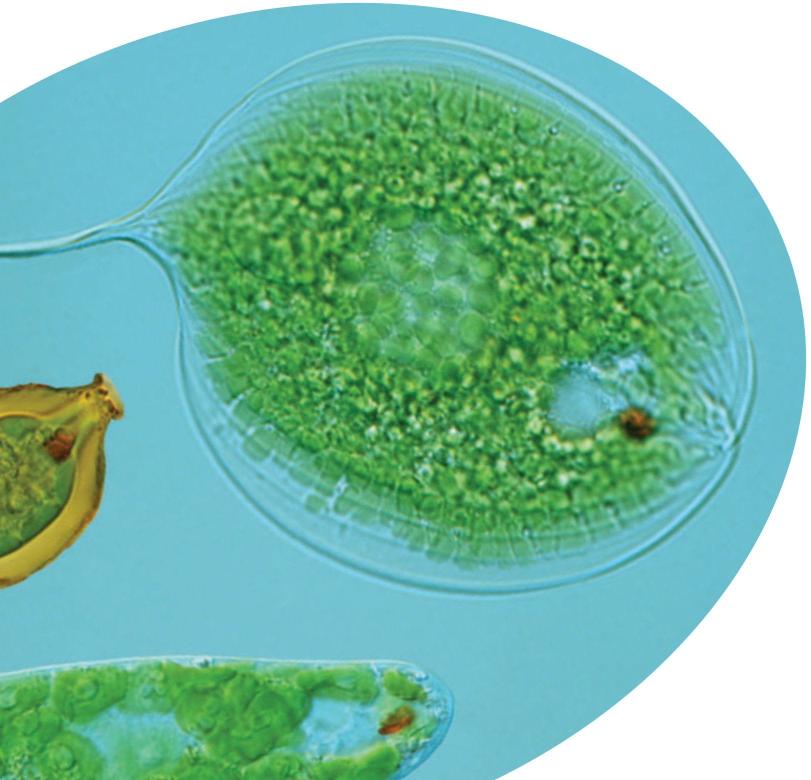
UNIVERSITY OF WARSAW

University of Warsaw Biological and Chemical Research Centre

Evolution of eukaryotic cell

genomics, phylogenomics & biology



Anna Karnkowska

Department of Molecular Phylogenetics and Evolution

University of Warsaw
Biological and Chemical
Research Centre

about me

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

PhD
2011

UNIVERSITY OF WARSAW

Workshop on genomics
student

Post-doc
2013

CHARLES UNIVERSITY IN PRAGUE

Workshop on molecular evolution
student

Post-doc
2016

UBC

Workshop on genomics
TA

Assistant Professor
2017

UNIVERSITY OF WARSAW

Workshop on phylogenomics
Co-director

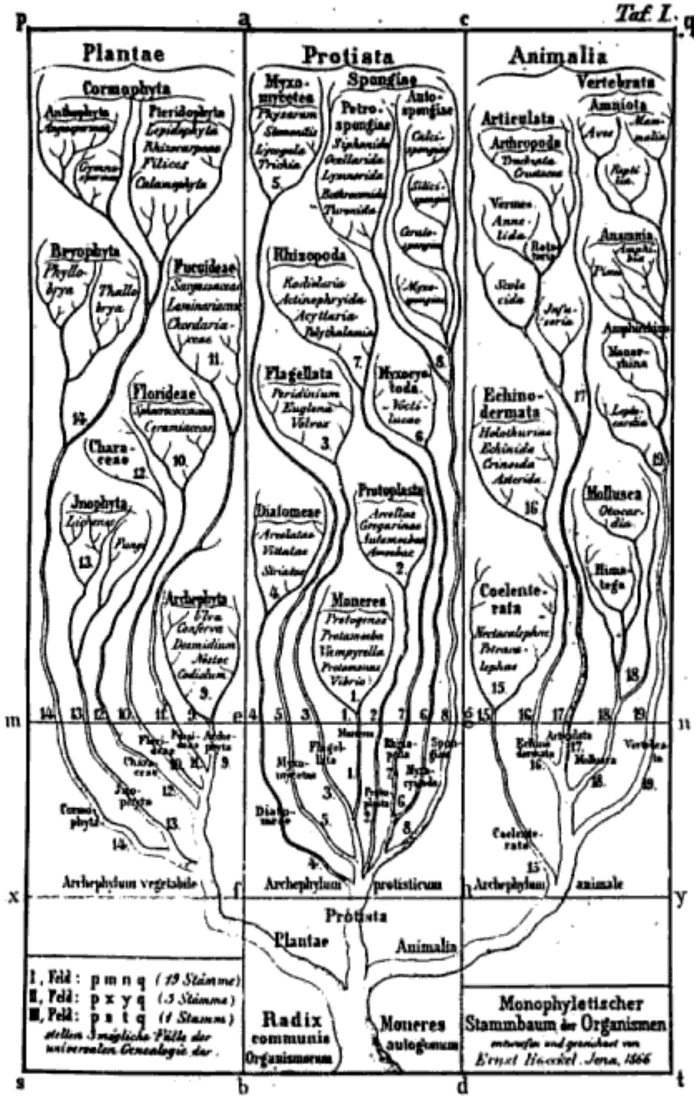
Group Leader
2019

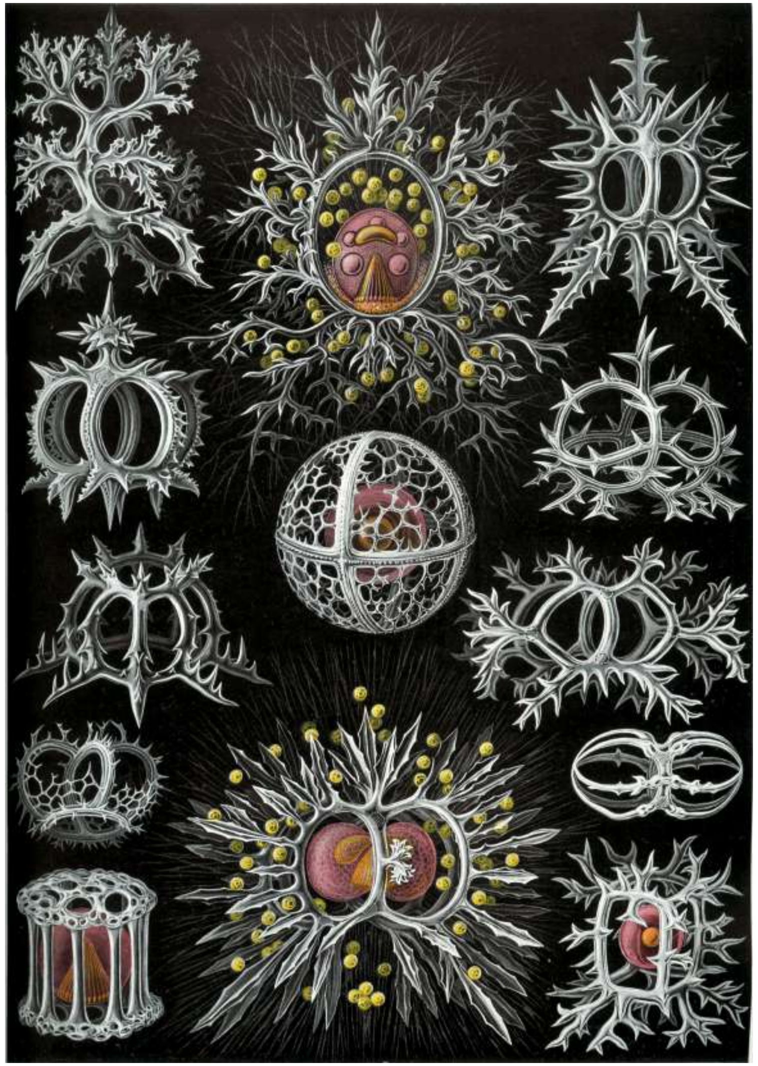
Eukaryotic microbes aka protists


Antonie Philips van Leeuwenhoek

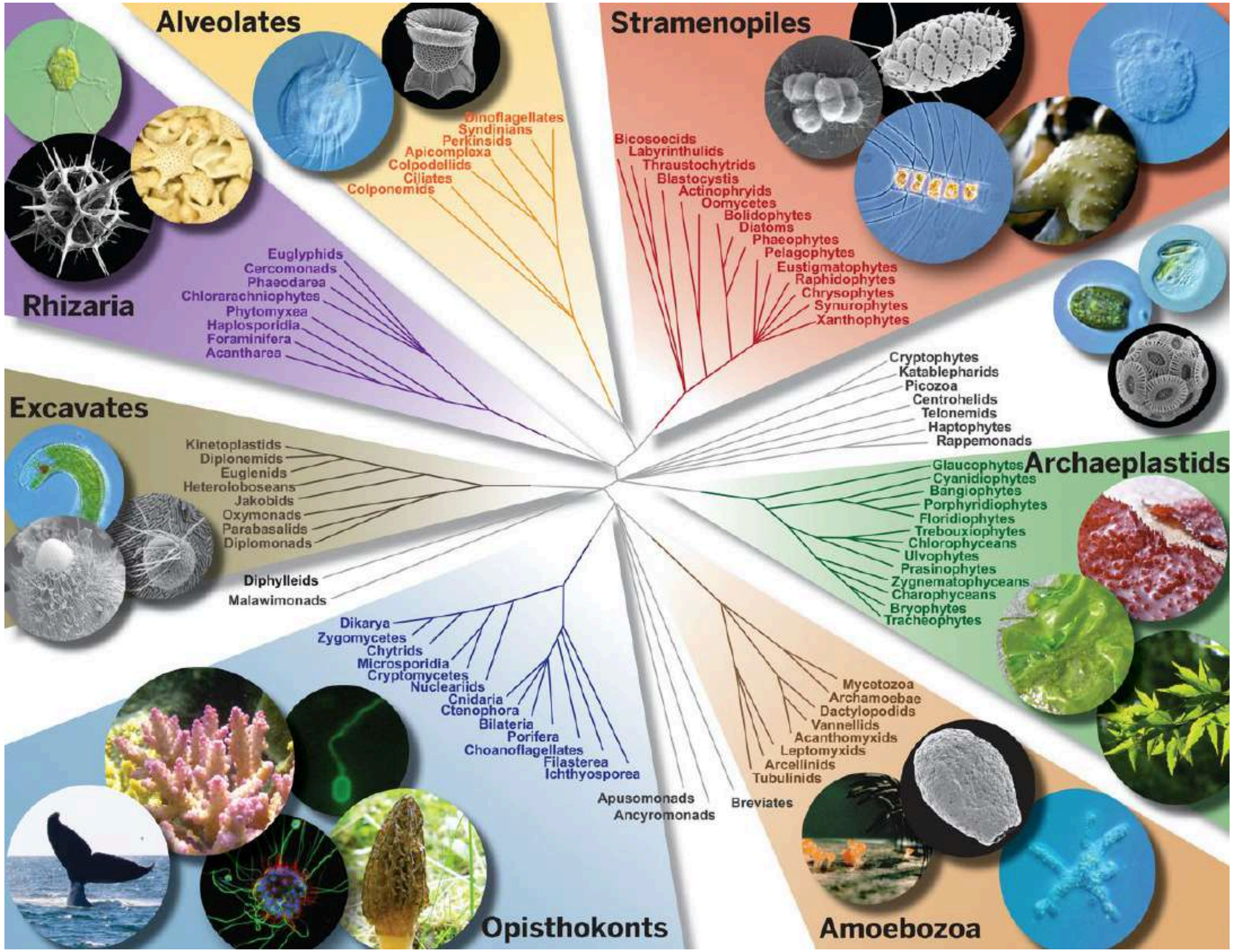
"These animacules had diverse colours…others again were green in the middle, and before and behind white…"

Ernst Haeckel's classification of life
Protista "kingdom of primitive forms"

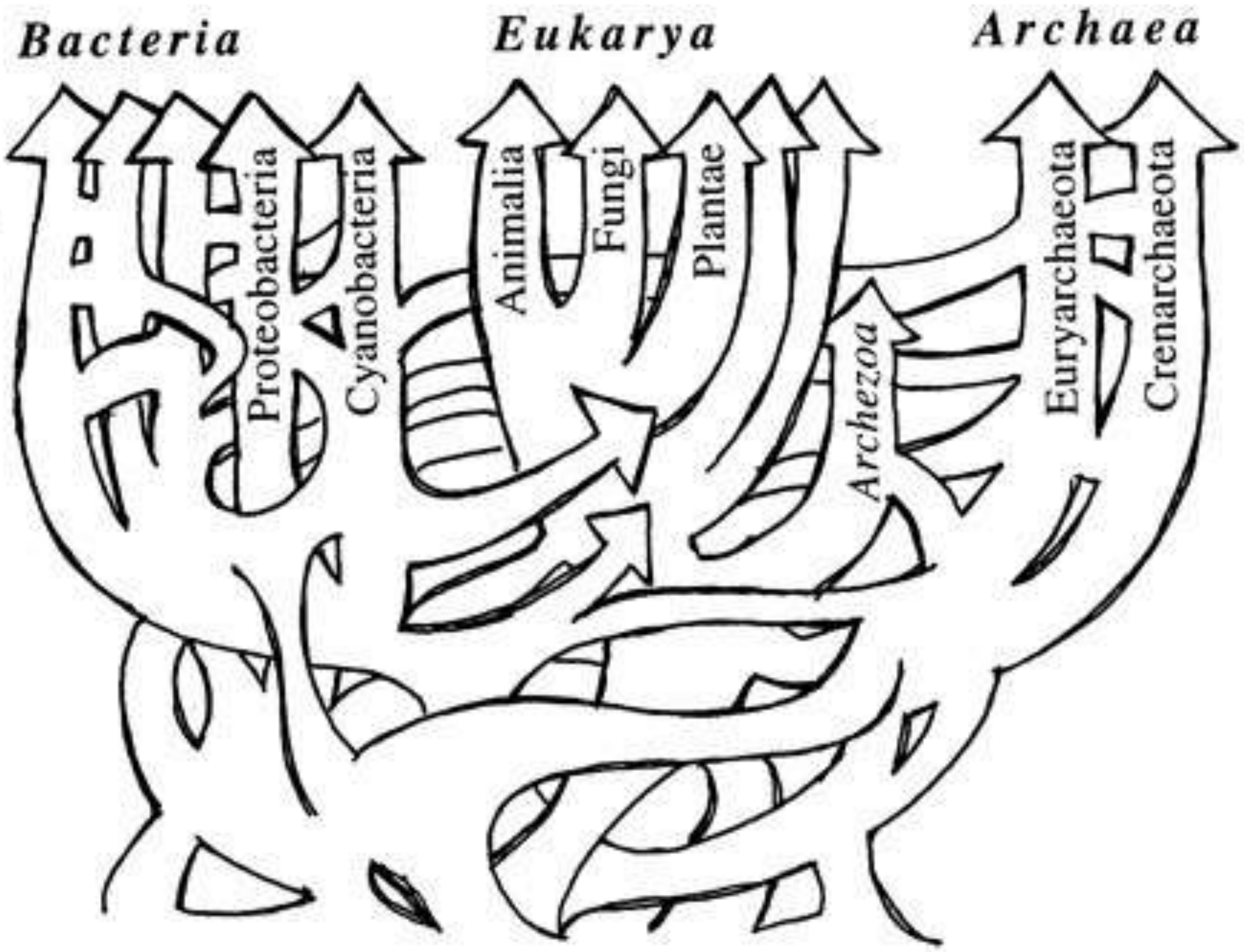


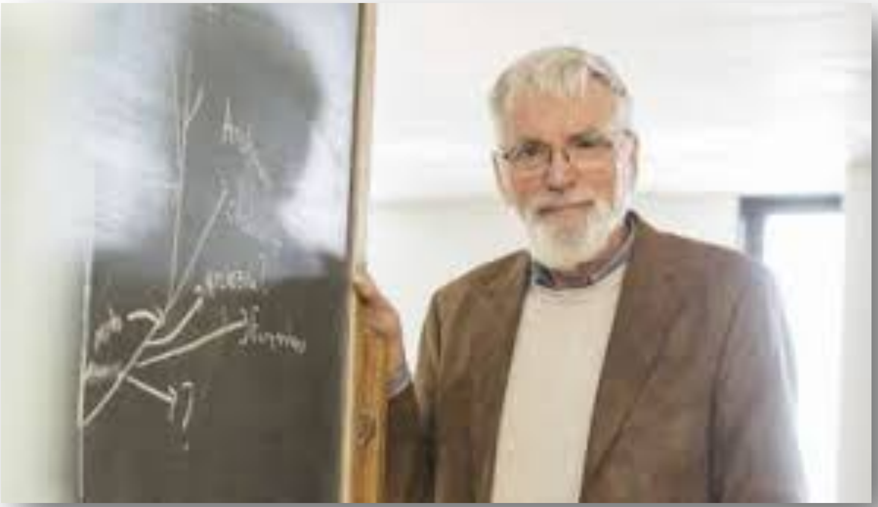


Protists constitute the majority of lineages across the eukaryotic tree of life



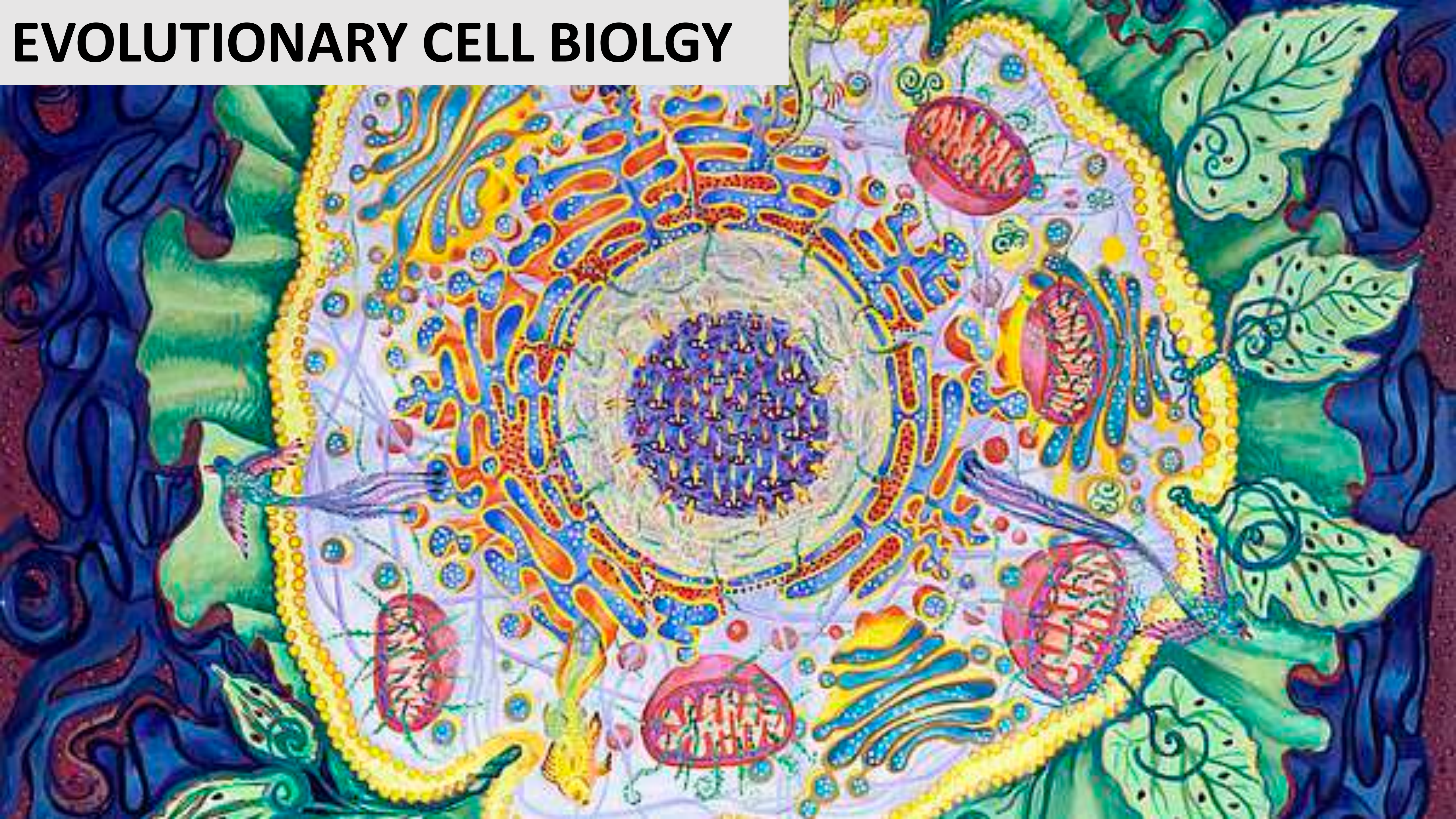
Warden et al. 2015





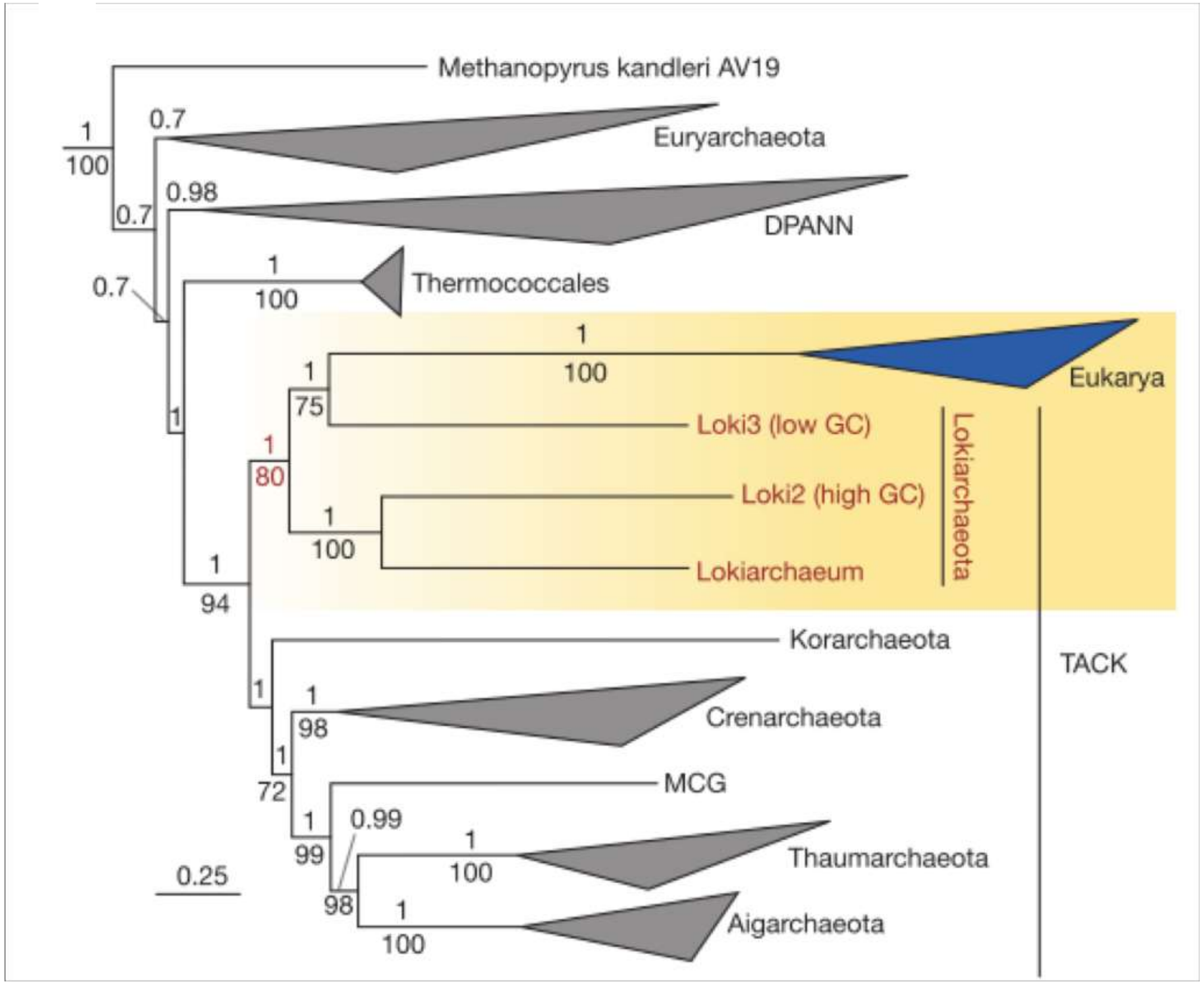
Doolittle, 1999

EVOLUTIONARY CELL BIOLGY



Lokiarcheota – missing link?

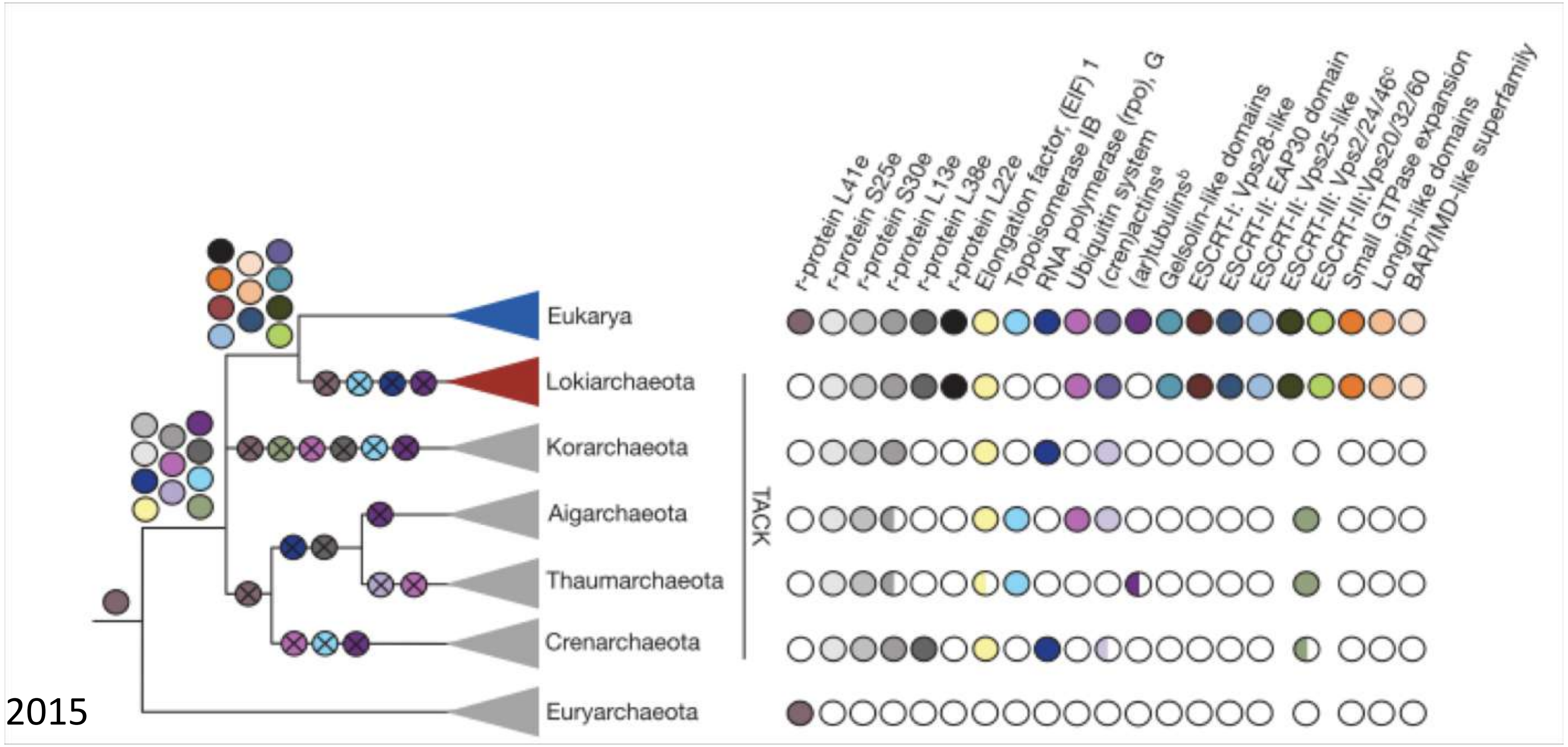
„Our results provide strong support for hypotheses in which the eukaryotic host evolved from a bona fide archaeon"



