

# **L03b: Diversity of Marine Bacteria, Archaea, Eukarya and Viruses**



*Tara Oceans*  
new results

# THE SECRET LIFE OF PLANKTON



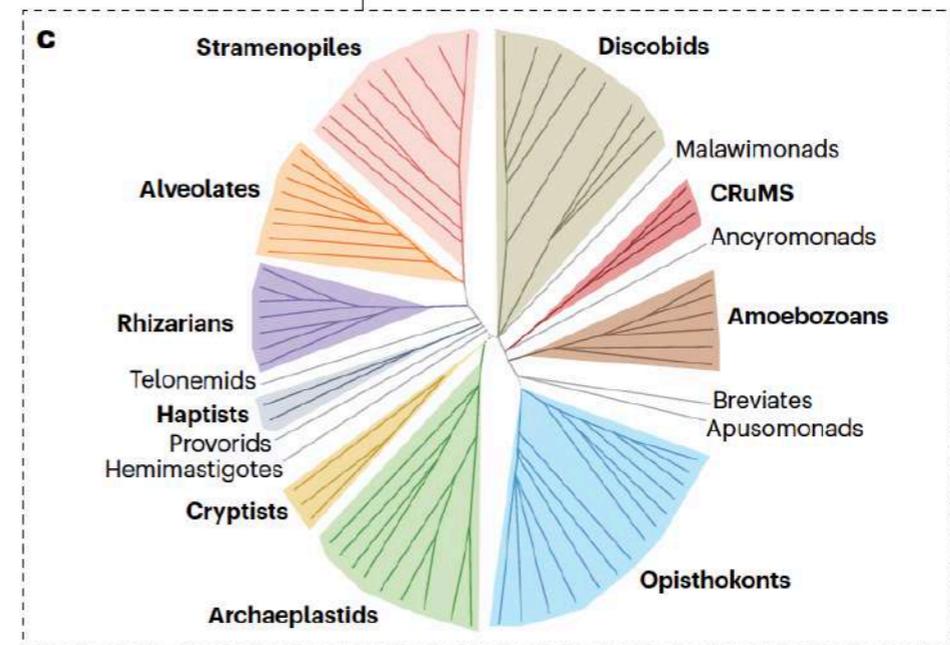
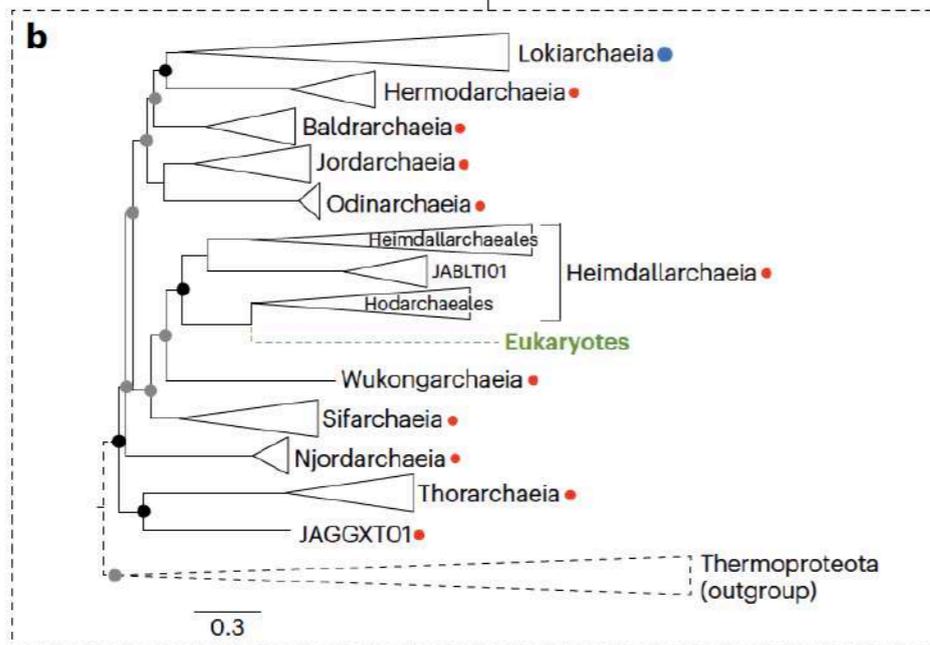
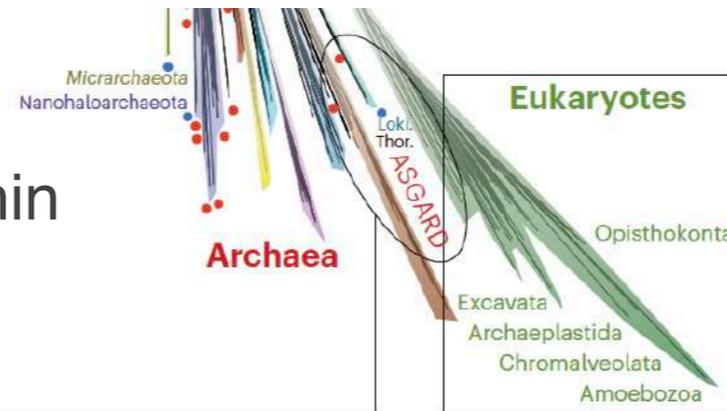
# FEEDING THE SEA

Phytoplankton Fuel Ocean Life



# Archaea and Eukaryotes

A two-domain tree with Eukarya branching from within the Archaea, sister to the Asgardarchaeota



Hug et al., 2016; Hug, 2024

# Phylum Euryarchaeota, I

- **Meso- to thermophilic obligate anaerobes**
  - **Anoxic sediment, symbiont of anoxic protists**
  - **Hydrothermal vents**
  - **Production of methane as a final step of anaerobic degradation of organic material**
  - **Some fast grow 1h generation time at 110°C**
- **ANME, anaerobic methanotrophic Archaea**
  - **Anaerobic oxidation of methane (AOM)**
  - **In consortia with sulfate-reducing bacteria, reverse methanogenesis and provide N**
  - **Diverse clades: anoxic sediment and mud volcanos**
  - **Soluble cytochrome and nanowires to exchange electrons**
- **Thermococci, hyperthermophiles**
  - **Biotechnological interest for heat-resistant enzymes**
  - **Hydrothermal vents and subsurface rocks**

