BACTERIA AND ARCHAEA

Evolution and the Natural World

Lecture 9

06/10/2021

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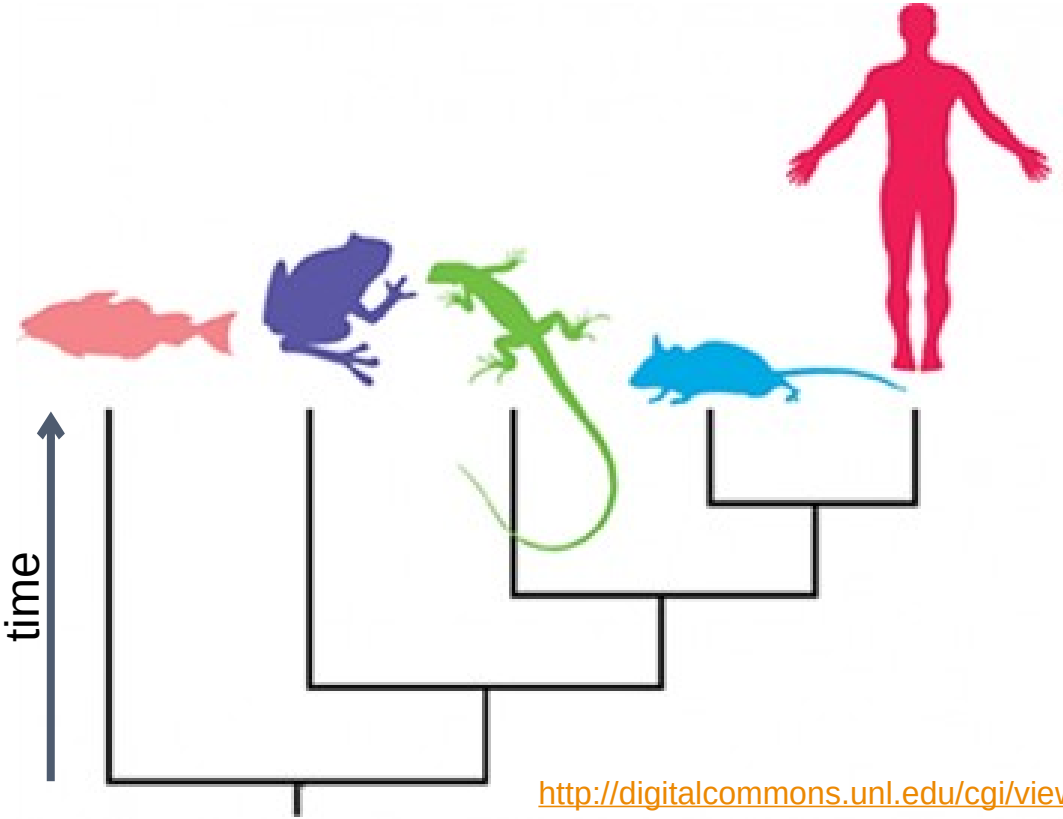
Phylogenetic trees

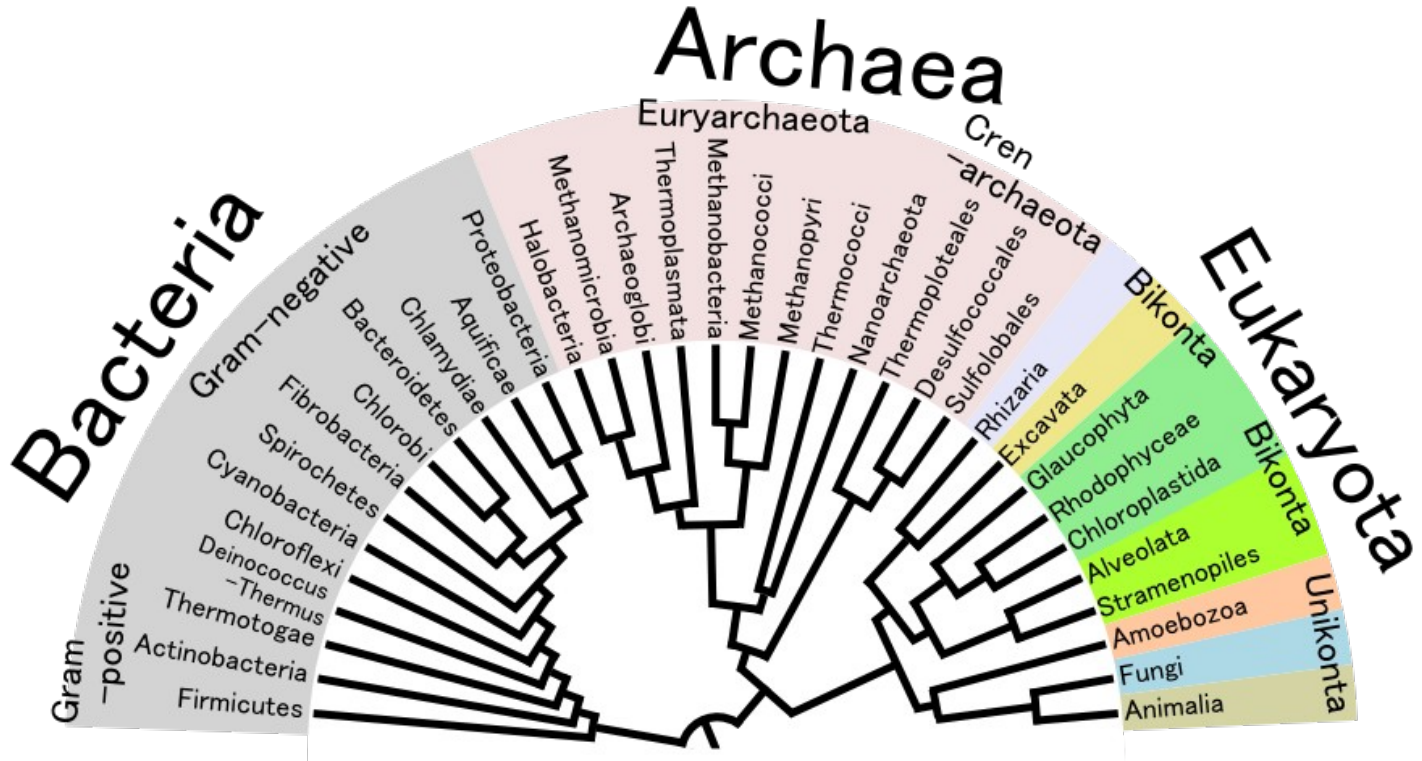


http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1104&context=bioscifacpub

