212 SM

Environmental microbiology


You belong here !

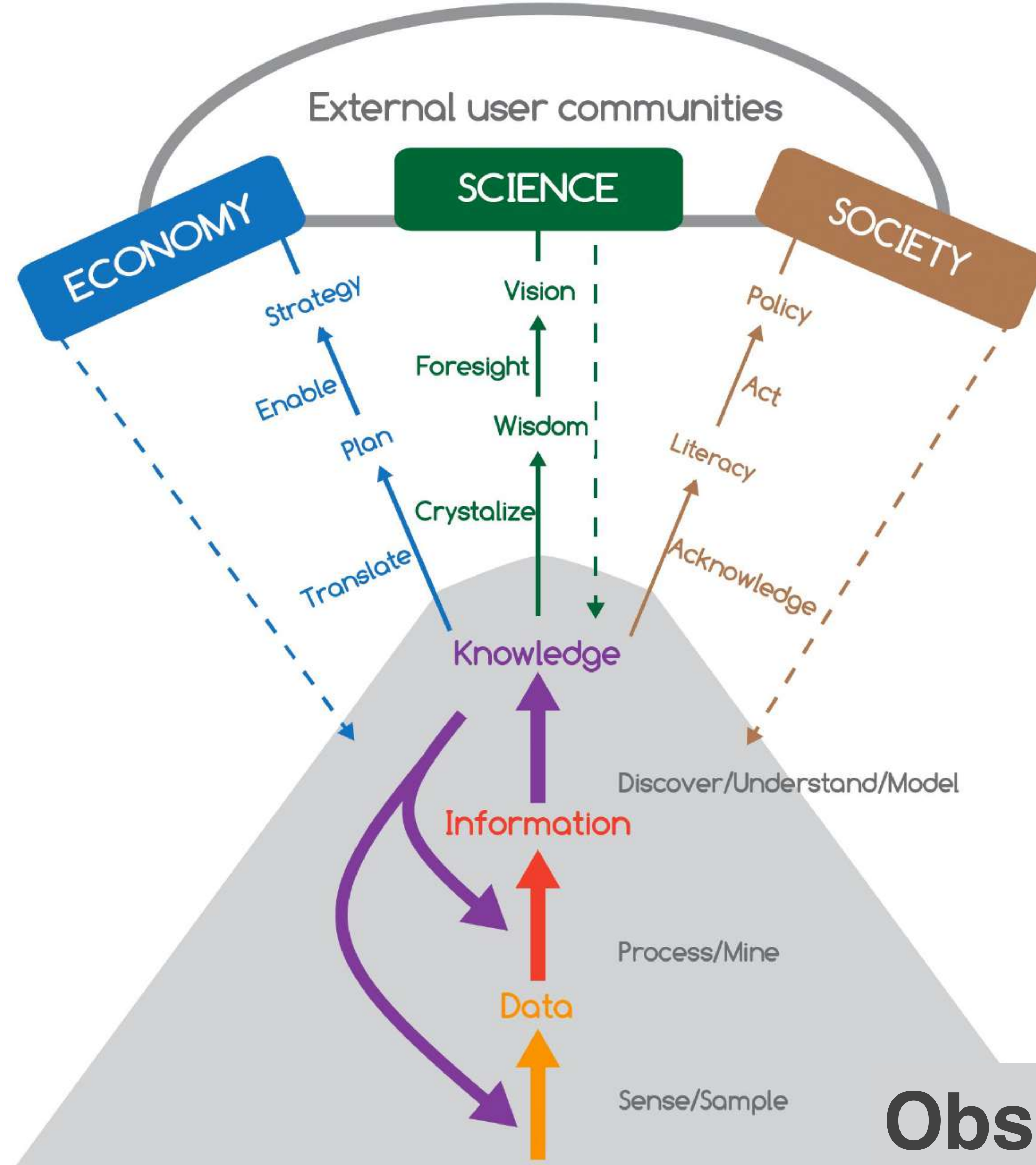
★ Inclusivity statement:

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.

My personal goal as a teacher/educator

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



Observation

ENVIRONMENT - MODEL ORGANISM

TRECCANI

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

Logistics, I

- Instructor: Francesca Malfatti (fmalfatti@units.it; FC, 3rd floor left)
  ★ **Office hour TBD via email;**

- Schedule
  – *Tuesday 8-10 and Thursday 11-13*
  – *Lab on Friday 8-12*

- Course structure
  – **Lectures: 10 topics**

- Books
  – **Madigan et al. (year 2018-2020; 15th, 16th Edition). Brock Biology of Microorganisms**
  – **Madigan et al. (anno 2016: 14 Edizione). Brock Biologia dei Microrganismi**

Logistics, II

Sistema misto di valutazione dell’apprendimento:

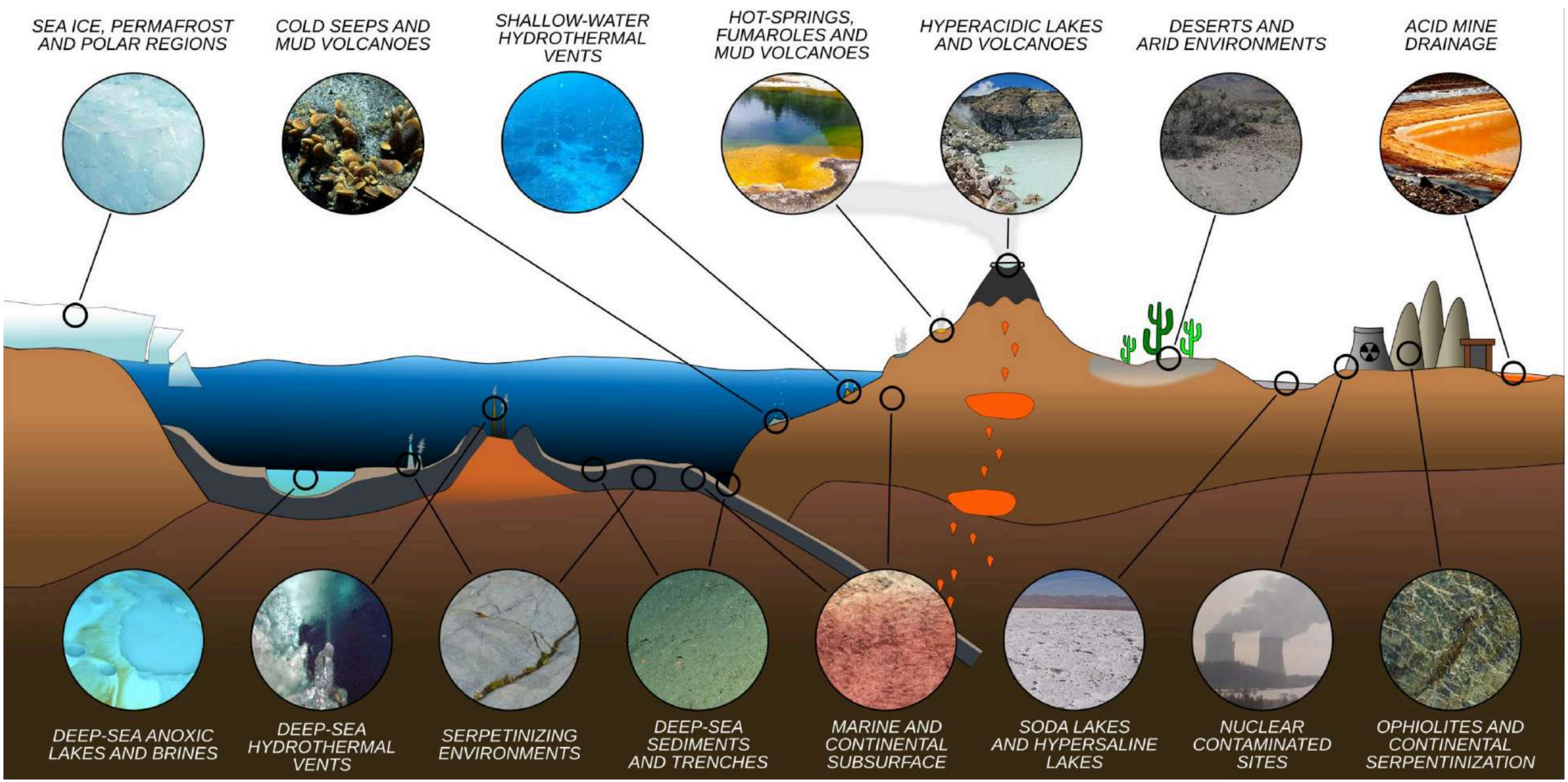
1. Presentazione orale di gruppo pari a punti 3/30 del voto finale individuale su un argomento microbico trattato nel programma.

2. Esame scritto della durata di un'ora, per un valore di punti 27/30 del voto finale individuale.

Esame scritto conterrà 2 domande a risposta aperta, 1 fotografia da commentare e descrivere e 12 domande a risposta vero-falso. Le domande a risposta aperta e la fotografia valgono ognuna 5/30. Le risposte vero-falso valgono 1/30.

Extreme microbial environments on Earth

Merino et al. 2019



Logistics, III

Gli studenti con certificati (i.e., DSA) devono informare il docente all'inizio del corso per poter meglio pianificare i metodi di valutazione dell'apprendimento

Syllabus, I

Il corso è organizzato in 10 argomenti diversi volti ad analizzare aspetti importanti e attuali della microbiologia ambientale:
1-Introduzione al concetto di microbiologia, microbiologia ambientale e la loro storia dal XVII secolo fino ad oggi ed origine della vita sulla terra.

2- Biologia di Batteri ed Archaea con particolare attenzione alla morfologia della cellula batterica e ad alcuni meccanismi metabolici di base (capsula, parete cellulare, peptidoglicano, membrana, appendici batteriche con flagelli e pili, endospore, aspetti del genoma batterico, crescita batterica, diffusione attiva e passiva delle molecole attraverso la membrana).

3- Metabolismo batterico e nutrizione microbica (macro- e micronutrienti, diversi tipi di metabolici in base alla fonte di energia utilizzata: fototrofi e chemiotrofi, oppure 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, II

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

7. Ecologia microbica: concetto di specie ed evoluzione, ecosistemi microbici (suolo, sedimento marino, oceano, lago-fiume, atmosfera) cicli biogeochimici degli elementi e microrganismi-clima.

8. Comportamento: quorum sensing, biofilm dall'ambiente all'essere umano e simbiosi.

9. Tecniche di biorisanamento (*in situ*- *ex situ*, fito-risanamento, biomining e bioleaching) e microbial factories.

10. Metodologie di isolamento, caratterizzazione e fenotipizzazione di microorganismi ambientali e tecniche di microscopia. Accenni sulle nuove metodologie-omiche e la loro importanza rivoluzionaria nel campo della microbiologia (genomica, trascrittominca, proteomica, metabolomica, meta-genomica, meta-proteomica, metatrascrittomica).

Tell me and I will forget, show me and I may remember; involve me and I will understand

6 h, C1 basement

Esperienze di laboratorio per imparare le tecniche di sterilita', coltivazione e fisiologia dei microorganismi

Questions

Why are the slides written in English?

Brief self-introduction

LAB Dimensions

UNIVERSITÀ DEGLI STUDI DI TRIESTE

CAICE NSF center for aerosol impacts™ on chemistry of the environment

SCRIPPS INSTITUTION OF OCEANOGRAPHY
UC San Diego

Università di Genova

OGS Istituto Nazionale di Oceanografia e di Geofisica Sperimentale

Microscale interactions (Human & Ocean)

Ocean - Atmosphere microbiology & biogeochemistry

Ocean - Sediment microbiology (Human and Climate impact)

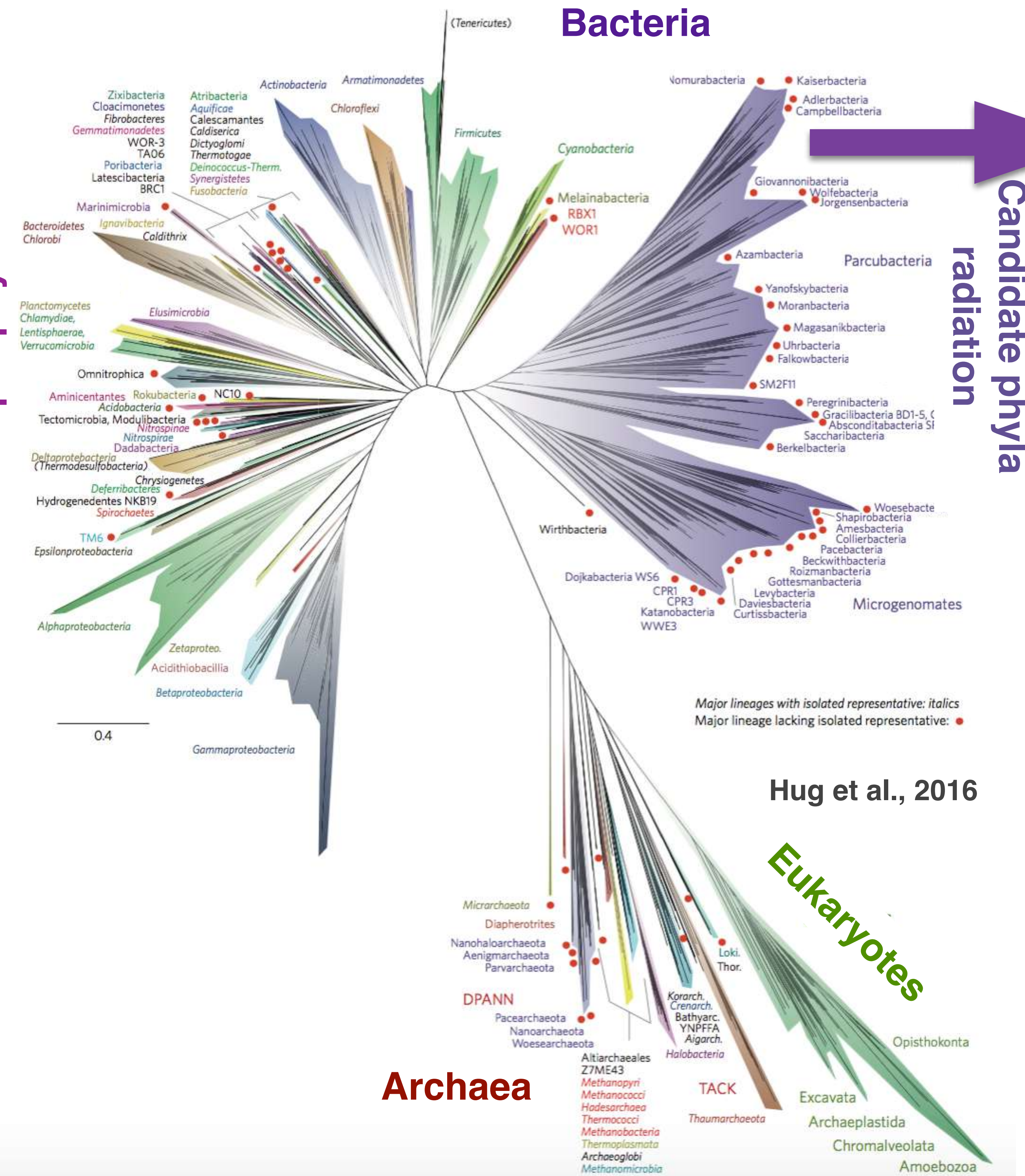
Scientific Milieu

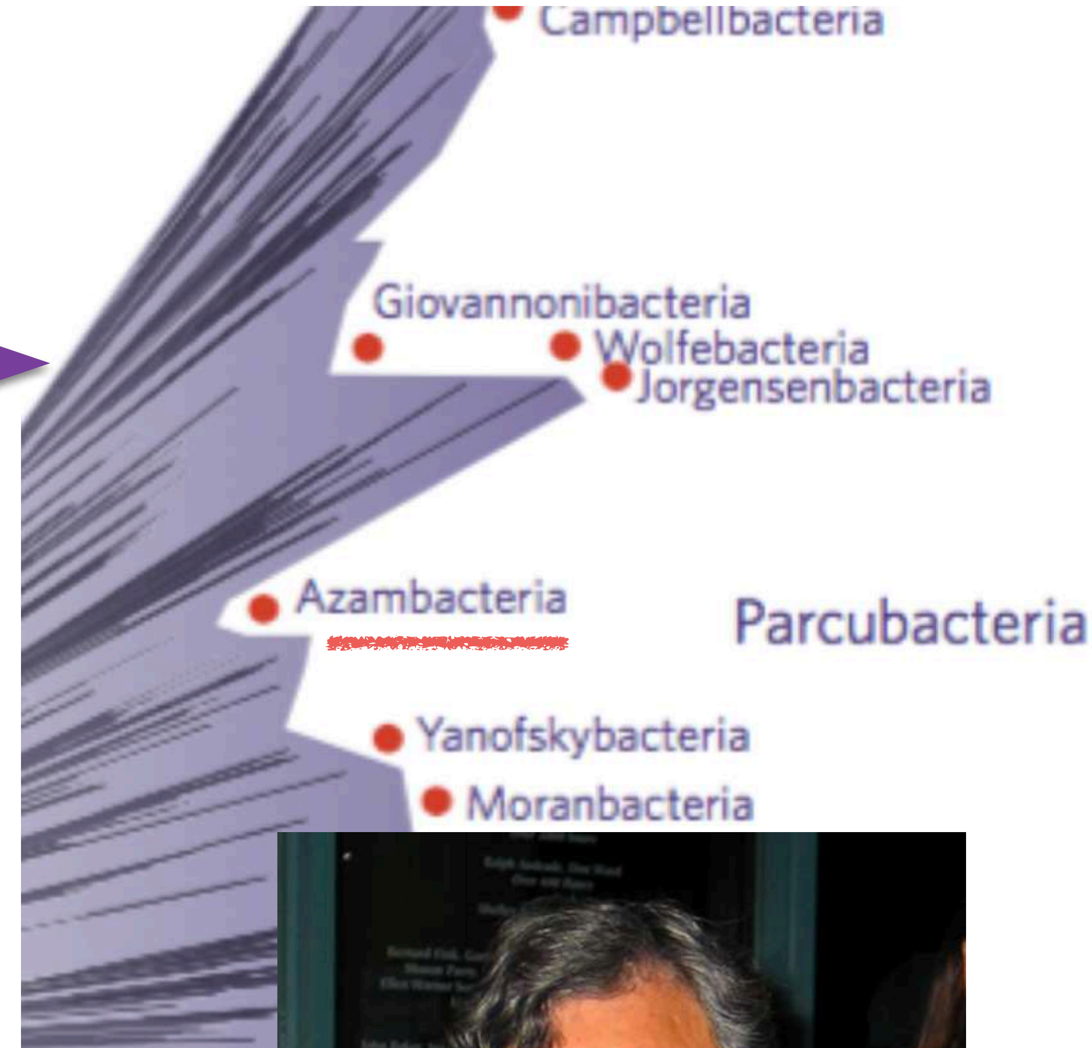
Dr. Farooq Azam

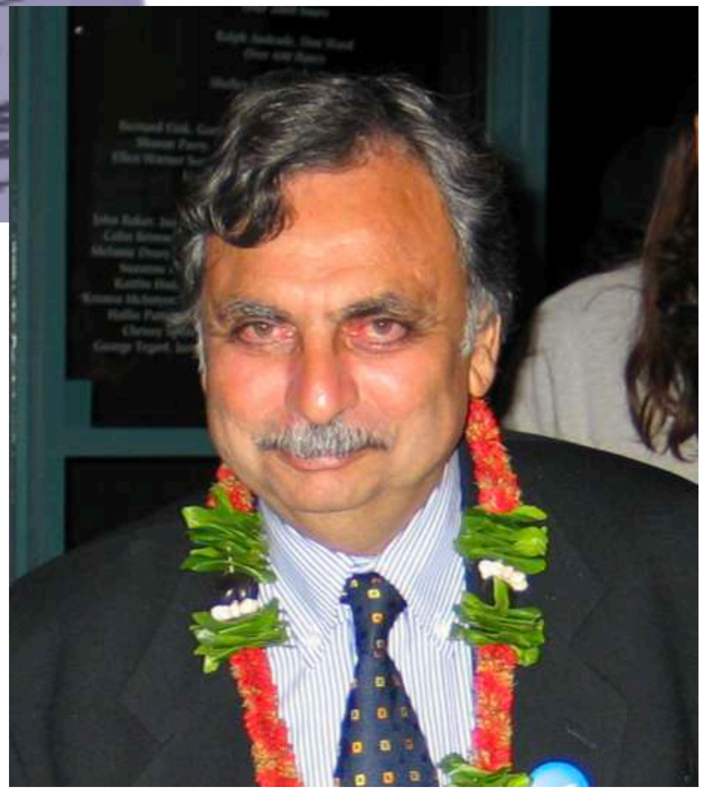
Dr. Andrew Benson (Calvin-Benson-Bashar: Photosynthesis)

Ms. Judith Munn (wife of Dr. Walter Munn, Normandy landing, 2 WW)

PVC super phylum

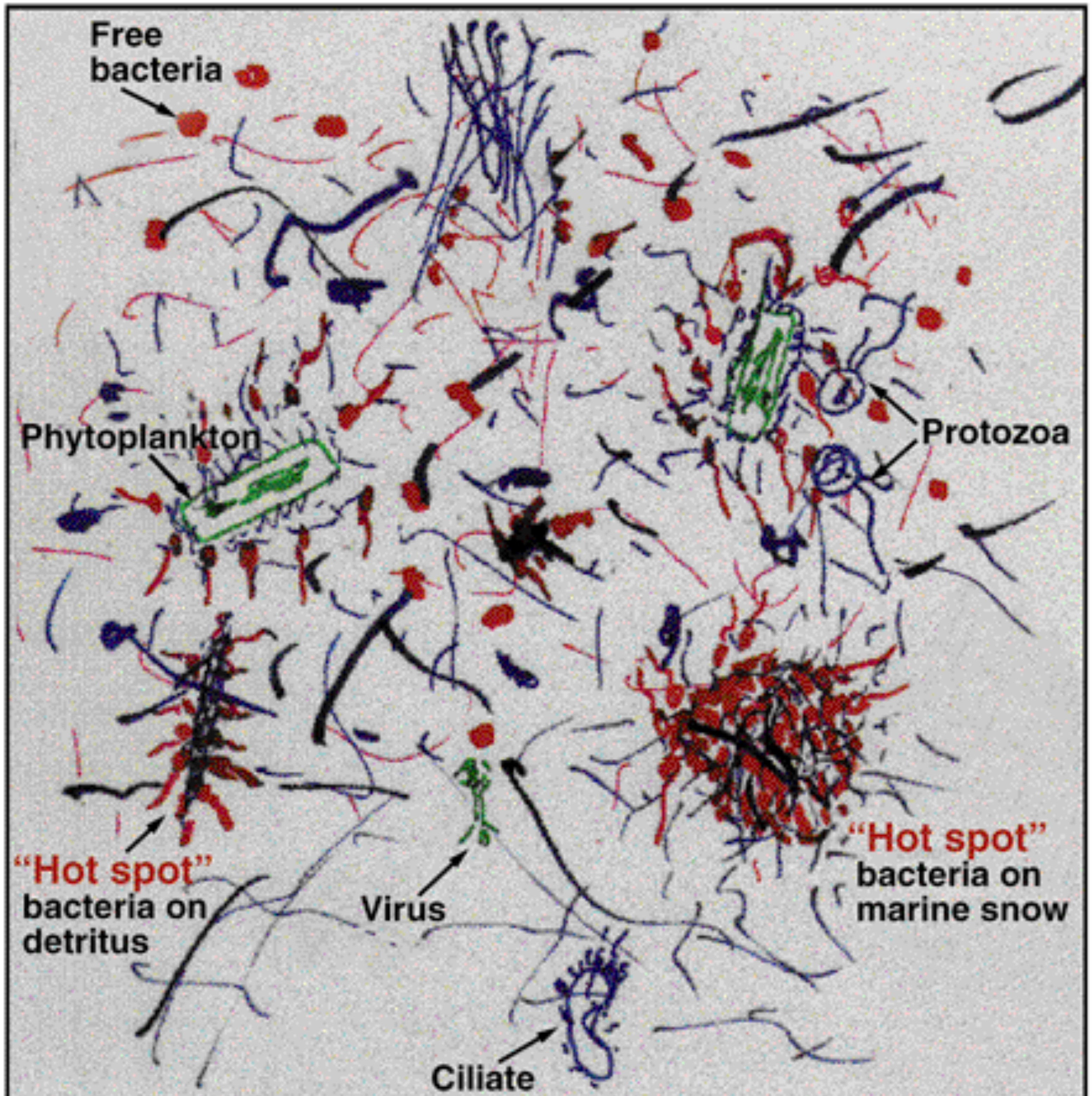






Dr. Farooq Azam

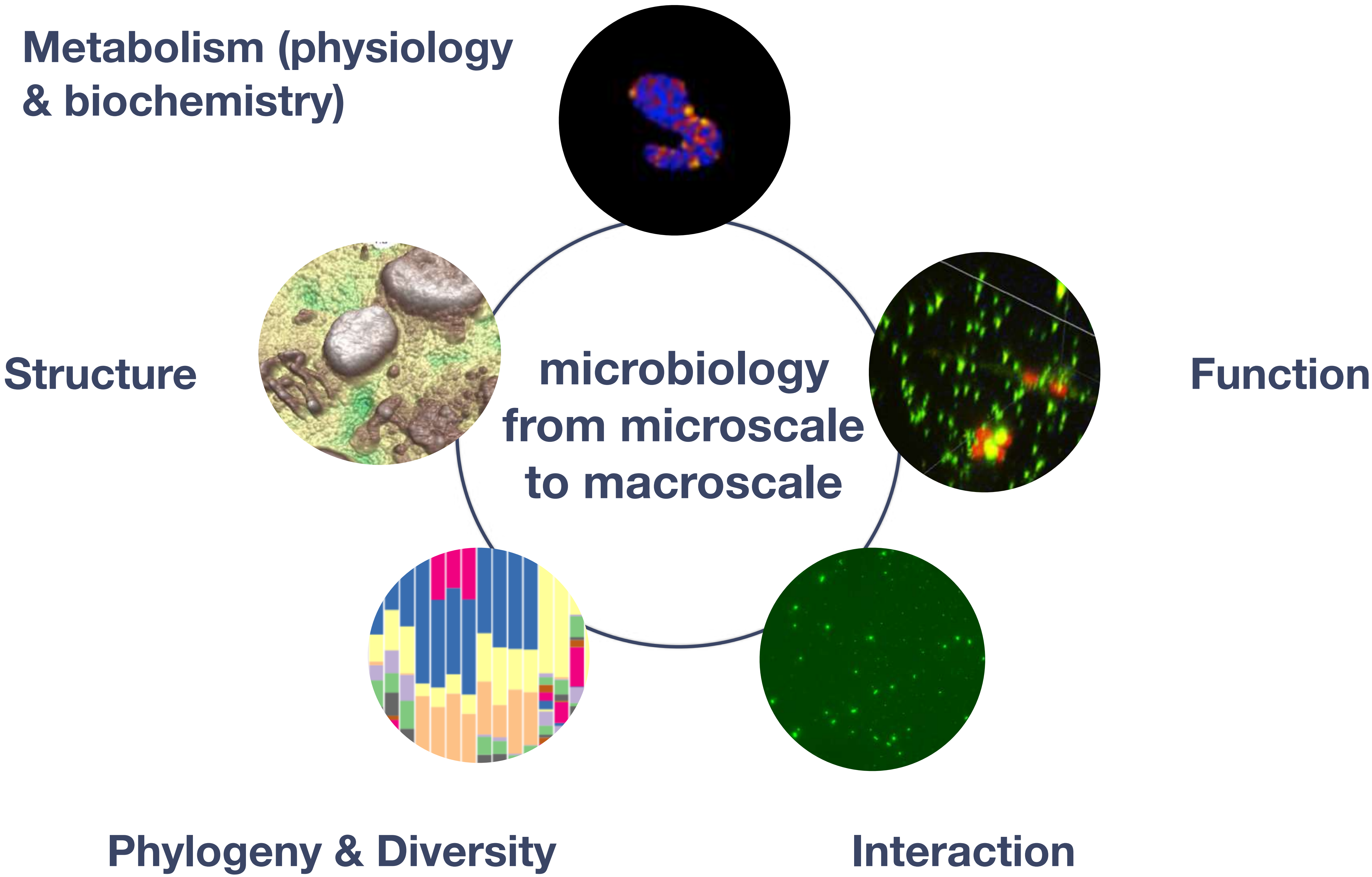
Impressionistic view, F. Azam



The microscale structure, chemistry and physics of the microbial environment dictate microbial life

Azam, F. 1998 Science 280:694-696

Mechanistic integrative approach



Questions

Che domande avete sui microbes?

Che cosa volete ottenere da questo corso?

WOOCLAP WOOCLAP WOOCLAP WOOCLAP WOOCLAP WOOCLAP WOOCLAP WOOCLAP

How to participate?

1. Go to wooclap.com
2. Enter the event code in the top banner

Event code
IADYNT

Copy participation link

Scrivete una frase "falsa" sui microrganismi (aka fake news)

Scrivete cosa volete sapere sui microrganismi

What is LIFE?

What is LIFE?

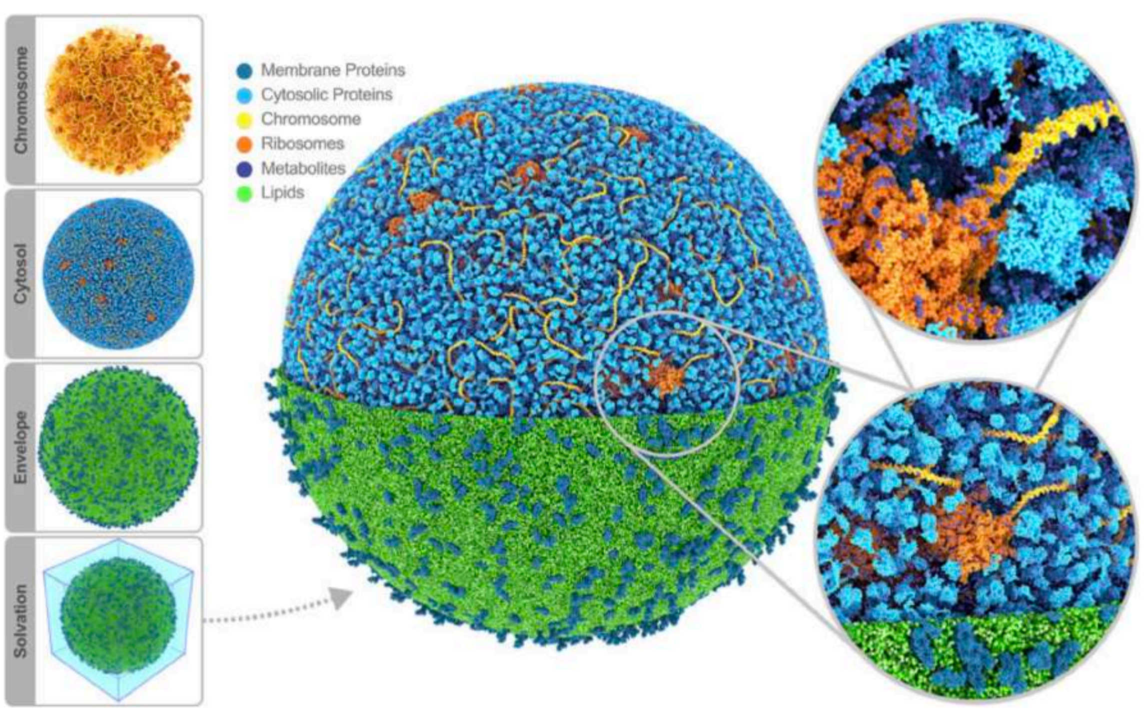
-Natural
-Synthetic
-Mirror

What is LIFE?