# Phylum Euryarchaeota, II

- **Archaeoglobus and Ferroplasma**
  - Extreme thermophiles
  - Strictly anaerobes
  - Archaeoglobus: reduction of sulfate with oxidation of H<sub>2</sub> to produce H<sub>2</sub>S → “souring” crude oil
  - Ferroplasma: iron-oxidizing and nitrate reducing chemolithoautotrophs
- **Halobacteriaceae**
  - Extreme halophiles > 9% or saturated solution of NaCl
  - Chemoorganotrophs
  - Cell lysis without enough NaCl
  - Pigmented → produce ATP using light with bacteriorhodopsin
- **Uncultivated Marine Group II, III, IV**
  - Particle associated
  - MG-II, up to 4-20% of total microbial community in surface waters

# Phylum Crenarchaeota

- Growing at high temperature
- Terrestrial hot springs and hydrothermal vents
- Chemororganotrophic or chemoheterotrophic, chemolithoautotrophic (—> very important source of organic carbon)
- Most obligate anaerobes
- Decomposers organic matter
- *Ignioccus* is the host of an archaeon parasite (*Nanoarchaeum equitans*) —> blebbing periplasmic space with secretory functions. Anaerobic and CO<sub>2</sub> fixation via sulfur reduction with molecular hydrogen

# Phylum Thaumarchaeota

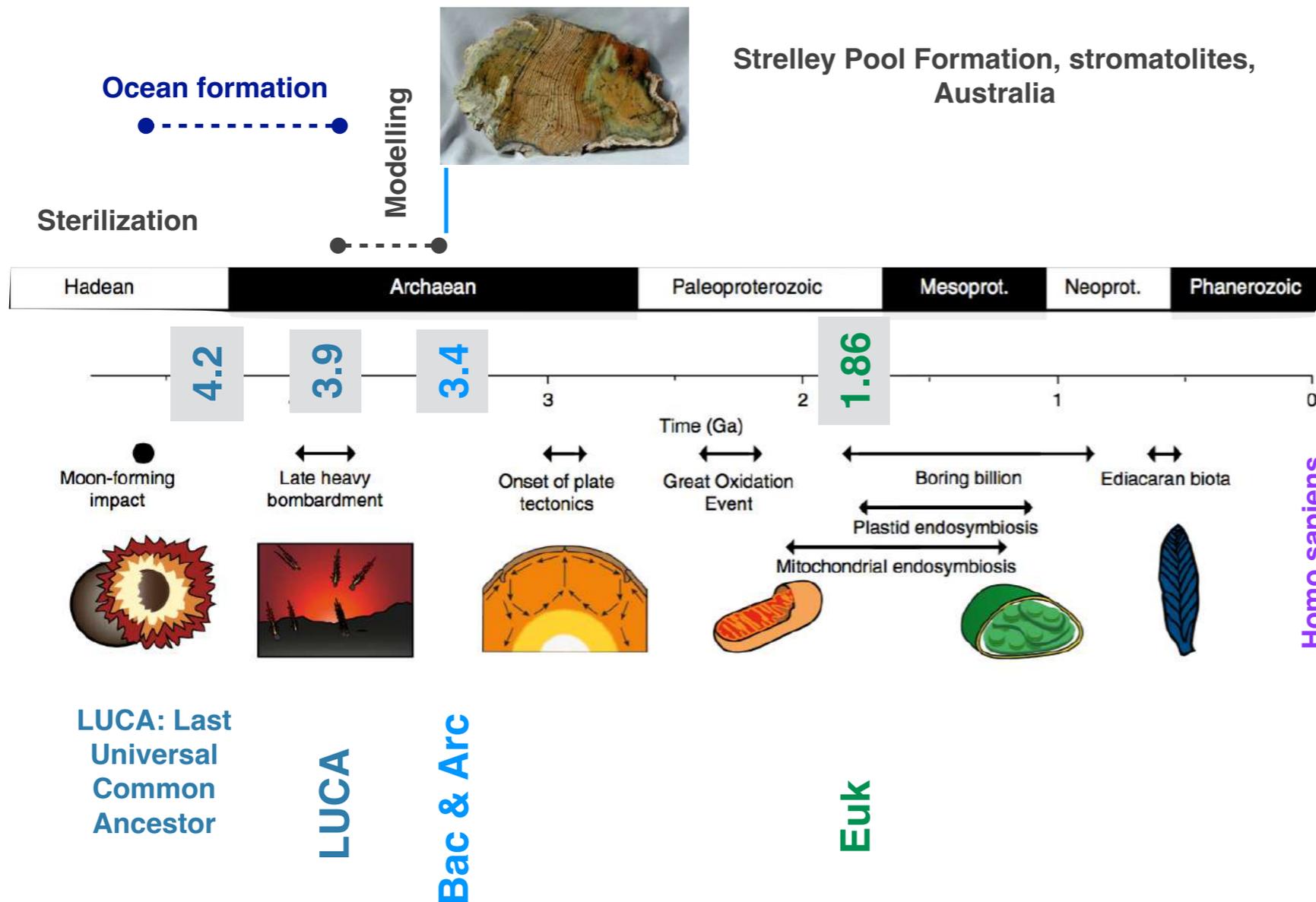
- Water column cold and polar waters
- Symbionts of cold-water sponges → ammonia oxidation
- Marine Group I, MG-I, very abundant → chemolithotrophic autotrophs → ammonia oxidation → nitrification and carbon fixation in deep cold ocean