BACTERIA AND ARCHAEA

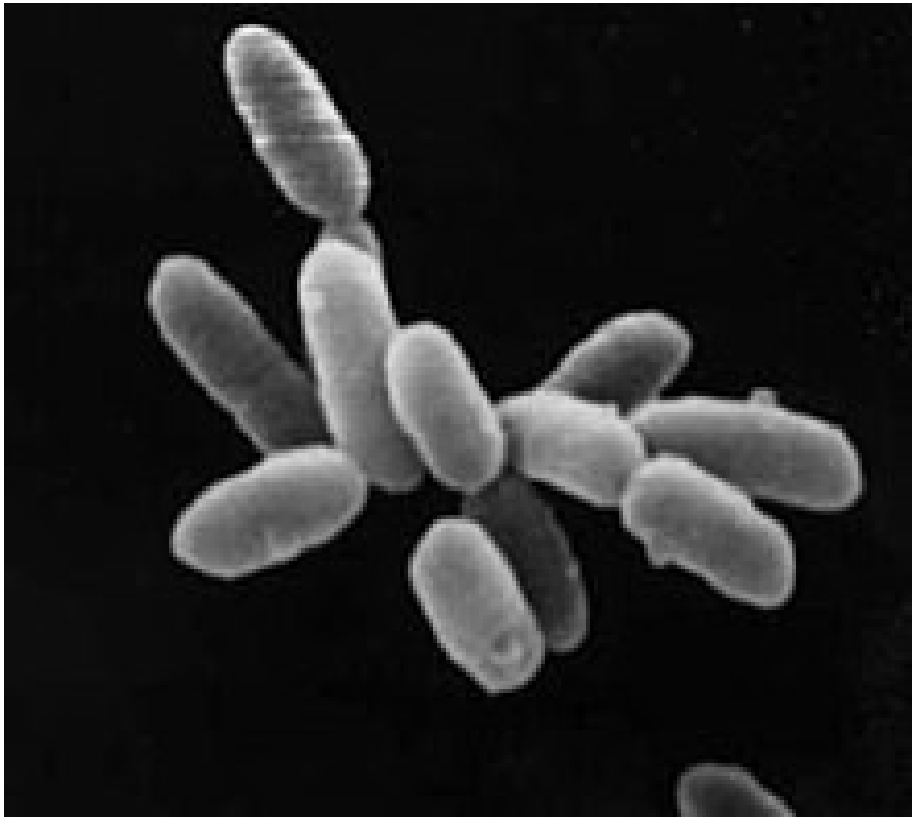
Overview

~~Prokaryotes~~ Bacteria and Archaea



https://www.pinterest.com/pin/113504853078502673/

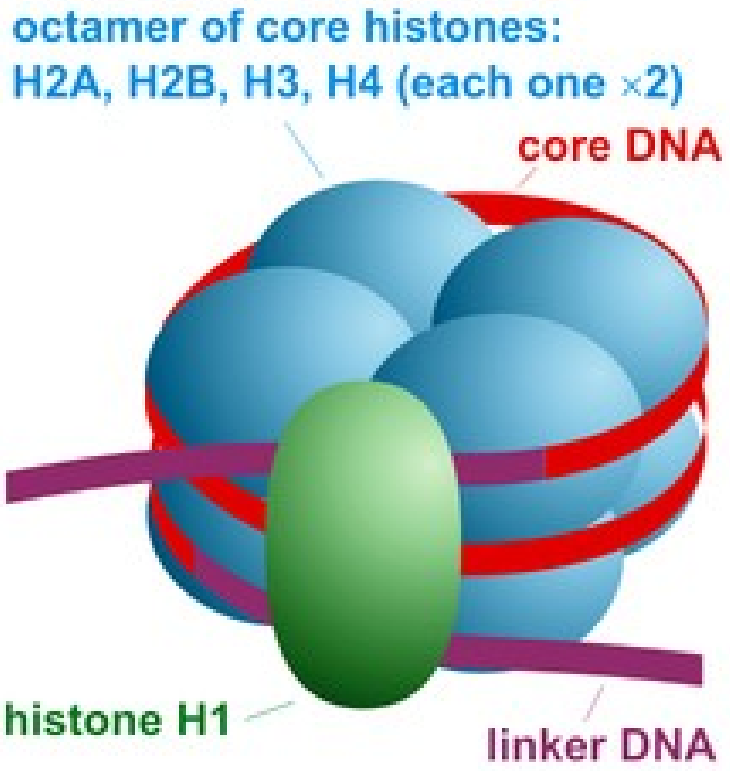
Archaea: similarities to bacteria



- Cell size and morphology
- Cell division
- Circular DNA
- Genome size
- Similarities in gene expression