-Natural
-Synthetic
    -Mirror

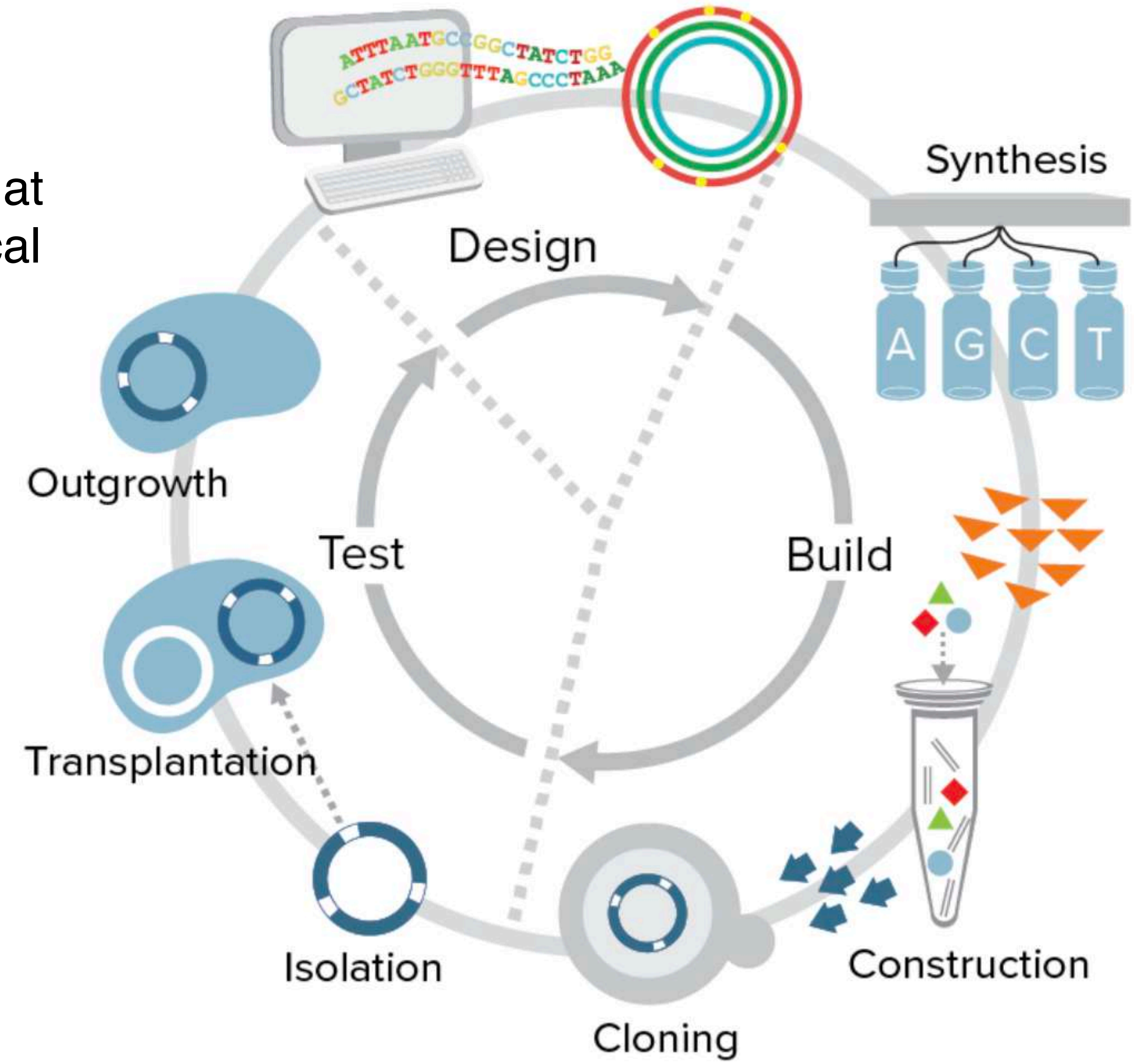
SYNTHETIC LIFE

A major goal in synthetic biology is to have the capacity to predictably design and build DNA that produces a cell with new and improved biological functions that do not already exist in nature



Stevens et al. 2023

The new minimal synthetic cell contains only 531,000 base pairs and just 473 genes making it the smallest genome of any self-replicating organism (from *Mycoplasma mycoides* JCVI-syn1.0)



https://www.jcvi.org/research/first-minimal-synthetic-bacterial-cell#overview

Mirror Bacteria

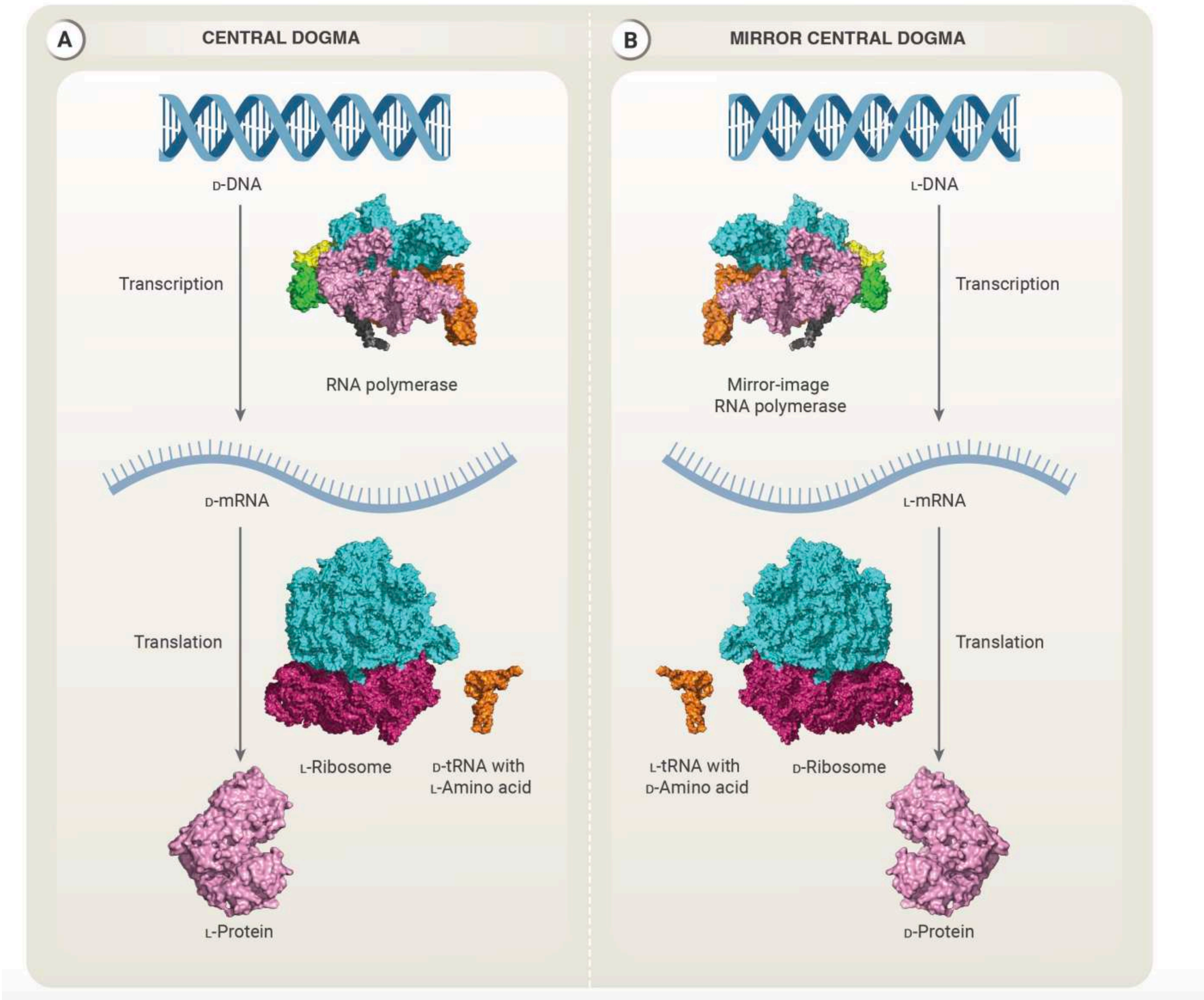
All known life on Earth shares a common set of chiral molecules. Proteins, sugars, lipids, and nucleic acids can all physically exist in either of two mirror-image configurations, but living organisms overwhelmingly use only one of these two configurations.

By convention, one member of the pair is designated to be the L, or "left-handed" form, while the other is designated the D, or "right-handed" form. **Their crystalline structures are mirror images of each other and melt at the same temperatures**. They have **identical solubilities in water and identical acid-base dissociation constants**, but they ***rotate polarized light in opposite directions.***

Virtually all proteins are constructed solely from the 20 canonical amino acids, of which all but achiral glycine are **L-amino acids**. Their mirror images are D-amino acids, which play only marginal roles in existing life.

The ribose in RNA is always in the form of **D-ribose**; its mirror image L-ribose is essentially absent from nature. Pairs of molecules that are mirror images of each other are known as enantiomers, which have almost exactly mirrored physical and chemical properties.

Adamala et al., 2024



Adamala et al., 2024

Confronting risks of mirror life

- No natural predator
- No natural antibiotic or chemical warfare
- Potentially share same habitat and niche of “natural” microbes
- Potentially might outcompete “natural” microbes

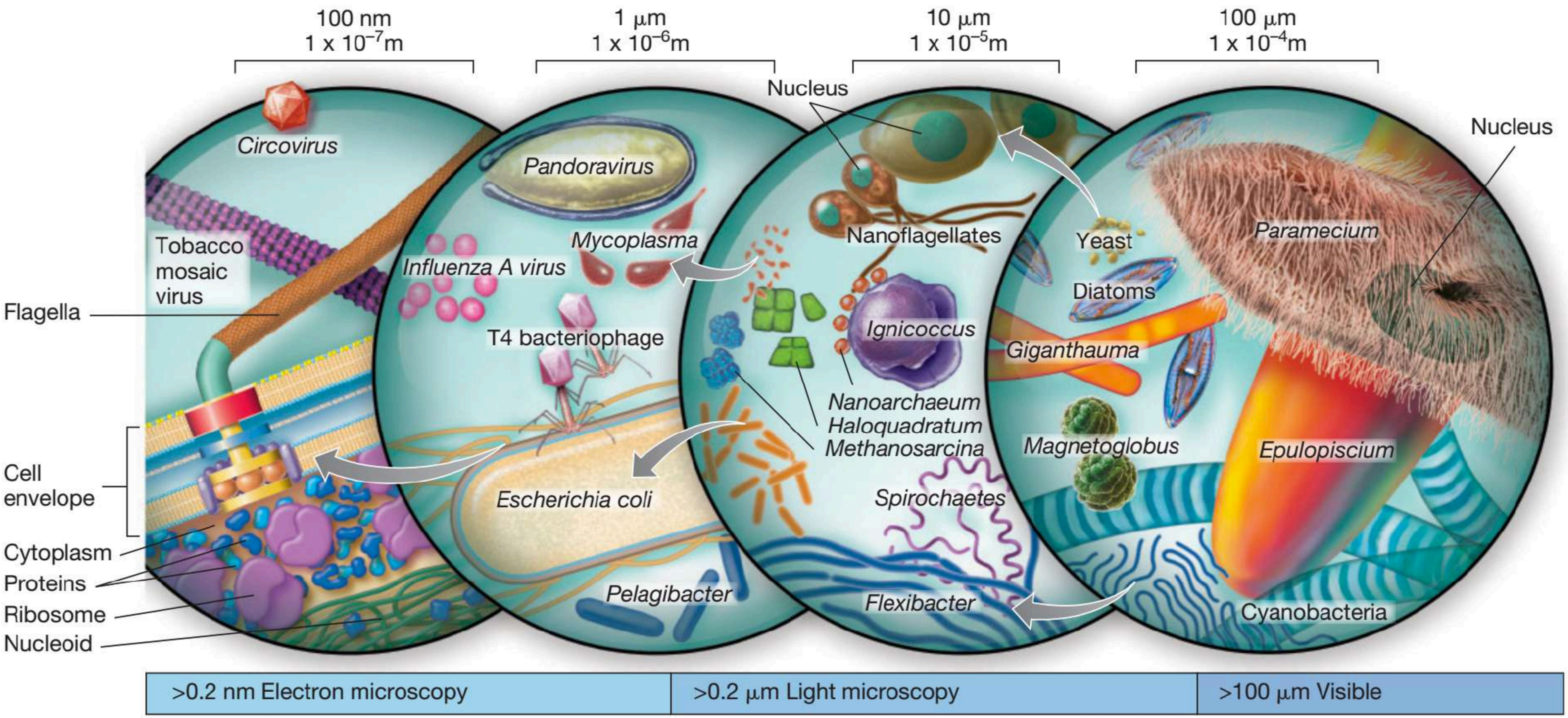
BEFORE	AFTER
	Microbes are everywhere and will always be…
Microbes not important	Microbes as ecosystem engineers
Microbes=Disease	Microbes keep the ecosystem functioning
Microbiologists stay only in the lab	Humans and biota as microbial ecosystems
	Microbiologists go sampling in the field
	Microbes produce antibiotics as weapons

Topic 01: Course Overview & Introduction to the Microbial World, History of Microbiology and Origin of Life

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

- History
- Microbiology
- Goals of the course
- Origin of life

Microbial size range



Madigan et al. 2018

- 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

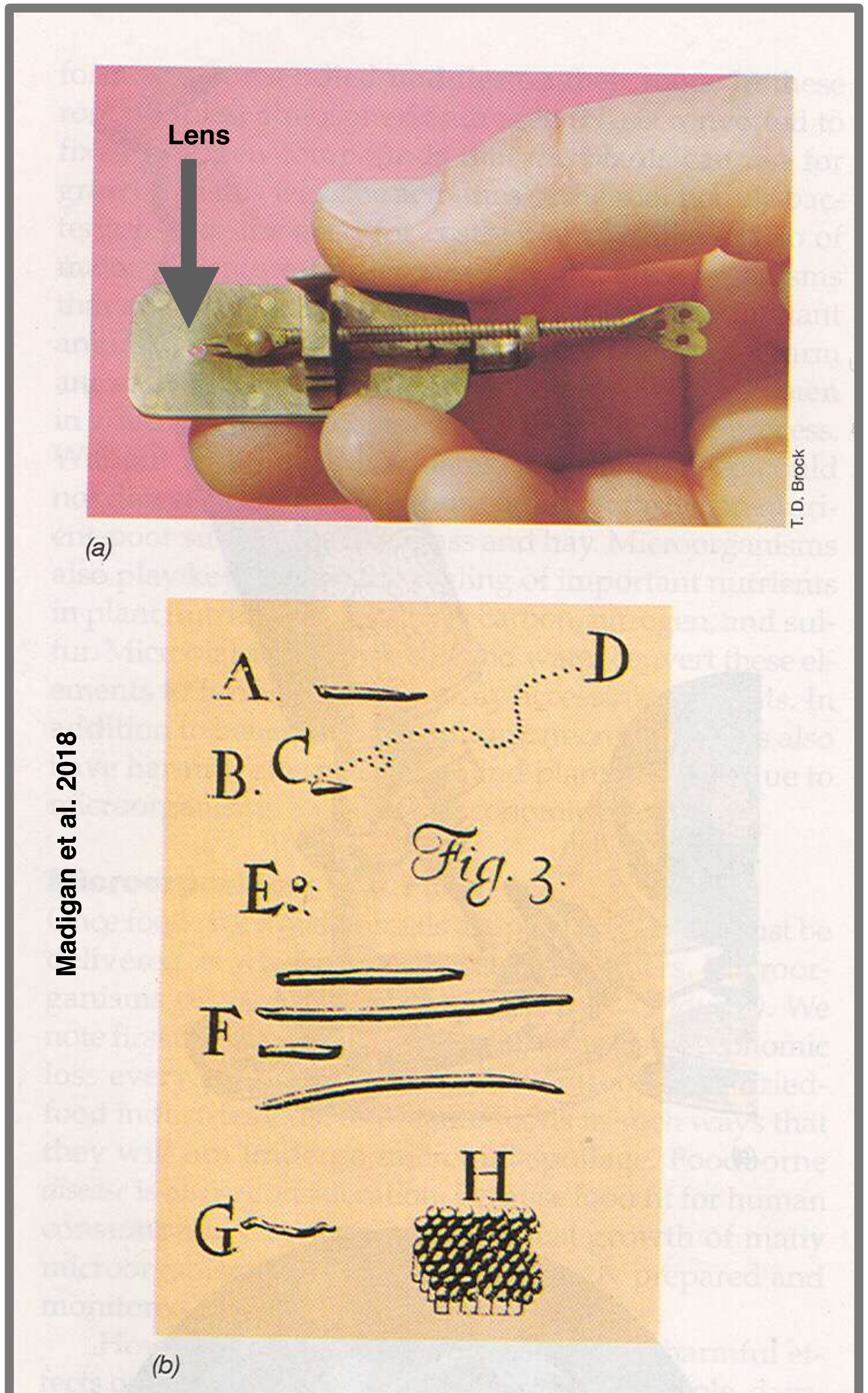
Bacteria, Archaea, Viruses & small Eukarya

Everywhere on Earth and in/on every organism

History

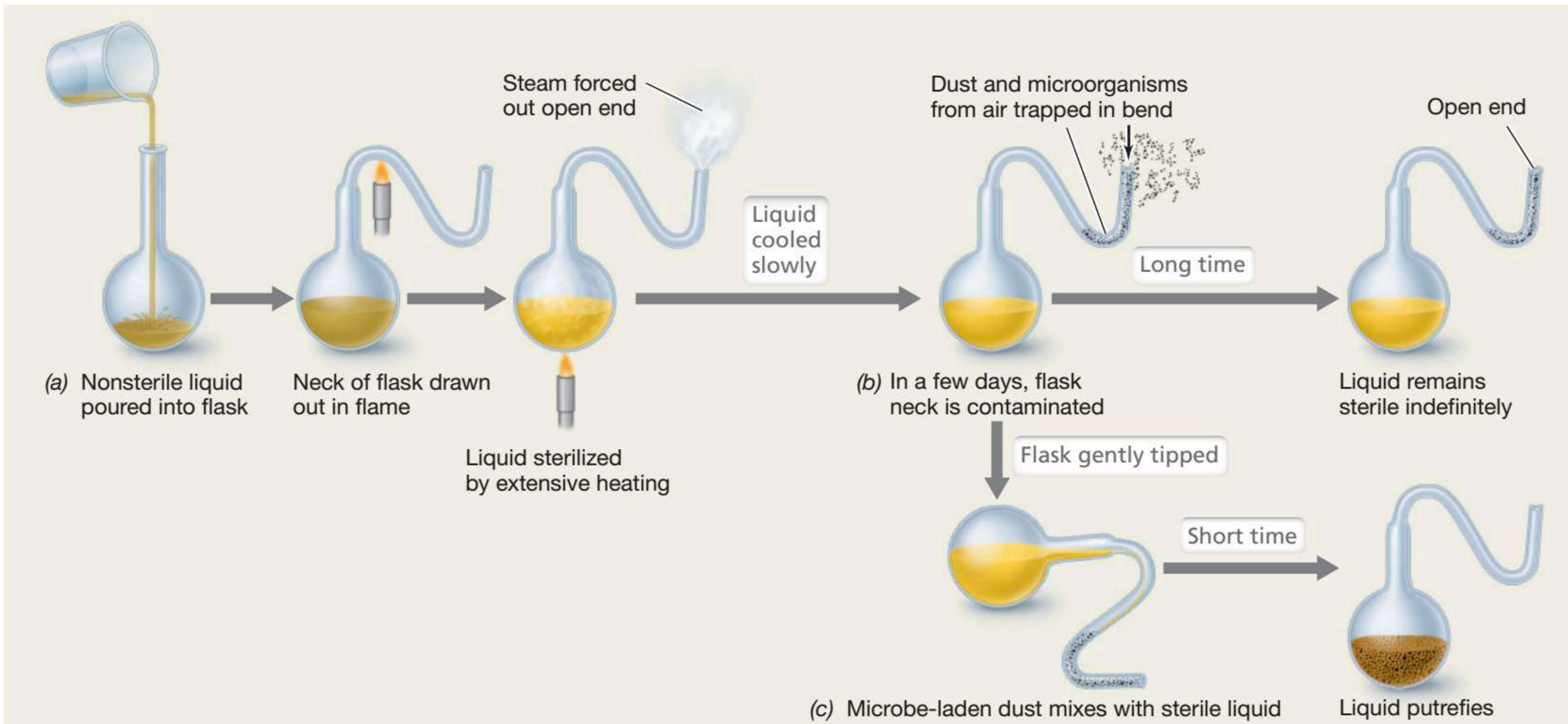
- 1665 Robert Hooke, invention of the microscope
- 1676 van Leeuwenhoek, discovery bacteria at the microscope
- 1857 Pasteur, microbes cause fermentation & dispelling spontaneous generation of life
- 1881 Koch, Germ theory of disease & use of gelatin plates
- End 19th century Beijerinck and Winogradsky —> **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

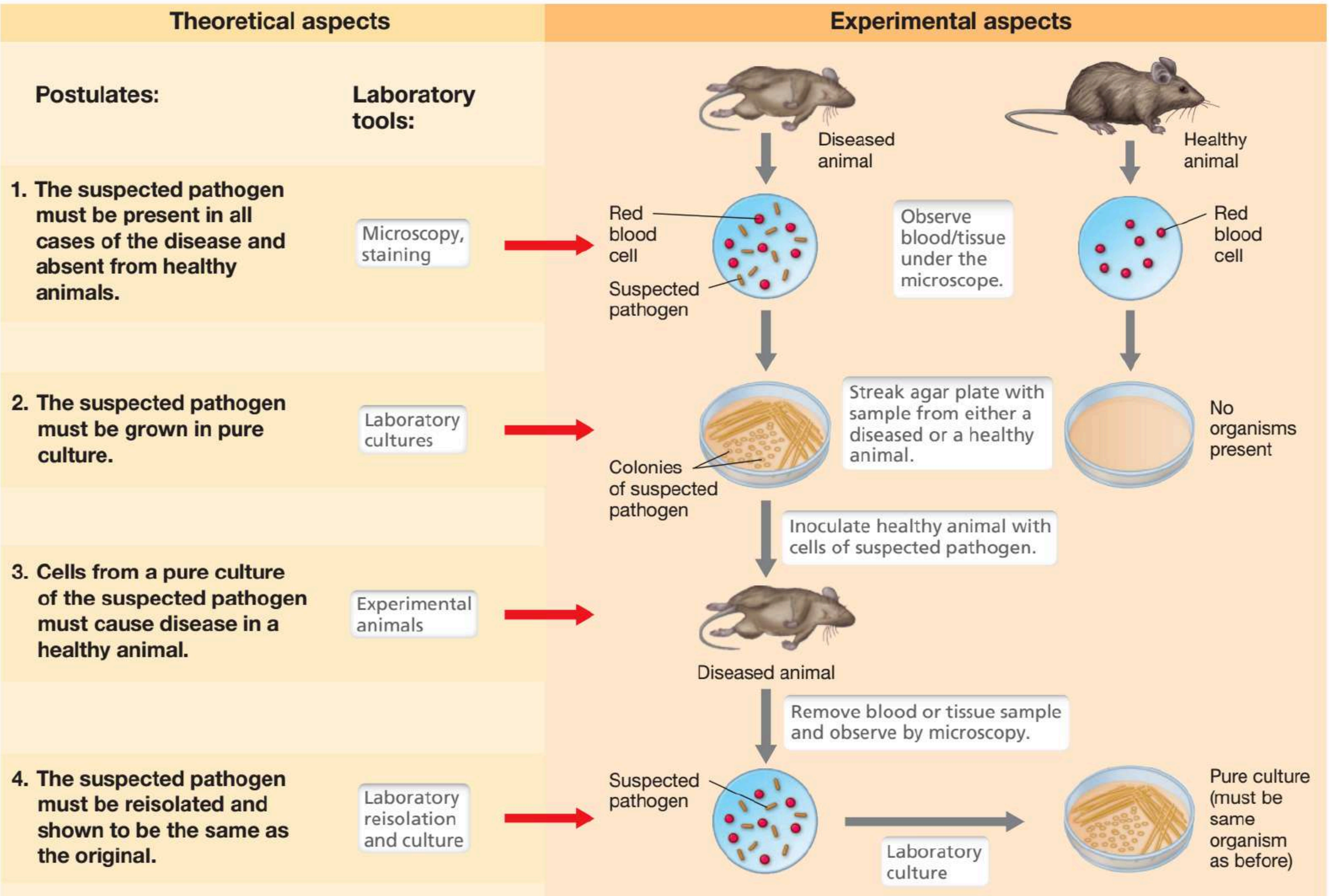
Early focus: Human microbial diseases
Later focus: Biogeochemical role
Today focus: One Health



Madigan et al. 2018

Pasteur: Experiment dispelling the theory of spontaneous generation of life (environmental change is microbe 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

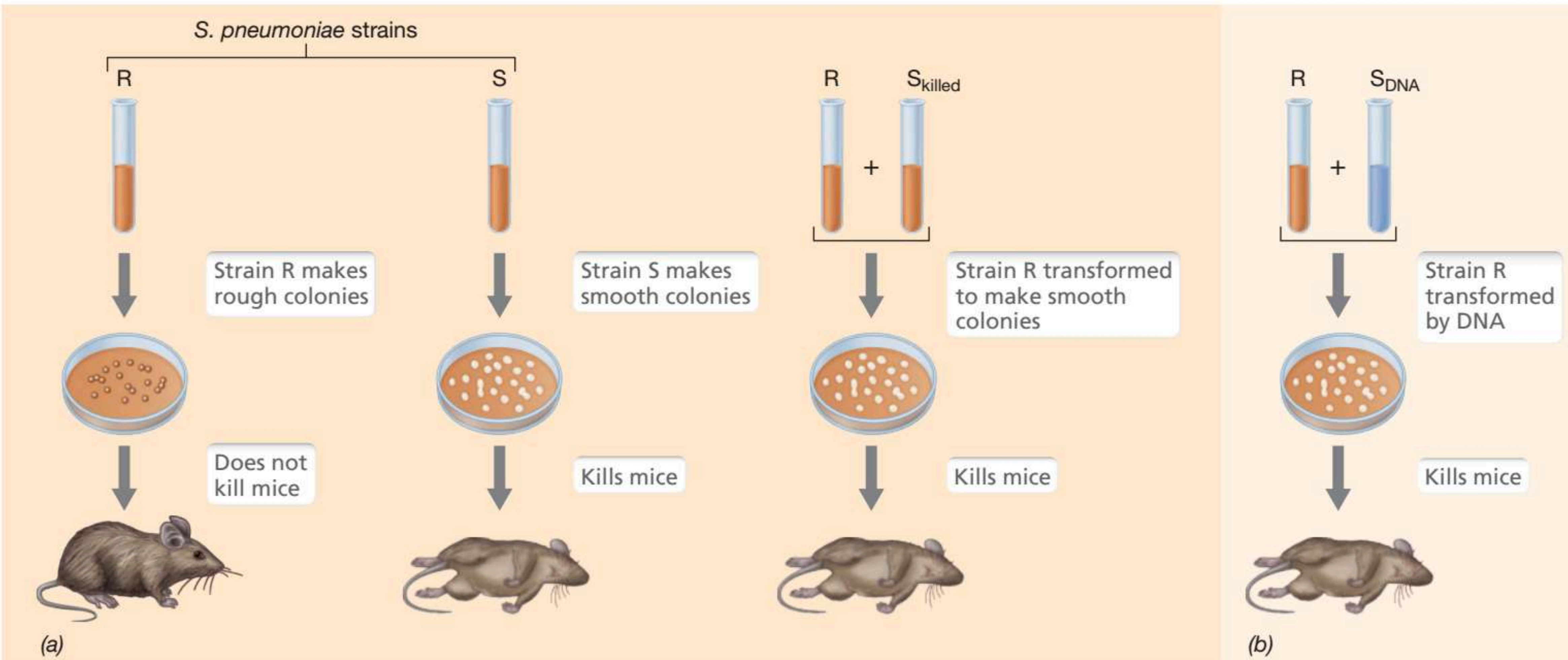
2. Need to create specific enrichment media to imitate the environment

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**)

