Nouveaux concepts sur la préhistoire des êtres vivants à la fin du XX^{ème} siècle

et au début du XXI^{ème} ..!

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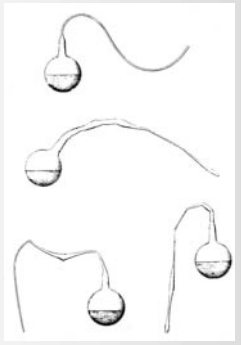
Petit rappel : les avancées du XIXème siécle en biologie

Différence fondamentale et irréductible entre les êtres vivants et le monde « inanimé » : création du terme Biologie

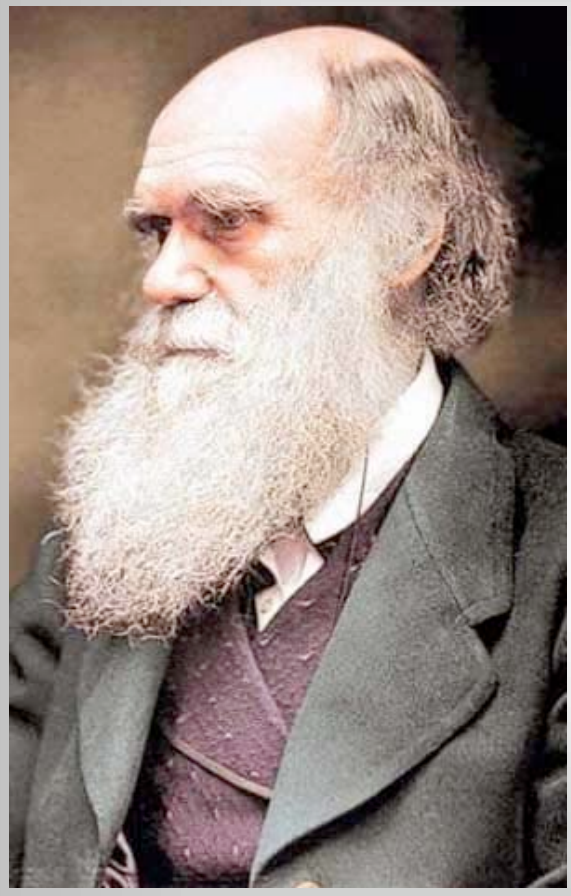
Théorie cellulaire

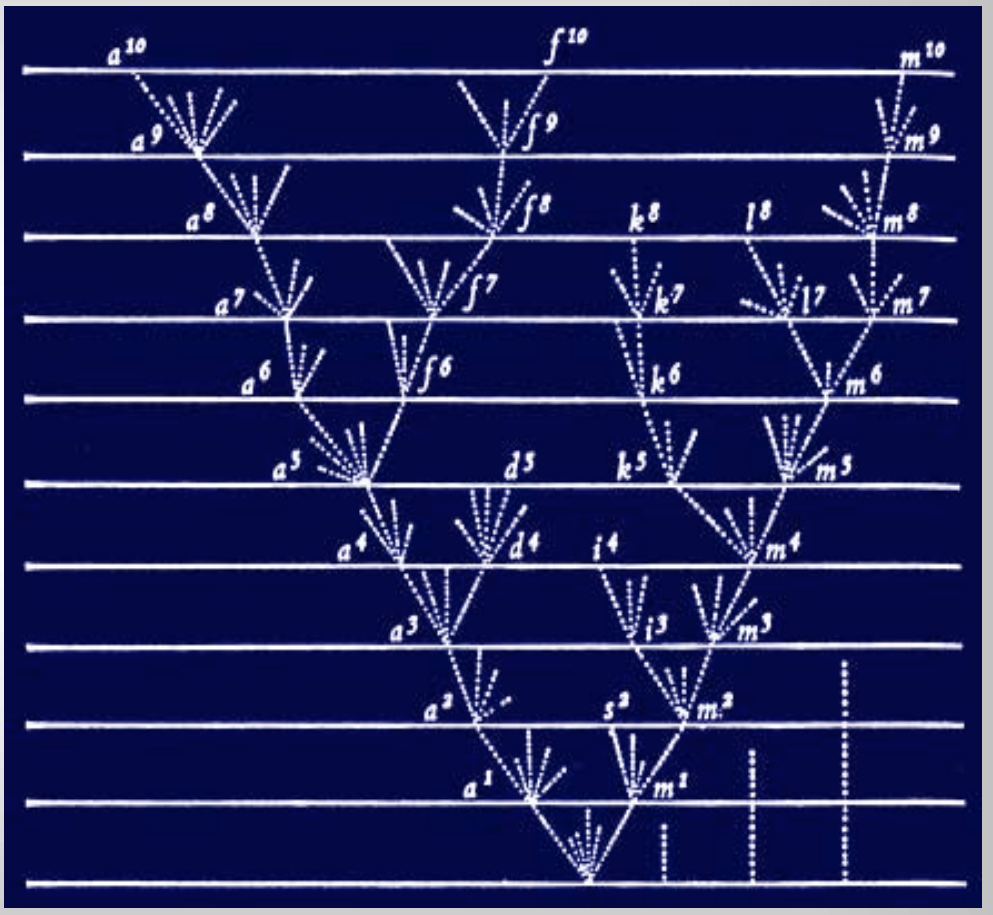


Notion d'évolution (histoire de la vie)

Théorie de la sélection naturelle (Darwin) : identification du mécanisme de l'évolution

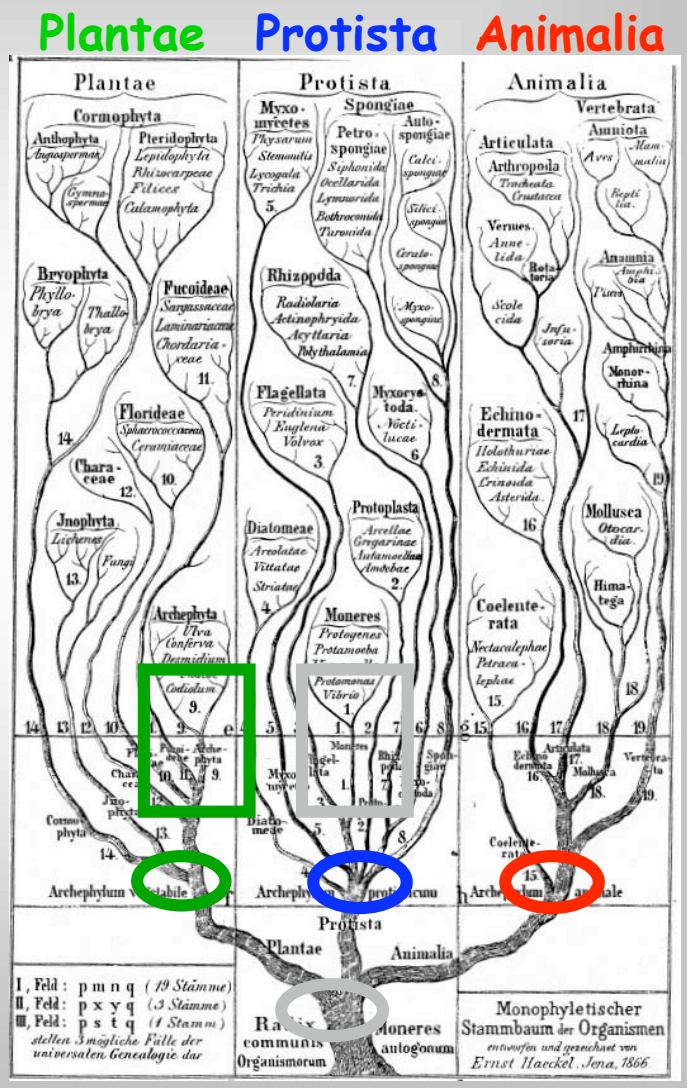
Les êtres vivants ont une histoire...il reste à la déchiffrer





Le premier arbre universel du vivant (Haeckel, 1866)

- **Séparation du monde vivant en 3 règnes Plantae, Animalia et Protista**
- **Objectif = clarifier la frontière Plantae/ Animalia devenue trop floue à cause des micro-organismes**
  - **Protista = organismes unicellulaires, à l 'exception des algues bleues-vertes**
  - **Monera = Protista dépourvus de noyau (futurs Procaryotes)**
  - **Archephyta = Algues bleues-vertes unicellulaires (Cyanobactéries)**
- **Cette classification ne rencontre pas un énorme succès et la dichotomie Animalia/Plantae se maintient**

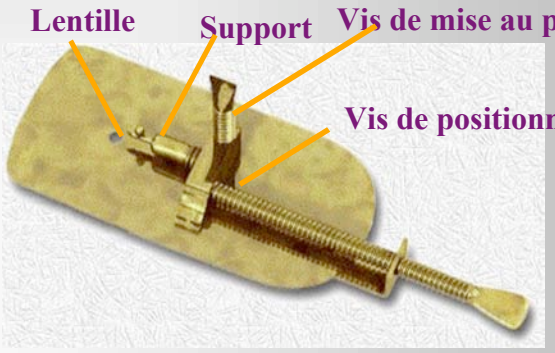


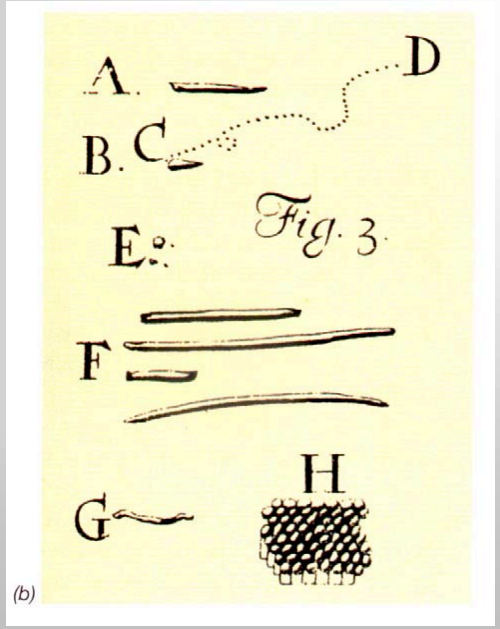
Les micro-organismes

Les micro-organismes ont été découverts au milieu du 17ième siècle par Van Leeuwenhoek

Ces organismes sont

- **Des intermédiaires probables entre le monde minéral et le monde vivant**
- **Classés au sein des Plantes ou au sein des animaux**





La première moitié du XXème siécle

Les différentes approches pour reconstituer l'histoire des êtres vivants

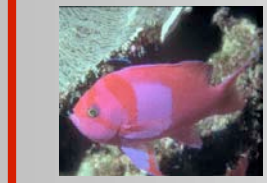
Phénétique
(qui se ressemble s'assemble)

Gradisme
(du simple au complexe)

Phylogénétique évolutive
(analyse cladistique)

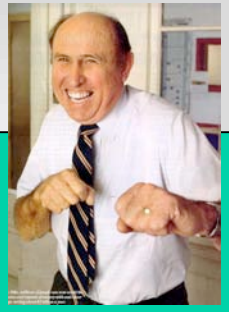
Willi Hennig (1950, 1966)

Phénétique



Qui se ressemblent s'assemblent
Les poissons !

Gradisme



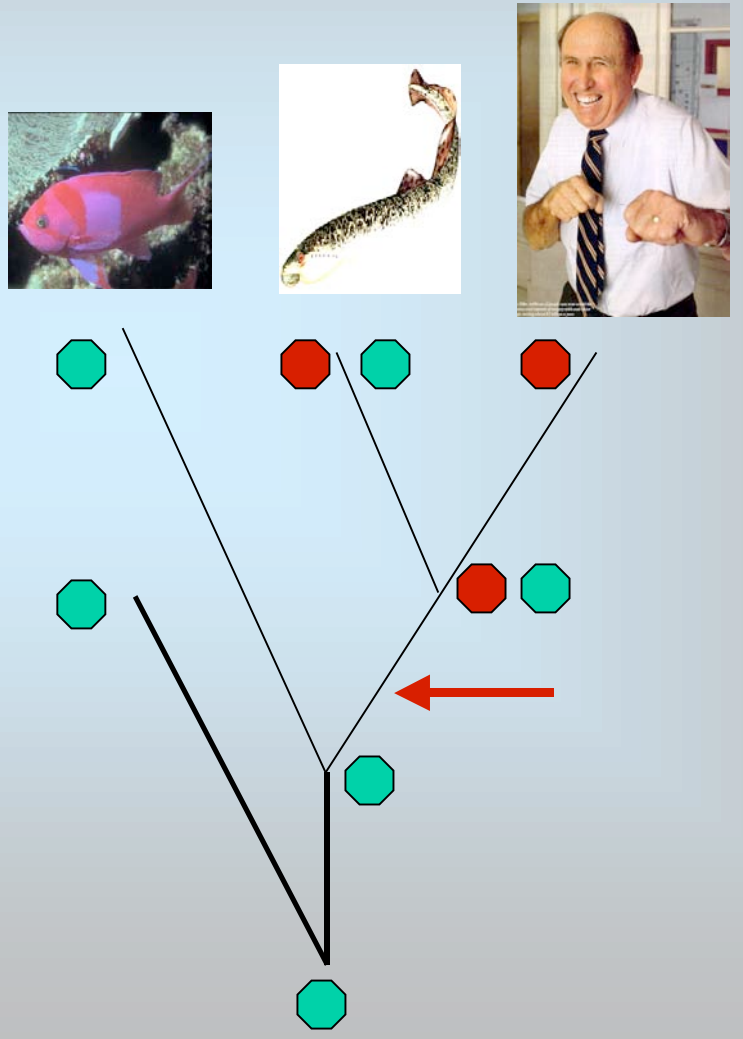
Mammifère

Poisson

Analyse Cladistique

Willi Hennig (1950, 1966)

Notion de synapomorphie
polarisation des caractères



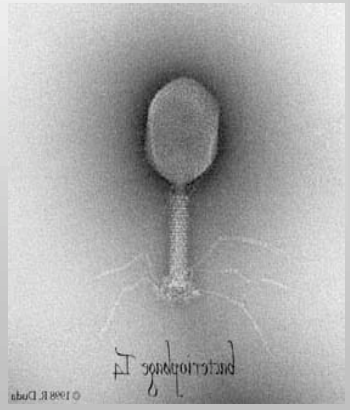
La première moitié du XXème siécle

Unité chimique du monde vivant

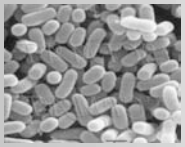
Identification du gène et des mécanismes de le « variation »
Théorie synthétique de l'évolution

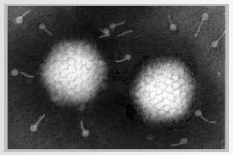
Définition de deux types cellulaires : eucaryote et procaryote

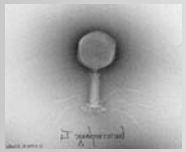
Découverte des virus
(une entorse à la théorie cellulaire ?)

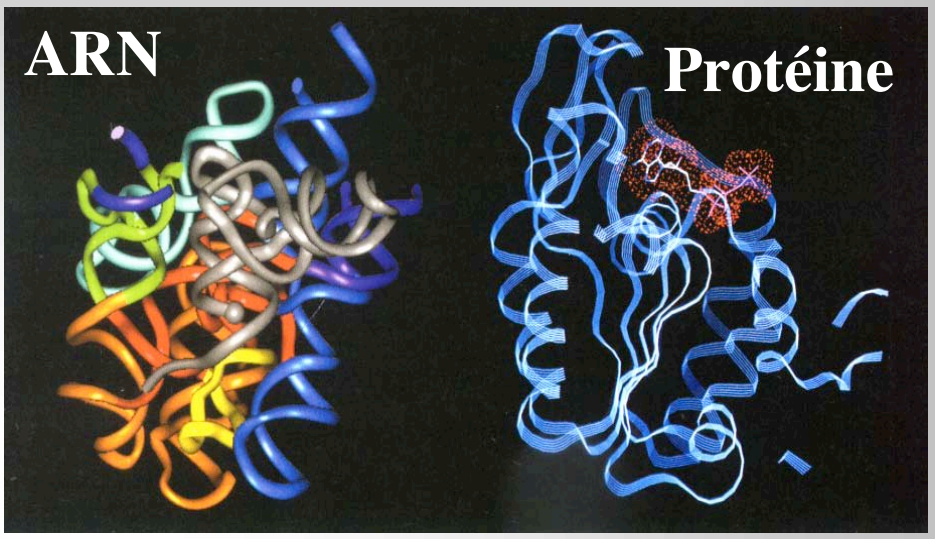


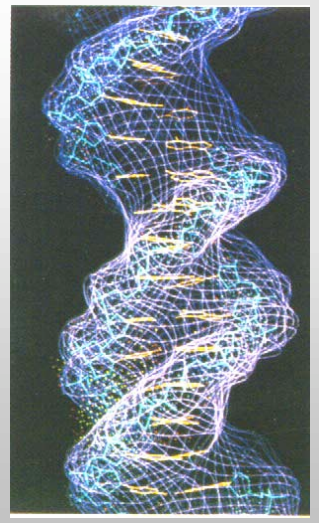
Tous les êtres vivants actuels sont composés des mêmes macromolécules











ADN

Ils ont une histoire commune nous descendons tous d'un même ancêtre

La définition de la cellule Procaryote par Chatton (1937)

- Le microbiologiste français Édouard Chatton met en évidence des différences fondamentales entre les cellules bactériennes et des autres orga

=> Il propose de diviser le monde vivant selon ces 2 types cellulai
PROCARYOTES et EUCARYOTES

  - Procaryotes = organismes à cellules sans noyau
  - Eucaryotes = organismes à cellules avec noyau

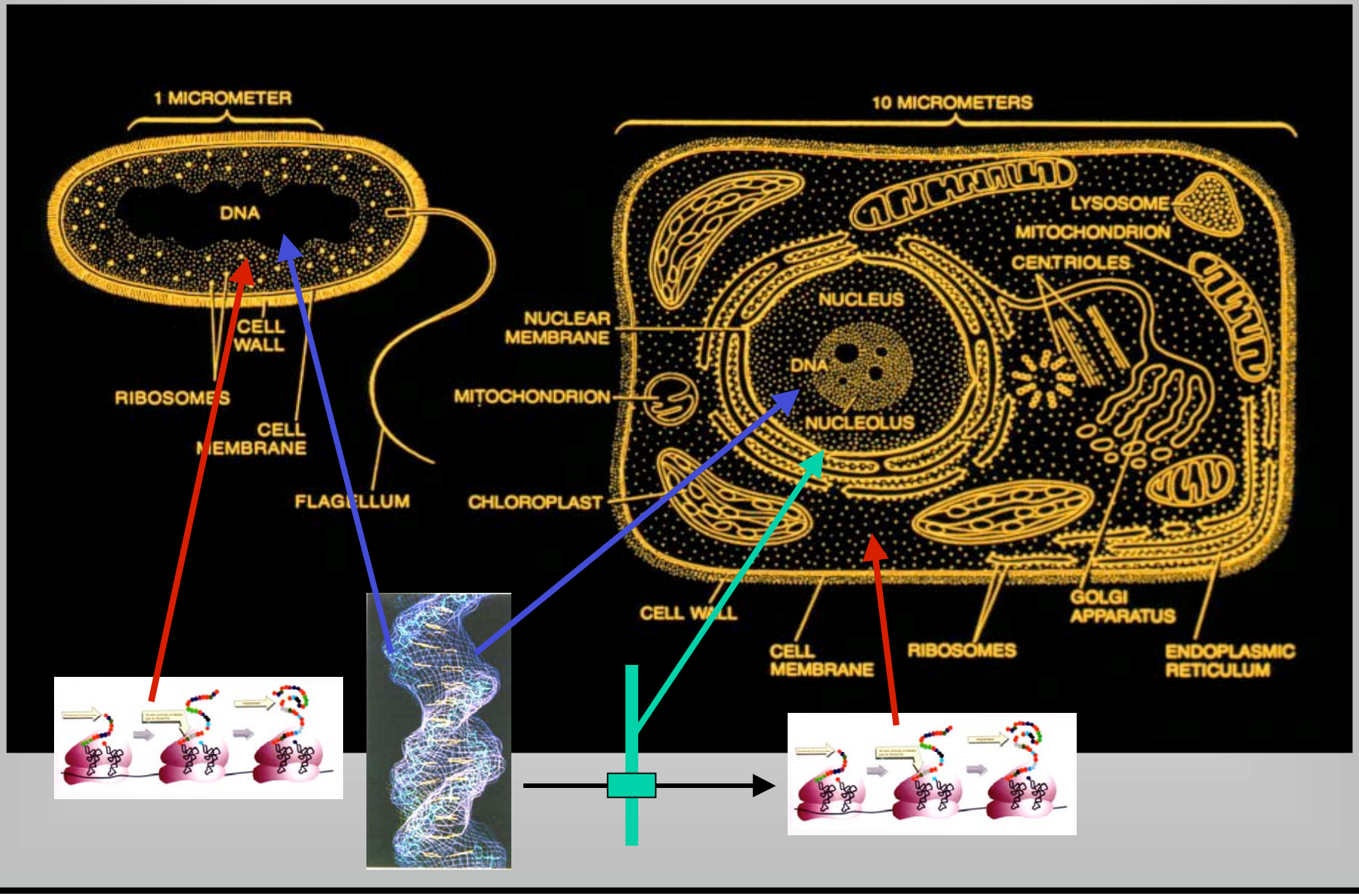
- D'un point de vue évolutif, le terme **Pro**caryote implique, par que la cellule Procaryote, plus simple, s'est mise en place avar

- Cette vision **gradiste** de la construction cellulaire au cours de très profondément les esprits et définit comme un groupe natu d'organismes **sur la base d'un caractère négatif** qu'est l'abs

- Ces travaux ne reçoivent pas d'échos dans la communauté scientifique de l'époque et passent inaperçus jusque dans les années 60

