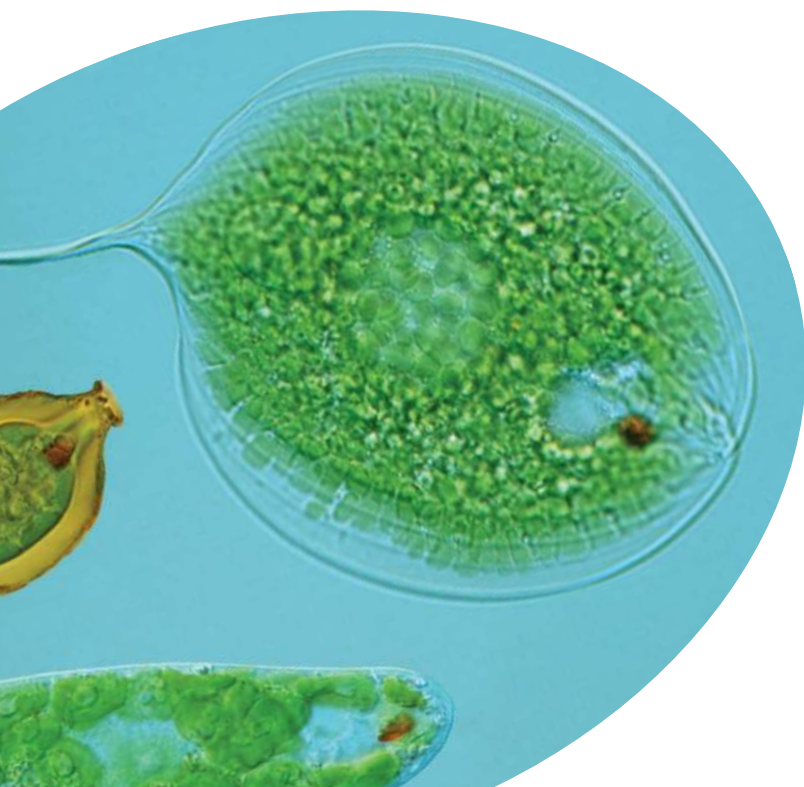




University of Warsaw
Biological and Chemical
Research Centre

Evolution of eukaryotic cell genomics, phylogenomics & biology



Anna Karnkowska

Department of Molecular Phylogenetics and Evolution

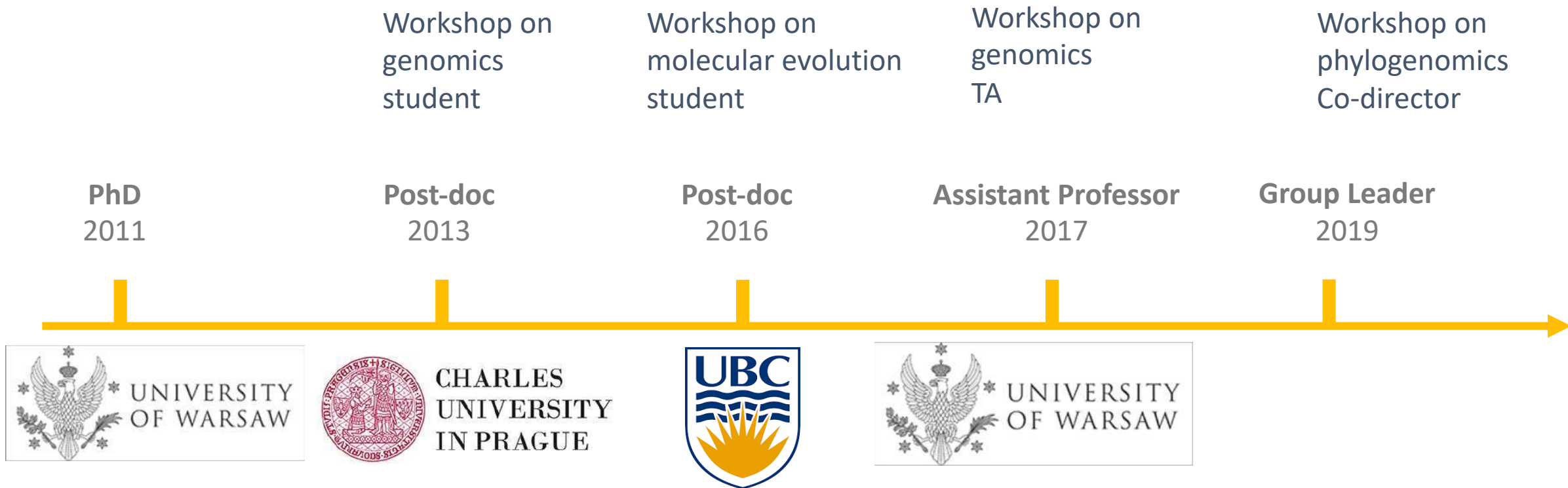


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about me

taxonomy & phylogeny of protists, reductive evolution of mitochondria and plastids, eukaryotic cell evolution, microbial eukaryotes genomics & transcriptomics, evolution of phototrophy in eukaryotes



Eukaryotic microbes aka protists



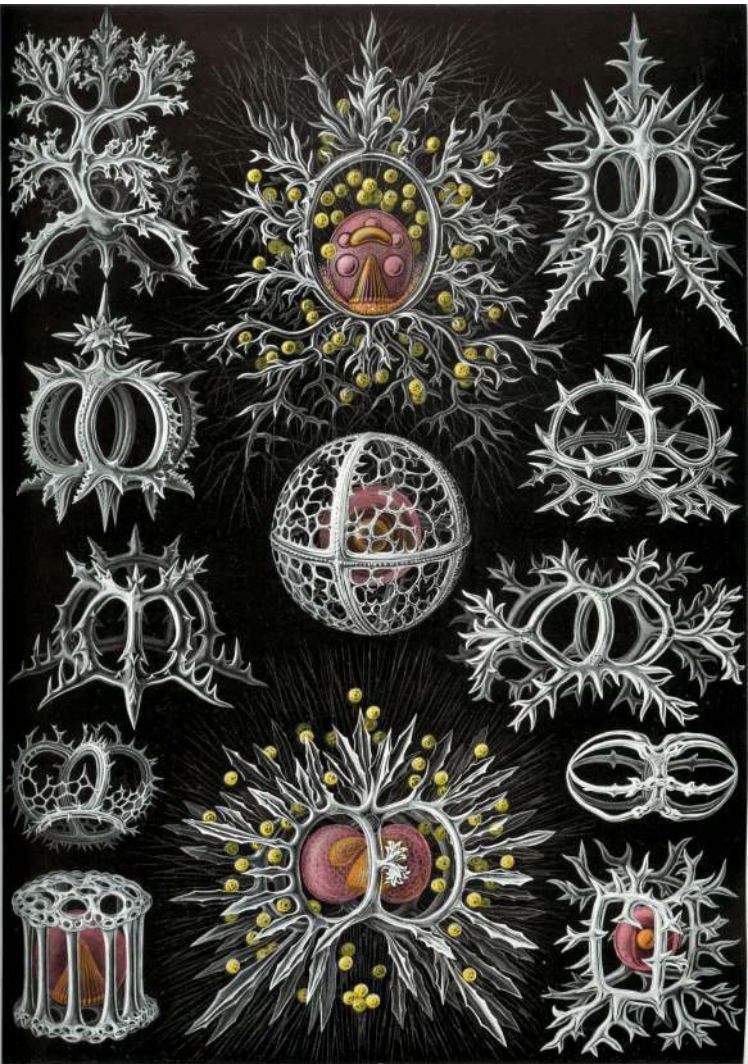
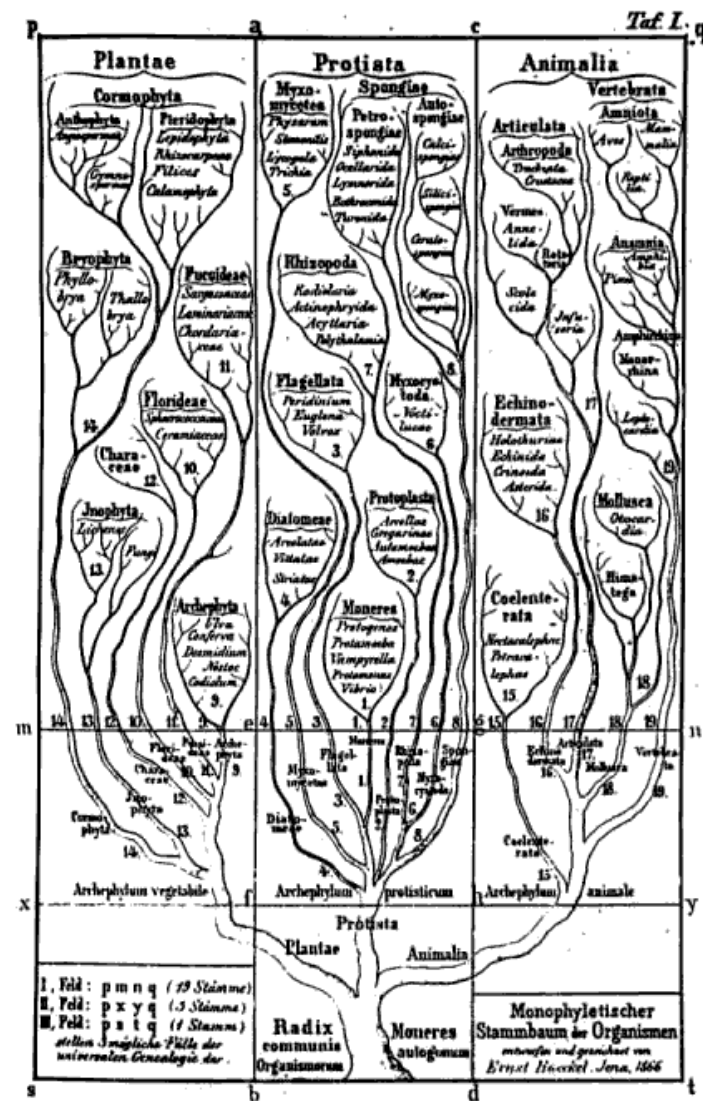
Antonie Philips van Leeuwenhoek

“These animacules had diverse colours...others again were green in the middle, and before and behind white...”

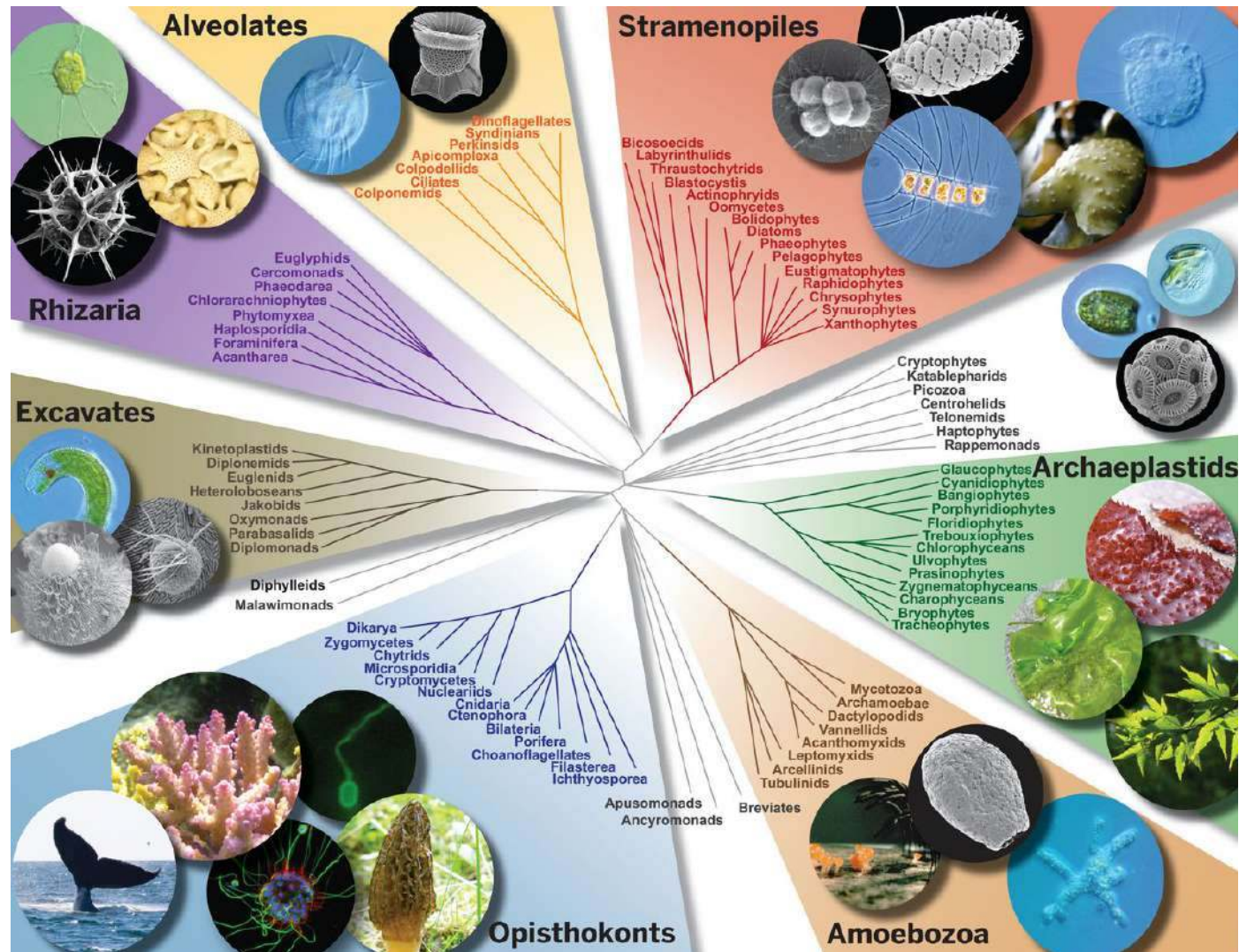


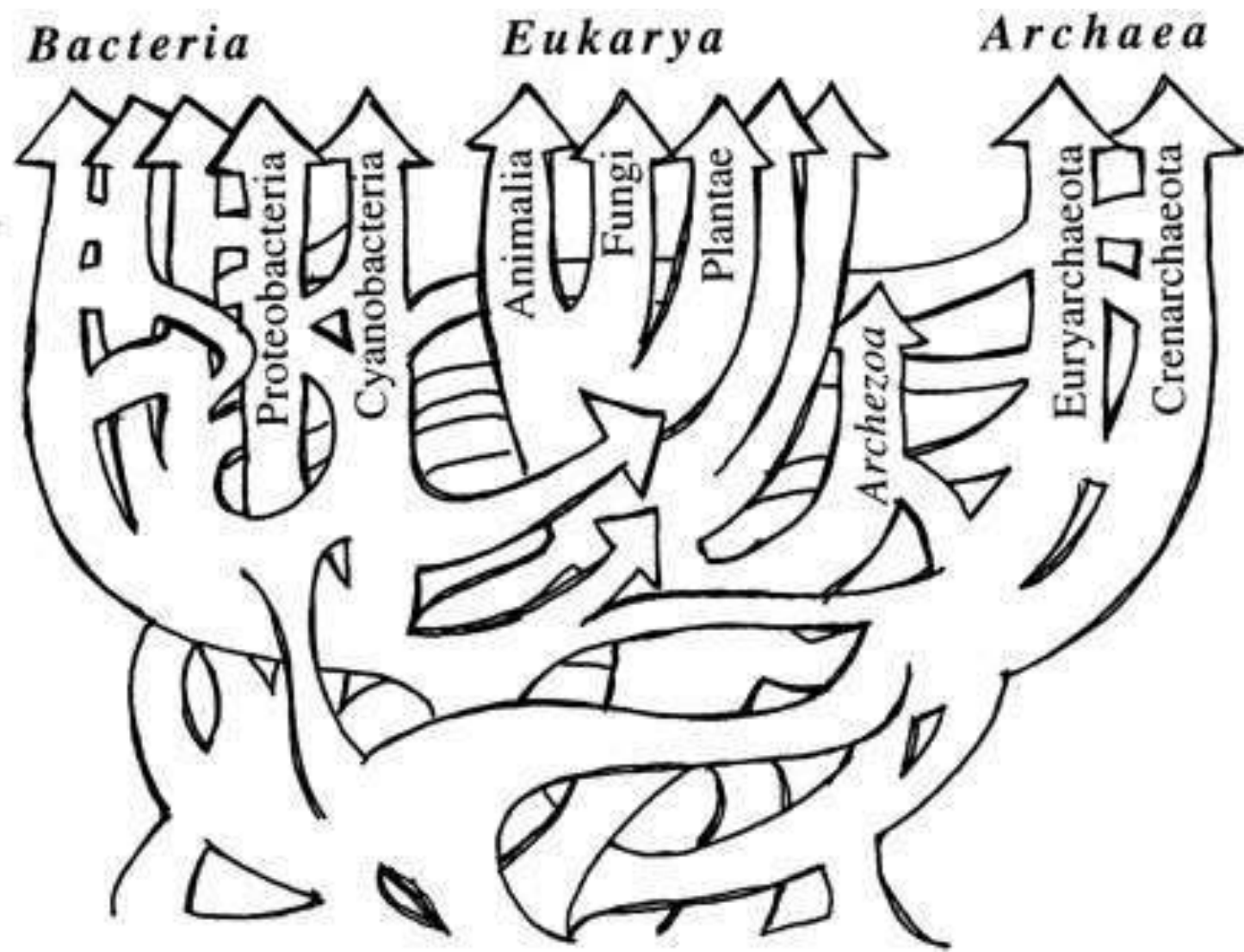
Ernst Haeckel's classification of life

Protista “kingdom of primitive forms”

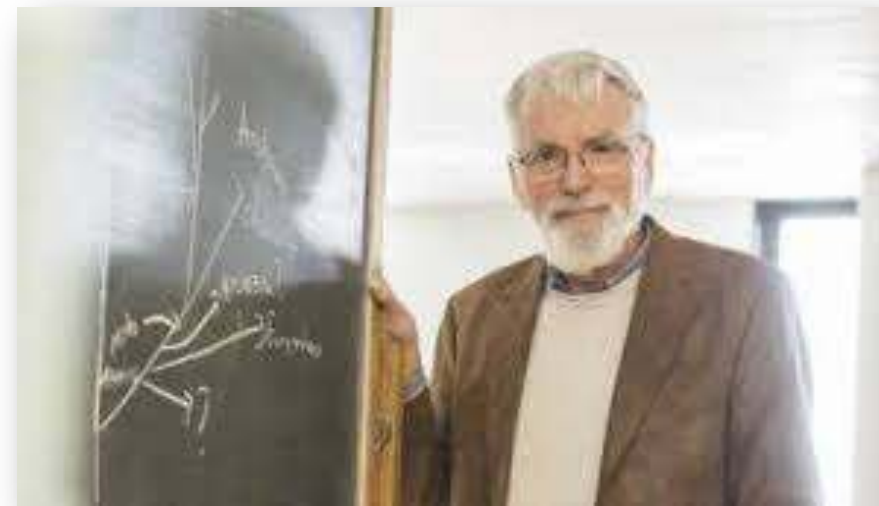


Protists constitute the majority of lineages across the eukaryotic tree of life

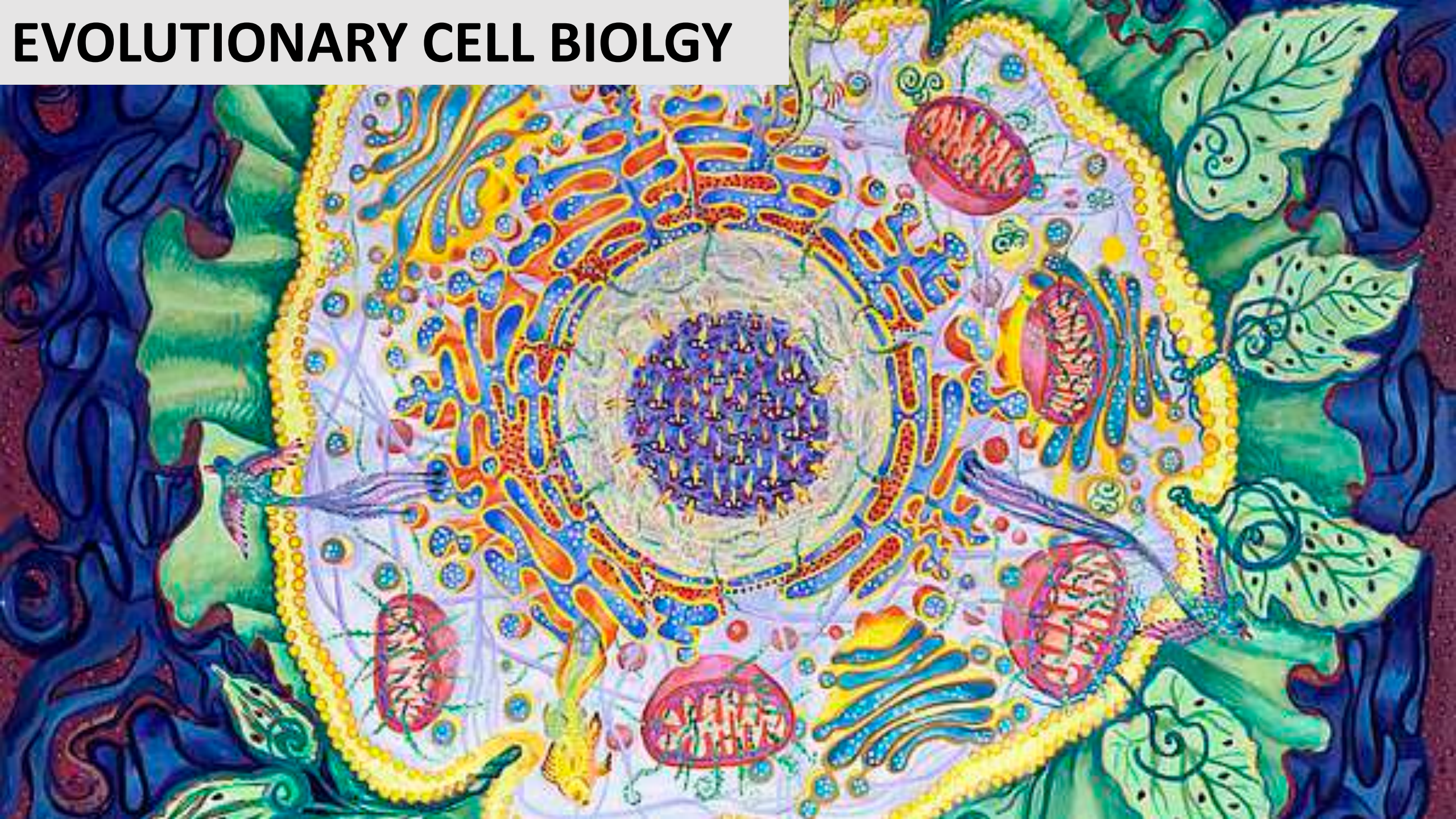




Doolittle, 1999

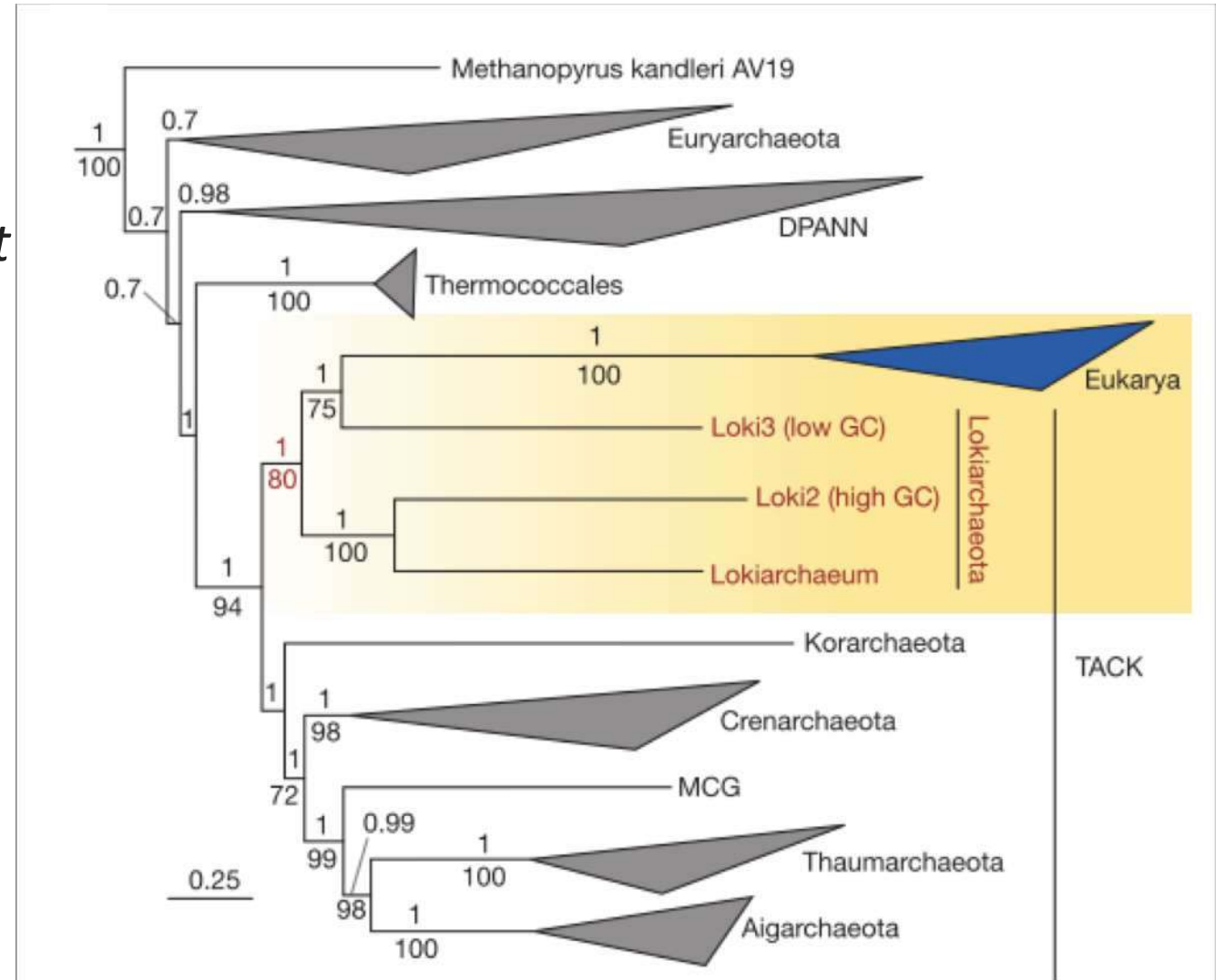


EVOLUTIONARY CELL BIOLOGY



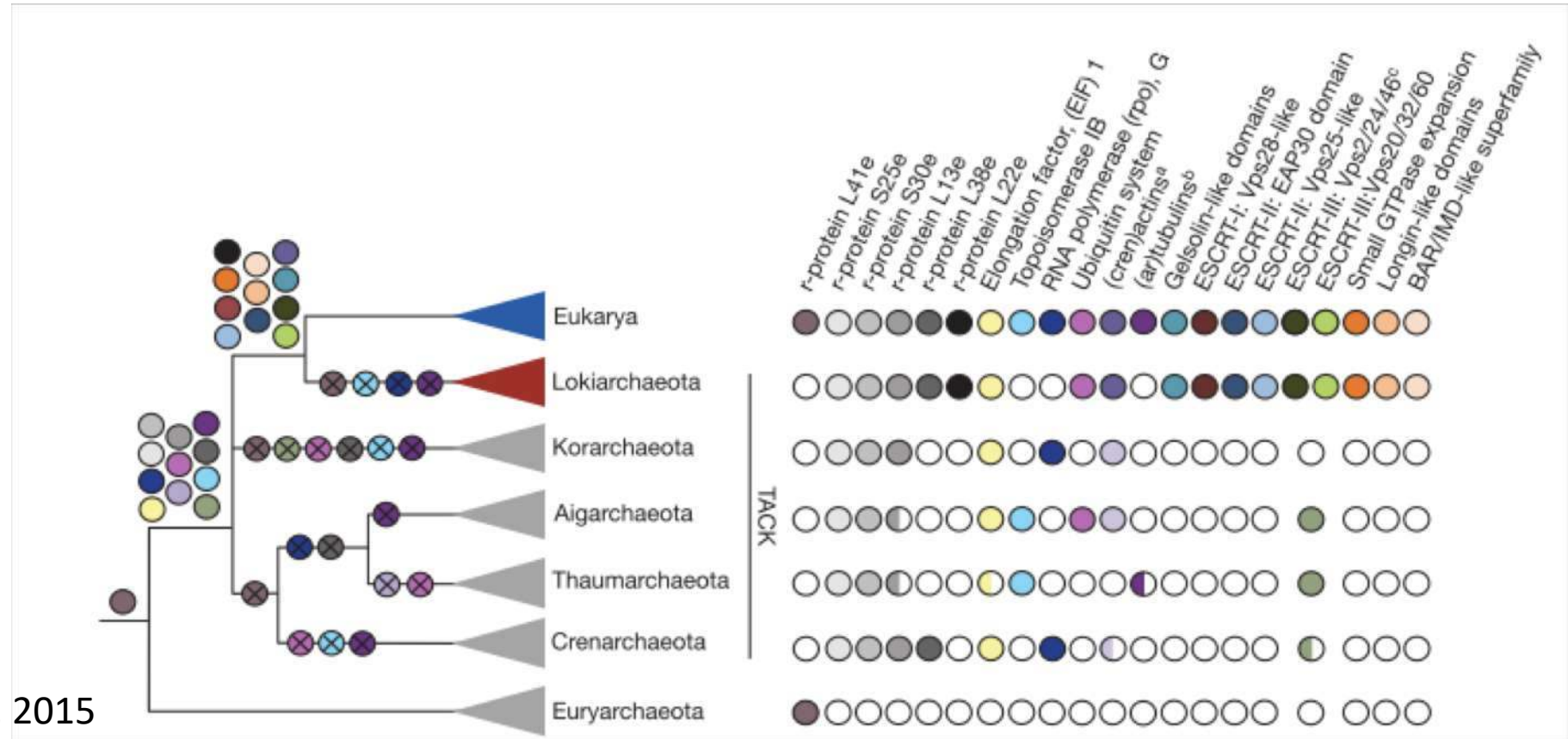
Lokiarcheota – missing link?

