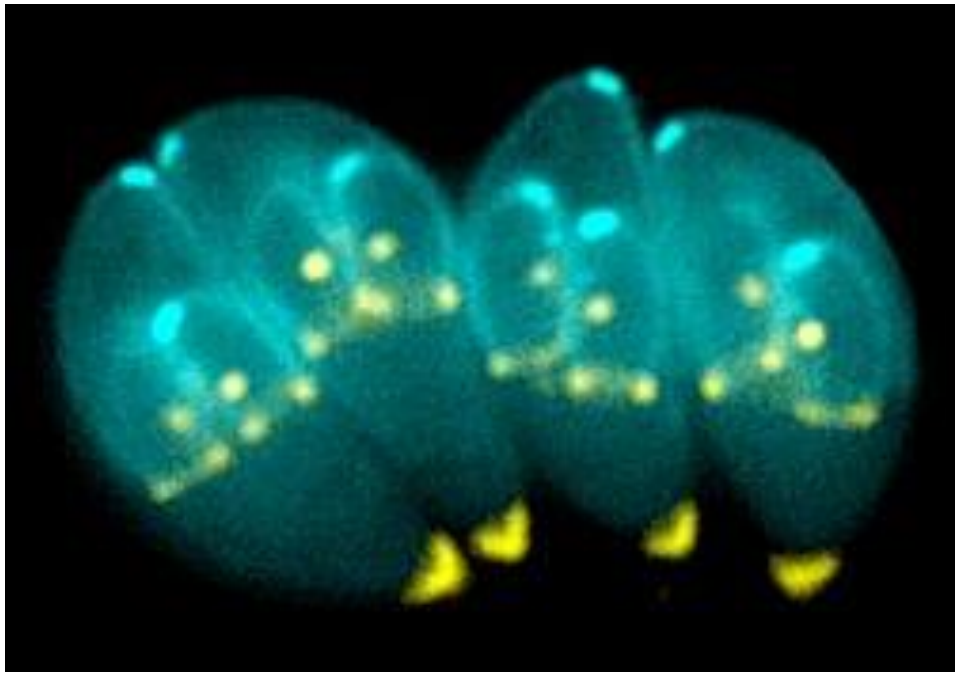
Red tide in the Gulf of Carpentaria in Australia

- Red tides are toxic and can cause massive kills of invertebrates and fishes

- Humans who eat molluscs that have accumulated the toxins are affected as well, sometimes fatally.

Apicomplexans

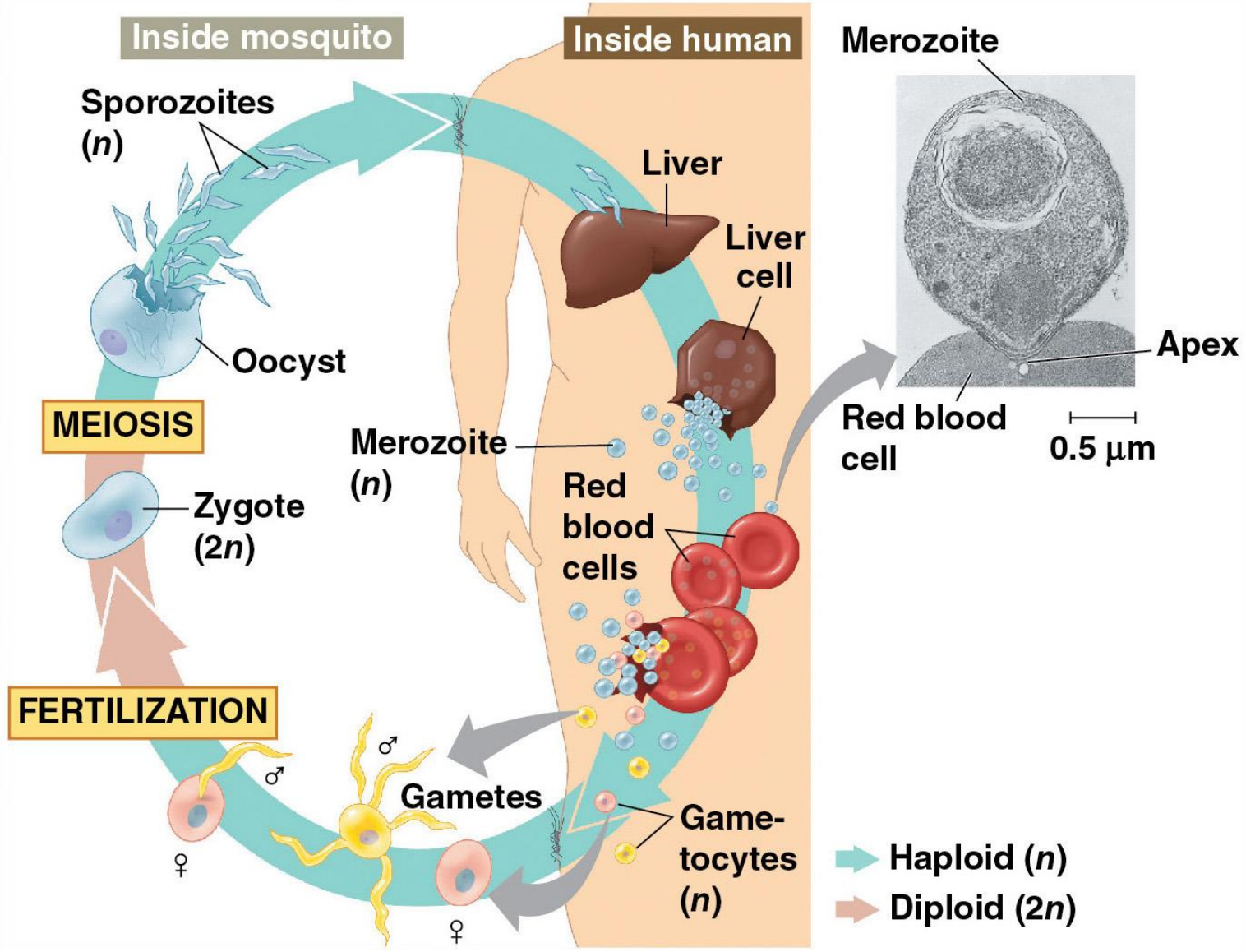
- Nearly all **apicomplexans**are parasites of animals
- They spread through the host as infectious cells
- E.g: Toxoplasmosis