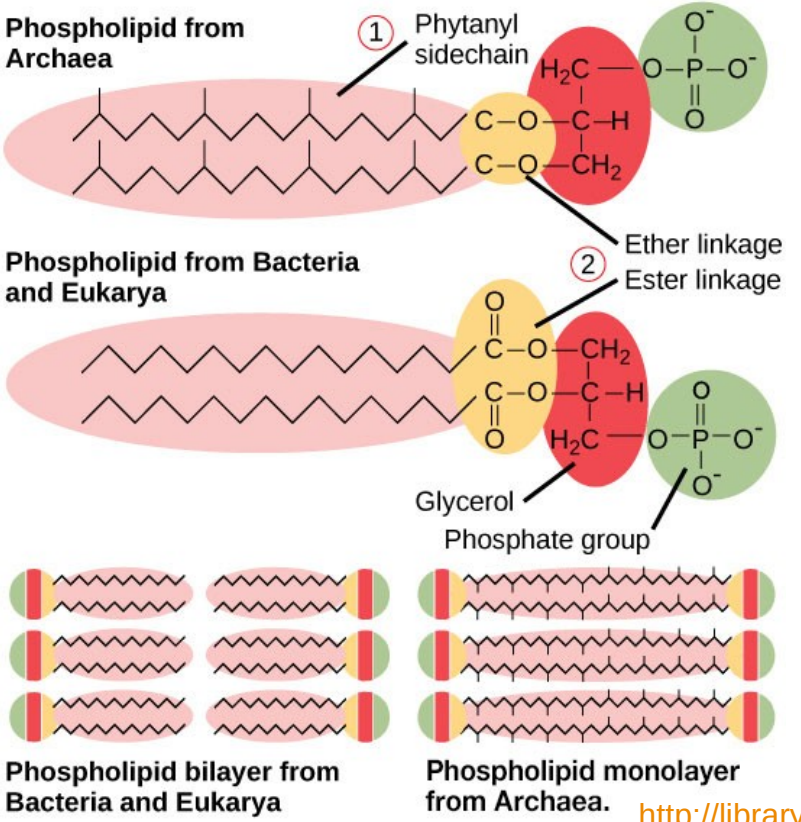
https://en.wikipedia.org/wiki/Archaea

Archaea: similarities to eukaryotes



- rRNA sequence
- Histones, homologous to the eukaryotic ones
- Homology of enzymes, involved in DNA replication and transcription

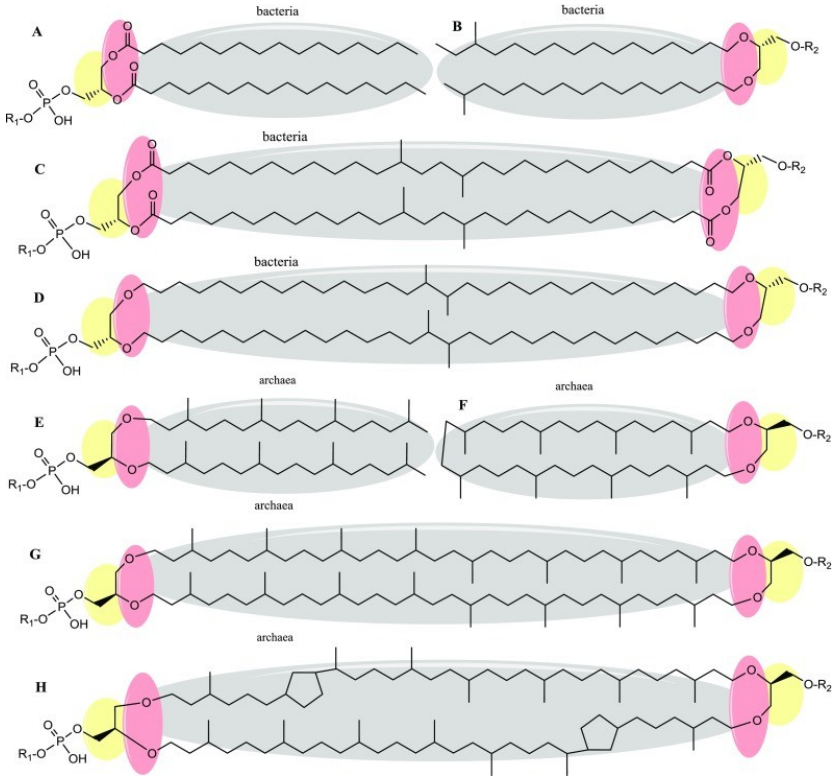
Archaea: unique features



- Some genes with no homologues in bacteria and eukaryotes
- Unique structure of their cell walls and flagella
- Atypical cell membranes

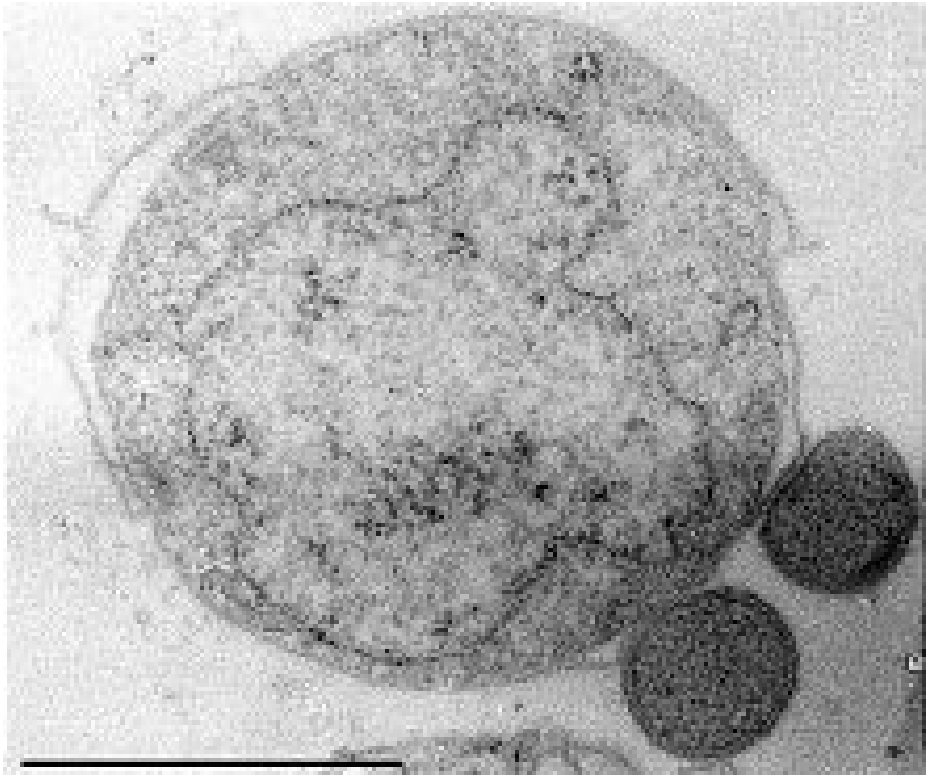
http://library.open.oregonstate.edu/microbiology/chapter/archaea/

