On the nature of the last common universal ancestor

David Moreira

david.moreira@u-psud.fr

CNRS - Université Paris-Sud

- **A historical approach**
- **A robot portrait of the last common ancestor**

"Phylogeny studies the <u>relationships</u> among organisms to understand their evolution"

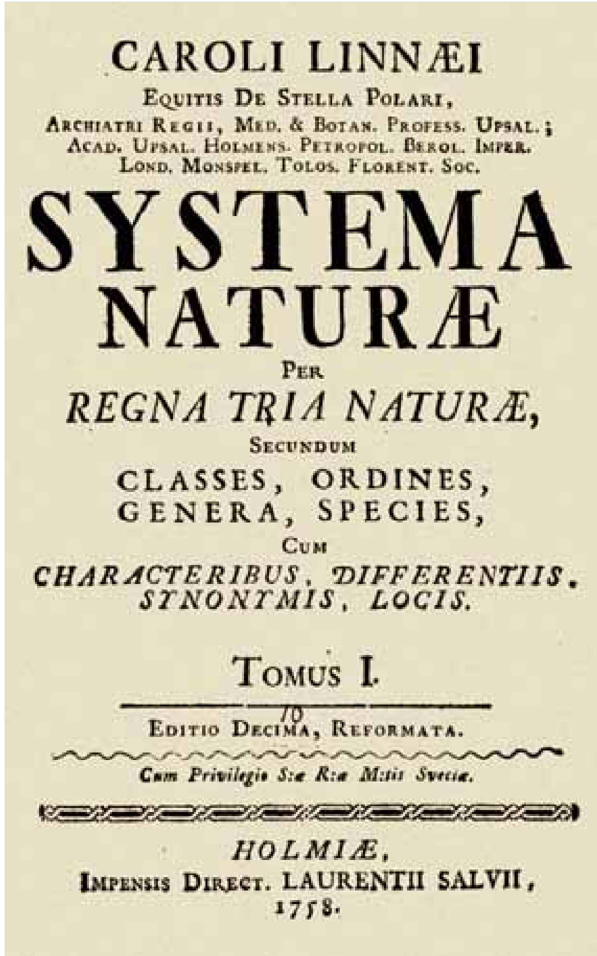
Two historical periods:

“before the evolutionary theory”

“after the evolutionary theory”

The ancestor of phylogeny: classification

Linné, 1707-1778



CAROLI LINNÆI

EQUITIS DE STELLA POLARI,

ARCHIATRI REGII, MED. & BOTAN. PROFESS. UPSAL.;
ACAD. UPSAL. HOLMENS. PETROPOL. BEROL. IMPER.
LOND. MONSPEL. TOLOS. FLORENT. SOC.

SYSTEMA NATURÆ

PER

REGNA TRIA NATURÆ,

SECUNDUM

CLASSES, ORDINES,
GENERA, SPECIES,

CUM

CHARACTERIBUS, DIFFERENTIIS.
SYNONYMIS, LOCIS.

TOMUS I.

10

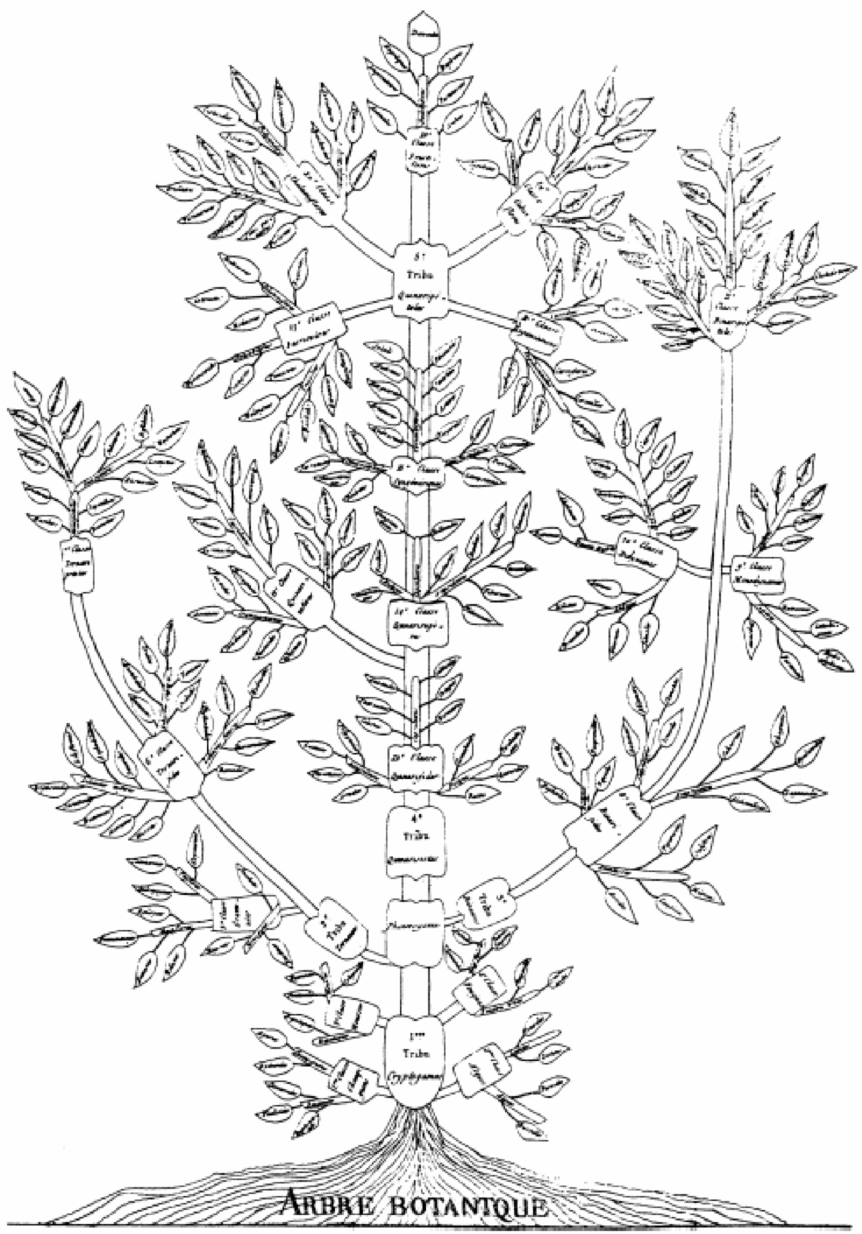
EDITIO DECIMA, REFORMATA.

Cum Privilegio S:æ R:æ M:tis Sveciæ.

HOLMIÆ,

IMPENSIS DIRECT. LAURENTII SALVII,
1758.

Hierarchical system with three kingdoms: animals, plants, and minerals.



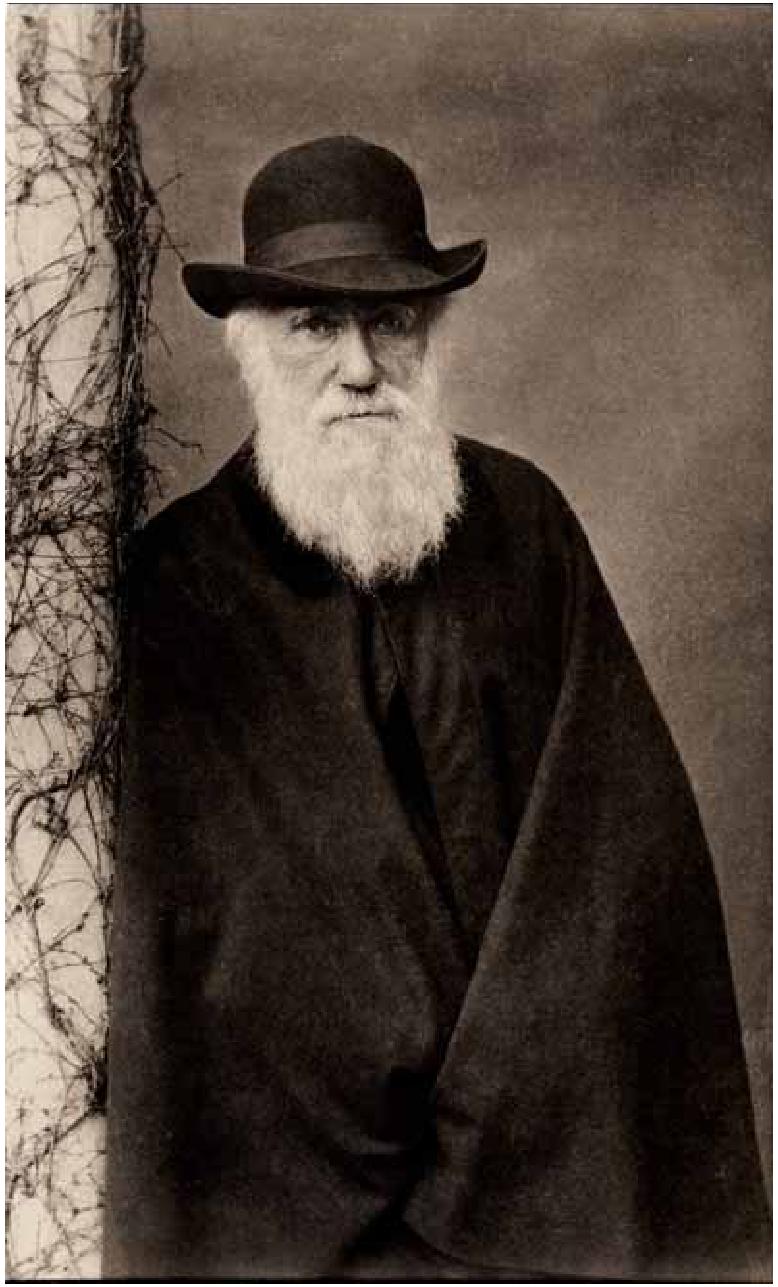
Augier, 1801

The beginings of evolutionary theory

- **Species can transform ("evolve")**
- **The different species are related**
- **They share a basic structural unit: <u>the cell</u>**

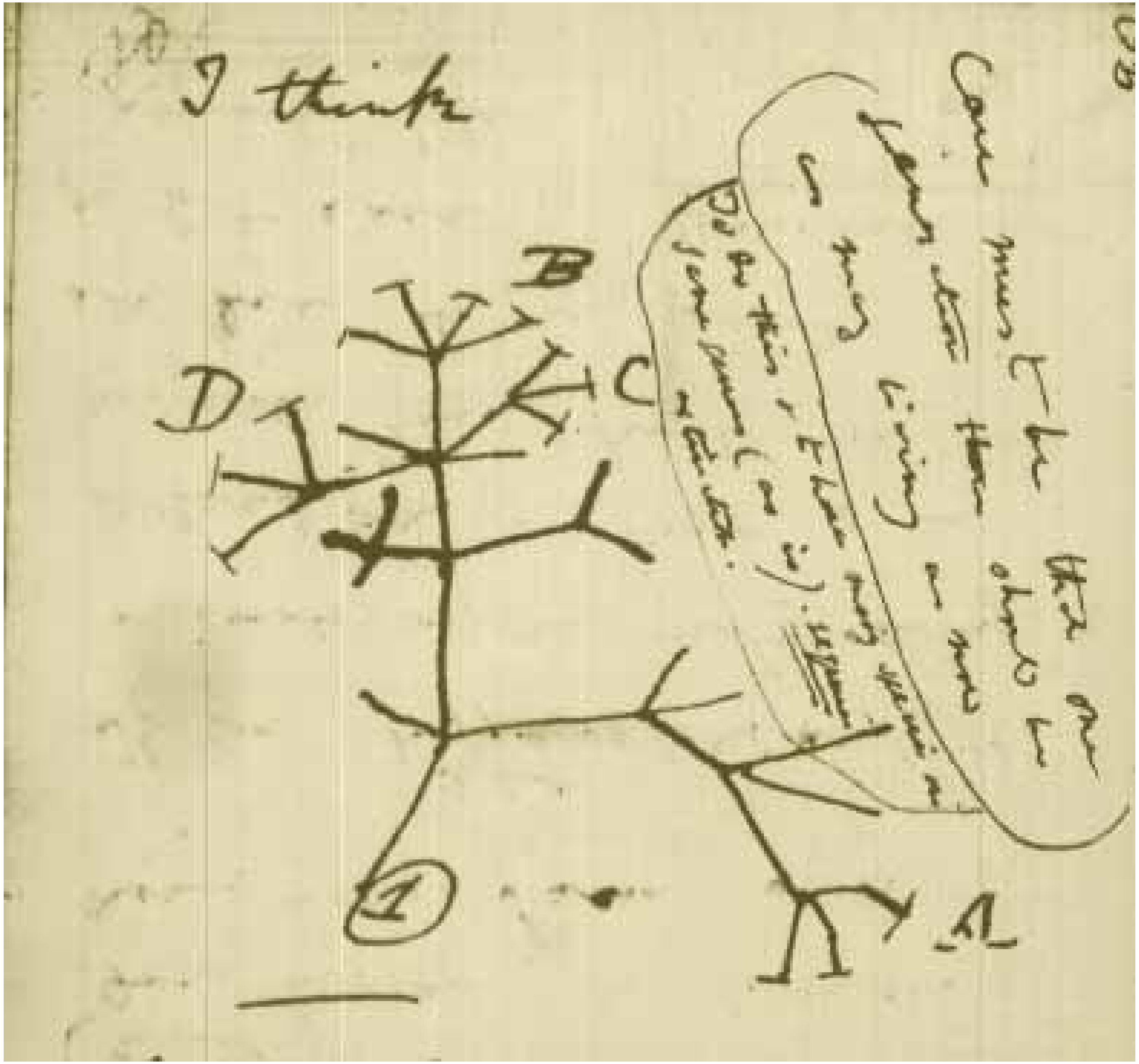
Theodor Schwann (1810-1882) :

