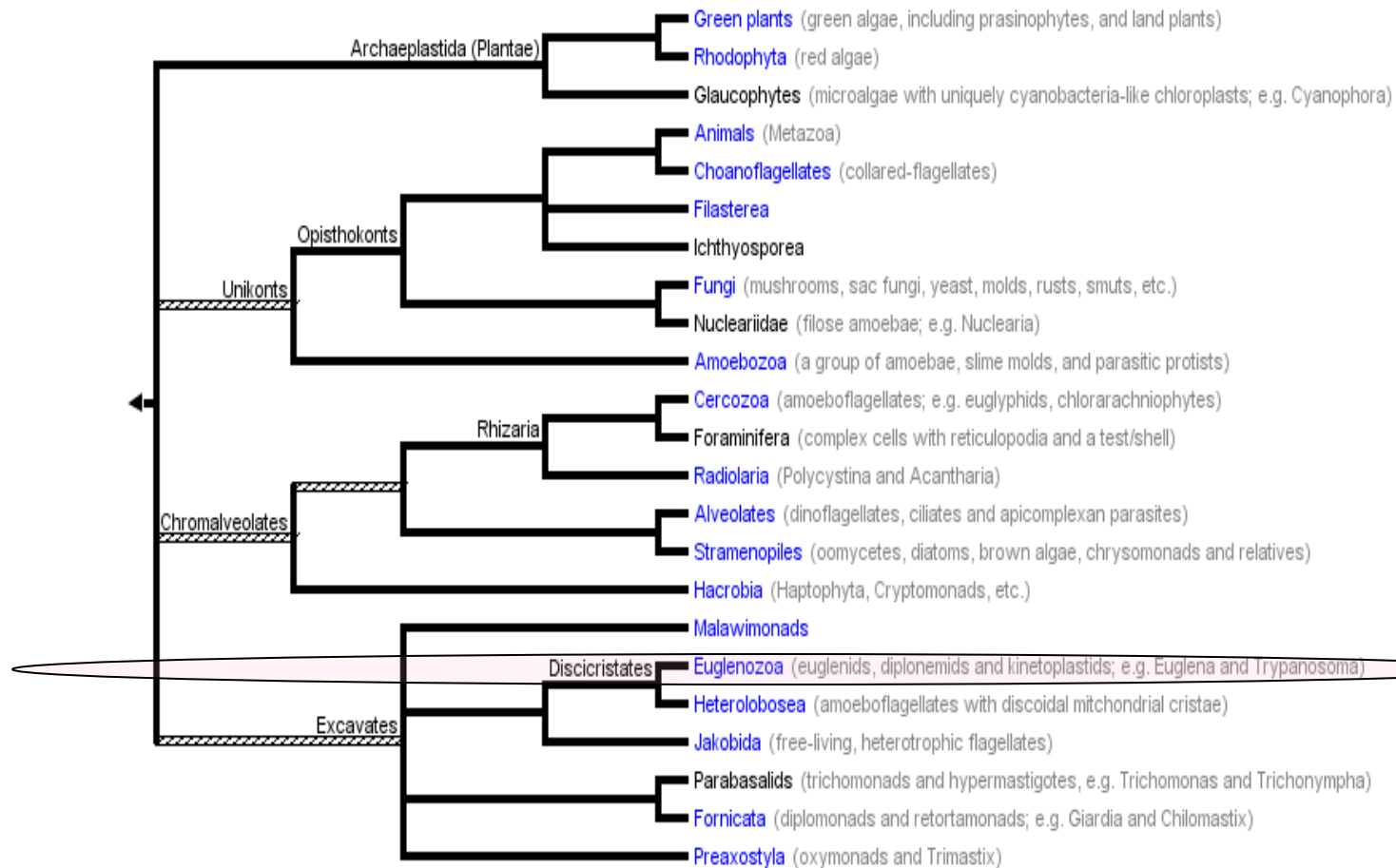


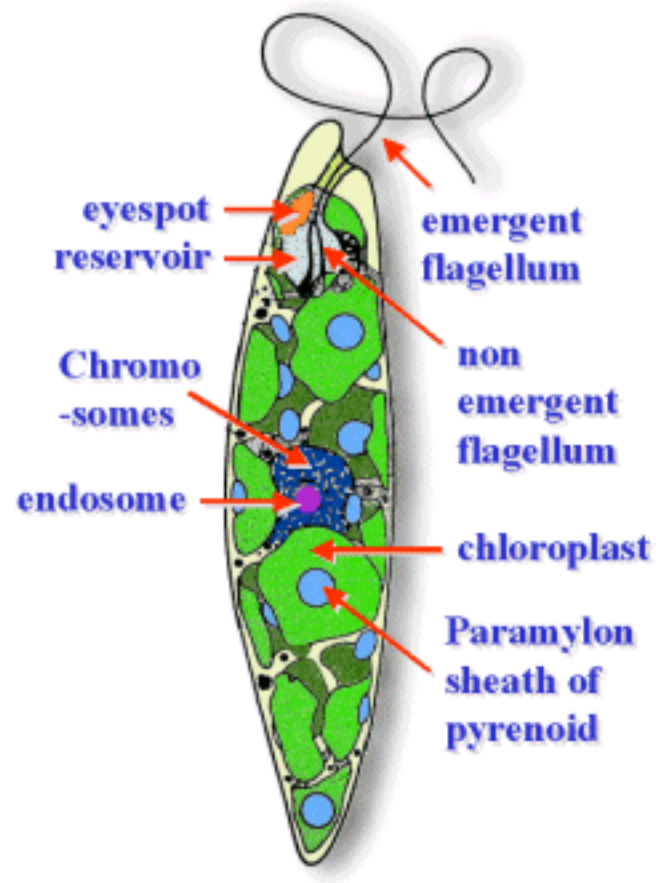
# Phylum *Euglenozoa*



?= Protists of uncertain placement

# Euglenophyta

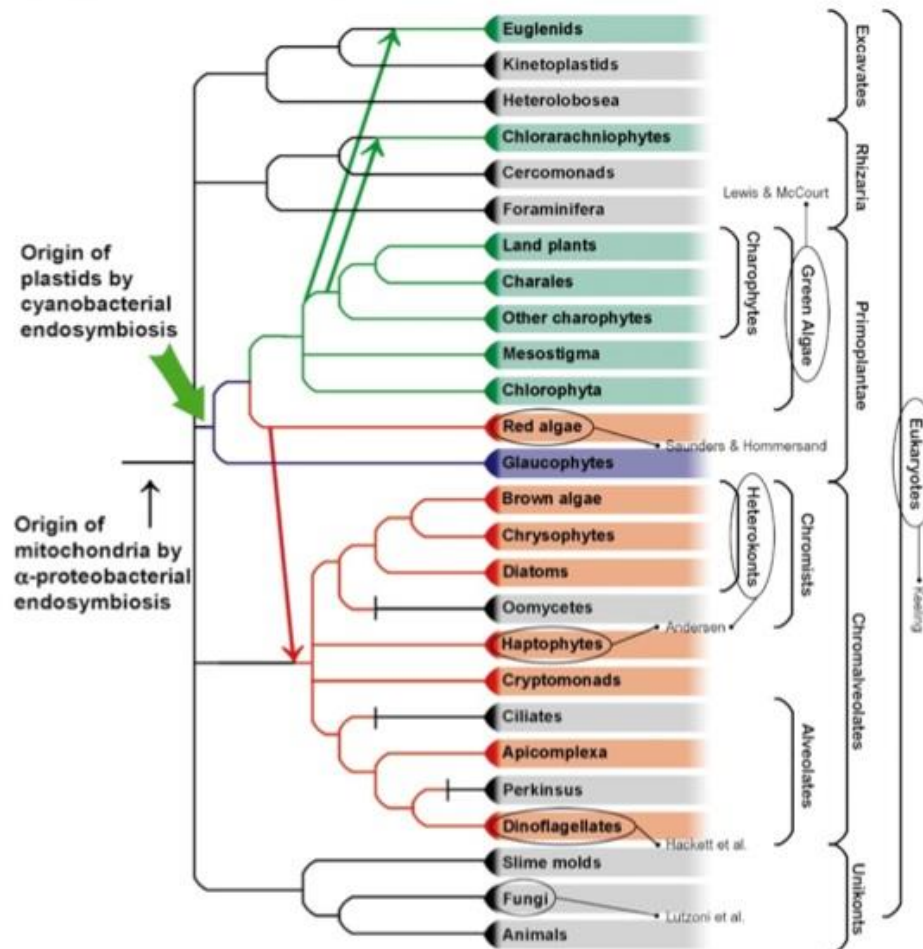
- Chloroplasts with 3 membranes
- Uni- or biflagellates
- Chlorophyll *a*, *b*
- Paramylon