Membranes: details



https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5487899/

Archaea: metabolism and ecology



- Many but not all are extremophiles: thermophiles, halophiles
- Some live in marshes: methanogens
- No human pathogens discovered; but are present in the human gut
- Form communities with other archaea and bacteria

https://en.wikipedia.org/wiki/Nanoarchaeum_equitans

BACTERIA AND ARCHAEA

Biochemistry

B&A are ubiquitous

- “Normal” environment:
  - Water, soil, rock surface
- Extreme environment:
  - Hot springs and hydrothermal vents;
  - Glaciers;
  - Deep sea;
  - Salty, alkaline and acidic bodies of water;
  - Deserts
  - Environments with high levels of radiation
  - Earth crust (up to 5 km)

B&A have specific adaptations to their environment

Adaptations to harsh conditions

Problem	Solution
High temperature	Protein – more bonds, tRNA and rRNA – more G and C, monolayer membranes and other modifications of lipids
Low temperature	Antifreeze solutes
High salinity	High intracellular osmotic pressure
High/low pH	Ion transporters
Desiccation/high radiation	Free radicals scavengers, enhanced DNA repair

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0184722

Types of metabolism

Energy source	sunlight	photo-			trophes
	chemical reactions (e.g. oxidation during respiration)	chemo-			
Electron donor	inorganic compound (e.g. H_2, H_2S)		litho-		
	organic compound (e.g. sugars)		organo-		
Carbon source	inorganic compound (e.g. CO_2)			auto-	
	organic compound (e.g. sugars)			hetero-	

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Types of metabolism

- *E.coli* (like humans) is **chemoorganoheterotrophes**
- Cyanobacteria (like plants) are **photolithoautotrophes**
- Nitrifying bacteria are **chemolithoautotrophes**

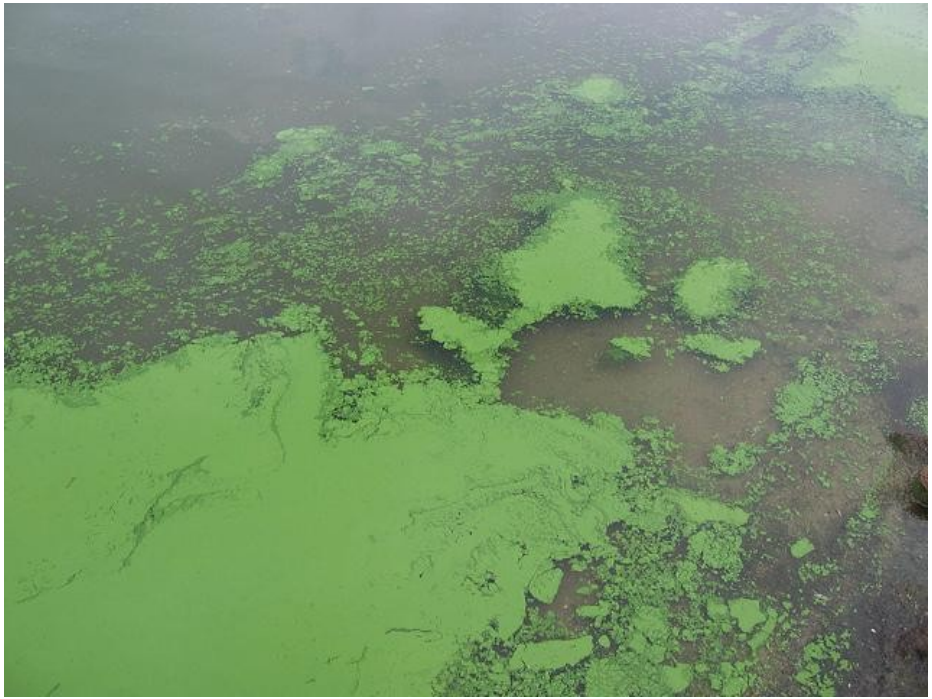
(they get energy and electrons from NH_4^+ > NO_2^- to fix CO_2)

Autotrophy in B&A

https://en.wikipedia.org/wiki/Riftia_pachyptila#/media/File:Riftia_tube_worm_colony_Galapagos_2011.jpg

- Conversion of CO_2 (CH_4, CH_3OH etc) to organic compounds needs energy (ATP and NADH)
- Energy sources: light or inorganic RedOx reactions (photo- and chemosynthesis)
- Great diversity of biochemical pathways of CO_2 fixation

Phototrophy in B&A



https://www.epa.gov/national-aquatic-resource-surveys/indicators-cyanobacteria

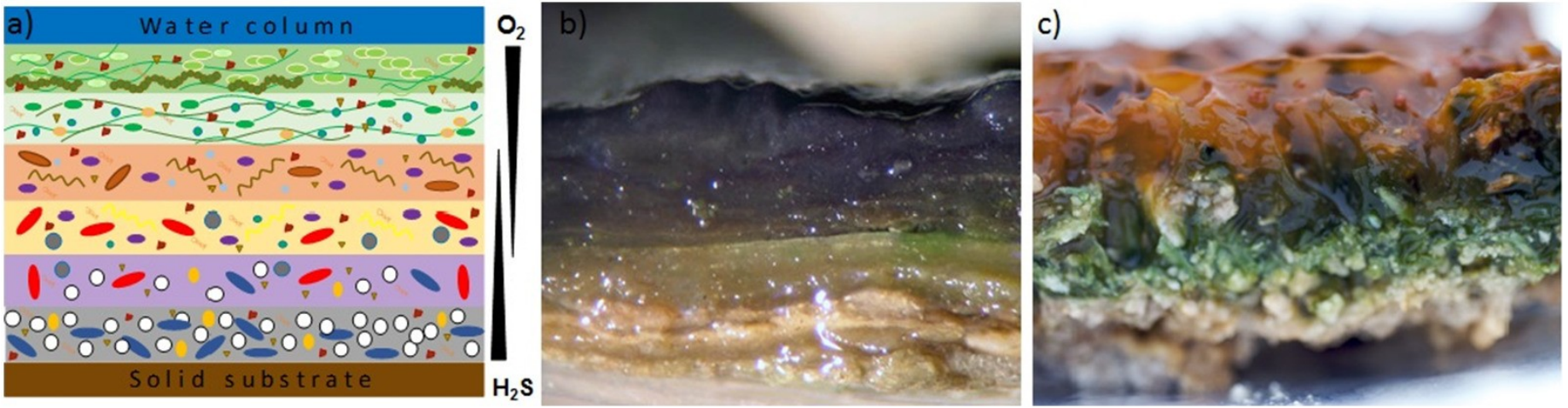
- “Real” photosynthesis found in 5 groups of bacteria (Cyanobacteria, Chlorobi, Chlorofexi, Heliobacteria and alpha-proteobacteria) and in chloroplast-carrying organisms
- Horizontal gene transfer involved