'<u>Cell theory</u>': *all living beings are composed of cells*

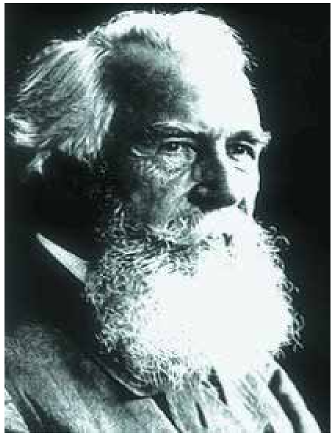


Charles Darwin (1859) :

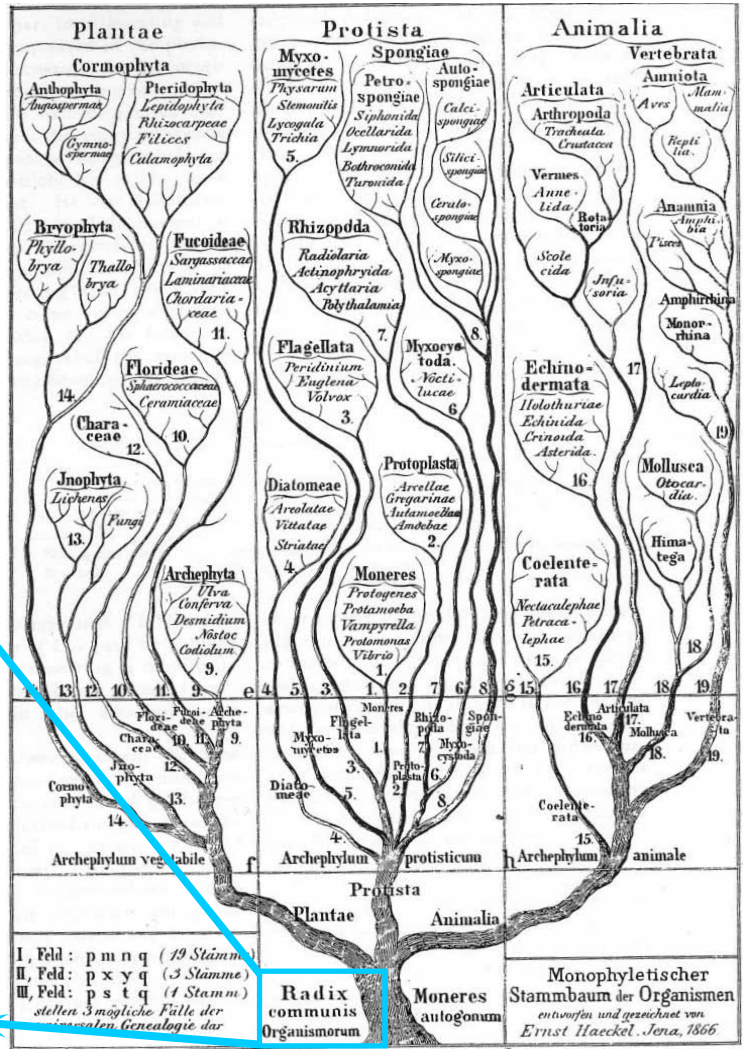
‘*Probably all the organic beings which have ever lived on this earth have descended from some <u>primordial form</u>, into which life was first breathed*’


I think
1
A
B
C
D
Case must be that one generation then should be as many living as now
To do this & to have many species in same genus (as is) requires extinction.

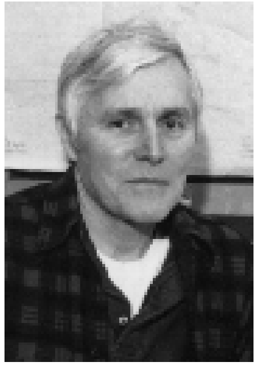
Ernst Haeckel (1834-1919) :



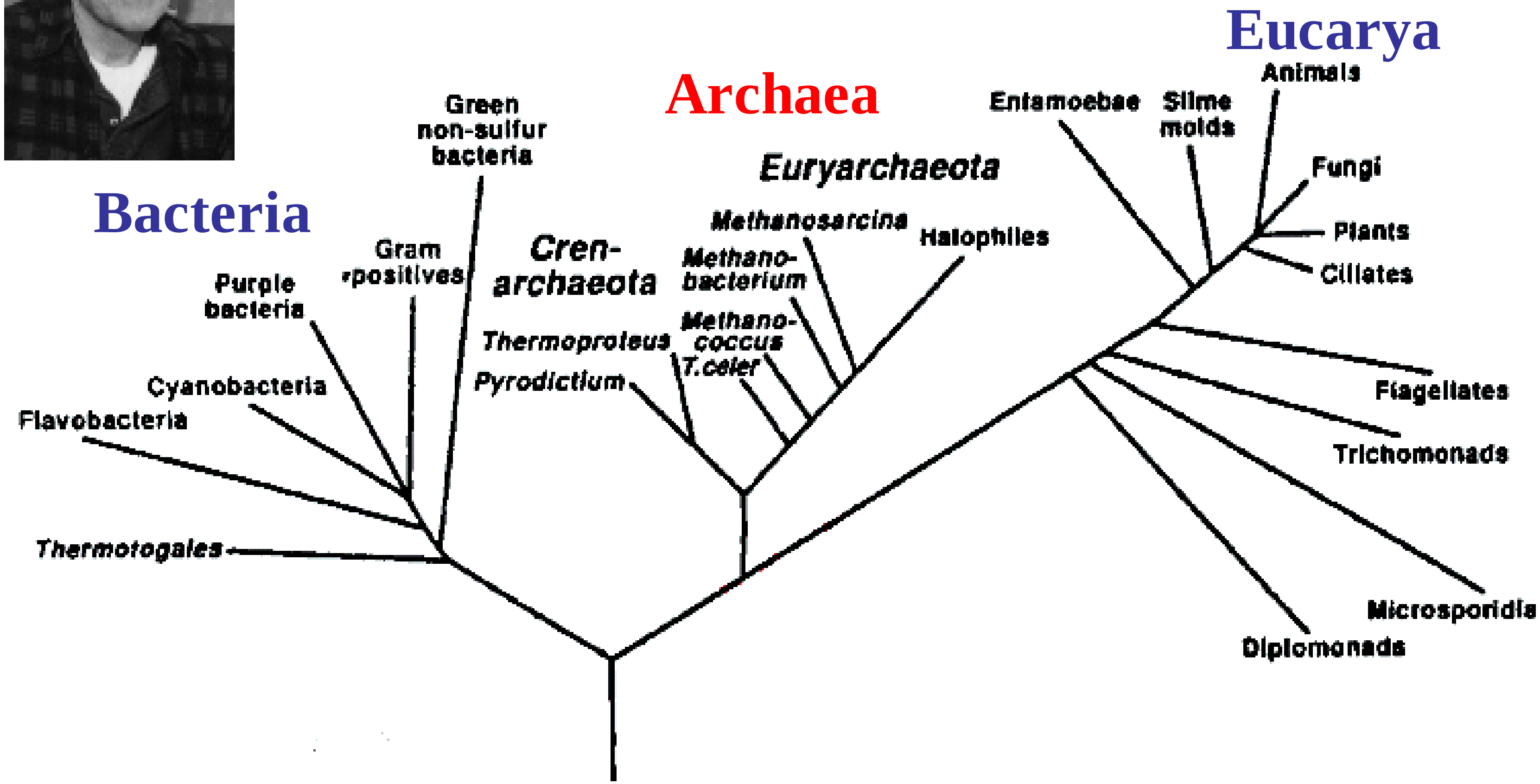
First ‘universal phylogeny’



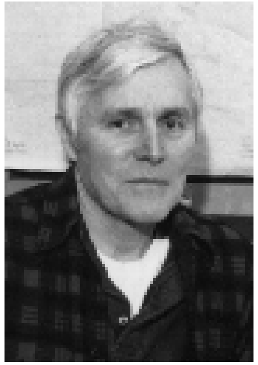
La phylogénie moléculaire



Carl Woese (70's) : la révolution 'woesienne'



La phylogénie moléculaire



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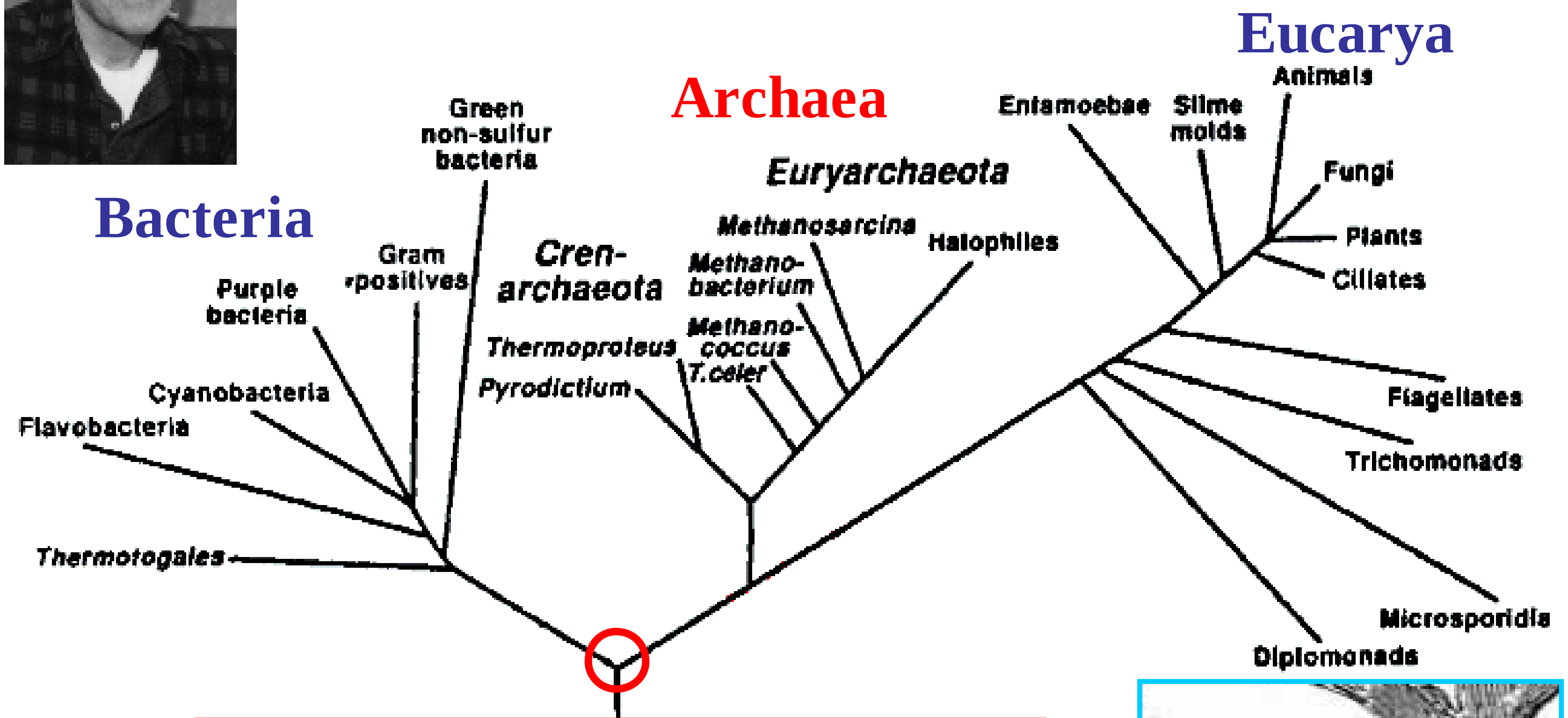
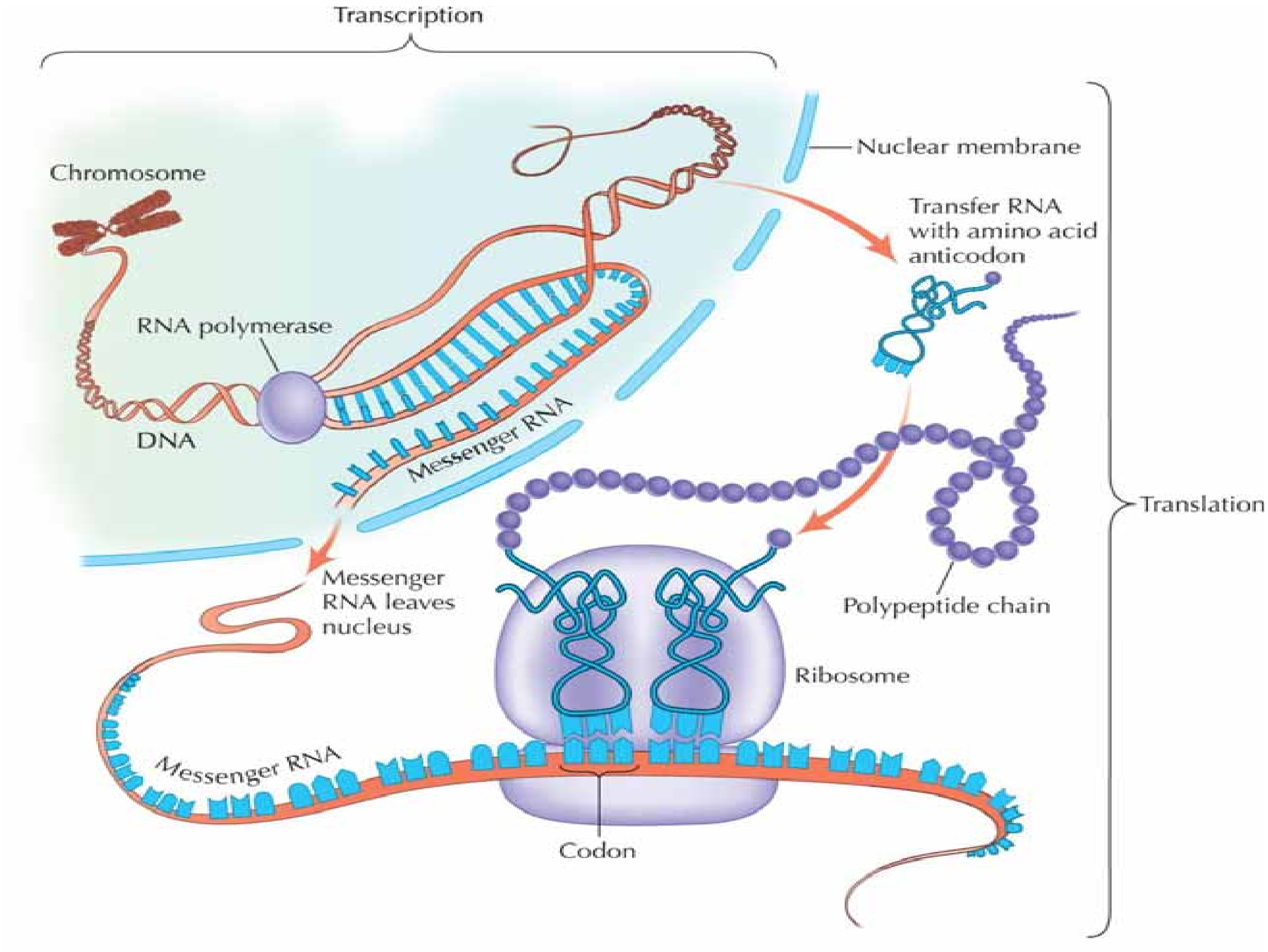