# Horizontal gene transfer (HGT) between megagroups

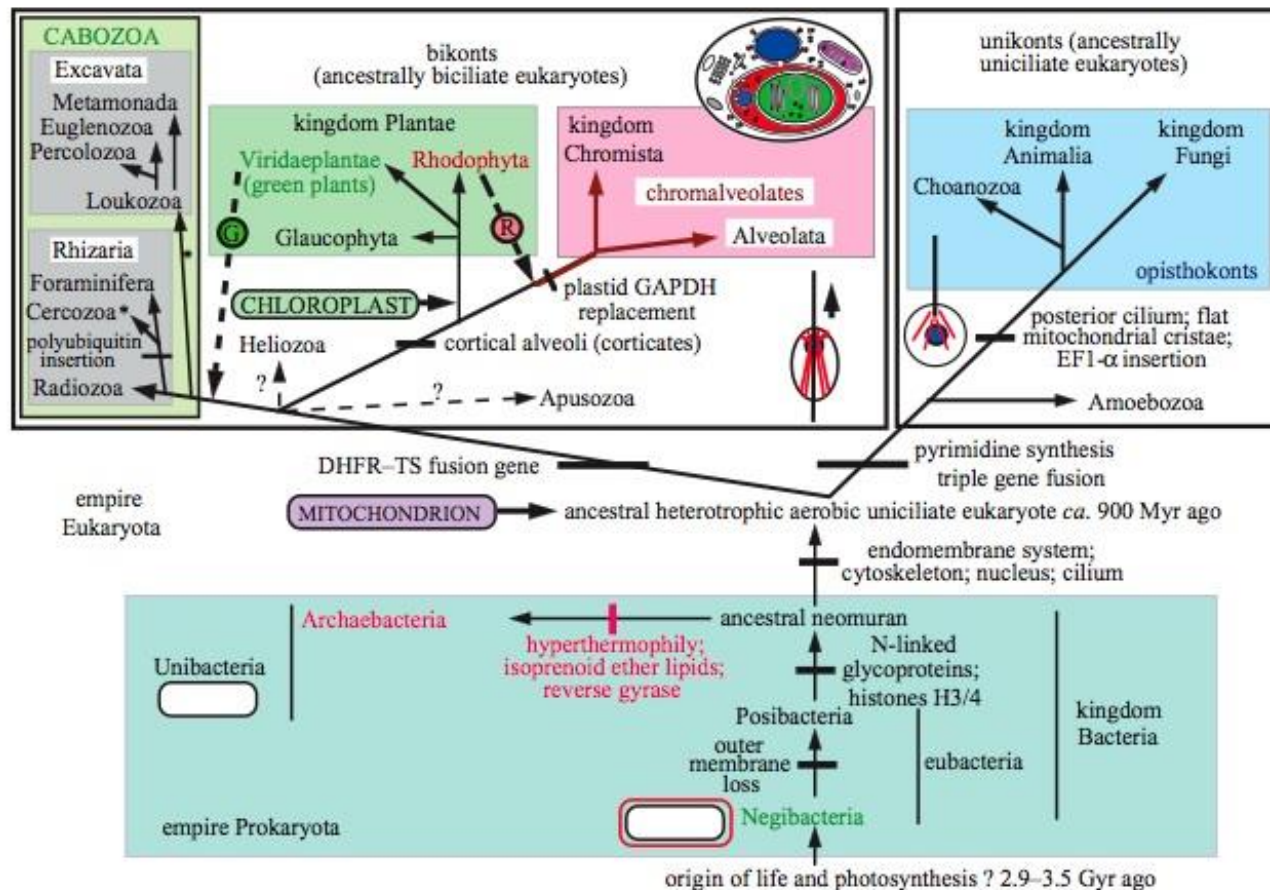
October 2004]

PALMER ET AL.—OVERVIEW OF PLANT TOL



# Multilinear evolution

Only six kingdoms of life T. Cavalier-Smith 1253





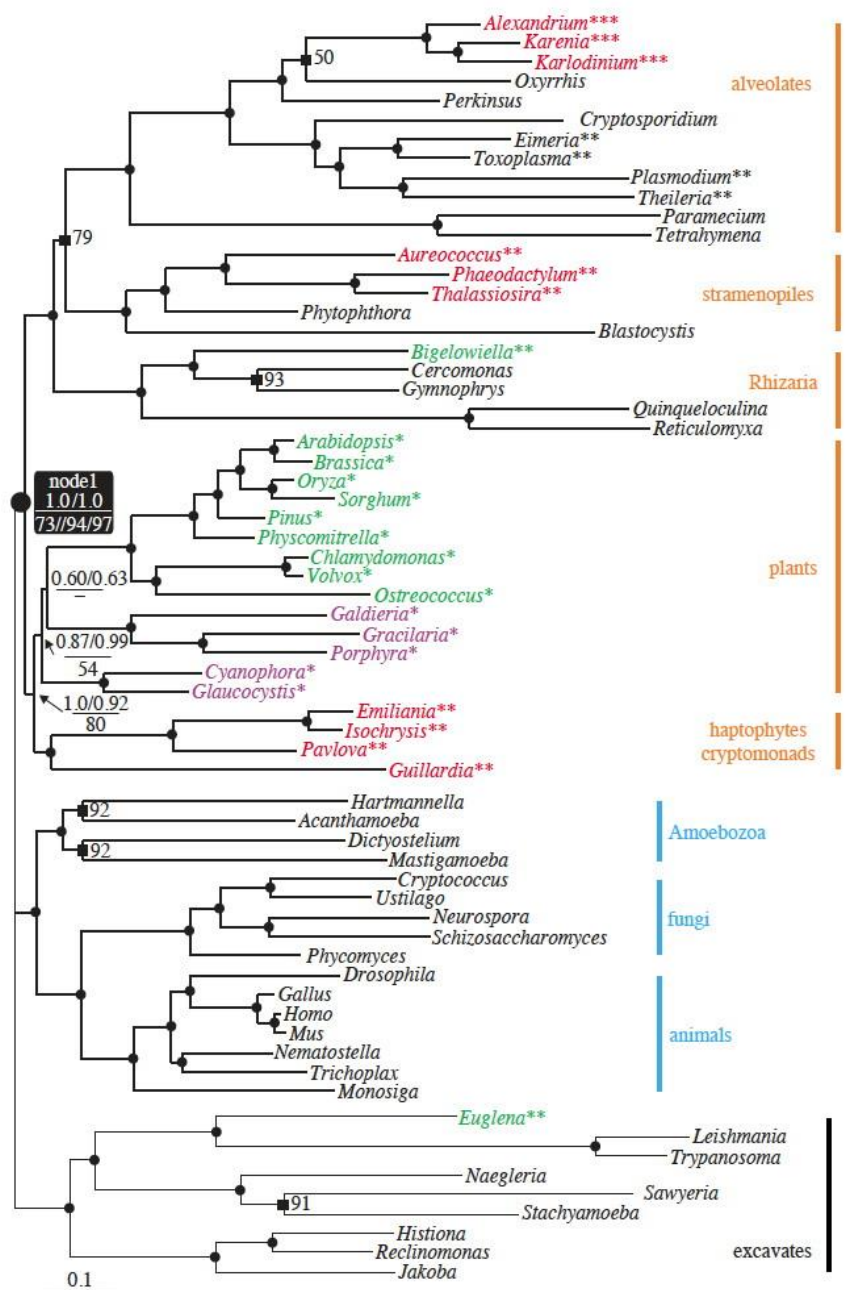
# Problems caused by HGT

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- It may confuse monophyletic relationships (especially in eubacteria)
- The oomycetes and ciliates, both belonging to the lineage *Chromalveolata* (Stramenopiles and Alveolata), have traces of nuclear genes of plastid origin, suggesting that the process of endosymbiotic capture of a red algae that gave rise to the chloroplast was an event single ... or not?



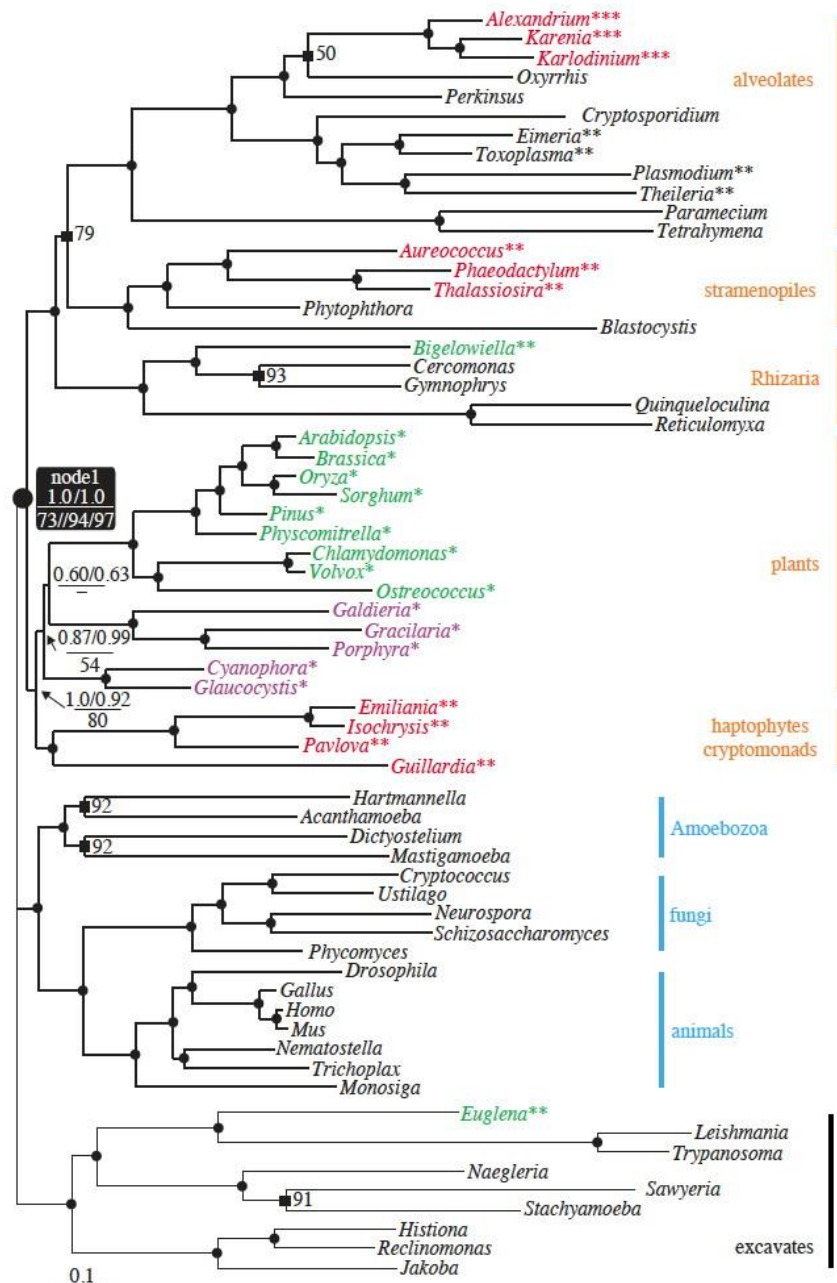
# Photosynthetic megagroups



Burki et al. (2008)