„Our results provide strong support for hypotheses in which the eukaryotic host evolved from a bona fide archaeon”

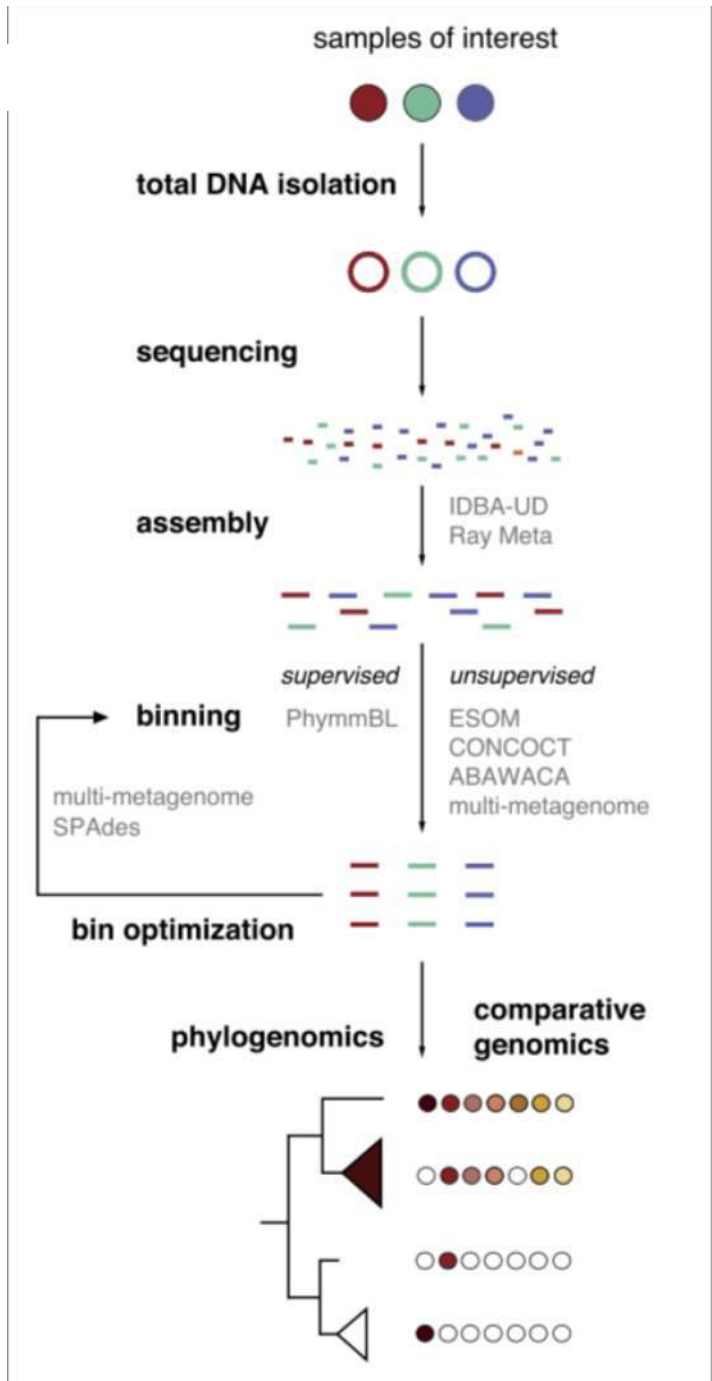
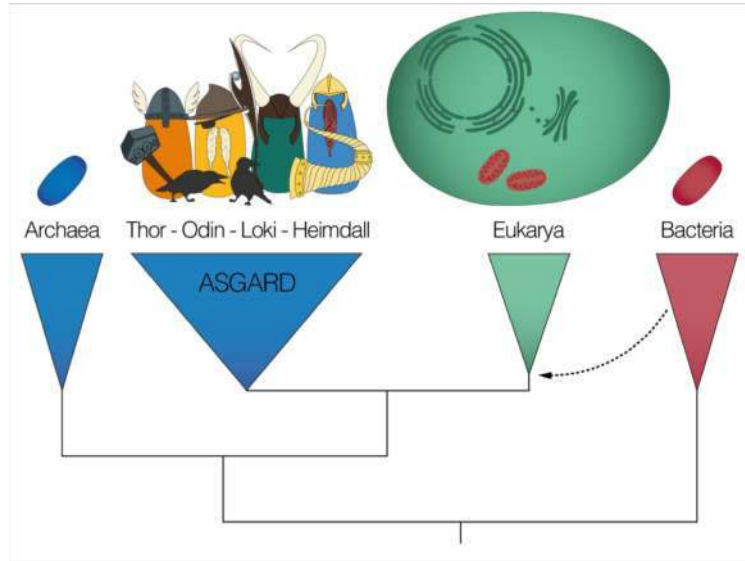


Lokiarcheota phylogenomics

Lokiarcheota genomes contain expanded repertoire of eukaryotic signature proteins that are suggestive of sophisticated membrane remodelling capabilities

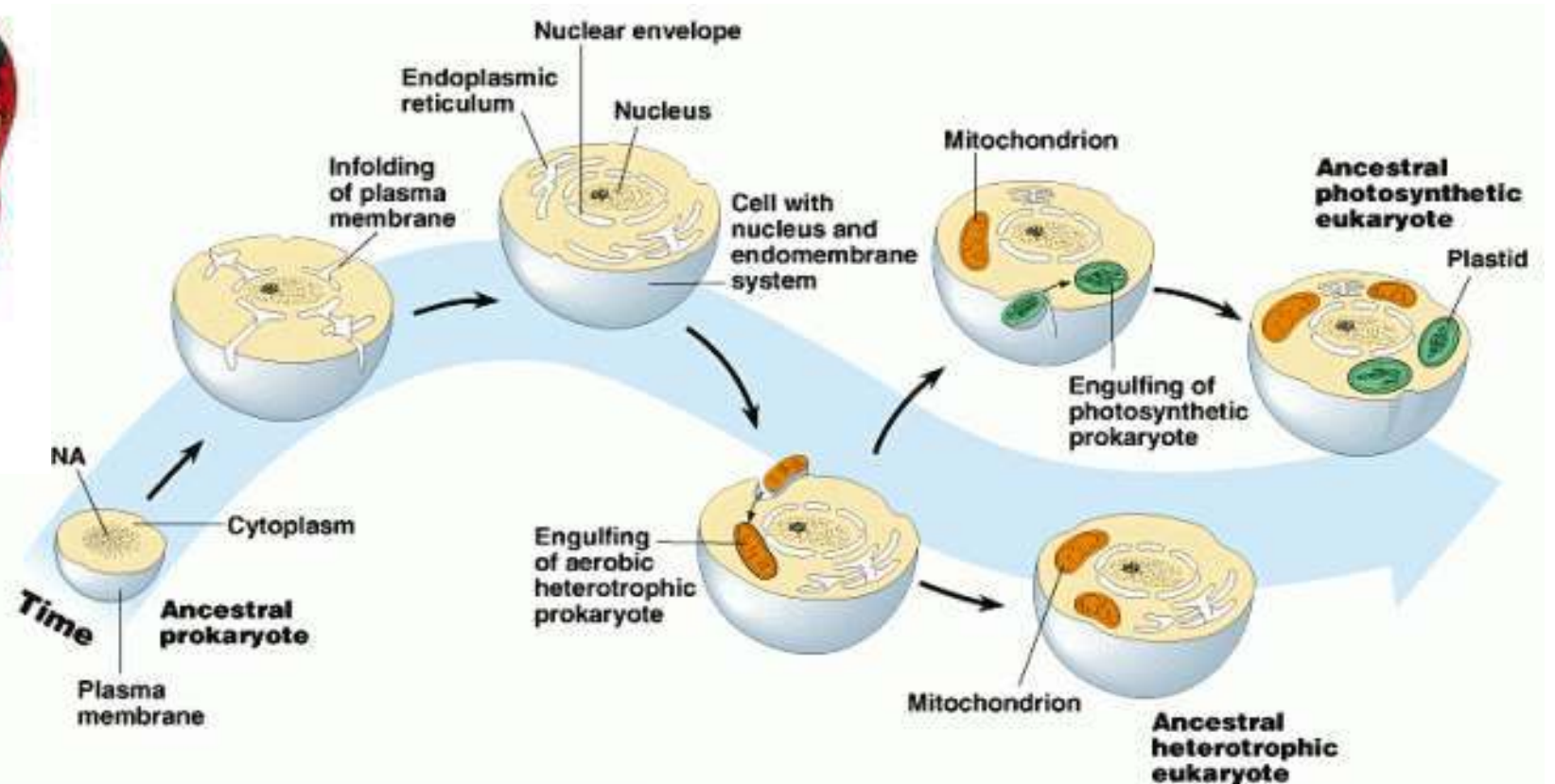


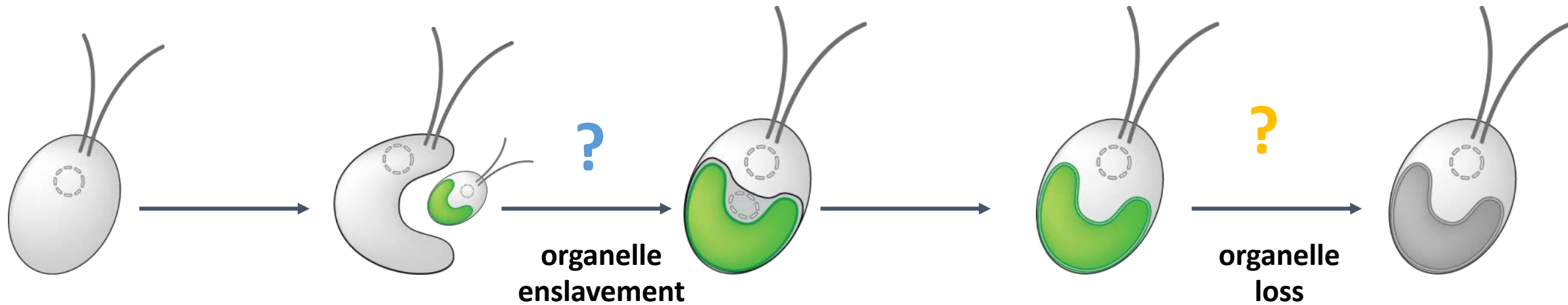
Pipeline for ASGARD study



endosymbiosis

understanding origin and fate of organelles

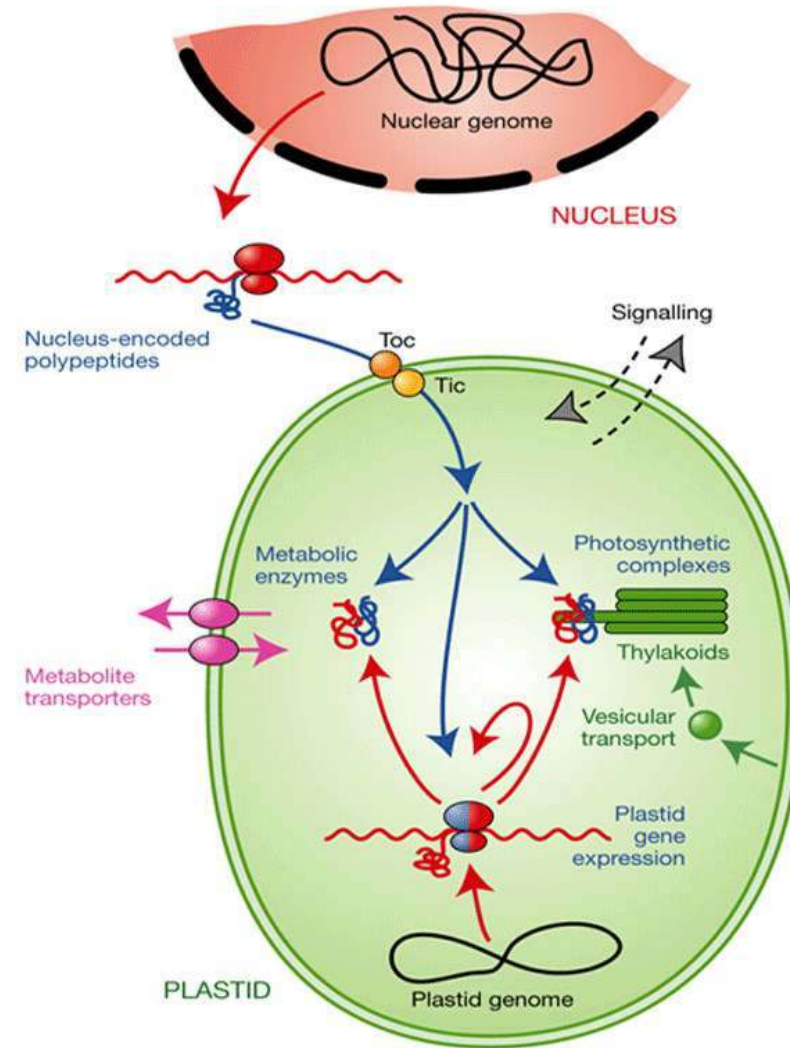




- What are the initial steps of the enslavement of endosymbiont?
- What is the order of events in this phase of transition from prey to endosymbiont?

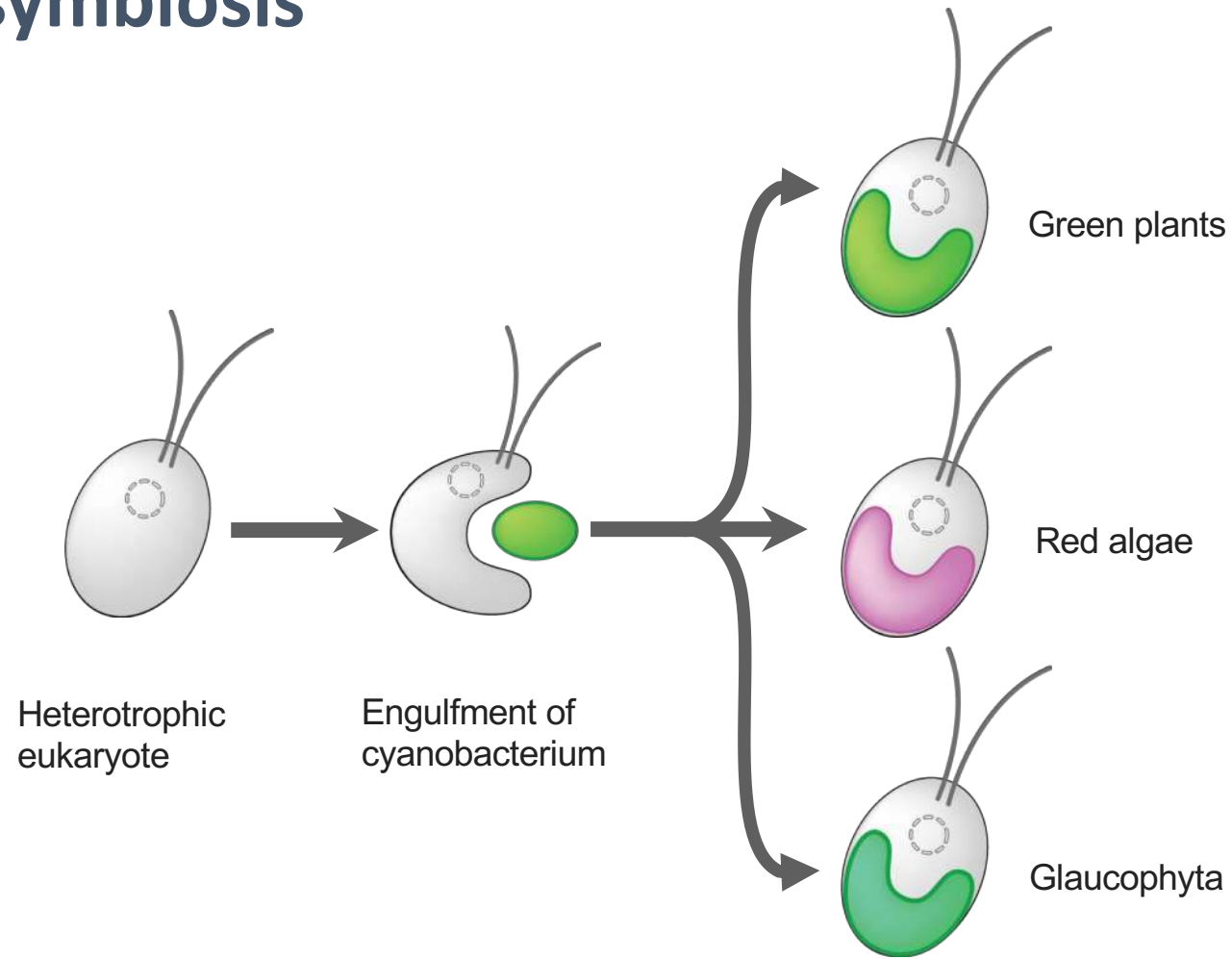
- Are there any universal patterns during the loss of organellar functions?
- What are the indispensable functions of the vestigial organelles?

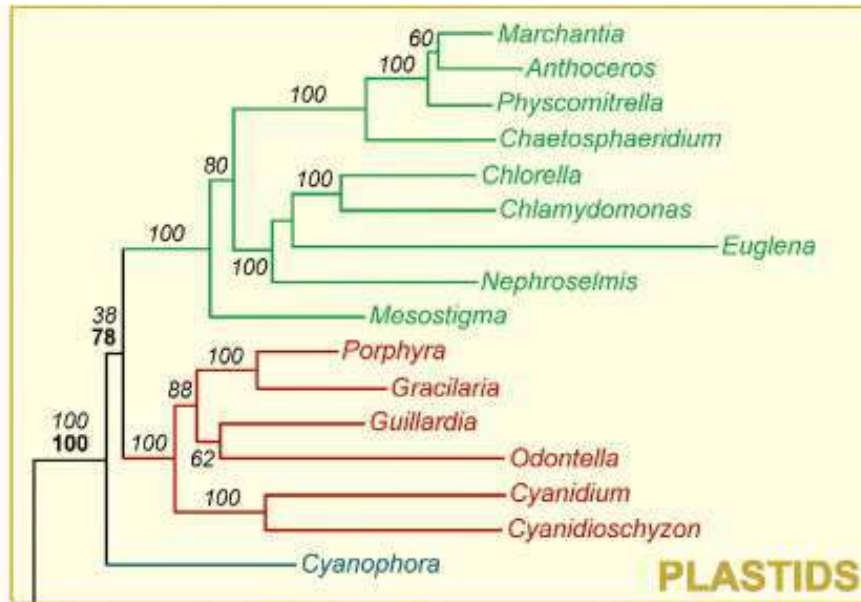
plastids



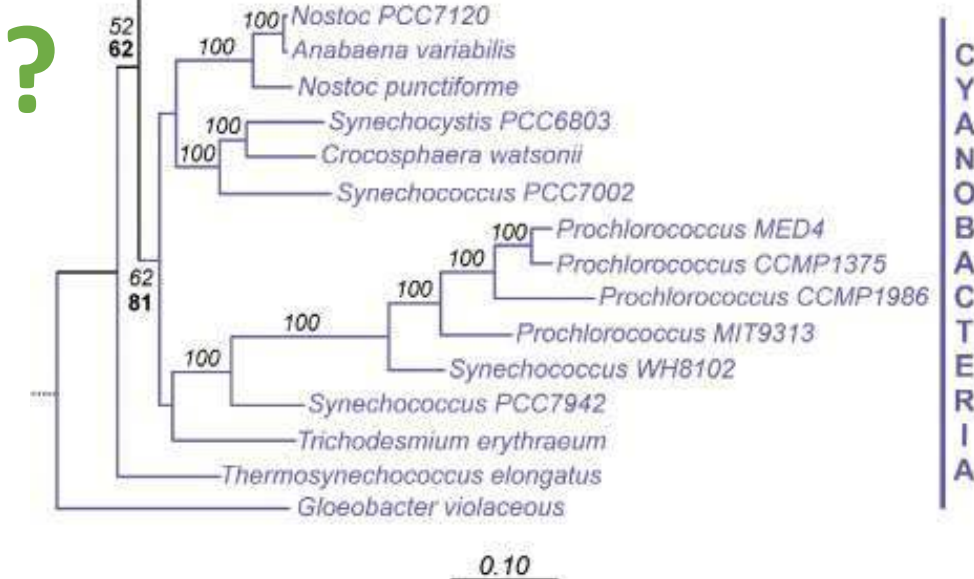
Origin of chloroplasts

primary endosymbiosis



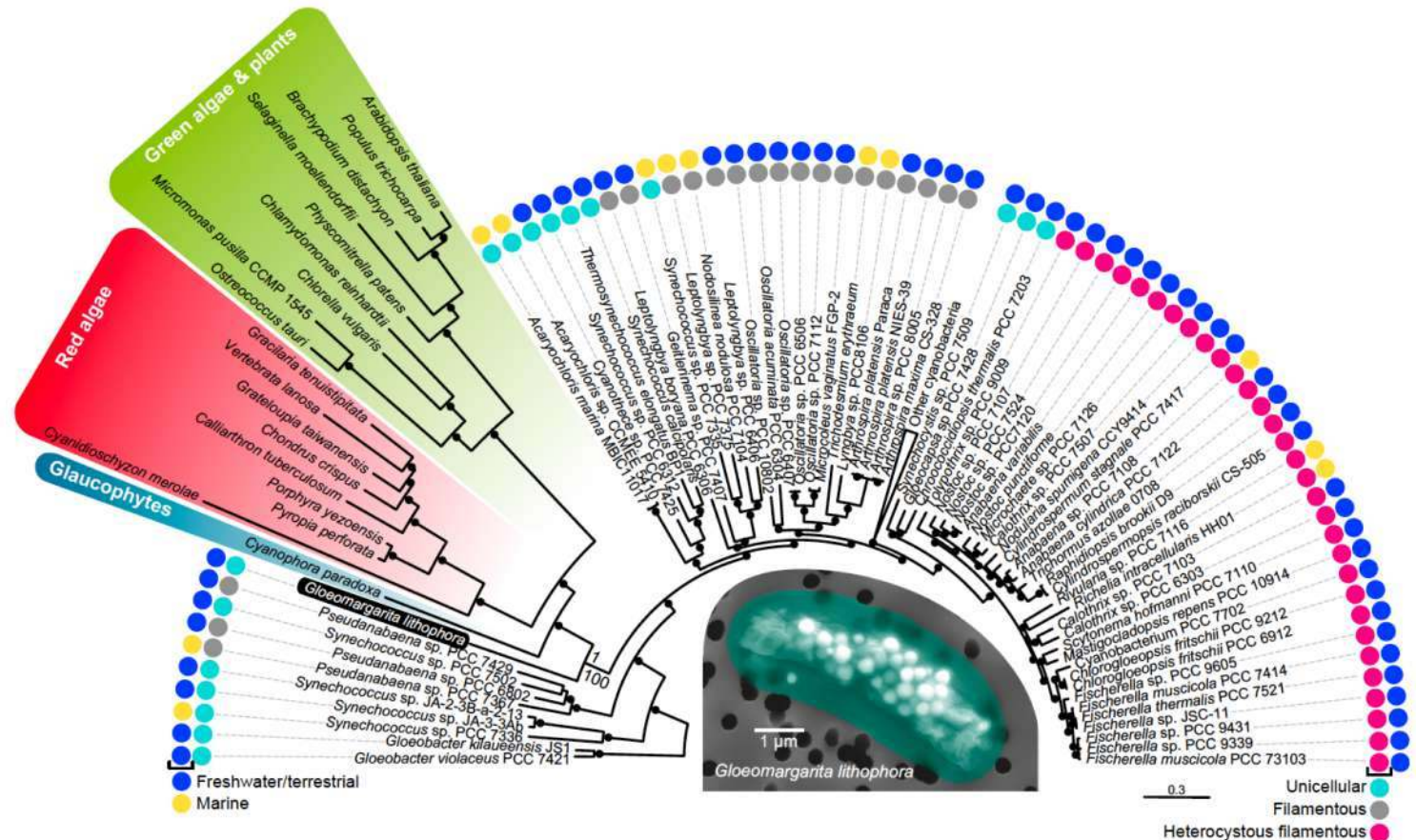


Plastids and cyanobacteria are recovered repeatedly as a monophyletic group

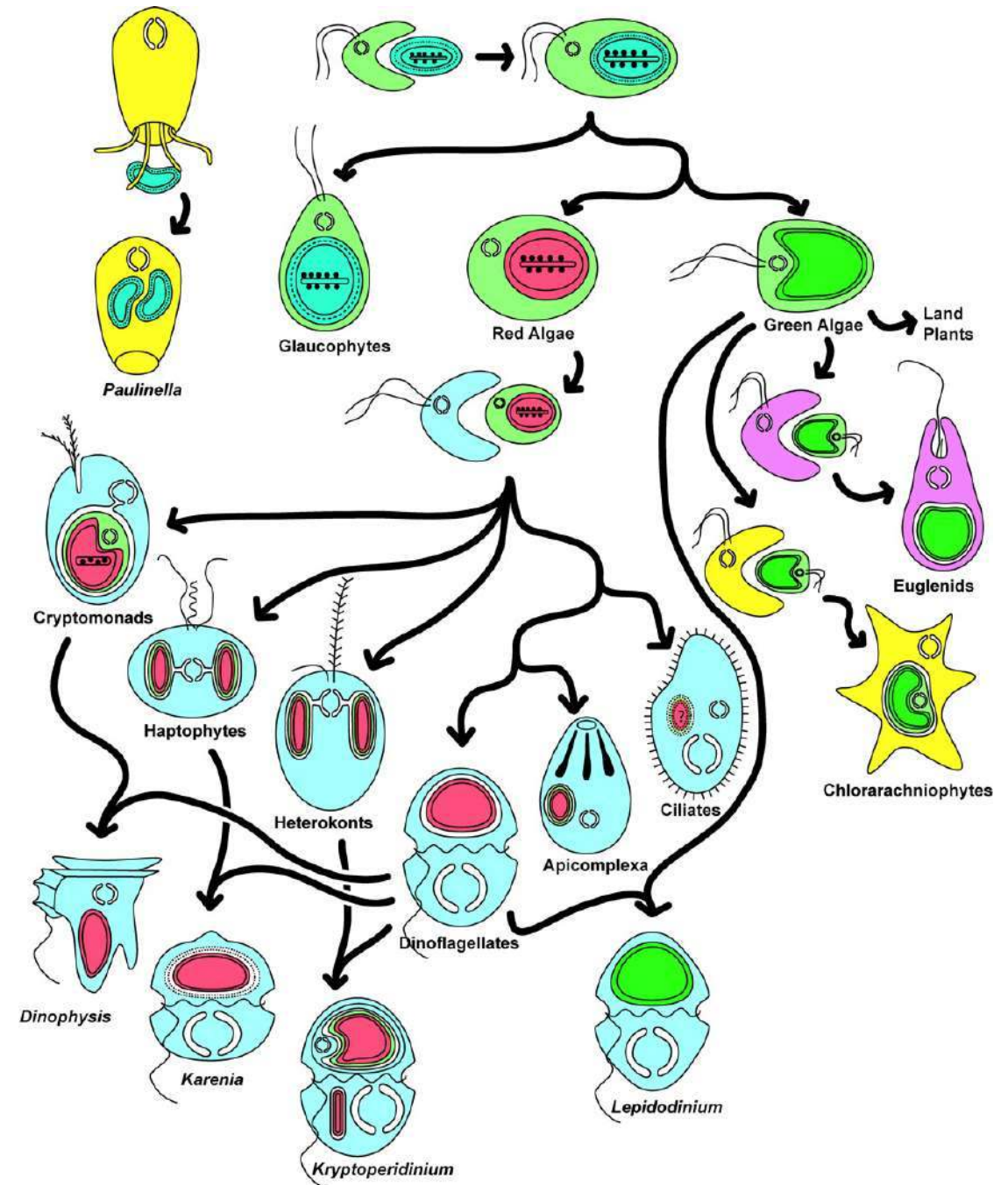
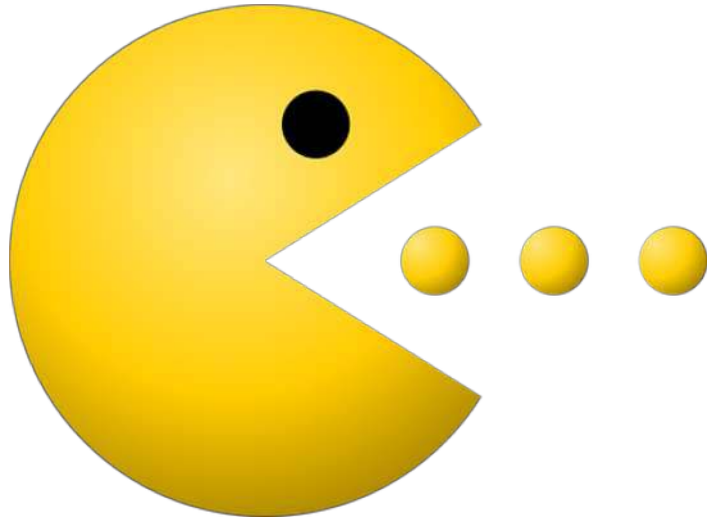