# Phylum Nanoarchaeota

- Cytoplasmatic parasite
- Hyperthermophile
- Small size and genome reduction

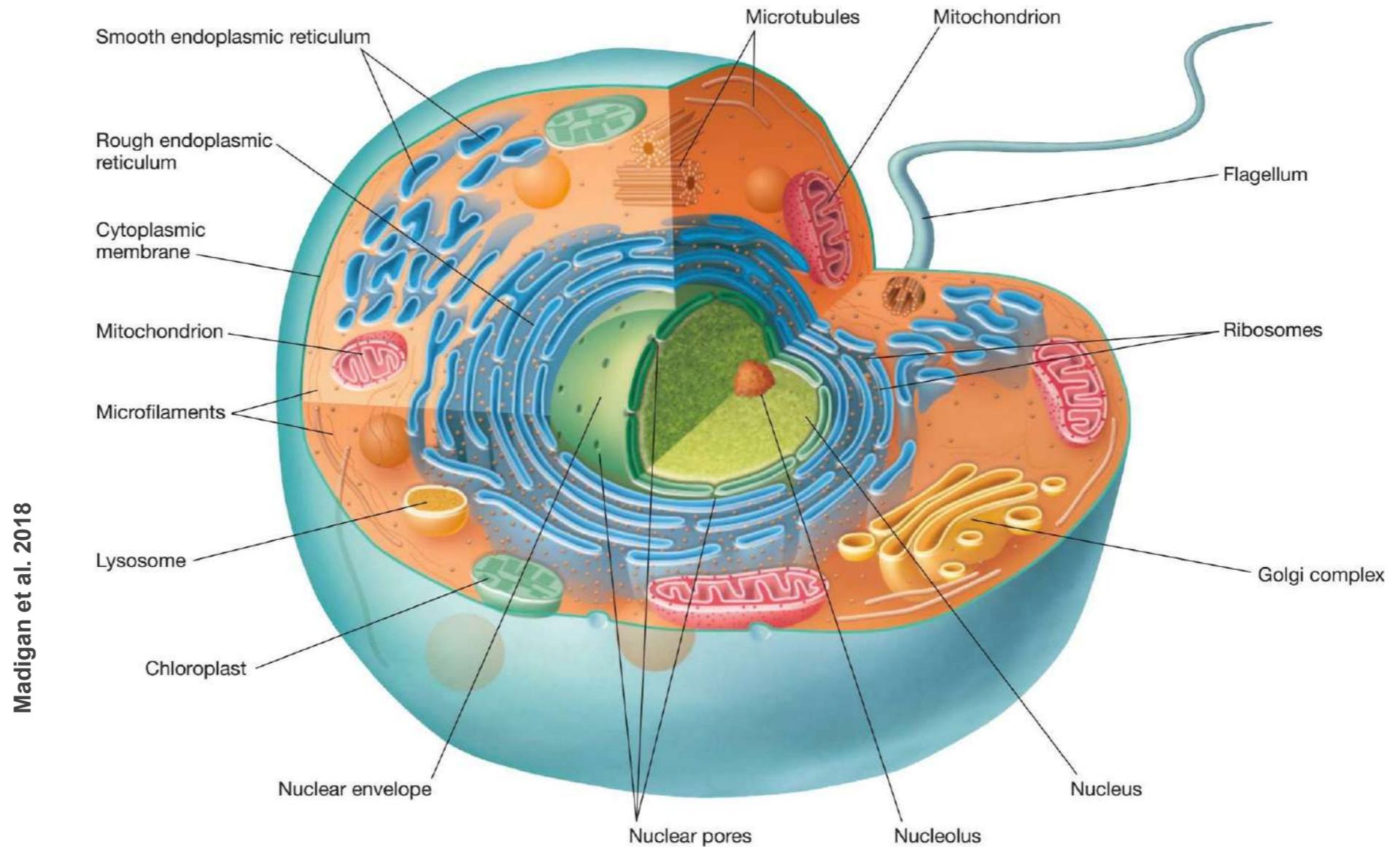
# Origin of the EUKARYA

- From Archaeon (nucleus) and H<sub>2</sub>-producing bacterium (mitochondria)
- Chloroplasts arisen on several occasions



