026SV_L01

Ricevimenti concordati *via* email usando la vostra email istituzionale:

fmalfatti@units.it

SYLLABUS

1. Introduzione al concetto di microbiologia e storia dal XVII secolo fino ad oggi ed **origine della vita sulla terra**

2. Biologia di **Bacteria e Archaea** con particolare attenzione alla **morfologia della cellula** batterica e ad alcuni meccanismi metabolici di base (capsula, parete cellulare, peptidoglicano, spazio periplasmico, membrane, citoplasma, vescicole appendici batteriche con flagelli e pili, endospore, aspetti del **genoma**, **crescita**, **diffusione** attiva e passiva delle molecole attraverso la membrana)

3. **Metabolismo batterico, nutrizione microbica** (macro- e micronutrienti, diversi tipi di metabolici in base alla fonte di energia utilizzata: fototrofi e chemiotrofi, in base alla fonte di carbonio: autotrofi o eterotrofi; differenti strategie metaboliche come la fermentazione, la respirazione aerobica ed anaerobica) e **crescita**

4. **Virus** (Bacteria, Archaea e Eukarya)

5. **DNA-RNA-Proteine** (antibiotici) e meccanismi di **movimento di DNA** tra microorganismi (trasposizione, trasformazione, coniugazione e trasduzione)

SYLLABUS

6. **Regolazione dell'espressione genica** in risposta a diversi stimoli ambientali (fattore sigma, regolazione positiva e negativa tramite molecole attivatrici, repressori, sistema a due componenti e punti di controllo a livello tradizionale, stress e motilita', metiloma)

7. **Interazioni tra microrganismi ed essere umano** I. (**Quorum sensing, simbiosi e biofilm**)

8. Interazioni tra microrganismi ed essere umano II. (**Infezioni e patogenicita'** dei microrganismi & **OneHealth**)

9. **Interazioni tra microrganismi ed ambiente** (**Diversita', abbondanza e servizi ecosistemici**)

10. **Metodologie** di isolamento, caratterizzazione e fenotipizzazione di microrganismi ambientali e tecniche di microscopia, nuove metodologie-omiche (genomica, trascrittomica, proteomica, metabolomica, meta-genomica, meta-proteomica, meta-trascrittomica)

SYLLABUS

-1. Benessere socio mentale e fisico e diversita’
0. Etica nella scienza, plagio ed uso intelligenza artificiale

Approccio collaborativo sistema educatore-classe

LABORATORIO

VOTO FINALE:

2 Report di gruppo punti 3/30
Test scritto individuale punti 27/30

2 Report di gruppo punti 3/30

- **Due report di laboratorio (foglio protocollo + e-book)**, in forma guidata, di gruppo per un valore totale di 3 punti su 30 punti (i.e. trentesimi).
- **Foglio protocollo ritirato a fine laboratorio**
- Ogni report (= **foglio protocollo + e-book**) puo' esser valutato da 0 a 1.5 punto in trentesimi.
- **Consegna e-book report 1 settimana dopo con smaltimento microrganismi, pena 0 punti.**

TEST SCRITTO

Esame scritto

della durata di **1 ora**, per un valore pari a **27 su 30** del voto finale individuale.

Struttura:

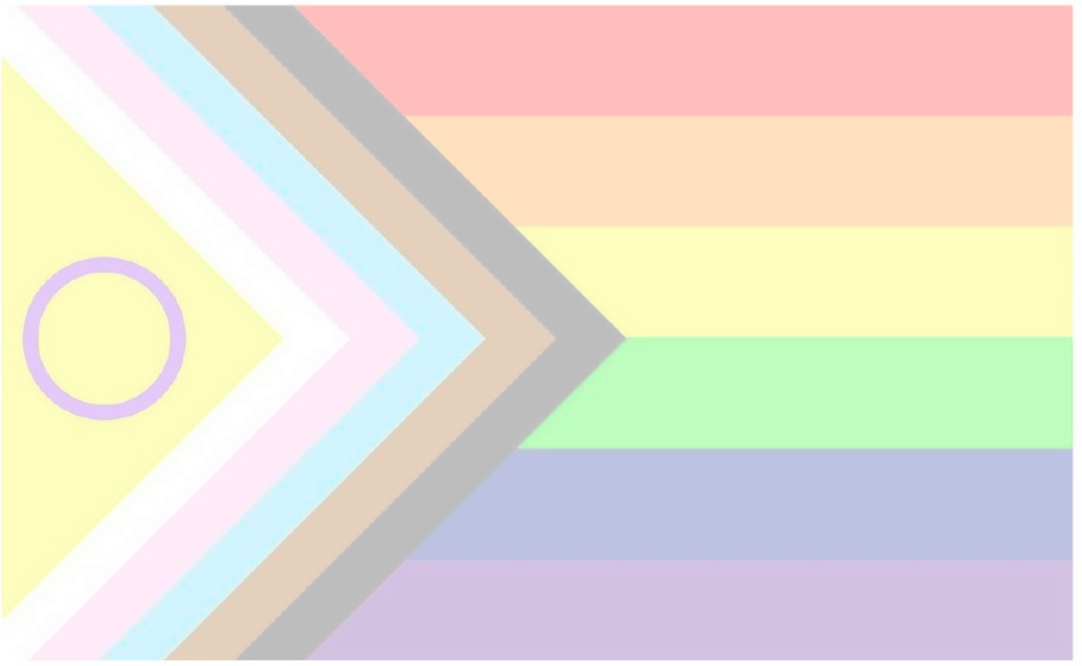
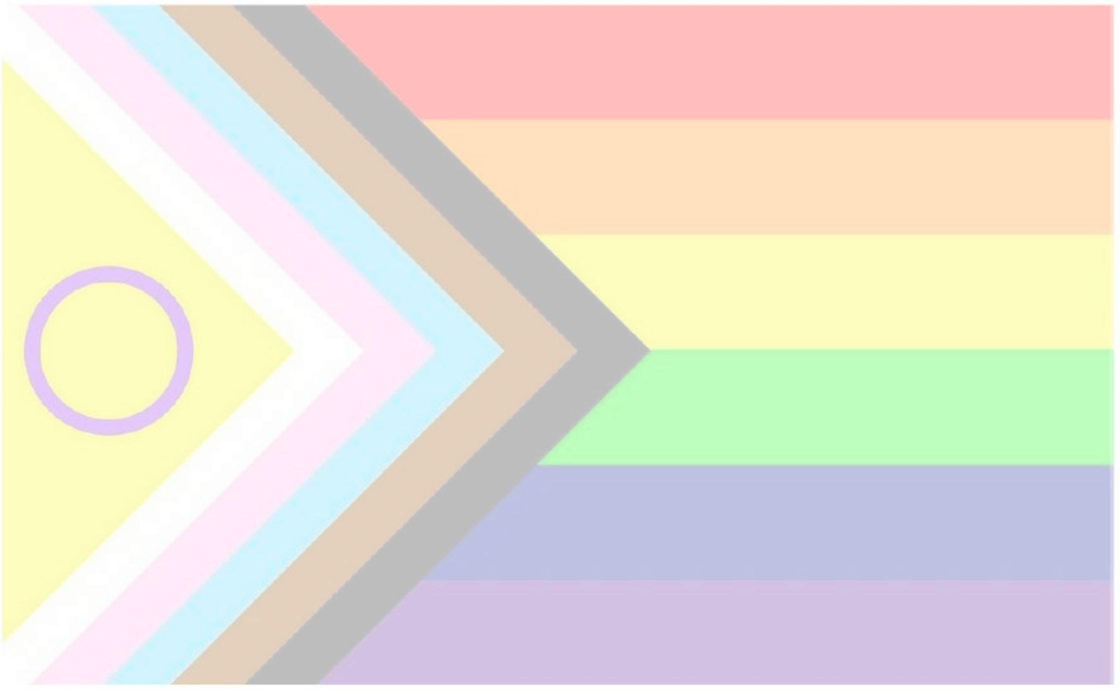
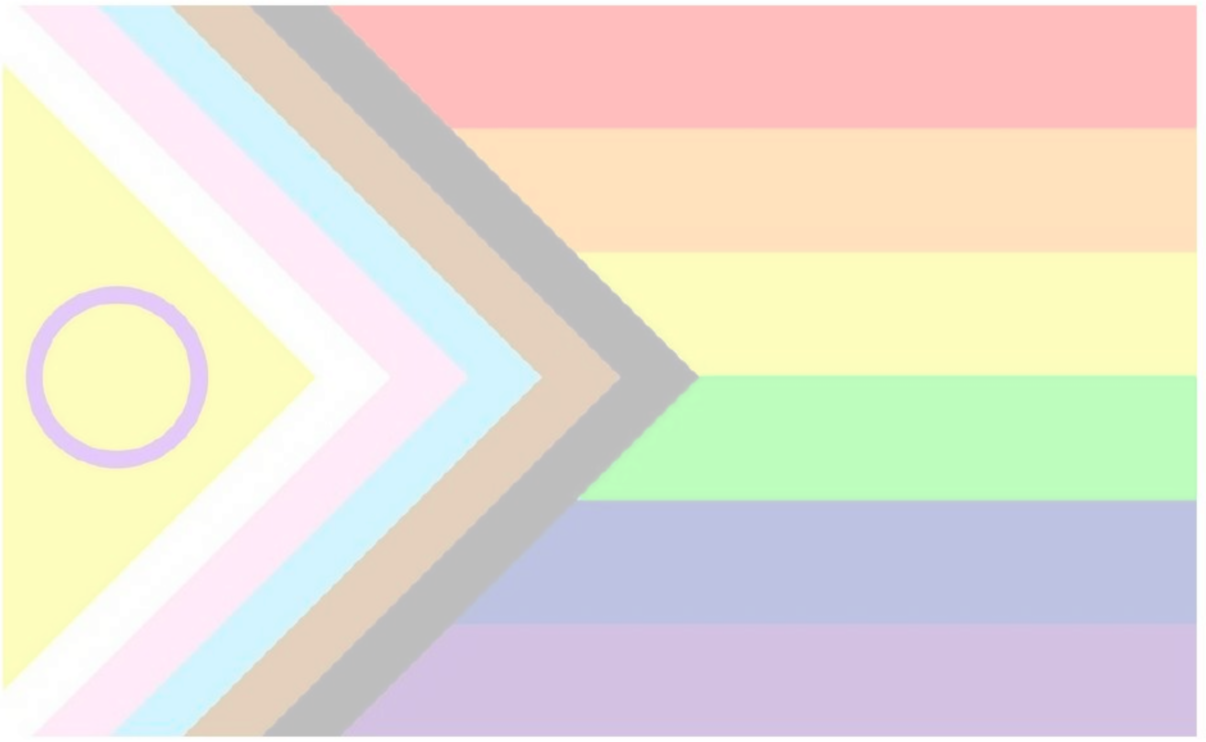
a. 12 domande vero-falso pari a 1/30
b. 1 disegno/schema da fare e descrivere, pari a 5/30
c. 2 domande aperte pari a 2x 5/30

Libro di testo

Brock Biology of Microorganisms
by Michael T. Madigan; Kelly S. Bender; Daniel H. Buckley; W. Matthew Sattley; David A. Stahl

PRODUCT INFORMATION
Sold By: Pearson
ISBNs: 0134874404, 9780134874401, 0135845556, 9780135845554, 09780134626123, 09780134874401, 9780135845608
Language: English
Edition: 16th

My principles

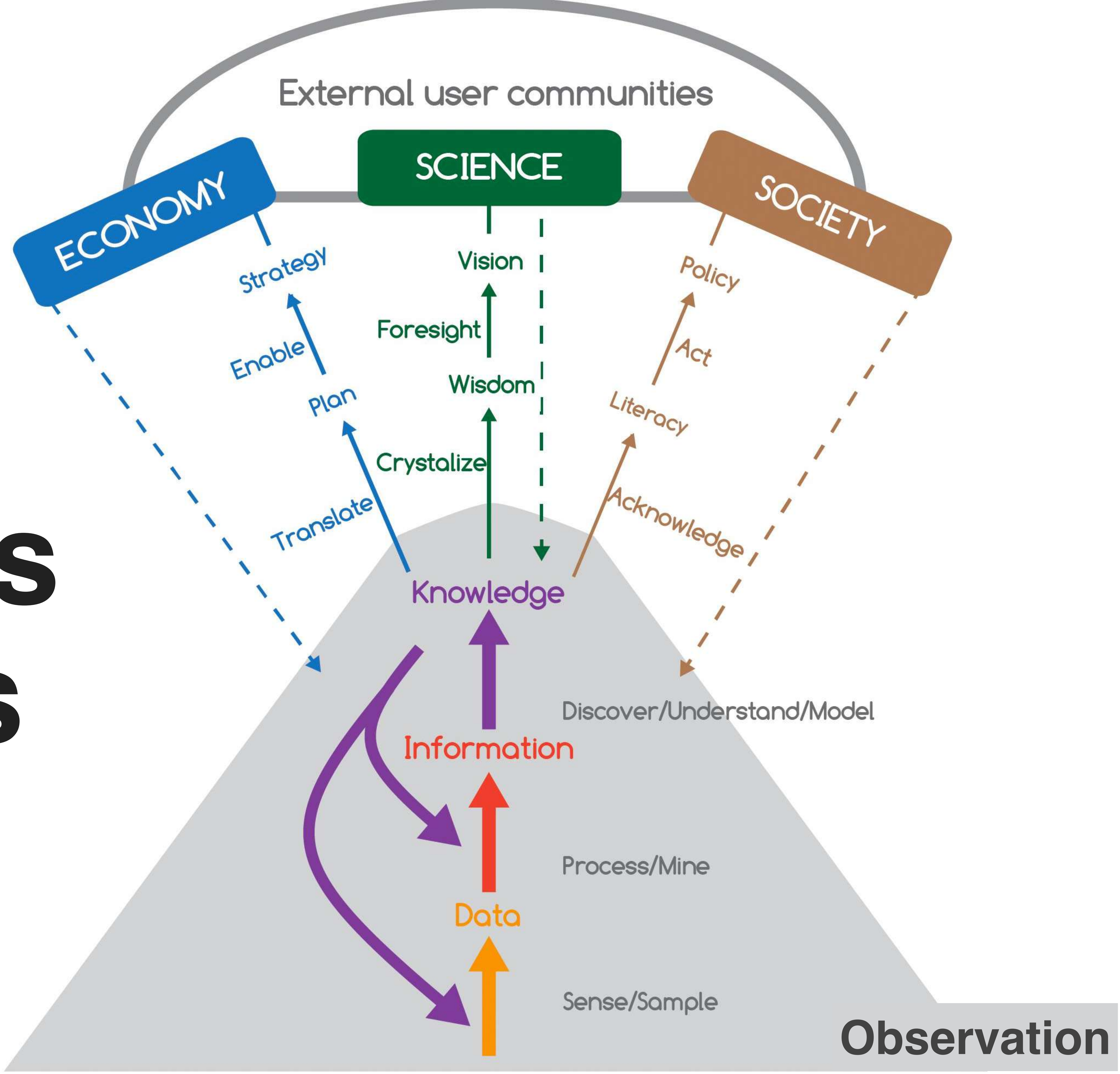
You belong here !

★Inclusivity statement:

My laboratory and my philosophy aim to create an inclusive environment in which students of all backgrounds, cultures and orientations can feel safe learning, growing, and participating within their community.

From my experience and working with many people in my field, I have found this to be an important topic to bring up and present myself as a resource for those who find they might need it.

Our mission as scientists



ENVIRONMENT - MODEL ORGANISM

Crise A, Ribera d'Alcalà M, Mariani P, Petihakis G, Robidart J, Iudicone D, Bachmayer R and Malfatti F (2018) A Conceptual Framework for Developing the Next Generation of Marine OBservatories (MOBs) for Science and Society. Front. Mar. Sci. 5:318. doi: 10.3389/fmars.2018.00318

Creating knowledge —> microbiology literacy

BEFORE

Microbes not important

Microbes=Disease

AFTER

Microbes are everywhere and will always be…

Microbes as ecosystem engineers

Microbes keep the ecosystem functioning

Humans and biota as microbial ecosystems

Sviluppo cognitivo e **pensiero critico**: due antidoti ai pregiudizi e ai preconcetti del presente

di Daniele Scarampi

https://www.treccani.it/magazine/lingua_italiana/articoli/scritto_e_parlato/pensiero_critico.html

Why you should attend class?

Interaction is richness
Interaction is knowledge

Tell me and I will forget,

show me and I may remember,

involve me and I will understand.

Why English?

Questions?

Lecture 01: **Introduction, History & Origin of Life**

- History
- Microbiology
- Origin of LIFE
- Origin of microbes

- How big are microbes? - How small are microbes?
- Who are the microbes?
- Where do microbes live?

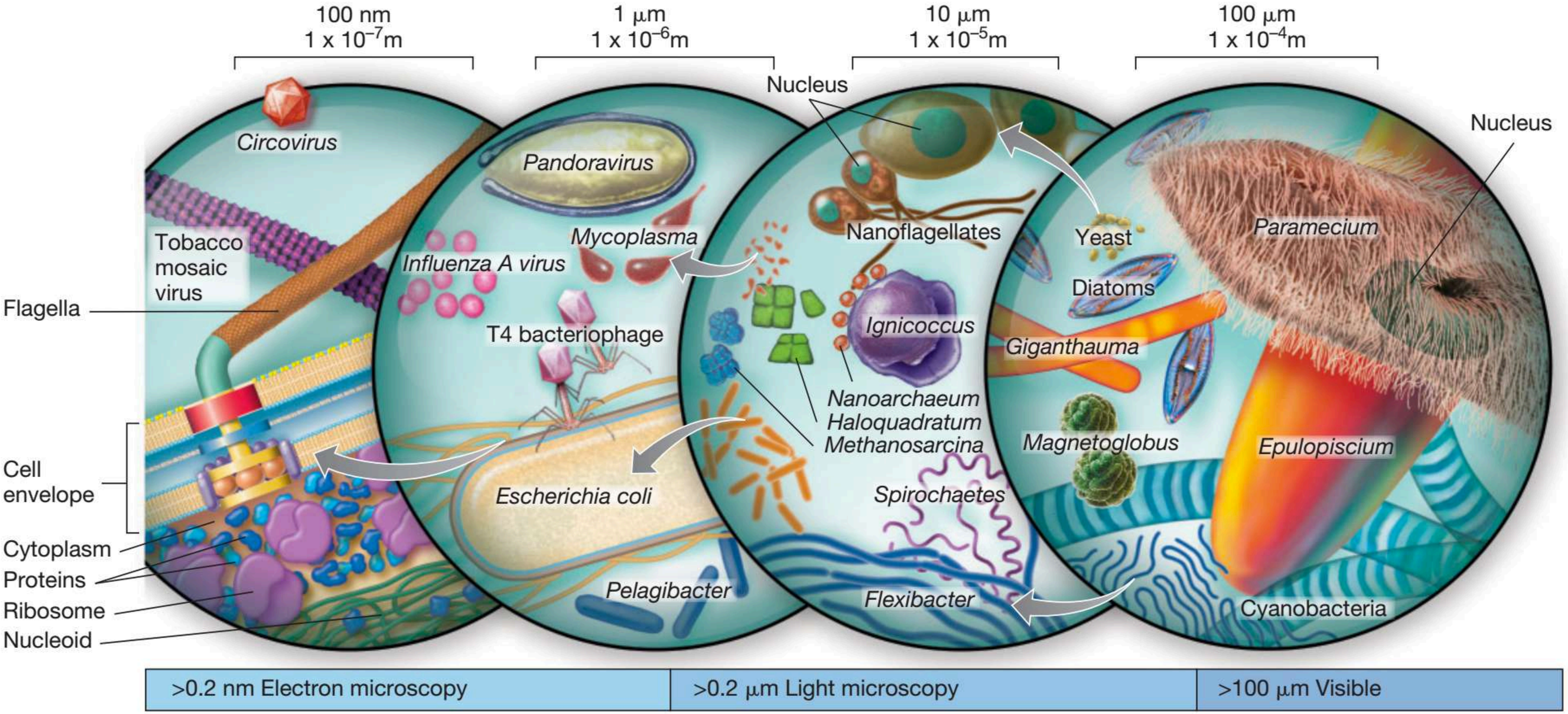
1 µm= 1 micrometer is $1/10^6$ meter

1 nm= 1 nanometer is $1/10^9$ meter

Bacteria, Archaea, Viruses & small Eukarya

Everywhere on Earth and in/on every organism

Microbial size range



Madigan et al. 2018

Microbiology is the discovery of LIFE
as we know it

★

LIVING vs NON living

You are alive if you have:

1. A membrane subsystem for compartmentalizing the functional network components

2. An autocatalytic metabolic subsystem that functions out-of-equilibrium by capturing energy and material resources

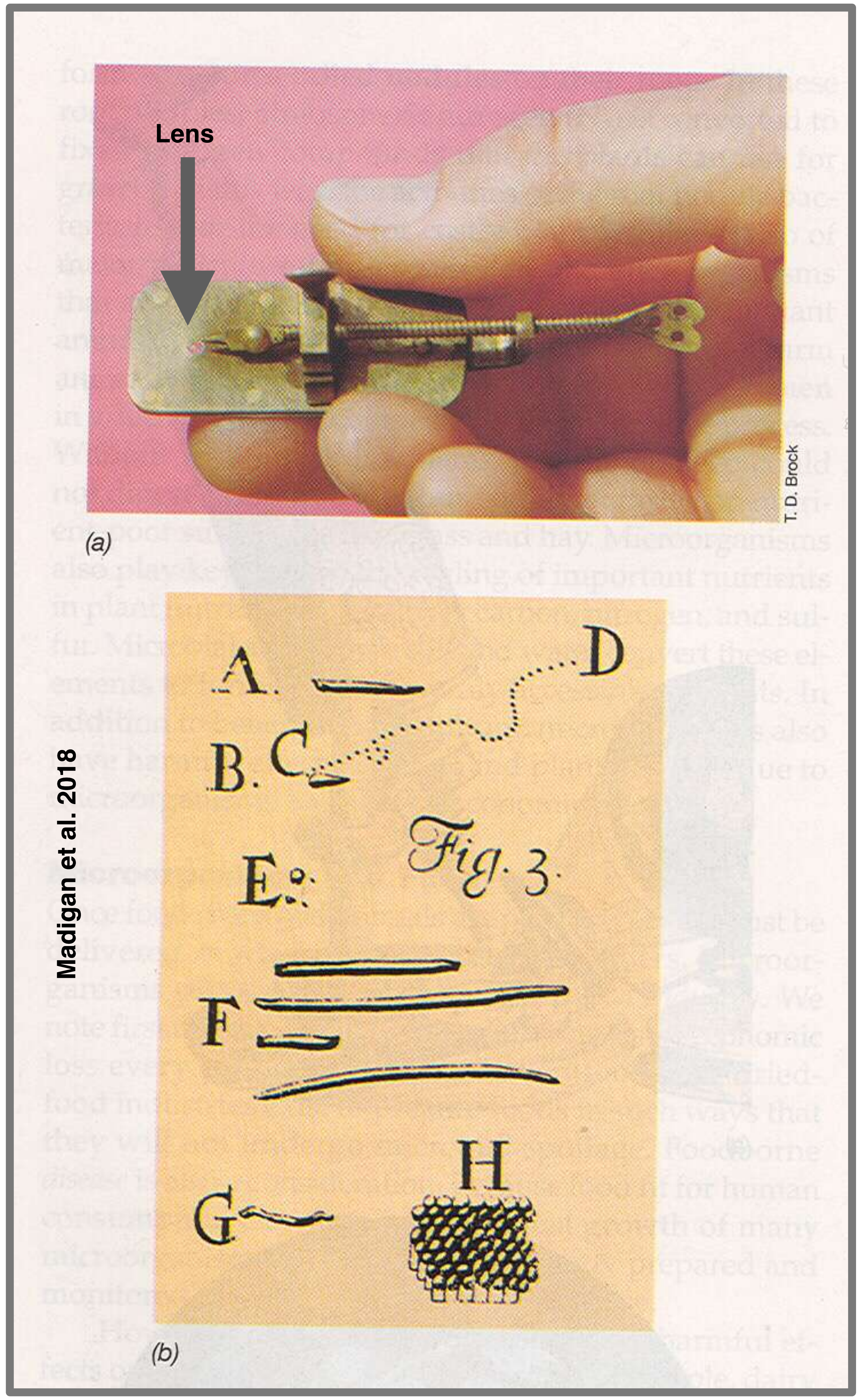
3. An information-based subsystem for processing and transferring genetic information to the progeny via self-replication

Ganti, T. in The Principles of Life (ed. Szathmary, E. and Griesemer, J.) Ch. 3(Oxford Univ. Press, Oxford 2003).

History

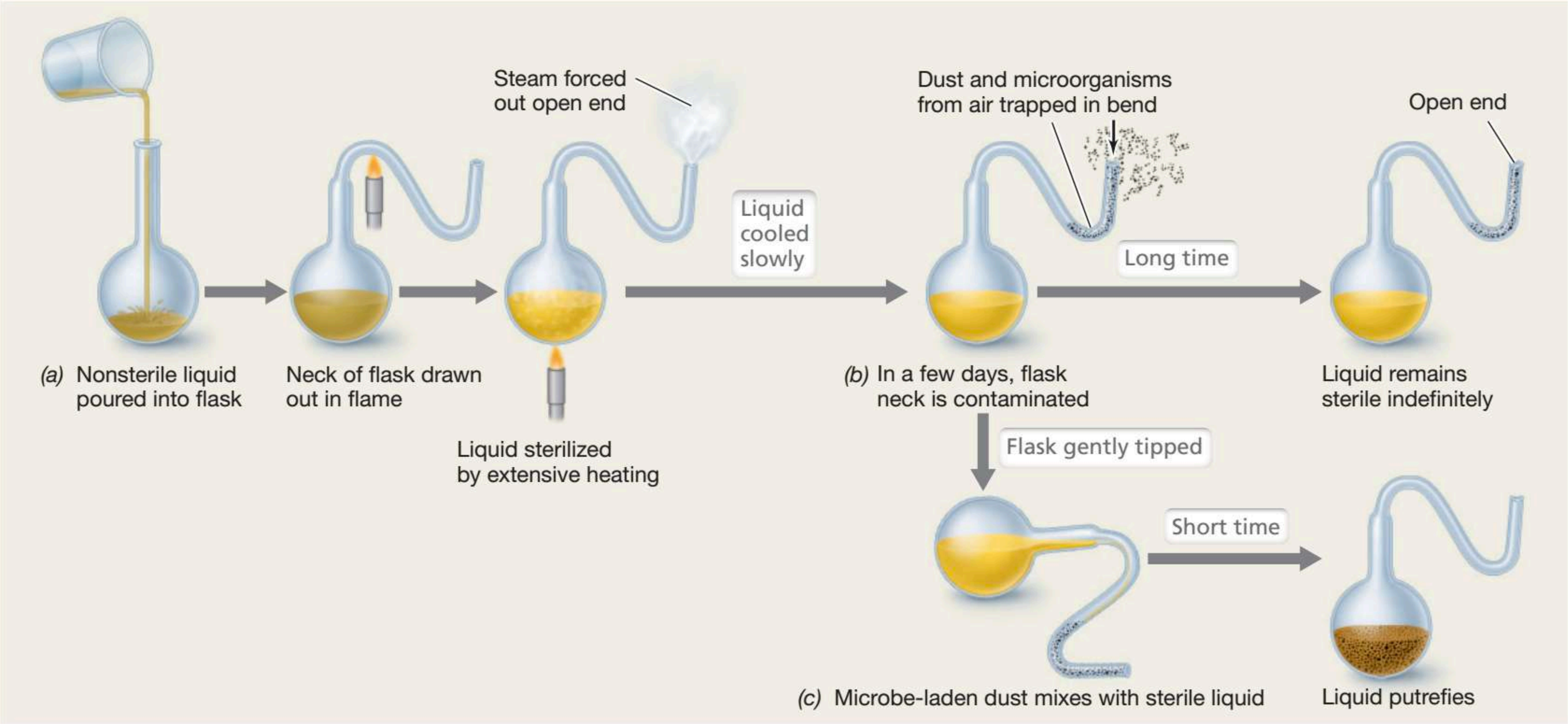
- 1665 Robert Hooke, invention of the microscope
- *1676 van Leeuwenhoek, discovery bacteria at the microscope*
- 1857 Pasteur, microbes cause fermentation & dispelling spontaneous generation of life
- *1881 Koch, Germ theory of disease & use of gelatin plates*
- End 19th century Beijerinck and Winogradsky —> environmental microbiology
- *End 20th One Health and Human being as a microbial world*

Developing Tools enabling discovery of the microbial worlds!