Procaryote

Eucaryote

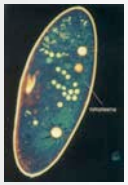
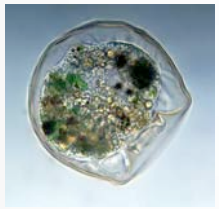


La vision traditionnelle du vivant

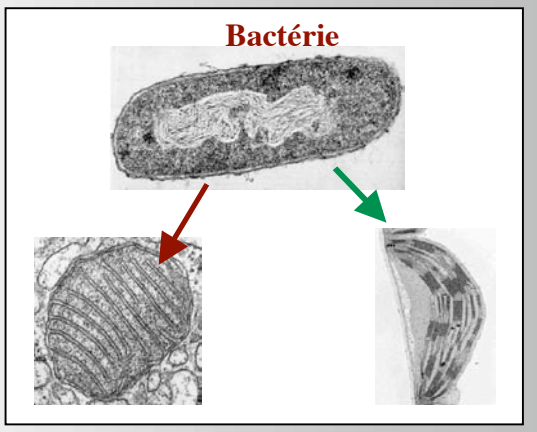


Eucaryotes supérieurs

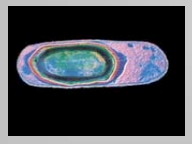
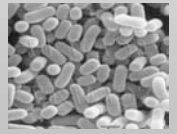
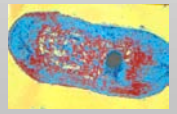


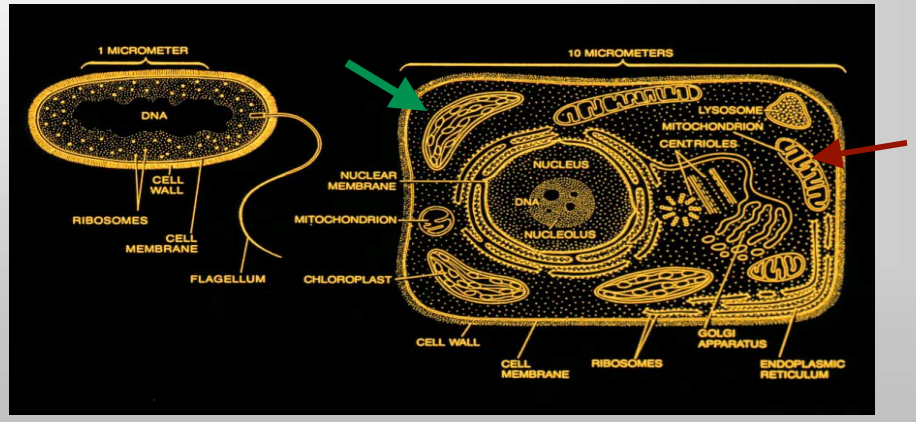



« Eucaryotes »
inférieurs

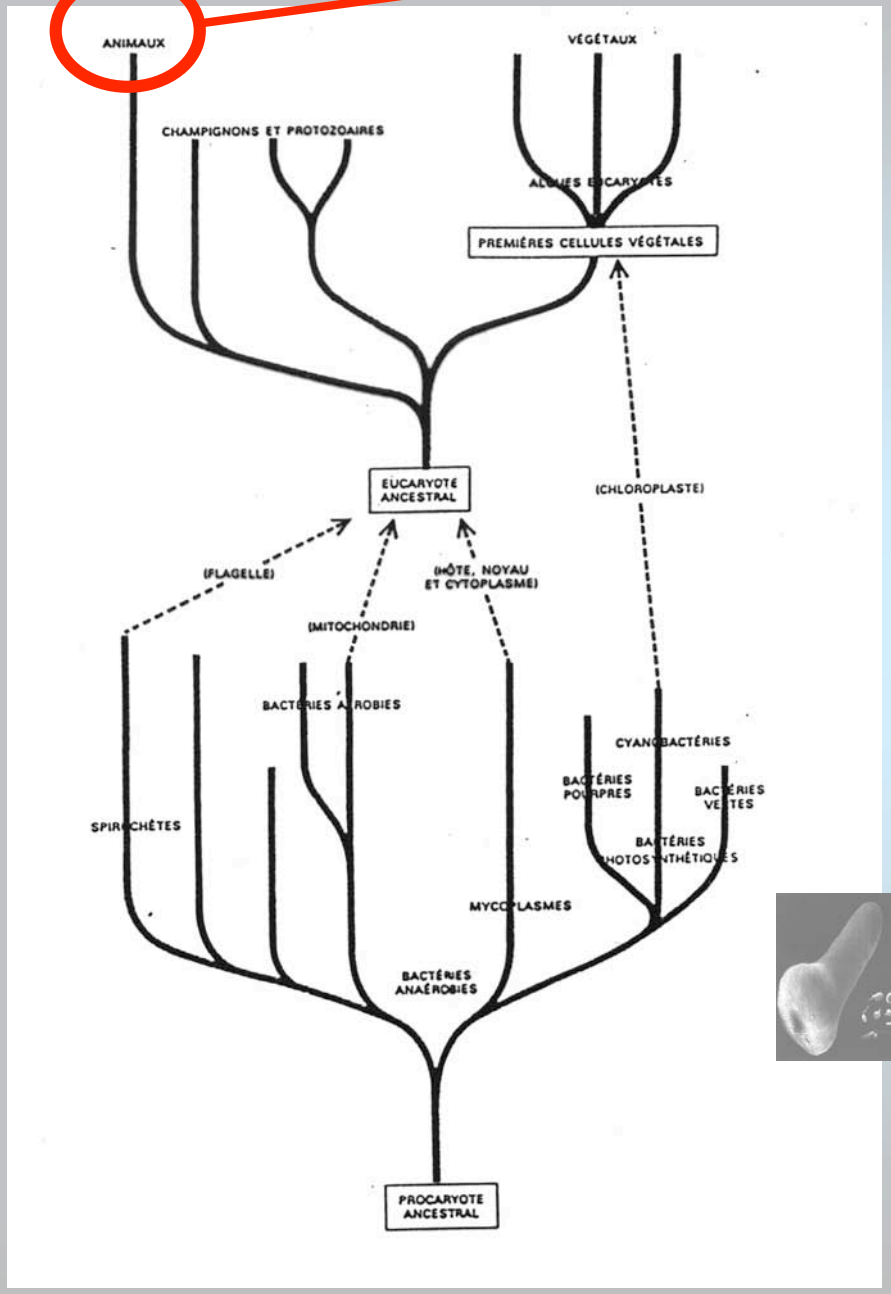


Procaryotes

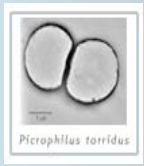


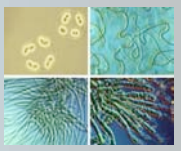
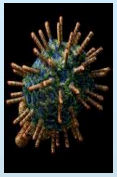
Homo sapiens

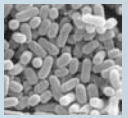
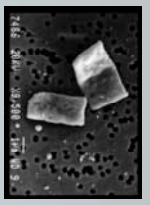


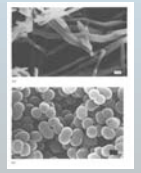
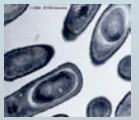
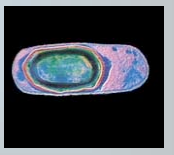
L 'arbre Universel du vivant
Au début des années 70
La fusée à deux étages !

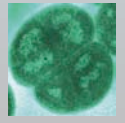
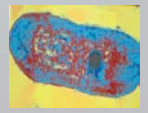




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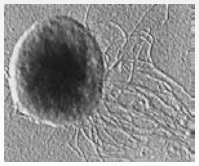
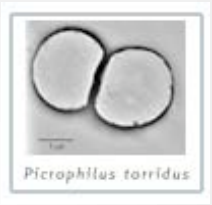
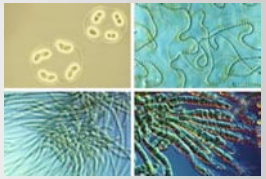
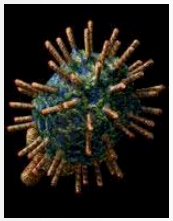
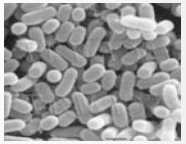
Comment classer les microorganismes ?

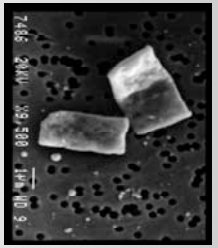


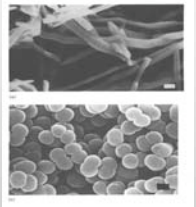


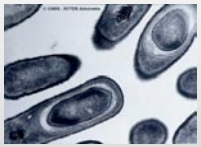


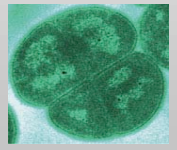


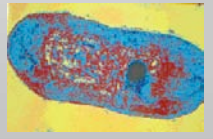








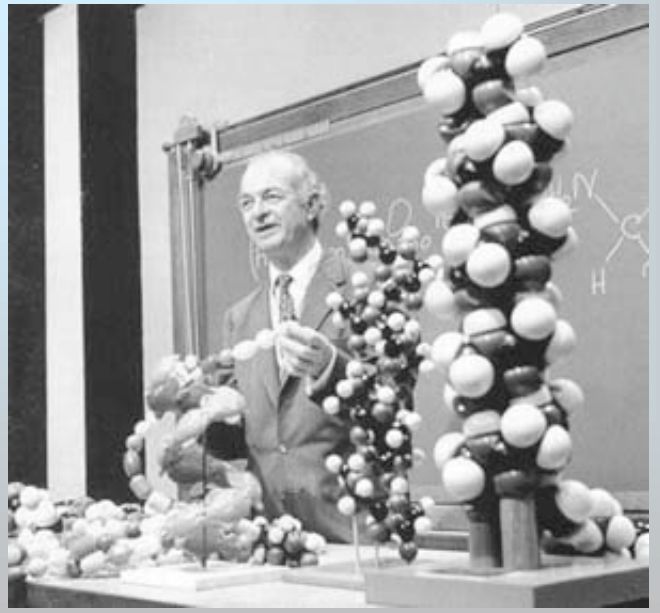




Très peu de caractères homologues
Impossible de les polariser !

Les macromolécules, témoins de l'évolution

- **1955 : Sanger développe une méthode de séquençage des protéines et séquence l'insuline.**
- **1965 : Zuckerkandl et Pauling publient leur article " Molecules as Documents of Evolutionary History " qui marque la transition vers l'ère des phylogénies moléculaires**



L'idée de comparer les séquences des macromolécules pour retracer l 'évolution date de 1968 (*Zuckerland et Pauling*)

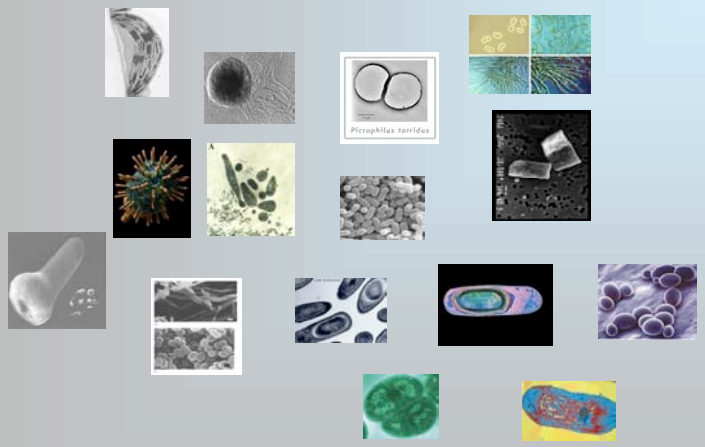
1 AUGCGUAUUACGCGGT

2 AUGCGUACAACGGGGT

AUGCGUGUCACGCGAT

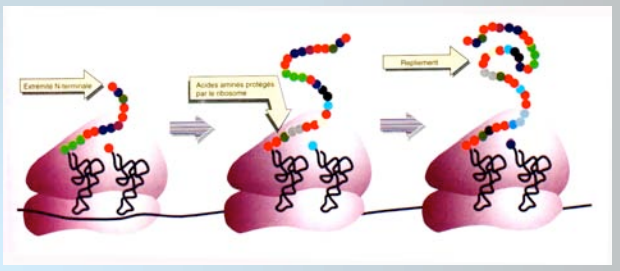
3 AAGCGCGUCACGCUAU

4 ACGCGGGUCACGCUAC



Il existe trois types de ribosome sur terre

Carl Woese
1977



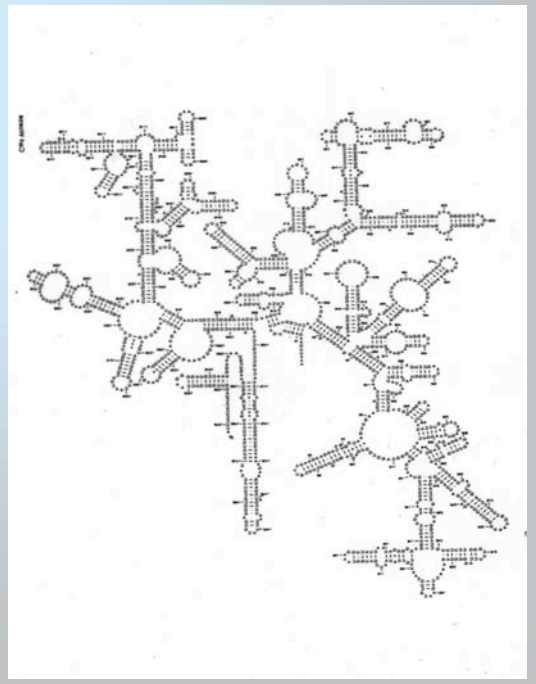
ubiquitaire

même fonction
chez tous les organismes

facile à isoler

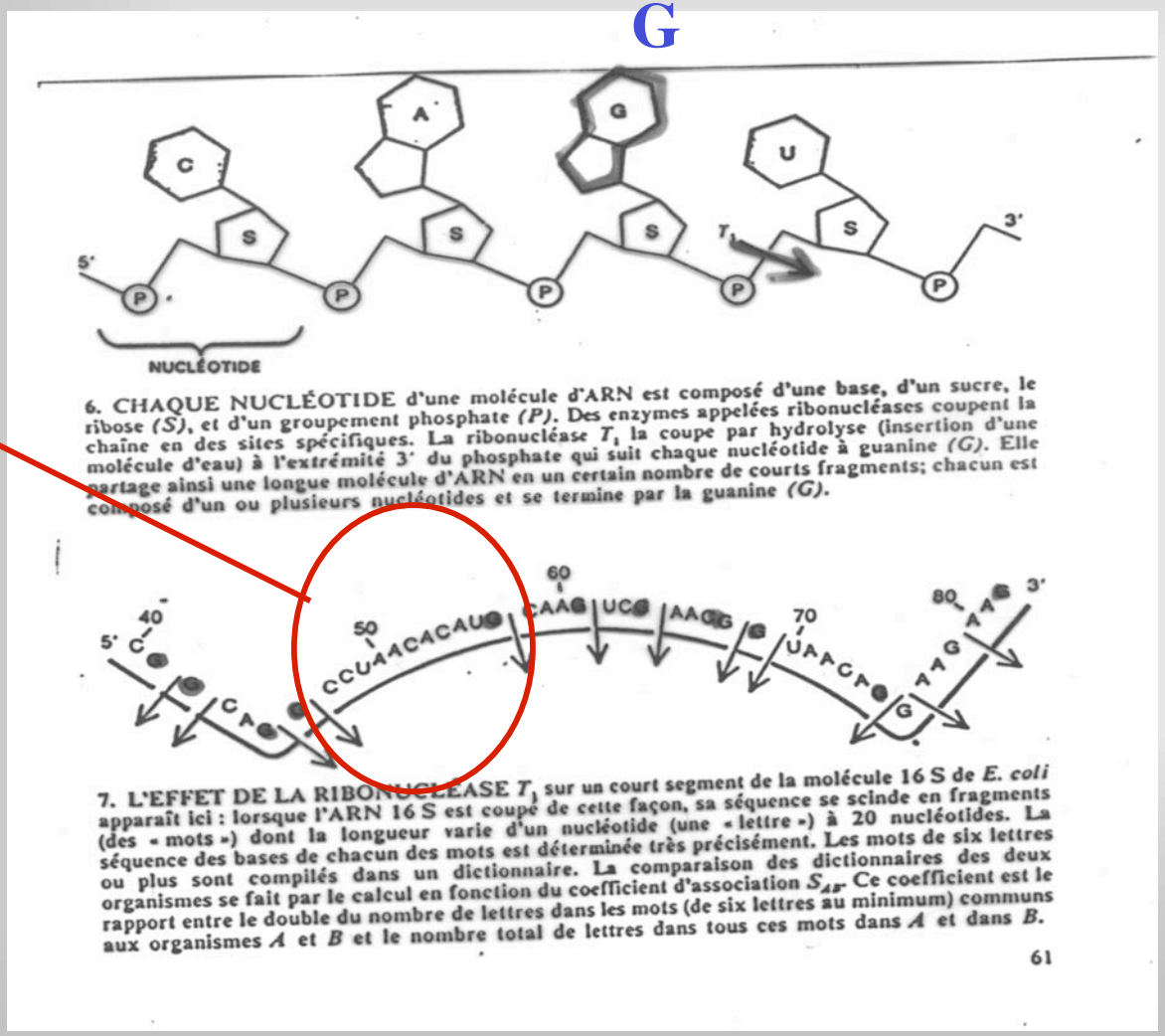
riche en information
(comparée au 5S)

plus facile à étudier que le 23S



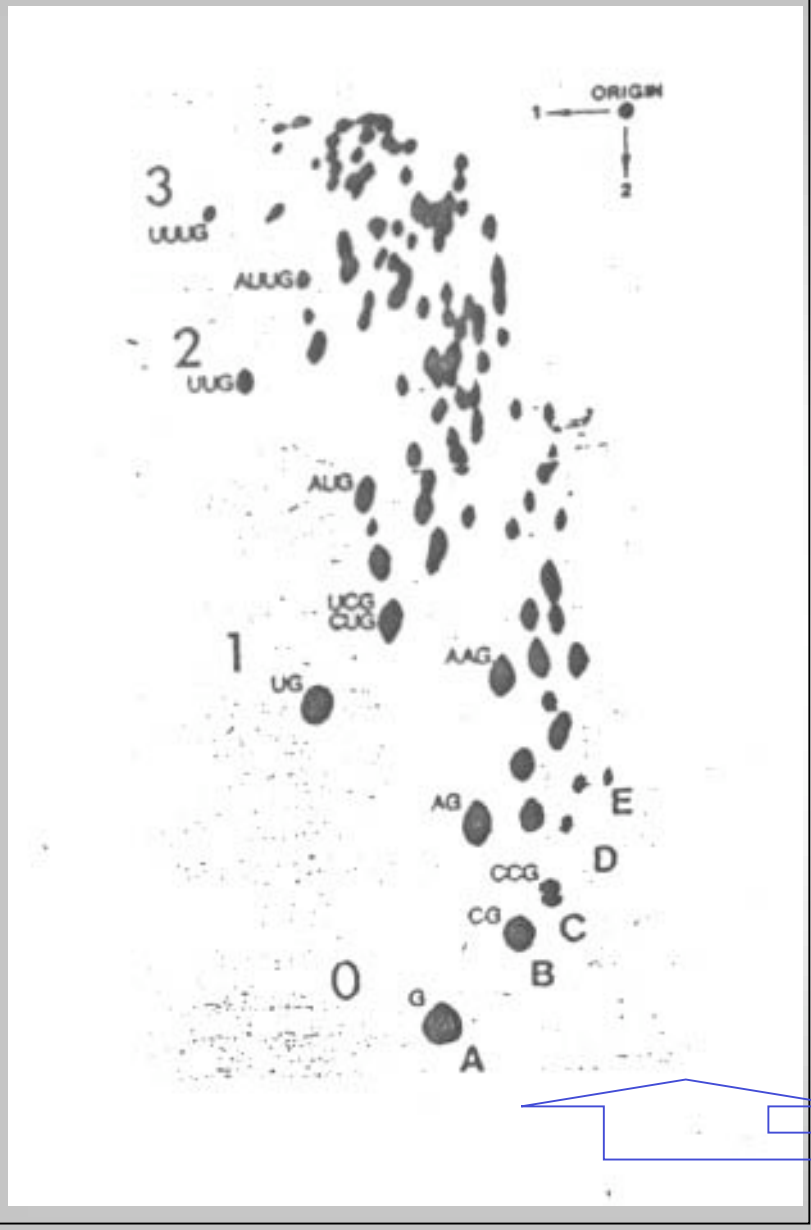
Production d'un catalogue d 'oligonucléotides digérés par la RNAse T1