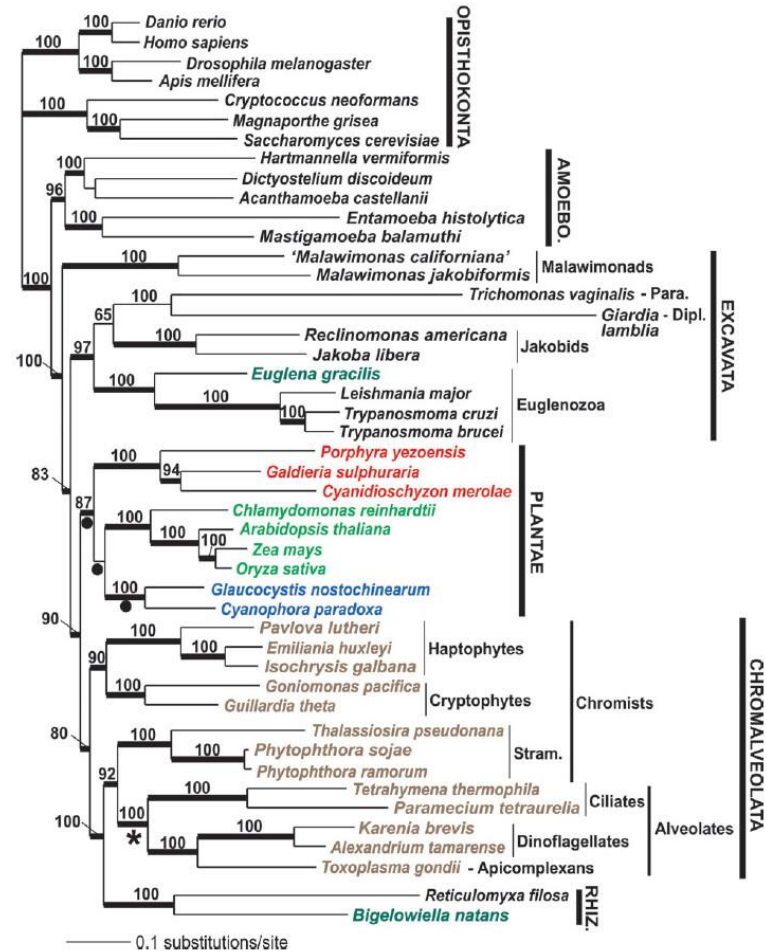
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# Photosynthetic Megagroups

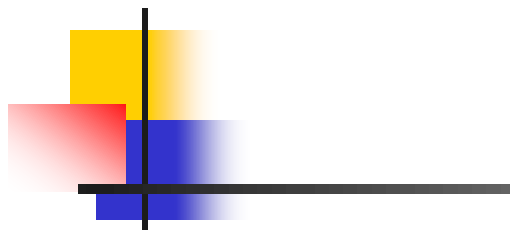


Burki et al. (2008)

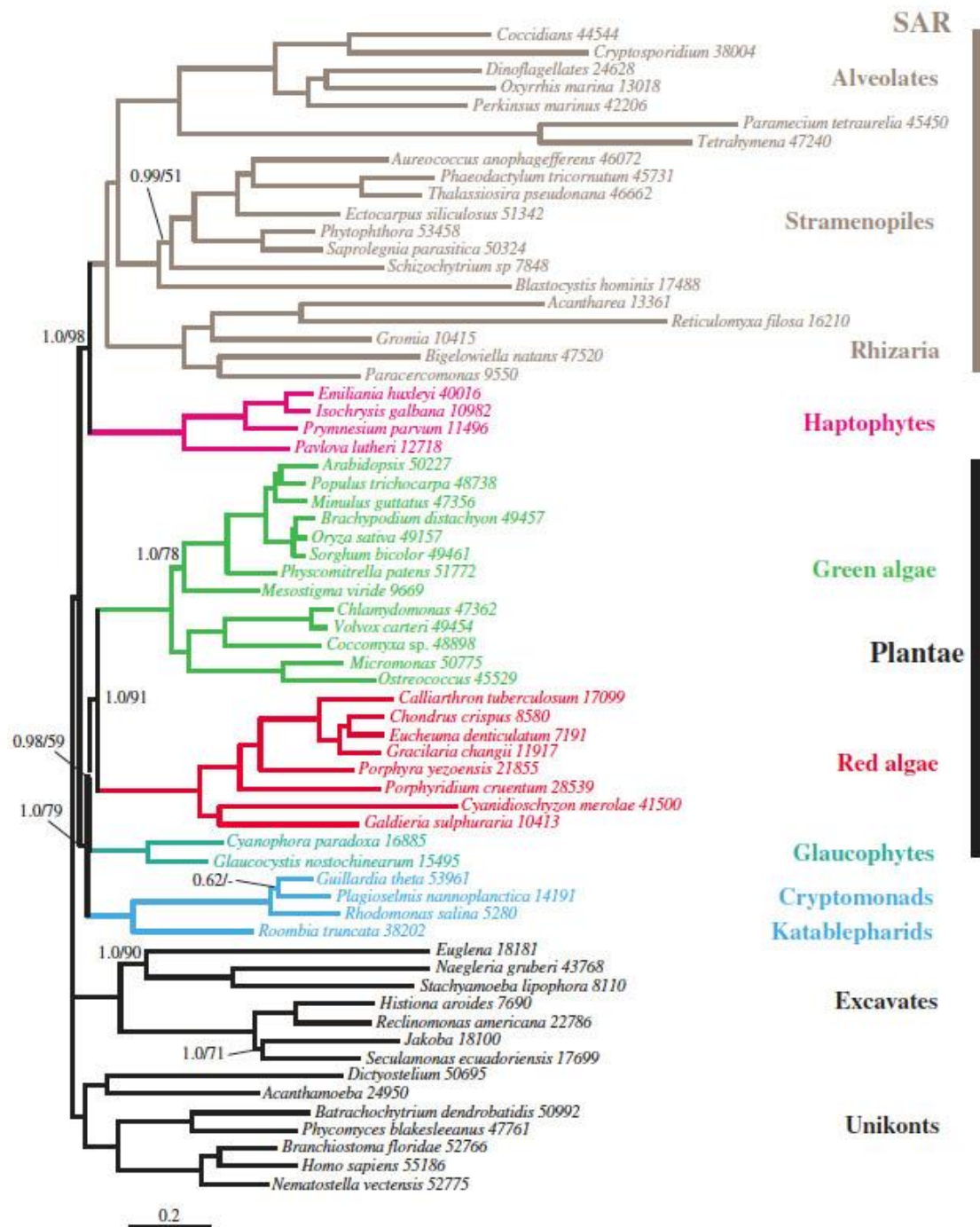
# 6 Eukaryotic Megagroups



Hackett *et al.* (2007)