Sang, **Saw**, et al. Nature, 2015

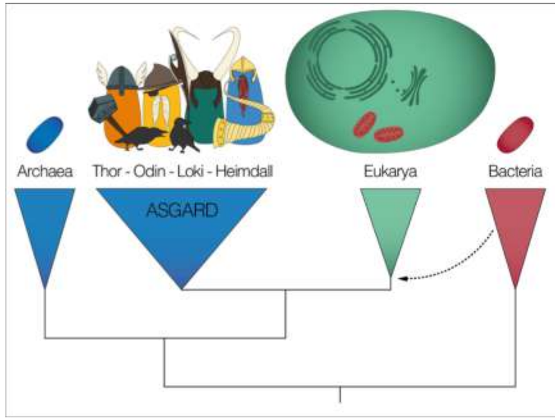
Lokiarcheota phylogenomics

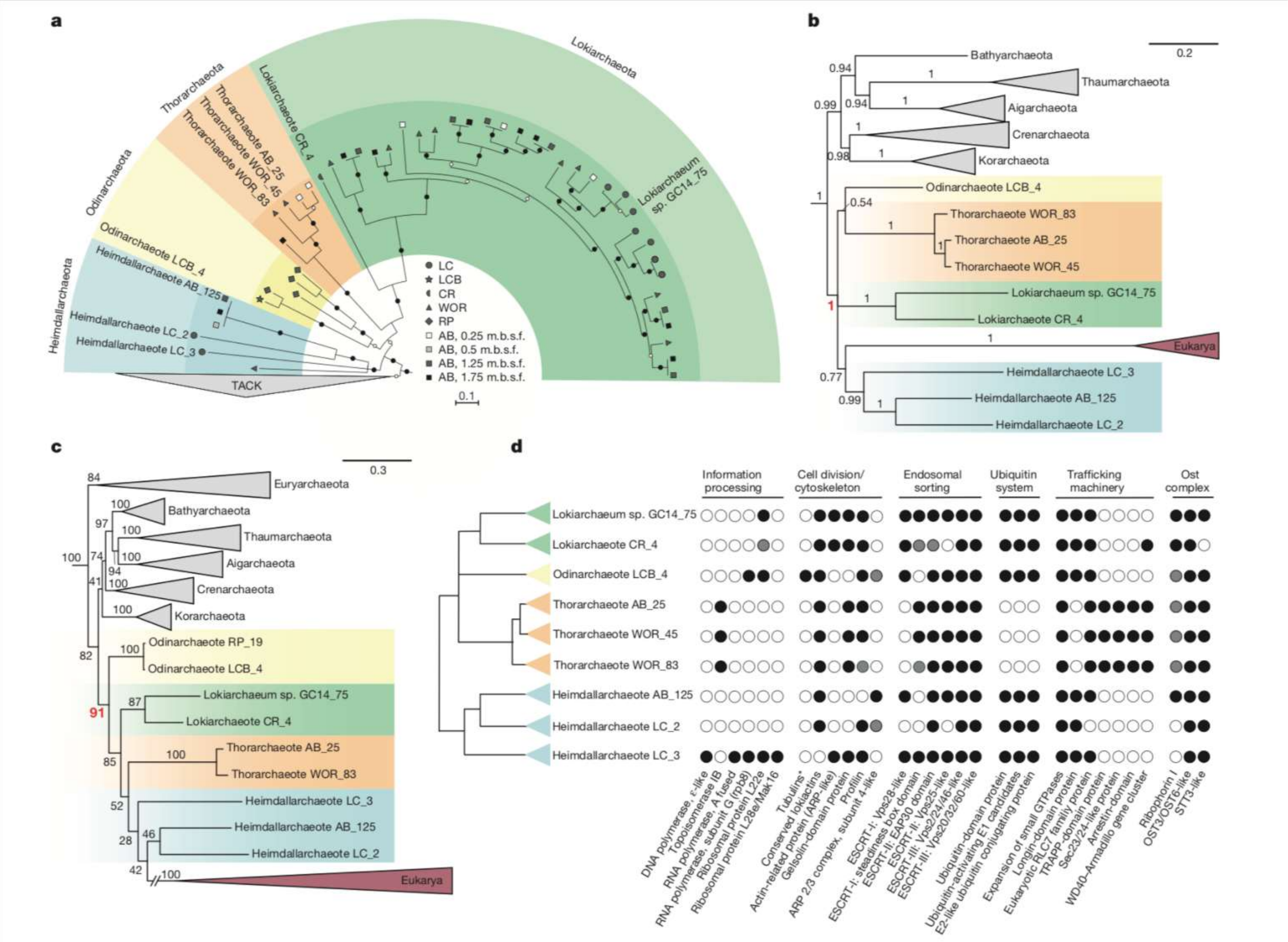
Lokiarcheota genomes contain expanded repertoire of eukaryotic signature proteins that are suggestive of sophisticated membrane remodelling capabilities



Sang, **Saw**, et al. Nature, 2015

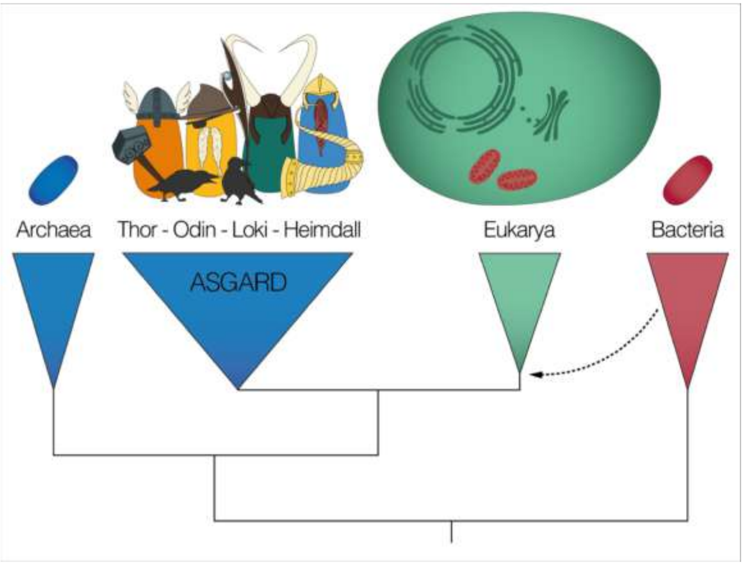
ASGARD

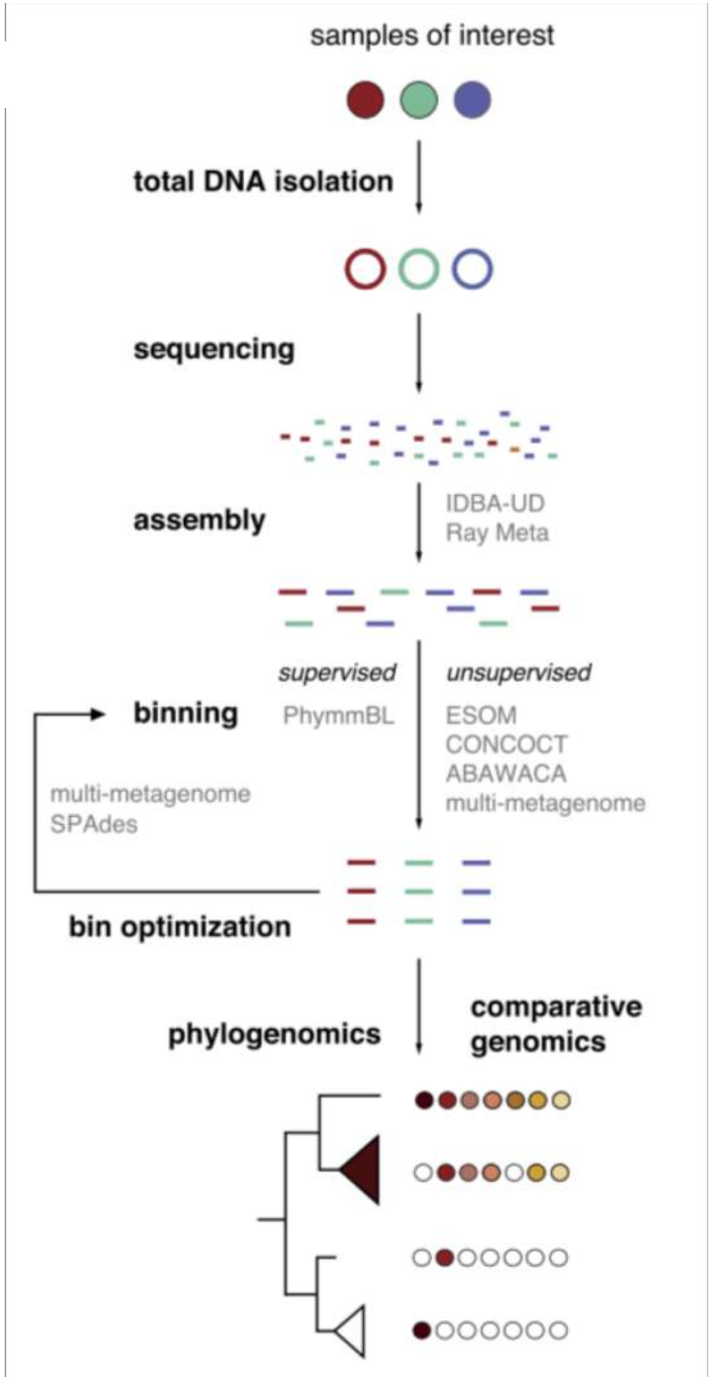




Zaremba-Niedźwiedzka et al. Nature, 2017

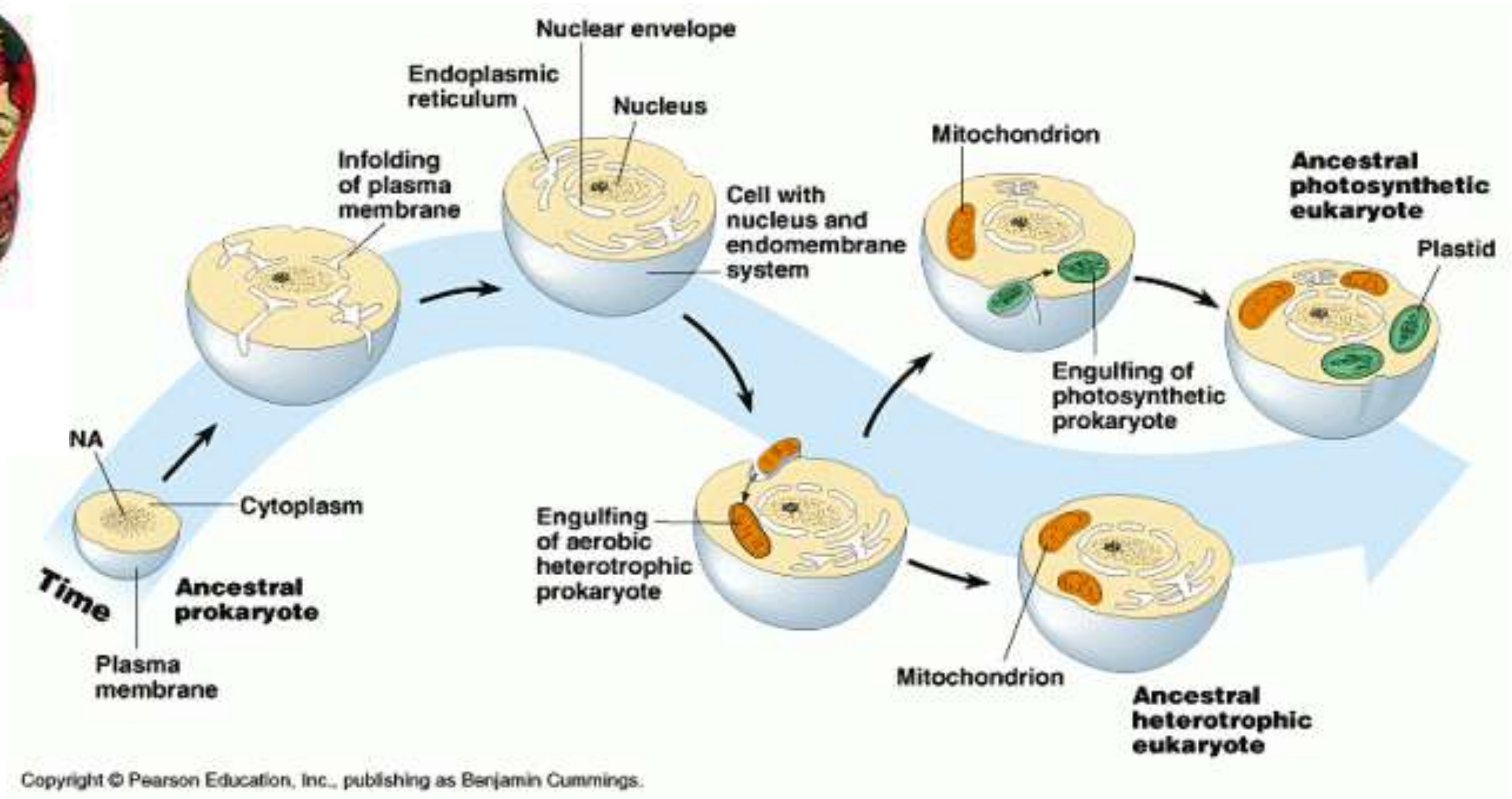
Pipeline for ASGARD study

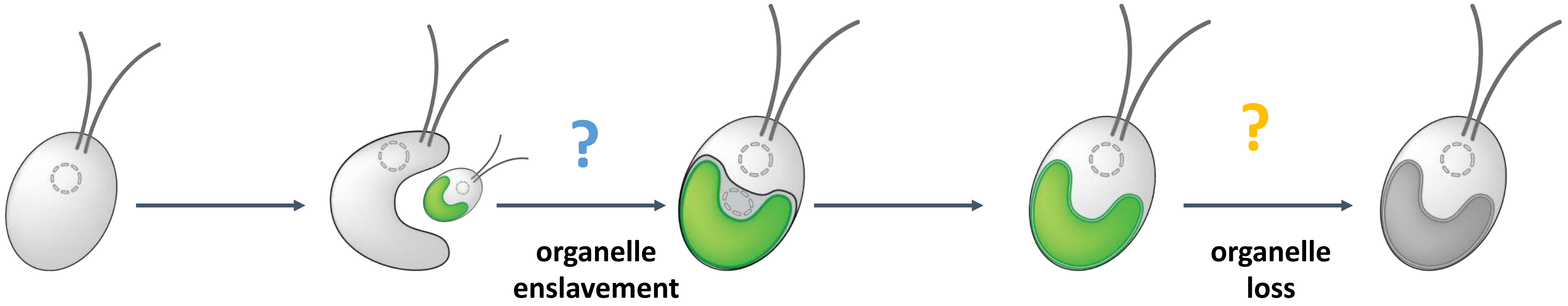




Zaremba-Niedźwiedzka et al. Nature, 2017

endosymbiosis
understanding origin and fate of organelles

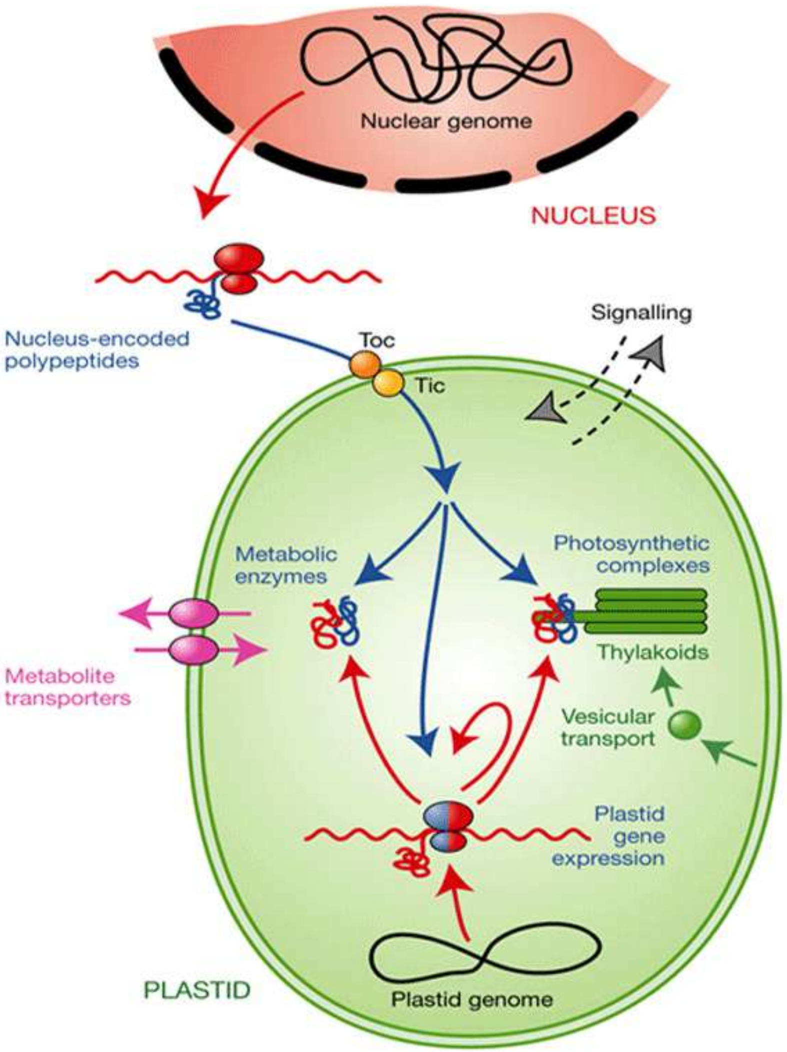




- What are the initial steps of the enslavement of endosymbiont?
- What is the order of events in this phase of transition from prey to endosymbiont?

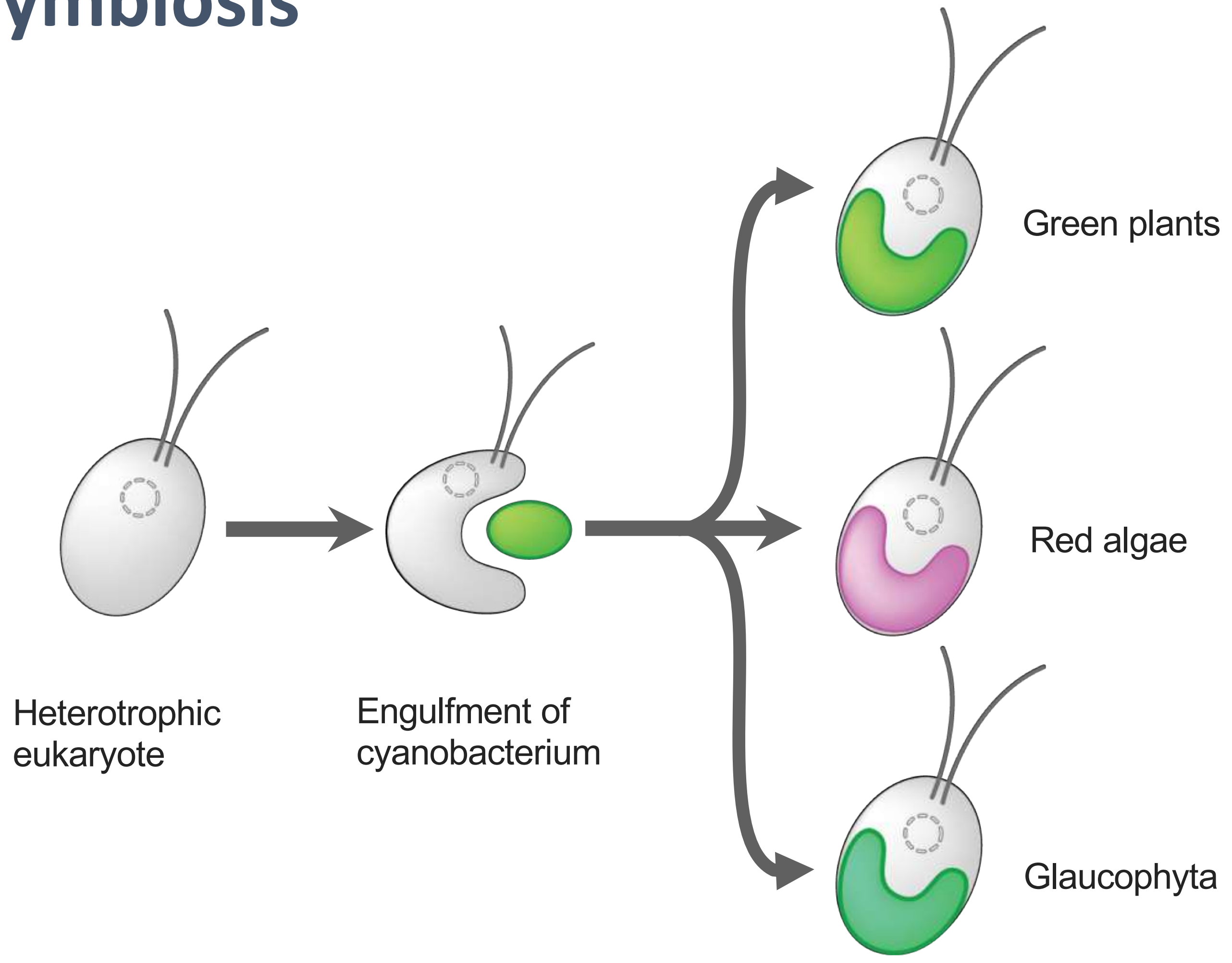
- Are there any universal patterns during the loss of organellar functions?
- What are the indispensable functions of the vestigial organelles?

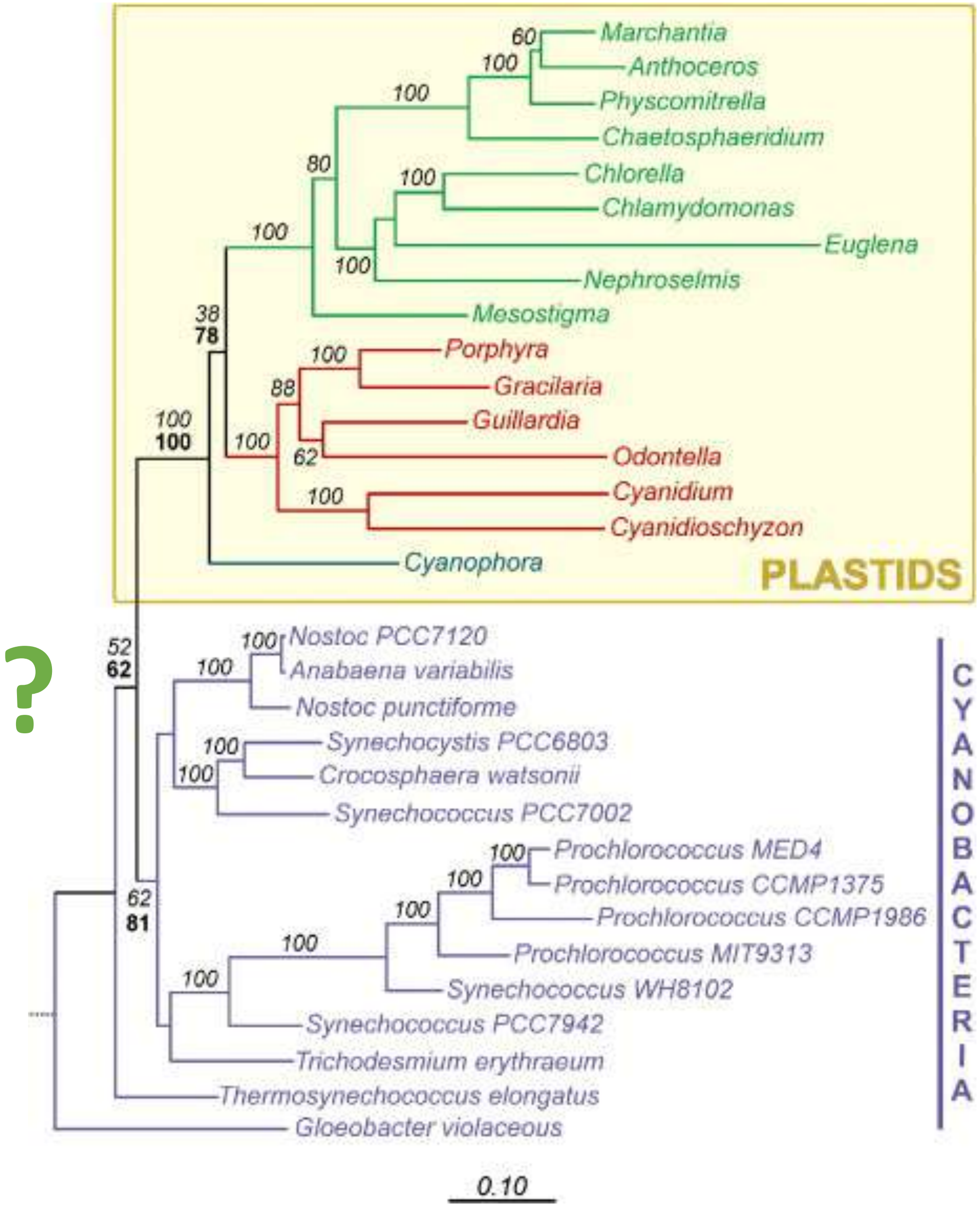
plastids



Nuclear genome
NUCLEUS
Nucleus-encoded
polypeptides
Toc
Tic
Signalling
Metabolic
enzymes
Photosynthetic
complexes
Thylakoids
Metabolite
transporters
Vesicular
transport
Plastid
gene
expression
PLASTID
Plastid genome

Origin of chloroplasts
primary endosymbiosis



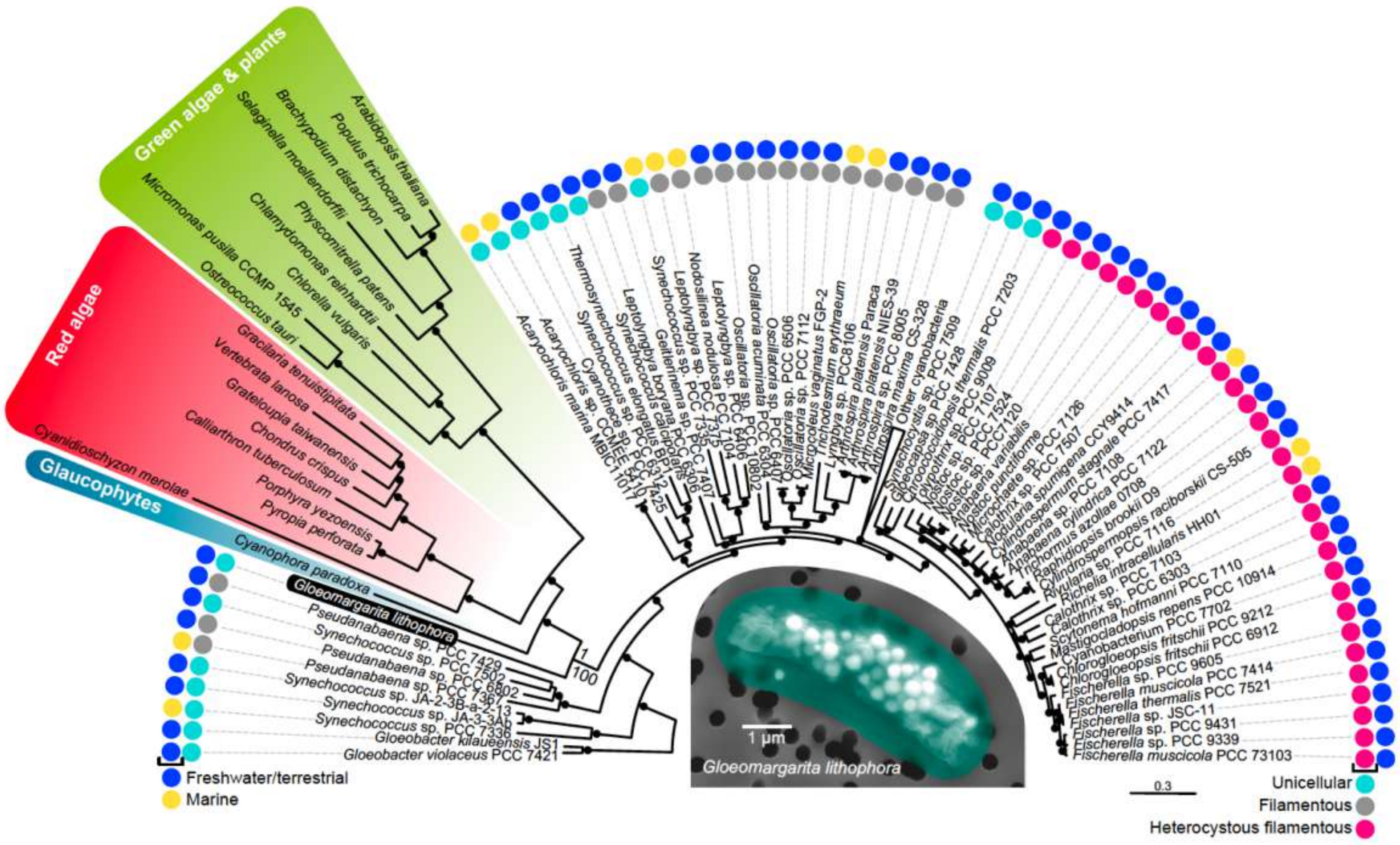


Rodriguez-Ezpeleta et al. (2005) Curr Biol

Plastids and cyanobacteria are recovered repeatedly as a monophyletic group

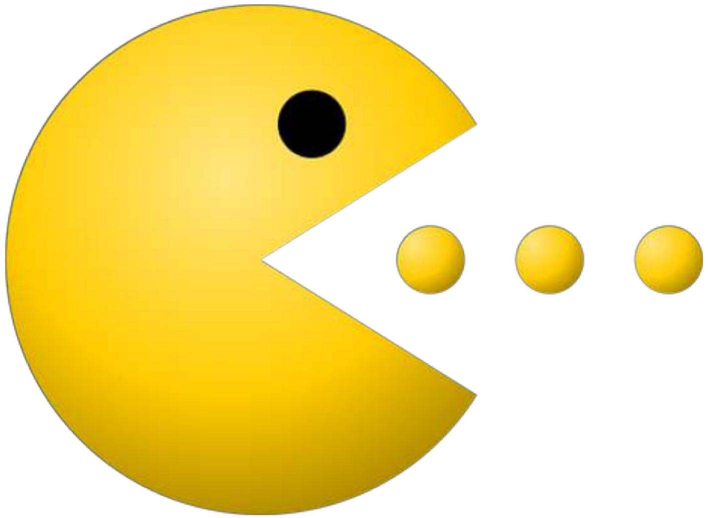
Cyanobacteria which became a chloroplast