G



Oligo
N≥6

La Rnase
T1
Coupe
En 3' d'un G



Marquage des cellules au P32

⇩

Isolement des ribosomes

⇩

Isolement des ARN ribosomiques

⇩

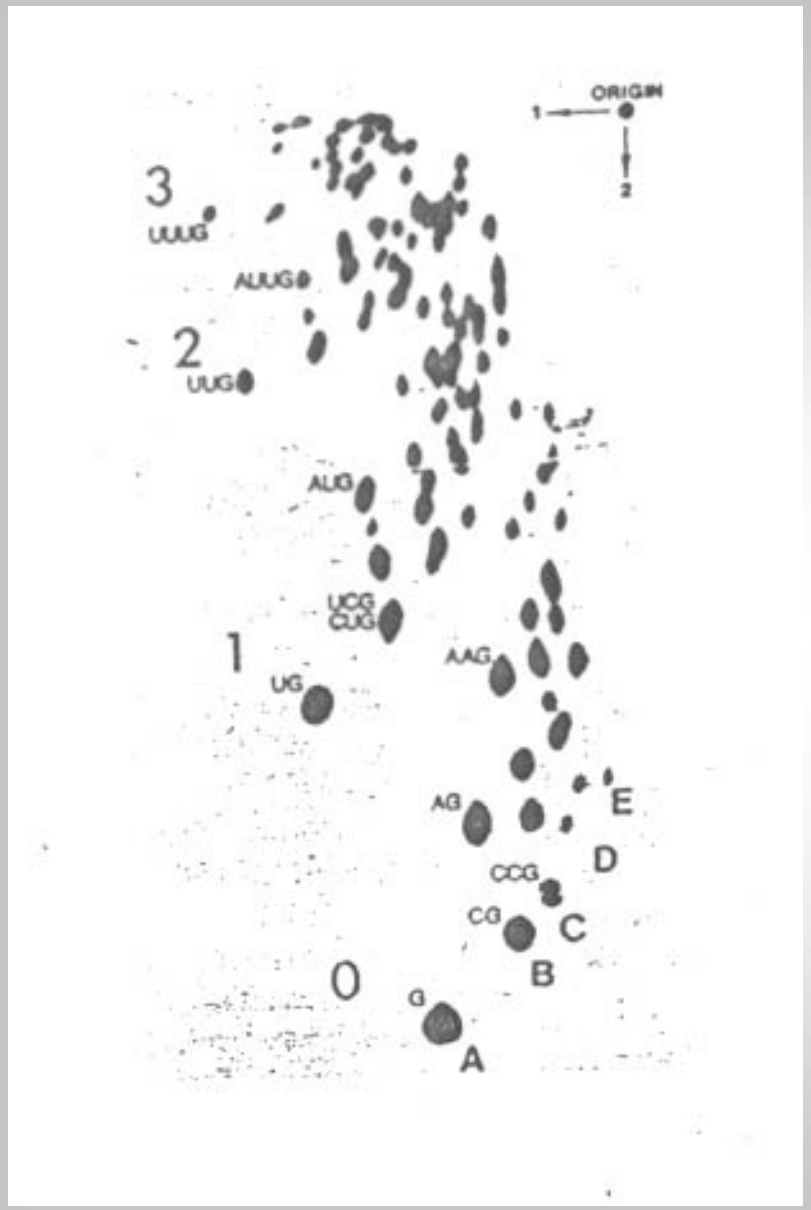
Isolement de l ’ARN 16S

⇩

Digestion par la RNAse T1

⇩

Autoradiographie



Na = Nombre d 'oligo dans le catalogue De l'espèce a

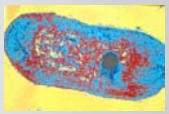
Nb = Nombre d 'oligo dans le catalogue De l'espèce b

Nab = Nombre d 'oligo Commun aux catalogued des espèces a et b

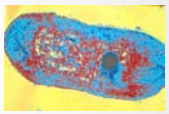
Sab = 2Nab/Na + Nb

Homme-levure de bière 0.33

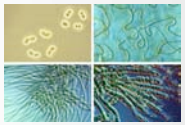
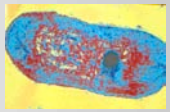

Homme-Colibacille 0.06

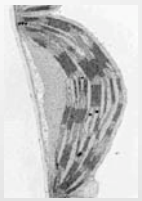
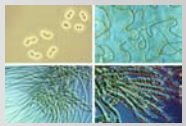
Levure de bière-Colibacille 0.05




Cyanobactérie-Colibacille 0.26

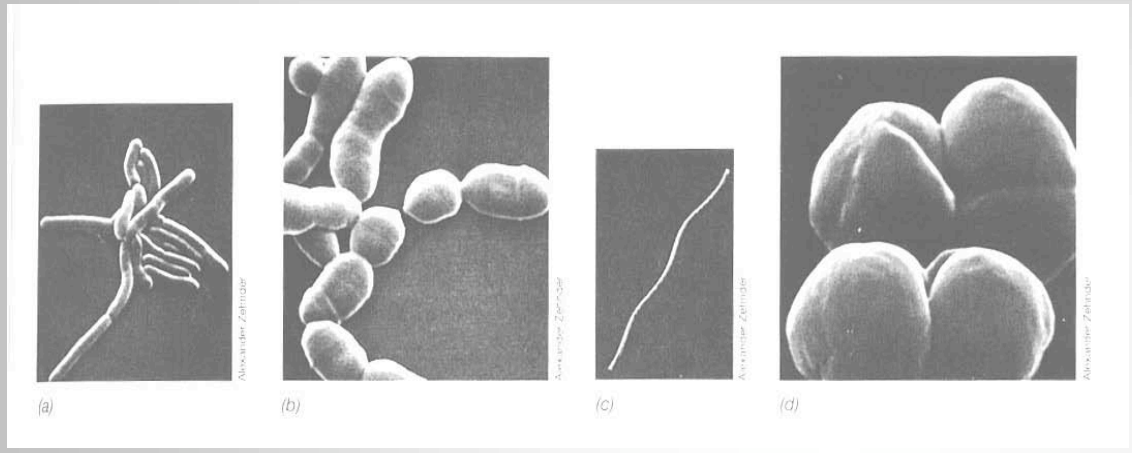



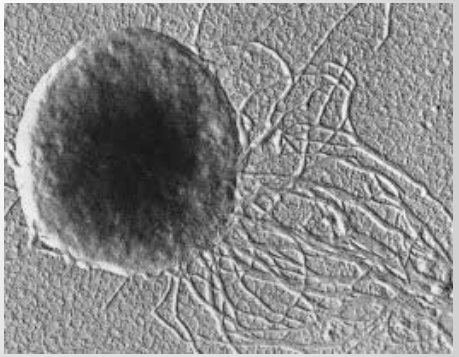
Cyanobactérie-Chloroplaste 0.31

Plante-Chloroplaste 0.09


Comment classer les « bactéries » méthanogènes ?





$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

Méthanogène--Homme 0.05

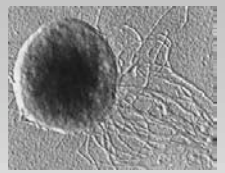
Méthanogène--Colibacille 0.06

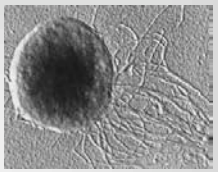
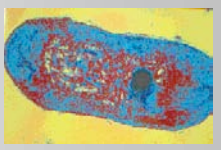
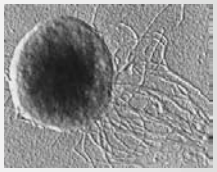
Méthanogène- *Halobacterium* 0.19

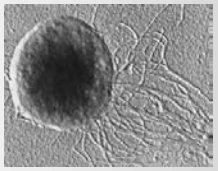
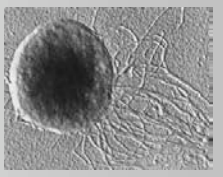
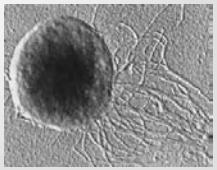
Méthanogène 1-Méthanogène 2 0.25

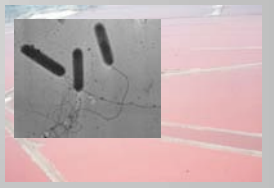
Méthanogène-*Sulfolobus* 0.13

Halobacterium-Sulfolobus 0.15



Phylogenetic structure of the prokaryotic domain: The primary kingdoms

(archaebacteria/eubacteria/urkaryote/16S ribosomal RNA/molecular phylogeny)

CARL R. WOESE AND GEORGE E. FOX*

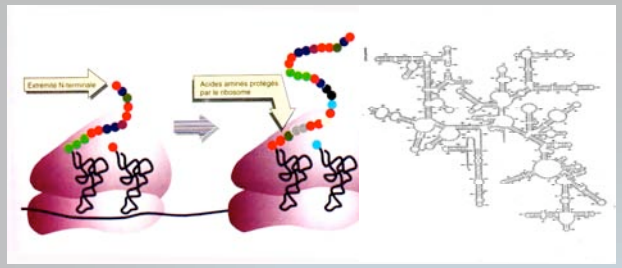
Department of Genetics and Development, University of Illinois, Urbana, Illinois 61801

Communicated by T. M. Sonneborn, August 18, 1977

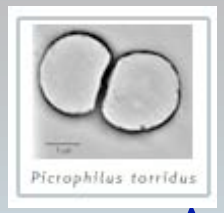
ABSTRACT **A phylogenetic analysis based upon ribosomal RNA sequence characterization reveals that living systems represent one of three aboriginal lines of descent: (*i*) the eubacteria, comprising all typical bacteria; (*ii*) the archaebacteria, containing methanogenic bacteria; and (*iii*) the urkaryotes, now represented in the cytoplasmic component of eukaryotic cells.**

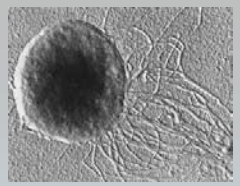
to construct phylogenetic classifications between domains: Prokaryotic kingdoms are not comparable to eukaryotic ones. This should be recognized by an appropriate terminology. The highest phylogenetic unit in the prokaryotic domain we think should be called an "urkingdom"—or perhaps "primary kingdom." This would recognize the qualitative distinction between prokaryotic and eukaryotic kingdoms and emphasize

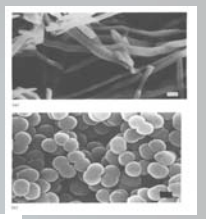
« the archaebacteria, containing methanogenic bacteria »



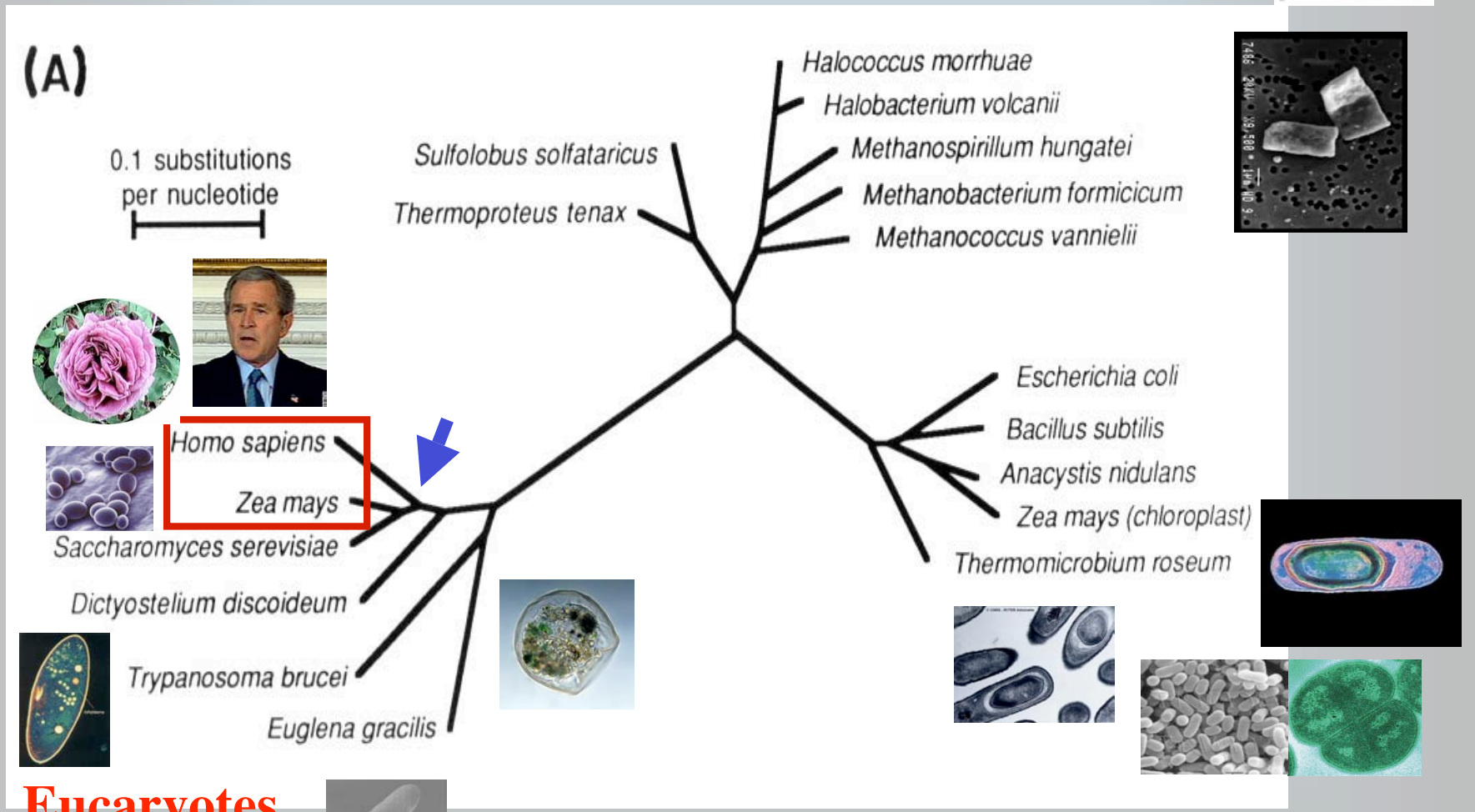
ARN16S







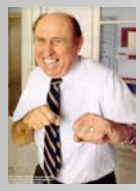
Archaea



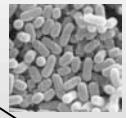
Eucaryotes

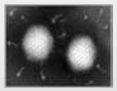
Bacteria

Macro-organismes




580 millions d'années






Micro-organismes

3-4 milliard d'années

Bacteries/Eucaryotes

Archaea

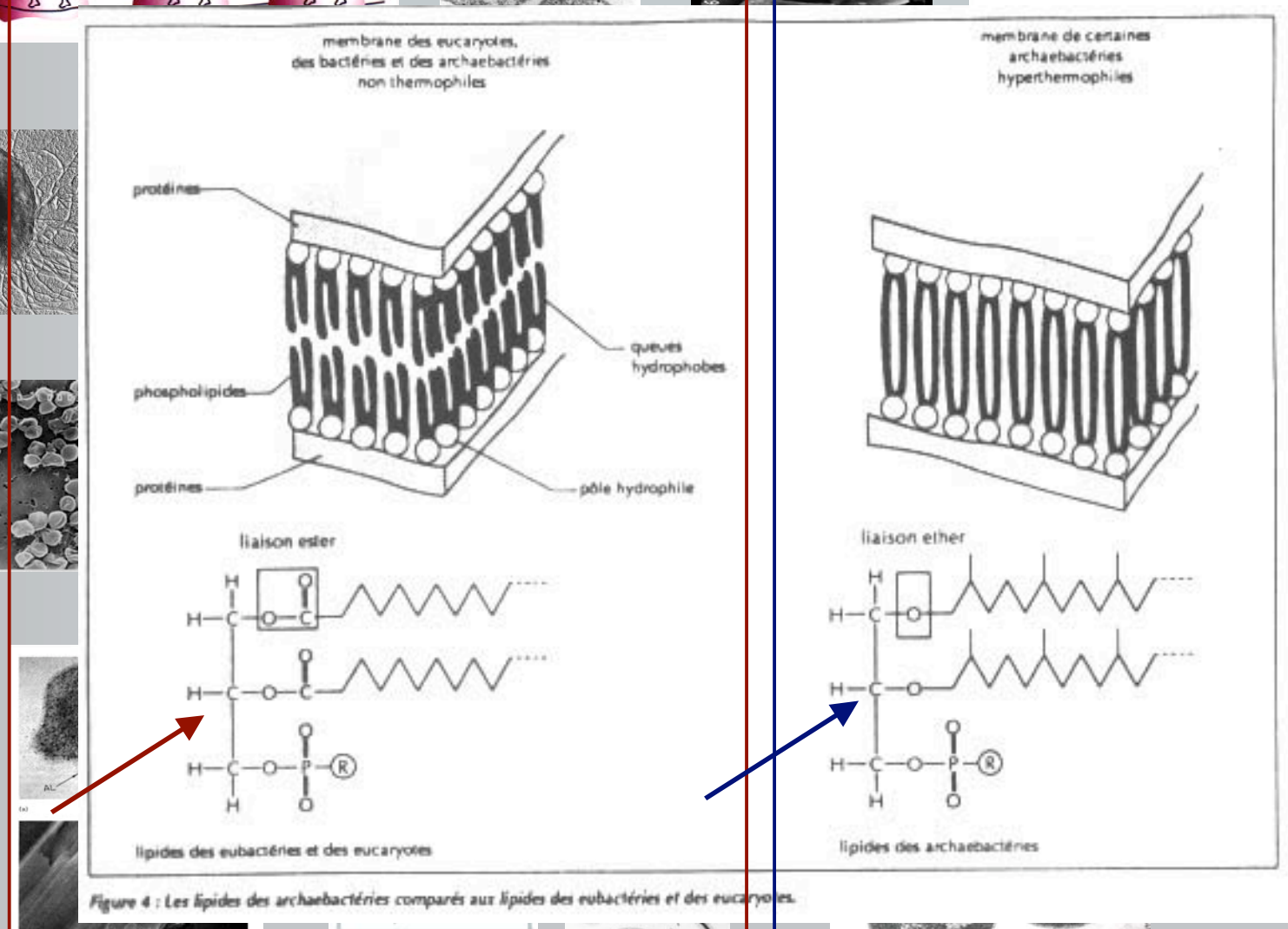
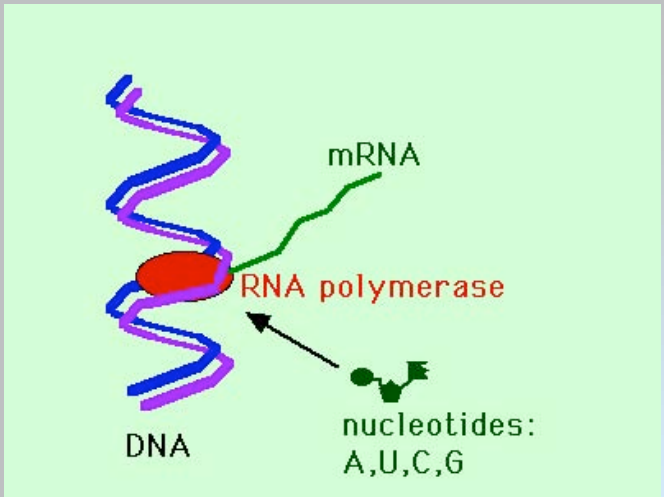


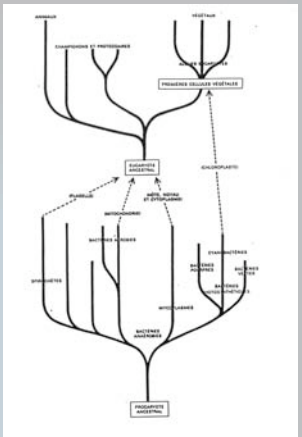
Figure 4 : Les lipides des archaebactéries comparés aux lipides des eubactéries et des eucaryotes.