Phototrophy in B&A

- “Real” photosynthesis means it involves chlorophylls, electron-transport chain, transmembrane H^+ gradient and ATP synthase and is linked to autotrophy
- But details are different, e.g. only cyanobacteria (and chloroplasts) use H_2O and produce O_2
- There are other ways of converting light into useful energy (ATP). Example: bacteriorhodopsin of halophilic archaea which is a “light-powered” transmembrane H^+ pump

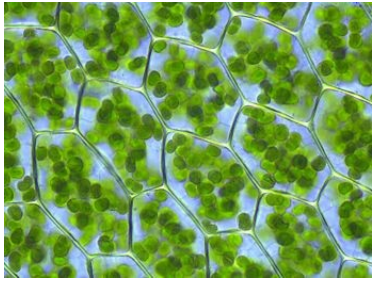
Living together with others

- Complex microbial communities like microbial mats
- BTW these can form fossils (stromatolites)



https://www.sciencedirect.com/science/article/pii/S0717345817300738

Mutualistic symbionts



- Mitochondria and chloroplasts
- Some lichens
- *Rhizobium* (nodules on plant roots)
- Human (and other animals) gut, skin and mucosa microbiota (both B & A)

https://fineartamerica.com/featured/1-nodules-of-rhizobium-leguminosarum-dr-jeremy-burgessscience-photo-library.html

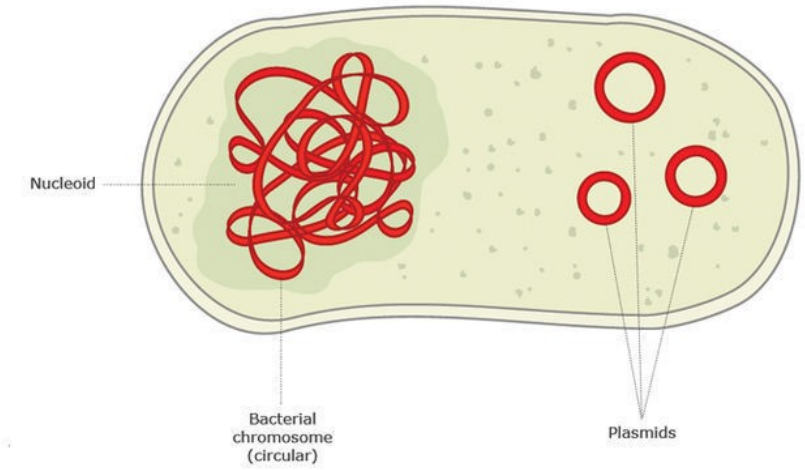
Parasitic Bacteria

- No pathogenic Archaea found so far
- All eukaryotes have bacterial pathogens
- Many pathogenic species of bacteria in different groups >
  - Pathogenicity is easily gained and lost; also due to HGT
- Some are intracellular pathogens (e.g. Chlamydia, Rickettsia, Mycobacterium) – the simplest cellular life forms known
- The line between parasites and mutualists is thin

BACTERIA AND ARCHAEA

Genetics

Genetic material



- Typically 1 circular “chromosome” (=nucleoid) (+ plasmids)
- Many possible exceptions (linear chromosomes, more than 1 chromosome)