Cyanobacteria which became a chloroplast

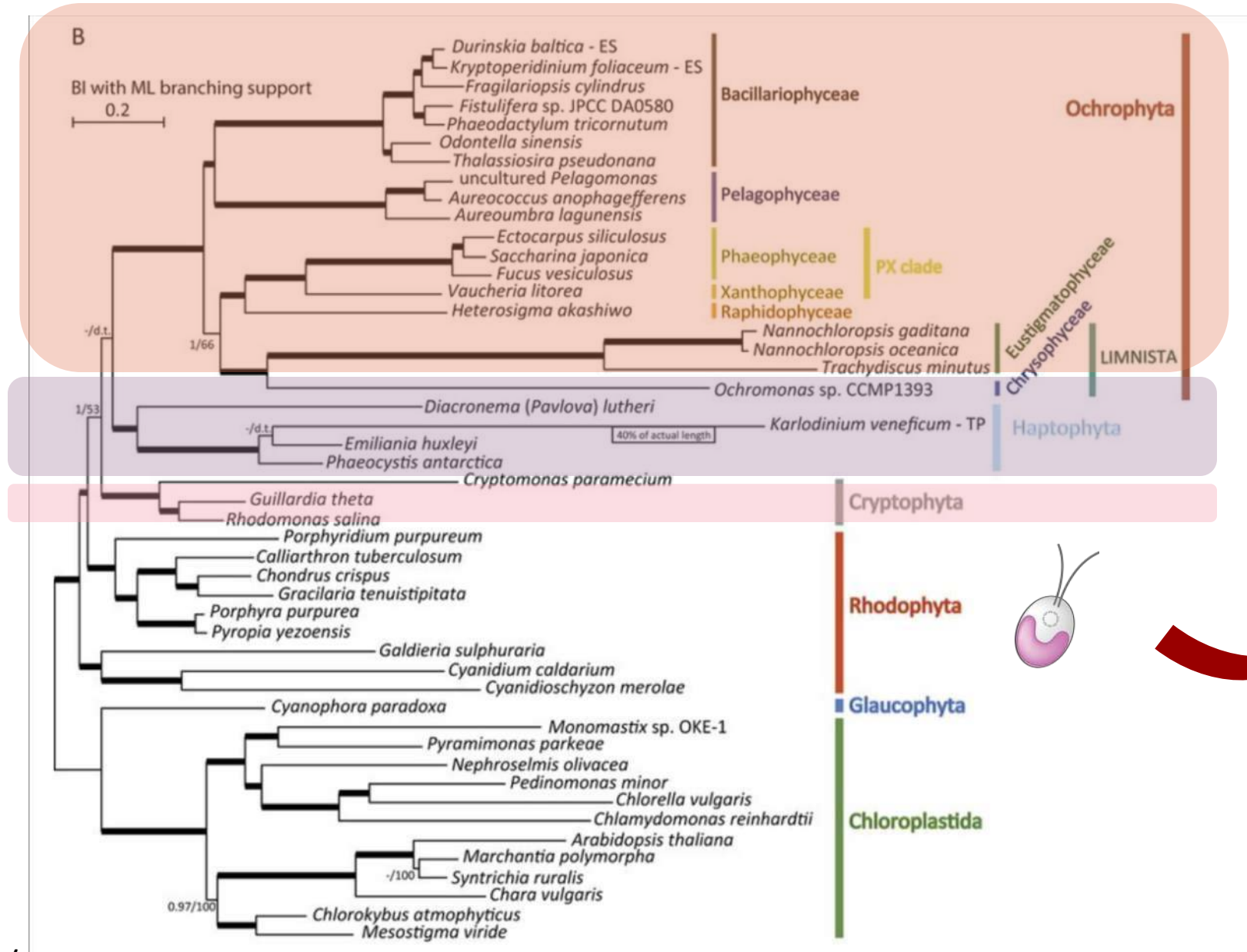
- *Gloeomargarita lithophora* is the closest extant cyanobacteria to plastids
- old cyanobacterial lineage
- freshwater cyanobacteria



Secondary endosymbioses in several lineages of microbial eukaryotes

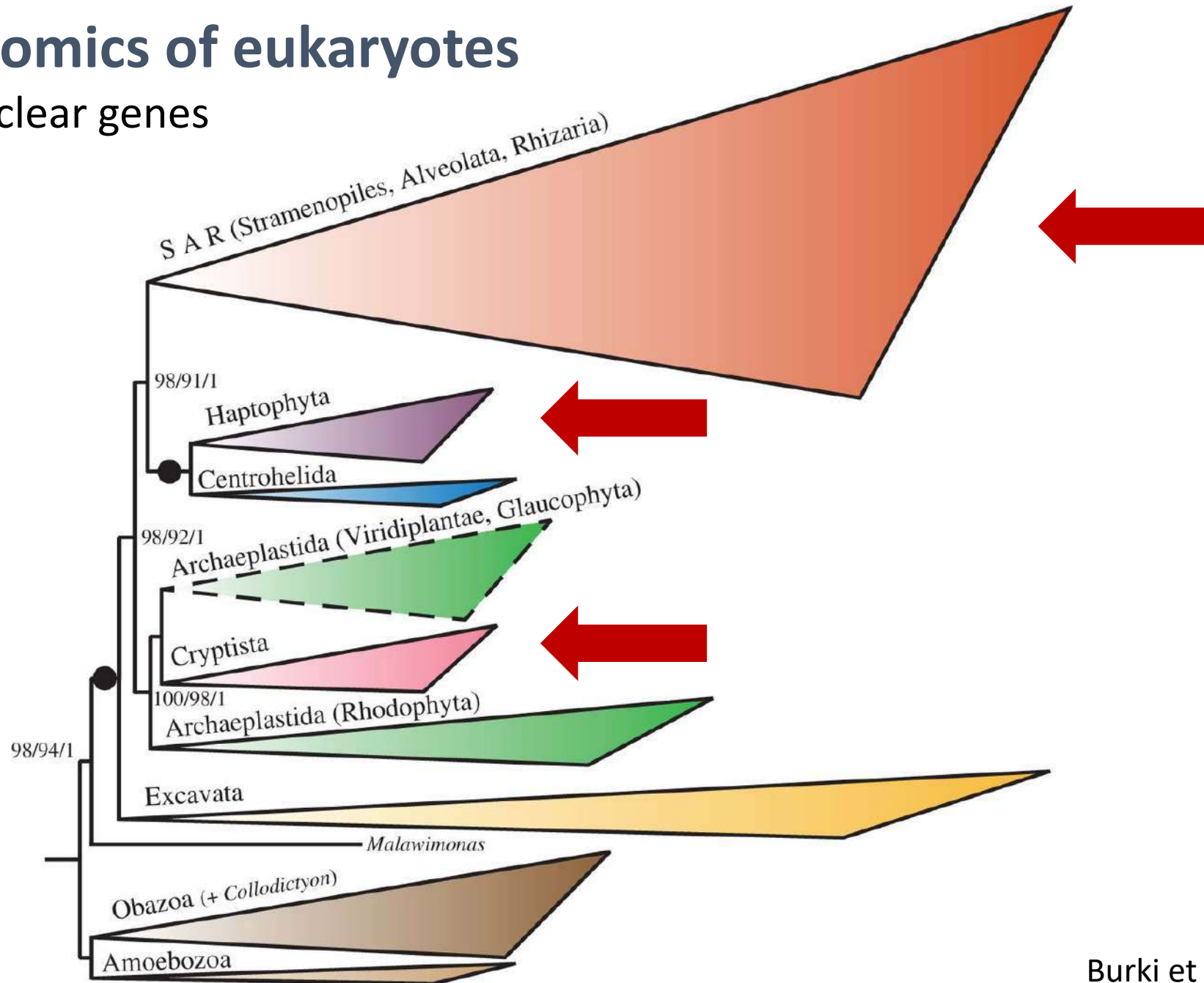


Phylogenomics of plastids



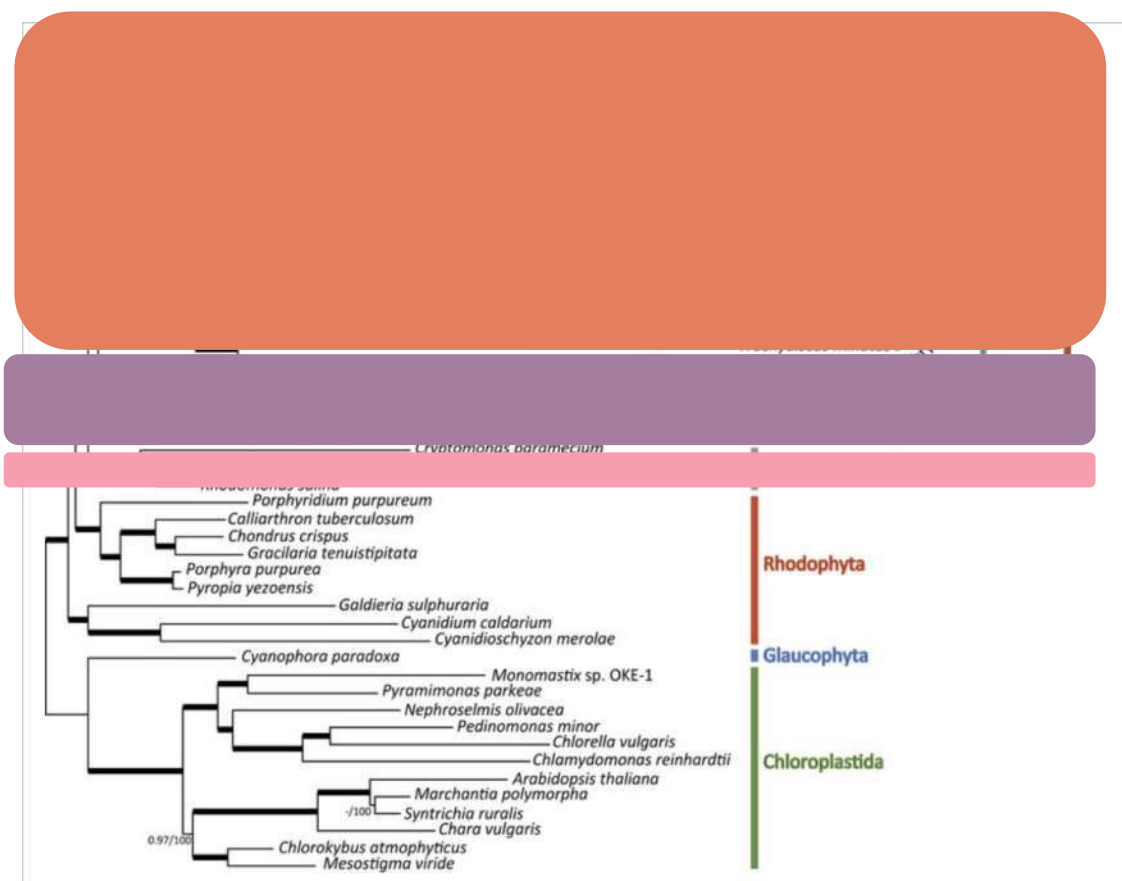
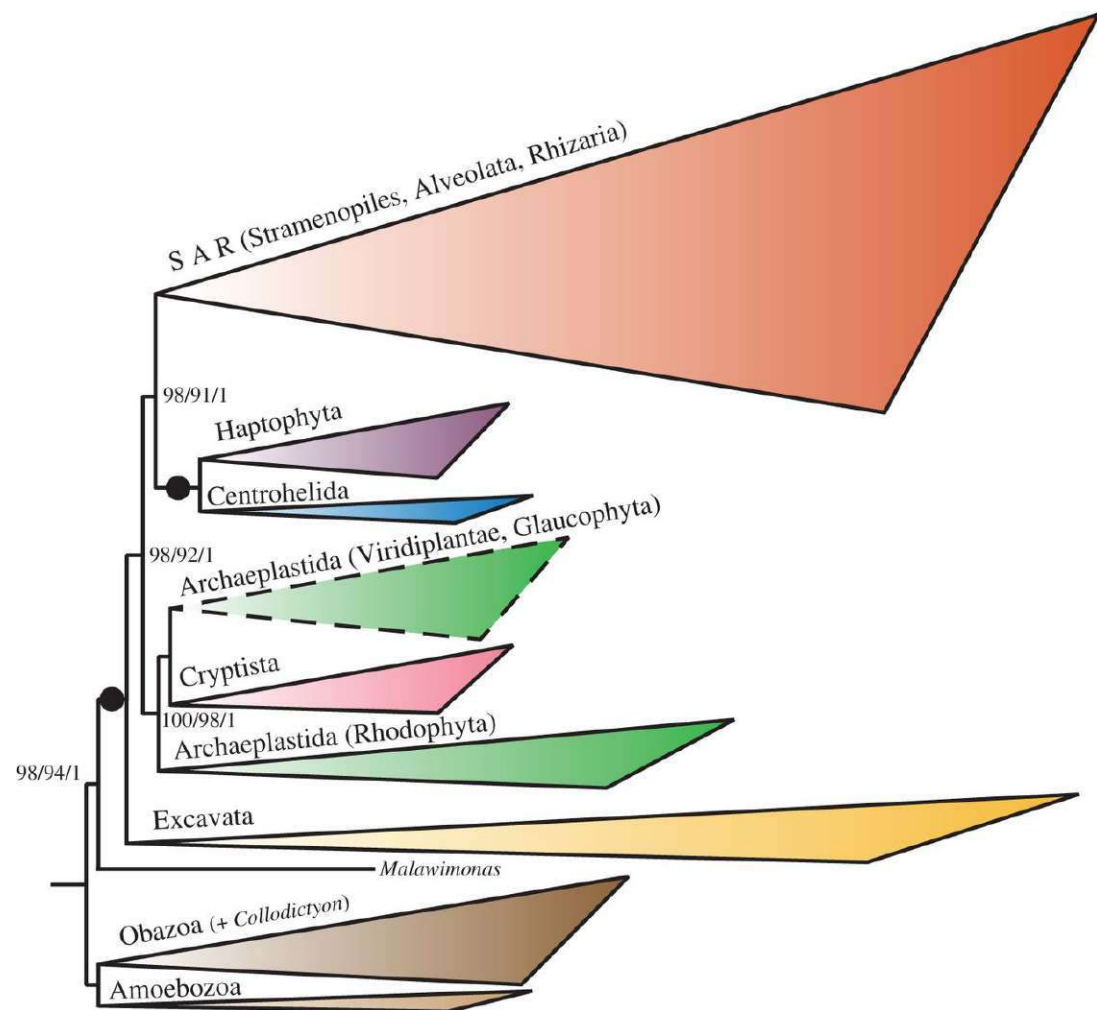
Phylogenomics of eukaryotes

based on nuclear genes

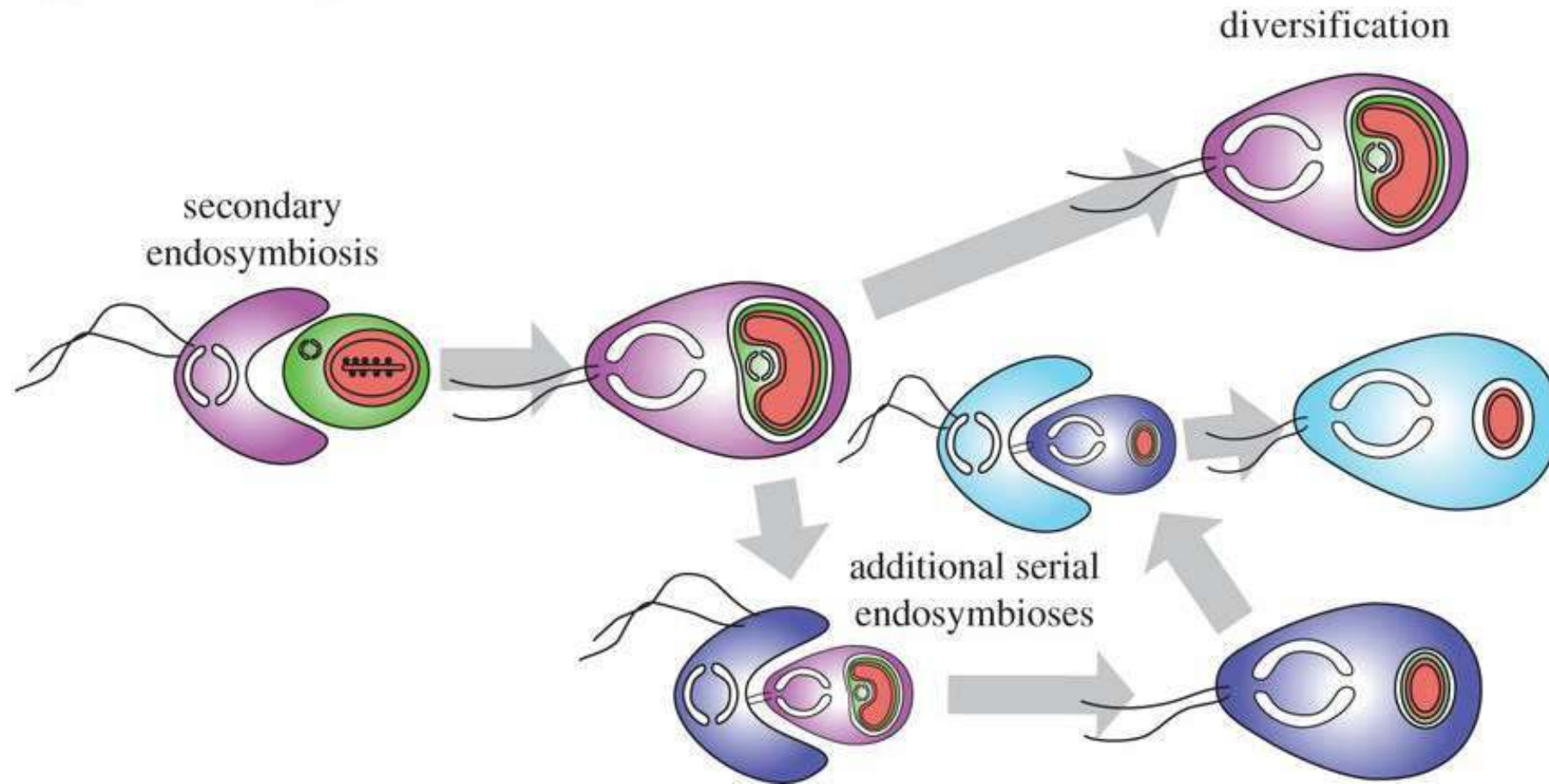


ML/BI 250 genes

Burki et al. 2016

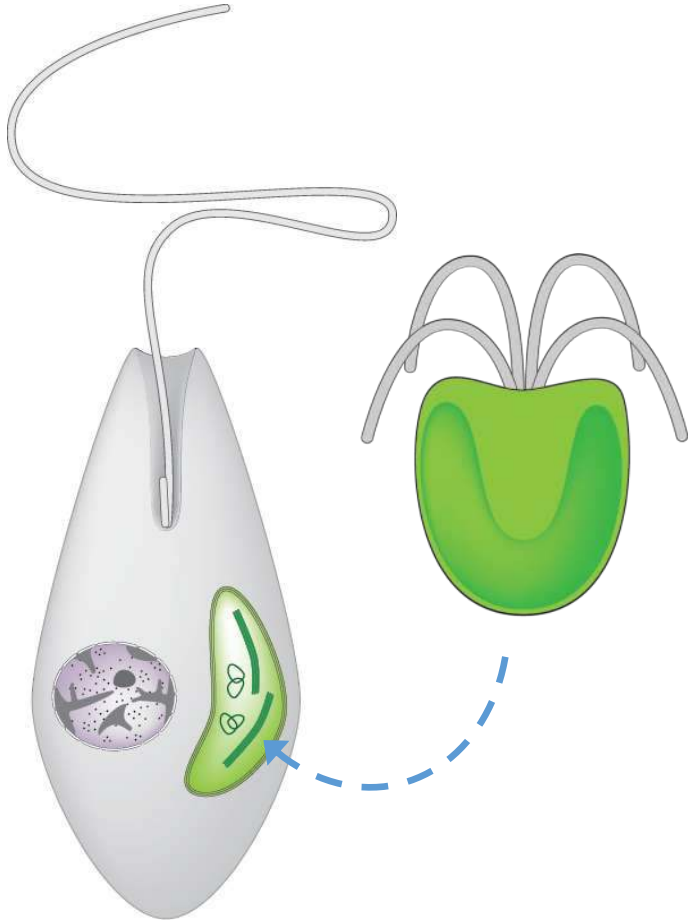


Cryptic serial endosymbiosis



organelle enslavement

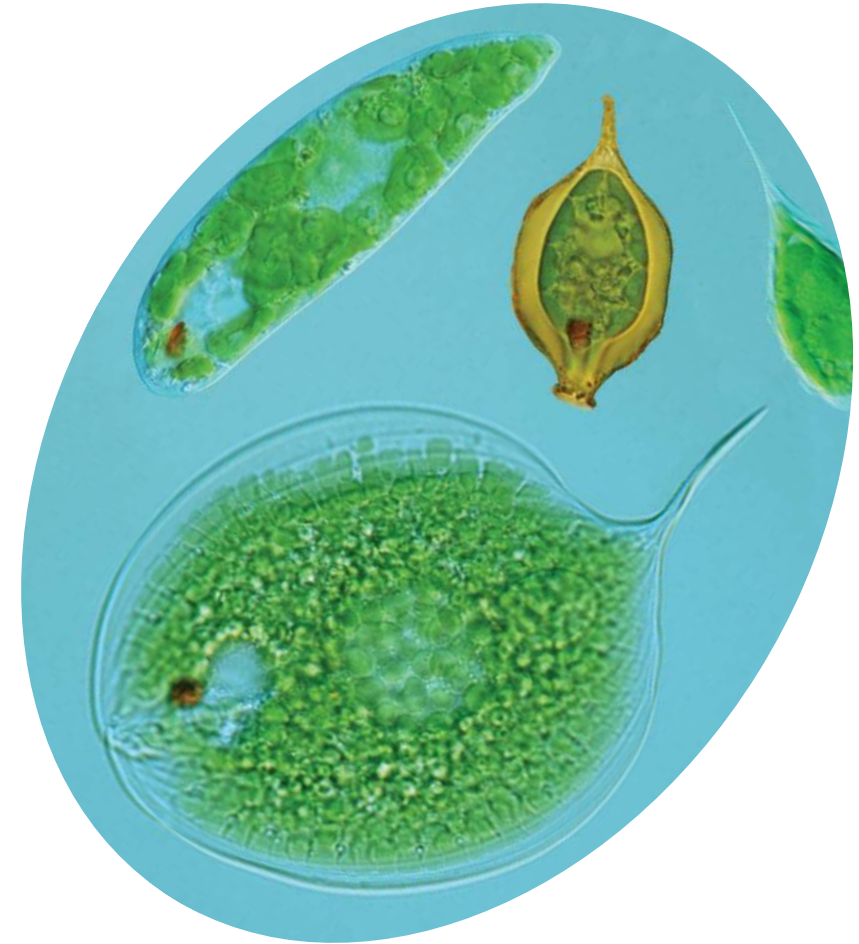
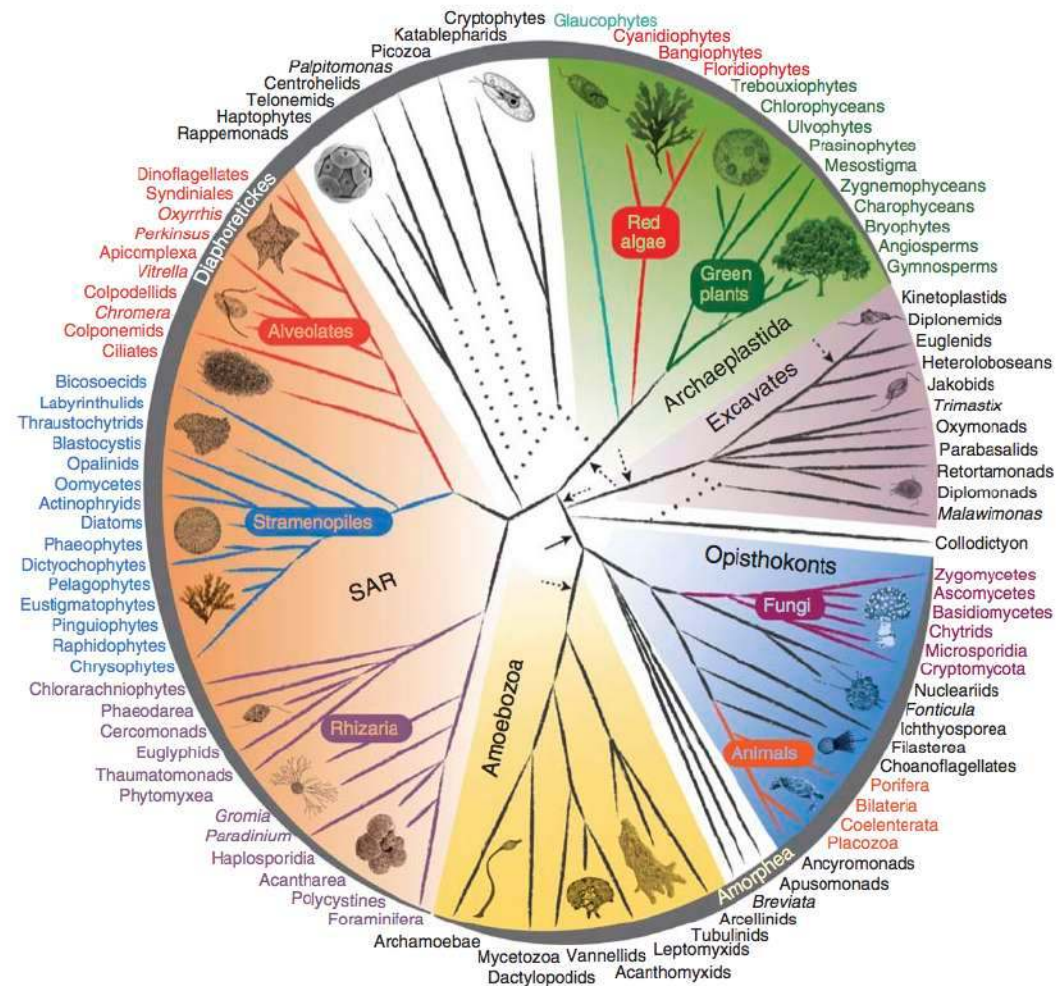
origin of plastids via kleptoplastidity



kleptoplasty

transient association between host and endosymbiont, which might resemble the initial steps of the establishing endosymbiosis

photosynthetic euglenids - the only Excavates with secondary plastids



Rapaza viridis – mixotrophic euglenid

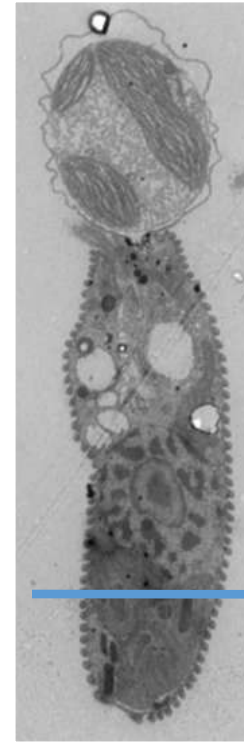
feeds on a specific strain of green algae, *Tetraselmis* sp.