LAST COMMON ANCESTOR

Molecular biology (1950…)

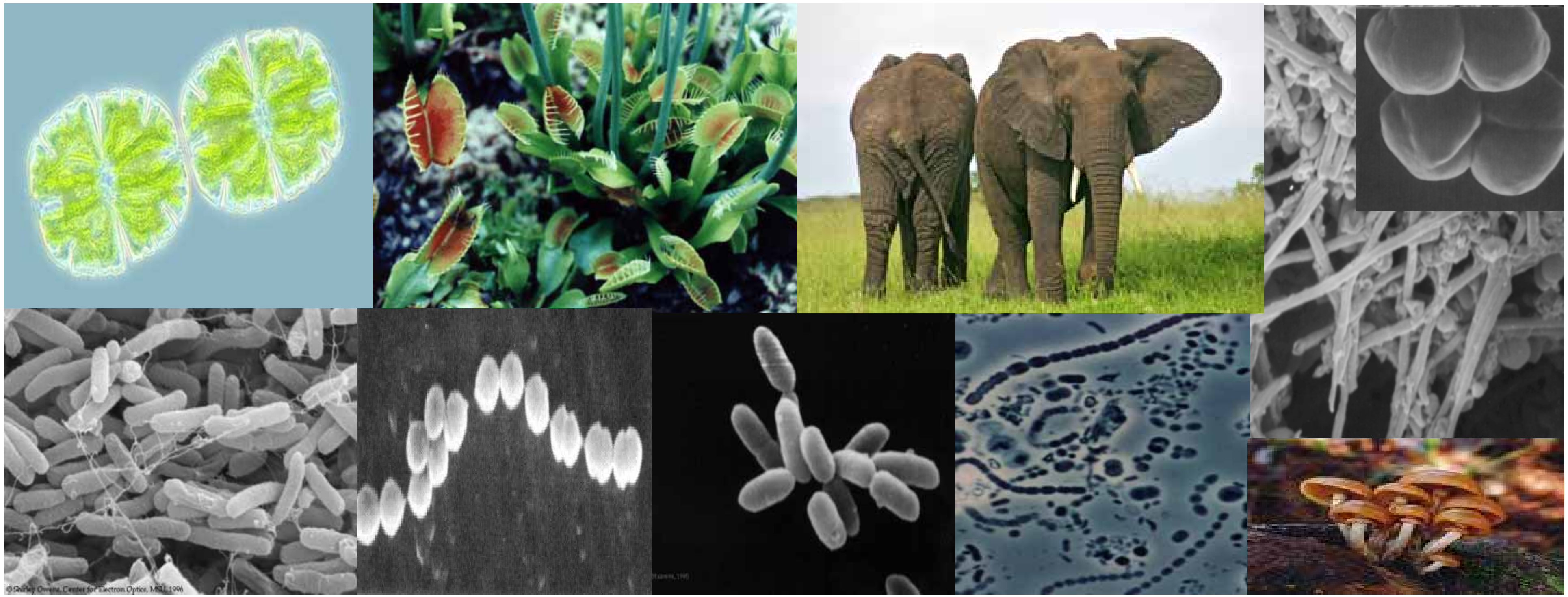


Molecular biology

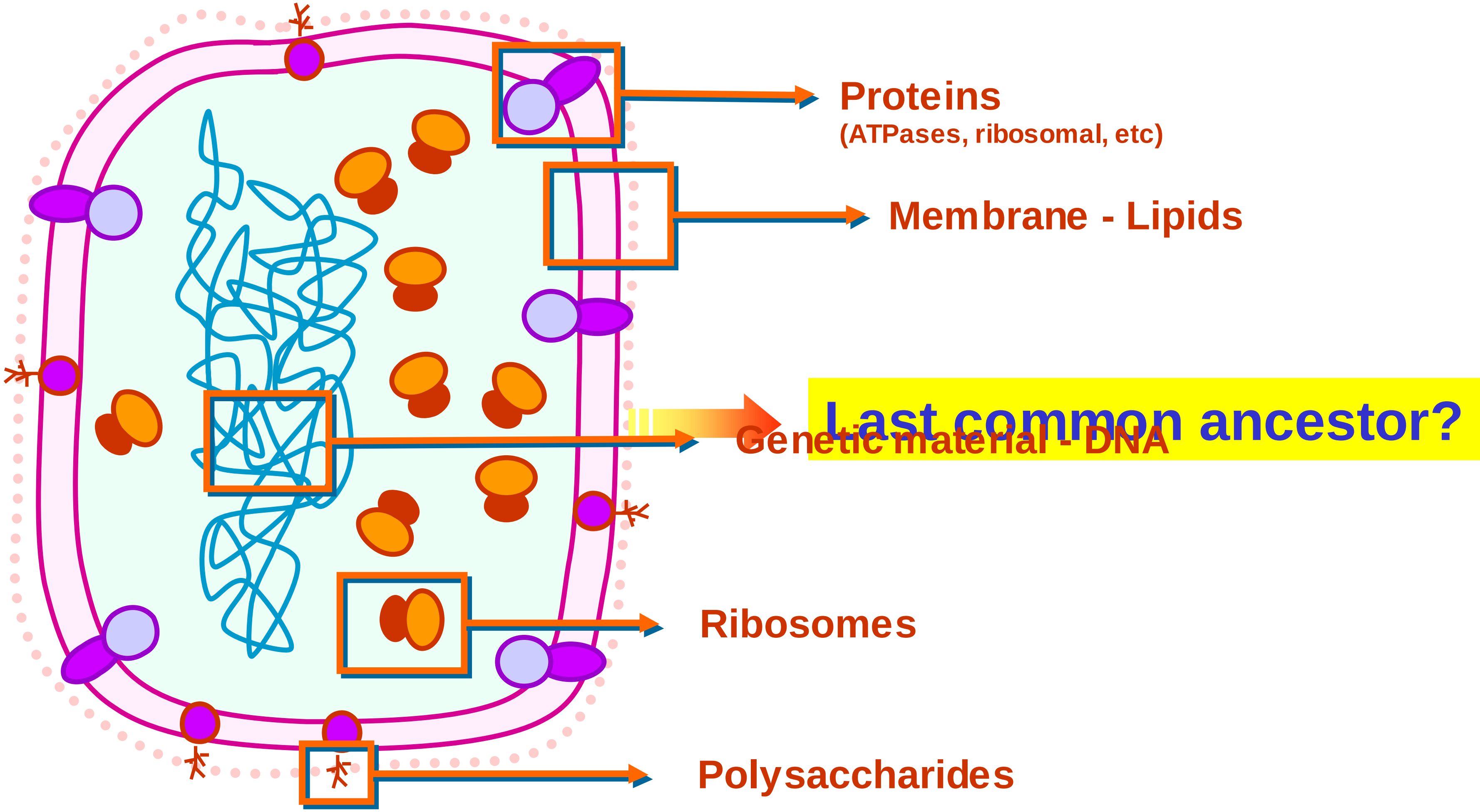
All living beings share similar biochemical traits

'What is true for Escherichia coli is true for elephants'

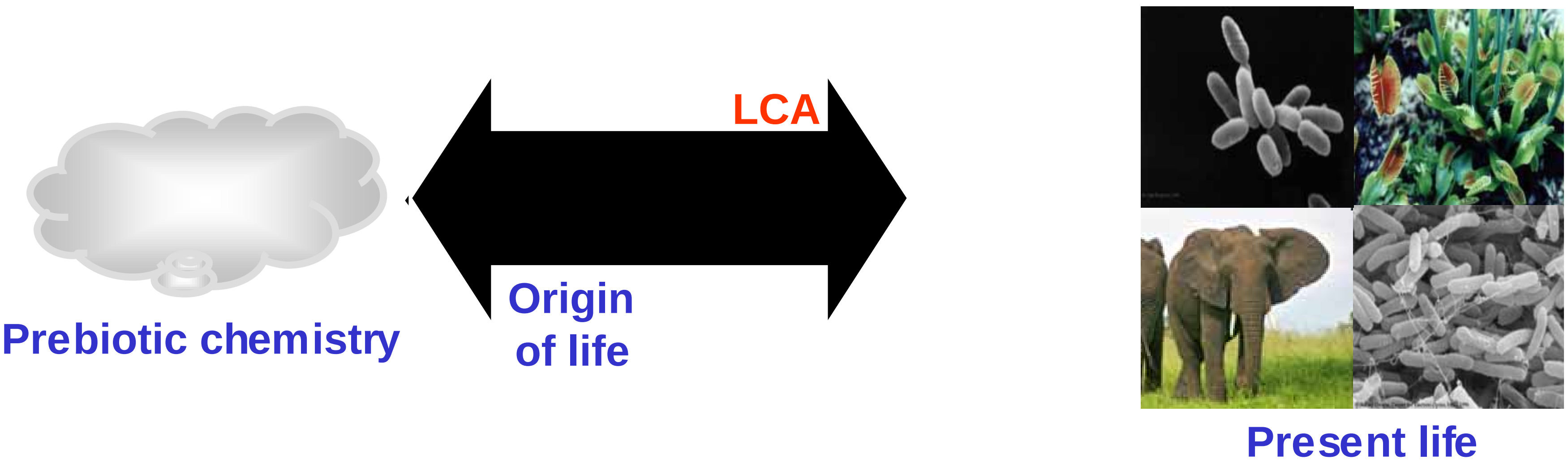
(Jacques Monod)