1676 van Leeuwenhoek
the first microscope for bacteria

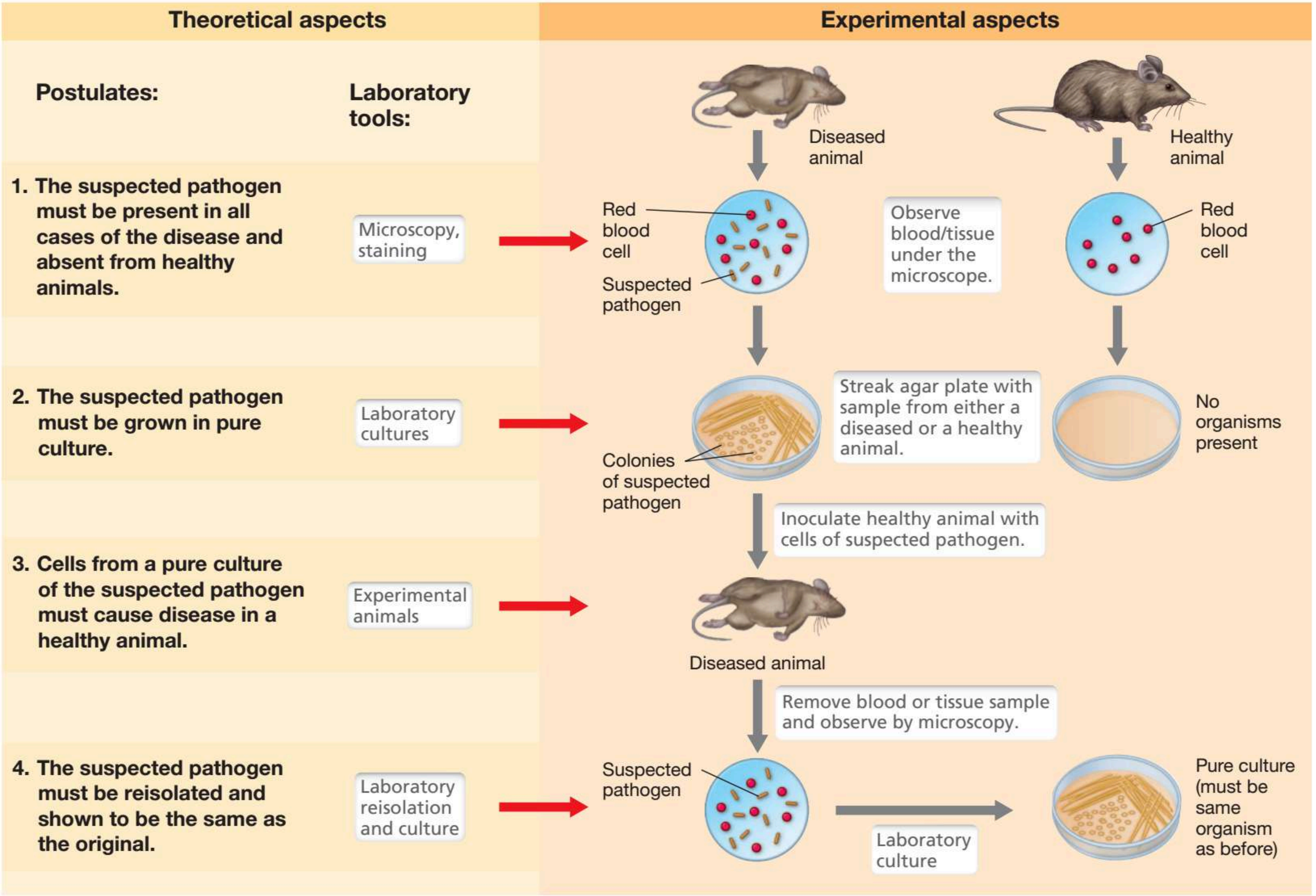
Early focus: Human microbial diseases
Later focus: Biogeochemical role
Today focus: One Health



Madigan et al. 2018

Pasteur: Experiment dispelling the theory of spontaneous generation of life (environmental change is microbial driven)

Koch —> infectious diseases: Koch's postulates



Madigan et al. 2018

Vibrio cholerae and *Mycobacterium tuberculosis*

…what is missing?

Environmental microbiology *—> need to understand environment*

1. Bacteria from environment don't live on Koch rich media

2. Need to create specific enrichment media to imitate the environment

Delft School of Microbiology, Holland

Beijerinck **Winogradsky** **Kluyver**

Environmental microbiology —> ***need to understand environment***

1. Bacteria from environment don't live on Koch rich media

2. Need to create specific enrichment media to imitate the environment

1. **Beijerinck**: **Enrichment culture: Isolated pure** culture of soil and aquatic microbes (aerobic nitrogen fixing bacteria, sulfur reducing and sulfur oxidizing bacteria);

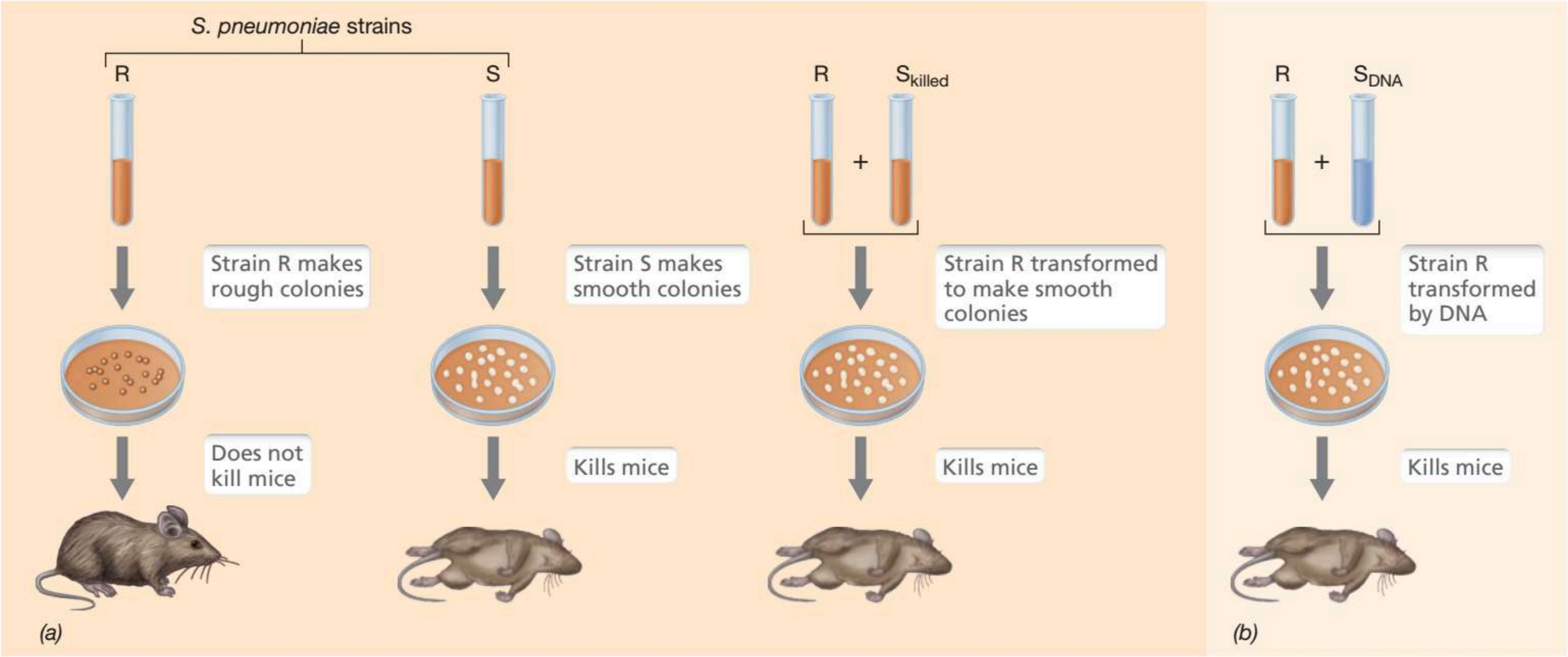
2. **Winogradsky**: **Diversity and environmental functions of microbes**: Discovered nitrifying & sulfur oxidizing bacteria; chemolithotrophy;

3. **Kluyver**: **unity of the biochemistry, stating that same biochemical pathways and thermodynamic constrains are similar for microbes**

- End 19th century Griffith & 1944 Avery-MacLeod-McCarty, **DNA as a transforming principle**
- Early 20th century Alexander Fleming's **discovery of penicillin as an antiseptic antibiotic** (Howard Florey, Ernst Chain and Norman Heatley) and **lysozyme**
- First half 20th century Watson, Crick & Franklin: **DNA structure**
- 20th century Zuckerkandl & Pauling: **molecular sequences for evolutionary reconstruction relationship**
- 20th century Woese: **ribosomal RNA (rRNA) genes** for studying **evolution** in microbes (**cultivation dependent**)
- 20th century Pace: **ribosomal RNA (rRNA) genes** for assessing **diversity** of microbes (**cultivation independent**)

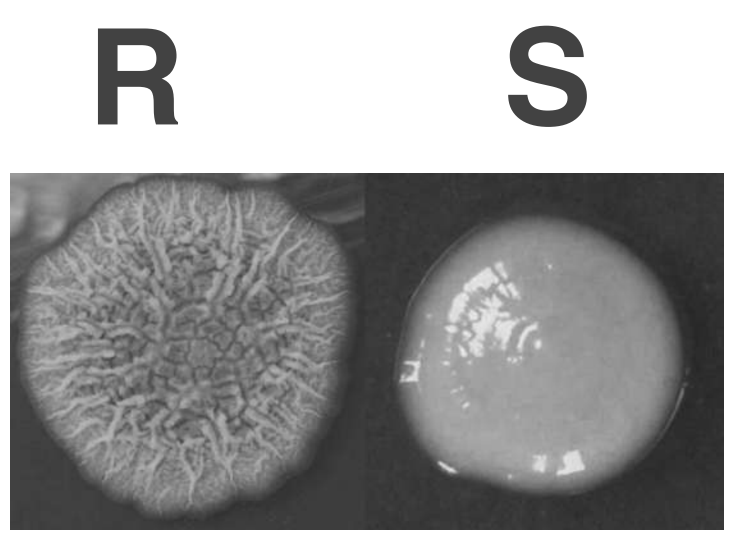
Griffith & Avery-MacLeod-McCarty

Streptococcus pneumoniae

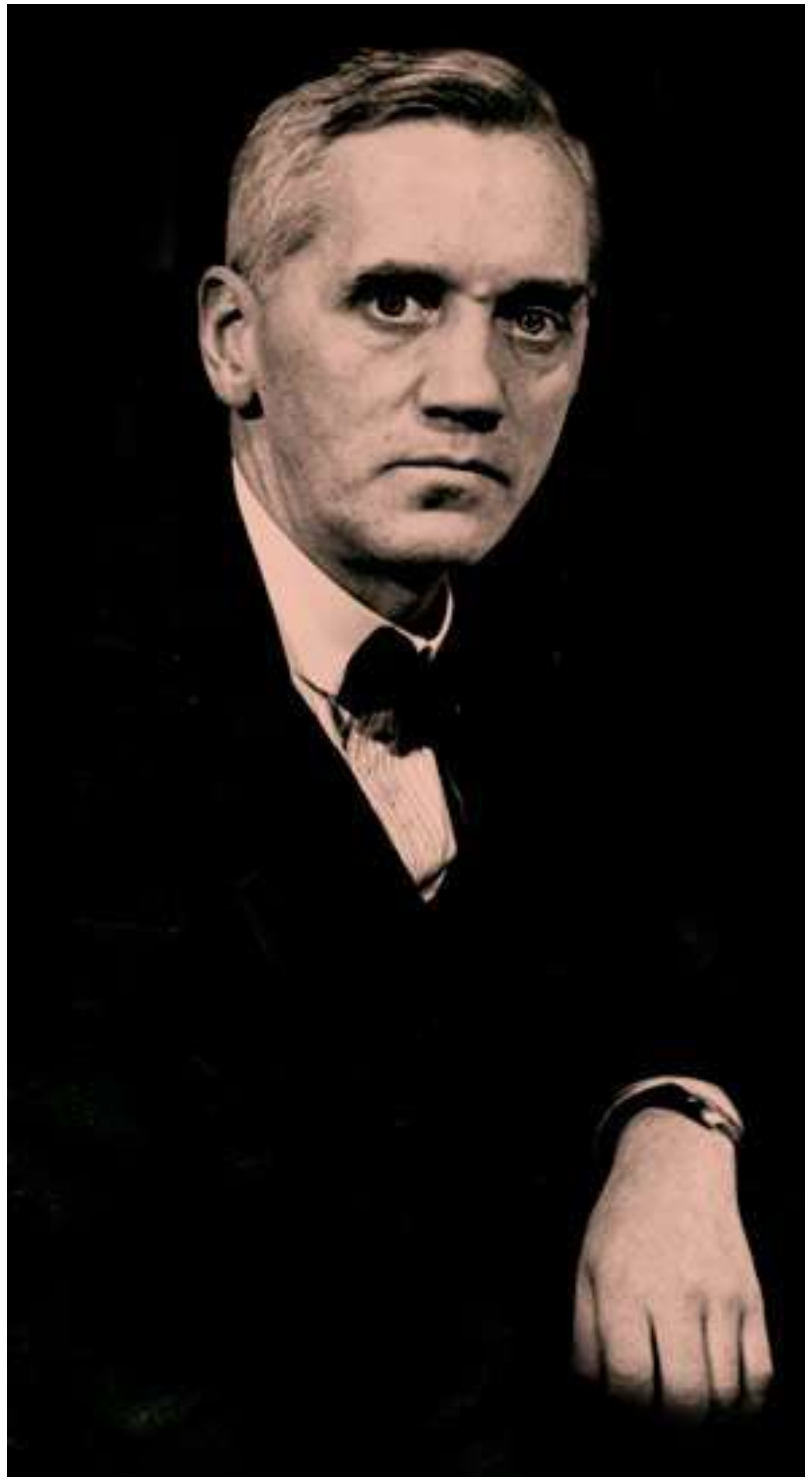


Madigan et al. 2018

DNA contains genetic information
DNA is the molecular basis of hereditary



10.1128/JCM.01249-13 Rüger et al.,



Alexander Fleming (1881-1955)

The **discovery of antibiotics** is a great milestone in the history of medicine

Many doctors believe that penicillin is one of the greatest medical advances

Penicillin can treat most forms of killer diseases such as meningitis, pneumonia and diphtheria, blood poisoning and septic wounds

In 1922, Fleming discovered a way of destroying bacteria with the lysozyme (saliva)

Alexander Fleming Laboratory Museum (Imperial College Healthcare NHS Trust).

How to study evolution in microbes?

An information-based subsystem for processing and transferring genetic information to the progeny via self-replication

The genetic information is **put in action** by creating micromachines that dictate metabolism and allow persistence = LIFE

—>

RIBOSOME a good place to start

The different molecular components are colored for identification: cyan, 16S rRNA; grey, 23S rRNA; light blue, 5S rRNA (5S); dark blue, 30S proteins; magenta, 50S proteins. Proteins fitted to the electron density are numbered in orange; 50S proteins whose electron density has been identified but not fitted are numbered in magenta. A, P, E, the A-, P- and E-site tRNAs (gold, orange and red, respectively).

Woese

Ribosomal RNAs are components of ribosomes, the structures that synthesize new proteins in the process of translation

16S ribosomal RNA

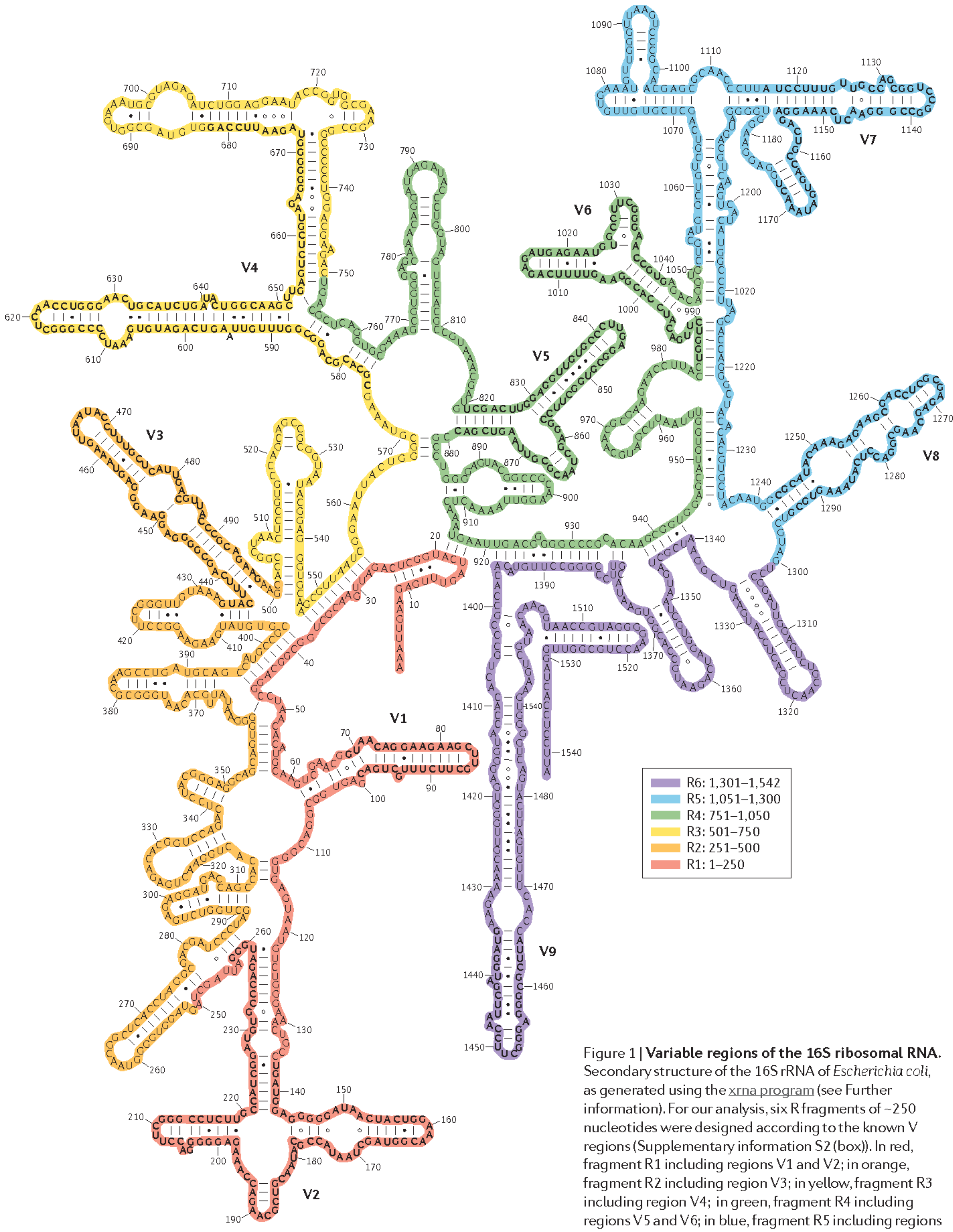
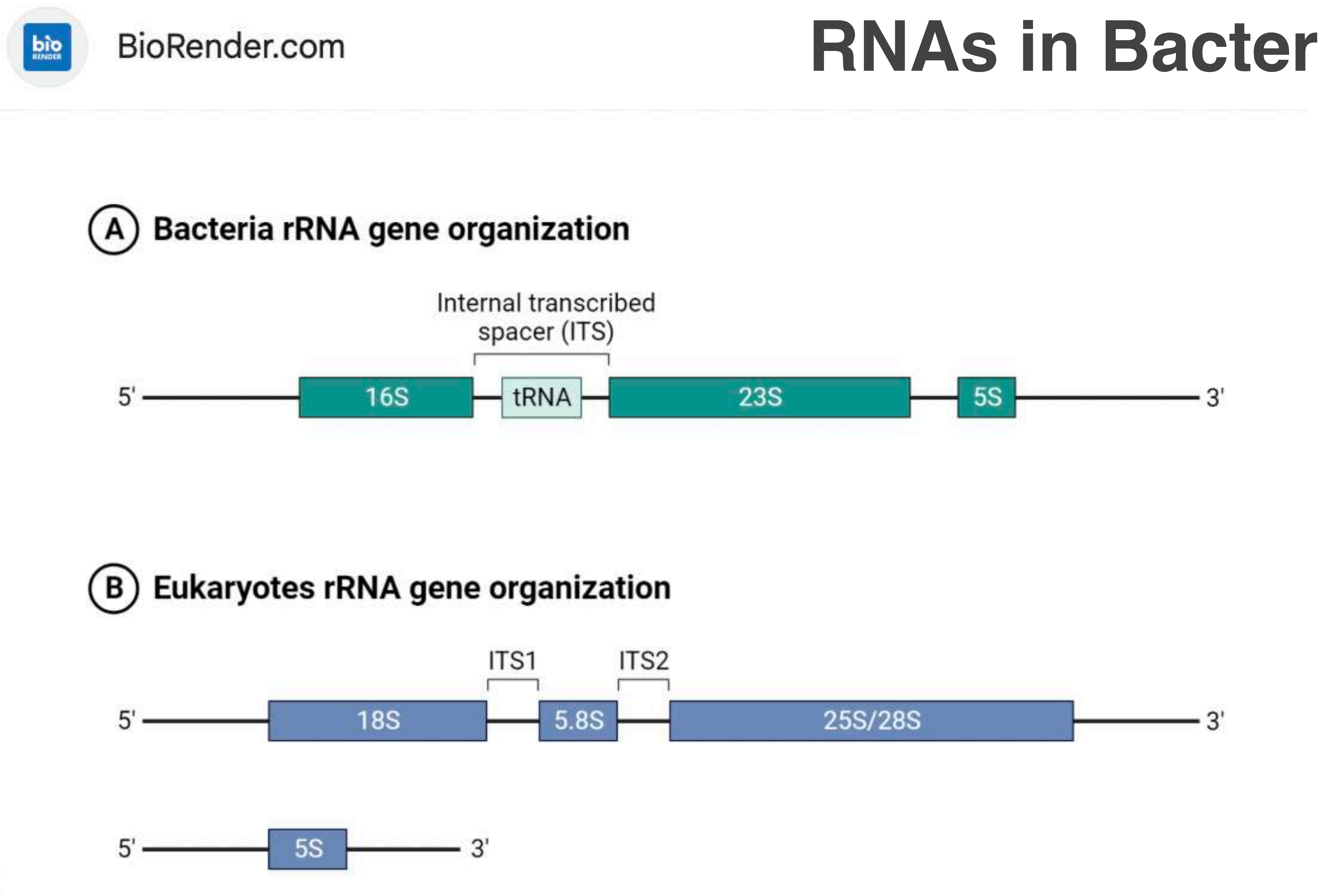


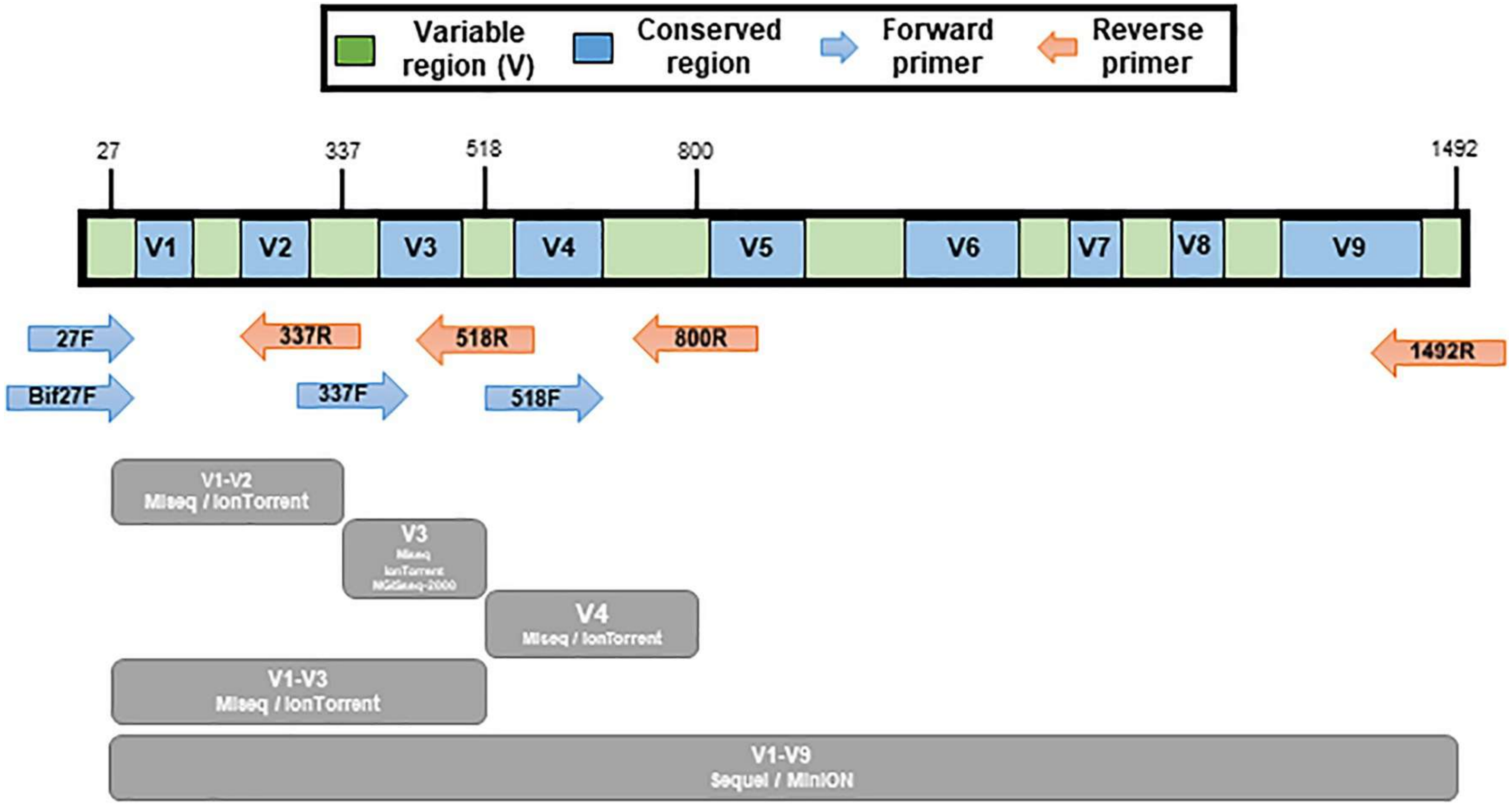
Figure 1 | **Variable regions of the 16S ribosomal RNA.** Secondary structure of the 16S rRNA of *Escherichia coli*, as generated using the xrna program (see Further information). For our analysis, six R fragments of ~250 nucleotides were designed according to the known V regions (Supplementary information S2 (box)). In red, fragment R1 including regions V1 and V2; in orange, fragment R2 including region V3; in yellow, fragment R3 including region V4; in green, fragment R4 including regions V5 and V6; in blue, fragment R5 including regions

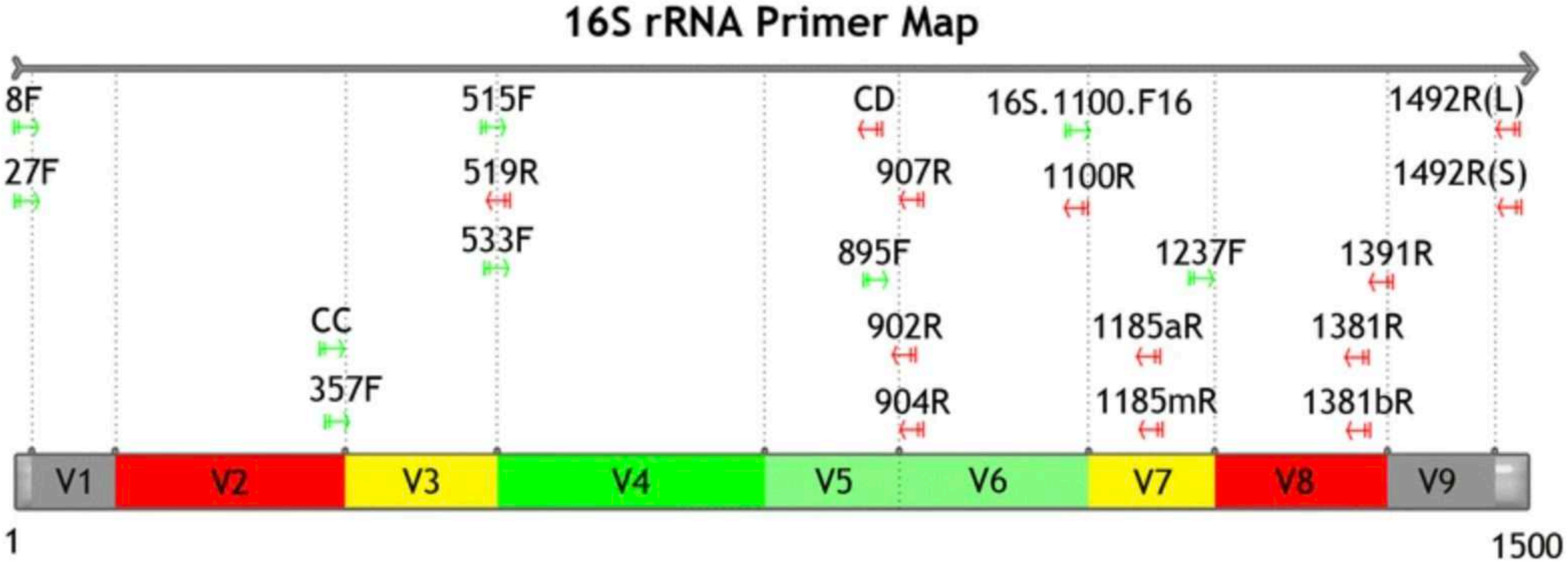
Yarza et al. 2014 10.1038/nrmicro3330

RNAs in Bacteria



Primers for Prokaryotes on 16S rRNA gene





Woese

Genes encoding rRNAs are excellent candidates for **phylogenetic analysis** because they are:

(1) universally distributed,

(2) functionally constant,

(3) highly conserved (that is, slowly changing),

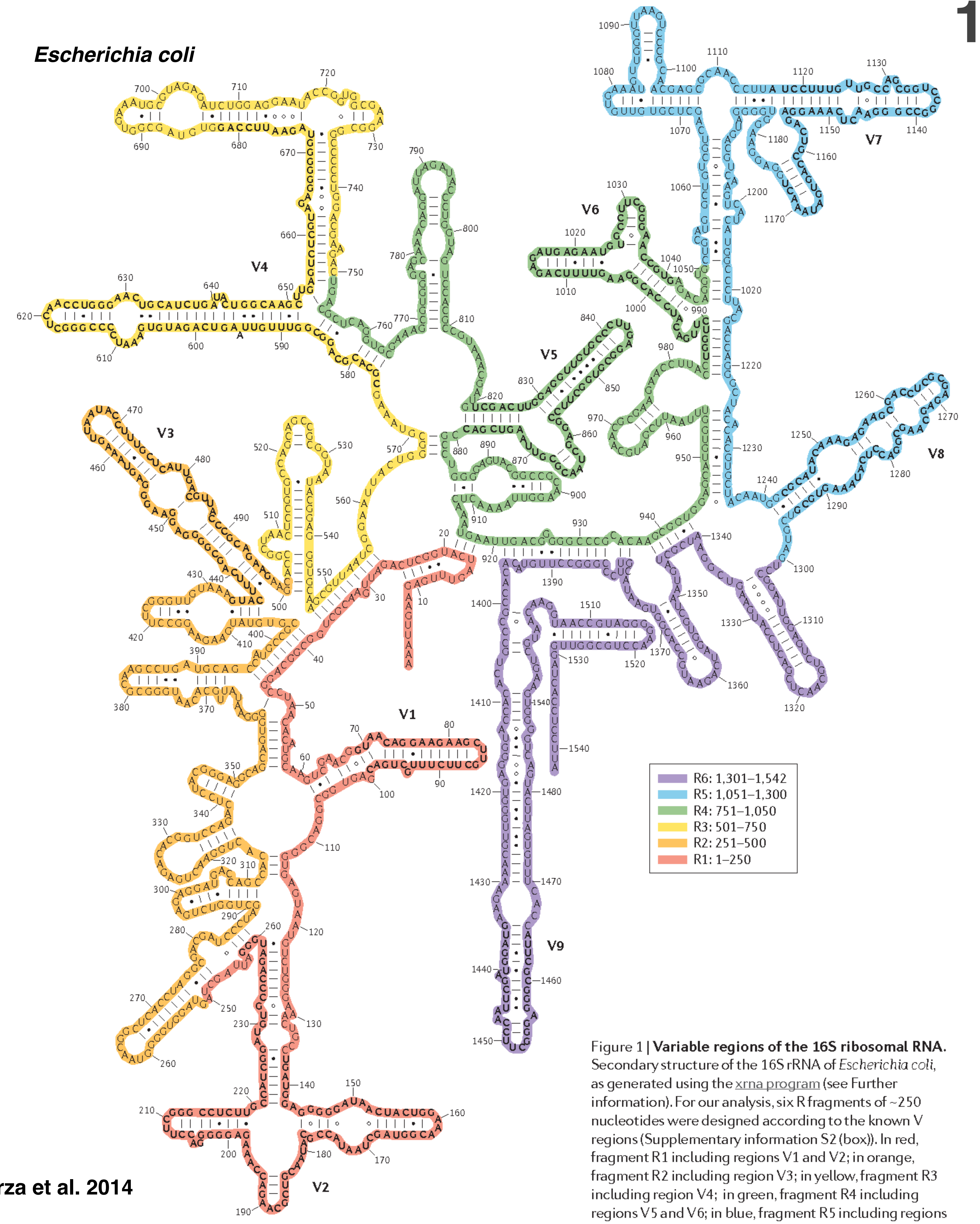
(4) adequate length to provide a deep view of evolutionary relationships,