Toxoplasma gondii

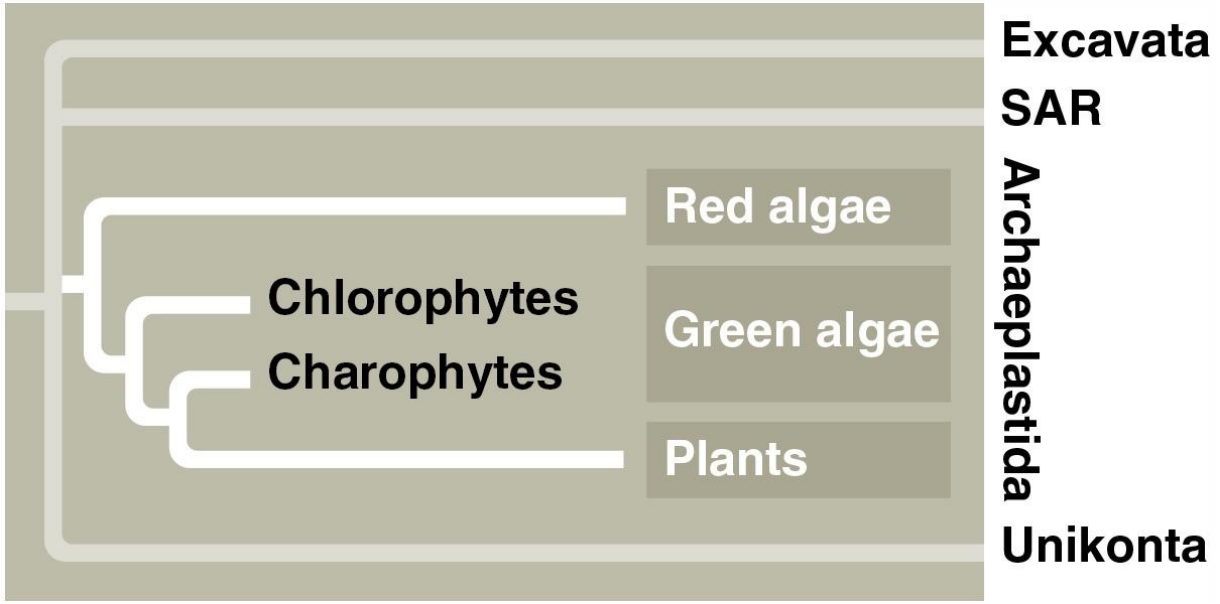
Felis catus

- Most life cycles include both sexual and asexual stages, and require two or more different hosts
  - E.g.: *Plasmodium*, the parasite causing malaria, lives in both mosquitoes and humans



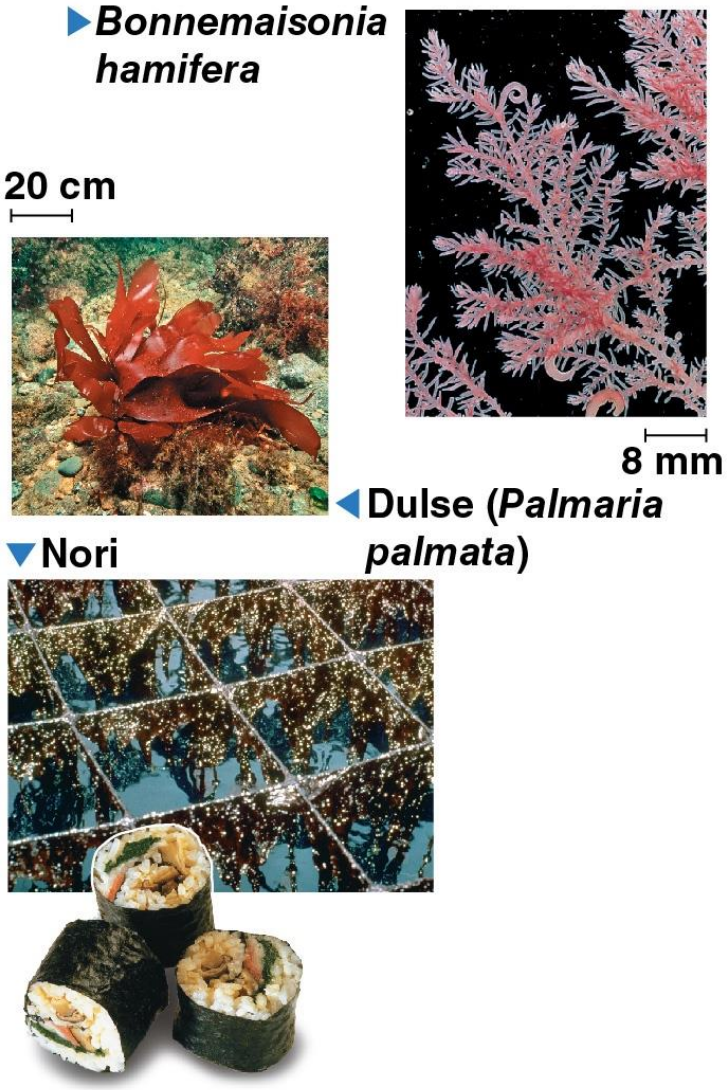
Red algae and green algae are the closest relatives of plants

- A heterotrophic protist acquired a cyanobacterial endosymbiont
- The photosynthetic descendants of this ancient protist evolved into red algae and green algae
- Plants are descended from the green algae
- **Archaeplastida** is the supergroup that includes red algae, green algae, and plants
  - Red and green algae include unicellular, colonial, and multicellular species