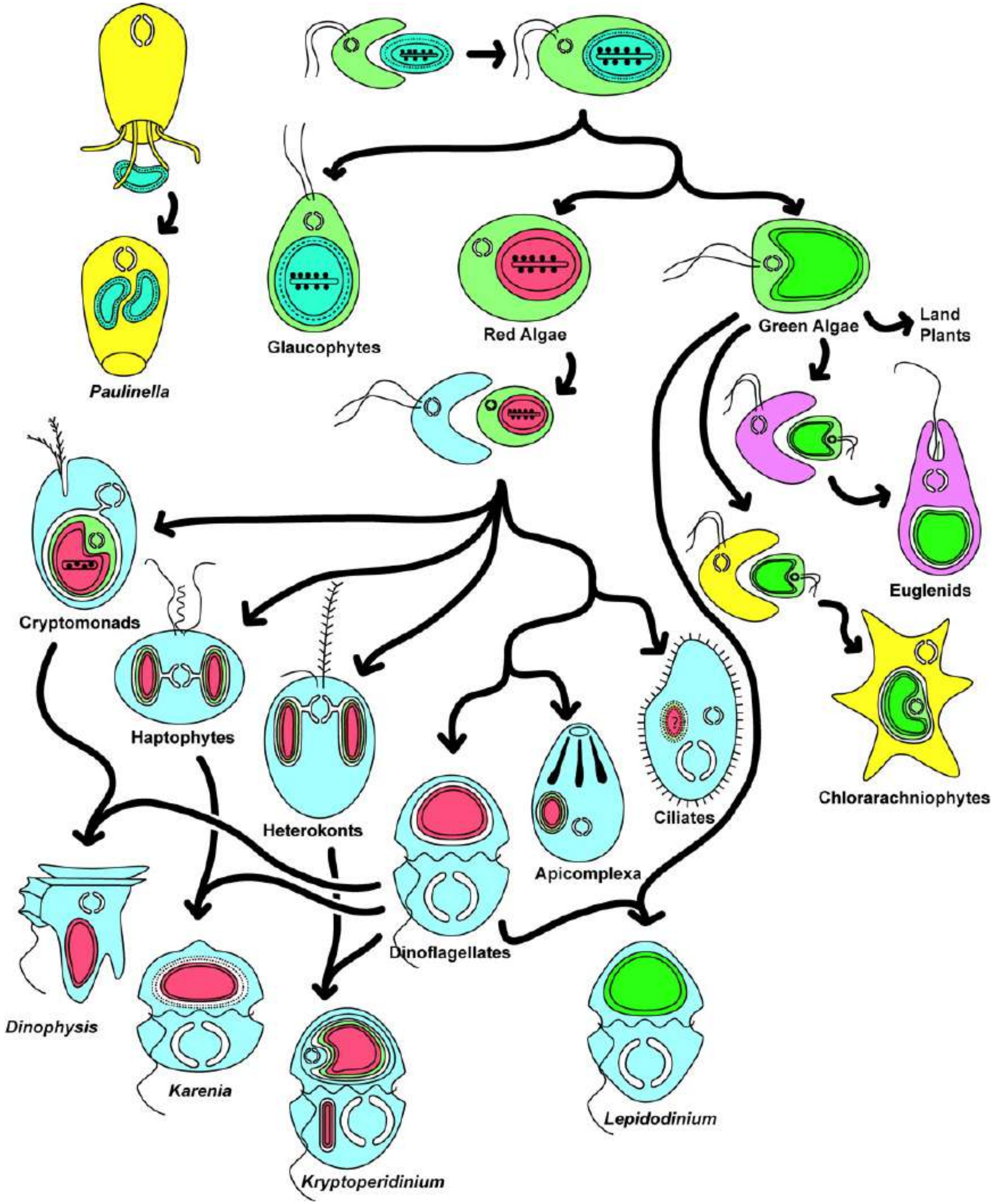
- *Gloeomargarita lithophora* is the closest extant cyanobacteria to plastids
- old cyanobacterial lineage
- freshwater cyanobacteria



Ponce-Toledo et al., 2017

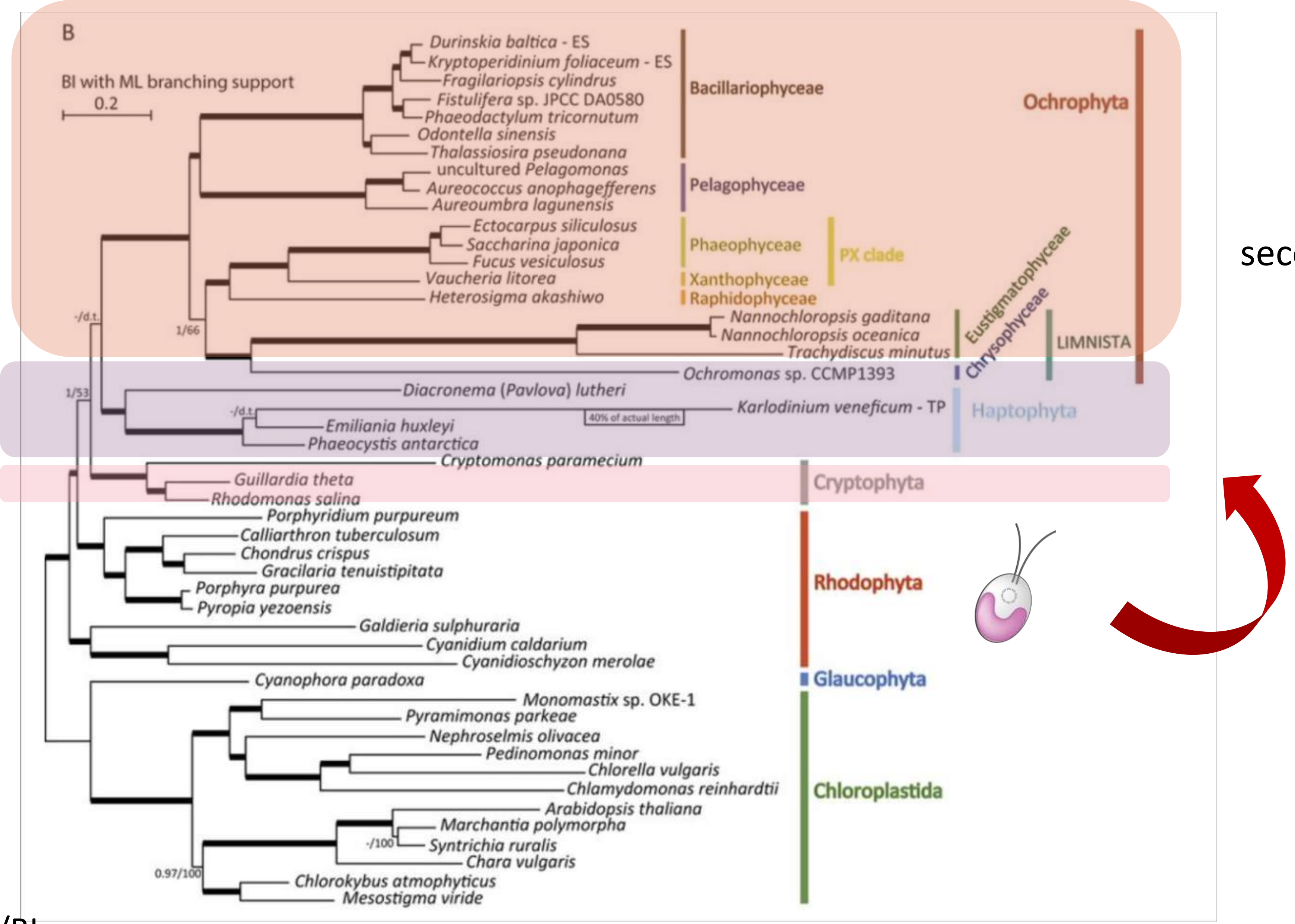
Secondary endosymbioses in several lineages of microbial eukaryotes





Keeling (2004) Am J Bot

Phylogenomics of plastids



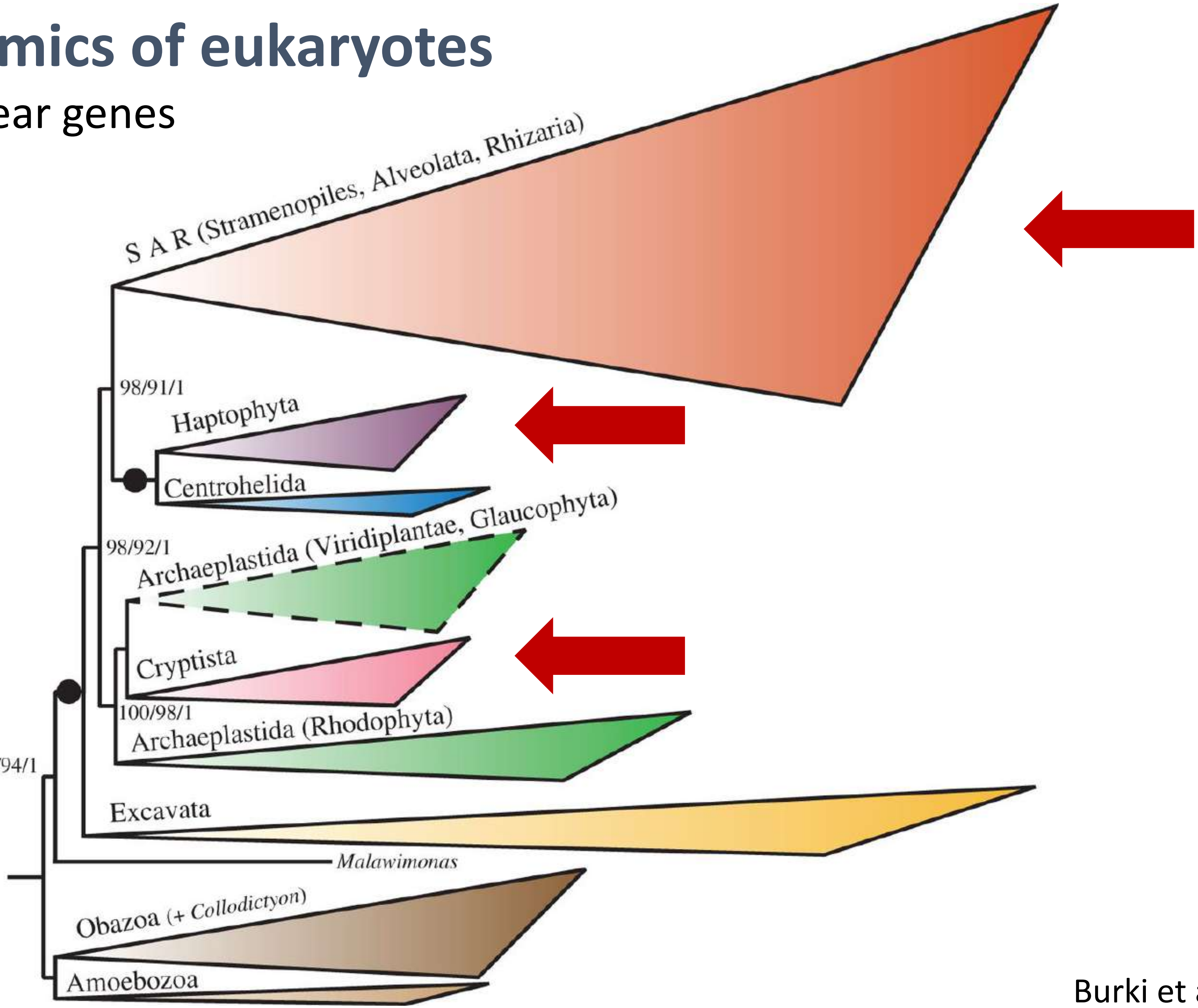
secondary „red” endosymbionts

ML/BI

Sevcikova et al. 2015

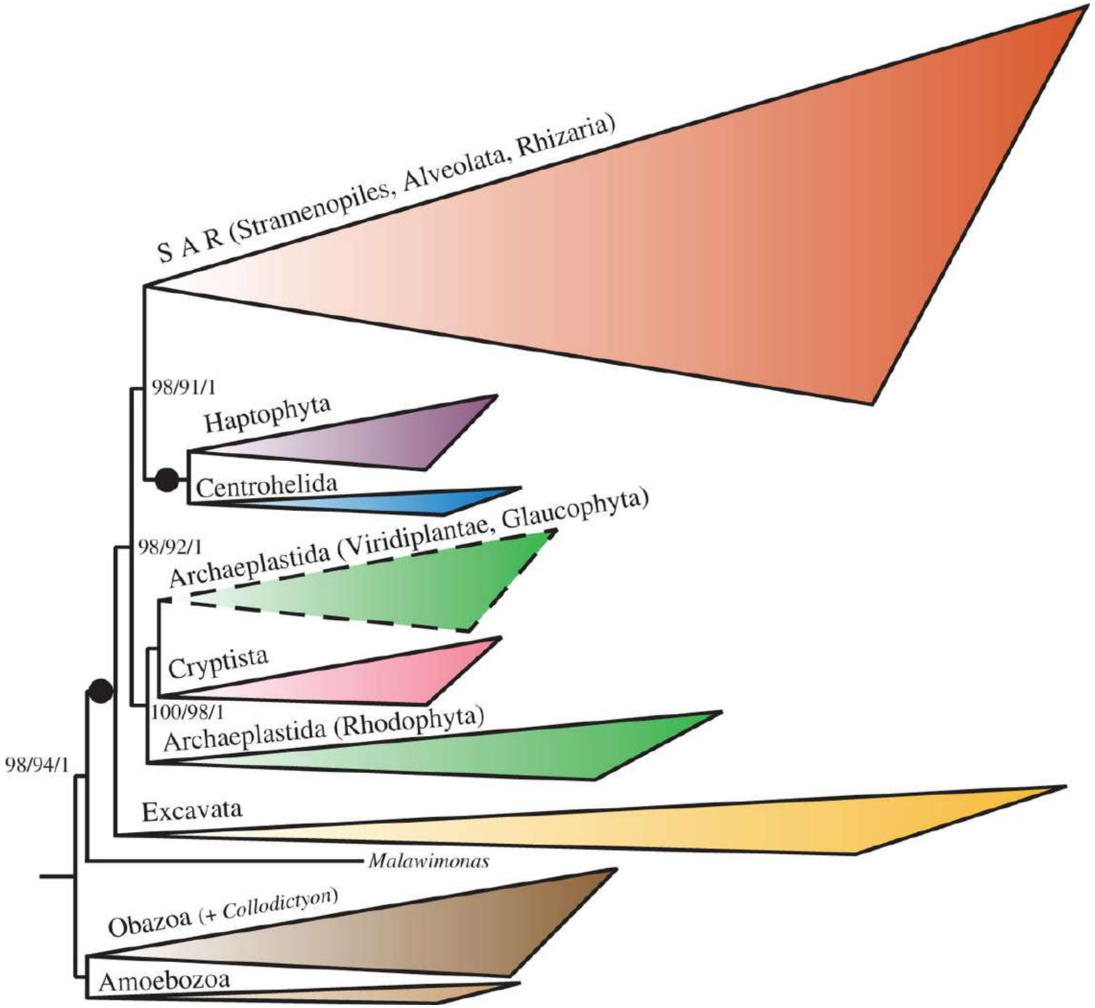
Phylogenomics of eukaryotes

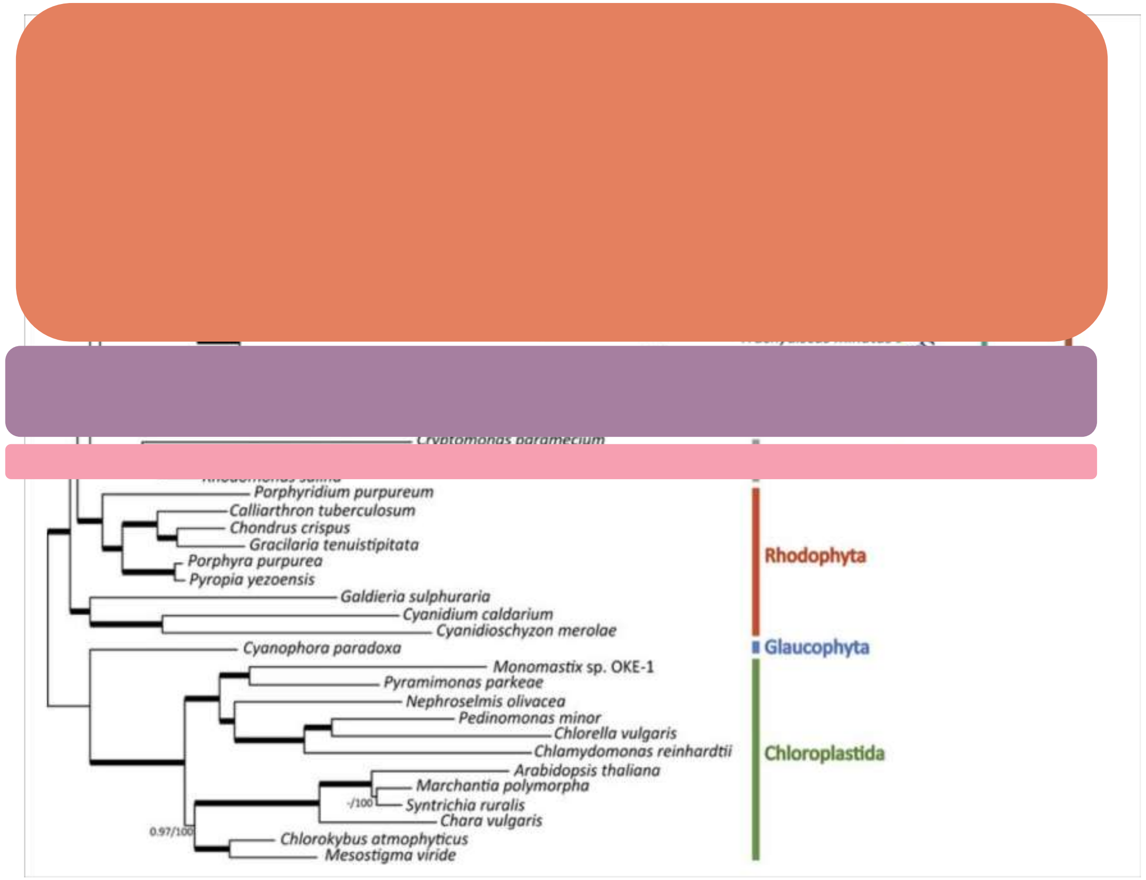
based on nuclear genes



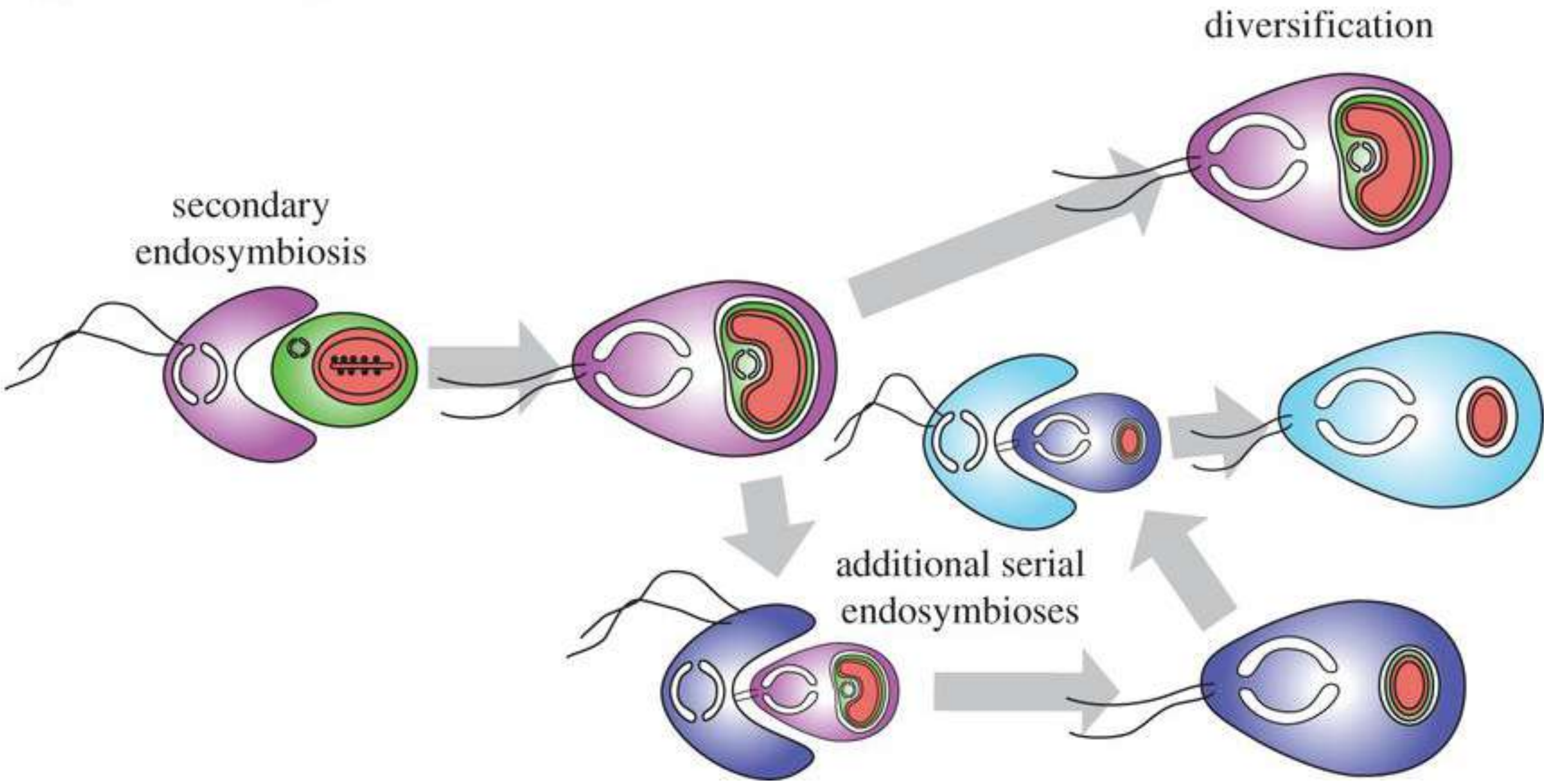
ML/BI 250 genes

Burki et al. 2016


S A R (Stramenopiles, Alveolata, Rhizaria)
98/91/1
Haptophyta
Centrohelida
98/92/1
Archaeplastida (Viridiplantae, Glaucophyta)
Cryptista
100/98/1
Archaeplastida (Rhodophyta)
98/94/1
Excavata
Malawimonas
Obazoa (+ Collodictyon)
Amoebozoa


Porphyridium purpureum
Calliarthron tuberculosum
Chondrus crispus
Gracilaria tenuistipitata
Porphyra purpurea
Pyropia yezoensis
Galdieria sulphuraria
Cyanidium caldarium
Cyanidioschyzon merolae
Cyanophora paradoxa
Monomastix sp. OKE-1
Pyramimonas parkeae
Nephroselmis olivacea
Pedinomonas minor
Chlorella vulgaris
Chlamydomonas reinhardtii
Arabidopsis thaliana
Marchantia polymorpha
-/100
Syntrichia ruralis
Chara vulgaris
0.97/100
Chlorokybus atmophyticus
Mesostigma viride
Rhodophyta
Glaucophyta
Chloroplastida