(5) diverse in different ‘species’

Using pure cultures of Bacteria and Archaea (16S rRNA gene)

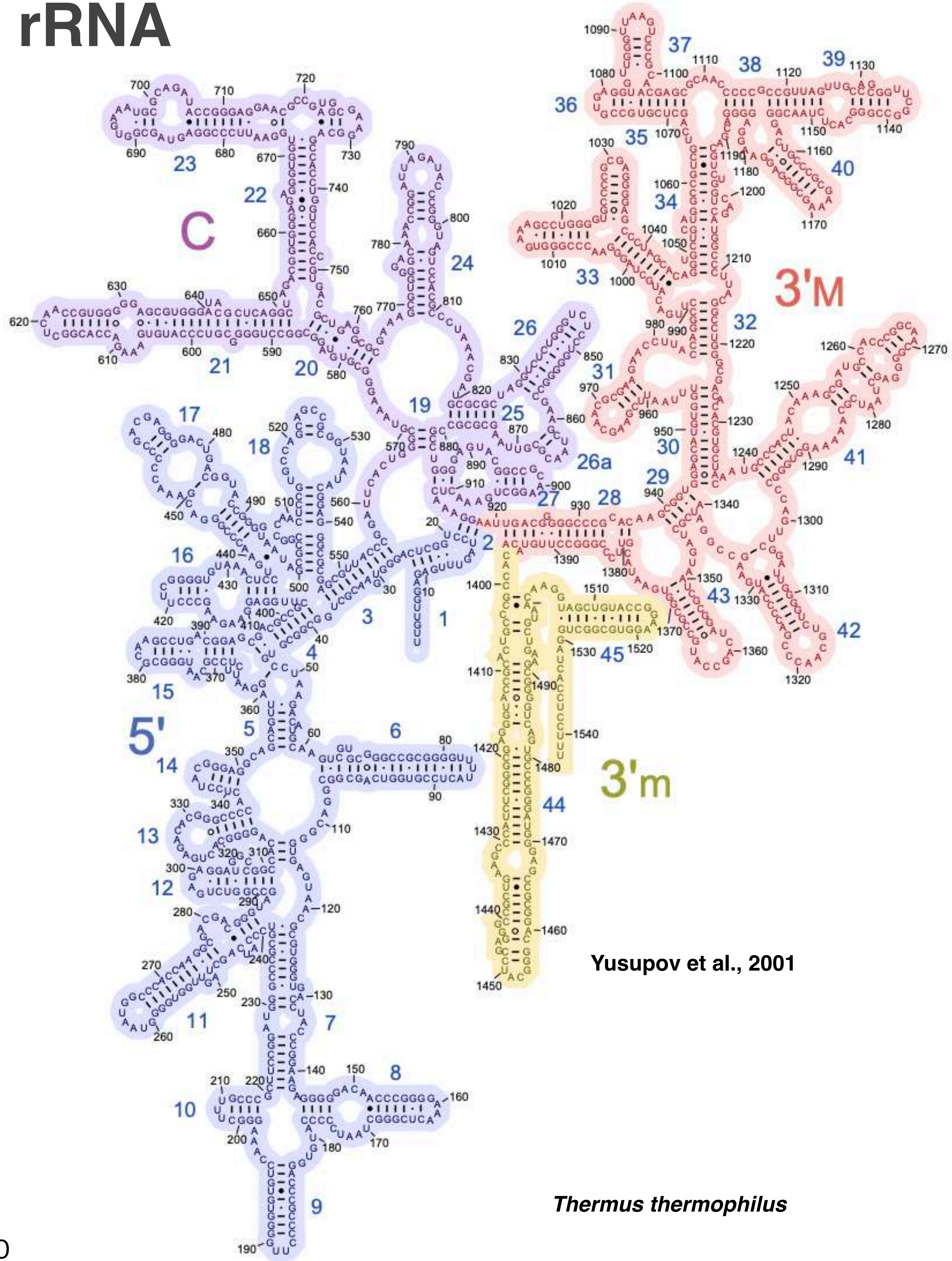
16S rRNA

Escherichia coli



Yarza et al. 2014

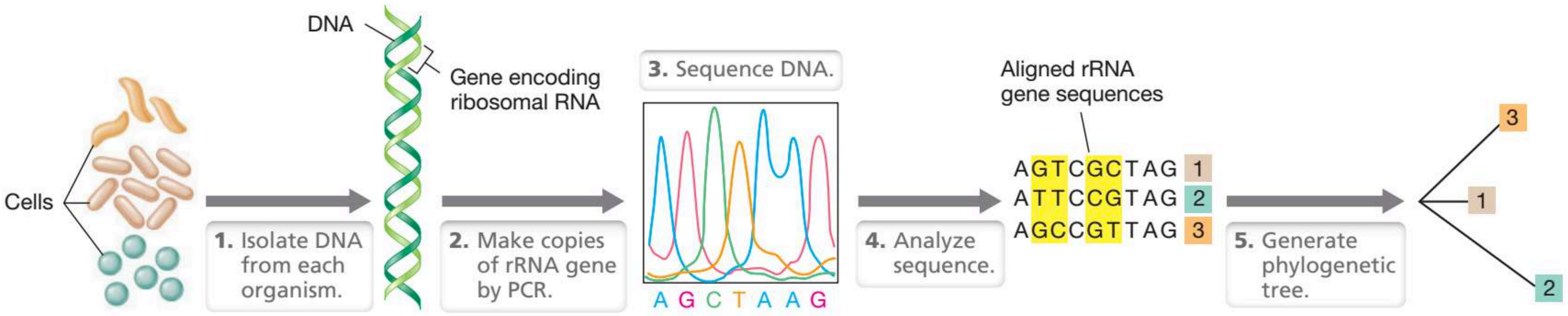
Figure 1 | **Variable regions of the 16S ribosomal RNA.** Secondary structure of the 16S rRNA of *Escherichia coli*, as generated using the xrna program (see Further information). For our analysis, six R fragments of ~250 nucleotides were designed according to the known V regions (Supplementary information S2 (box)). In red, fragment R1 including regions V1 and V2; in orange, fragment R2 including region V3; in yellow, fragment R3 including region V4; in green, fragment R4 including regions V5 and V6; in blue, fragment R5 including regions



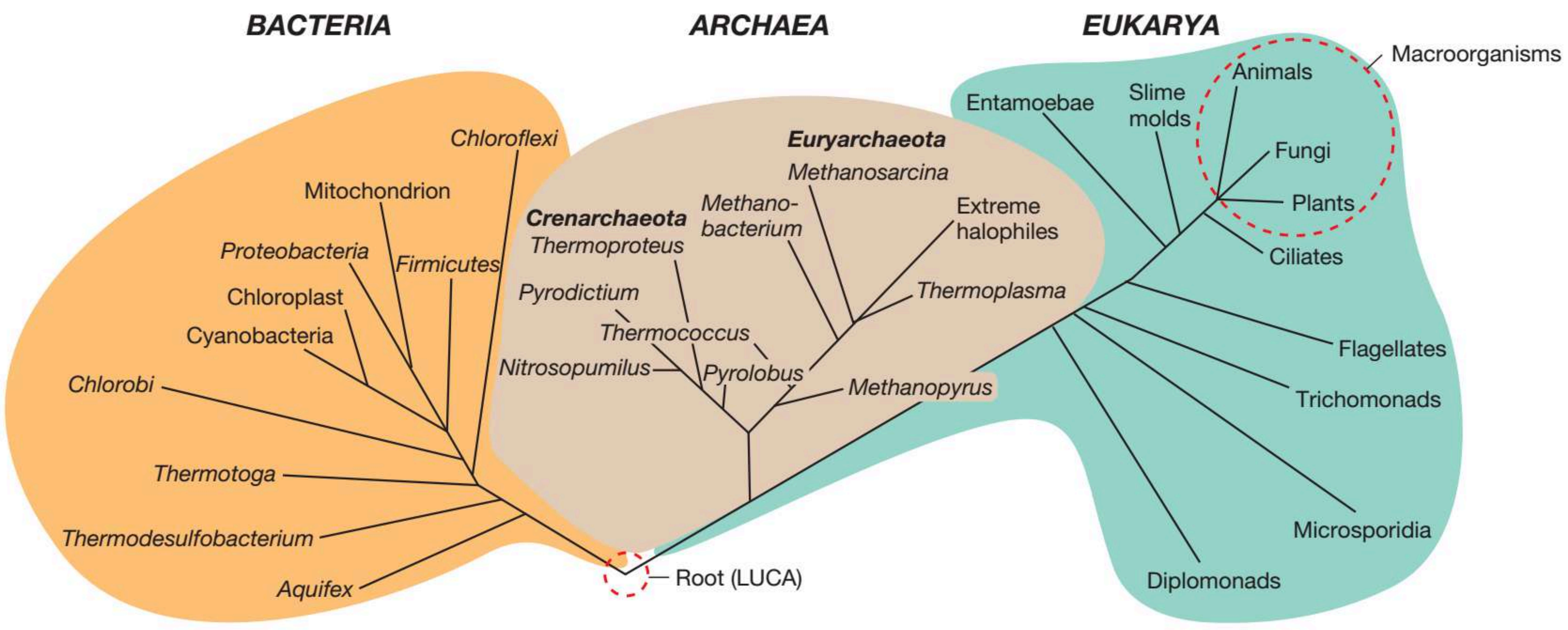
Yusupov et al., 2001

Thermus thermophilus

Step-by-step technology for evolutionary classification of microbes



Phylogenetic Tree of Life

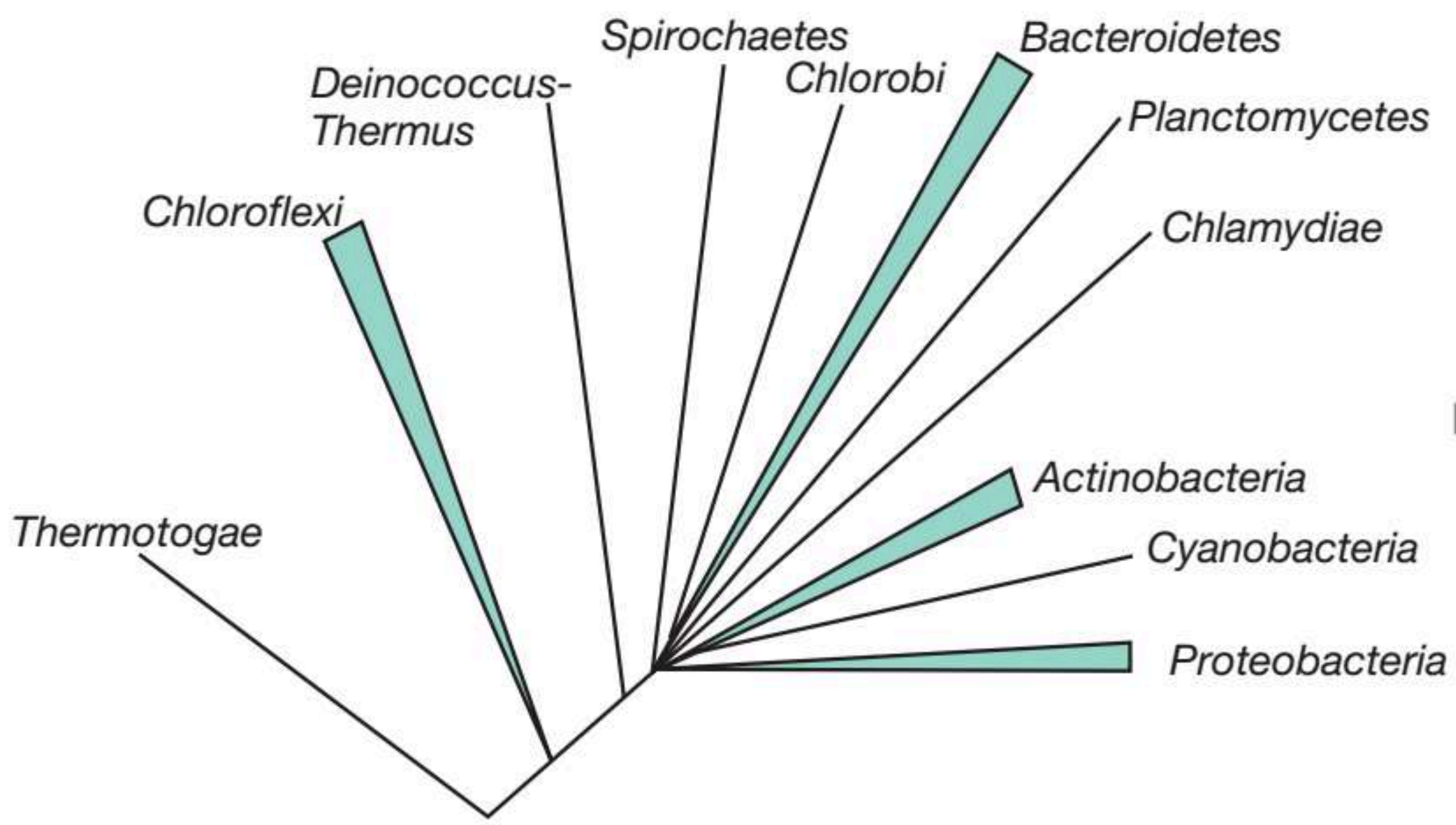


LUCA: Last Universal Common Ancestor

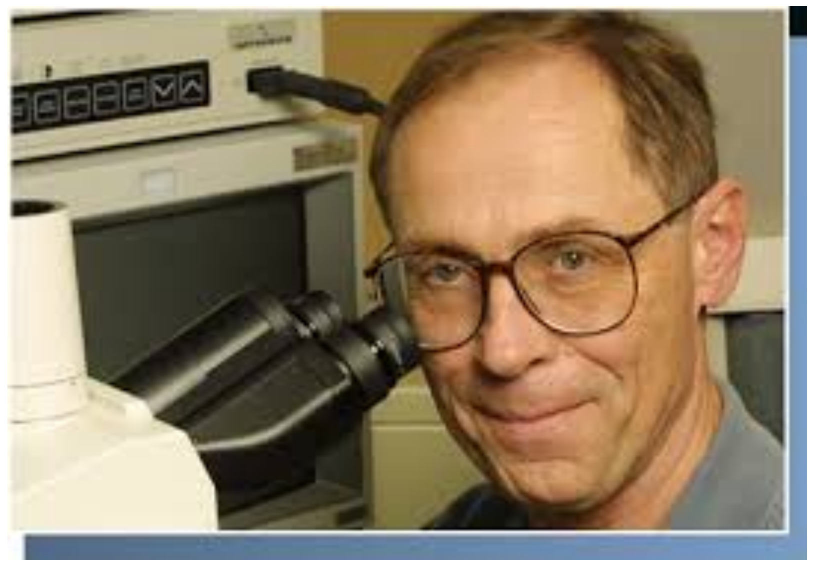
Madigan et al. 2018

Woese

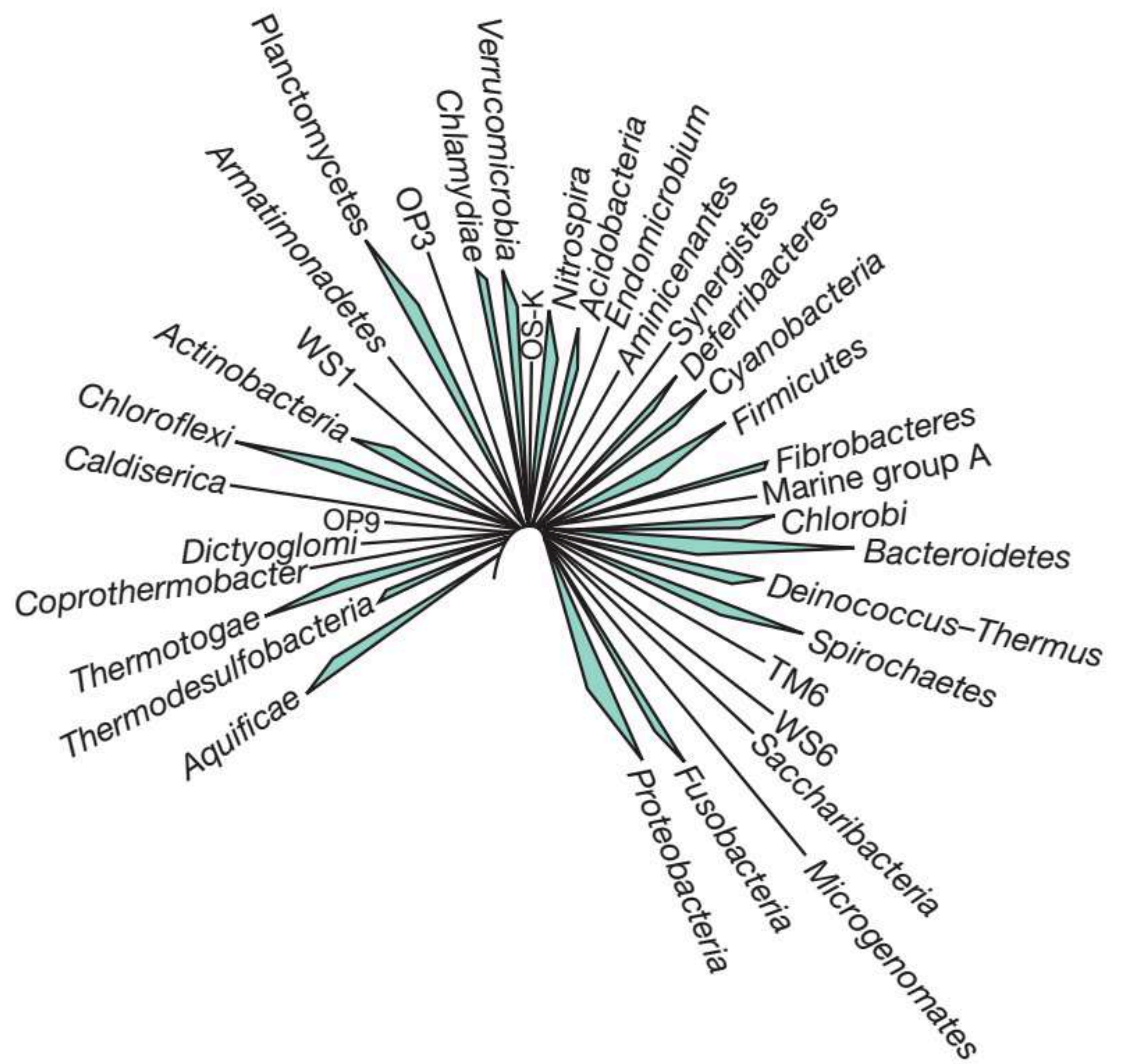
Woese



Cultivation dependent



Pace



Madigan et al. 2018

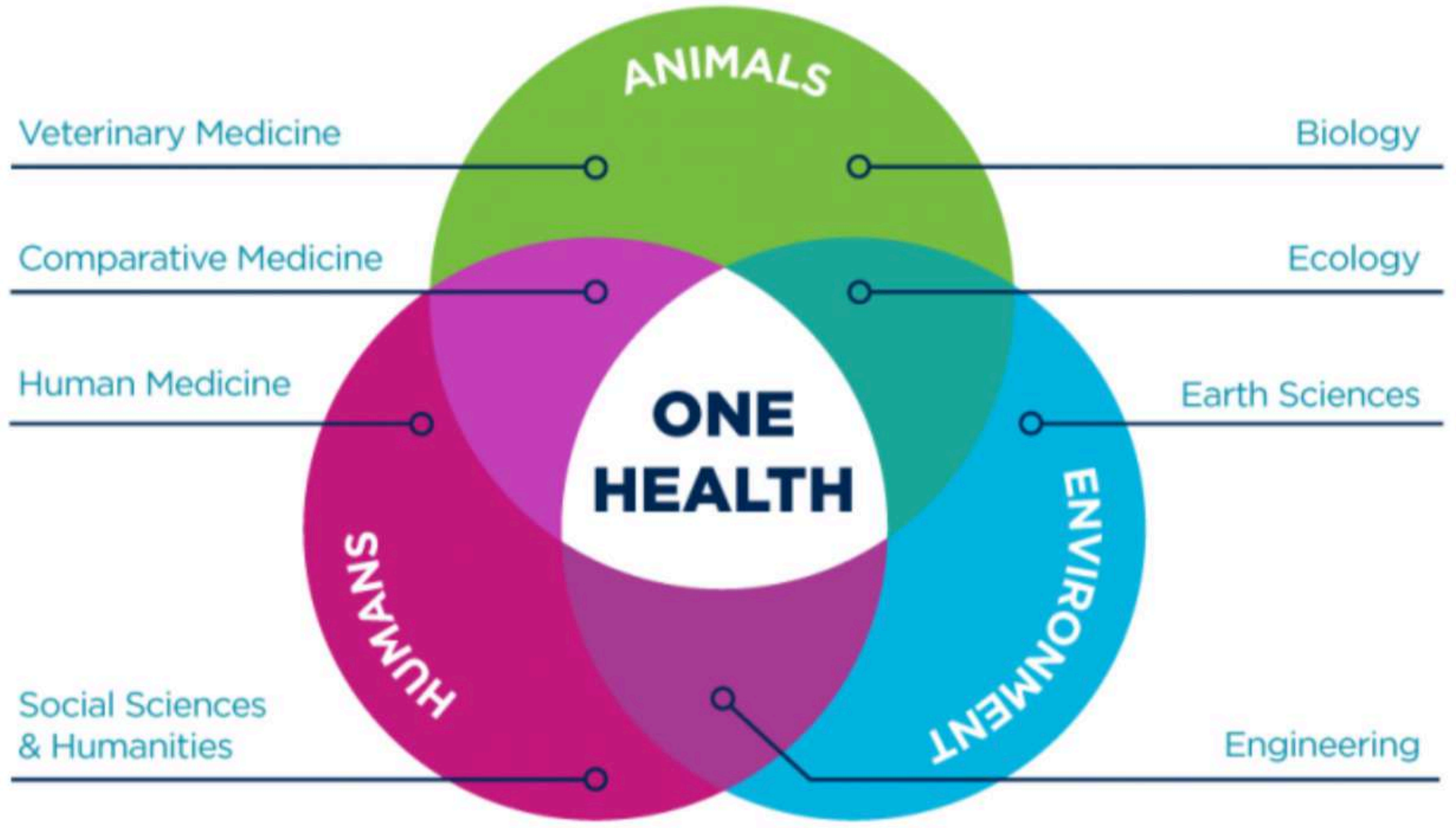
Cultivation independent

Microbes living in the environment

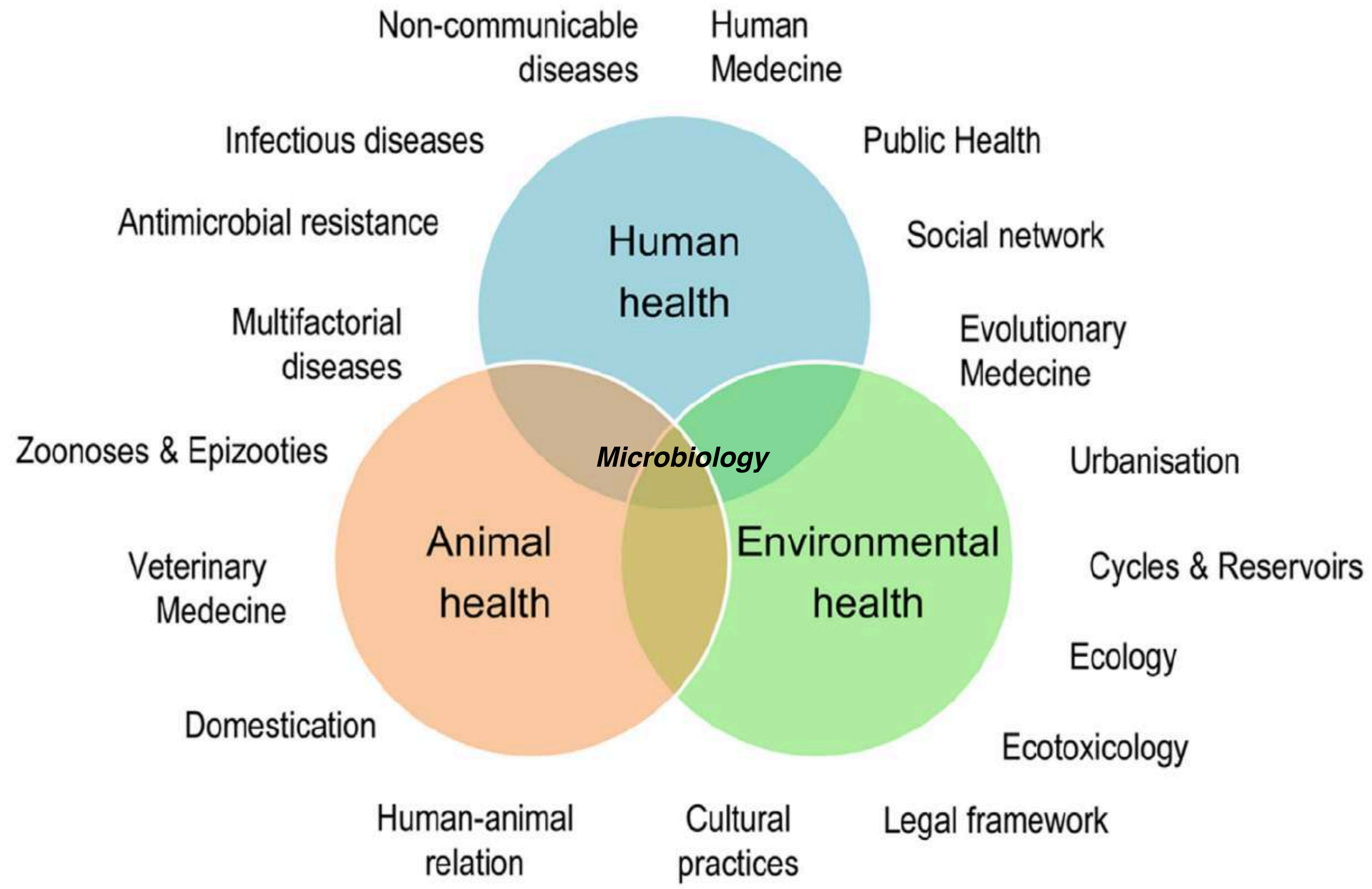
Microbes can or can't be cultivable

- Now and in the near FUTURE: **One Health**: approach to designing and implementing programs, policies, legislation and research in which multiple sectors communicate and work together **to achieve better public health outcomes**

Holistic approach where interactions matter



Original author not found



Destoumieux-Garzon et al., 2018

Microbiology:

Holistic study of the function of microbial cells and their impact on medicine, industry, environment and technology (Madigan et al. 2018).

Goals of the course:

Proficiency in microbial literacy and gaining fundamental understanding of microbes life and their function in the environment, thus included the human beings in health and disease

Core Concept in Microbiology

01: Evolution, Thermodynamics, Habitat diversity, Ecology, Physiology their integration define Microbiology

02: Unique goal of microbial life: survival, maintenance, generation of ATP, growth of new cells

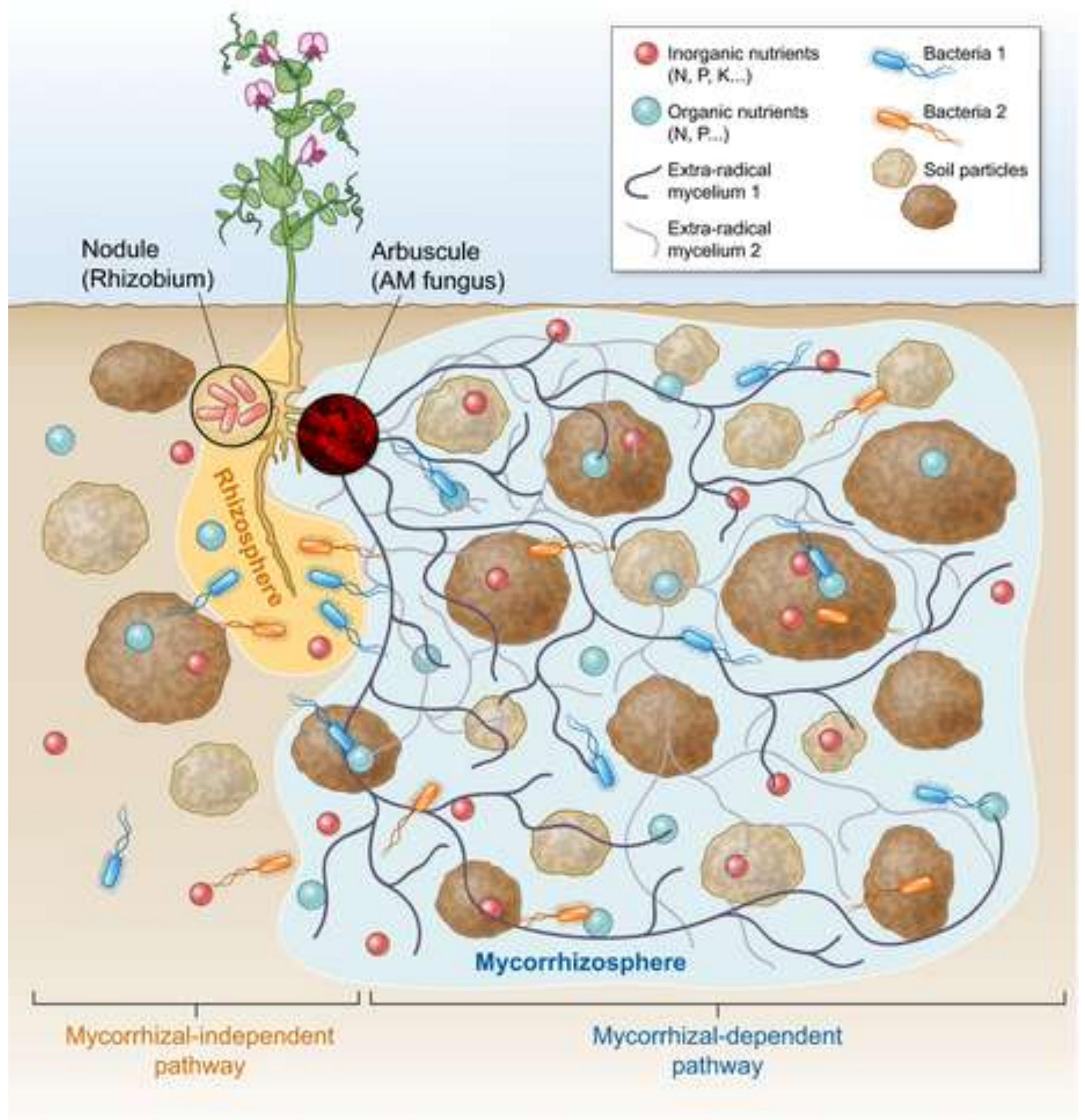
03: Planet's habitat diversity results in genetic, molecular, metabolic and physiological microbial diversity

Where are microbes?