Red Algae

- An accessory pigment called phycoerythrin masks the green of chlorophyll giving **red algae** its color
- Color varies from greenish-red in shallow water to dark red or almost black in deep water
- Most are multicellular; the largest are seaweeds
- Red algae are common in coastal waters of tropical oceans
- Some species are consumed by humans, such as *Porphyra* (“nori”) that is used to wrap sushi

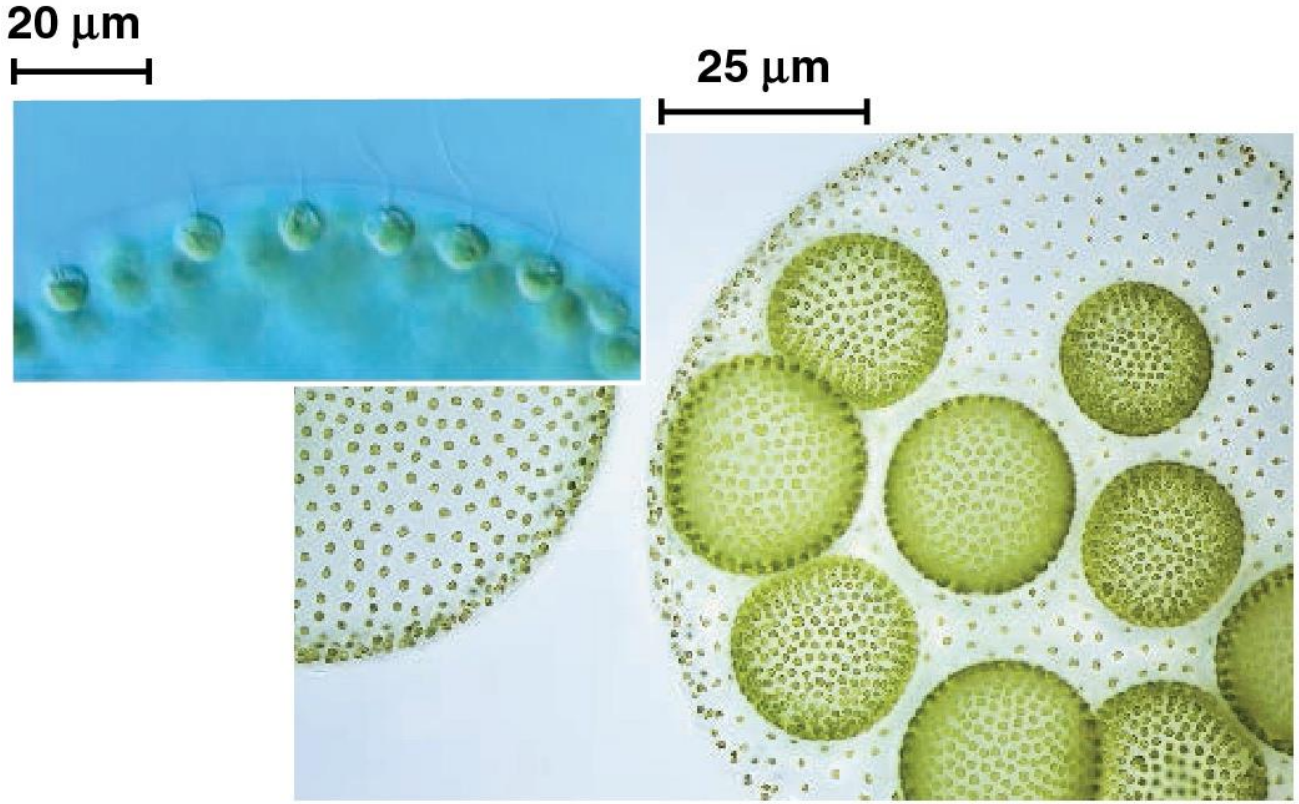


Green Algae

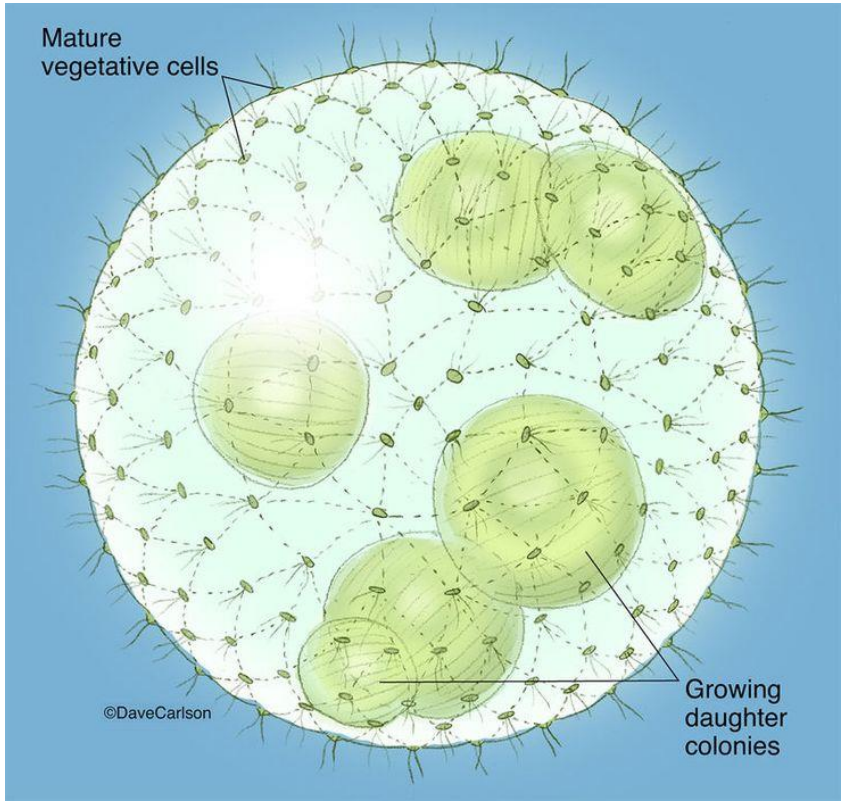
- **Green algae** are named for their green chloroplasts, which are structurally and chemically similar to ones found in plants