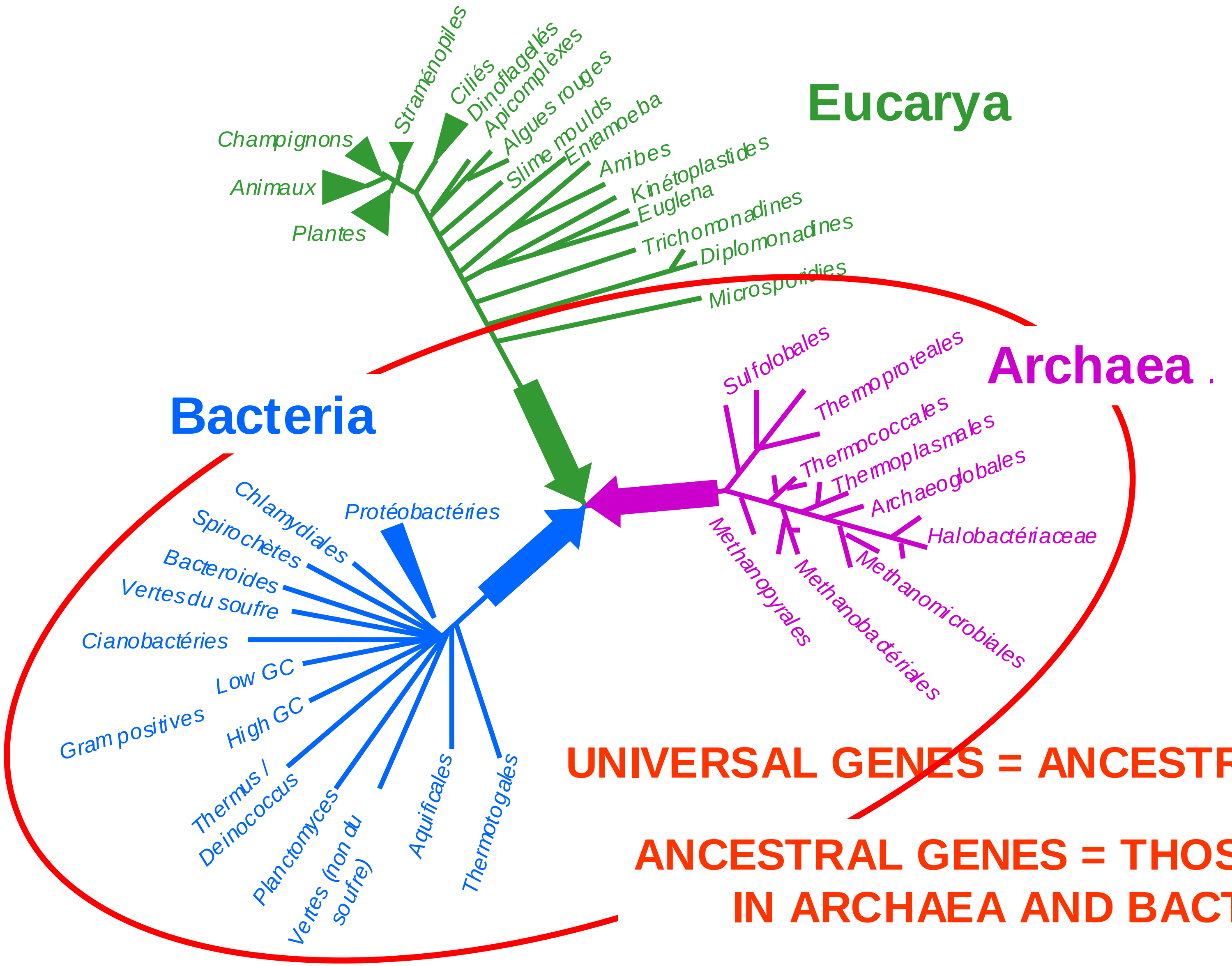
Molecular biology



The last common ancestor and the origin of life



Comparative genomics



UNIVERSAL GENES = ANCESTRAL GENES

ANCESTRAL GENES = THOSE FOUND IN ARCHAEA AND BACTERIA

Comparative genomics: ancestral genes

Archaea and bacteria share many caracters

but...

only ~60 genes are shared by all species

- **rRNAs et ribosomal proteins** : protein synthesis with a very evolved molecular machinery
- **RNA polymerase**: RNA synthesis similar to that of contemporary cells
- **Membrane ATPase**: ATP synthesis using a H^+ gradient

  ⇨ presence of a cell membrane?

Comparative genomics: ancestral genes

~60 genes are not enough to assure a cell metabolism, even the simplest one

Certain genes are lost in certain species (parasites…)

<u>Less strict criteria</u> are necessary

- **Comparison of groups of species instead of individual species**
- **Looking for gene families instead of specific individual genes**

500-600 ancestral genes

Comparative genomics: ancestral genes

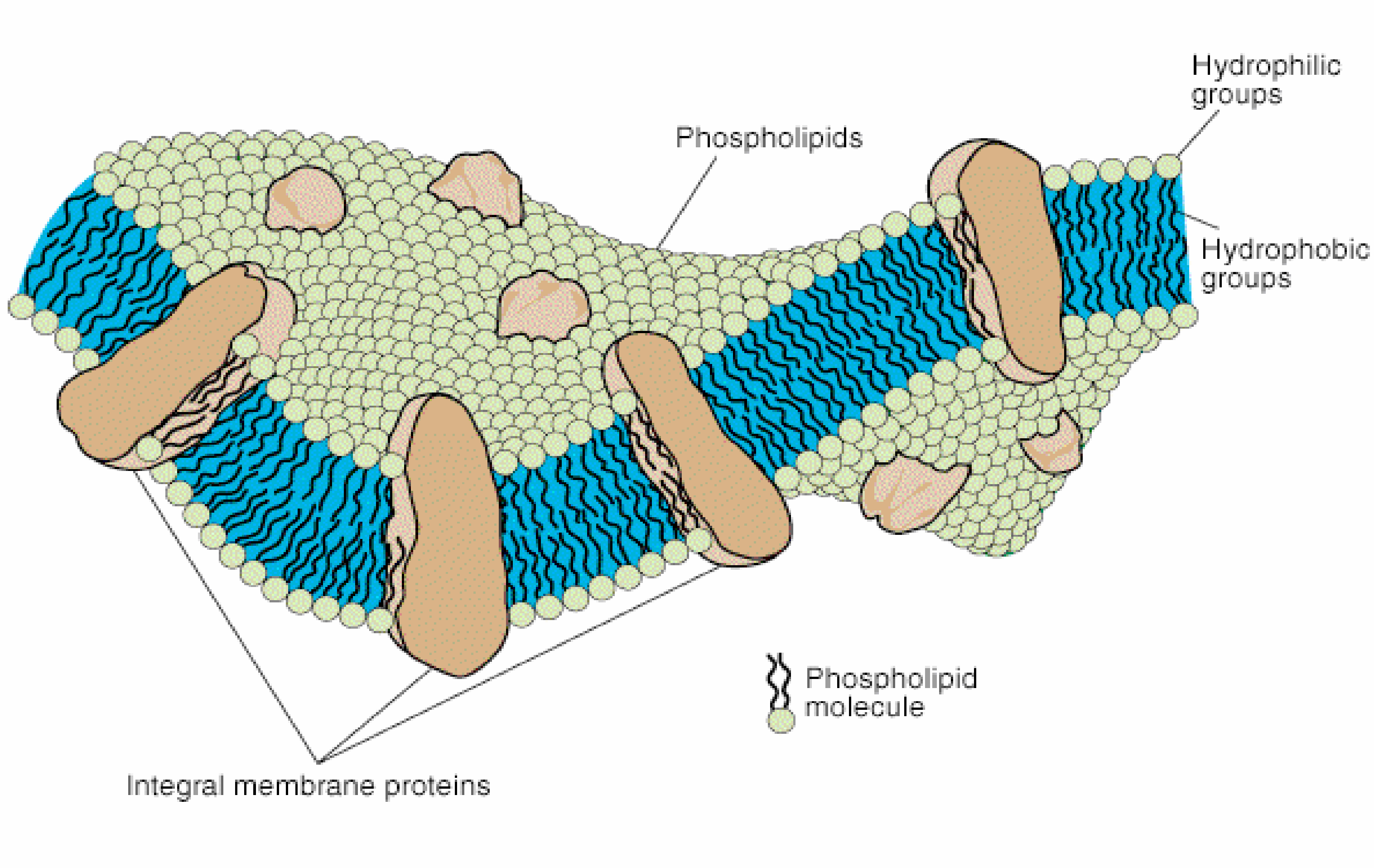
- **>500 genes : genome size comparable to that of many small prokaryotes**

- **Capacity to code for a <u>complex metabolism</u>**

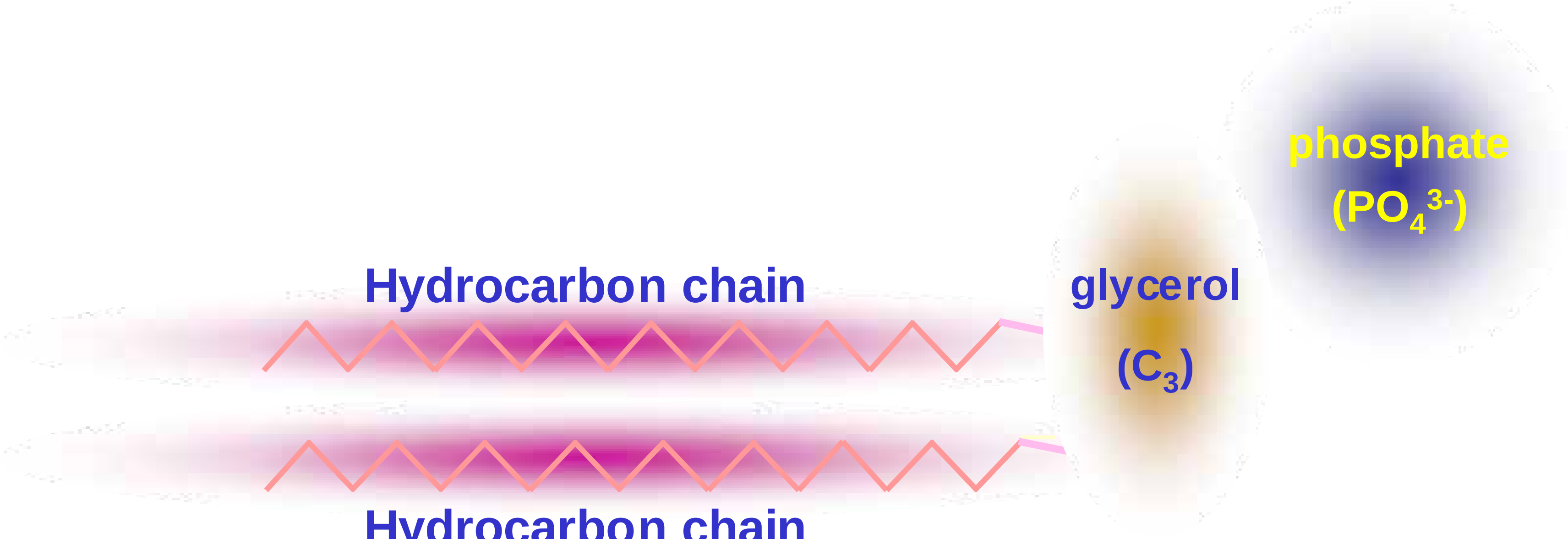
but many caracteristics of this ancestral metabolism remain controversial…

Genomes may help to find the good answer

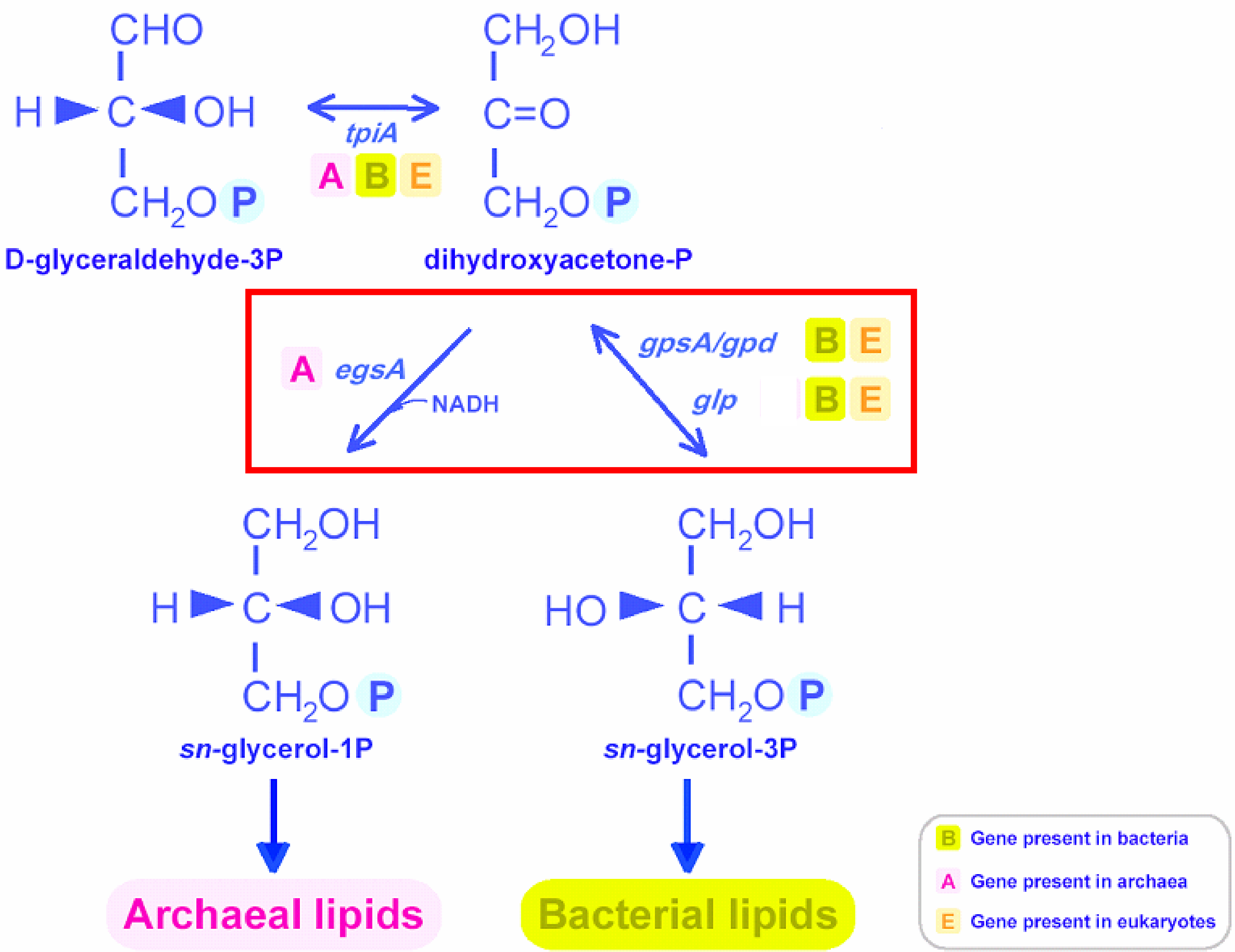
The lipid problem:
Had the last common ancestor a lipid membrane?