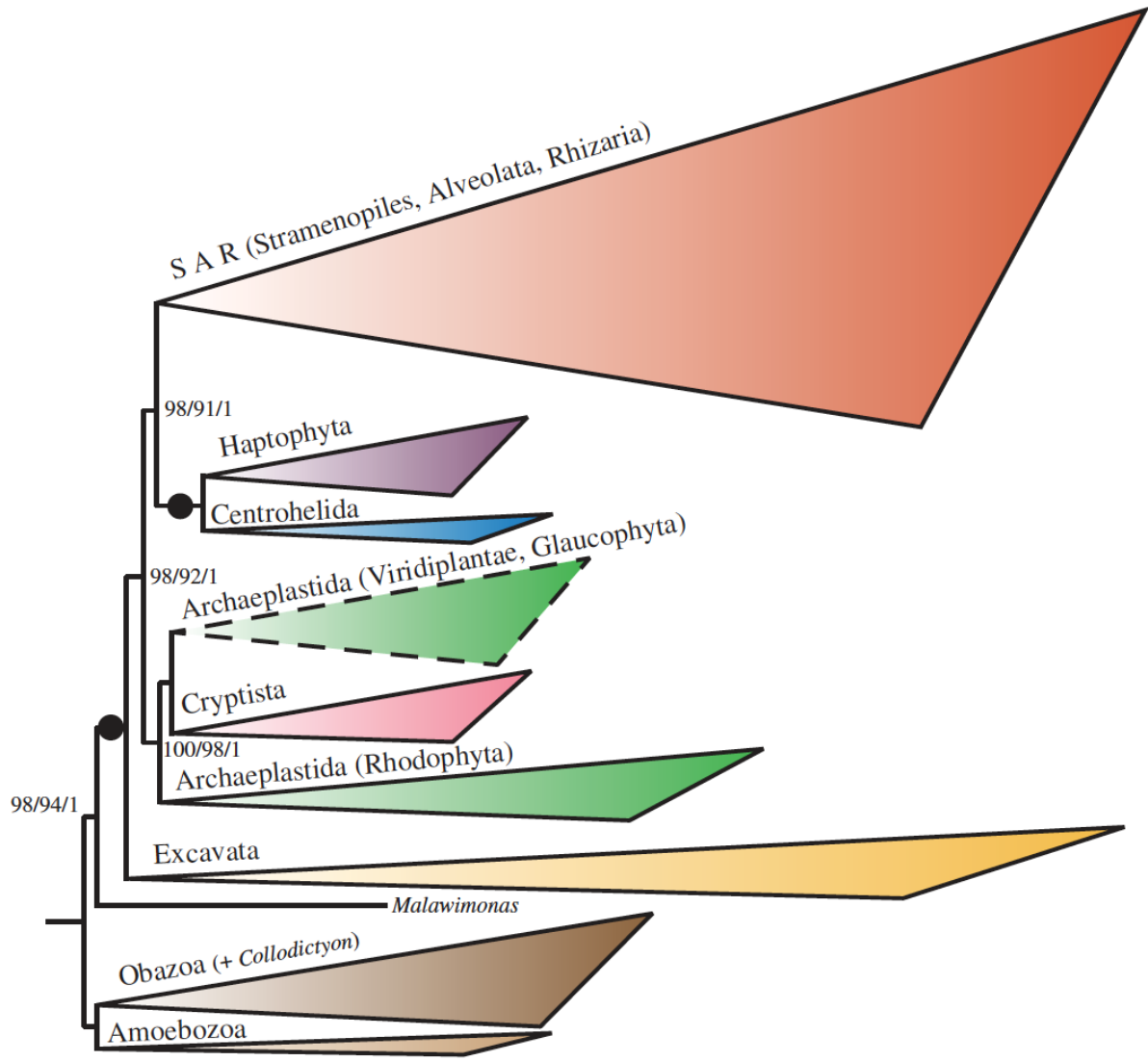
# Evidence against the Hacrobia



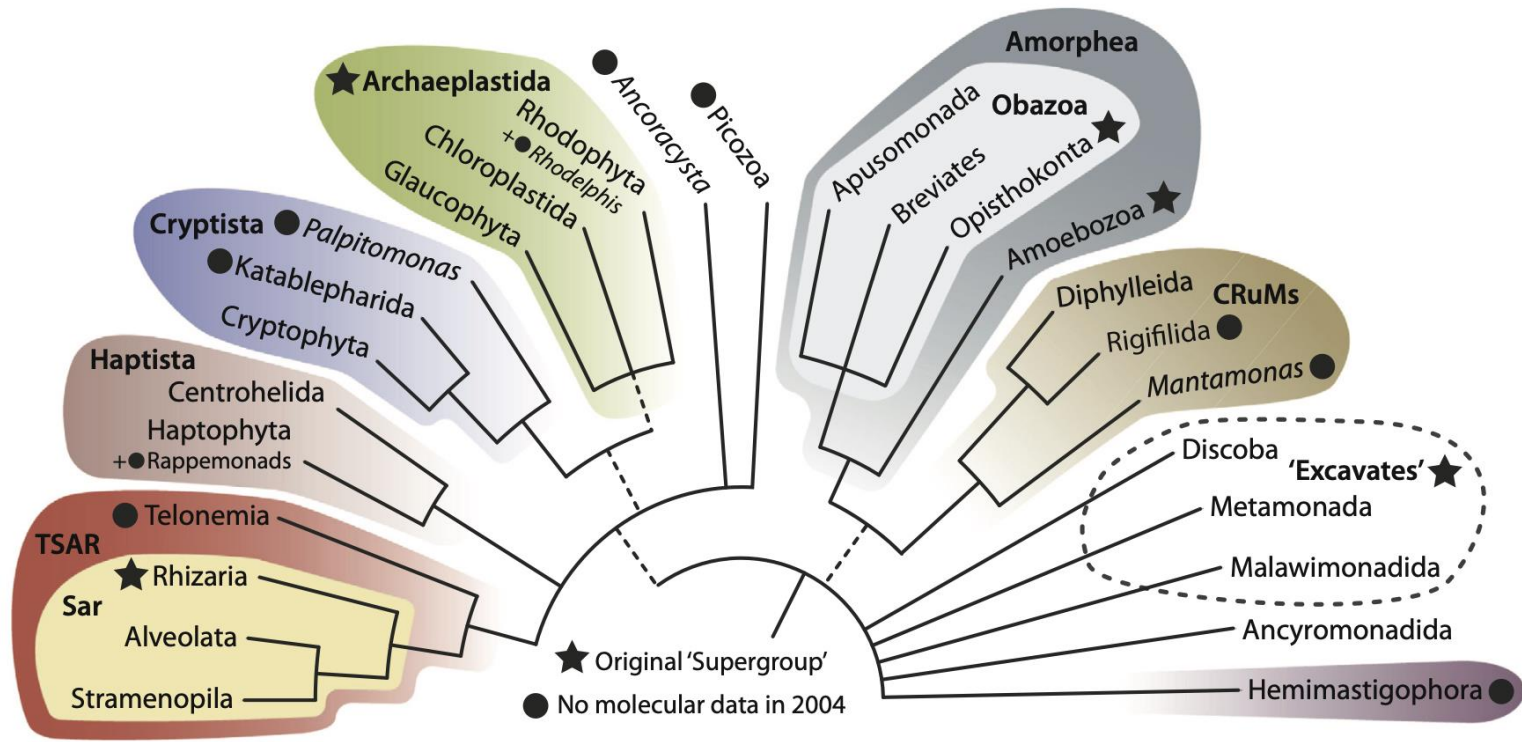
Burki et al. (2012)



# Evidence against the Hacrobia



# The most recent view of the Eukaryotic tree of life



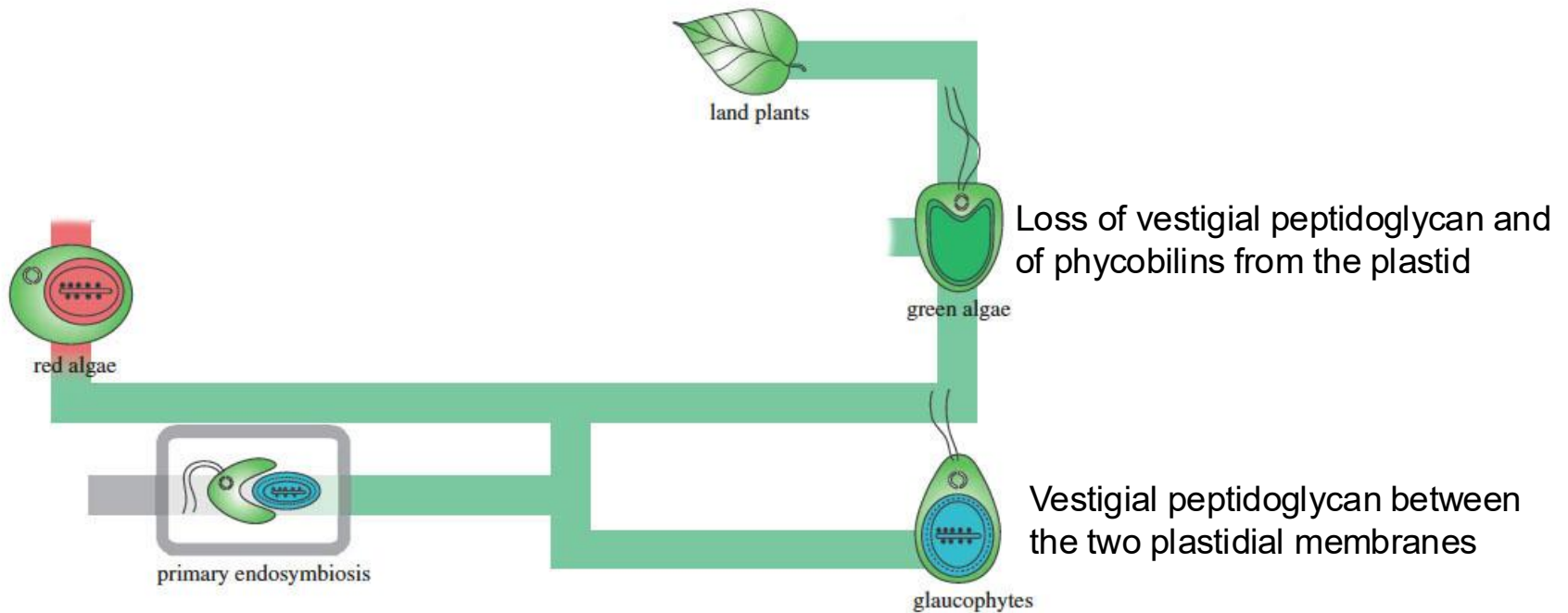


# Evolutionary paradoxes

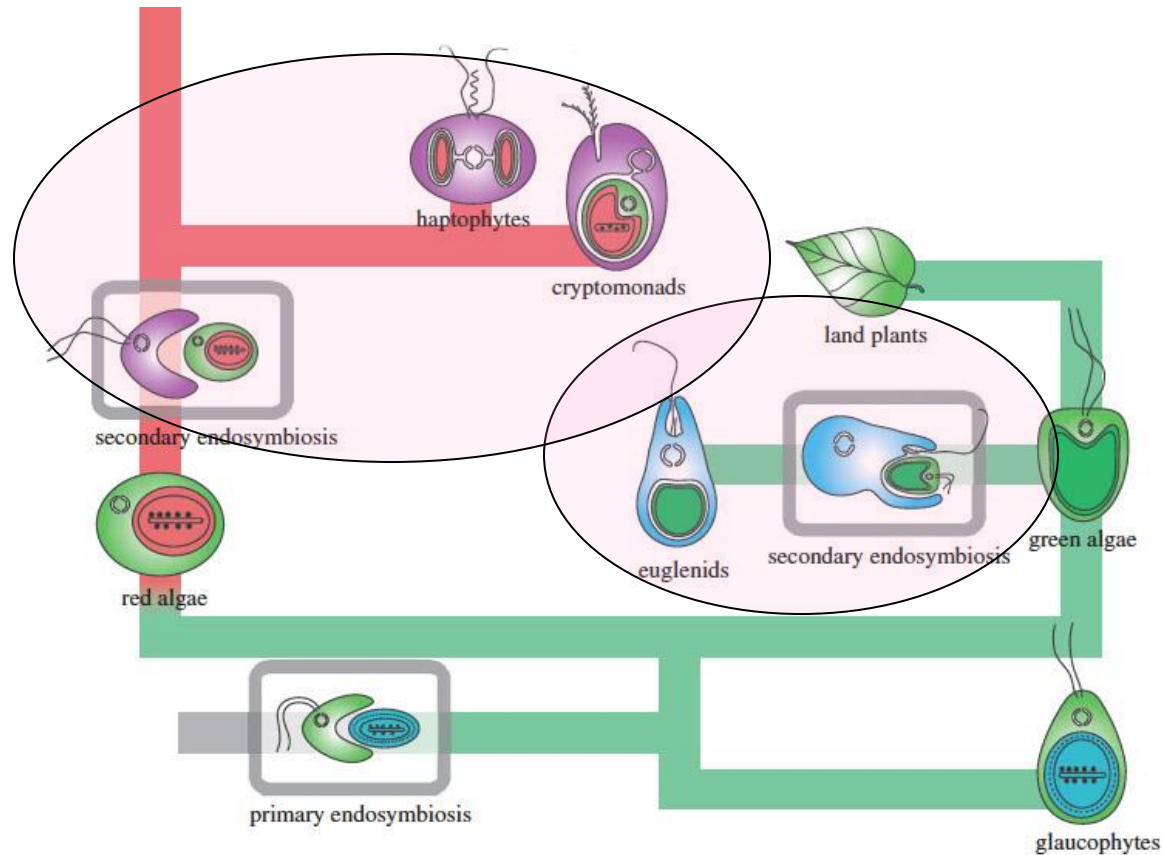
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- Mitochondria - single endosymbiotic event, although there is evidence of more recent mitochondrial retention
- Chloroplasts - various endosymbiotic events or by cleptoplastidia via myzocytosis