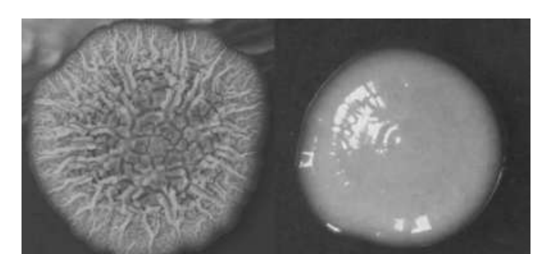
Griffith & Avery-MacLeod-McCarty

Streptococcus pneumoniae

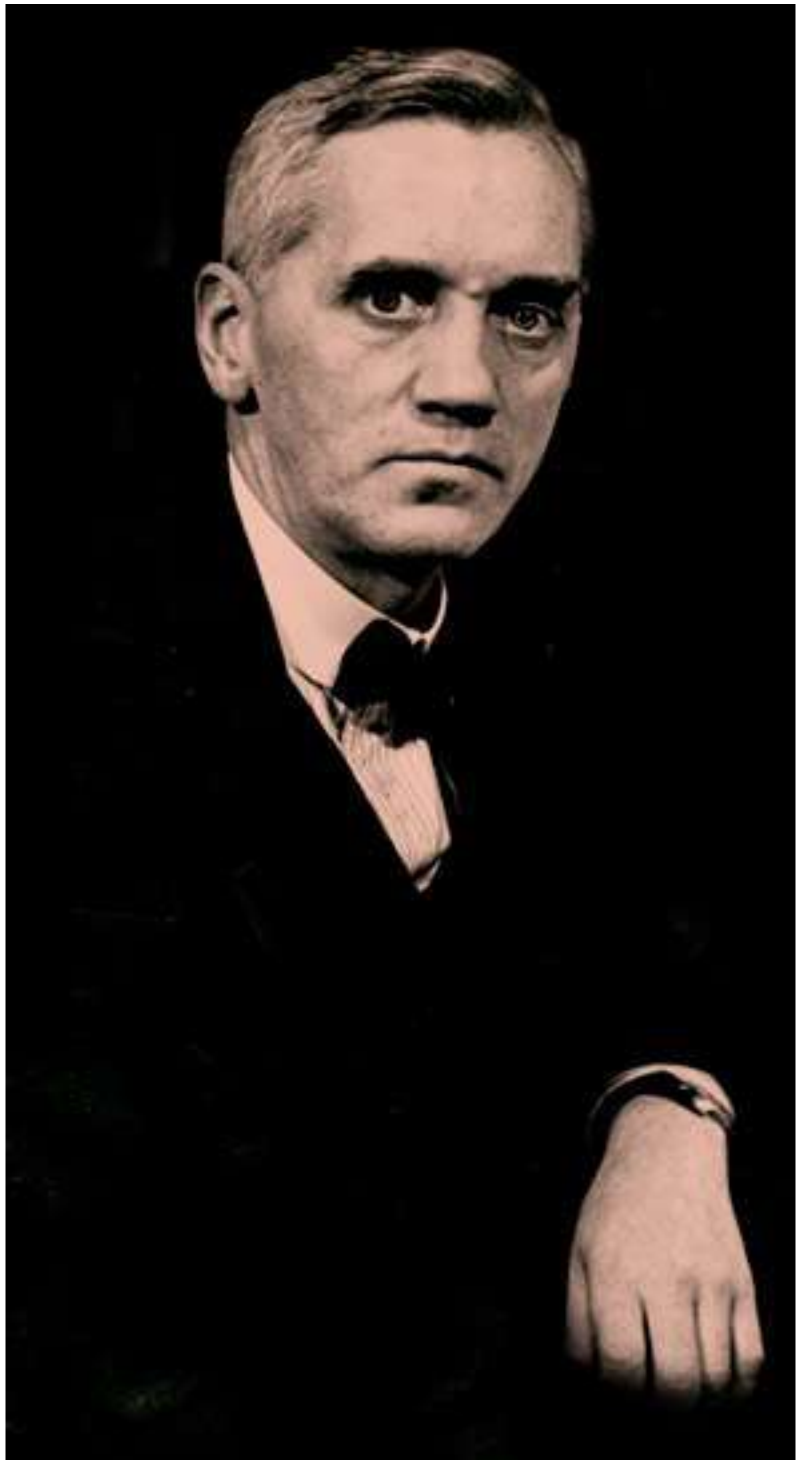


DNA contains genetic information
DNA is the molecular basis of hereditary

R **S**



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, lysozyme

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

Woese

16S ribosomal RNA gene

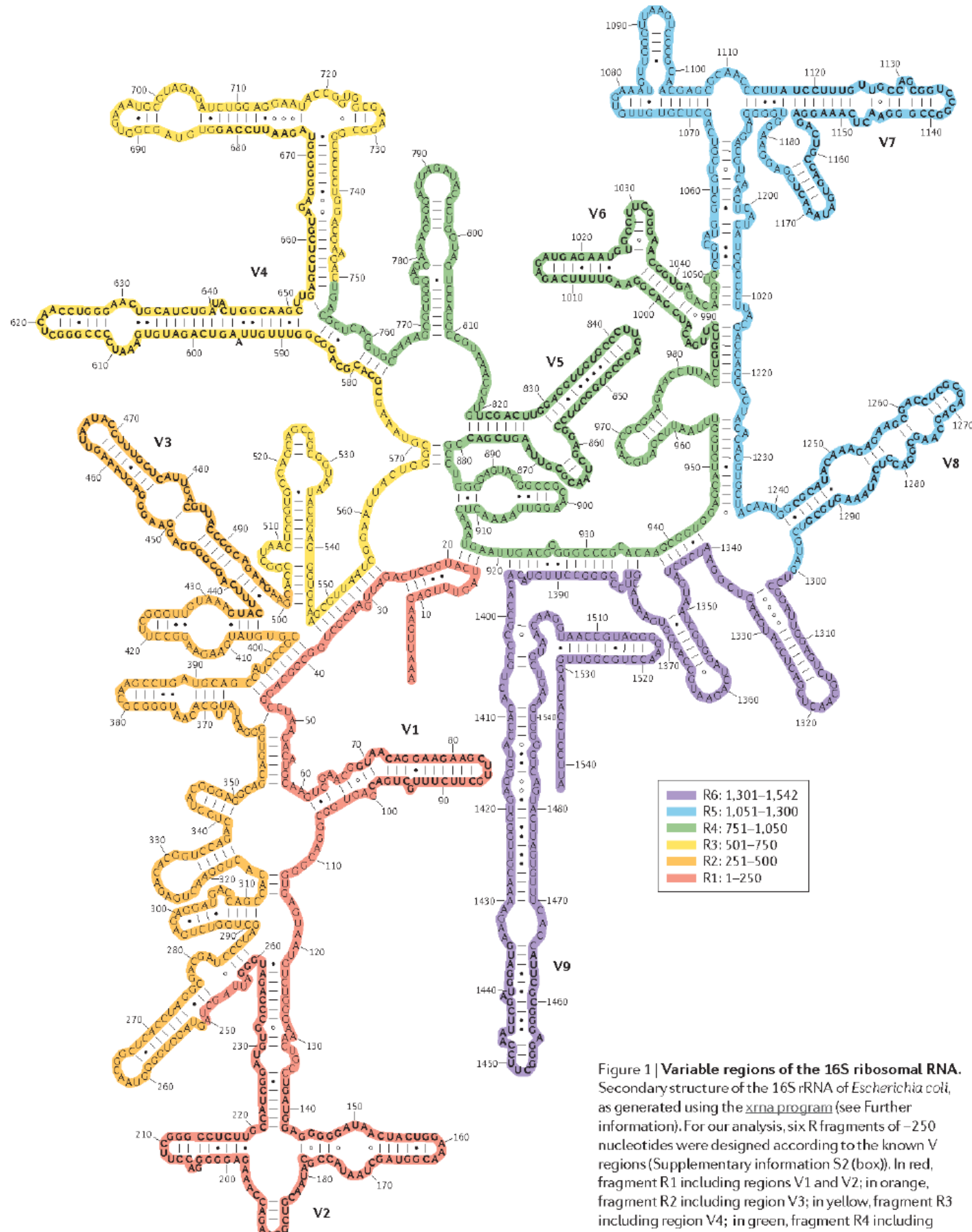


Figure 1 | **Variable regions of the 16S ribosomal RNA.** Secondary structure of the 16S rRNA of *Escherichia coli*, as generated using the xrna program (see Further information). For our analysis, six R fragments of ~250 nucleotides were designed according to the known V regions (Supplementary information 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

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

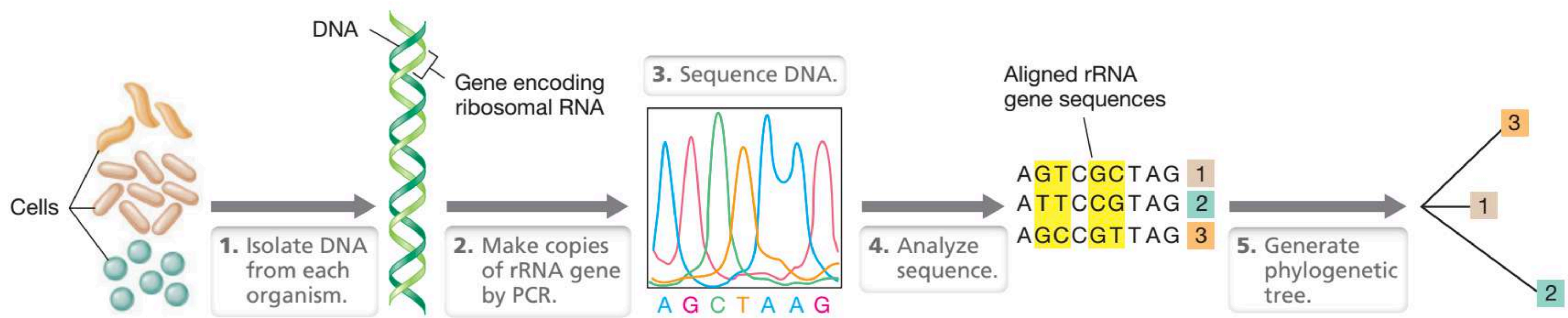
Yarza et al. 2014 10.1038/nrmicro3330

Woese

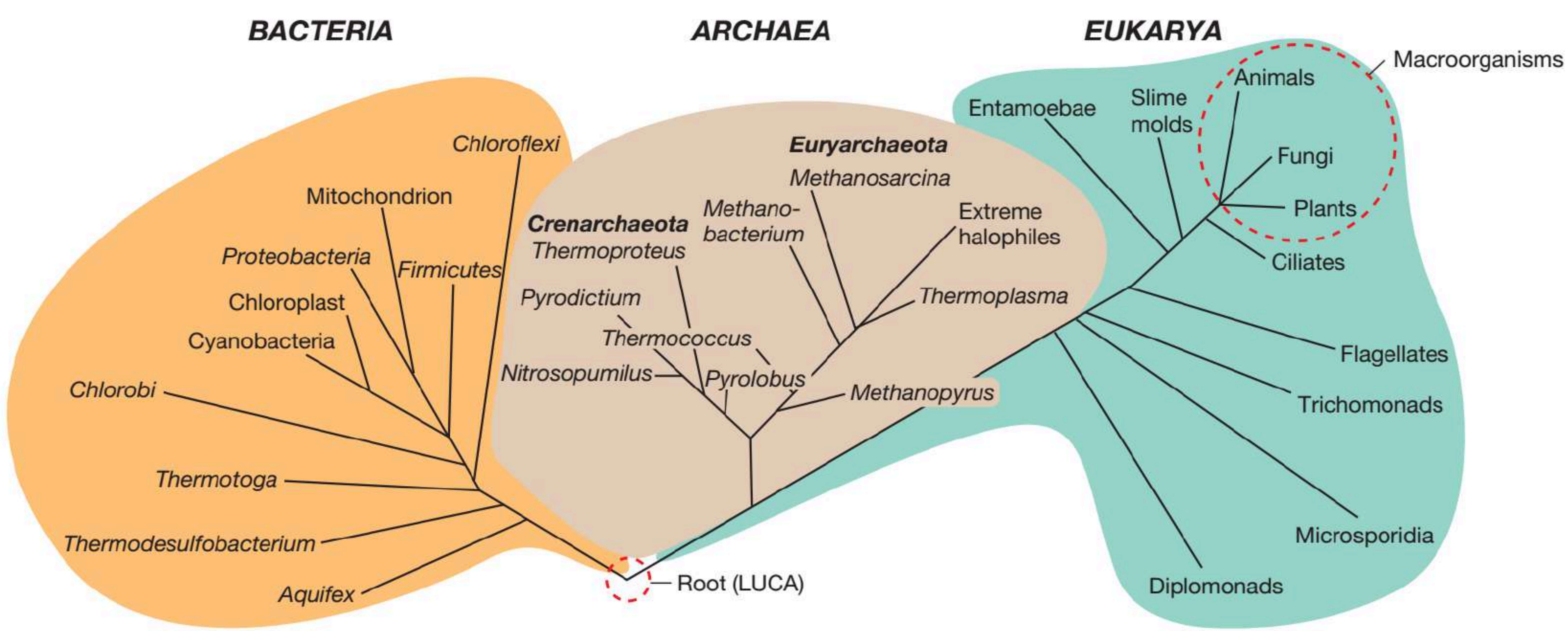
Genes encoding rRNAs are excellent candidates for **phylogenetic analysis** because they are:
(1) universally distributed,
(2) functionally constant,
(3) highly conserved (that is, slowly changing),
(4) adequate length to provide a deep view of evolutionary relationships,
(5) diverse in different ‘species’

Using pure cultures of bacteria and Archaea

Step-by-step technology for evolutionary classification of microbes



Phylogenetic Tree of Life



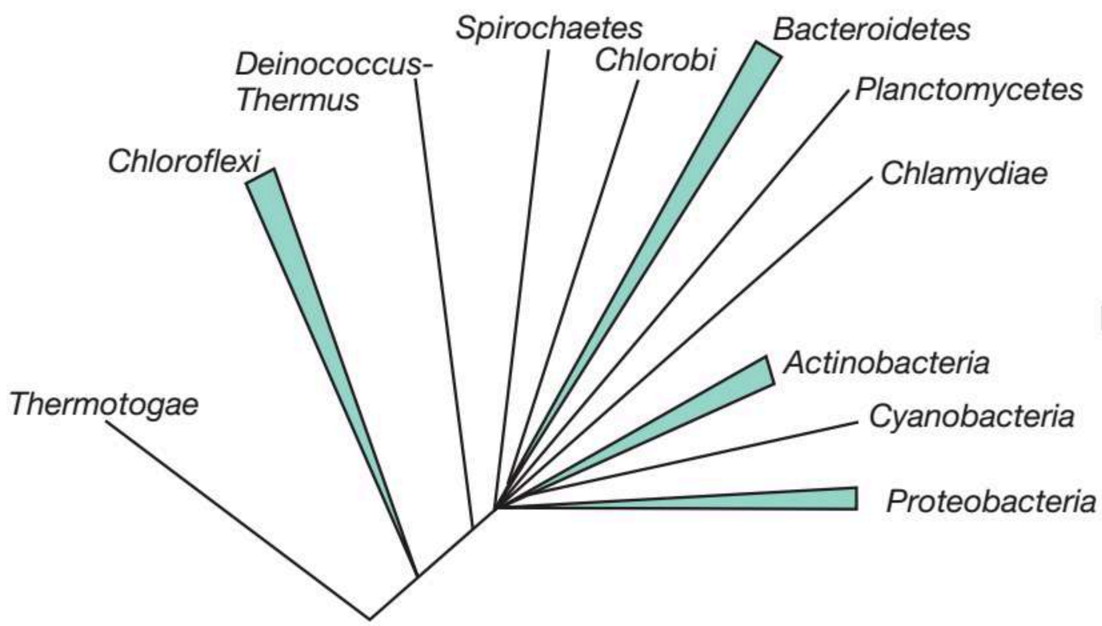
LUCA: Last Universal Common Ancestor

Madigan et al. 2018

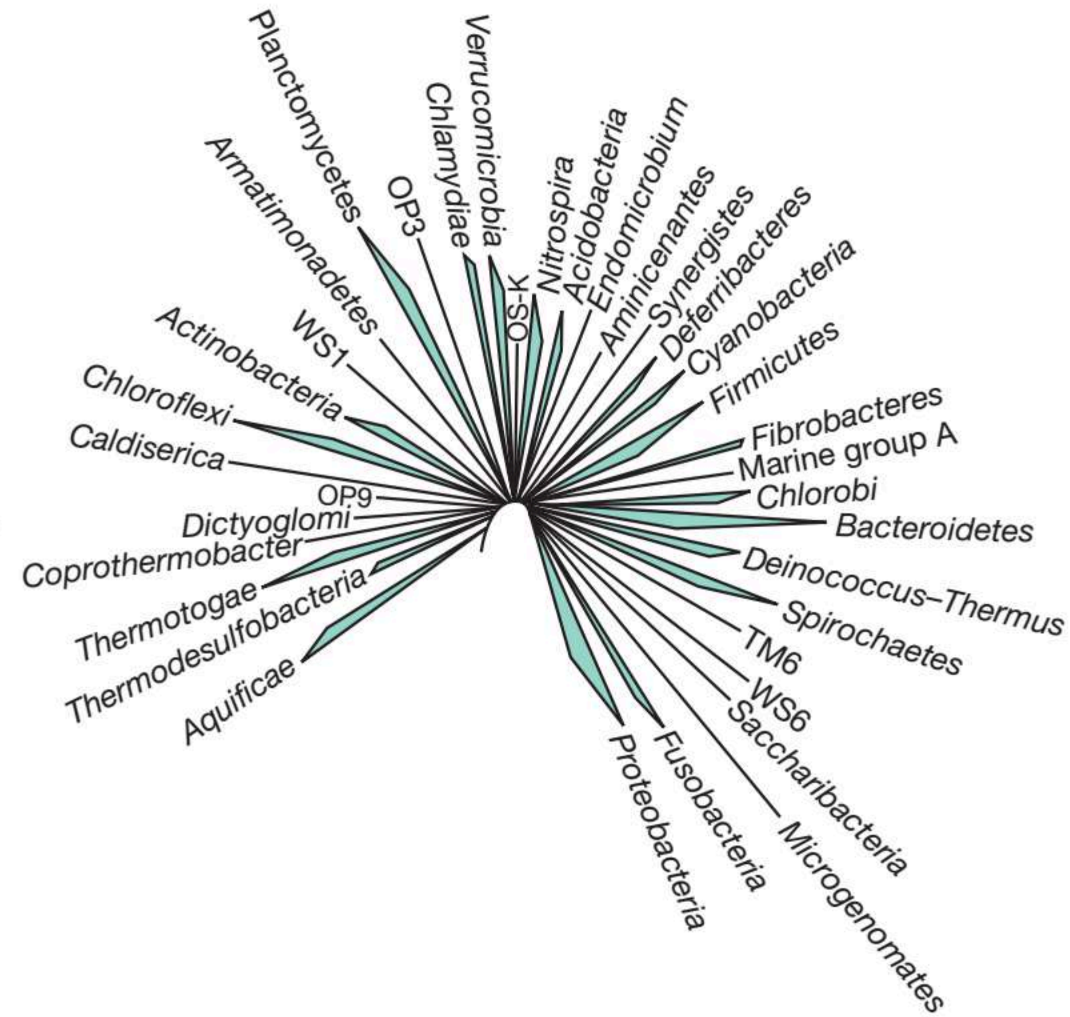
Woese

16S ribosomal RNA gene

Woese



Pace



Madigan et al. 2018

Cultivation dependent

Cultivation independent

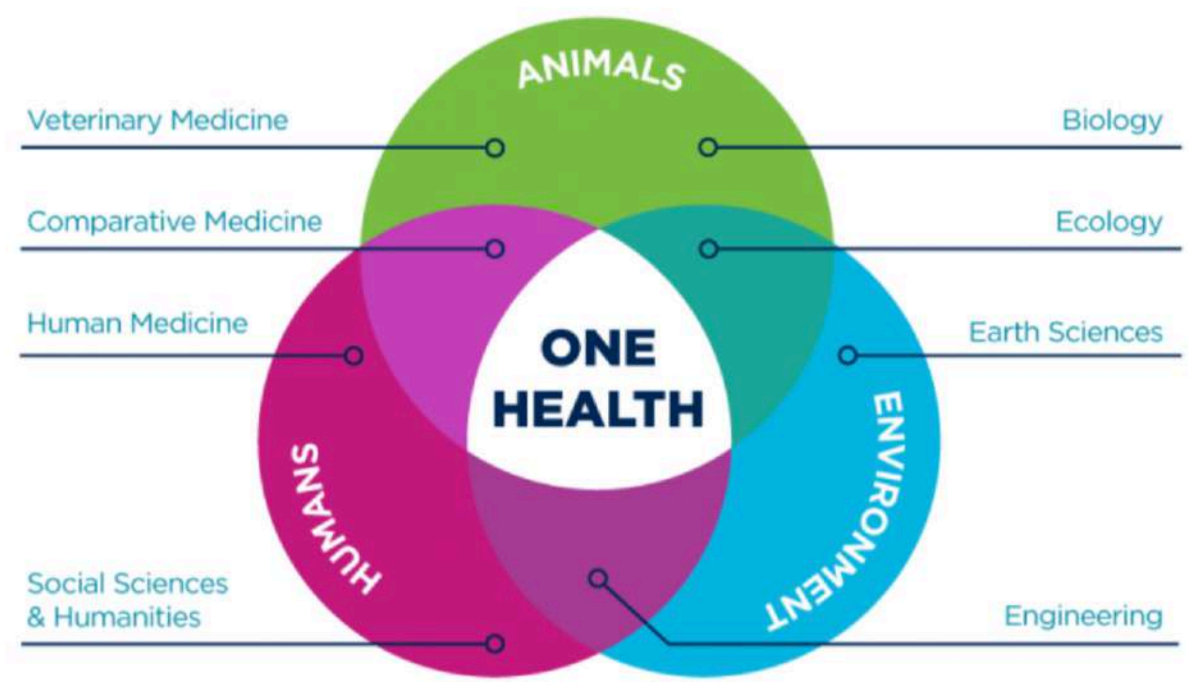
Microbes living in the environment

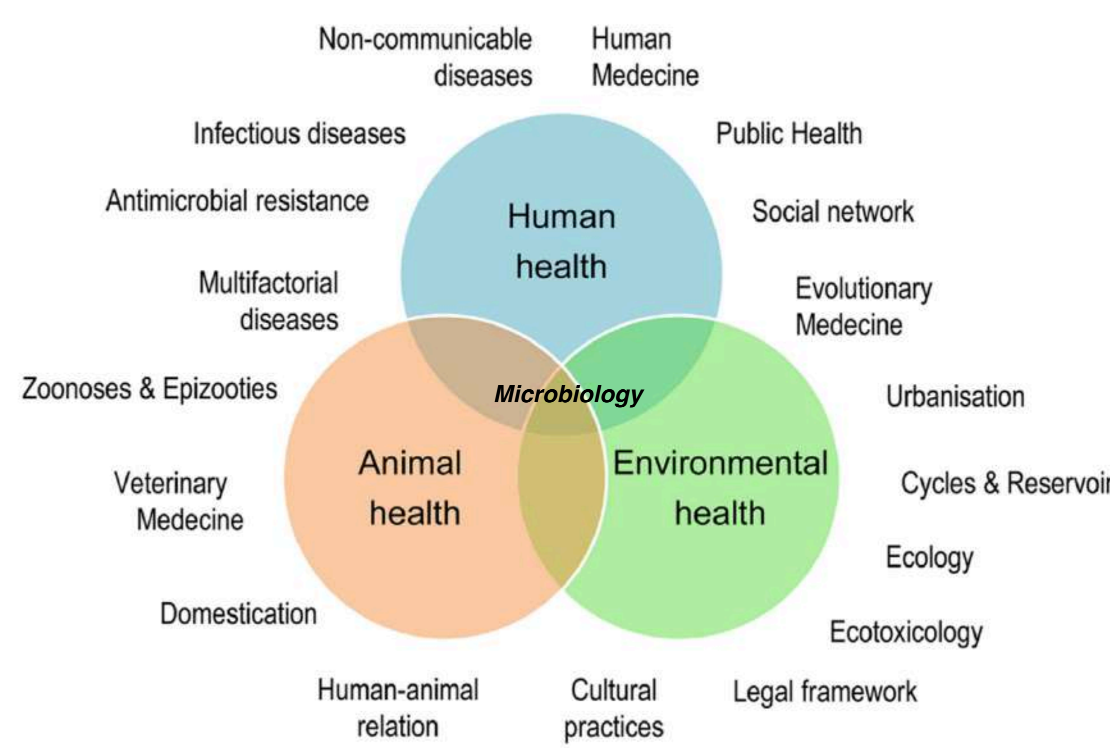
Microbes can or can't be cultivable

Pace

- 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

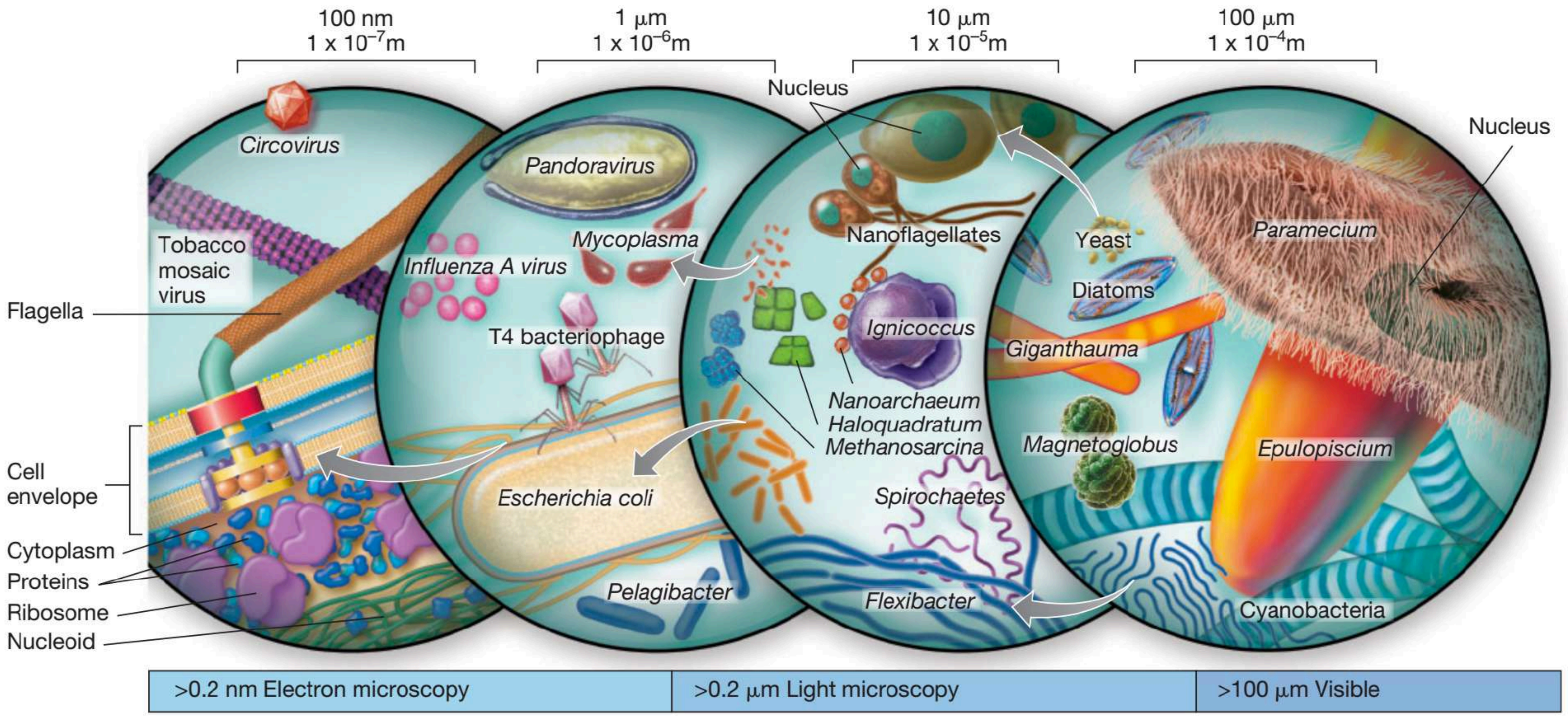
Microbiology:

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

Microbial literacy and fundamental understanding of microbes life and their function in the environment, thus included the human beings.

