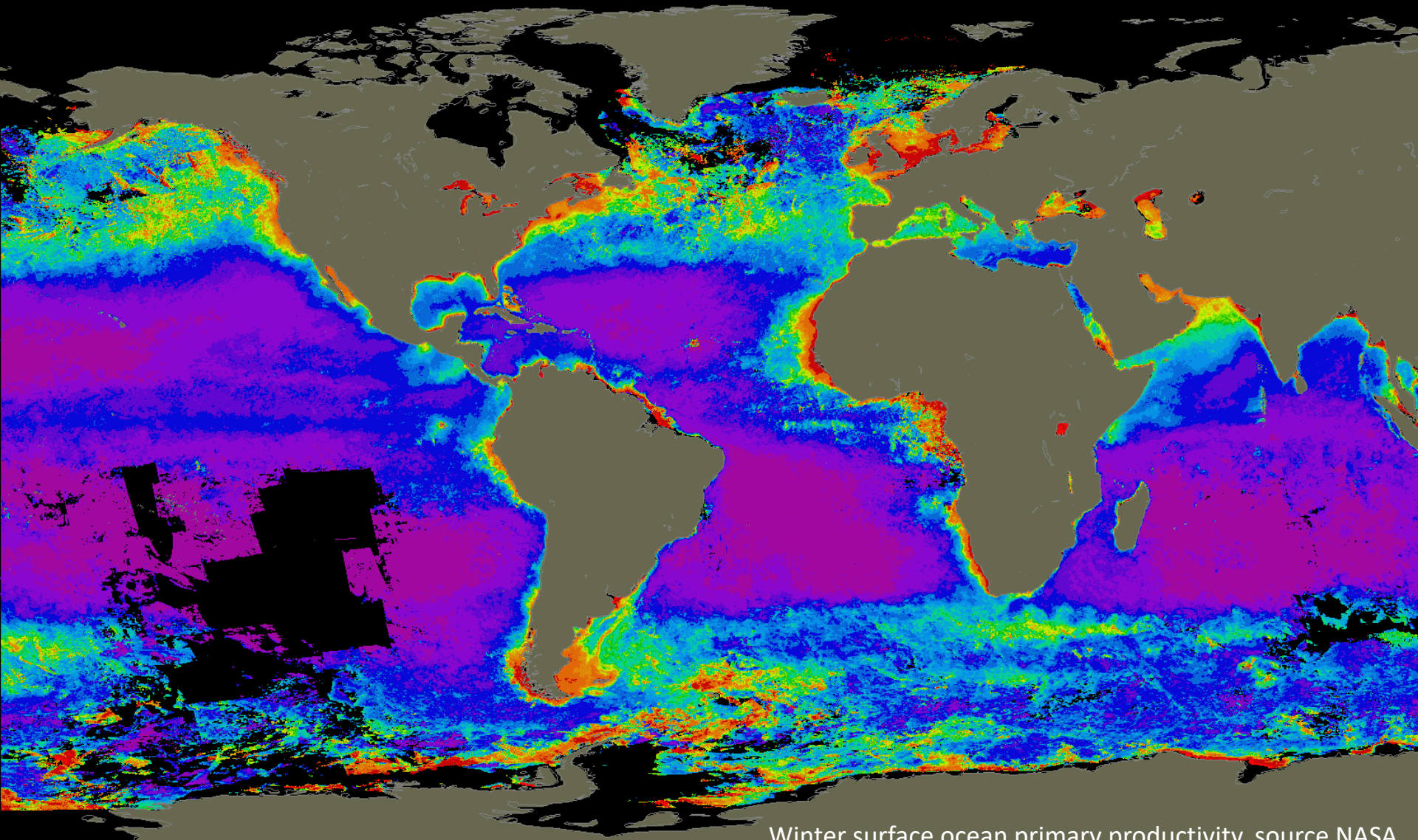
Exploring new branches on the tree of life

Brett Baker
@archaeal

Microbes are small but mighty!

For example – Microbes in the ocean's create half of the oxygen you are breathing right now

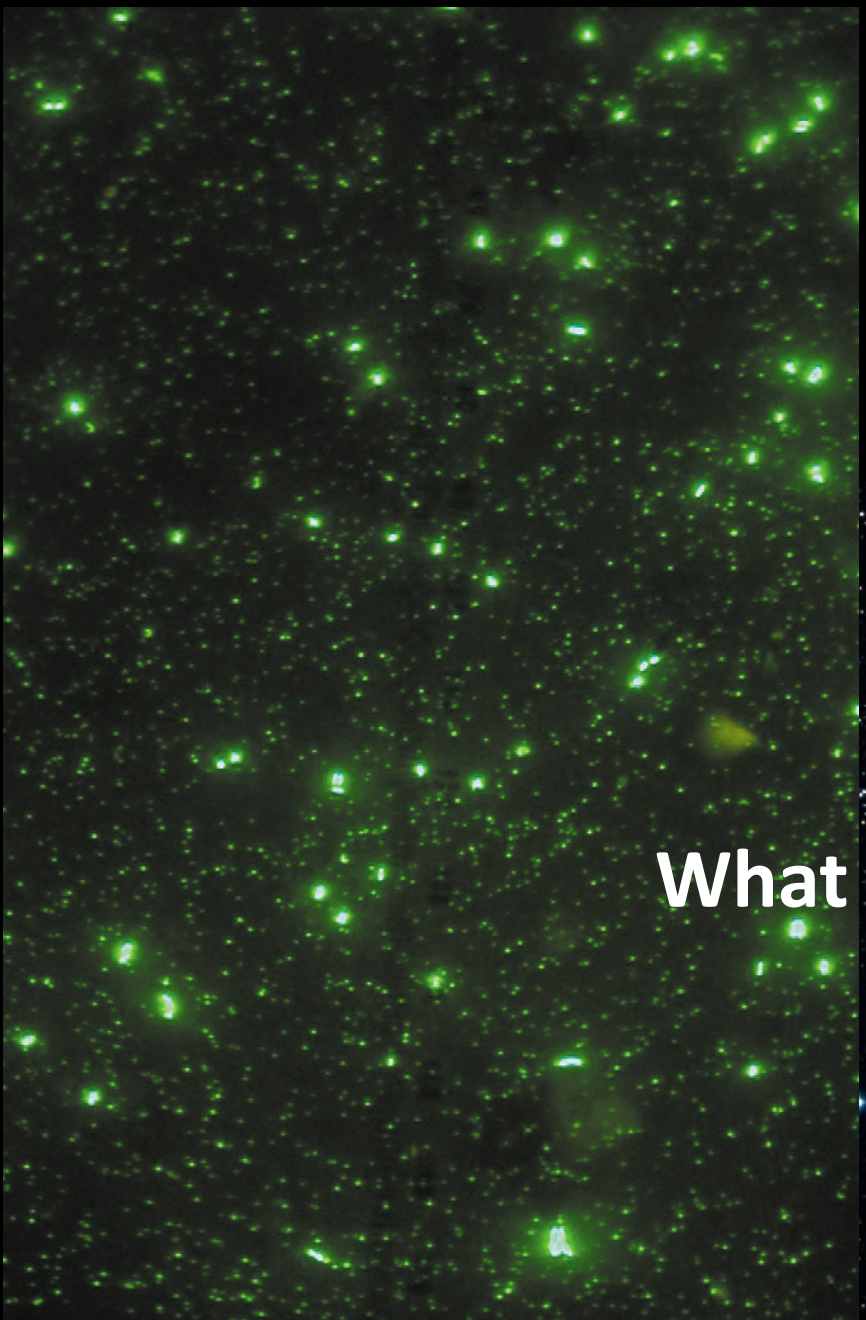


Winter surface ocean primary productivity, source NASA

Microbes get energy from lots of sources

"Edible"	"Breatheable"	Process
CH_2O (organic carbon)	O_2	Heterotrophy ALL ANIMALS!

Microbes are the most abundant life on the planet



Microbes in the oceans =

118,100,000,000,000,000,000,000,000

Stars in the universe =

70,000,000,000,000,000,000

What is out there?

How do we investigate the microbes in nature?

Photo by Greg Dick

Culturing

Microbial dark matter

Growth in the lab

≠

Natural community

At best 0.1% of what is present in nature can be grown in the laboratory

How do we investigate the microbes in nature?

Photo by Greg Dick

Culturing

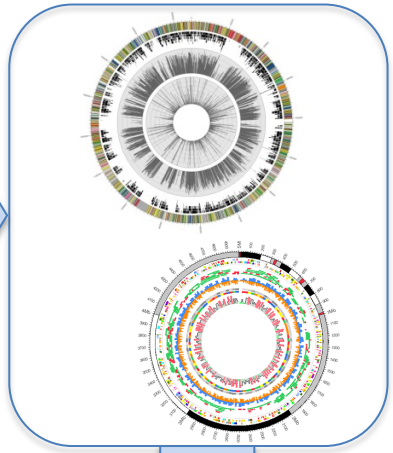
DNA sequencing

Metagenomic characterization of microbial communities

Extract DNA

Sequence DNA

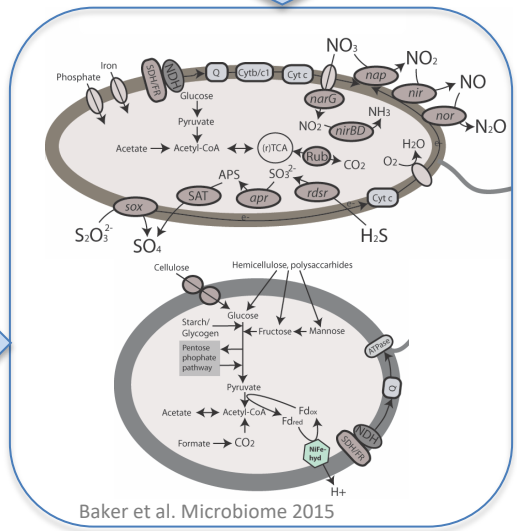
Genome assembly



In house pipeline overview:

1. Illumina HiSeq4000
2. Genomic assembly optimized with with IDBA-UD
   MetaSpades
3. Genomes binned using coverage and TNF
   CONCOT, Metabat, ESOM (in-house pipeline)
4. Bins were refined using DAStool and mmgenome
5. Functional predictions – KEGG, InterProScan,
   COG, phylogeny, and structural models

BONCAT
DNA-SIP

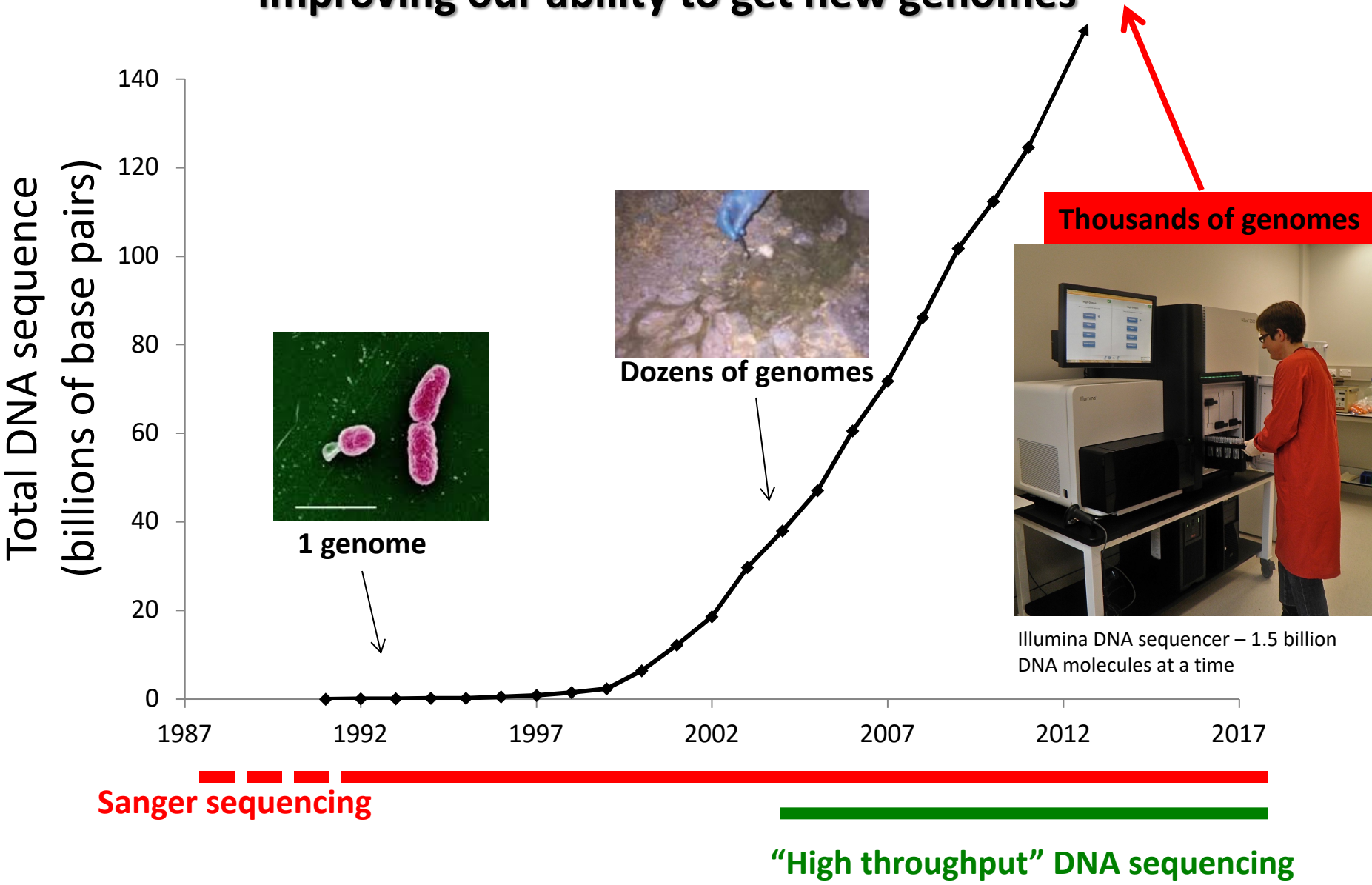


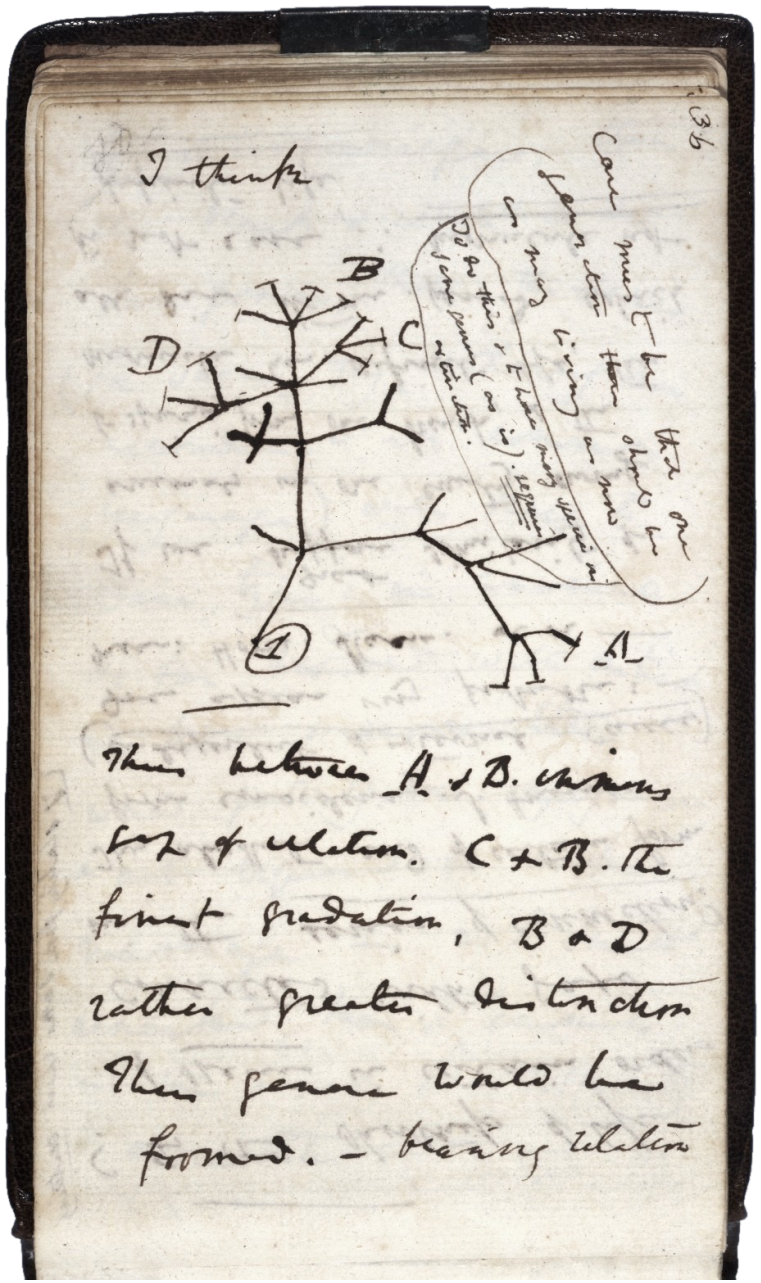
Baker et al. Microbiome 2015

Reconstruct metabolisms of all the microbes

Constructing genomes from nature is challenging

New DNA technologies and computational approaches are improving our ability to get new genomes

