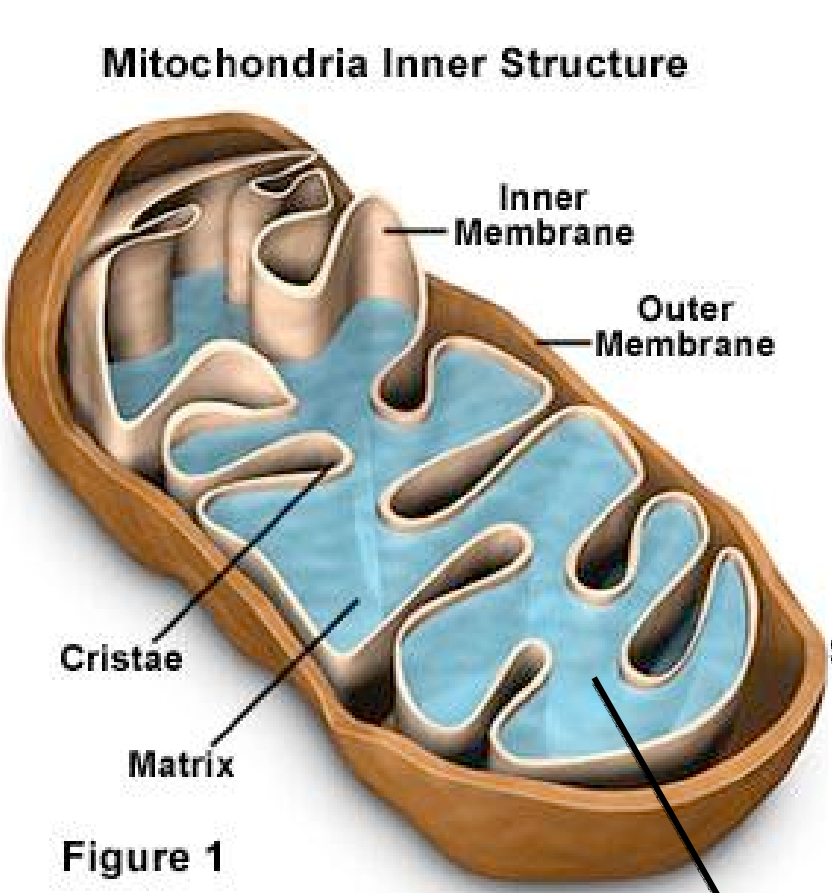
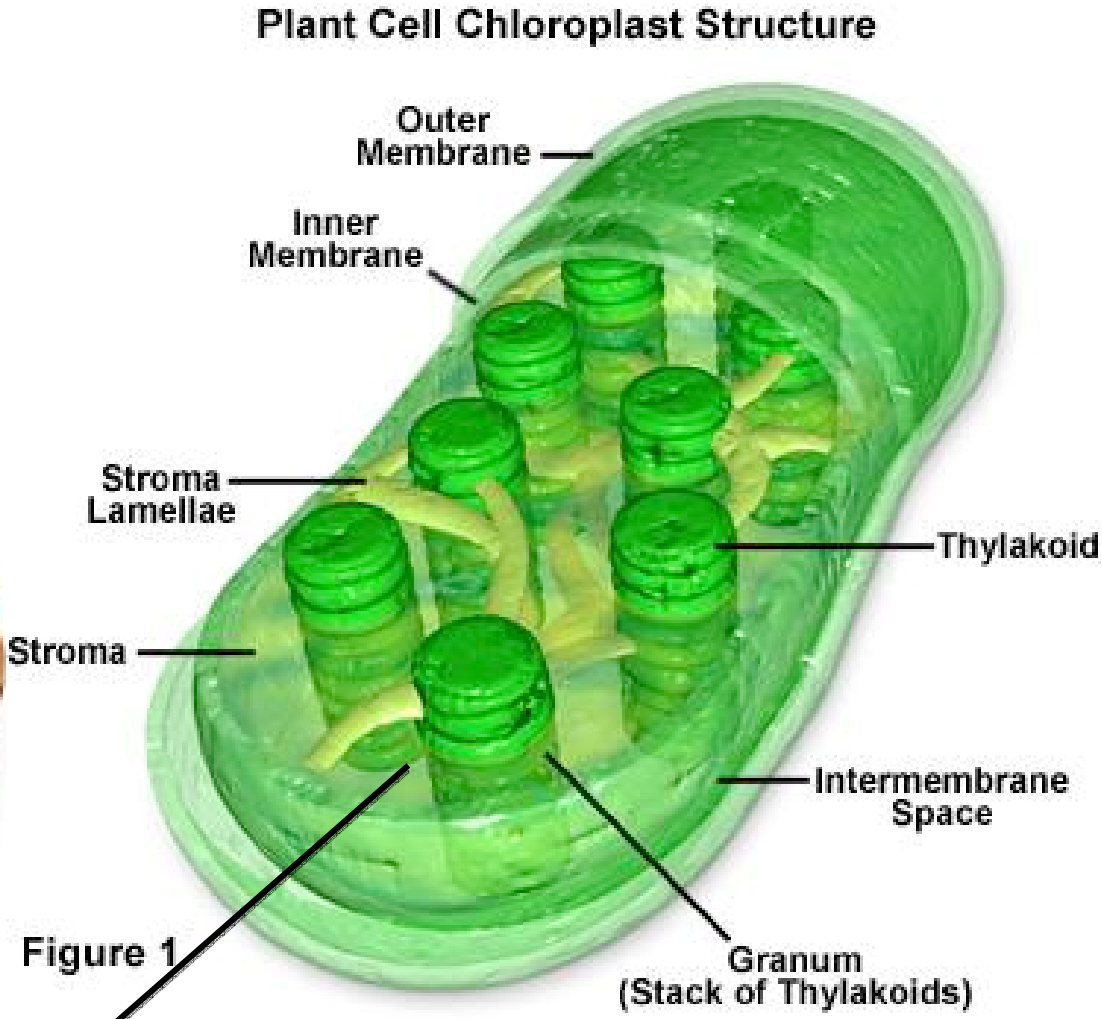
Evolutionary and Molecular Biology of Mitochondria and Chloroplasts