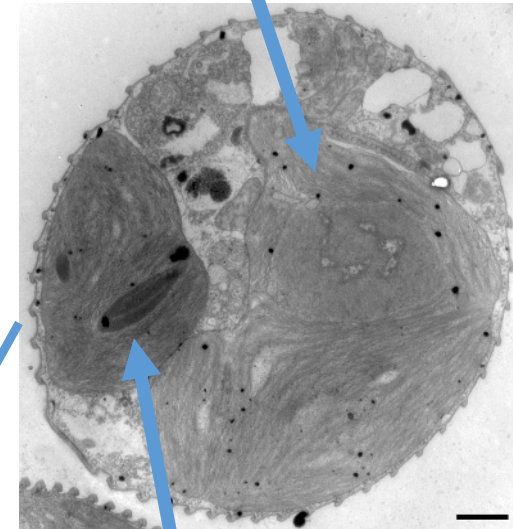
Naoji Yubuki



Rapaza viridis

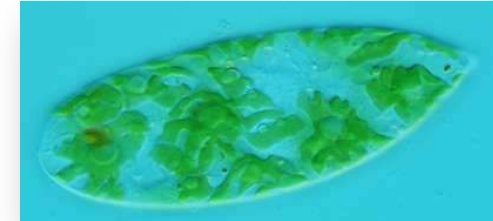
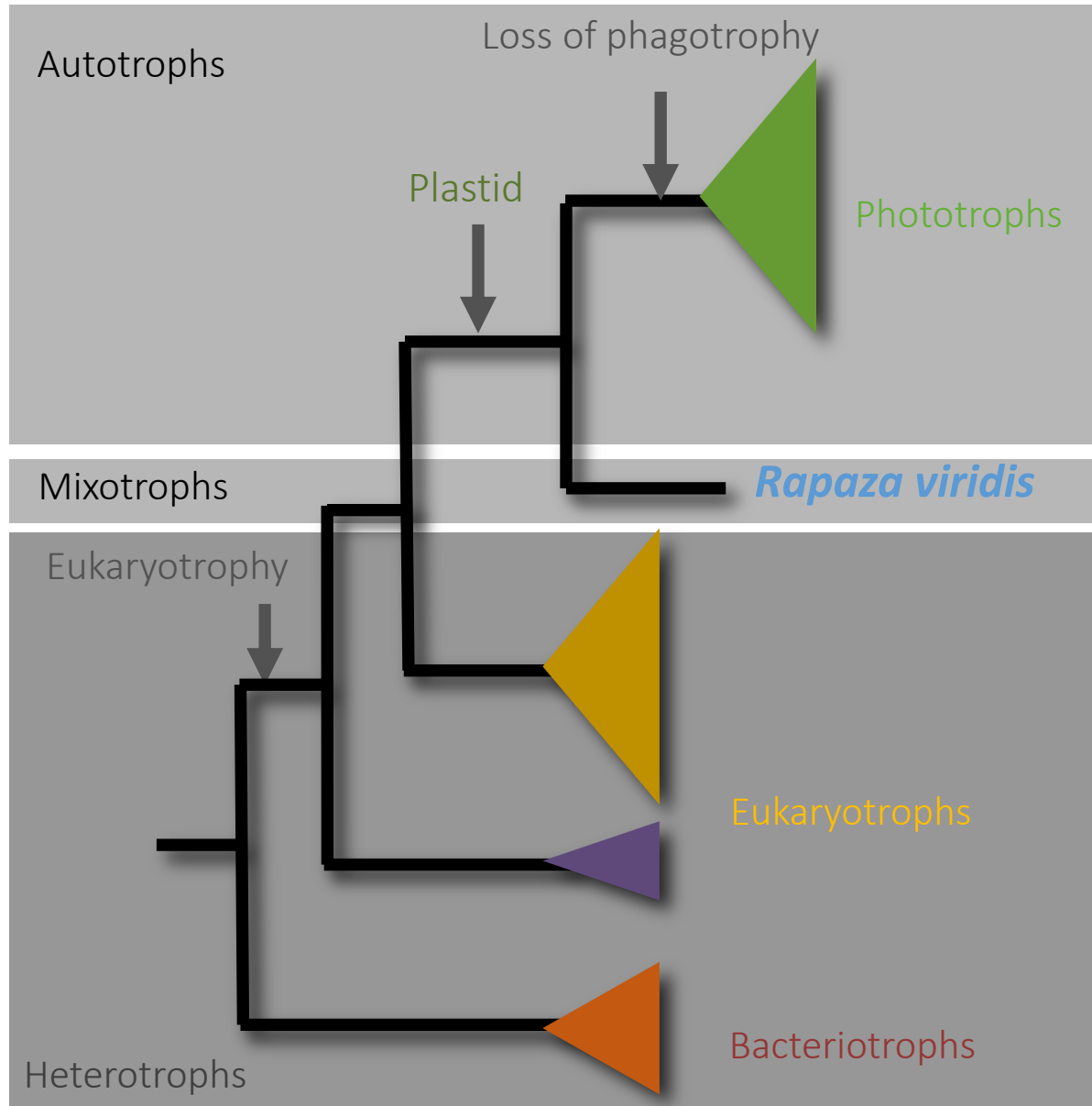


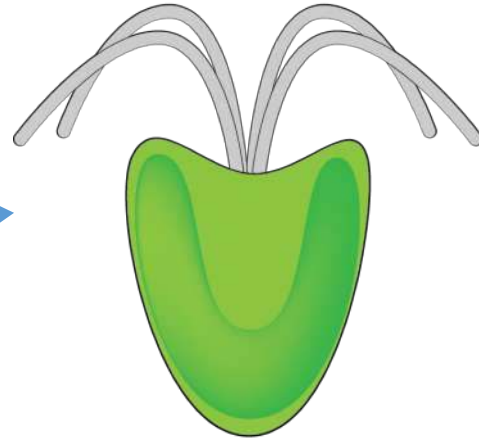
Tetraselmis chloroplast



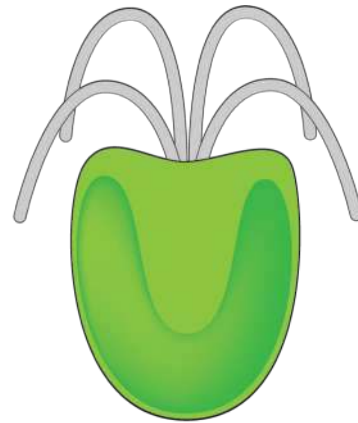
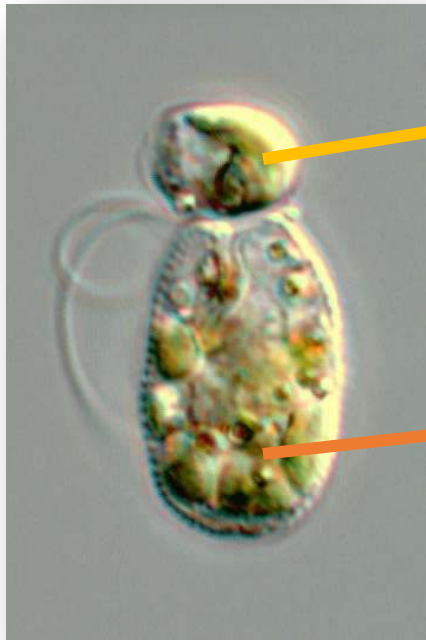
Rapaza chloroplast

Yamaguchi, Yubuki & Leander (2013)



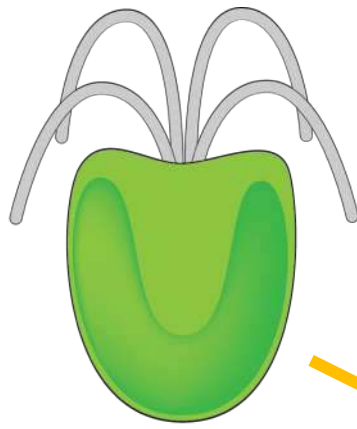


Pyramimonas
Prasinophytes

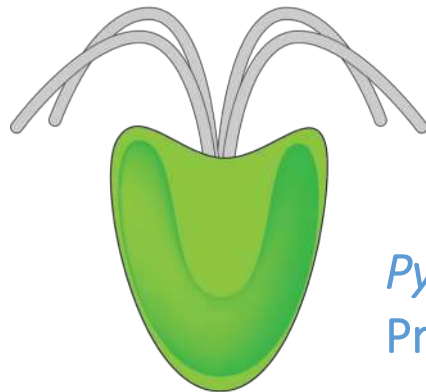
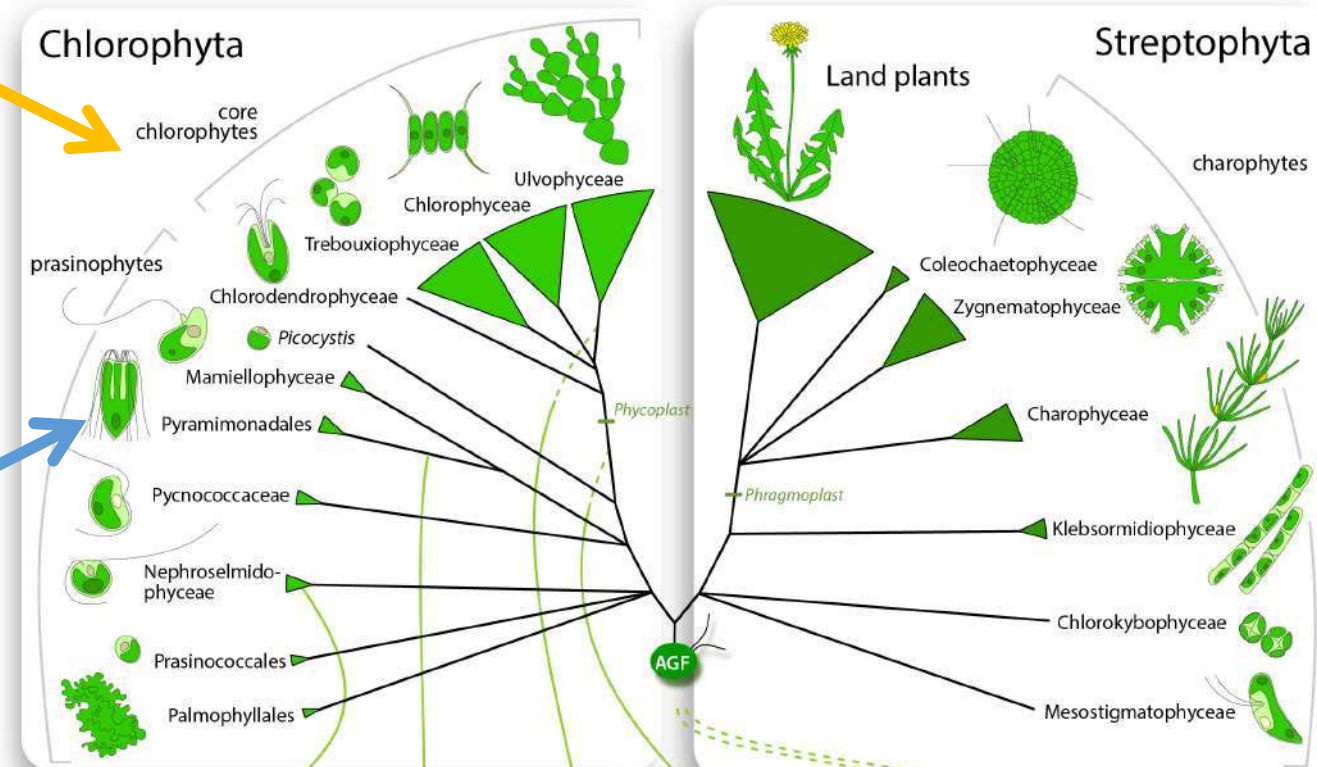


Tetrastelmis
'core' chlorophytes

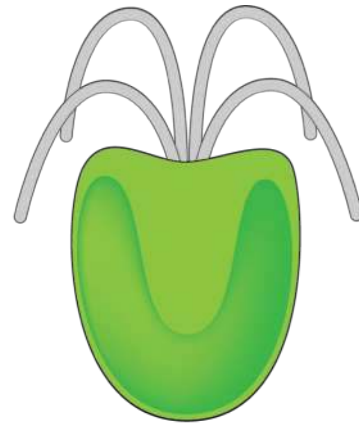
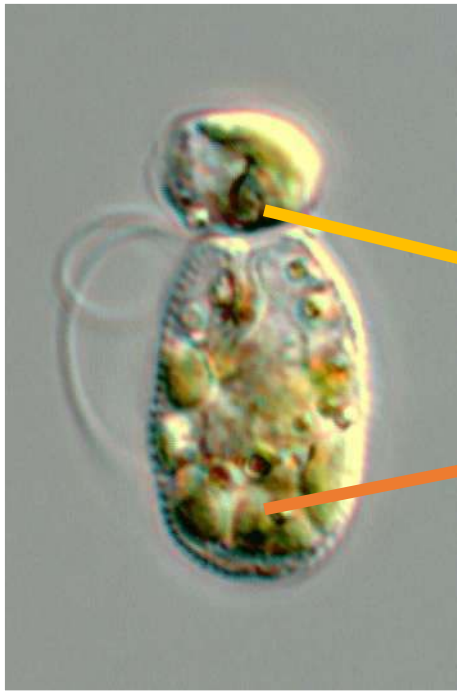
?



Tetrastelmis
'core' chlorophytes



Pyramimonas
Prasinophytes



Tetrastelmis

**Kleptochloroplast
(stolen plastid)**

Rapaza possesses only ***Tetrastelmis*-derived** plastid but
no *Pyramimonas*-like (Euglenophyceae-type)

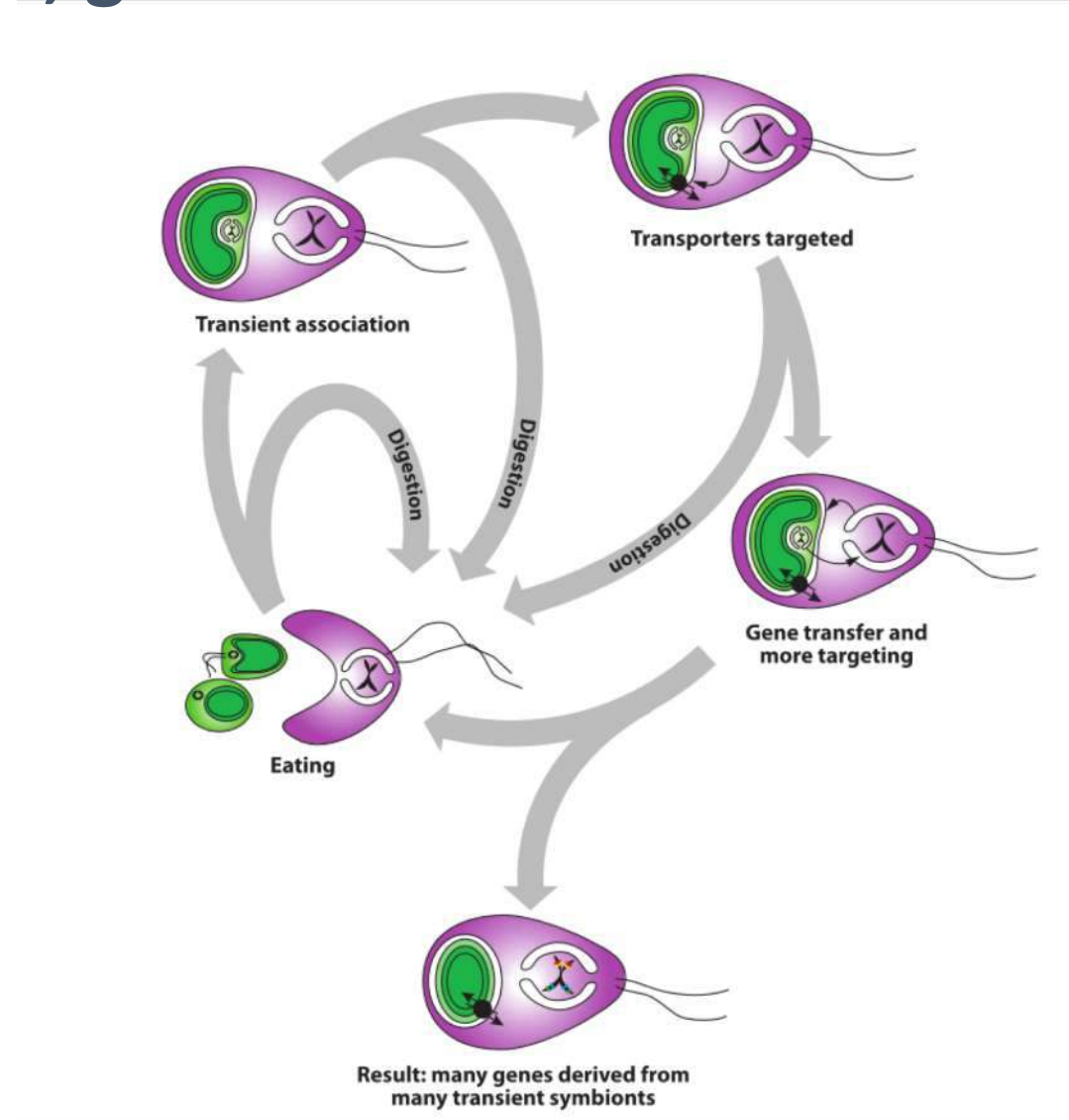
Plastid proteins are encoded in plastid and nuclear genome



Genes encoding chloroplast proteins are transferred to nuclear genome via endosymbiotic gene transfer (EGT).

Plastid proteins encoded in nuclear genome are **targeted** to the plastids.

Which comes first, gene transfer or cellular fixation?



A targeting-ratchet model for the endosymbiotic origin of plastids
Keeling, 2013



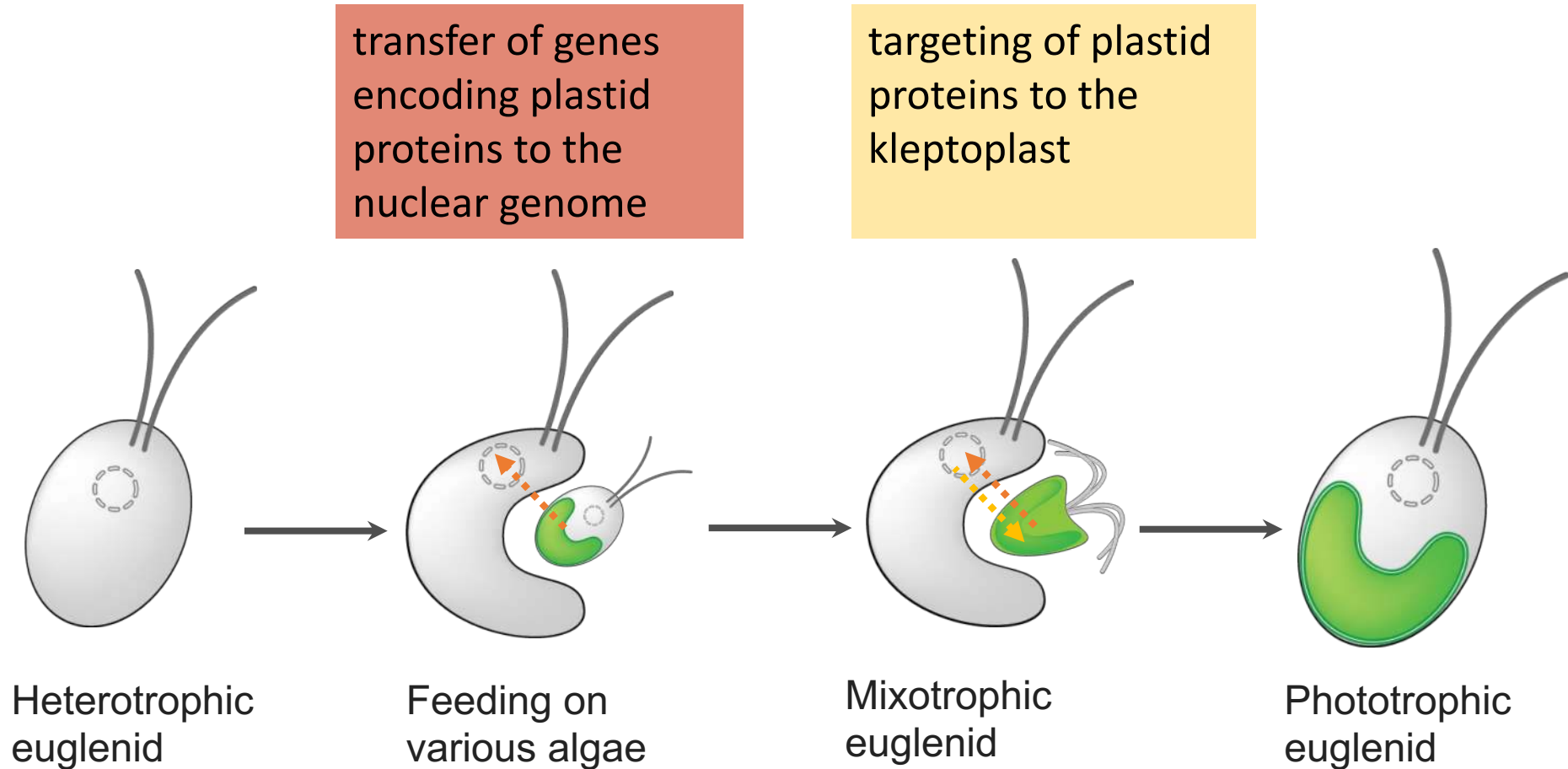
Are there any plastid proteins encoded in nuclear genome of *Rapaza* **targeted to kleptochloroplasts?**



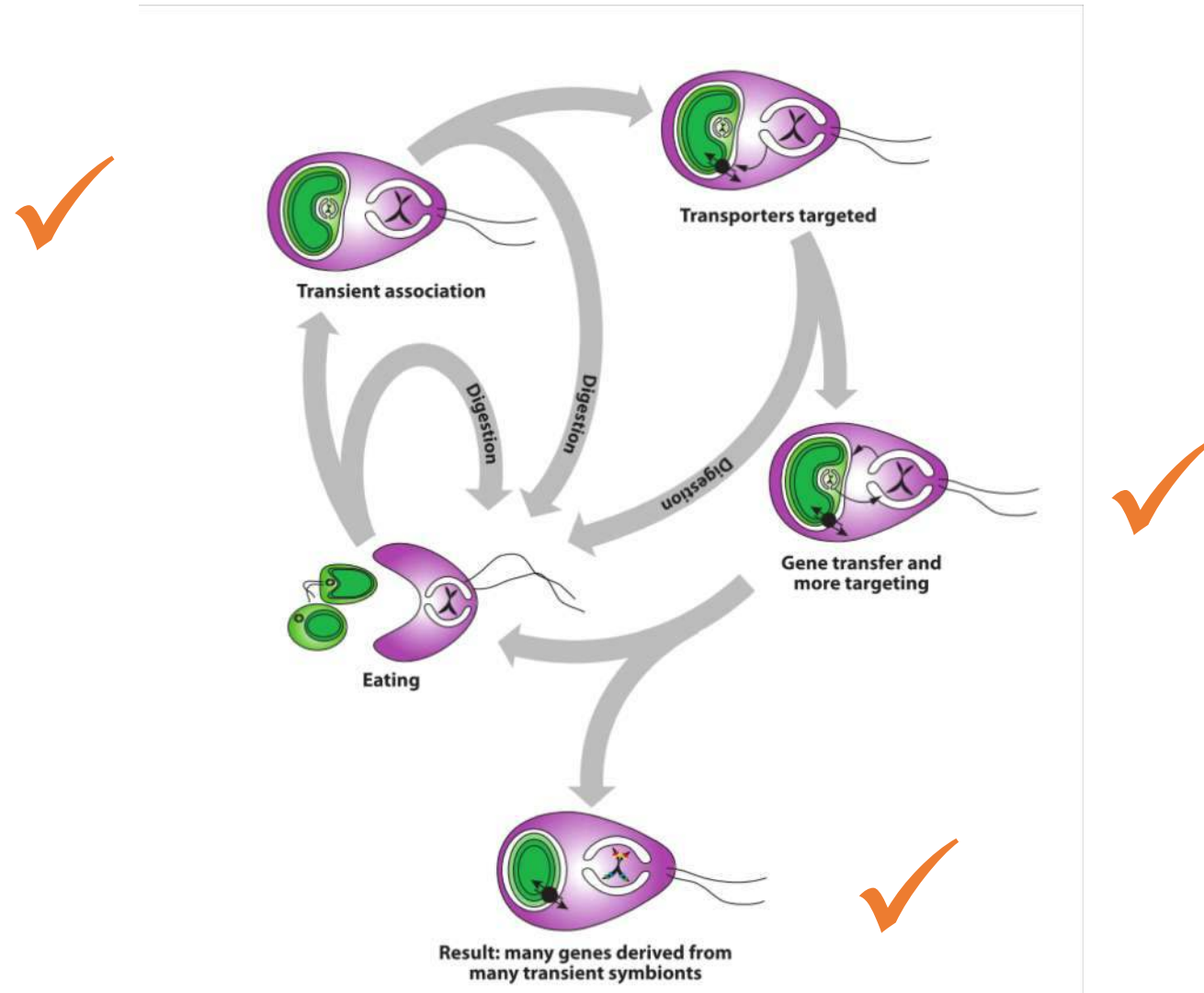
What is the origin of
plastid-targeted proteins?

origin of plastids via kleptoplastidity

Which comes first, gene transfer or cellular fixation?

