The origin of cells, and how to classify them

Dr. Nick Coleman

The origin of life 1. Inorganic → organic chemicals

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The Miller Volcanic Spark Discharge Experiment

REVISITED!

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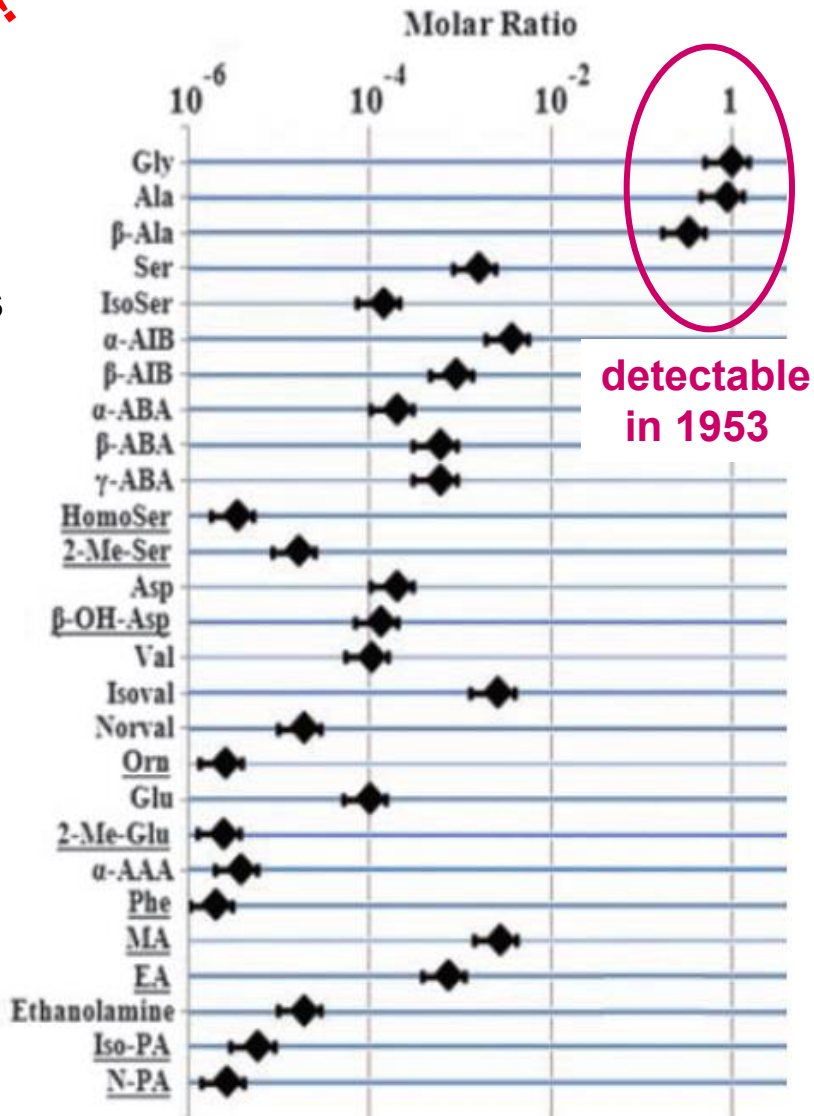
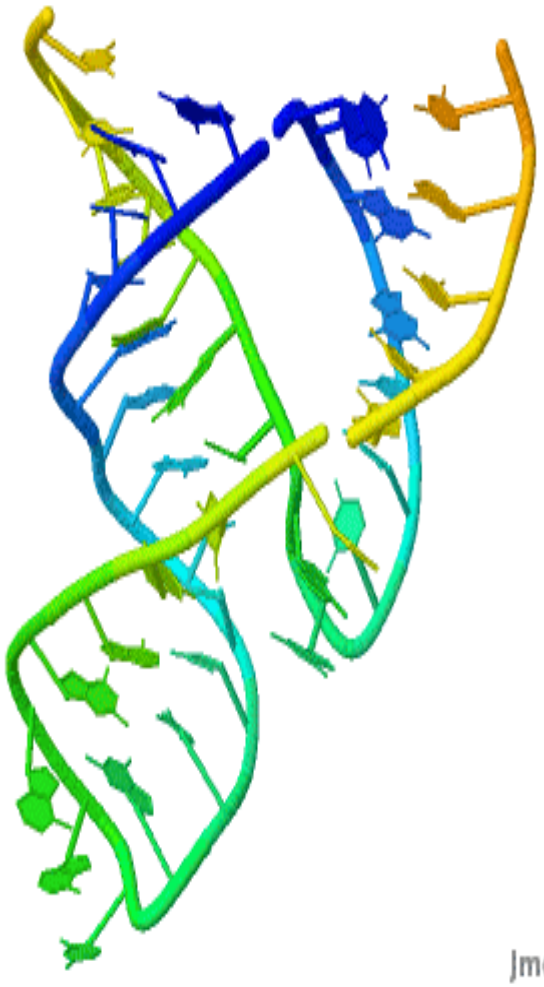
"After Miller's death in 2007, we found vials of residues from his 1953 experiments. We reanalysed them by liquid chromatography time of flight mass spectrometry"



The origin of life 2. Replicating organic chemicals



- Ribozymes are good candidates for the first self-replicating biomolecules
- A ribozyme is made of RNA, and has both information content and catalytic activity
- Solves the 'ribosome paradox' ?
- Just a hypothesis ? There is no fossil record for RNA…