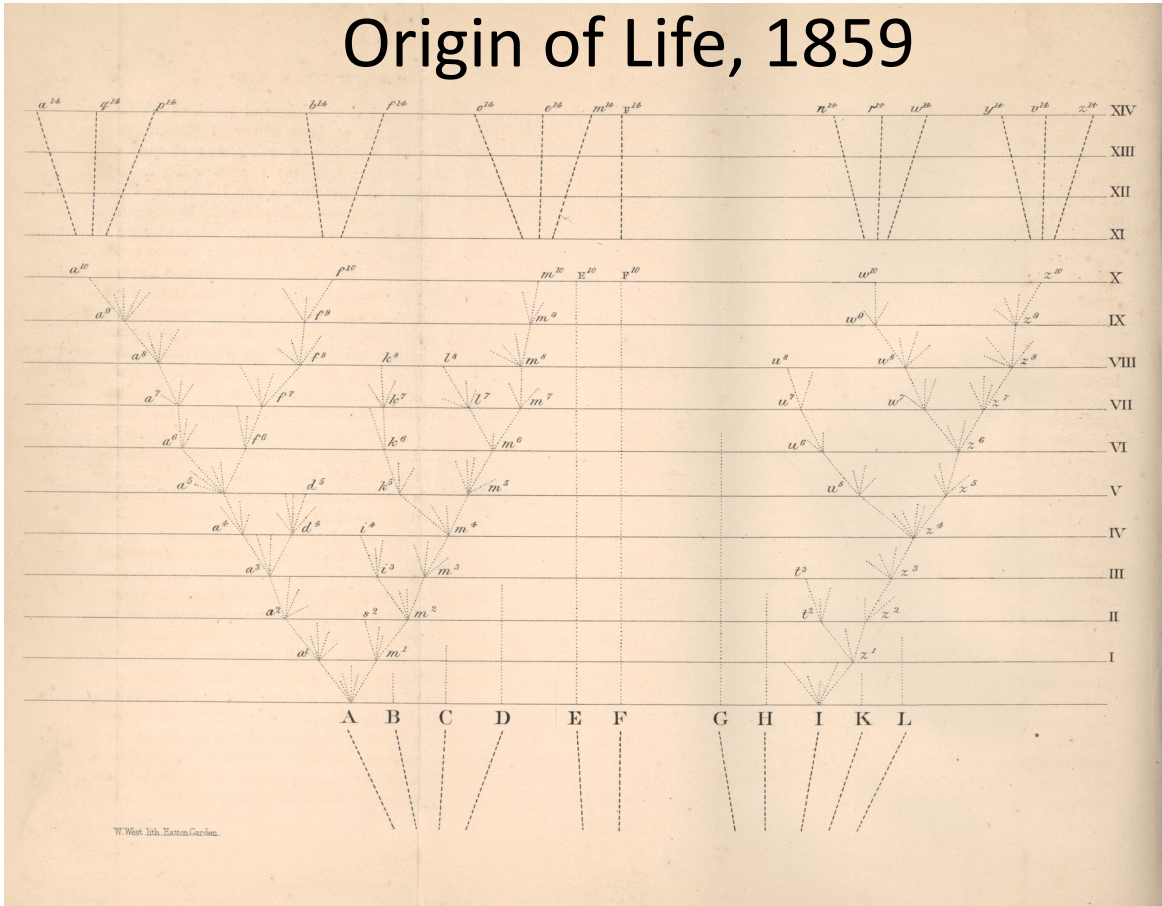




1837

Darwin's tree of life

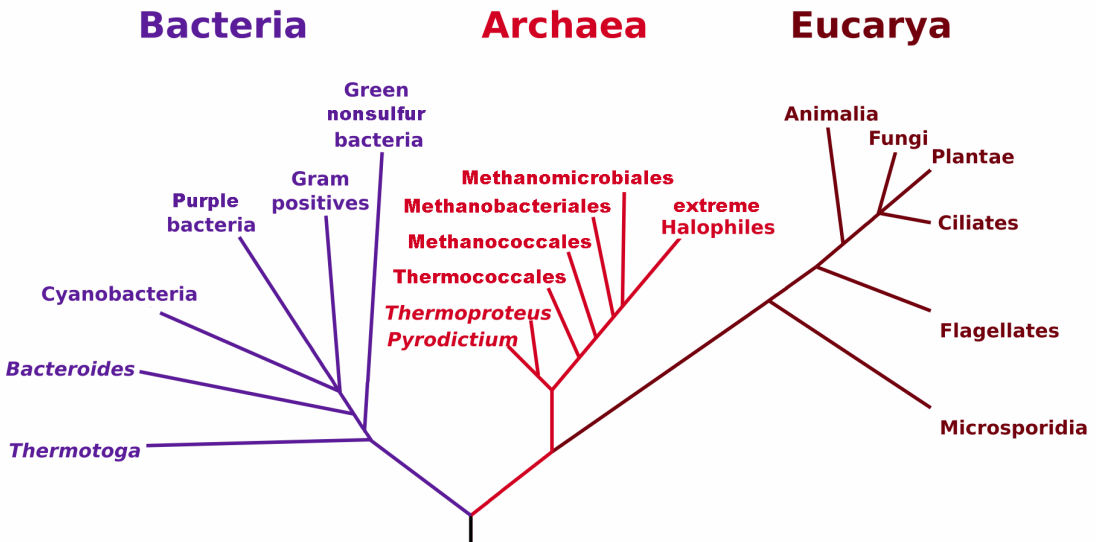
Origin of Life, 1859



Evolutionary analysis through comparison of gene sequences

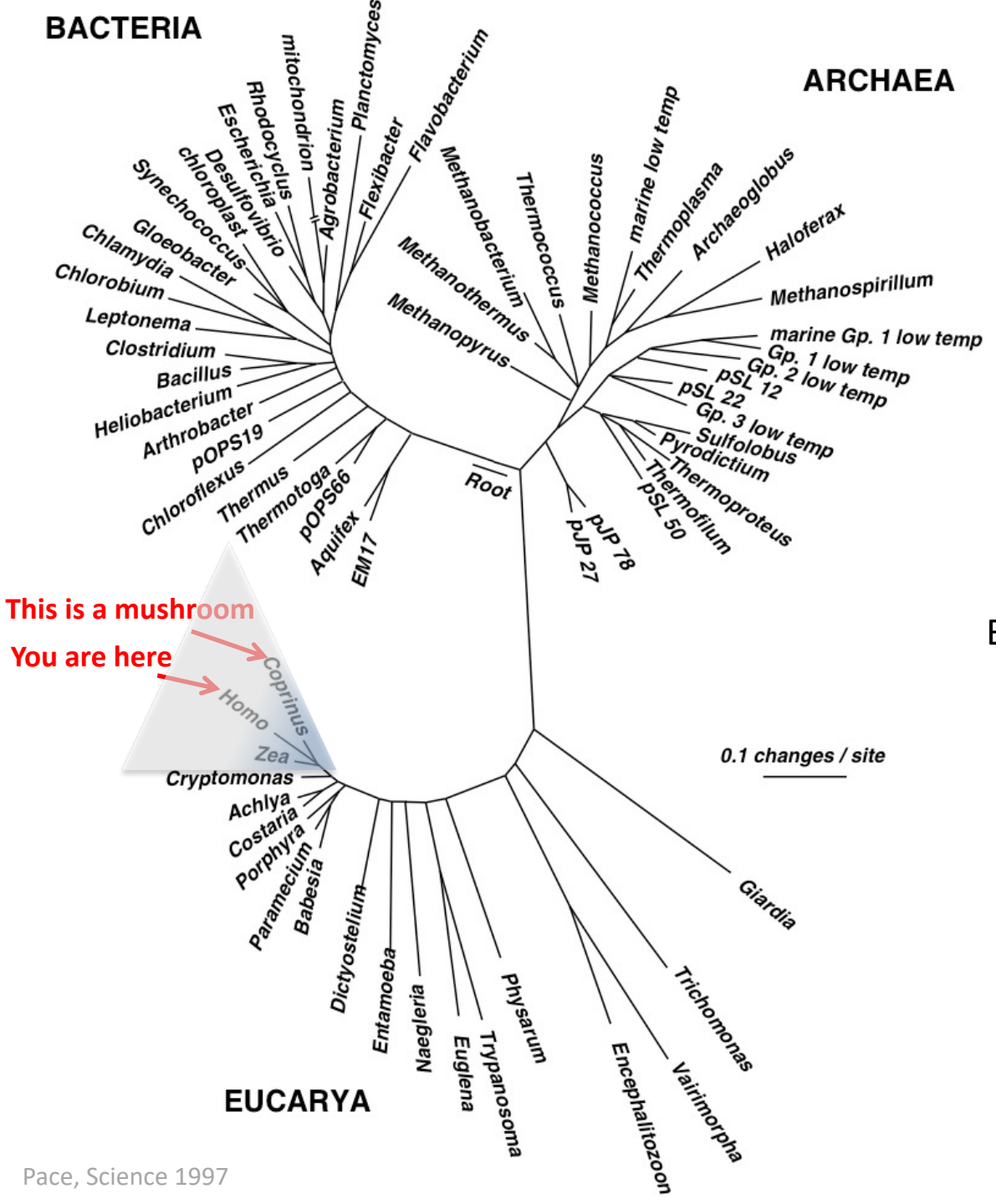
Human	...GTGCCAGCAGCCGCGGTAATTCCAGCTCCAATAGCGTATATTAAAGTTGCTGCAGTTAAAAAG...
Brewer' Yeast	...GTGCCAGCAGCCGCGGTAATTCCAGCTCCAATAGCGTATATTAAAGTTGTTGCAGTTAAAAAG...
Corn	...GTGCCAGCAGCCGCGGTAATTCCAGCTCCAATAGCGTATATTTAAGTTGTTGCAGTTAAAAAG...
Intestinal Bacterium	...GTGCCAGCAGCCGCGGTAATACGGAGGGTGCAAGCGTTAATCGGAATTACTGGGGGTAAAGCG...
Environmental Bacterium	...GTGCCAGCAGCCGCGGTAATACGGGAGAGGCAAGCGTTATCCGGAATTATTGGGGGTAAAGCG...
Deep Ocean Bacterium	...GTGCCAGCAGCCGCGGTAATACGTAGGGGGCAAGCGTTACCCGGATTTACTGGGGGTAAAGGG...
Methane Producer	...GTGCCAGCAGCCGCGGTAATACCGACGGCCCGAGTGGTAGCCACTGTTATTGGGGCTAAAGCG...
"Bacterium" 1	...GTGGCAGCCGCCGCGGTAATACCGGCGGCGCGAGTGGTGGGGGCTATTATTGGGGCTAAAGCG...
"Bacterium" 2	...GTGTCAGCCGCCGCGGTAATACCAGCTCCGCGAGTGGTCGGGGTGATTACTGCAGTTAAAGCG...

Carl Woese

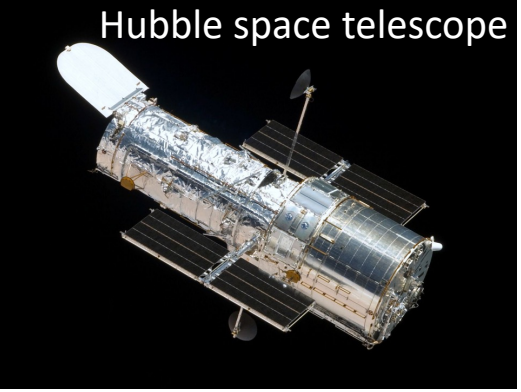


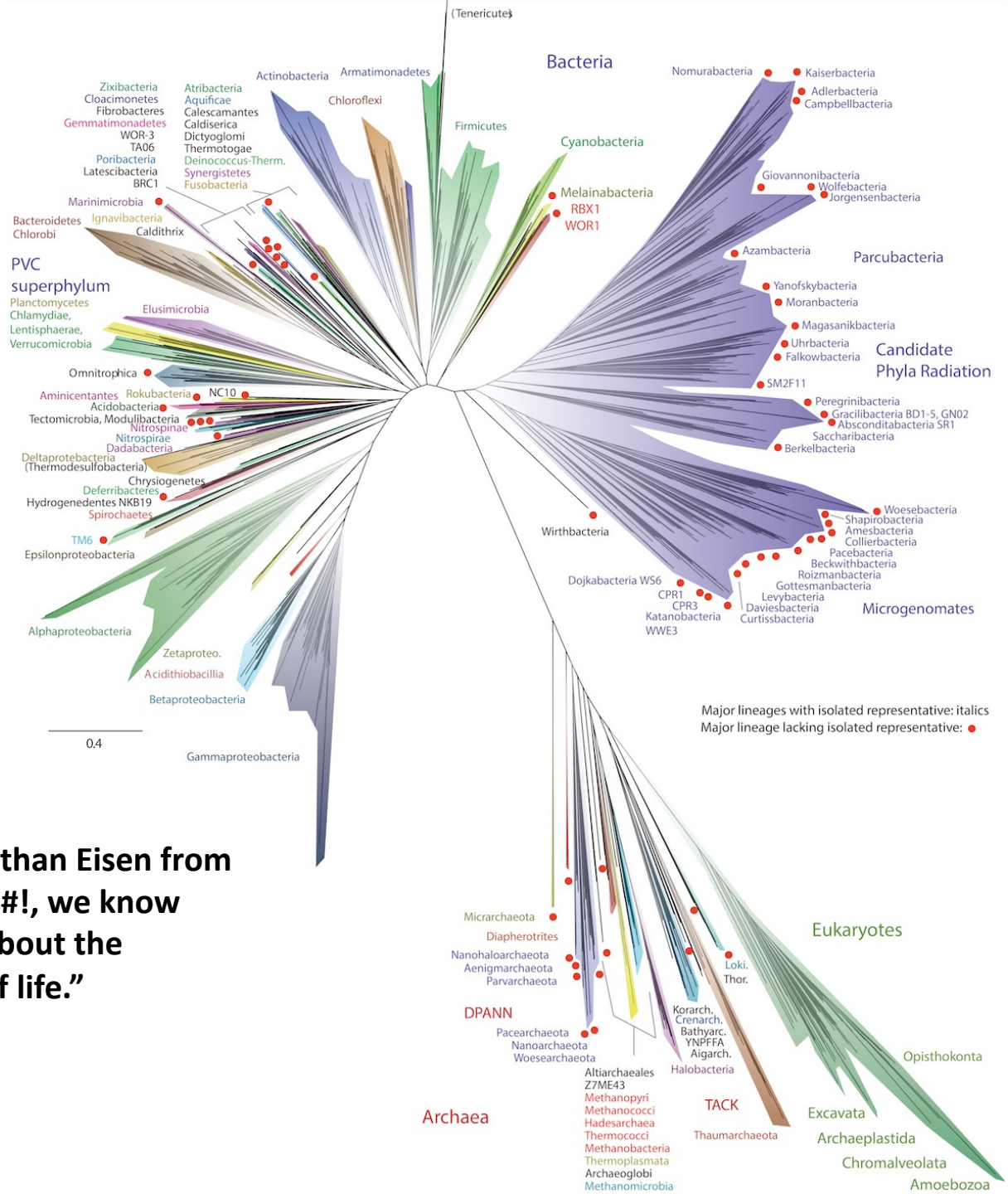
1997 tree of life

Based on 1 gene - 16S rRNA gene



Pace, Science 1997

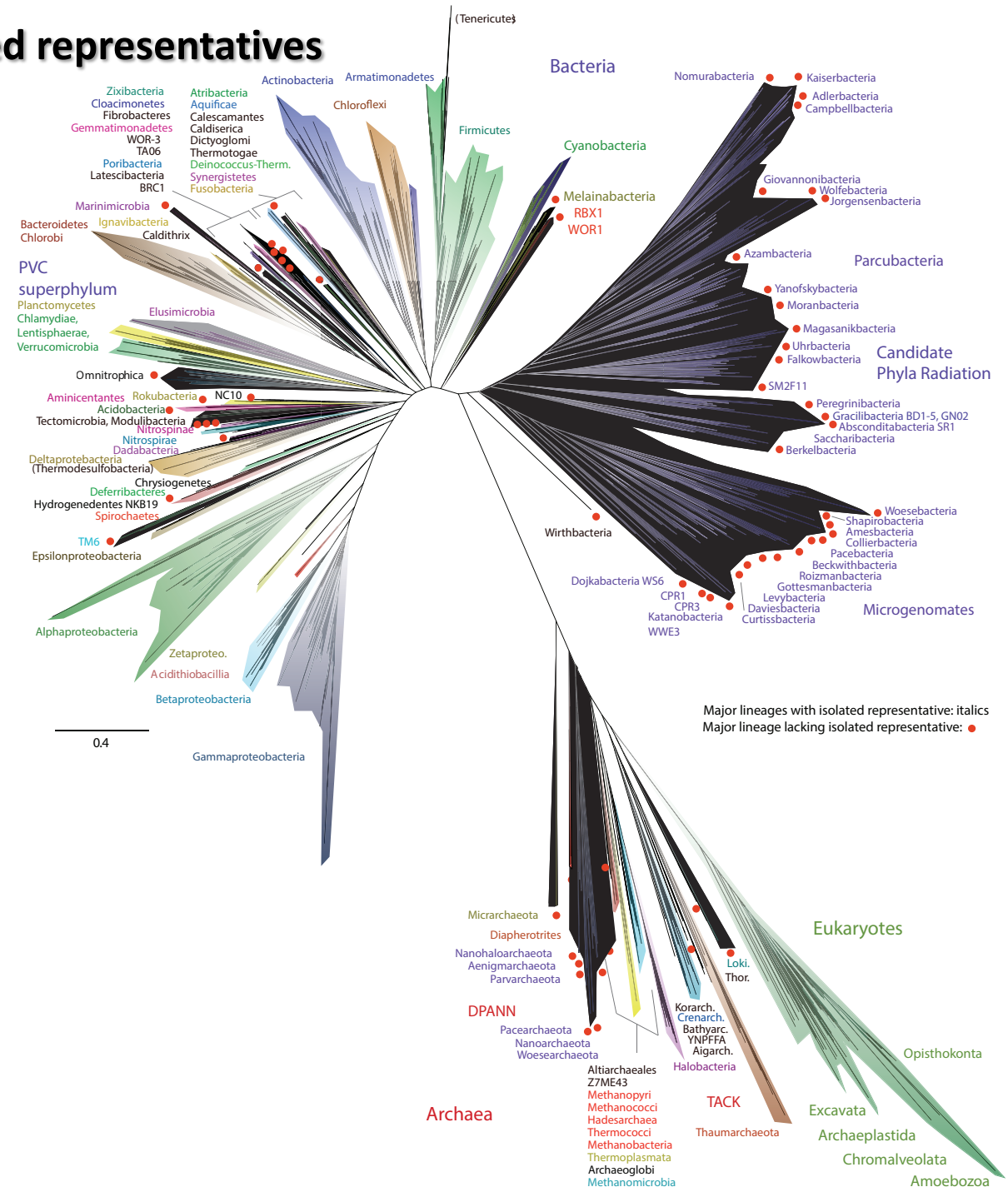




“This is humbling,” says Jonathan Eisen from UC Davis, “because holy **%#!, we know virtually nothing right now about the biology of most of the tree of life.”