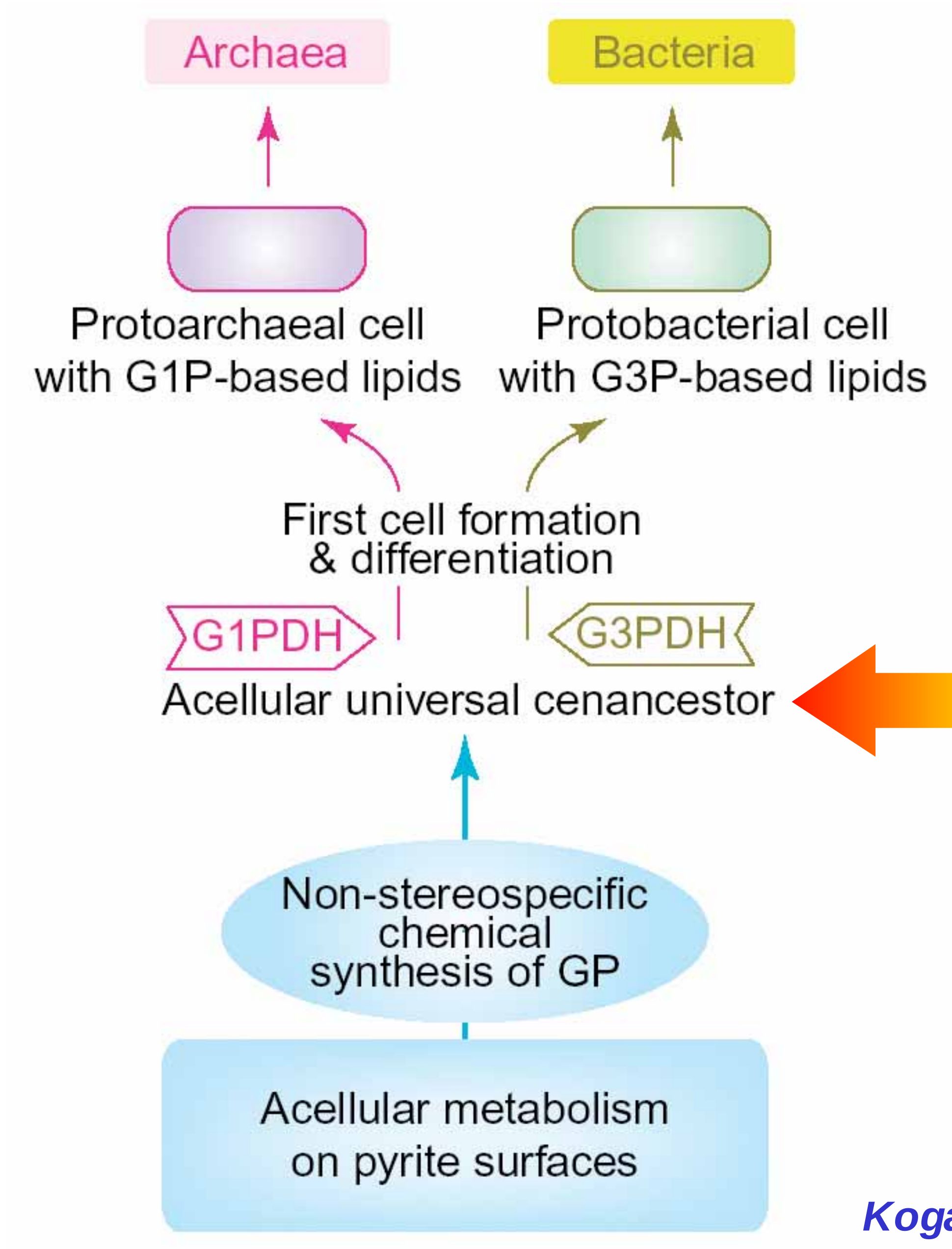


Phospholipid structure

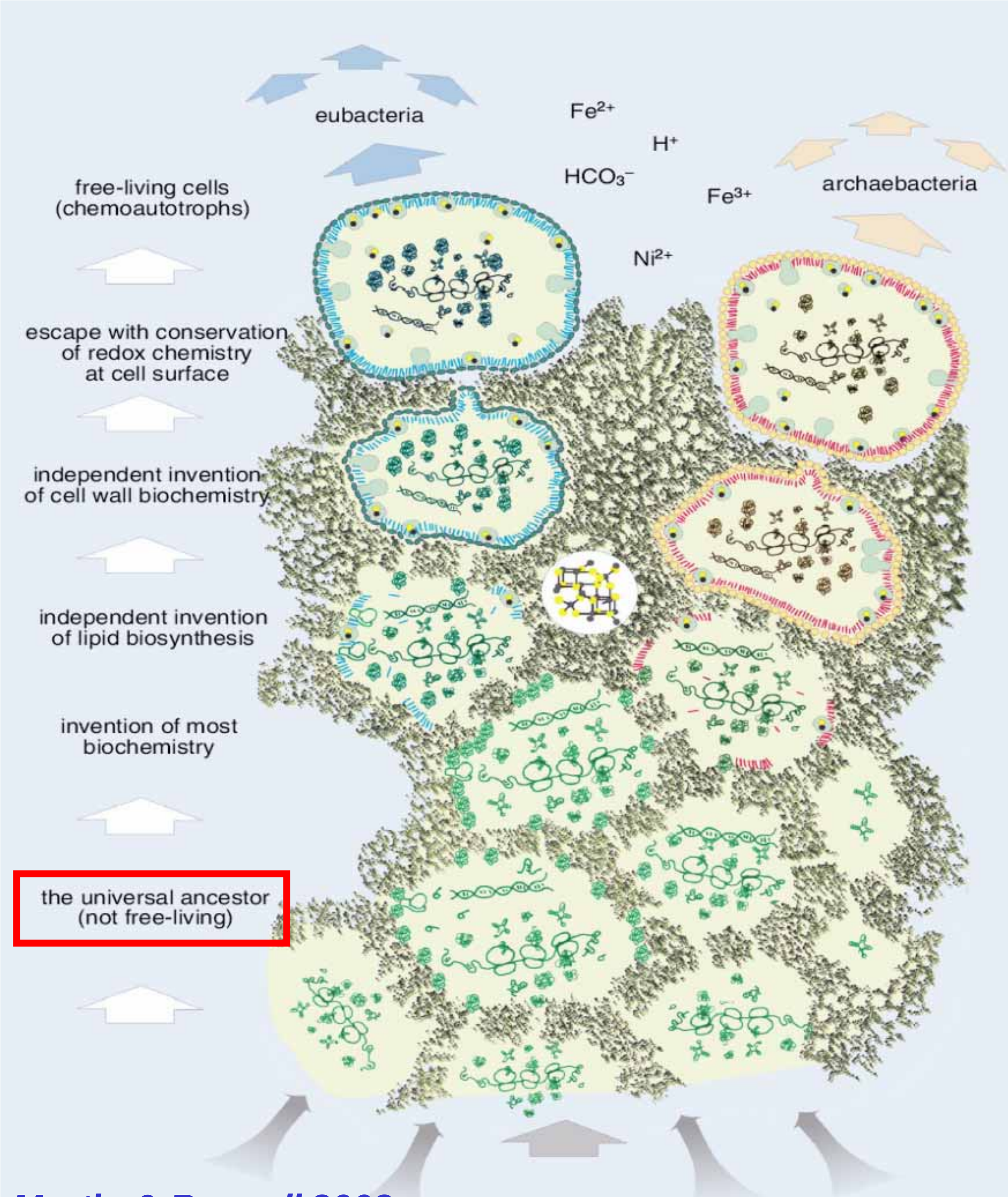


(C_{14}-C_{20})


CHO
H C OH
CH_2O P
D-glyceraldehyde-3P
tpiA
A B E
CH_2OH
C=O
CH_2O P
dihydroxyacetone-P
A egsA
NADH
gpsA/gpd B E
glp B E
CH_2OH
H C OH
CH_2O P
sn-glycerol-1P
CH_2OH
HO C H
CH_2O P
sn-glycerol-3P
Archaeal lipids
Bacterial lipids
B Gene present in bacteria
A Gene present in archaea
E Gene present in eukaryotes



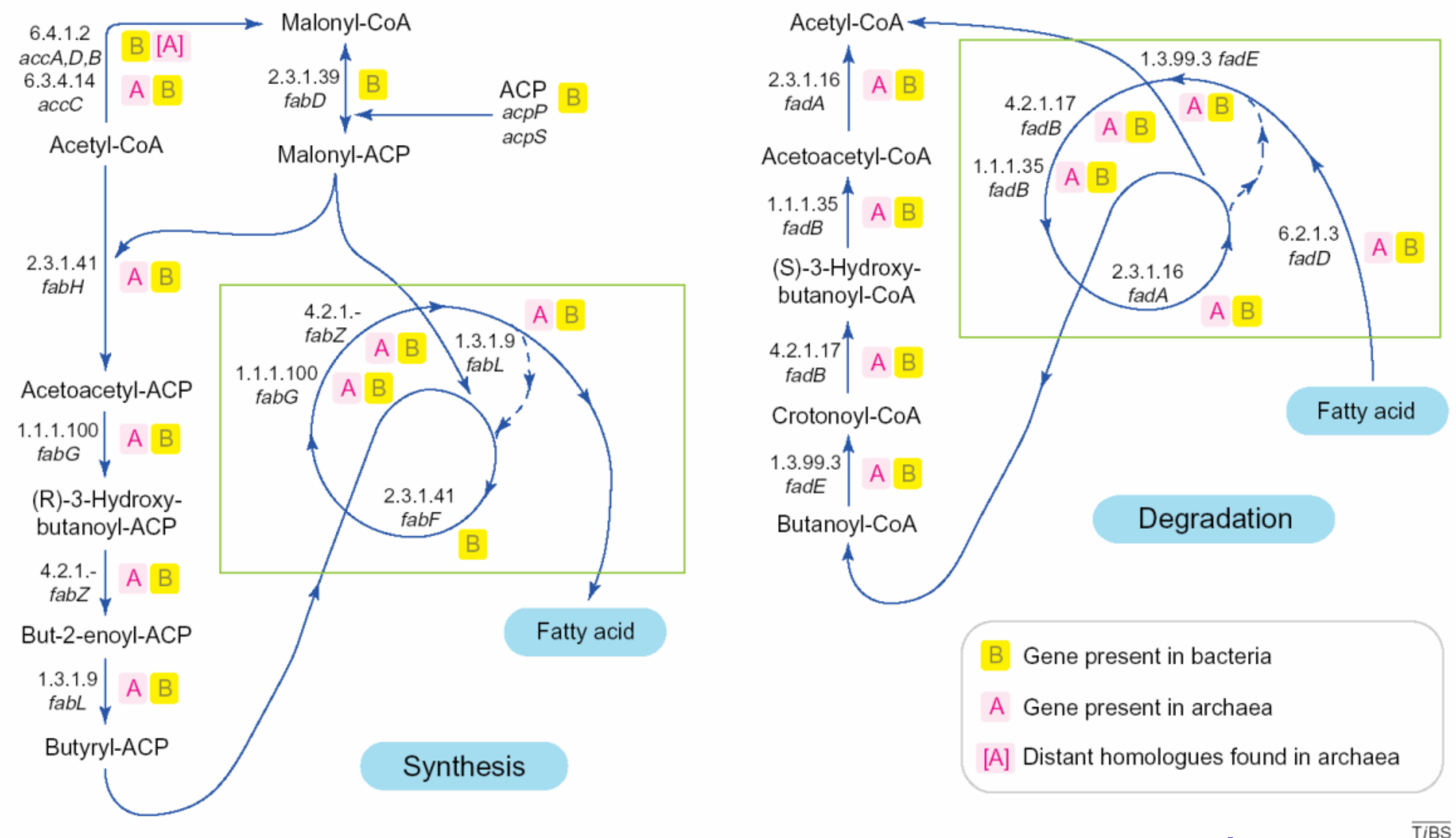
Koga et al. 1998



Martin & Russell 2003

Had the last common ancestor a lipid membrane?

