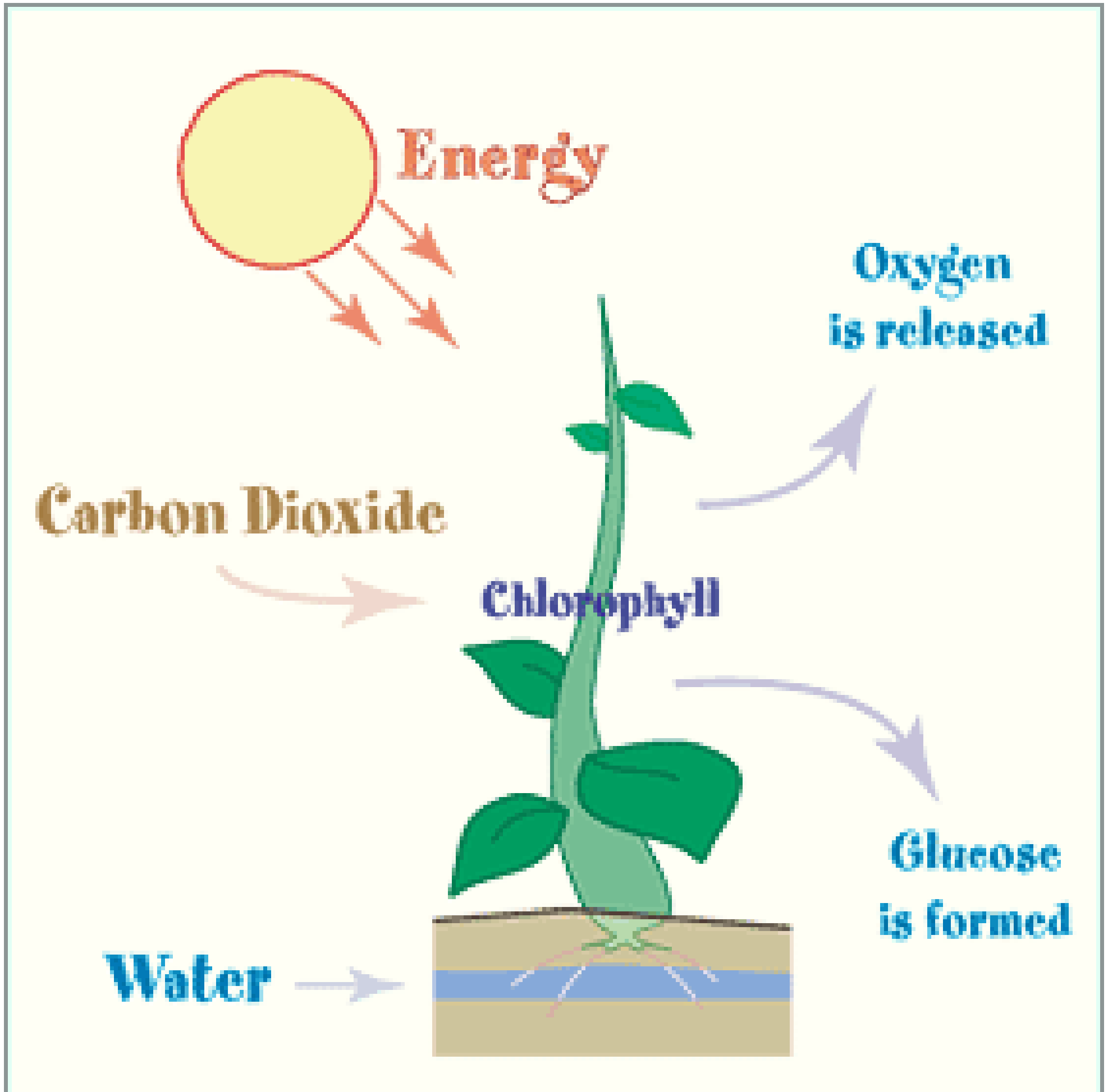
ALGAL DIVERSITY – PHOTOSYNTHETIC BACTERIA

Plant Systematics - BIOS 471/871

Spring 2016

Plant Photosynthesis

sunlight + CO_2 + H_2O = sugars + O_2



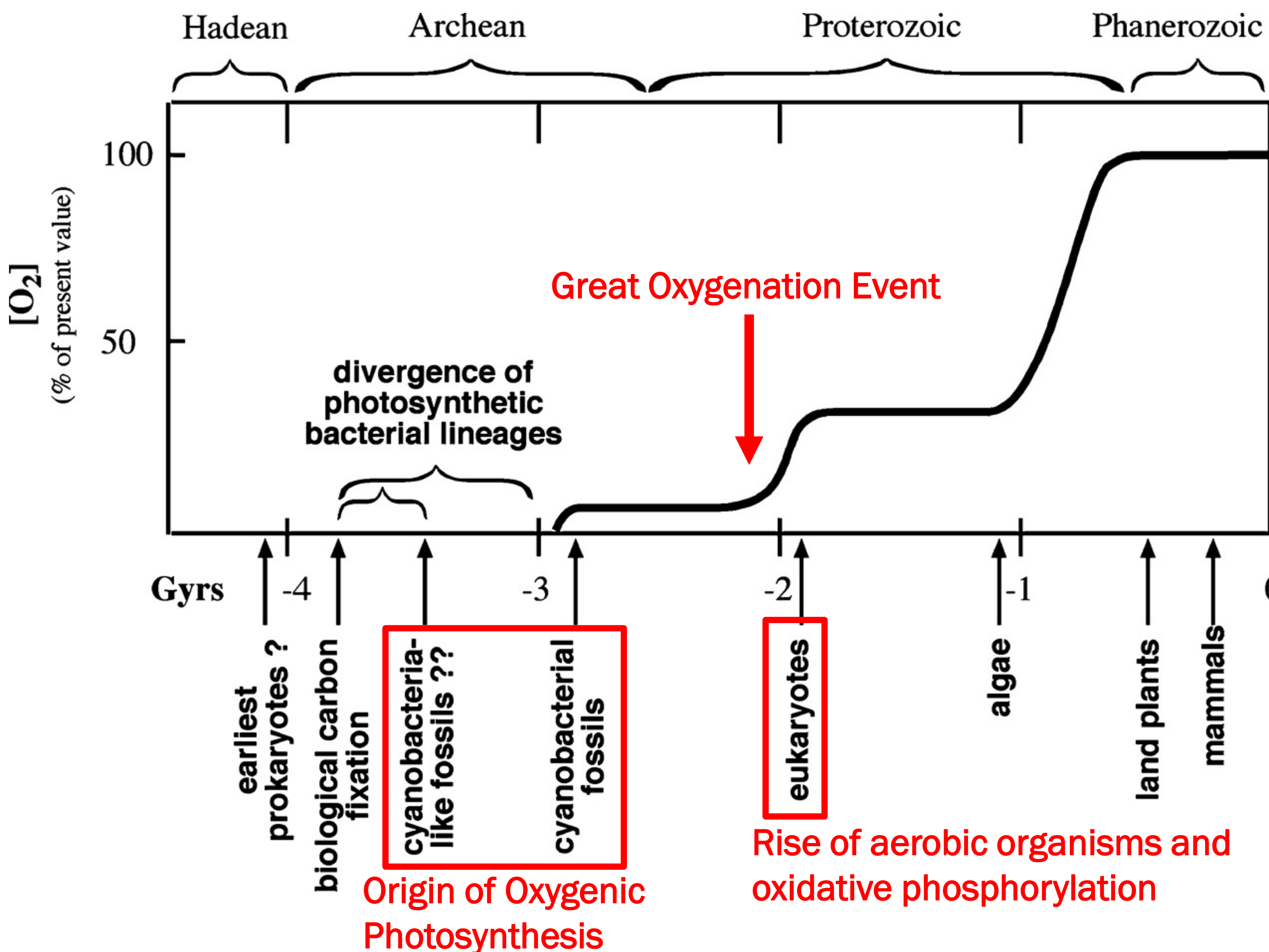
Plant Photosynthesis

- Conversion of **solar energy** into **chemical energy**
  (light) (food)