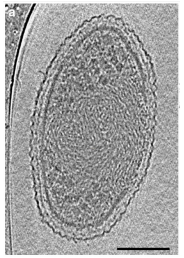
Hug et al. *Nature Micro* 2016

Phyla that lack cultured representatives

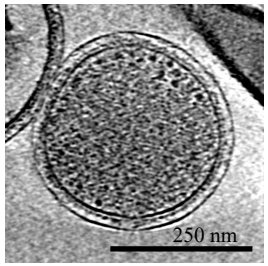


Hug, Baker, et al. *Nature Micro* 2016

Genomic era – Tree of Life



Candidate Phyla Radiation (CPR)



DPANN

Small cells <400 nm and small genomes <0.8-1.2 Mb

Leuf et al. Nat Comm 2015
Baker et al *Science* 2006

Lokiarchaeota

Eukarya

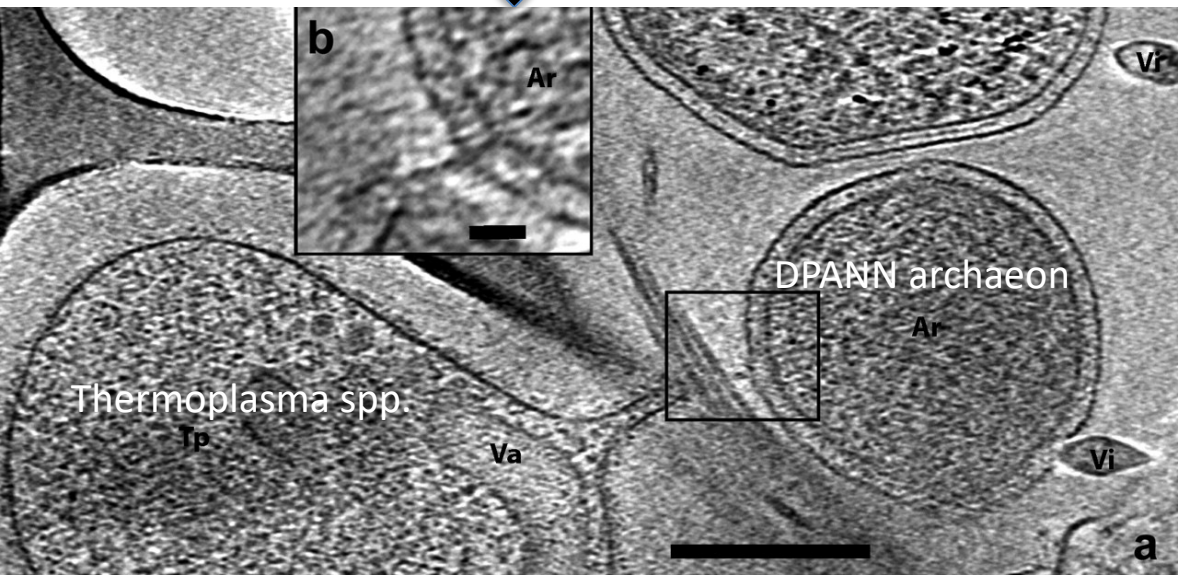
Bacteria (74–76 phyla)

Archaea (24–28 phyla)

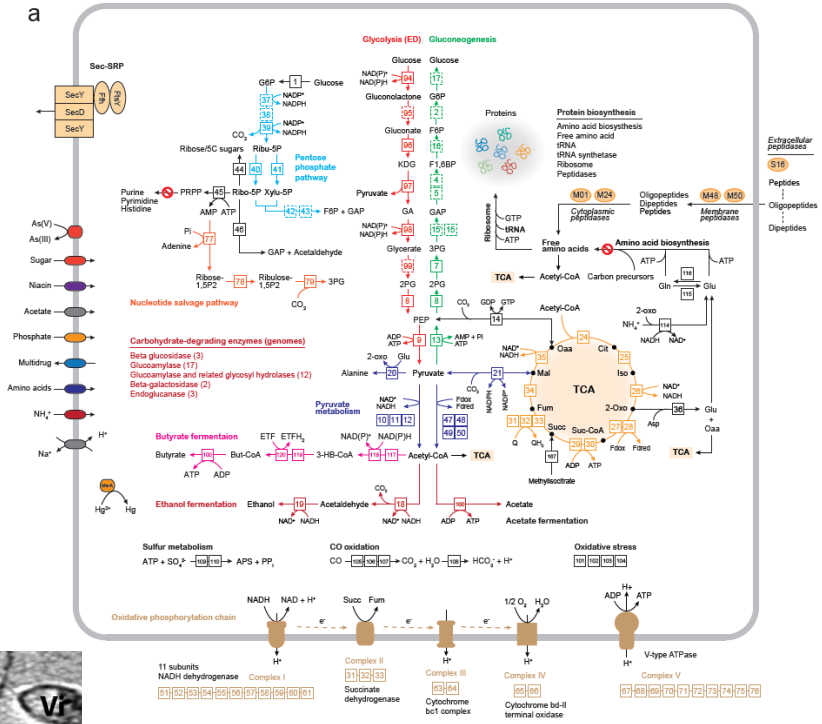
Spang and Ettema, 2016

DPANN and CPR are metabolically limited and have associations with other species in nature

- Little/no respiratory pathways, appear to be fermenters
- Lacking many core biosynthetic pathways (eg. nucleotide, amino acids, and membranes)
- Many have been shown to be associated with other cells in nature

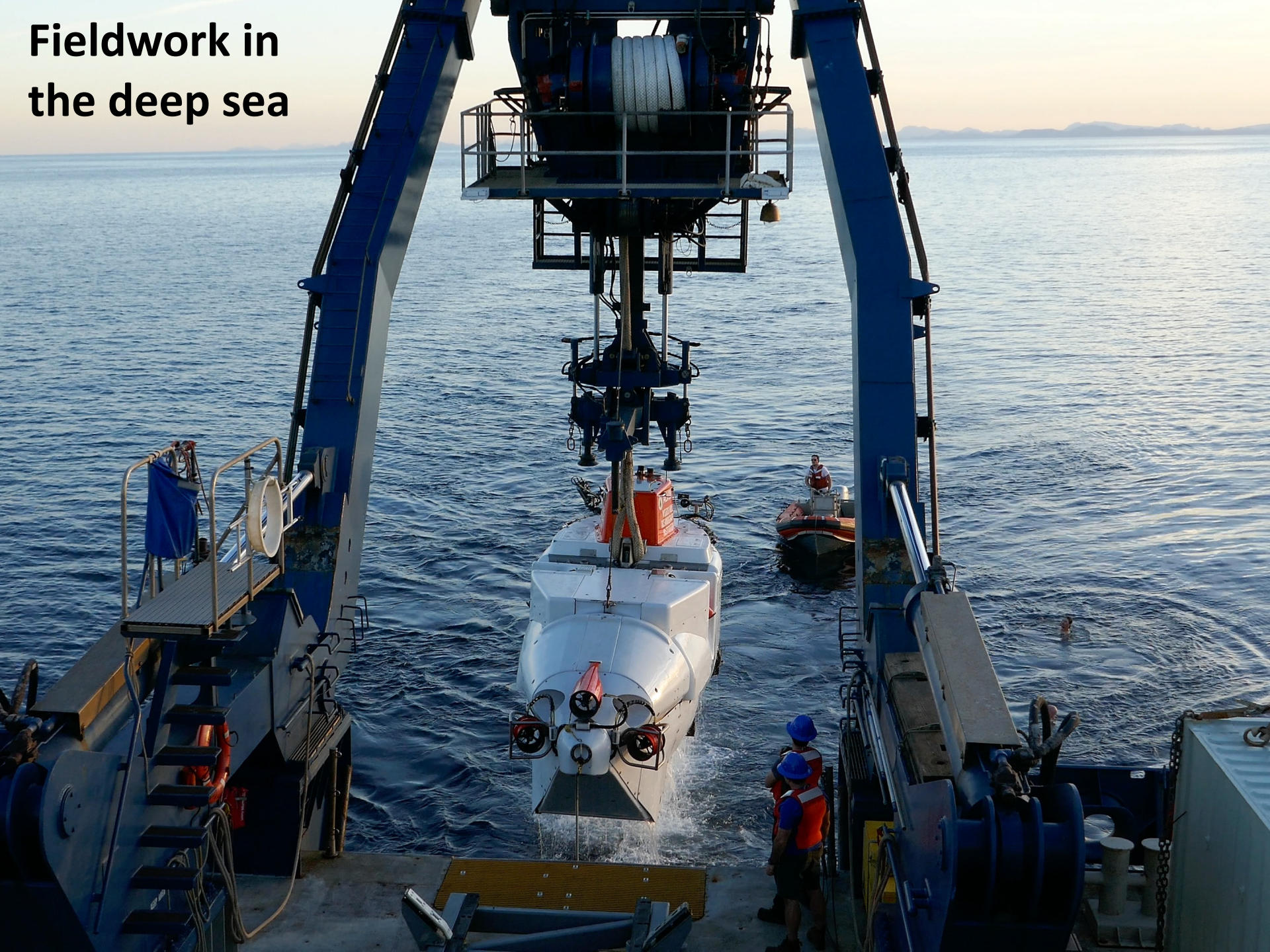


Baker et al. *PNAS* 2010



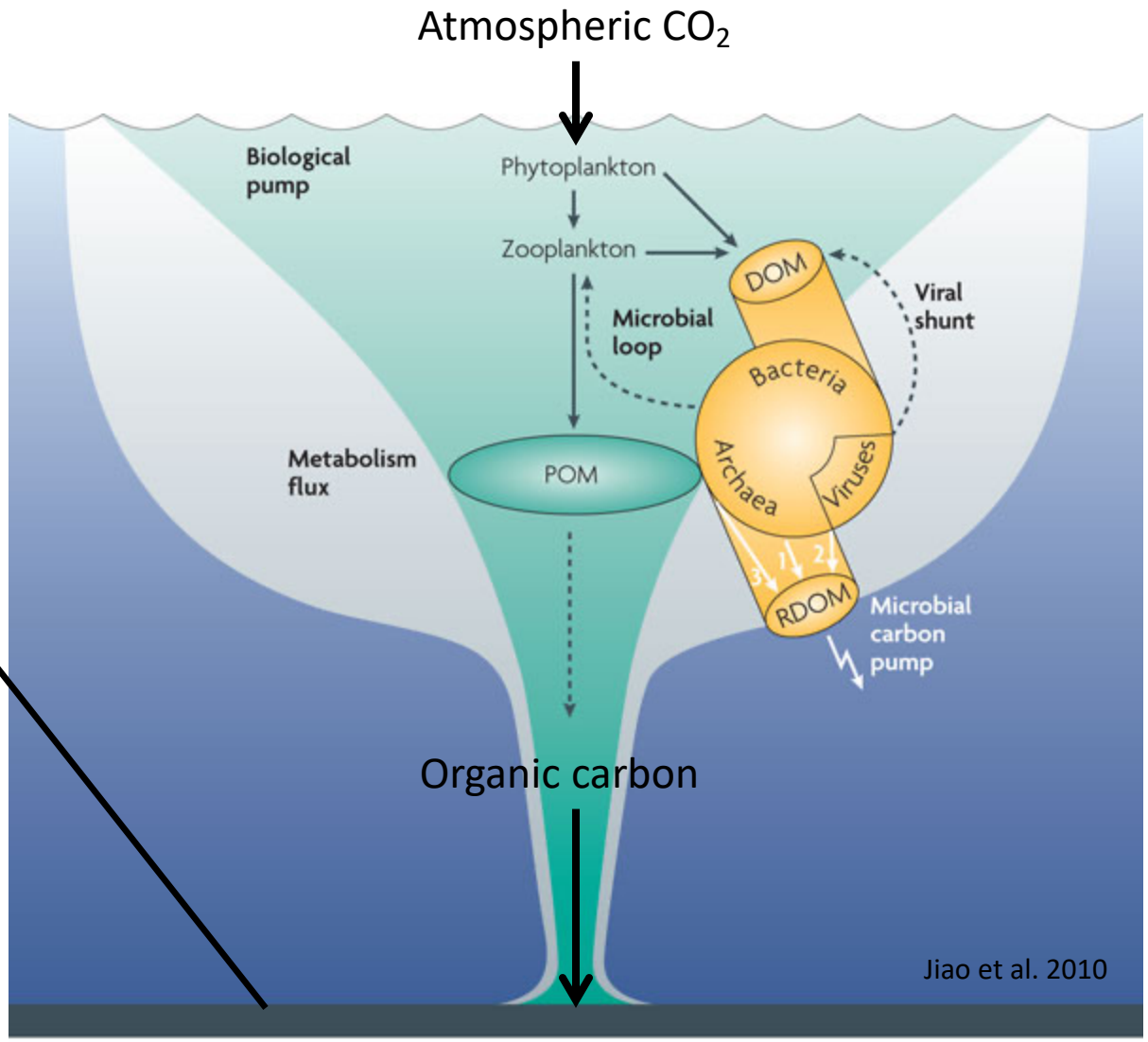
Chen, Baker et al. 2018 *ISME J.*

Fieldwork in the deep sea



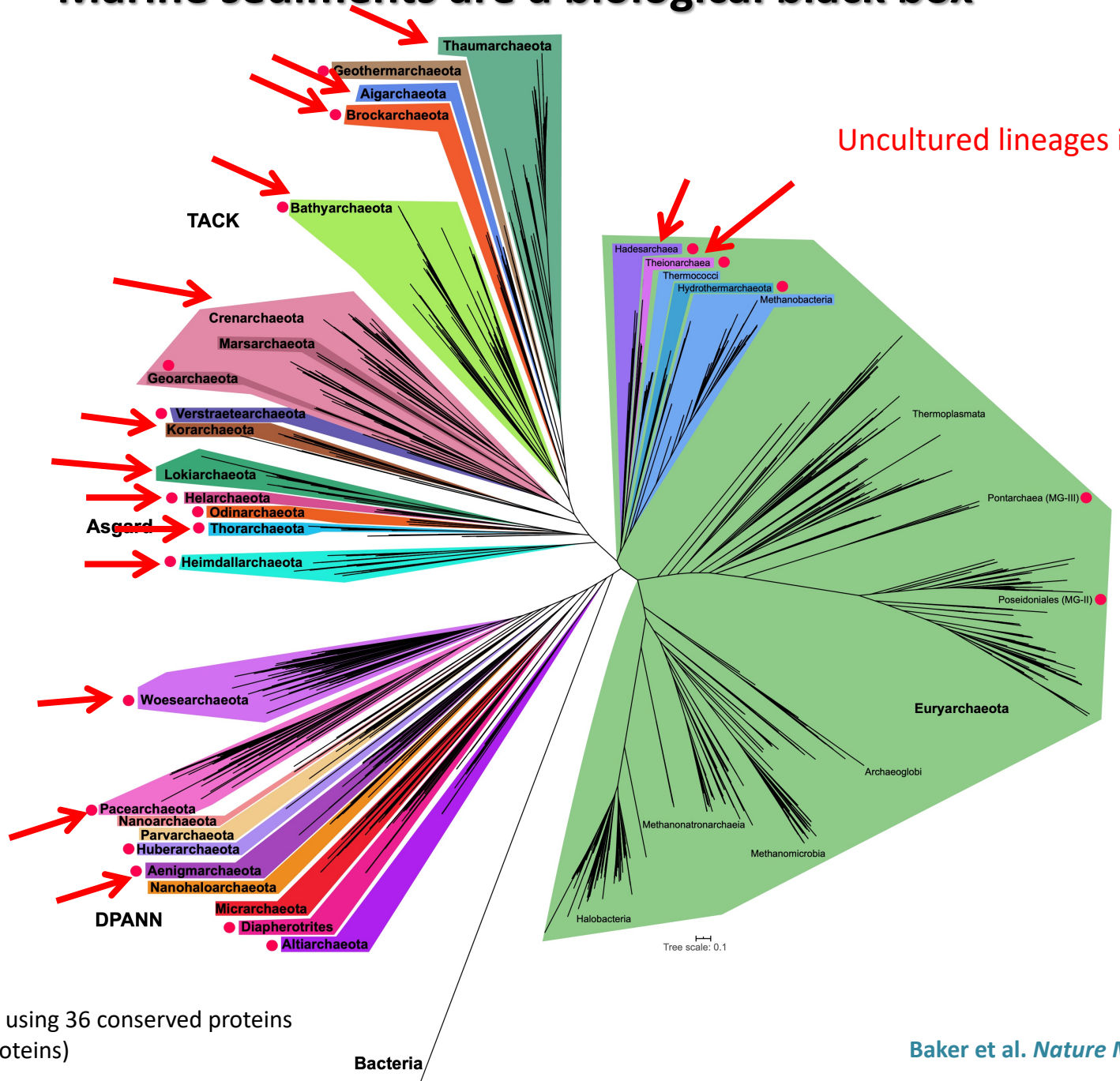
Sediments are the final resting place for detrital matter in the oceans