- G1PDH et G3PDH belong to two ancestral enzymatic superfamilies
- Most of the enzymes involved in synthesis and degradation of fatty acids and isopreénoids are also ancestral

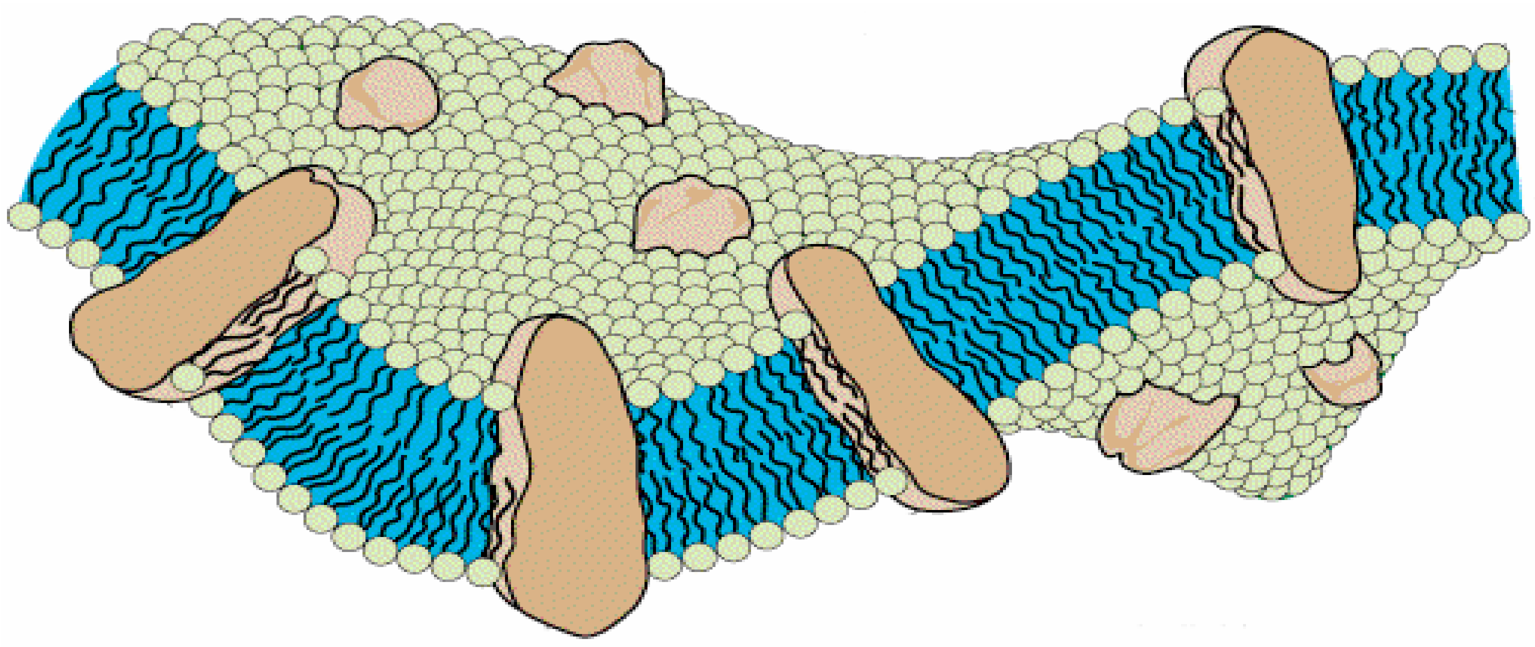


Pereto et al. 2003
Lombard et al. 2013

Had the last common ancestor a lipid membrane?

It had the enzymes to synthesize <u>glycerol</u>, <u>fatty acids</u>, and <u>isoprenoids</u> :

It had a lipid membrane



The ancestral genome : DNA or RNA?

- **Many proteins involved in RNA metabolism are universal**

- **Few proteins involved in DNA replication and repair are conserved between bacteria and archaea**

The last common ancestor synthesized RNA but not DNA?

Had it a RNA genome?

Mushegian & Koonin 1996

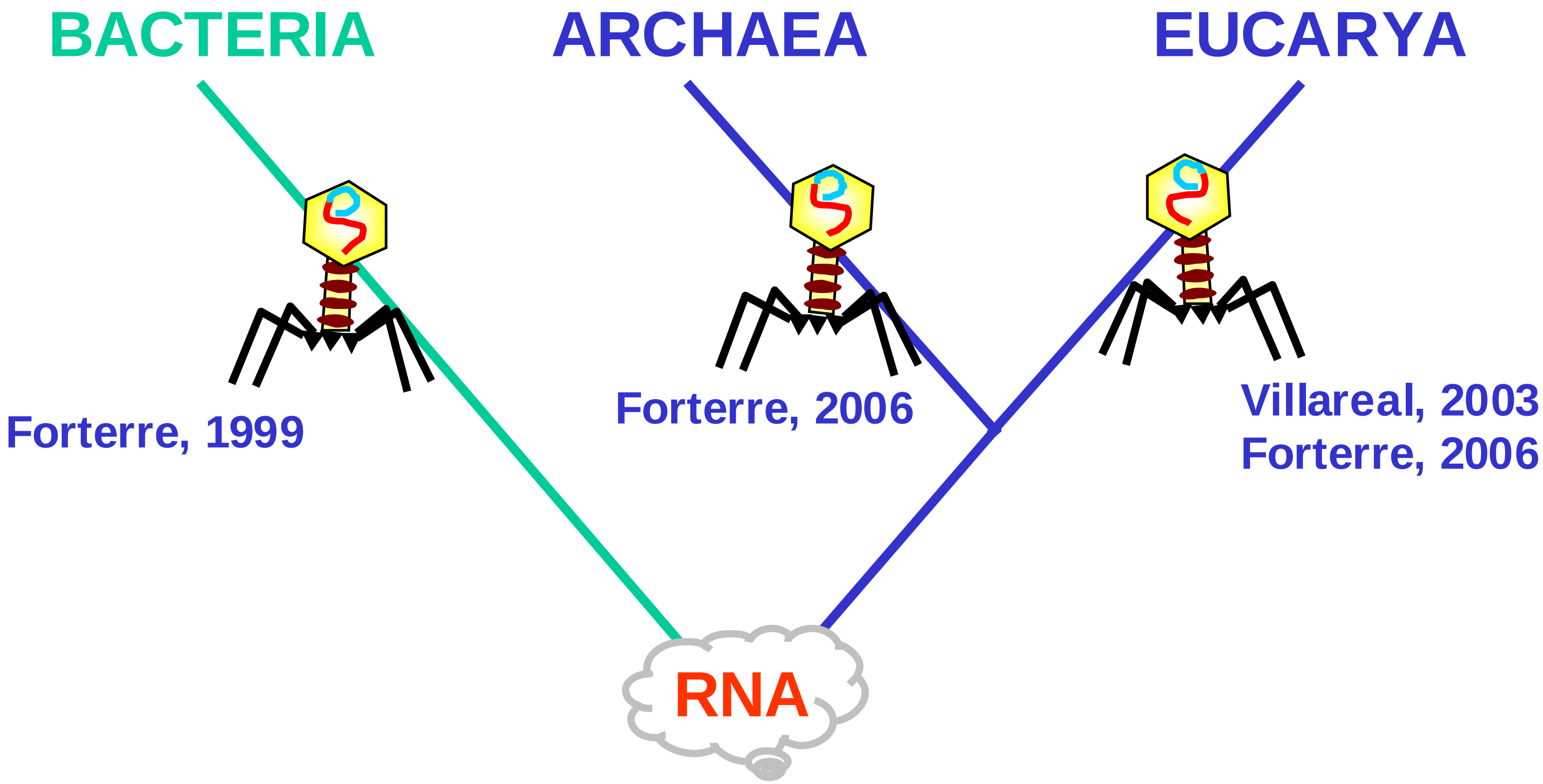
Leipe et al. 1999

Koonin & Martin 2005

Forterre 2006

Glansdorff, Xu & Labedan 2008

The origin of DNA and its replication



The origin of DNA and its replication

HOWEVER **:**

• No known virus has all the genes needed for the synthesis and replication of DNA. All viruses depend on the machineries of the infected cells.

• Genes involved in DNA synthesis and replication have been transferred from the host cells towards the viruses that infect them.

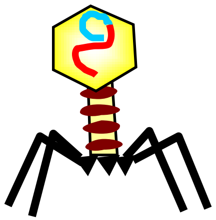
No evidence to support that viruses have "invented" DNA

The origin of DNA and its replication

• **Some DNA replication and repair enzymes are ancestral:**

Evidence for a DNA genome in the last common ancestor?

• **RNA genomes have a <u>maximum size of 35-50 kb</u>, this is the 'Eigen limit' which is due to:**

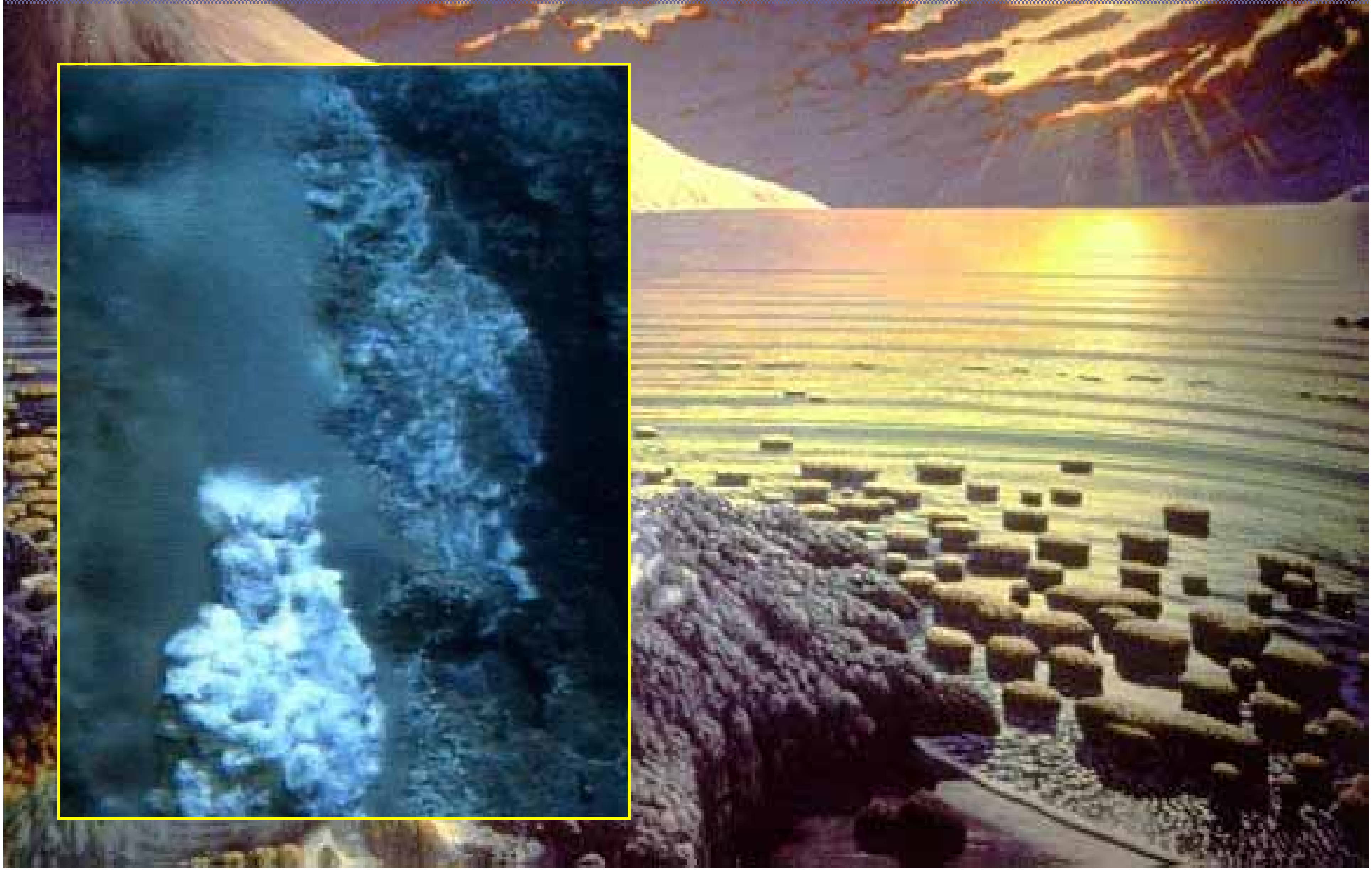


- **High error frequency during RNA replication**
- **High mutation rate**

Incompatible with a genome of >500 genes inferred for the last common ancestor

It likely had a DNA genome

The question of temperature :
Was the last common ancestor hyperthermophilic?