- **Structure and metabolic function of mito and chloroplast-**
  - **# membranes and their organization-**
  - **which metabolic functions performed**
- **Origins of mitochondria and chloroplasts- bacterial (!)**
  - **Evidence – features in common with bacteria**
  - **different models of how this occured: aerobic vs. anaerobic**
- **Genomes of mitos and chloro- organization, size (gene reduction), number**
- **Energy and metabolism**
- **Protein targeting and import (and evolutionary aspects)**

Organelle Structure





DNA

Organelle Function

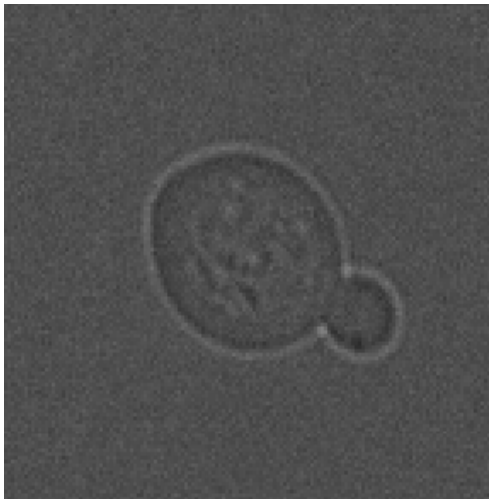
- Mitochondria
  - Burn sugar to make ATP
- Chloroplasts
  - Assimilate CO2 to make sugar

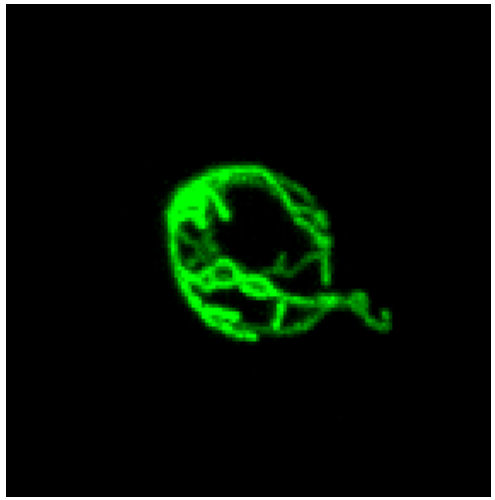
Organelle Function

- Mitochondria
  - Burn sugar to make ATP (and release CO2 in the process)
  - Store Ca++ ions
  - Manufacture of heme and other iron-sulfur compounds
  - Heat production
  - Regulation of cell death
- Chloroplasts
  - Assimilate CO2 to make sugar (and release oxygen in the process)
  - Manufacture of molybdenum and

Organelle biology is a complex interaction between the endosymbiont and host

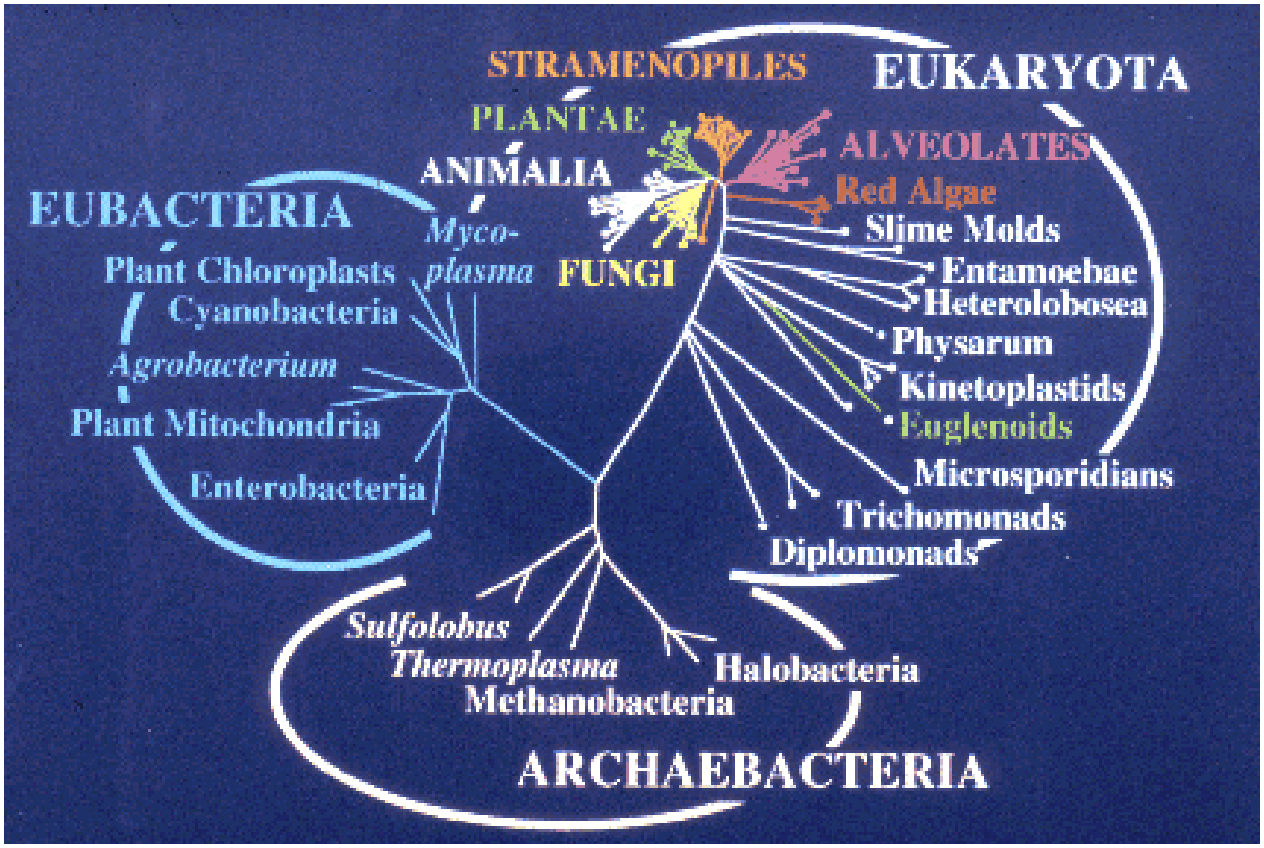
1. Most organelle localized proteins are encoded in the nucleus
2. Must replicate its own genome and divide appropriately
3. Multi-subunit complexes must properly assemble in the (correct) membranes of the organelle
4. Complex, regulated intracellular localization requiring the cytoskeleton; localization and structure is important for function