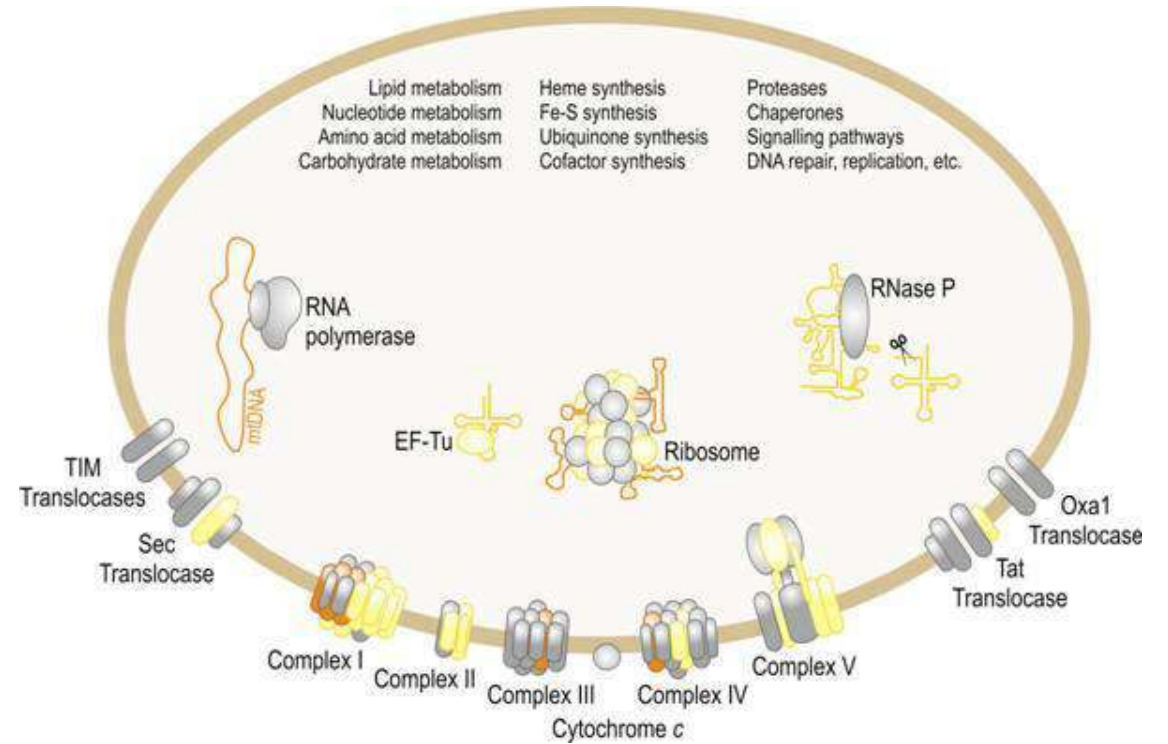


Which Comes First, **Gene Transfer** or Cellular Fixation?

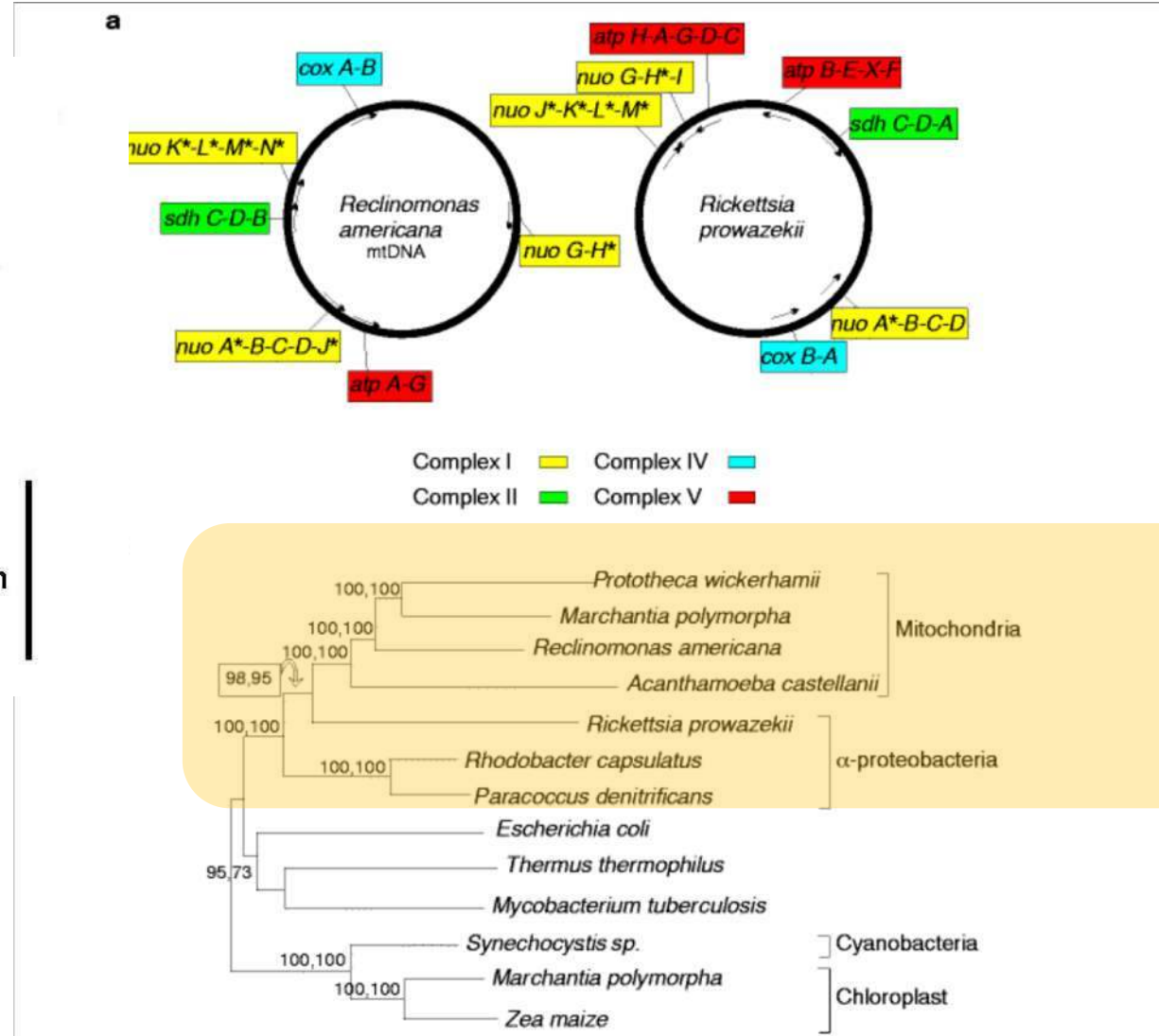


A targeting-ratchet model for the endosymbiotic origin of plastids
Keeling, 2013

mitochondria

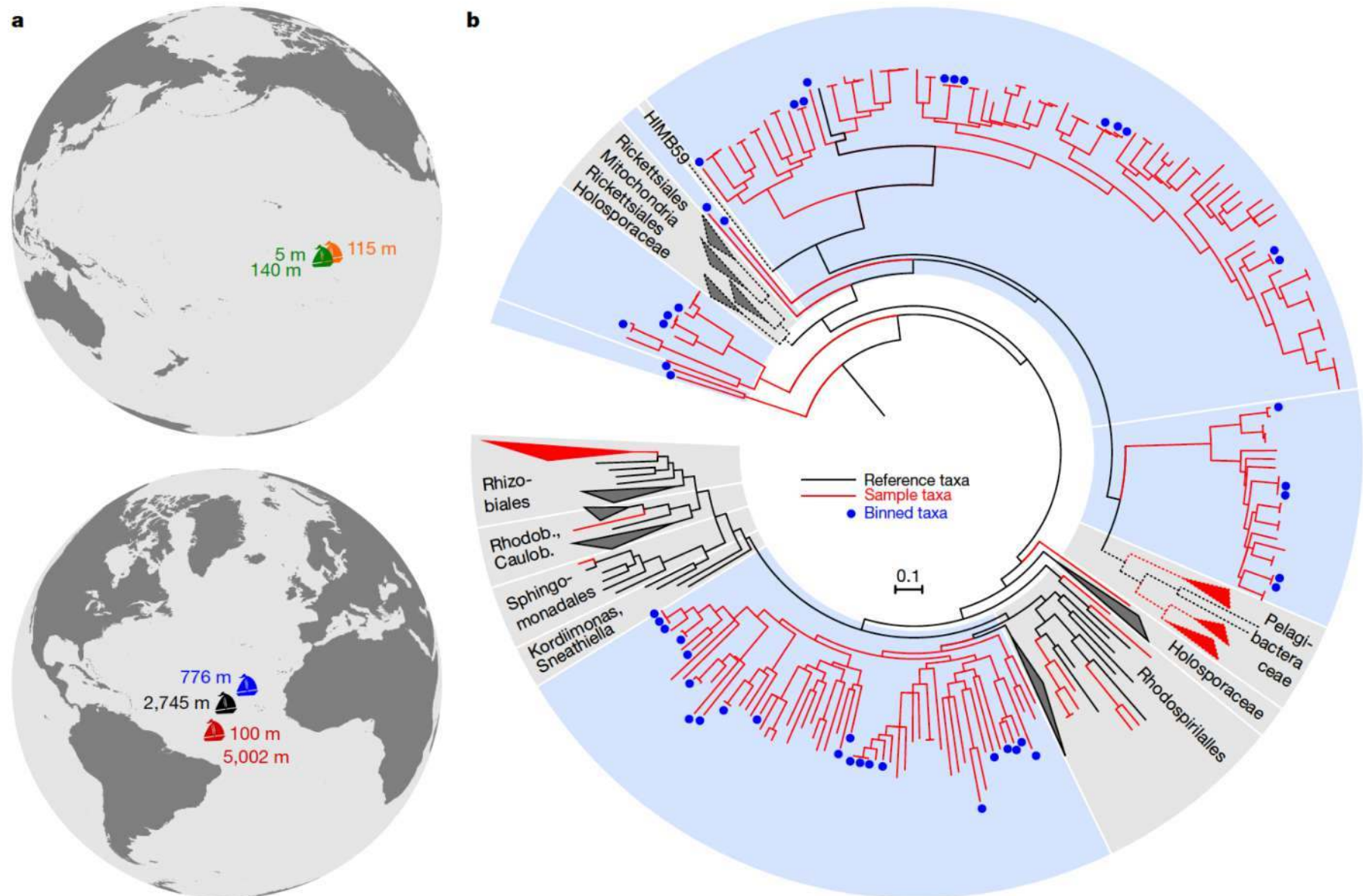


The genome sequence of *Rickettsia prowazekii* and the origin of mitochondria

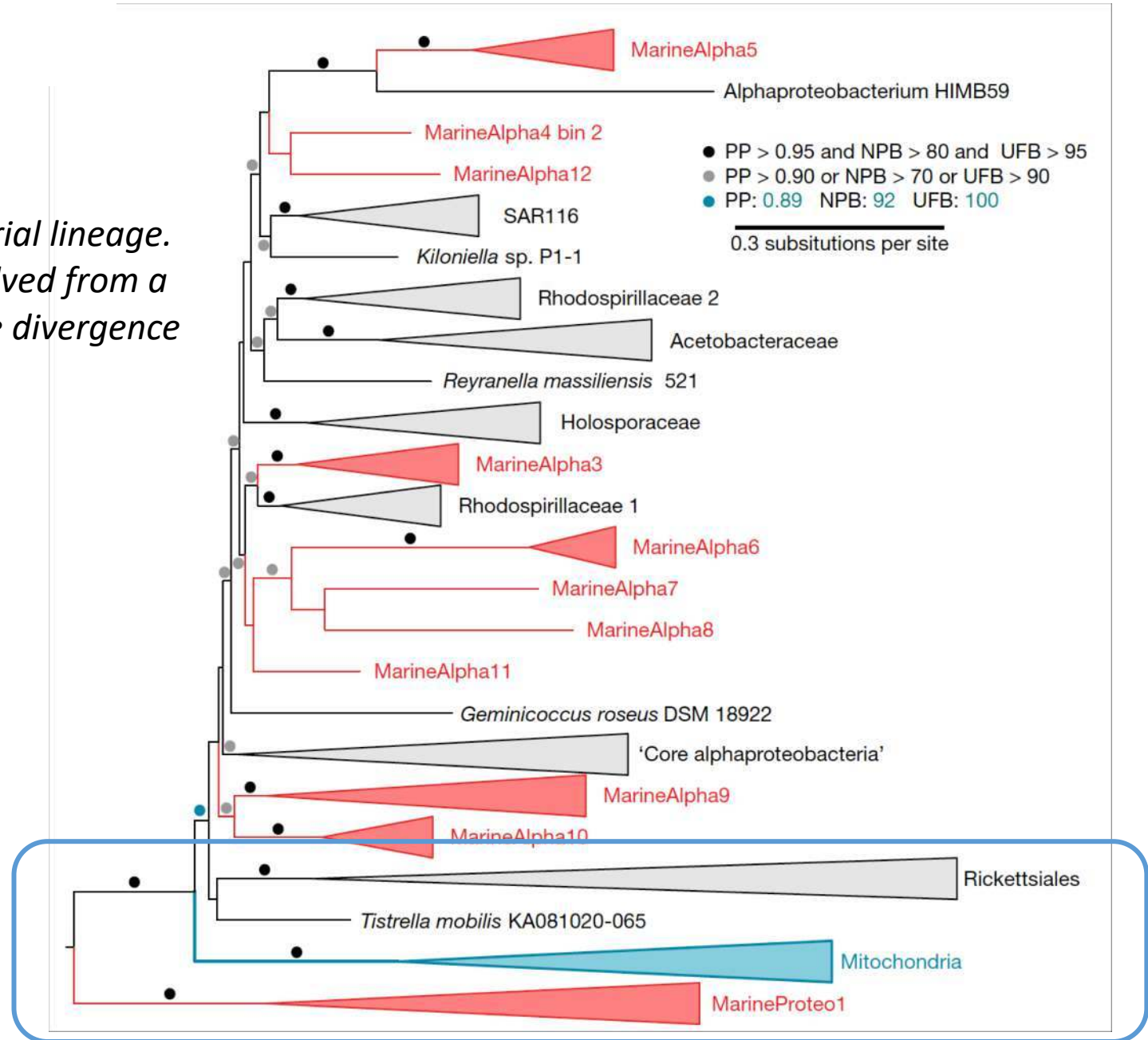


Andersson (1998), Nature

Deep mitochondrial origin outside the sampled alphaproteobacteria



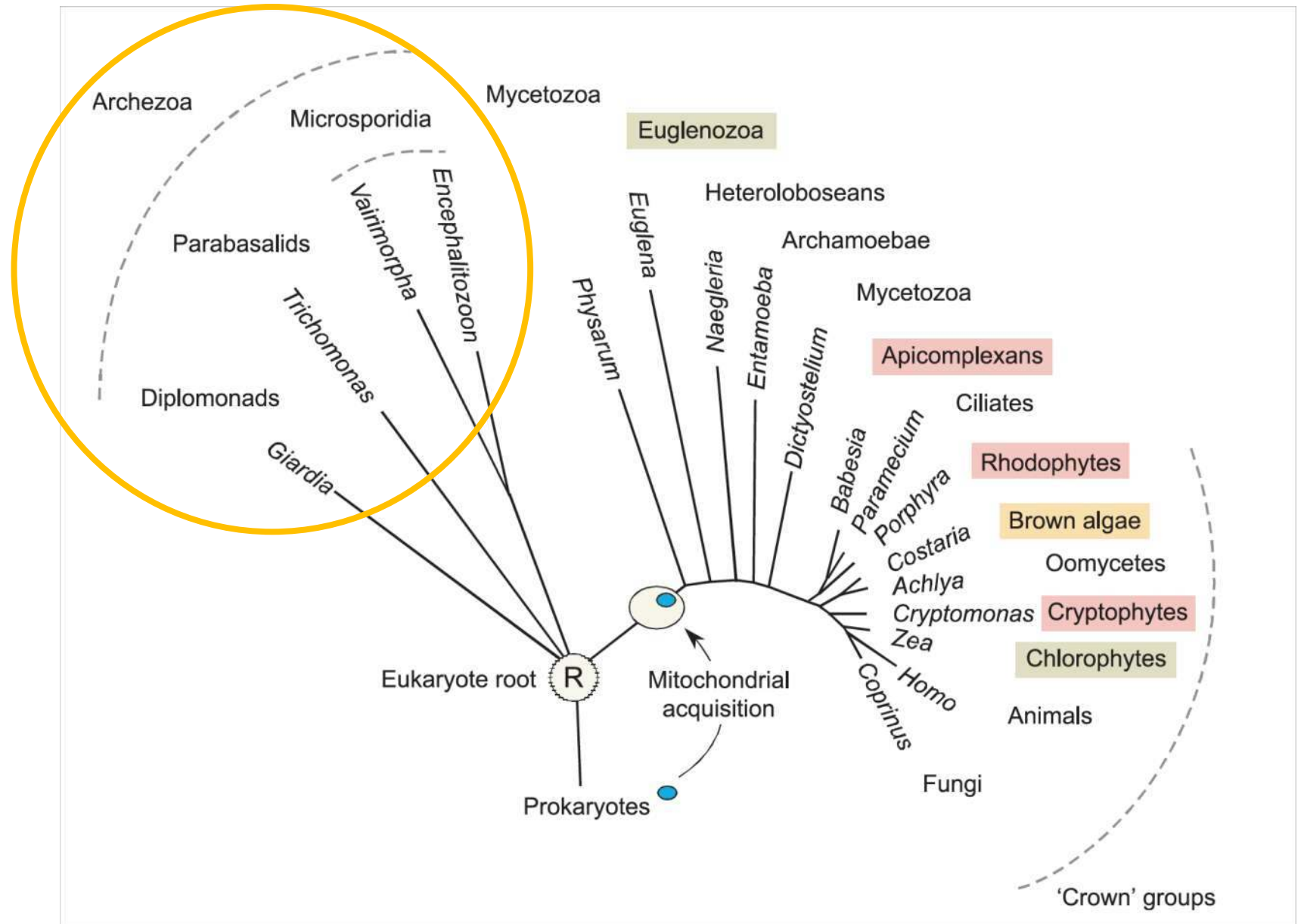
„mitochondria did not evolve from Rickettsiales or any other currently recognized alphaproteobacterial lineage. Rather, our analyses indicate that mitochondria evolved from a proteobacterial lineage that branched off before the divergence of all sampled alphaproteobacteria.”



Which came first nucleus or mitochondrion?

Archezoa hypothesis

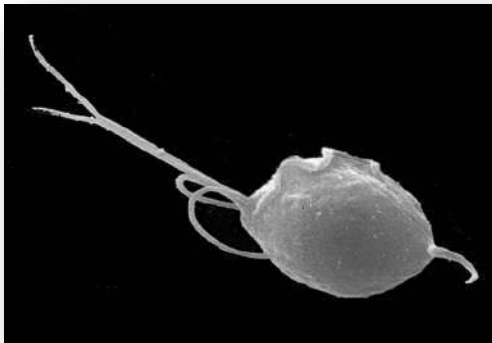
Cavalier-Smith, 1989



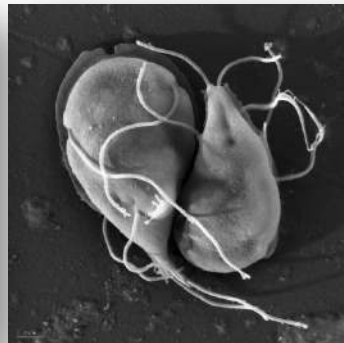
Embley and Martin (2006) Nature

Archezoa

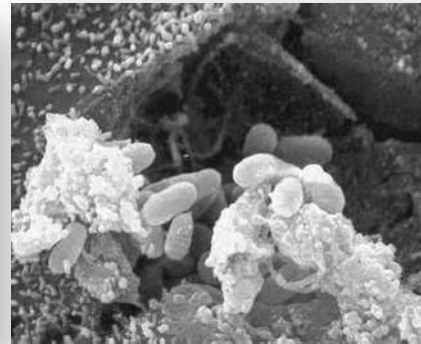
- early branching eukaryotes
- lack of introns
- no sexual reproduction
- lack of peroxisomes
- lack of Golgi apparatus
- lack of mitochondria



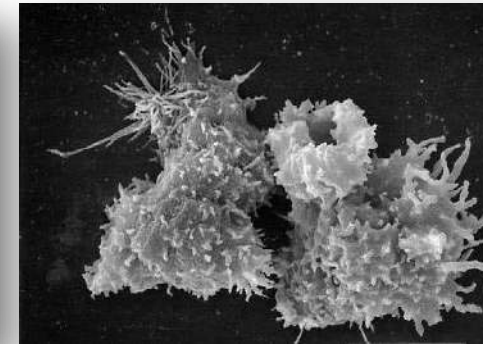
Trichomonas



Giardia

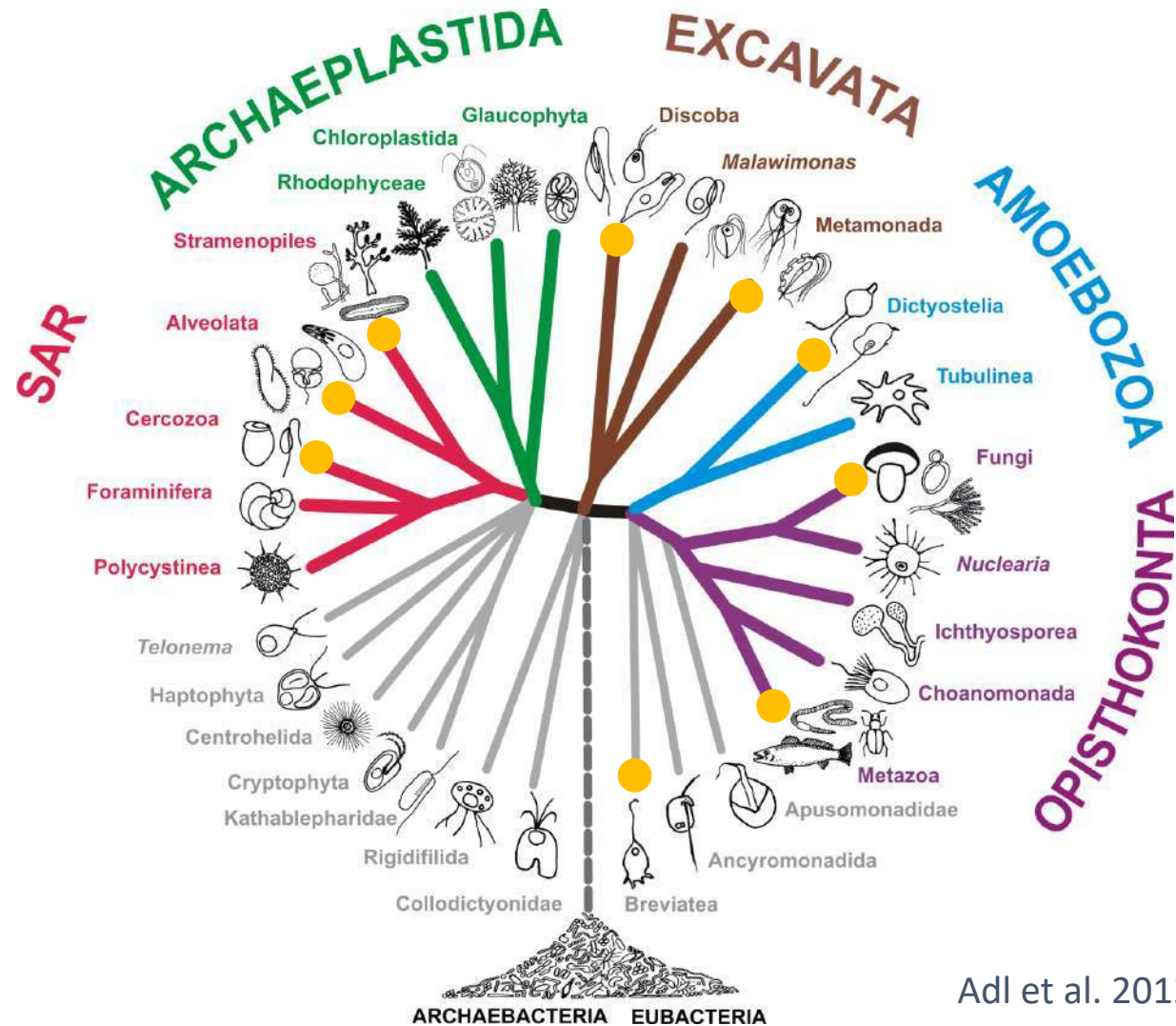
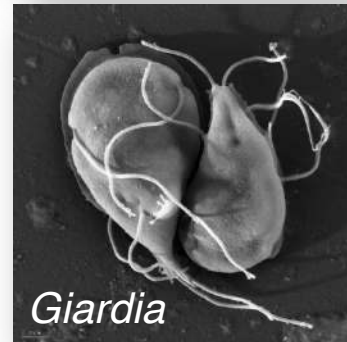
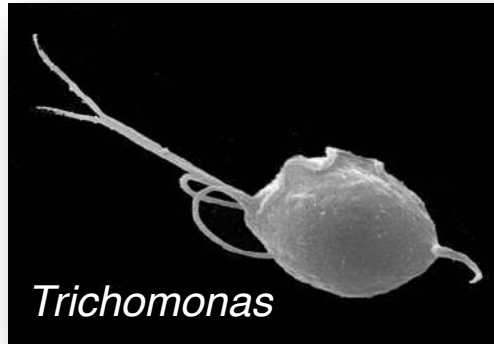