Chromosome vs plasmids

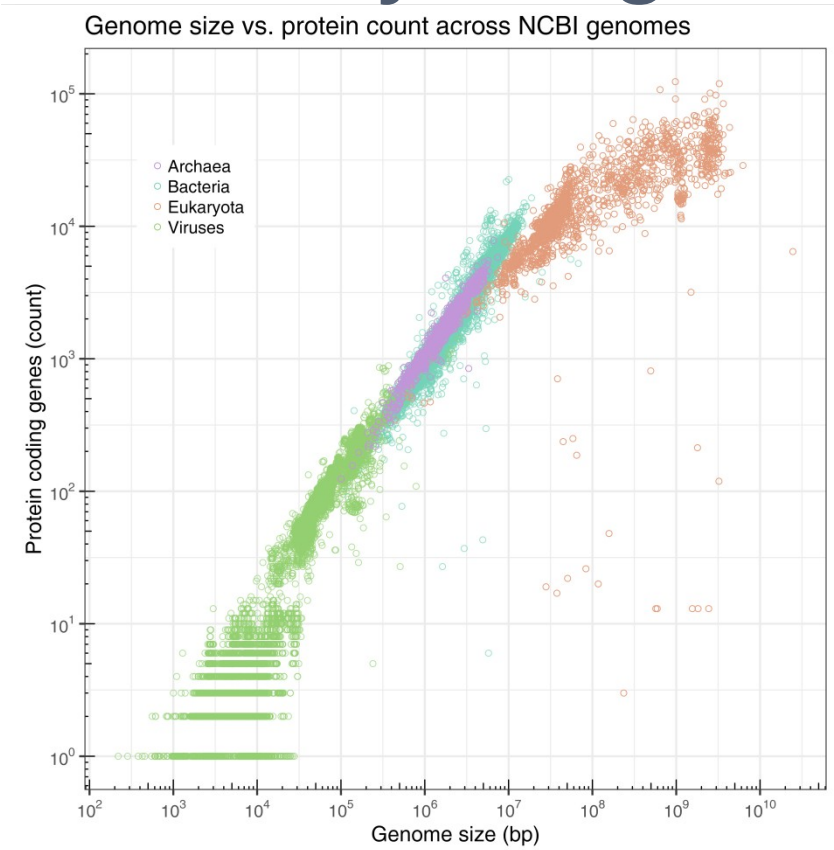
Chromosome

- Carry all the essential, “house-keeping” genes
- Control of copy number

Plasmids

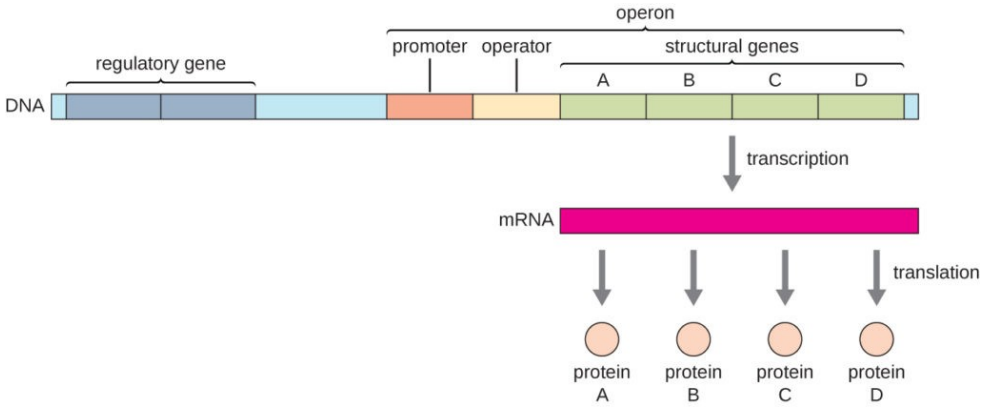
- Normally are not essential – can be lost
- But may carry genes like
  - Antibiotic resistance
  - Pathogenicity
  - Conjugation and DNA transfer
- Often many copies
- Are selfish elements

Prokaryotic genomes



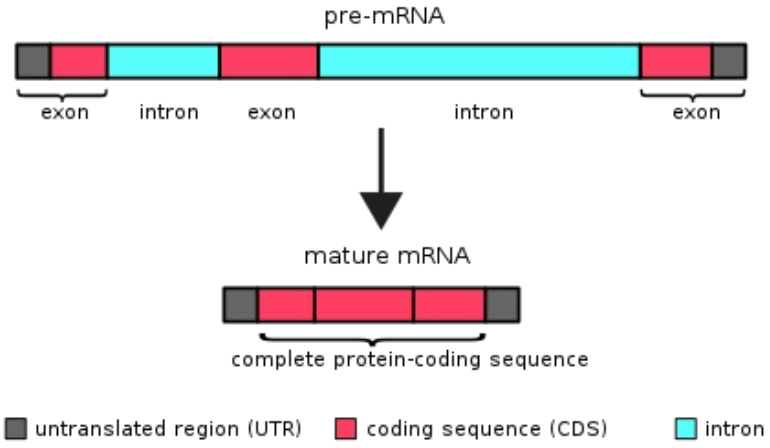
- Genomes are small compared to those of eukaryotes (average 1 mln bp; 1000 genes)
- Normally genes make up most of the genome and an average gene is ~ 1 kb long
- (In eukaryotes a lot of DNA does not code for proteins)

Gene expression



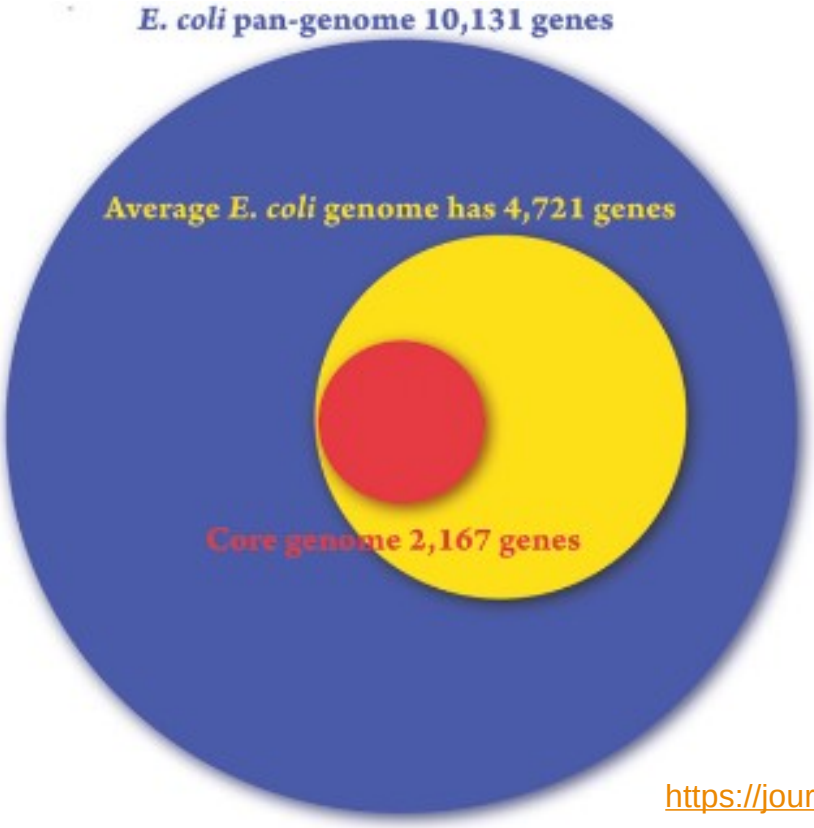
- Most genes in Bacteria and Archaea are grouped into operons: groups of genes that are transcribed together into one transcript and are involved in a common process

Introns



- Typically Eukaryotic genes have introns
- Bacteria and Archaea also can have introns but these are less widespread and of different type compared to Eukaryotes

Gene content



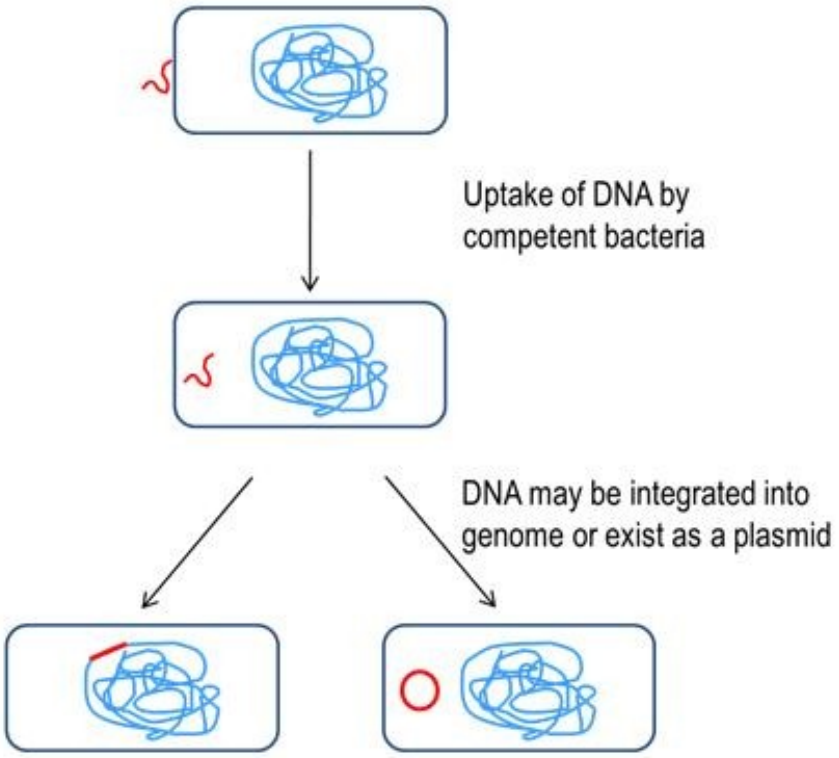
- Number of genes varies even within a species
- Core genome – genes found in every strain
- Pangenome – all genes found in a particular species