D

L



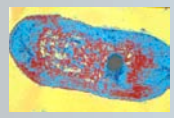
Transcription

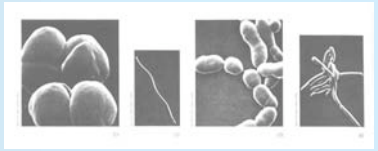


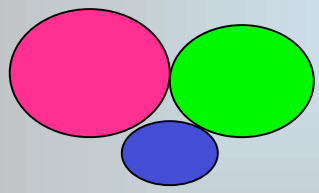
Eucarya

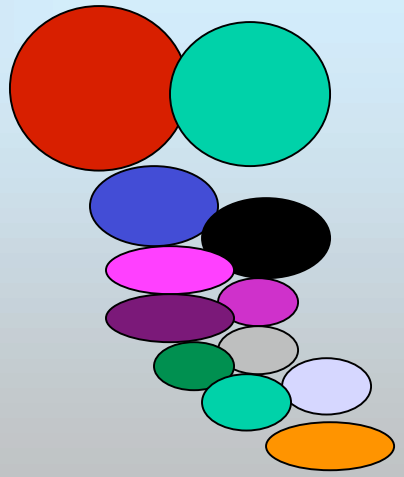
Archaea

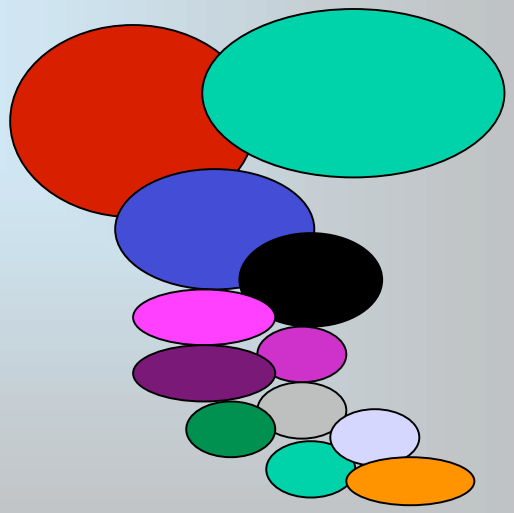
Bacteria











1990 Article « Toward a natural system of oragnisms: Proposal for the domains Archaea, Bacteria, and Eucarya. *Woese CR, Kandler O, Wheelis ML , Proc Natl Acad Sci U S A. 1990, 87:4576-9*

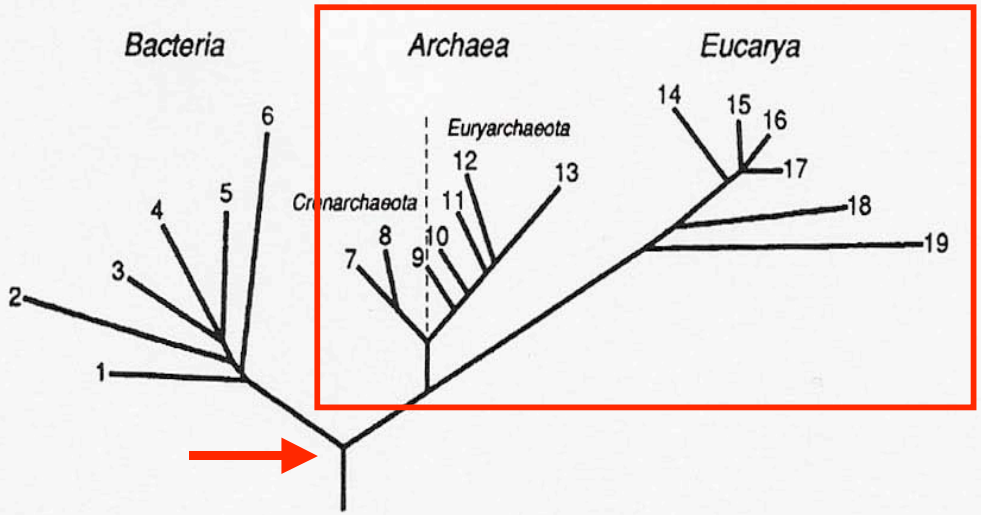
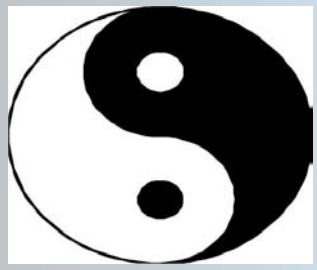


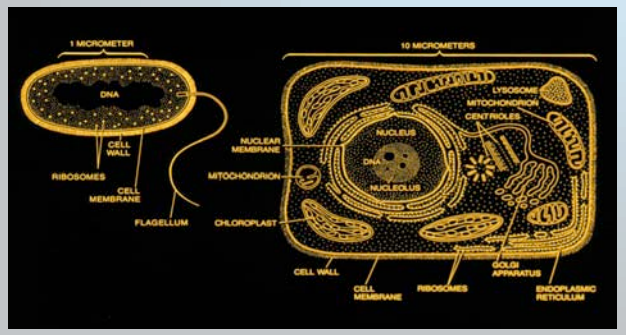
FIG. 1. Universal phylogenetic tree in rooted form, showing the three domains. Branching order and branch lengths are based upon rRNA sequence comparisons (and have been taken from figure 4 of ref. 2). The position of the root was determined by comparing (the few known) sequences of pairs of paralogous genes that diverged from each other before the three primary lineages emerged from their common ancestral condition (27). [This rooting strategy (28) in effect uses the one set of (aboriginally duplicated) genes as an outgroup for the other.] The numbers on the branch tips correspond to the following groups of organisms (2). Bacteria: 1, the Thermotogales; 2, the flavobacteria and relatives; 3, the cyanobacteria; 4, the purple bacteria; 5, the Gram-positive bacteria; and 6, the green nonsulfur bacteria. Archae: the kingdom Crenarchaeota: 7, the genus *Pyrodictium*; and 8, the genus *Thermoproteus*; and the kingdom Euryarchaeota: 9, the Thermococcales; 10, the Methanococcales; 11, the Methanobacteriales; 12, the Methanomicrobiales; and 13, the extreme halophiles. Eucarya: 14, the animals; 15, the ciliates; 16, the green plants; 17, the fungi; 18, the flagellates; and 19, the microsporidia.

En 2003, il reçoit le prix Craaford à Stockholm

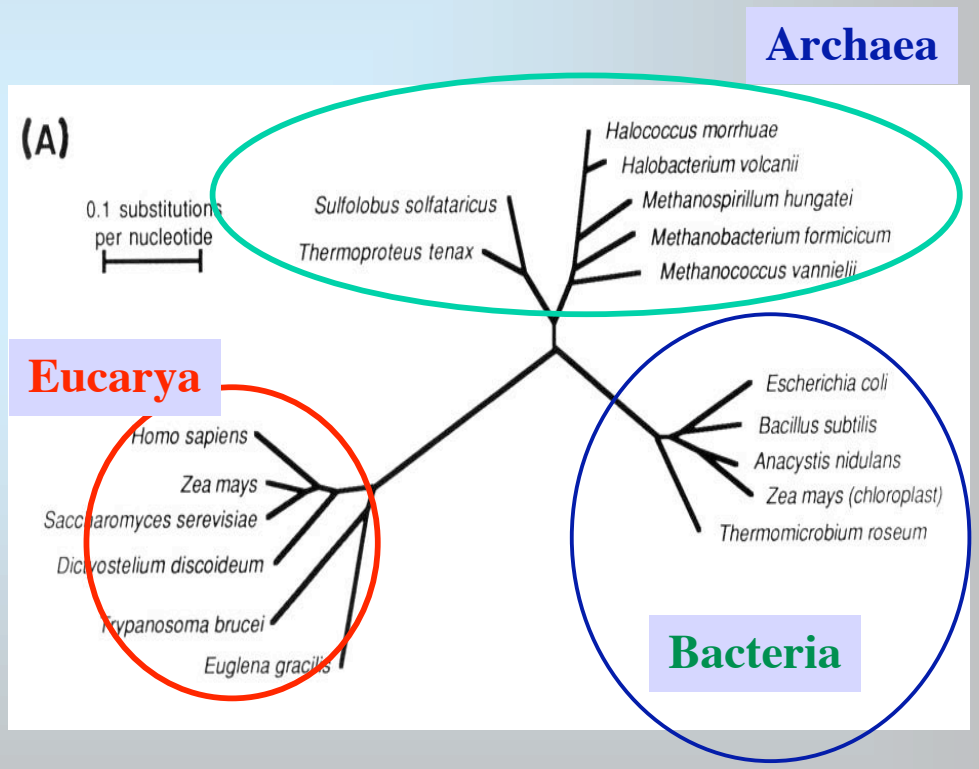
Le concept des trois domaines et l'abandon de la dichotomie eucaryote/procaryote ne sont pas encore accepté par tous les biologistes

soit dans la théorie, soit dans la pratique



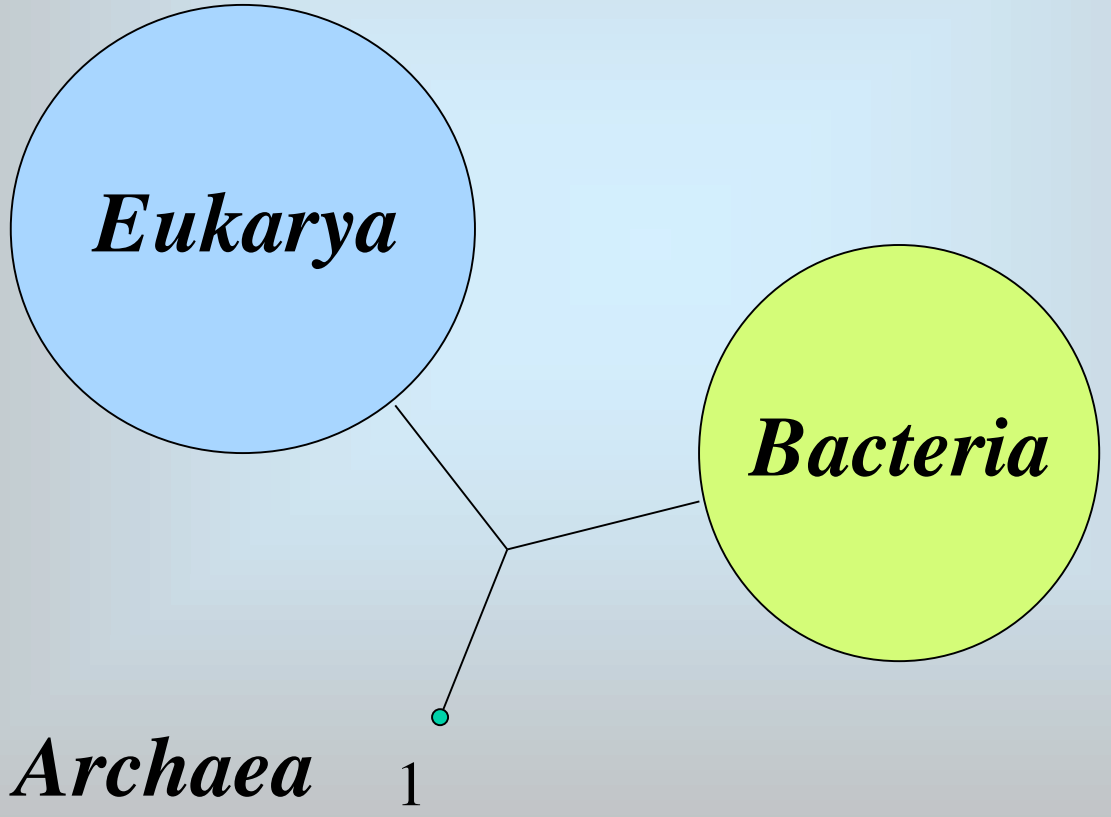



LA SAINTE TRINITE

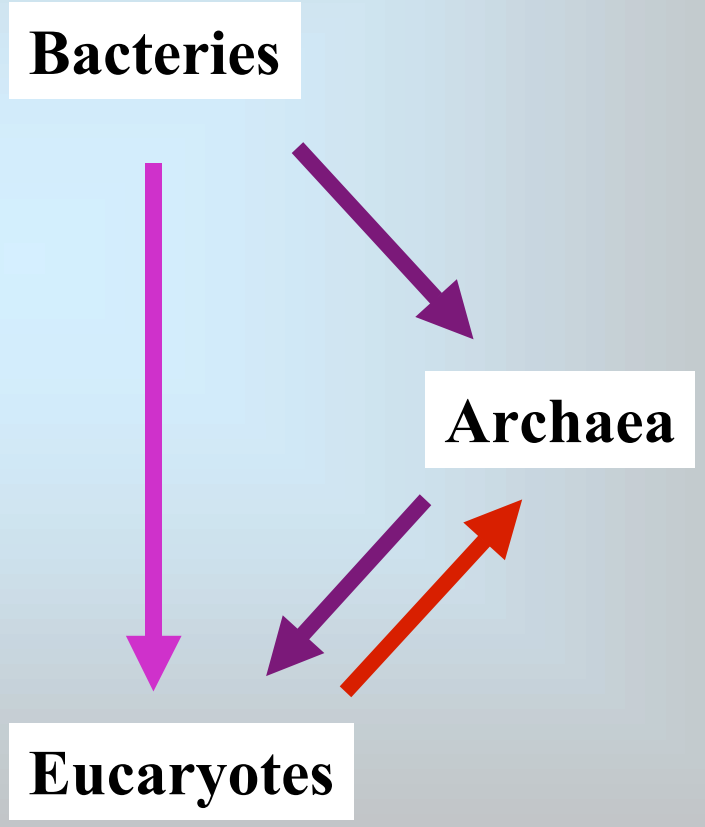

Archaea
(A)
0.1 substitutions per nucleotide
Halococcus morrhuae
Halobacterium volcanii
Methanospirillum hungatei
Methanobacterium formicicum
Methanococcus vannielii
Sulfolobus solfataricus
Thermoproteus tenax
Eucarya
Homo sapiens
Zea mays
Saccharomyces serevisiae
Dictyostelium discoideum
Trypanosoma brucei
Euglena gracilis
Escherichia coli
Bacillus subtilis
Anacystis nidulans
Zea mays (chloroplast)
Thermomicrobium roseum
Bacteria

INSTITUT PASTEUR

L ’arbre universel du vivant à l’Institut Pasteur

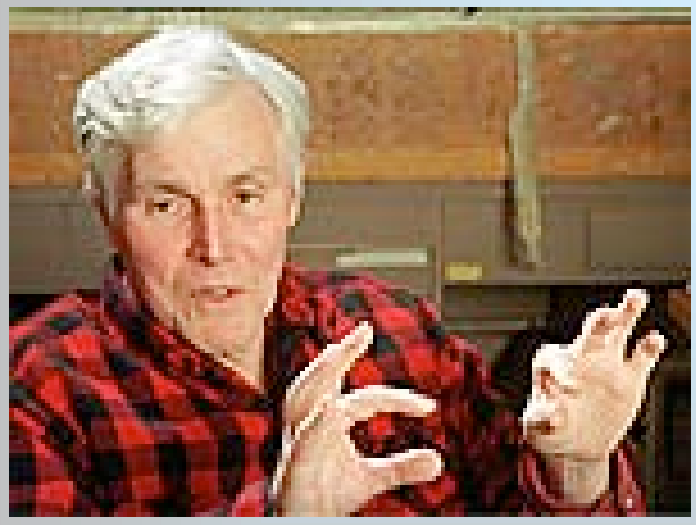


Ce qui est vrai pour le colibacille est vrai pour l'éléphant (Jacques Monod)

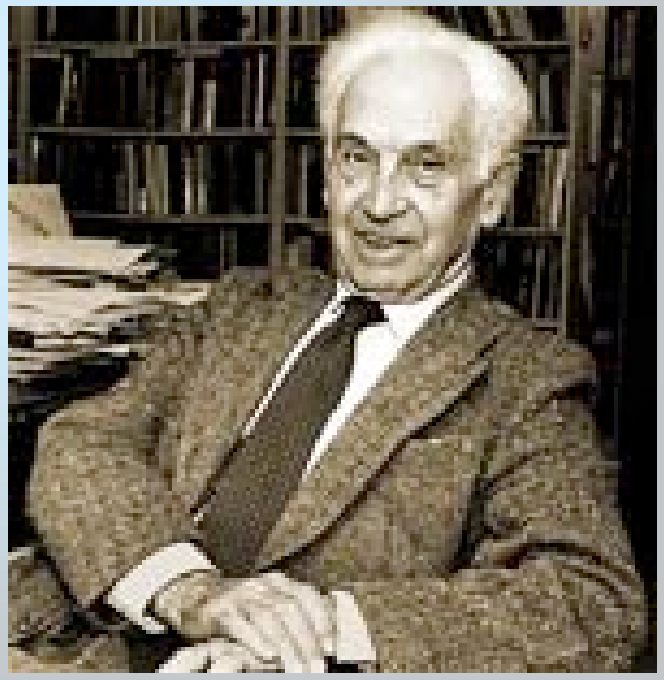


Un petit nombre d'évolutionistes Anglo-Saxon veulent maintenir la dichotomie eucaryote/procaryote
(Lynn Margulis, Tom Cavalier-Smith, Ernst Mayr)
Gradisme

1998: controverse avec Ernst Mayr (PNAS)

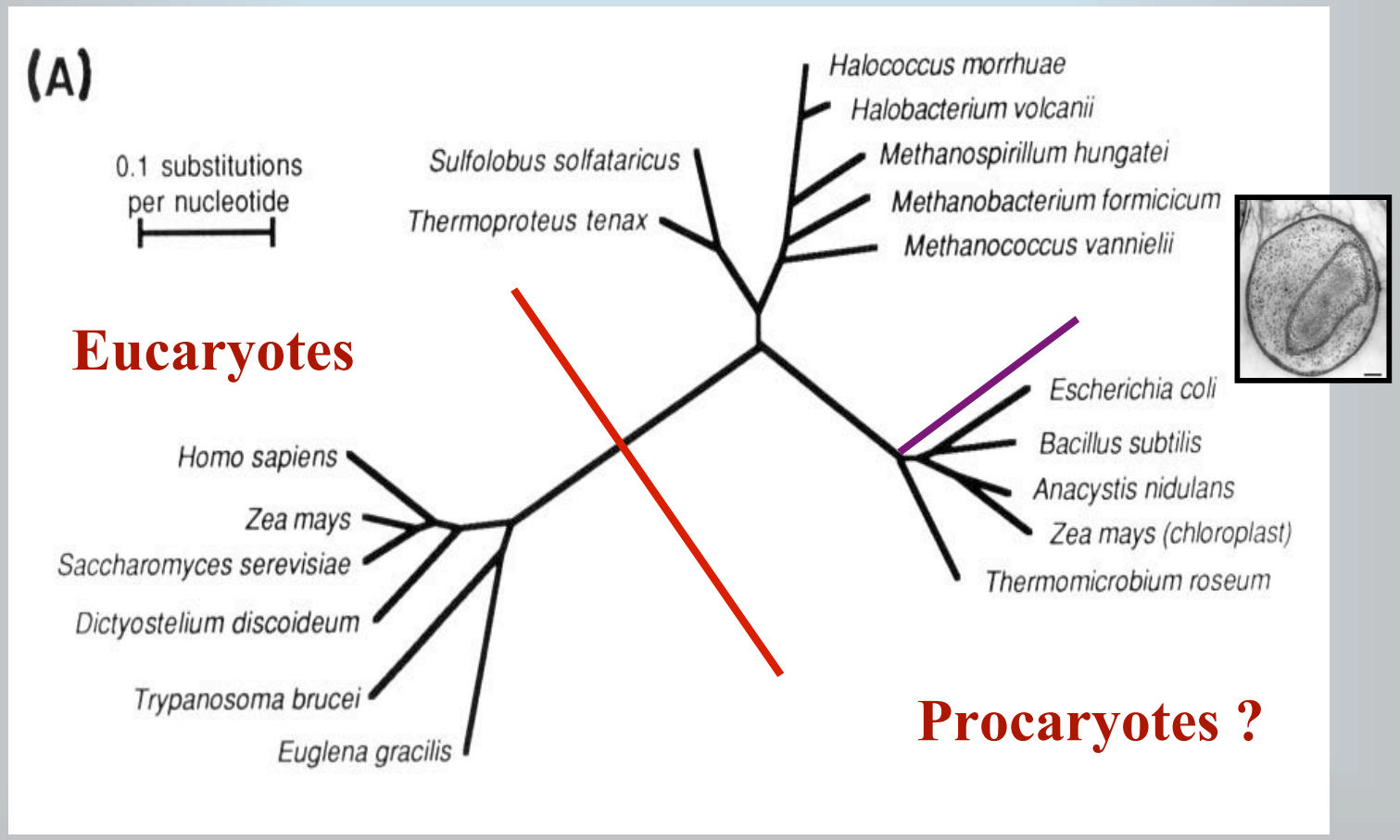


Carl R. Woese

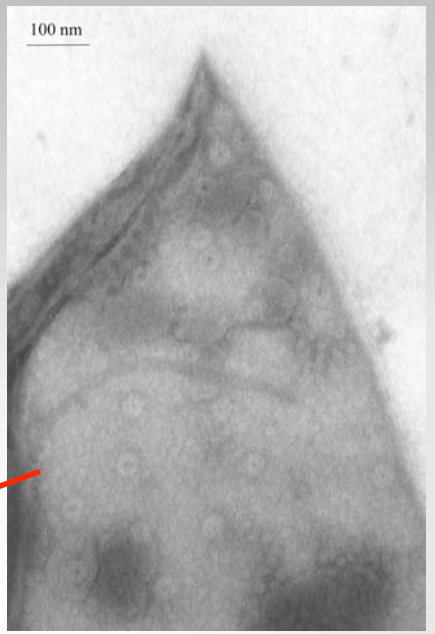


Ernst Mayr

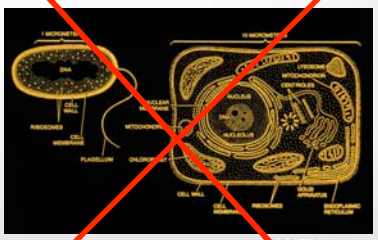
Peut-on en finir une fois pour toute avec la distinction procaryote/eucaryote ?

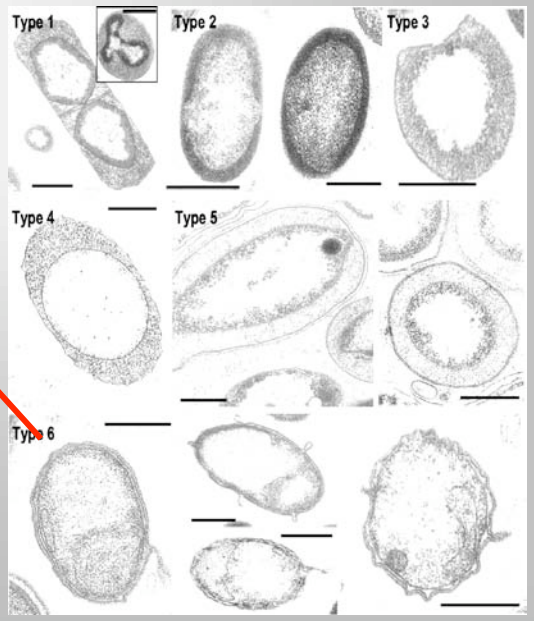


Gemmata obscuriglobus
Une bactérie eucaryote ?



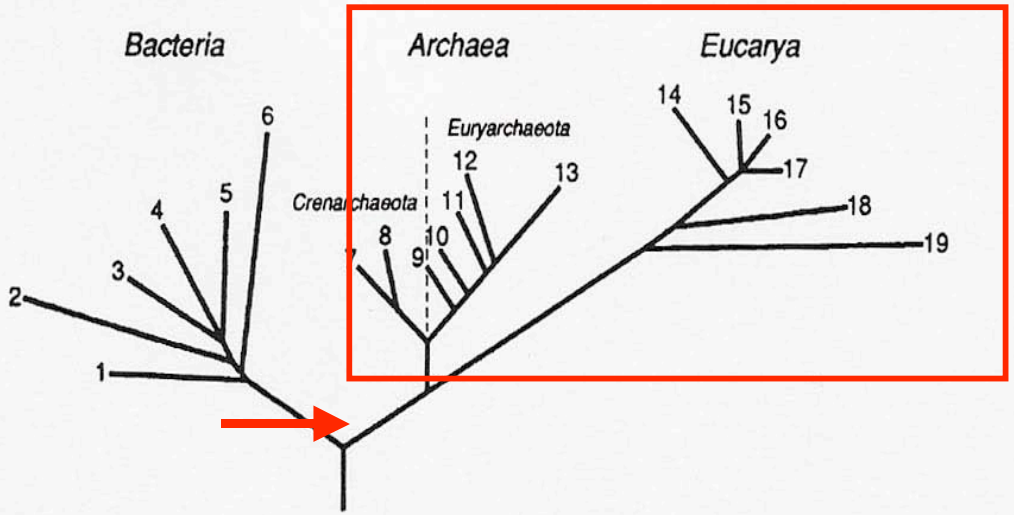
John Fuerst (Australie)





Cell compartmentalization in symbionts from *Aplysina aerophoba* sponge

L'arbre de Woese : Cladisme ou Gradisme ?