The origin of life 2. Replicating organic chemicals

SCIENCE VOL 292 18 MAY 2001 ARTICLE

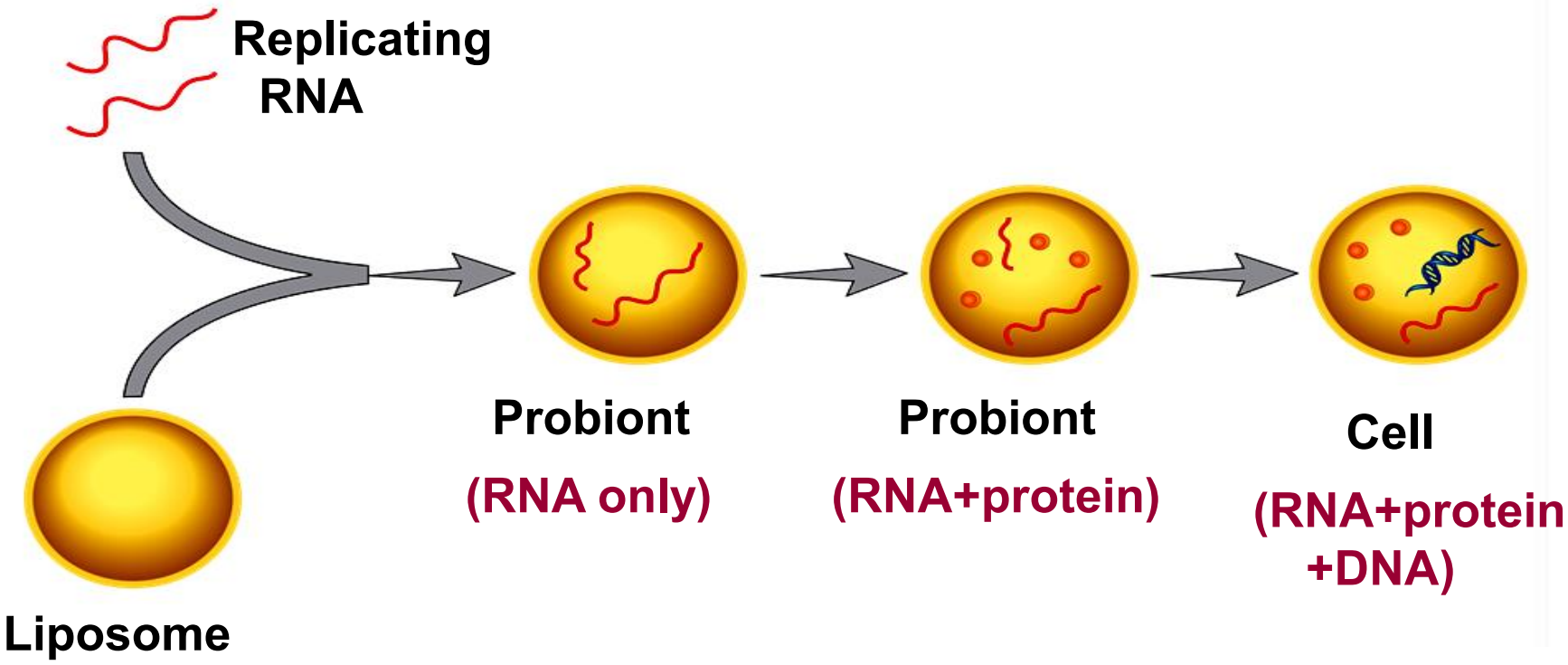
RNA-Catalyzed RNA Polymerization: Accurate and General RNA-Templated Primer Extension

Wendy K. Johnston, Peter J. Unrau,* Michael S. Lawrence, Margaret E. Glasner, David P. Bartel†

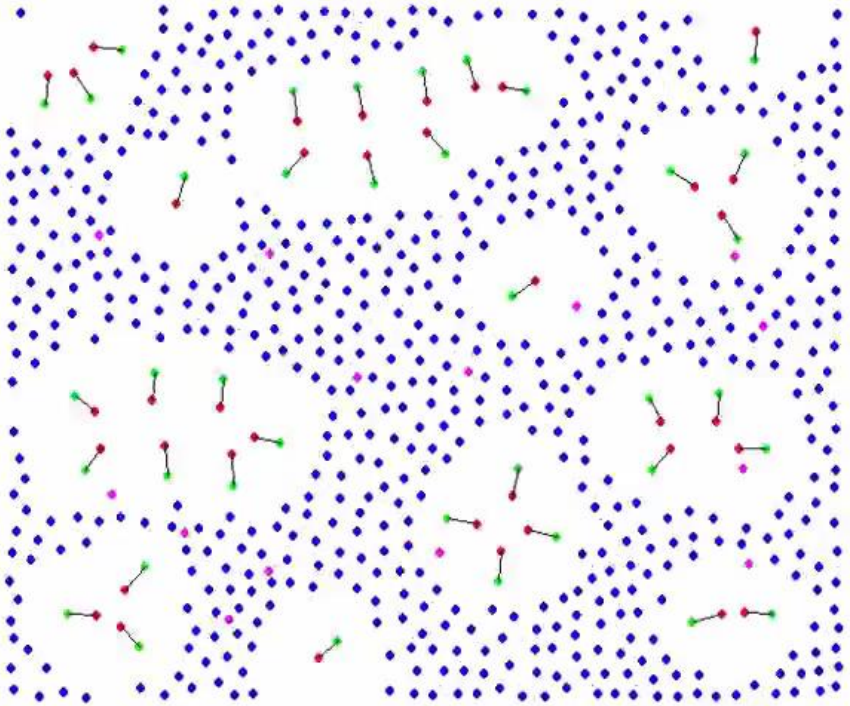
The RNA world hypothesis regarding the early evolution of life relies on the premise that some RNA sequences can catalyze RNA replication. In support of this conjecture, we describe here an RNA molecule that catalyzes the type of polymerization needed for RNA replication. The ribozyme uses nucleoside triphosphates and the coding information of an RNA template to extend an RNA primer by the successive addition of up to 14 nucleotides

The origin of life 3. Making cells

- All modern life is based on CELLS
- Cells provide organisation, and a barrier to separate inside (ordered) from outside (chaotic)



The origin of life. Self-assembly – a crucial idea in biology



- Phospholipids are amphipathic (polar end and non-polar end)
- Because of this, they self-assemble in aqueous solution → bilayers and micelles

- Viral capsids are made of proteins with special shapes that allow self assembly

The origin of life. Fossil evidence

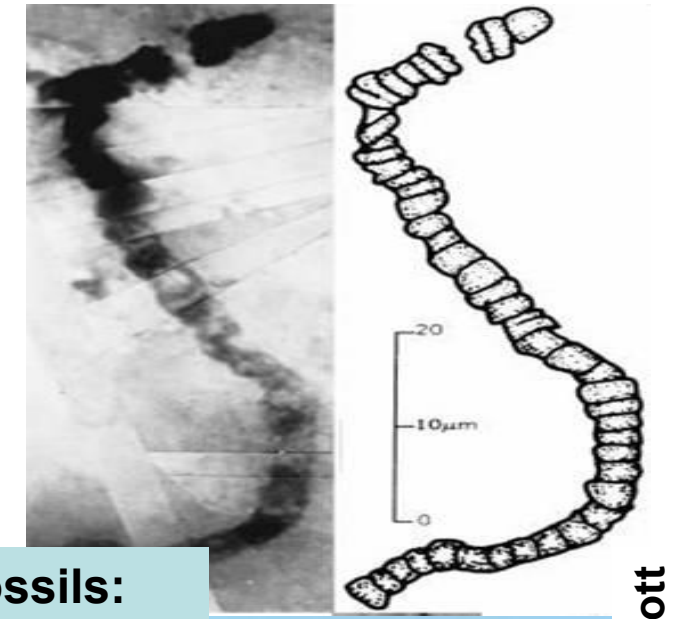
- **Oldest fossils (3.8 billion yr): cyanobacteria in stromatolites**