https://journals.plos.org/plosgenetics/article?id=10.1371/journal.pgen.1000335

B&A genomes are labile

- Genes can be easily lost if not essential
- Bacteria exchange genetic material – horizontal (lateral) gene transfer (HGT/LGT)
  - HGT is of great importance for B&A evolution (a way to acquire new genes)
  - Can happen between distinct taxa, even between Bacteria and Archaea -> the concept of a species is very vague
  - The fraction of the genome recently acquired can exceed 15%

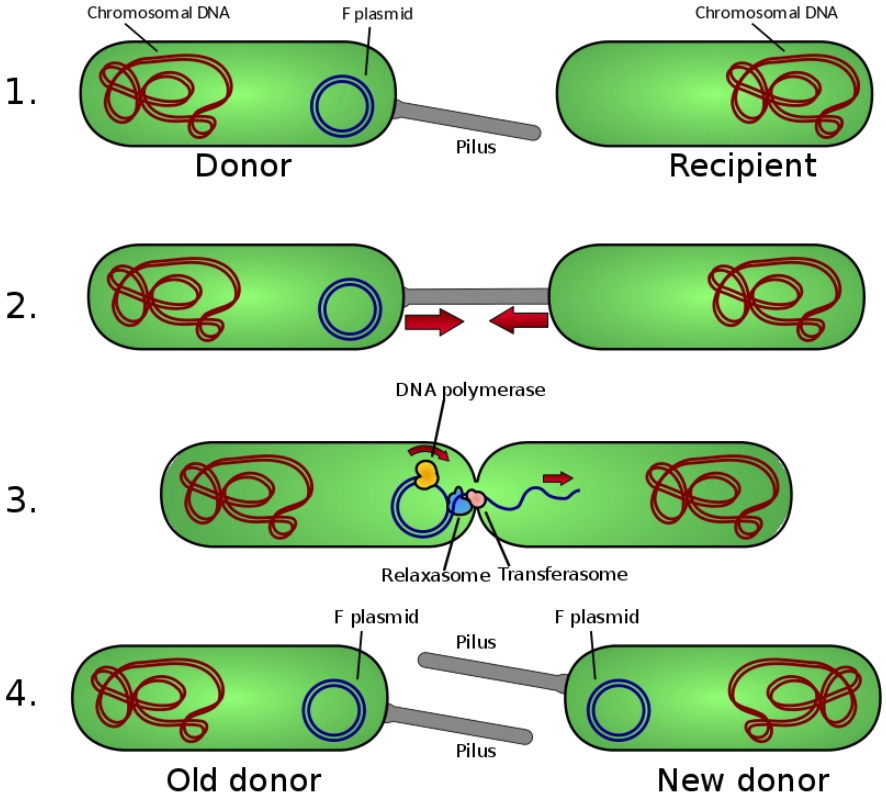
Transformation



- Bacteria cells can take DNA molecules from the environment
- These may get inserted into the chromosome if homologous
- Or such molecules can replicate on their own - plasmids

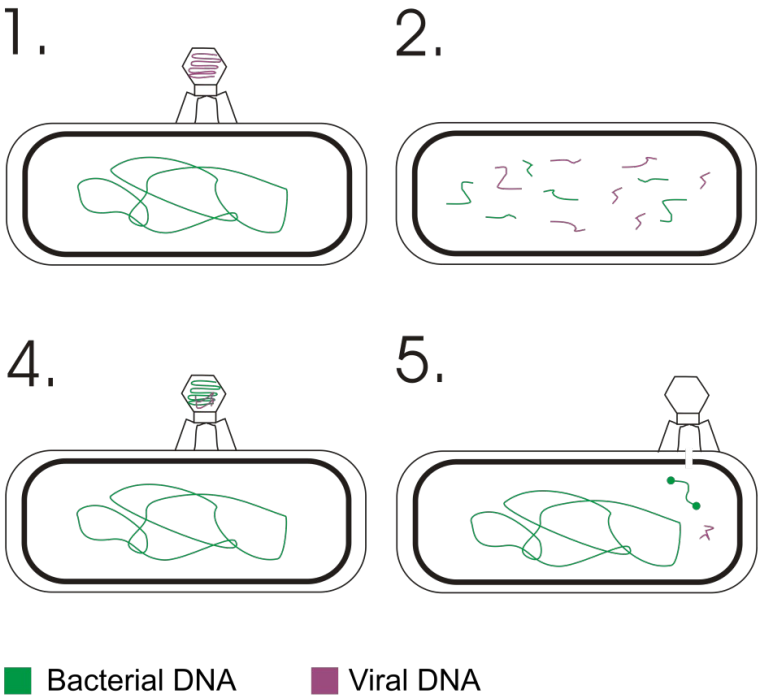
https://www.sigmaaldrich.com/technical-documents/protocols/biology/transformation.html

Conjugation



- Presence of certain plasmids (F-factor in the case of E.coli) turn bacteria into **Donors**
- Donors have pili that they use to attach to recipient cells
- A copy of the plasmid is transmitted to the recipient cell