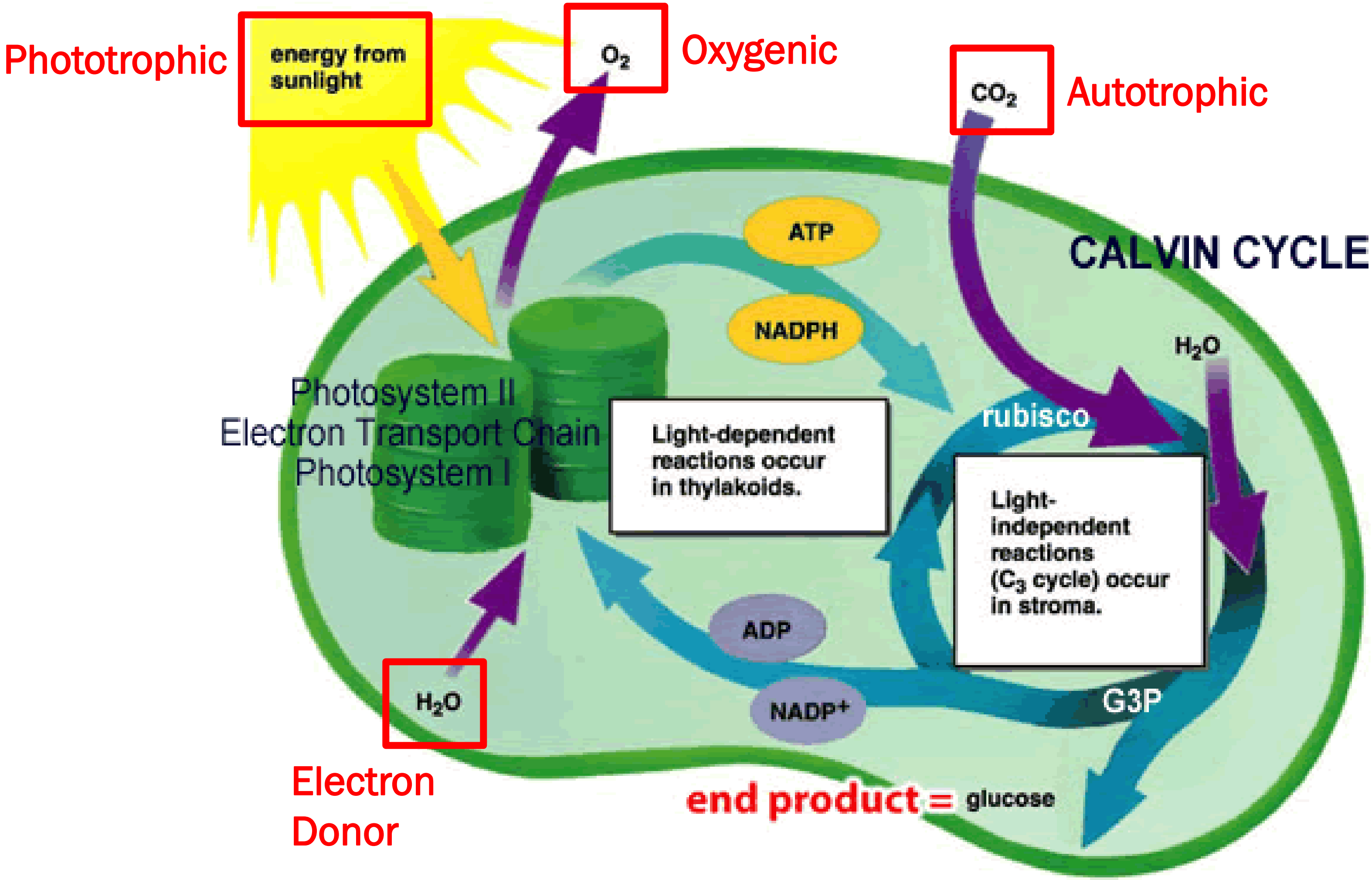
- The most important chemical process on earth