# Primary endosymbiosis gave rise to *Archaeplastida* / *Plantae*

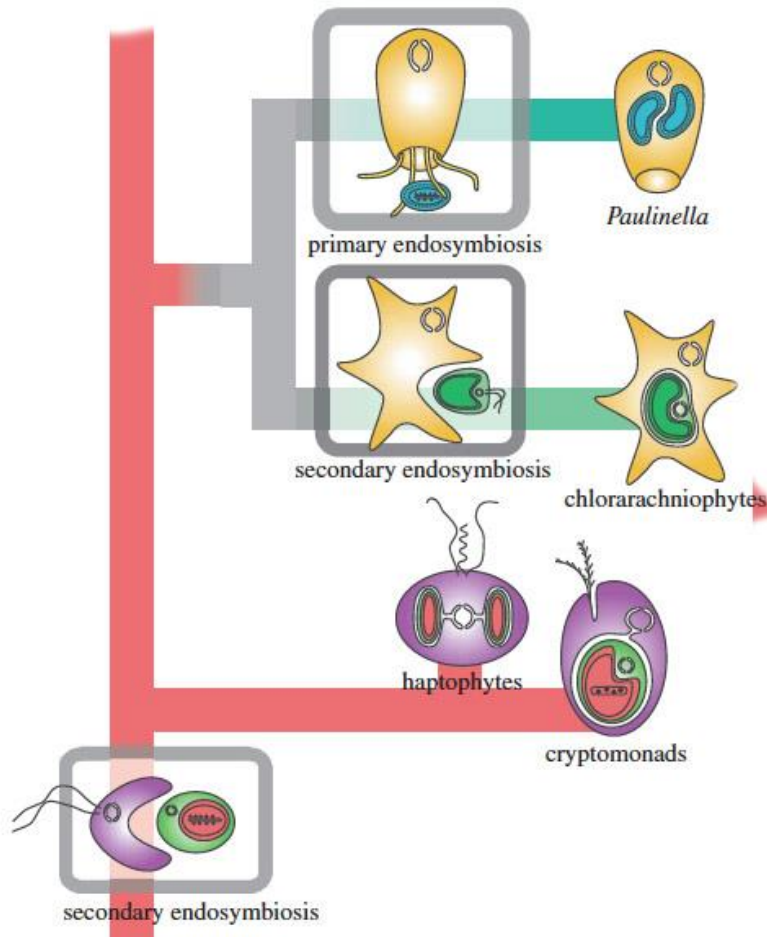


# Secondary endosymbiosis gave rise to the “Hacrobia” and euglenids

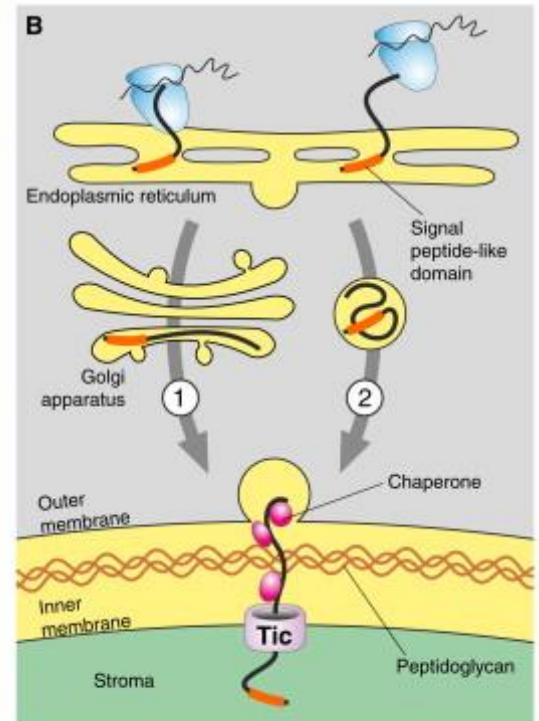
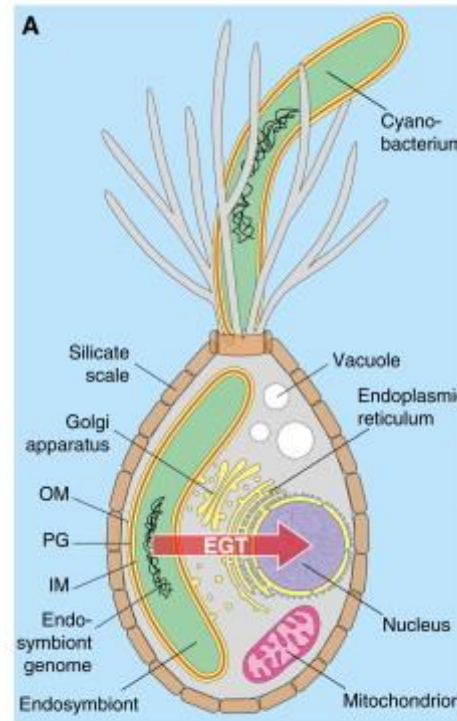
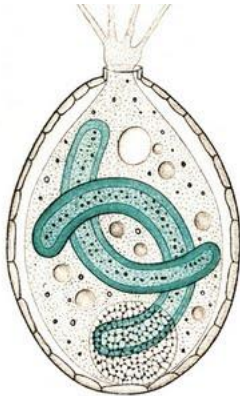


Keeling (2010)