Marine sediments contain the largest pool of organic carbon on the planet



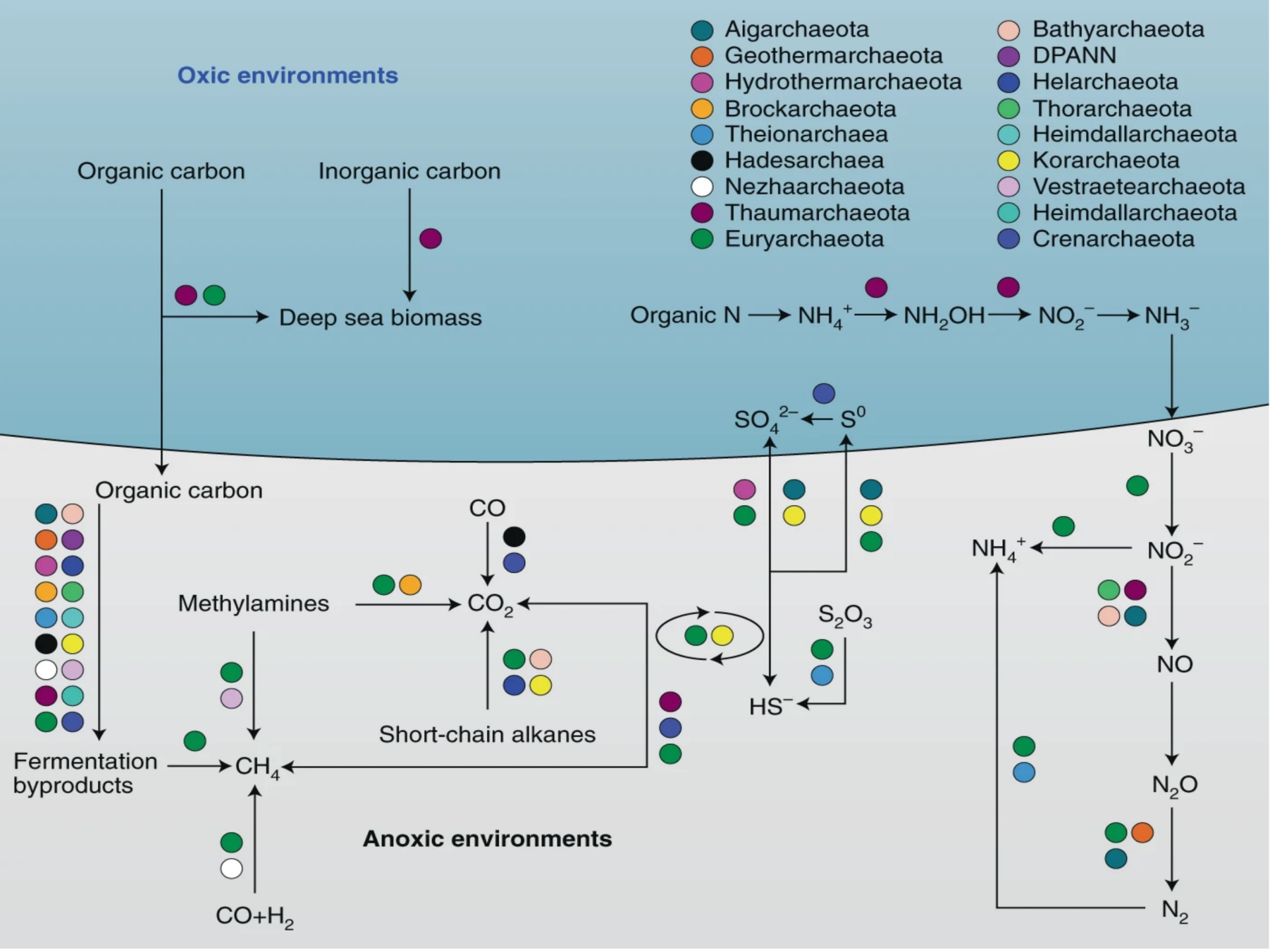
Nature Reviews | Microbiology

Marine sediments are a biological black box

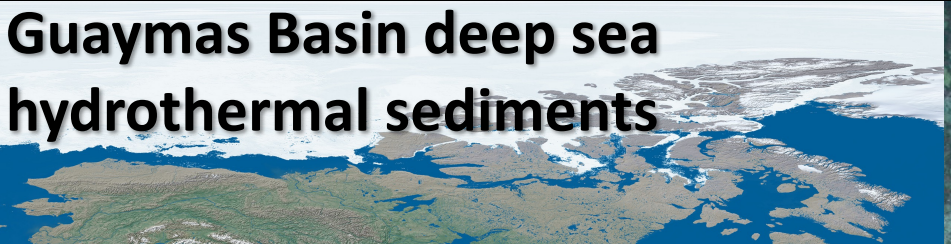


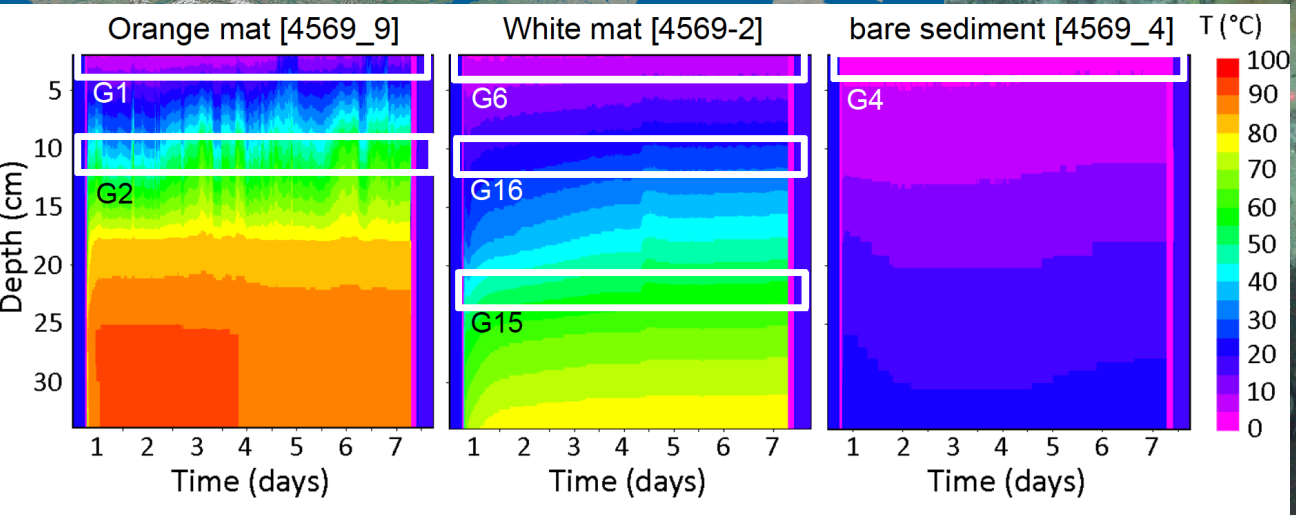
Phylogeny generated using 36 conserved proteins
(30 are ribosomal proteins)

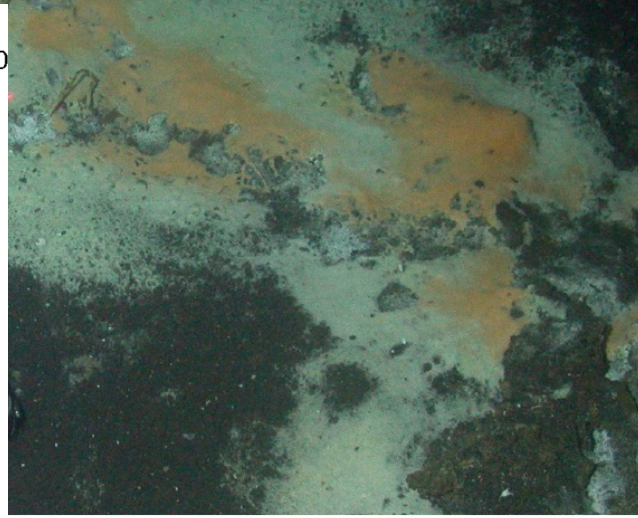
Baker et al. *Nature Micro* 2020


Oxic environments
Aigarchaeota
Geothermarchaeota
Hydrothermarchaeota
Brockarchaeota
Theionarchaea
Hadesarchaea
Nezhaarchaeota
Thaumarchaeota
Euryarchaeota
Bathyarchaeota
DPANN
Helarchaeota
Thorarchaeota
Heimdallarchaeota
Korarchaeota
Vestraetearchaeota
Heimdallarchaeota
Crenarchaeota
Organic carbon
Inorganic carbon
Deep sea biomass
Organic N → NH4+ → NH2OH → NO2− → NH3−
SO4 2− ← S0
NO3−
Organic carbon
CO
NH4+
NO2−
Methylamines
CO2
S2O3
NO
HS−
Short-chain alkanes
Fermentation byproducts
CH4
N2O
Anoxic environments
CO+H2
N2

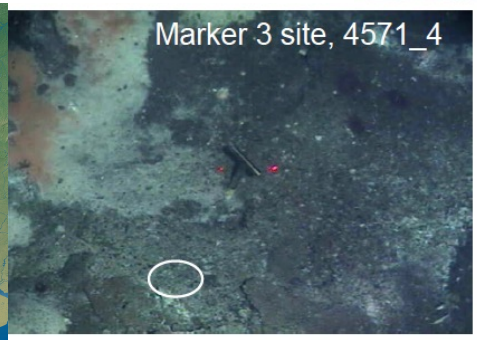
Guaymas Basin deep sea hydrothermal sediments



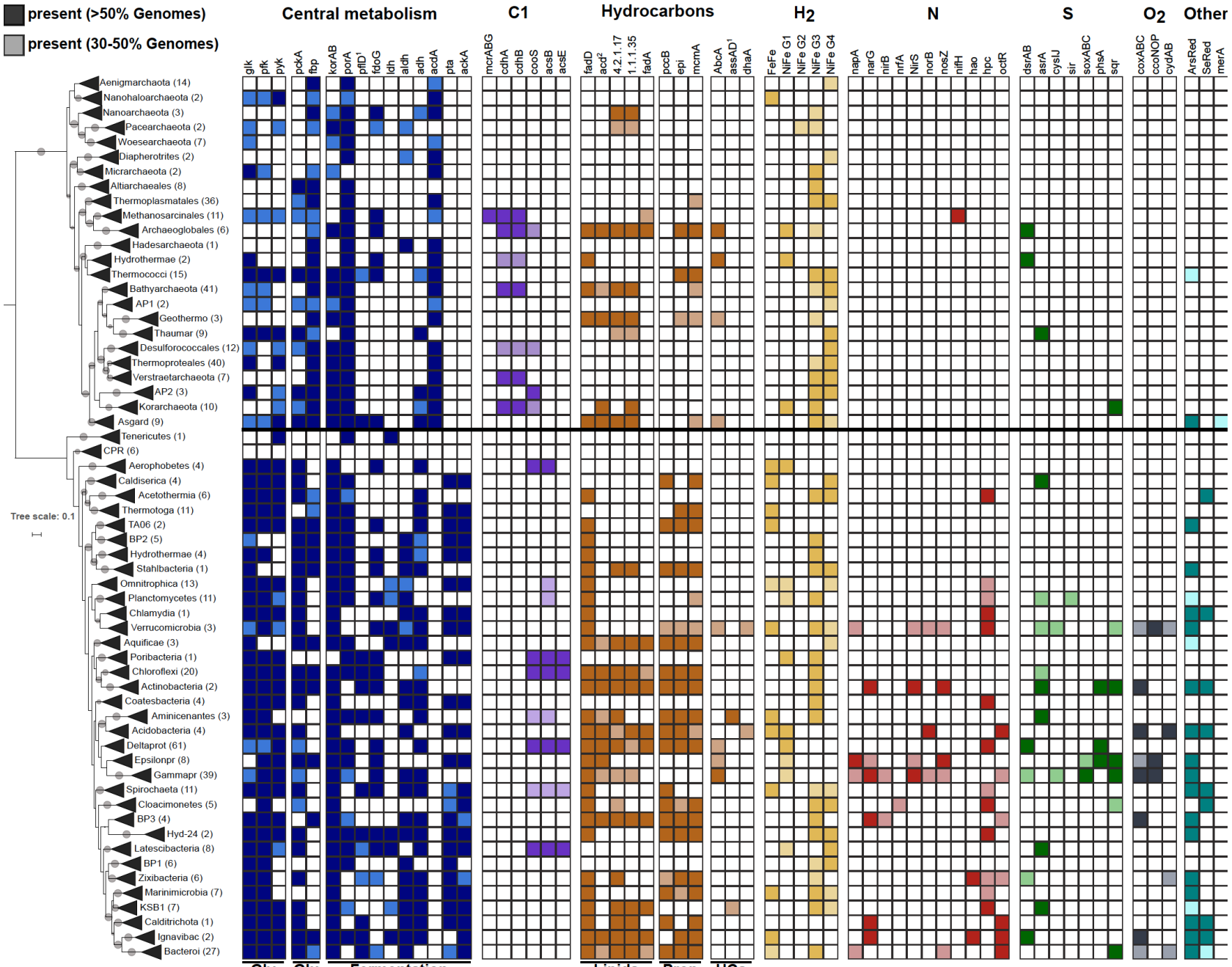




45+ communities have been sequenced
(up to 1 billion reads/sample now)

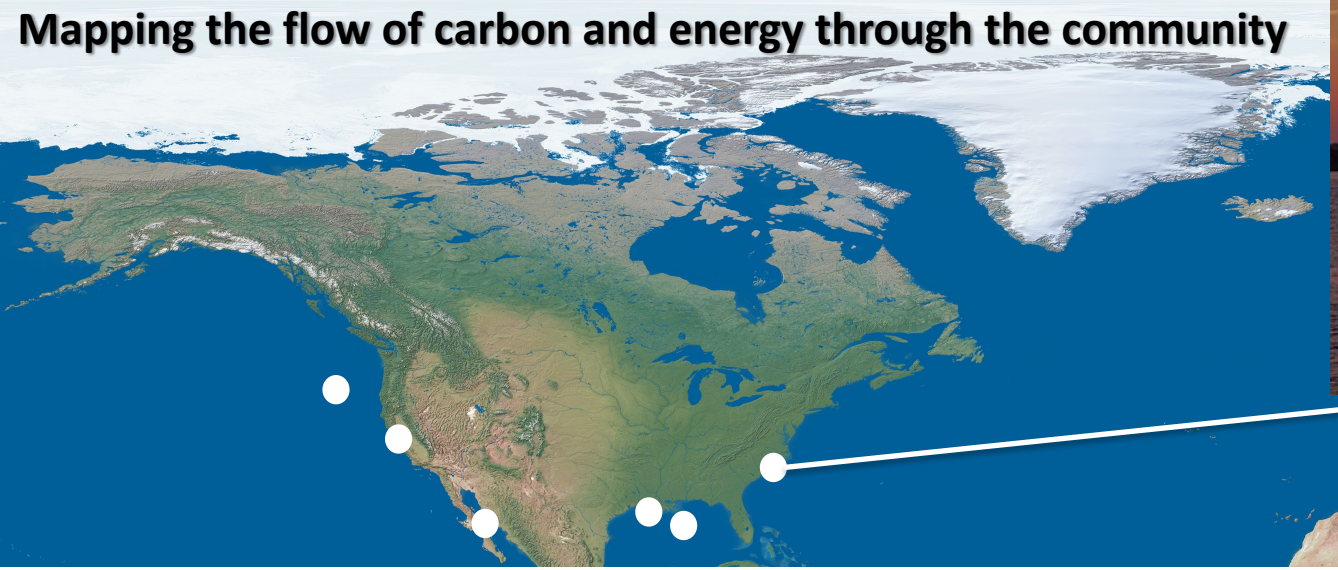


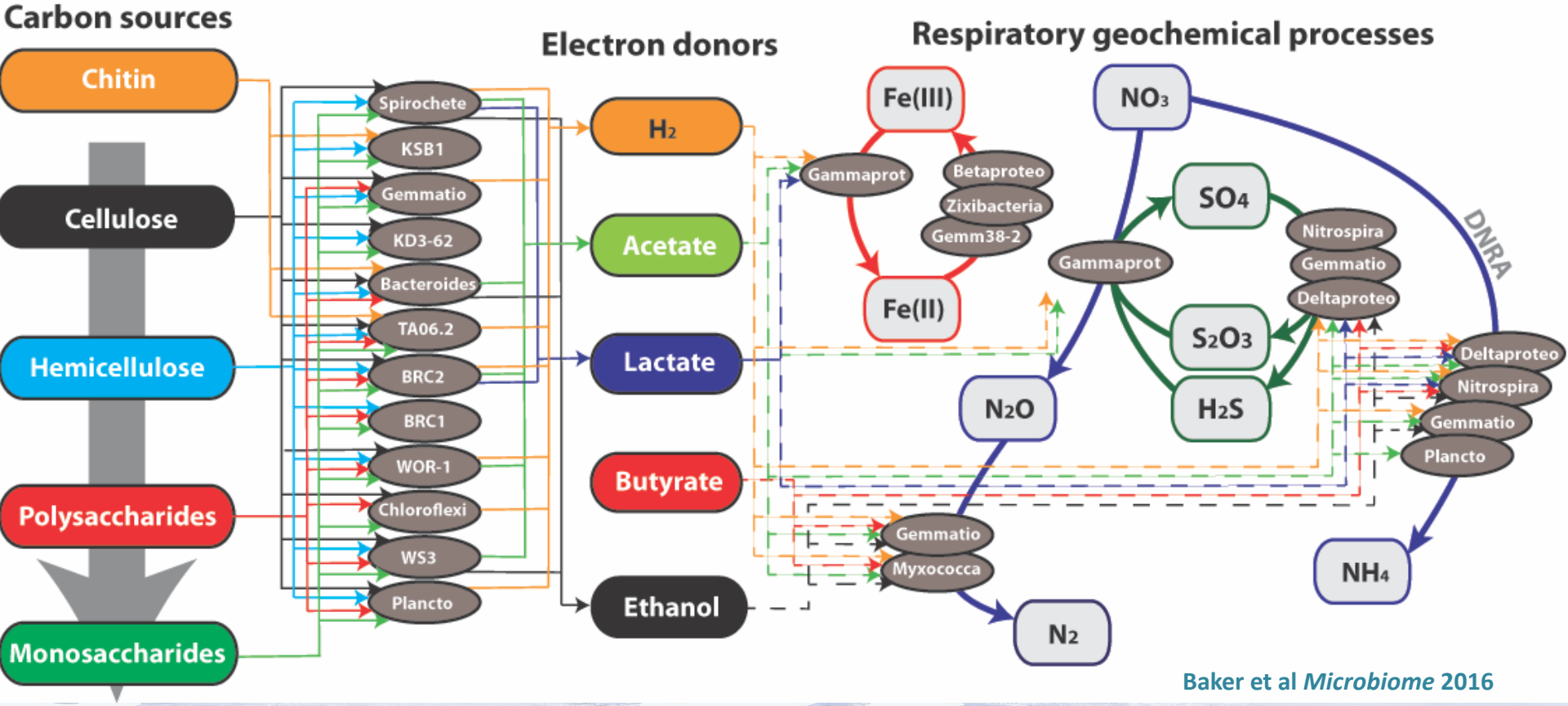
Guaymas sediments contain considerable metabolic diversity