Green Algae

- For example, *Volvox* is a multicellular green algae



***Volvox*, a multicellular freshwater green alga**



- Larger size and greater complexity evolved in green algae by three different mechanisms:

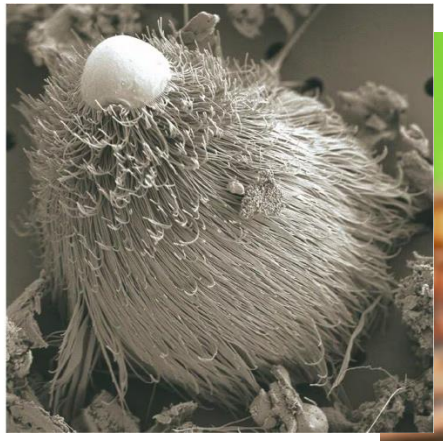
    1. Formation of colonies from individual cells

    2. Formation of true multicellular bodies by cell division and differentiation

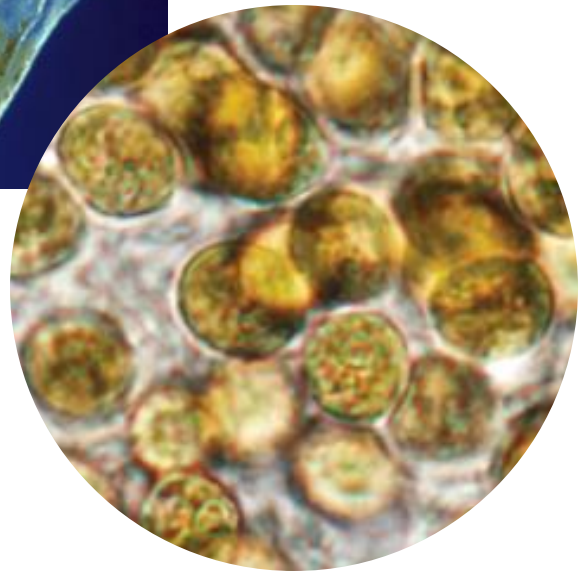
    3. Repeated division of nuclei with no cytoplasmic division

Symbiotic Protists

- Some protist symbionts benefit their hosts
  - Dinoflagellates nourish coral polyps that build reefs
  - Wood-digesting protists inhabit the gut of termites



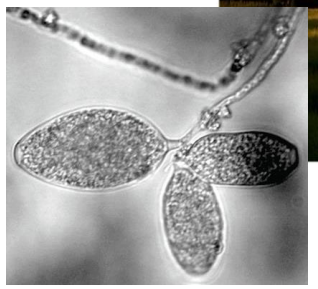
hypermastigote



Parasitic Protists

- Some protists are parasitic
  - *Plasmodium* causes malaria
  - *Pfiesteria shumwayae* is a dinoflagellate that kills fish
  - *Phytophthora infestans* causes potato late blight, which contributed to the Irish famine of the 19th century
  - *Phytophthora ramorum* causes sudden oak death