Betts et al., 2018  
Moody et al., 2024

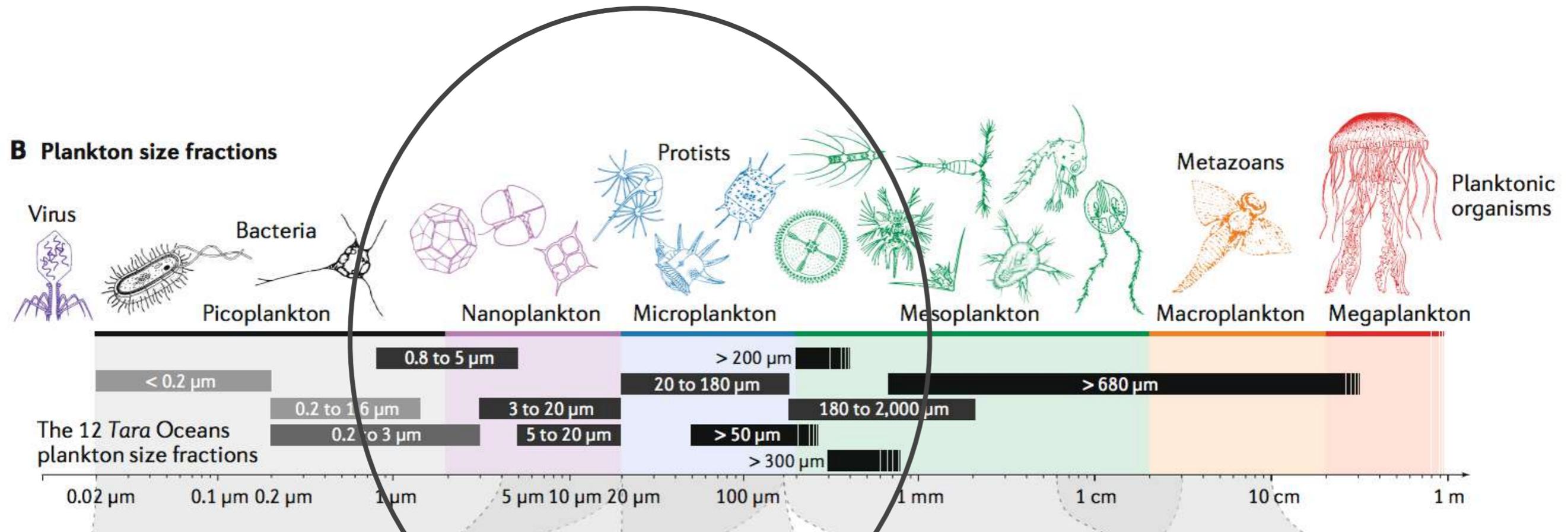
# Eukaryotes



## Eukaryote:

Defined **nucleus** with nuclear membrane genomes structured in chromosomes-bodies containing the hereditary material)  
Organelles: **mitochondria** (cellular energy, oxidation); **hydrogenosomes** (fermentative metabolism); **Golgi apparatus** (secretory device); an **endoplasmic reticulum** (a canal-like system of membranes within the cell for protein, lipid synthesis); **lysosomes** (digestive apparatus within many cell types); **chloroplast** (glucose and ATP production and O<sub>2</sub> in plants); **cytoskeleton** (3D structural architecture); **flagella** and **cilia**

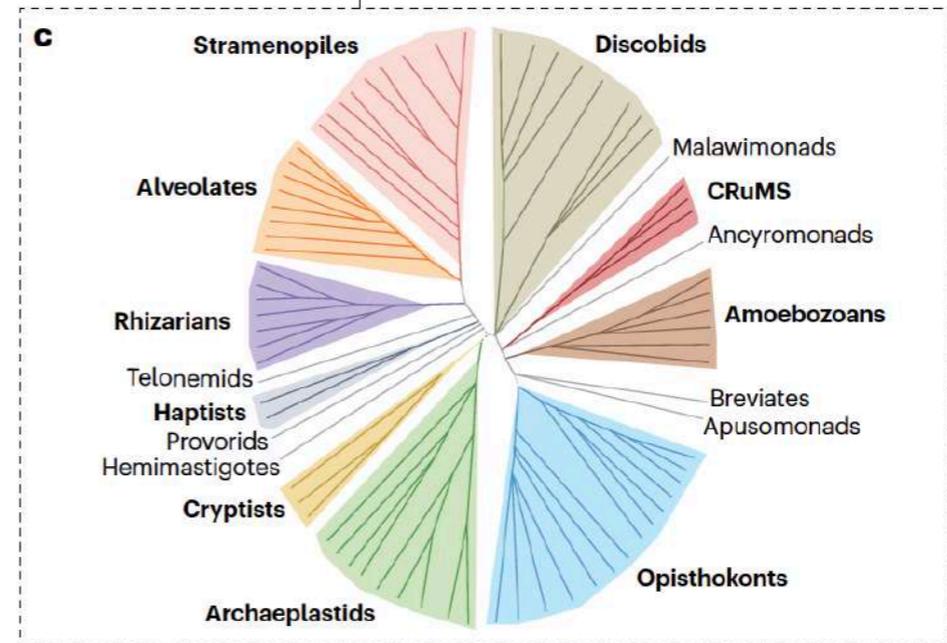
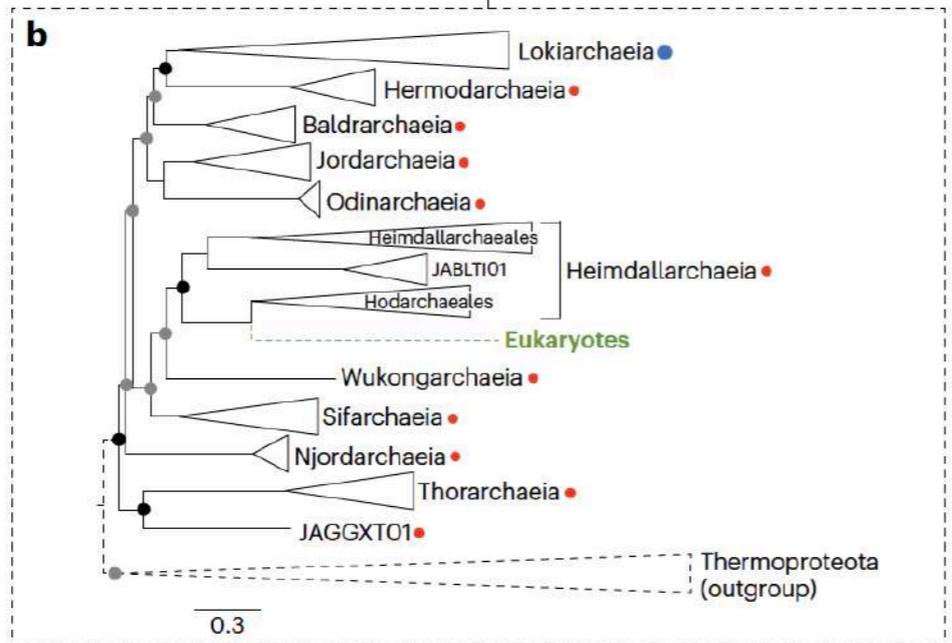
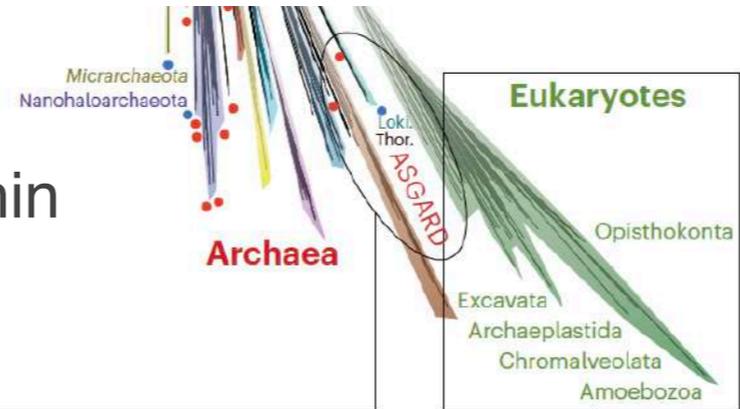
# Size-range of marine EUK-microbes