Origins of Mitochondria and Chloroplasts

- Phylogeny of small subunit RNA



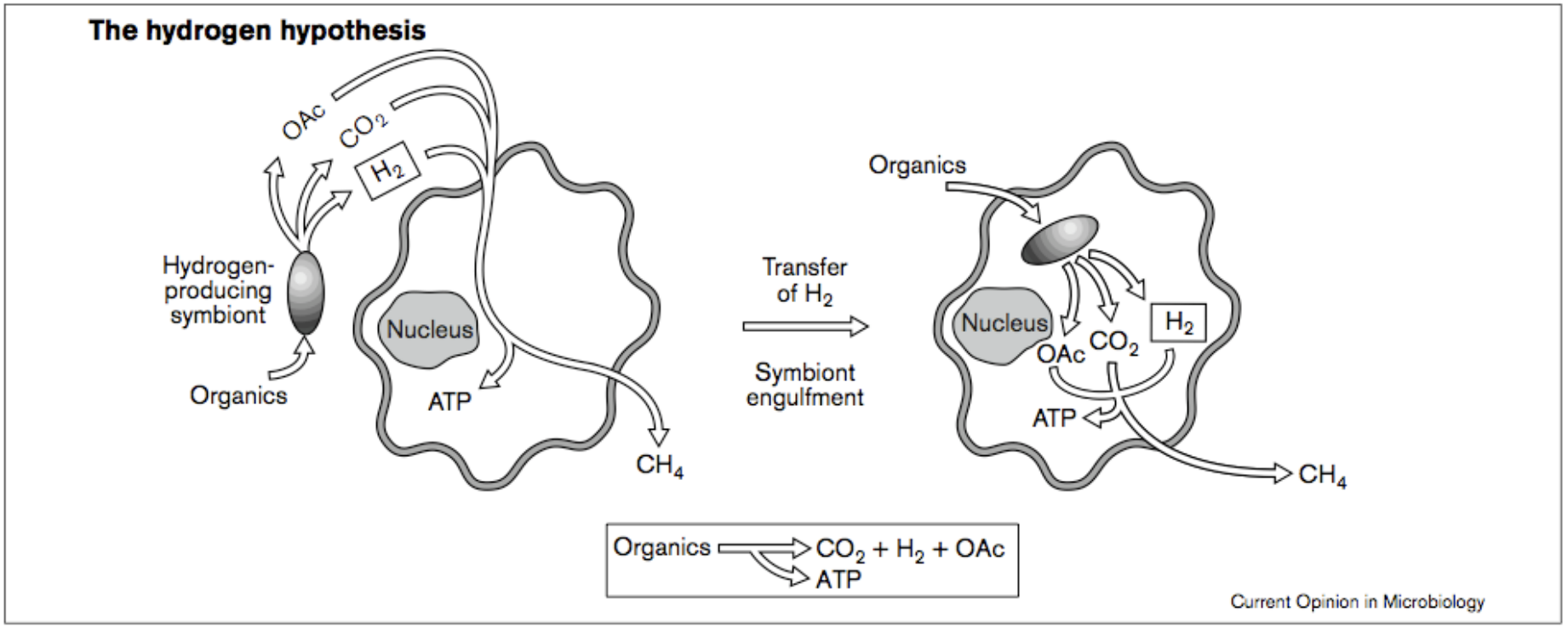
Mitochondria and chloroplasts are of bacterial origin

- Size is consistent with a prokaryote
- Organelles are surrounded by two membranes, an outer one from the host and an inner one from the bacteria
- Organelles contain their own genome
- Ribosomal RNAs and proteins encoded by the genome resemble those of bacteria rather than eukaryotes

Evolution of Endosymbiosis

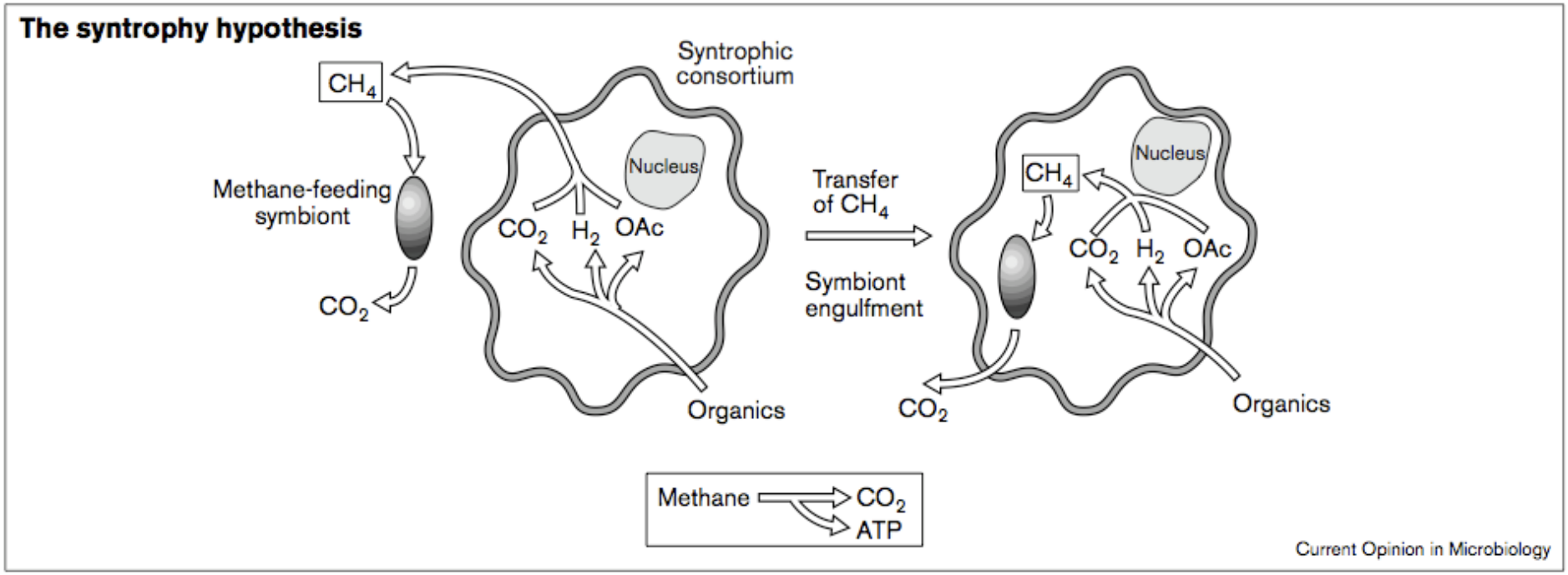
- Early atmosphere was very different from present – initially no oxygen, lots of hydrogen and methane (a reducing environment, where there are many free electrons)
- The emergence of photosynthesis meant the production of oxygen
- There are no bacterially encoded ATP transporters (like those used to export ATP from mitochondria), so the initial currency of symbiosis was likely a different compound that the eukaryote could use
- Phylogenetic analysis of genome content (both nuclear and organelle) is helpful in predicting what might have happened