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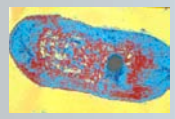
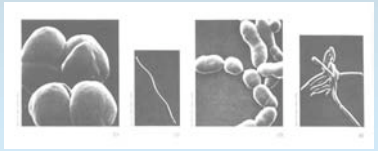
Le retour du gradisme

The Darwinian threshold (Woese, 2000)

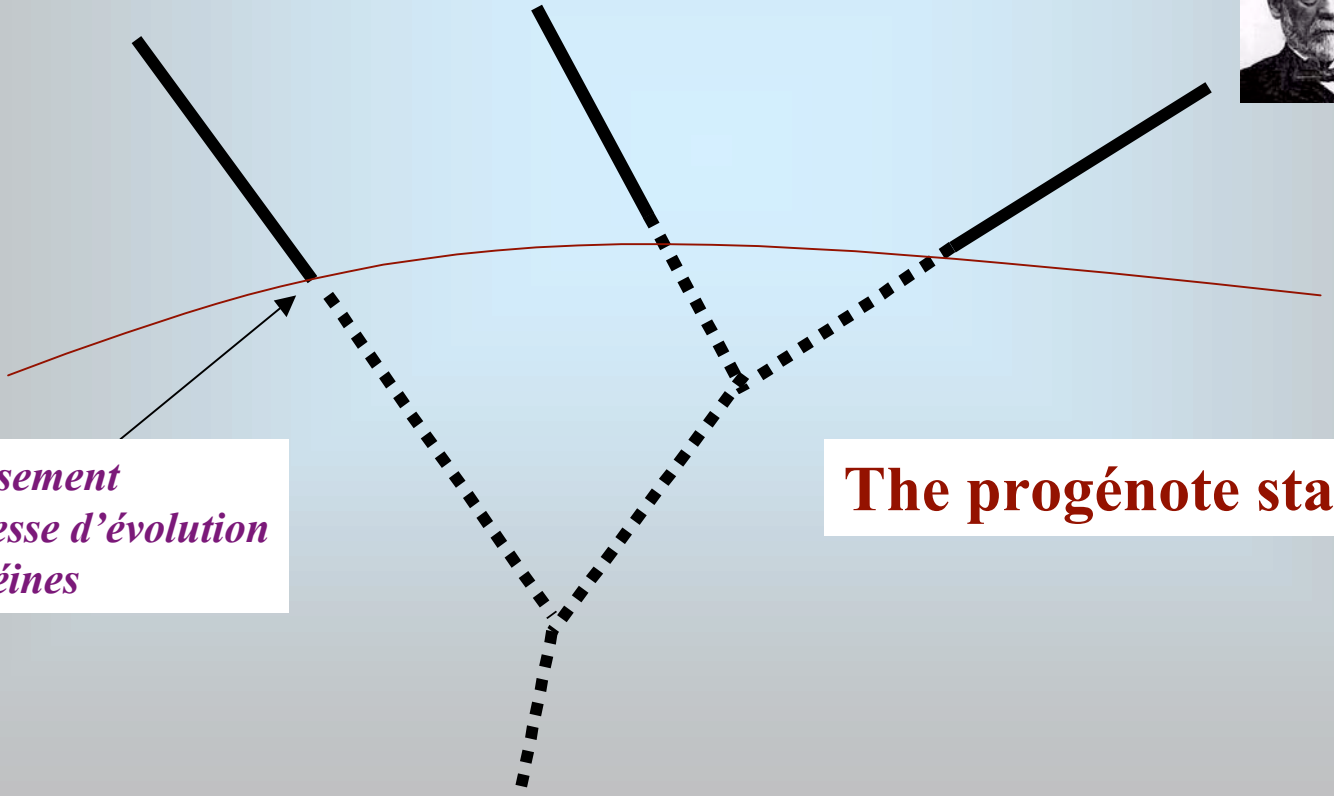
Bactéries



Archées

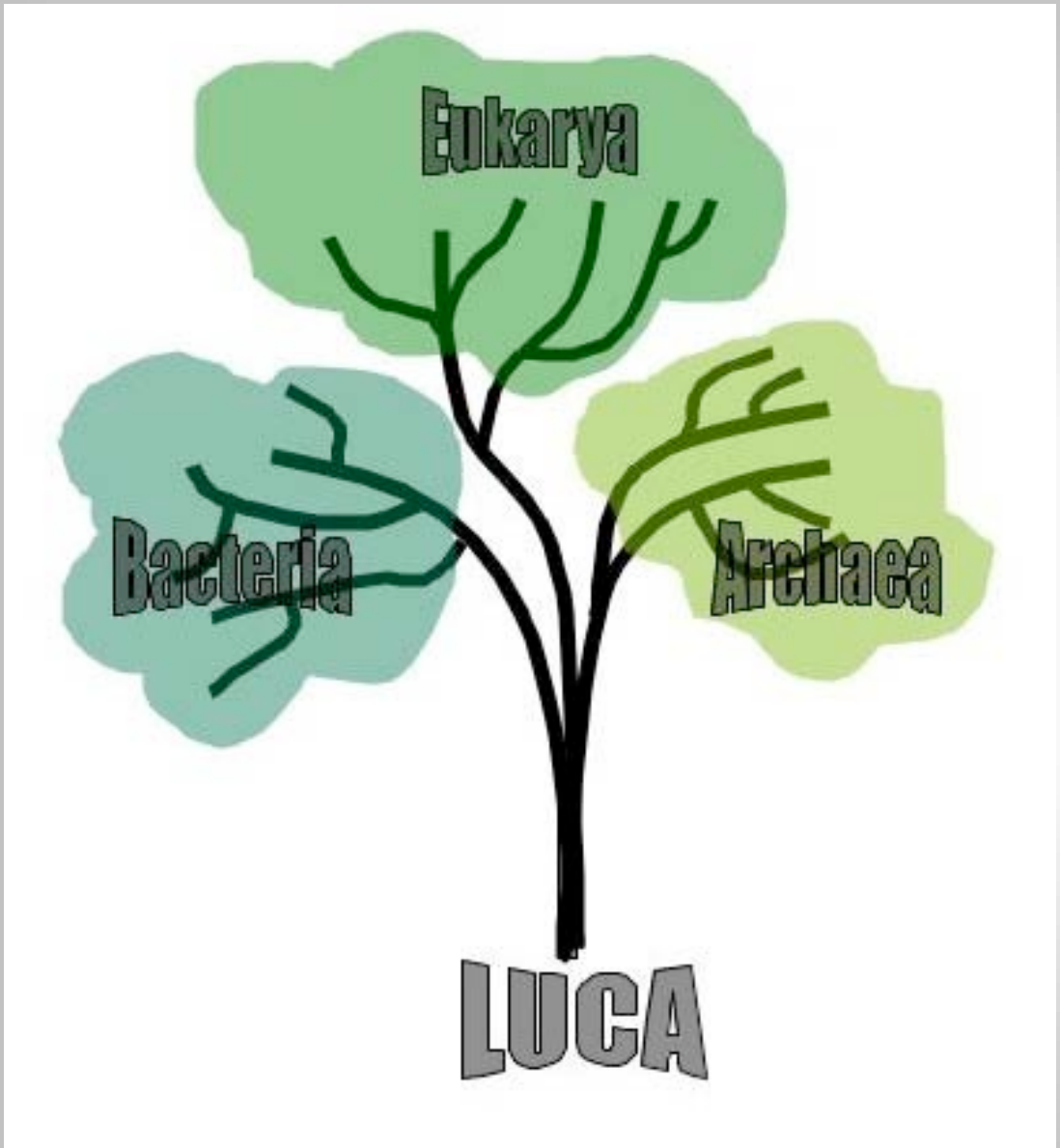


Eucarya



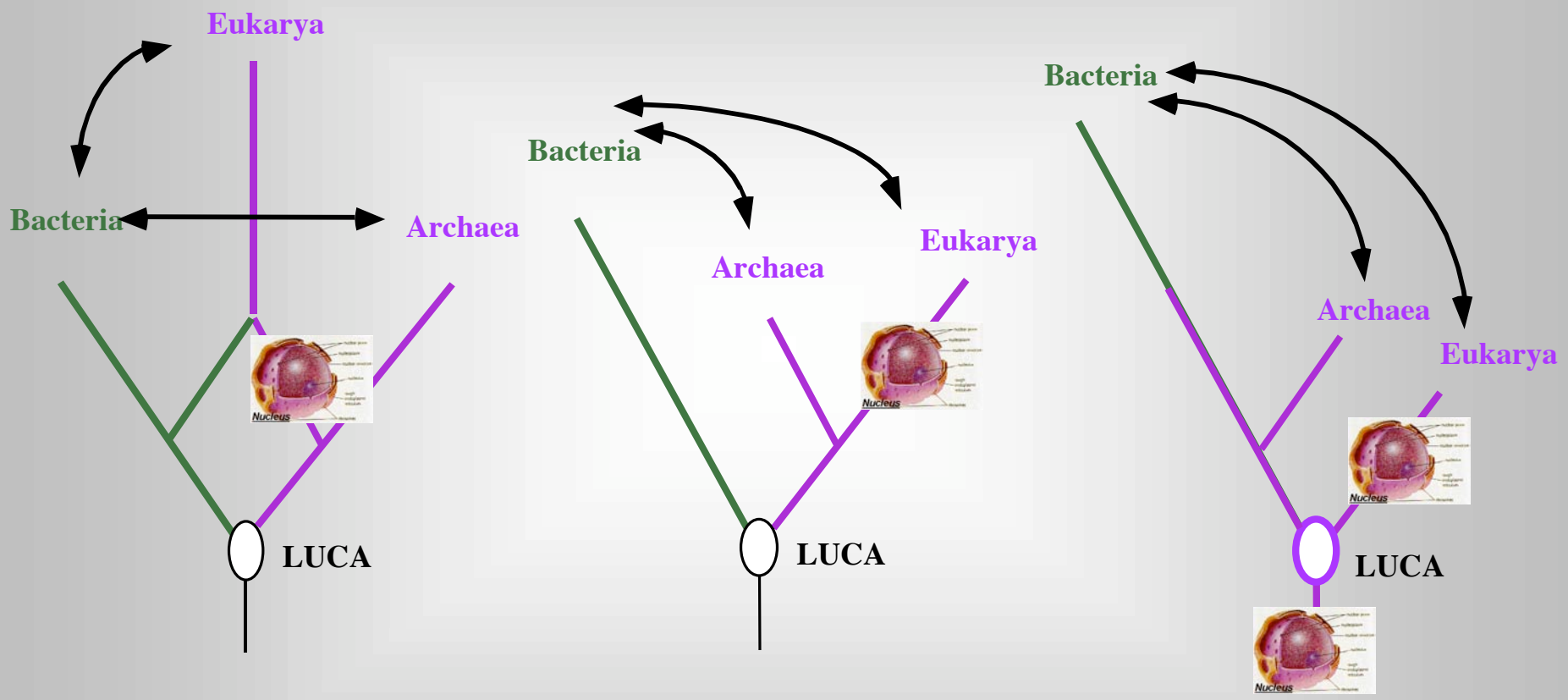
Ralentissement de la vitesse d'évolution des protéines

The progénote stage

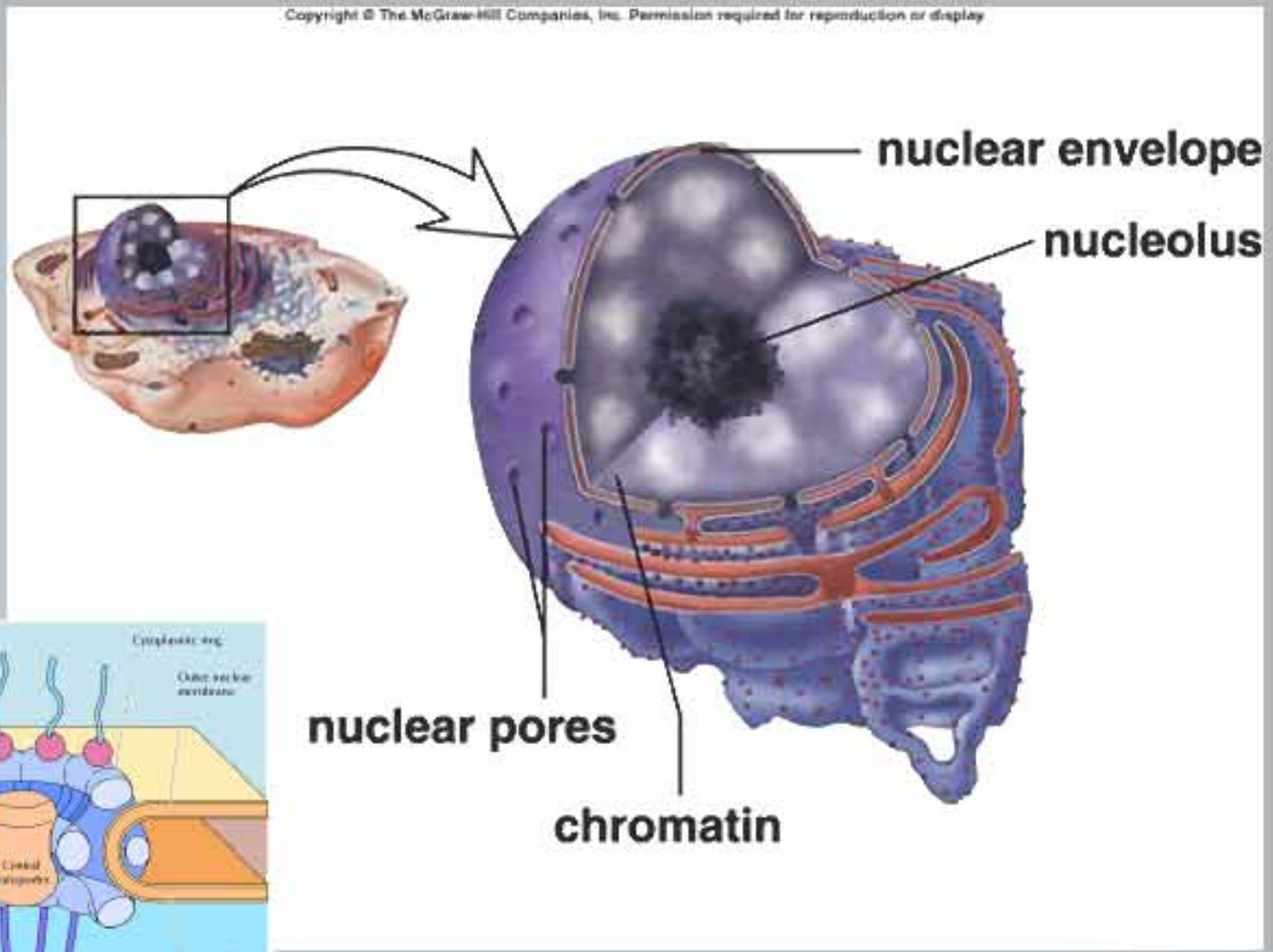


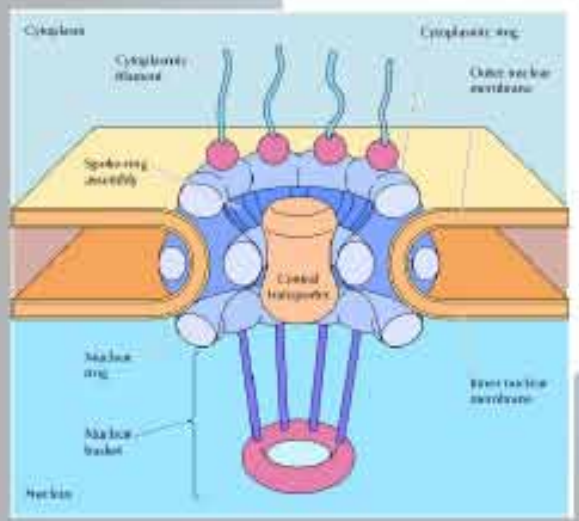
LUCA :
the
Last
Universal
Common
Ancestor

Three possible models for the Universal Tree of life

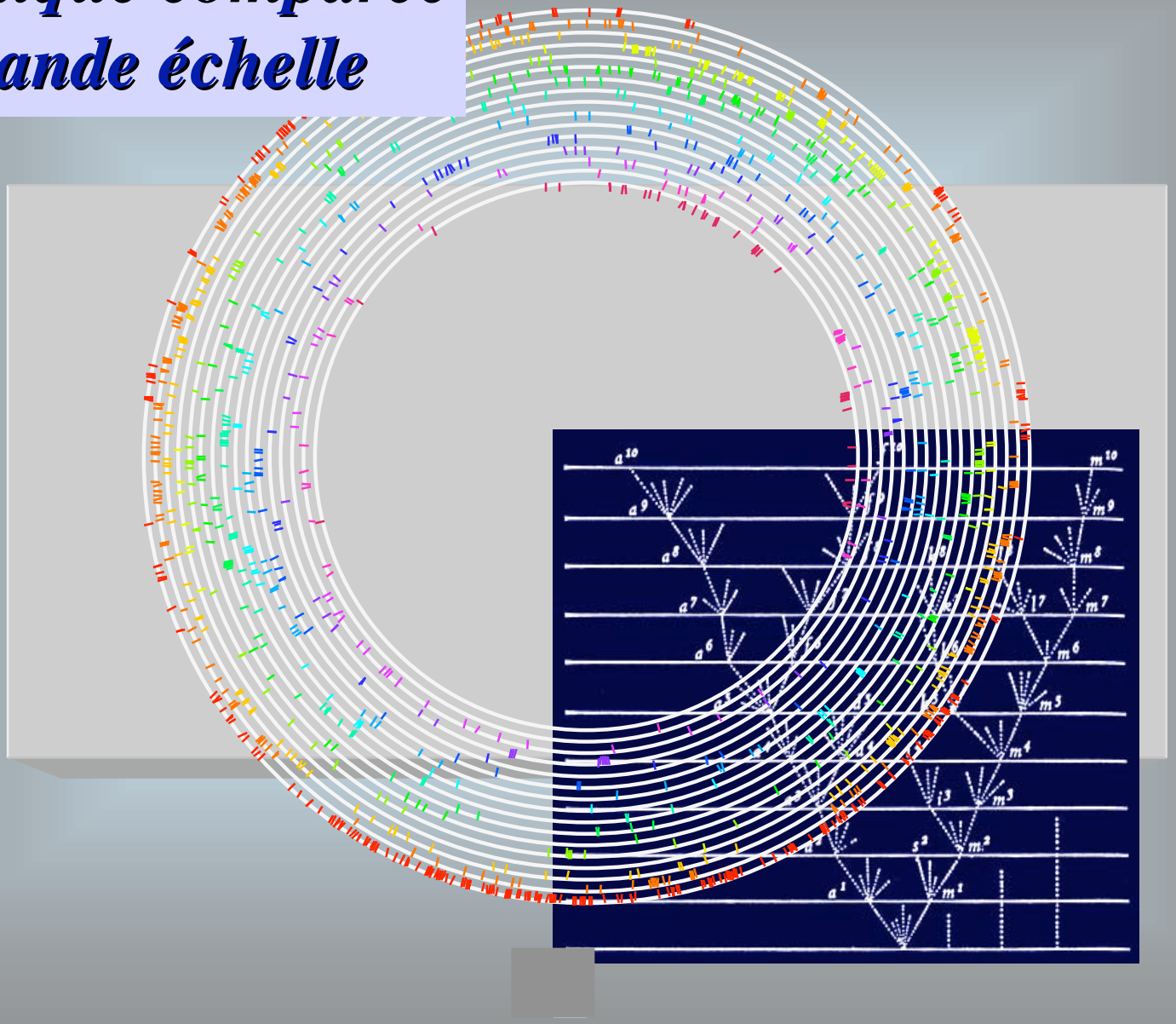


Informational proteins





Génomique comparée à grande échelle



La révolution génomique

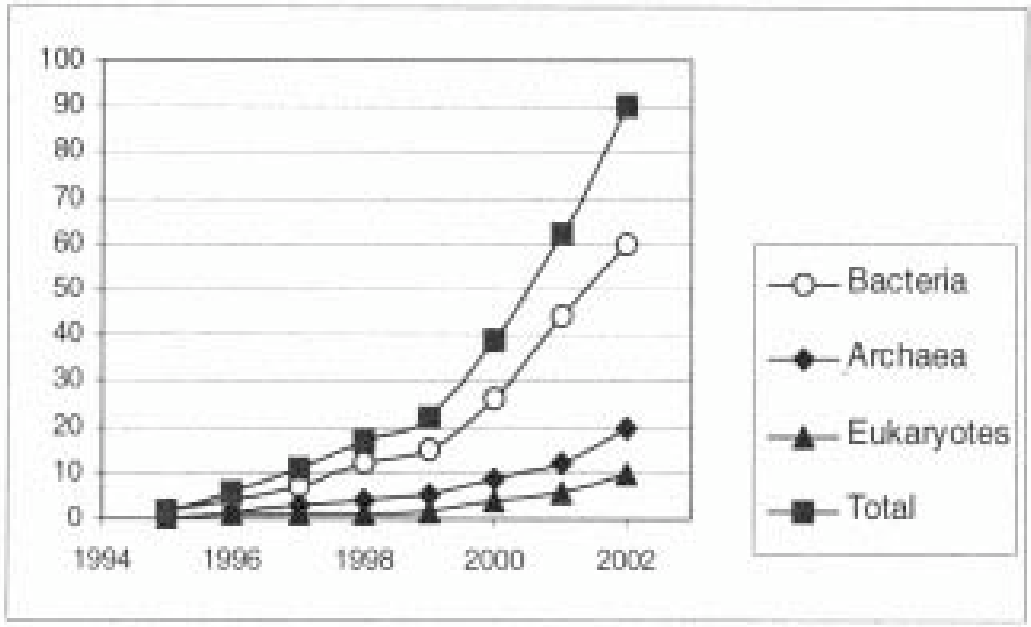
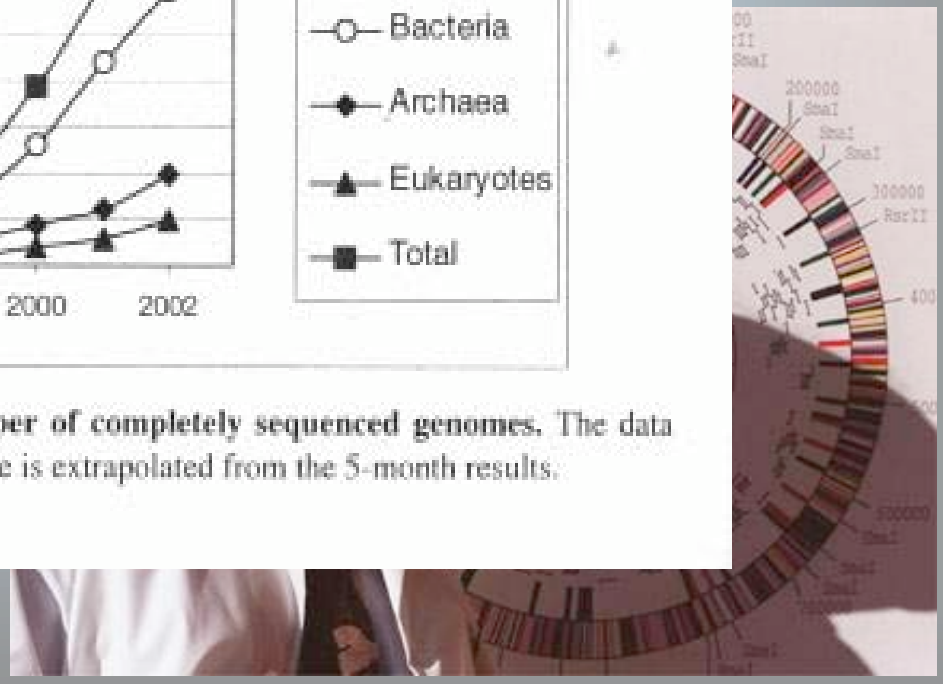


Figure 1.1. Growth of the number of completely sequenced genomes. The data are from Table 1.4. The 2002 figure is extrapolated from the 5-month results.