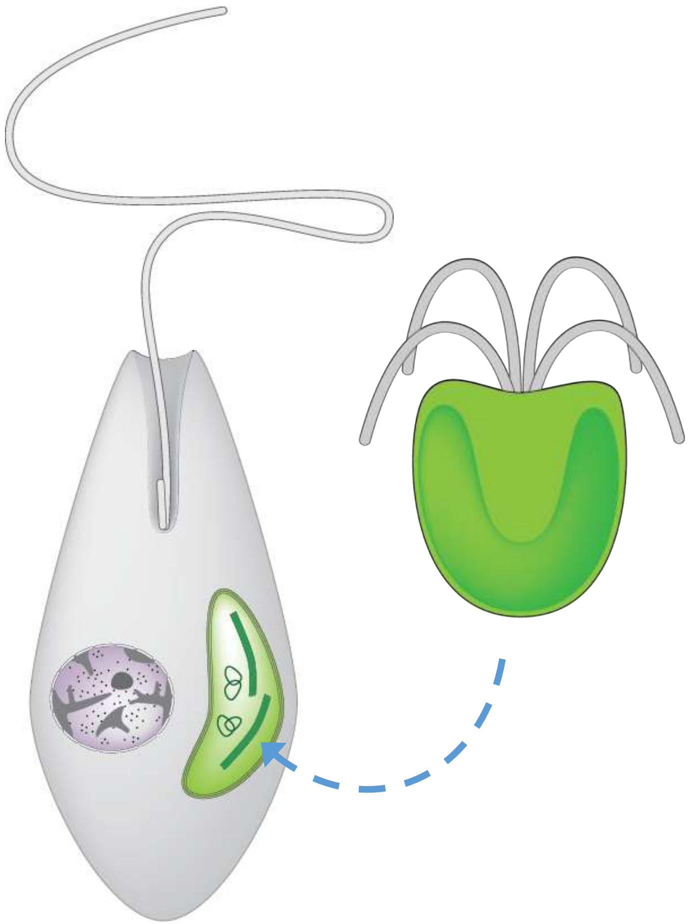
Cryptic serial endosybiosis



Burki et al. 2016

organelle enslavement

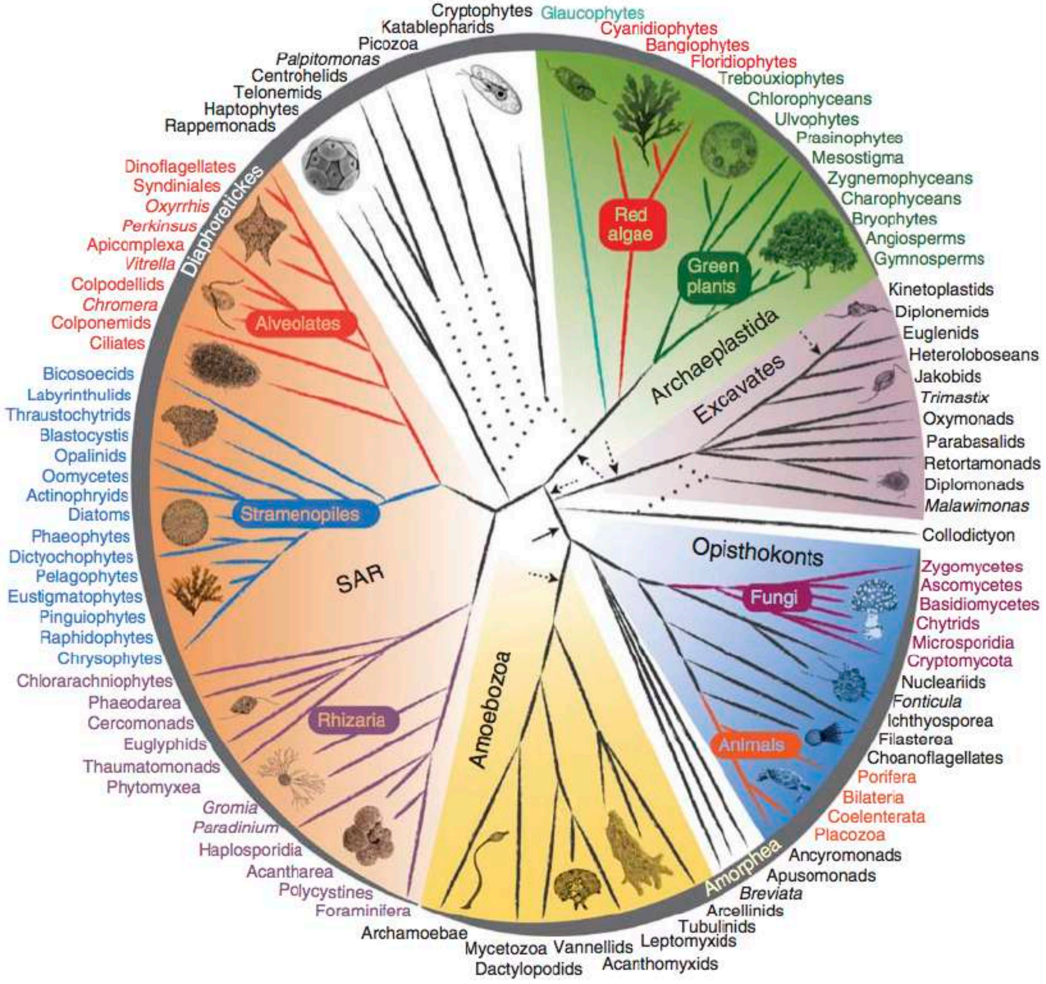
origin of plastids via kleptoplastidity

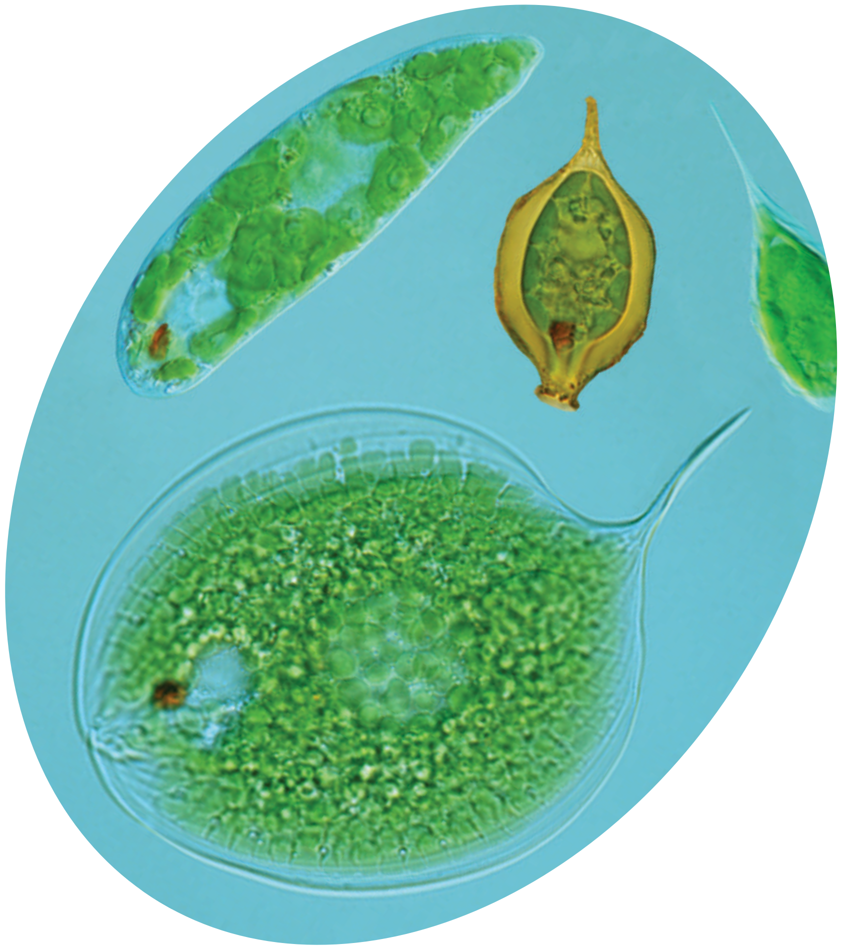


kleptoplasty

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

photosynthetic euglenids - the only Excavates with secondary plastids

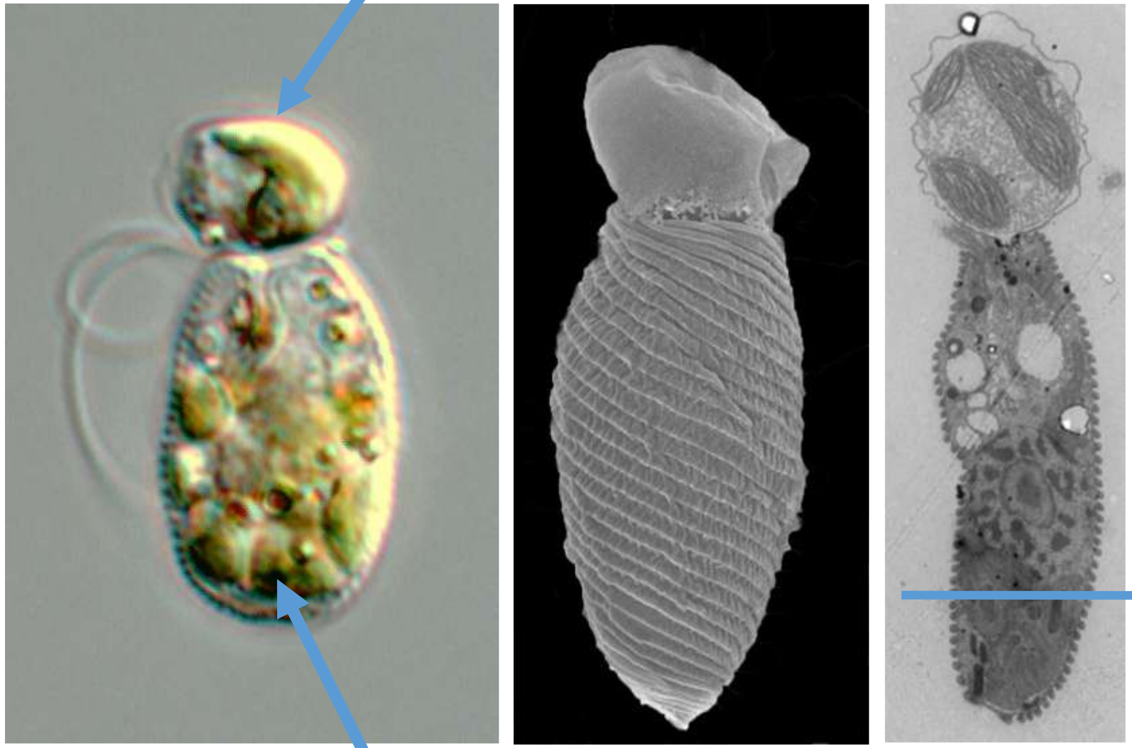




Burki et al. 2014

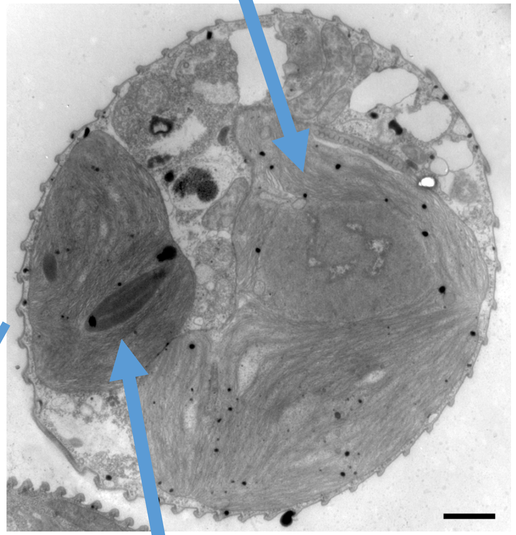
Rapaza viridis – mixotrophic euglenid

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



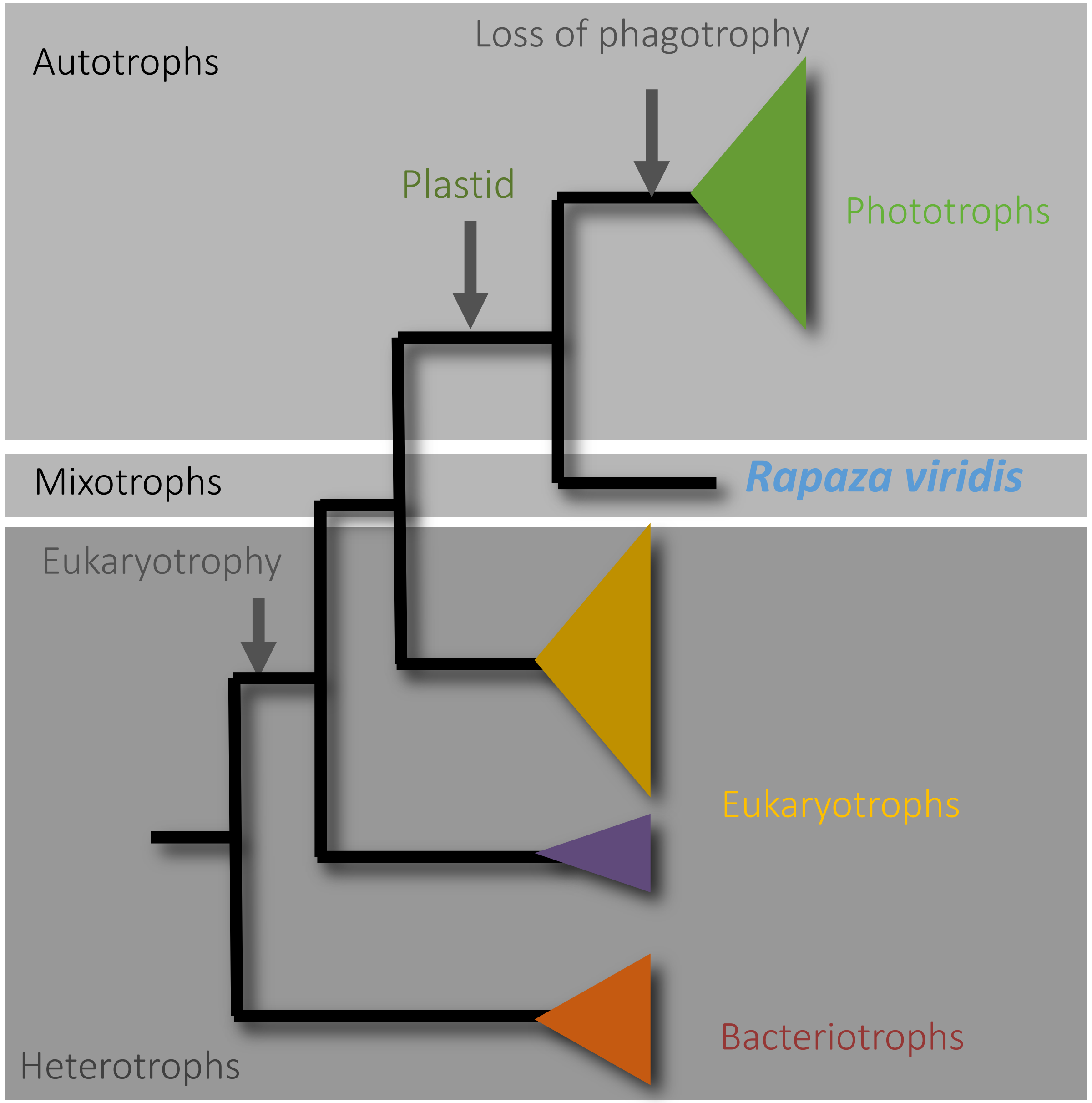
Rapaza viridis

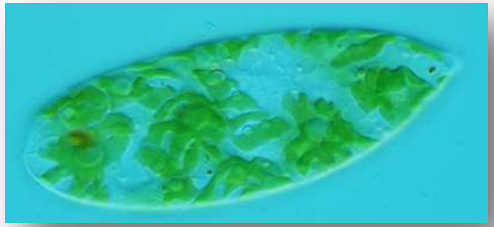
Tetraselmis chloroplast

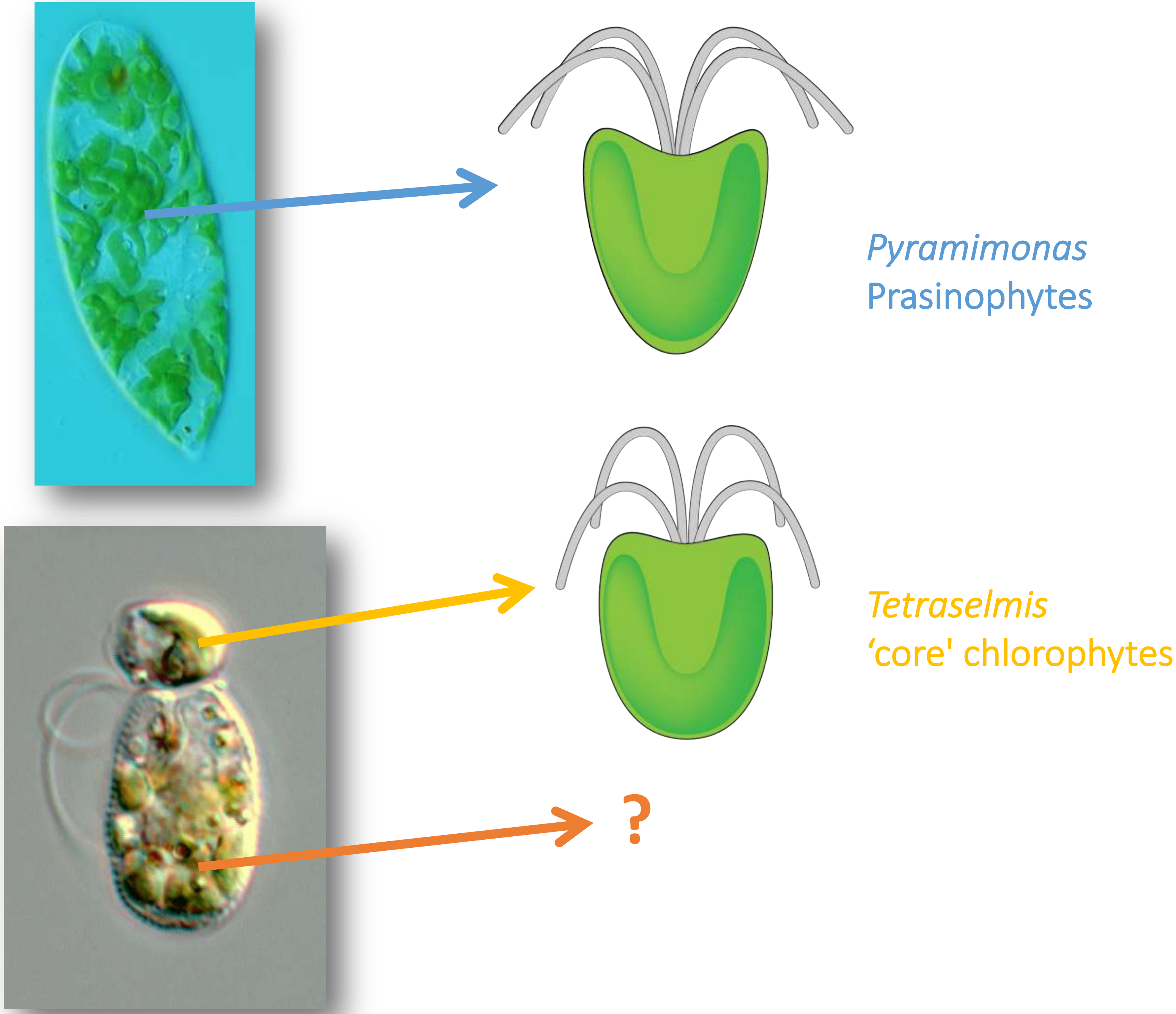


Rapaza chloroplast

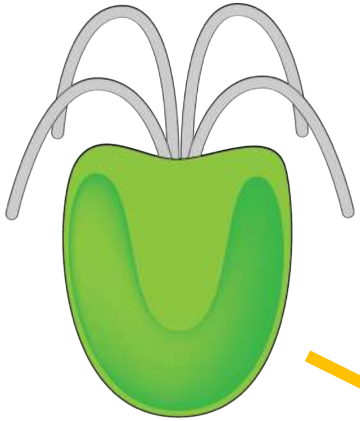
Yamaguchi, Yubuki & Leander (2013)


Autotrophs
Loss of phagotrophy
Plastid
Phototrophs
Mixotrophs
Rapaza viridis
Eukaryotrophy
Eukaryotrophs
Bacteriotrophs
Heterotrophs

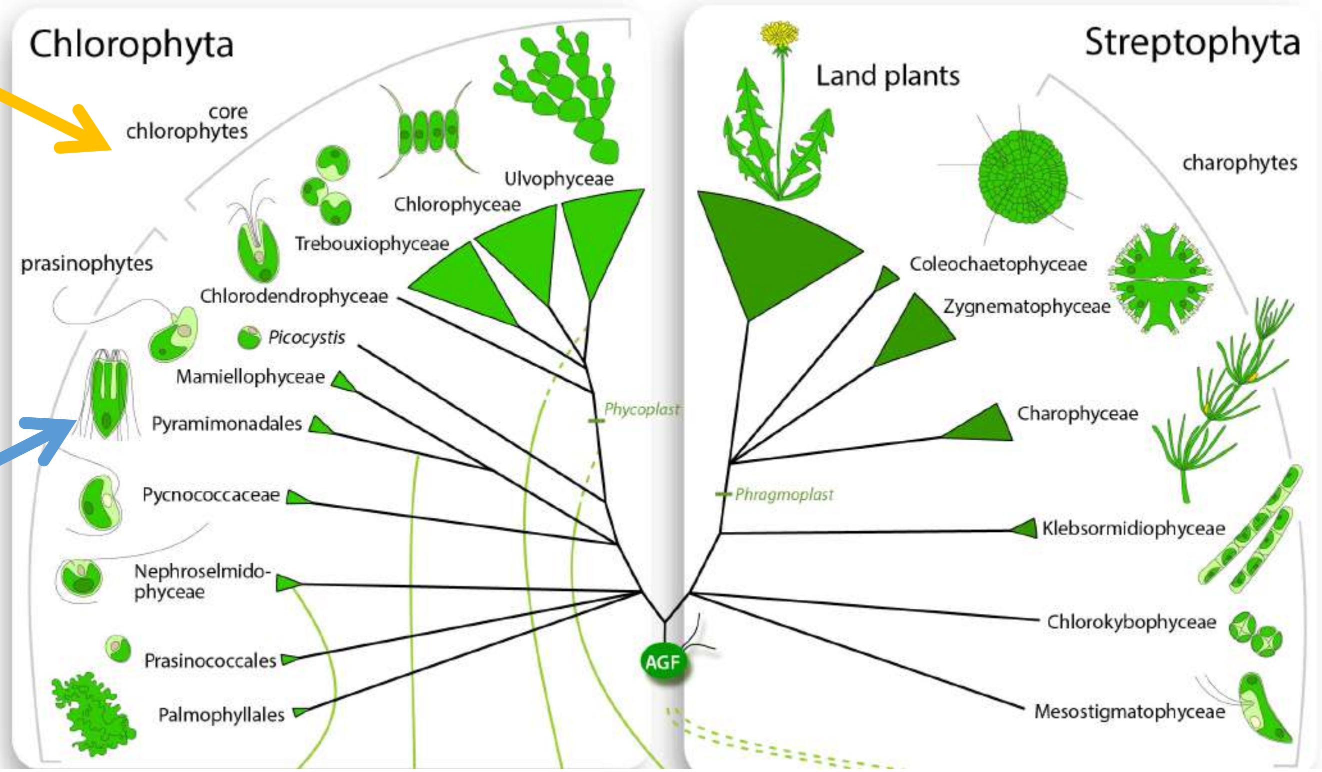


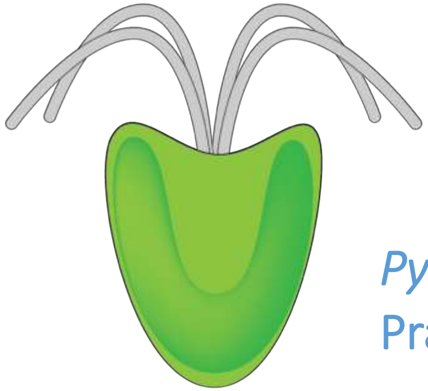


Pyramimonas
Prasinophytes
Tetraselmis
'core' chlorophytes
?

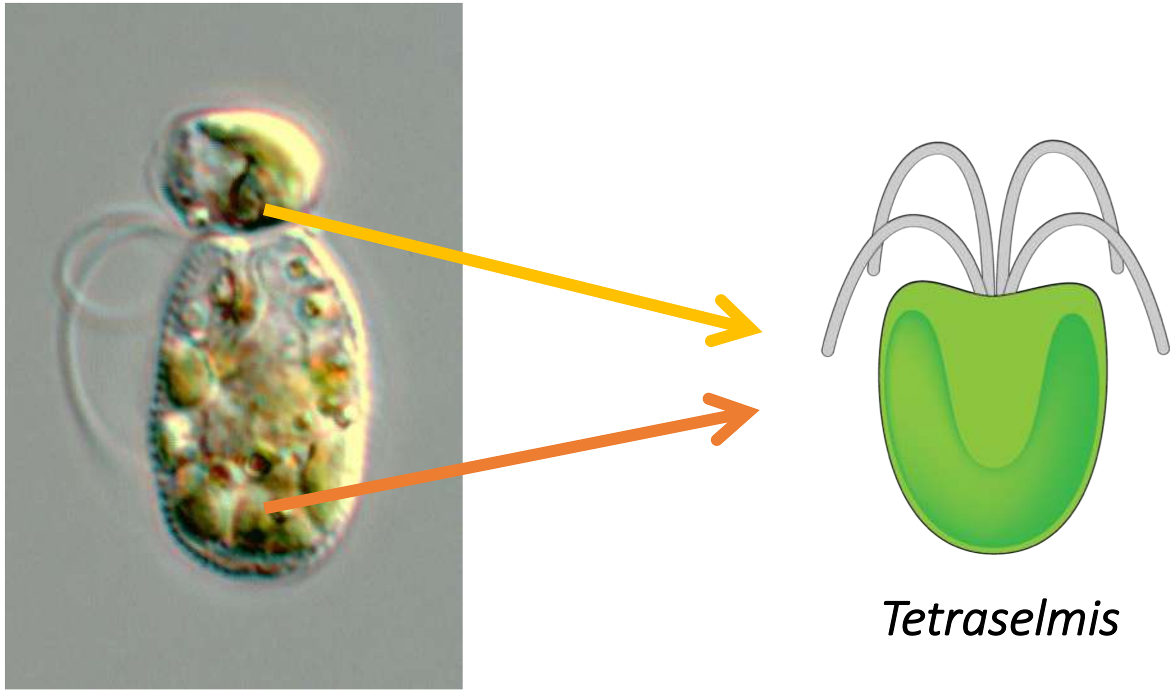


Tetraselmis
'core' chlorophytes





Pyramimonas
Prasinophytes



Kleptochloroplast (stolen plastid)

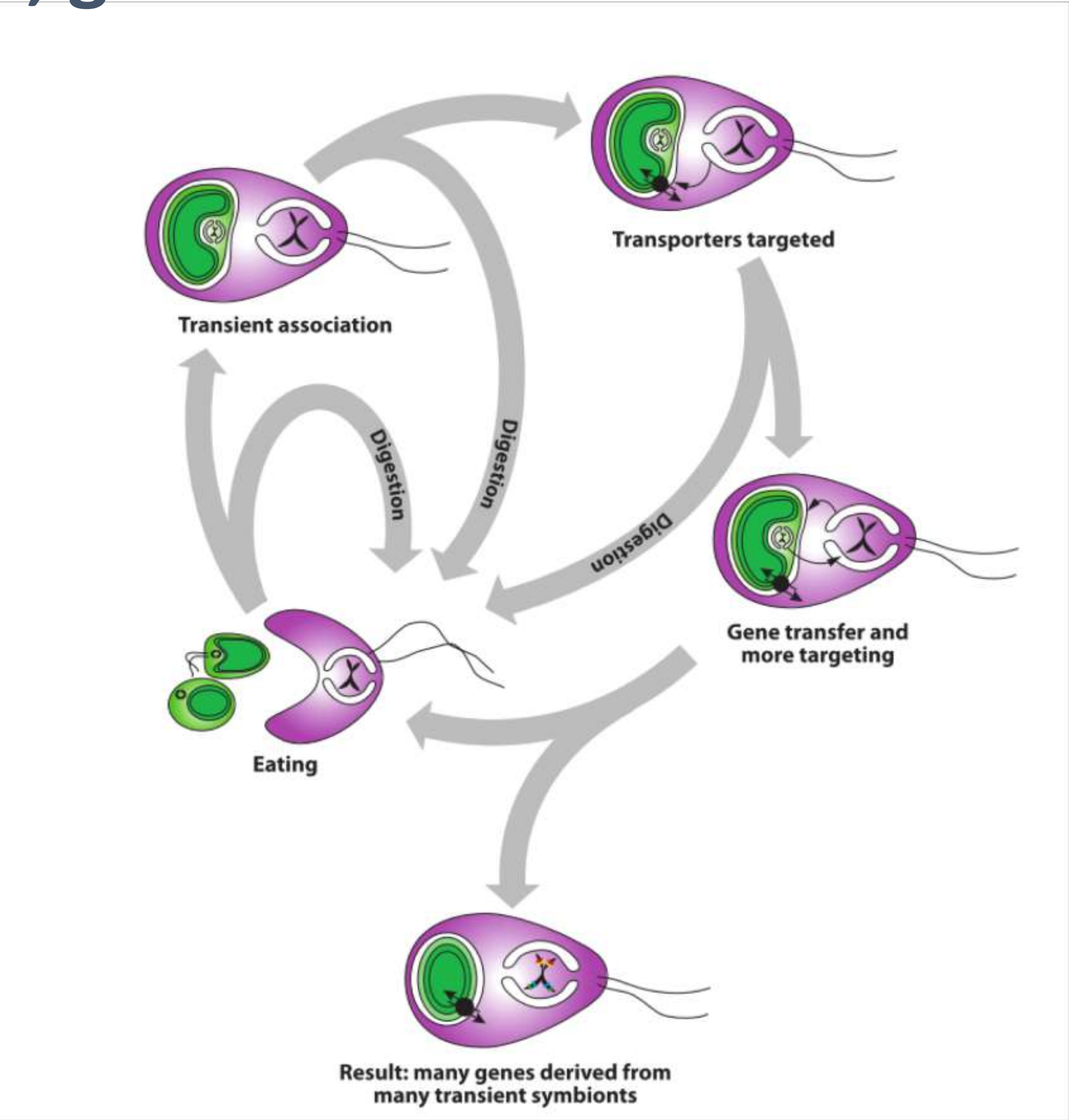
Rapaza posses only ***Tetraselmis*-derived** plastid but no *Pyramimonas*-like (Euglenophyceae-type)

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?



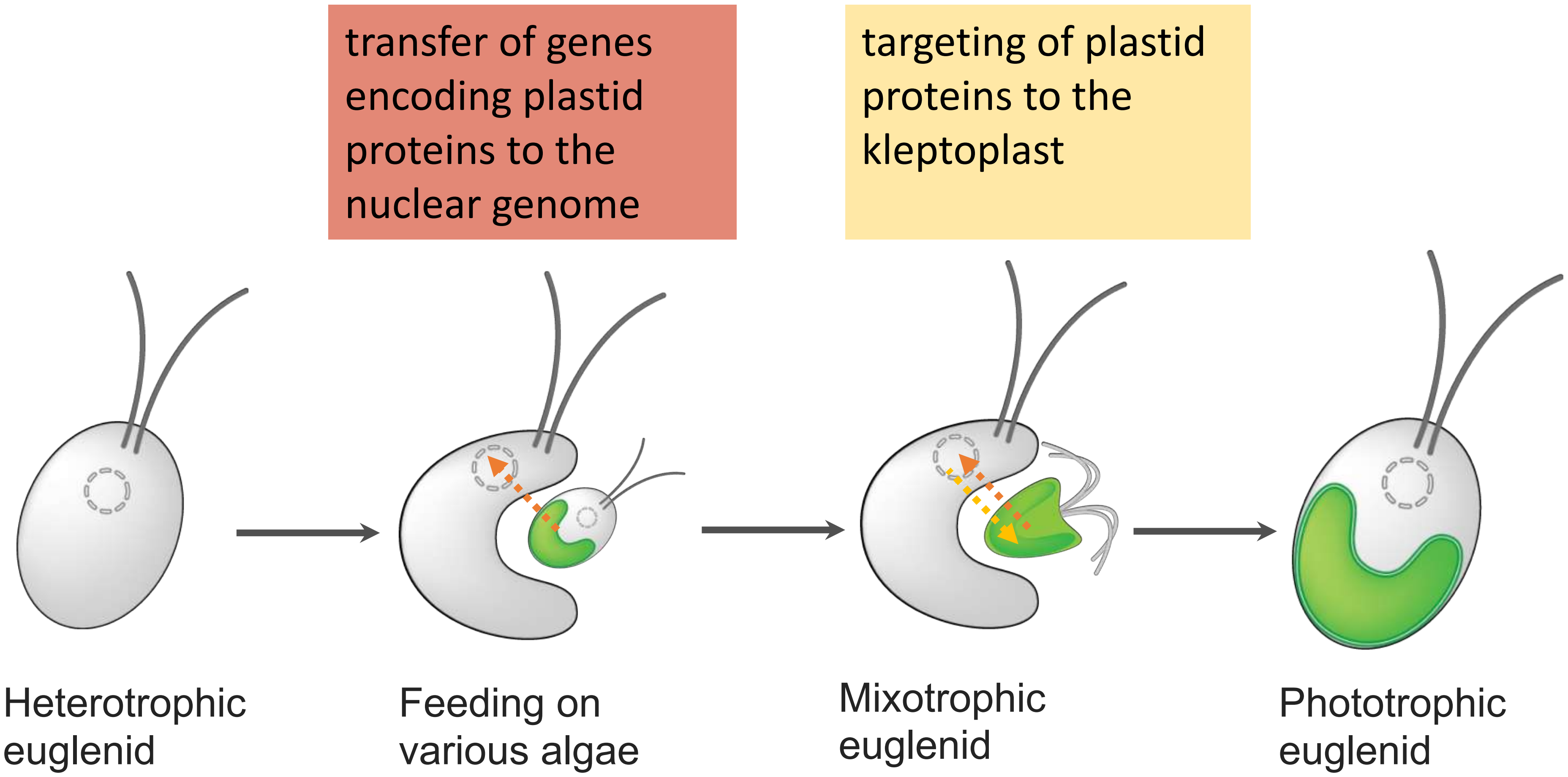
A targeting-ratchet model for the endosymbiotic origin of plastids
Keeling, 2013

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

What is the origin of plastid-targeted proteins?