BUT

- **Biochemical complexity of photosynthesis suggests cyanobacteria NOT first cells**

THEREFORE

- **Fossils alone are not enough to understand the origins of life !**



First fossils: cyanobacteria

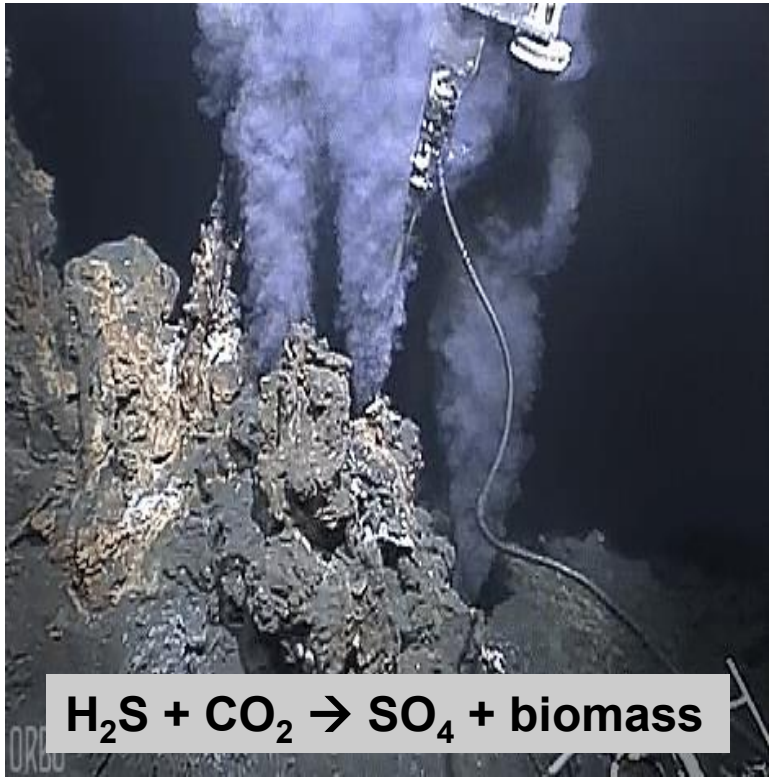
Prescott

"Living fossils": stromatolites

The origin of life. DNA evidence

- The Tree of Life based on DNA sequences suggests a "hot, dark" origin of life eg. hydrothermal vent

- Likely characteristics of first cells:
  - Bacteria
  - thermophilic
  - anaerobic
  - chemoautotrophic



The first cell is known as the Last Universal Common Ancestor (LUCA)

The nature of LUCA is still the subject of intense debate !

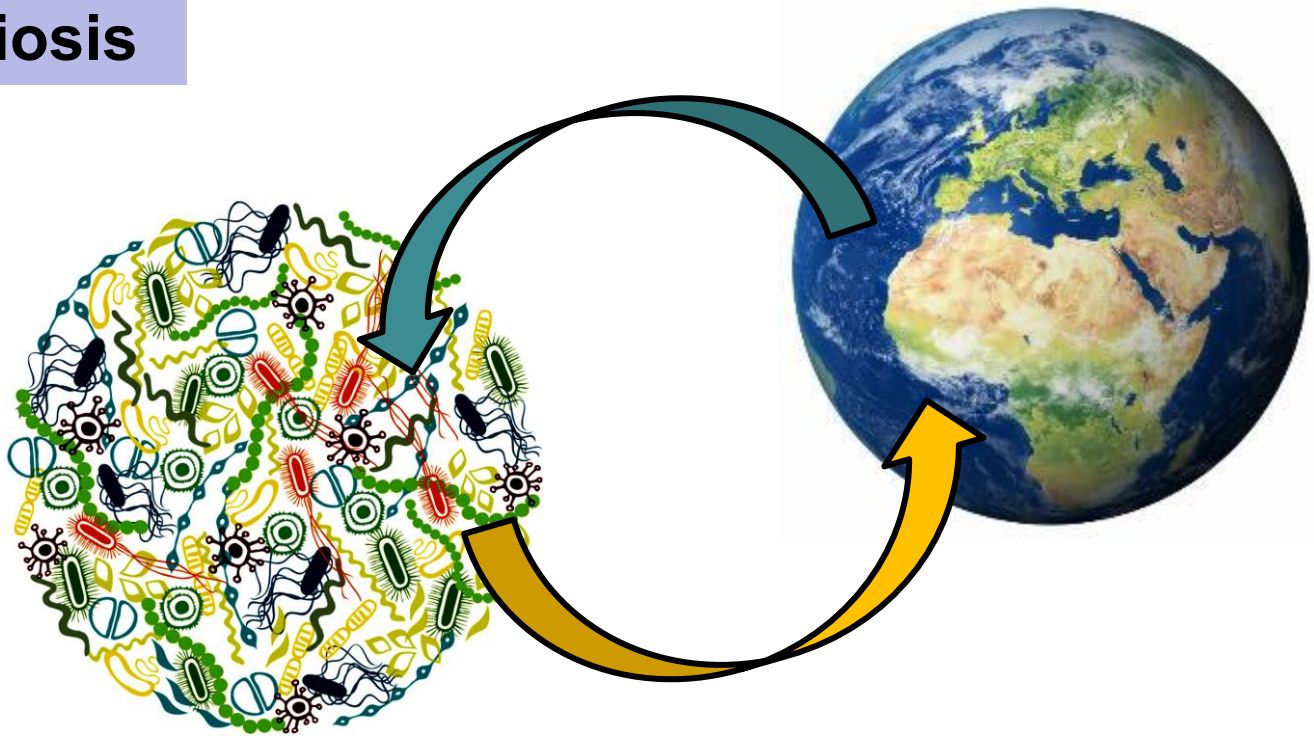
So what happened next ?