Hypotheses for endosymbiosis events: Hydrogen Hypothesis



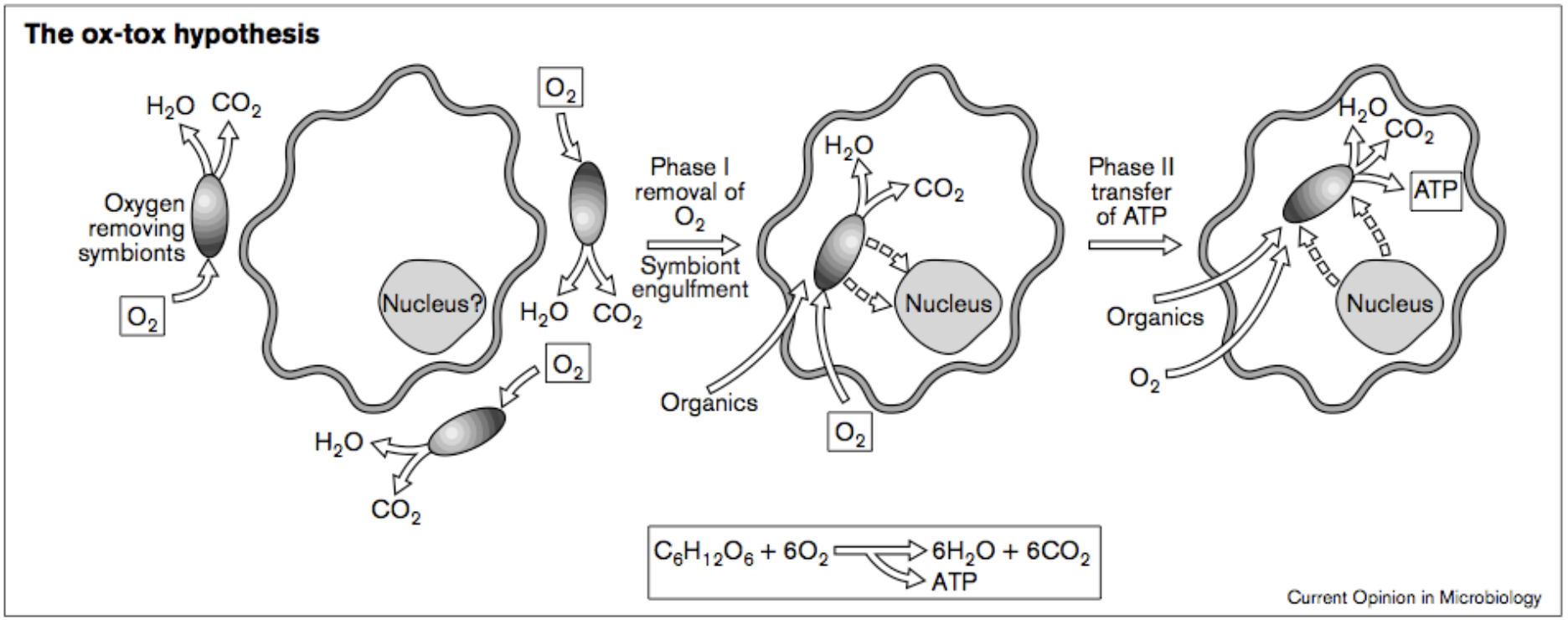
Andersson and Kurland. Origins of mitochondria and hydrogenosomes. CurrOpinMicrobiol (1999) pp. 535-41

Hypotheses for endosymbiosis events:SyntrophyHypothesis



Andersson and Kurland. Origins of mitochondria and hydrogenosomes. CurrOpinMicrobiol (1999) pp. 535-41