Oxygenated Air	Food
Wood	Clothes
Fuel	Drugs

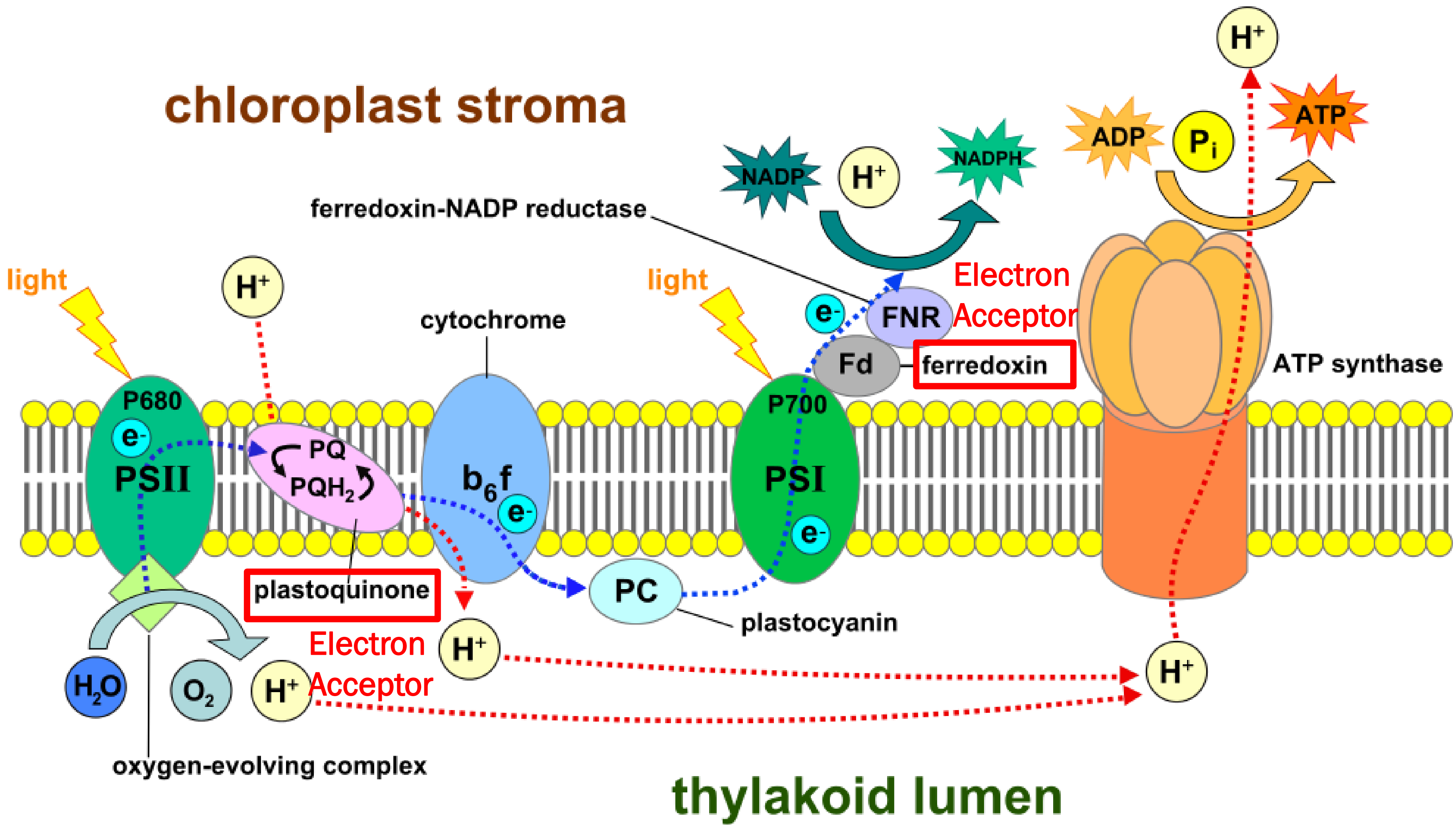
Oxygenic Photosynthesis



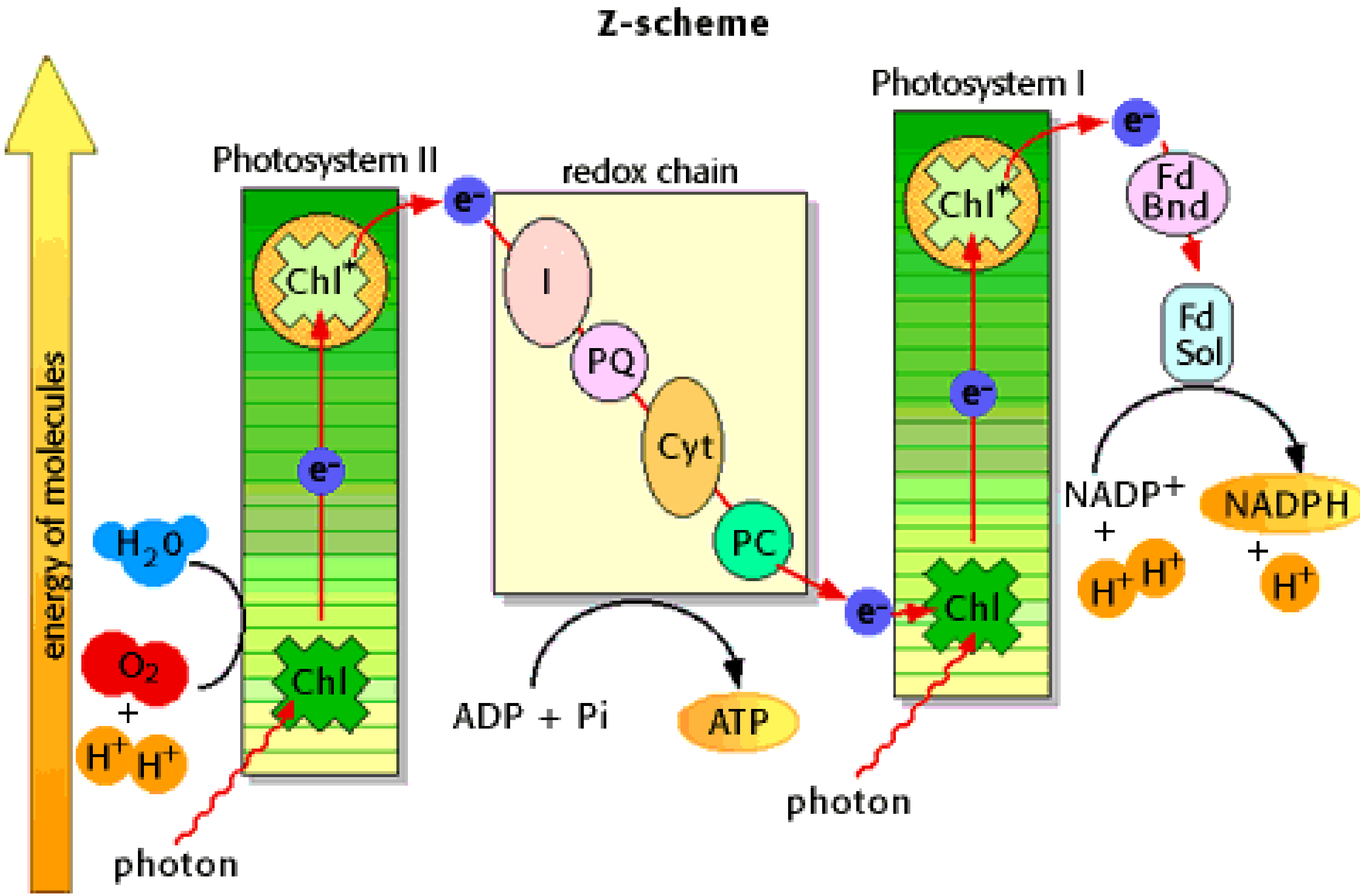
Photosynthesis Reactions



Photosystems I and II



Photosystems I and II

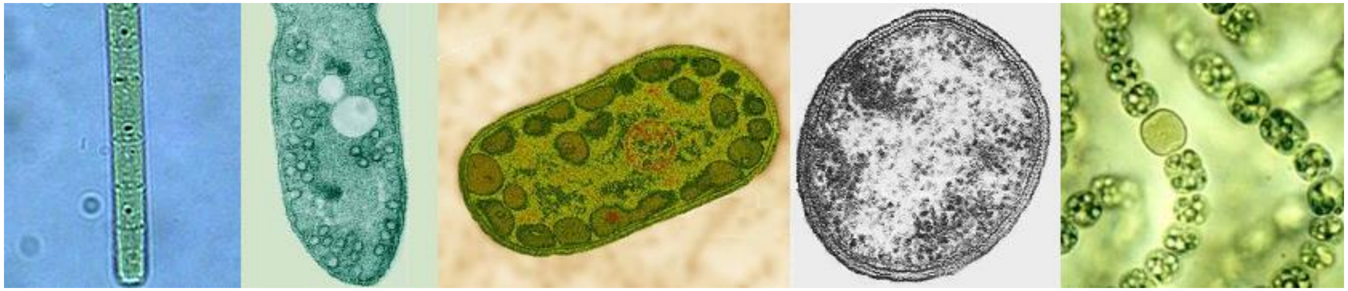


Photosynthetic Bacteria

- Taxonomy
  - Description of major groups
- Phylogeny
  - Relationships among photosynthetic groups and other (non-photosynthetic) bacteria
- Evolution
  - Origin of bacterial photosynthesis

Photosynthetic Bacterial Taxonomy

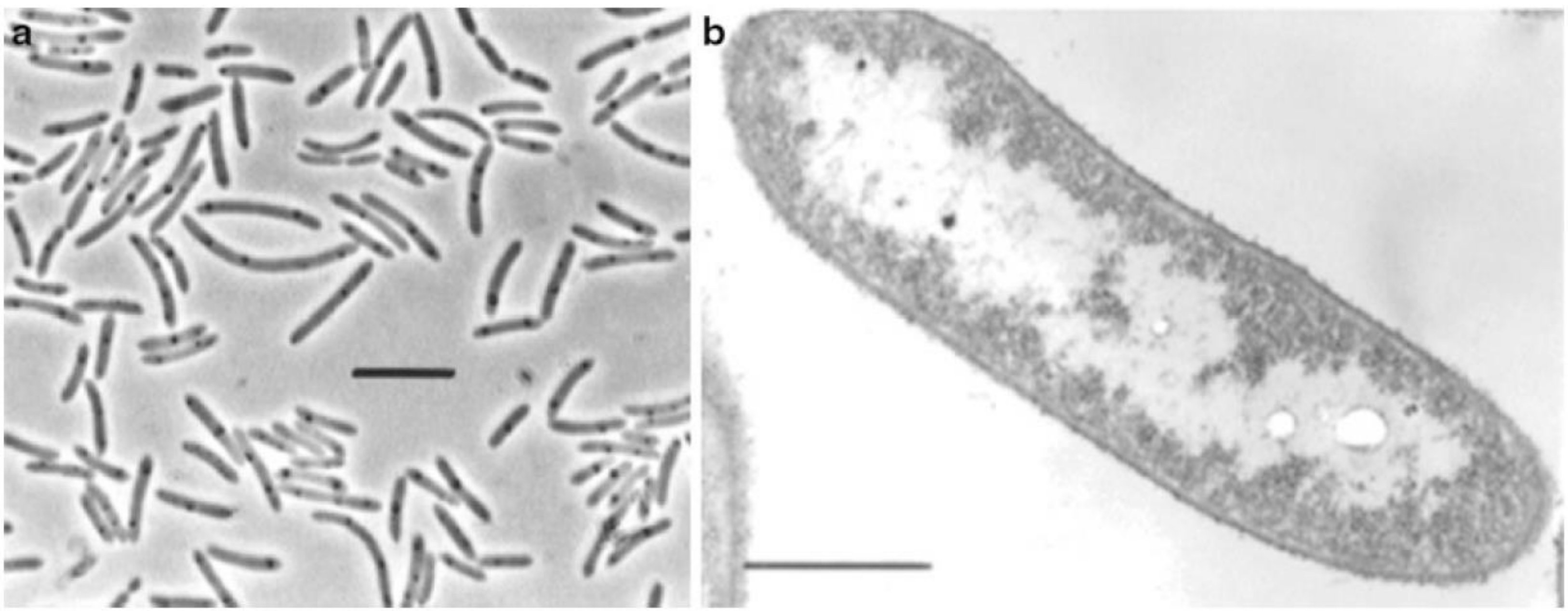
- Heliobacteria
- Chlorobi (green sulfur bacteria)
- Proteobacteria (purple bacteria)
- Chloroflexi (green nonsulfur bacteria)
- Cyanobacteria (blue-green algae)



Heliobacteria

Firmicutes | Clostridia | Clostridiales | Heliobacteriaceae

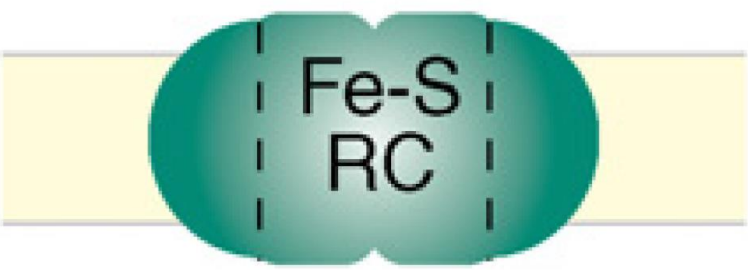
- Very small group in Firmicutes; 1 family with 5 species
- Anaerobic and anoxygenic photoheterotrophs
- Grow in soils, hot springs; common in agricultural soil
- Representative: *Heliobacterium modesticaldum*



Heliobacteria

Firmicutes | Clostridia | Clostridiales | Heliobacteriaceae

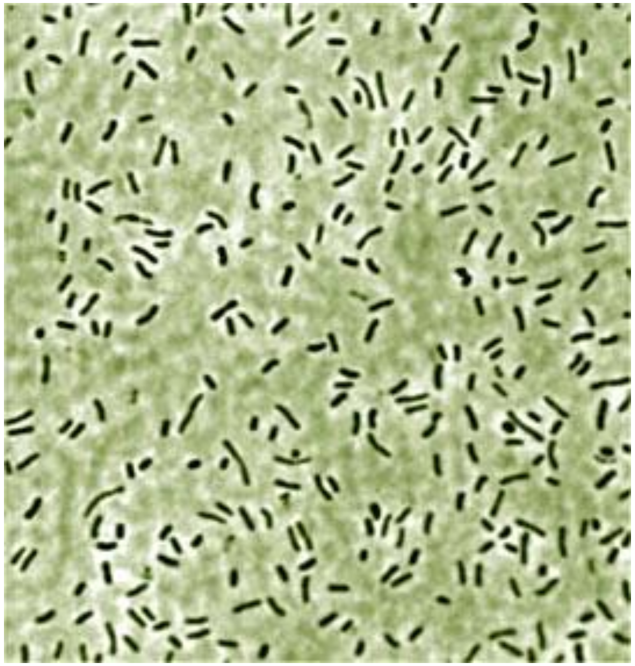
- Anoxygenic photosynthesis
  - Photosystem: simplified type I
  - Reaction center: homodimeric
  - Electron donor: ??
  - Electron acceptor: Fe-S
  - RC pigments: Bchl *g*
  - Antennas: none

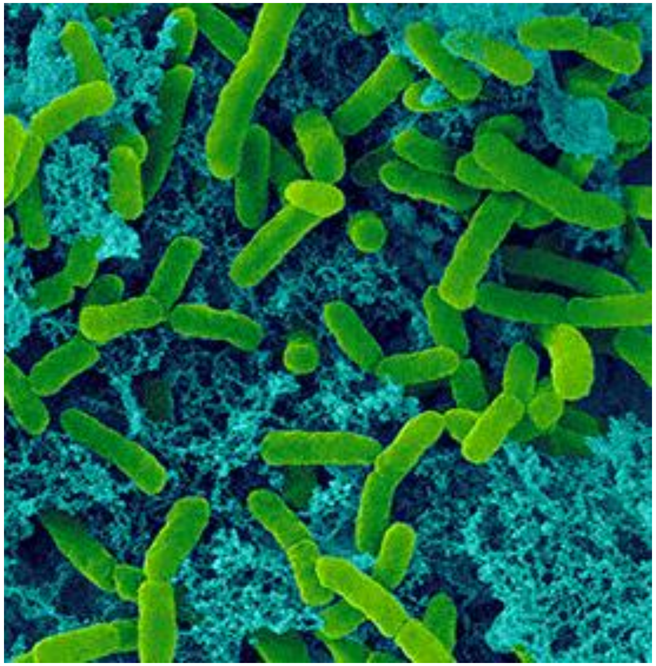


Chlorobi (green sulfur bacteria)