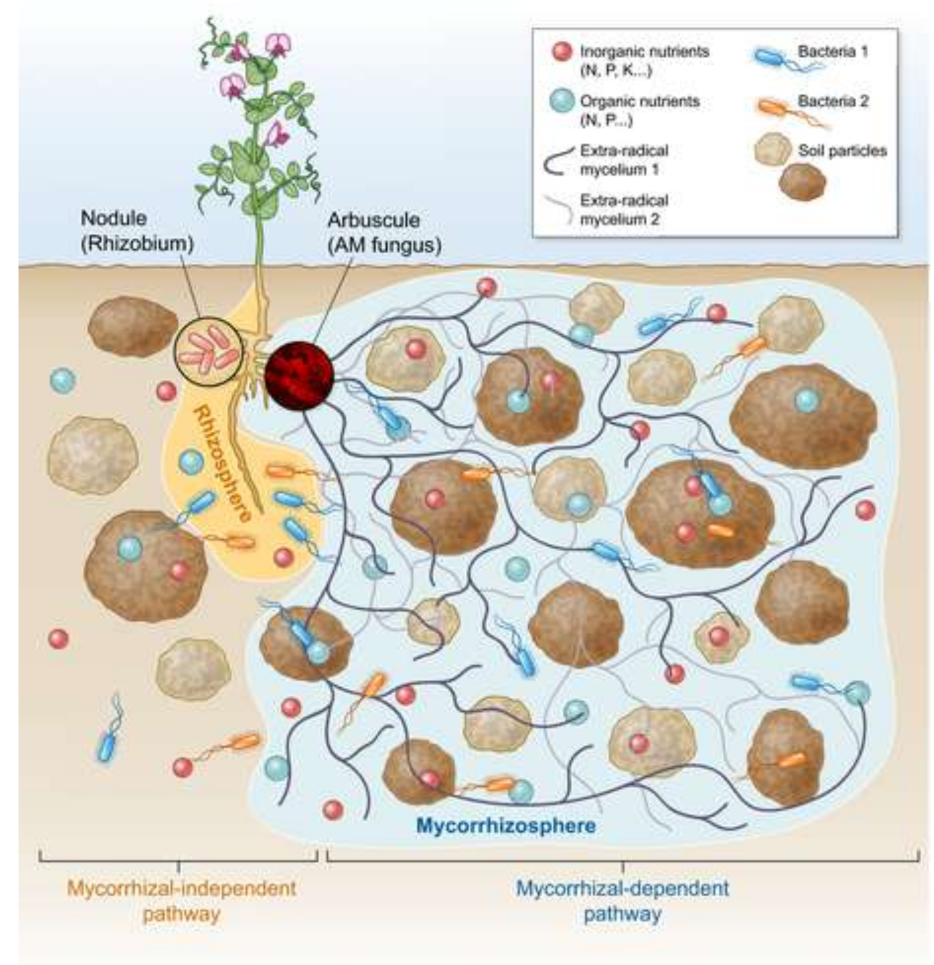
Microbial size range



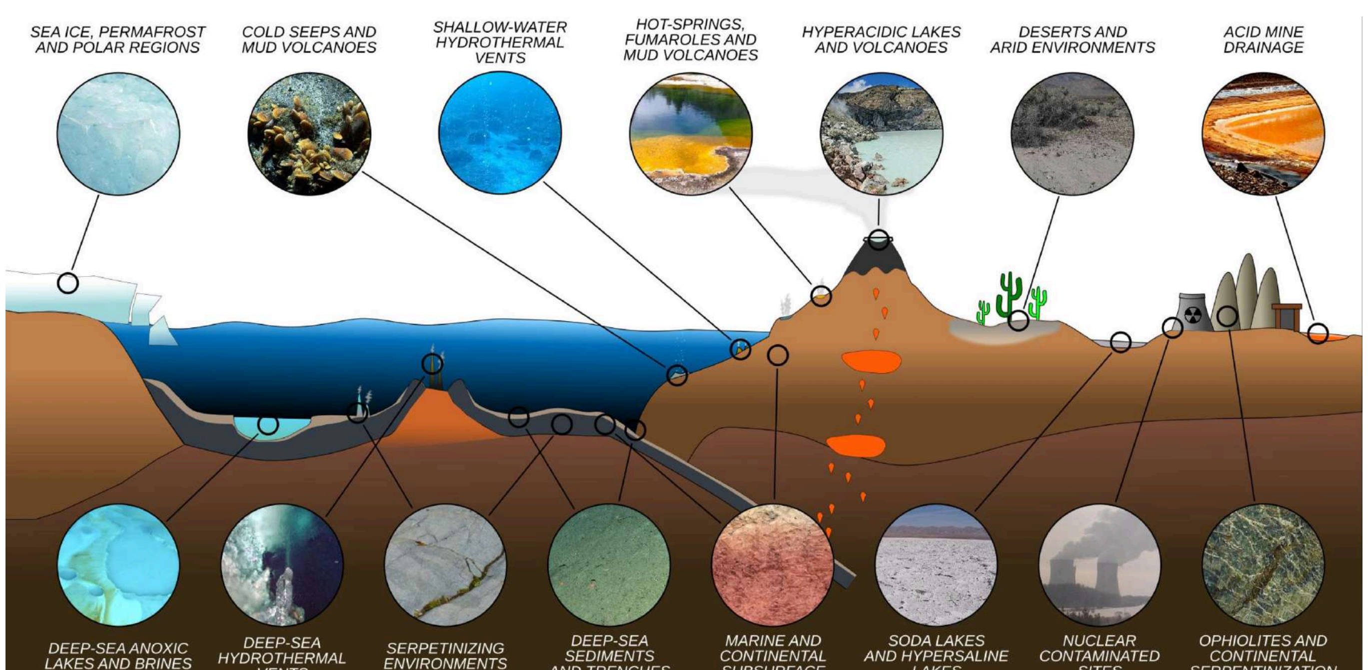
Madigan et al. 2018

Microbial environments

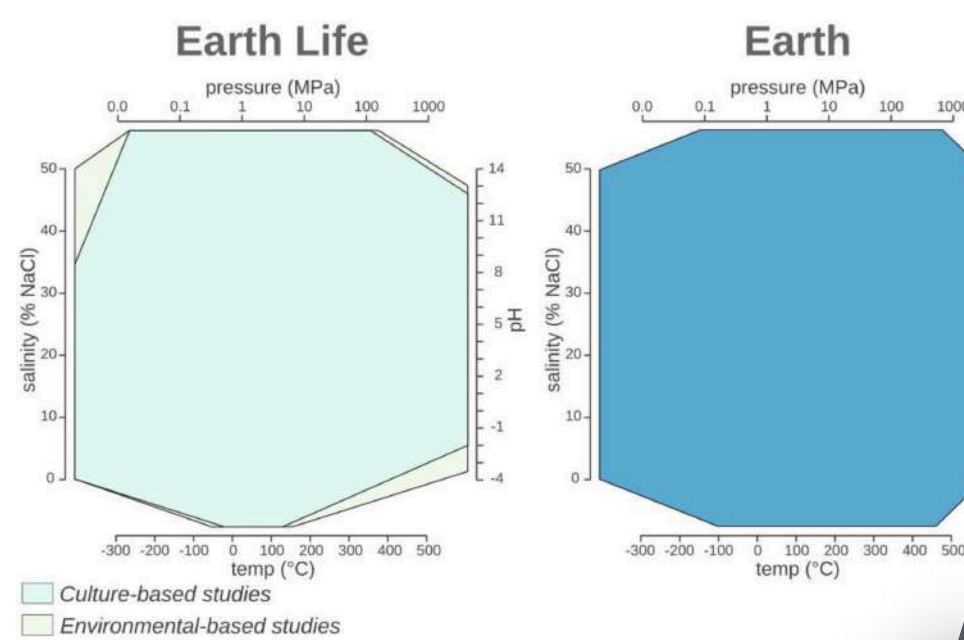
- Temperature
- pH
- Light/Dark
- Humidity
- Pressure
- Radiations (not on Earth)



Wipf et al. 2019



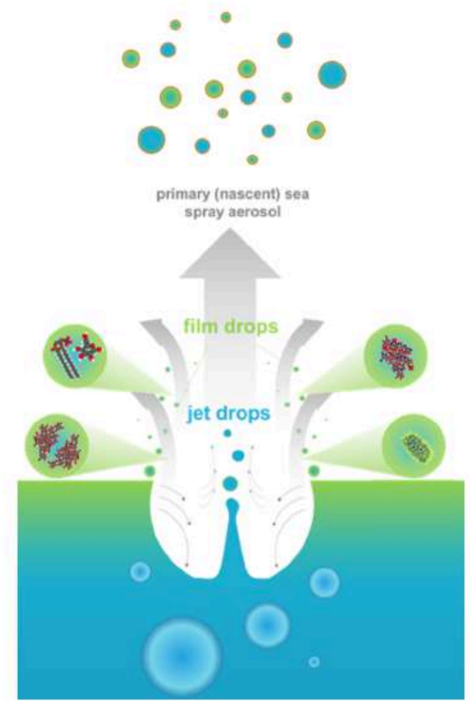
Merino et al. 2019



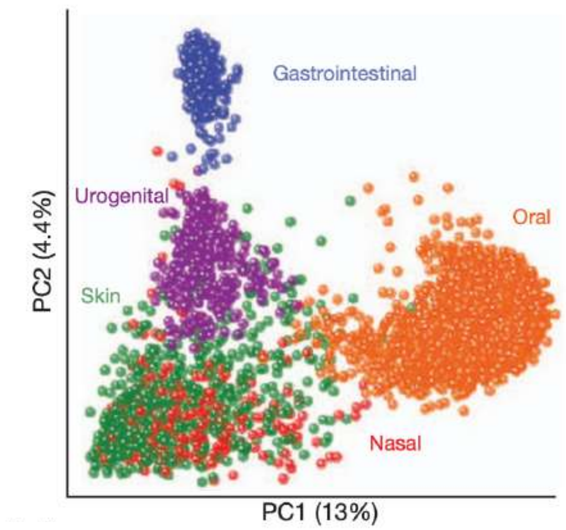
Merino et al. 2019

https://youtu.be/i-icXZ2tMRM

Microbial environments



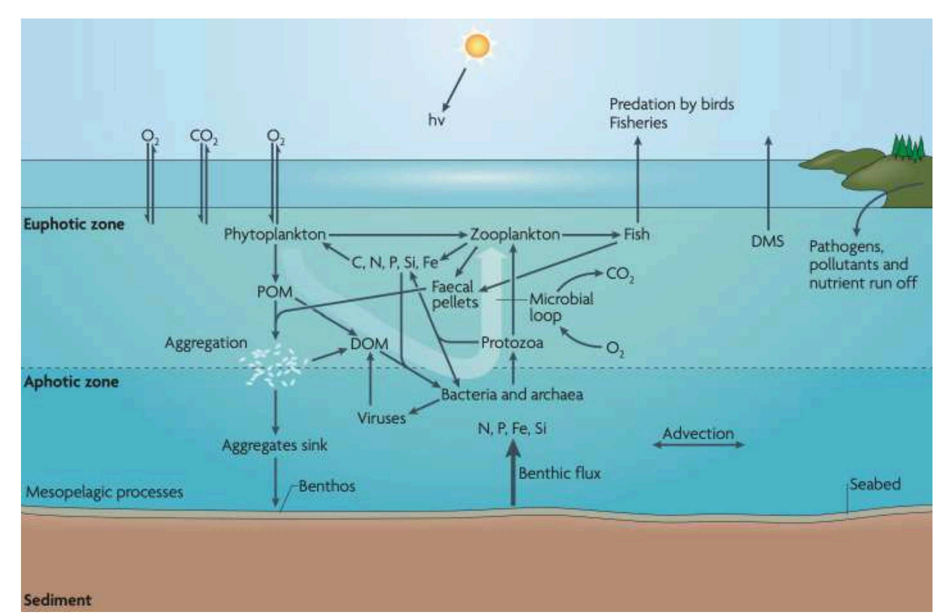
2020 CENTER FOR AEROSOL IMPACTS ON CHEMISTRY OF THE ENVIRONMENT



HMPC 2012

- 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

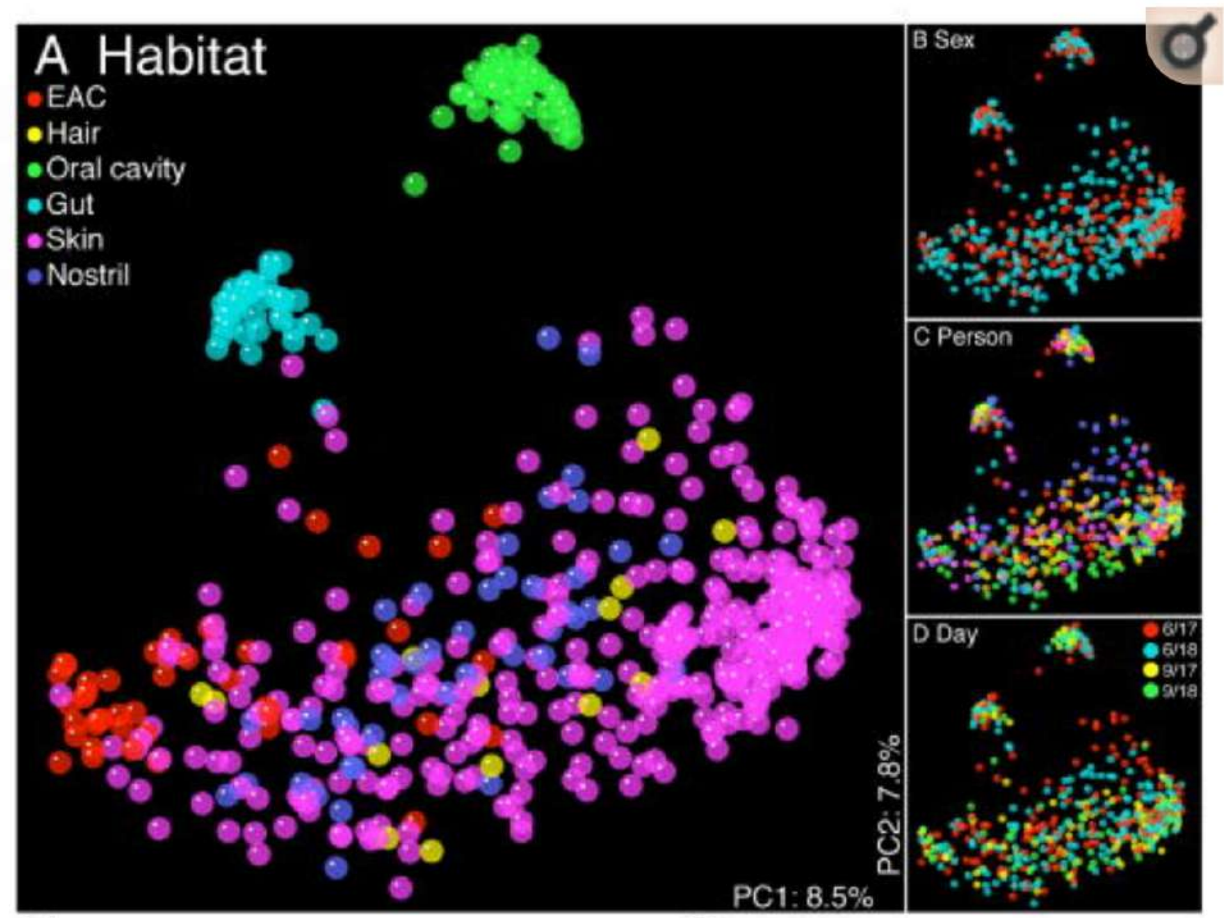
Azam & Malfatti 2007



Specific adaptation to grow in the microenvironment

Human as a microbial 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
- Immune system
- Eukaryotes and Viruses (ecology, chemistry and physiology)
- pH:
  - ★ skin~5.5
  - ★ blood~7.4
  - ★ mouth~ 6.7-7.3
  - ★ vagina ~3.8-4.5
  - ★ oesophagus 5-7
  - ★ stomach 2-5
  - ★ duodenum 6.8



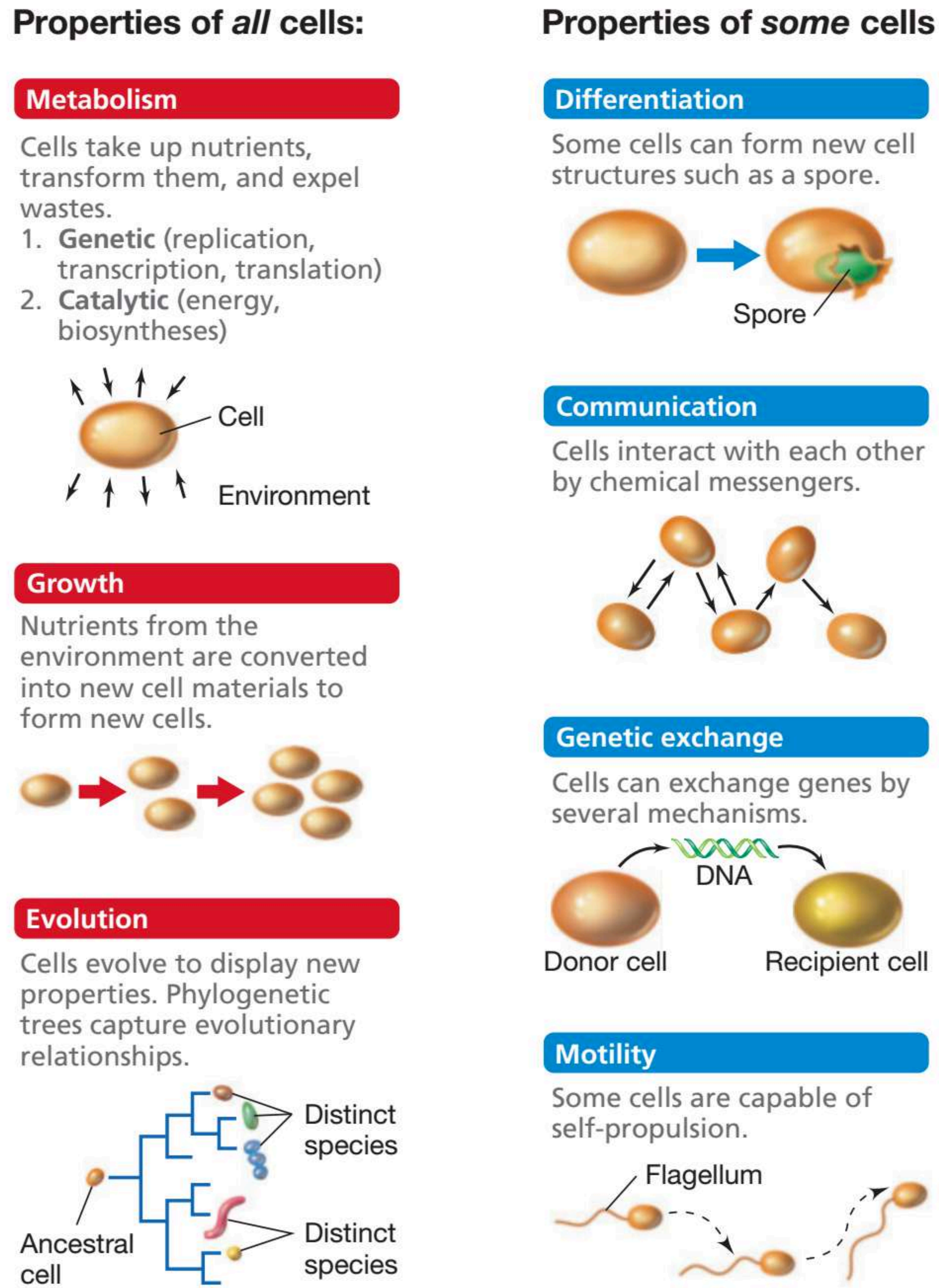
Costello et al., 2005

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

From where do we start? —> *ab initio*

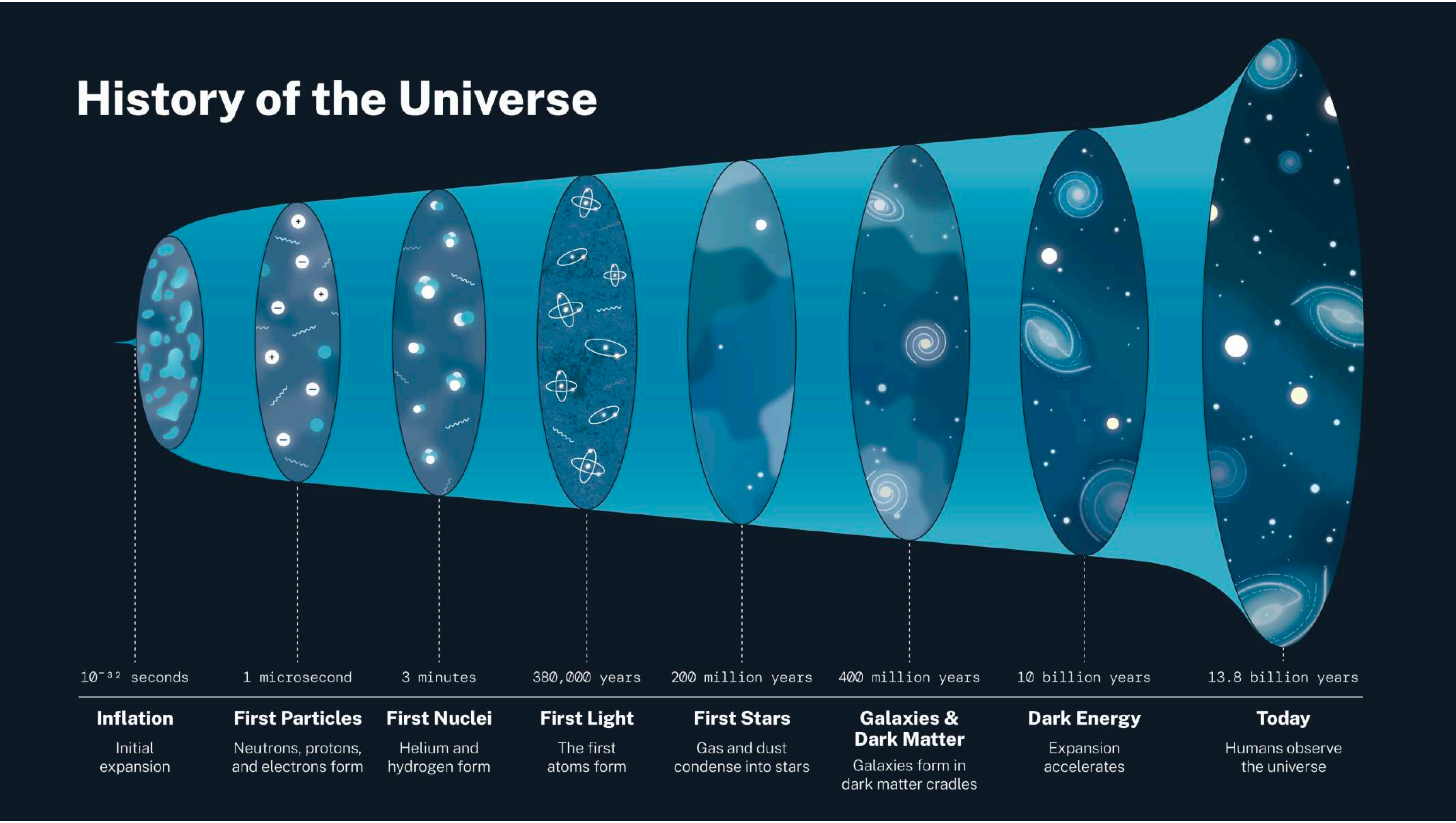
Being a microbe



Madigan et al. 2018

Ab initio

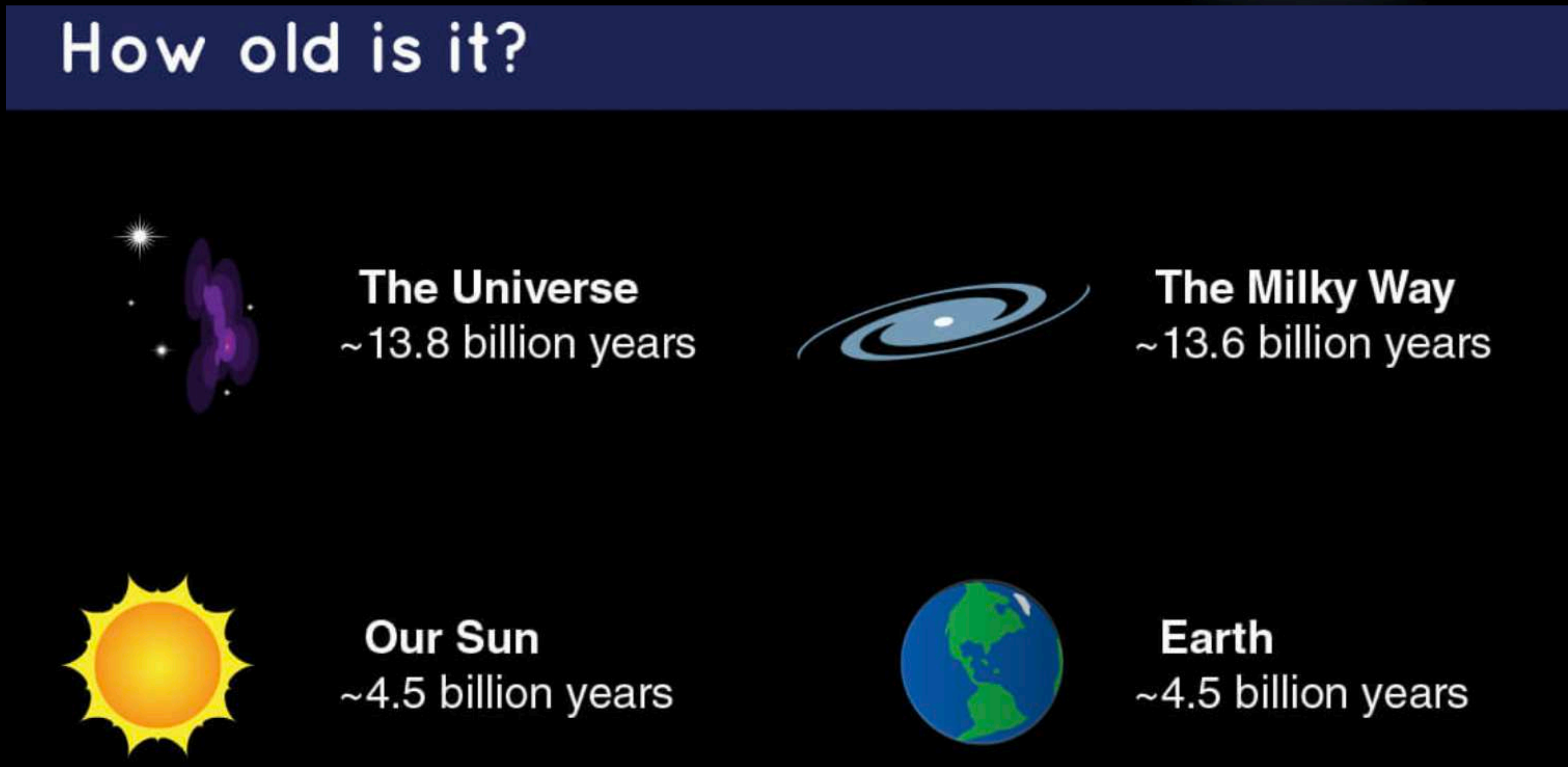
BIG BANG



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

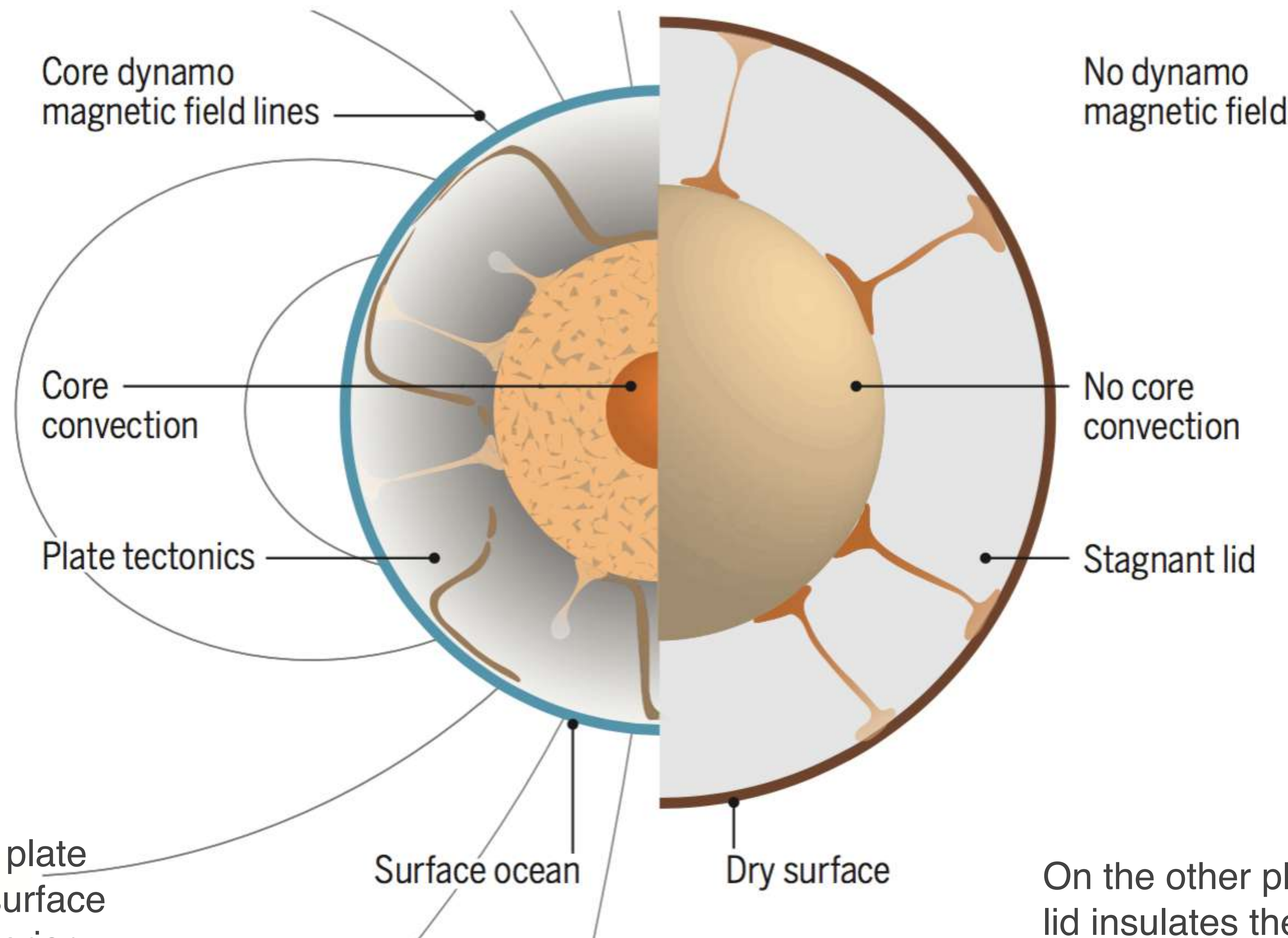
GALAXIES

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.