Hypotheses for endosymbiosis events: Ox-Tox hypothesis



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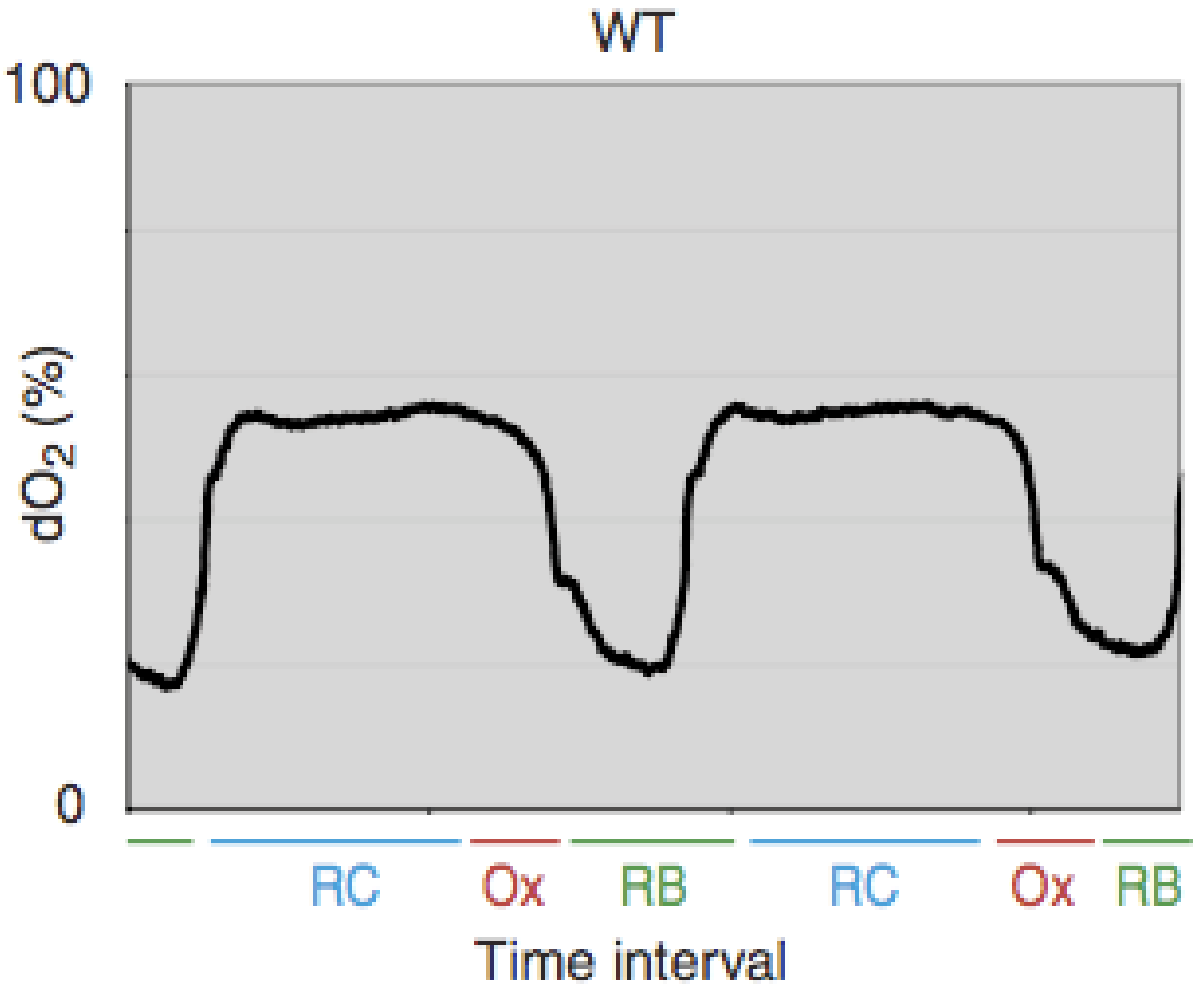
Yeast metabolic cycle supports the idea of ox-tox

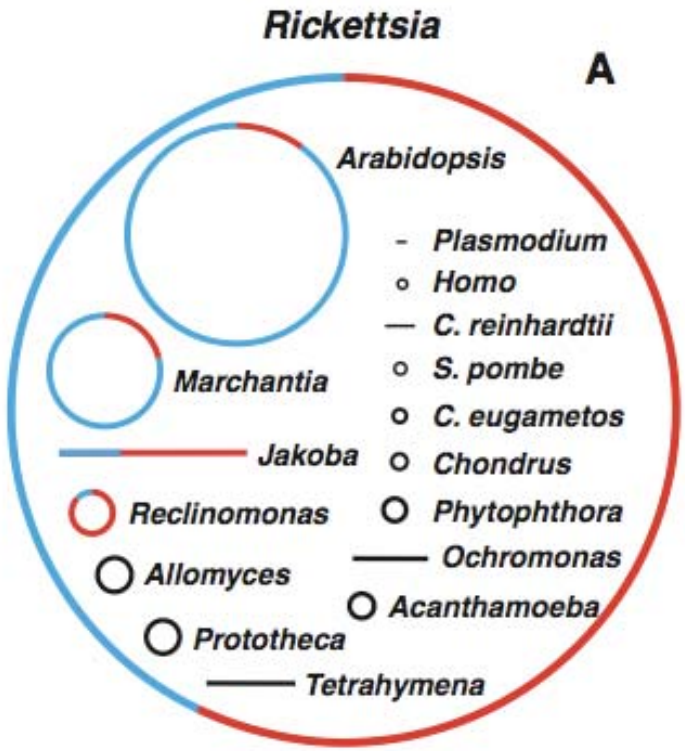


Tu and McKnight. Evidence of carbon monoxide-mediated phase advancement of the yeast metabolic cycle. Proc NatlAcadSci USA (2009) vol. 106 (34) pp. 14293-6

Origins of Mitochondria and Chloroplasts

- Recommended: http://dna.kdna.ucla.edu/parasite_course-old/trichomonas/subchapters/hydrogenosome.htm