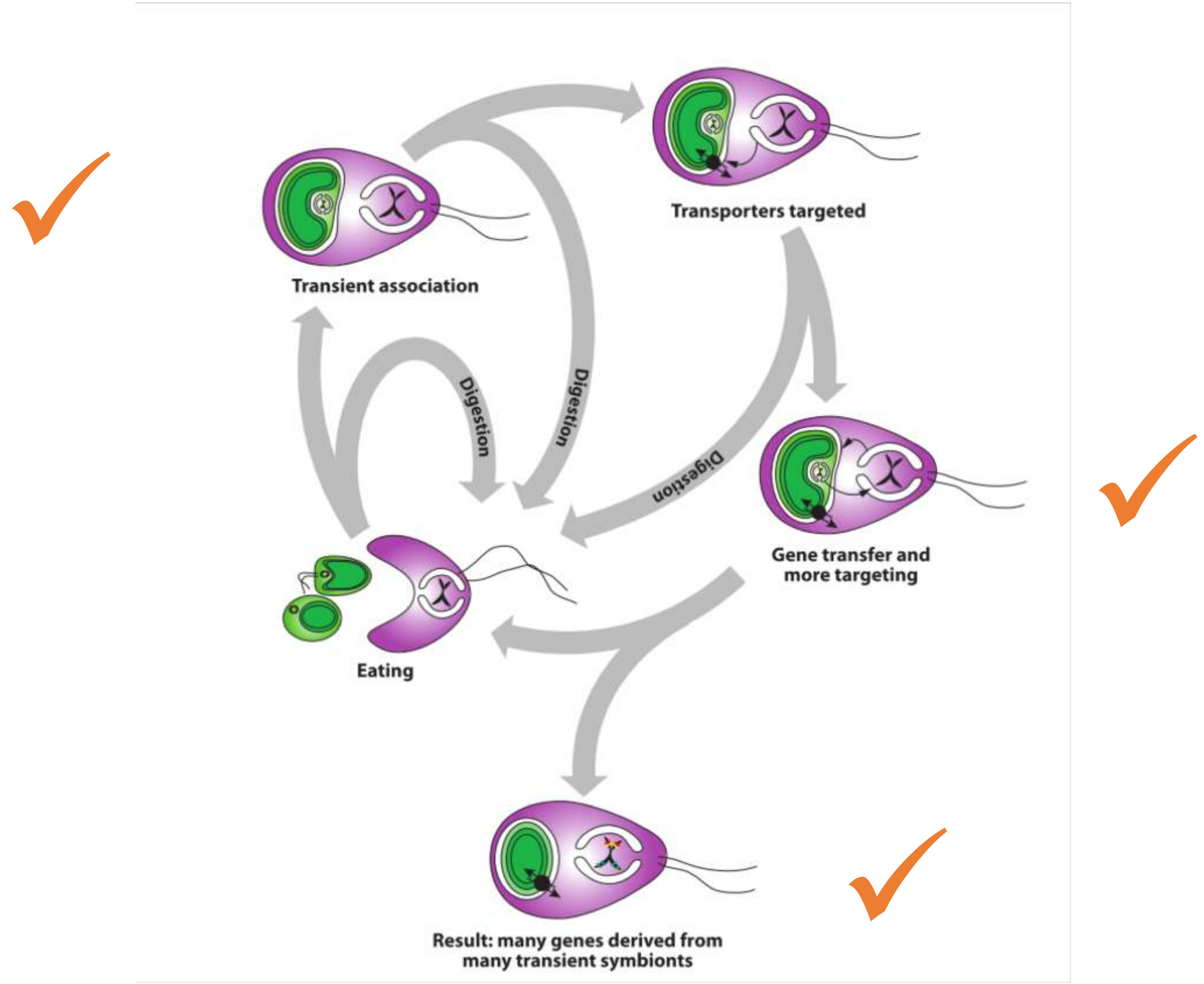
origin of plastids via kleptoplastidity

Which comes first, gene transfer or cellular fixation?



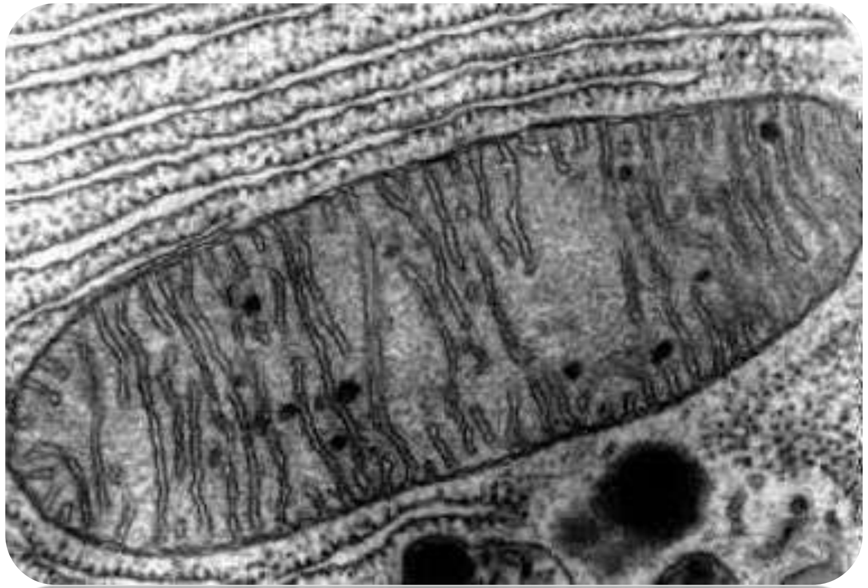
Yubuki, Karnkowska, et al. unpublished

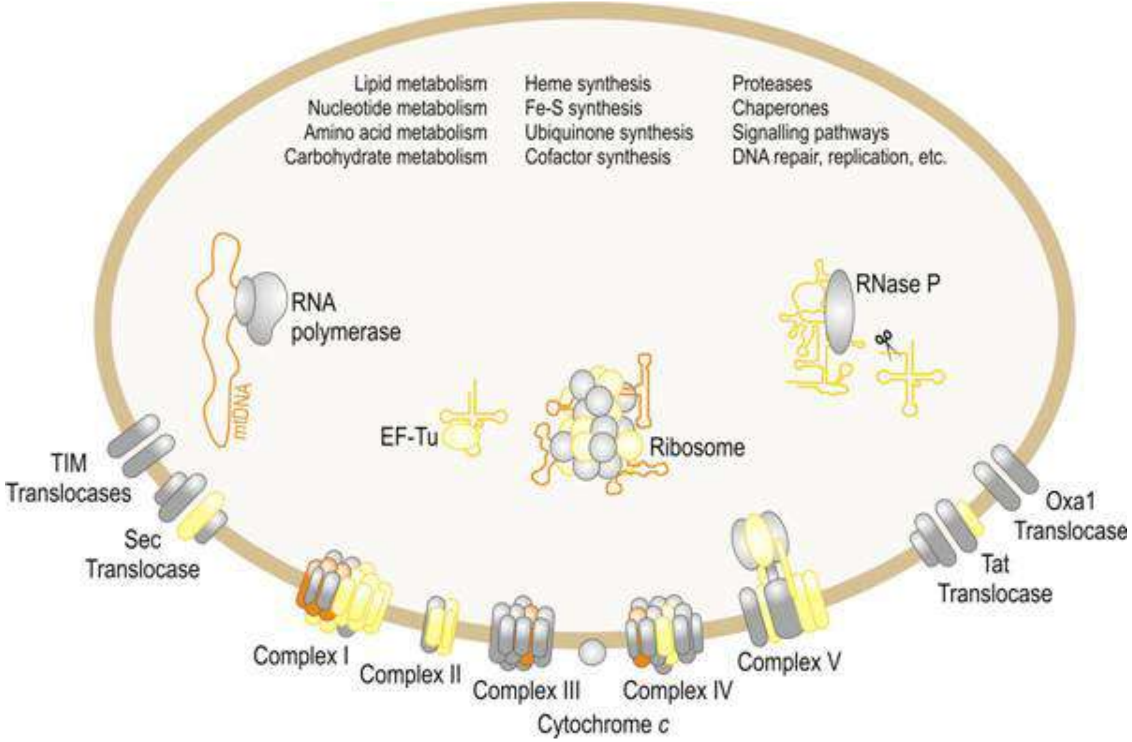
Which Comes First, **Gene Transfer** or Cellular Fixation?



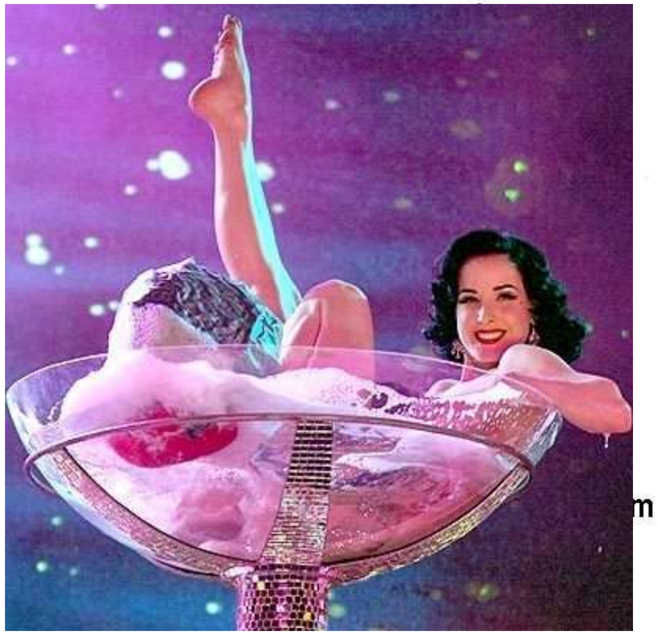
A targeting-ratchet model for the endosymbiotic origin of plastids
Keeling, 2013

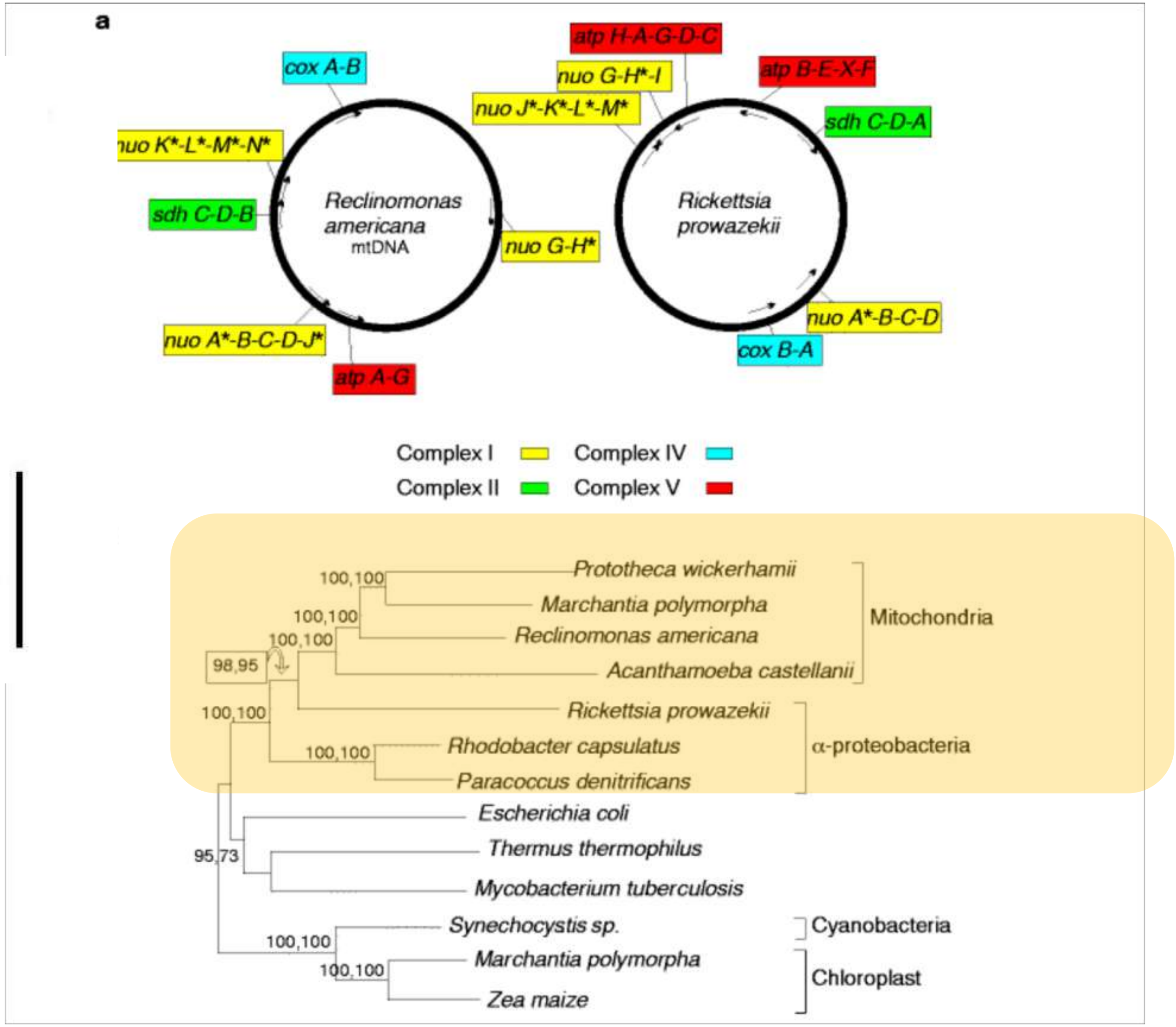
mitochondria





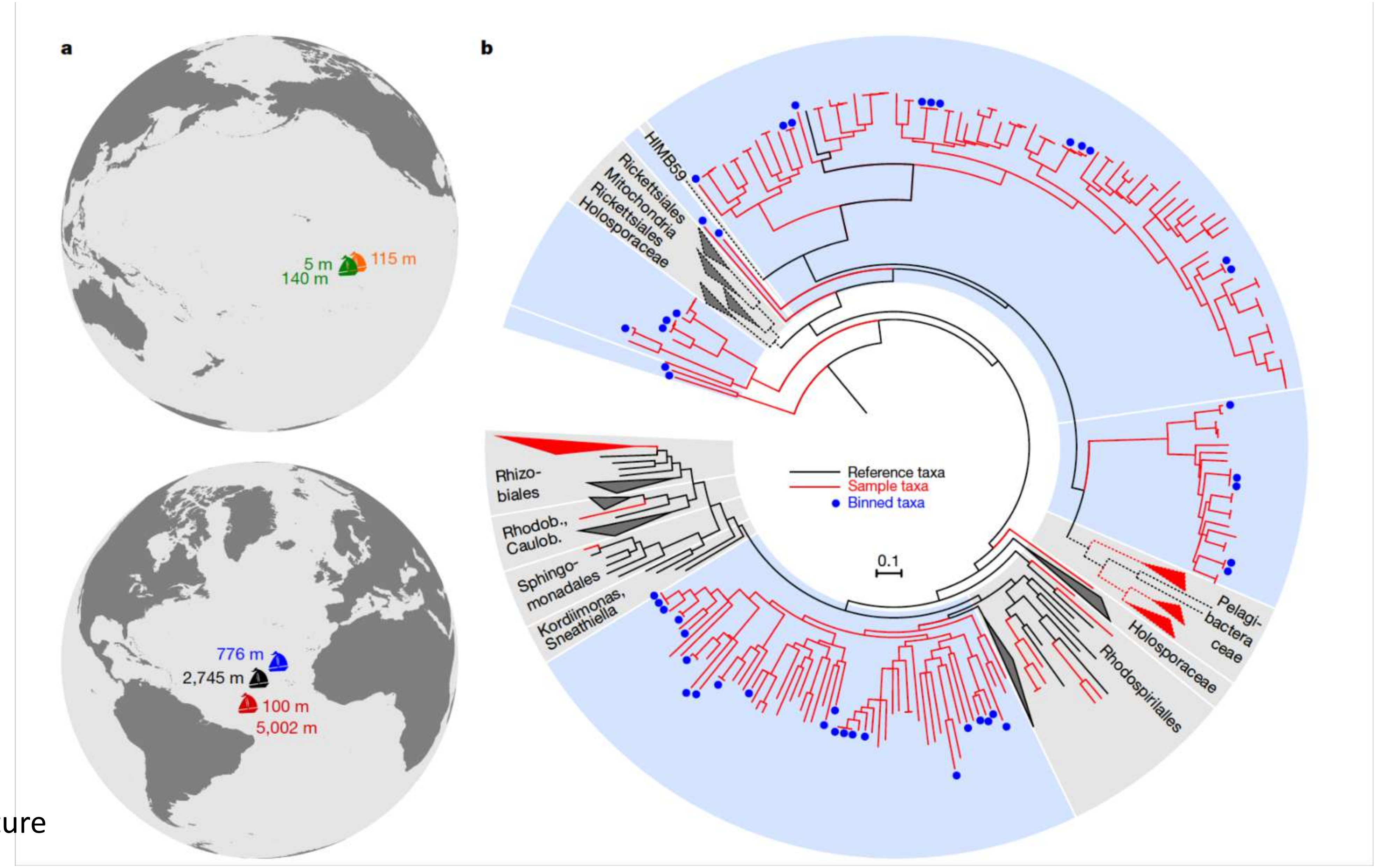
The genome sequence of *Rickettsia prowazekii* and the origin of mitochondria





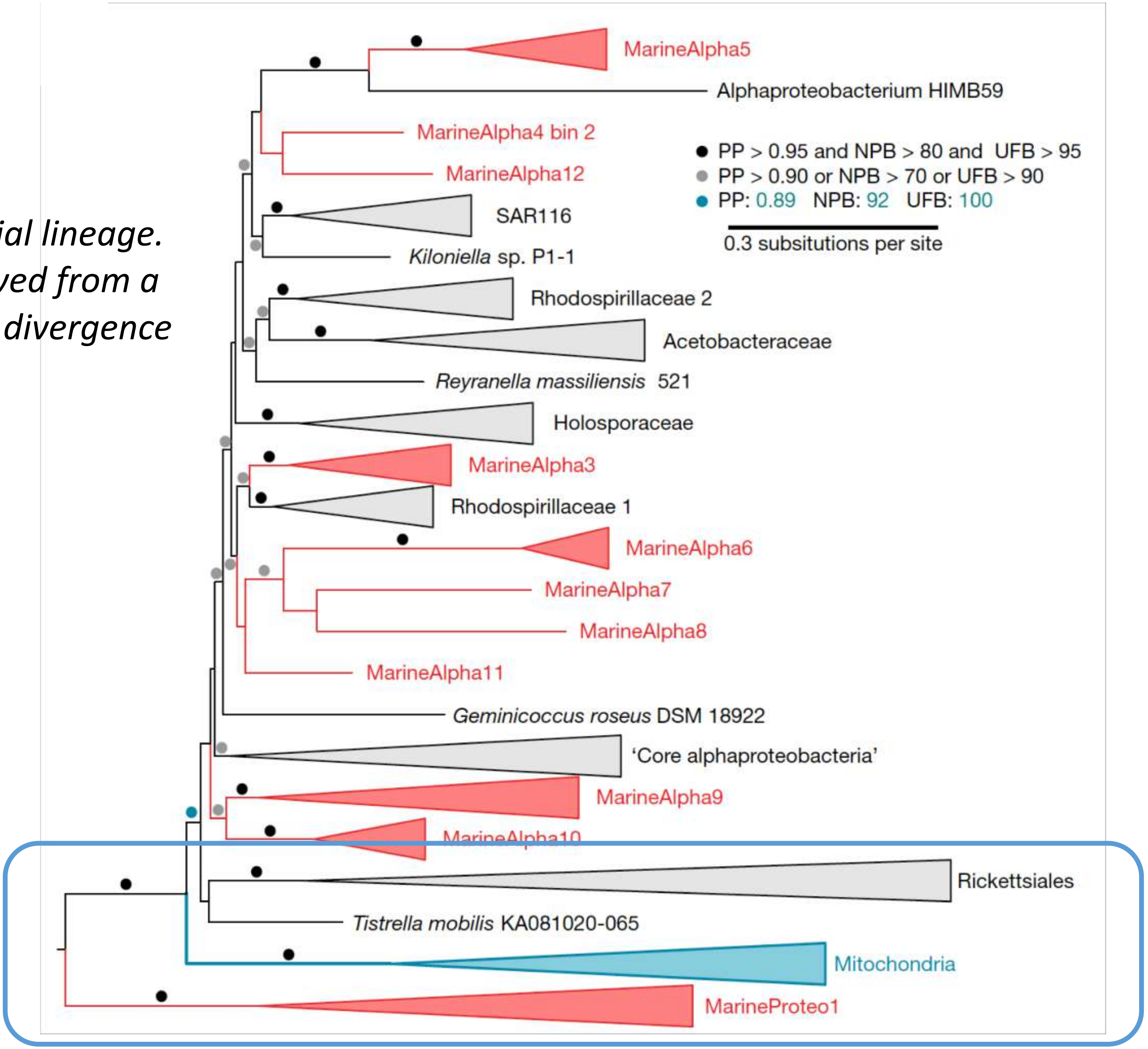
Andersson (1998), Nature

Deep mitochondrial origin outside the sampled alphaproteobacteria



Martijn et al. (2018) Nature

„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."

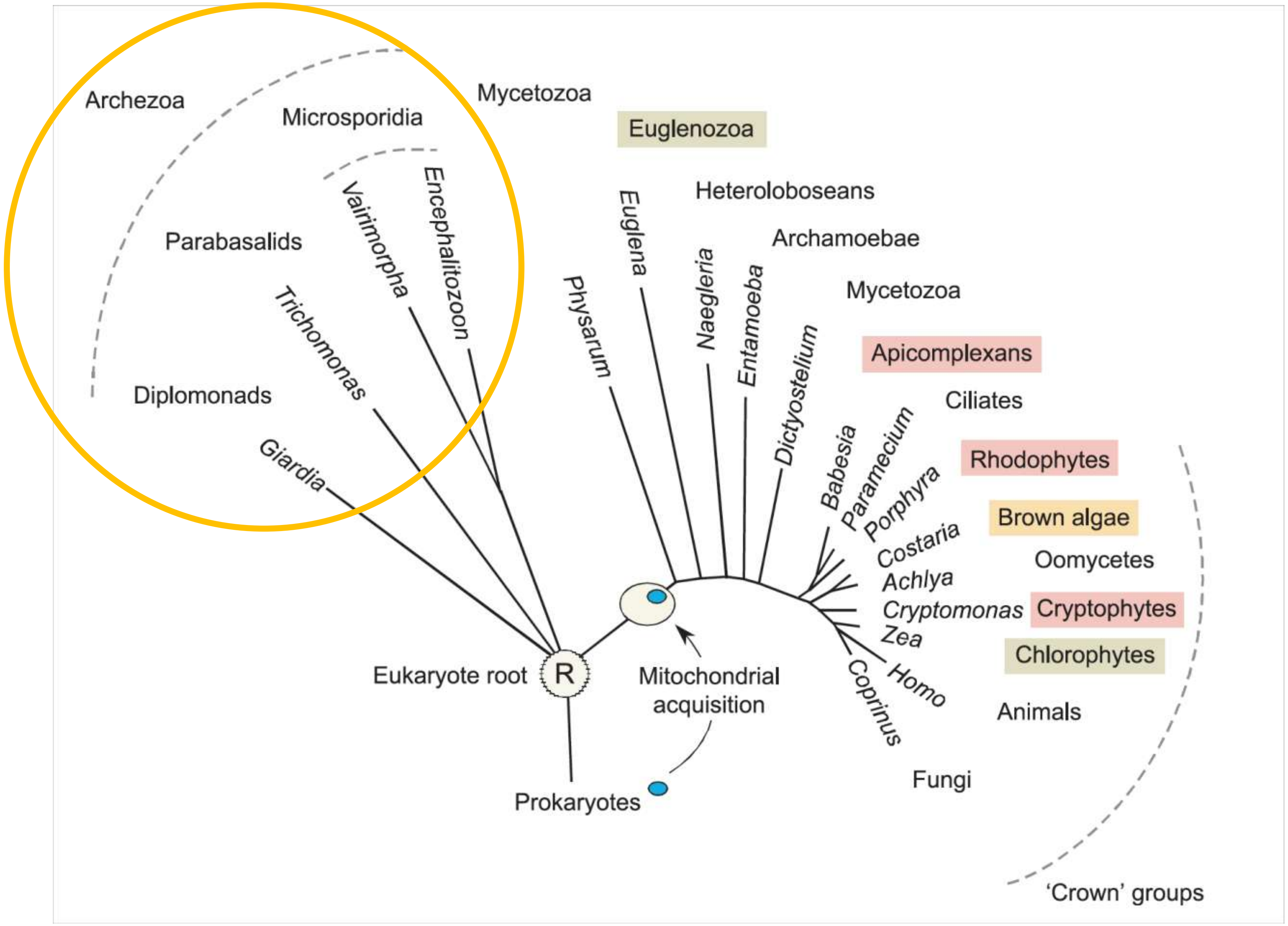


Martijn et al. (2018) Nature

Which came first nucleus or mitochondrion?