diversification

adaptation

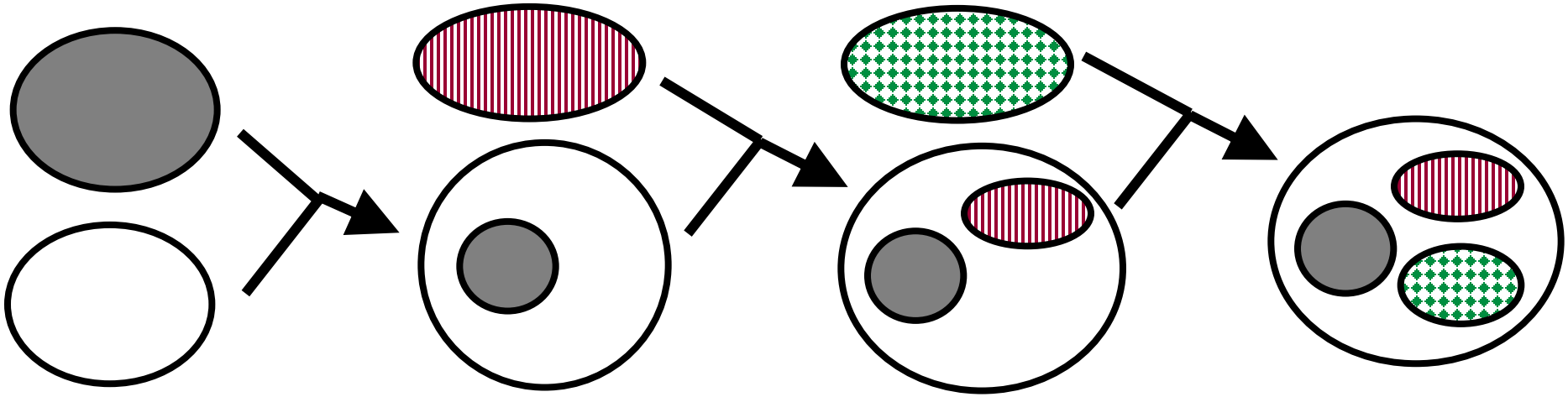
new types of metabolism

endosymbiosis



Life diversifies: oxygen appears, endosymbiosis

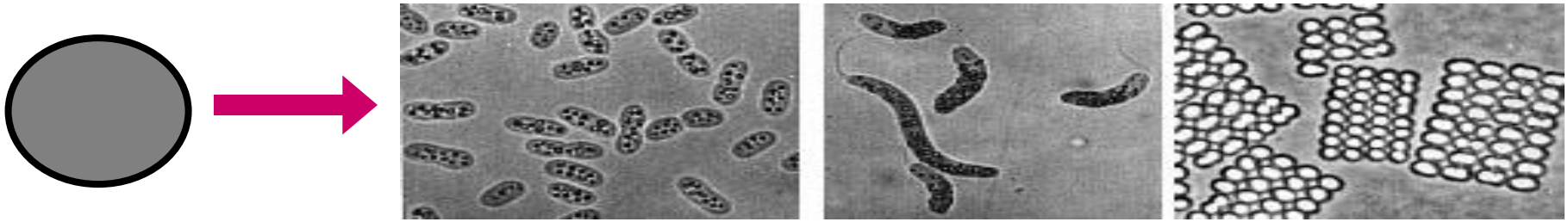
- Evolution of cyanobacteria → oxygenation of atmosphere
- Availability of O_2 as a high-energy electron acceptor spurred development of more complex organisms
- Endosymbiosis between bacteria → eukaryotes



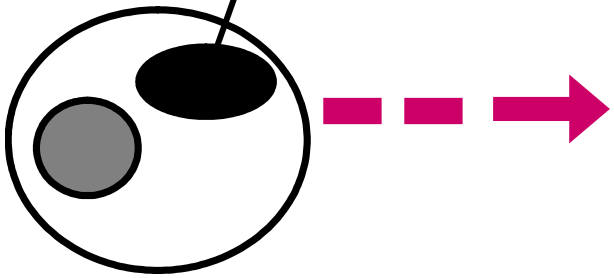
Evolution often involves cooperation, not just competition !

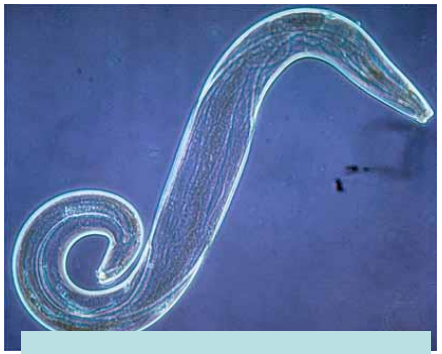
Life diversifies: single-celled forms

- **Bacteria continued to evolve, colonising new niches**

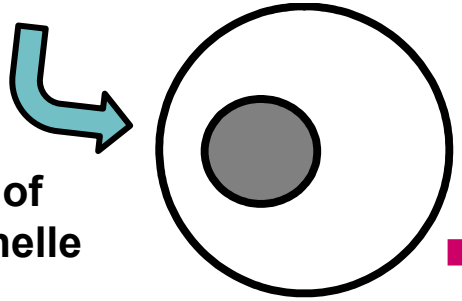


- **Some eukaryotes remained unicellular (the protozoa)**



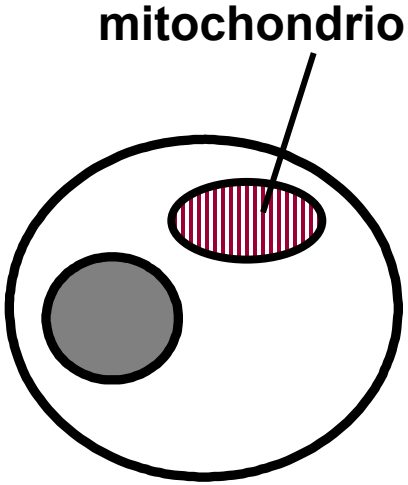


eg. *Plasmodium* (malaria)

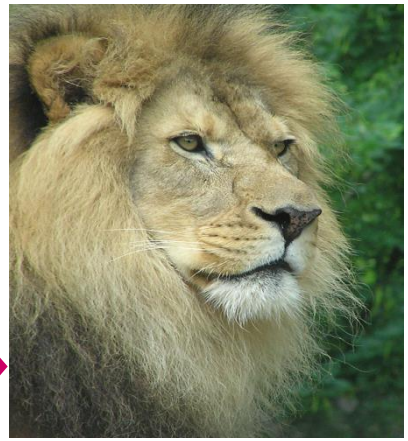


eg. *Giardia*, gut pathogen

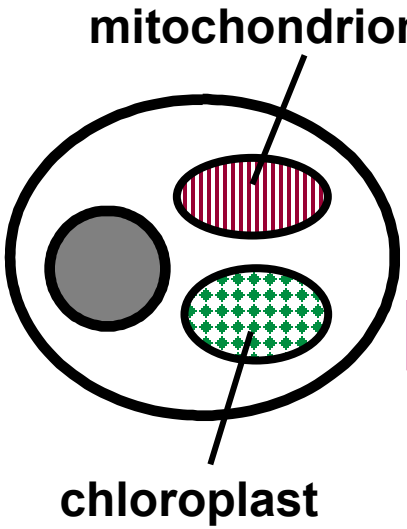
Life diversifies: multicellular forms



FUNGI



ANIMALS



ALGAE

PLANTS

How to make sense of life's diversity?