Habitable features of Earth and Exoplanets



On the habitable planet, plate tectonics stabilizes the surface climate and cools the interior fast enough to generate a magnetic field that in turn shields the surface from water loss and harmful radiation

On the other planet, the stagnant lid insulates the interior, inhibiting magnetic field generation, allowing water loss to space, and rendering the surface too hot and dry for life

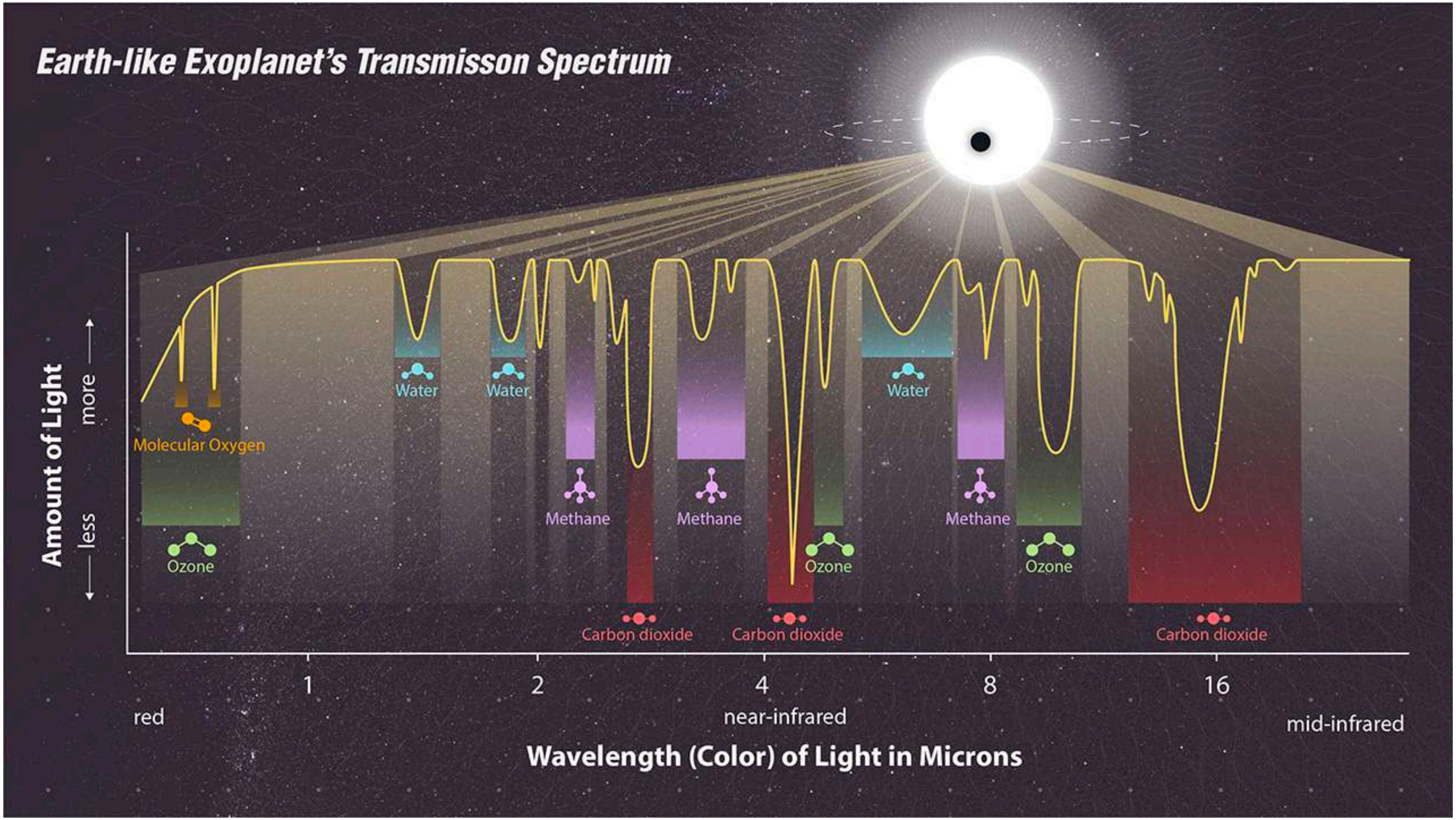
The James Webb Space Telescope, due to launch in 2021, will attempt to detect atmospheres

Volume of planet Earth

1.08321×10^{12} km^3

The Biosphere occupies about 0.00008 % of the mass of the Earth, $M_\oplus = 5.9722 \times 10^{24}$ kg (Knight and Schlager 2002) and or 0.0007 % of Earth volume

Prokaryote volume 1µm^3



https://webbtelescope.org/contents/media/images/01FEE26XVSM851DHPVCE1KB4S2

This is a transmission spectrum of an Earth-like exoplanet. The graph, based on a simulation, shows what starlight looks like as it passes through the atmosphere of an Earth-like exoplanet. As the exoplanet moves in front of the star, some of the starlight is absorbed by the gas in that exoplanet's atmosphere and some is transmitted through it. Each element or molecule in the atmosphere's gas absorbs light at a very specific pattern of wavelengths. This creates a spectrum with dips that show where the wavelengths of light are absorbed, as seen in the graph. Each dip is like a "signature" of that element or molecule.

Just saying atmospheres around us….

Object	Mass (kilograms)	Carbon Dioxide	Nitrogen	Oxygen	Argon	Methane	Sodium	Hydrogen	Helium	Other
Sun	$3.0x10^{30}$							71%	26%	3%
Mercury	1000			42%			22%	22%	6%	8%
Venus	$4.8x10^{20}$	96%	4%							
Earth	$1.4x10^{21}$		78%	21%	1%					<1%
Moon	100,000				70%		1%		29%	
Mars	$2.5x10^{16}$	95%	2.7%		1.6%					0.7%
Jupiter	$1.9x10^{27}$							89.8%	10.2%	
Saturn	$5.4x10^{26}$							96.3%	3.2%	0.5%
Titan	$9.1x10^{18}$		97%			2%				1%
Uranus	$8.6x10^{25}$					2.3%		82.5%	15.2%	
Neptune	$1.0x10^{26}$					1.0%		80%	19%	
Pluto	$1.3x10^{14}$	8%	90%			2%				

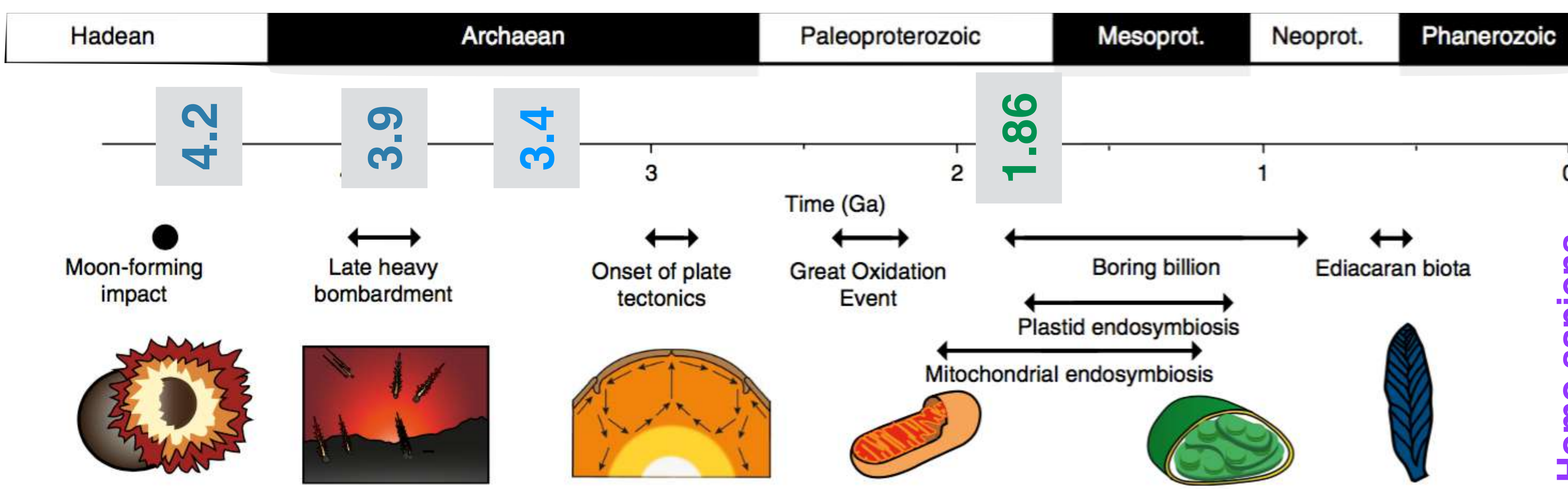
Origin of Life: **when**

Ocean formation

Sterilization

Modelling

Strelley Pool Formation, stromatolites, Australia



Betts et al., 2018

4.2

3.9

3.4

1.86

Homo sapiens

LUCA

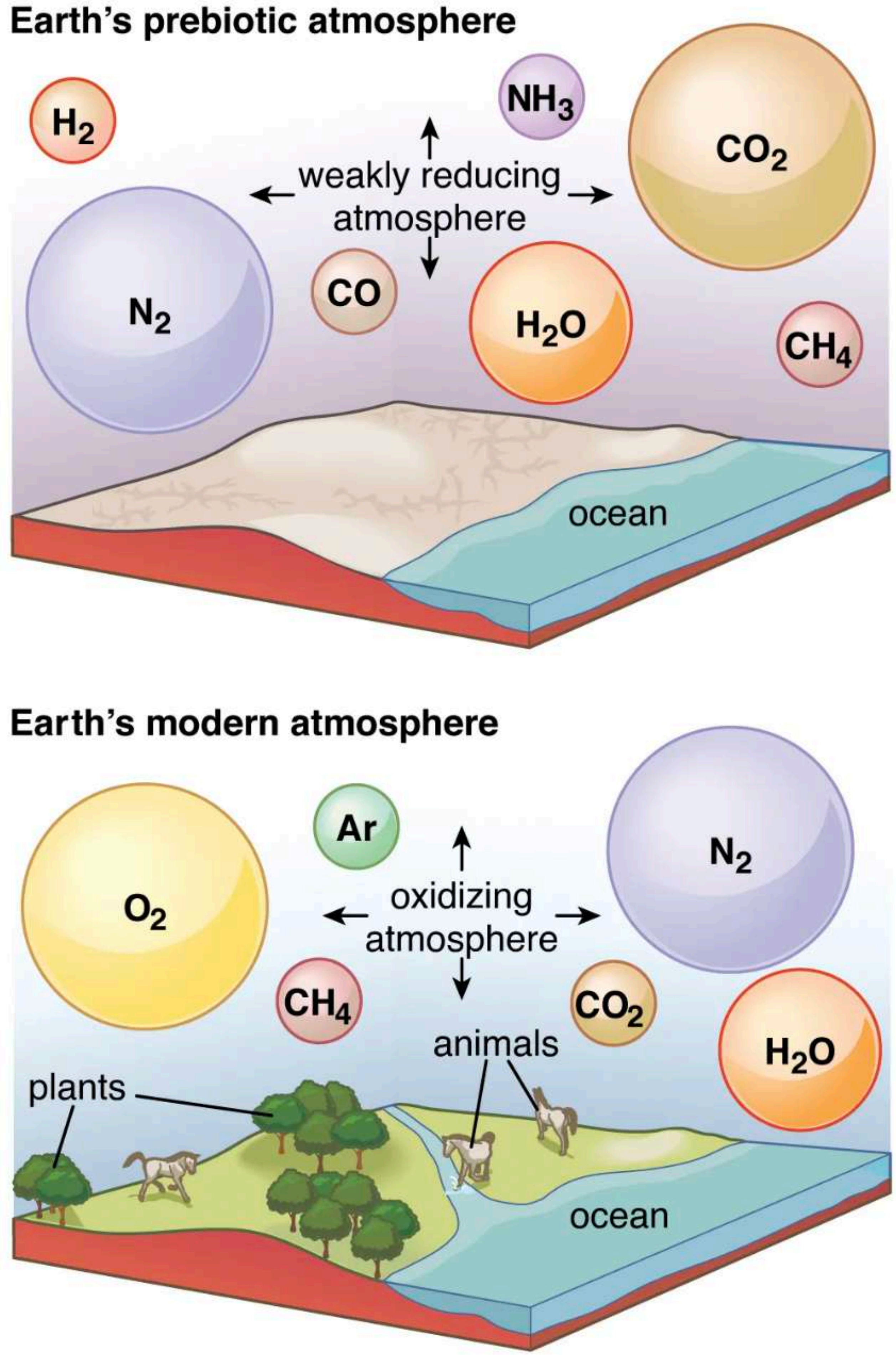
Bac & Arc

Euk

LUCA: Last Universal Common Ancestor

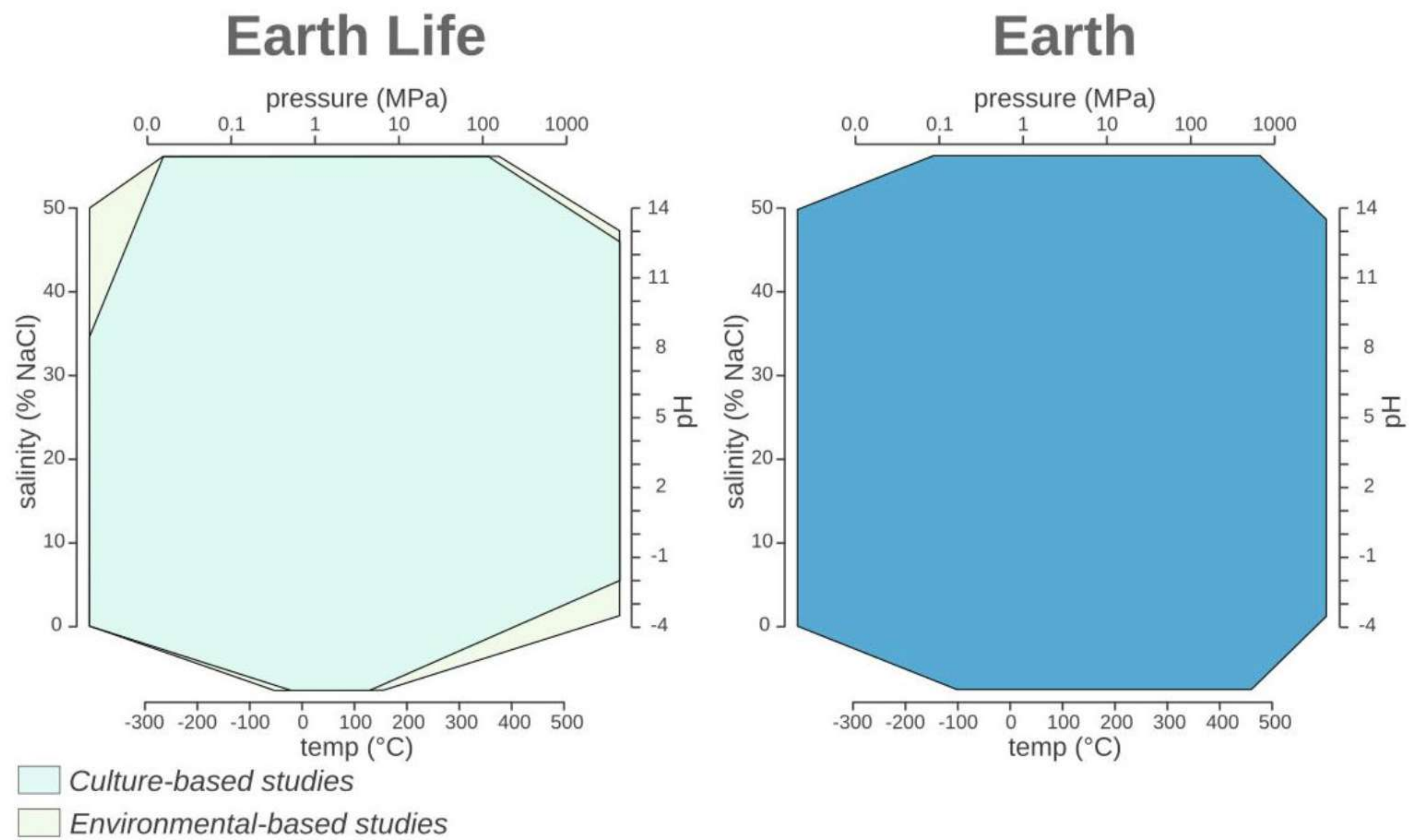
Life induce changes in gas far from equilibrium in atmosphere

EARTH'S ATMOSPHERE



Microbial Life on Earth

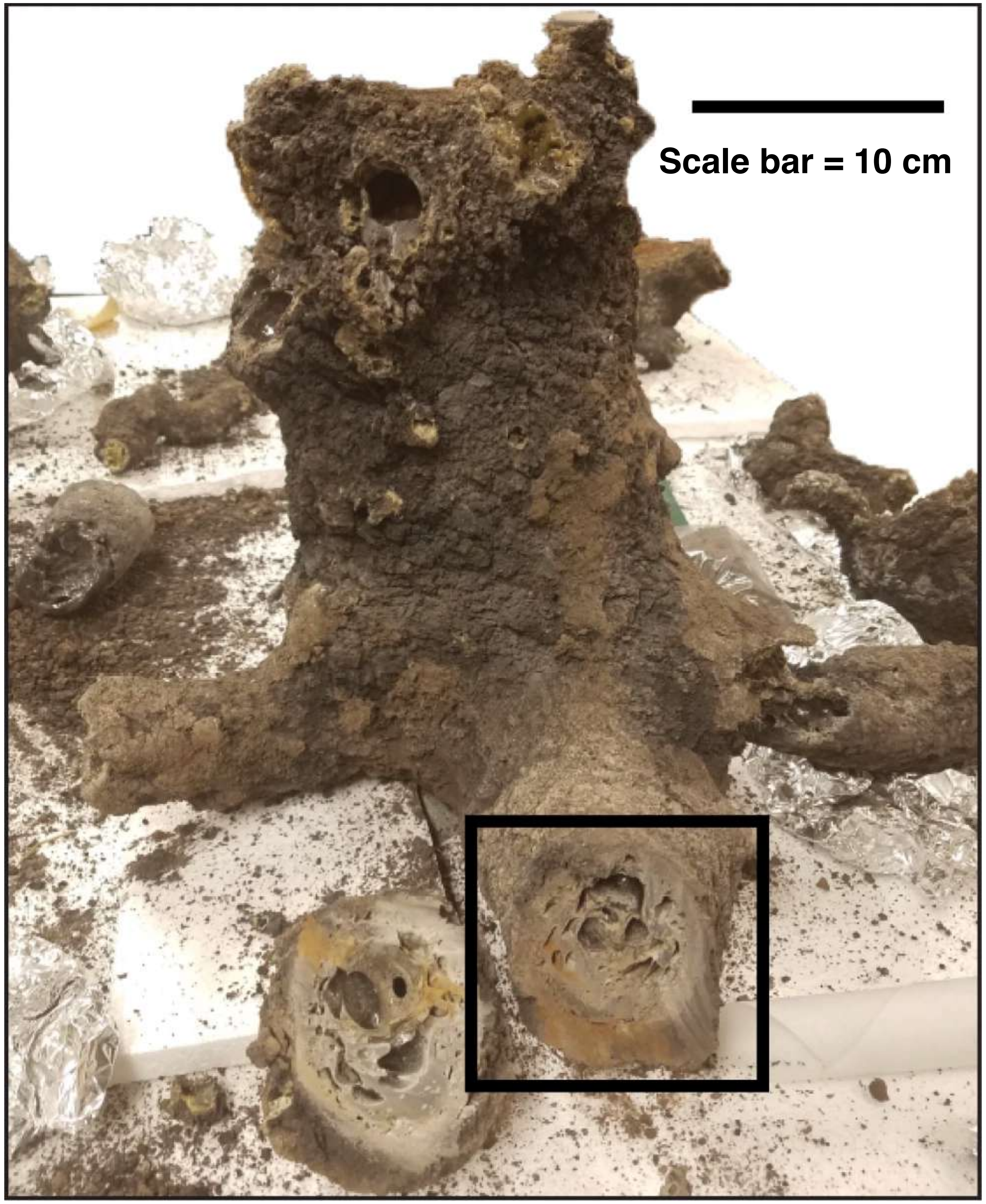
Merino et al., 2019



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

Lightning strikes as a major facilitator of prebiotic phosphorus reduction on early Earth

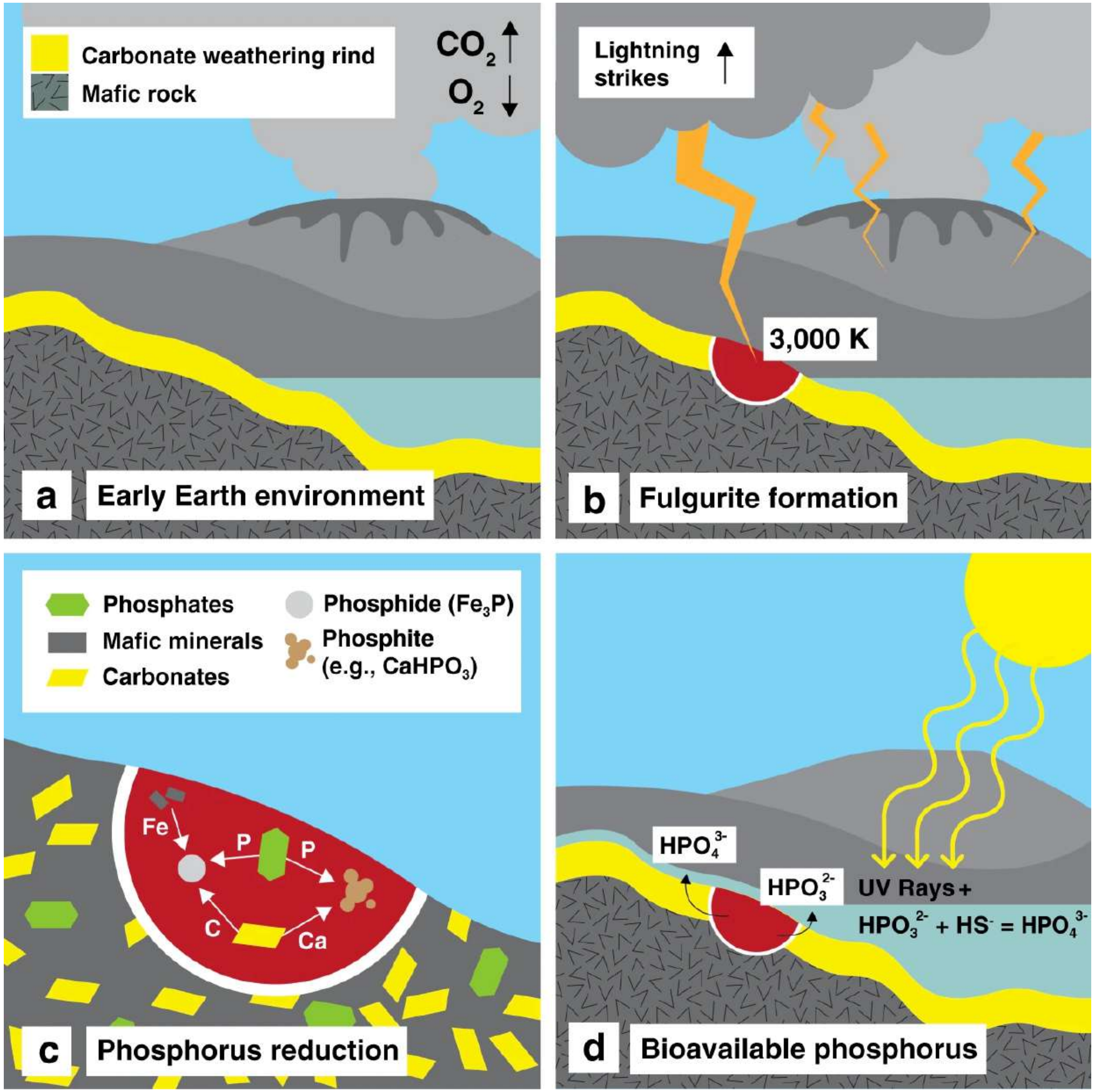


- Reduced phosphorus such as phosphide (P0)
- Present in meteorite
- Present in fulgurite
- Significant source of prebiotic, reactive phosphorus which would have been concentrated on landmasses in tropical regions

Hess et al., 2021

www.joelambjr.com

Phosphorus reduction by lightning on early Earth



Intermediate phosphorus species react with UV rays and volcanically sourced HS– to form additional phosphates available for prebiotic chemistry

Hess et al., 2021

LIFE

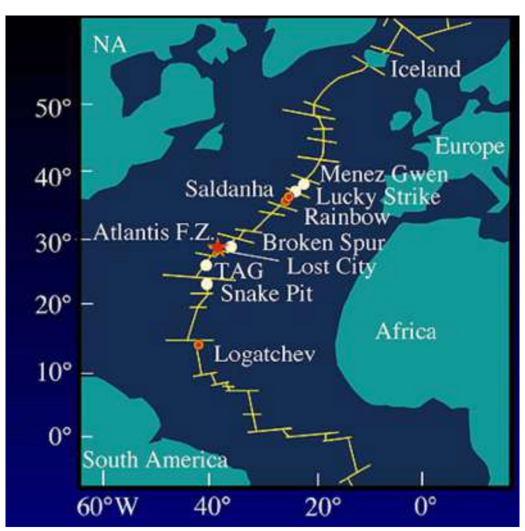
The origin of life is an extended continuum rom the prebiotic chemistry to the first reproducing cells

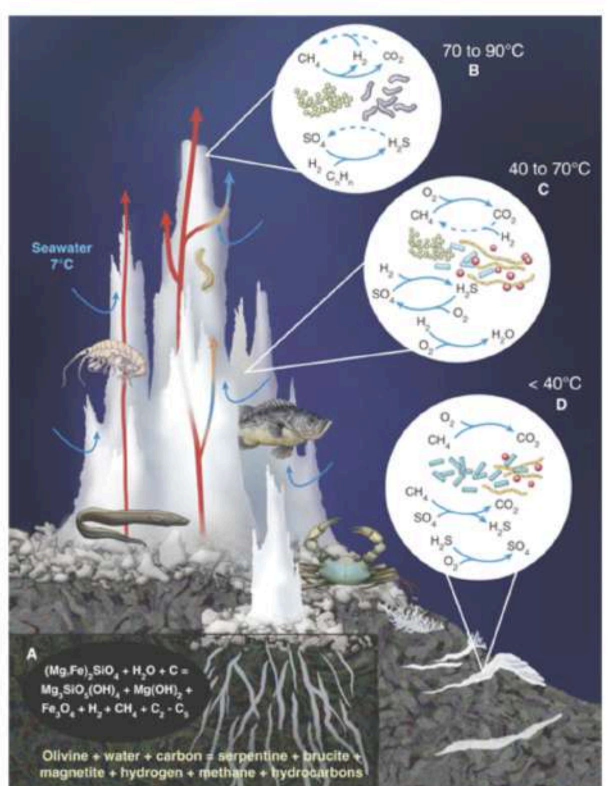
Origin of Life: **where**

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

- **Mineral surfaces on microporous rock (similar at hydrothermal vent, LOST CITY)**





Boetius 2005 and NOAA

- **Shallow terrestrial ponds with geothermal energy**

yellowstonepark.org

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

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

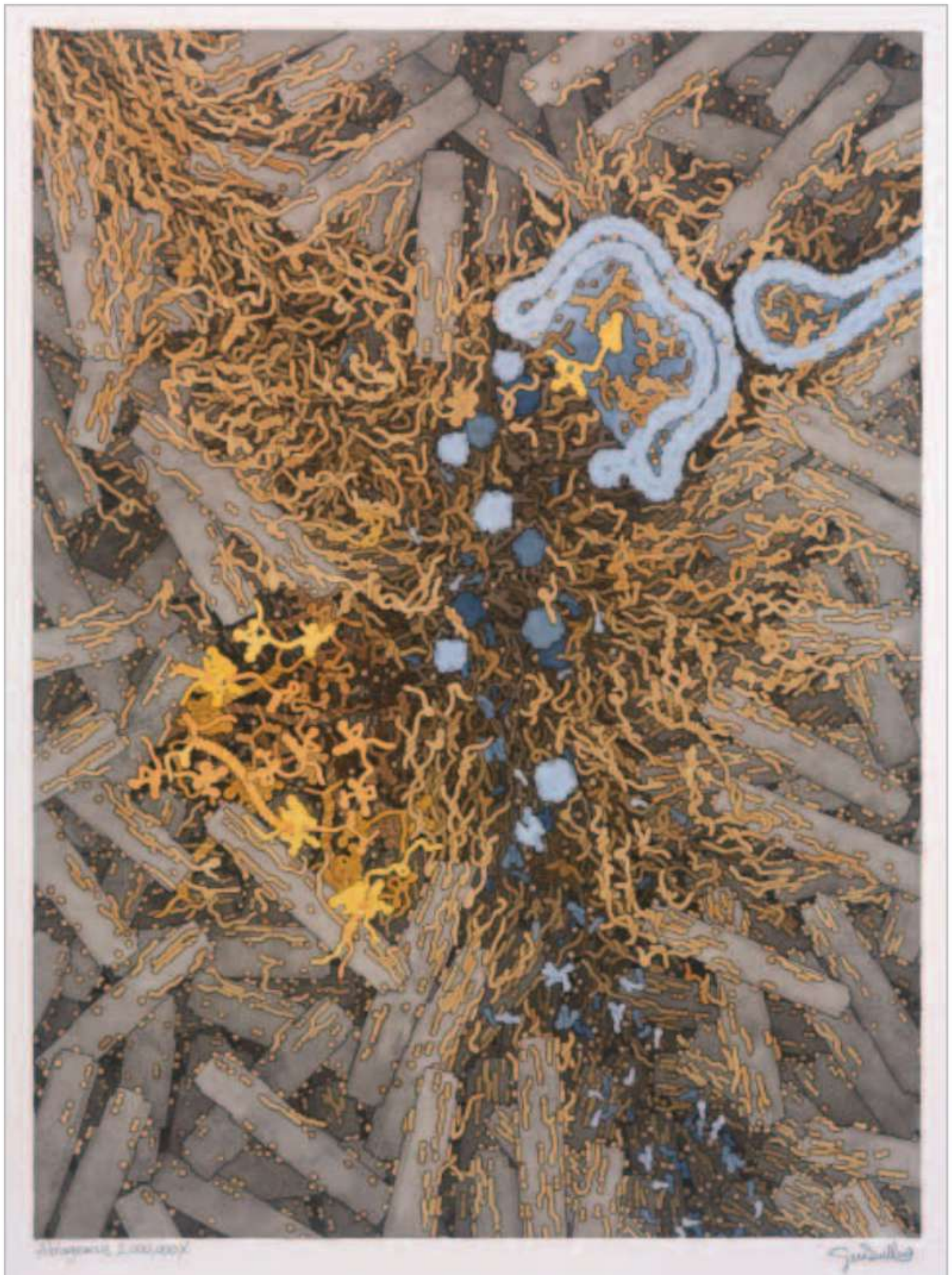
Carbon dioxide and hydrogen feed a network of reactions with a topology resembling metabolism