Chlorobi | Chlorobea | Chlorobiales | Chlorobiaceae

- Small group; single family of ~20 species
- Obligately anaerobic, anoxygenic photoautotrophs
- Aquatic sediments, sulfur springs, hot springs
- Representative: *Chlorobium tepidum*

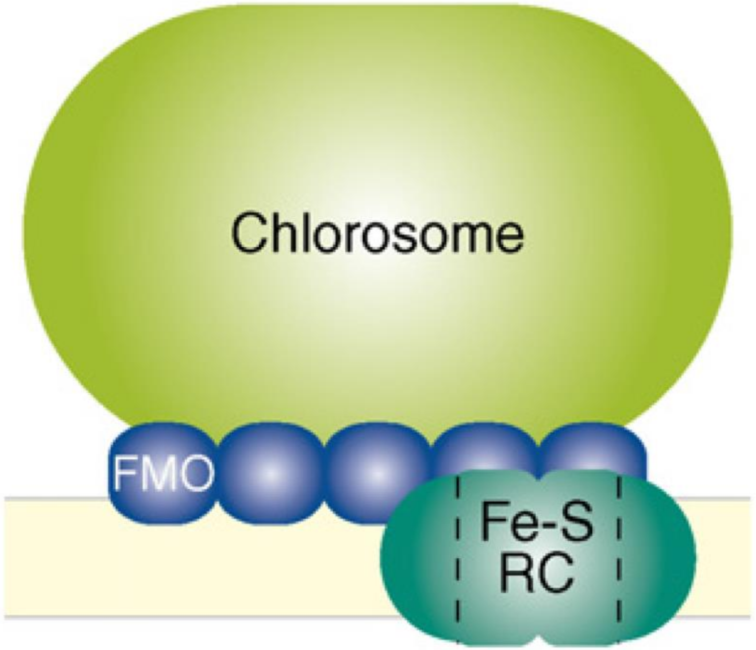




Chlorobi (green sulfur bacteria)

Chlorobi | Chlorobea | Chlorobiales | Chlorobiaceae

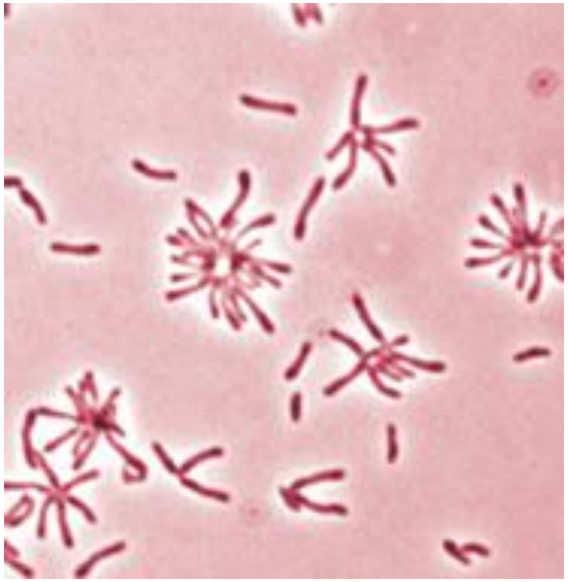
- Anoxygenic photosynthesis
  - Photosystem: simplified type I
  - Reaction center: homodimeric
  - Electron donor: sulfide, H_2, Fe
  - Electron acceptor: Fe-S
  - RC pigments: Bchl *a*, Chl *a*
  - Antennas: Chlorosomes with Bchl *c, d* or *e*

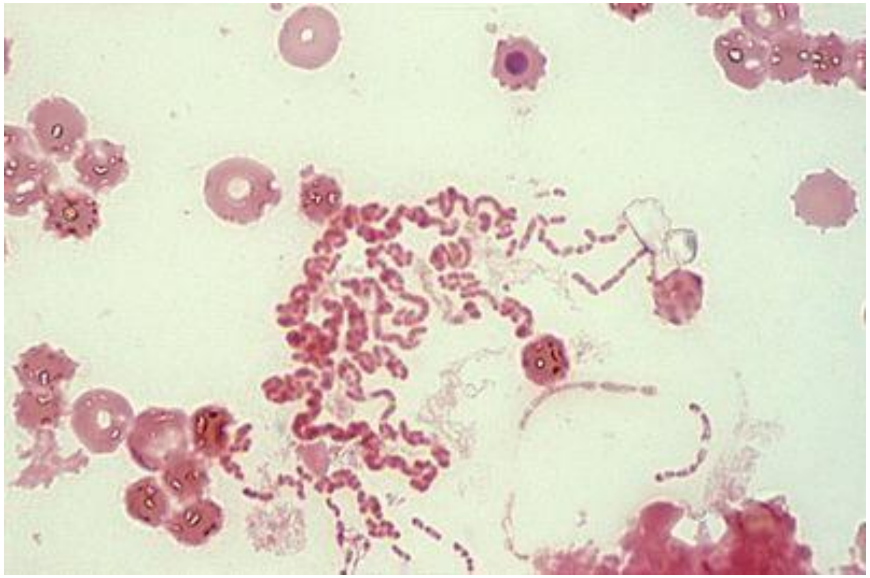


Proteobacteria (purple bacteria)

Proteobacteria

- Large and physiologically diverse group
- Aerobic and anaerobic heterotrophs; some anaerobic photoautotrophs, patchy distribution (mainly α, β, γ)
- Marine, freshwater, hot springs
- Representative: *Rhodobacter, Rhodopseudomonas*





Proteobacteria (purple bacteria)

Proteobacteria

- Anoxygenic photosynthesis
  - Photosystem: simplified type II
  - Reaction center: heterodimer
  - Electron donor: various sulfur compounds, H_2, Fe
  - Electron acceptor: quinones
  - RC pigments: BChl *a* or *b*
  - Antennas: LH1, LH2 containing peptides, BChl

Chloroflexi (green non-sulfur bacteria)

Chloroflexi

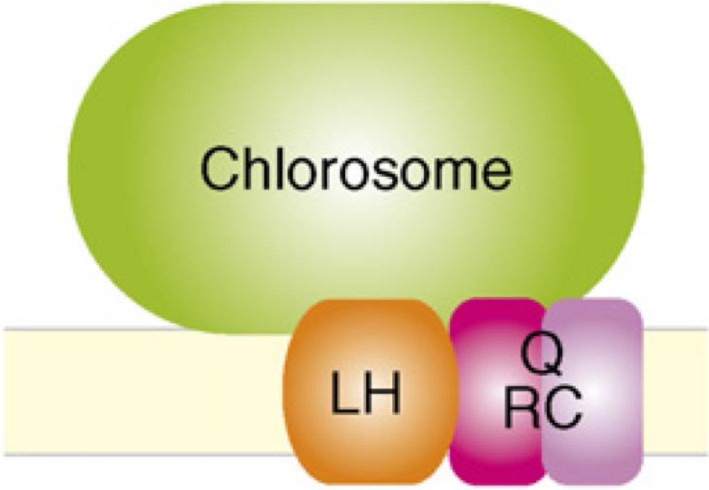
- Large and physiologically diverse group
- Aerobic heterotrophs; anaerobic photoheterotrophs
- AKA: filamentous anoxygenic photosynthesizers (FAPs)
- Hot springs, alkaline springs, marine
- Representative: *Chloroflexus*

Chloroflexi (green non-sulfur bacteria)

Chloroflexi

- Anoxygenic photosynthesis
  - Photosystem: simplified type II
  - Reaction center: heterodimer
  - Electron donor: sulfide
  - Electron acceptor: quinones
  - RC pigments: Bchl *a*
  - Antennas: LH1-like complexes; chlorosomes with Bchl *a, c*

Red FAPs

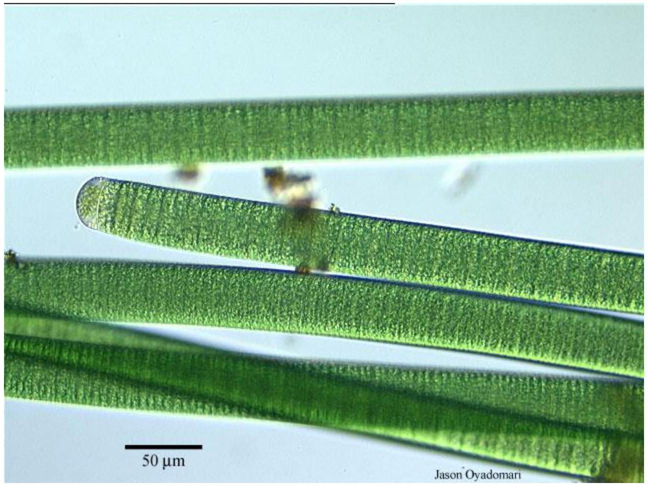


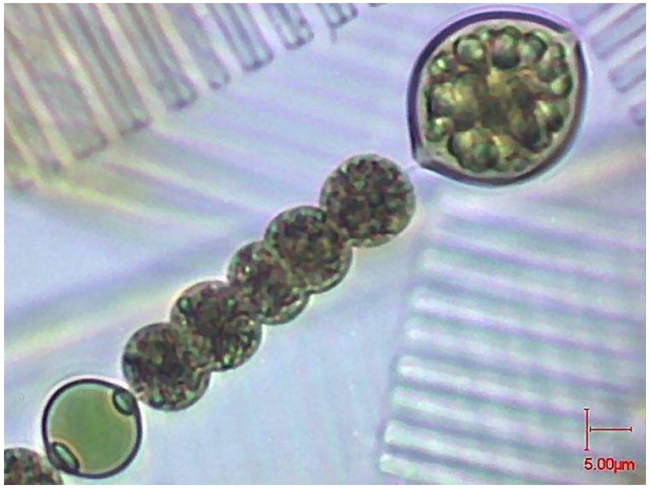
Green FAPs

Cyanobacteria (blue-green algae)