Microsporidia



Archamoebae

mitochondria related organelles (MROs) in eukaryotic microbes



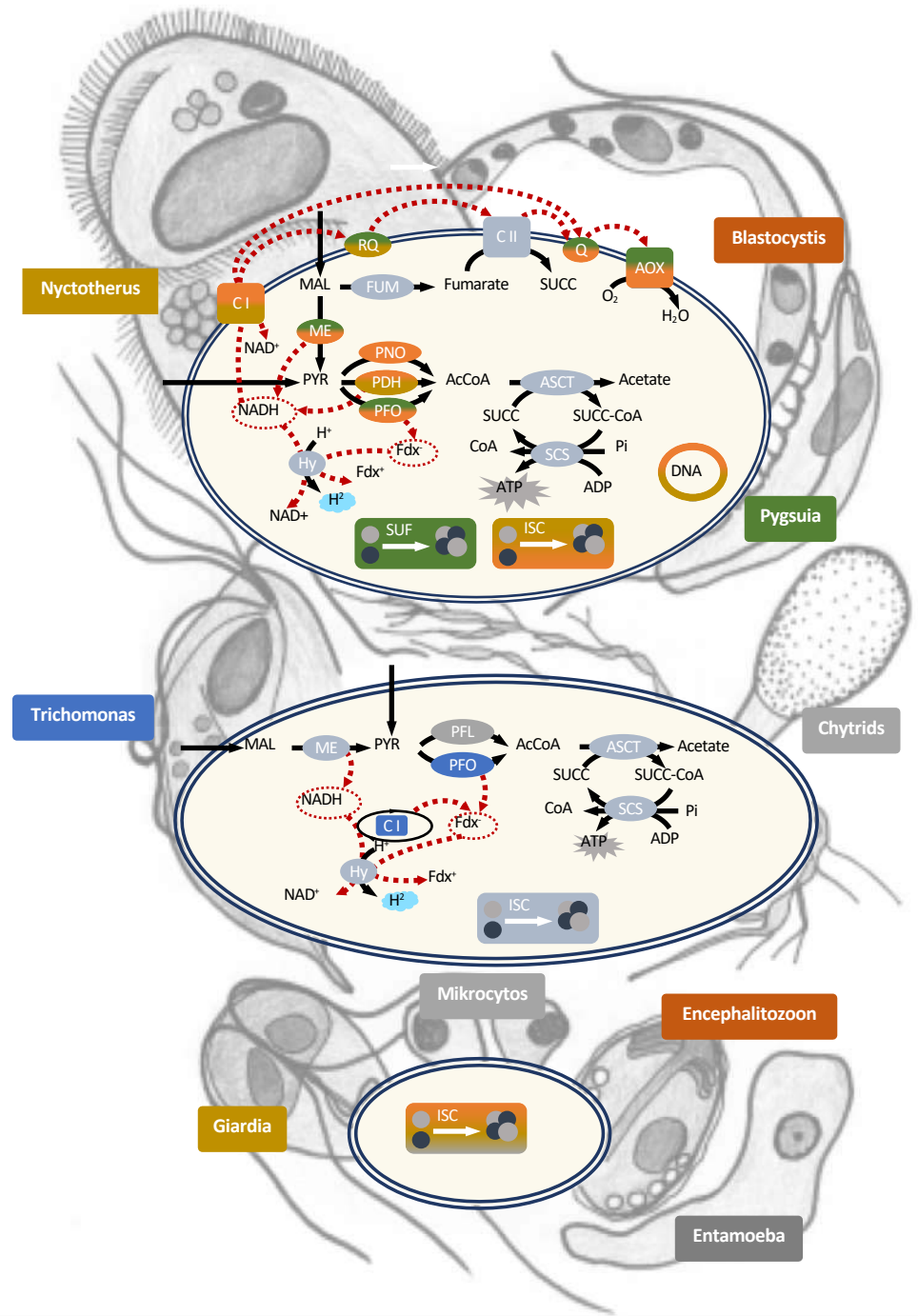
Adl et al. 2012

Hydrogen producing mitochondria

Hydrogenosomes

Mitosomes

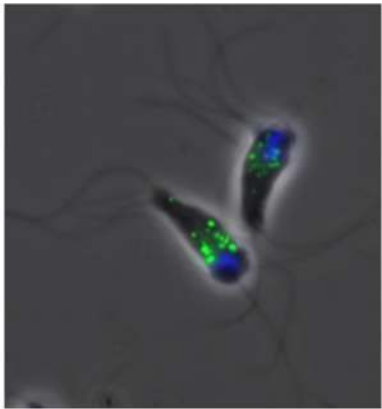
metabolic diversity of MROs



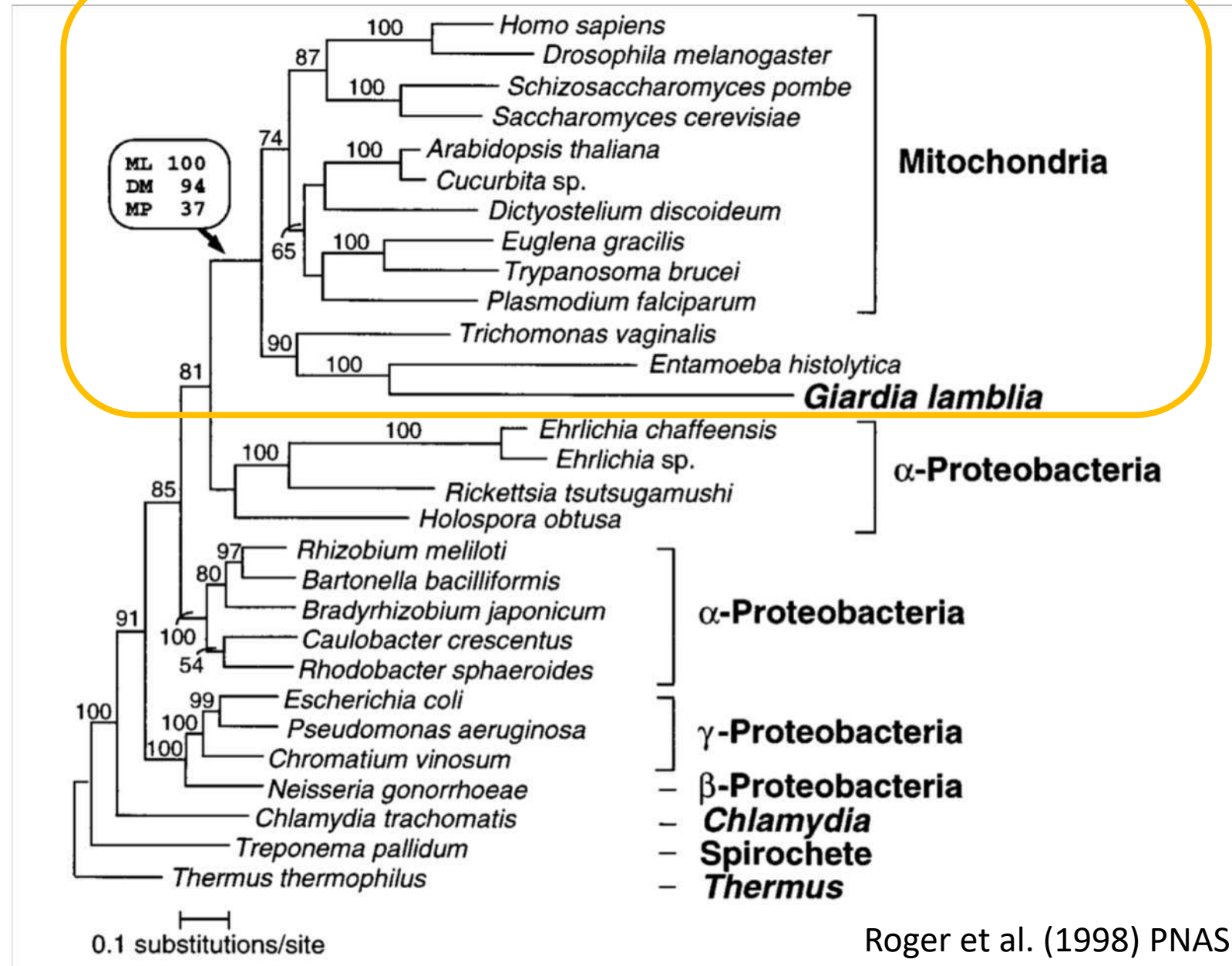
common origin of mitochondria and MROs

Cpn60 chaperonin

- mitochondrial chaperonins
- ATP transporters
- mitochondrial membrane transport proteins
- Fe-S cluster assembly proteins



cpn60 localization
Jerlström-Hultqvist et al. 2013



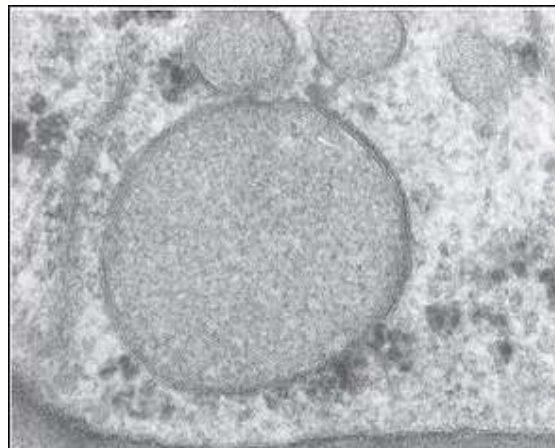
Archezoa hypothesis rejected

- All “archezoa” possess:
 - mitochondrial genes in nuclear genomes
 - degenerate derivatives of mitochondria
 - they do not group together on the modern tree of life

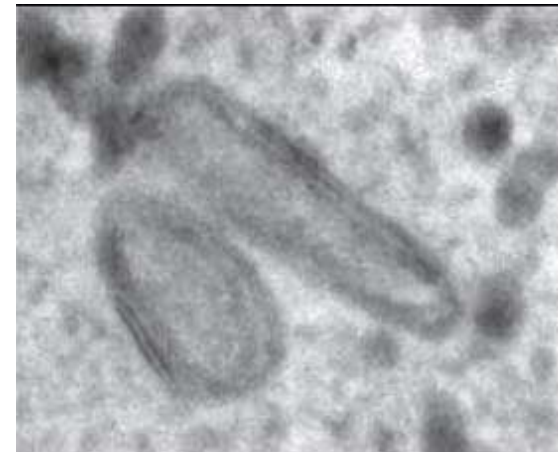
Common ancestor of all eukaryotes possessed mitochondria



mitochondrion

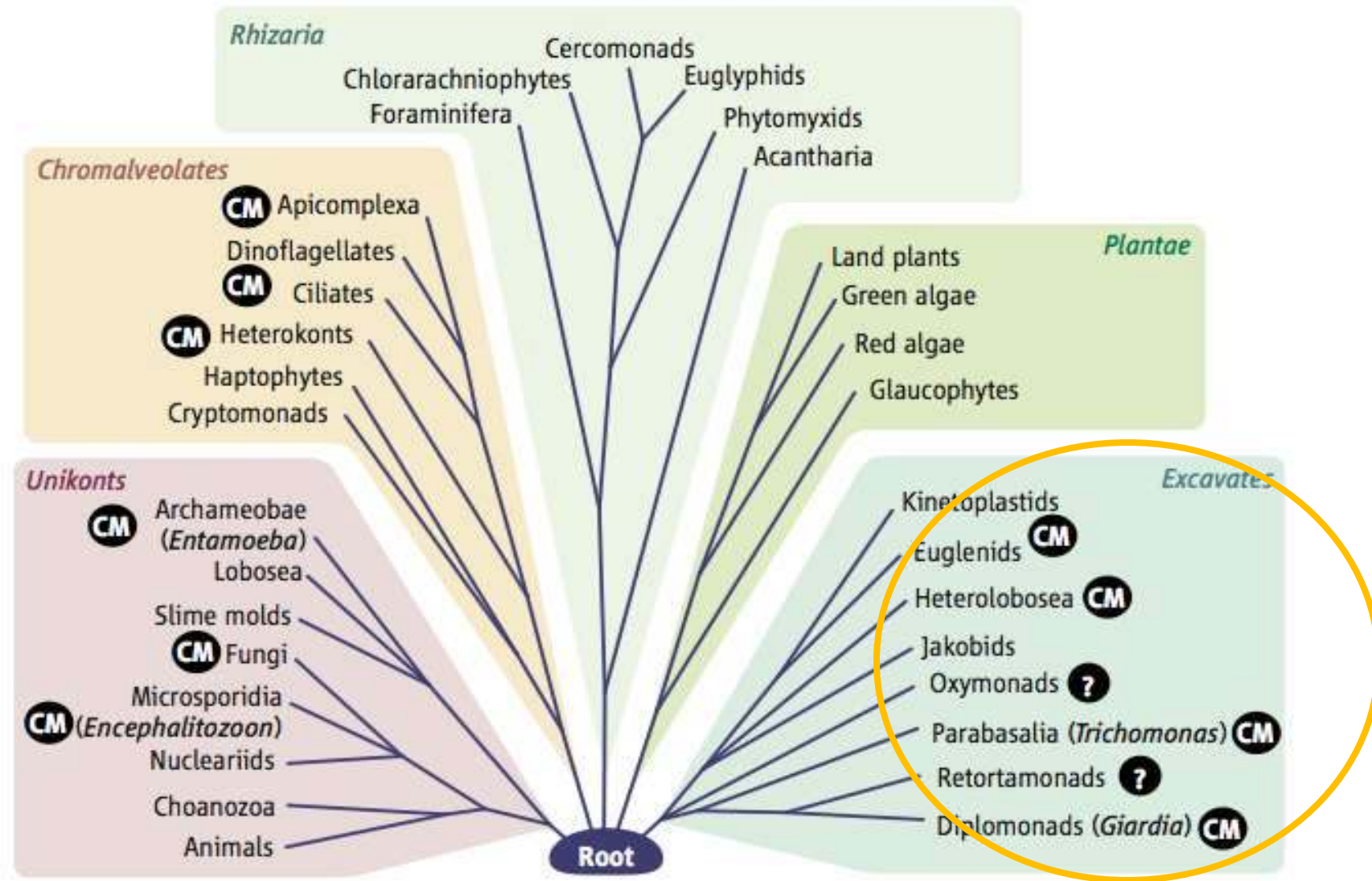


hydrogenosome



mitosomes

Does amitochondriate eukaryote exist?

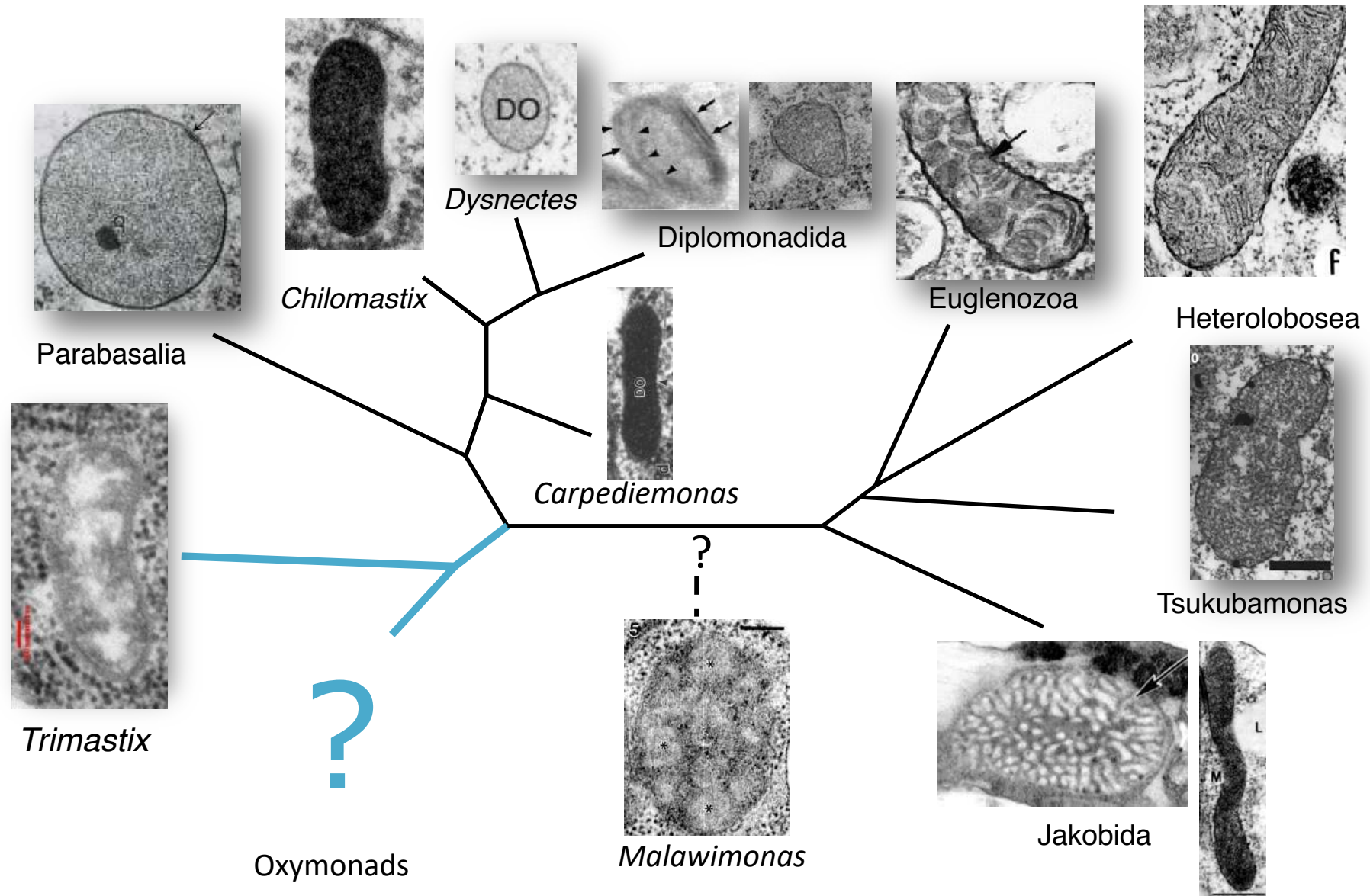


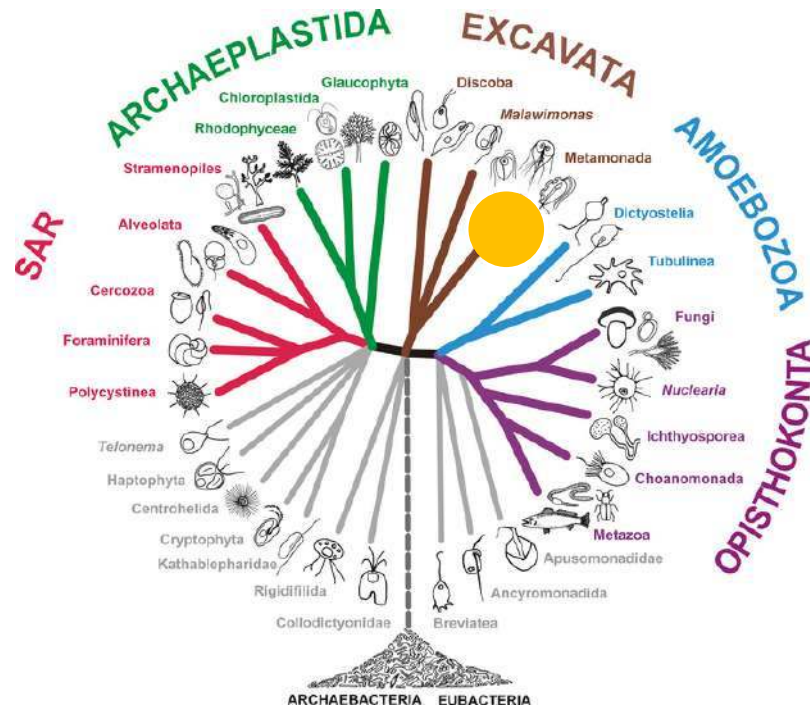
CM

cryptic mitochondria

Keeling, 2007

mitochondria in Excavata





Metamonada

Parabasalia (*Trichomonas*)

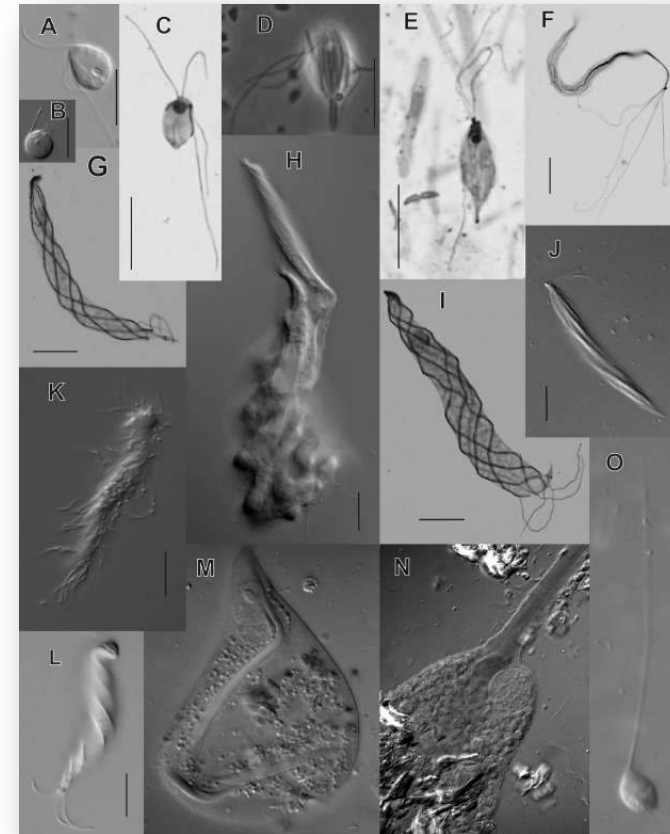
Fornicata (*Giardia*)

Preaxostyla

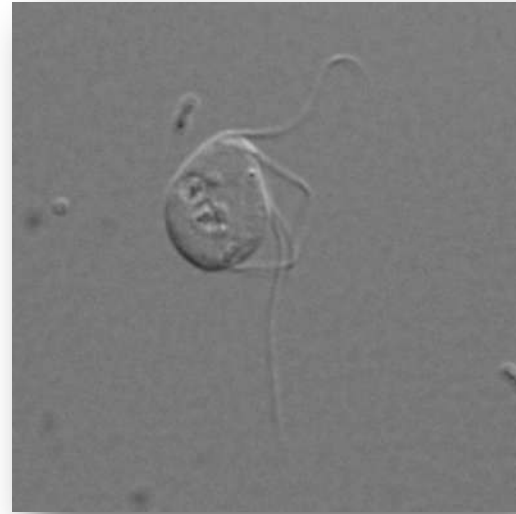
Trimastix

oxymonads

- found in the intestinal tracts of termites, insects, and vertebrates
- sexual reproduction debatable
- no peroxisomes
- no Golgi apparatus
- no mitochondria



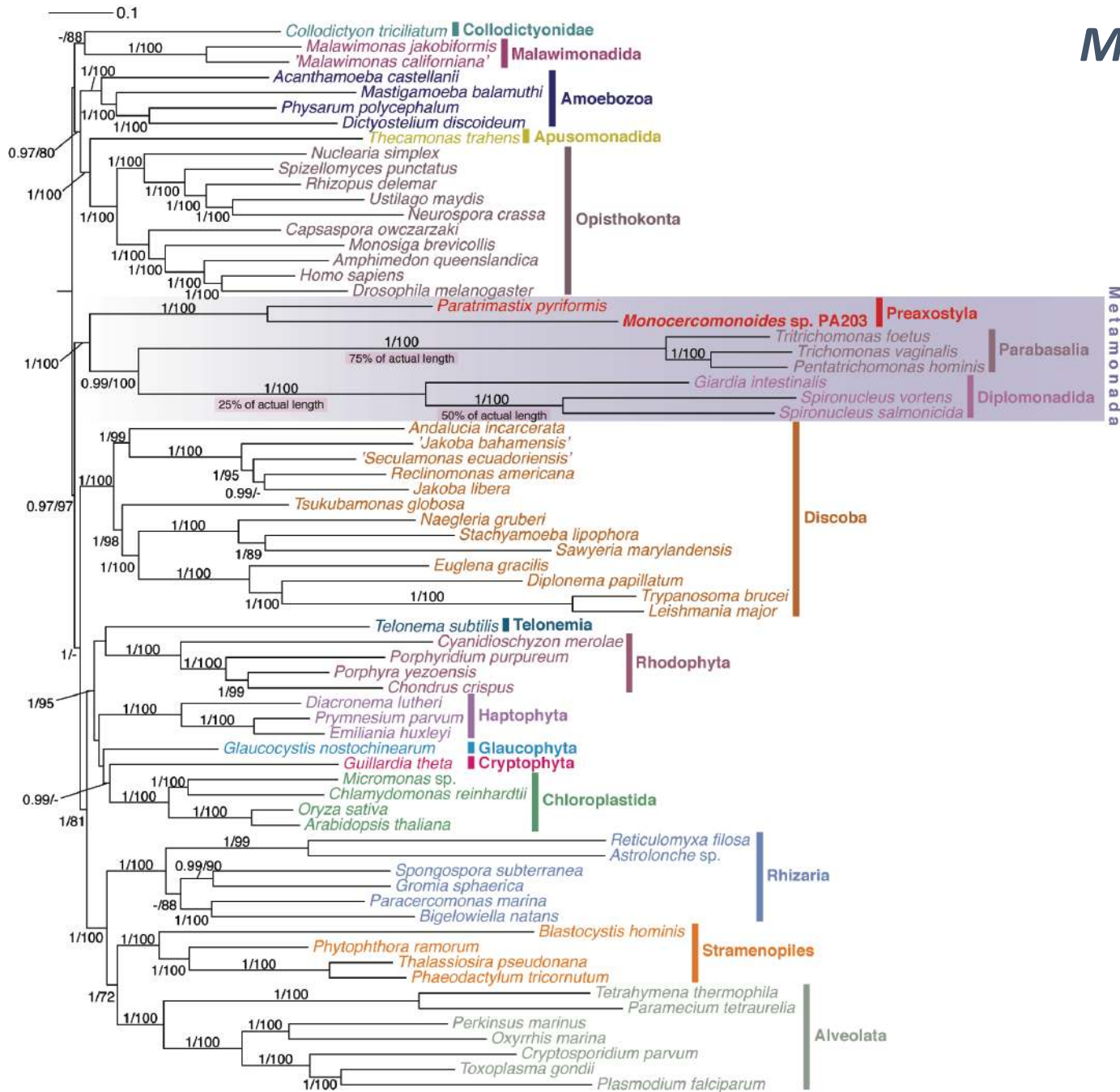
Monocercomonoides microaerophilic, commensal of animals



Genome analysis

- intron rich
- meiotic toolkit present
- no stacked Golgi, but most of the proteins present
- lack peroxisomes
- genome exhibit most of the typical eukaryotic features

Monocercomonoides is less divergent than Parabasalids and Diplomonads

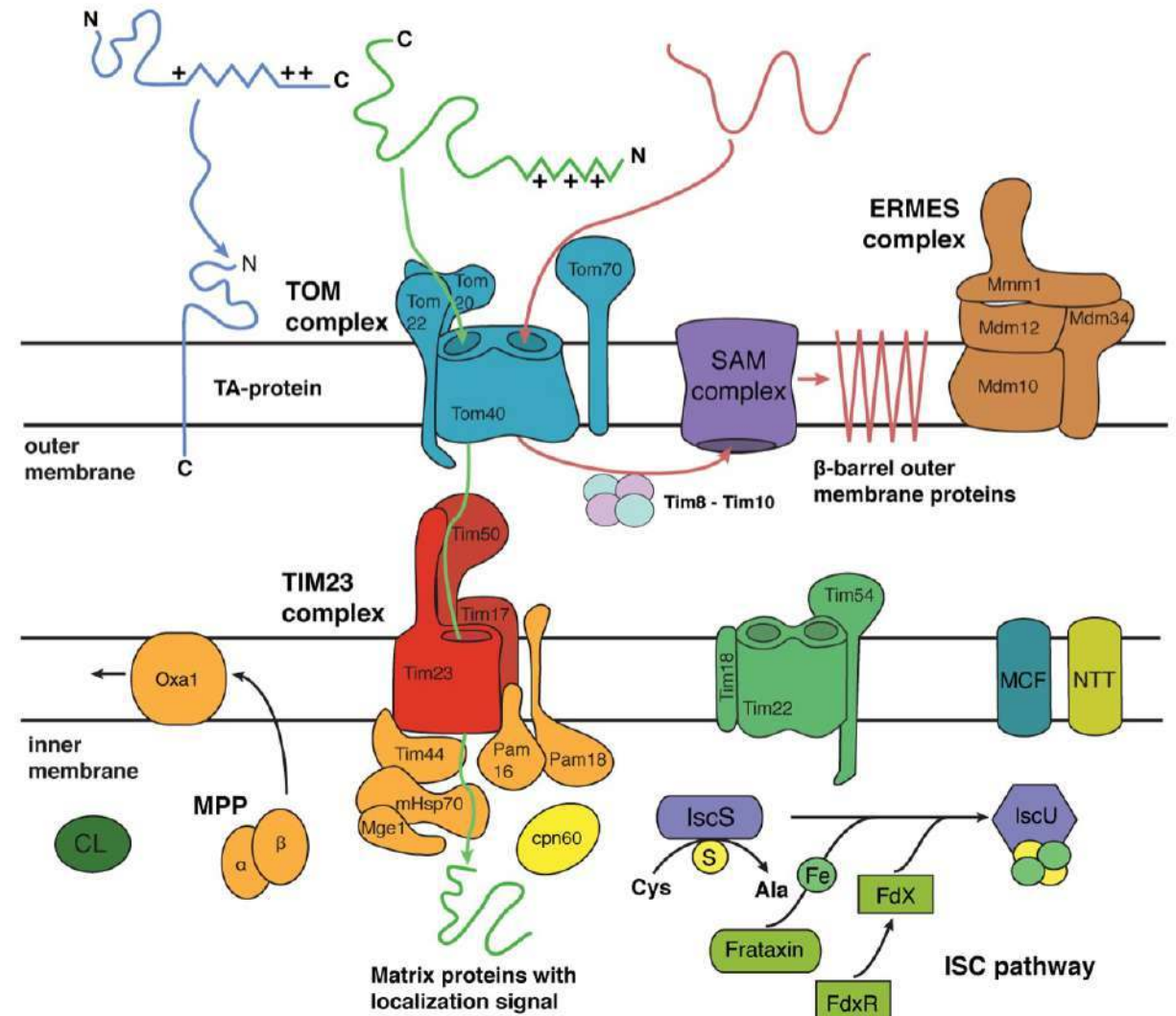


Searching for mitochondrial proteins

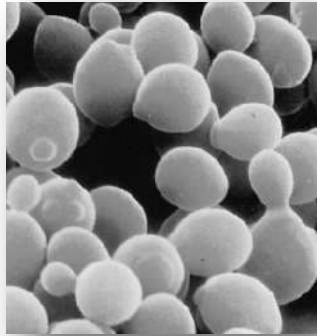
Mitochondrial outer membrane targeted proteins (TA)