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: **“Abiogenesis”**

David S. Goodsell

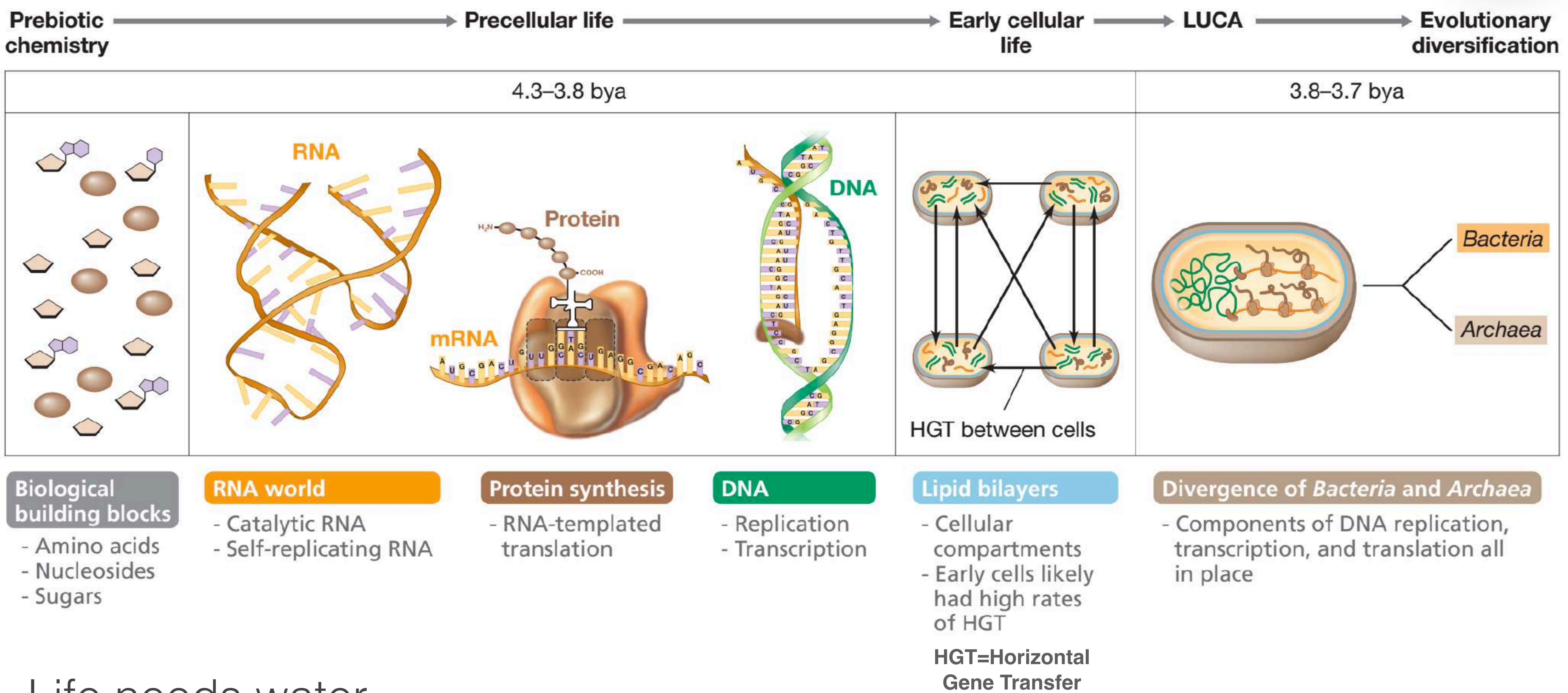


- Dawn of life, when **molecules gained the ability to replicate**
- **Cavity** in a mineral deposit at an alkaline hydrothermal vent
- **Nucleotide and lipid** building blocks are flowing in from lower right
- The nucleotides **interact** with the **mineral** crystals, catalyzing the formation of **RNA strands (brightest yellow**) —> ability to replicate other RNA strands (many copies of itself)
- The molecules in blue are simple lipids that have a useful property: they **assemble into membranes** that allow the nucleotides, but not RNA, to cross
- **If a closed vesicle is formed with a replicator inside** (like the autophagy-type vesicle forming at top right), nucleotides can enter and the RNA products will be retained inside, forming the **first protocell**

Origin of Life: **how**

Inorganic molecules → Organic Precursors → Building blocks → Functional Polymers → Earliest life

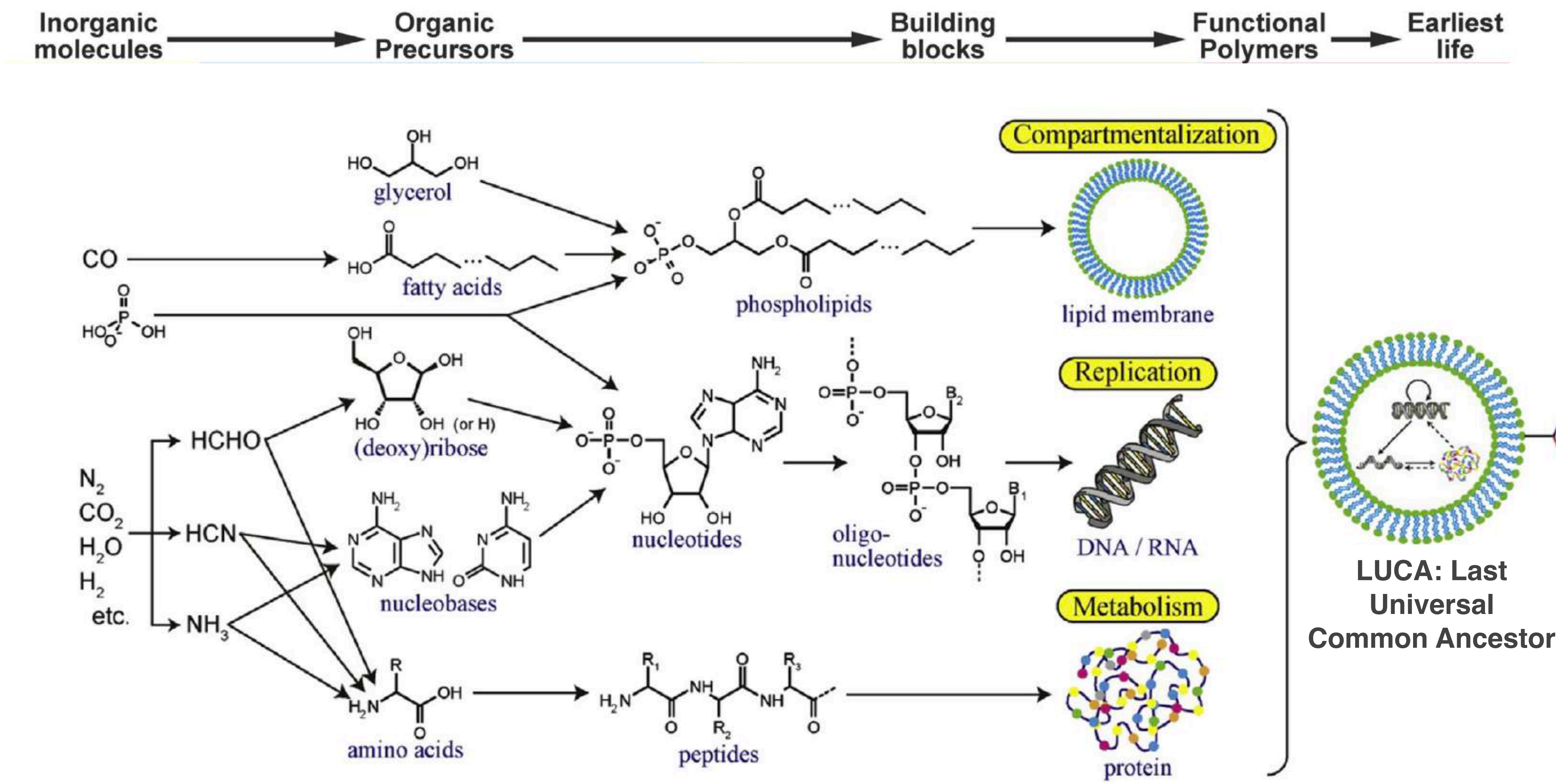
Kitaday & Maruyama, 2018

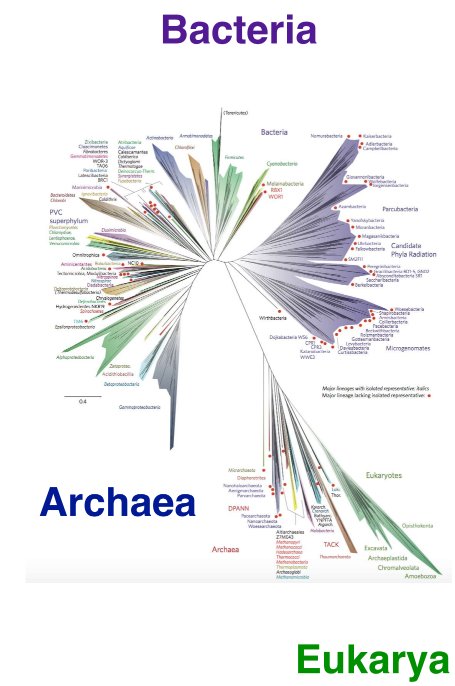


Life needs water

Building complexity to achieve the 3 fundamental functions of Life

Kitaday & Maruyama, 2018





Hug et al., 2016

primordial soup

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

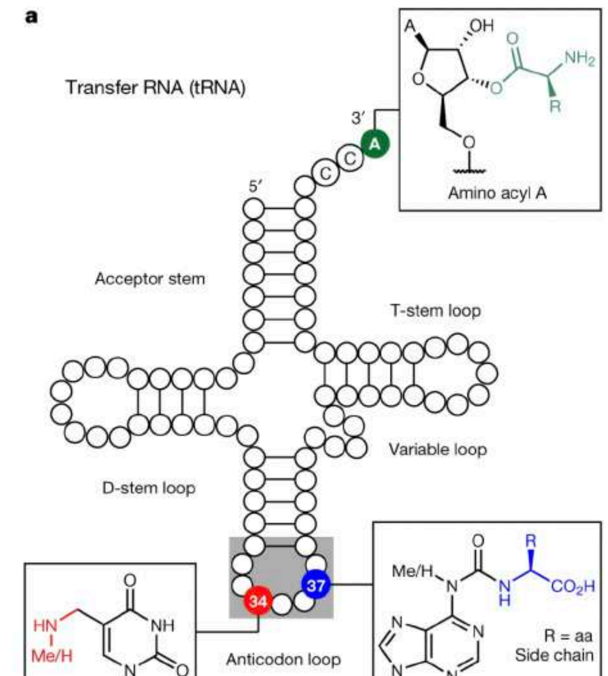
Haldane JB. The origin of life. Rationalist Annu. 1929

Miller-Urey's experiment mimicked lightning by the action of an electric discharge on a mixture of gases representing the early atmosphere (CH_4/H_2O/NH_3/H_2S and later H_2O, N_2, and CH_4, CO_2, 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



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

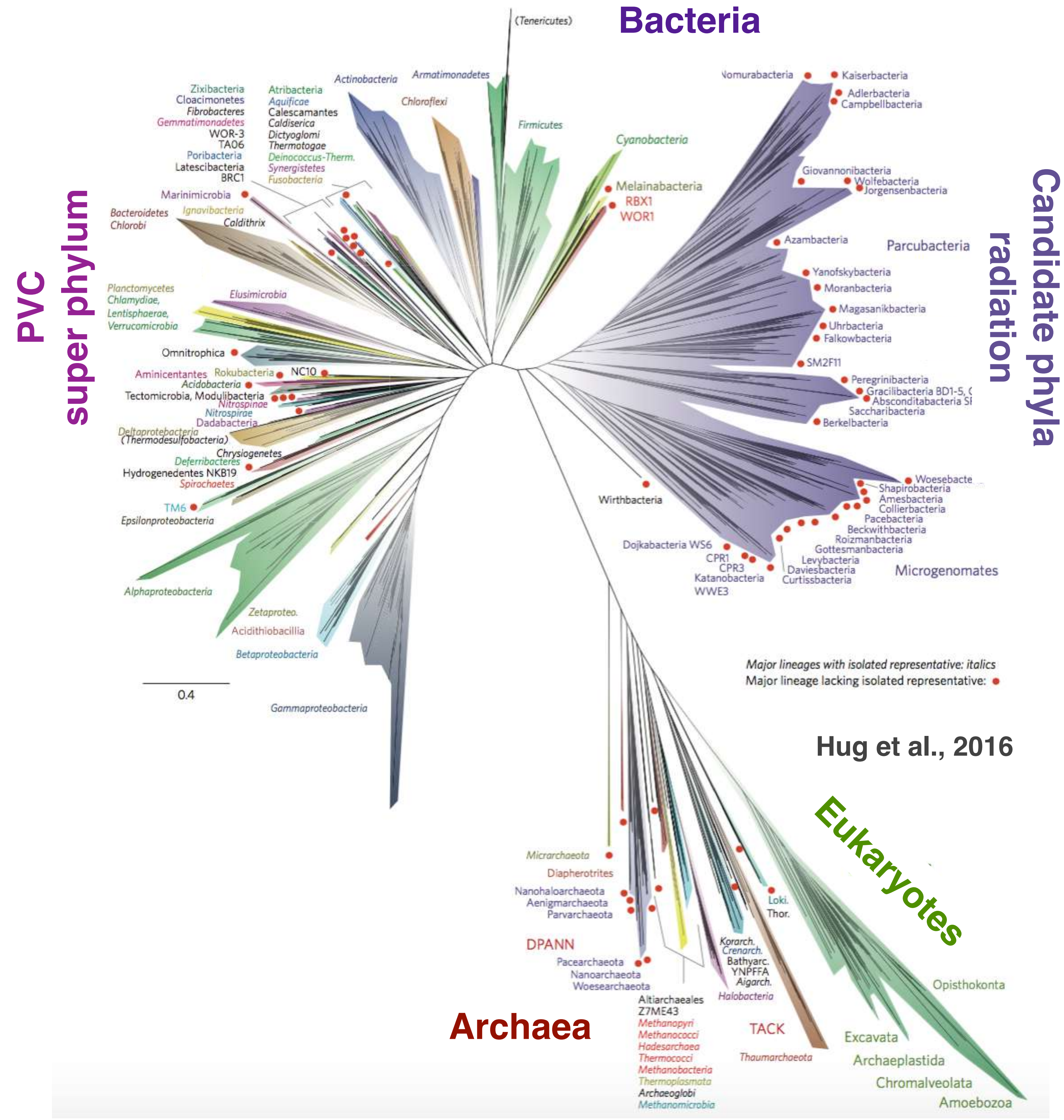
The amino acid-modified carbamoyl adenosine, (m6)aa6A (aa, amino acid), is present at position 37 in certain tRNAs

Müller et al., 2022

LUCA code

- **Smaller amino acids were added to the code earlie**r, with no additional predictive power in the previous consensus order
- **Metal-binding (cysteine and histidine) and sulfur-containing (cysteine and methionine) amino acids were added** to the genetic code much earlier than previously thought.
- Methionine and histidine were added to the code earlier than expected from their molecular weights and glutamine later.
- Early methionine availability is compatible with inferred early use of S-adenosylmethionine
- and early histidine with its purine-like structure and the demand for metal binding.
- Even more ancient protein sequences—those that had already diversified into multiple distinct copies prior to LUCA—have significantly **higher frequencies of aromatic amino acids (tryptophan, tyrosine, phenylalanine, and histidine) and lower frequencies of valine and glutamic acid than single-copy LUCA sequences**.
- If at least some of these sequences predate the current code, then their distinct enrichment patterns provide hints about earlier, alternative genetic codes.

Microbial diversity on Earth



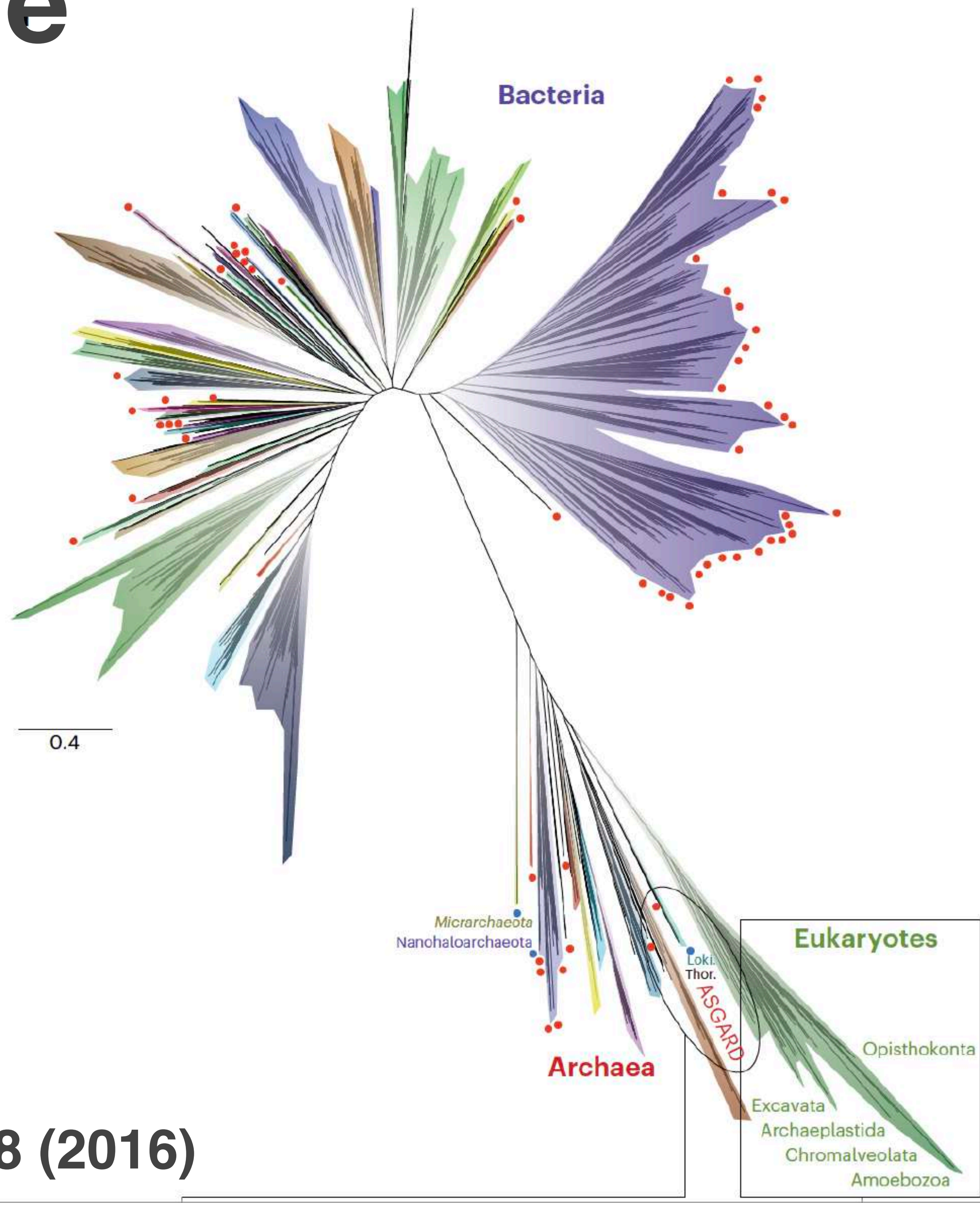
Hug et al., 2016

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

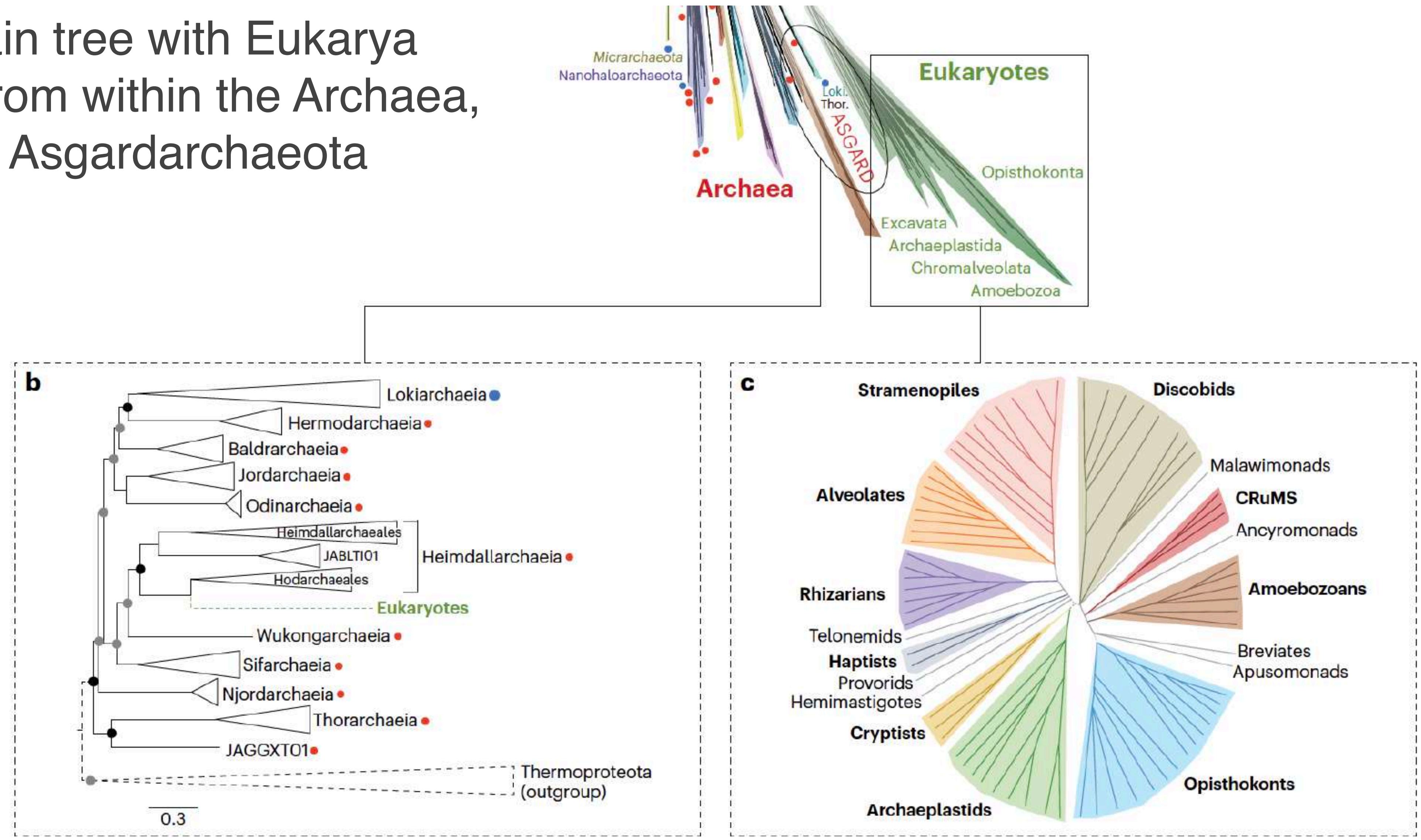


Hug et al. Nat. Microbiol. 1, 16048 (2016)

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



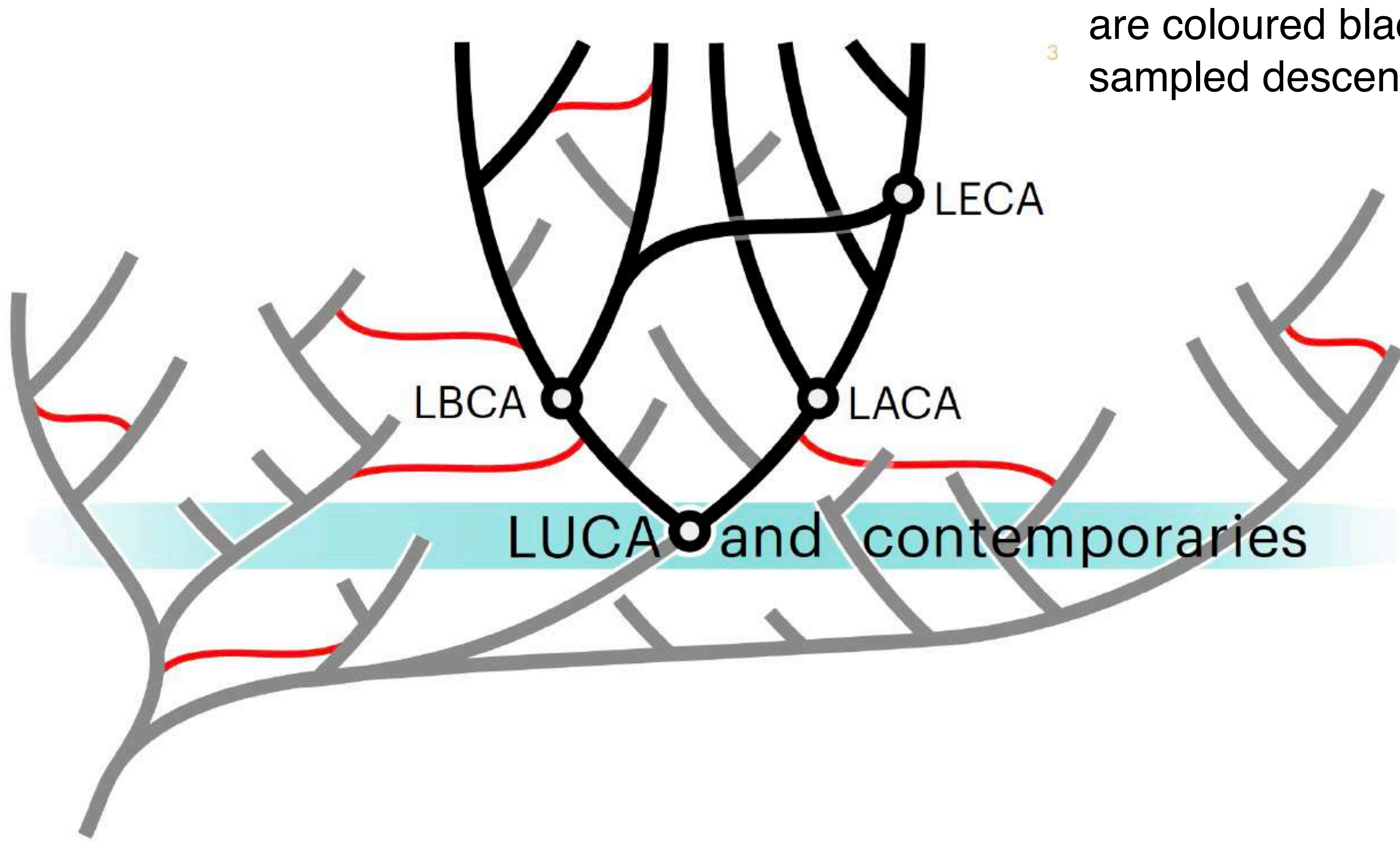
Hug et al., 2016; Hug, 2024

Microbial/Life evolution on Earth

Many different and diverse microbial communities rose and got extinct

Only LUCA survived

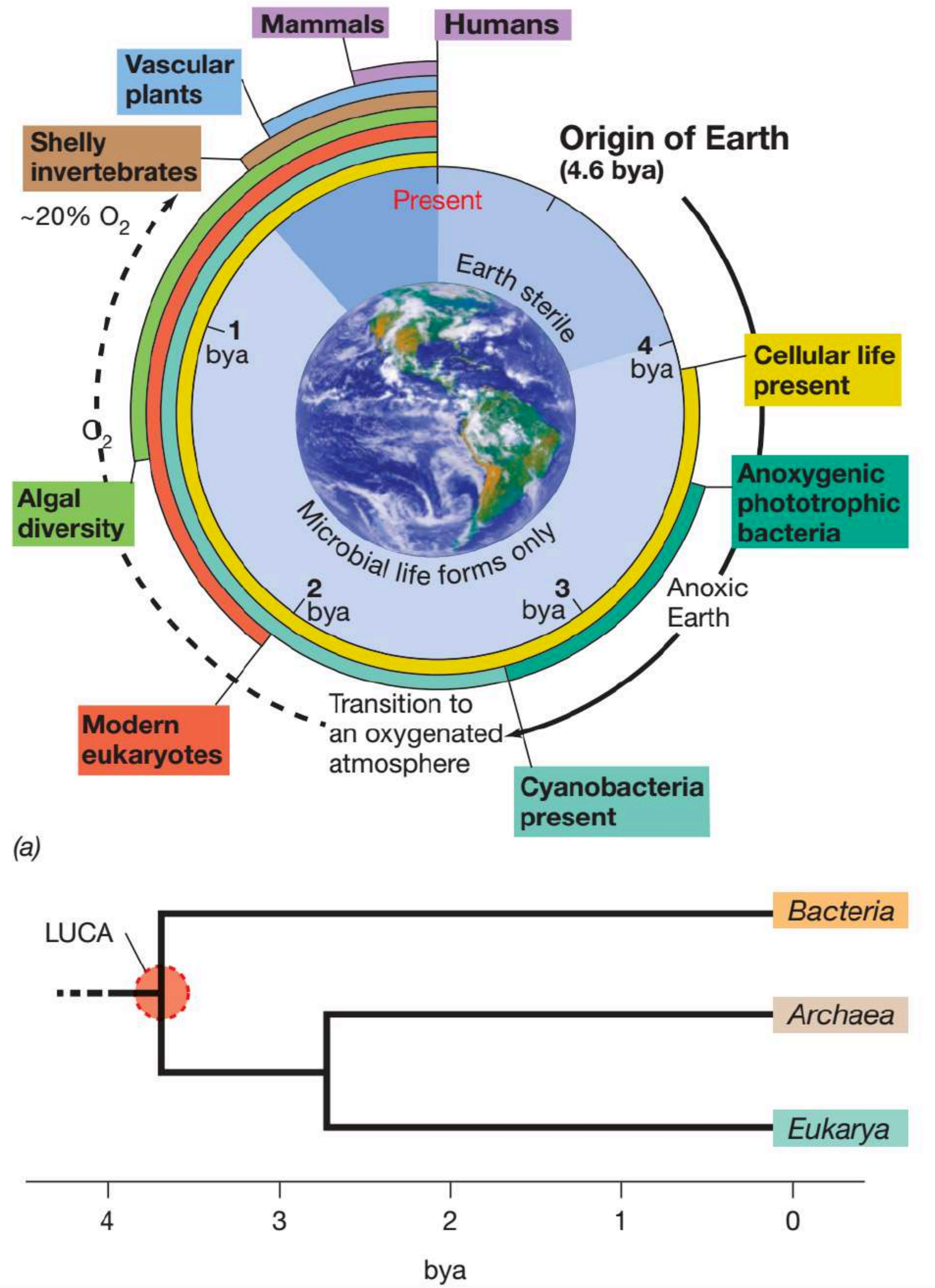
Branches on the tree of life that have left sampled descendants today are coloured black, those that have left no sampled descendants are in grey