Transduction



- Viruses of B&A (phages) can randomly incorporate pieces of the host DNA and transfer it to other B&A cells
- Generalized – random DNA fragments are transferred
- Specialized – DNA close to viral integration site is transferred

https://bio.libretexts.org/Bookshelves/Microbiology/Book%3A_Microbiology_(Boundless)/7%3A_Microbial_Genetics/7.11%3A_Genetic_Transfer_in_Prokaryotes/7.11C%3A_Bacterial_Transduction

Barriers to HGT

- Foreign DNA can get degraded by restriction enzymes and similar systems (CRISPR/Cas9)
- Foreign DNA has to be replicated in the cell – have its origin of replication (plasmids) or integrate into host DNA
- Foreign DNA has to be expressed

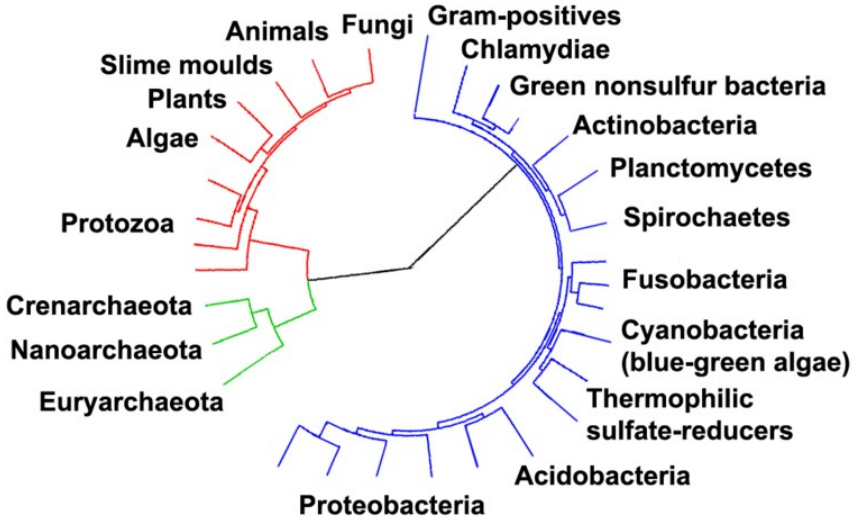
BACTERIA AND ARCHAEA

Phylogeny

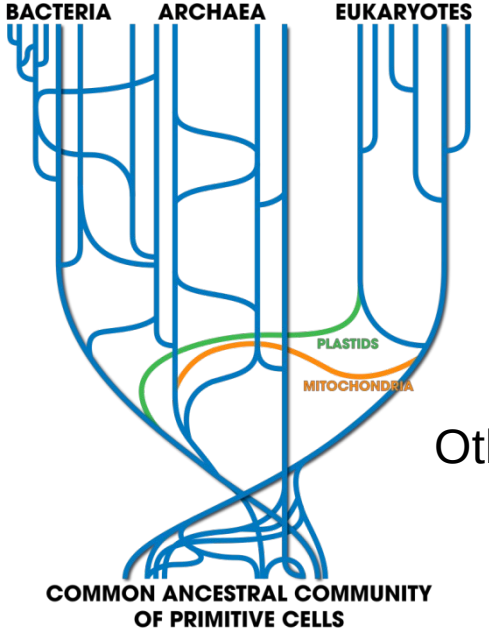
Systematics of Bacteria and Archaea

- Classical approach:
  - based on morphology and biochemistry, which change fast during evolution
  - restricted to cultivated species
- DNA-based approach:
  - no need to cultivate; DNA, isolated from the environment can be used – metagenomics
  - usually rRNA genes are used
  - fewer problems with parallel evolution and trait loss
  - but horizontal gene transfer makes things complicated and challenges the very concept of a tree

Vertical vs horizontal inheritance



Genes involved in replication, transcription, translation – **the tree of life**

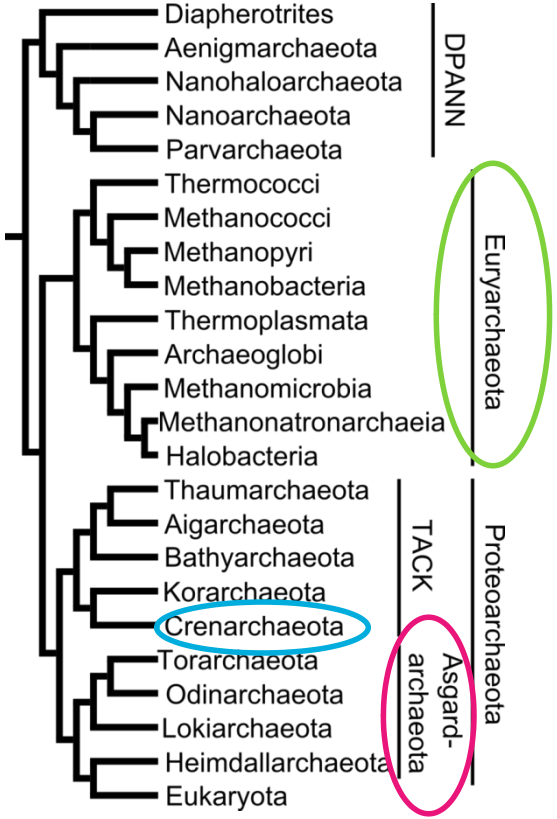


Other genes – **the web of life**

Bacterial phyla (some examples)

- **Cyanobacteria**
- **Proteobacteria** (incl. *Escherichia coli, Vibrio cholerae, Yersinia pestis, Helicobacter pilori*)
- **Spyrochetes** (*Borrelia burgdorferi, Treponema pallidum*)
- **Firmicutes** (1 of 2 Gram+, incl. *Staphylococcus, Streptococcus, Bacillus, Clostridium*)
- **Actinobacteria** (2nd Gram+ group, incl. *Mycobacterium tuberculosis, M. leprae, Streptomyces*)

Archaea phyla



- Euryarchaeota – widespread, incl. methanogens
- Crenarchaeota – widespread, incl. thermophiles
- Asgardarchaeota – deserved a lot of attention

B&A: key points

- Morphologically “simple”, but highly adapted to their environment, e.g. by biochemical adaptations > enormous phenotypic diversity
- Phylogenetically highly diverged – old MRCA
- HGT – the concept of the web of life
- Important for understanding the origin of life and the origin of Eukaryotes