# Archaea and Eukaryotes

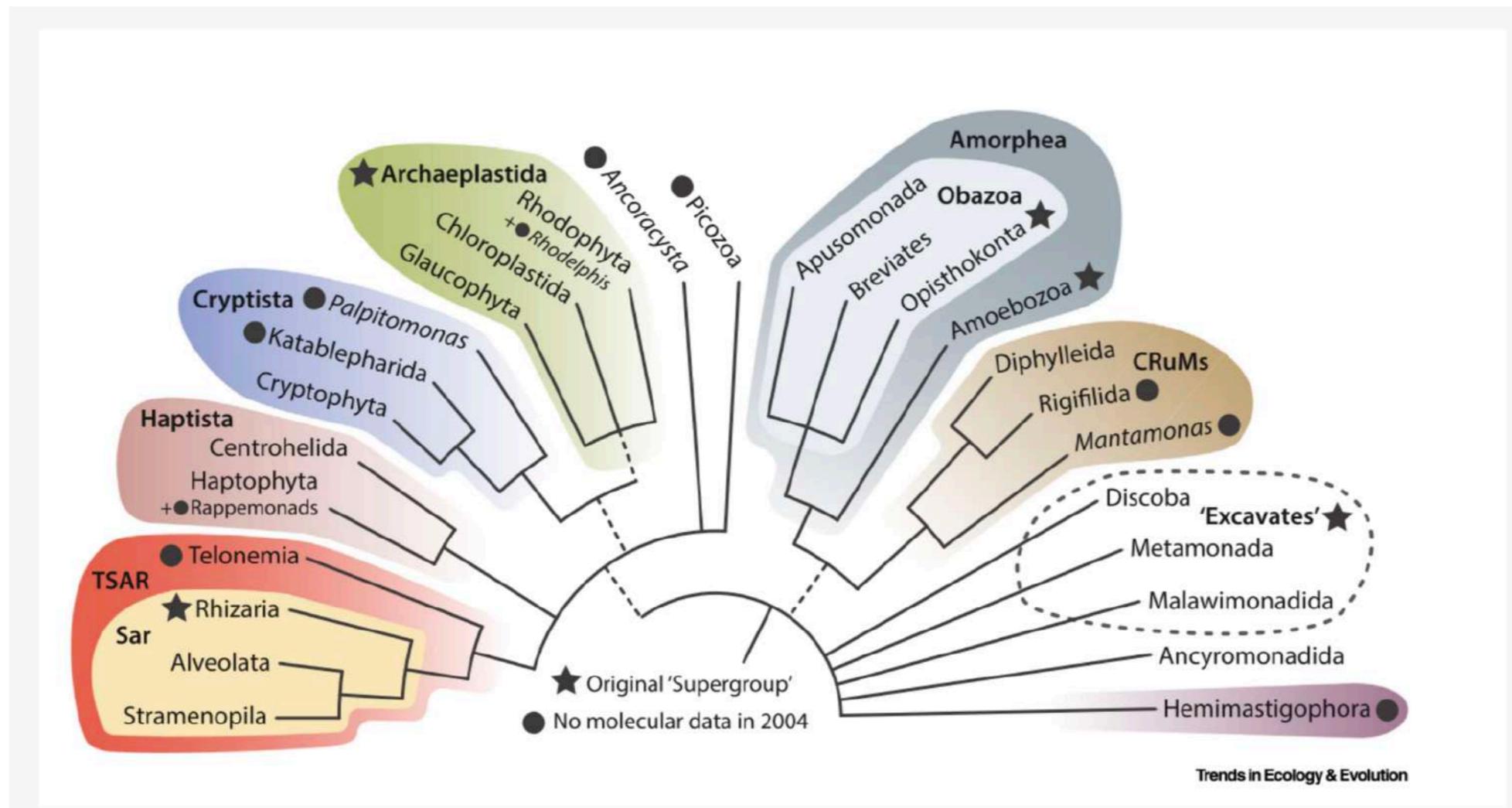
A two-domain tree with Eukarya branching from within the Archaea, sister to the Asgardarchaeota