# Primary and secondary endosymbiosis gave rise to photosynthetic rhizarians

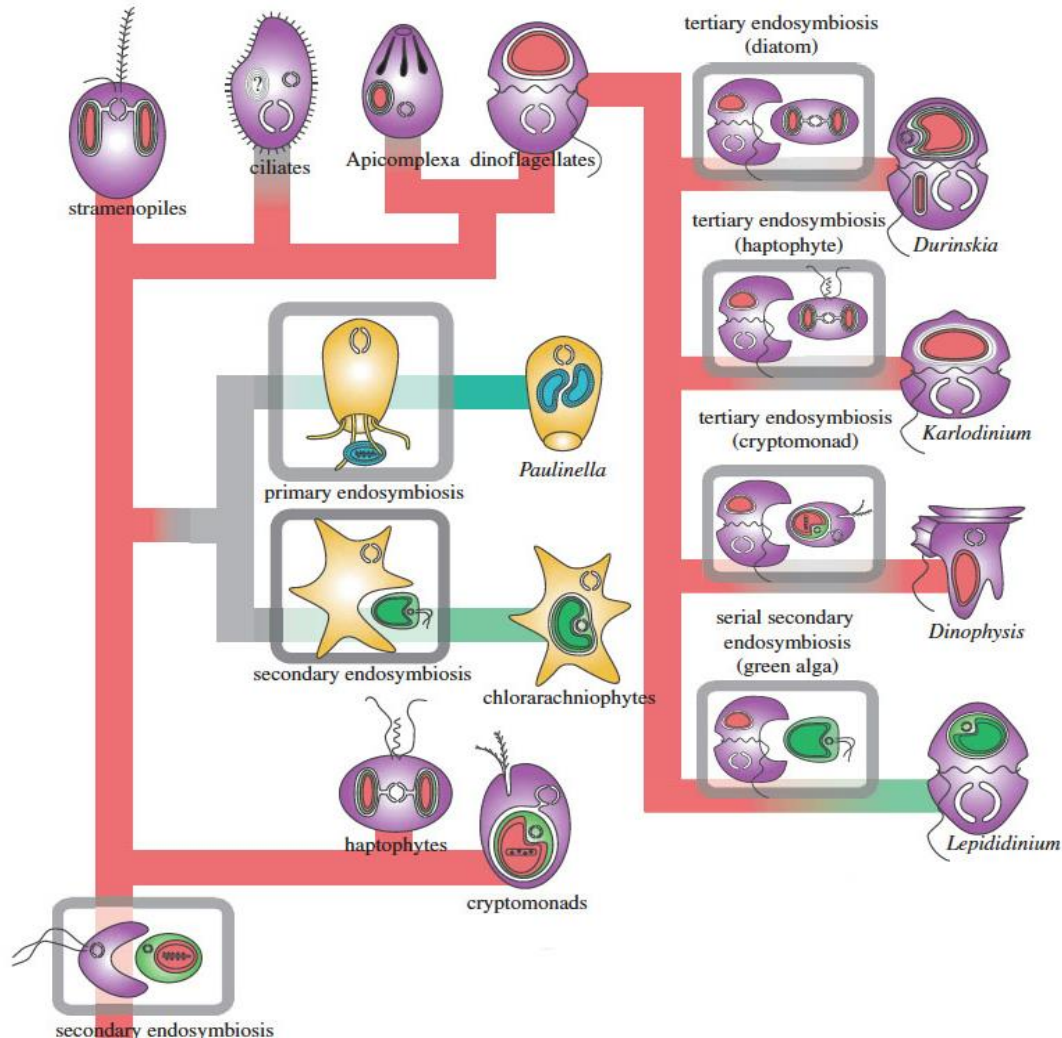


# Paulinella: A recent primary endosymbiosis in a euglyphid amoeba:

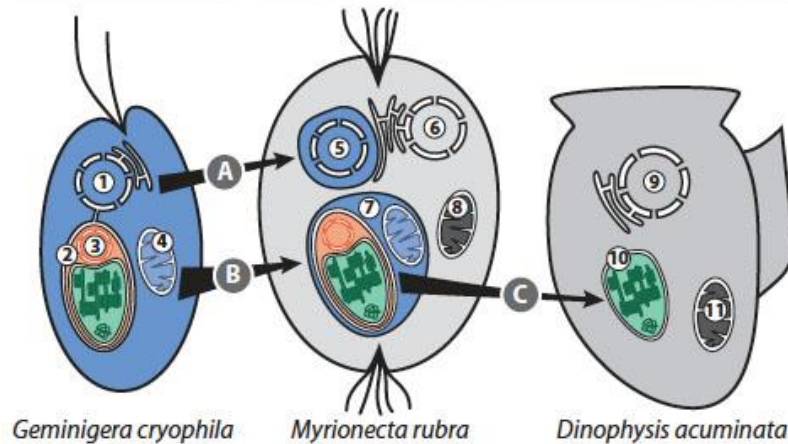
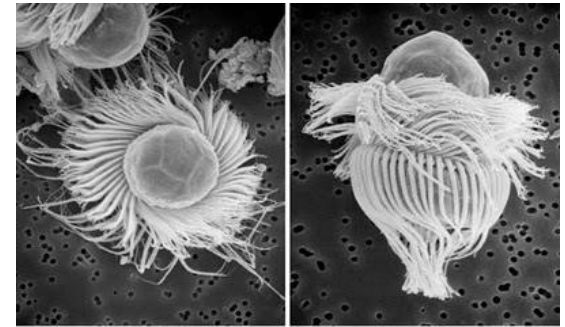


Current Biology

# Multiple secondary and tertiary endosymbioses in “Chromalveolata”



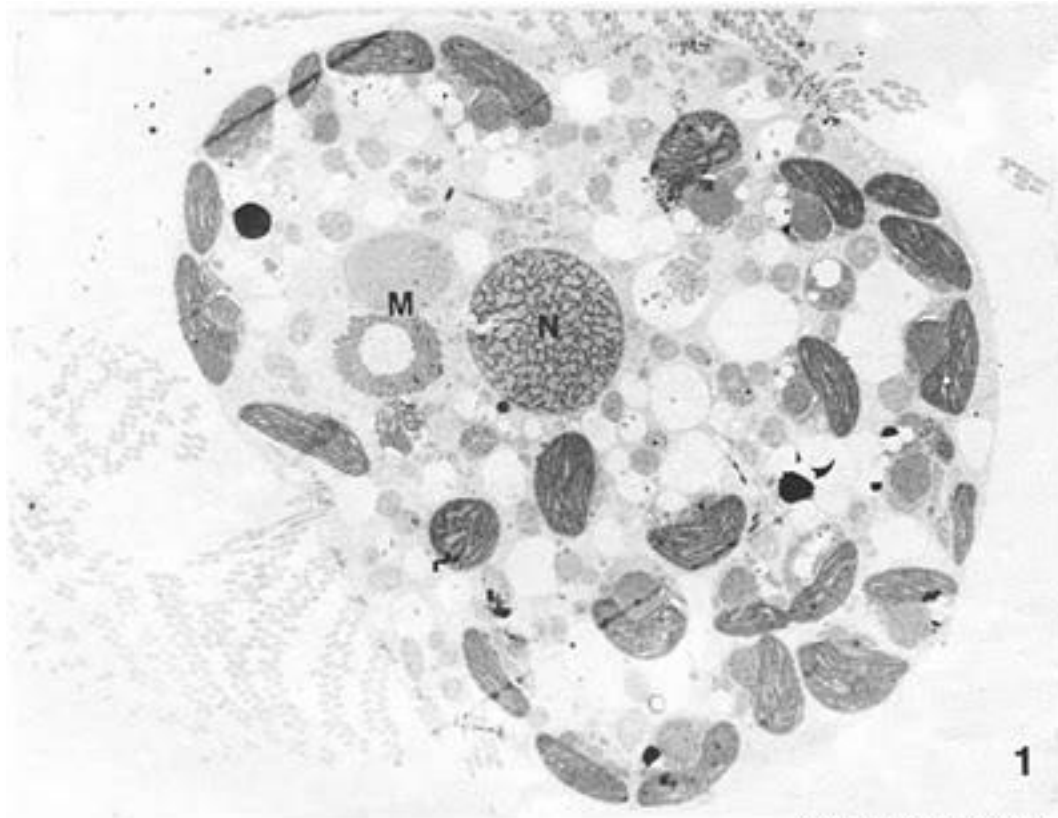
# Kleptoplastidy with an intermediate ciliate via mizocytosis



Park et al 2006 Aquat Microb Ecol

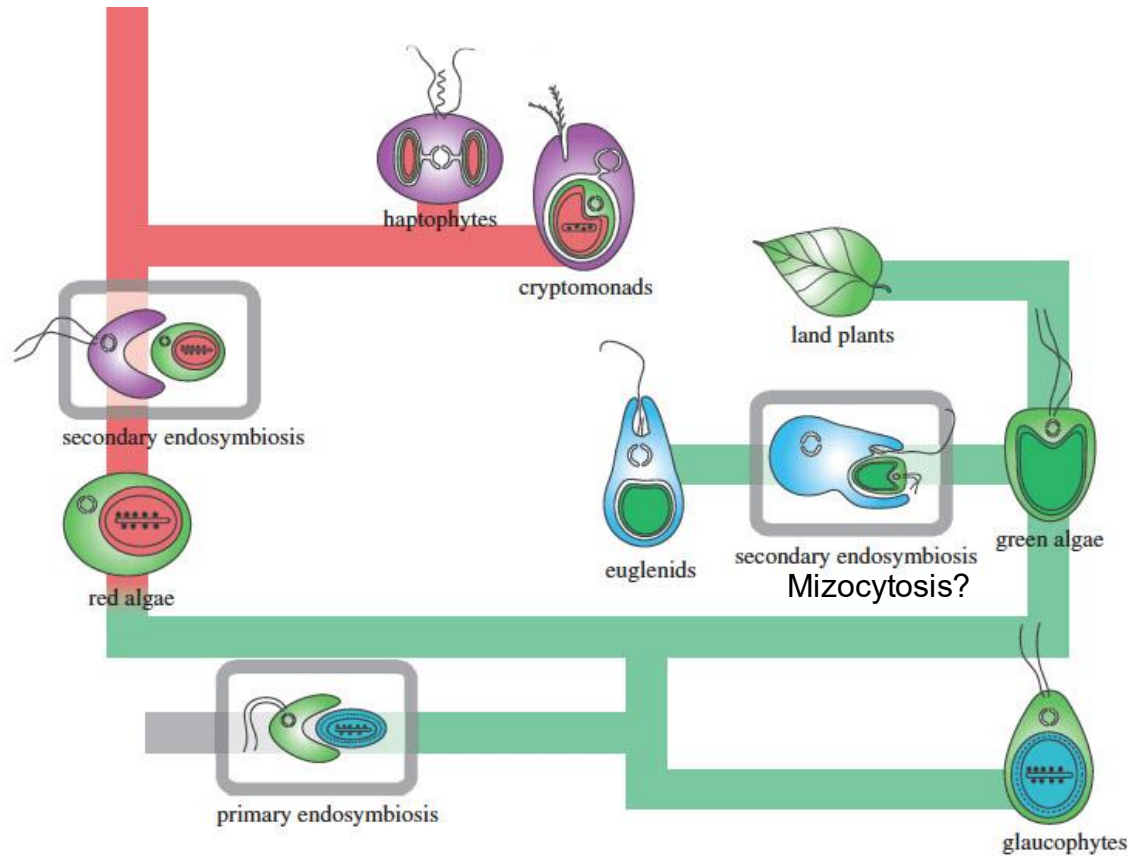
Cryptophyte → Ciliate → Dinoflagellate

# Cryptoplasts in ciliates derived from endosymbiosis or kleptoplastidy?



Oakley & Taylor 1978 BioSyst

# Can kleptoplastidy via mizocytosis explain the 3-membrane plastid of euglenids?



Keeling (2010)



# Conclusions

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- The acquisition of photoautotrophy is a much more frequent and complex event than previously thought
- The photosynthetic capacity can be obtained by:
  - **endosymbiosis** (an intracellular association between a heterotrophic host and a previously autonomous prokaryote [cyanobacterium] or eukaryotic [green or red algae] photosynthetic organism)
  - **retention of chloroplasts** (sometimes together with nuclei and mitochondria) after phagocytosis or mizocytosis - retention may be permanent (e.g., *Noctiluca scintillans*) or transient (e.g., *Pfiesteria piscicola*)
  - **theft of chloroplasts (kleptoplastidy) by mizocytosis** (a form of cytolysis that involves the suction of cell contents by a predator from its prey).