Les protéines universelles : sans doute héritées de LUCA

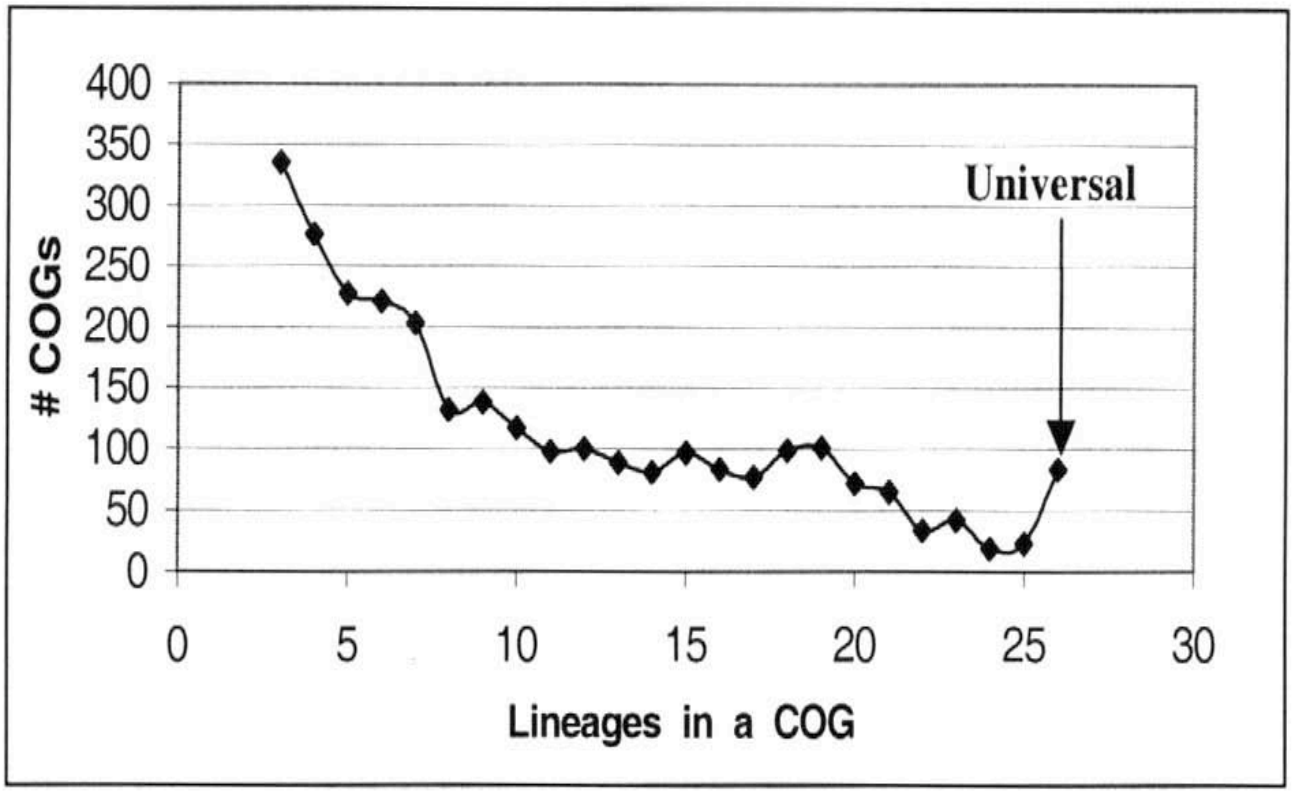
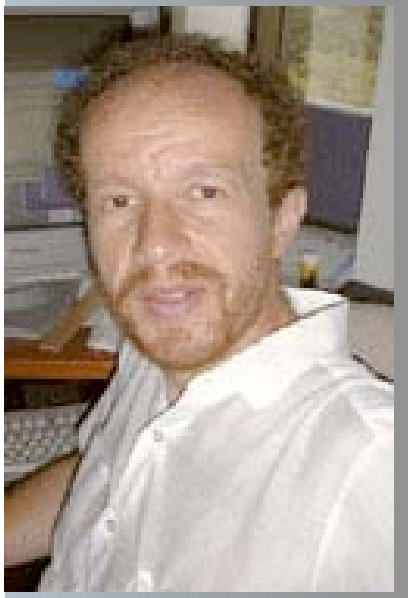


Figure 2.8. Distribution of different phylogenetic lineages in the COG database. The plot shows the number of protein families (COGs) in a release of the COG database (♦3.4), which included proteins from the given number of phylogenetic lineages out of the total of 26 lineages [827].



Eugene Koonin (NCBI)

Les 60-100 protéines Universelles

30-40 protéines ribosomales
des amino-acyl tRNA synthétase
Facteurs d'élongation

Synthèse des protéines

Facteurs impliquées dans le localisation des protéines membranaires

LUCA avait une membrane

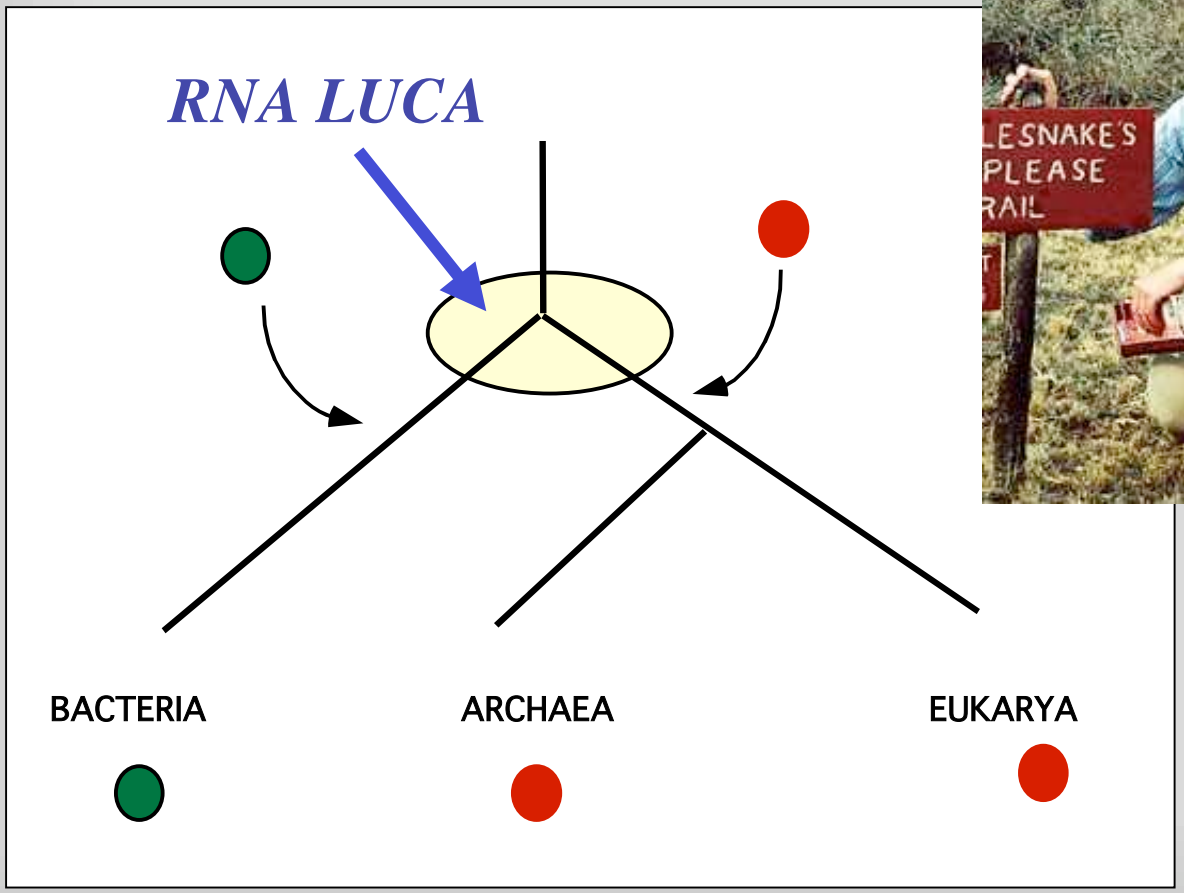
ATP synthétases

ARN polymérases
Quelques protéines 3R (recombinaison de l'ADN)

On ne trouve pas dans la liste les protéines qui répliquent l'ADN ??

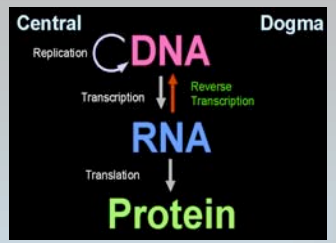
Koonin's hypothesis : twice independent invention of DNA and DNA replication mechanisms

(Mushegian and Koonin, PNAS, 1996)

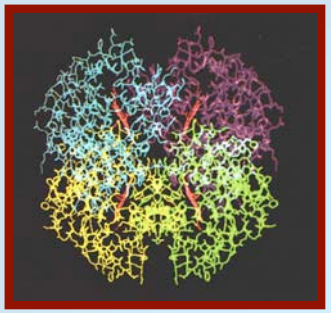


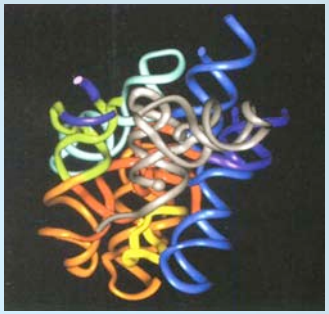
LUCA faisait-il encore parti du monde à ARN (Progénote)

Monde à ARN

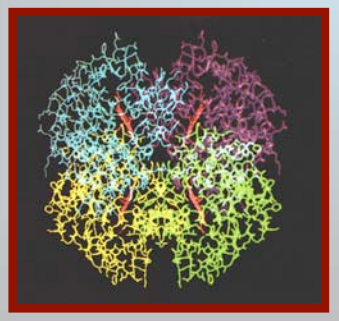


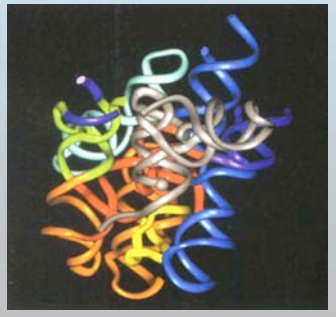
Monde à ARN + protéines





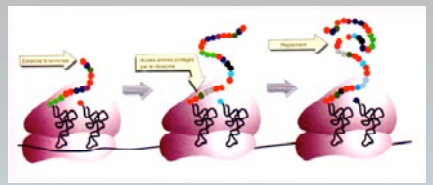
Monde à ADN



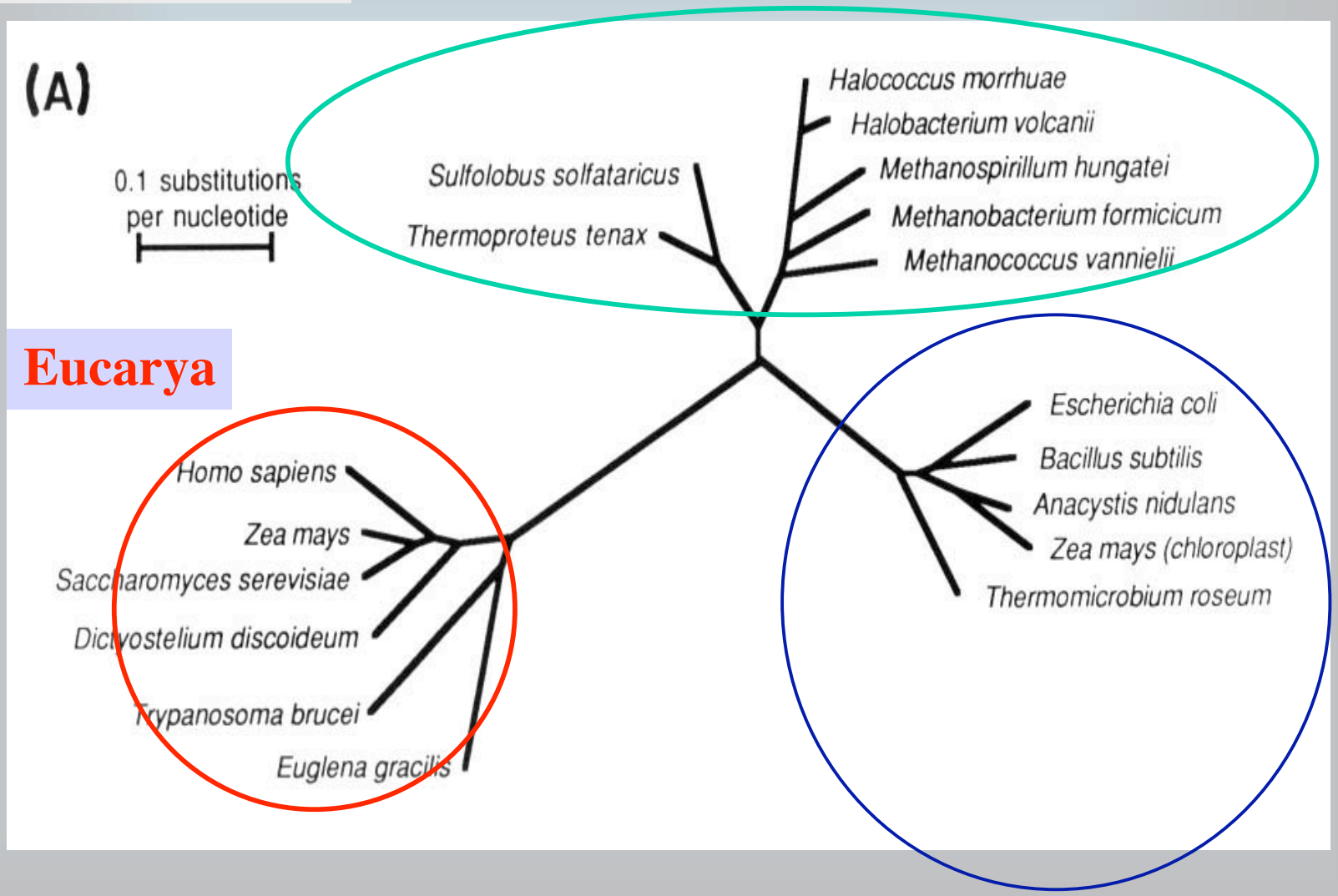


LUCA ?

Ou sont les virus dans l'arbre universel ?

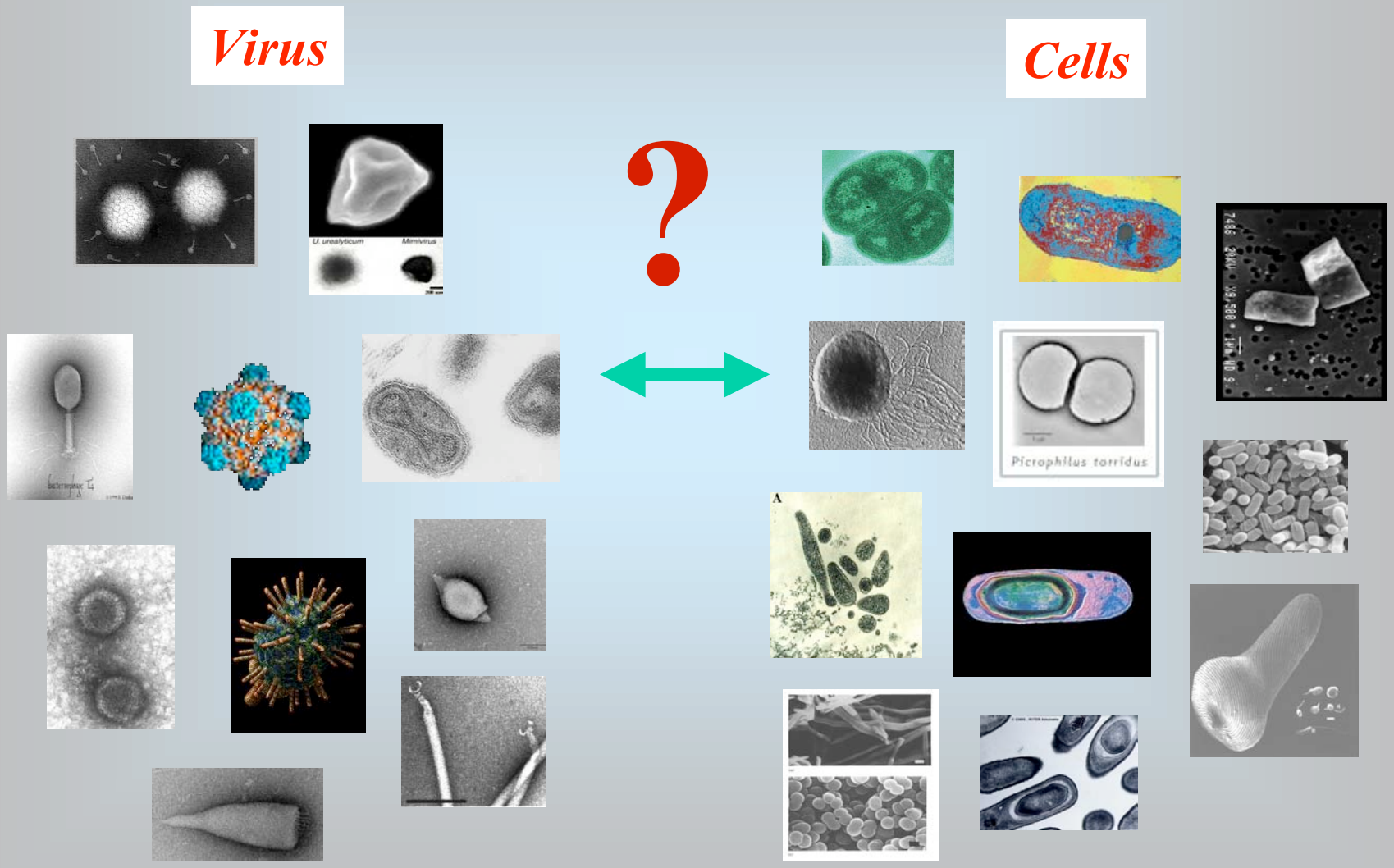


Archaea



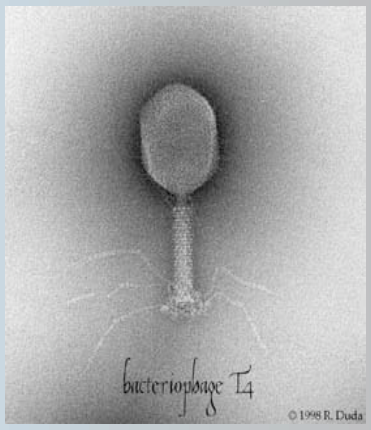
Eucarya

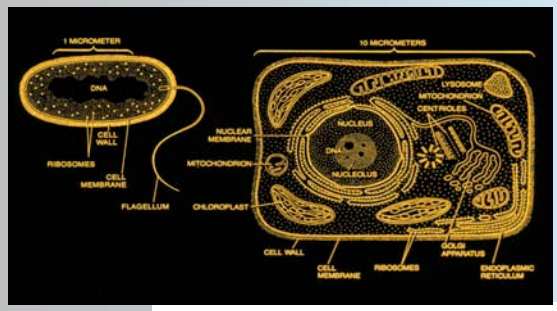
Quelles relations évolutives entre organismes cellulaires et virus ?