Cyanobacteria

- Facultative aerobes; oxygenic photoautotrophs
- Marine, freshwater, soils
- Single celled or differentially oligocellular
- Representatives: *Cyanobacterium, Prochlorococcus*

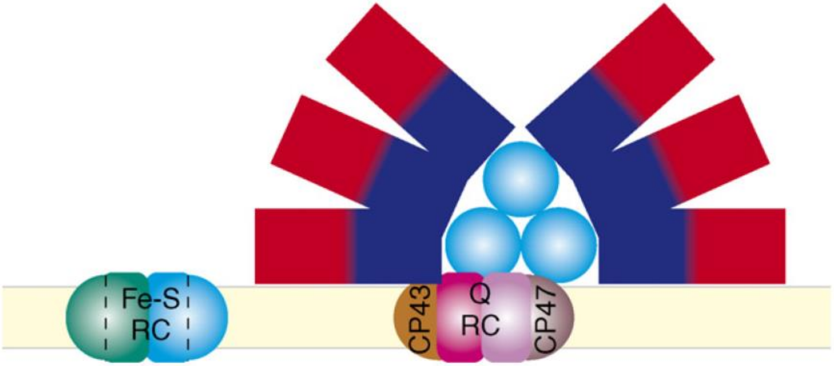




Cyanobacteria (blue-green algae)

Cyanobacteria

- Oxygenic photosynthesis
  - Photosystem: type I and II
  - Reaction center: heterodimers
  - Electron donor: H_2O
  - Electron acceptor: Fe-S (I); quinones (II)
  - RC pigments: Chl *a*
  - Antennas: phycobilisomes (II) with phycocyanin and phycoerythrin

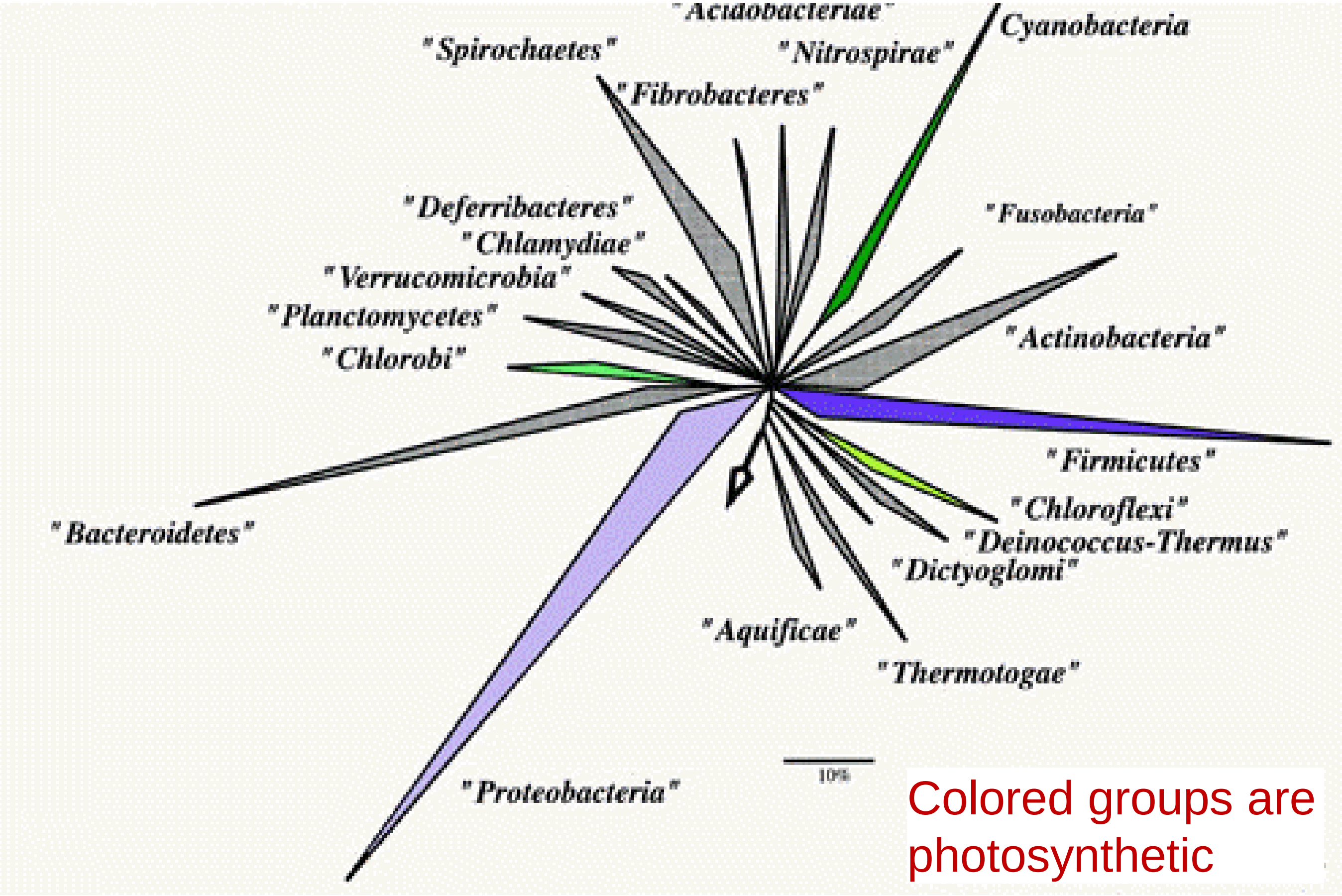


Photosynthetic Bacterial Diversity

	Heliobacteria	Chlorobi	Proteobacteria	Chloroflexi	Cyanobacteria
Diversity	Small group	Small group	Large, diverse group	Large, diverse group	Large, diverse group
Carbon source	Heterotrophs	Autotrophs	Autotrophs, heterotrophs	Heterotrophs	Autotrophs
Photosynthesis	Anoxygenic	Anoxygenic	Anoxygenic	Anoxygenic	Oxygenic
Photosystems	PS I	PS I	PS II	PS II	PS I + II
Antennas	None	Chlorosomes	LHC	LHC, Chlorosomes	Phycobilisomes
Pigments	Bchl g	Chl a, Bchl a, c, d, e	Bchl a, b	Bchl a, c	Chl a, phycobilins

Bacterial Phylogeny

- An unresolved issue
  - 16s rRNA tree – early on considered to be the true topology (photosynthetic organisms not monophyletic)

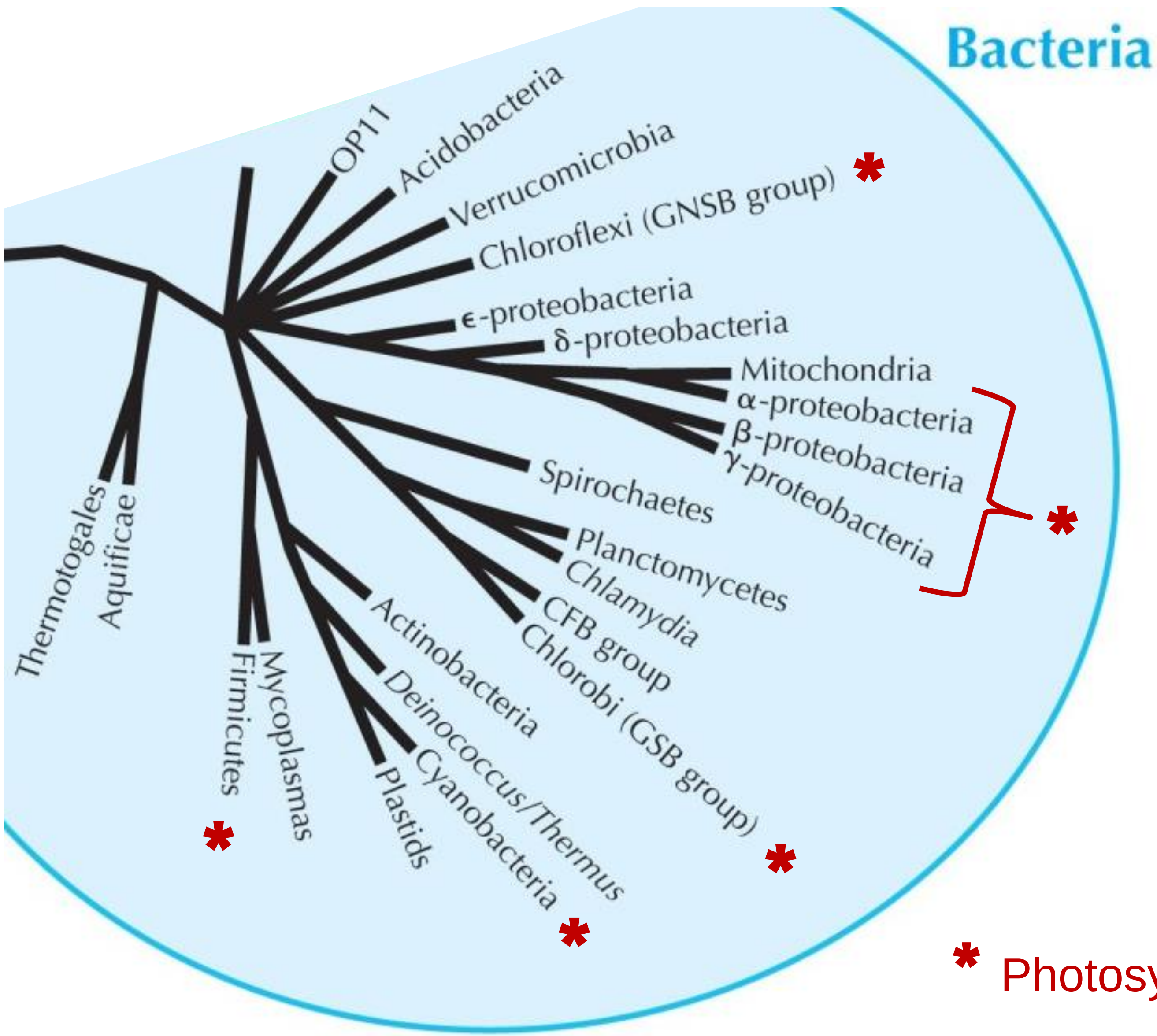


Colored groups are photosynthetic

Bacterial Phylogeny

- An unresolved issue
  - **16s rRNA tree** – early on considered to be the true topology (photosynthetic organisms not monophyletic)
  - **Core metabolic genes** – produce similar or different relationships (photosynthetic organisms still not monophyletic)