Proteins with mitochondrial localization signal

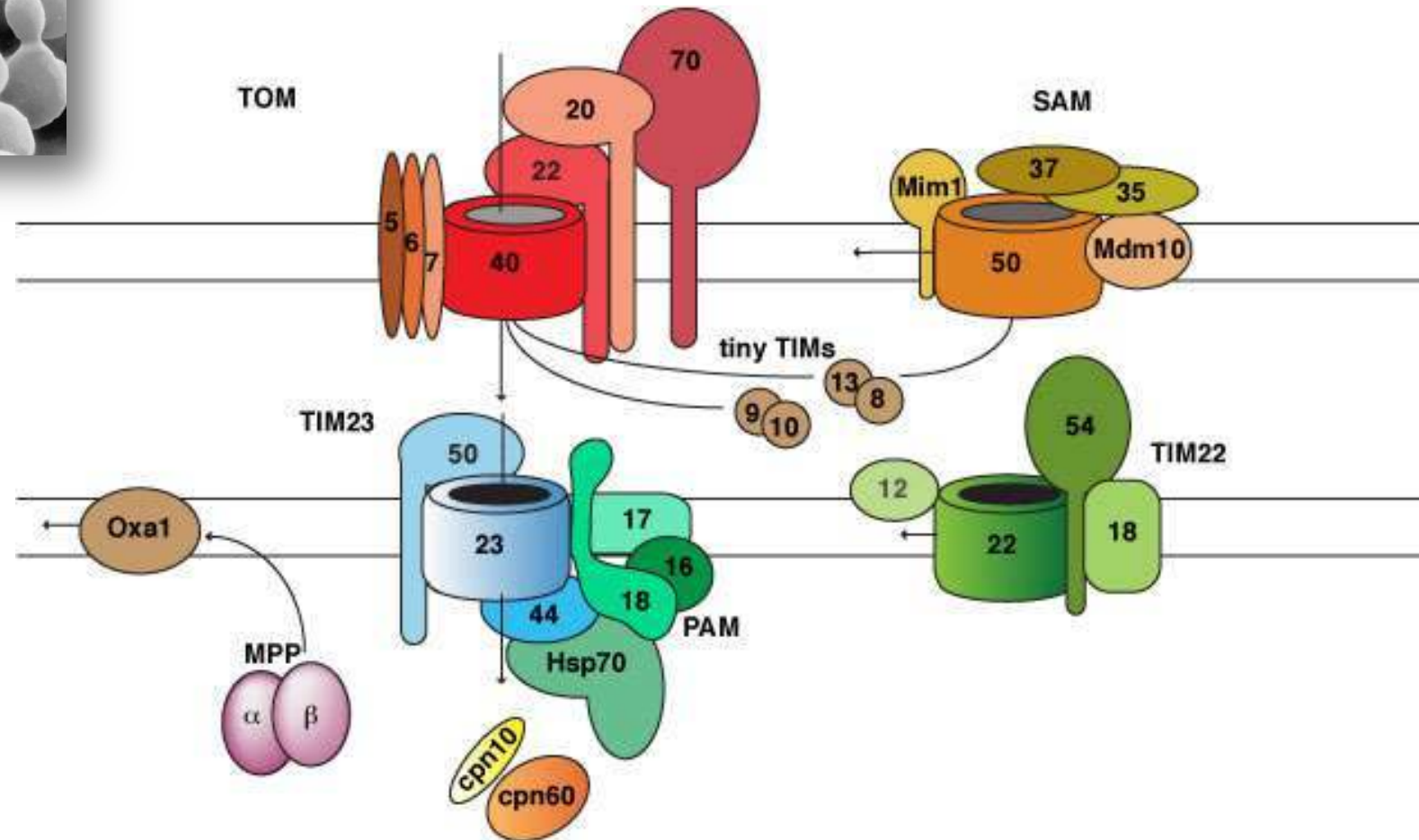
β -barrel mitochondrial outer membrane proteins



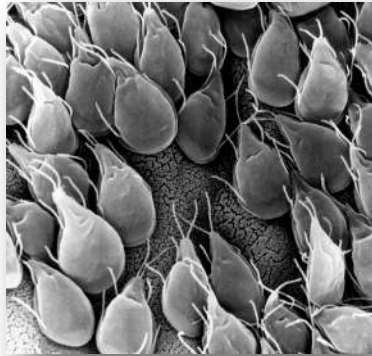
mitochondrial membrane transport proteins



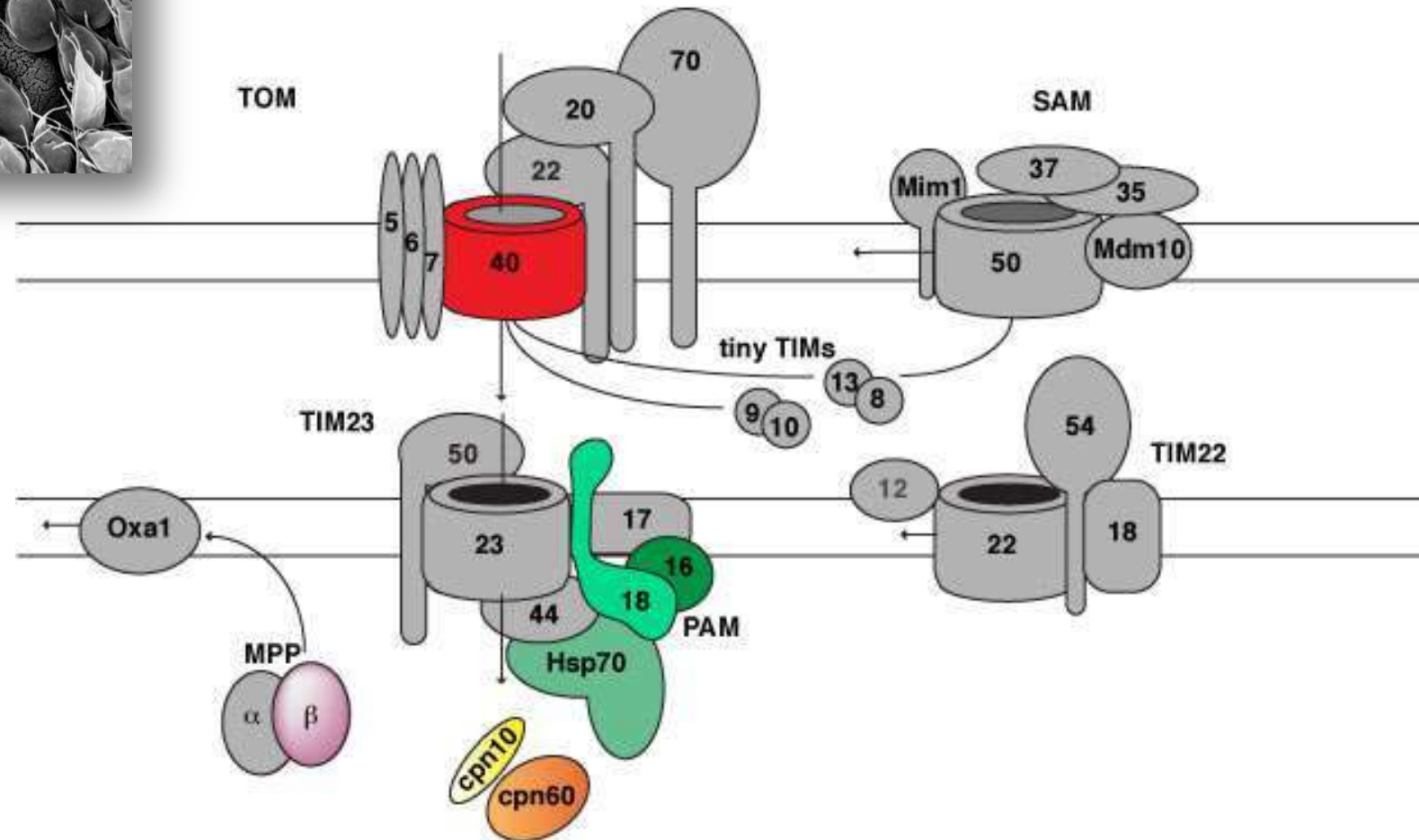
yeast



mitochondrial membrane transport proteins



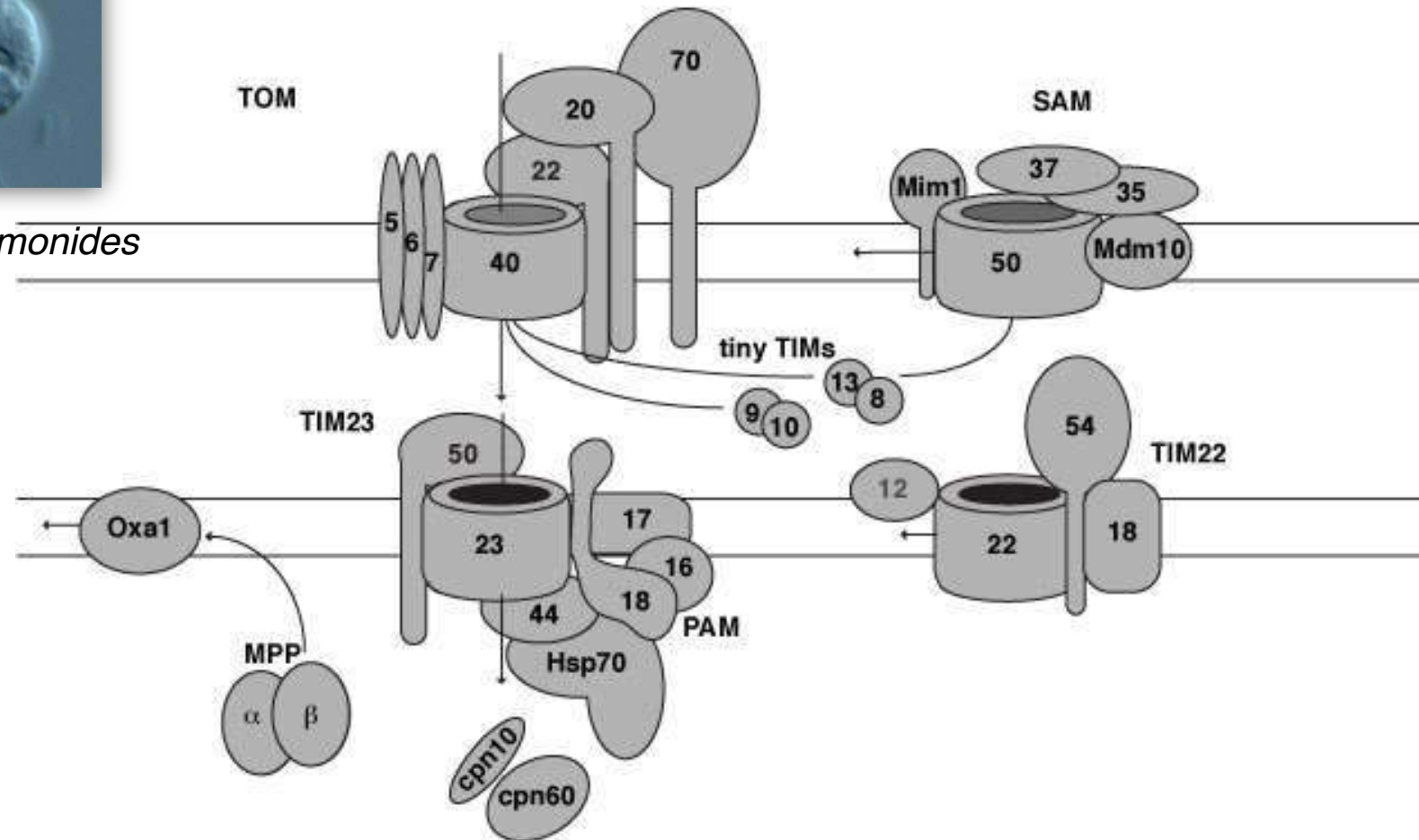
Giardia



mitochondrial membrane transport proteins



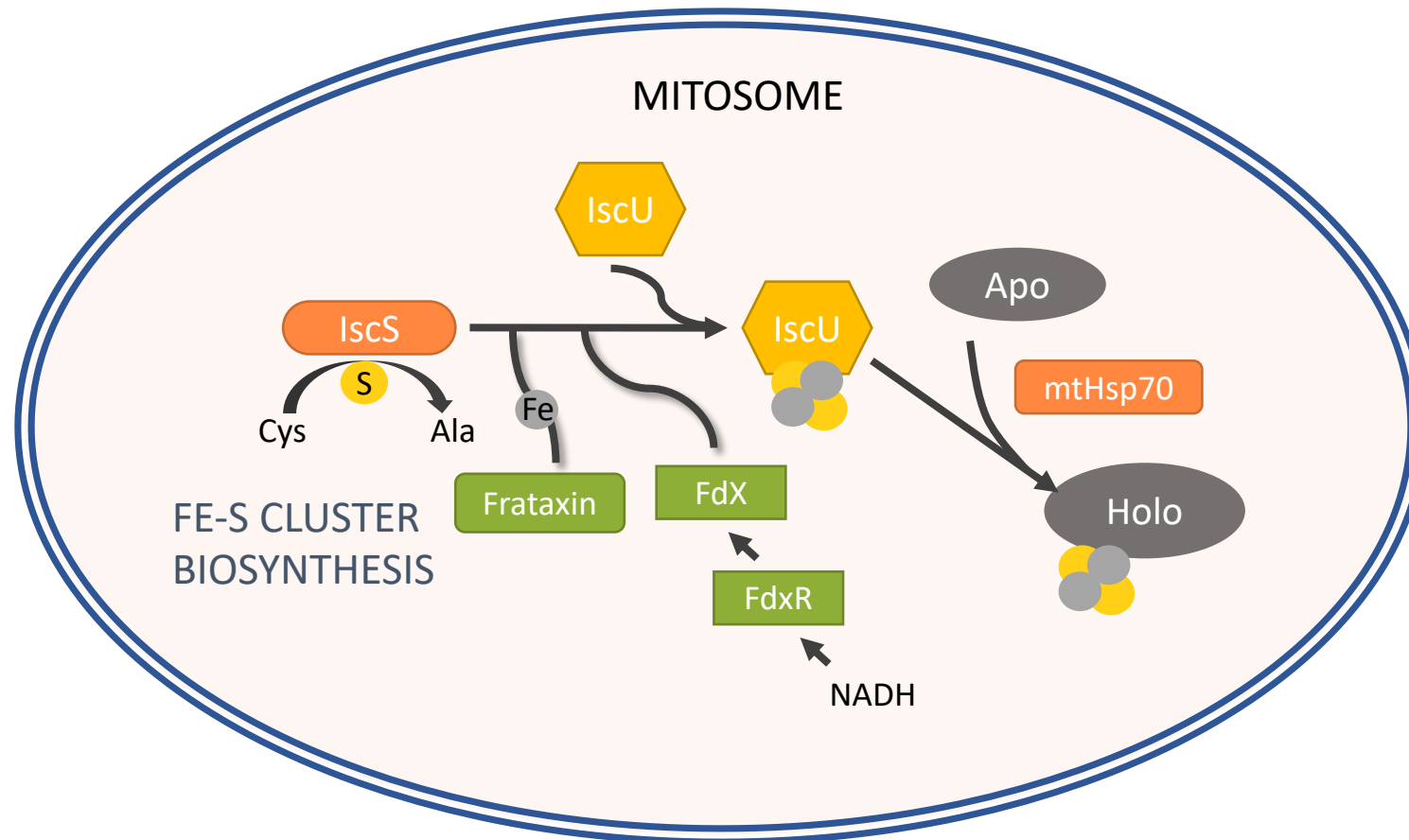
Monocercomonoides



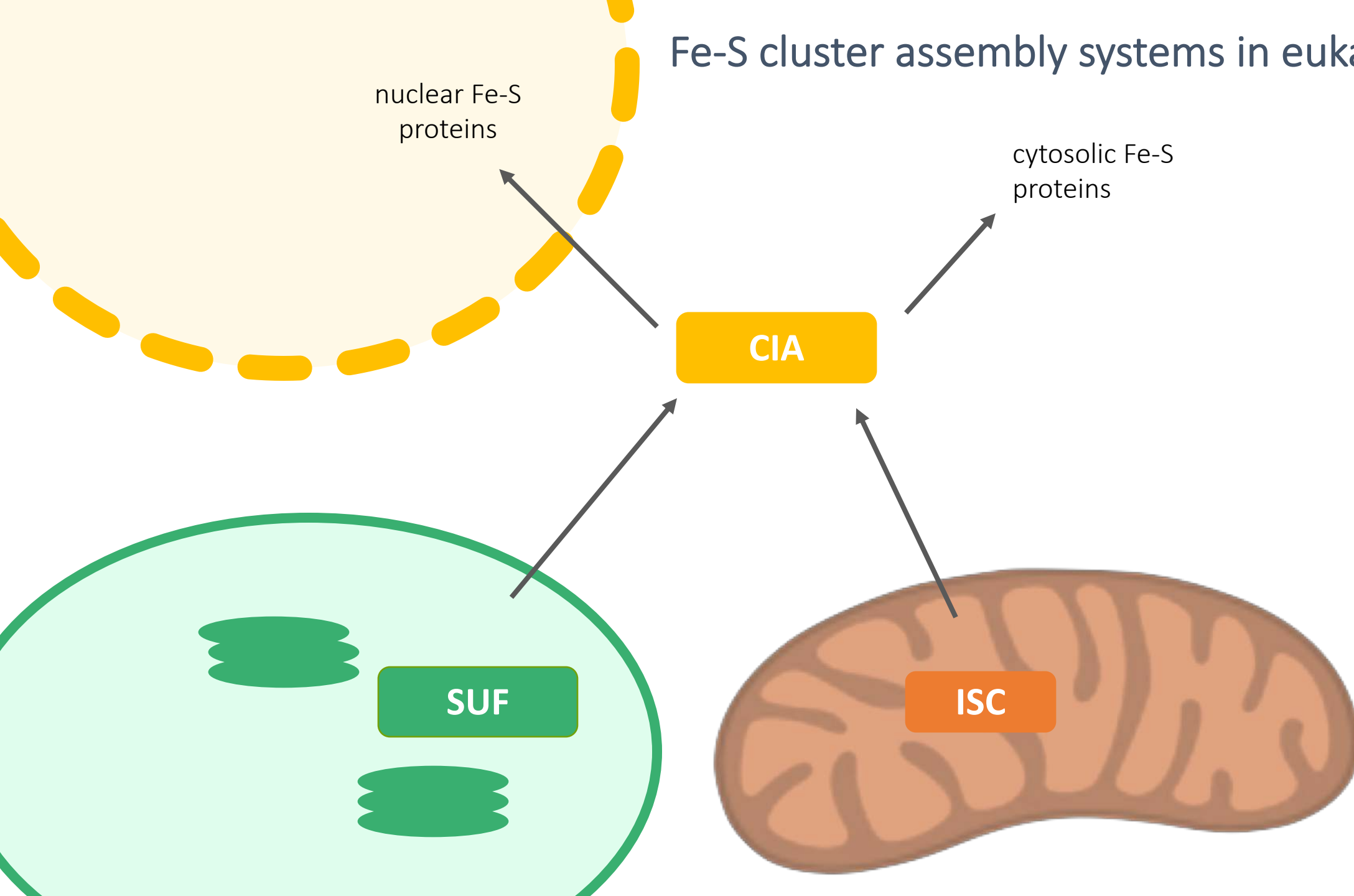
Fe-S cluster assembly

the most conserved mitochondrial process

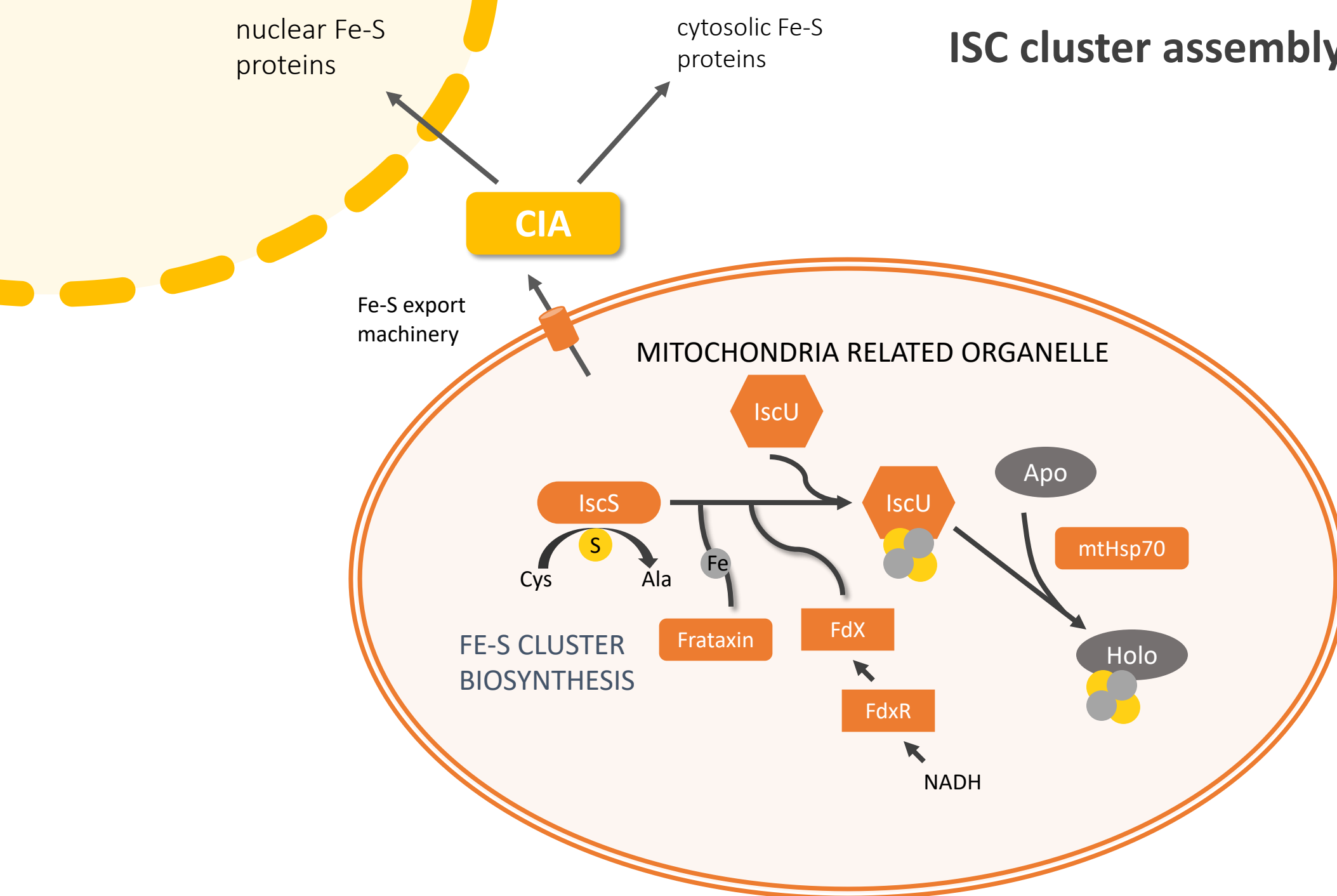
- Fe/S proteins are essential for viability
- they are involved in: DNA repair, DNA replication, ribosome assembly



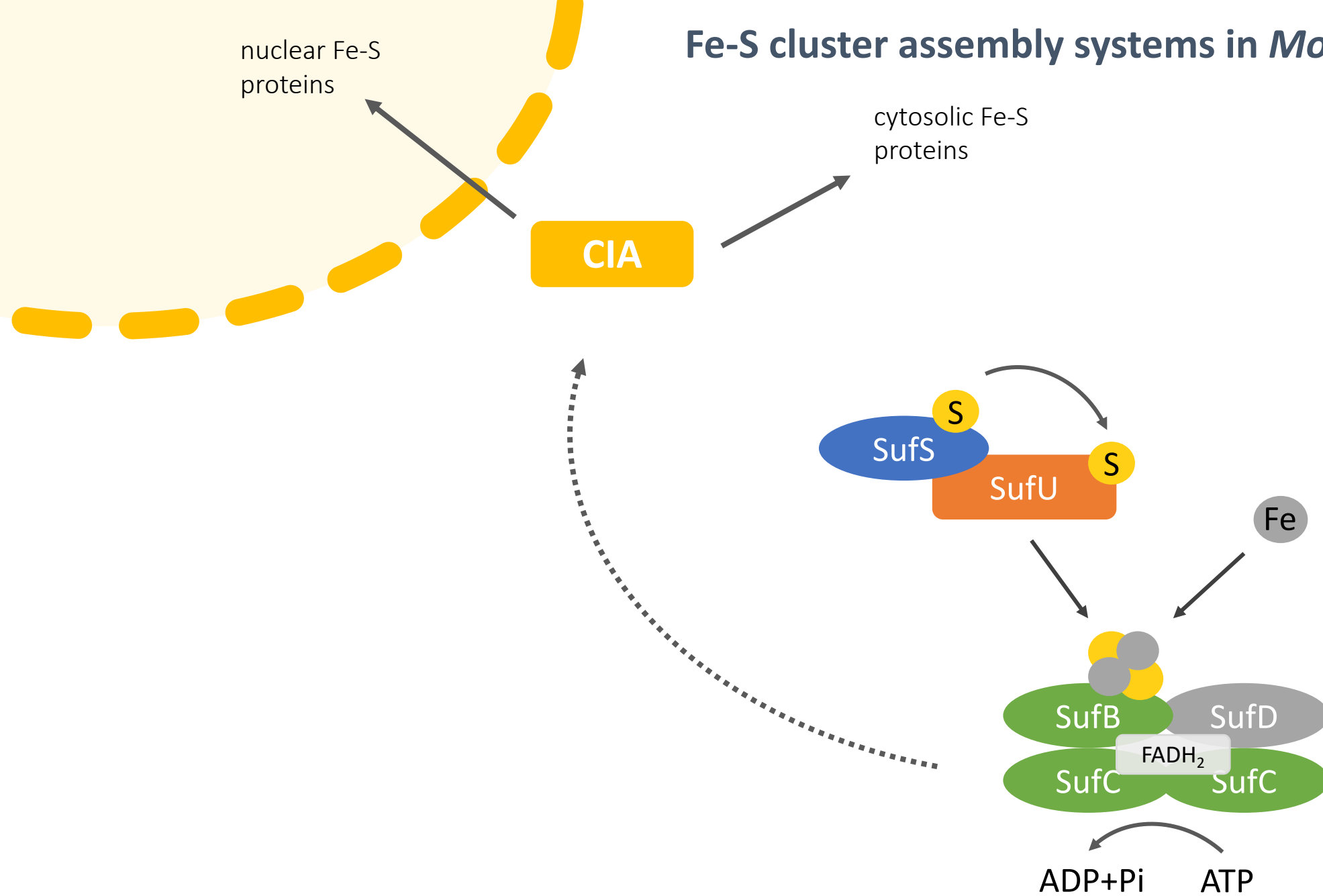
Fe-S cluster assembly systems in eukaryotes