# Conclusions

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- The transfer of genes from the endosymbiont to the host is more frequent than once thought
- Horizontal gene transfer is more frequent than previously thought (eukaryotic genomes have a high number of genes of prokaryotic origin: *e.g.*, *Chlamydiae*, bacteria that parasite algae)
- There are traces of genes in nuclei of heterotrophic eukaryotes (*e.g.*, ciliates) that are typical of photosynthetic organisms

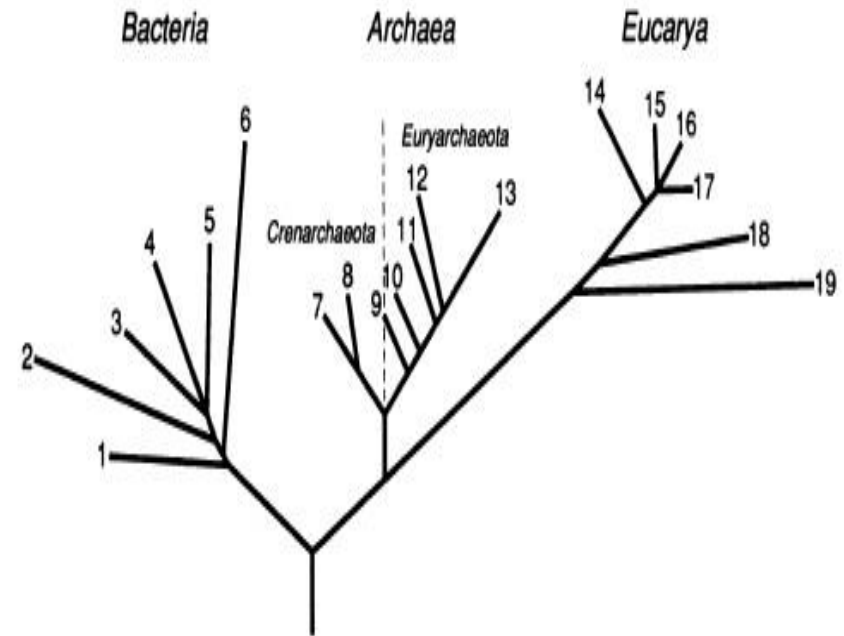
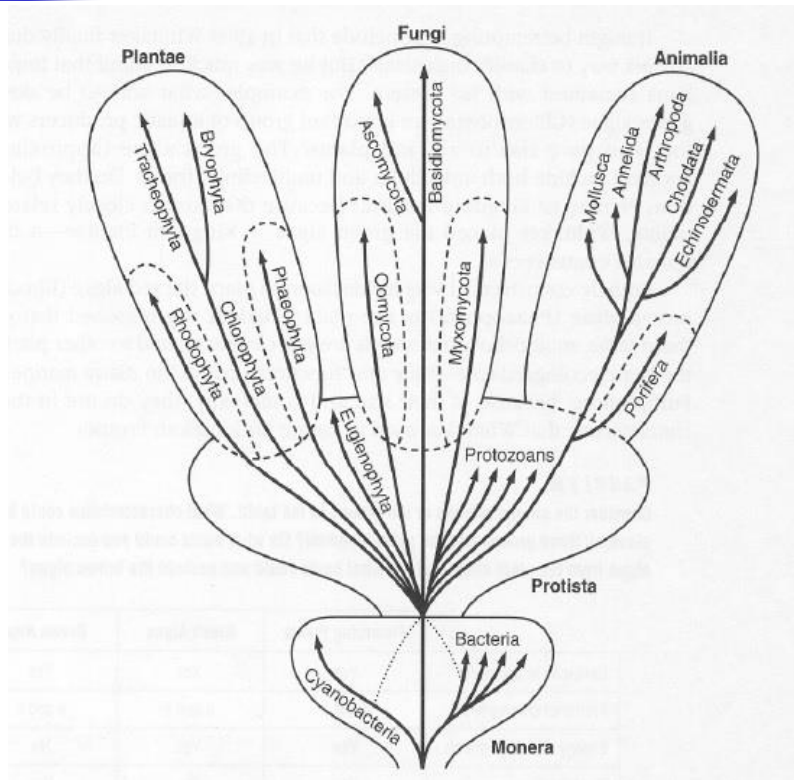


# Conclusions

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- Vestigial genes may facilitate the acquisition of transient and / or permanent photoautotrophy
- Mixotrophic organisms with facultative photoautotrophy often grow better in the presence of light
- All these factors reveal a high adaptive capacity that implies a huge evolutionary plasticity, especially organisms with chloroplasts derived from red algae

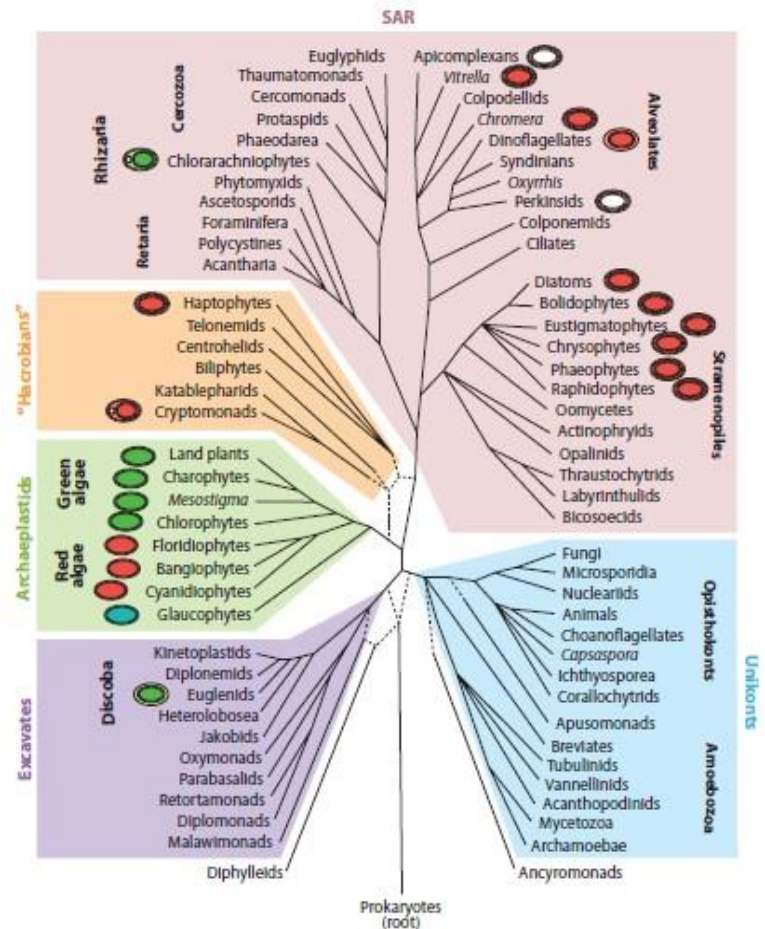
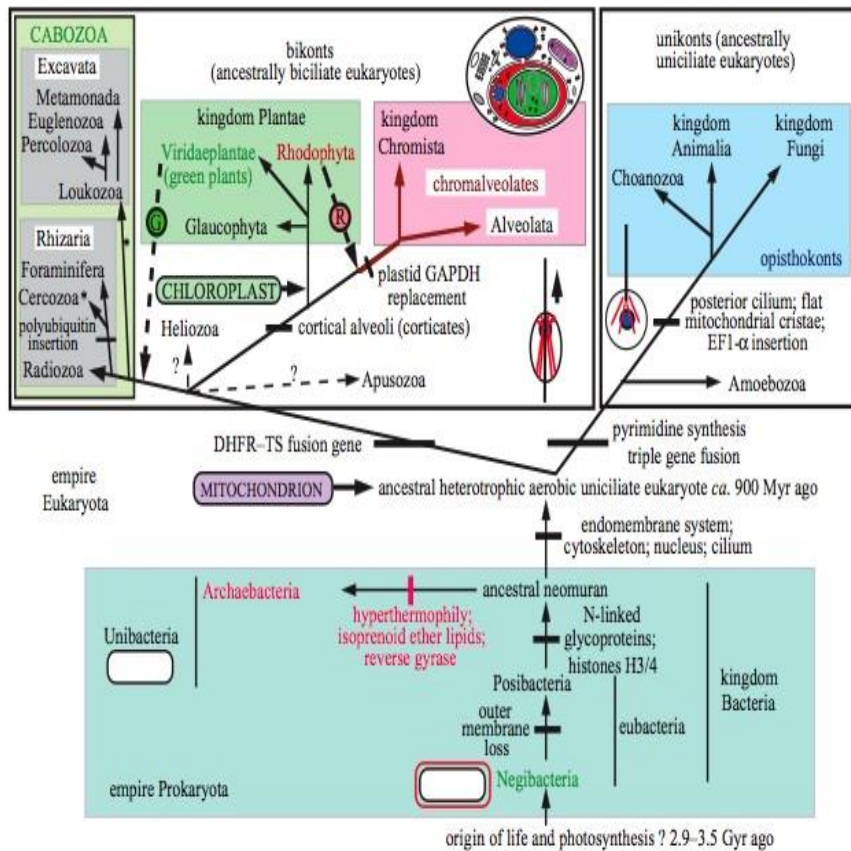
# Five kingdoms vs. Domains