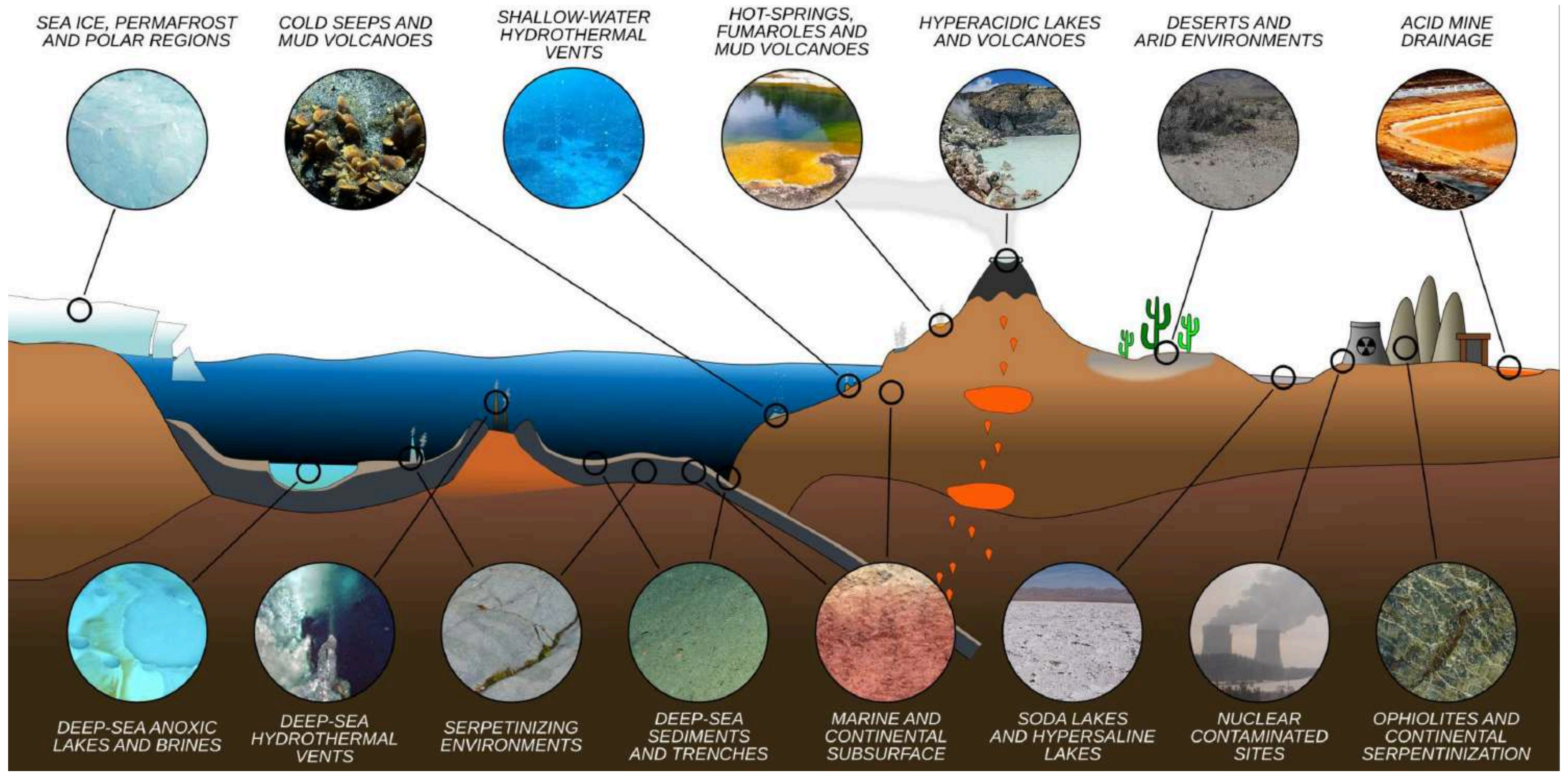
Everywhere

Structuring parameters in microbial environments I

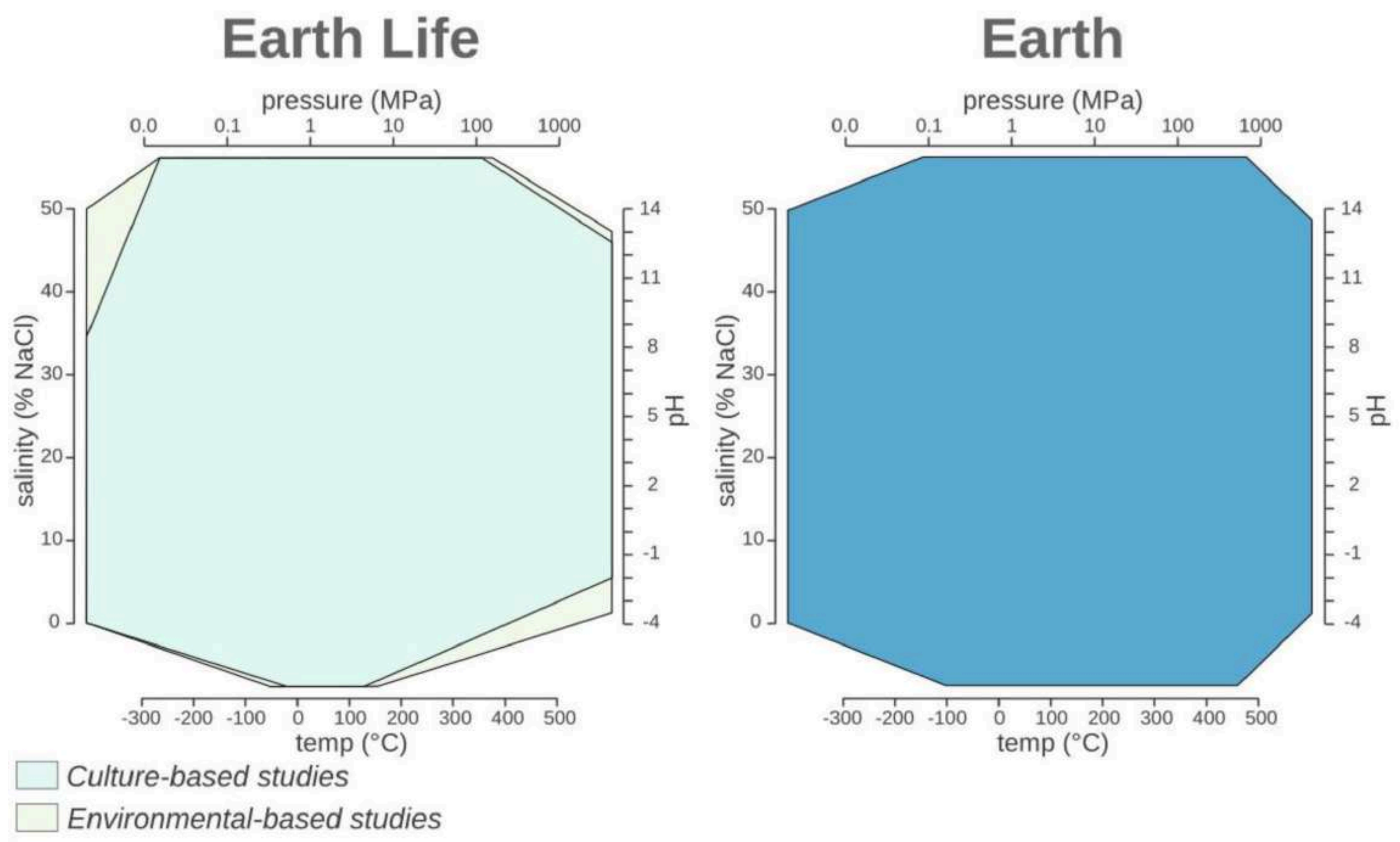
- Temperature
- pH
- Light/Dark
- Humidity
- Pressure
- Radiations (not on Earth)



Wipf et al. 2019



Merino et al. 2019

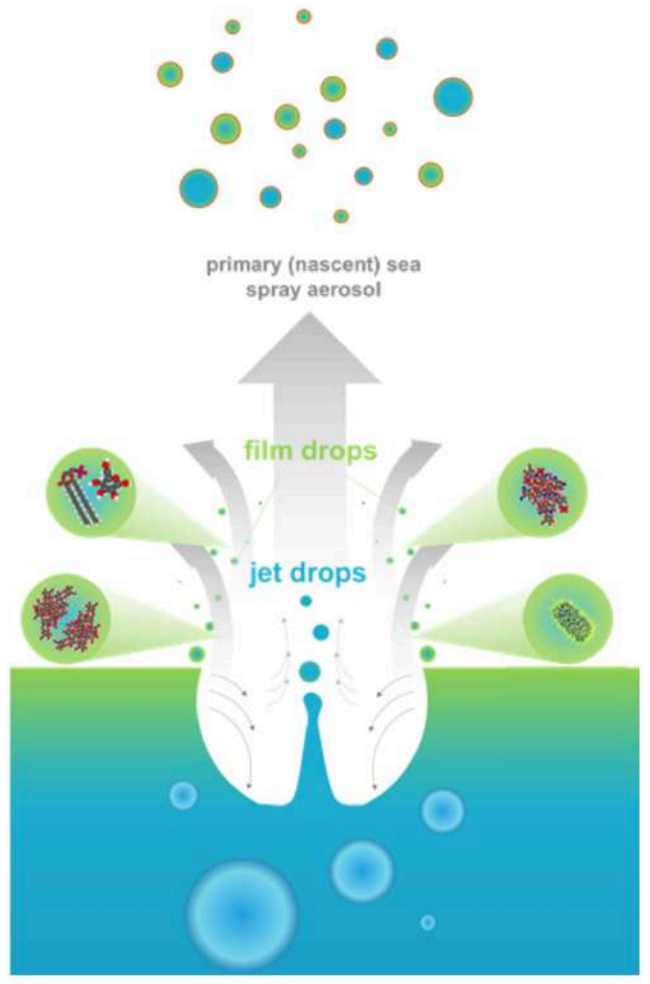


Structuring parameters in microbial environments II

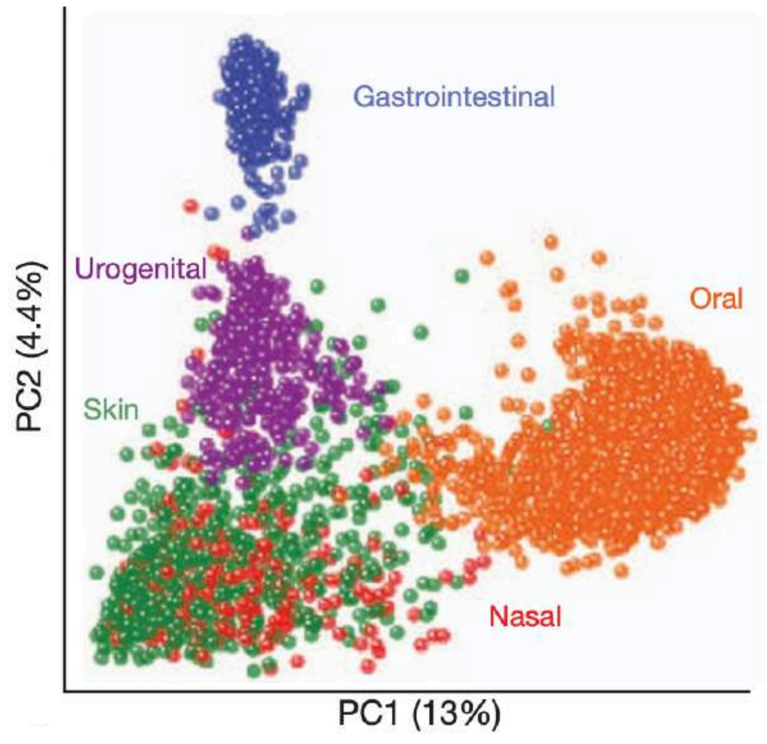
- Ionic strength/Salinity
- State of water
- Organic matter concentration
- Oxygen and other redox active molecules
- 3D structure in space and time
- Other microorganisms and their biology
- Humans

Specific adaptations to grow in the microenvironment

https://youtu.be/i-icXZ2tMRM

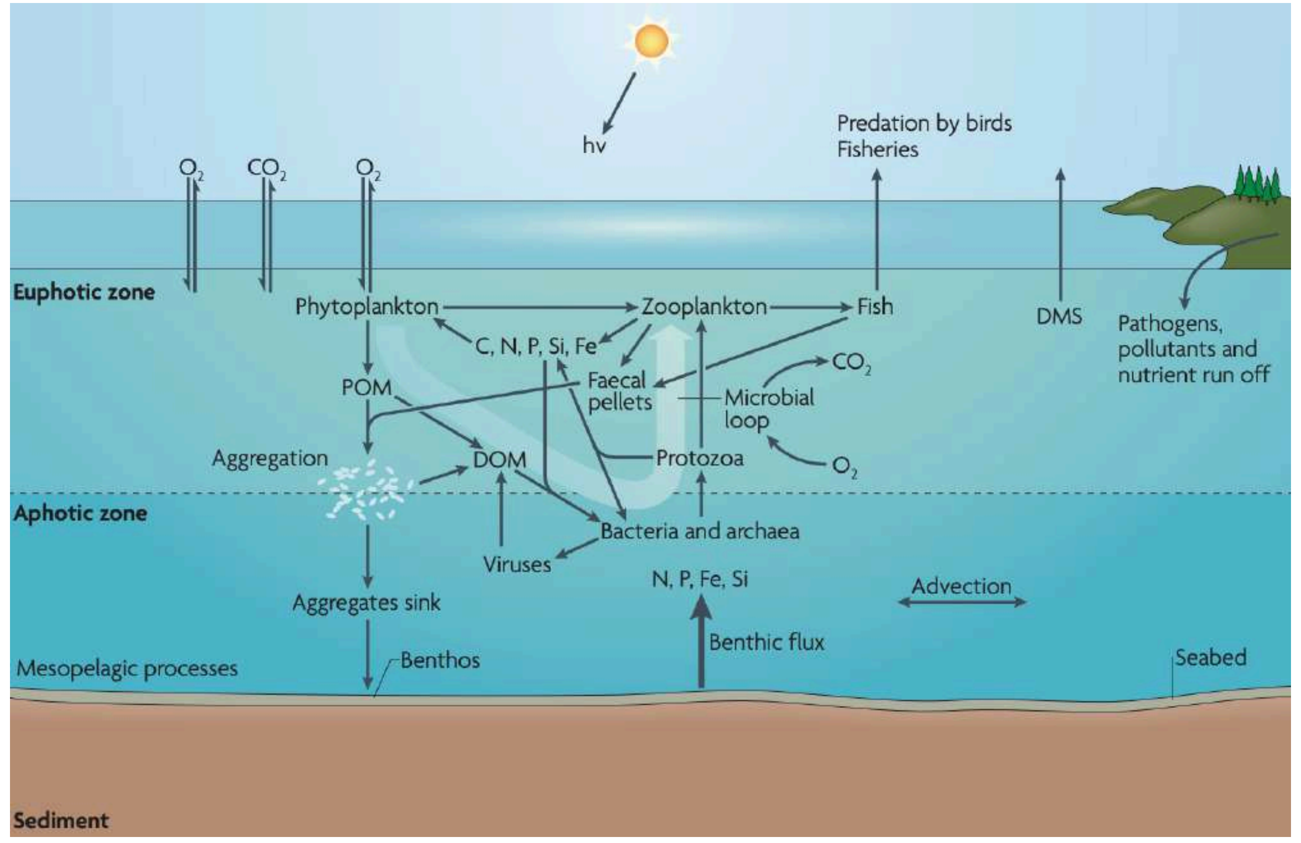


2020 CENTER FOR AEROSOL IMPACTS ON CHEMISTRY OF THE ENVIRONMENT



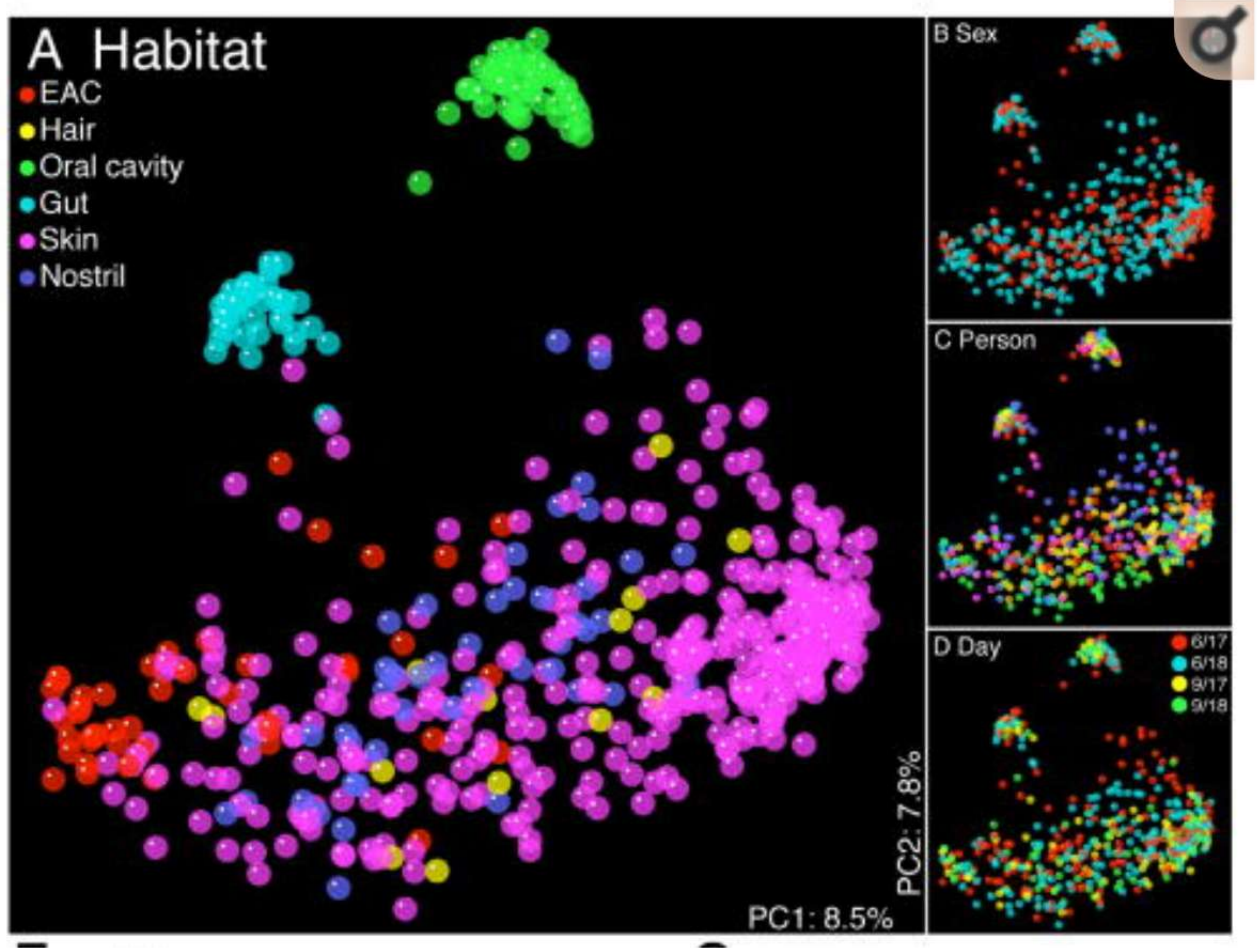
HMPC 2012

Azam & Malfatti 2007



Human as microbial multiverse environment

- 36-37 ^{o}C and > 38 ^{o}C
- Rich environment: proteins, sugar and lipids
- Oxygen: 5-20 mL/dL (in the blood) to 0 (in the stomach)
- Oxygen changes with altitude 100 mmHg = 20 mL/dL (148-43 mmHg from London to Mt. Everest)
- Light/Dark cycles
- Eukaryotes and Viruses (ecology, chemistry and physiology)
- pH:
  - ★ skin~5.5
  - ★ blood~7.4
  - ★ mouth~ 6.7-7.3
  - ★ vagina ~3.8-4.5
  - ★ esophagus 5-7
  - ★ stomach 2-5
  - ★ duodenum 6.8