Mitochondrial genome DNA content varies greatly



Gray et al. Science 1999

Organelle genomes

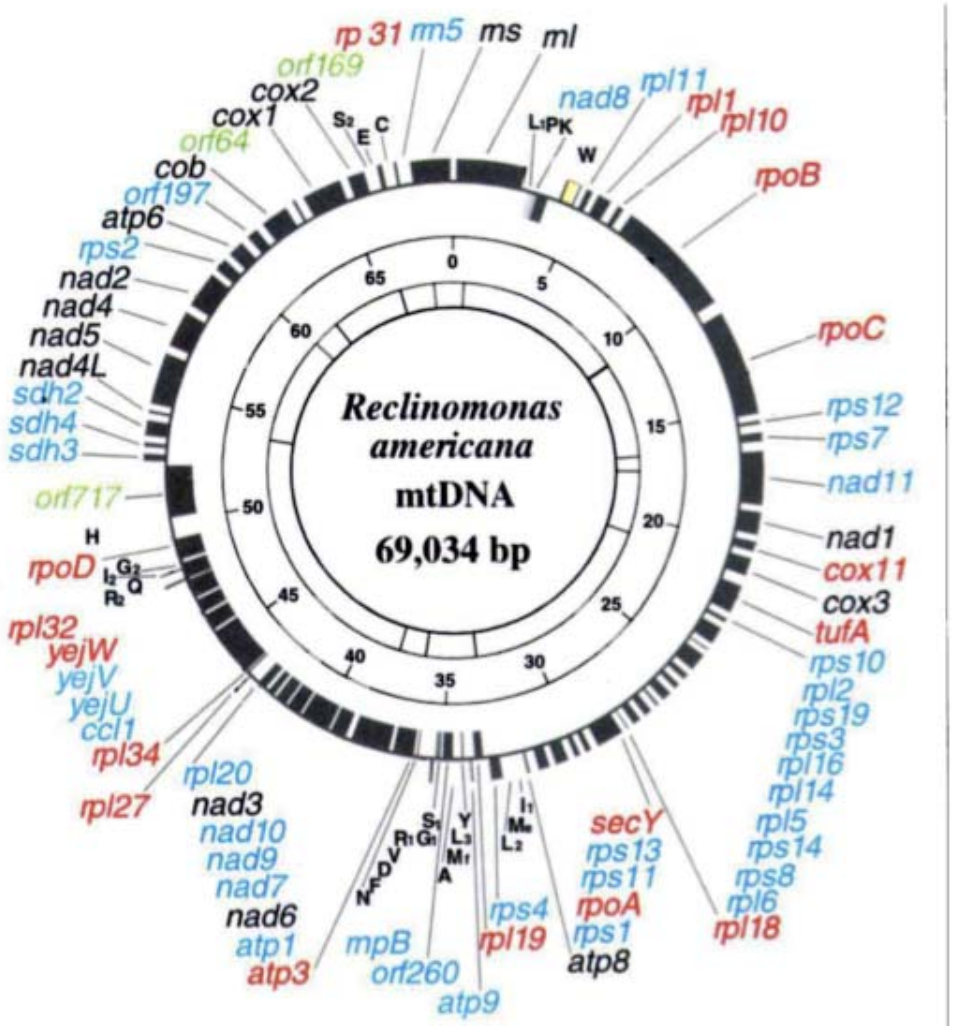
- Gene loss is continual

Organelle genomes – why have one at all?