- **Taxonomy**: classification, nomenclature, identification

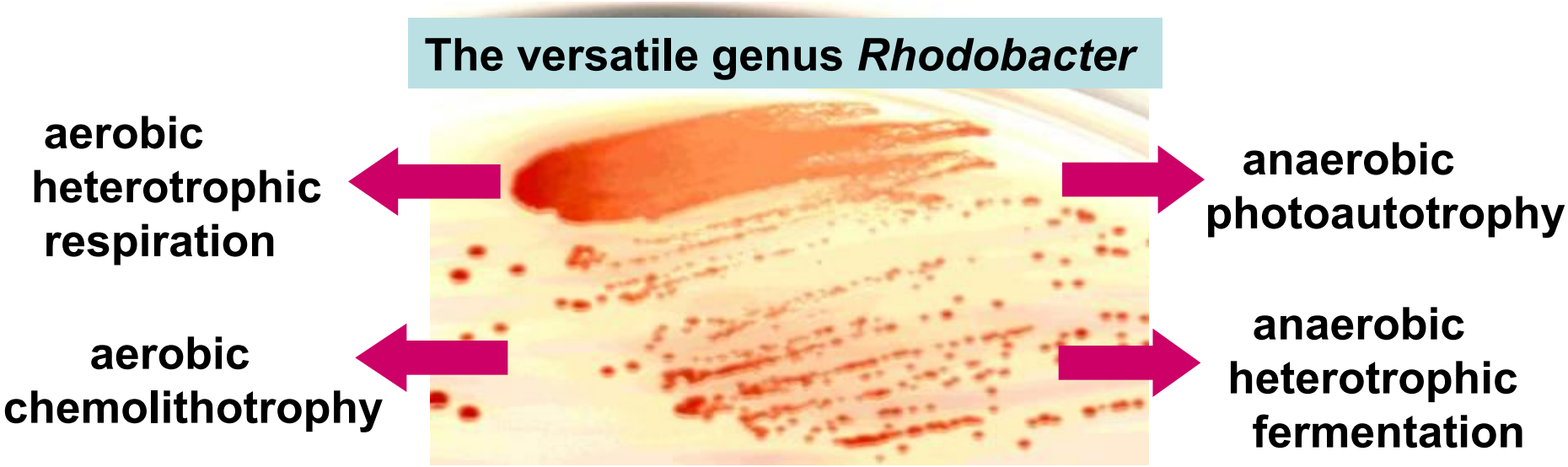
  - classification: arranging units into groups
  - nomenclature: naming units and groups
  - identification: putting unknown units in known groups

- Why is taxonomy important for microbiology?
  - allows predictions and hypotheses to be made
  - allows accurate communication between scientists
  - essential for identification of unknown microbes

- Taxon (pl. taxa): taxonomic unit, a grouping of organisms

Microbial classification presents unique challenges

- **Simple morphology:** few observable features
- **Convergent evolution:** similar features arise independently
- **Horizontal gene transfer:** features not just inherited 'vertically'
- **Facultative metabolism:** features impacted by environment



Phenetic classification

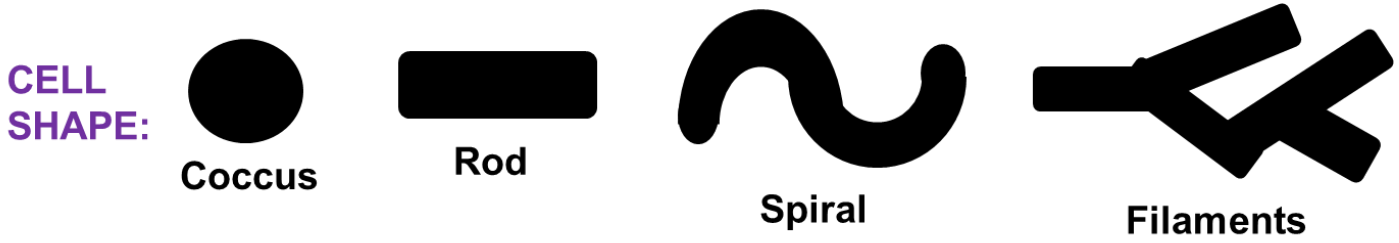
- **Based only on similarity of phenotype (observable features), independent of evolutionary considerations**
- **Which are the most informative features to use?**
  - **Stable over time**
  - **Stable within a taxon**
  - **Vary between taxa**
- **Phenotypic features only give natural classifications if they are homologous: ie. have same evolutionary origins**

≠

Duck & platypus bills are NOT homologous …an example of CONVERGENT EVOLUTION

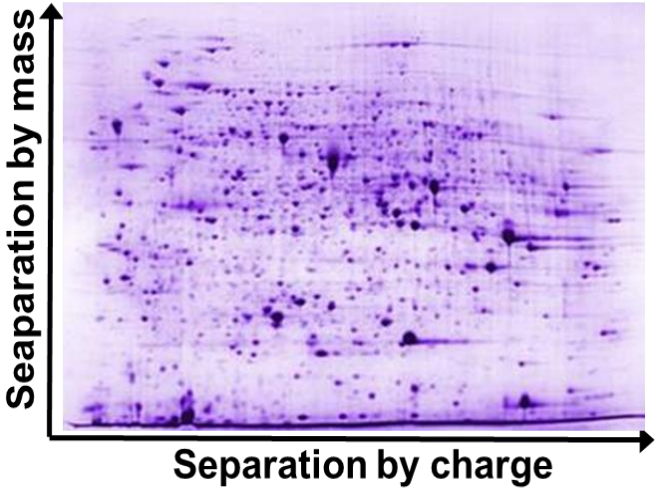
Useful phenotypes for microbial classification

- **Cell morphology**: shape, size, arrangement, flagella, spores, inclusion bodies, staining reactions



- **Biochemical tests:** carbon sources, enzyme activities, aerobic or anaerobic, temp / pH preferences