Dombrowski et al. 2018 *Nature Comm.*

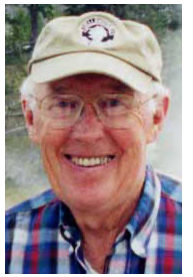
Mapping the flow of carbon and energy through the community



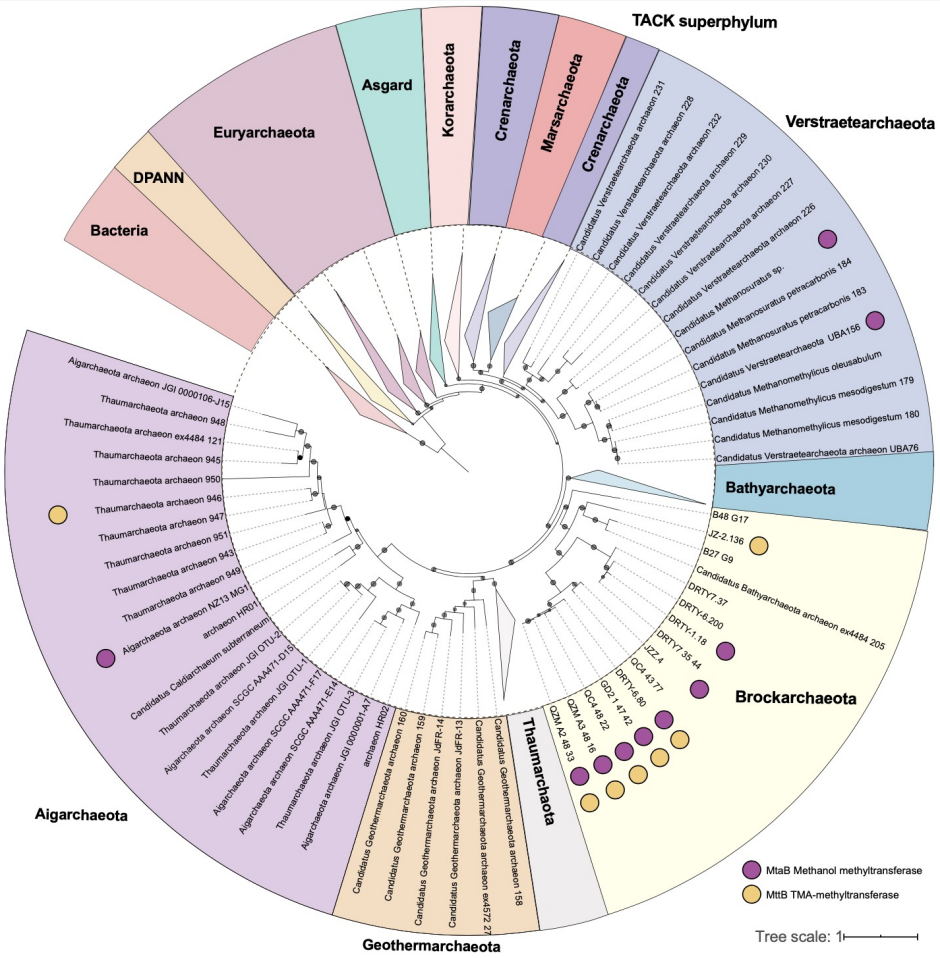


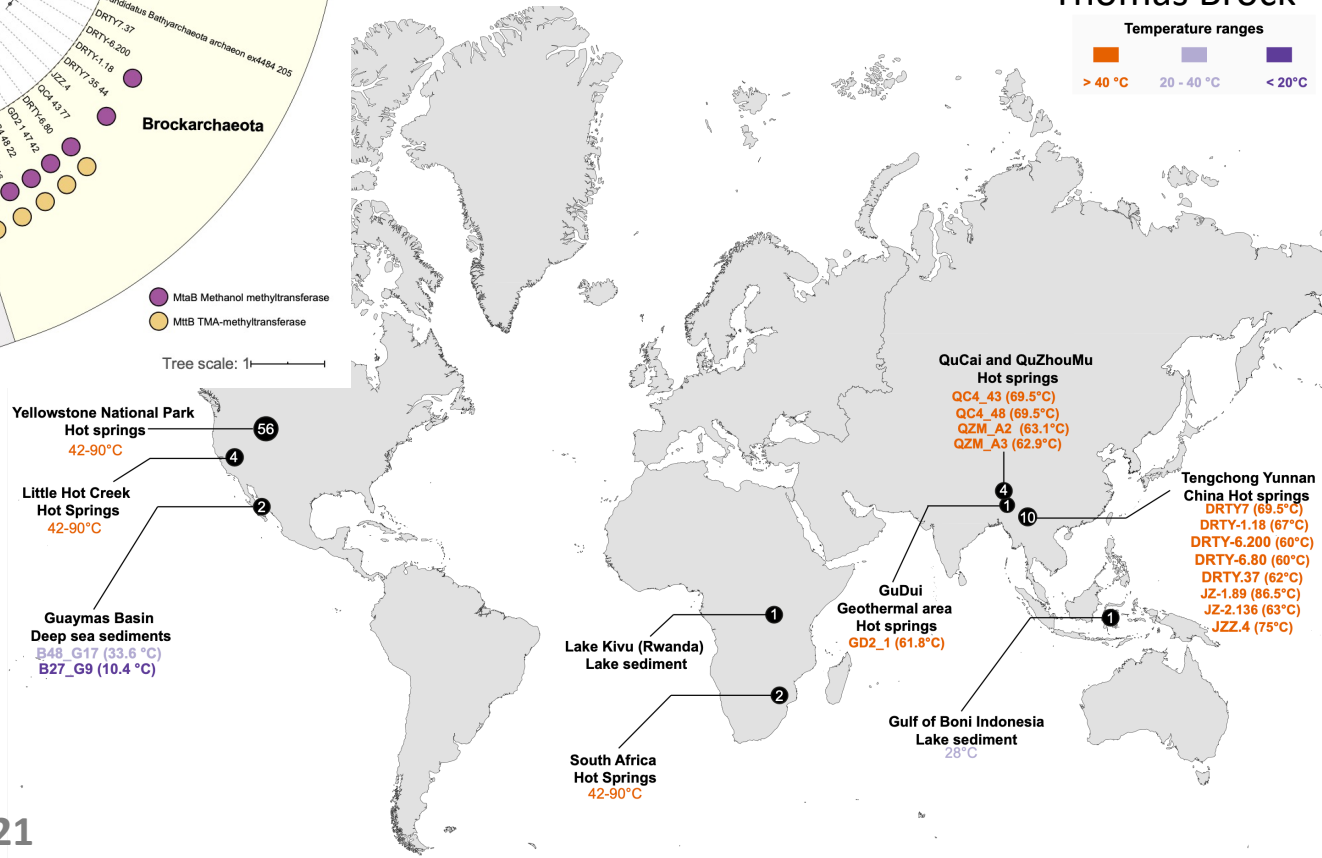
Baker et al *Microbiome* 2016

Brockarchaeota – an overlooked, widespread archaeal phylum



Thomas Brock

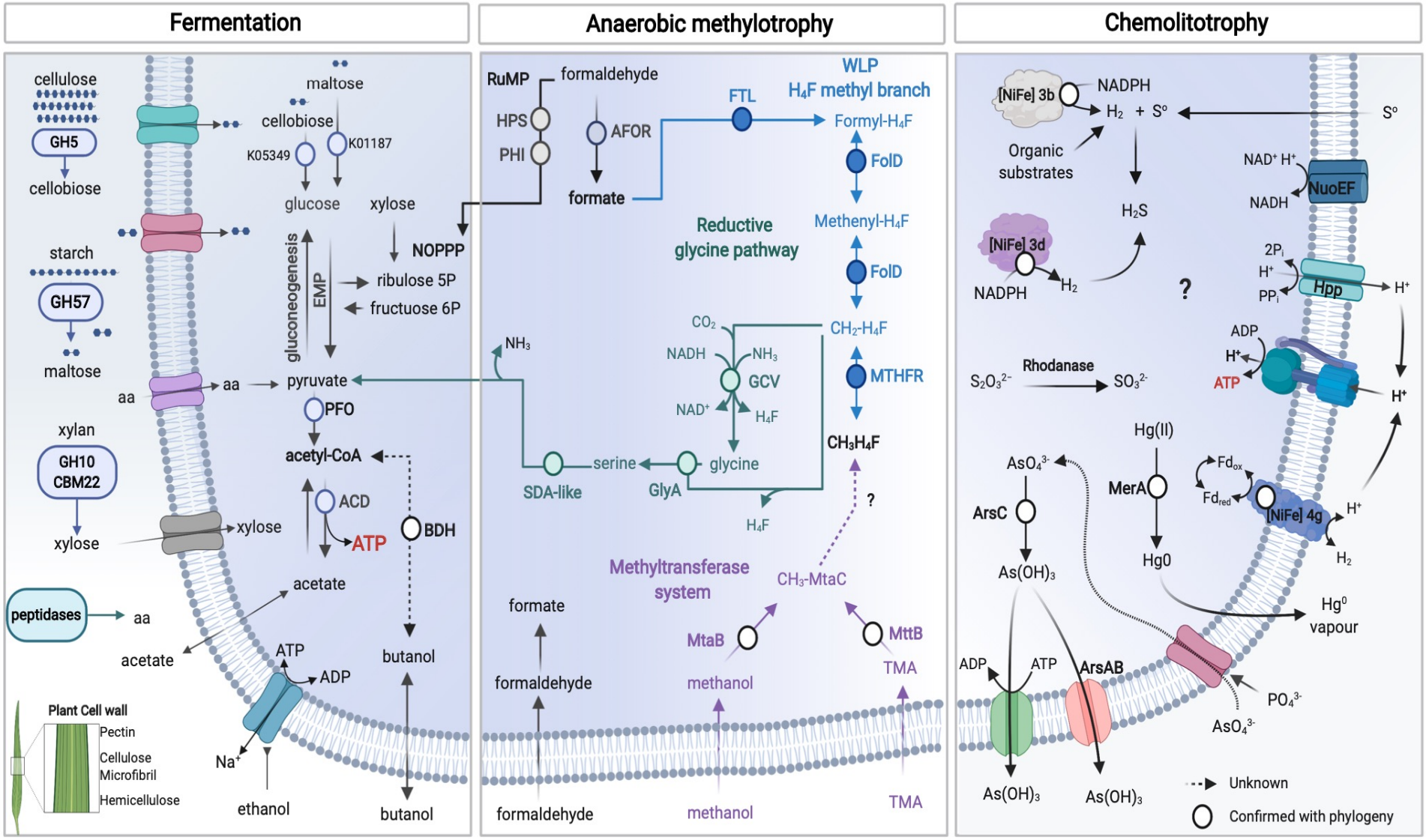




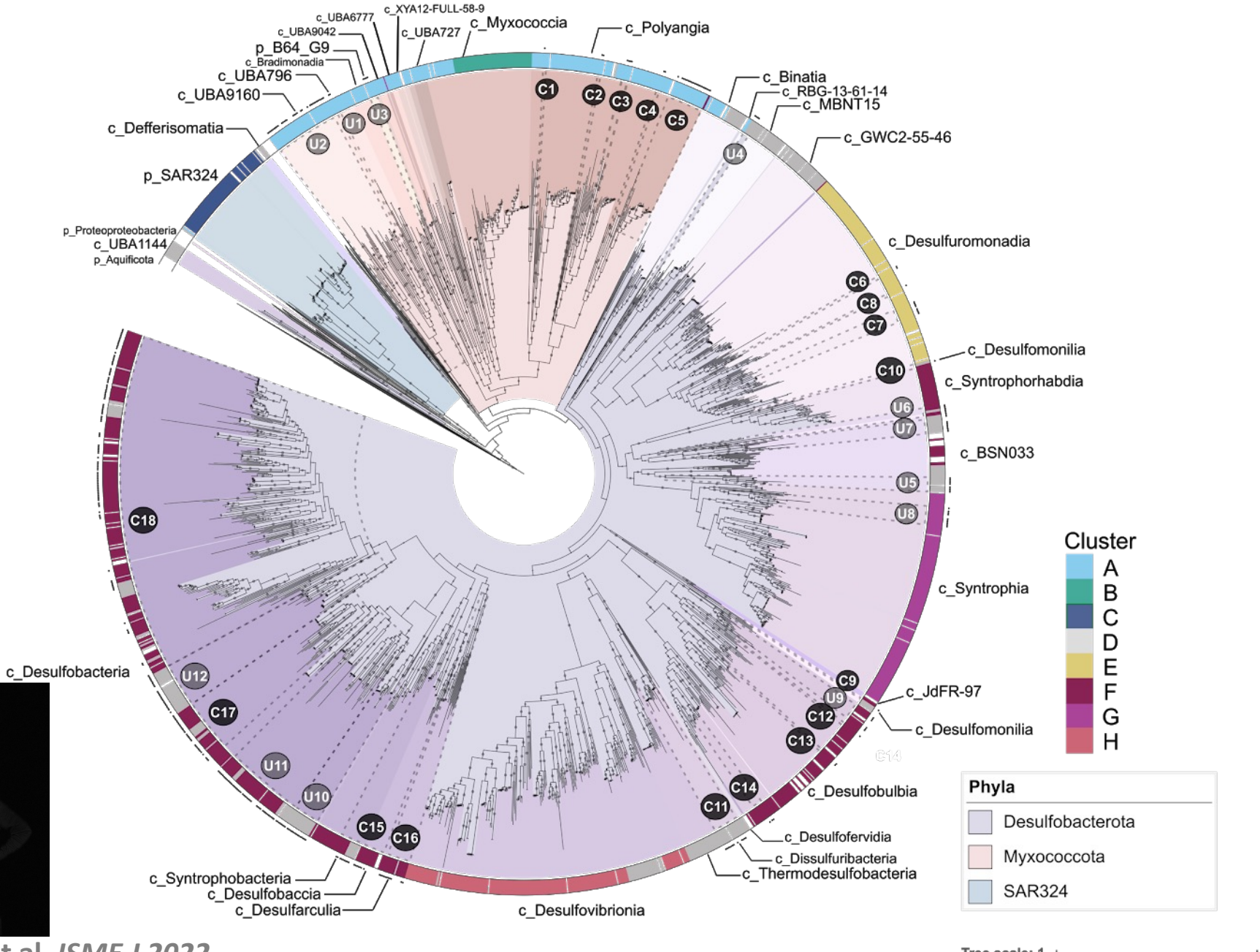
De Anda et al. Nature Comm. 2021

Brockarchaeota are non-methanogenic methylotrophs