- Useful: http://en.wikipedia.org/wiki/CoRR_Hypothesis

Reclinomonasamericana

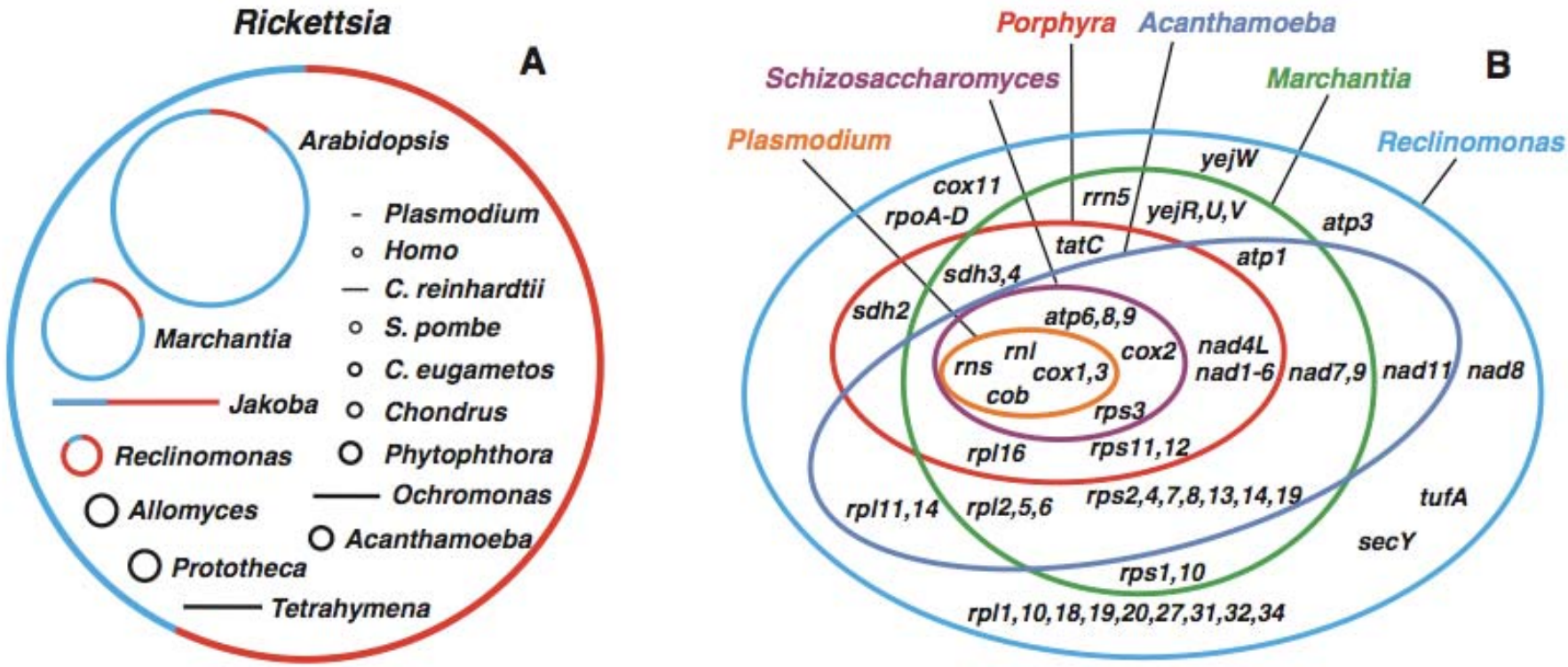
Mitochondrial genome of the protozoan



Eubacterial-like features of the *Reclinomonas*mitochondrial genome

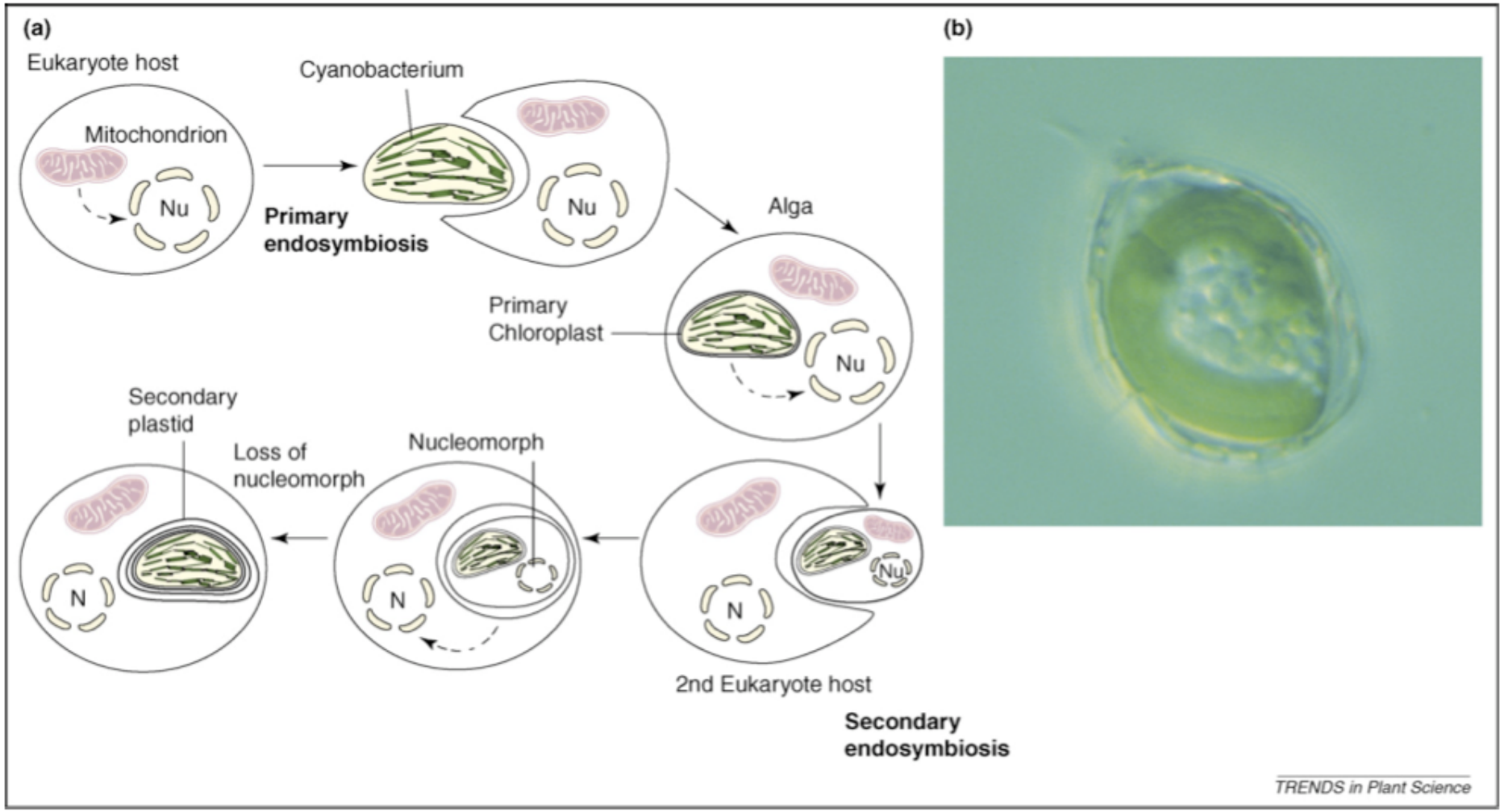
- Bacterial-like four subunit RNA polymerase, encoded in mitochondrial genome (rather than a single-subunit phage polymerase seen elsewhere)
- Operon organization of genes
- Protein trafficking system similar to bacteria
- Base pairing between ribosomes and messages, as in eubacteria