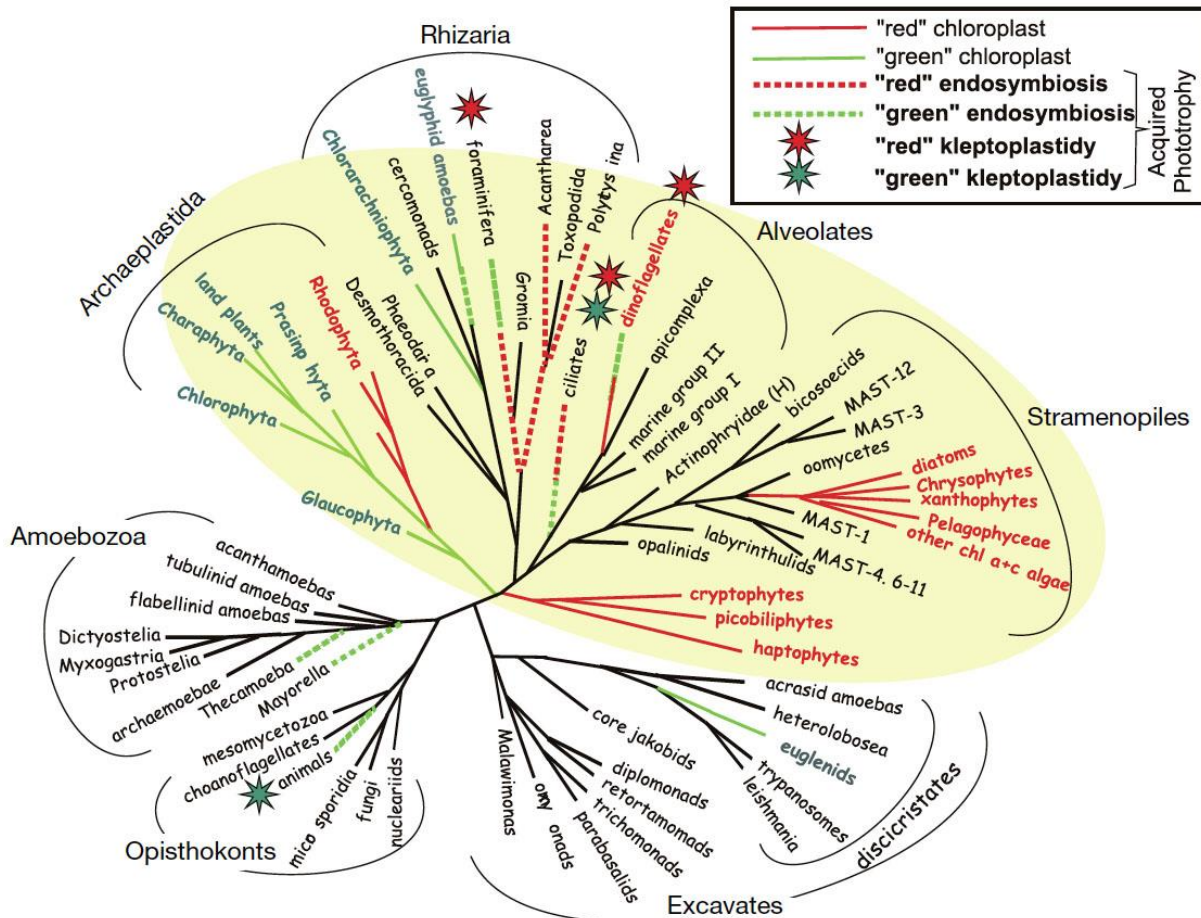
Woese, C. R., Kandler, O. & Wheelis, M. L. (1990). Towards a natural system of organisms, proposal for the domains *Archaea*, *Bacteria*, and *Eucarya*. *Proceedings of the National Academy of Sciences, USA* **87**, 4576±4579

# Cavalier-Smith vs. Keeling

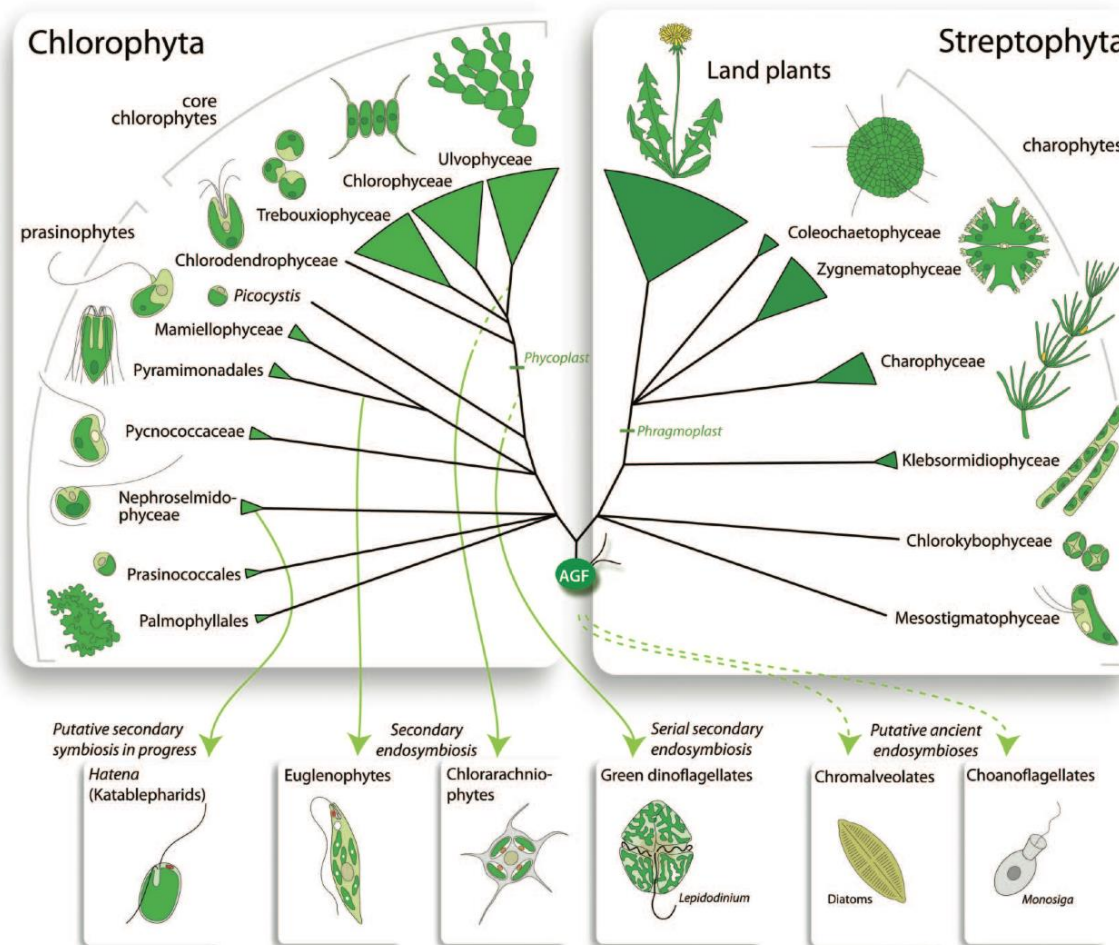
Only six kingdoms of life T. Cavalier-Smith 1253



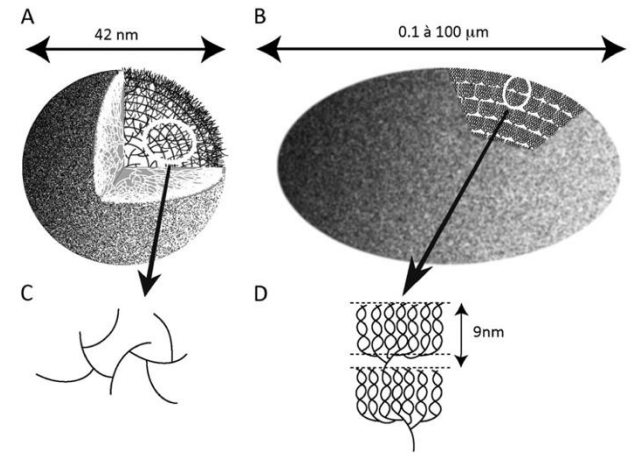
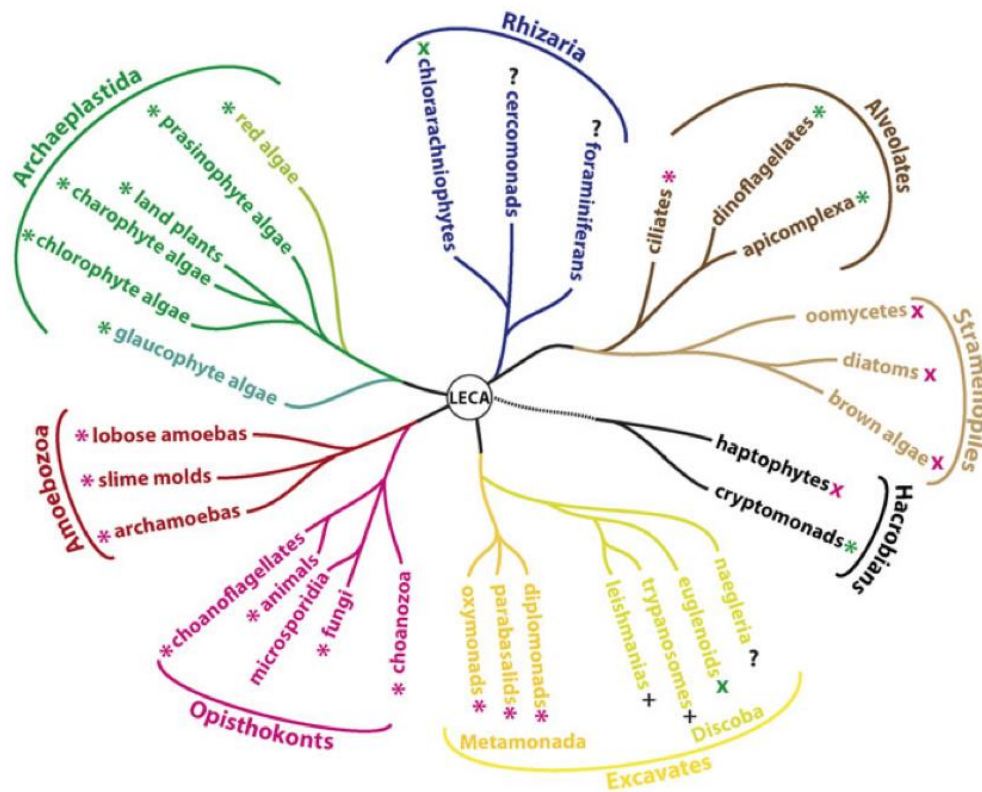
# A recent view of evolution of the acquisition of photosynthesis



# Chlorophyta and other megagroups



# Distribution of storage polysaccharides



**Glycogen** (soluble) and **starch** (crystalline):  
α-1,4, α-1,6-glucans

**Laminarins**: β-1,3, β-1,6-glucans (soluble)  
sometimes phosphorylated or they end with mannitol

**Paramylon**: β-1,3-glucans (soluble) –  
accumulation in the pyrenoid

\*: starch      \*: glycogen      +: mannans  
x: paramylon    x: β-glucans      ?: not reported

Ball *et al.* (2011)