De Anda et al. Nature Comm. 2021

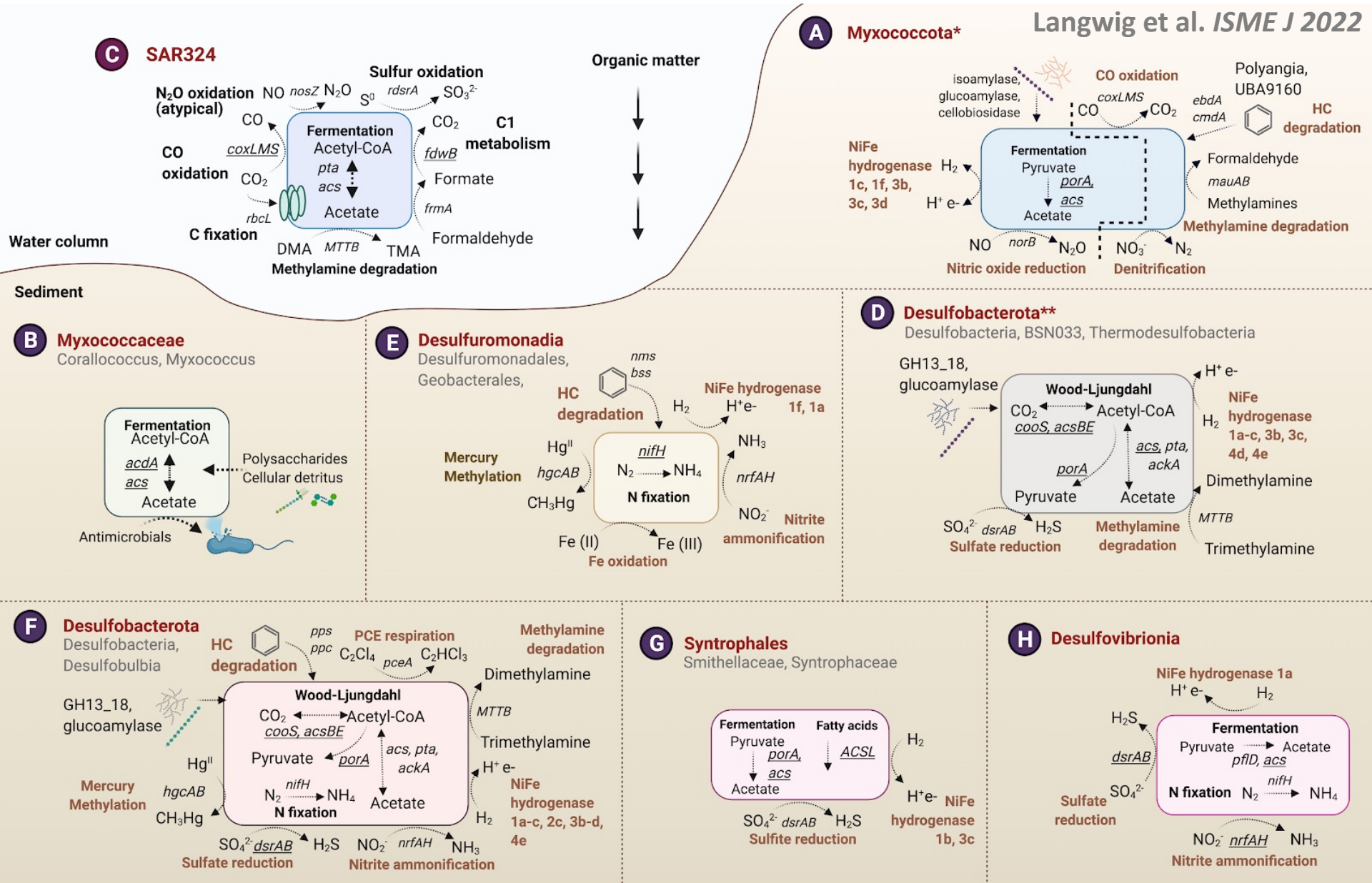


Protein clustering of dominant sediment bacteria



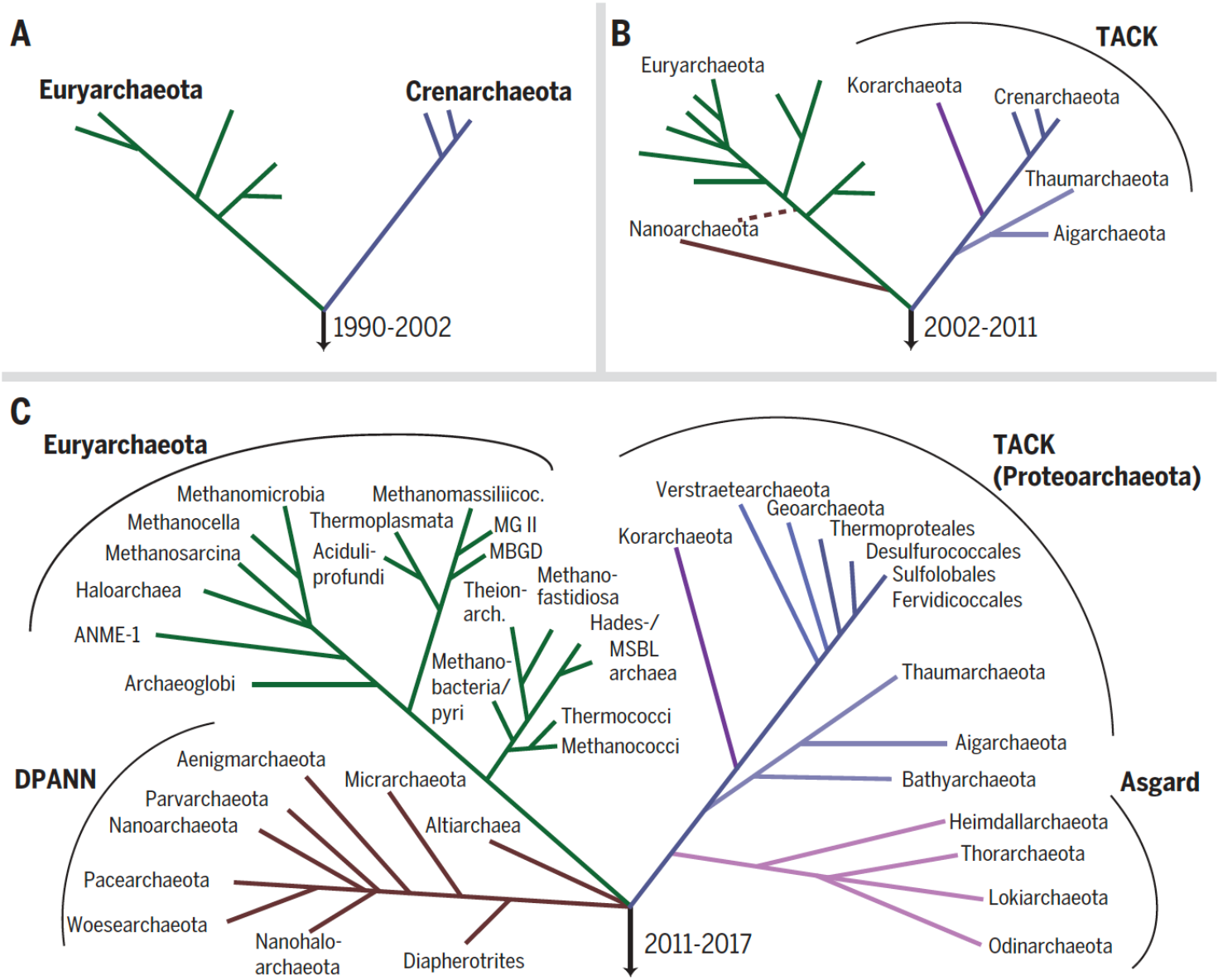
Langwig et al. *ISME J 2022*

Protein clusters have distinct metabolisms



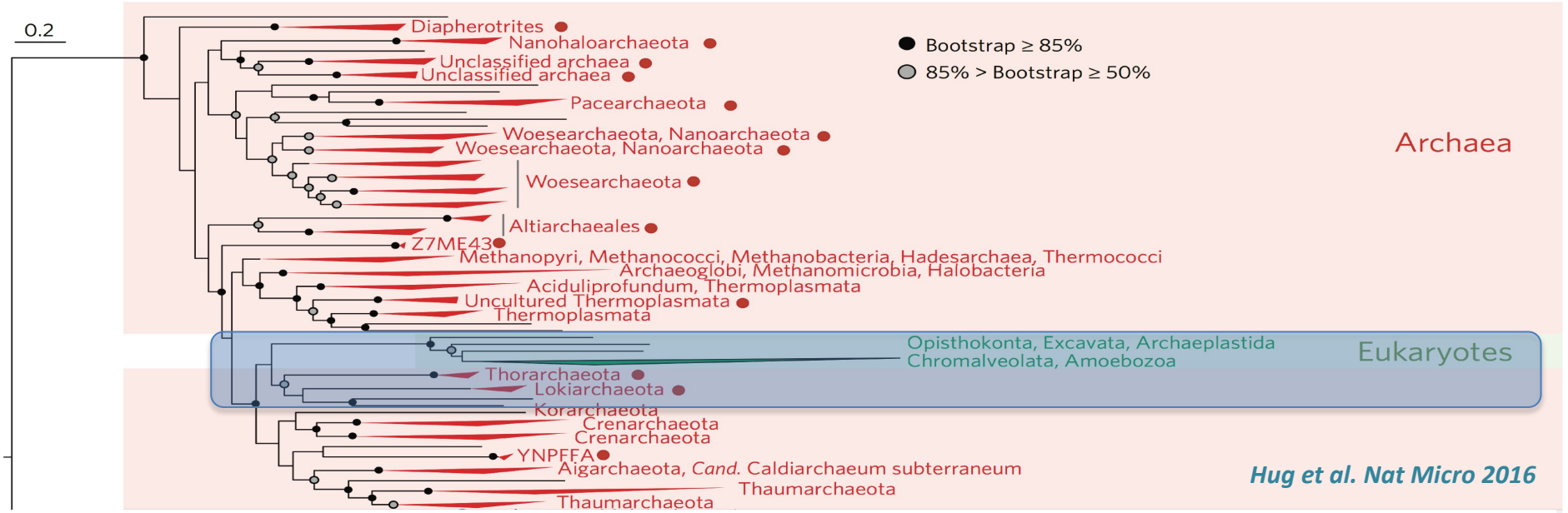

Asgard archaea

The growing tree of archaea



“The deepest branchings of this tree take us into uncharted evolutionary waters; the door to understanding earlier, more primitive forms of life has opened.” Carl Woese 2000