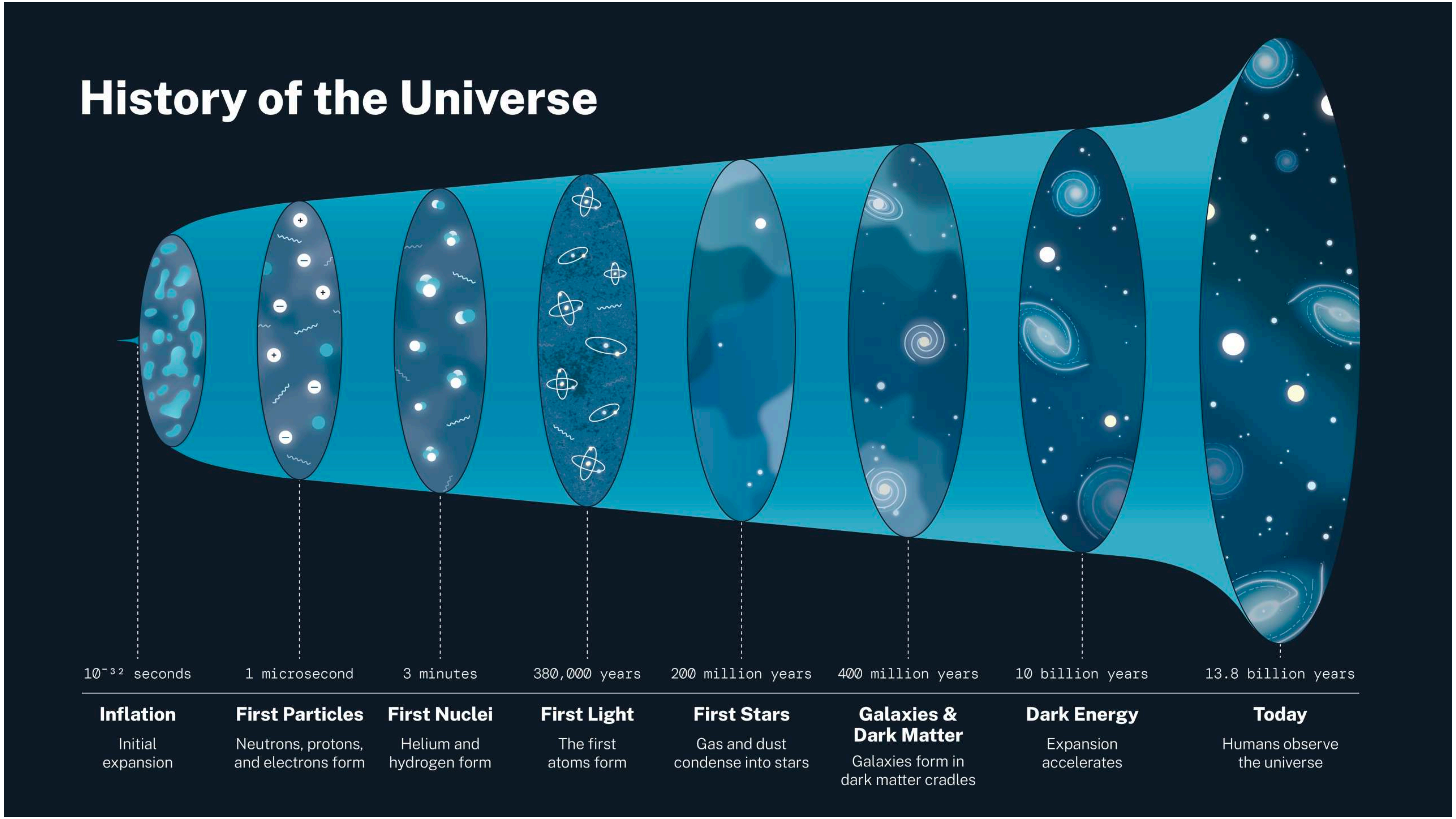


Costello et al., 2005

Whole Earth as a microbial ecosystem for billions of years

Ab initio

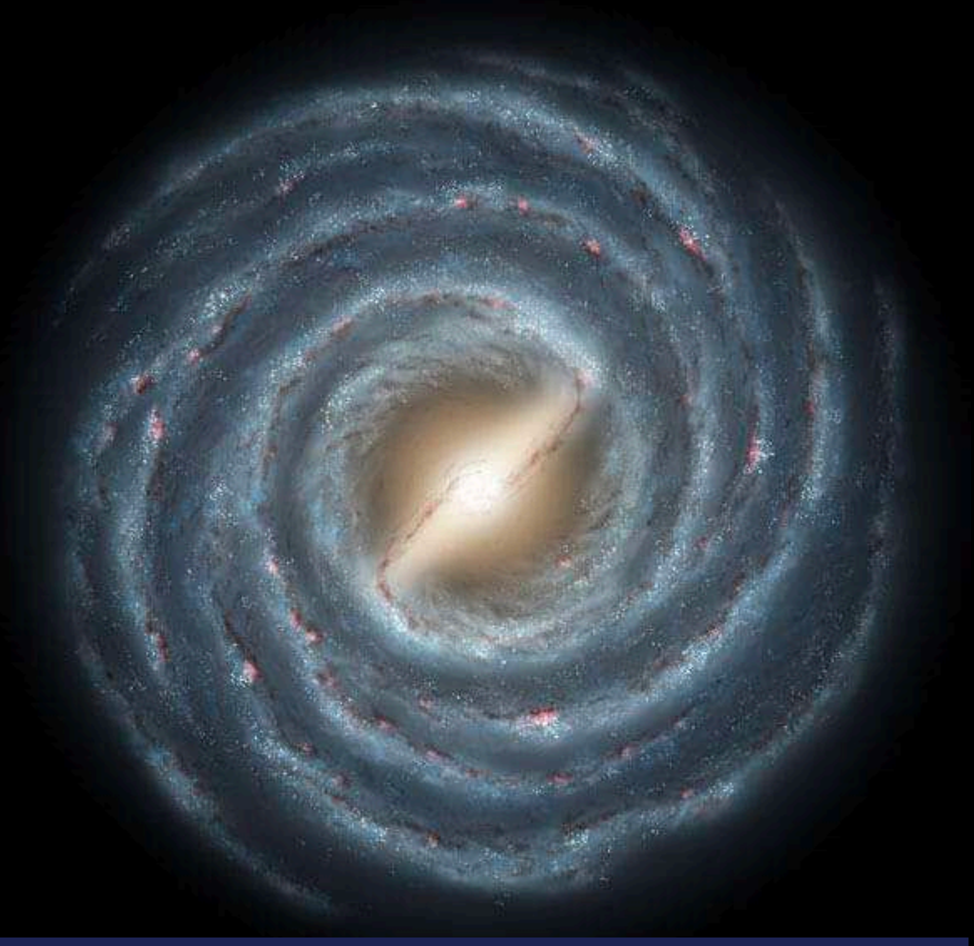
THE BIG BANG

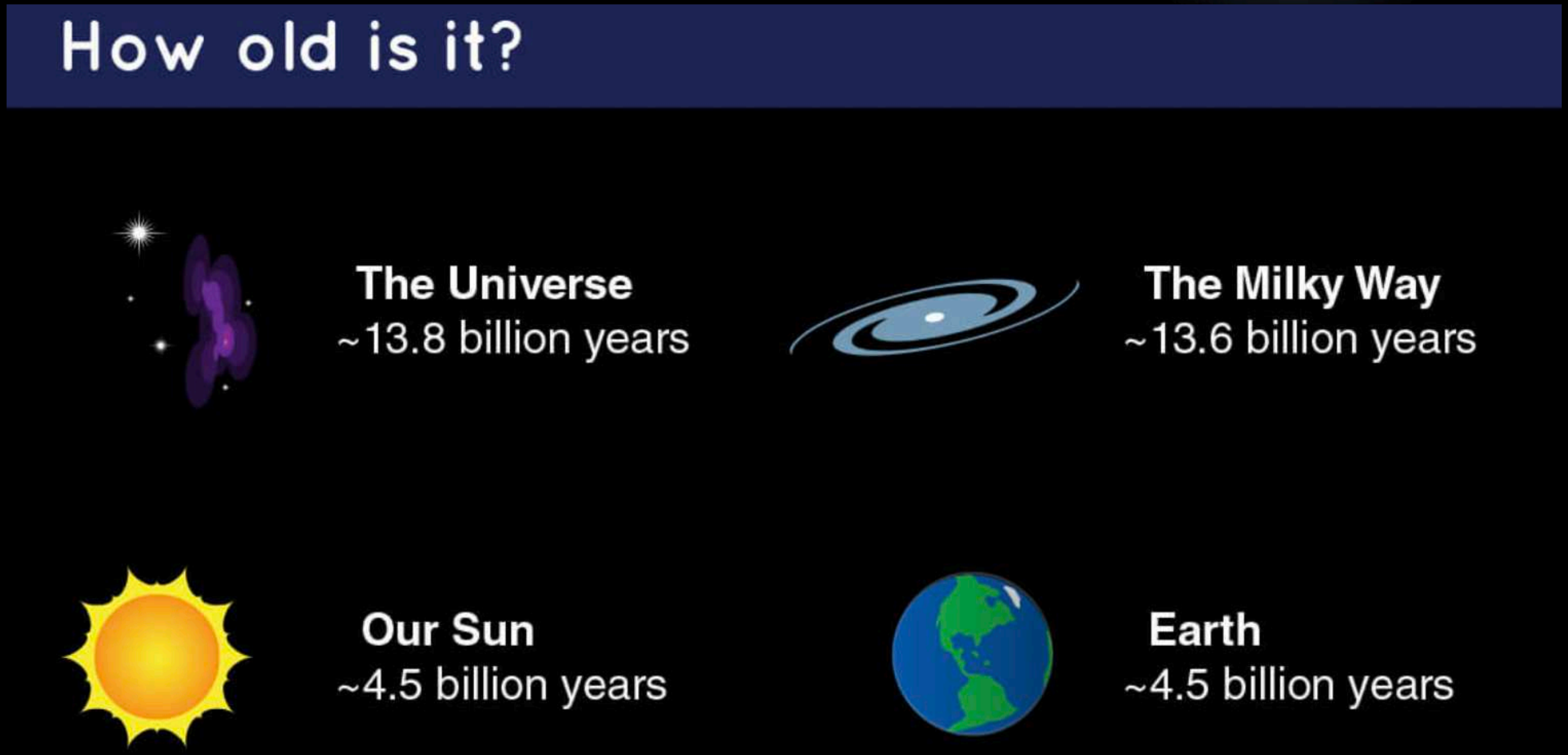


https://science.nasa.gov/universe/overview/

GALAXIES

10 billion and 13.6 billion years old

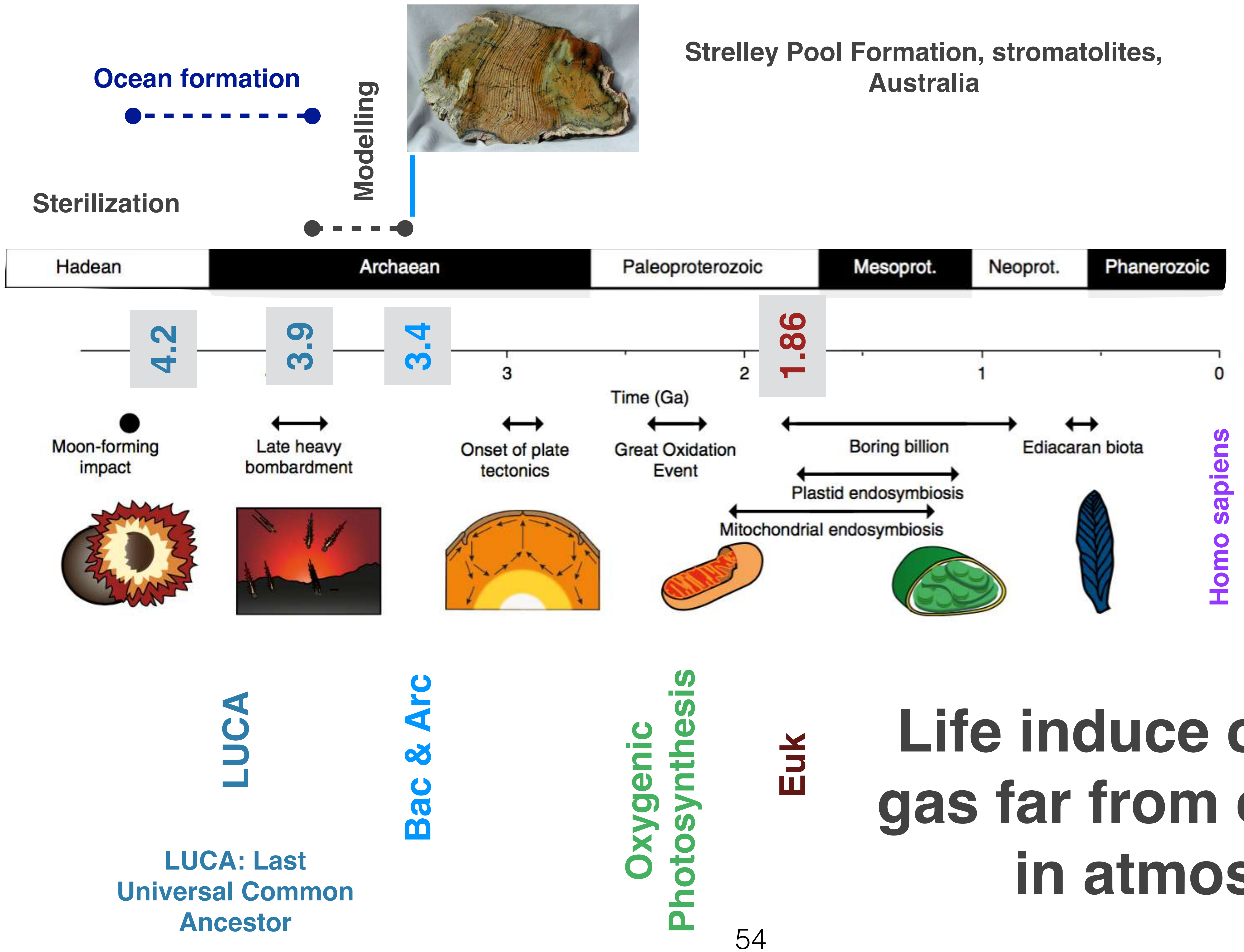




https://spaceplace.nasa.gov/galaxies-age/en/
#:~:text=Astronomers%20believe%20that%20our%20own,approximately
%2013.6%20billion%20years%20old.

★

Origin of Life: **when**



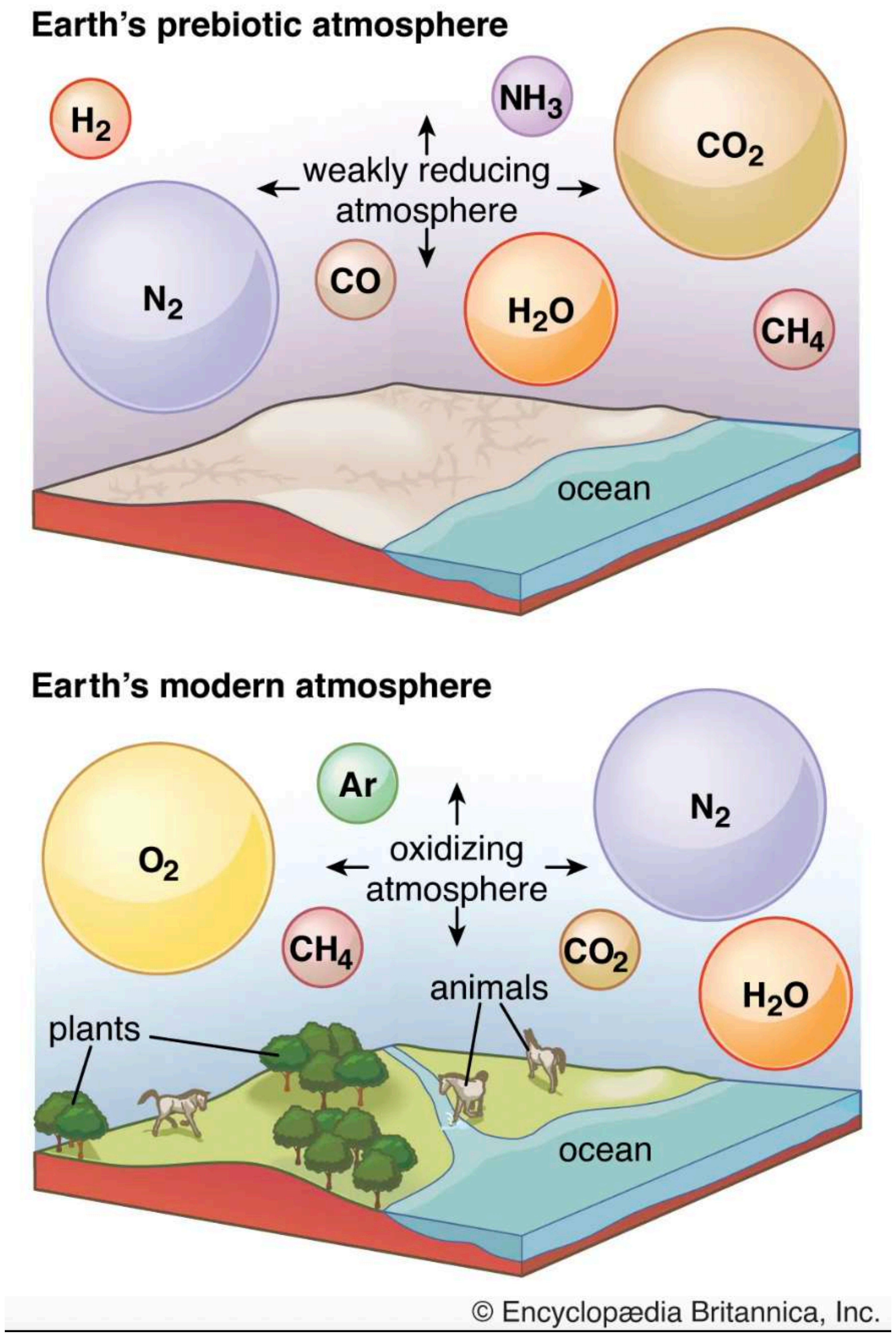
LUCA: Last Universal Common Ancestor

Betts et al., 2018
Moody et al., 2024

Life induce changes in gas far from equilibrium in atmosphere

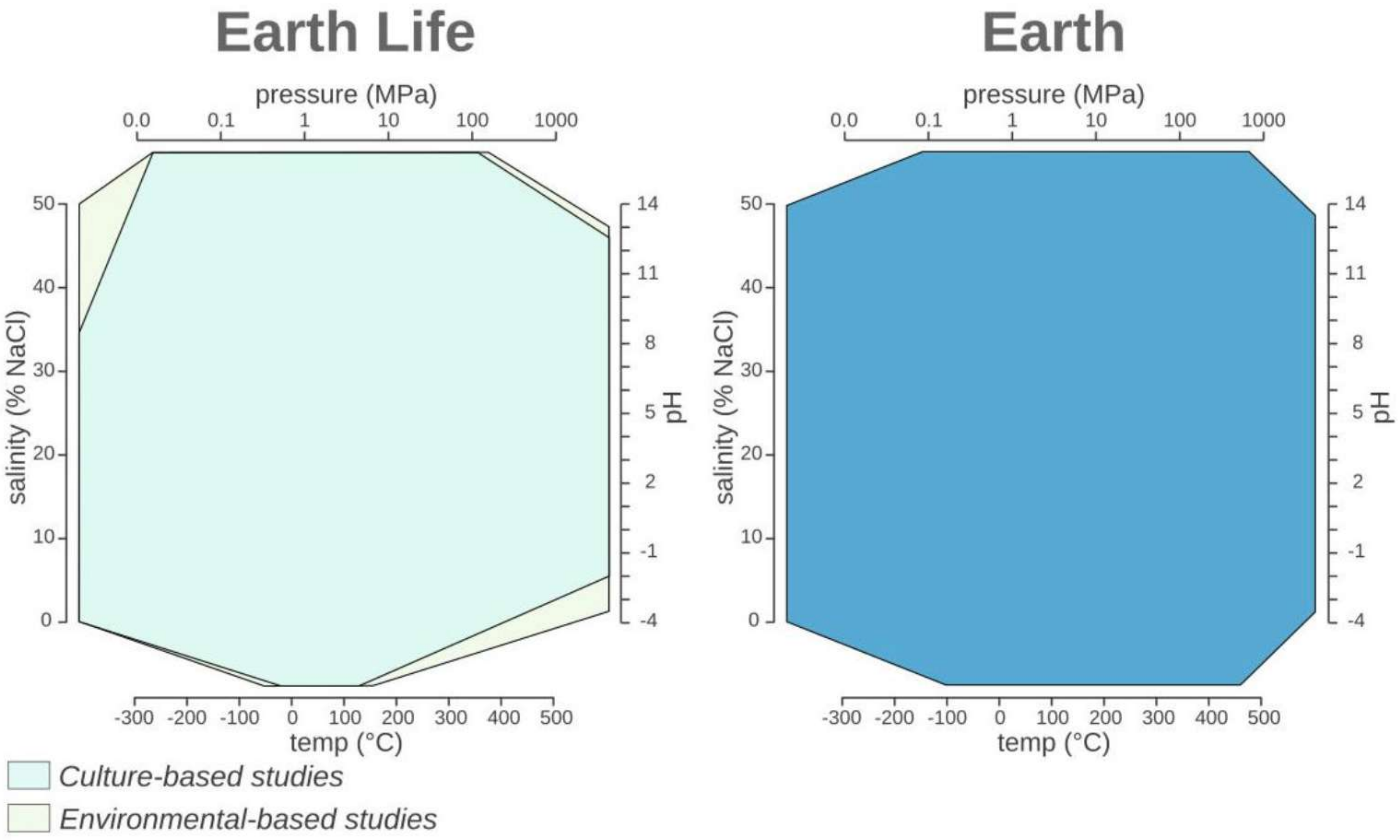
EARTH'S ATMOSPHERE

★



★ Microbial Life on Earth

Merino et al., 2019



Earth is bursting with life, and its **biosphere** extends from ~10 km altitude to ~10 km into the oceans and oceanic crust as well as ~5 km into the continental crust

Biospheric capacity equivalent to ~1% of Earth's geosphere and troposphere —> a minimum **biospheric volume** of ~1010 km^3

LIFE

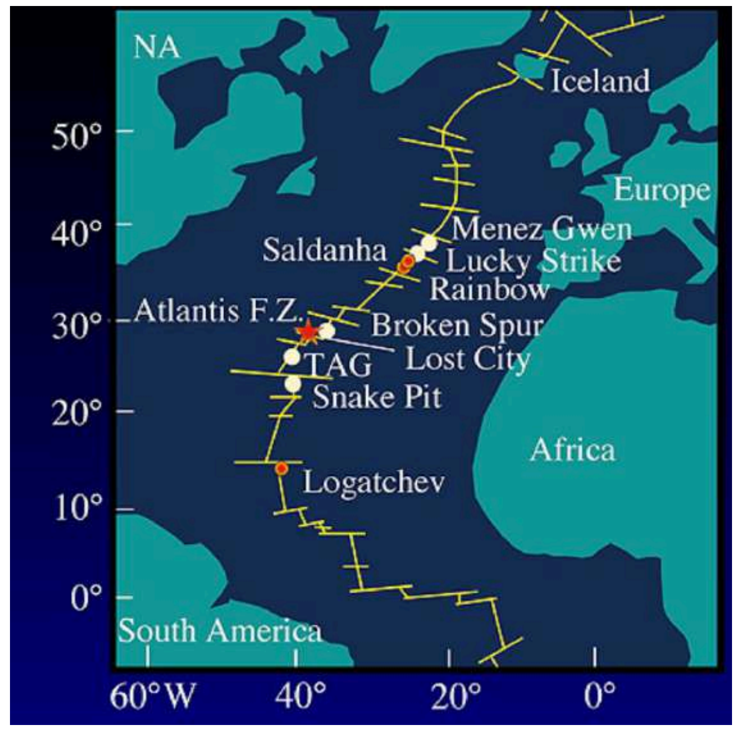
The origin of life is an extended continuum from the prebiotic chemistry to the first reproducing cells

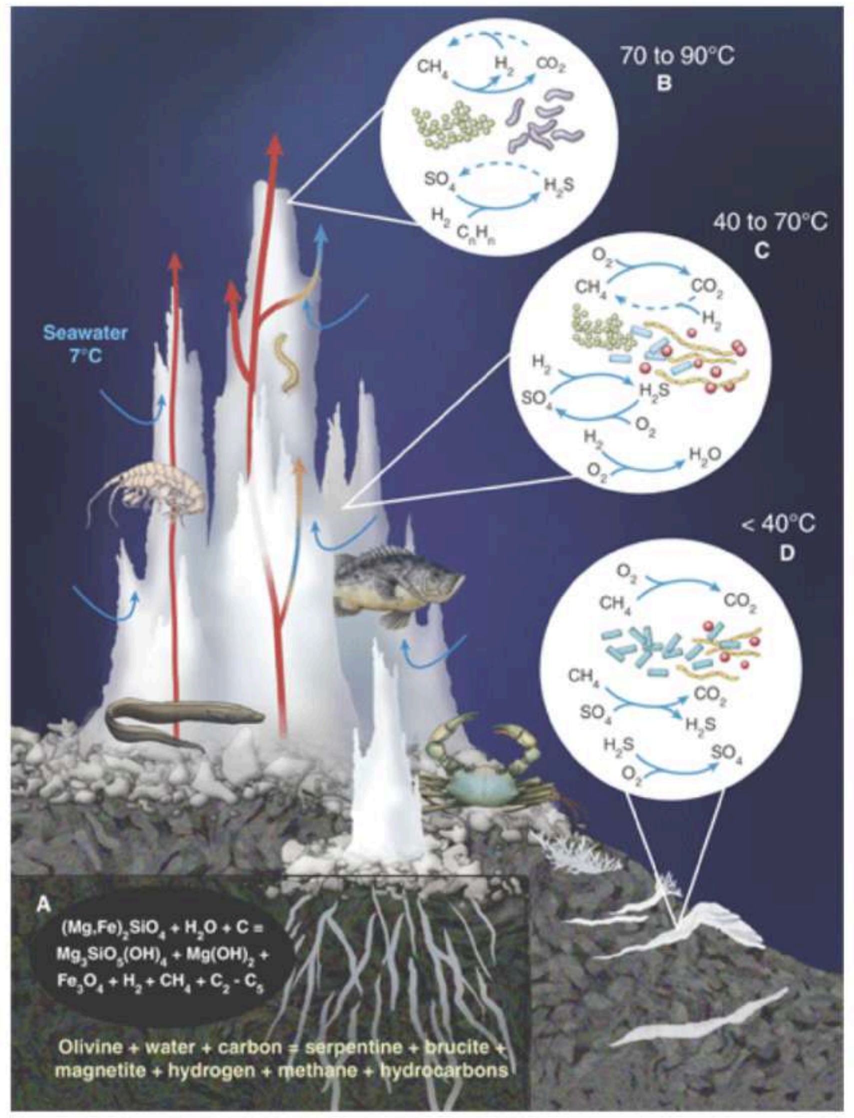
Origin of Life: **where**

At the interface:

a. Diffusion limited surfaces
b. Hydrophobic surfaces
c. Adsorption of organic pre-biotic molecules
d. Fe, S, other minerals acting as catalyst

1. Mineral surfaces on microporous rock (similar at hydrothermal vent, LOST CITY)





Boetius 2005 and NOAA

2. Shallow terrestrial ponds with geothermal energy

yellowstonepark.org

The need of testable predictions according to where the cradle of life has been started

PREBIOTIC SOUP

The synthesis of organic molecules begins with derivates of cyanide, energised by ultraviolet radiations

1. **Where does cyanide come from?**
2. **How these reservoir of materials come to life when condition changed?**
3. **Nucleotides are concentrated in small ponds that alternate dry and wet periods to polymerise and form RNA**

It implies: RNA act as a catalyst and a template —> favouring strands that are simpler, lacking metabolic capabilities…….

Nature **626, 948-951 (2024)**

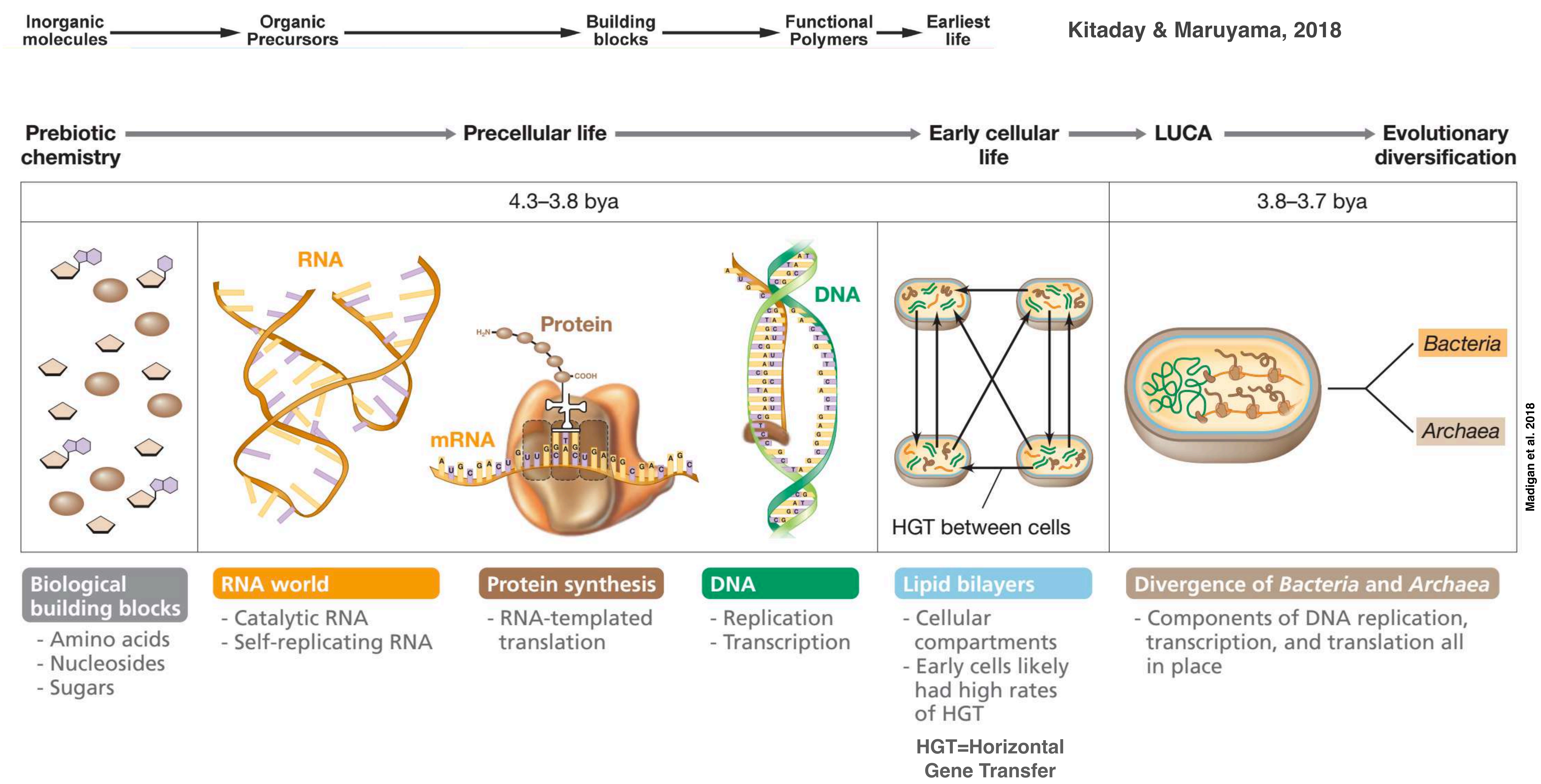
HYDROTHERMAL SYSTEMS

Carbon dioxide and hydrogen feed a network of reactions with a topology resembling metabolism

1. **Carbon dioxide and hydrogen are not very reactive**
2. **Deep-sea vents are labyrinths of interconnected pores with resembling cells, acids outsides and alkaline inside**
3. **Flow of protons that promotes synthesis of carboxylic acids and long-chain fatty acids —> assemble in cell-like structures (i.e., vesicles)**
4. **Enzymes are missing**
5. **Polymerization happening at the water mineral surface interface**

Nature **626, 948-951 (2024)**

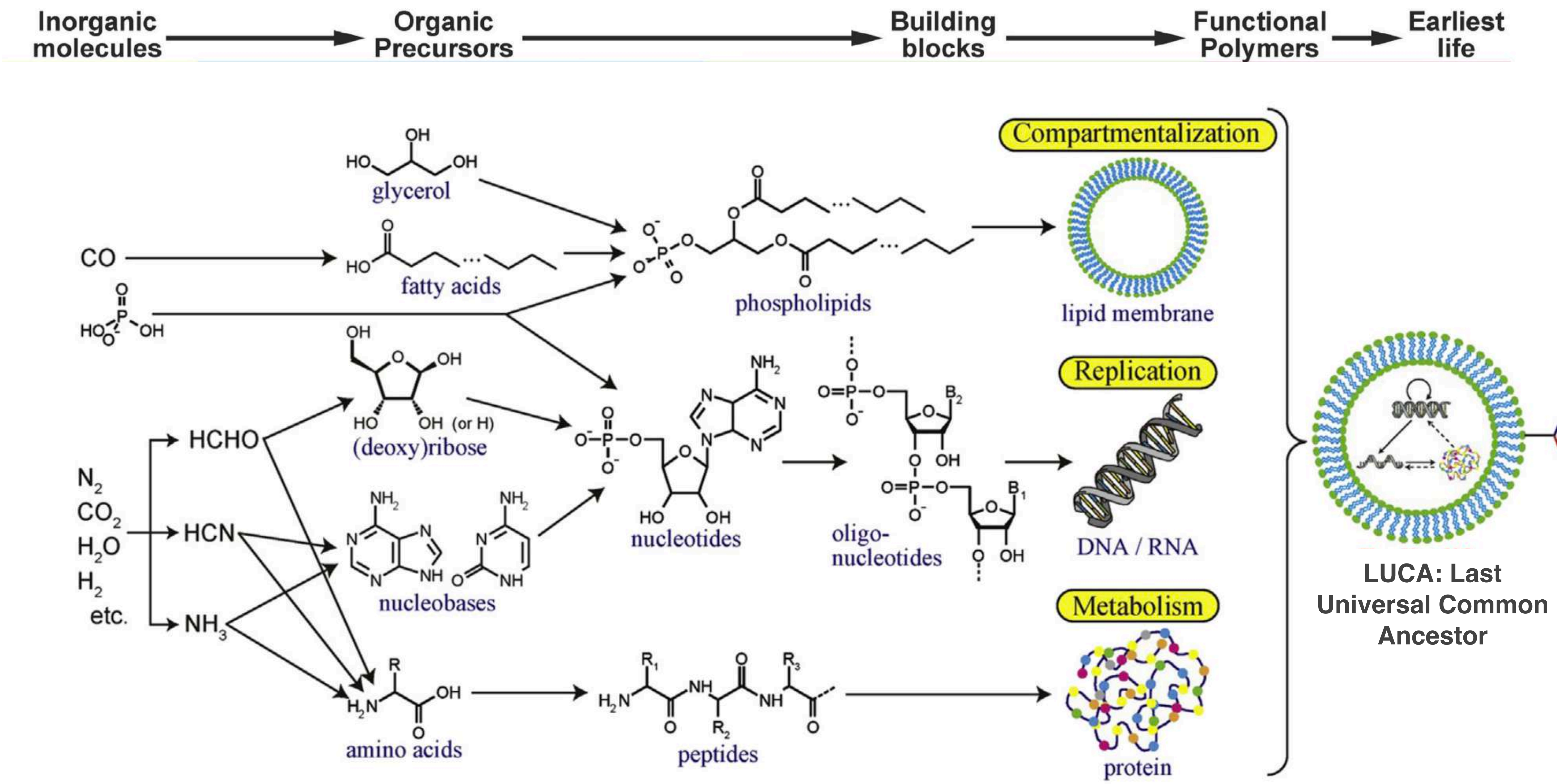
Origin of Life: **how**

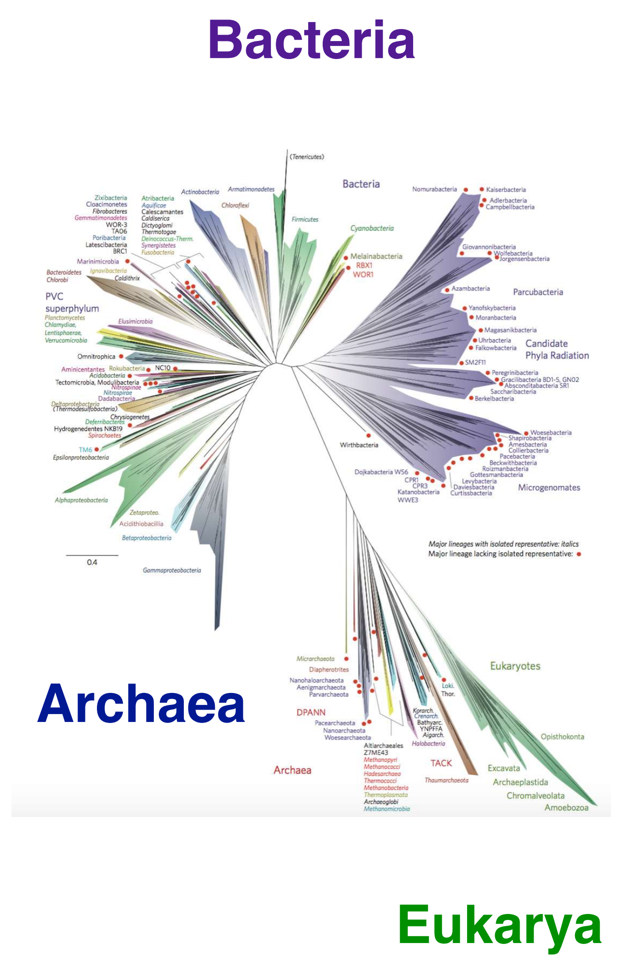


Life needs water and a stable inner environment

Building complexity to achieve the 3 fundamental functions of Life

Kitaday & Maruyama, 2018





primordial soup

Hug et al., 2016

Oparin AI. The Origin of Life. Izd. Moskovshii Rabochii; 1924

Haldane JB. The origin of life. Rationalist Annu. 1929

★ **Miller-Urey's experiment mimicked lightning by the action of an electric discharge on a mixture of gases representing the early atmosphere (CH4/H2O/NH3/H2S and later H2O, N2, and CH4, CO2, or CO), in the presence of a liquid water reservoir, representing the early oceans —> hydrogen cyanide, formaldehyde, and amino acids**

Parker et al. 2014

RNA-peptide world

RNA world concept: life evolved from increasingly **complex self-replicating RNA molecules**