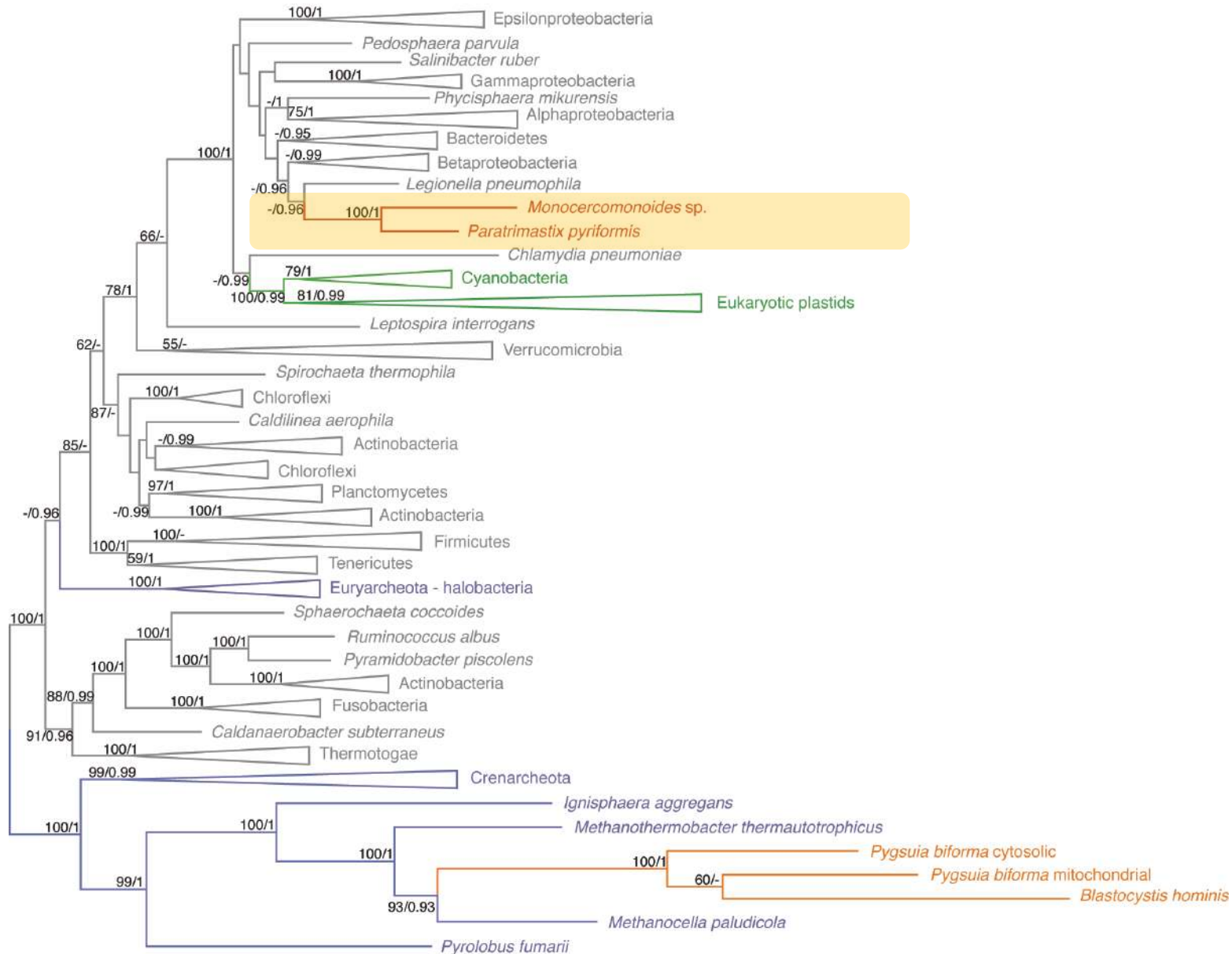
ISC cluster assembly system

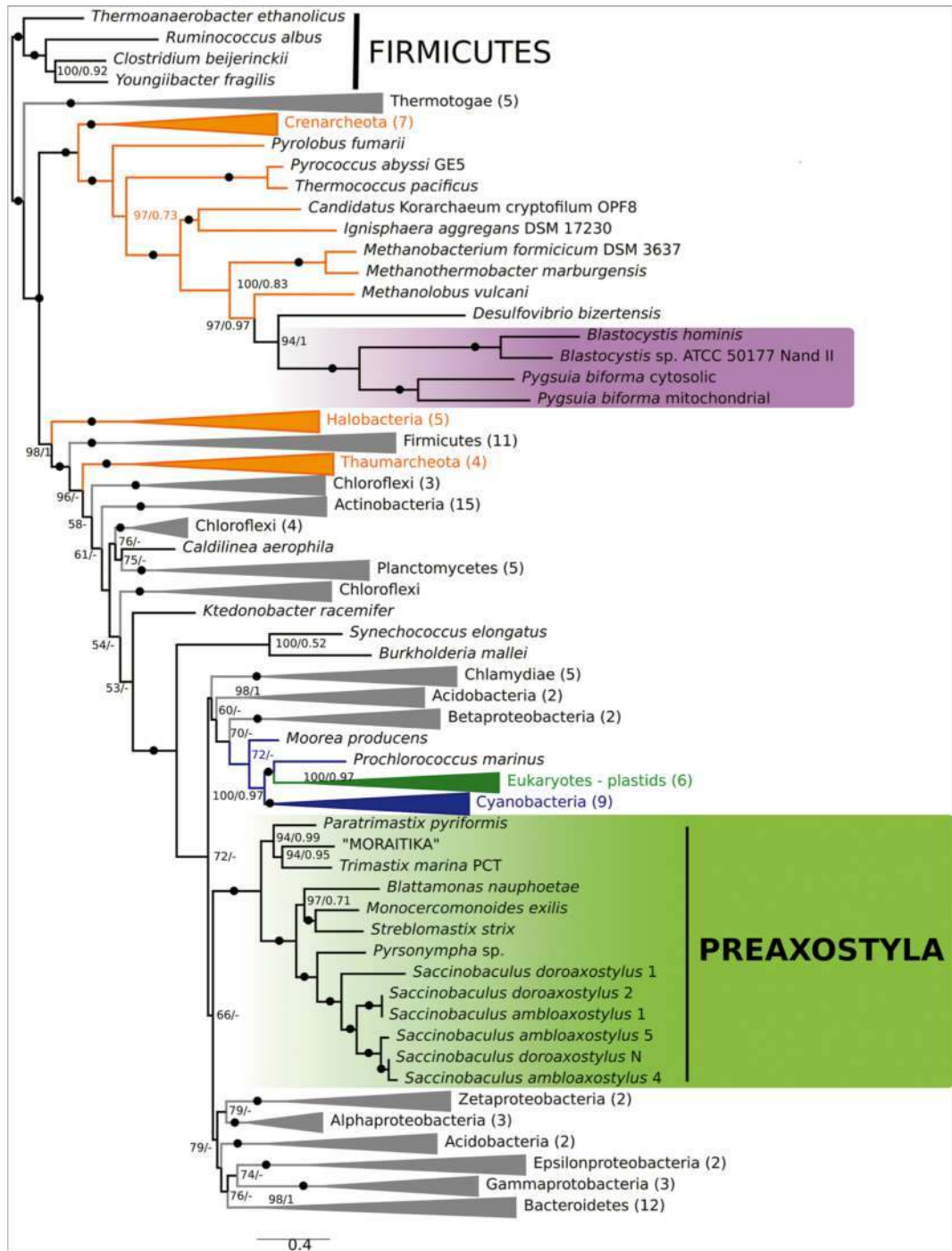


Fe-S cluster assembly systems in *Monocercomonoides*

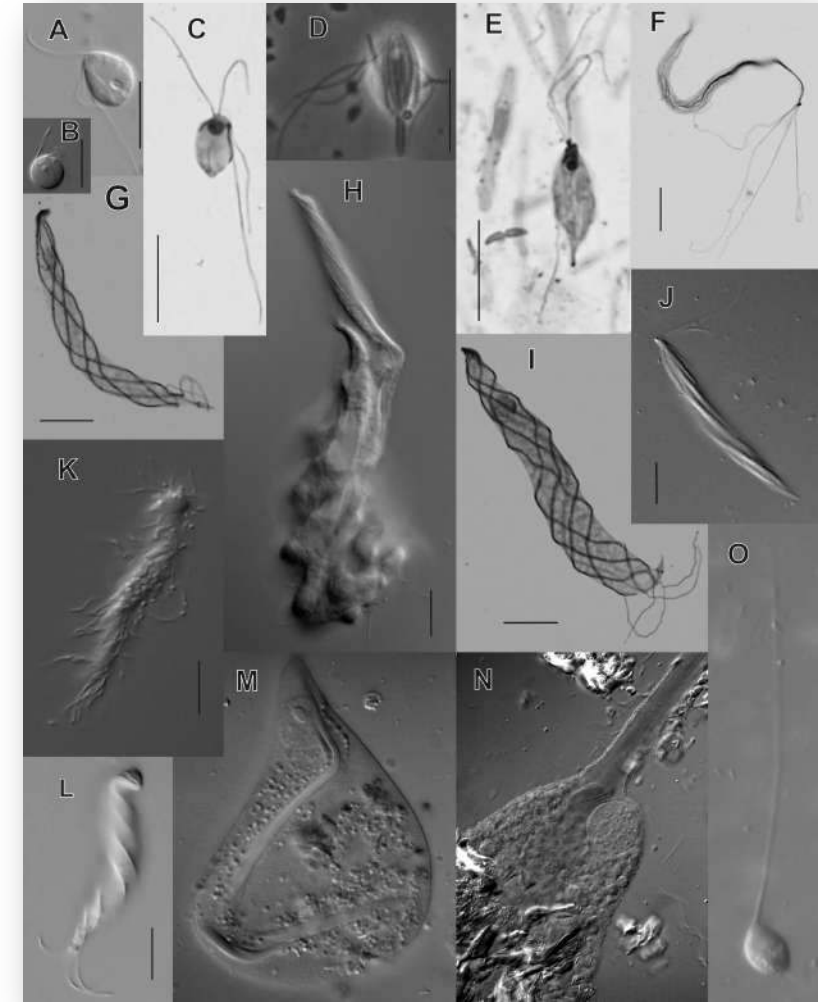


Lateral gene transfer (LGT) of SUF system

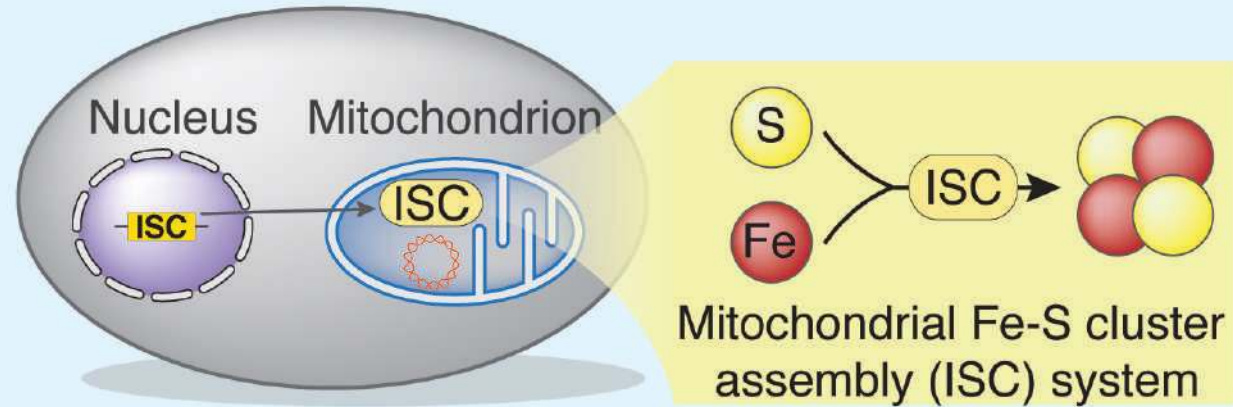




SUF system is widespread in Preaxostyla

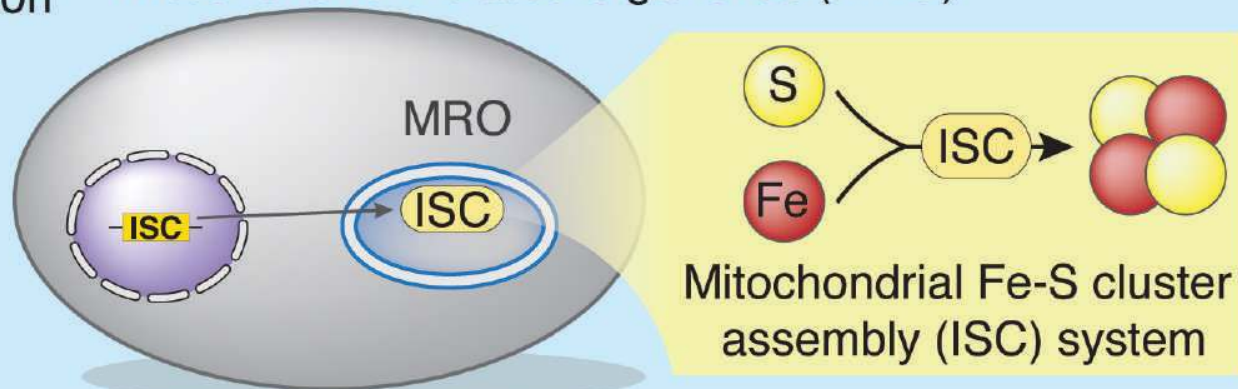


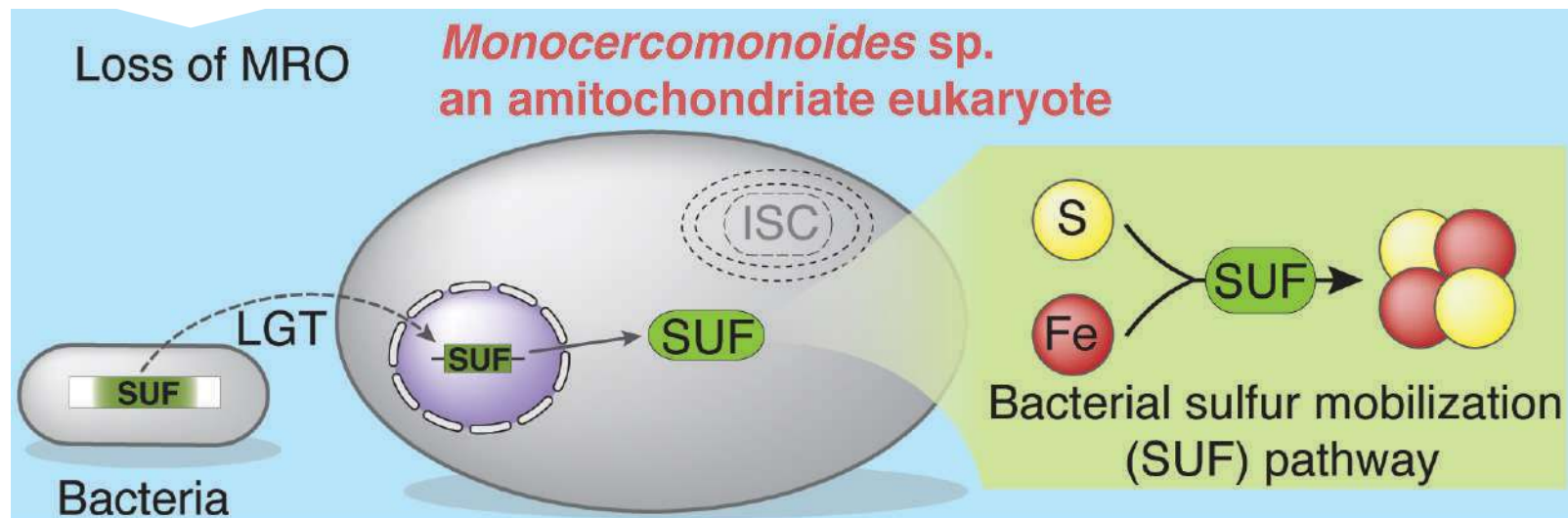
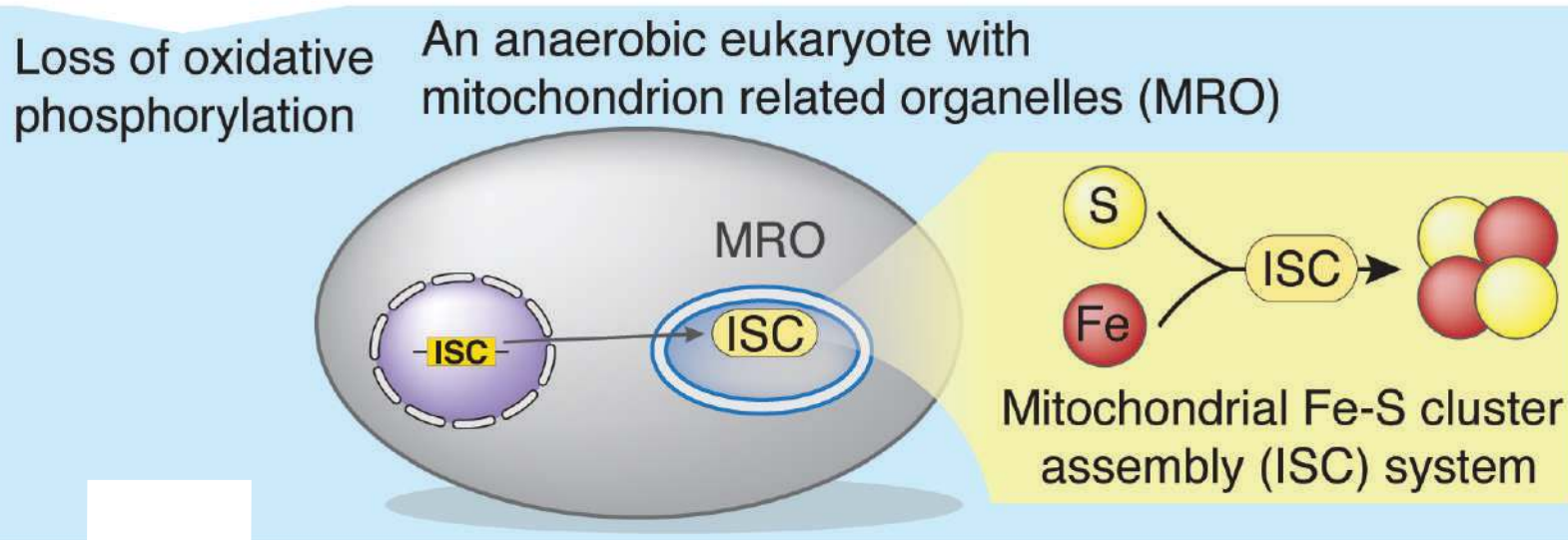
A eukaryotic cell with typical mitochondria



Loss of oxidative phosphorylation

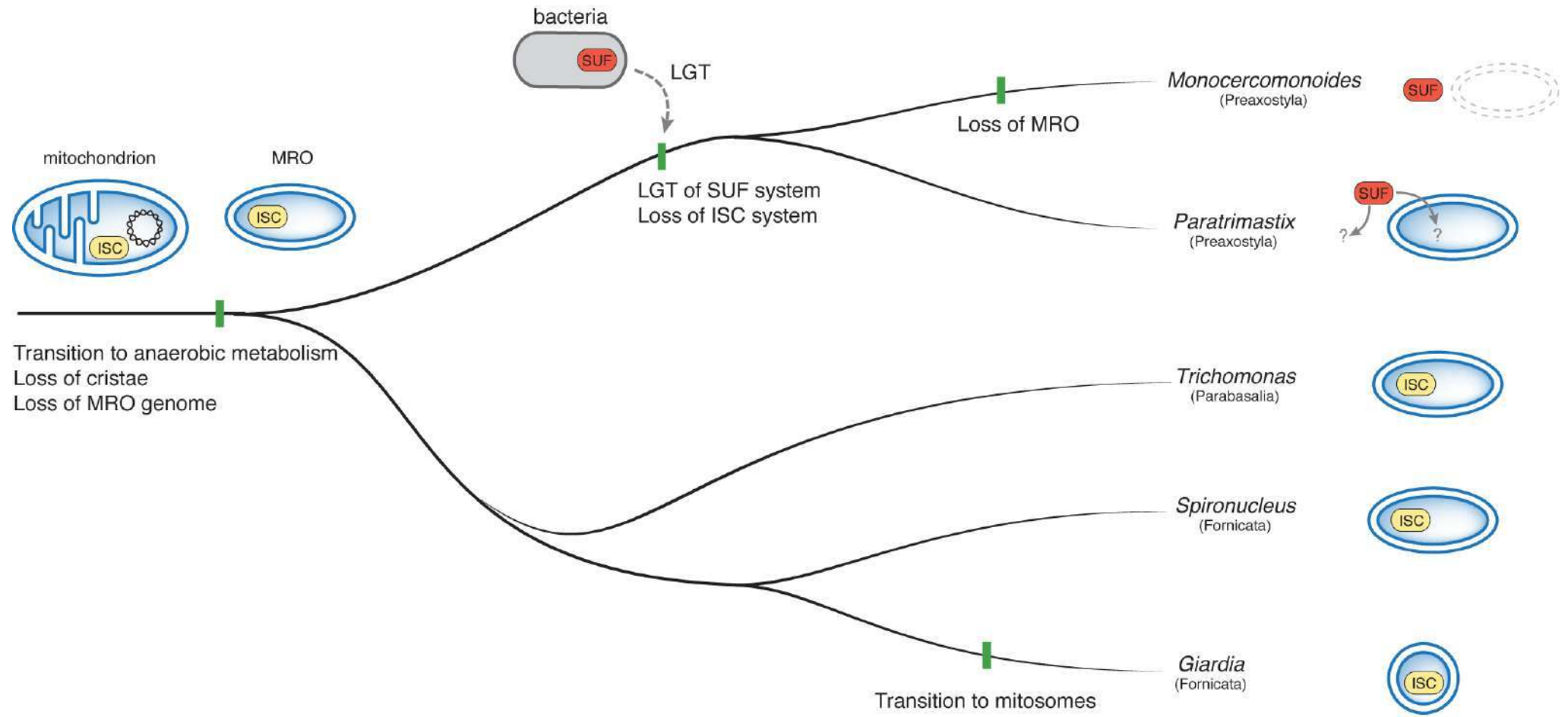
An anaerobic eukaryote with mitochondrion related organelles (MRO)





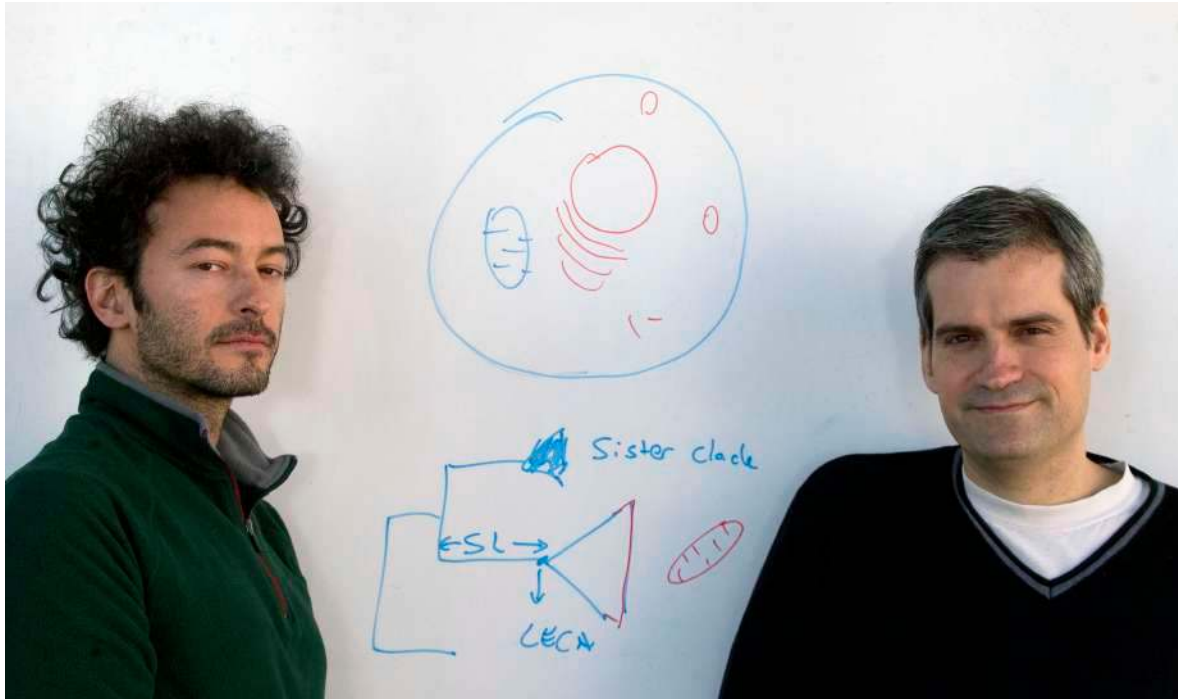
loss of a mitochondrial organelle

LGT of **SUF** system resulted in relocation of the pathway to the cytosol



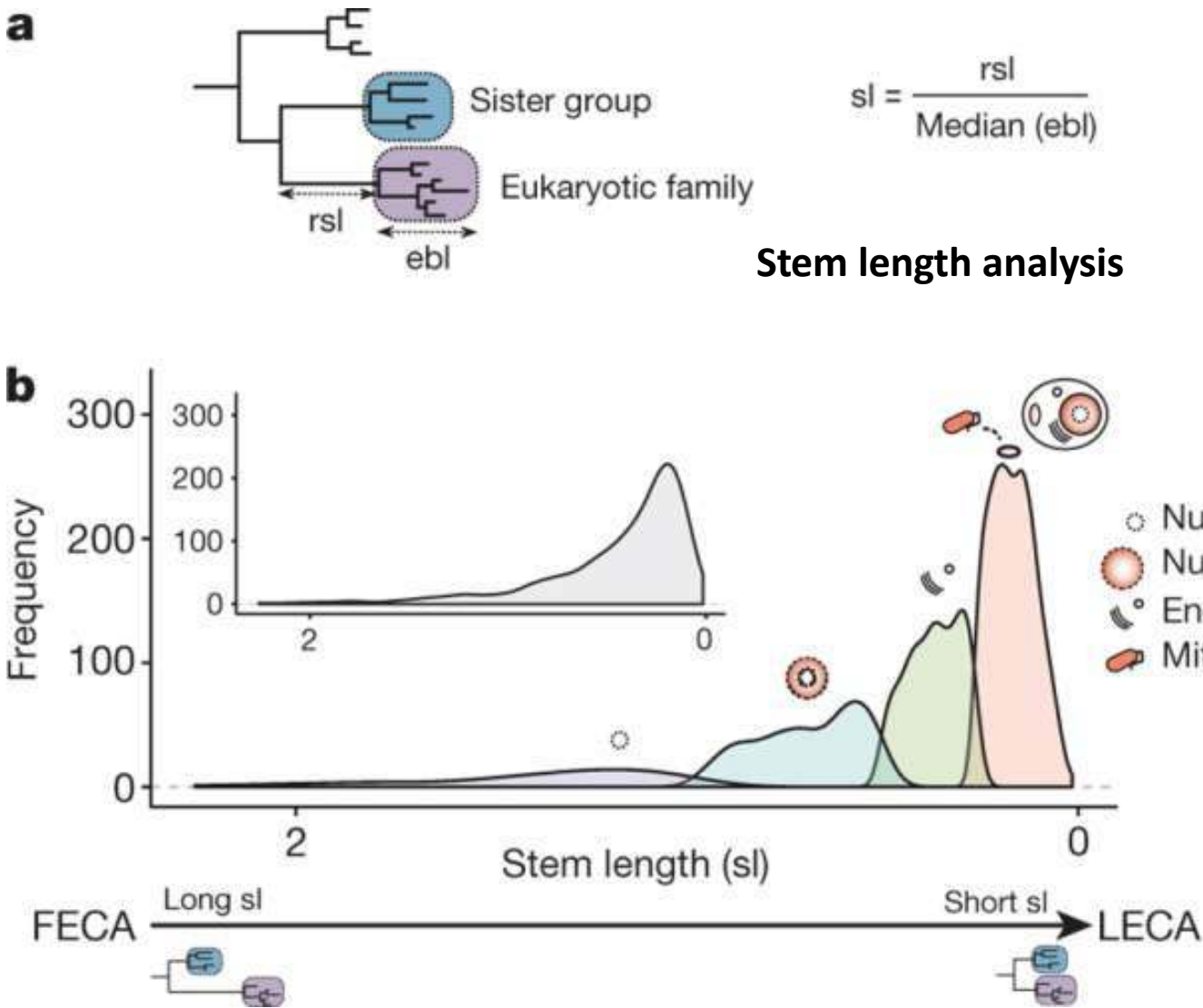
Endosymbiosis can be undone!

Which came first nucleus or mitochondrion?



Late acquisition of mitochondria

LECA protein families of alphaproteobacterial ancestry and of mitochondrial localization show the shortest phylogenetic distances to their closest prokaryotic relatives, compared with proteins of different prokaryotic origin or cellular localization.



The great advances in our understanding of the evolution of eukaryotic cell are coming from the species discovery and biological observations.

Genomics and phylogenomics are very powerful methods, which help to understand the evolution of eukaryotes.

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