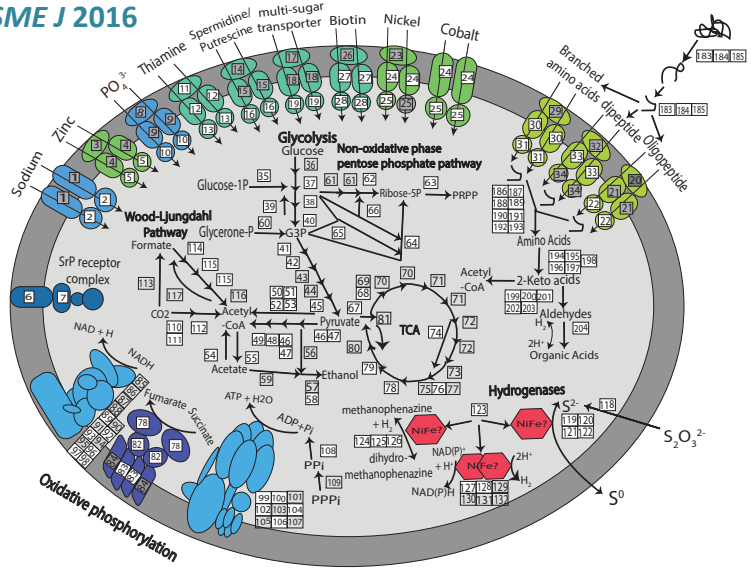
New Archaea related to eukaryotes



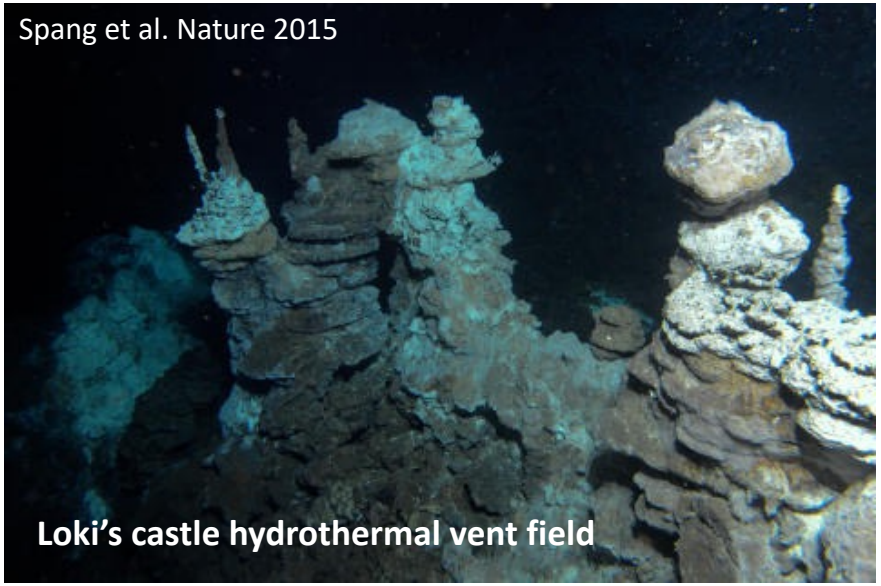
Hug et al. Nat Micro 2016

Thorarchaeota

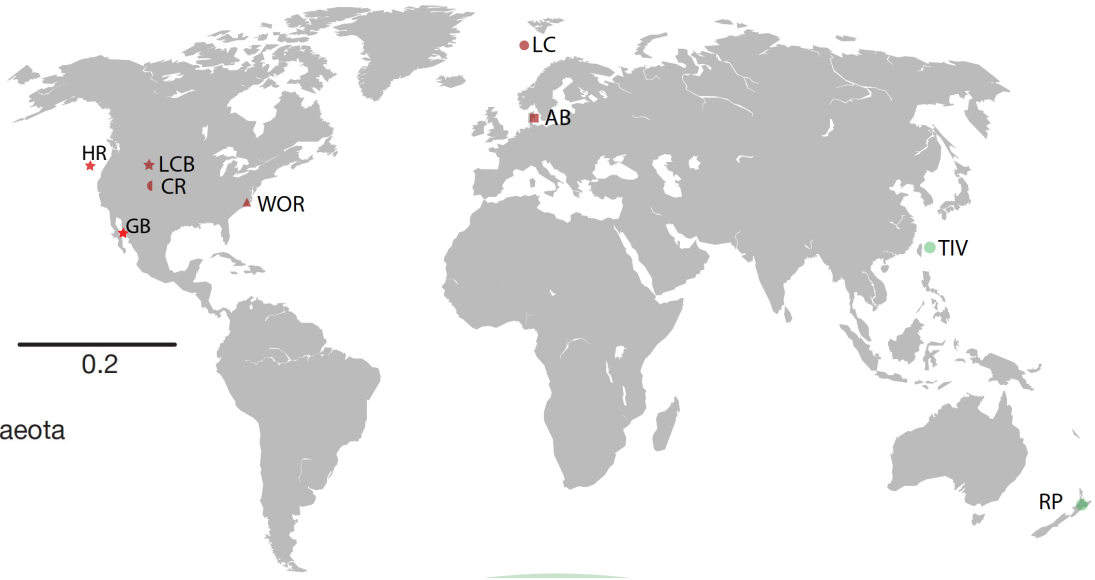
Seitz et al *ISME J* 2016

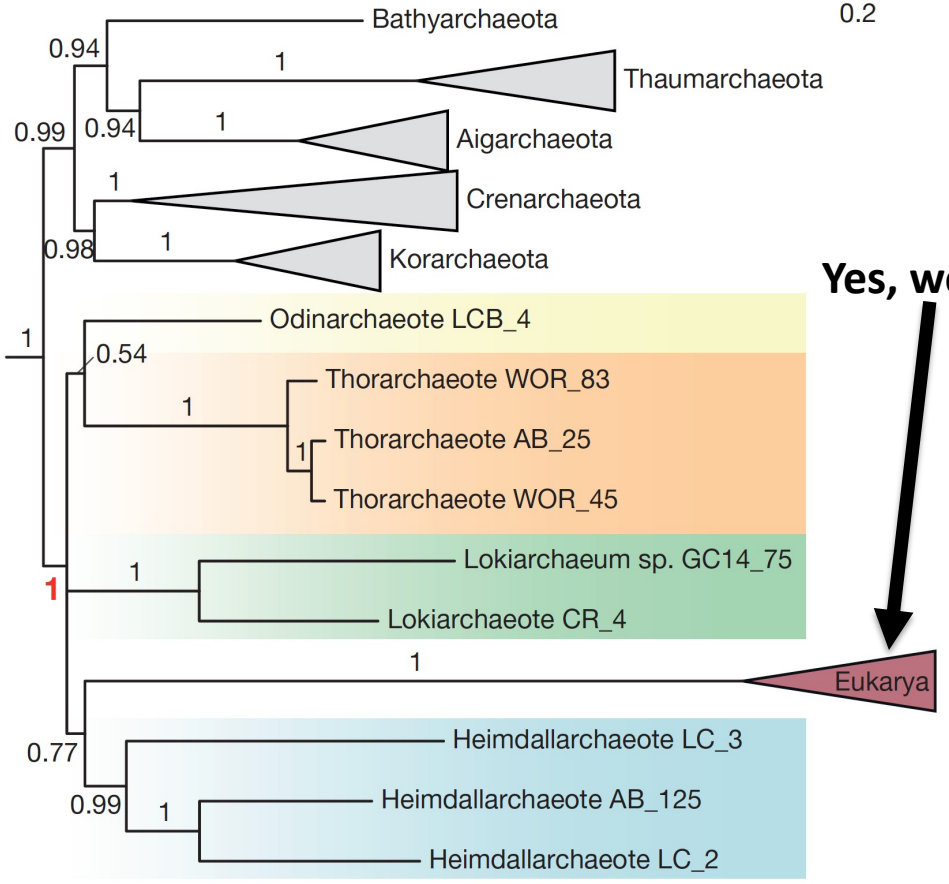


Lokiarchaeota

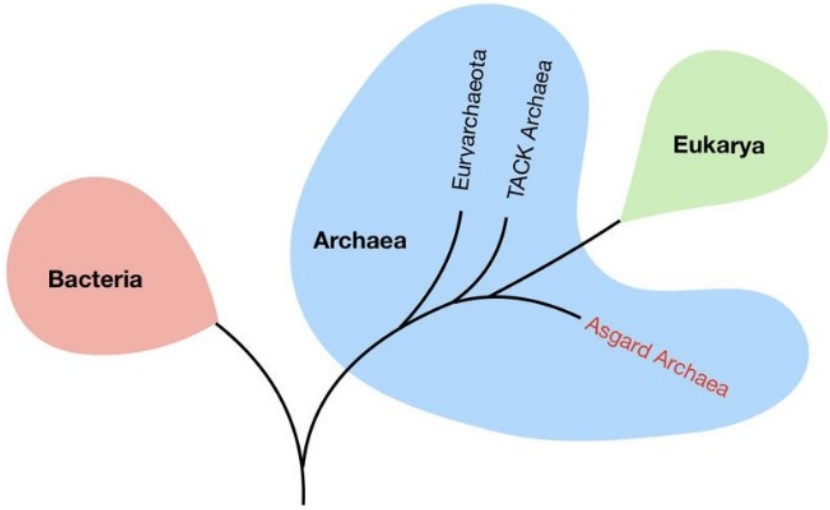


Asgard archaea





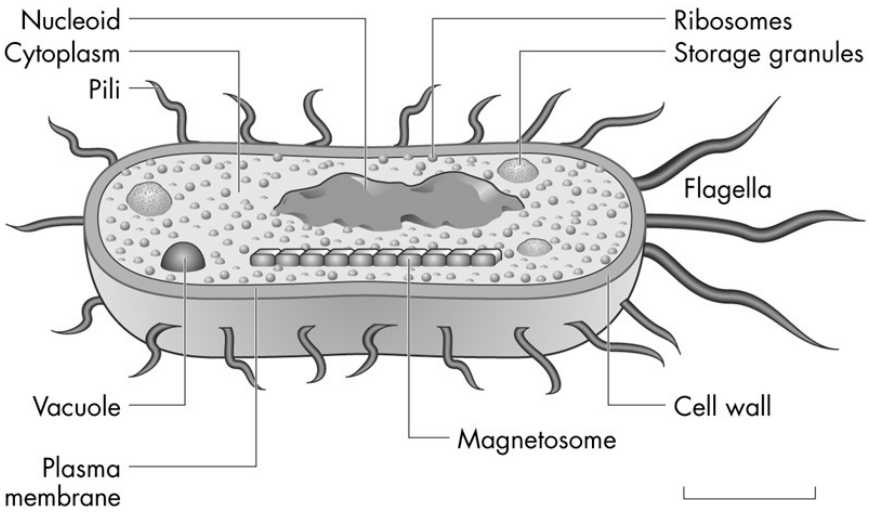
Yes, we are Asgardian!



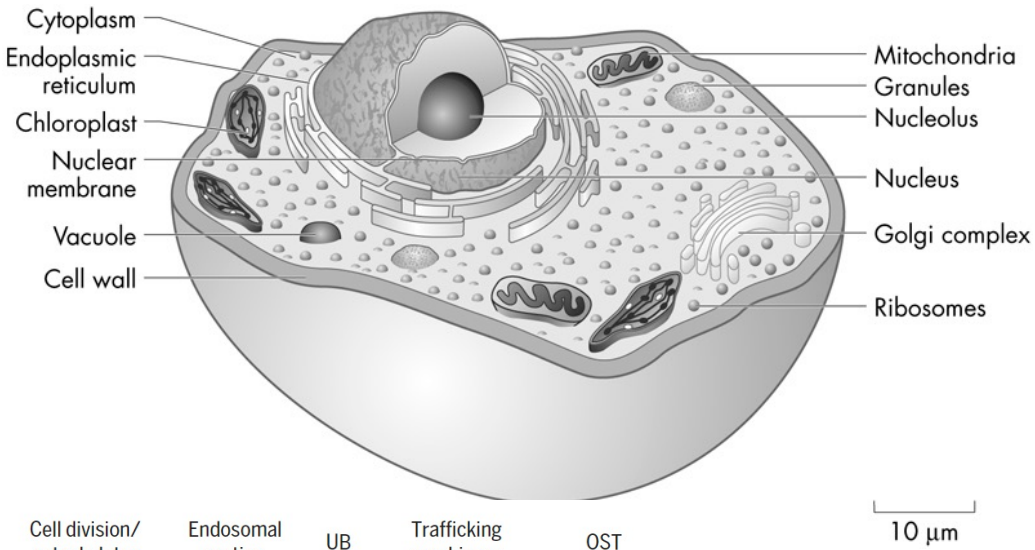
Zaremba-Niedziedzka et al *Nature* 2017

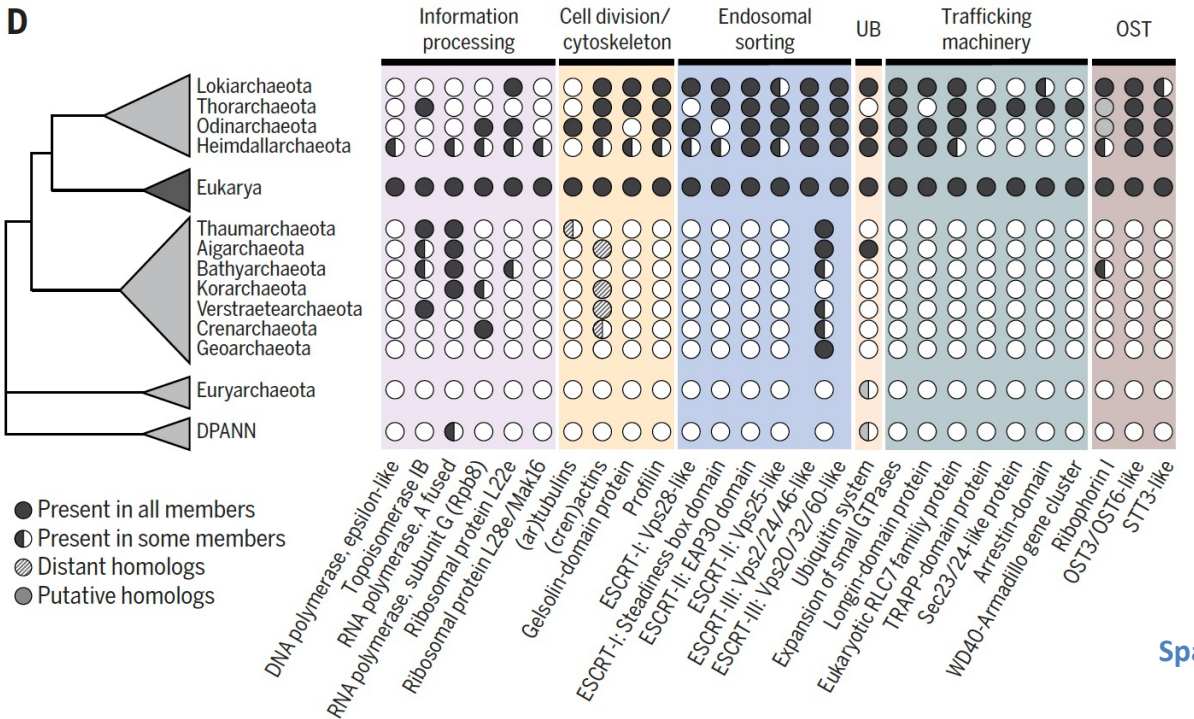
Asgard archaea contain several eukaryotic proteins

prokaryote



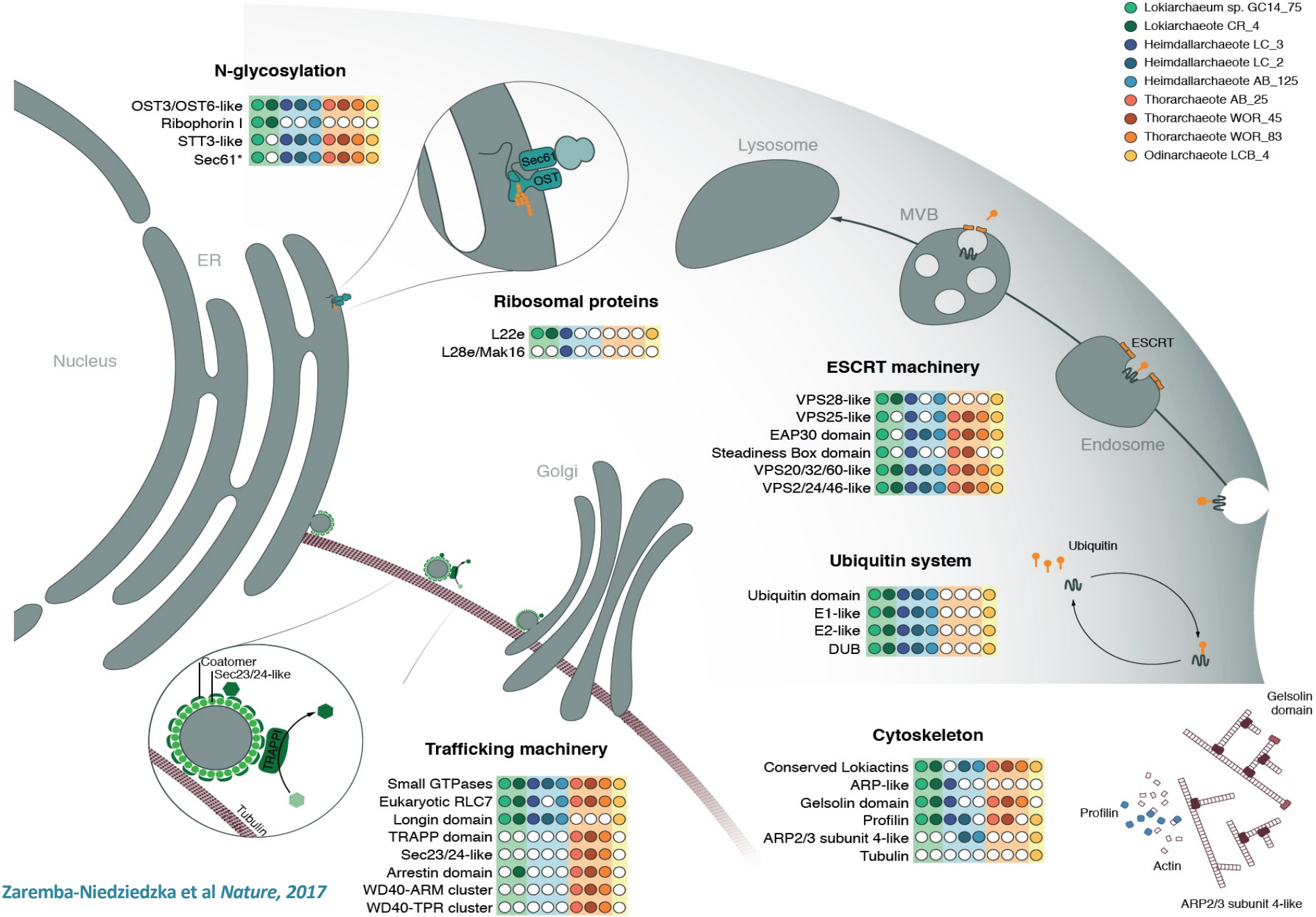
eukaryote





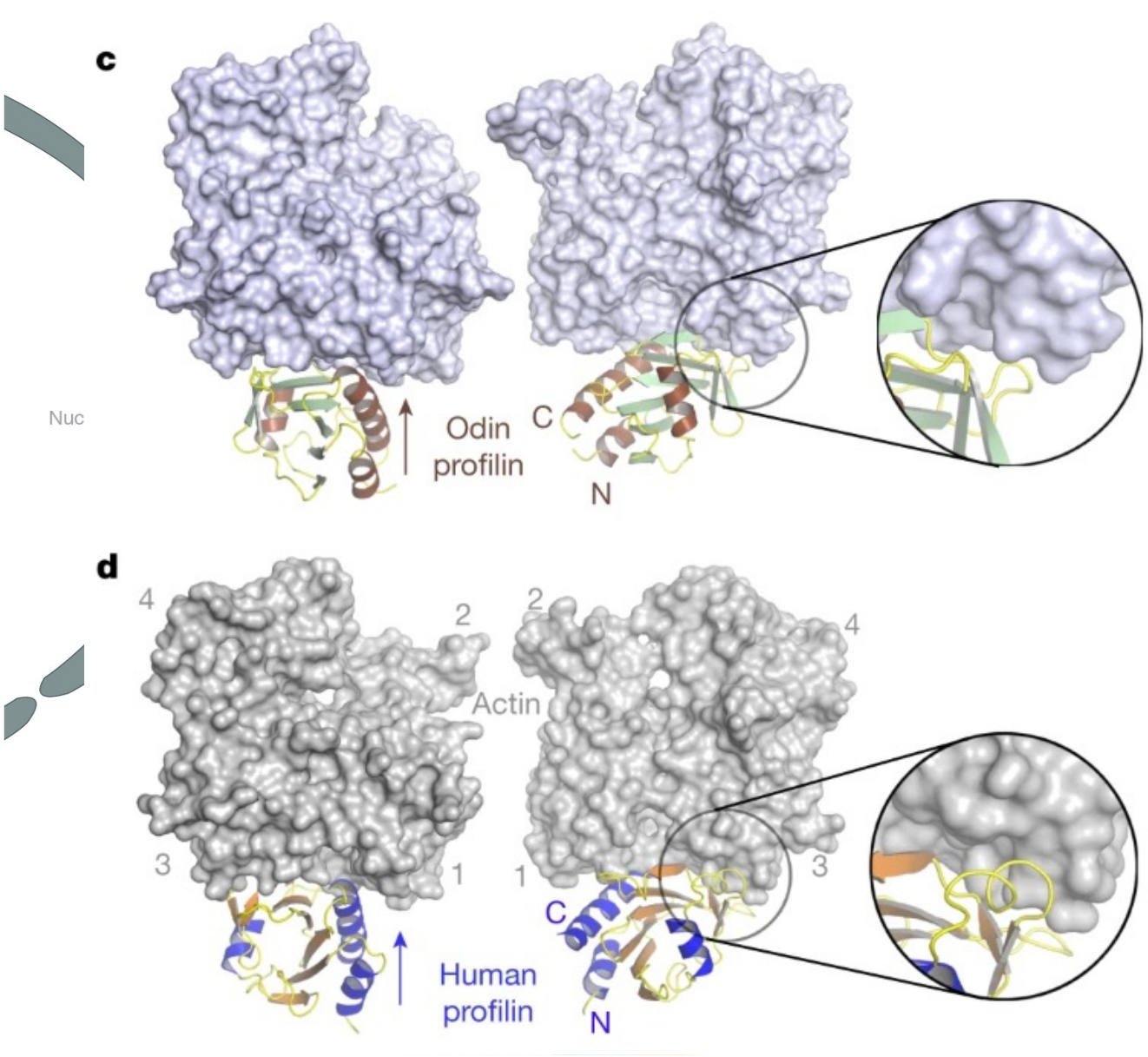
Spang et al. Science, 2017

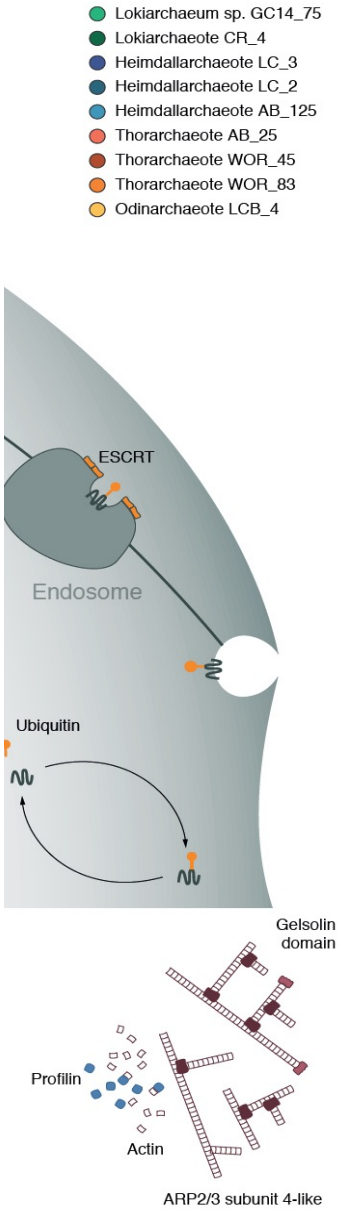
ESP = eukaryotic signature proteins are widespread in Asgard