Archezoa hypothesis

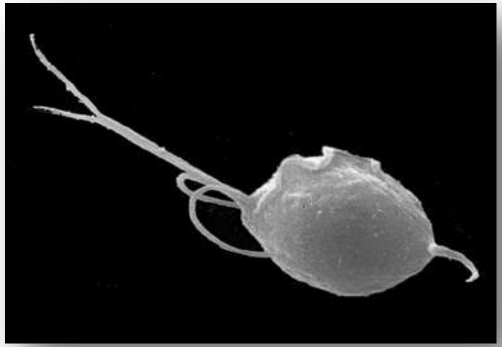
Cavalier-Smith, 1989



Embley and Martin (2006) Nature

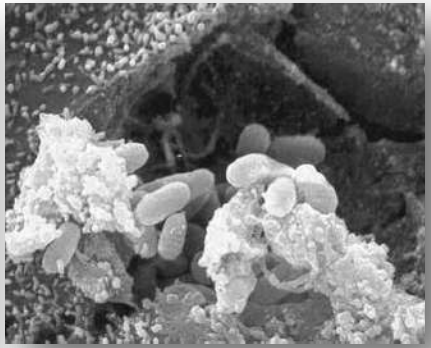
Archezoa

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

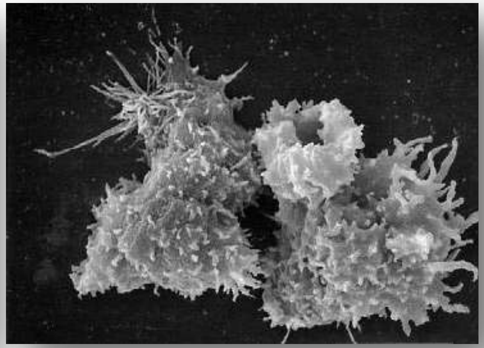


Trichomonas

Giardia

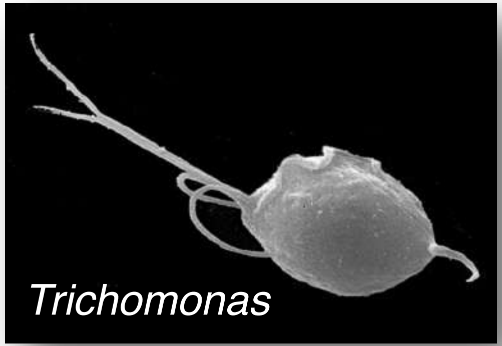


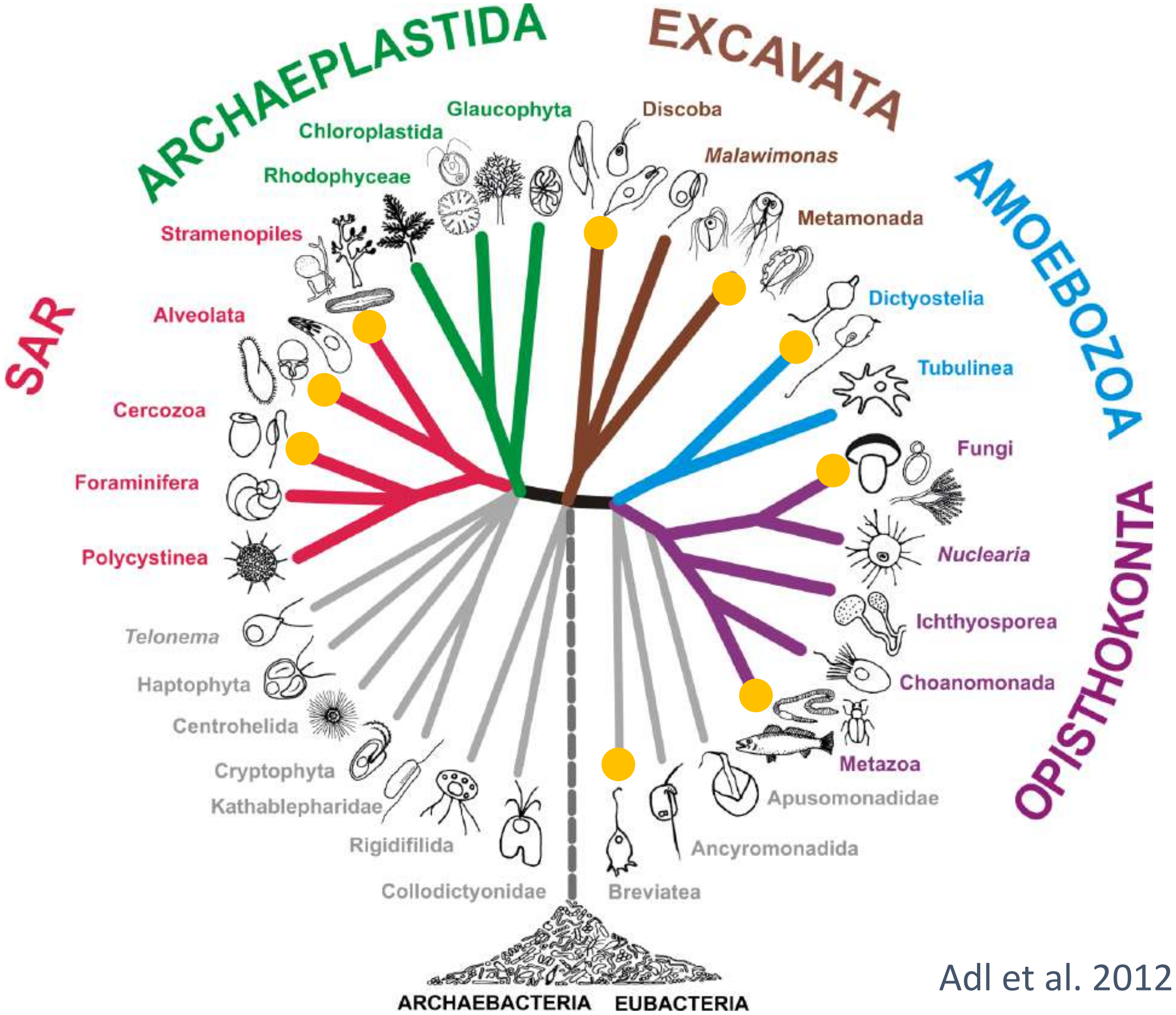
Microsporidia



Archamoebae

mitochondria related organelles (MROs) in eukaryotic microbes





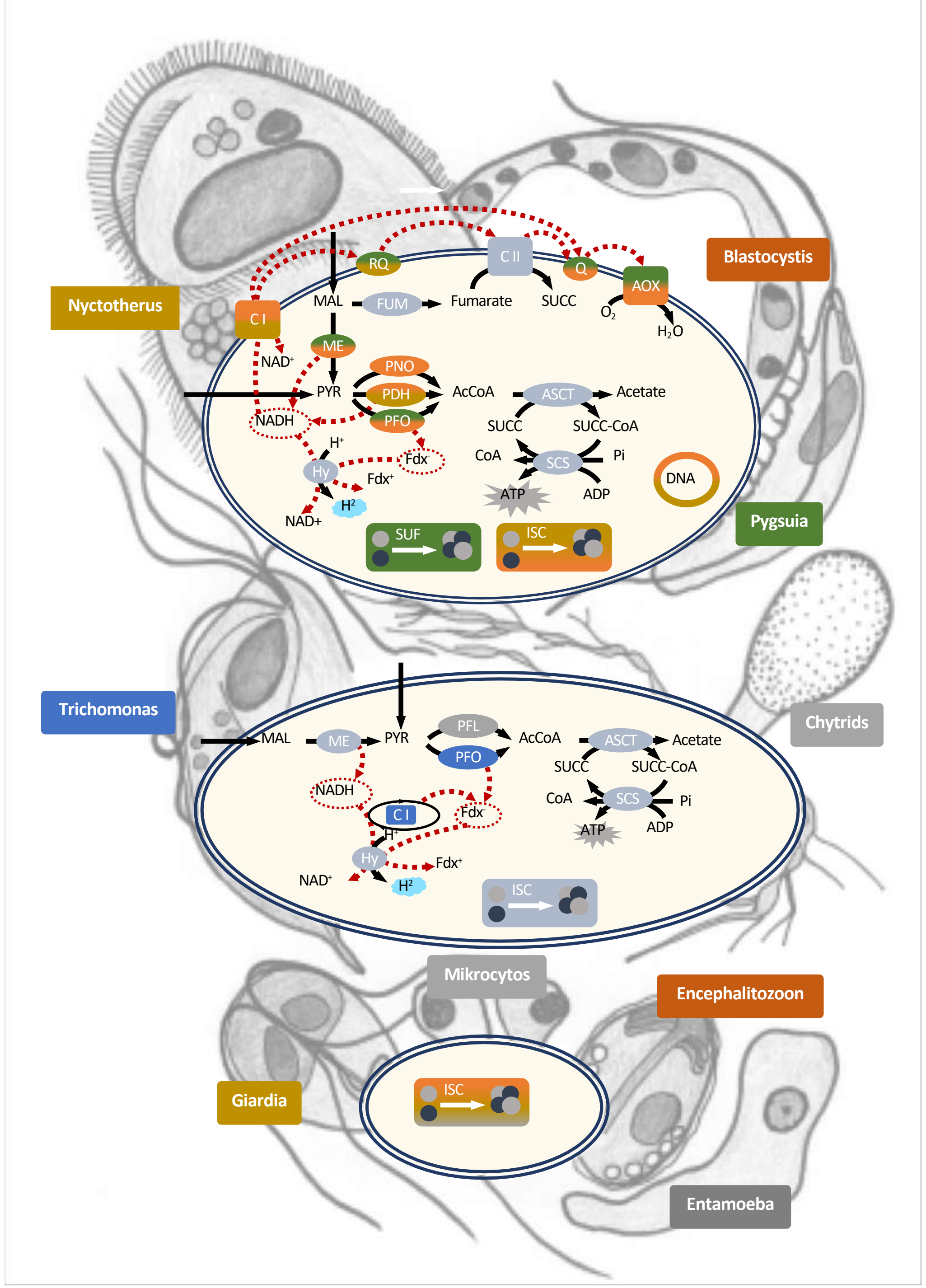
Adl et al. 2012

Hydrogen producing mitochondria

Hydrogenosomes

Mitosomes

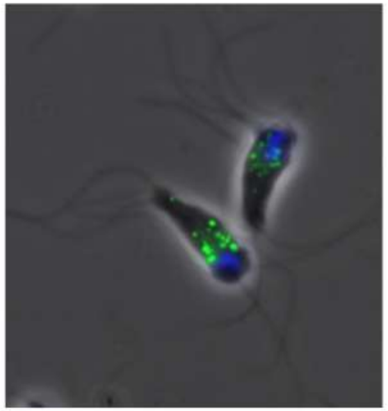
metabolic diversity of MROs



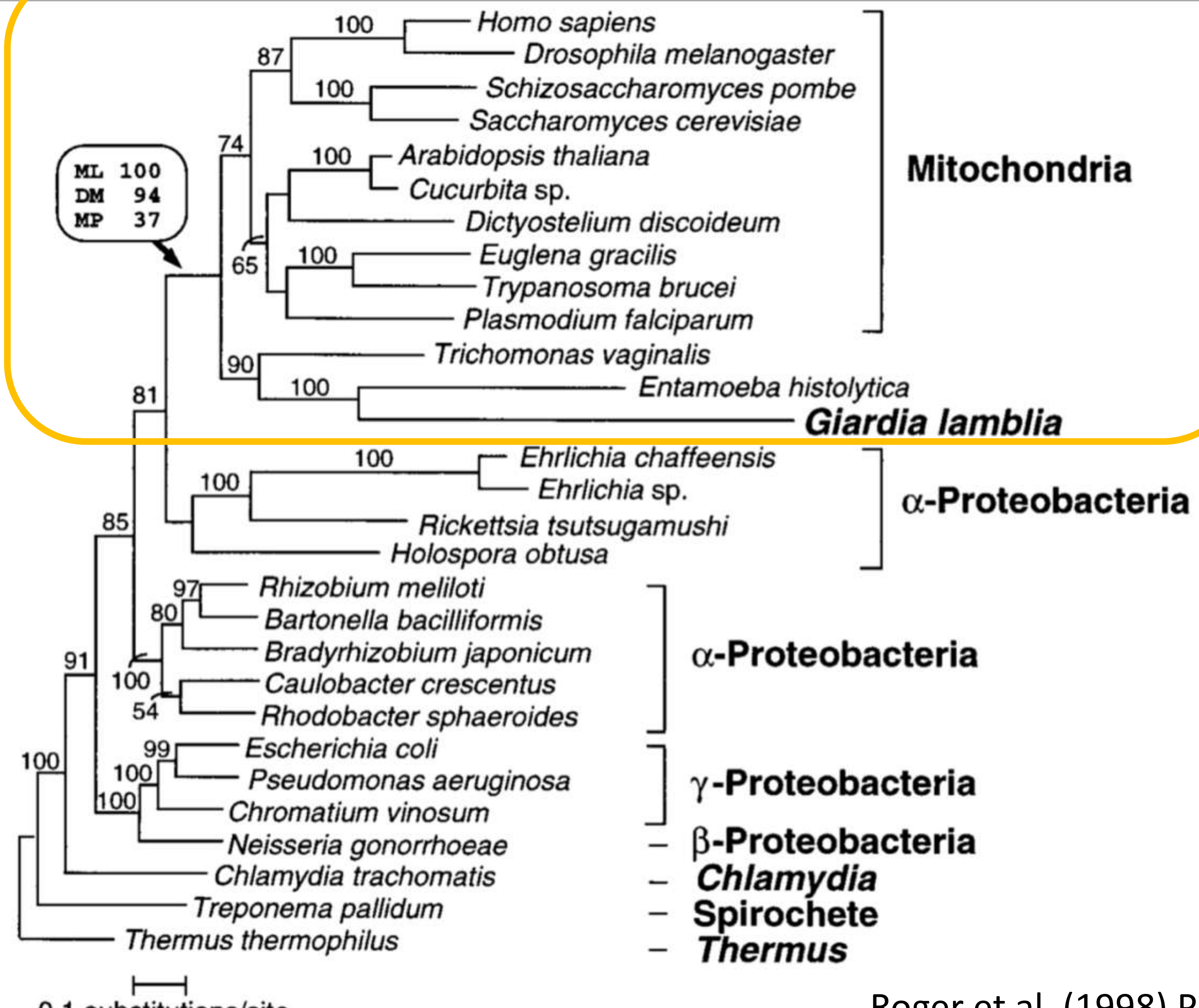
common origin of mitochndria and MROs

Cpn60 chaperonin

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



cpn60 localization
Jerlström-Hultqvist et al. 2013



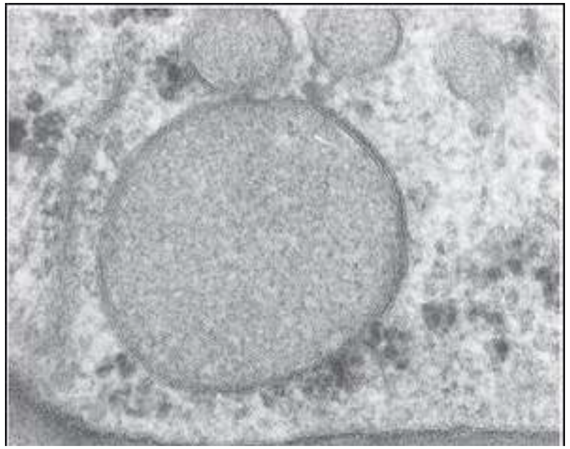
Roger et al. (1998) PNAS

Archezoa hypothesis rejected

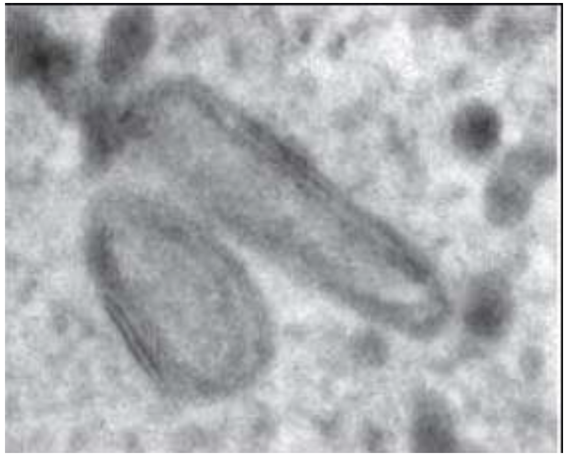
• All “archezoa” possess:
- mitochondrial genes in nuclear genomes
- degenerate derivatives of mitochondria
- they do not group together on the modern tree of life

Common ancestor of all eukaryotes possessed mitochondria

mitochondrion

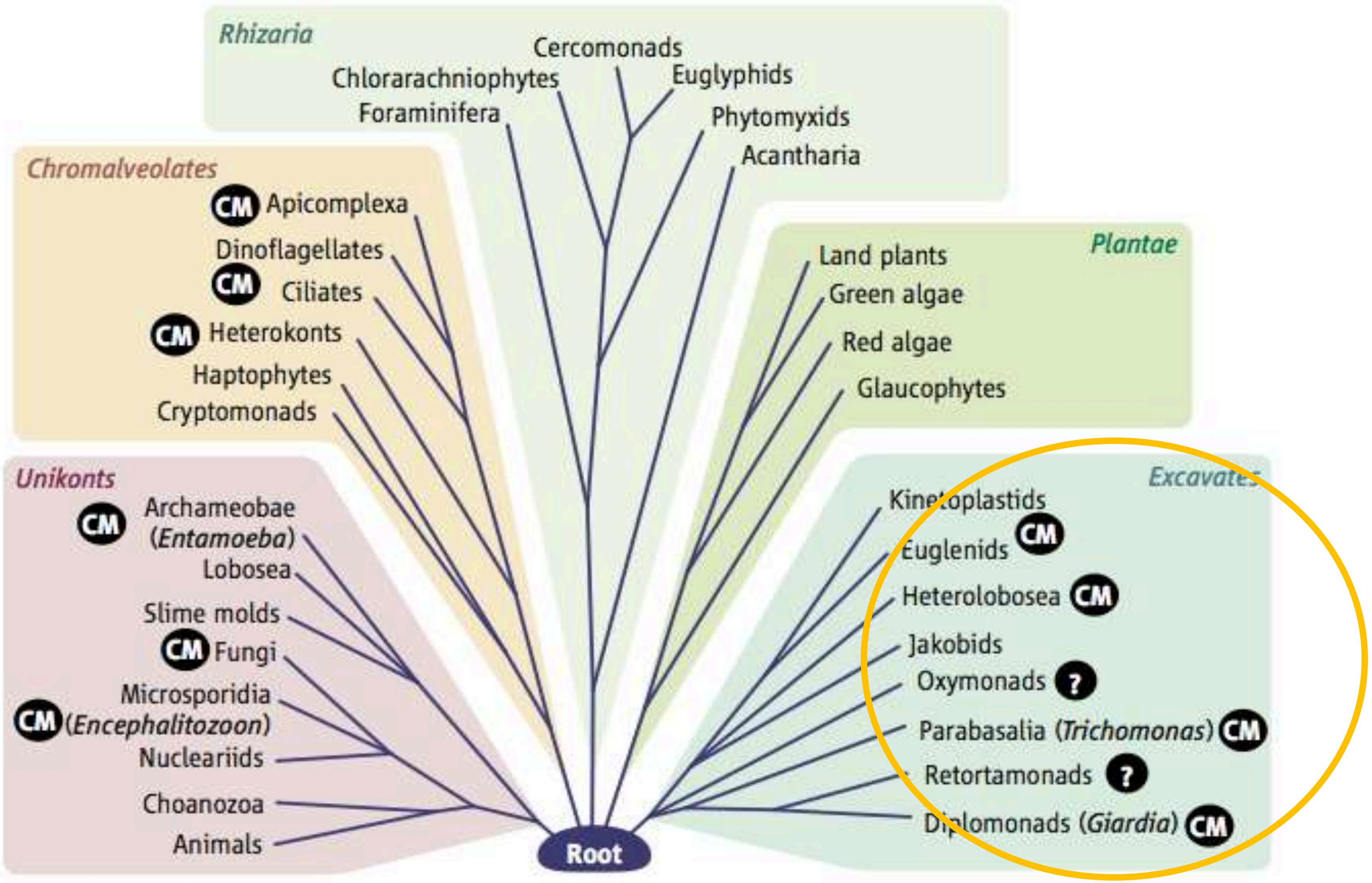


hydrogenosome



mitosomes

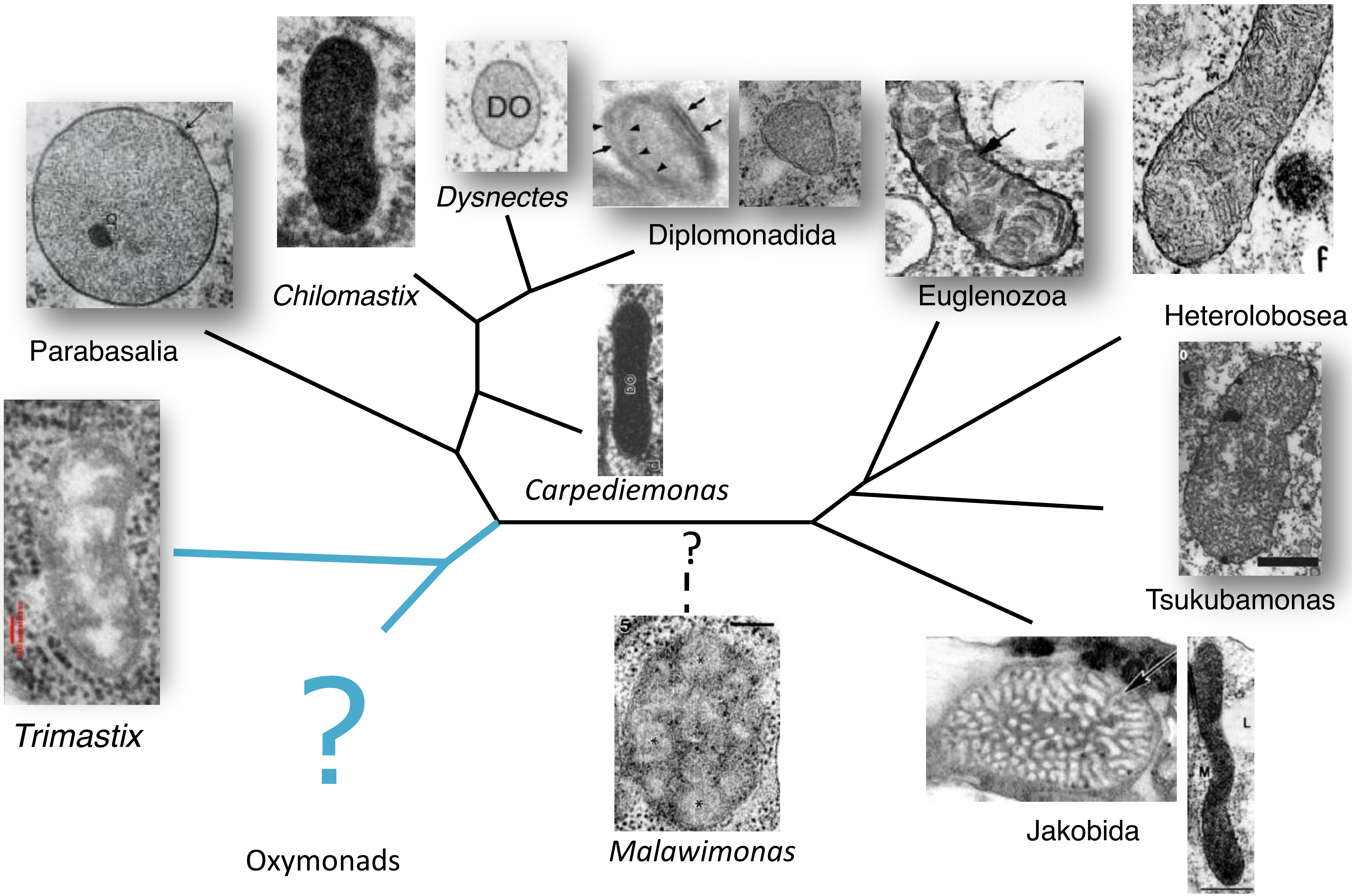
Does amitochondriate eukaryote exist?

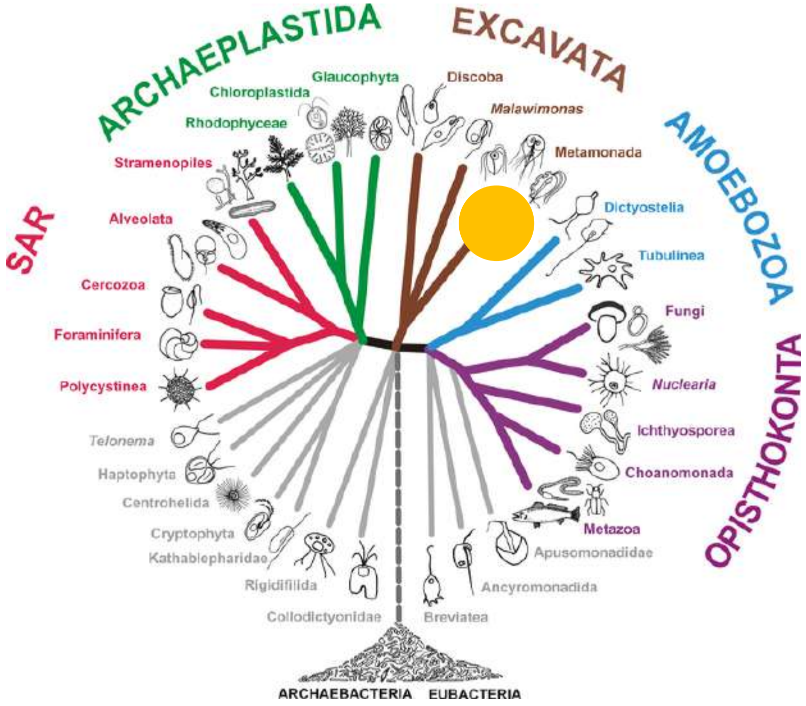


CM cryptic mitochondria

Keeling, 2007

mitochondria in Excavata





Metamonada

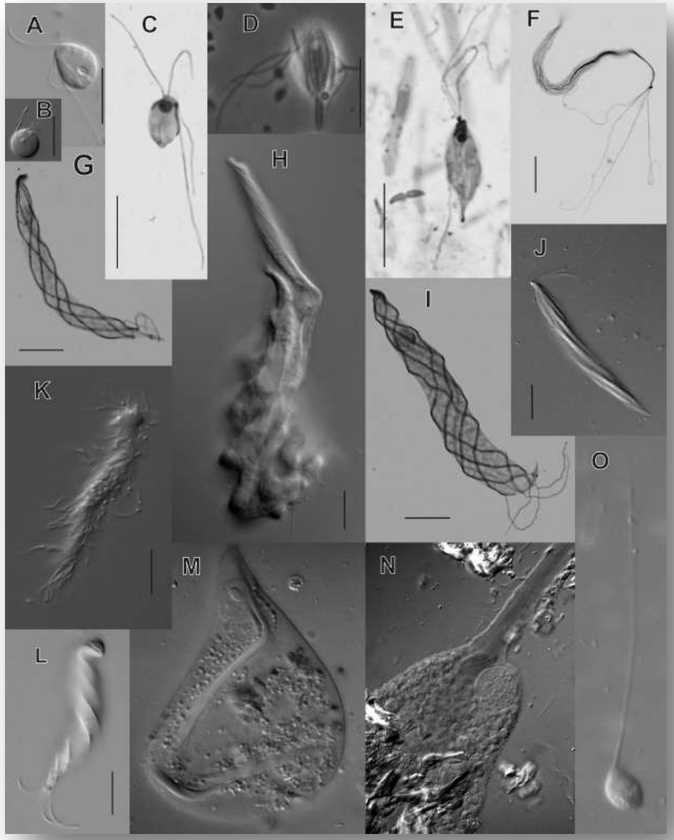
Parabasalia (*Trichomonas*)

Fornicata (*Giardia*)

Preaxostyla

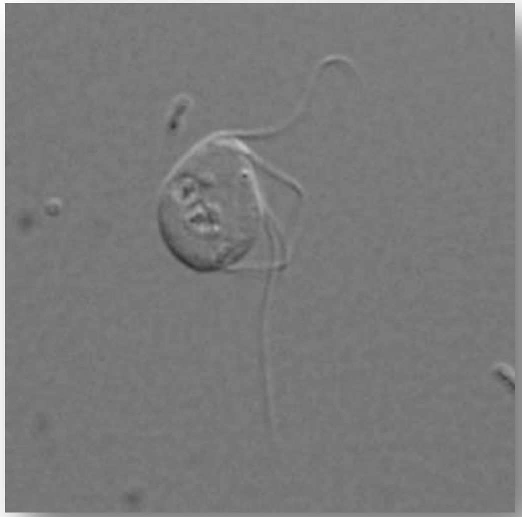
Trimastix

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

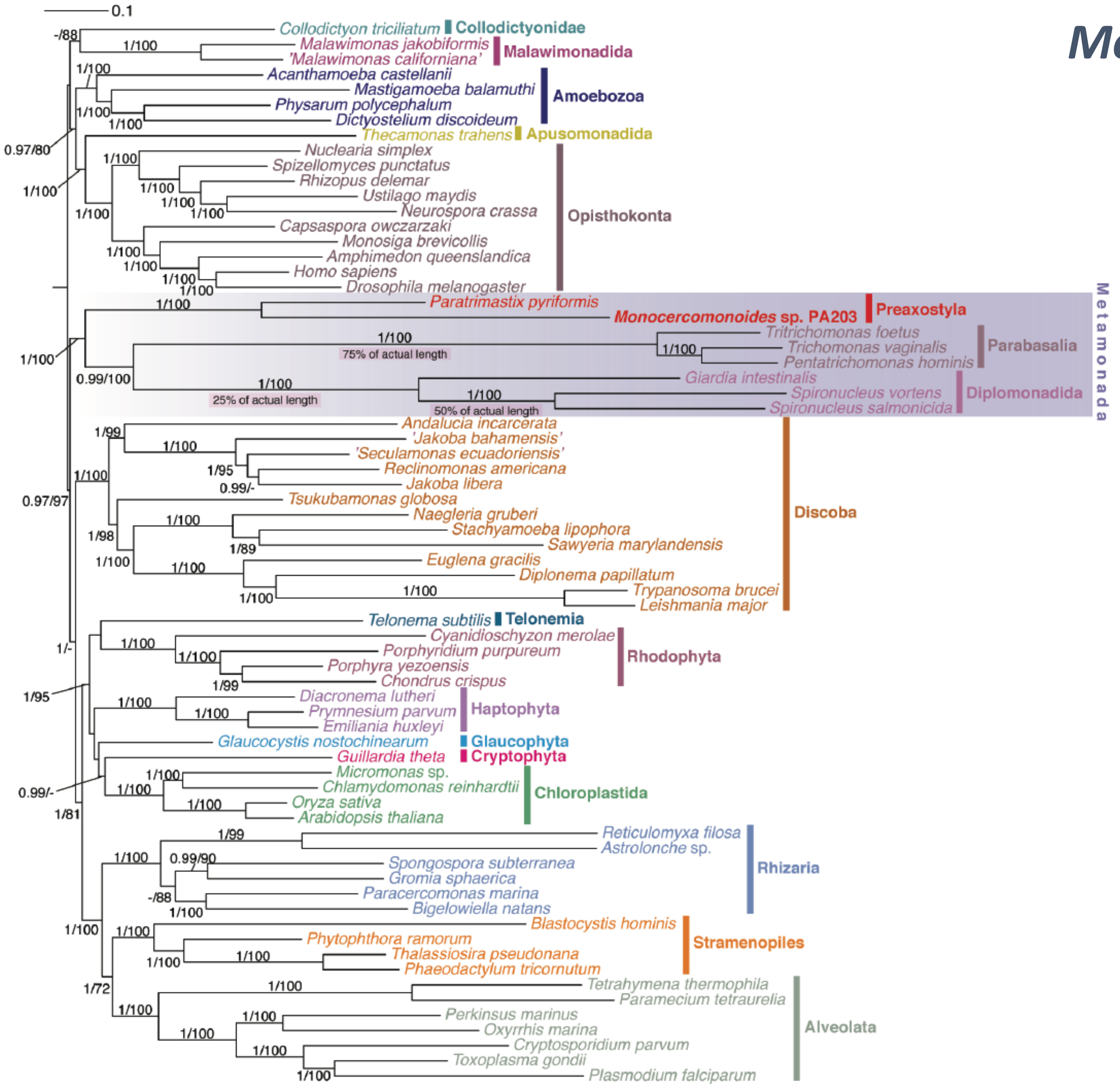


Genome analysis

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

Karnkowska et al. (2016) Curr Biol

Monocercomonoides is less divergent than Parabasalids and Diplomonads



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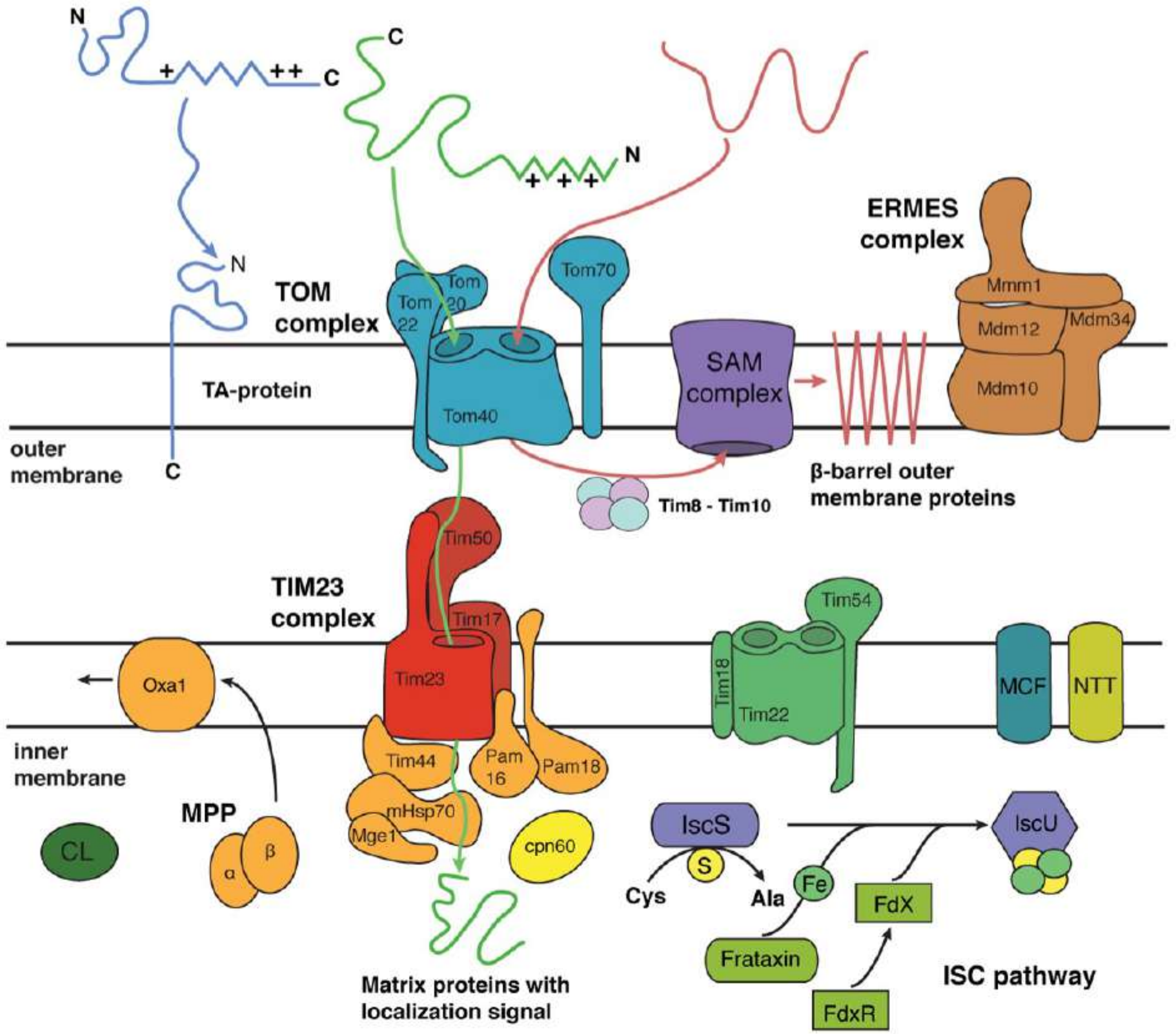
Searching for mitochondrial proteins