Hug et al., 2016; Hug, 2024

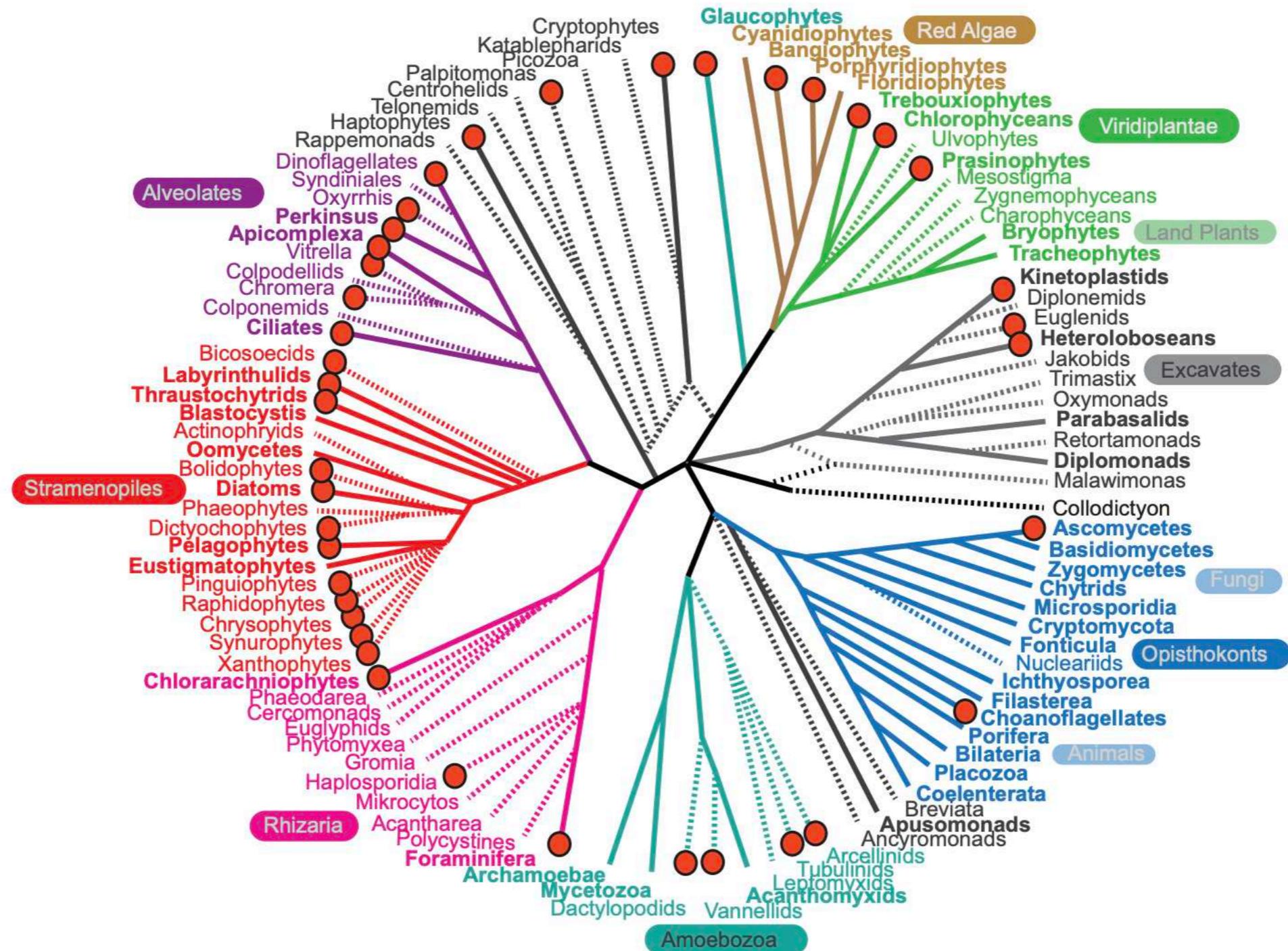
# Protists

- Unicellular eukaryotic microbes
- Photosynthetic, heterotrophic and mixotrophic life style
- 1- 200  $\mu\text{m}$  size
- Haeckel first classification of HMS Challenger expeditions
- 18S rRNA gene



The eukaryotic tree. From Burki et al. 2019. The New Tree of Eukaryotes. Trends in Ecology & Evolution. DOI: 10.1016/j.tree.2019.08.008.

# Major lineages in the eukaryotic tree of life



# Picoeukaryotes

- Photoautotrophs, osmotrophic heterotrophs, grazing predators, parasites
- 1-3  $\mu\text{m}$  cell diameter
- In surface waters,  $10^4$  cells/mL
- *Ostreococcus*, *Prasinophytes*
  - Chl a, primary producer
  - Up to 80% of primary production with *Prochlorococcus* and *Synechococcus* in subtropical ocean
  - 13.9 Mb, with 7932 predicted genes
  - C4 photosynthesis beside C3
- *Micromonas pusilla*, *Prasinophytes*
  - Open and coastal ocean
  - Summer bloom terminated by viruses
  - Autotrophic and phagotrophic (=bacterivore in Arctic Ocean)
  - 21.9 Mb, with 10242 predicted genes

# Heterotrophic flagellated protists

- One or more flagella for feeding and movement
- Important bacteria grazers in water column and sediment, sea ice, intestinal habitat
- Flagella structure is important to identify them
- Preying on bacteria they are then consumed by ciliates and dinoflagellates, that are then consumed by copepods
- Strong top-down control on bacteria population
- $10^5$  cells/mL
- Discard up to 30% of indigested food via vacuoles that becomes DOM and POM pool
- Produce pico-fecal pellets that funnel C export into the deep ocean
- Mixotrophic with chloroplasts that can be kept after ingesting prey

# Heterotrophic flagellated protists

- HNF: heterotrophic nanoflagellates 3-10  $\mu\text{m}$ 
  - Prey on Bacteria and Archaea
  - Prey difference
  - Suspension feeder, creating feeding currents that concentrate prey
  - Genome > than PicoEuk
  - *Bodo*, *Cafeteria*
- HMF heterotrophic microflagellates > 20  $\mu\text{m}$ 
  - Channel C to higher trophic levels
  - In deep ocean up to 30% carbon to higher trophic levels

# Choanoflagellates

- Similar to feeding cells in sponges
- 3-10  $\mu\text{m}$  cell diameter
- Single flagellum with microvilli around the mouth part
- Some have a basket-like shell (lorica) in silica
- Genome > than HNF

# Dinoflagellates

- **Traverse flagellum —> spinning motion**
- **Armor made by cellulose**
- **Important bacteria grazers in water column and sediment, sea ice, intestinal habitat**
- **Genome > than HNF and Choanoflagellates, Diatoms**
- **Huge genome: 1.2-272 Gb (e.g. humans 3.2 Gb), large region of repeated and interspersed non coding DNA, intensive HGT**
- **Benthic community, corals, sediment, seaweeds, on surface and water column**
- **Chl a, c and carotenoids and xanthophylls**
- **Important primary producers coastal in high latitudes**
- **Spring bloom of dinoflagellates and diatom**
- **Symbionts in corals: Symbiodiniaceae**
- **Endosymbionts in protists, ciliates, foraminiferans and colonial radiolarians**
- **Predators of bacteria, phytoplankton and zooplankton eggs**
- **Predated by copepods**
- **Vertical migrations during the night —> circadian rhythm**
- **Bioluminescence: *Gonyaulax* and *Lingulodinium***
- **Toxin producers, *Dynophysis***