Zaremba-Niedziedzka et al *Nature, 2017*

ESPs are widespread in Asgard archaea

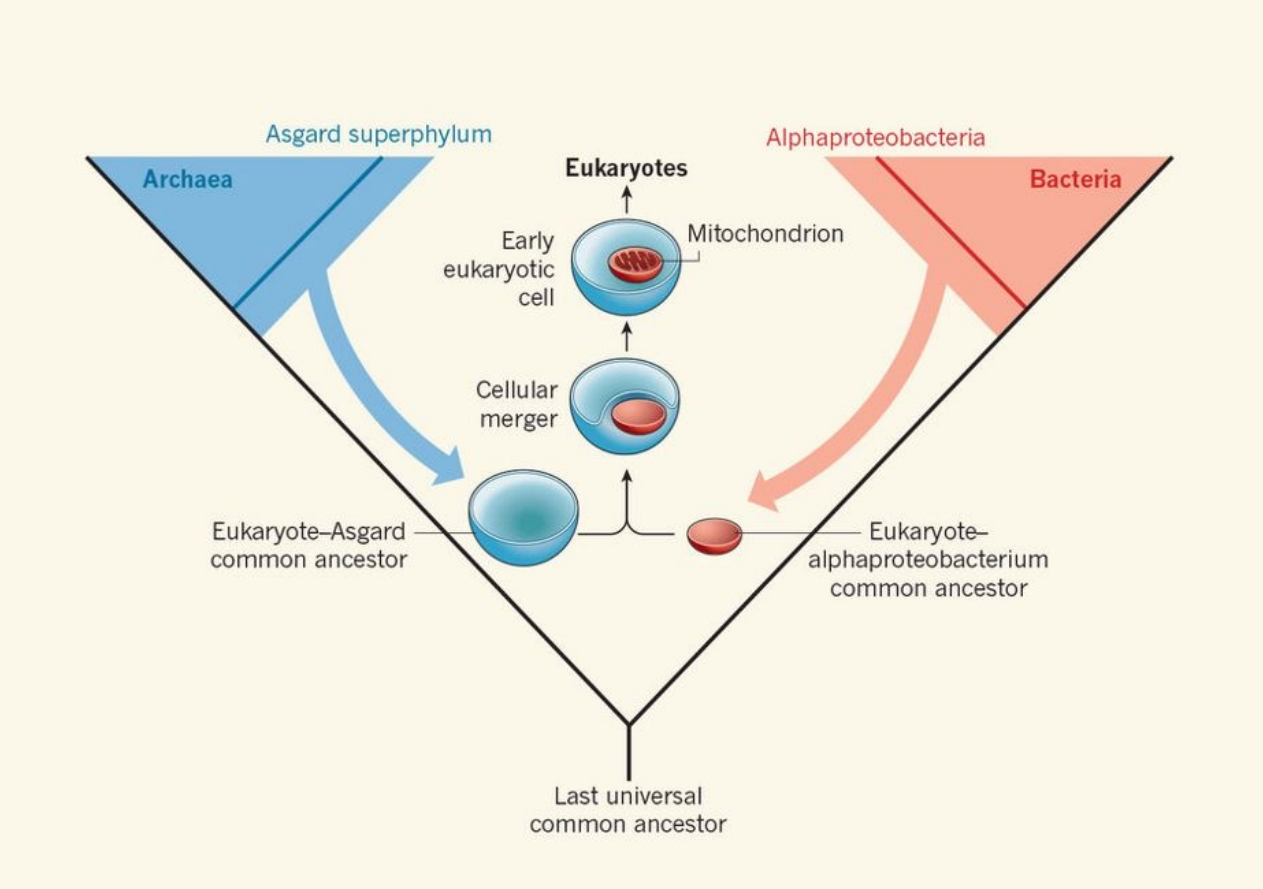




Akil and Robinson, Nature 2018

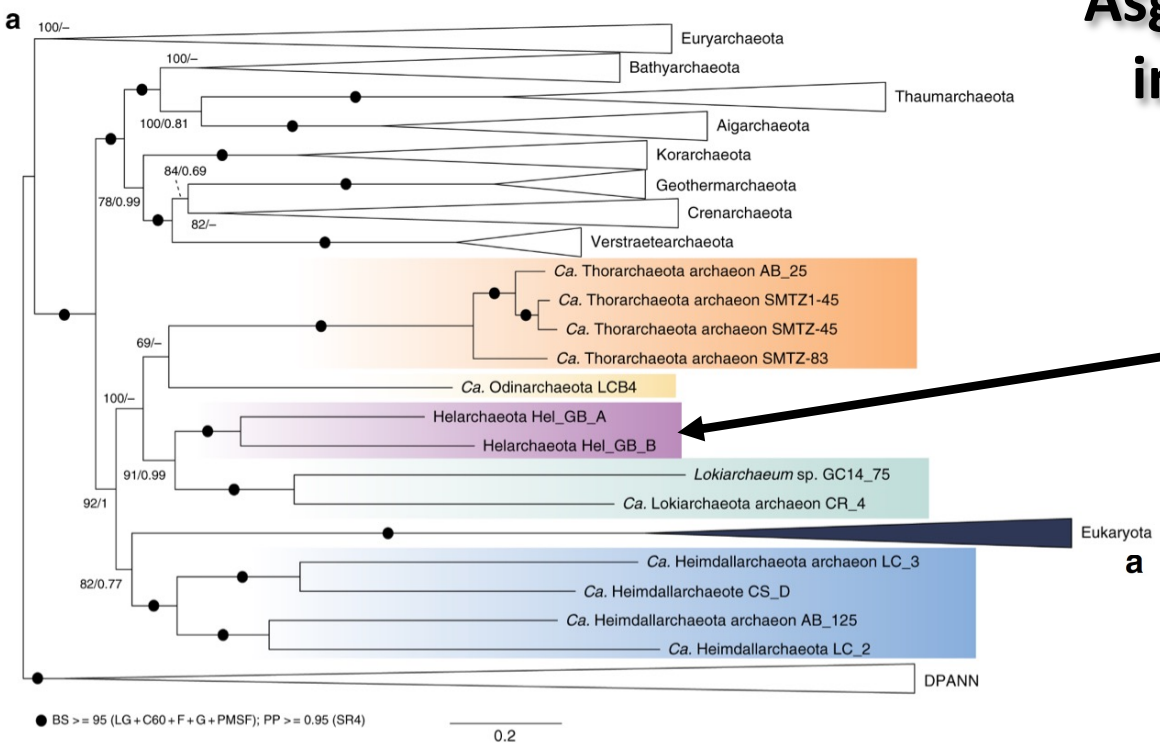
Zaremba-Niedziedzka et al *Nature* 2017

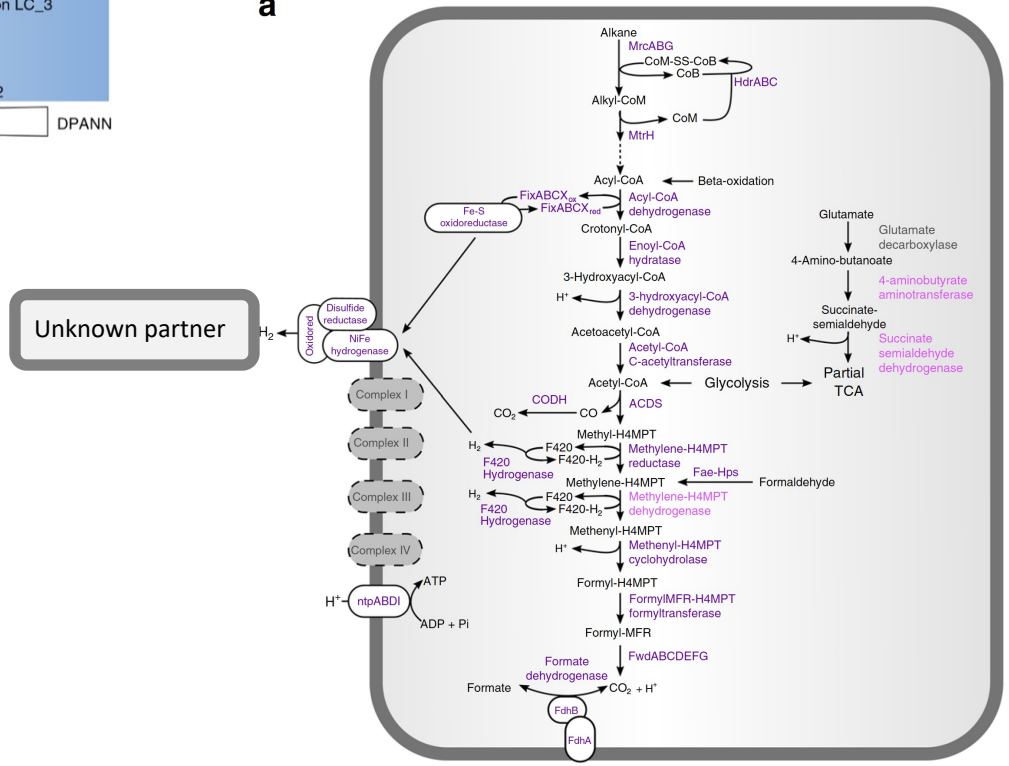
What does this mean for our understanding of eukaryotic evolution?



McInerney and O'Connell, Nature 2017

Asgard appear to be involved in symbiotic relationships



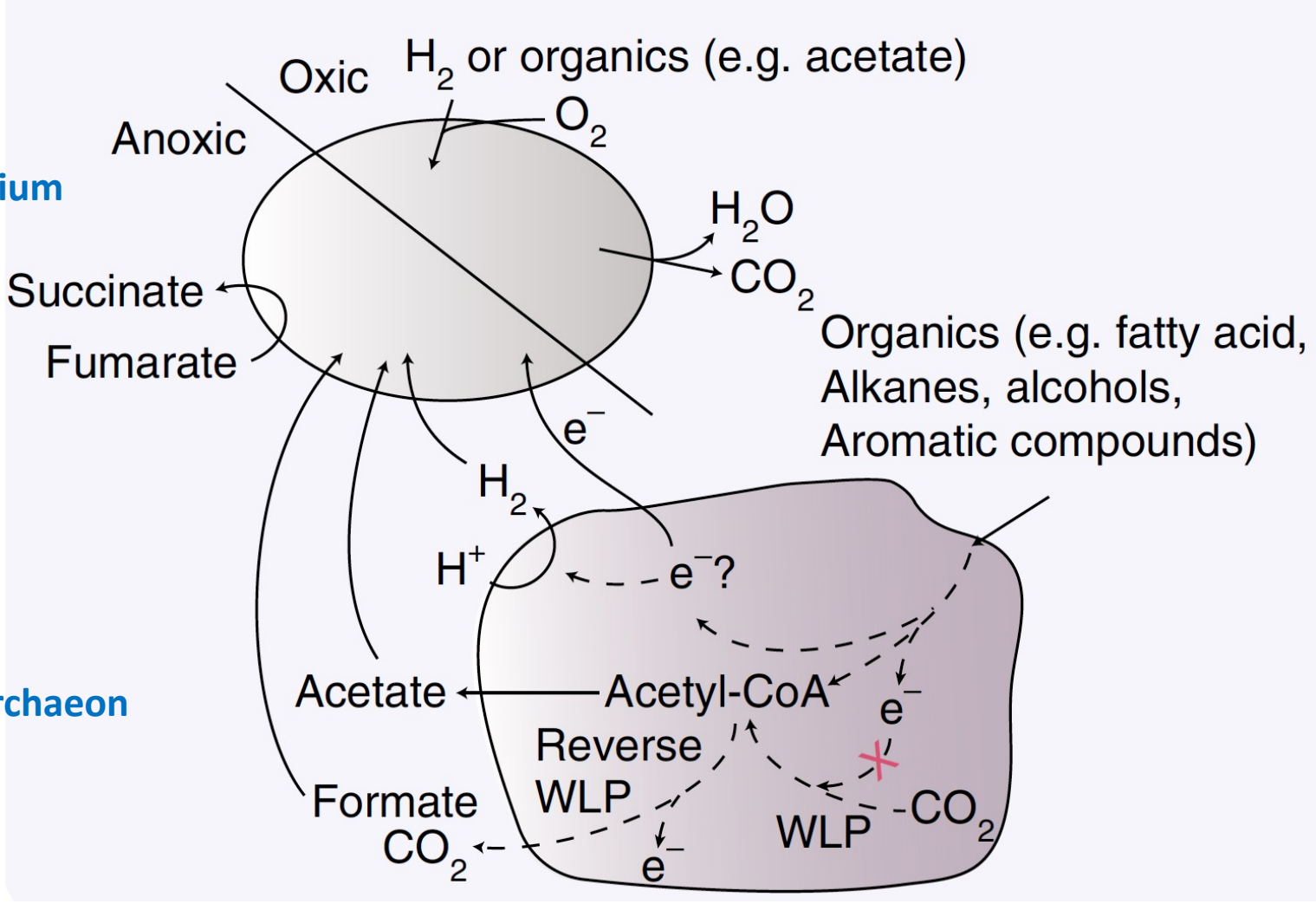


Seitz et al *in Nature Comm 2019*

New model for interactions -> origin of eukaryotes

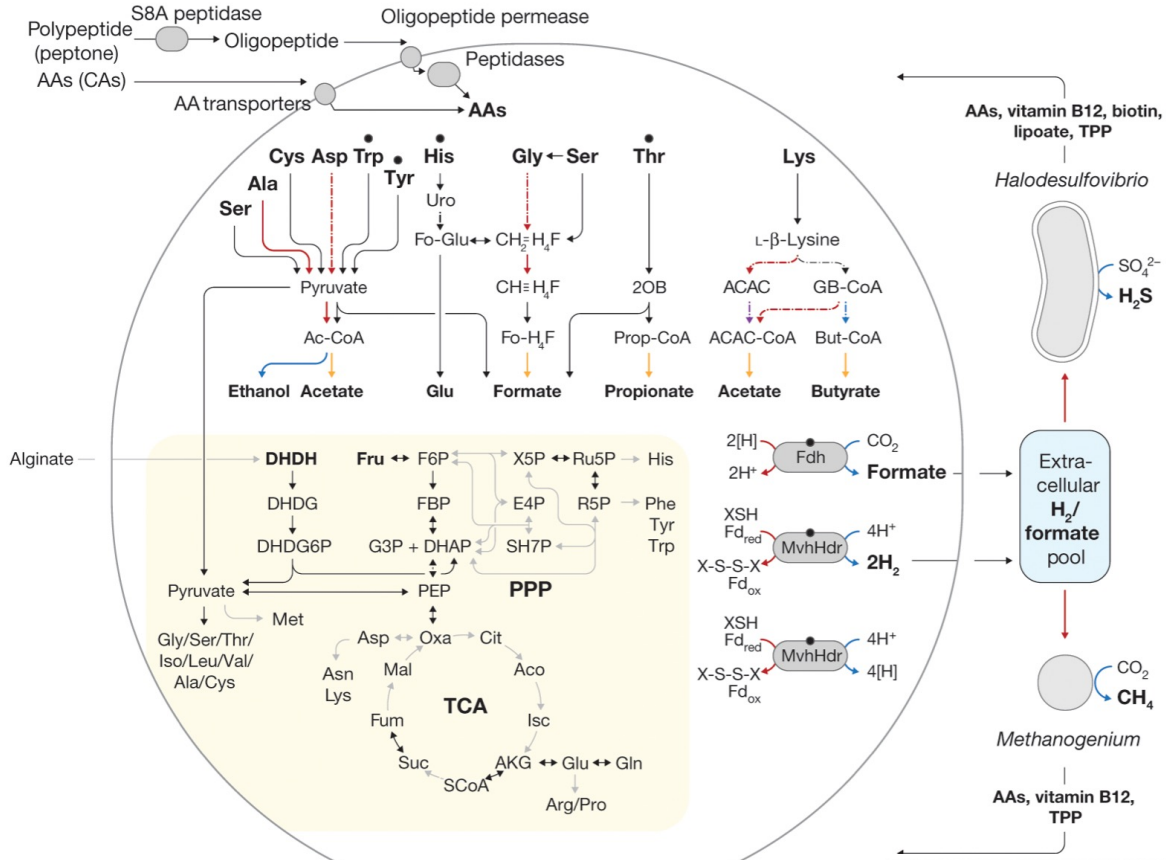
Alphaproteobacterium

Ancestral Asgard archaeon

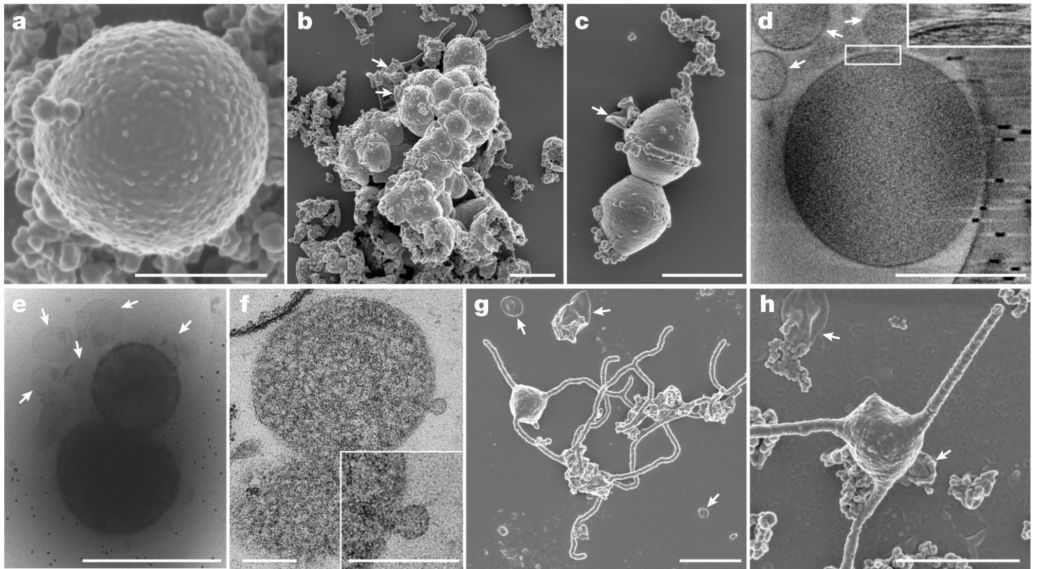


Spang et al. Nature Micro. 2019.

Cultivation of a Lokiarchaeum



Imachi et al Nature, 2020



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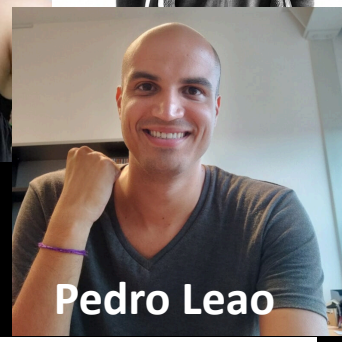

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