Pfiesteria shumwayae

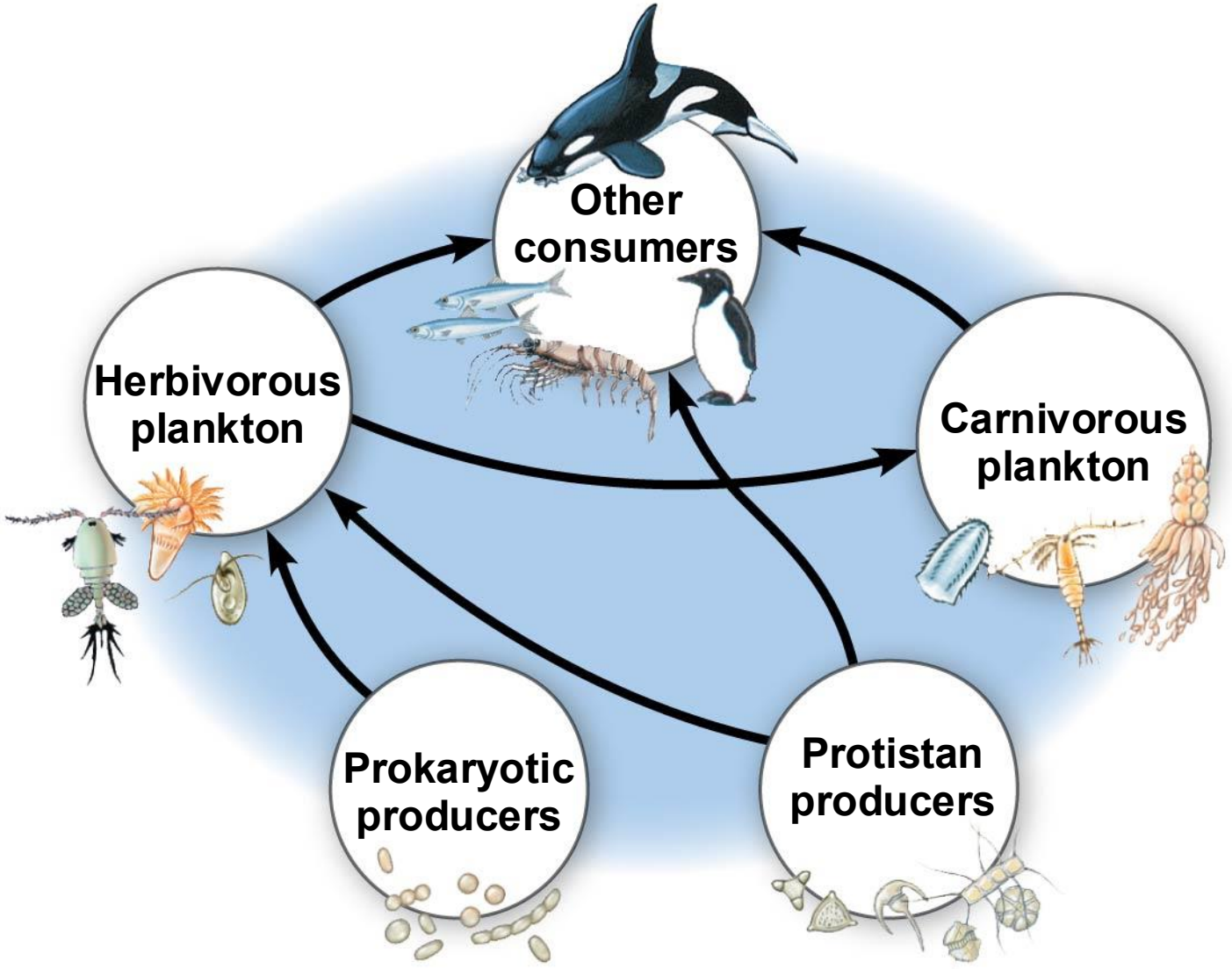


Phytophthora infestans

Phytophthora infestans

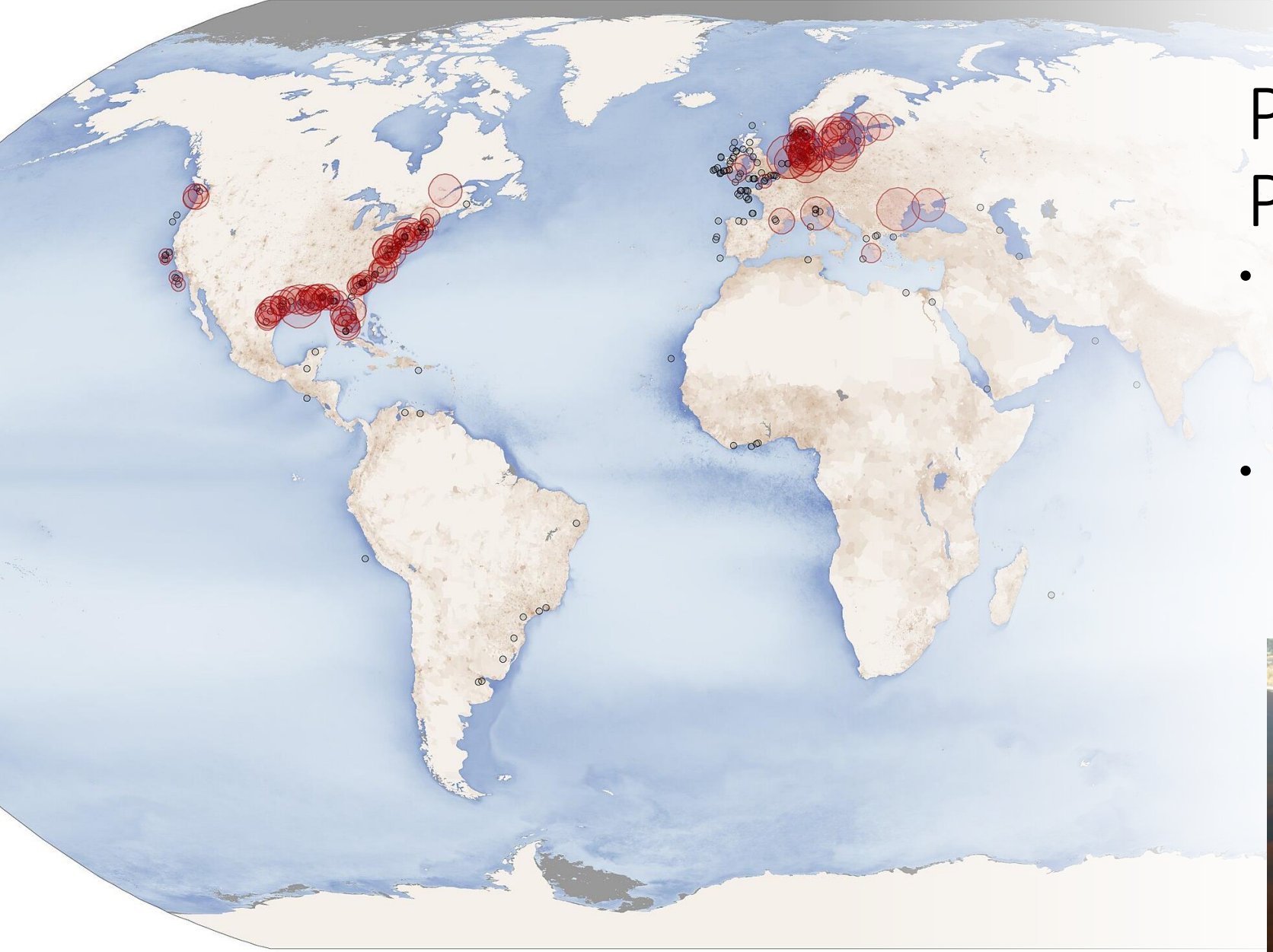
Photosynthetic Protists

- Many protists are important **producers** that obtain energy from the sun to convert CO_2 to organic compounds
- In aquatic communities, photosynthetic protists and prokaryotes are the main producers
- All other organisms are **consumers** that directly or indirectly depend on producers for food