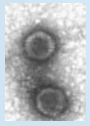


Hypothèse la plus populaires : les virus sont des gènes qui sont devenus indépendants ?

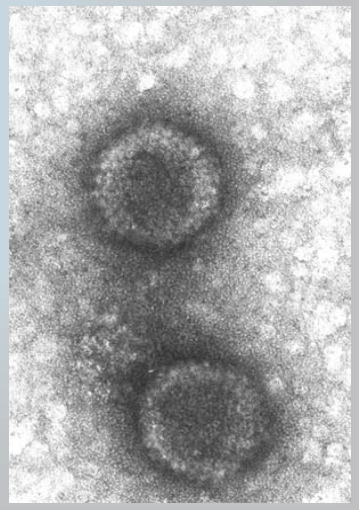
Gènes bactériens → **Génomes de bactériophages**







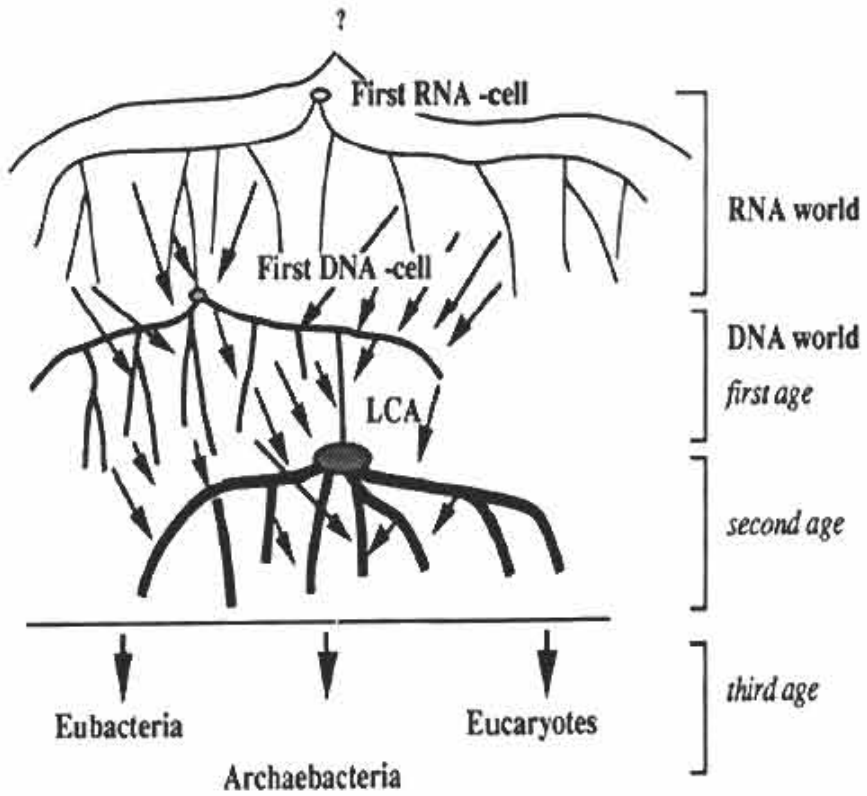
Gènes eucaryotes → **Génomes de virus « eucaryotes »**



Elle est basée sur l'ancient concept procaryote/eucaryote

Third "Rencontres de Blois"
Château de Blois, France - October 14-19, 1991

"Frontiers of Life"

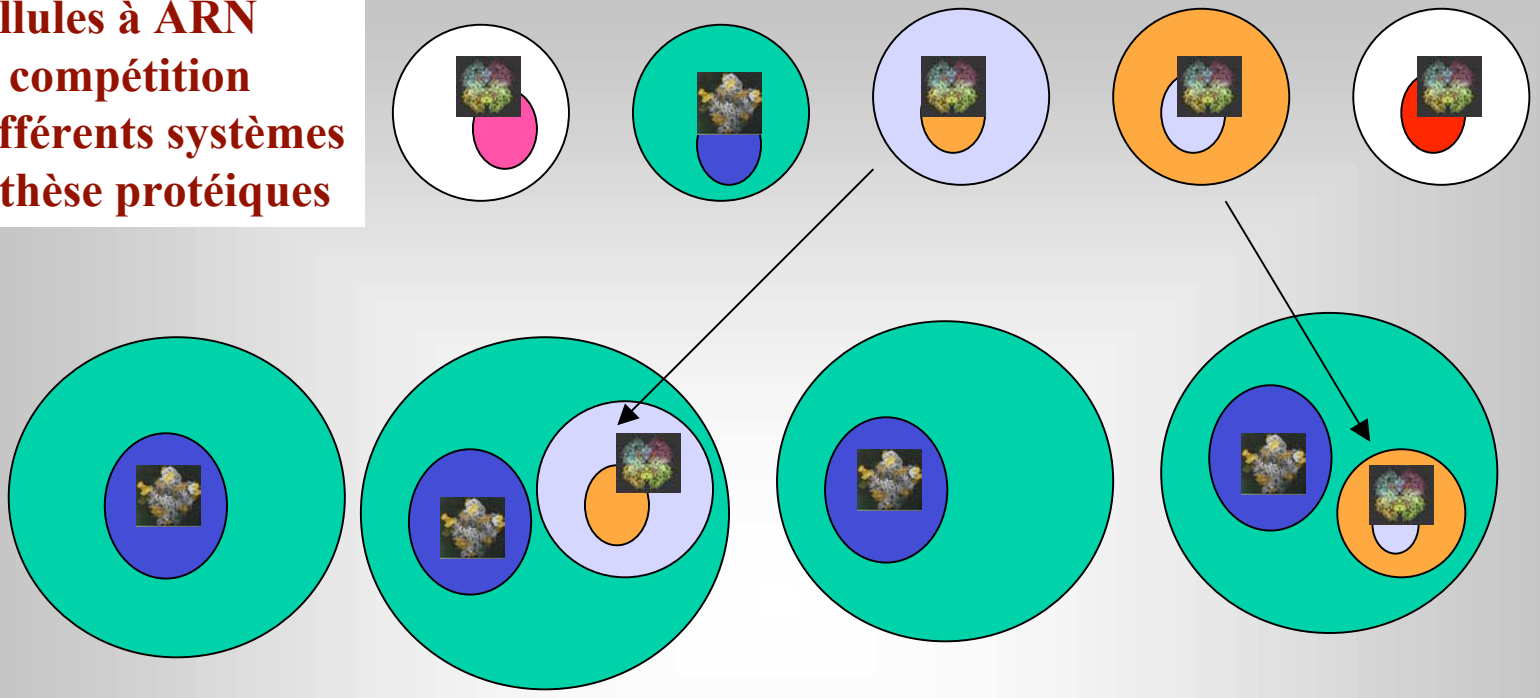


NEW HYPOTHESES ABOUT THE ORIGINS OF VIRUSES, PROKARYOTES AND EUKARYOTES

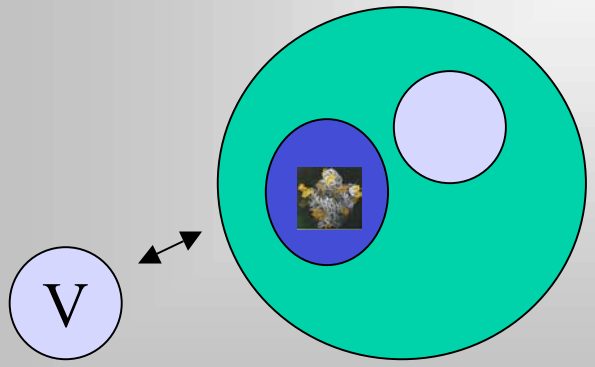
Patrick FORTERRE

Institut de Génétique et Microbiologie, Bat. 409, Université Paris-Sud, 91405, Orsay Cedex, France

Cellules à ARN
en compétition
avec différents systèmes
de synthèse protéiques

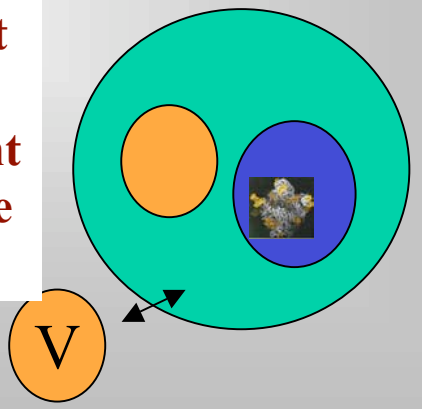


Le type « vert » avec l'ancêtre du ribosome actuel a éliminé tous ses compétiteurs

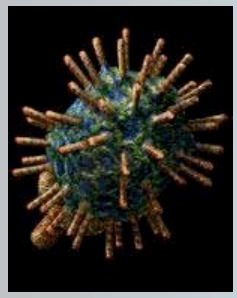


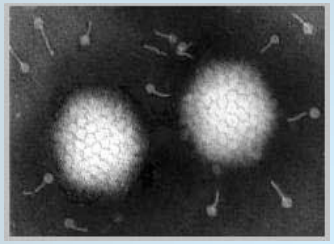
Ils se transforment en virus

Les ancient types qui ont survécu en parasitant le type « vert » abandonnent leurs système de synthèse protéiques



Il existe des caractères homologues entre virus animaux et bactériophages: origine commune avant LUCA ?



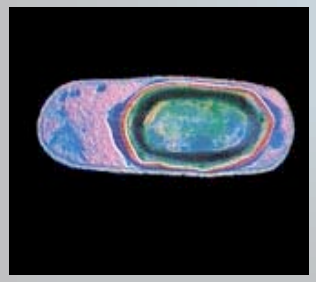


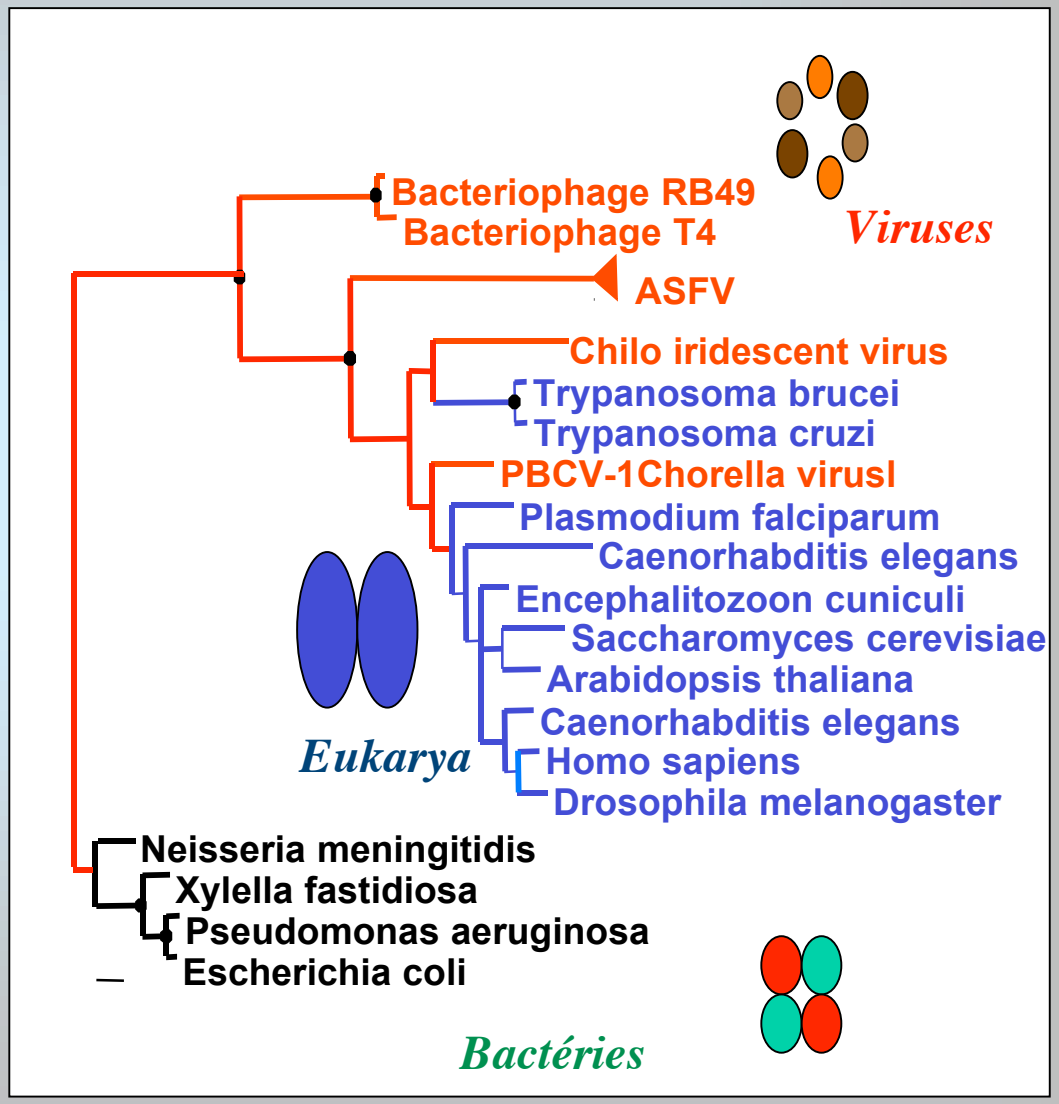
Génome du **bactériophage Φ29**

(*B. subtilis*)

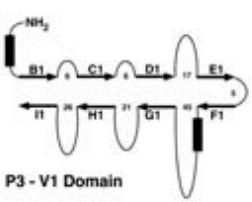
Génome des **Adenovirus**

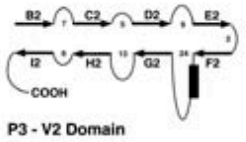
(*Homo sapiens*)

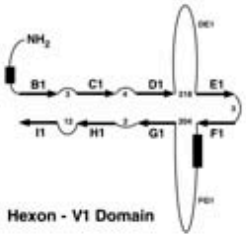


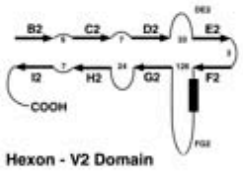


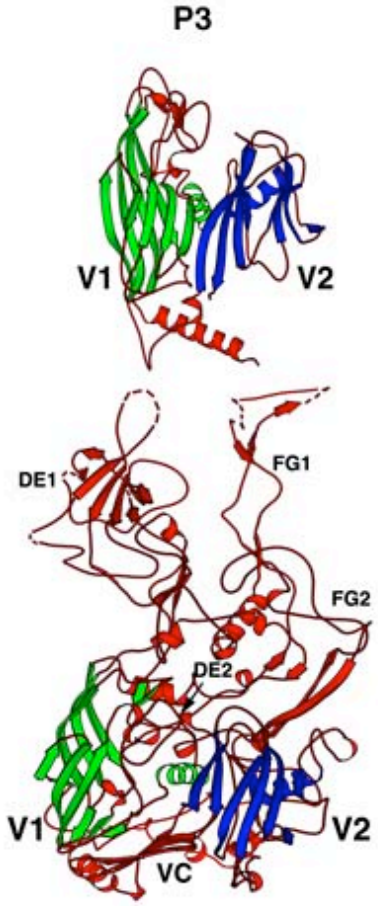
Dennis Bamford
(Université d'Helsinki)

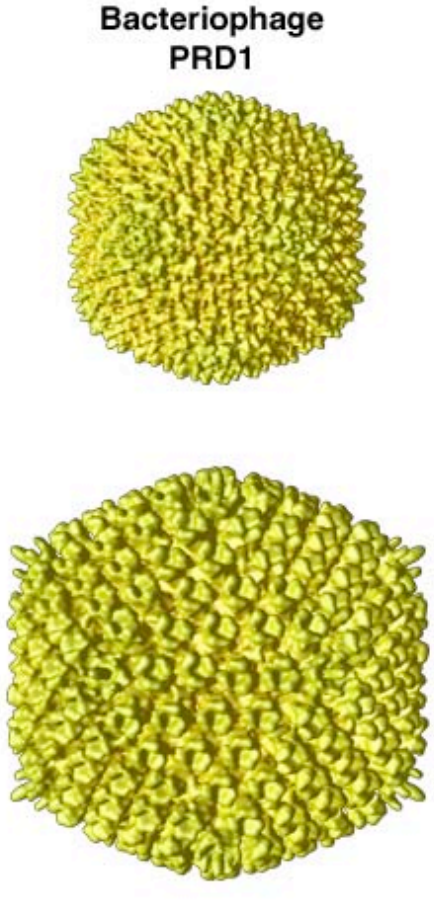


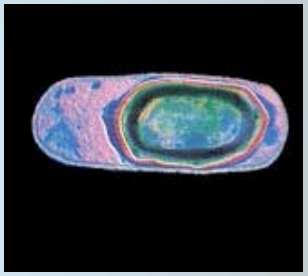




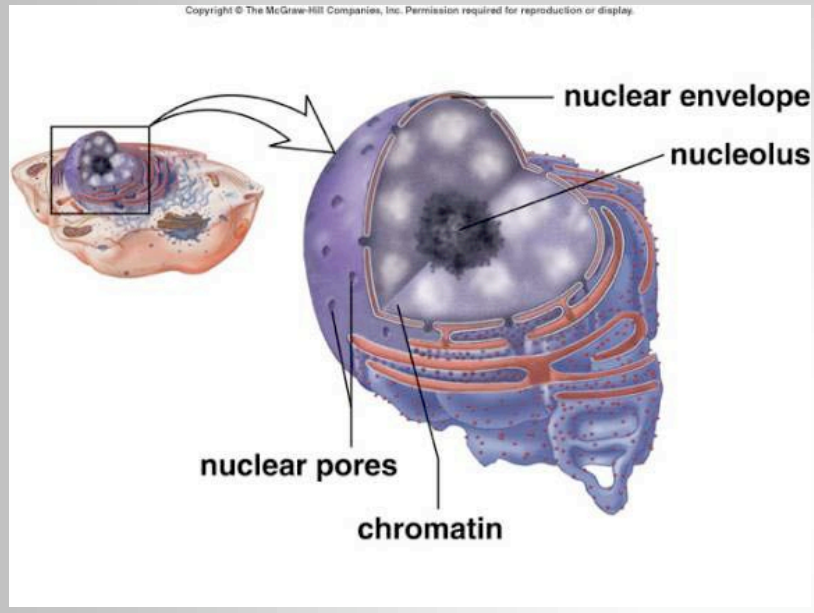








Le retour des virus !



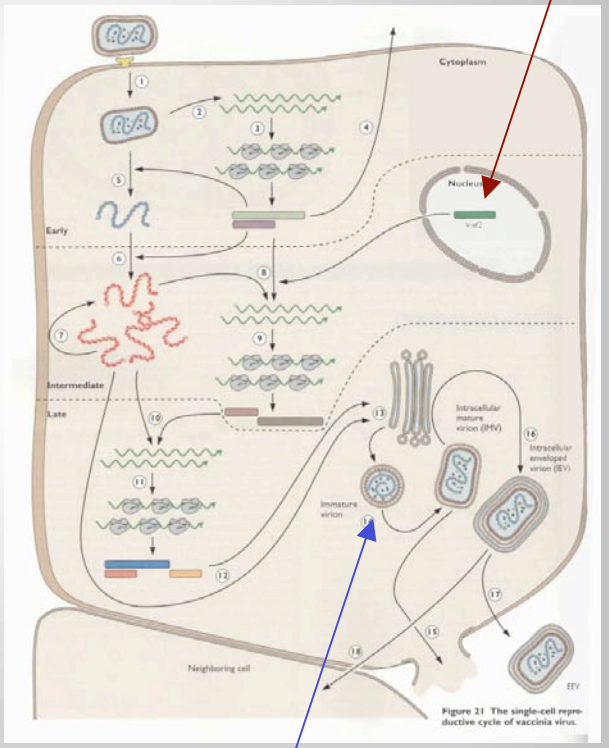
Le noyau des cellules eucaryotes dériverait d'un grand virus à ADN

Takemura, J Mol Evol, 2001

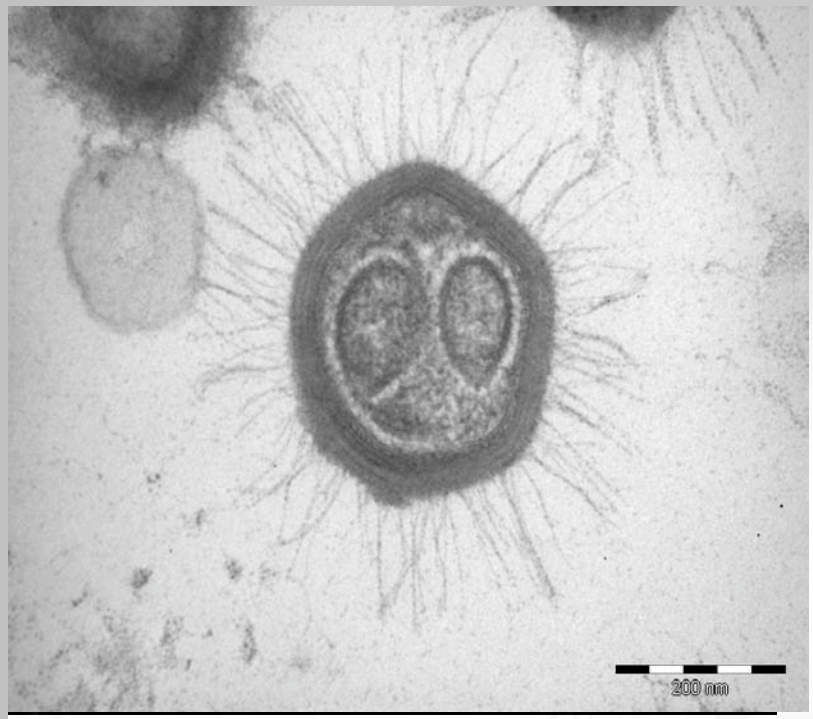
Bell, LJ. Mol. Evol. 2001

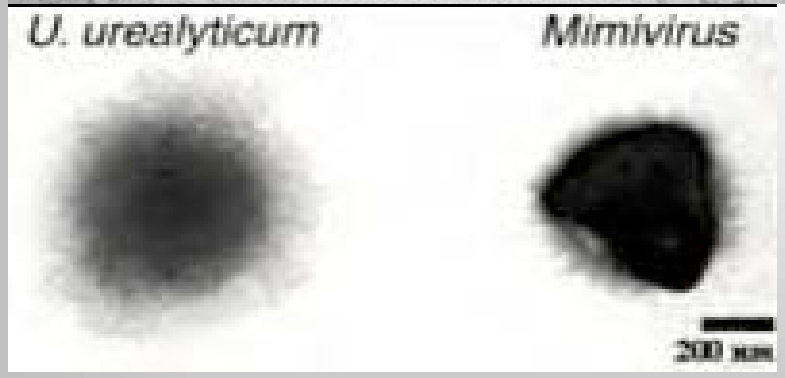
Cycle du virus de la variole

noyau



Mini-noyau (variole)