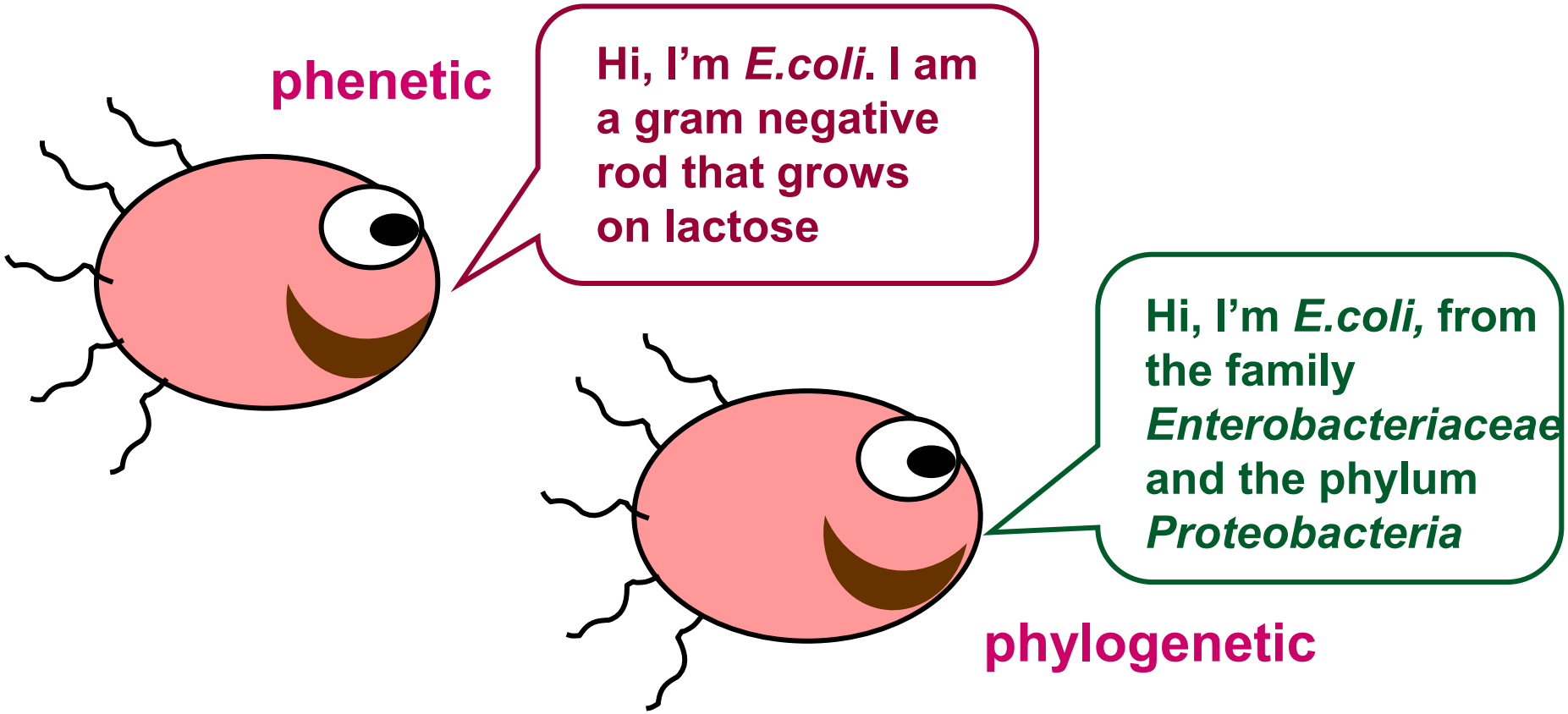
- **Chemical composition:** fatty acid profile, DNA G+C%, protein expression patterns



Phenetic vs. phylogenetic classification

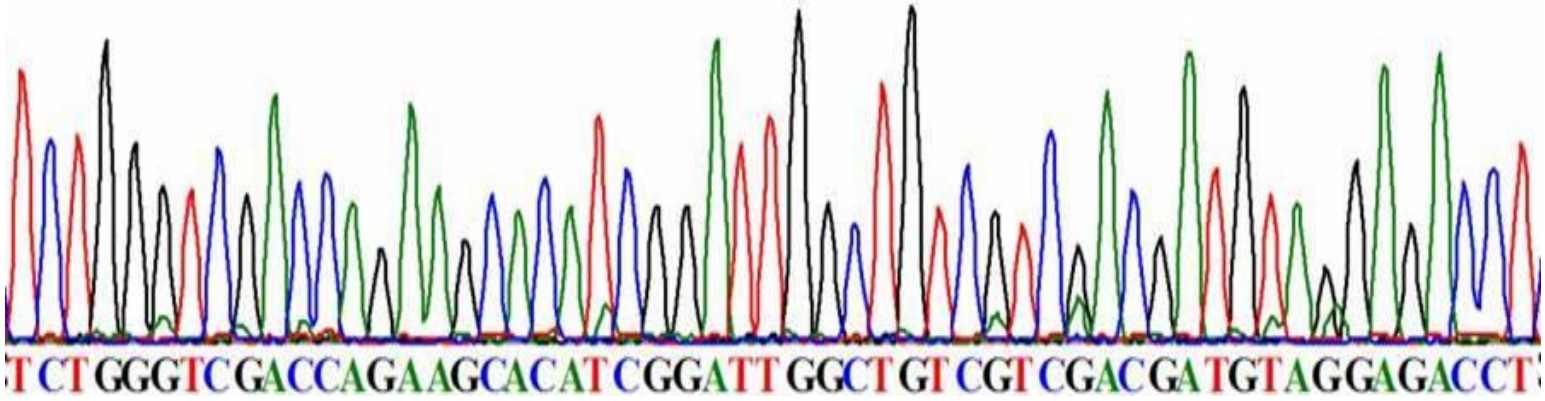
- **Phenetic methods are useful for identification of unknowns (this is the majority of microbiology !)**

- **Phylogenetic methods are useful for figuring out evolutionary relationships between microbes**