Bacterial Photosynthetic Distribution



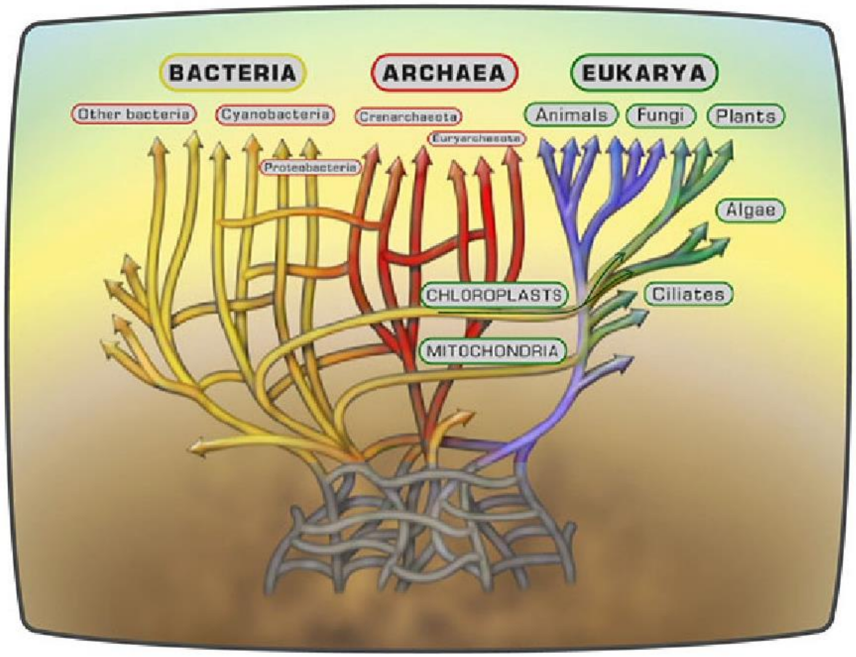
* Photosynthetic

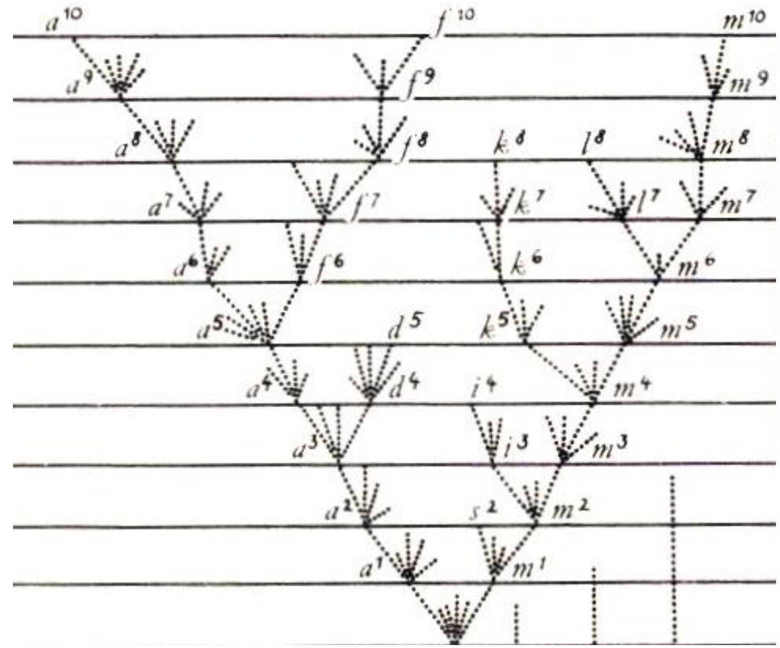
Bacterial Phylogeny

- An unresolved issue
  - **16s rRNA tree** – early on considered to be the true topology (photosynthetic organisms not monophyletic)
  - **Core metabolic genes** – produce similar or different relationships (photosynthetic organisms still not monophyletic)
- Complicating factors
  - Most ancient nodes in the tree may extend beyond the limits of phylogenetic resolution
  - Phylogenetic incongruence among genes suggests large amount of **horizontal gene transfer (HGT)** in bacterial evolution (up to 20-30% of genes in some species)