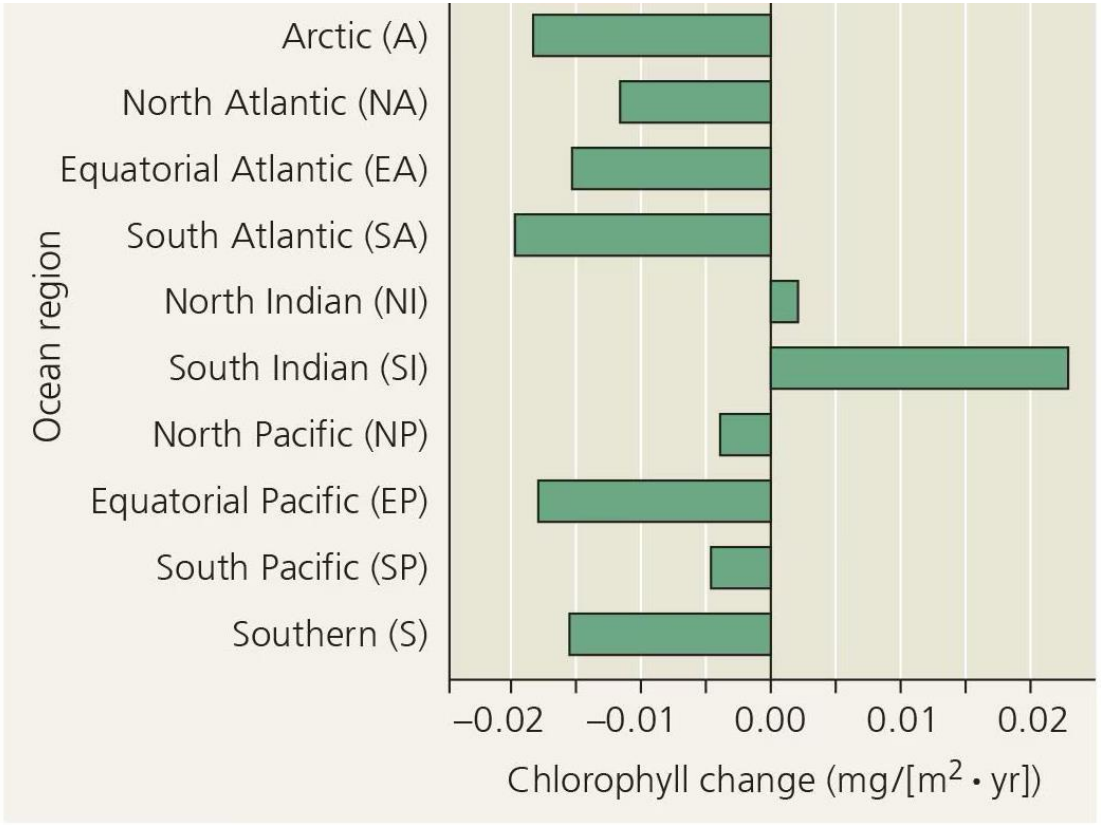

Other consumers
Herbivorous plankton
Carnivorous plankton
Prokaryotic producers
Protistan producers

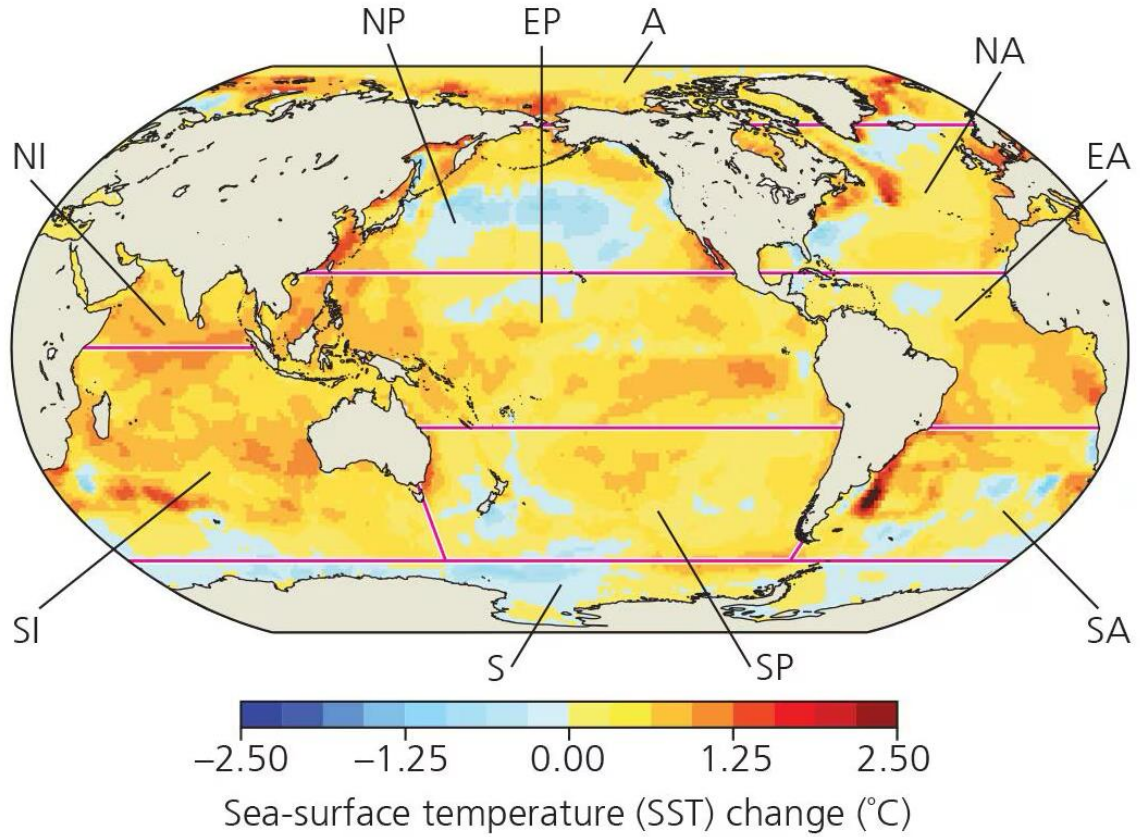
Photosynthetic Protists

- Photosynthetic protists are limited by nutrients; populations explode when nutrients are added
- Population booms can have major ecological consequences, such as the formation of marine “dead zones”