Moody et al., 2024

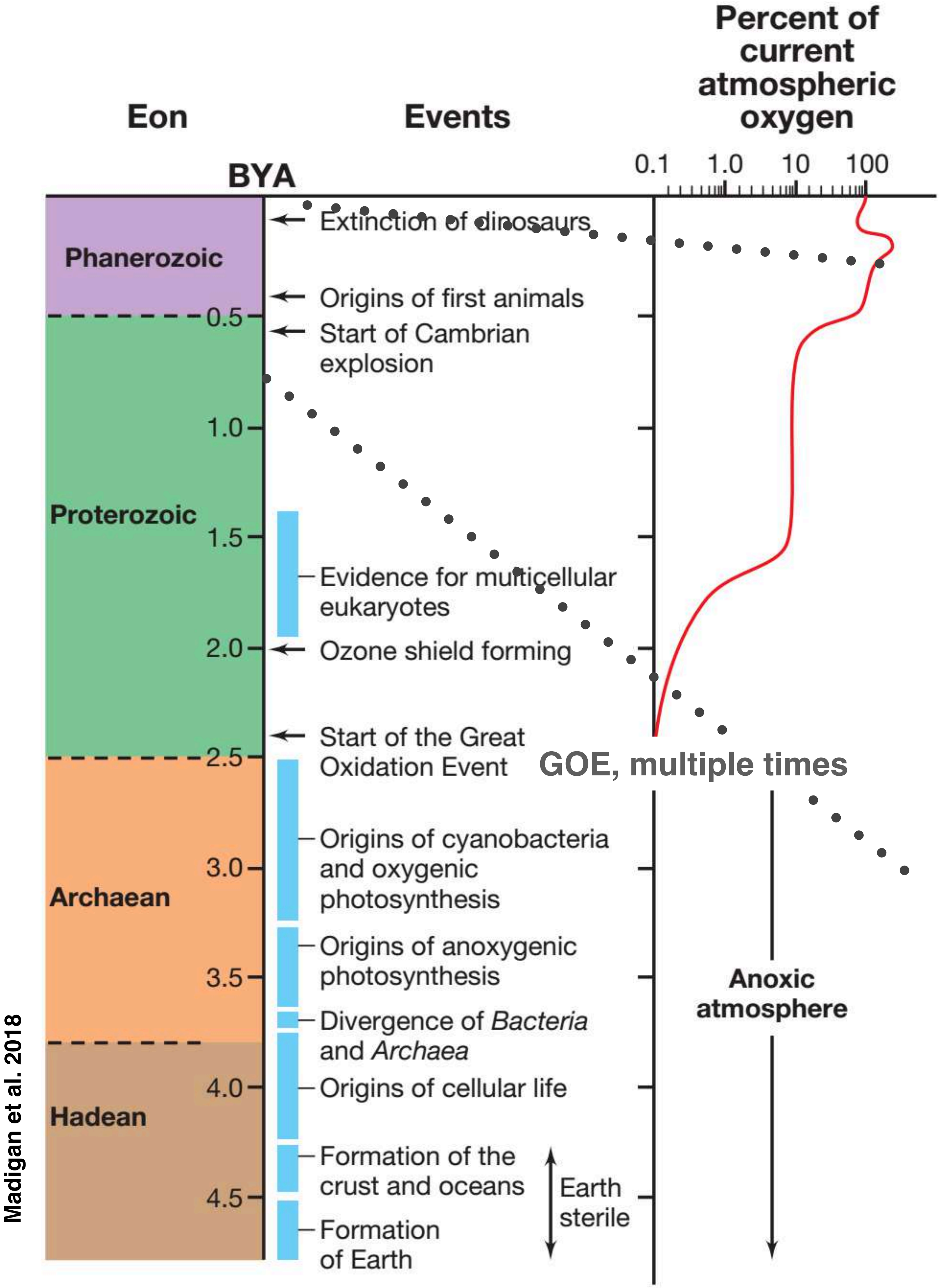
Last universal, archaeal, bacterial and eukaryotic common ancestors (LUCA, LACA, LBCA and LECA, respectively); the last common ancestor of the mitochondrial lineage (Mito-LECA); and the last plastid-bearing common ancestor (LPCA)

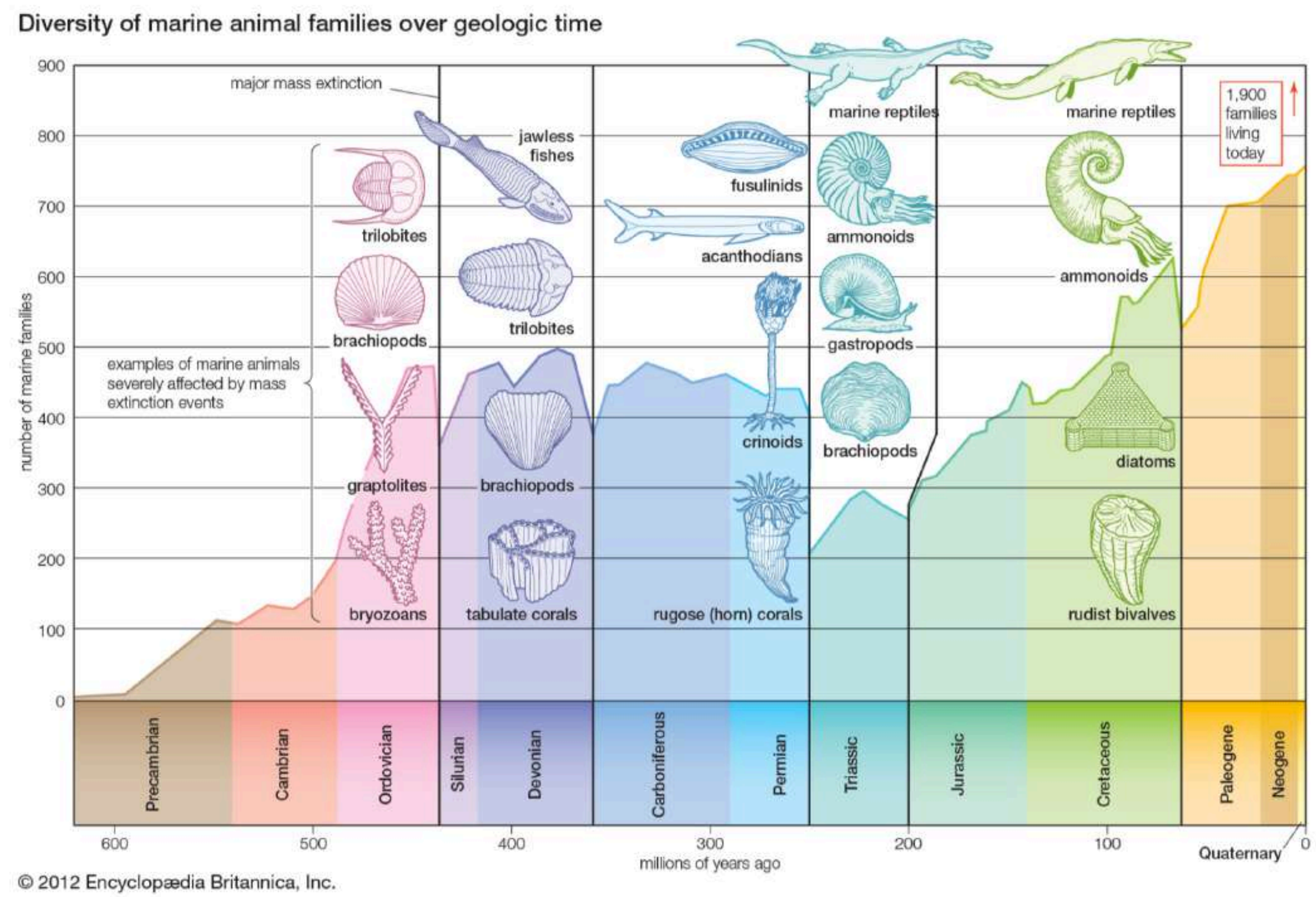
Microbial metabolic diversity impacts Earth



- Sulfur and Fe based-metabolism
- H_2 as e^- donor
- CO_2
- Acetate
- H_2S —> H_2O: Oxygenic photosynthesis

Origin of Life: **how**



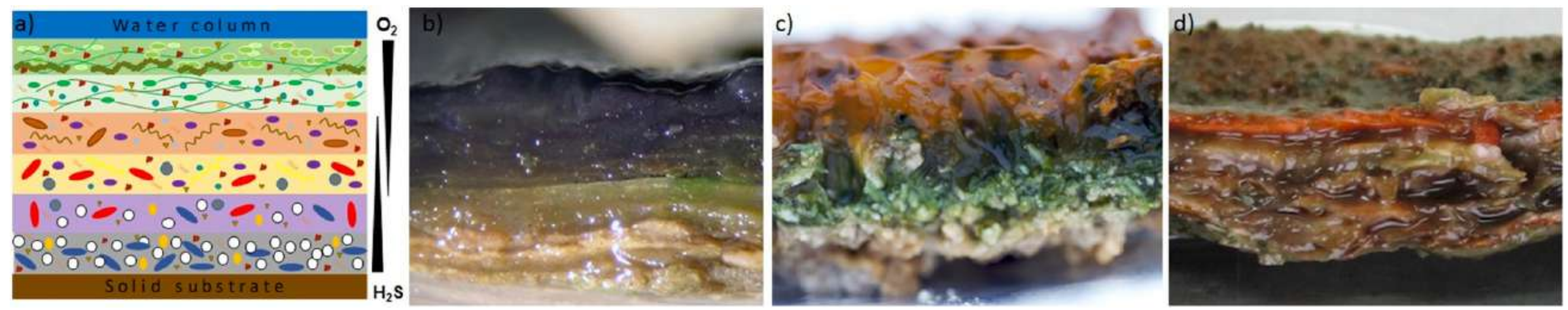


- **GOE: microbial extinction, segregation of anaerobes in microenvironment**
- **O_3 layer protecting UV**
- **Many massive extinctions for megafauna…still today**

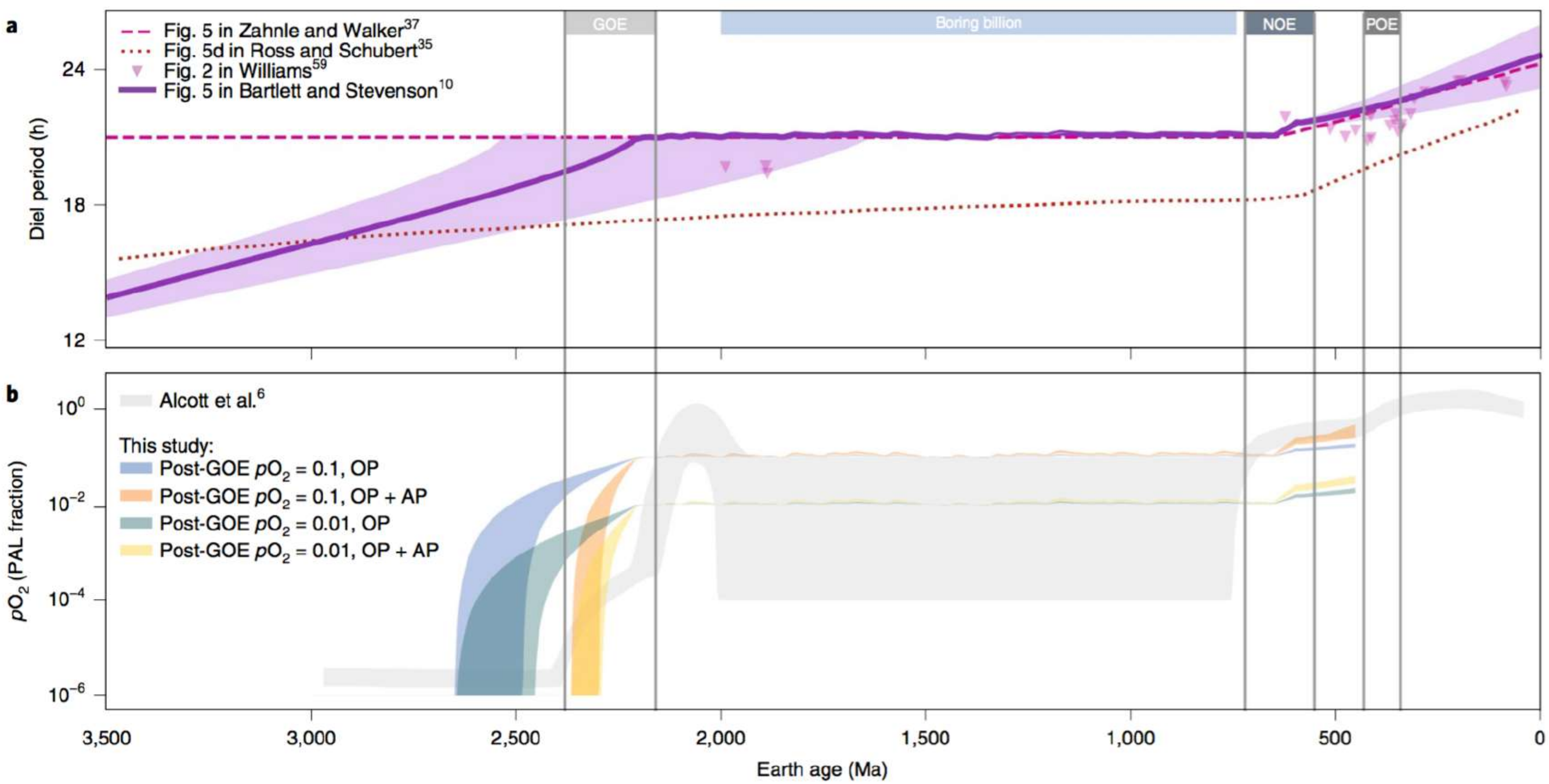
Earth’s rotation rate —> day-length—> and oxygenation

Oxygenic photosynthesis (OP) in microbial mats was a substantial source of O_2 for the Great Oxidation Event (GOE) ~2.4 billion years ago (Ga), during the stable low-O_2 conditions that followed and for the Neoproterozoic Oxygenation Event (NOE) ~600Ma

Day-length, which has increased through geological time due to Earth’s rotational deceleration caused by tidal friction

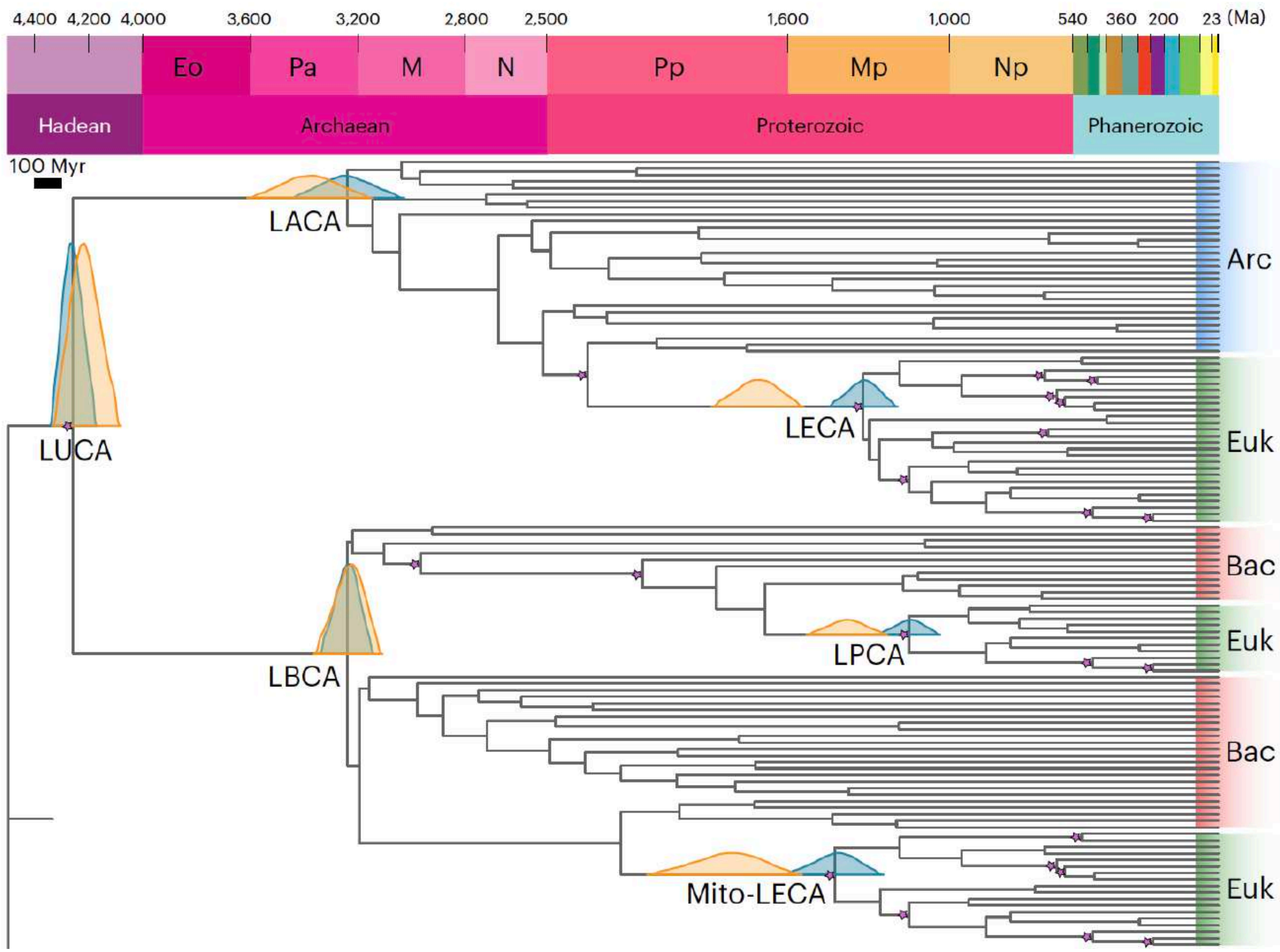


Prieto-Barajas et al. 2018



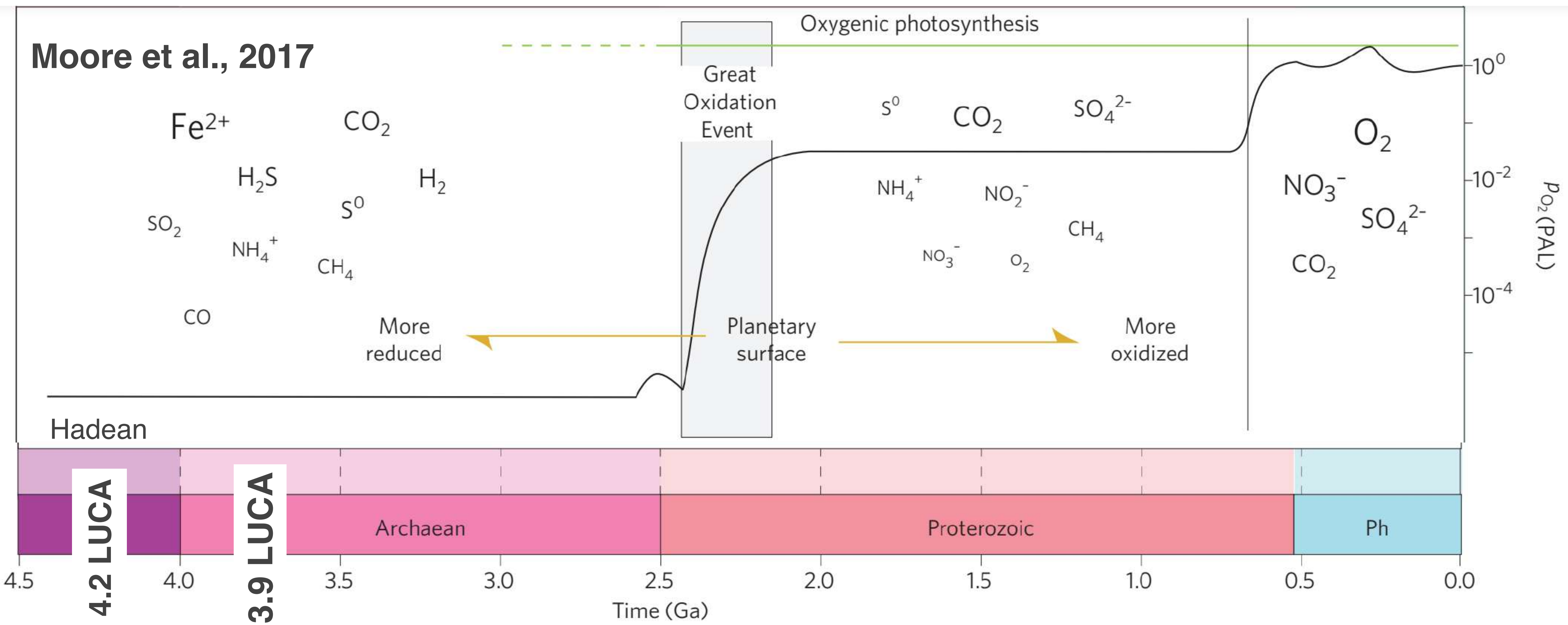
Klatt et al. 2021

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

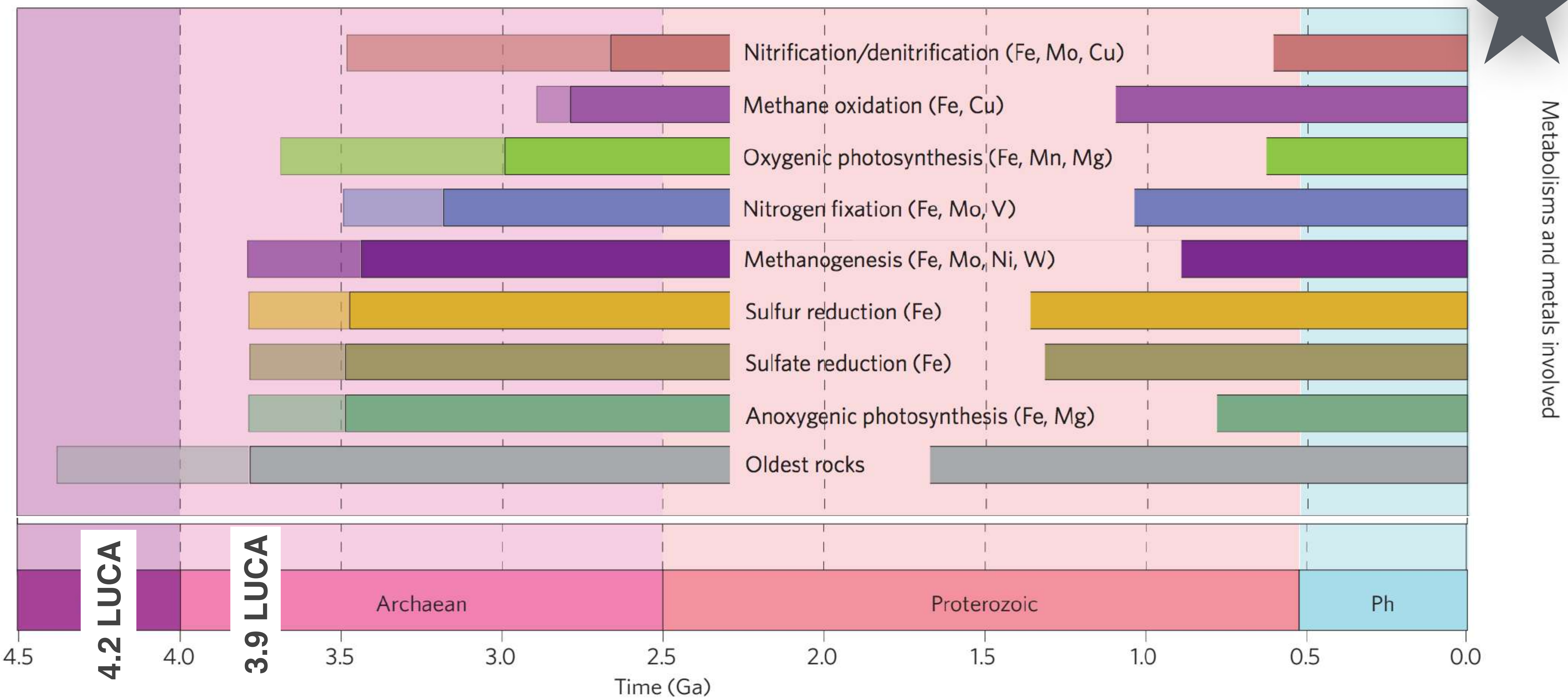


The availability of different metals and substrates has changed over the course of Earth's history as a result of secular changes in redox conditions of the mantel

Solar energy used by early microbes

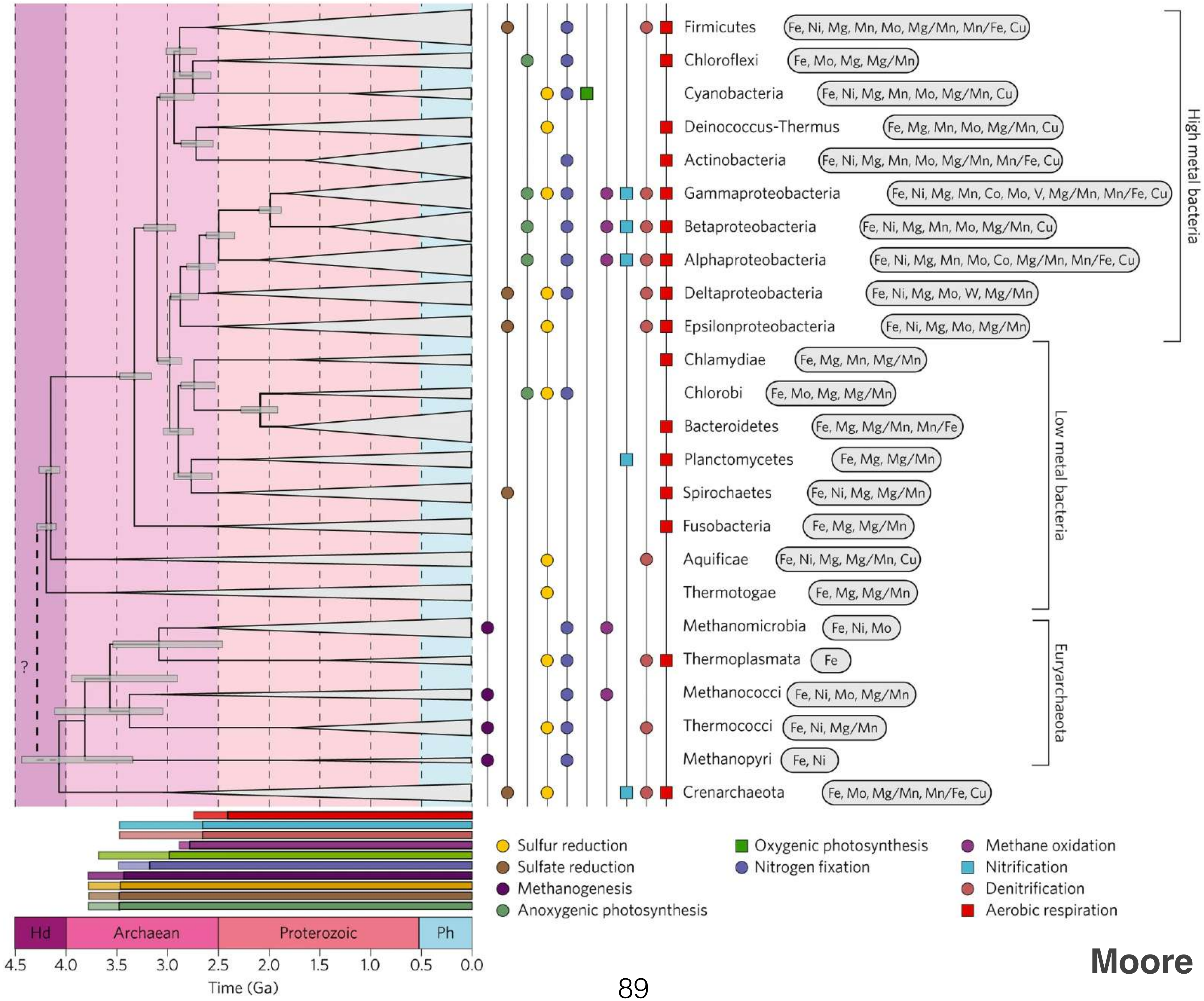
Emerging microbial metabolisms

Moore et al., 2017



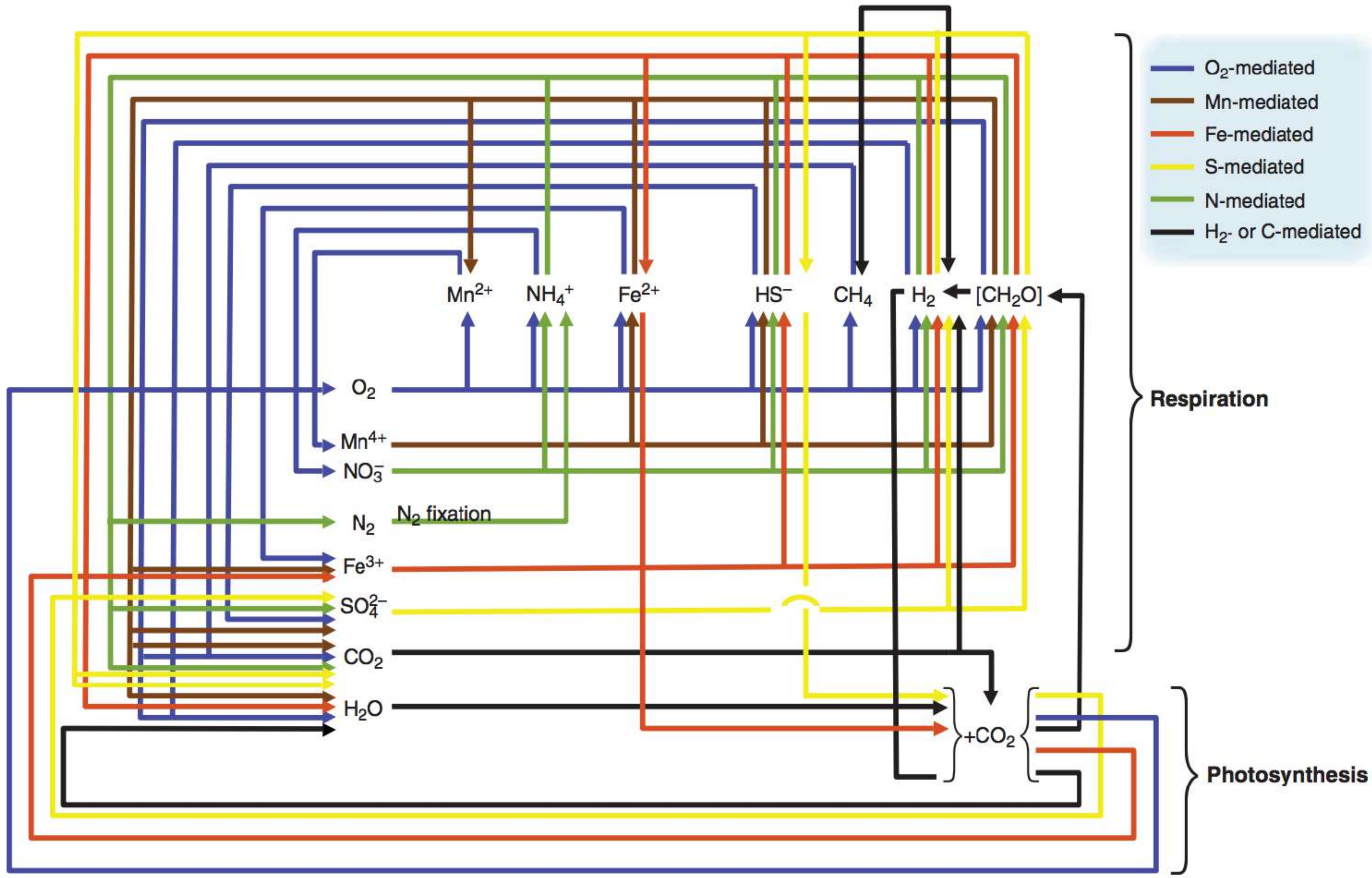
The oxidoreductases responsible for these metabolisms incorporated metals that were readily available in Archaean oceans: iron and iron–sulfur clusters