Bacterial Phylogeny and HGT

HGT: Transfer of genetic material between species





"Web of Life" **rather than** **"Tree of Life"**

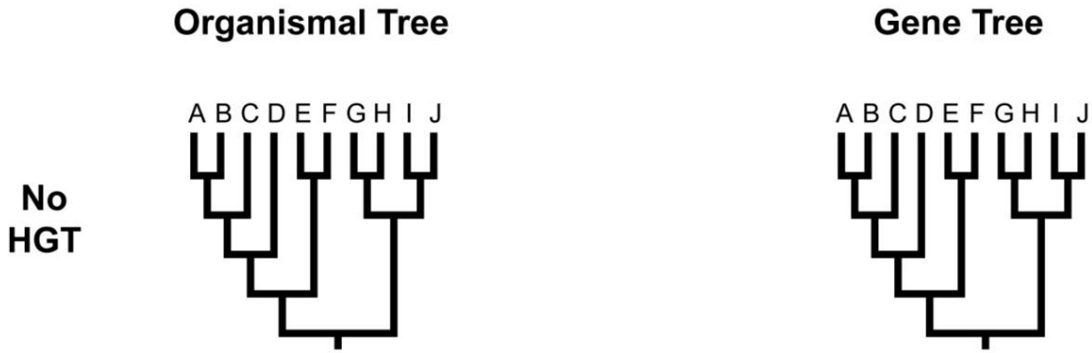
Effect of HGT on Phylogenetic Analysis

Organismal Tree

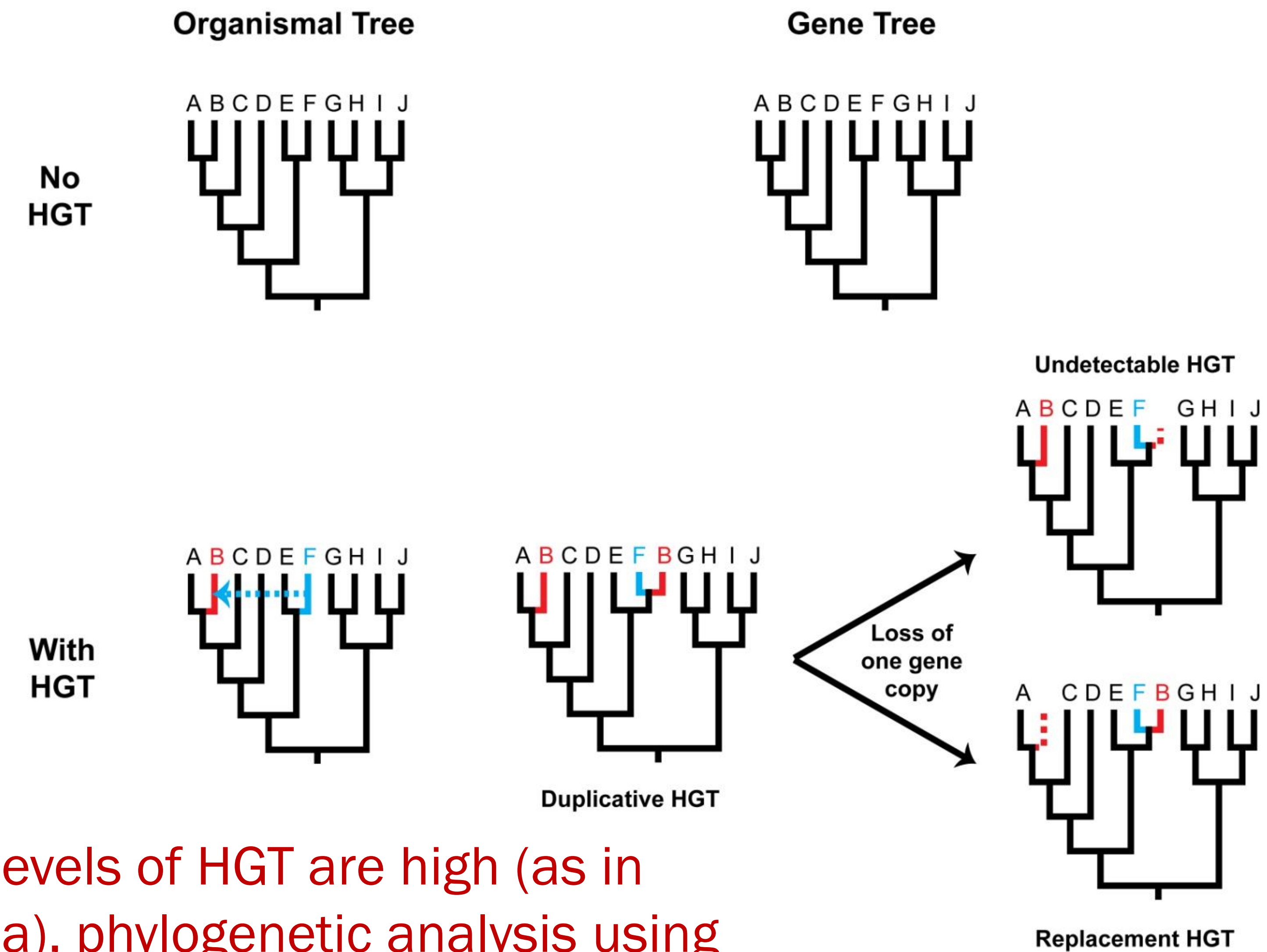
Gene Tree

Should be identical in phylogenetic analysis

Effect of HGT on Phylogenetic Analysis



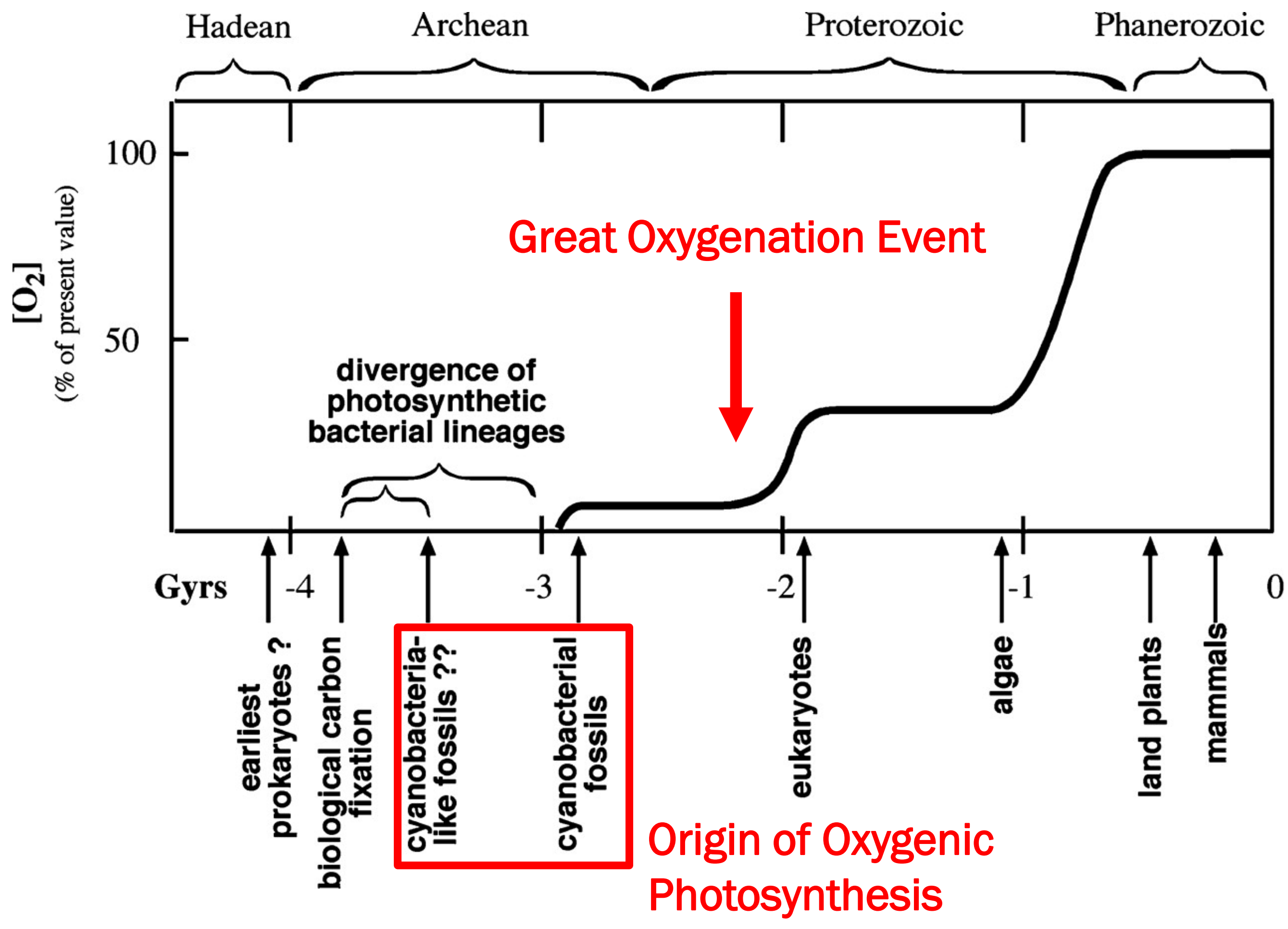
Effect of HGT on Phylogenetic Analysis



When levels of HGT are high (as in bacteria), phylogenetic analysis using multiple genes becomes unreliable

Origin of Photosynthesis

- Another unresolved issue
  - **Geologic record is unclear:** suggests oxygenic photosynthesis originated 3.8 – 2.3 billion years ago



Origin of Photosynthesis

- Another unresolved issue
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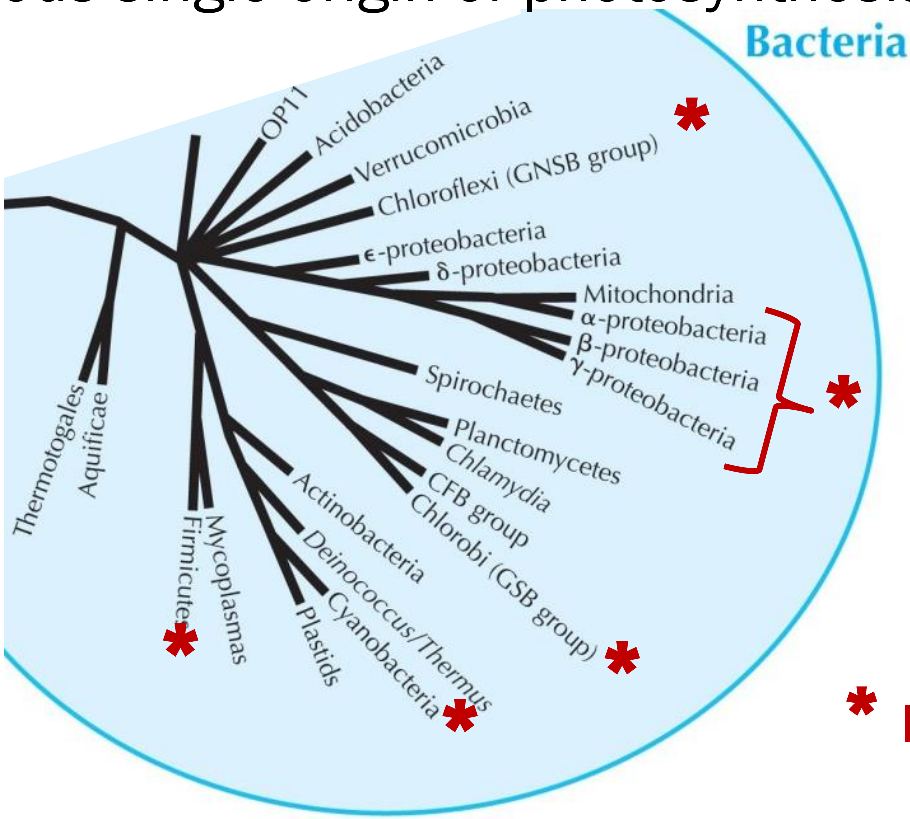
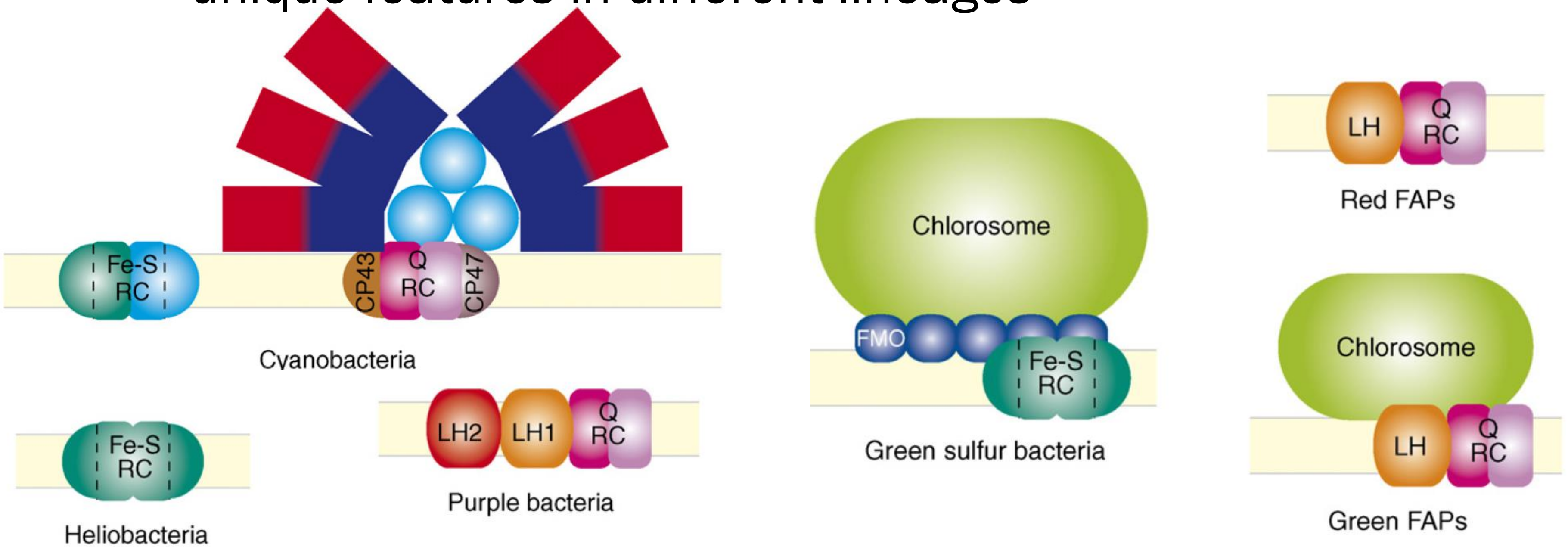
  - **Photosynthetic bacteria are not monophyletic:** no obvious single origin of photosynthesis