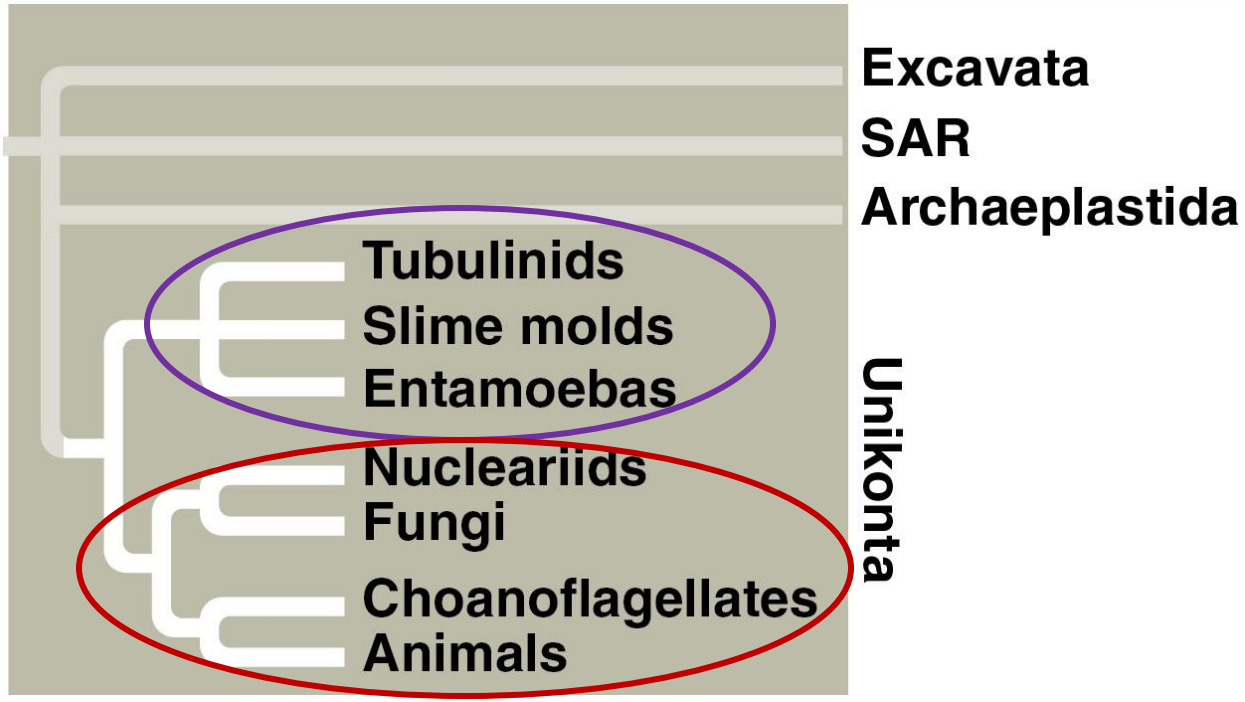
- Growth and biomass of photosynthetic protists and prokaryotes have declined with increasing sea surface temperature
- Phytoplankton communities rely on upwelling of cold, nutrient-rich water from the below
- Warm surface water acts as a barrier to upwelling





Unikonts include protists that are closely related to fungi and animals

- The supergroup **Unikonta** includes animals, fungi, and some protists
- The two major clades of unikonts are the amoebozoans and the opisthokonts (animals, fungi, and related protists)

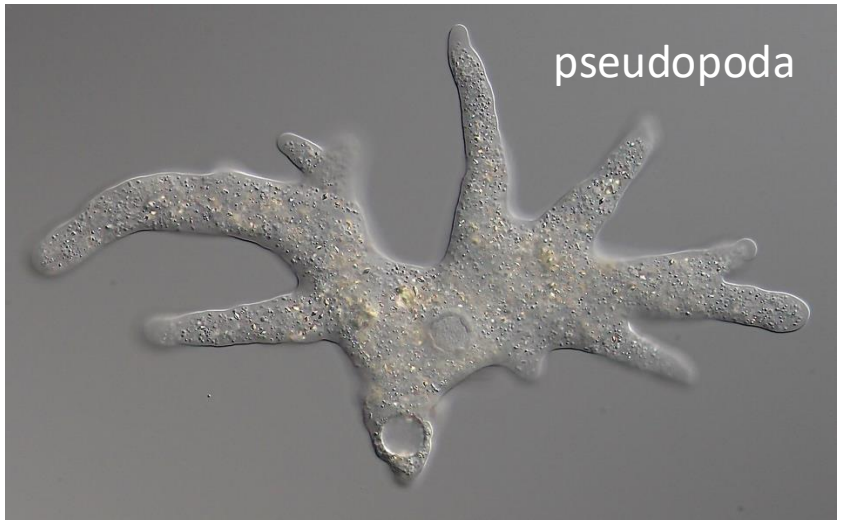


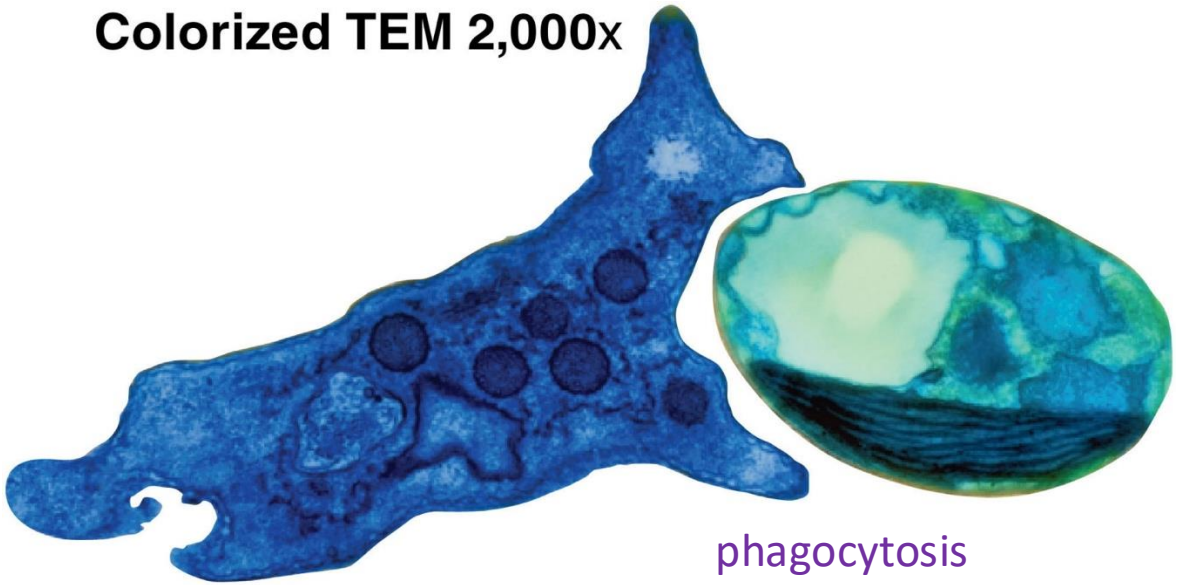
Unikonts include protists that are closely related to fungi and animals