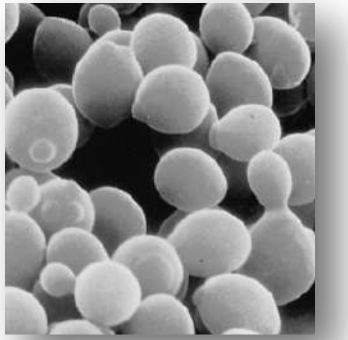
Mitochondrial outer membrane targeted proteins (TA)

Proteins with mitochondrial localization signal

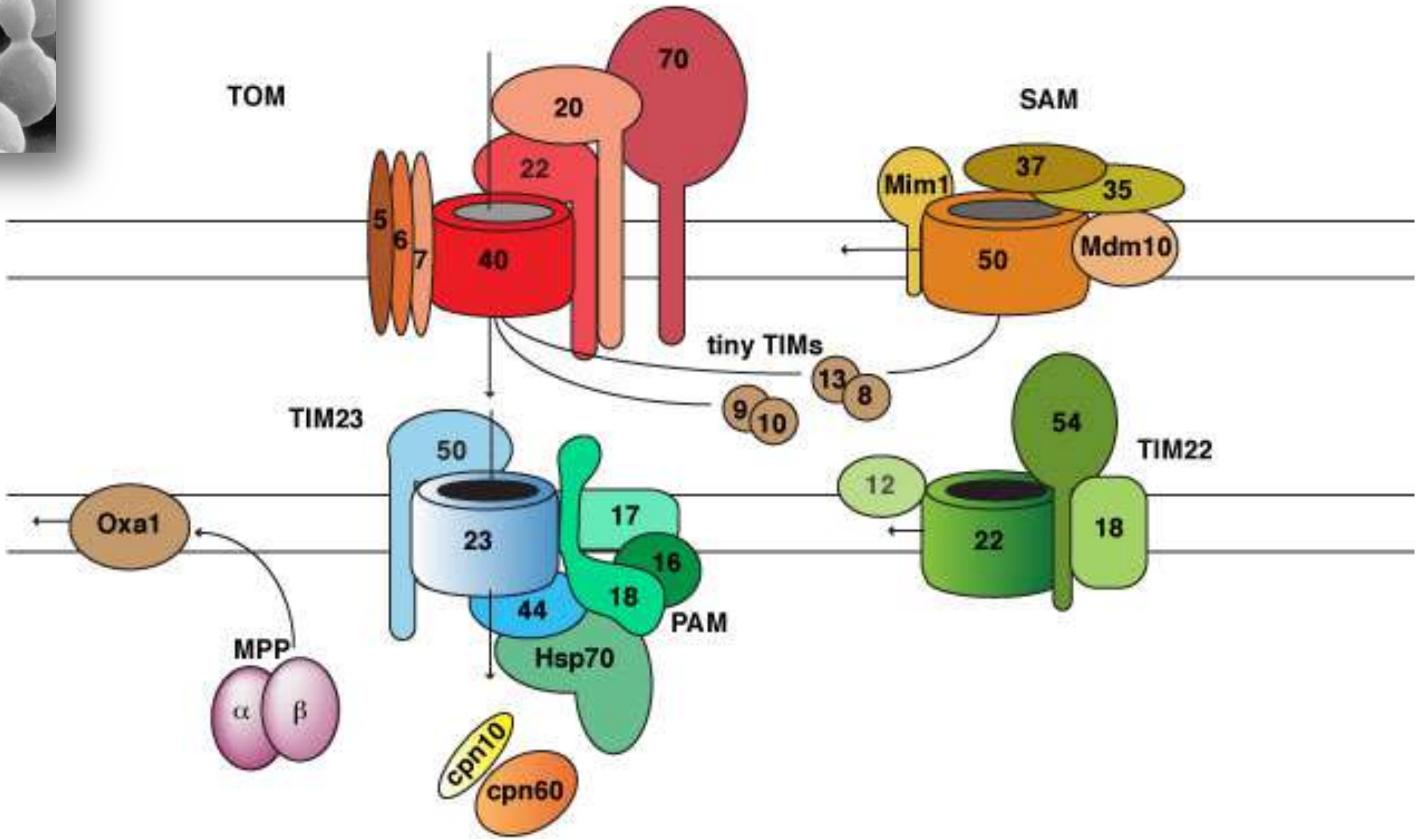
β-barrel mitochondrial outer membrane proteins



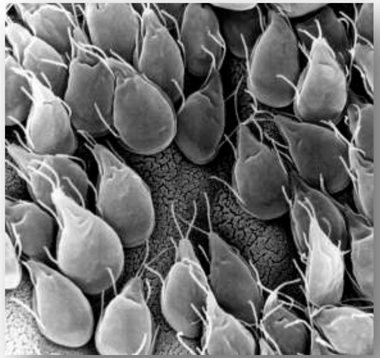
mitochondrial membrane transport proteins



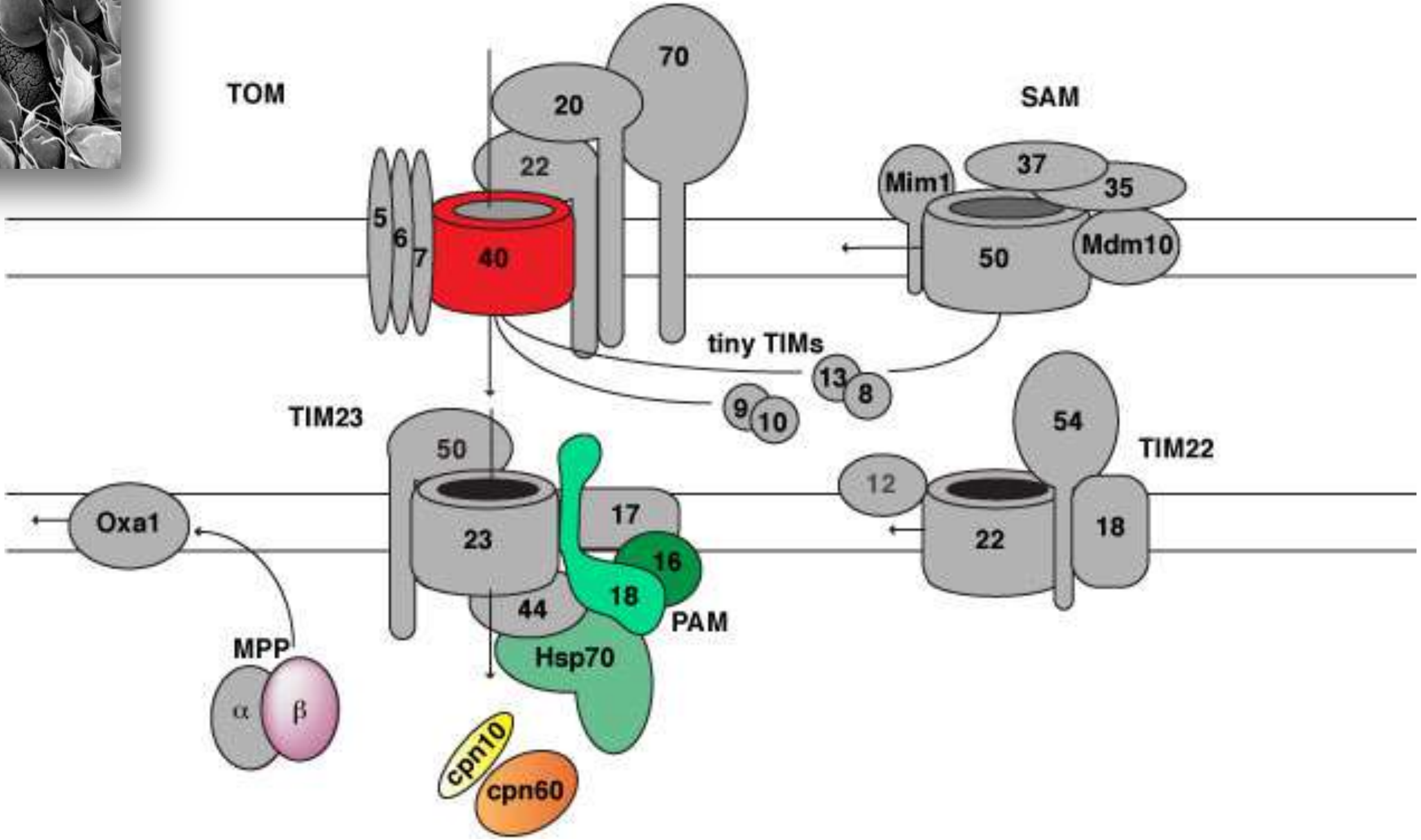
yeast



mitochondrial membrane transport proteins

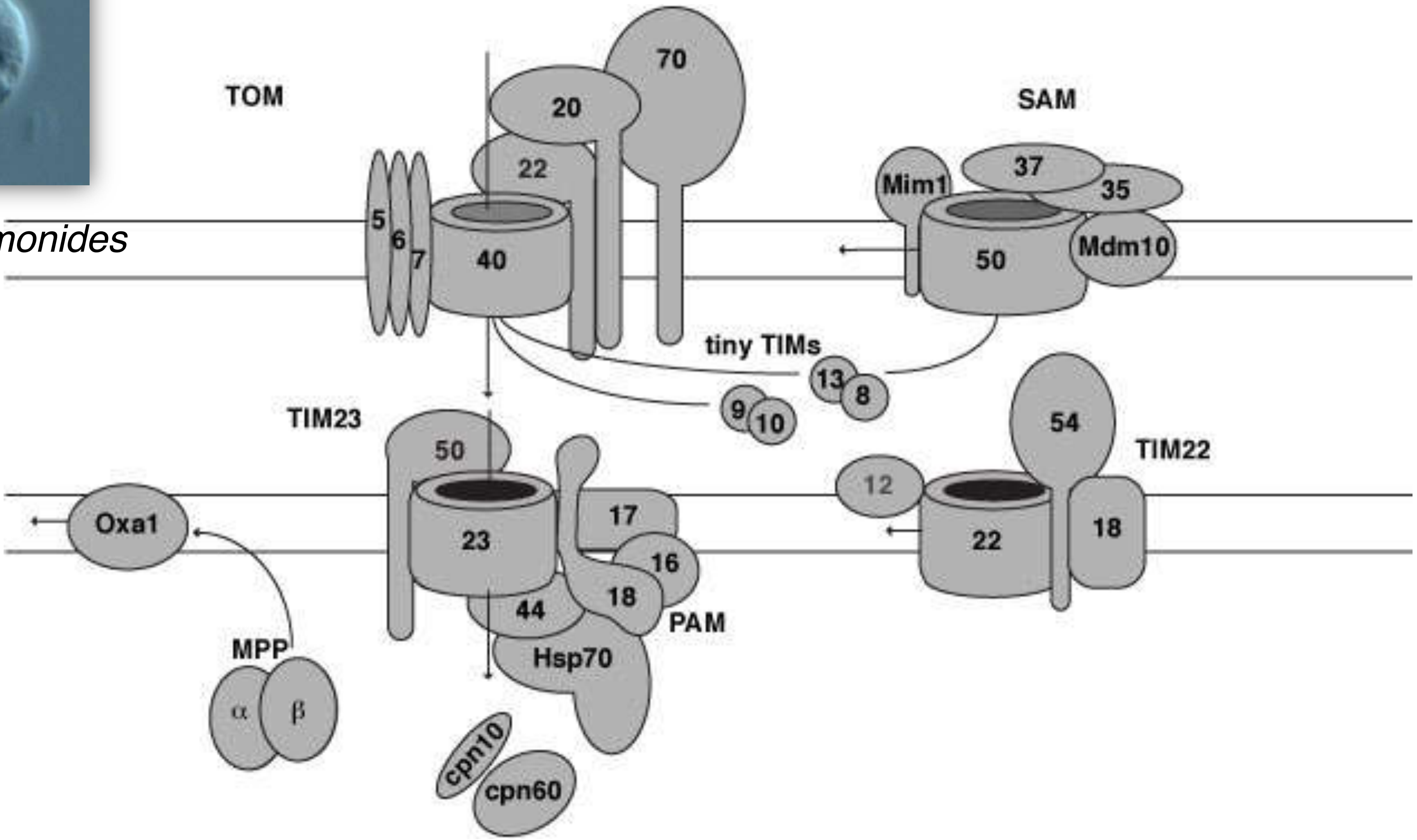


Giardia



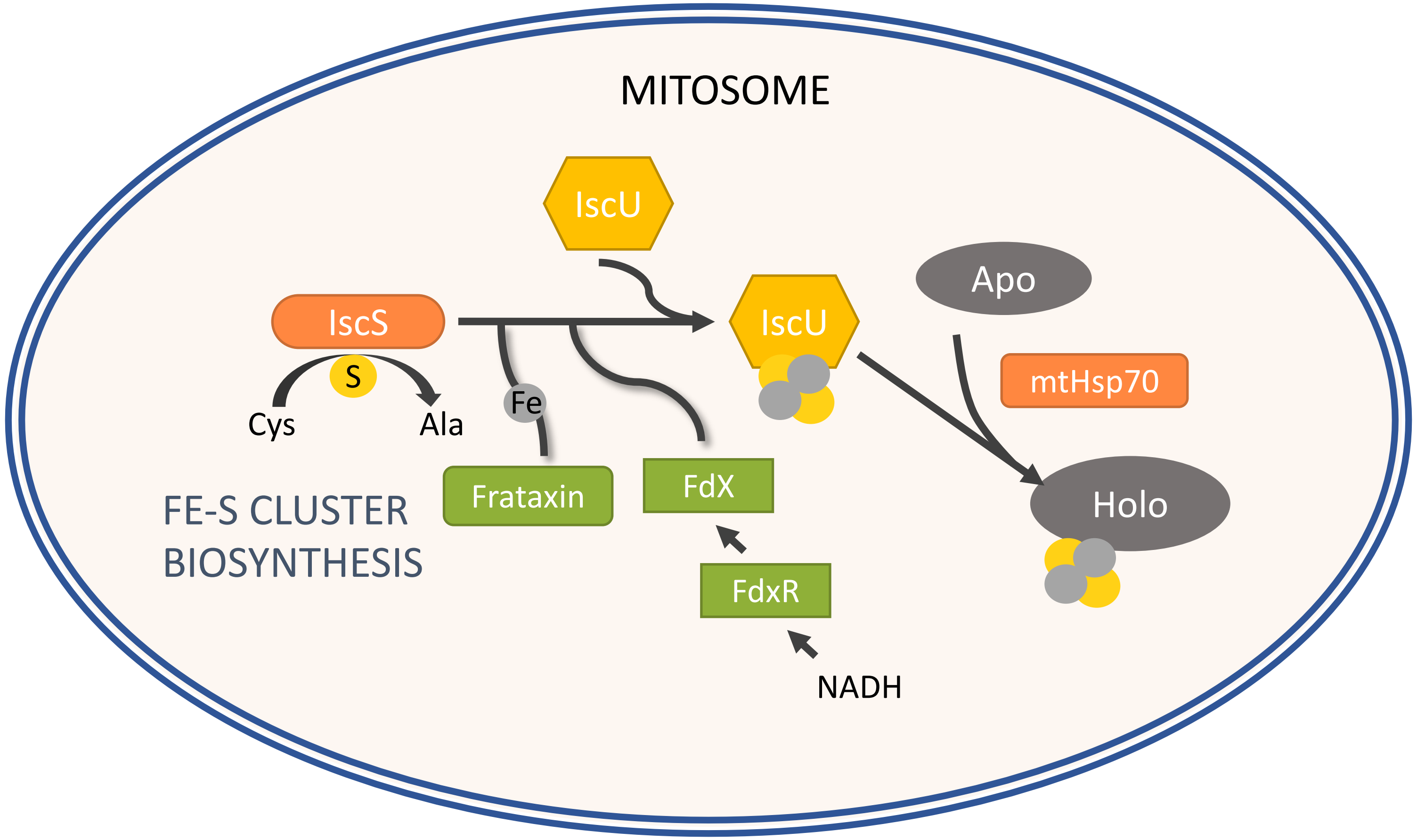
mitochondrial membrane transport proteins

Monocercomonides

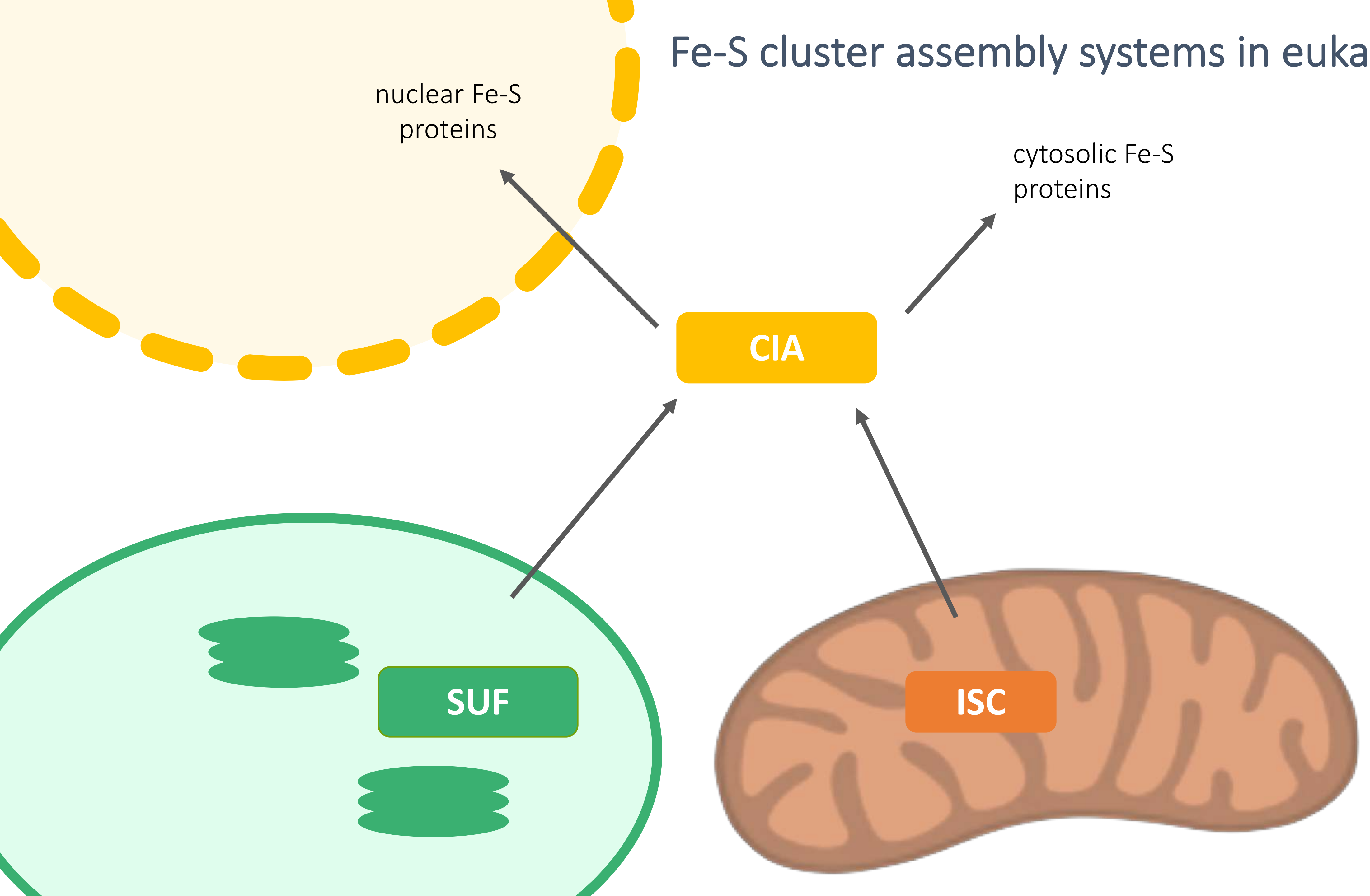


Fe-S cluster assembly
the most conserved mitochondrial process

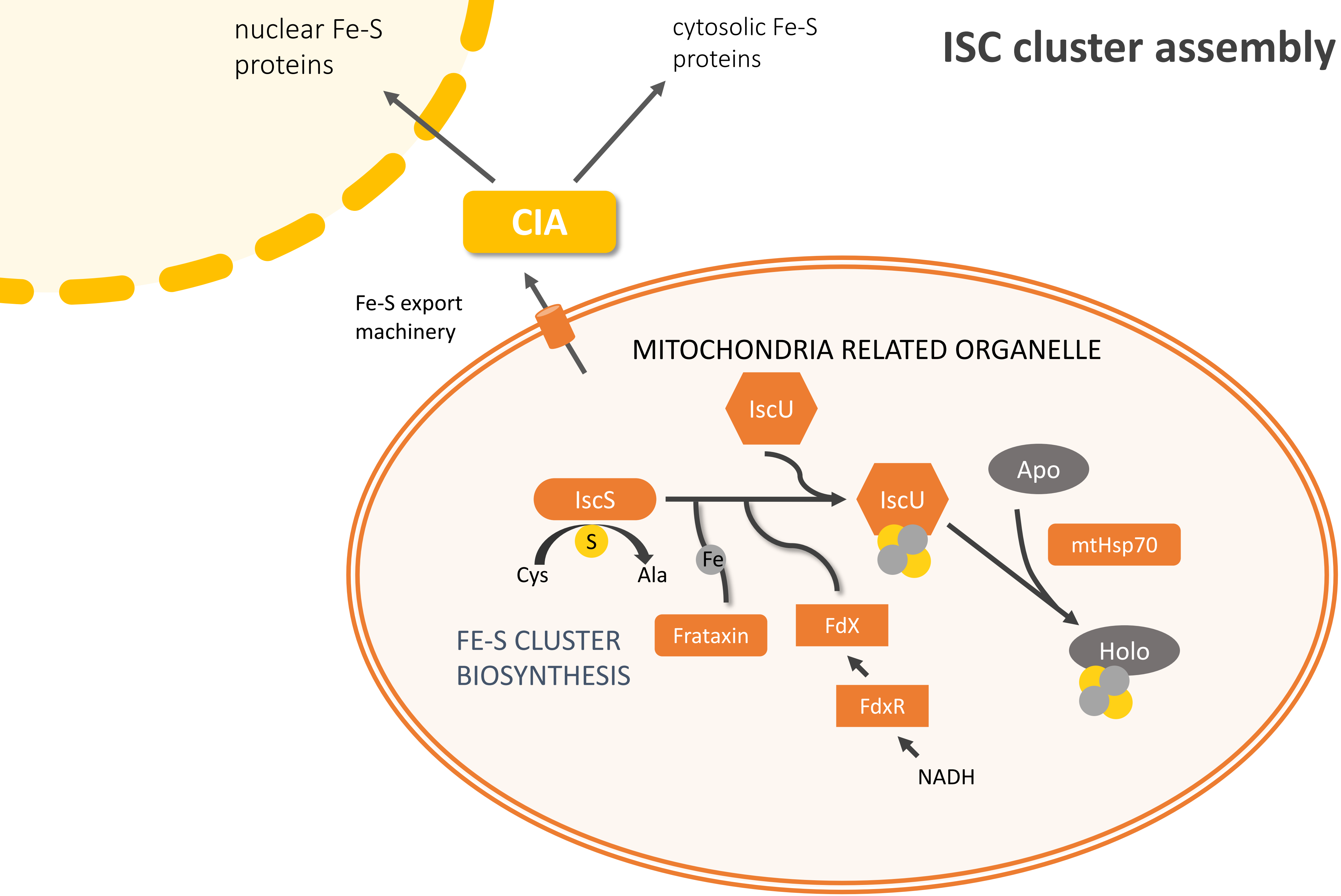
- Fe/S proteins are essential for viability
- they are involved in: DNA repair, DNA replication, ribosome assembly



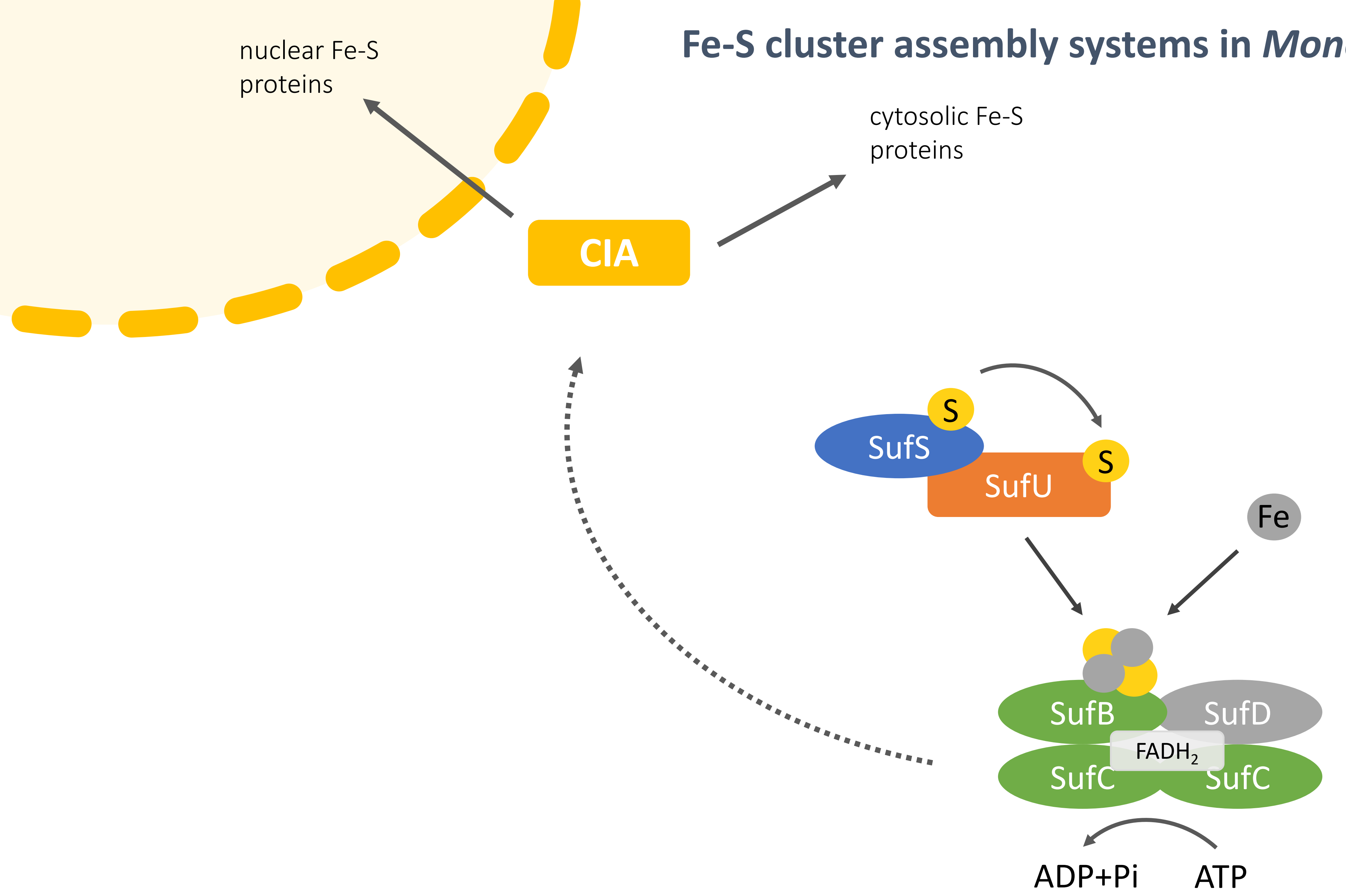
Fe-S cluster assembly systems in eukaryotes