In RNA world: complex proto-RNA strands were able to both **copy themselves** and compete with other strands

Later, these ‘**RNA enzymes**’ could have evolved the **ability to build proteins** and ultimately to **transfer** their **genetic information into more-stable DNA**

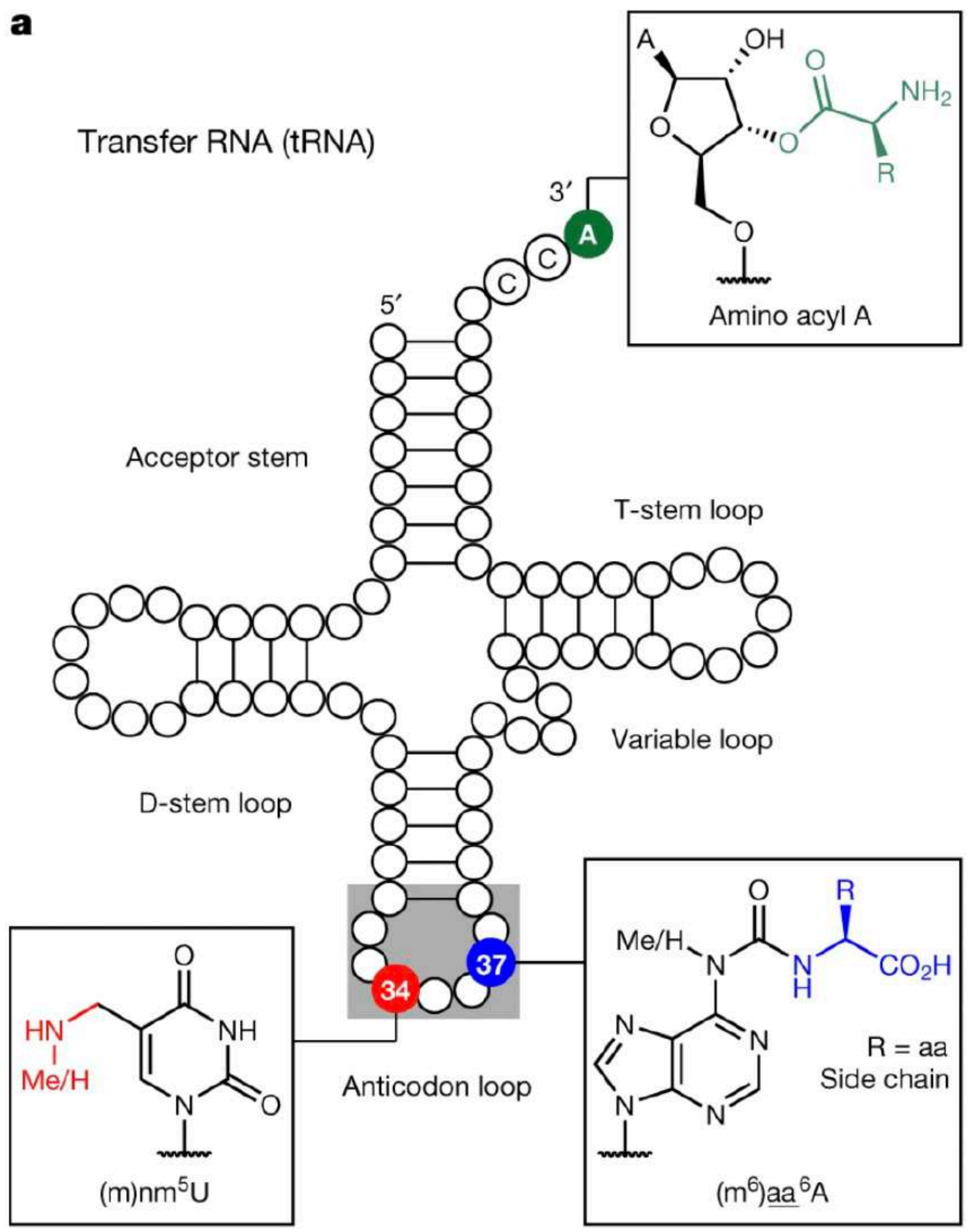
Catalysts made of RNA alone are much less efficient than the protein-based enzymes found in all living cells today

How this RNA world then advanced to the next stage, in which **proteins became the catalysts of life** and **RNA reduced its function** predominantly **to information storage**

Non-canonical RNA bases are considered to be relics of the RNA world and are able to establish peptide synthesis directly on RNA (transfer and ribosomal RNAs)

Complex peptide-decorated RNA chimeric molecules, which suggests the early existence of an RNA–peptide world —> ribosomal peptide synthesis may have emerged

Müller et al., 2022

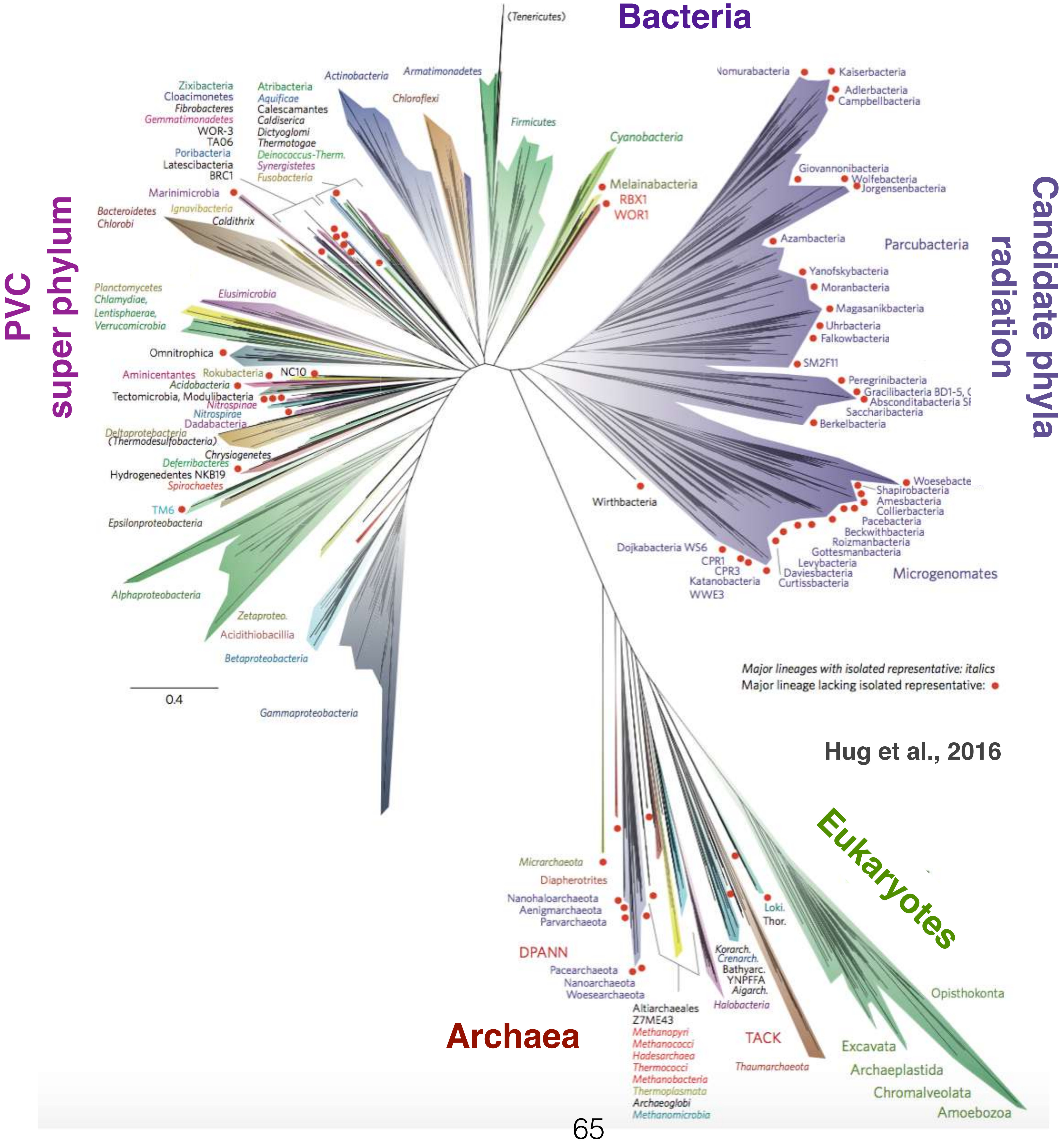


The 3′-amino acid-acylated adenosine is located at the CCA 3′ end in contemporary tRNAs

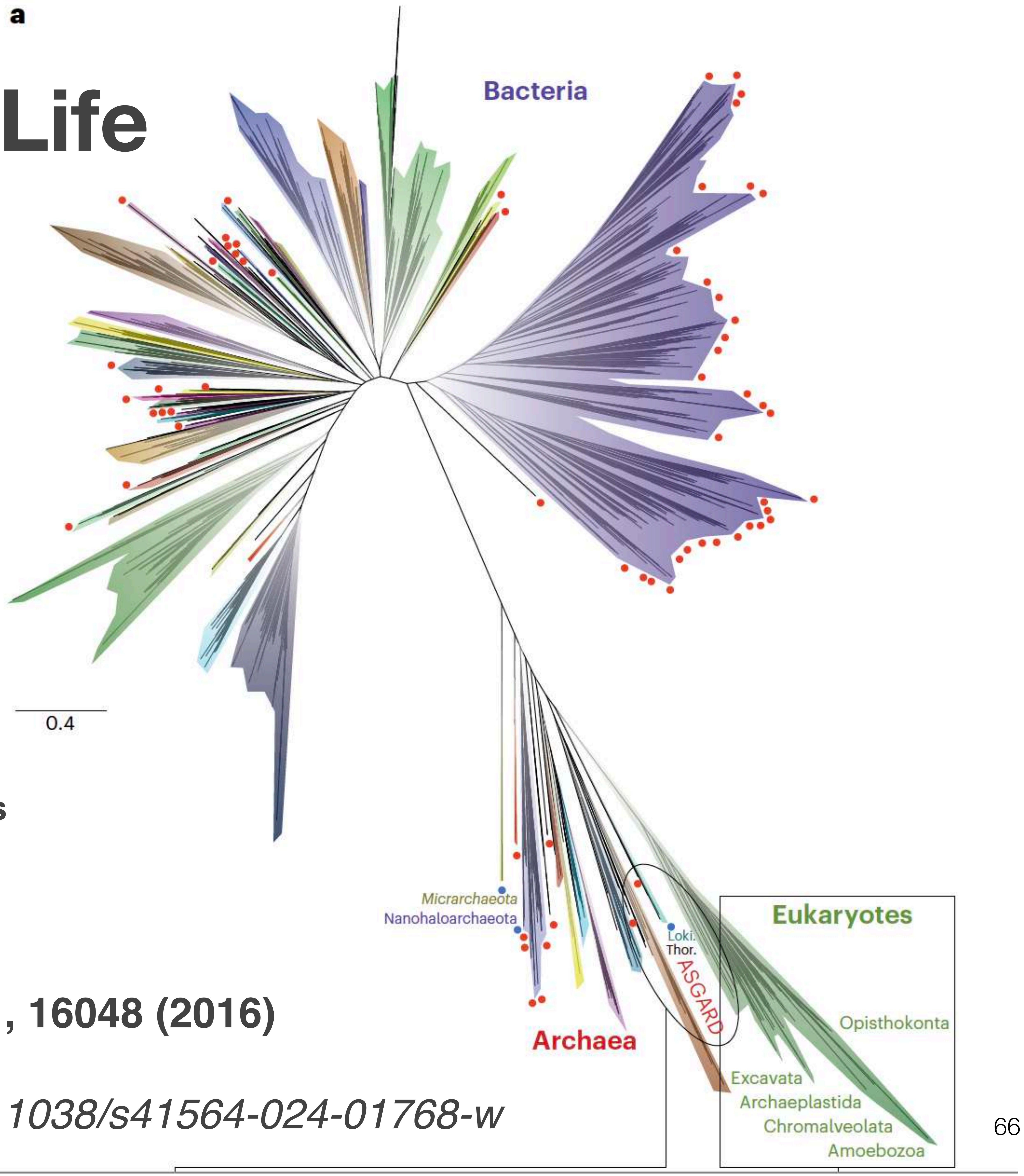
5-Methylaminomethyl uridine, mnm5U, is found in the wobble position 34

The amino acid-modified carbamoyl adenosine, (m6)aa6A (aa, amino acid), is present at position 37 in certain tRNAs

Microbial diversity on Earth



The Tree of Life



Concatenated 16-ribosomal protein tree with phyla highlighted with coloured wedges

Lineages with no cultivated representatives identified by red dots

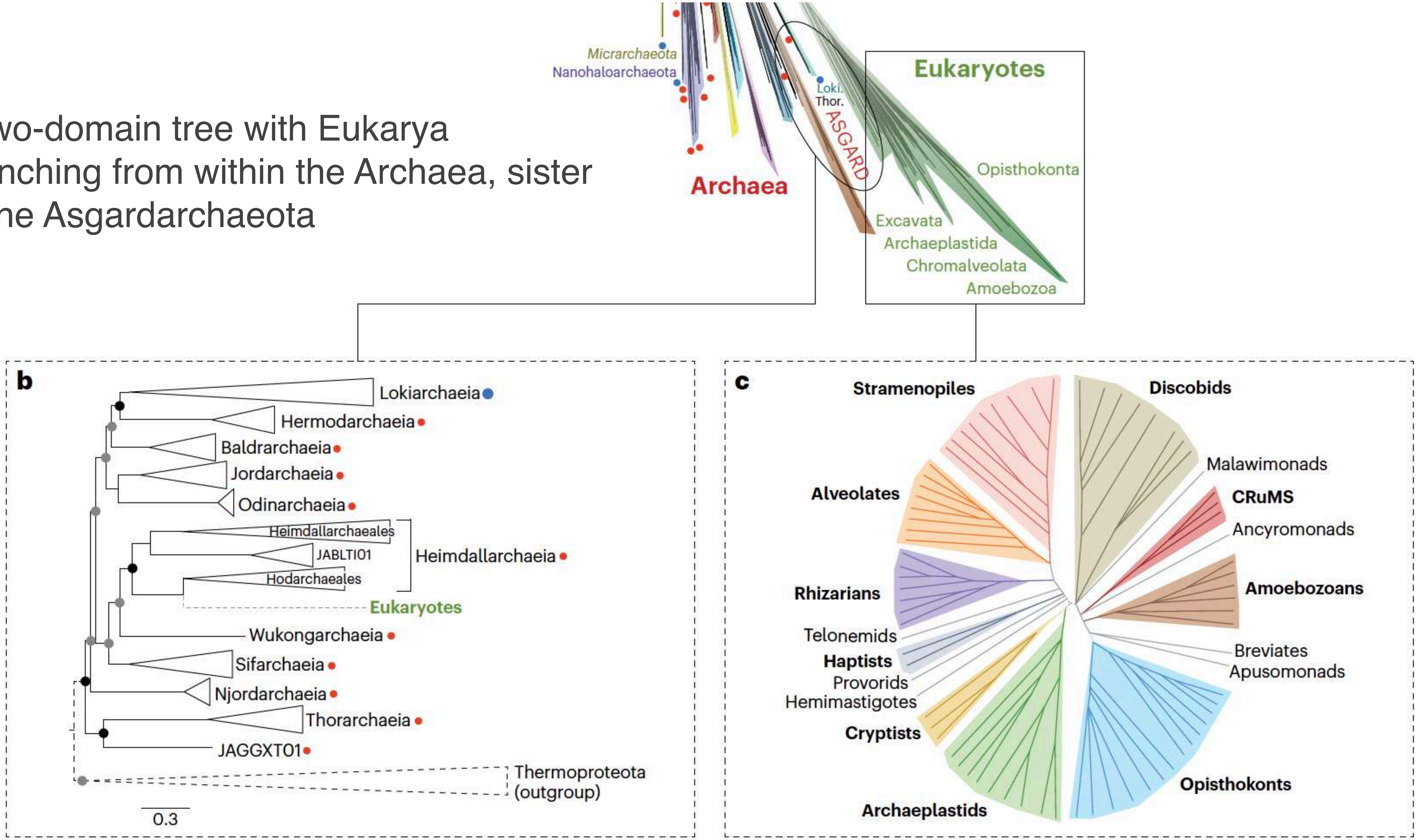
Blue dots: lineages that have gained cultivated representatives since 2016

Hug et al. Nat. Microbiol. 1, 16048 (2016)

Hug 2024 *https://doi.org/10.1038/s41564-024-01768-w*

Archaea and Eukaryotes

A two-domain tree with Eukarya branching from within the Archaea, sister to the Asgardarchaeota



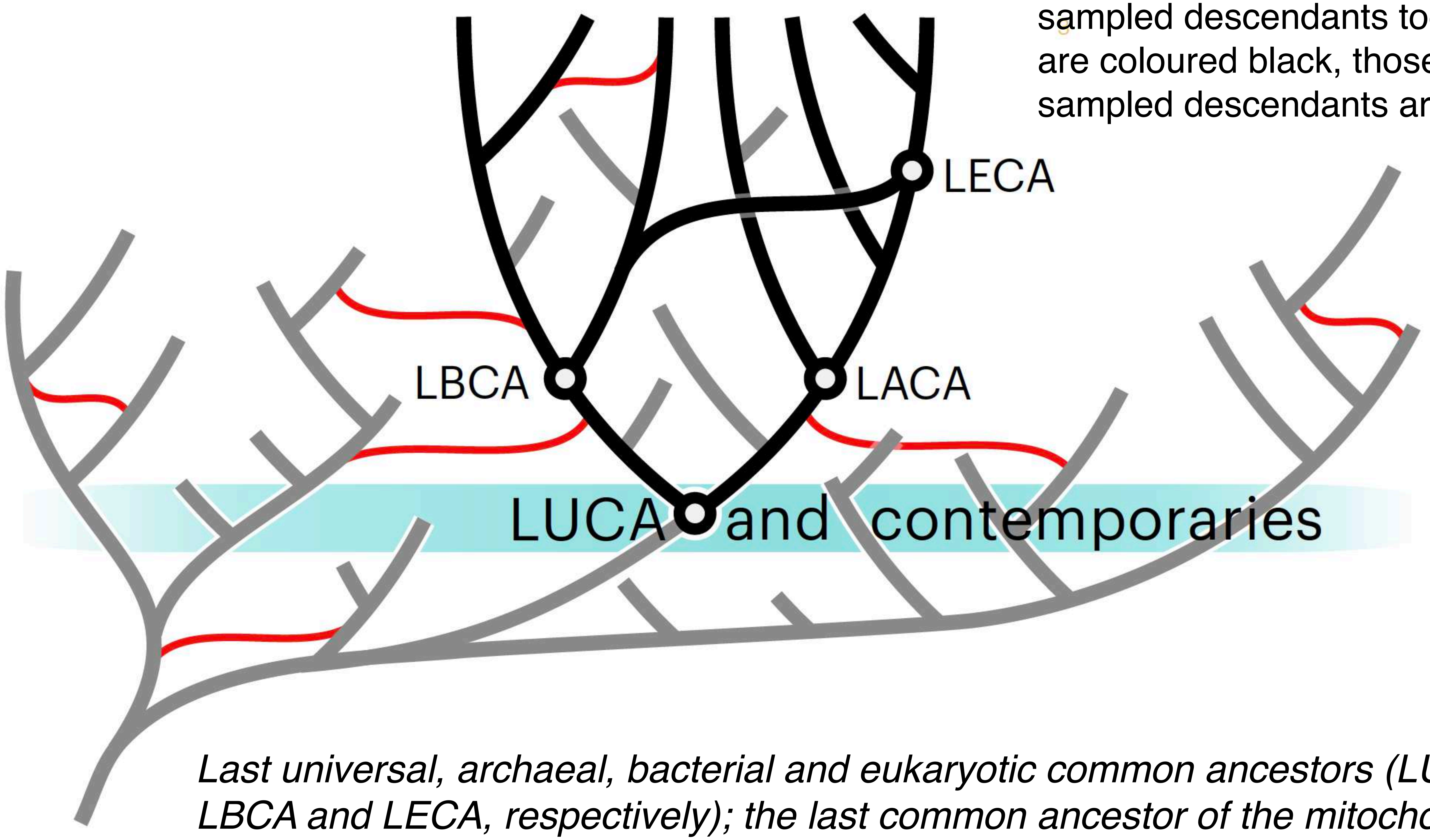
Hug et al., 2016; Hug, 2024

Microbial/Life evolution on Earth

Many different and diverse microbial communities rose and became extinct

Only LUCA survived

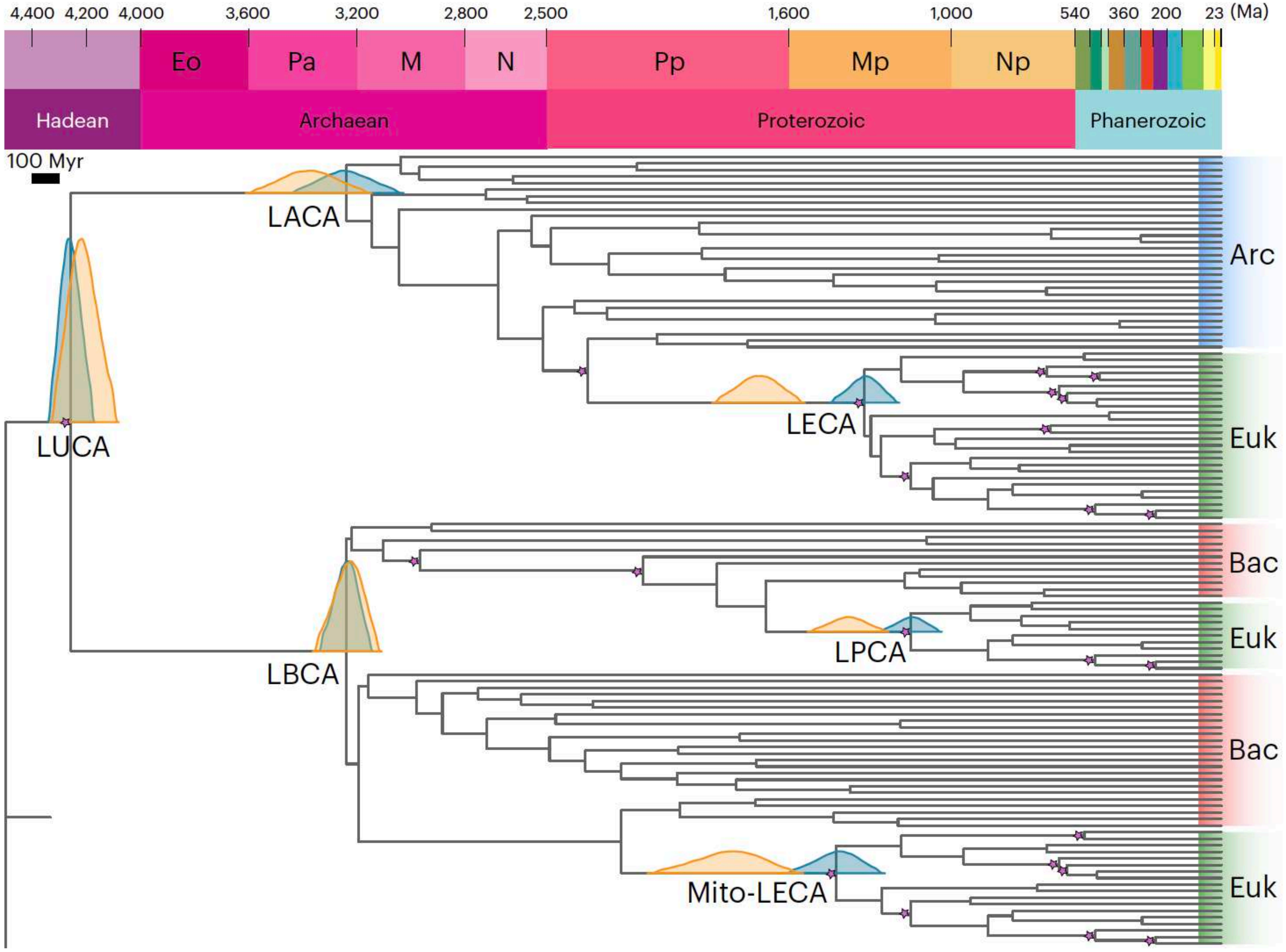
Branches on the tree of life that have left sampled descendants today are coloured black, those that have left no sampled descendants are in grey



Moody et al., 2024

Last universal, archaeal, bacterial and eukaryotic common ancestors (LUCA, LACA, LBCA and LECA, respectively); the last common ancestor of the mitochondrial lineage (Mito-LECA); and the last plastid-bearing common ancestor (LPCA)

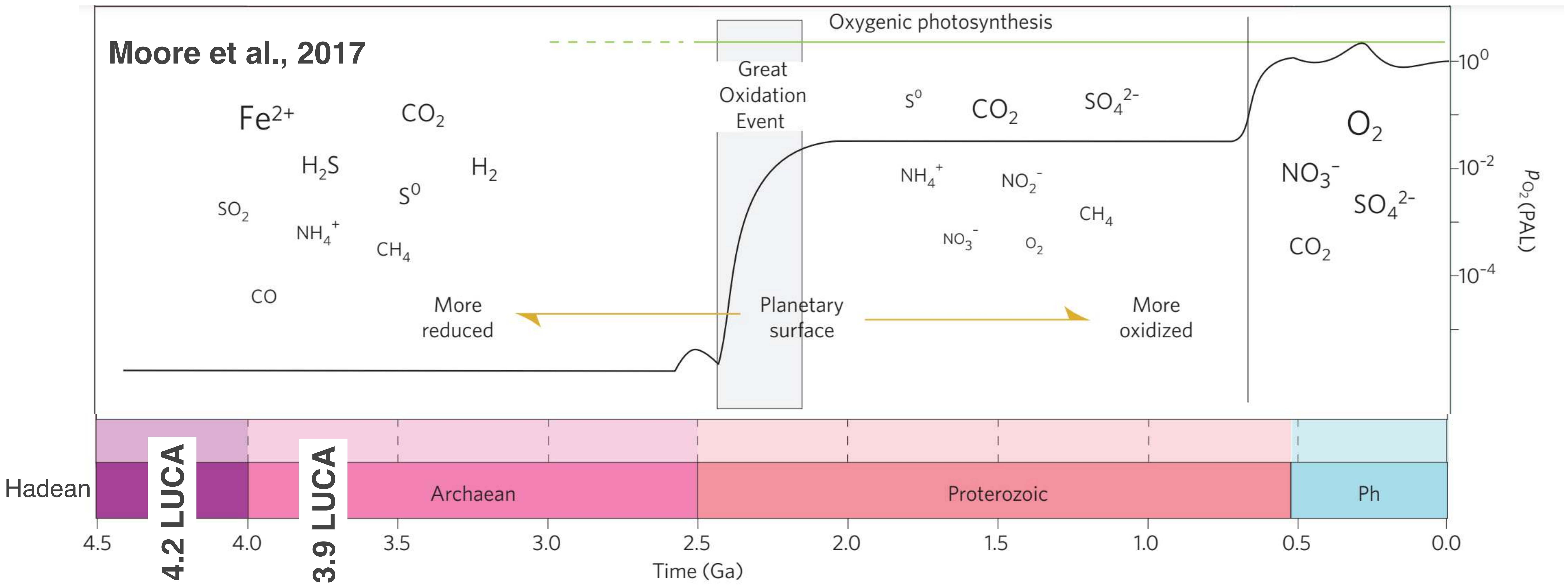
Inference: LUCA lived ~4.2 Ga (4.09–4.33 Ga) through divergence time analysis of pre-LUCA gene duplicates, calibrated using microbial fossils and isotope records under a new cross-bracing implementation



Moody et al., 2024

★

Earth redox state changes



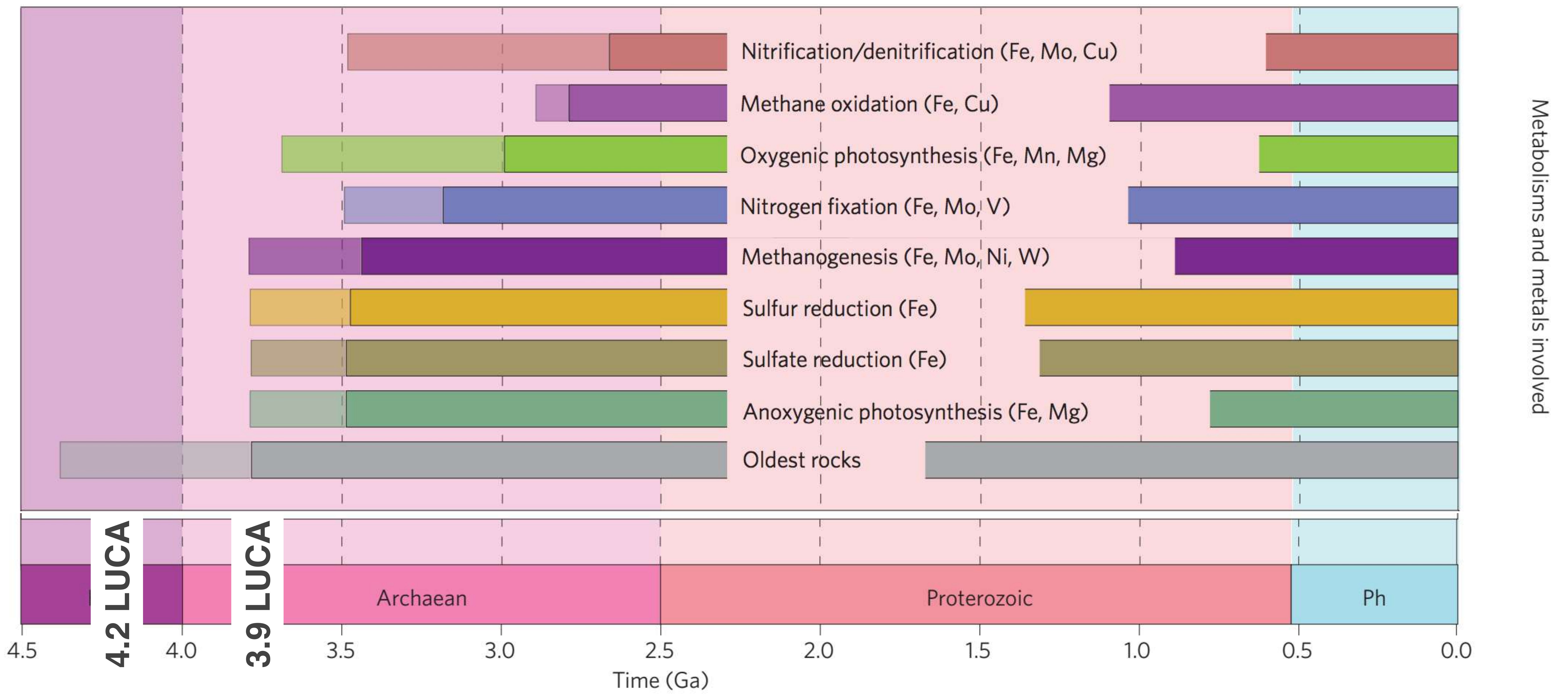
The availability of different metals and substrates has changed over the course of Earth's history as a result of secular changes in redox conditions of the mantel