# Ciliates

- **Voracious grazers**
- **Covered by cilia to create feeding currents and to move**
- **15-80  $\mu\text{m}$  - 200  $\mu\text{m}$**
- **Tintinnids lorica, house made of protein and carbohydrates and particles collected from water**
- **1- 150 ciliates/ mL, >> number in marine snow, benthic sediment and microbial mats**
- **Prey bacteria and smaller protists  $\rightarrow$  larger protists and zooplankton**
- **Some are photosynthetic**
- **Two nuclei: one with genes and mRNA, the second is diploid for sexual reproduction**

# Haptophytes (Primnesiophytes)

- Important primary producers
- Complex life style: motile and not-motile, naked or with coccoliths
- Accessory pigments diadinoxanthin and fucoxanthin
- Calcification depend on inorganic calcium carbonate
- Coccoliths are calcifying in the Golgi apparatus
- Calcification enhance photosynthetic efficiency by lowering cellular pH thus increasing CO<sub>2</sub> concentration for RuBisCO
- Coccoliths: grazing protection and photodamage protection
- At 3000 m, due to high pressure calcite dissolved
- Important carbon export, preyed by zooplankton
- Visible from satellite
- Evolved 290 MYA

# Haptophytes (Primnesiophytes)

- *Emiliana huxleyi* 167.7 Mb with 38544 predicted genes
  - 4-5  $\mu\text{m}$  cell diameter
  - Haploid stage non calcified scales and motile
  - Diploid stage calcified and non motile
  - Bloom in temperate and subtemperate waters and coastal and oligotrophic waters
- *Chrysochromulina* and *Phaeocystis* forms mucilage, DMS and foam

# Diatoms

- **Stramenopiles, Bacillariophyceae**
- **Important primary producers in coastal water**
- **Two valves, of hydrated silica, like a box**
- **2 - 200  $\mu\text{m}$**
- **Asexual reproduction until the cells becomes too small (*i.e.* 1/3 of regular size) than sexual reproduction**
- **Ge can be take-up instead of Si  $\rightarrow$  valves become fragile**
- **A dark period, synchronise the population in lab culture**
- **76.2 MB genome size with 18246 predicted genes**
- **Free-living or benthic**

# Diatoms II and Raphidophytes

- Some are heterotrophs
- Chl a, c, carotenoid fucoxanthin
- ~40% of total primary productivity
- On ice important primary producers, spring bloom in temperate waters and in upwelling areas
- Silica is limiting nutrients
- Silica is precipitated due to protein, silaffins that create a low pH environment → silica dissolve at seawater pH without protein protection
- Diatoms form the diatomaceous ooze in sediment at seawater pH
- Formation of petroleum hydrocarbon → biofuel production
- Toxin production
- Raphidophytes (Stramenopile)
  - 50-100 μm, no cell wall, two flagella
  - Red tides, *Heterosigma akashiwo*
  - Toxin production
  - Good food in aquaculture: *Nannochloropsis*, brown tide former

# Thraustochytrids and Labyrinthulids

- Stramenopile
- Slime/mucus net producers
- Look like Fungi
- 1-100 cell/mL
- Coastal water, parasite on mollusks, associated on macro algae
- Osmotrophy of DOM
- Extracellular enzyme in slime able to degrade large polymers
- Digest refractory material, including mangrove detritus
- Predate by Ciliates and Amoebae
- Produce high level of PUFA, omega-3-polyunsaturated fatty acid → important for Crustacea such as copepods (i.e. zooplankton)

# Amebozoa

- Grazers of particle associated bacteria
- Crawling with pseudopodia
- More abundant than Ciliate
- Coastal waters and estuaries