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

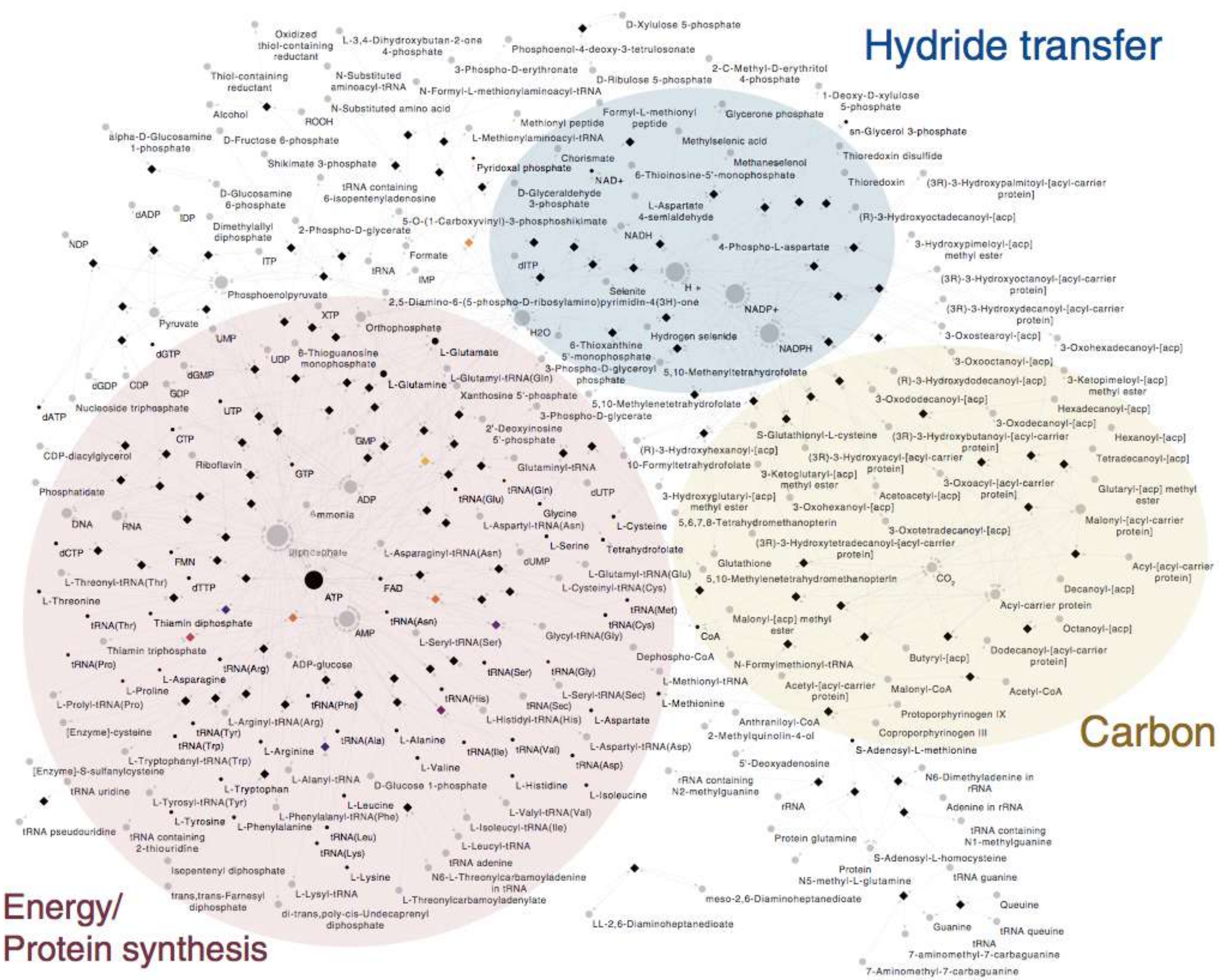
- LUCA was a thermophilic anaerobe that lived from gasses in a hydrothermal setting

- 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

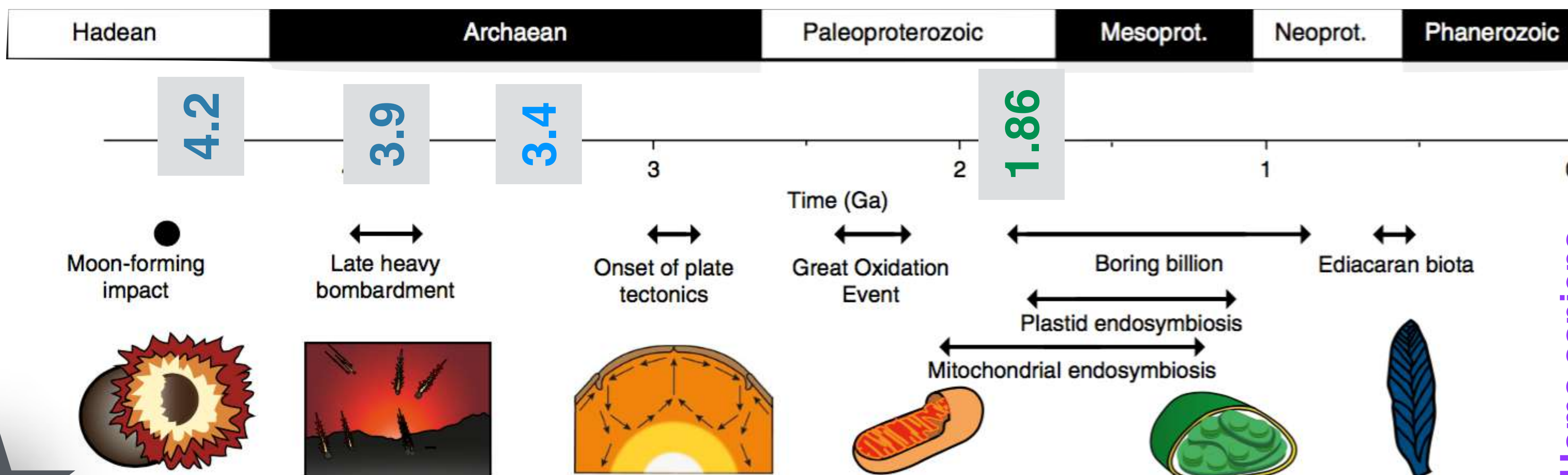
Oxygenic Photosynthesis Invention by CYANOBACTERIA

Strelley Pool Formation, stromatolites, Australia

Ocean formation

Modelling

Sterilization



Betts et al., 2018

4.2

3.9

3.4

1.86

Homo sapiens

LUCA

Bac & Arc

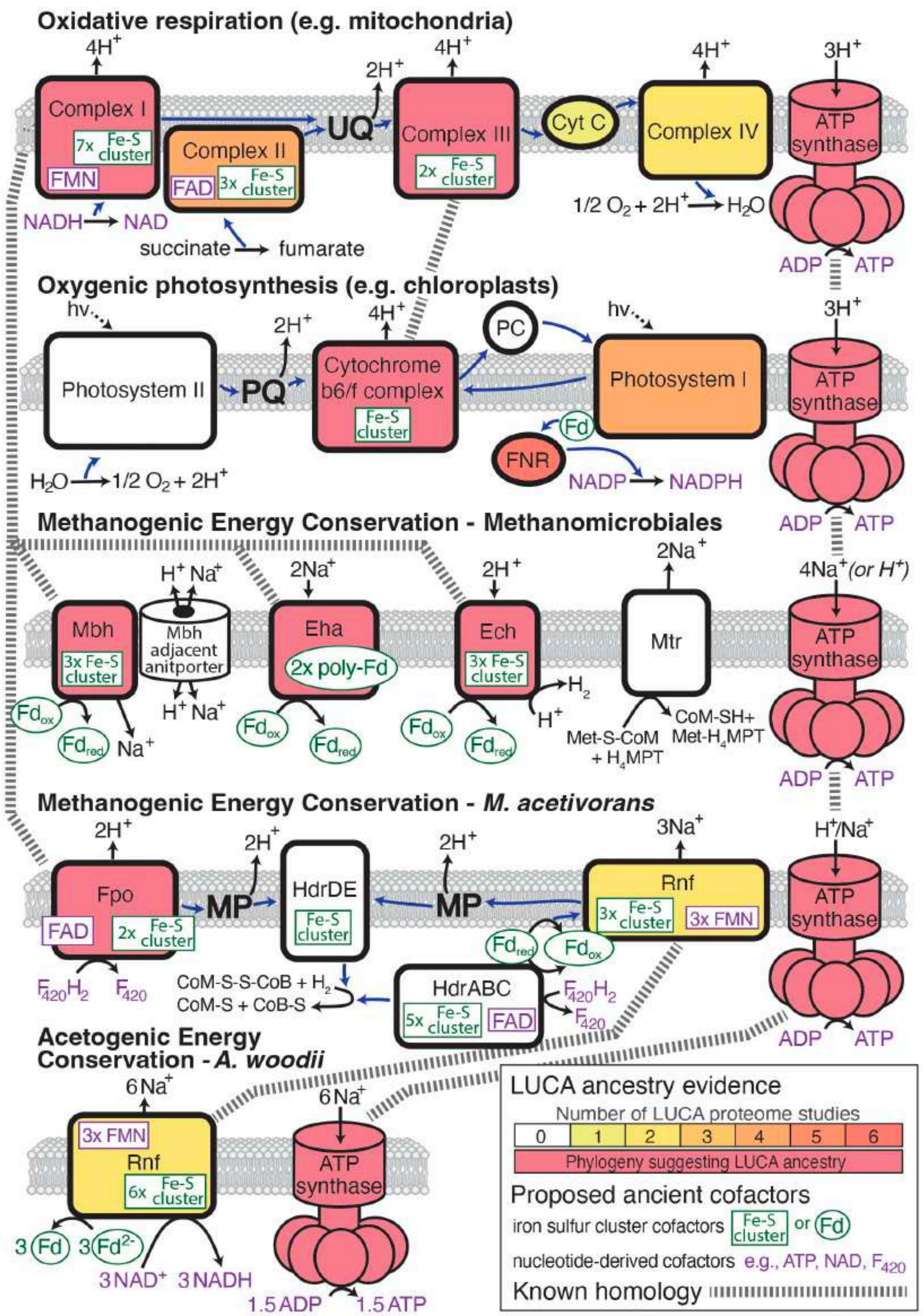
Euk

LUCA: Last Universal Common Ancestor

Life induce changes in gas far from equilibrium in atmosphere

The Great Oxygenation Event (GOE) spurred the global-scale relevance of the full oxidative suite of metabolisms

Rewiring of exhibiting membrane-associated micromachies



Goldman et al. 2023

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.

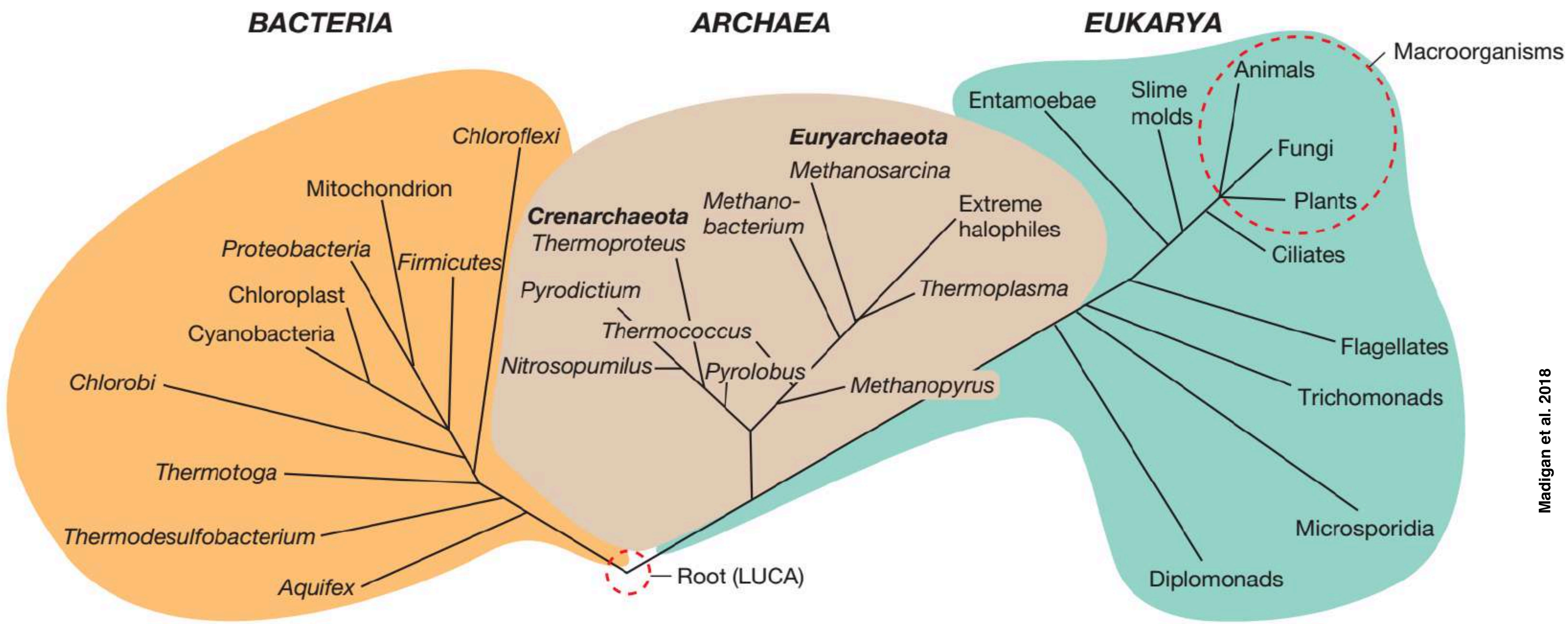
Likely ancestry from the LUCA is reflected by either direct phylogenetic evidence or the number of different LUCA proteome studies (out of eight total) that predict a component of the complex to be descended from the LUCA.

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

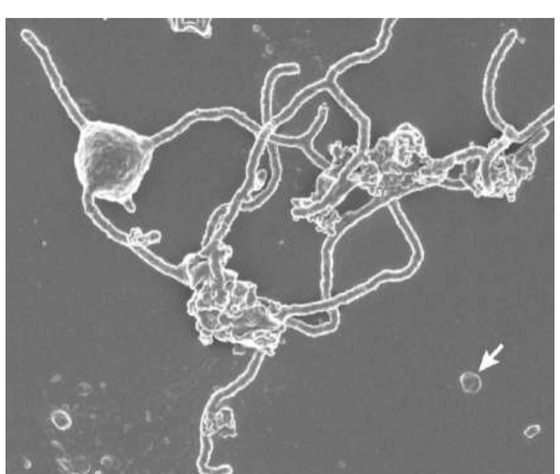


Madigan et al. 2018

LUCA: Last Universal Common Ancestor

~1.86 billions

Imachi et al. 2020

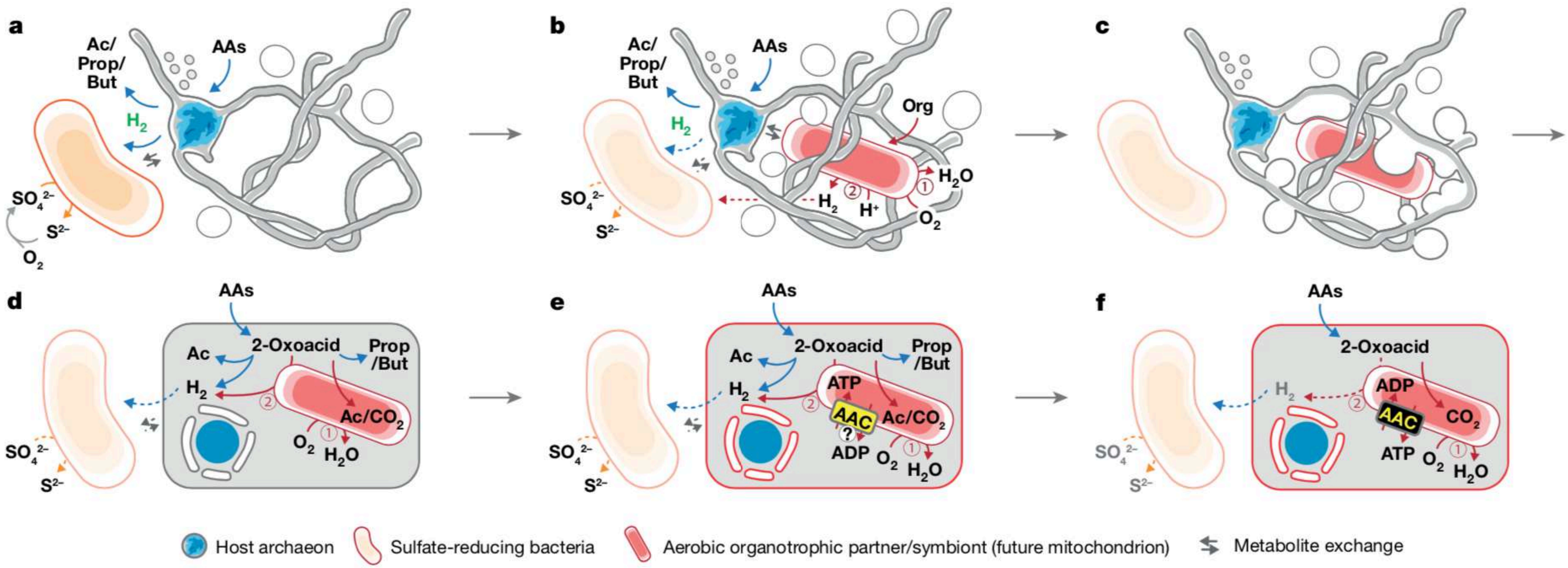


2,000 days to enrich such organisms from anaerobic marine methane-seep sediments

Entangle–Engulf–Endogenize (also known as E^3) model

Entangle–Engulf–Endogenize, E^3 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)

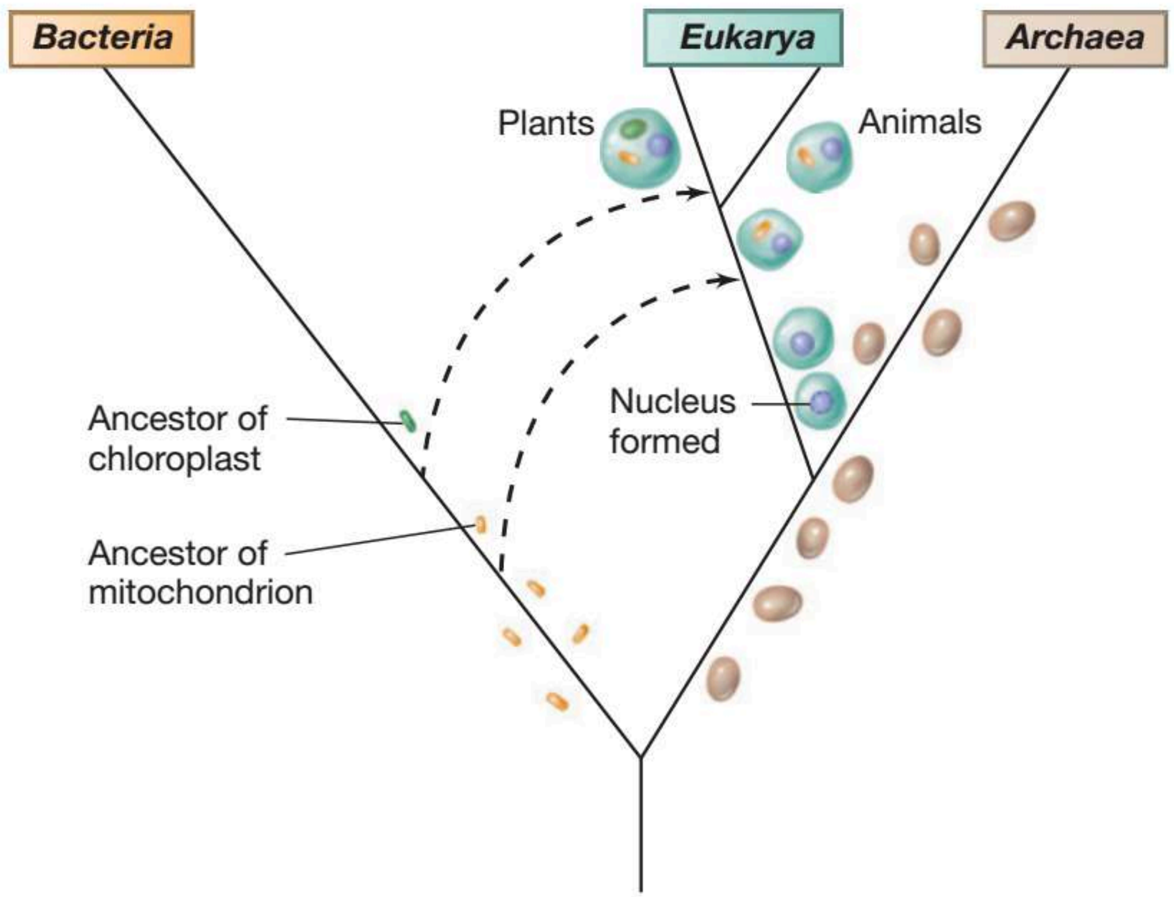
(3) Development of intracellular structures

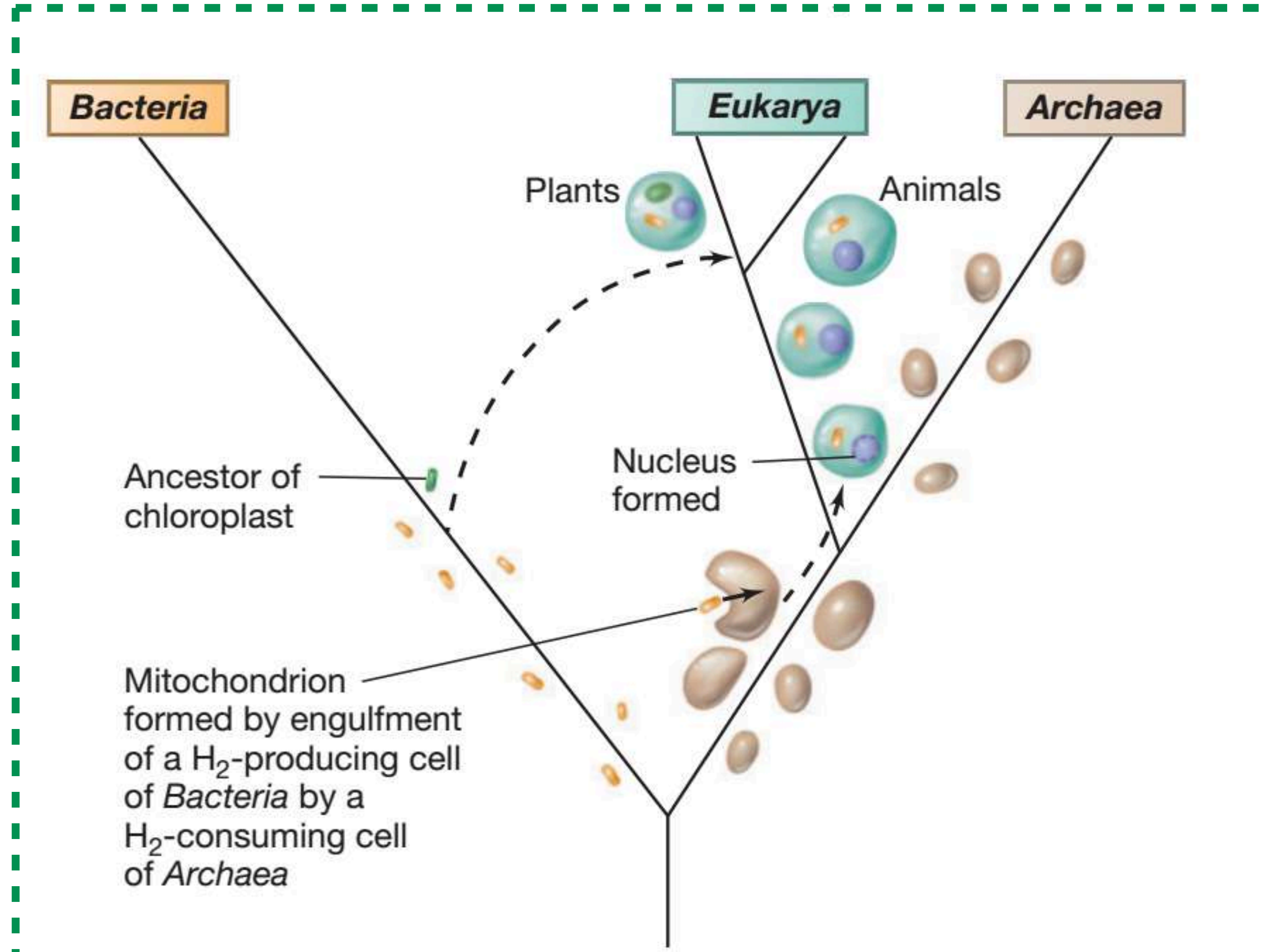
(4) Later stage Gain of a Cyanobacteria (future chloroplast)

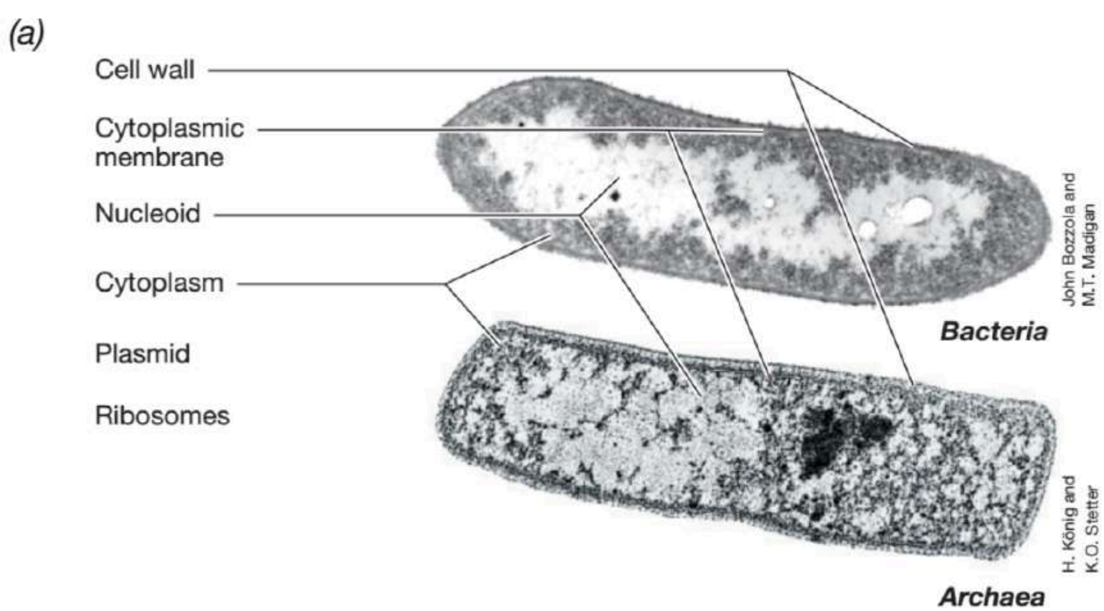
Host archaeon (isolated over 2000 days of culture from deep-sea methane-seep sediment, basalt medium + antibiotics) engulfed the metabolic partner using extracellular structures and simultaneously formed a primitive chromosome surrounding structure similar to the nuclear membrane

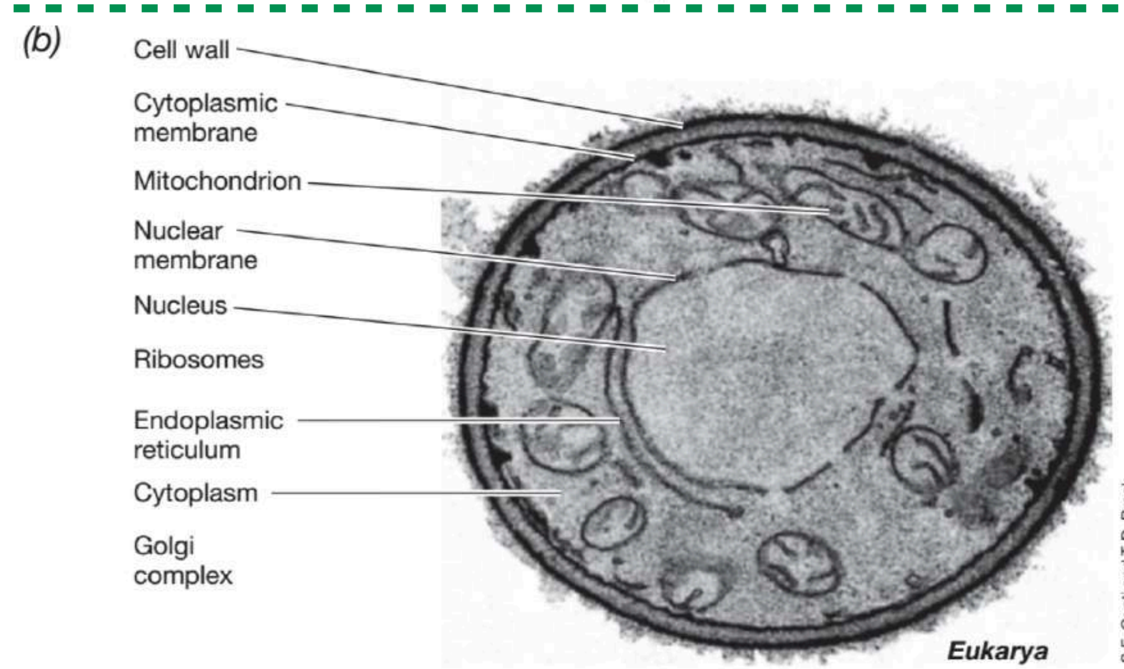
Entangle–Engulf–Endogenize model to solve the structural and metabolic puzzle

Madigan et al. 2018









Bacteria-Archaea-Eukarya Comparison

	16S rRNA gene		18S rRNA gene
	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

Core Concept

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

FYI:

https://climate.nasa.gov/news/2914/the-atmosphere-earths-security-blanket/

https://forces.si.edu/atmosphere/02_02_01.html

https://www.britannica.com/topic/evolution-of-the-atmosphere-1703862