Solar energy used by early microbes

★

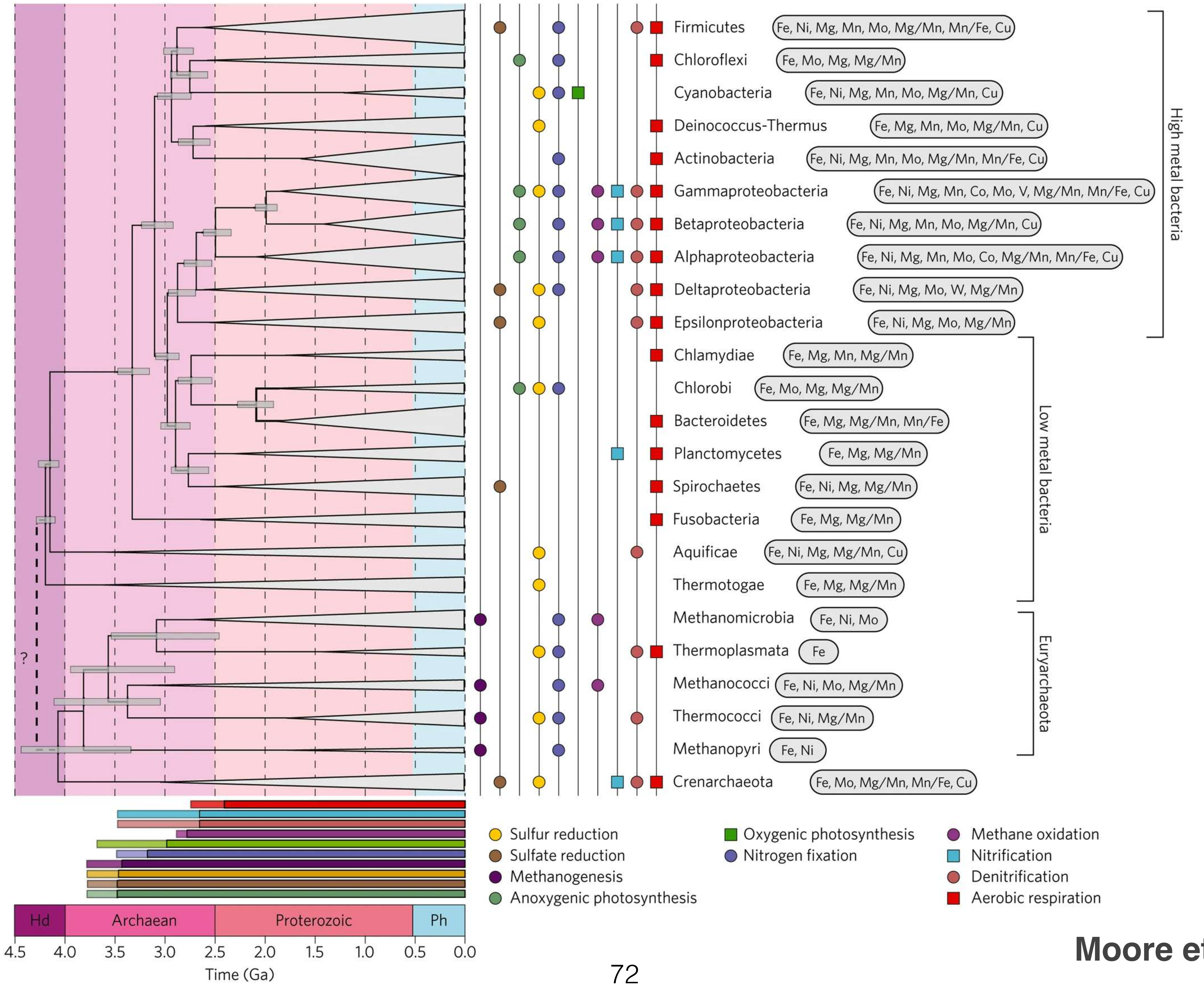
Emerging microbial metabolisms

Moore et al., 2017



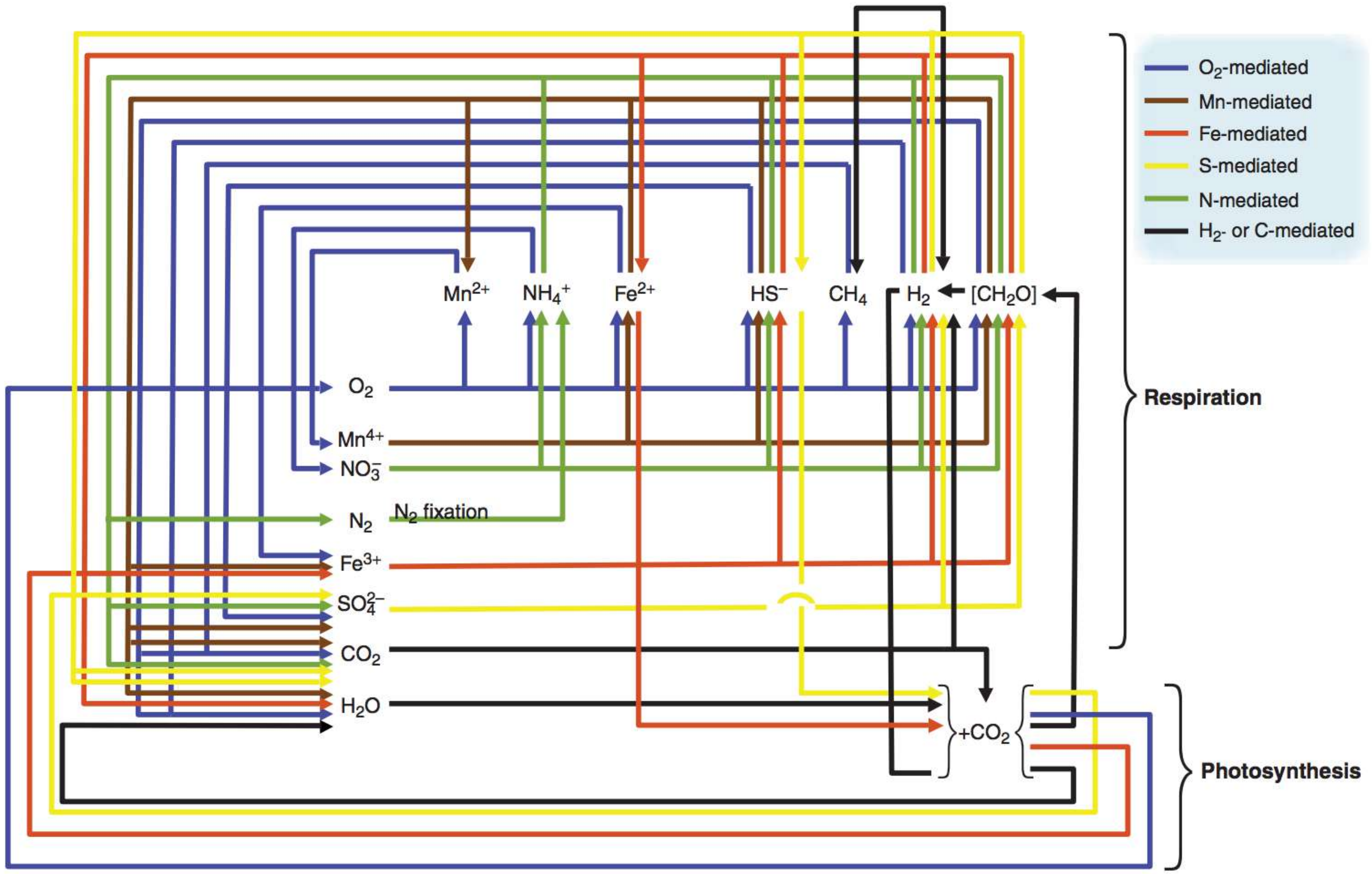
The oxidoreductases responsible for these metabolisms incorporated metals that were readily available in Archaean oceans: iron and iron–sulfur clusters

Phylogenetic tree of the main lineages of Bacteria and Archaea and their putative divergence times



Moore et al., 2017

Present microbial metabolism on Earth



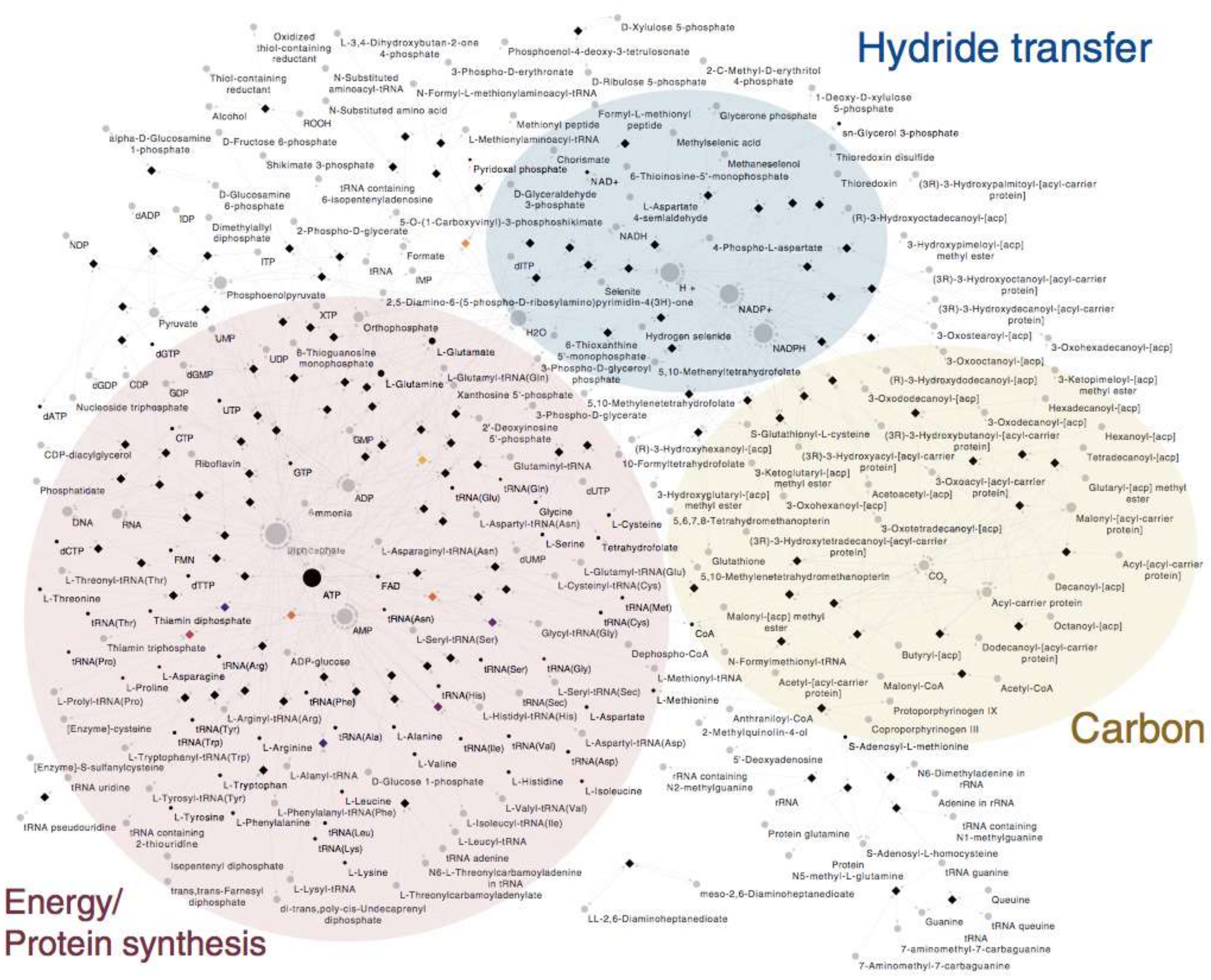
Falkoski et al., 2008

A global, interconnected network of the biologically mediated cycles for hydrogen, carbon, nitrogen, oxygen,sulfur, and iron
A large portion of these microbially mediated processes are associated only with anaerobic habitats

Phylogenomic reconstructions:

- **5443 reference genomes from bacteria** and selected those **1089** classified as **anaerobic** by virtue of **lacking oxygen reductases** and having **>1000 protein sequences—> manually annotated** in families
- LUCA was a thermophilic anaerobe that lived from gasses in a hydrothermal setting
- LACA was a methanogen, or a similar anaerobic autotroph that fixed carbon via the Wood–Ljungdahl (also known as acetylCoA) pathway
- Like LUCA and LACA, LBCA must have been an anaerobe
- The **most important difference** between anaerobes and aerobes is related to **energy**
- **Anaerobic pathways** such as fermentation, sulfate reduction, acetogenesis, and methanogenesis **yield only a fraction of the energy** when compared to aerobic pathways, but this is **compensated** by the circumstance that the **synthesis of biomass costs 13 times more energy per cell** in the presence of **O_2** than under anoxic conditions

The three major metabolic hubs of LBCA

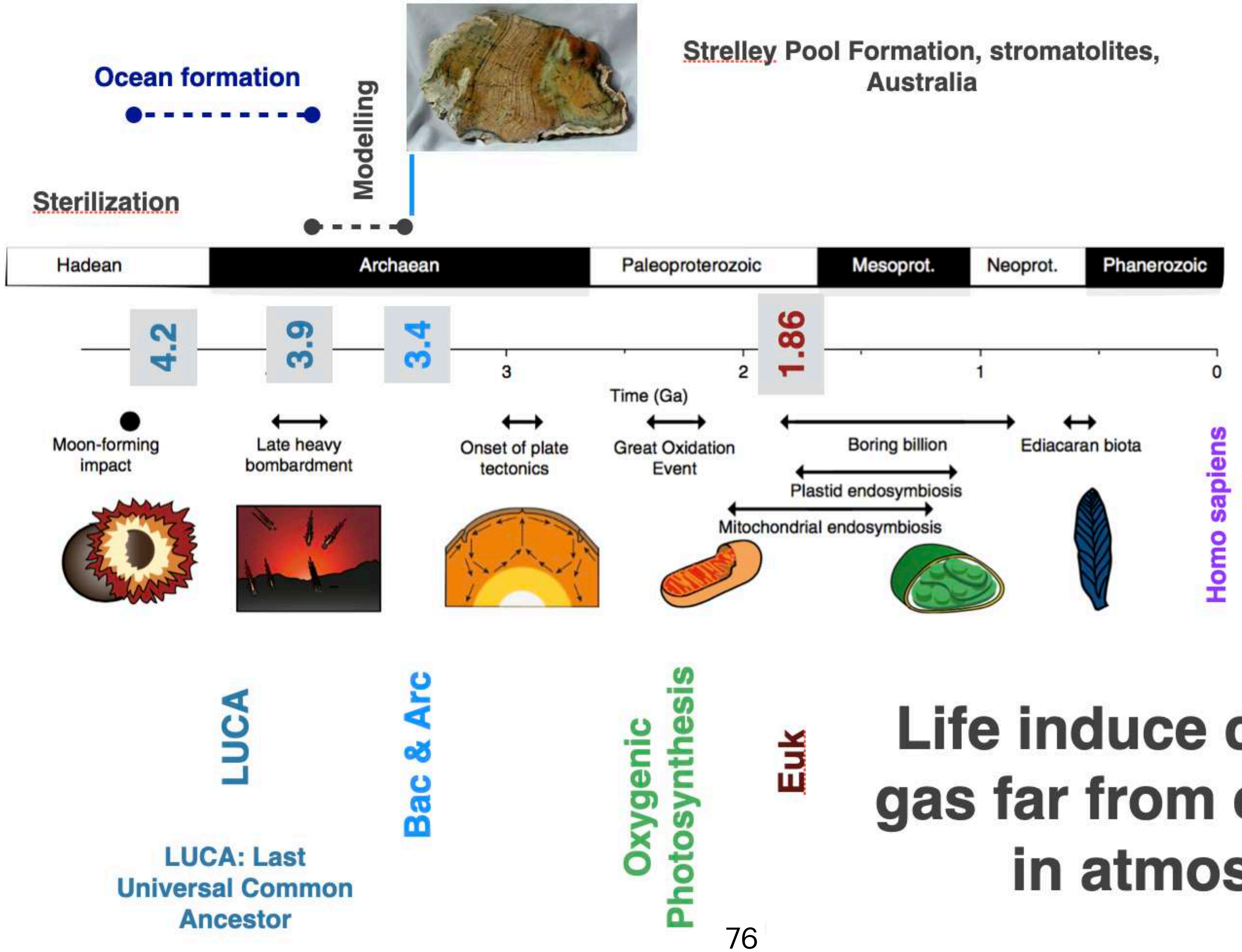


Xavier et al. 2021

LBCA's network is highly structured around three major metabolic hubs:
(i) ATP/diphosphate,
(ii) NADP(H)/H+, and
(iii) CO2/ACP/malonyl-ACP.

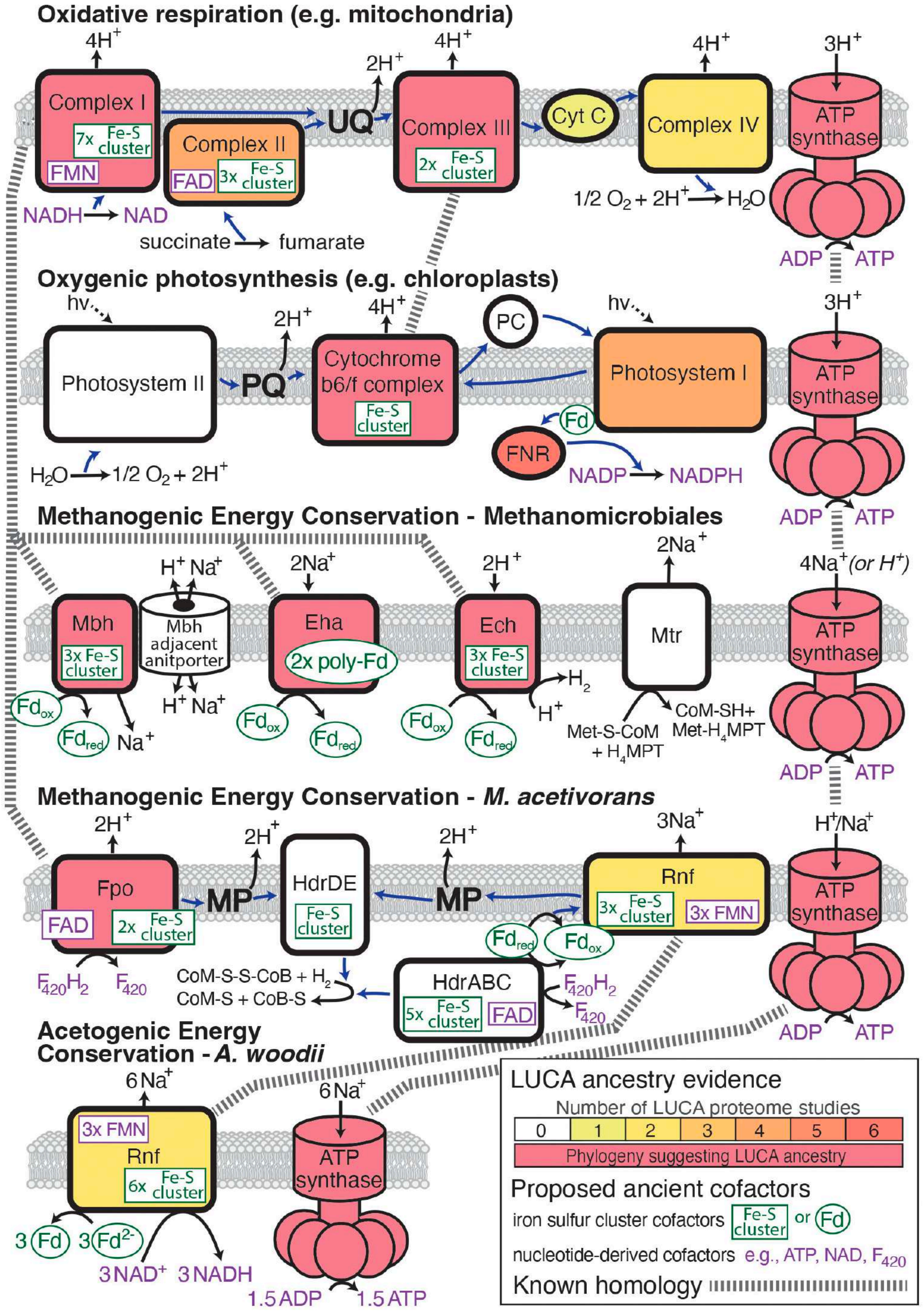
These represent the cores of (i) **energy**, (ii) **hydride transfer**, and (iii) **carbon metabolism** of LBCA

★ Oxygenic Photosynthesis Invention by CYANOBACTERIA has changed the game



Betts et al., 2018
Moody et al., 2024

Life induce changes in gas far from equilibrium in atmosphere



Goldman et al. 2023

Rewiring of exhibiting membrane-associated micromachies

Electron transport chains as a window into the earliest stages of evolution

Signatures of early evolution across different types of chemiosmotic energy conservation.

Electron flow is shown as blue arrows.

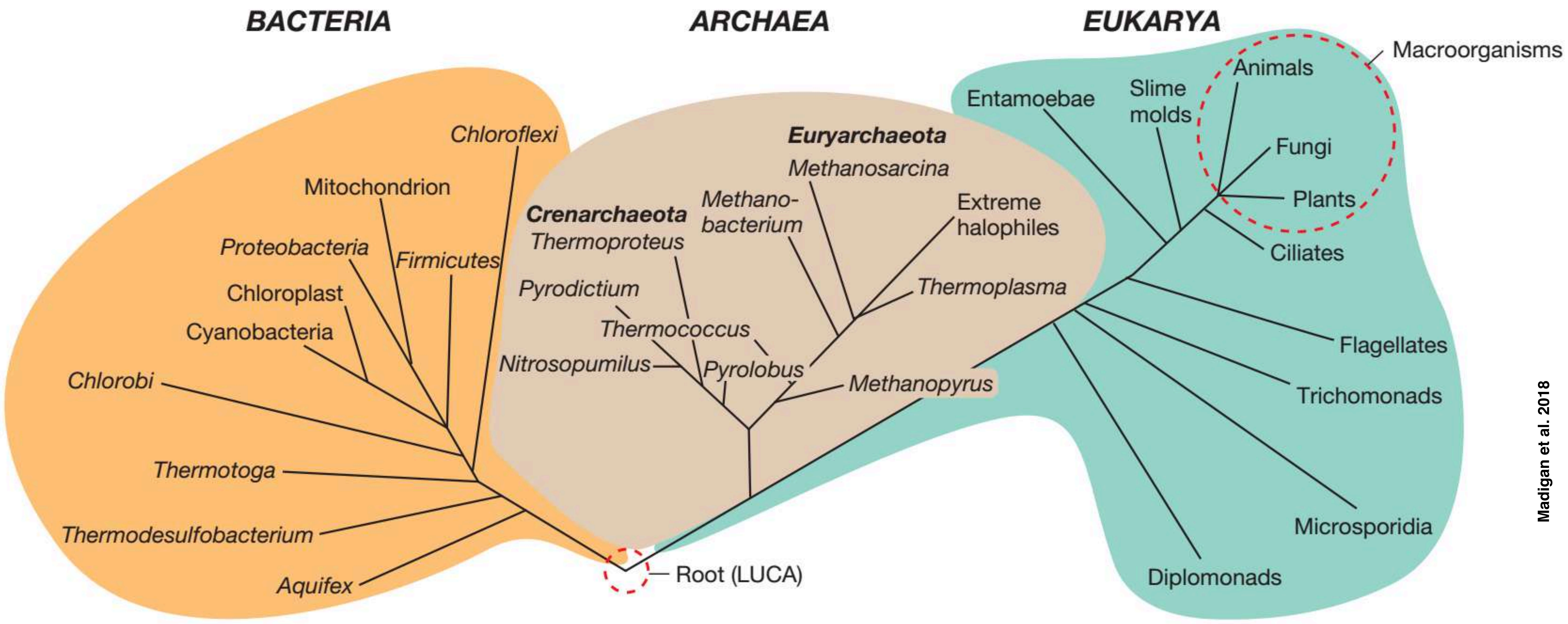
Likely ancestry from the LUCA is reflected by either direct phylogenetic evidence or the number of different LUCA proteome studies (out of eight total) that predict a component of the complex to be descended from the LUCA.

Protein cofactors that are potential relics of prebiotic mineral catalysis or ribozyme catalysts are highlighted in green and purple, respectively.

Homology across different ETC components is indicated by a dashed line.

Electron carrier proteins that are components of ETC complexes such as cytochrome B are not shown.

The rise of the Eukarya: eukaryogenesis

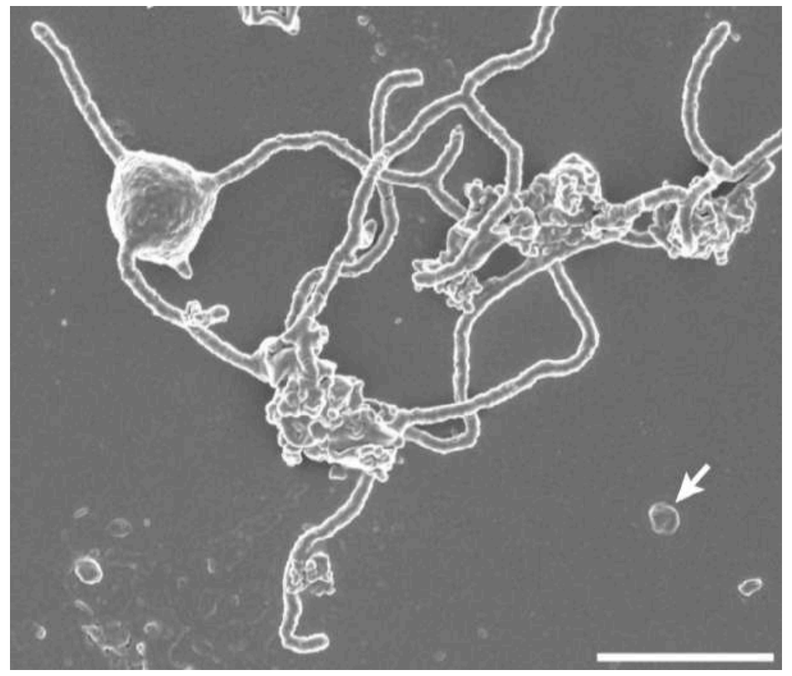


Madigan et al. 2018

LUCA: Last Universal Common Ancestor

~1.86 billions

Imachi et al. 2020

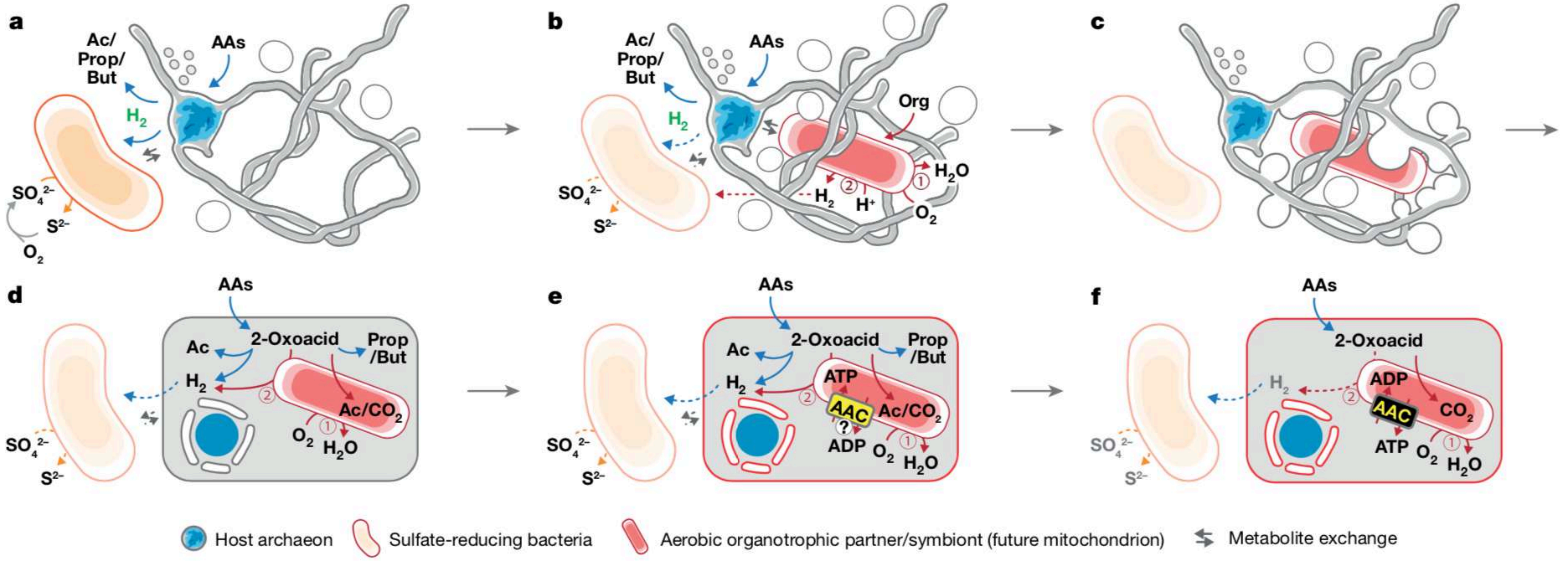


2,000 days to enrich such organisms from anaerobic marine methane-seep sediments

Entangle–Engulf–Endogenize (also known as E3) model

Entangle–Engulf–Endogenize, E3 model

Imachi et al. 2020



(1) Transition from anaerobiosis to aerobiosis

(2) Gain of an O_2-respiring and ATP-providing endosymbiont (future mitochondrion, alpha-Protobacterium)