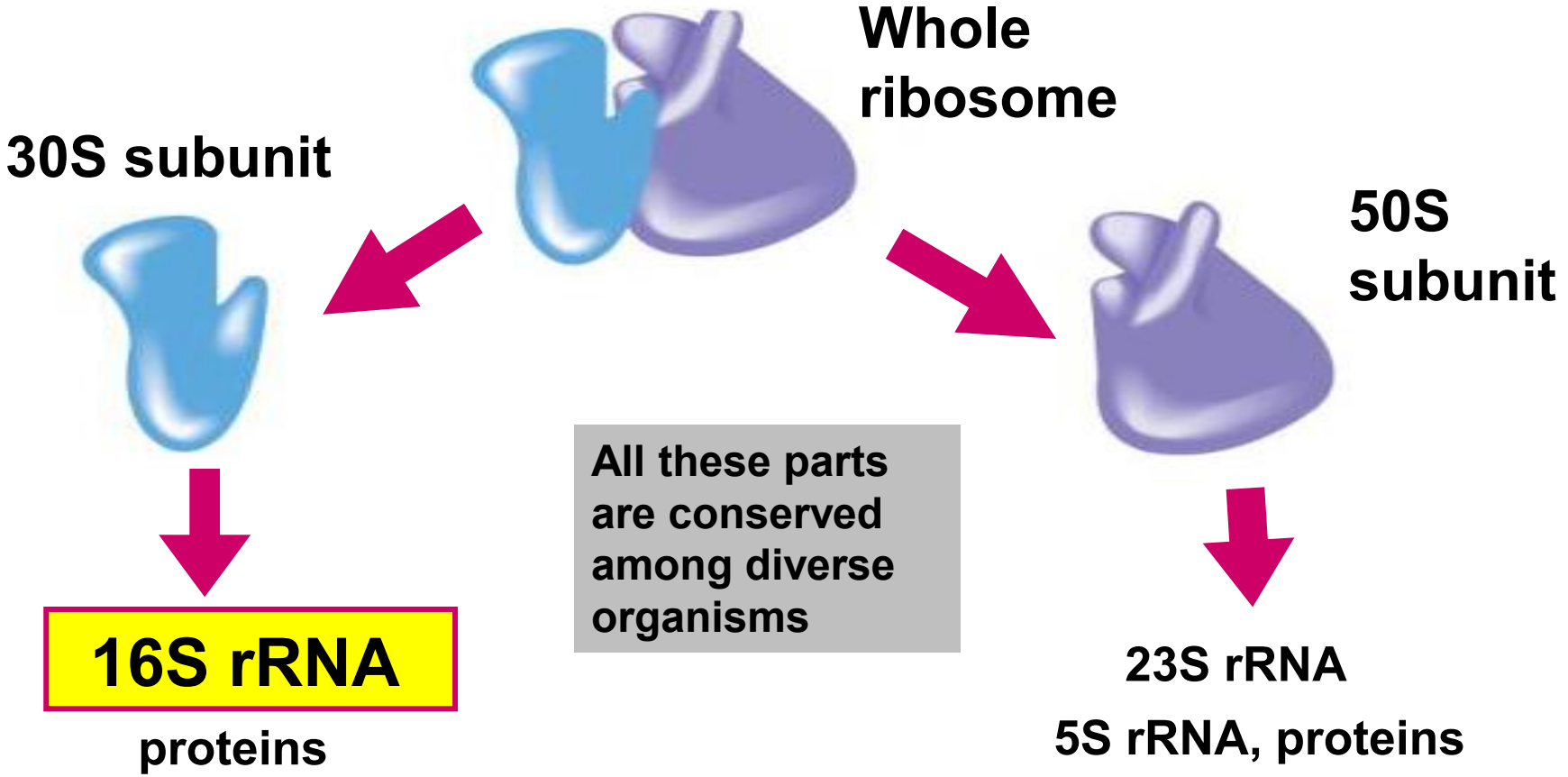
Phylogenetic classification: evolutionary relationships

- Phylogenetics is based on DNA, RNA, protein sequences
- Impact of DNA sequencing on microbiology is huge:
  - wealth of information
  - can compare universally-present genes
  - useful for both identification and classification



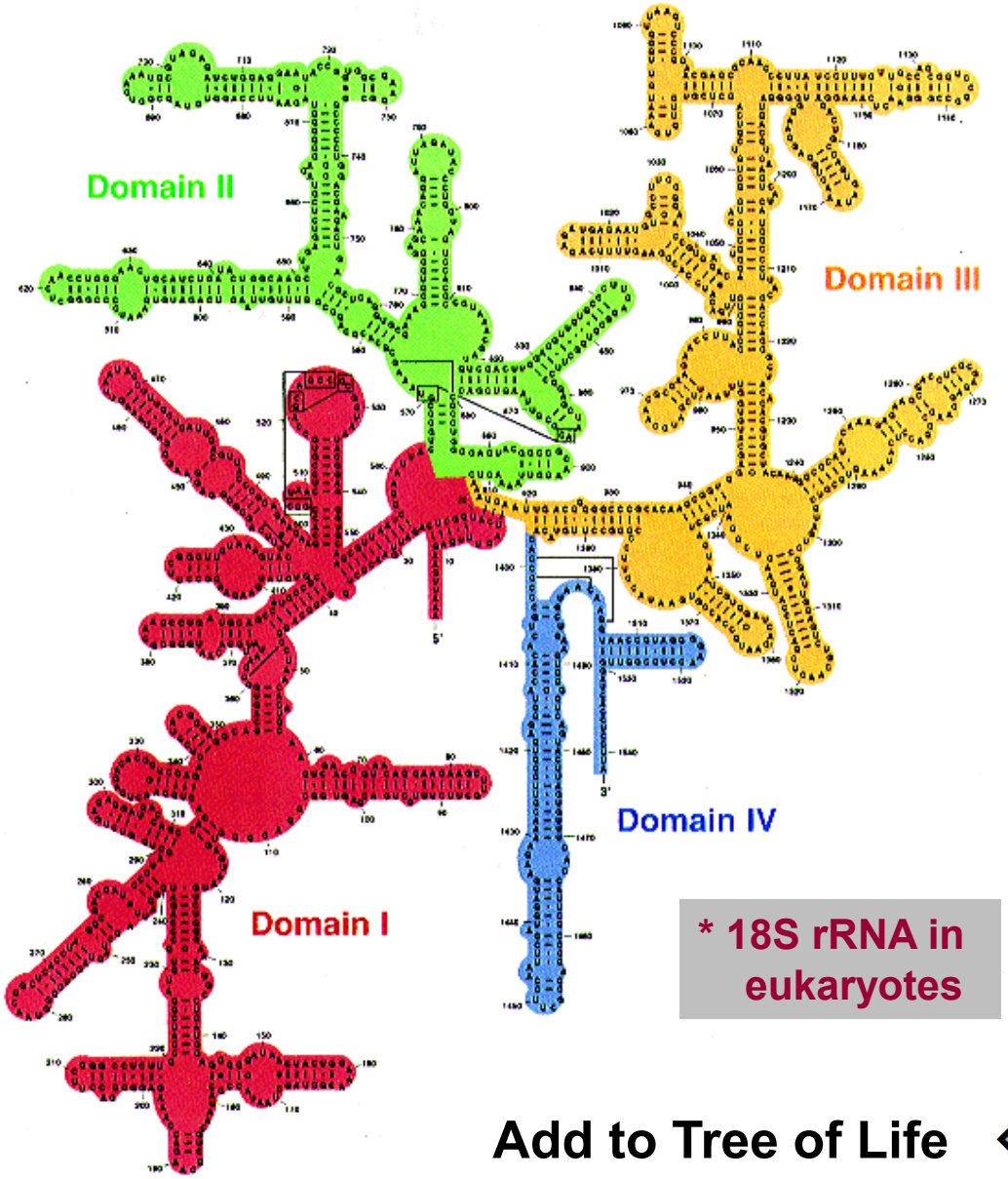
- Which genes should we use for studying phylogeny?