The question of temperature :
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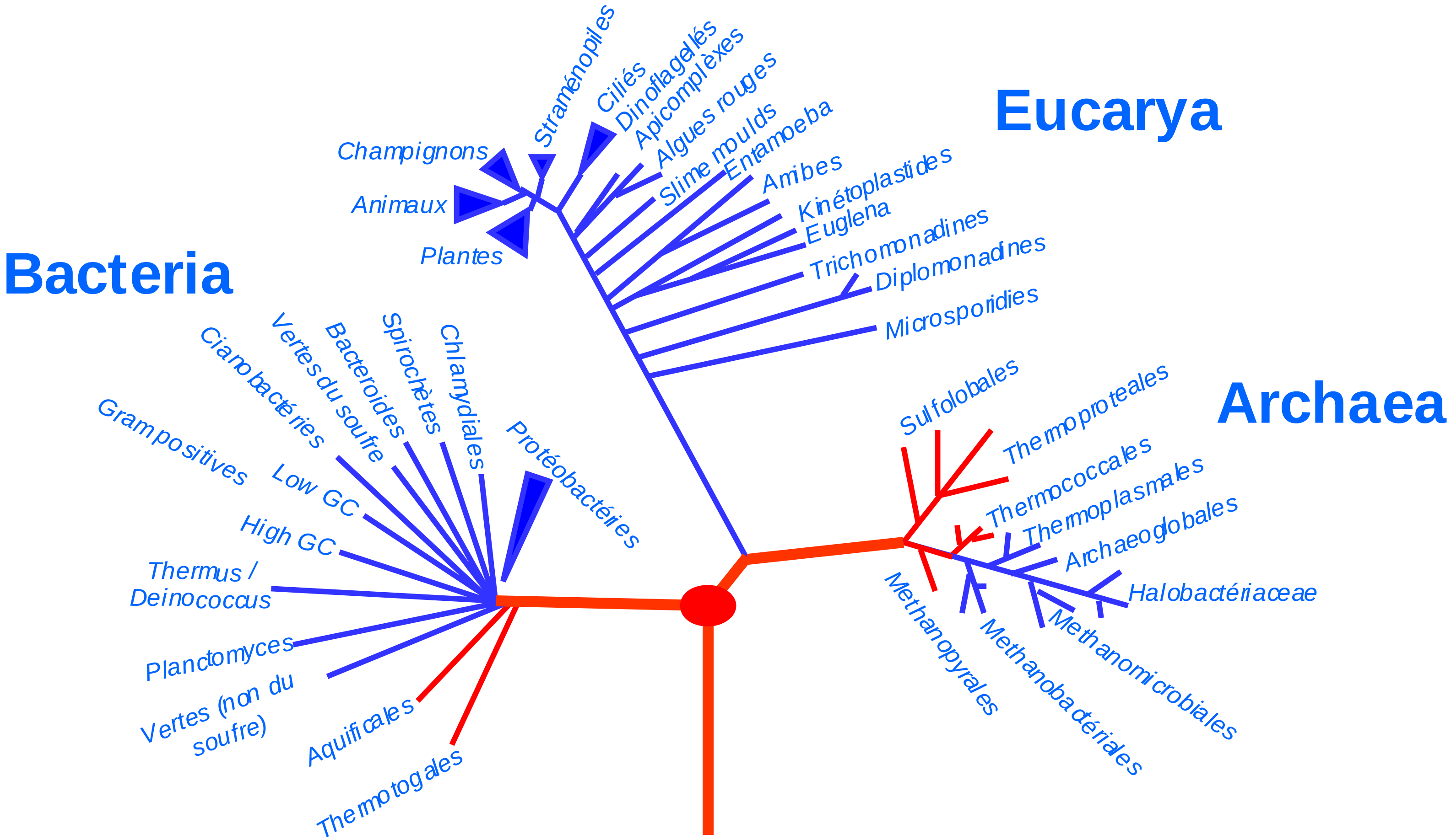
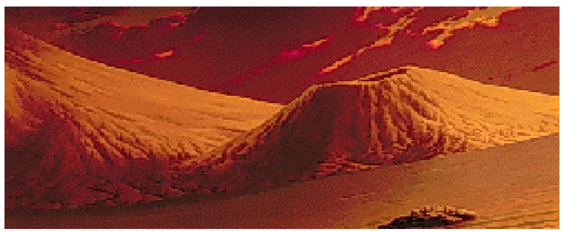
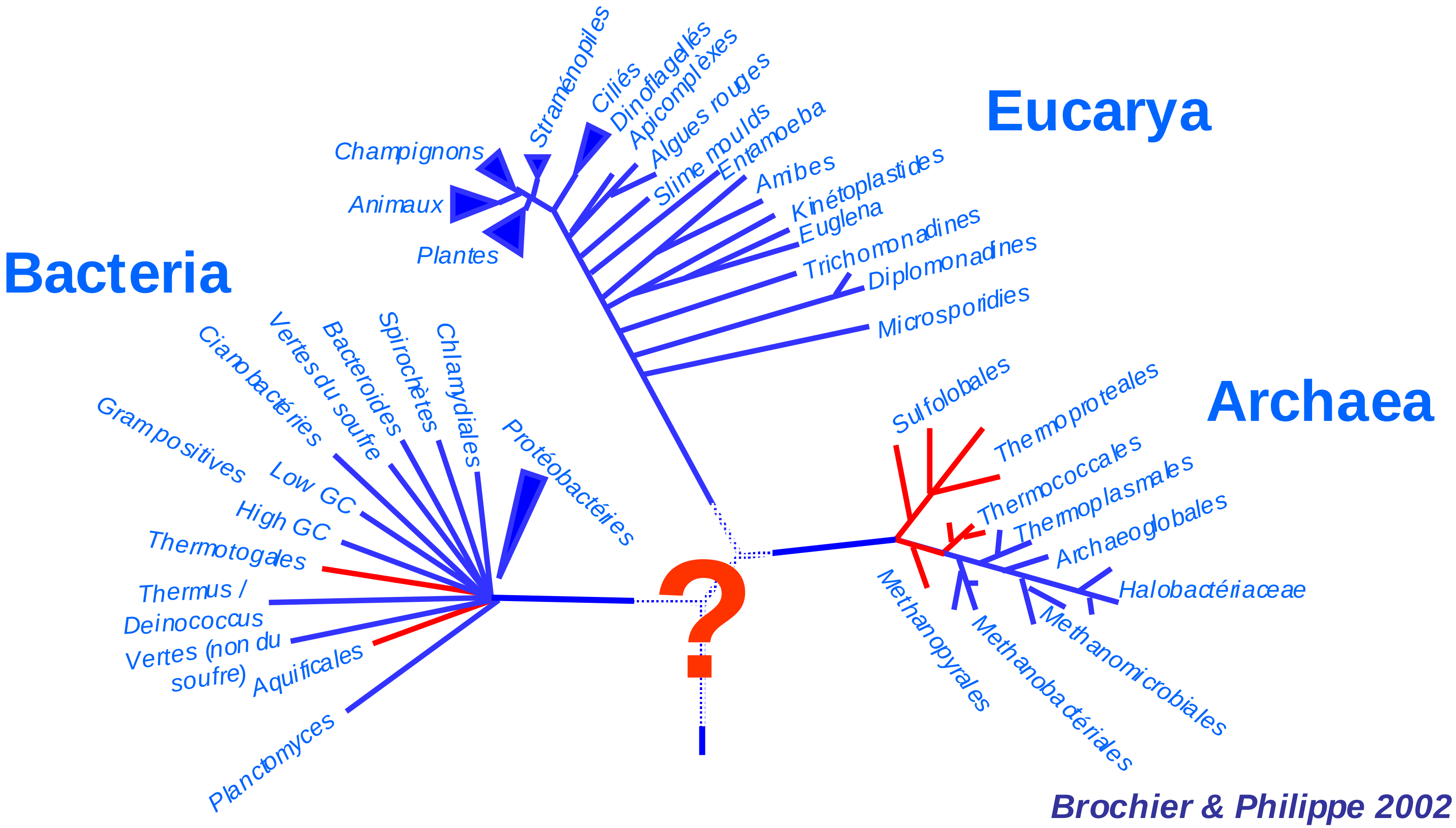




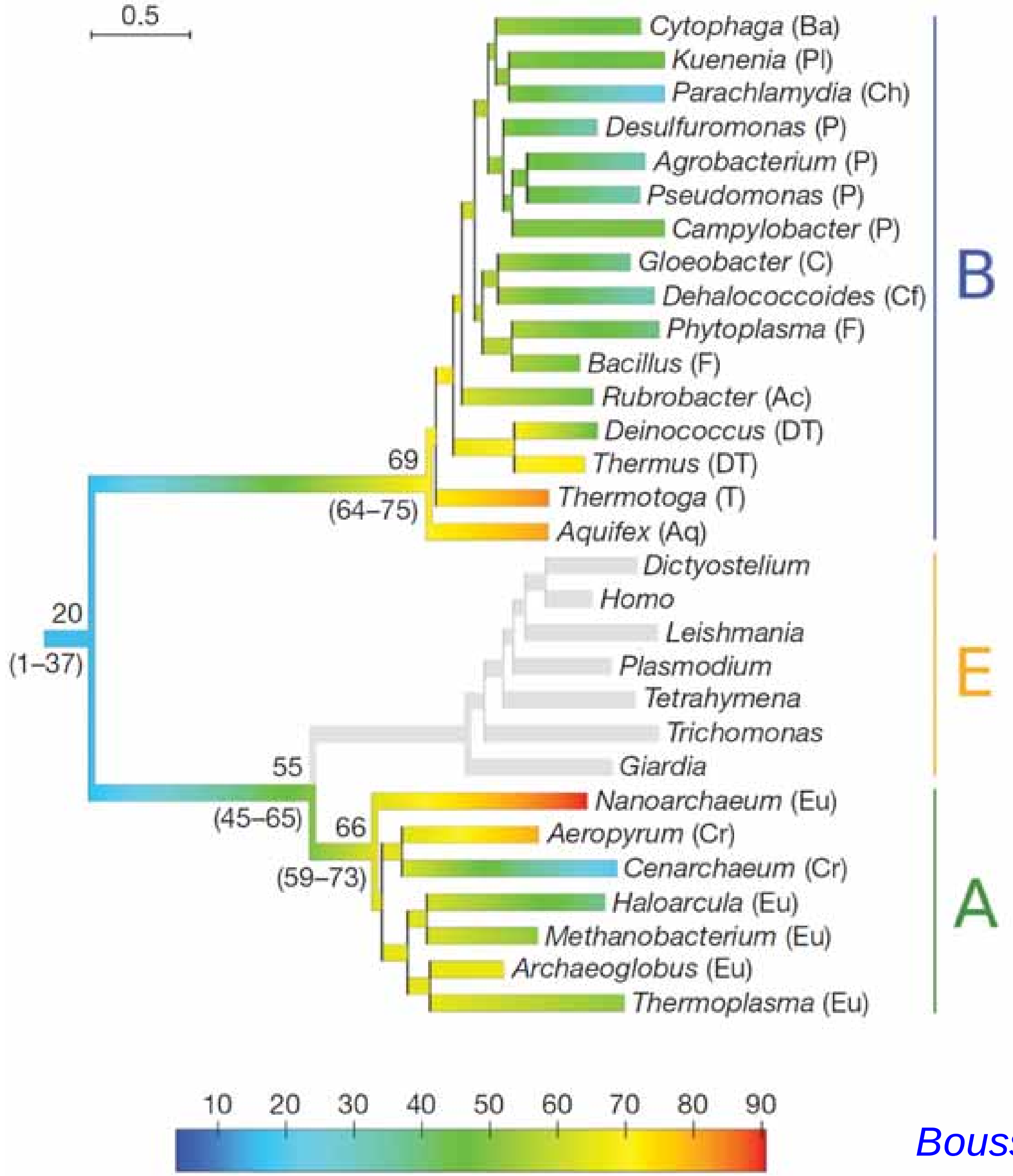
Stetter 1996



Adaptations of bacteria and archaea to high temperatures are not exactly the same, so probably they have not been inherited from a hyperthermophilic last common ancestor.

However, it may have been mesophilic or thermophilic

A mesophilic last common ancestor?



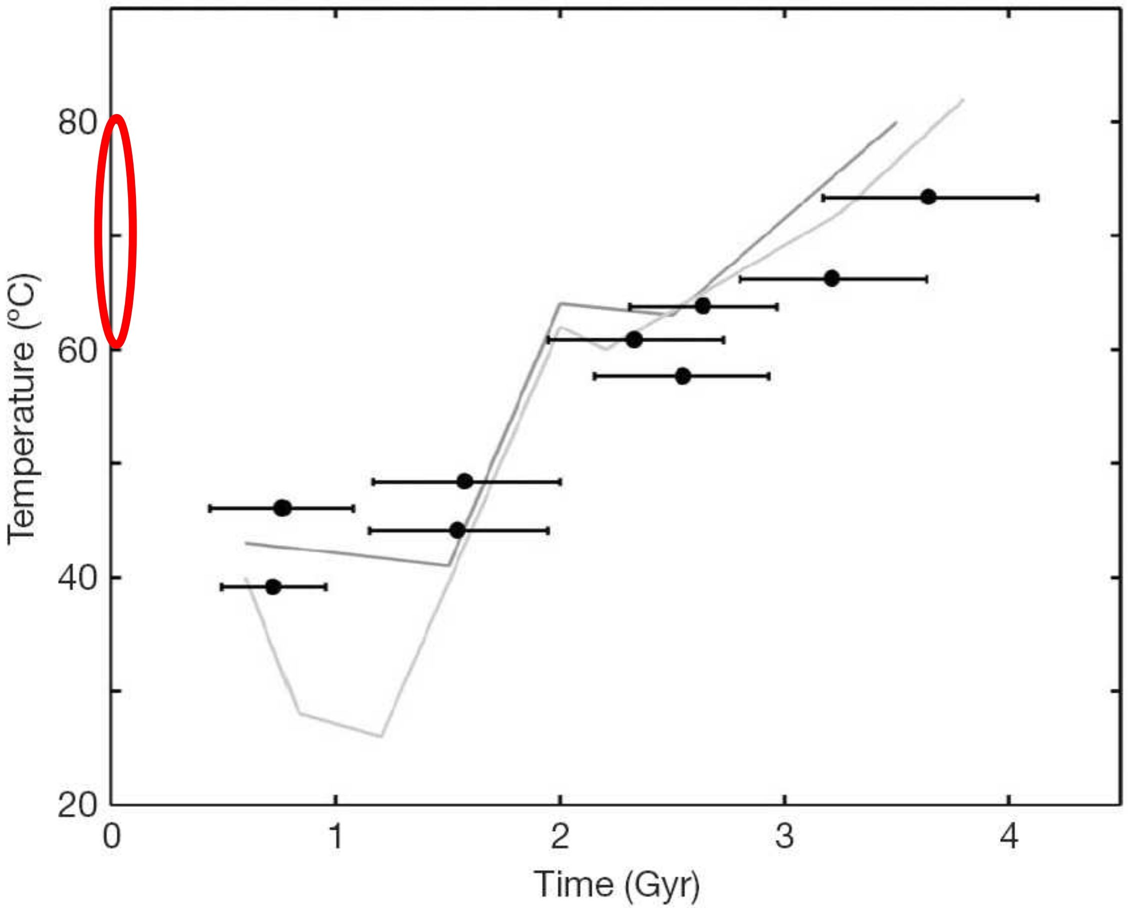
Boussau et al., 2008

A thermophilic last common ancestor?