animals

fungi

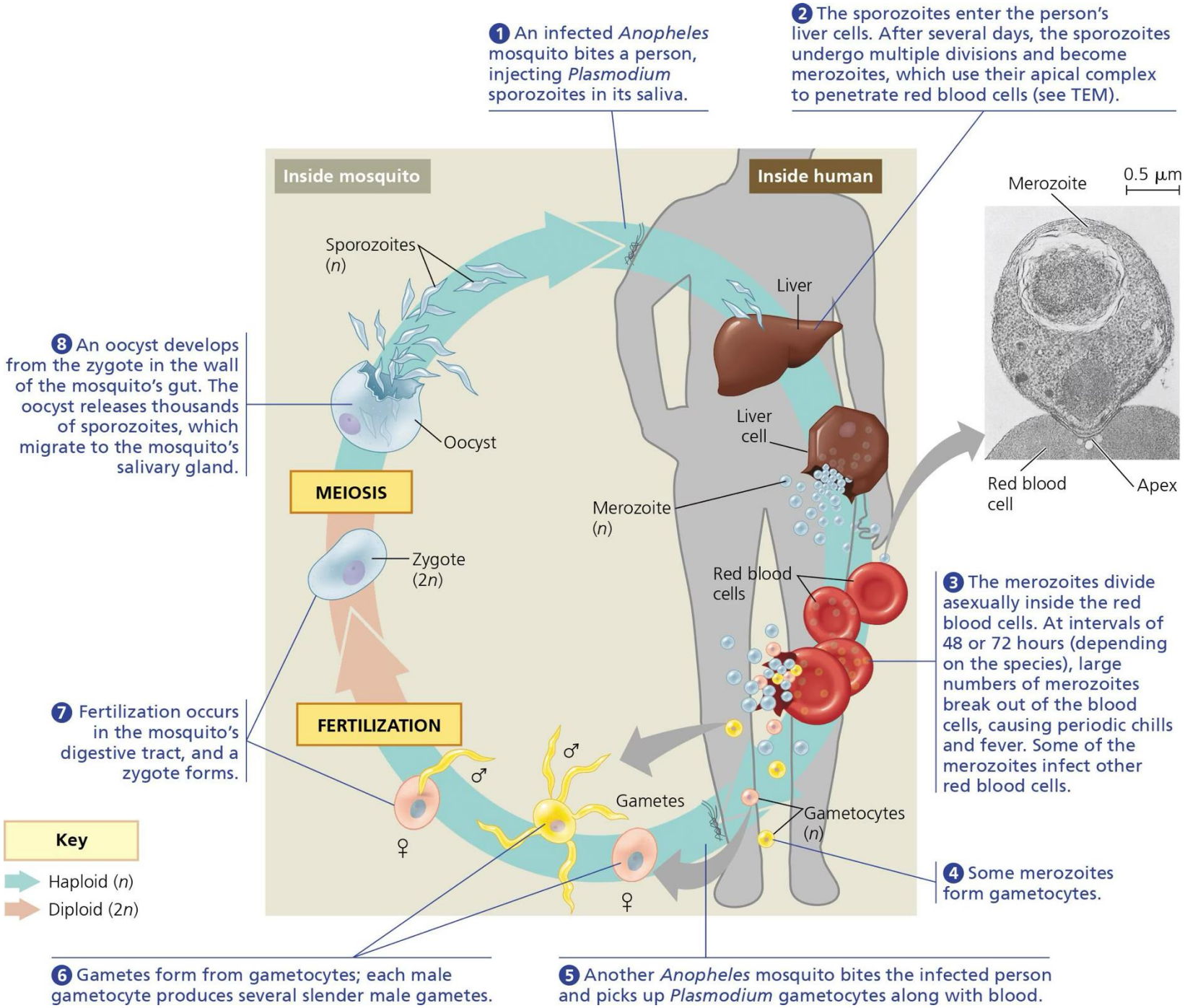
Amoeba





phagocytosis

Extra


1 An infected *Anopheles* mosquito bites a person, injecting *Plasmodium* sporozoites in its saliva.
2 The sporozoites enter the person's liver cells. After several days, the sporozoites undergo multiple divisions and become merozoites, which use their apical complex to penetrate red blood cells (see TEM).
Inside mosquito
Inside human
Sporozoites (*n*)
Liver
Liver cell
Merozoite (*n*)
Red blood cells
Merozoite
0.5 μm
Red blood cell
Apex
8 An oocyst develops from the zygote in the wall of the mosquito's gut. The oocyst releases thousands of sporozoites, which migrate to the mosquito's salivary gland.
Oocyst
MEIOSIS
Zygote (2*n*)
3 The merozoites divide asexually inside the red blood cells. At intervals of 48 or 72 hours (depending on the species), large numbers of merozoites break out of the blood cells, causing periodic chills and fever. Some of the merozoites infect other red blood cells.
7 Fertilization occurs in the mosquito's digestive tract, and a zygote forms.
FERTILIZATION
♂
♀
Gametes
Gametocytes (*n*)
4 Some merozoites form gametocytes.
Key
Haploid (*n*)
Diploid (2*n*)
6 Gametes form from gametocytes; each male gametocyte produces several slender male gametes.
5 Another *Anopheles* mosquito bites the infected person and picks up *Plasmodium* gametocytes along with blood.