Ribosome subunits: perfect for phylogenetic analysis



- Ribosomal components are coded by genes with both variable and conserved regions → perfect for PCR !

16S* rRNA: the most important molecule in microbiology?



* 18S rRNA in eukaryotes

Unknown microbe

Extract DNA

Amplify 16S* rRNA gene by PCR

Sequence PCR product

Compare to database

Identify unknown

Add to Tree of Life

Ribosomal RNA and the Tree of Life

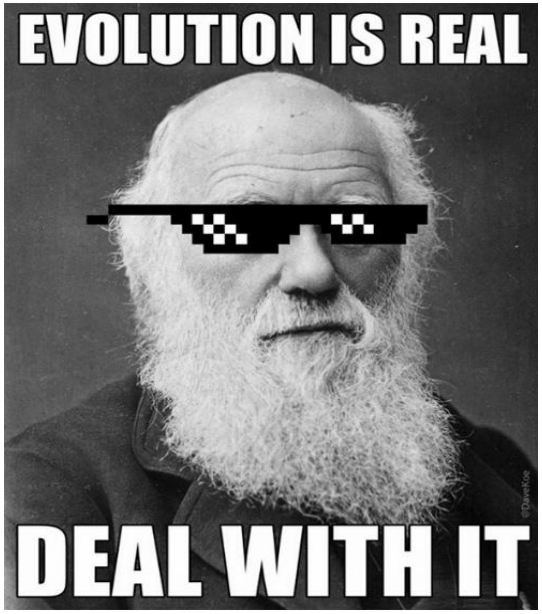
- **Sequencing of rRNA has provided:**

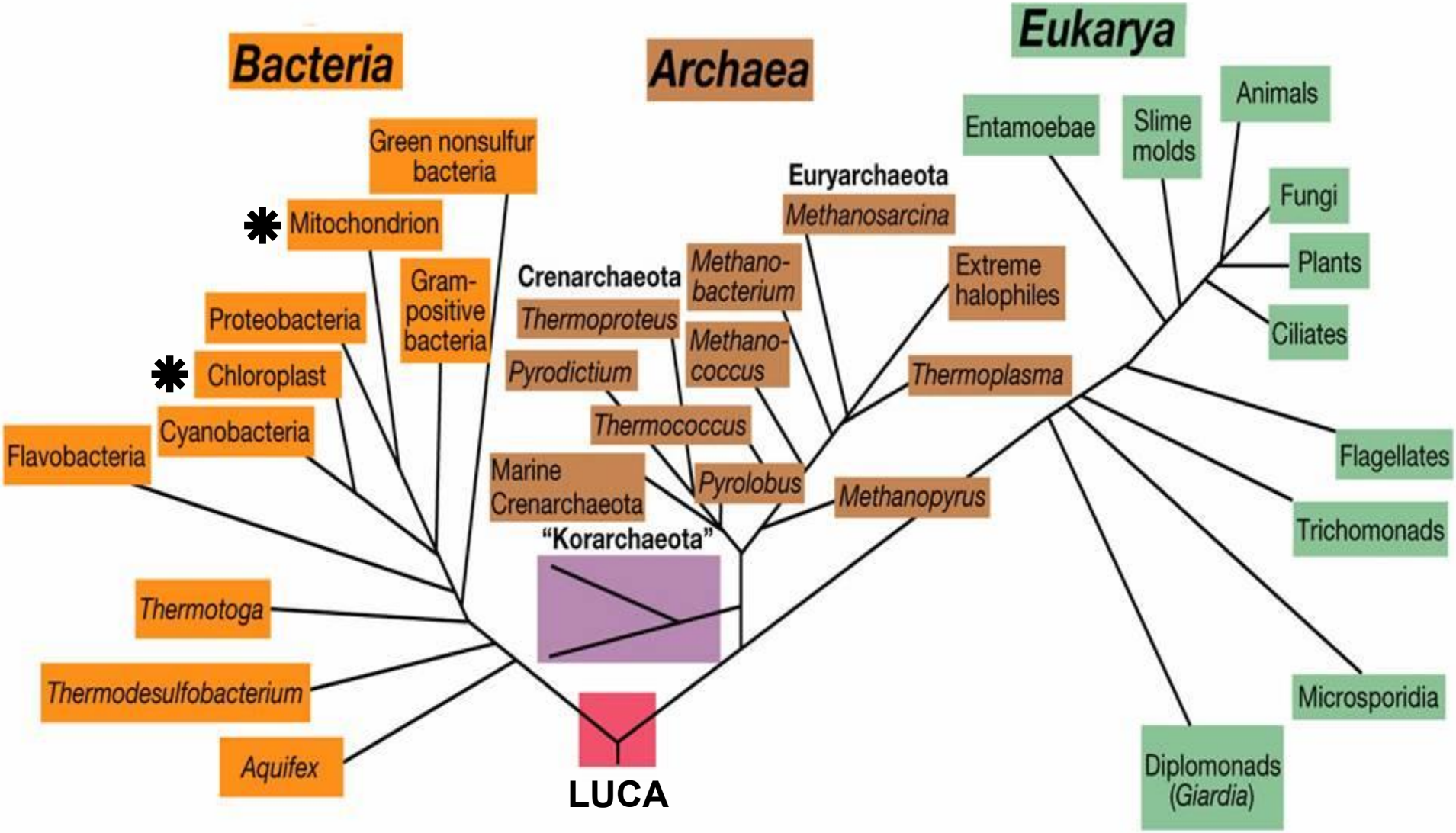
  → **rapid and reliable identification of unknowns**

  → **detection / quantification of 'unculturable' microbes**

  → **a universal classification system for all life**

rRNA sequences support a 'natural classification' of all organisms – this is known as the Tree of Life





- **Endosymbiotic origin of organelles (✱)**
- **Fungi are coherent, but algae and protozoa are not**
- **Vast majority of life's diversity is microbial**