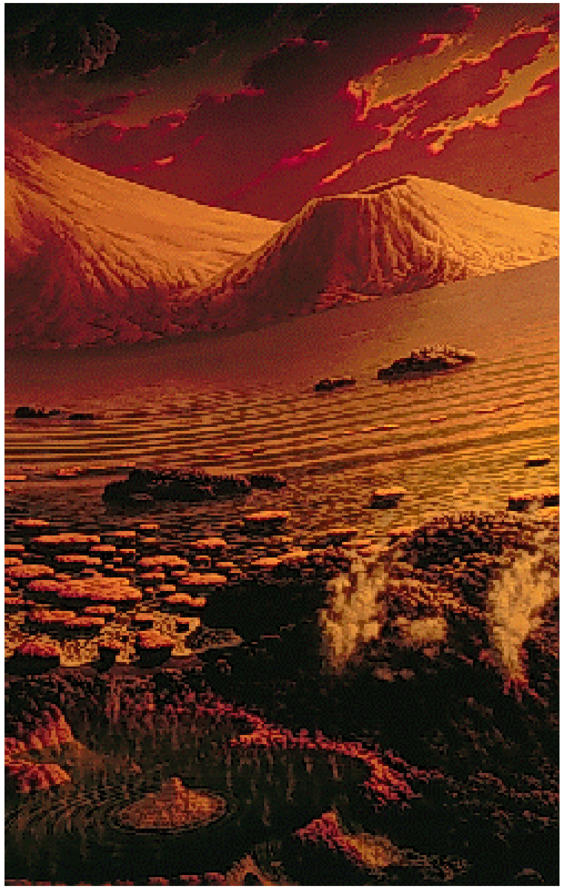
Palaeotemperature trend for Precambrian life inferred from resurrected proteins

Eric A. Gaucher[1], Sridhar Govindarajan[2] & Omjoy K. Ganesh[3]

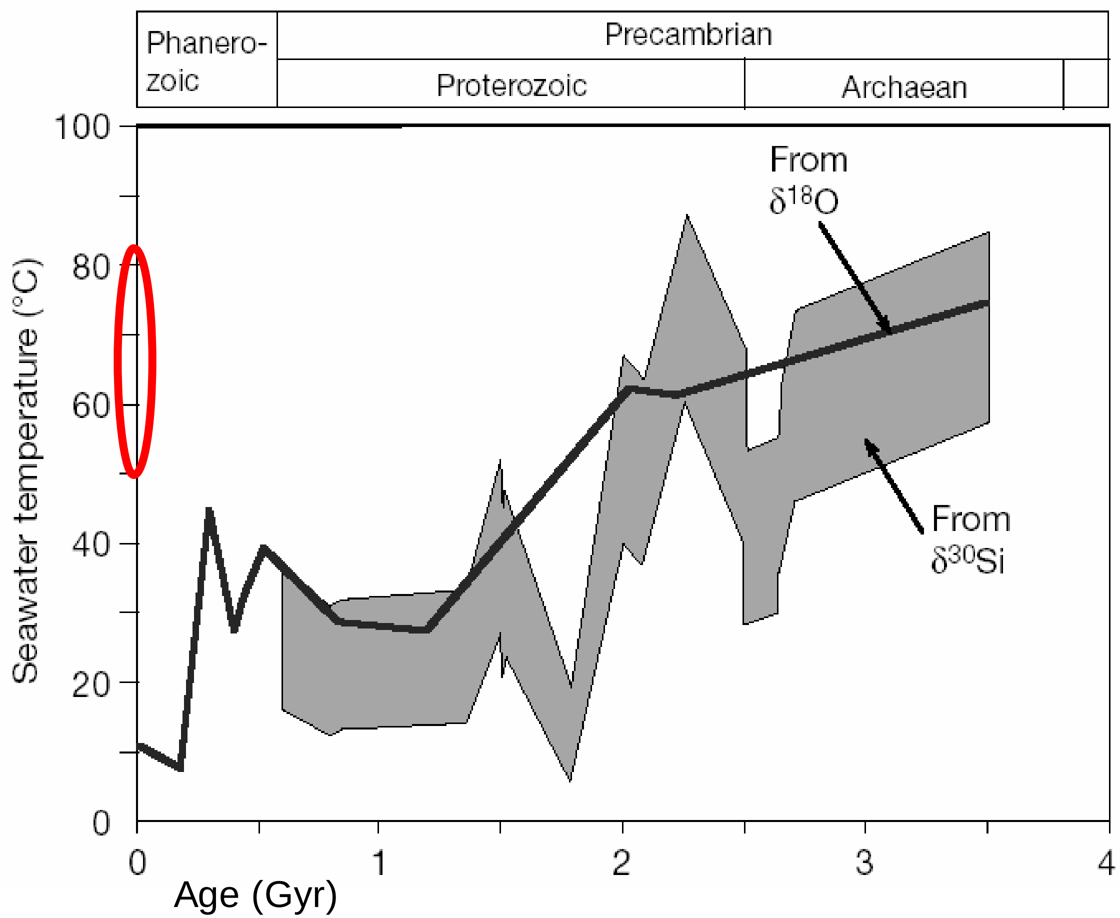
Nature, 2008



A thermophilic last common ancestor?



Earth was warmer during the Archaean period

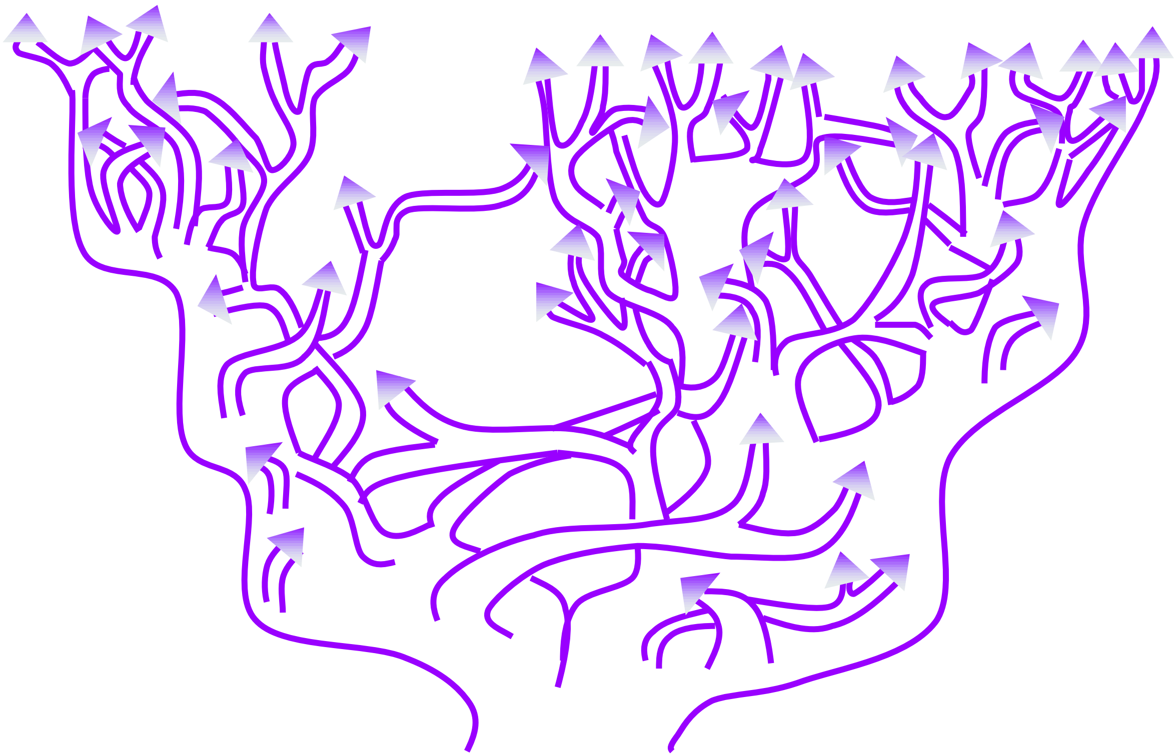


Robert & Chaussidon, 2006

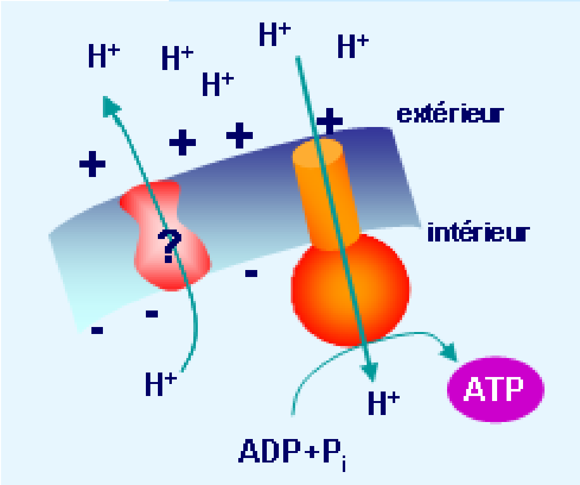
But… Hren *et al*. (2009) have found a temperature ~40°C colder!

Metabolism (C et energy)

Very difficult to study : the genes involved have been very frequently transferred between distant lineages



Metabolism (C et energy)

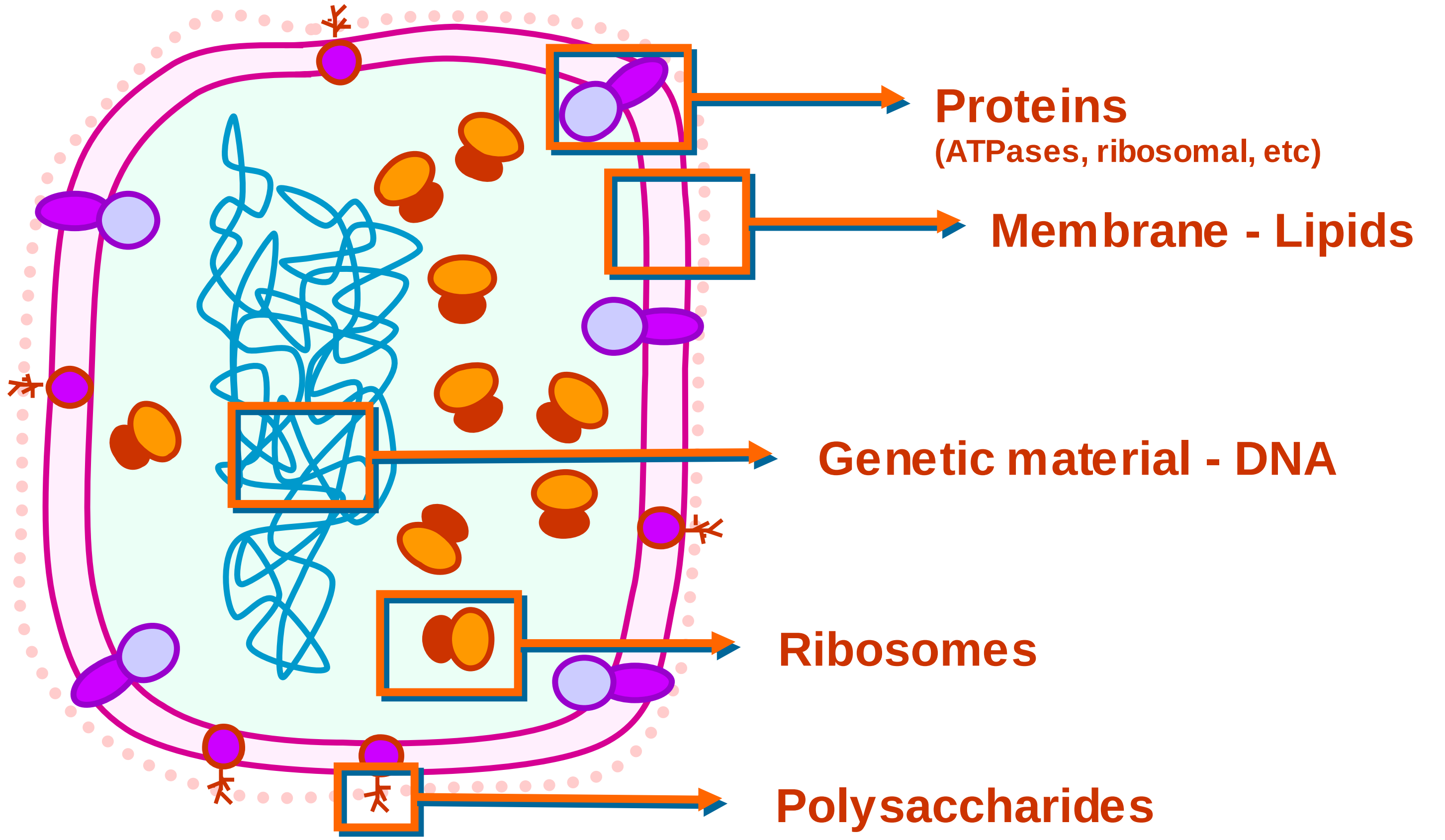


- A <u>membrane ATPase</u> was used to synthesize ATP with a proton gradient across the membrane

- Very likely a heterotrophic metabolism, with simple <u>glycolysis</u> and <u>fermentation</u> pathways

- Oxygen respiration? Very controversial, a possible source of oxygen before the evolution of oxygenic photosynthesis remains unknown

Conclusion: a very complex ancestor



Rapid evolution between the origin of life and the last common ancestor

Conclusions

- Phylogeny and genomics allow the study of the caracteristics of ancestral species

- The last common ancestor was a complex organism

- Several basic molecular functions of cells have not significantly changed for billions of years (no permanent "complexification" is observed)

Genome reduction as the dominant mode of evolution

Yuri I. Wolf and Eugene V. Koonin*