Genomic evidence of a single, eubacterial mitochondrial origin



Gray et al. Science 1999

Genome analysis and cell biology reveal complex history of some plastids

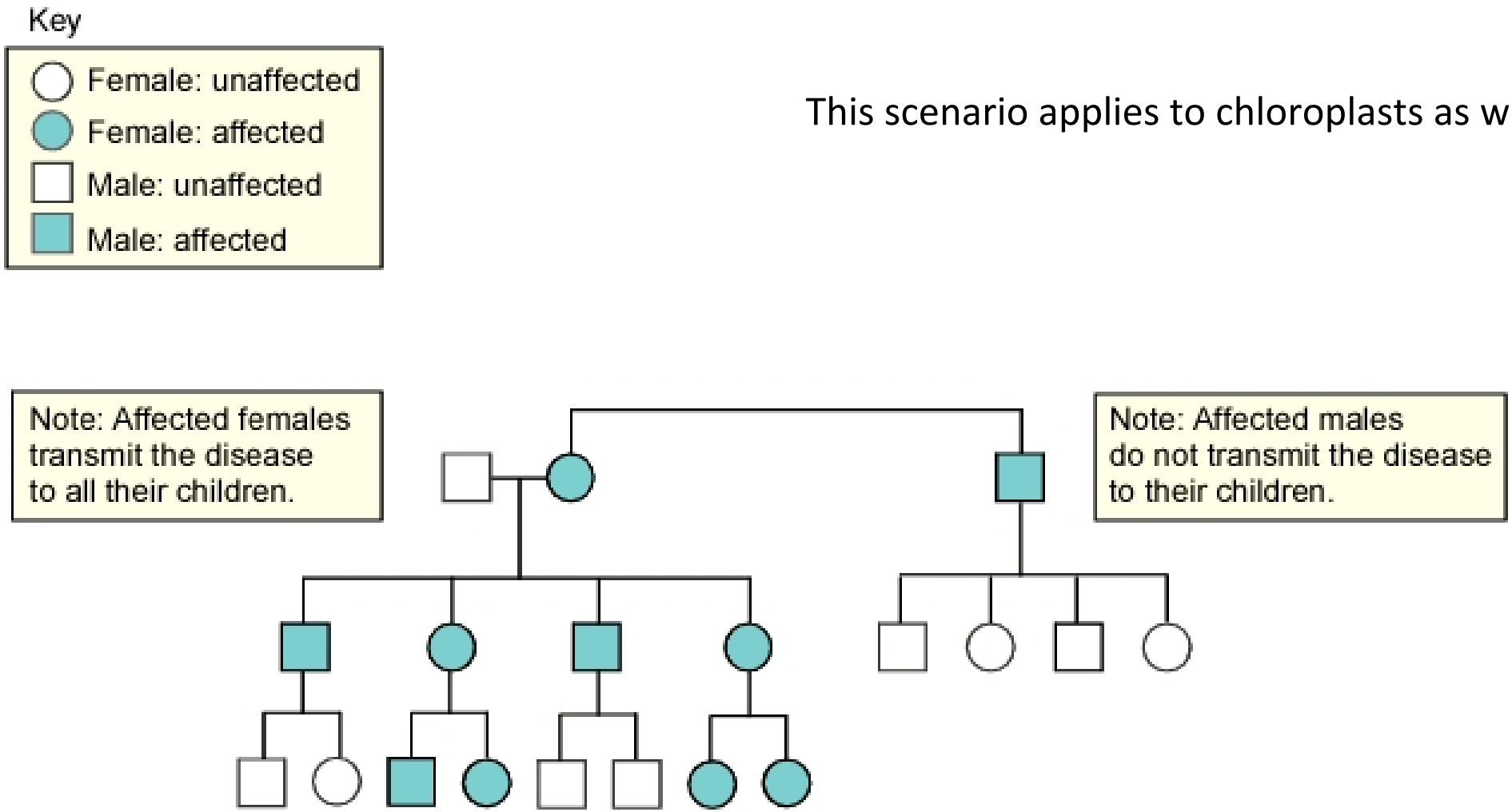


Larkum et al. Shopping for plastids. Trends Plant Sci (2007) vol. 12 (5) pp. 189-95

Genome analysis and cell biology reveal complex history of some plastids

- How does the host regulate something through multiple membranes?
- How are proteins transported to the correct location?

Organelle genomes are maternally inherited



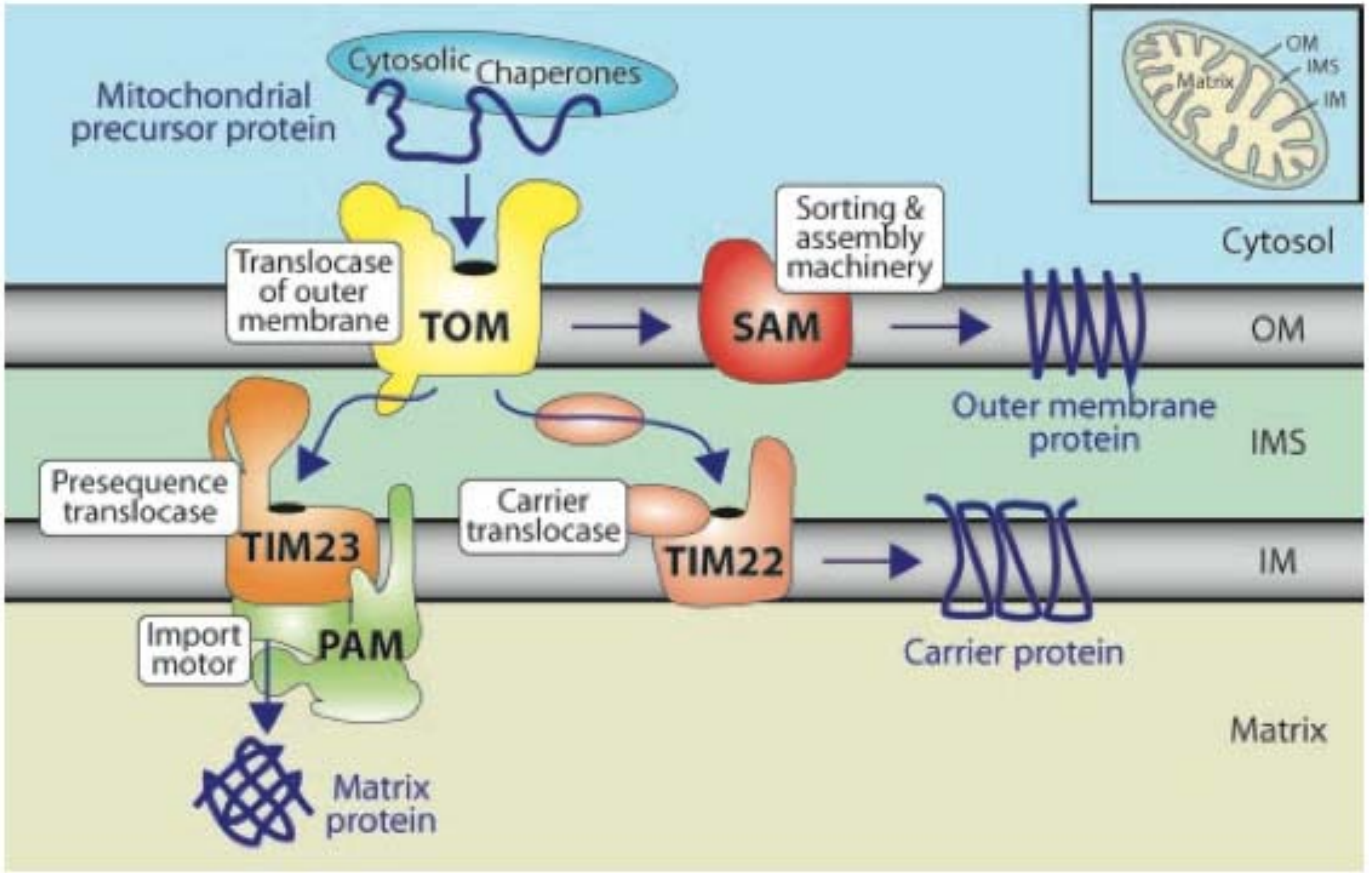
This scenario applies to chloroplasts as well

Gene Reviews, NIH

Organelle Protein Import

- Multiple locations for targeting:
  - Outer membrane
  - Intermembrane space
  - Inner membrane
  - Matrix space
  - Specialized regions within membranes (enzyme complexes form assemblies)
- Protein import requires energy

Organelle protein import



Wiedemann et al. The protein import machinery of mitochondria. J BiolChem (2004) vol. 279 (15) pp. 14473-6. (Highly Recommended!)

Chloroplast protein import