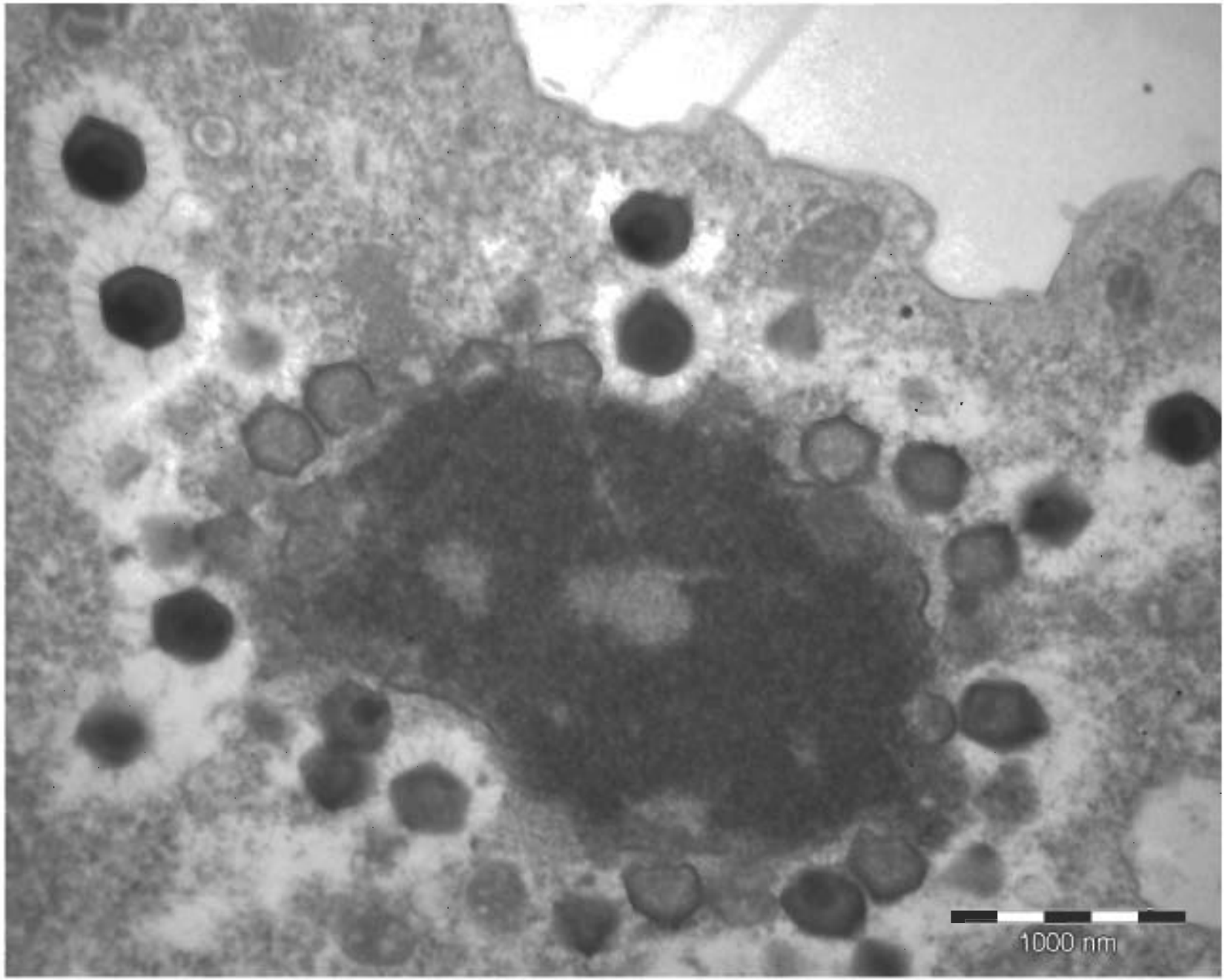


The Mimivirus: un virus geant (*mimic a microbe*) *giantvirus.org*

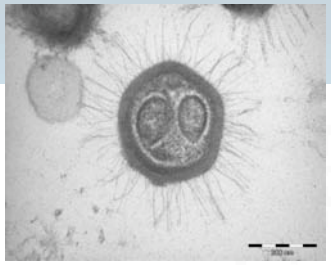
Didier Raoult.....
Jean-Michel Claverie
Science, Octobre 2004

un génome de 1200 000 paires de bases
(500 à 600 000
pour les plus petites bactéries)

Le génome du Mimivirus code pour des protéines de la traduction !


1000 nm

Le mimivirus est-il le représentant d'un quatrième virus ? Est-il apparenté à l'ancêtre du noyau eucaryote ? Ou bien a-t-il volé ses protéines de traduction à des amibes contemporaines ?



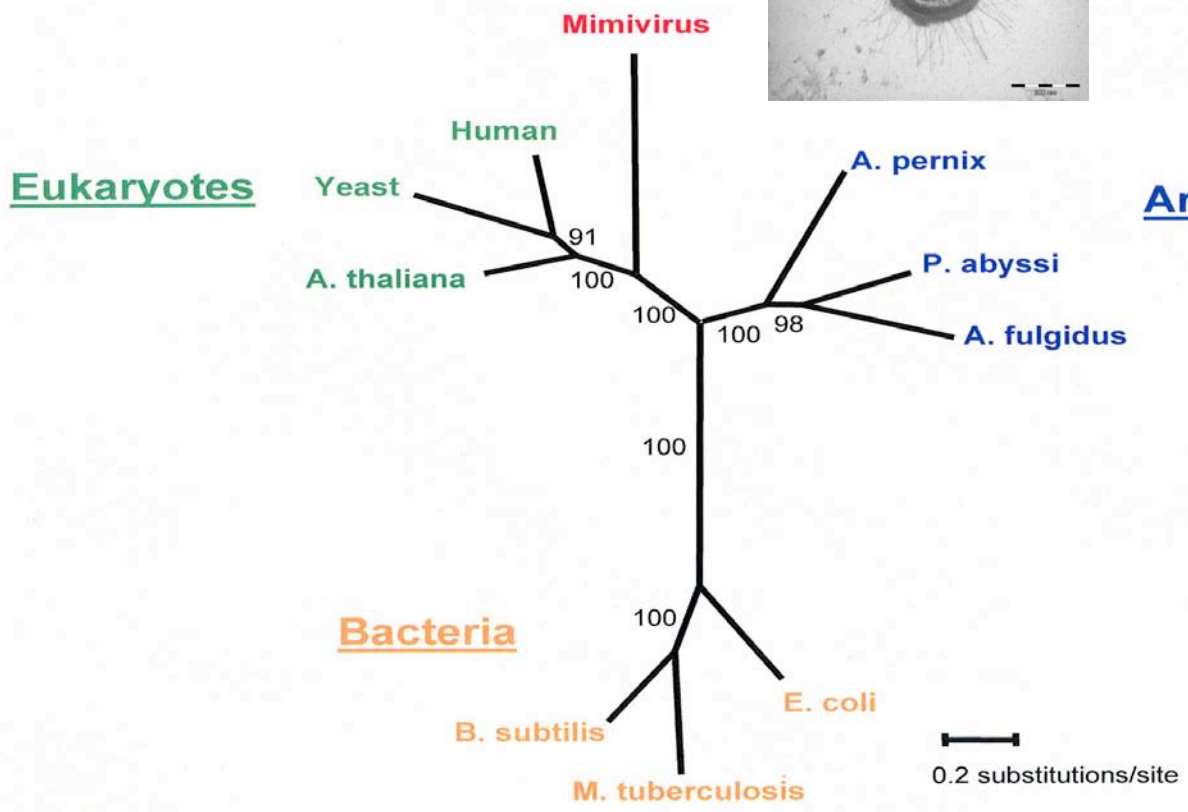


Fig. 3

Les virus ont-ils joué un rôle dans l'apparition de l'ADN ?

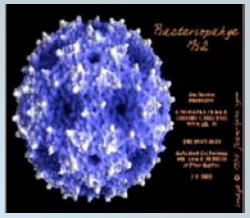
ARN (A, U, G, C) **ARN**

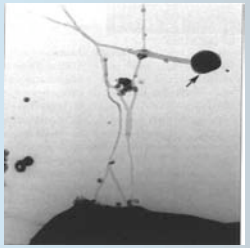
ADN (A, U, G, C) **ADN-U**

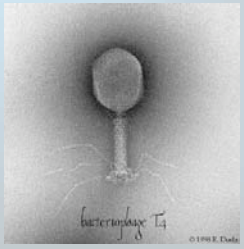
ADN (A, T, G, C) **ADN-T**

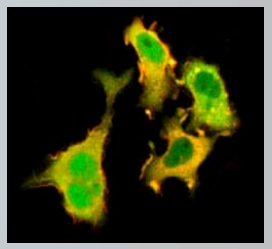
Pourquoi l'ADN à-t-il remplacé l'ARN ?

virus



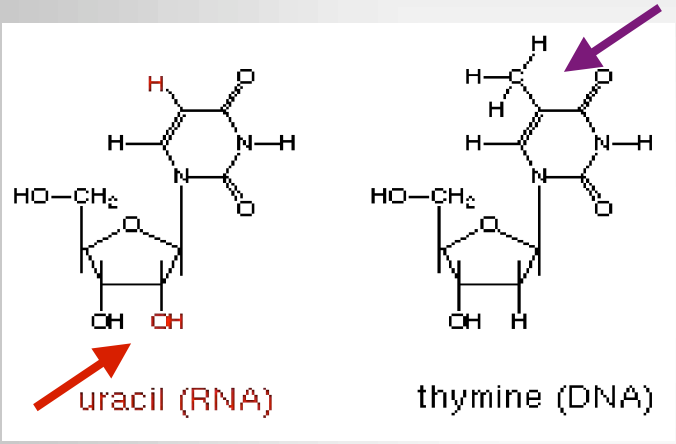


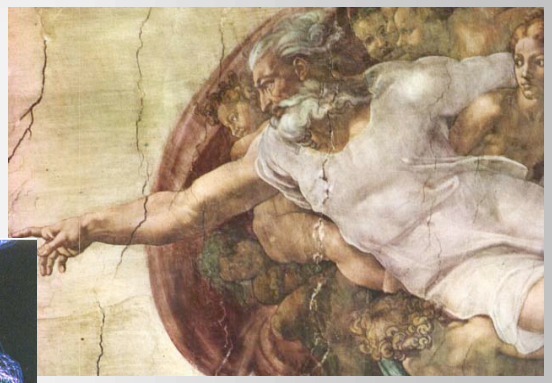


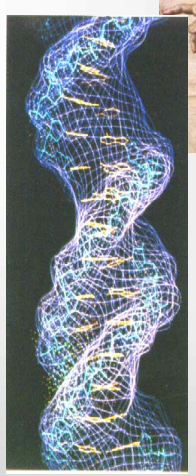


La réponse traditionnelle

1°) L'ADN est plus stable que l'ARN
2°) il peut être corrigé pour la déamination des cytosines (C → U)



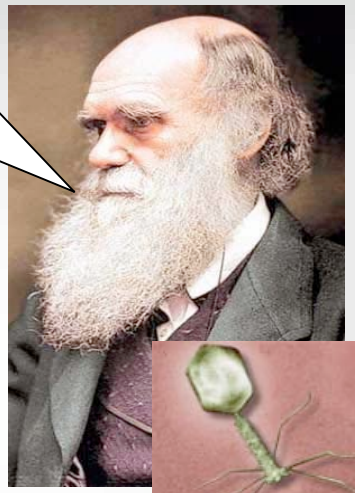


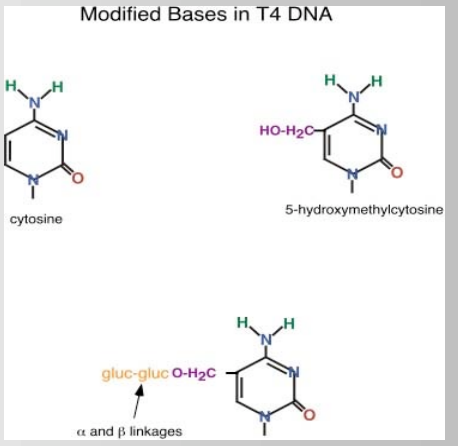


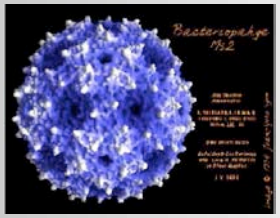
ce qui a permis l'augmentation de la taille des génomes

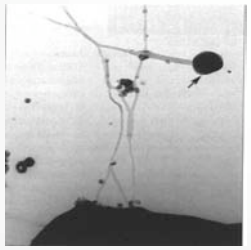
Oui, mais seul Dieu pouvait le prévoir !

Il faut comprendre quel a été l'avantage sélectif acquis par le premier organisme avec un génome à ADN









ADN-HMC

ARN → **ADN-U** → **ADN-T**

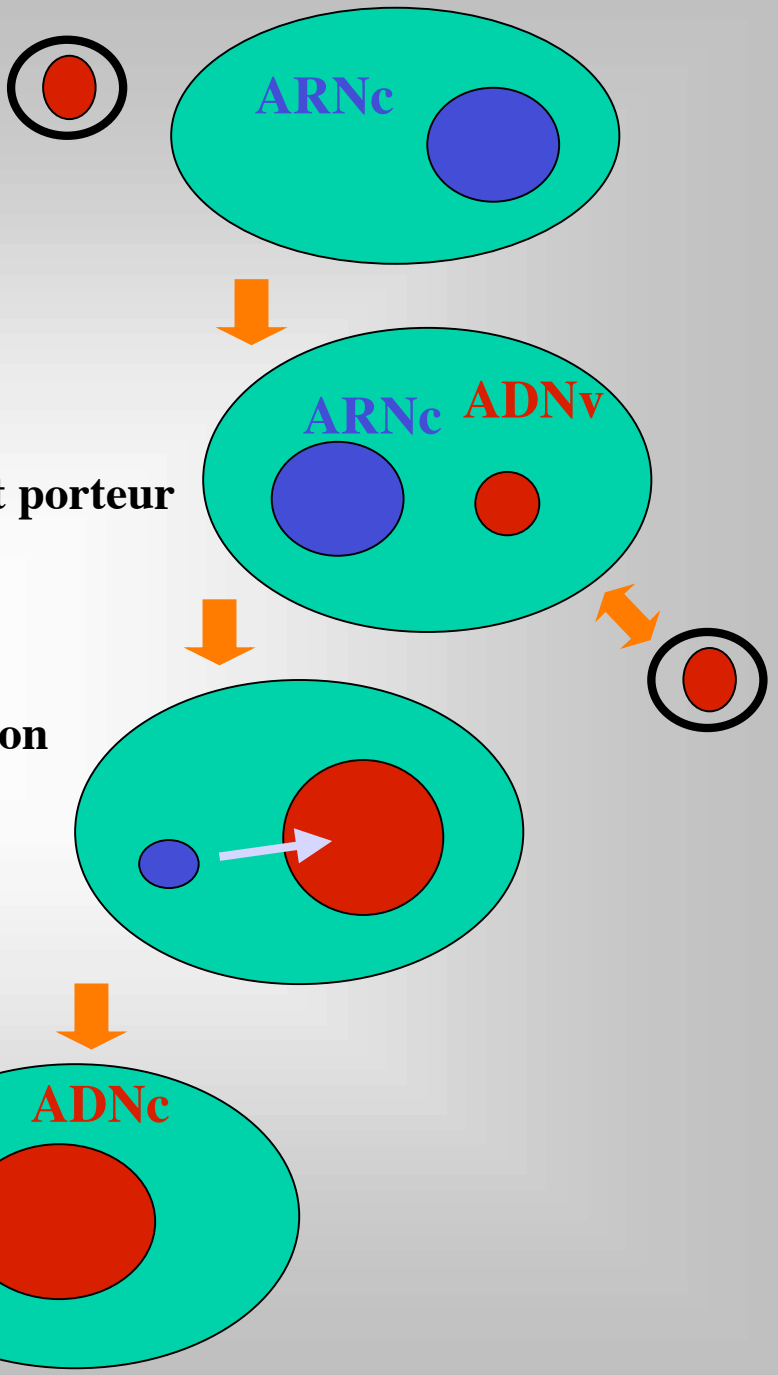
Les virus à ARN ont pu inventer l 'ADN-U (puis l 'ADN-T) tout comme le virus T4 a inventé l 'ADN HMC

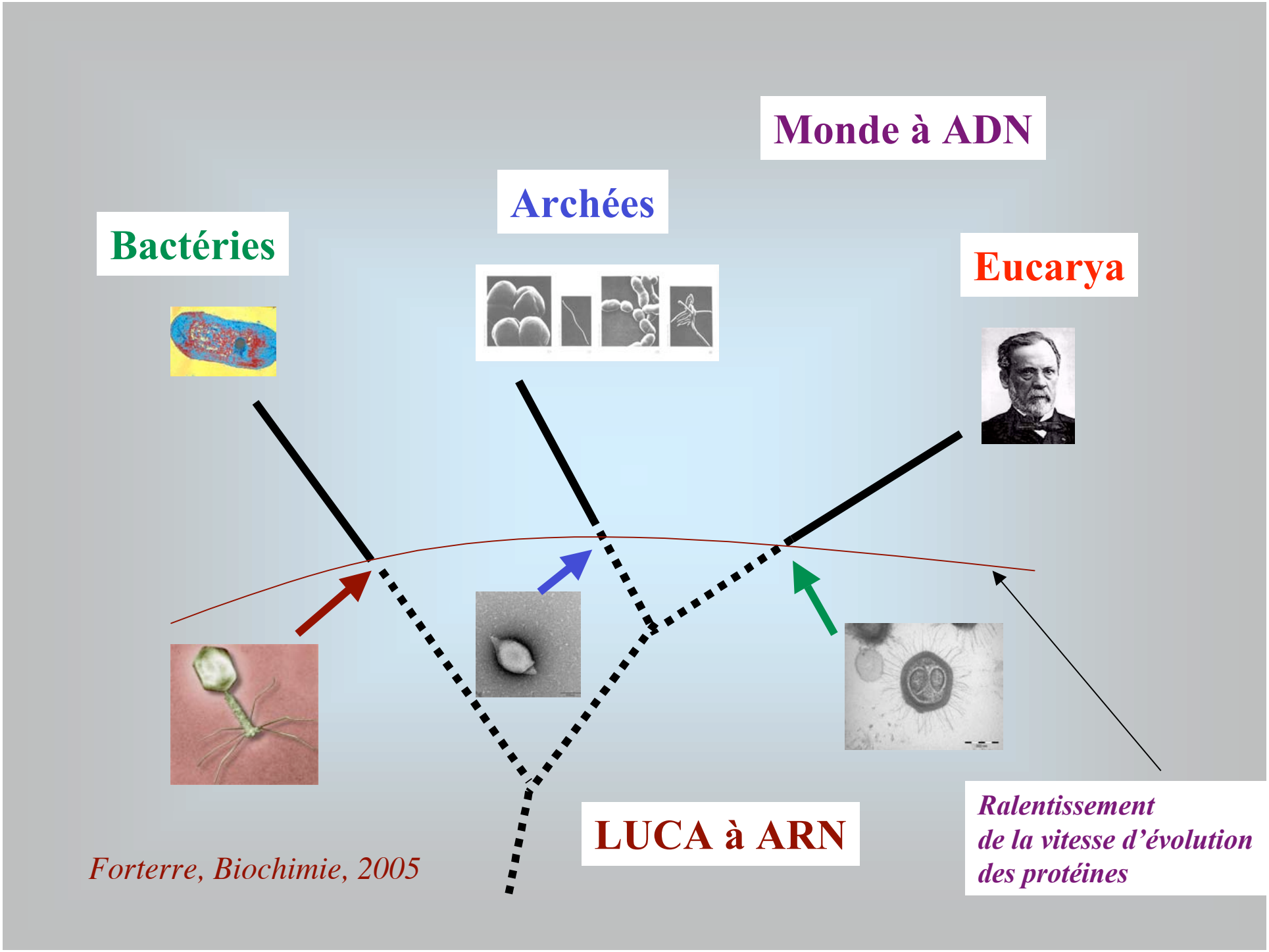
Forterre, Current opinion in Microbiol. 2002

Comment l'ADN a-t-il été transferré des virus aux cellules ?

Un virus à ADN a pu prendre le contrôle d'une cellules à ARN

Nos ancêtres les virus ??




Monde à ADN
Archées
Bactéries
Eucarya
LUCA à ARN
Forterre, Biochimie, 2005
Ralentissement
de la vitesse d'évolution
des protéines

D’ou viendrons les nouvelles avancées du XXI^{ème} siècle ?

nouvelles technologies
nouveaux concepts
poursuite de l’exploration