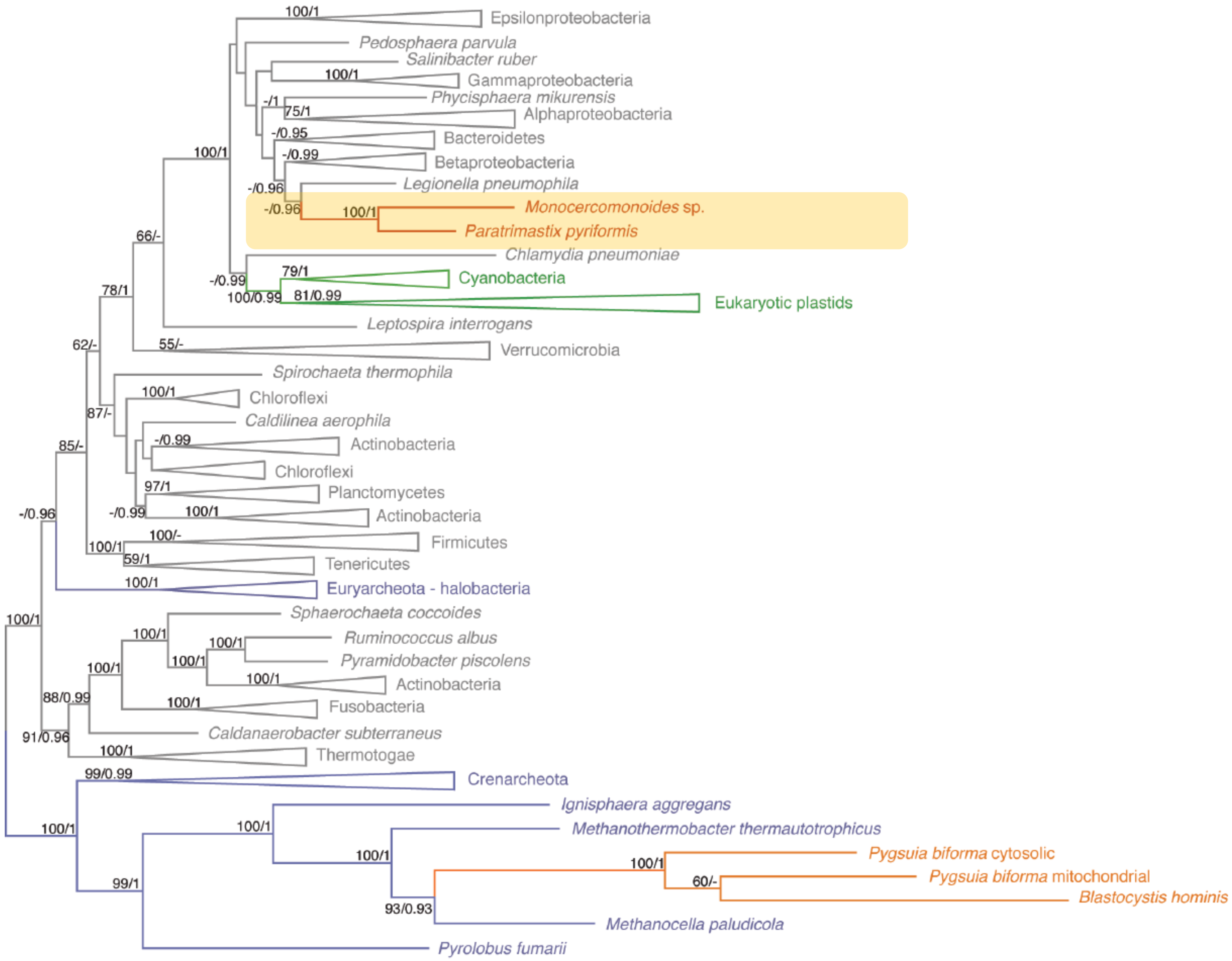
ISC cluster assembly system



Fe-S cluster assembly systems in *Monocercomonoides*



Lateral gene transfer (LGT) of SUF system



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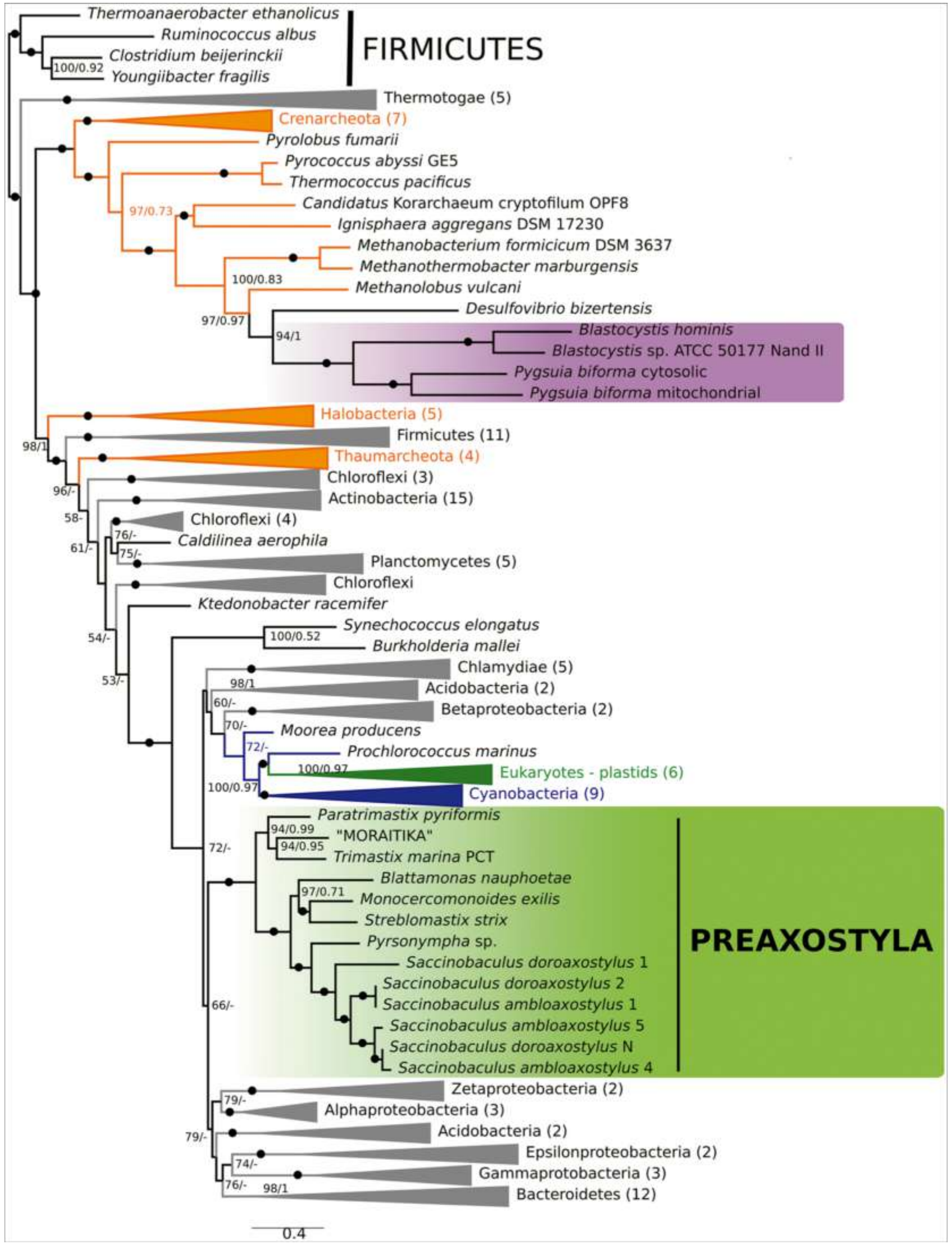
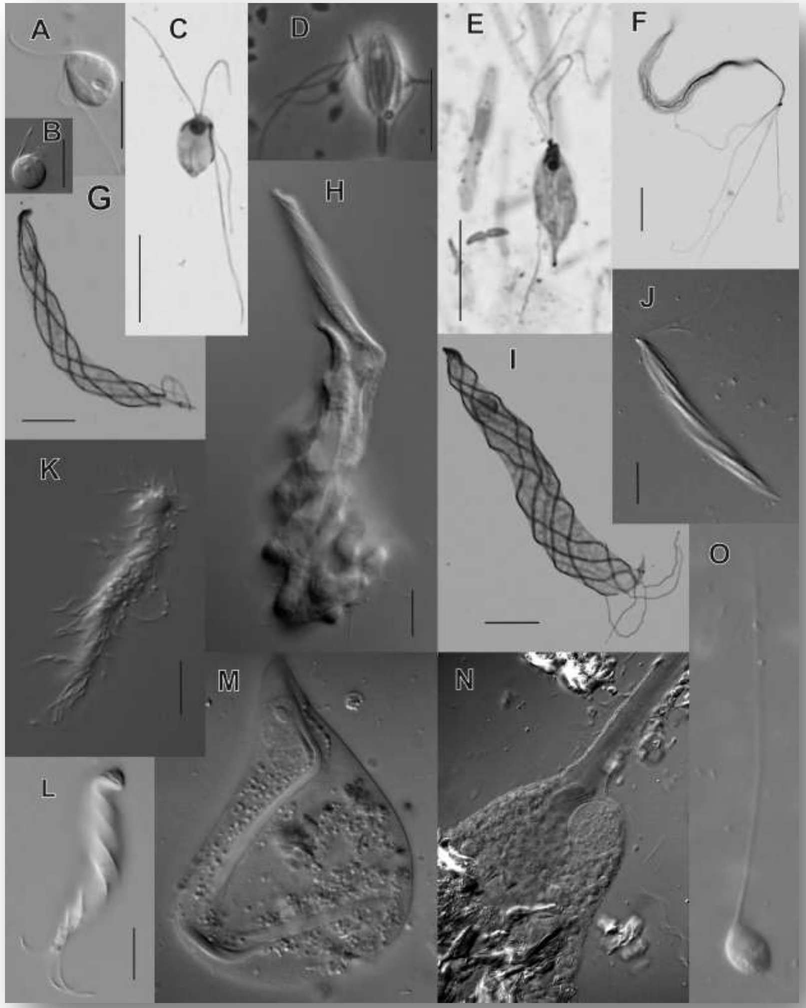
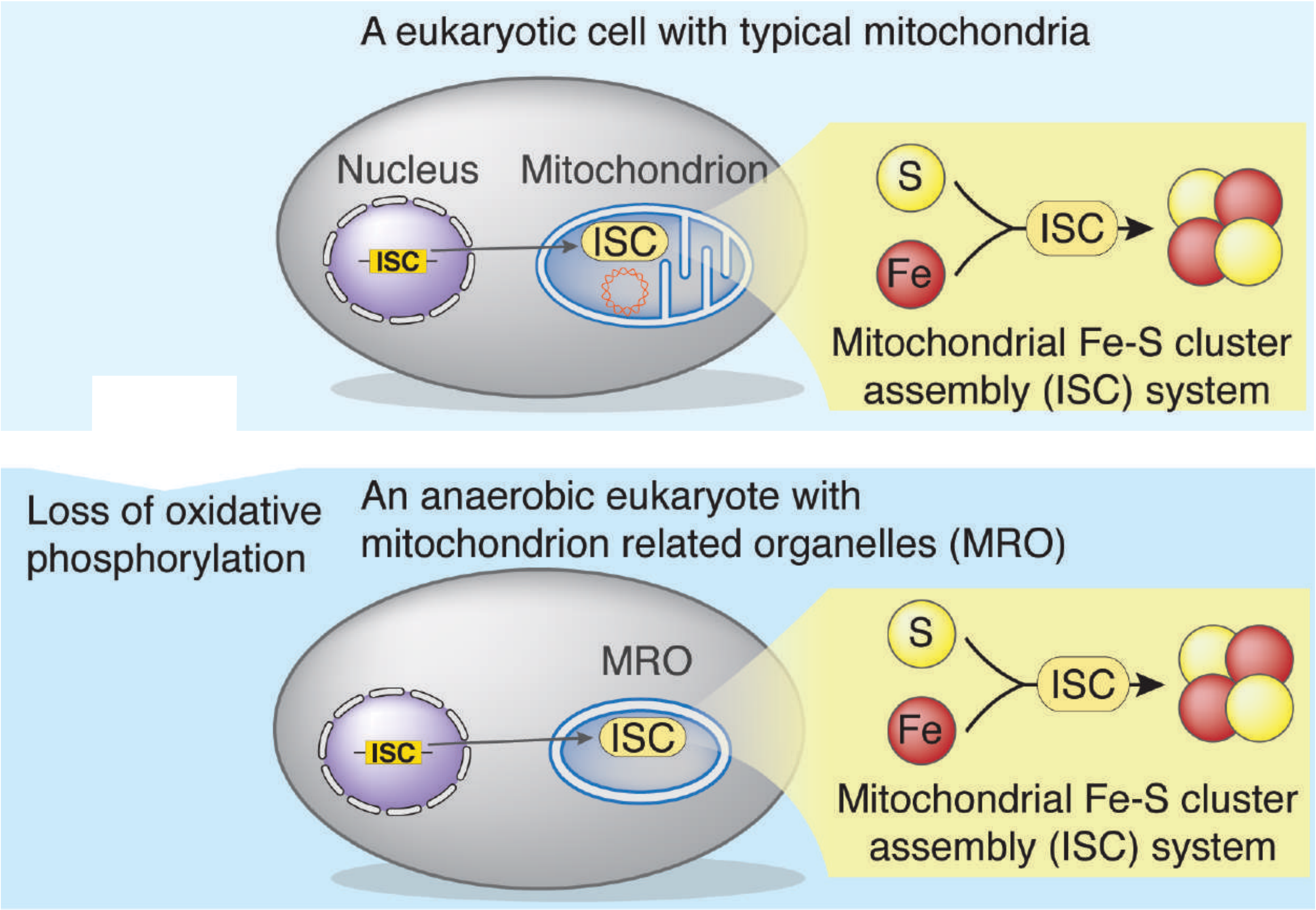
SUF system is widespread in Preaxostyla

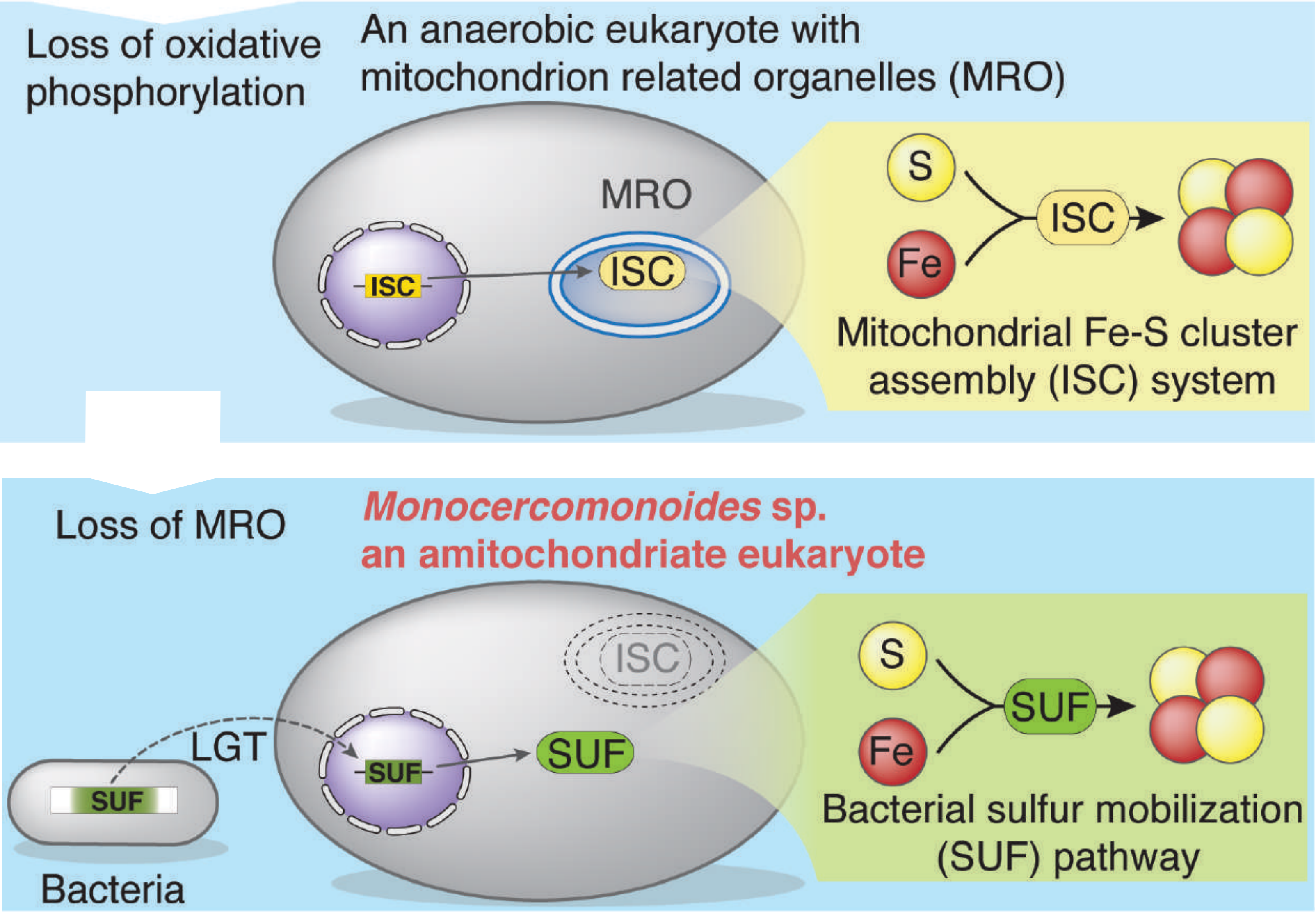




Vacek et al. (2018) MBE



Karnkowska et al. (2016) Curr Biol



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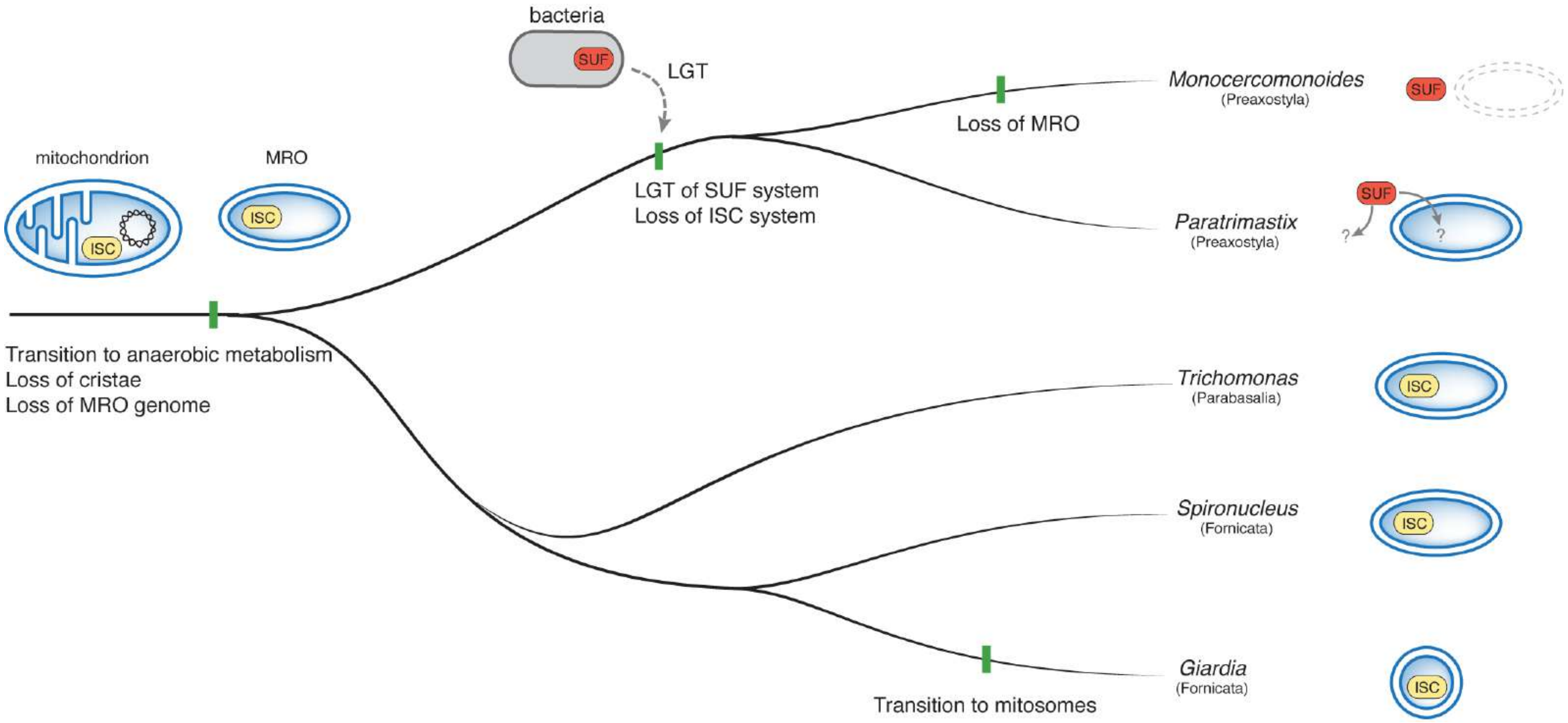
loss of a mitochondrial organelle

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



Endosymbiosis can be undone!

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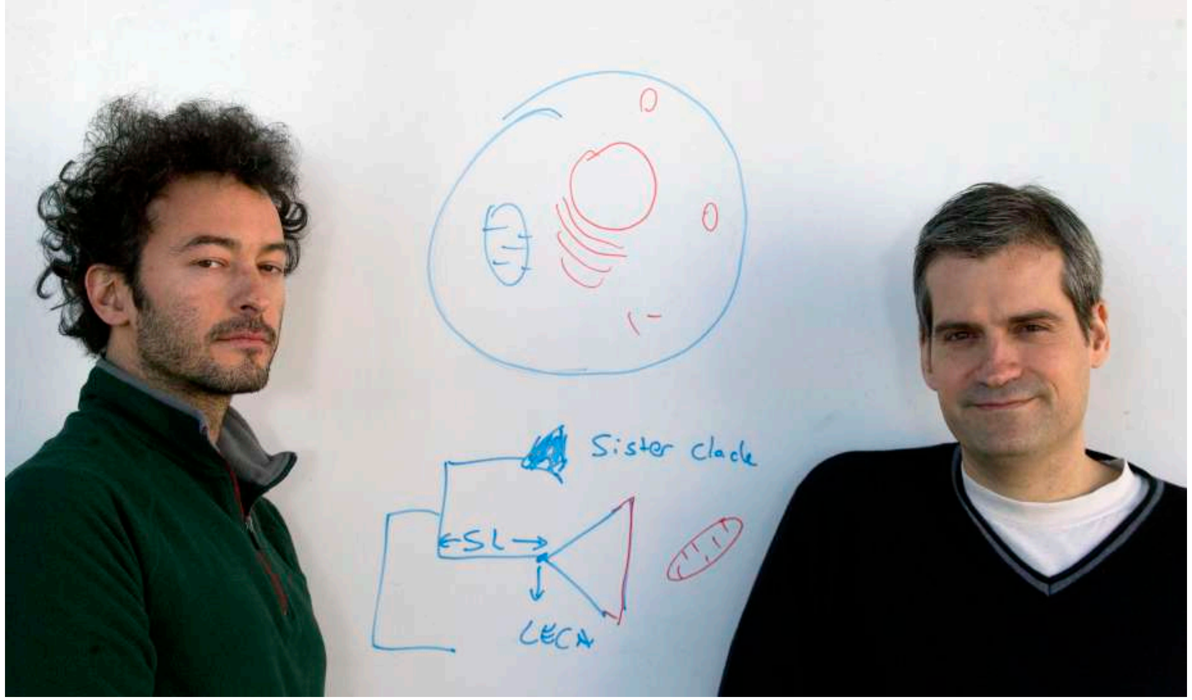
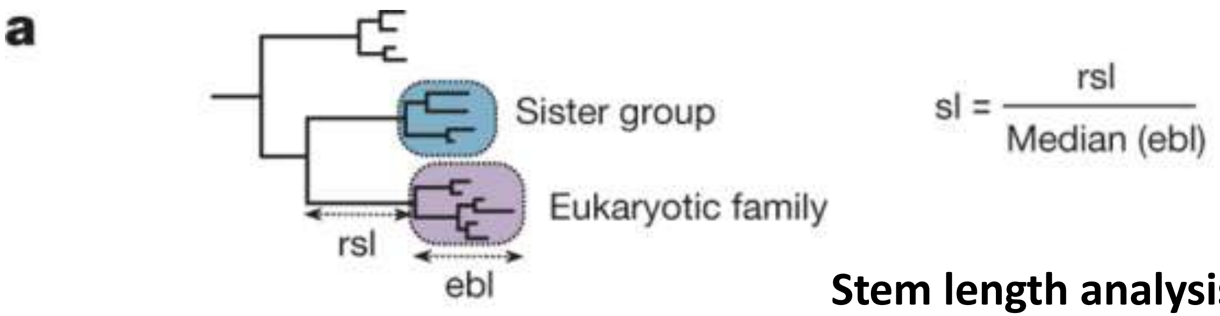
Which came first nucleus or mitochondrion?

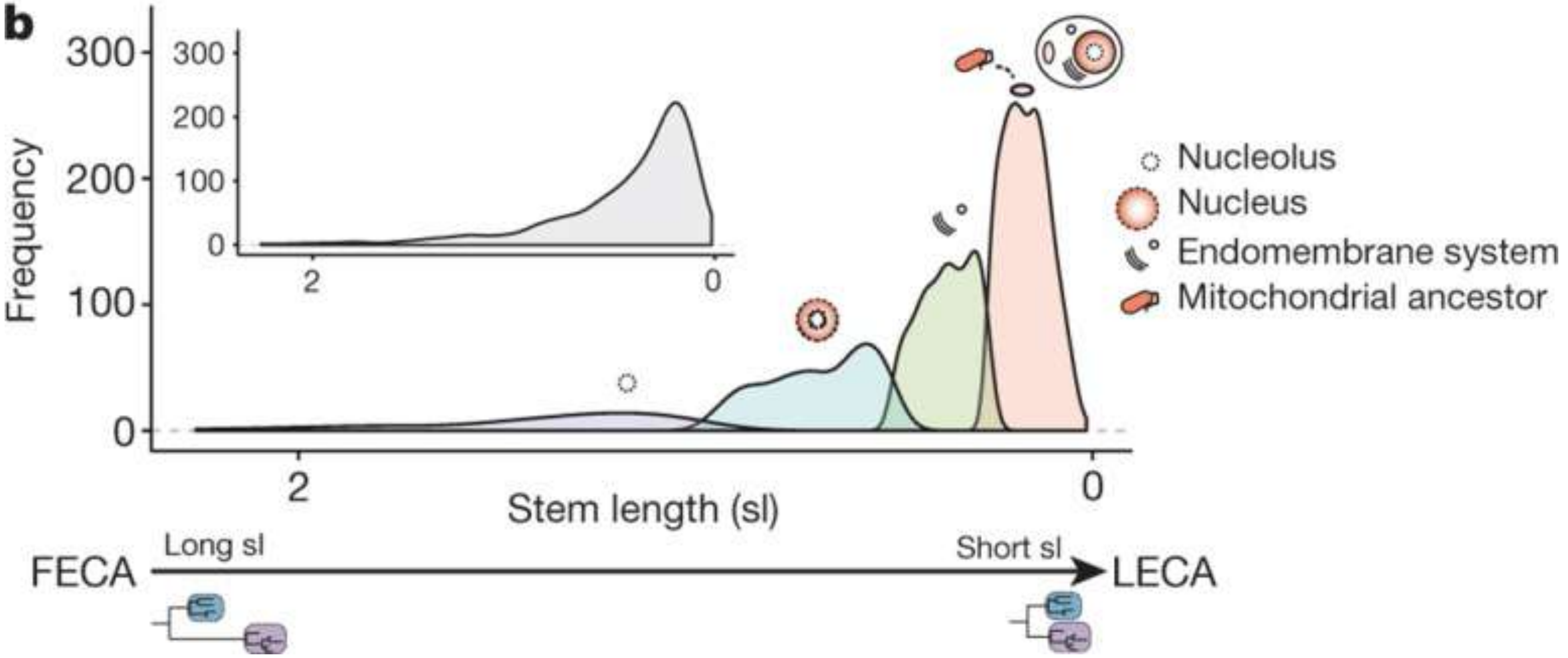


Late acquisition of mitochondria

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.



Stem length analysis



Pittis and **Gabaldon** (2016) Nature

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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