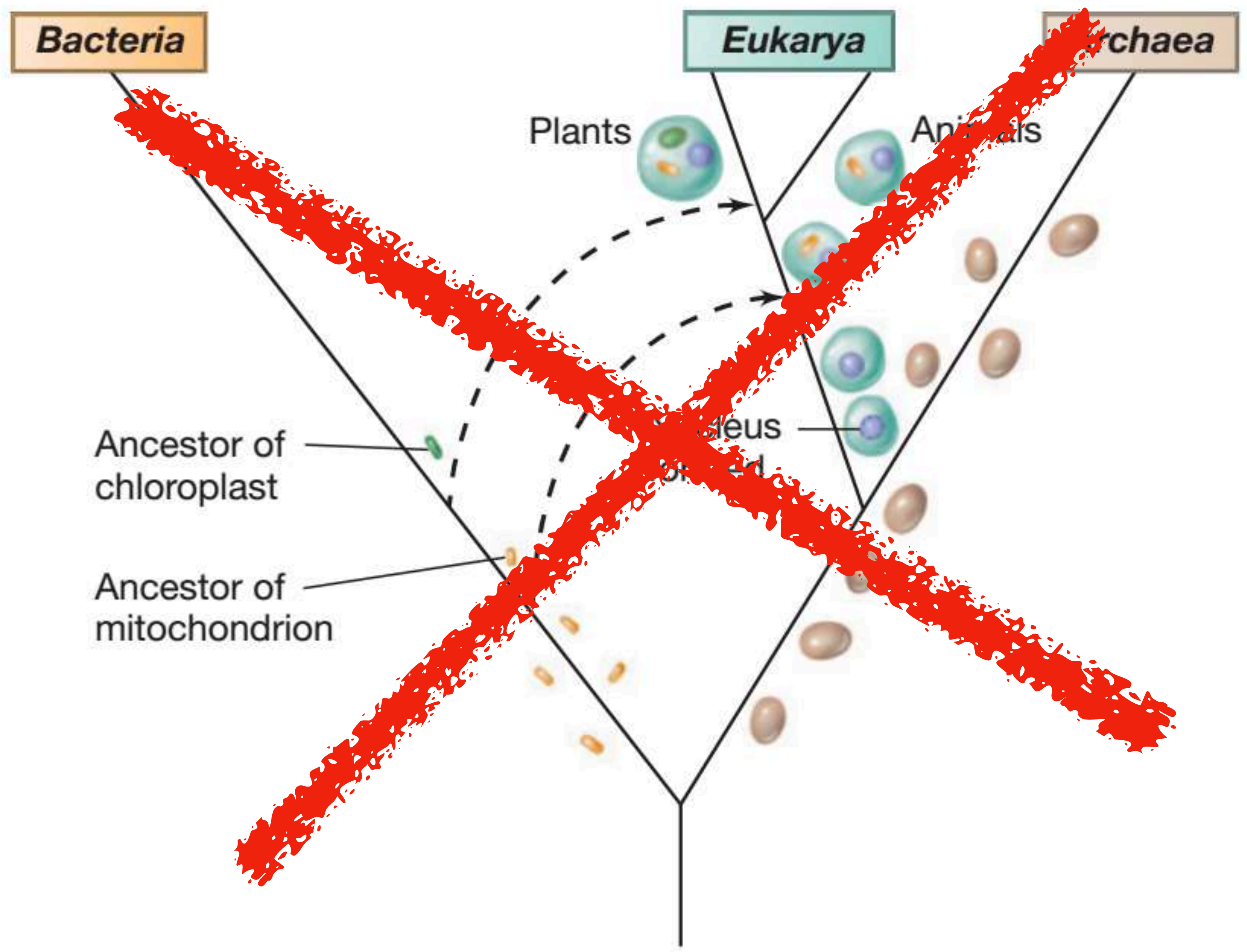
(3) Development of intracellular structures

(4) Later stage Gain of a Cyanobacteria (future chloroplast)

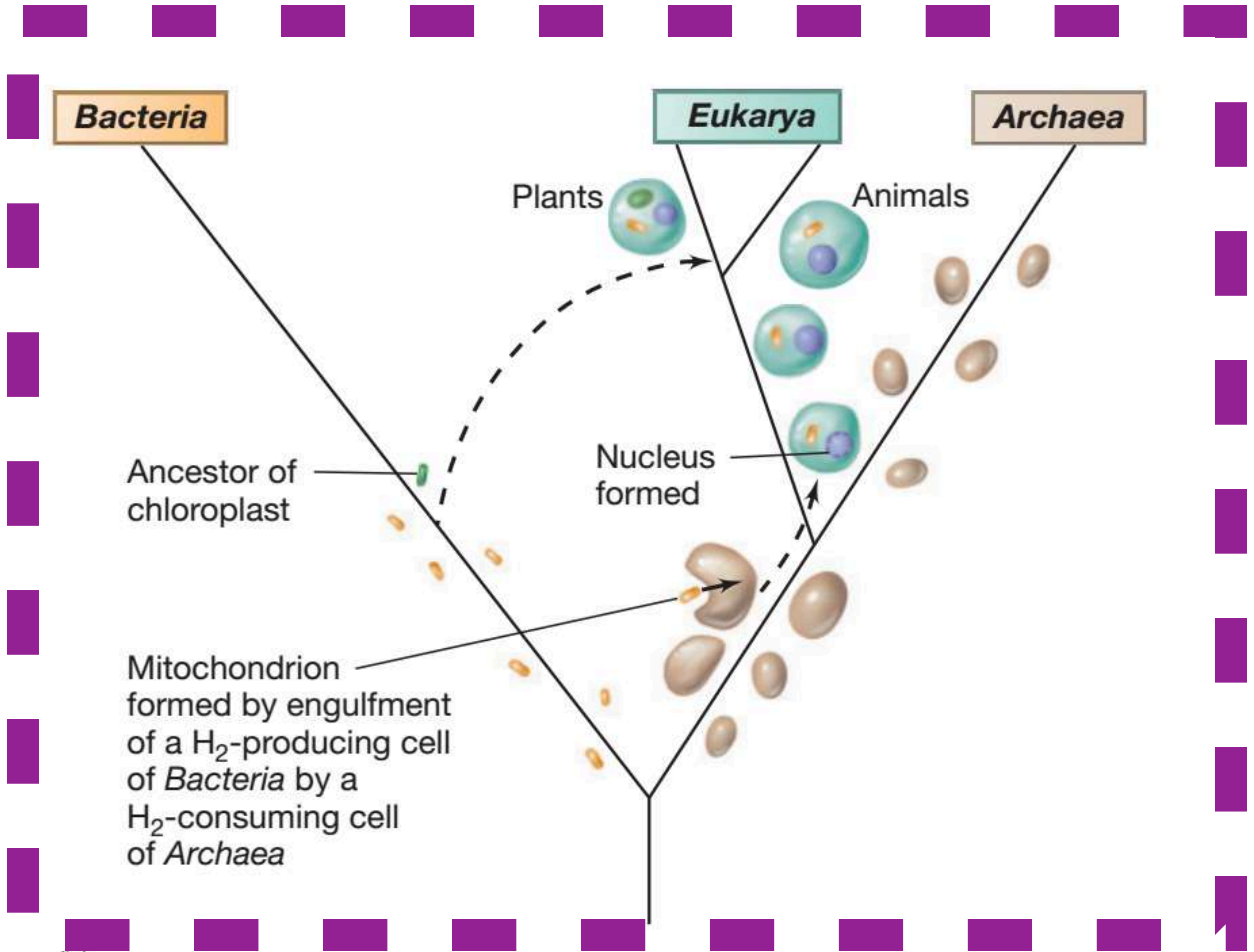
Host archaeon (isolated over 2000 days of culture from deep-sea methane-seep sediment, basalt medium + antibiotics) engulfed the metabolic partner using extracellular structures and simultaneously formed a primitive chromosome surrounding structure similar to the nuclear membrane

Entangle–Engulf–Endogenize model to solve the structural and metabolic puzzle

Madigan et al. 2018

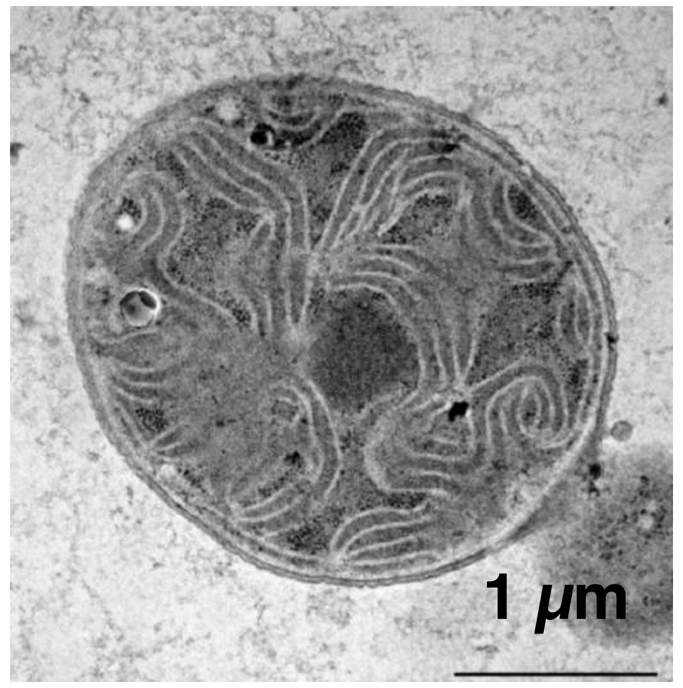


(a)

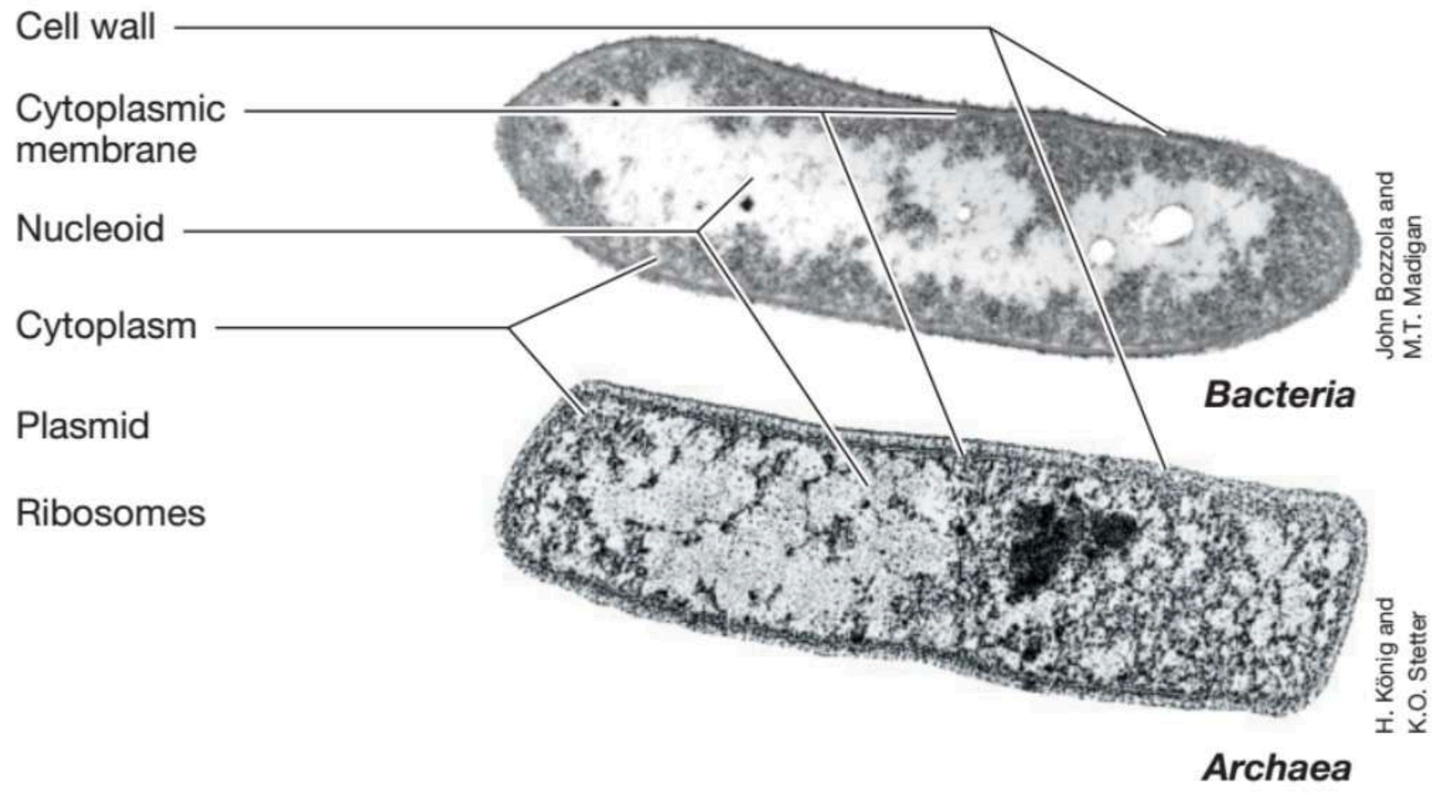


(b)

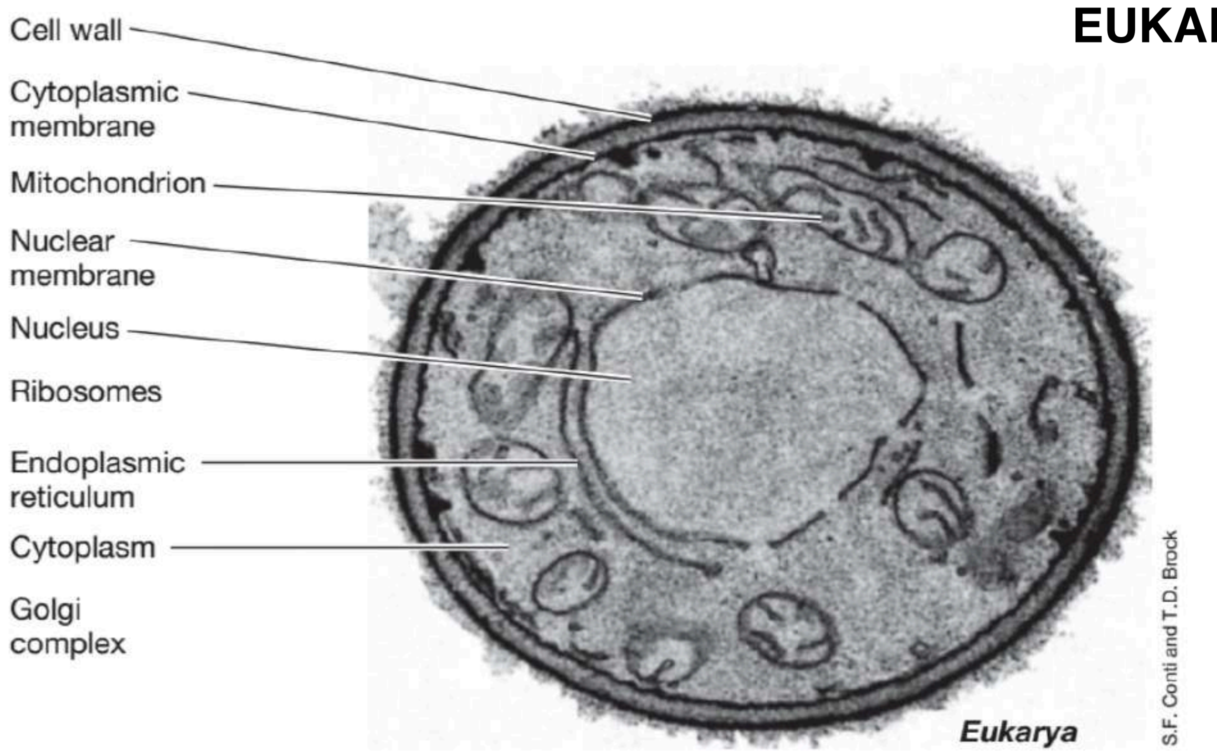
Austin et al., 2006

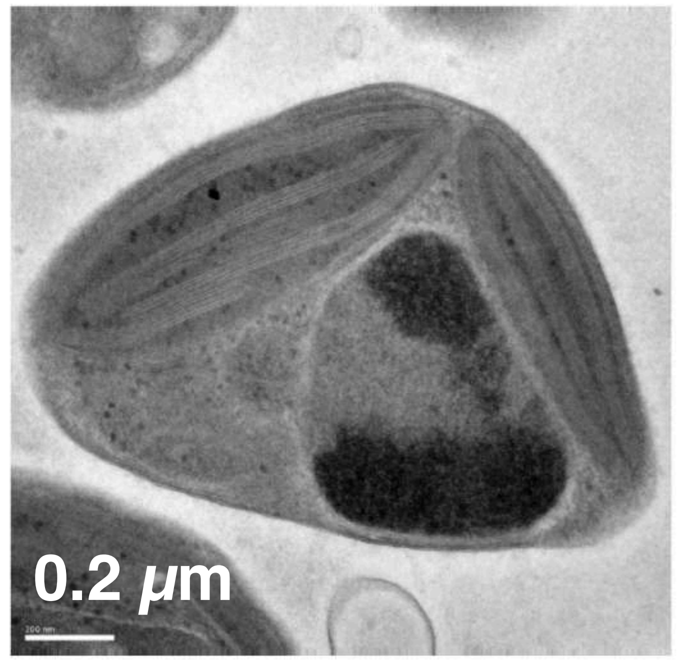


Cyanobacteria



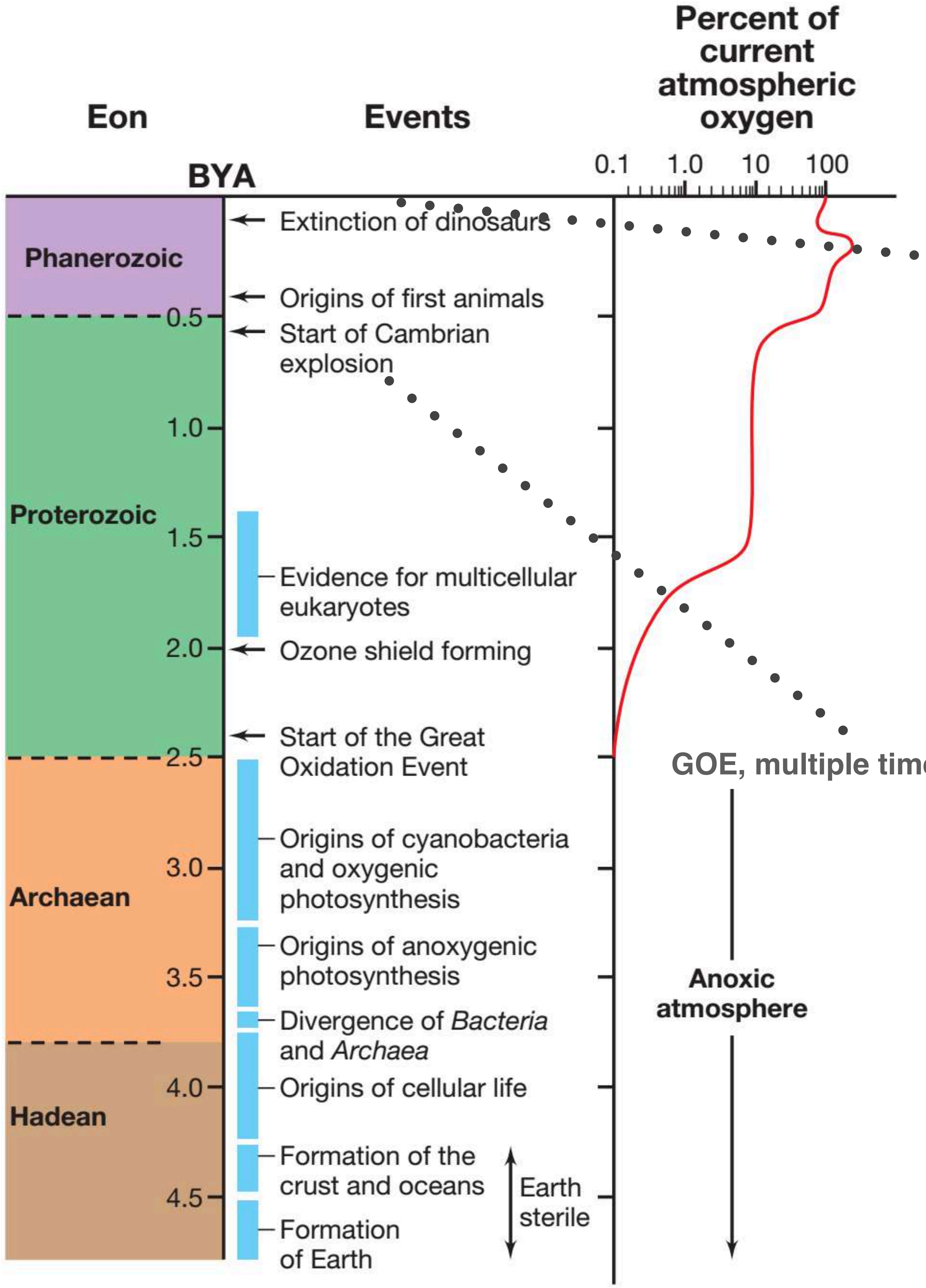
EUKARYA





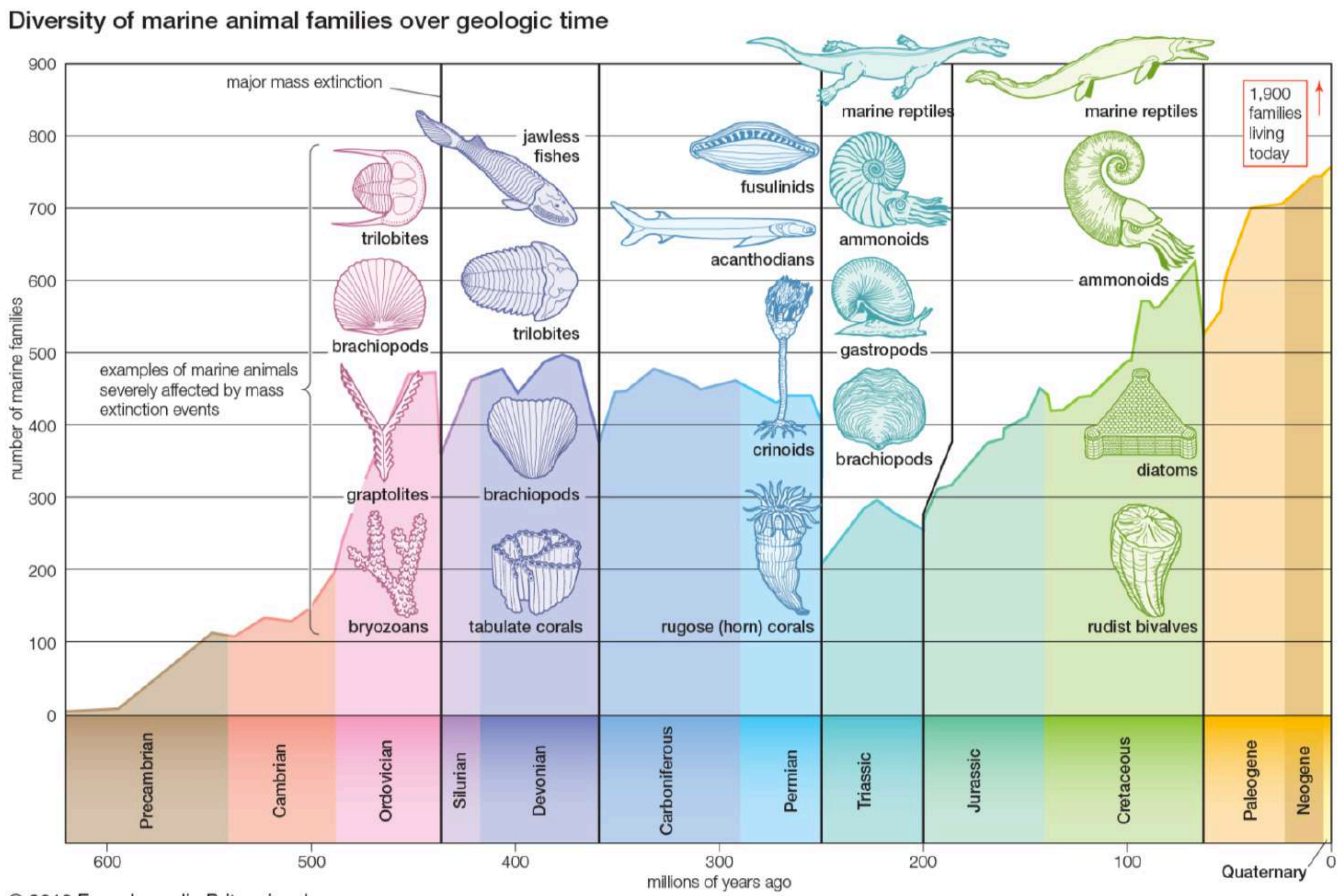
Ostreococcus taurii

From one cell to multicellularity in Eukarya



Madigan et al. 2018

GOE, multiple times



- GOE: microbial extinction, segregation of anaerobes in microenvironment
- O_3 layer protecting UV
- Many massive extinctions for megafauna… still today

Bacteria-Archaea-Eukarya Comparison

	Bacteria	Archaea	Eukarya
Prokaryotic cell structure	+	+	-
Chromosomal DNA in closed circle	+	+	-
Histone proteins with DNA	-	+	+
Nucleus	-	-	+
Mitochondria/chloroplast organelles	-	-	+
Cell wall with muramic acid	+	-	-
Membrane lipids	Ester-linked	Ether-linked	Ester-linked
Ribosome mass	70S	70S	80S
Intons	-	-	+
Initiator tRNA	FormylMet	Met	Met
RNA polymerase	One	Several	Three
Genes as operons	+	+	-
mRNA tailed polyA	-	-	+
Sensitivity to antibiotics	+	-	-
Growth above 70°C	+	+	-
Growth above 100°C	-	+	-
Chemolithotrophy	+	+	-
N_2-fixation	+	+	-
Nitrogen fixation	+	+	-
Denitrification	+	+	-
Dissimilatory reduction	+	+	-
Methanogenesis	-	+	-

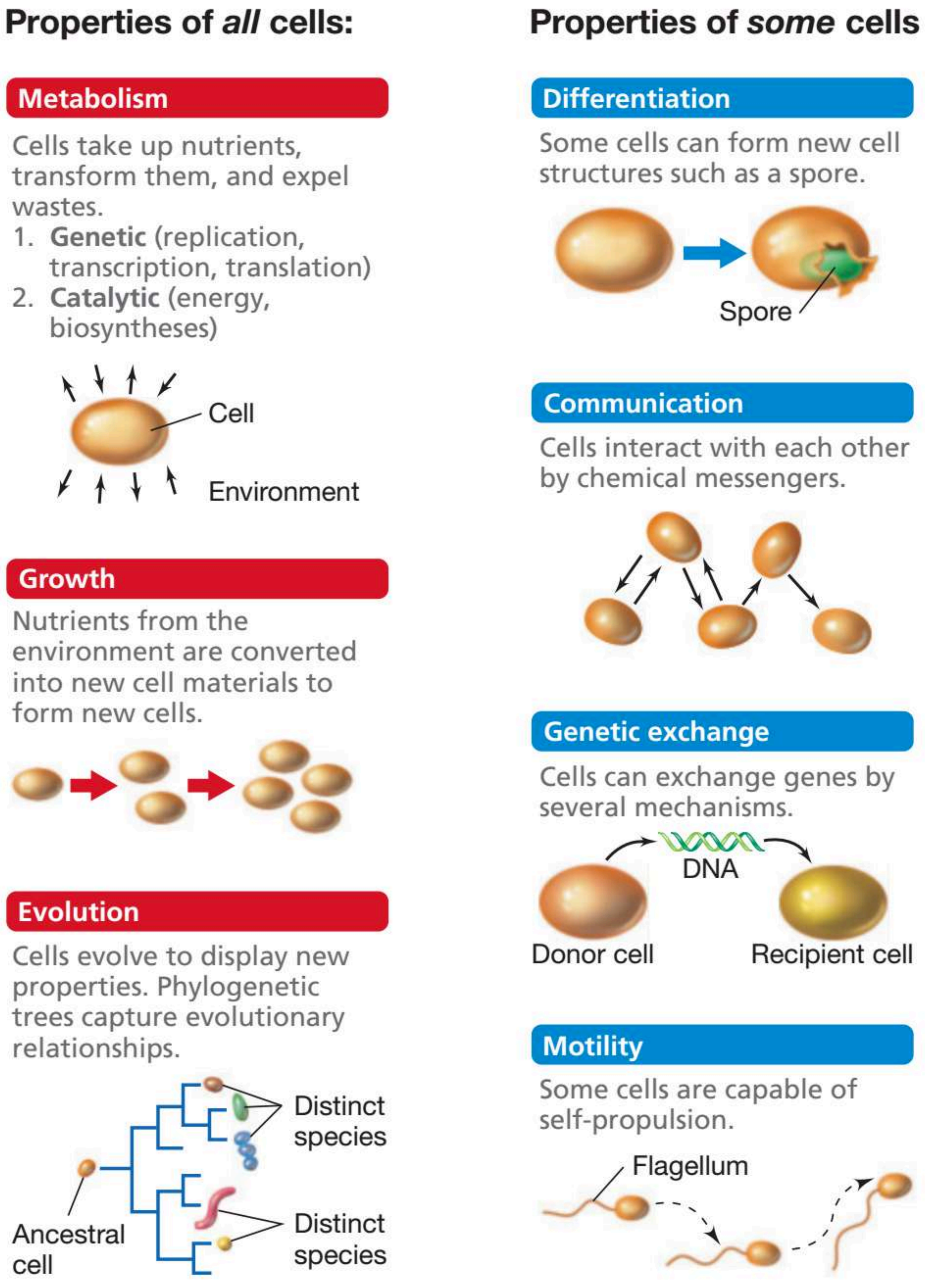
…and still evolving (we need to discover and study new species)

★

Being a microbe

Structure is coupled to function for survival under natural selection

"**Nothing in Biology Makes Sense Except in the Light of Evolution**" is a 1973 essay by the evolutionary biologist Theodosius Dobzhansky,



Madigan et al. 2018

Why are we studying microbes?

- Microbes have been profoundly shaping the Earth's environment
- Microbes have invented biochemistry (unifying concept, Kluyver, 1956)
- Microbes are very diverse and productive despite size
- Microbes are everywhere
- Microbes have made Earth habitable
- Humans have evolved from them
- Microbes have changed Humans and still changing them