* Photosynthetic

Origin of Photosynthesis

- Another unresolved issue
  - **Geologic record is unclear:** suggests oxygenic photosynthesis originated 3.8 – 2.3 billion years ago
  - **Photosynthetic bacteria are not monophyletic:** no obvious single origin of photosynthesis
  - **Photosynthetic apparatus is labile:** Array of shared and unique features in different lineages



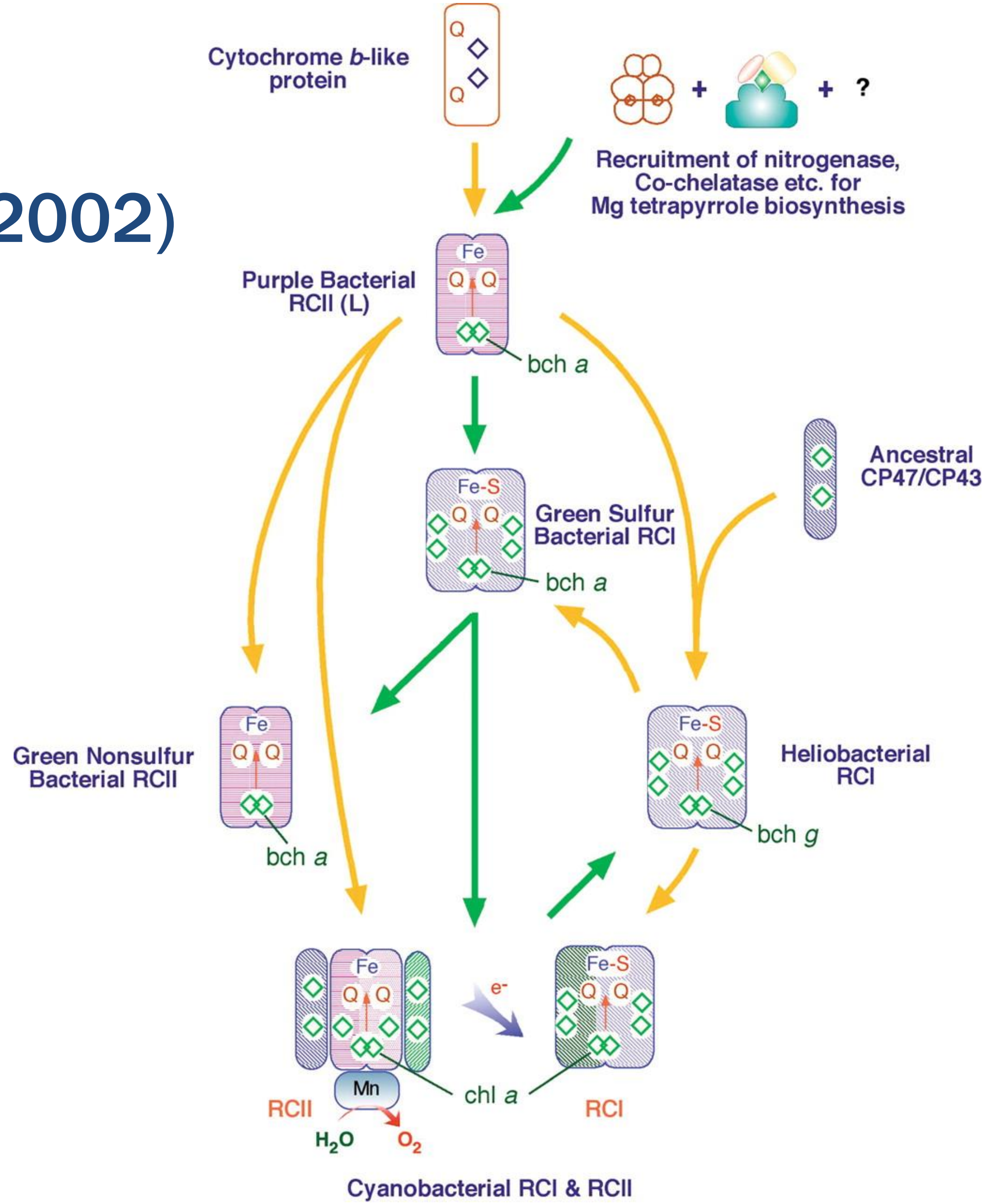
Models of Photosynthesis Origins

- **Fusion Model (Xiong and Bauer 2002):** First photosynthetic organism had one reaction center; second reaction center evolved later; cyanobacteria evolved late via fusion of two reaction center types

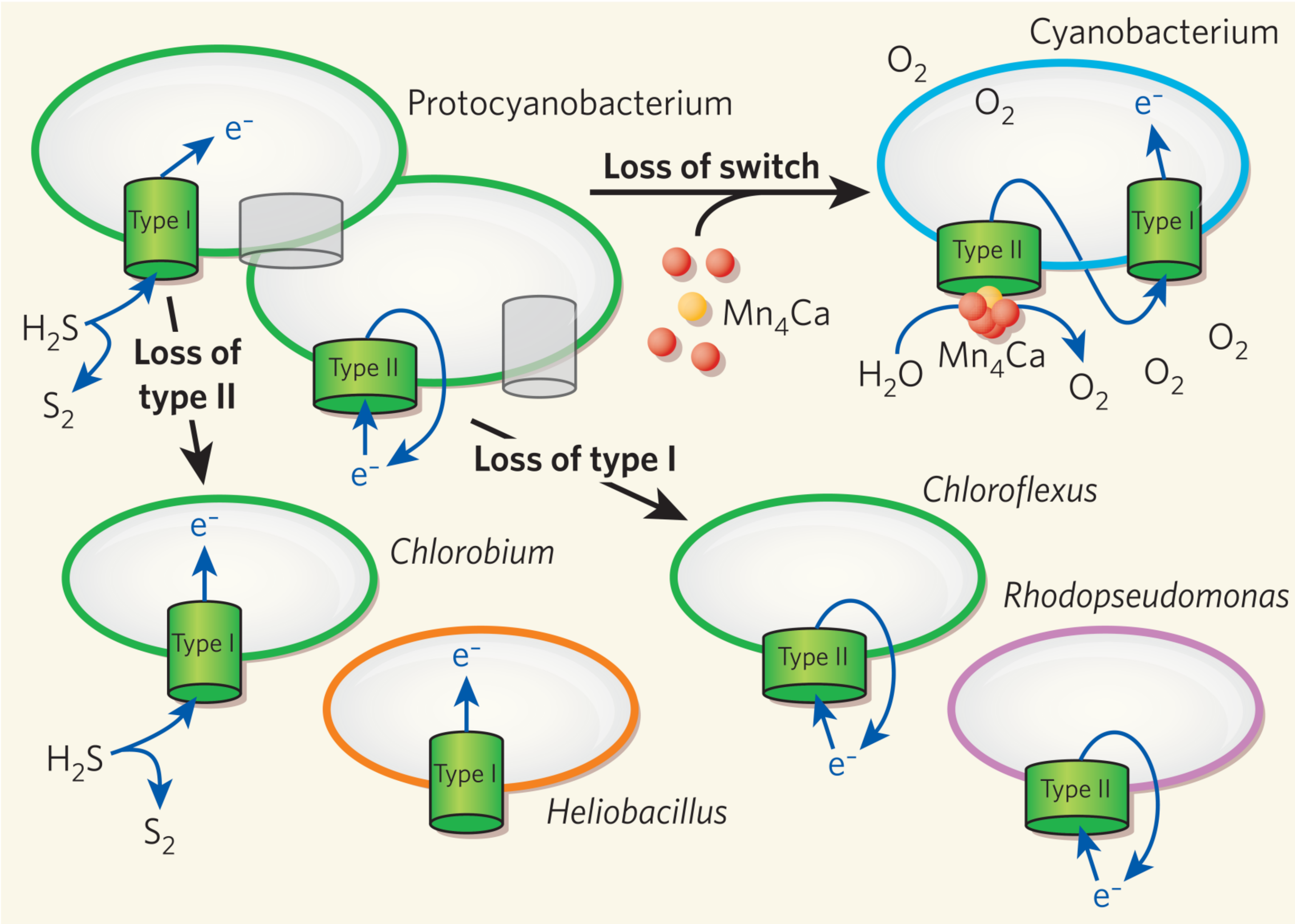
- **Selective Loss Model (Allen and Martin 2007):** Protocyanobacterium with two reaction centers evolved first; passed genes vertically to ALL other bacterial lineages, which selectively lost one or both of the reaction centers

- **Selective HGT Model (Mulkidjanian et al 2006):** Protocyanobacterium with two reaction centers evolved first; selectively passed some photosynthetic genes to other photosynthetic lineages via HGT

Fusion Model
(Xiong and Bauer 2002)



Selective Loss Model (Allen and Martin 2007)



Selective HGT Model (Mulkidjanian et al 2006)