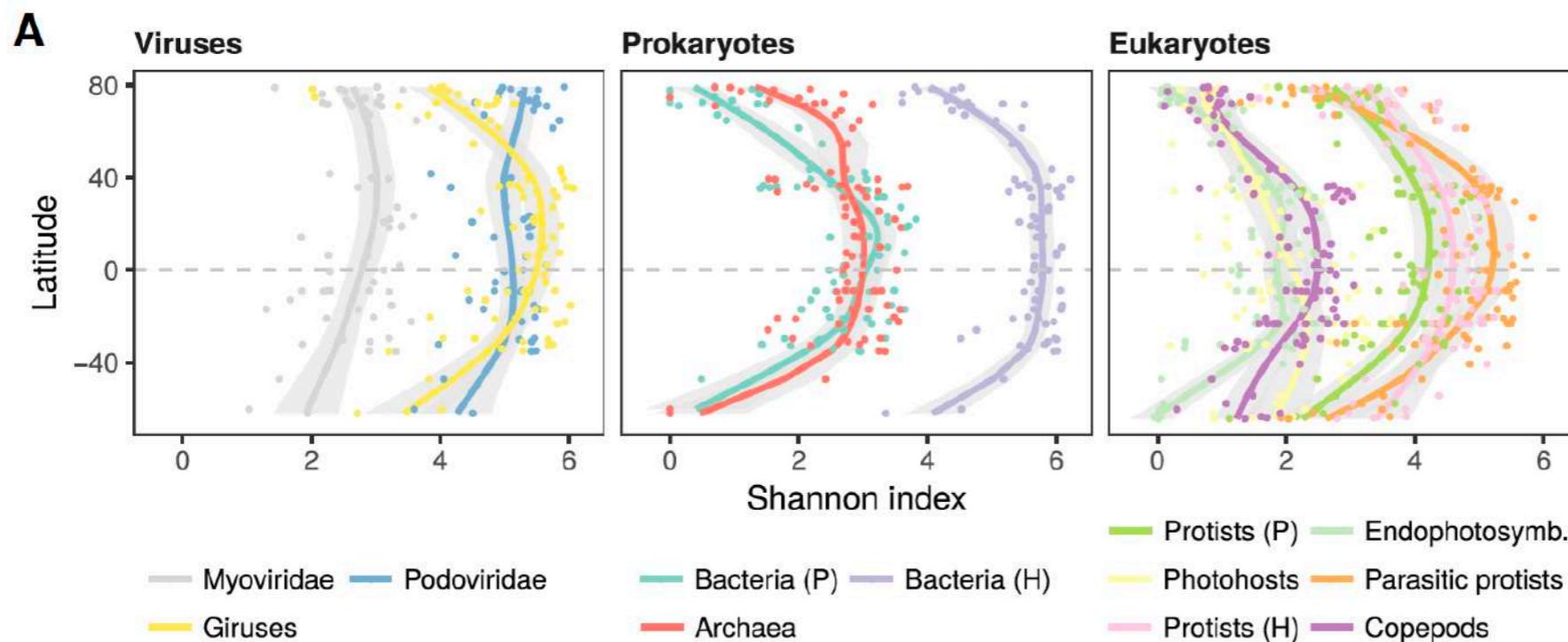
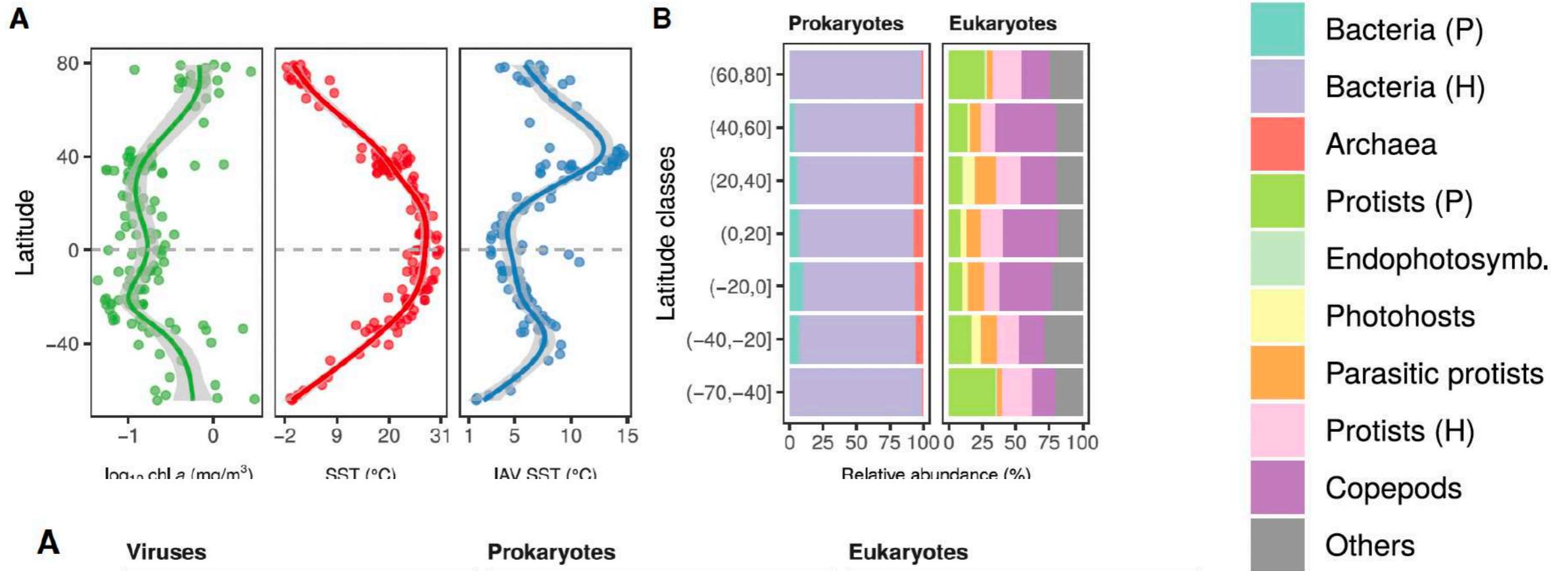
# Radiolarians & Foraminifera

- Rhizaria
  - Radiolarians
    - 0.1-0.2 mm, stiff needle-like pseudopodia in radial symmetry and internal silica skeleton (some have strontium)
    - $10^4$  cells/cm<sup>3</sup> in subtropical ocean
    - Preying protists and small zooplankton
  - Foraminifera
    - Multichambered organisms, with pseudopodia
    - Deep ocean, productive waters
    - Predators of bacteria, phytoplankton and small metazoan animals
    - Many fossils, globigerine ooze

# Marine Fungi

- **Monophyletic group**
- **Opisthokonta**
- **~1.5 BYA diverged from animals**
- **Ascomycota**
- **Basidiomycota**
- **Chytridiomycota**
- **Heterotrophic osmotrophs**
- **Secretion of extracellular enzymes → degrading recalcitrant compounds, hydrocarbons and xenocompounds and plastics**
- **Parassites of algae, other protists and animals and plants**
- **Cell-wall composed by N-acetyl-glucosamine polymer: chitin**
- **Spores can travel → sea foam**
- **Source of natural products**
- **Bioremediation**
- **Surface of coastal ocean waters, deep waters subsurface sediments from polar to tropical regions**

# Tara: surface ocean across a latitudinal gradient 0-1000 m



- Temperature is an important driver in shaping microbial community
- Drop in diversity at the Tropics-Poles

# From 18s rRNA genes to mRNAs

(A) Unicellular taxa in a marine sample based on environmental 18S rRNA genes

(C) MMETSP transcriptomes

