Biological diversity

Virginie COURTIER-ORGOGOZO

Sept 2019

What is life ?

From molecules to ecosystems

The tree of life
Individuals and interconnections

Anthropocene

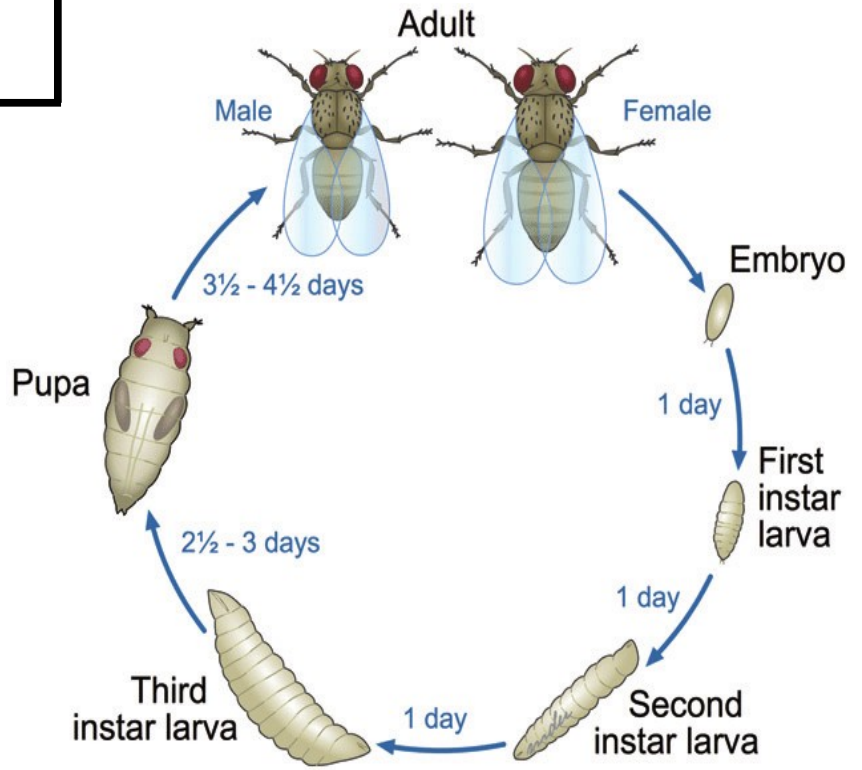
My lab topic: How do species diverge with time ?

D. pachea

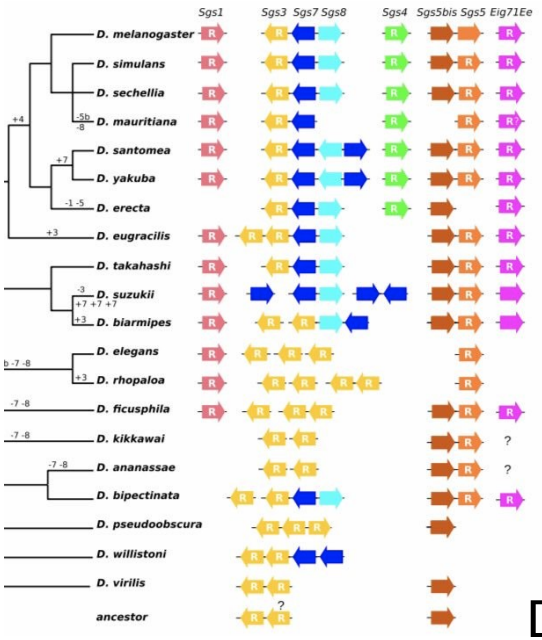
only senita cactus

D. nannoptera

many cactus species



Evolution of Drosophila glue



Da Lage et al. 2019 BMC Evol Biol

Evolution of left-right asymmetry in *D. pachea*

What is life ?

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Anthropocene

LIFE SCIENCES

LS1 Molecular Biology, Biochemistry, Structural Biology and Molecular Biophysics

LS2 Genetics, 'Omics', Bioinformatics and Systems Biology

LS3 Cellular and Developmental Biology

LS4 Physiology, Pathophysiology and Endocrinology

LS5 Neurosciences and Neural Disorders

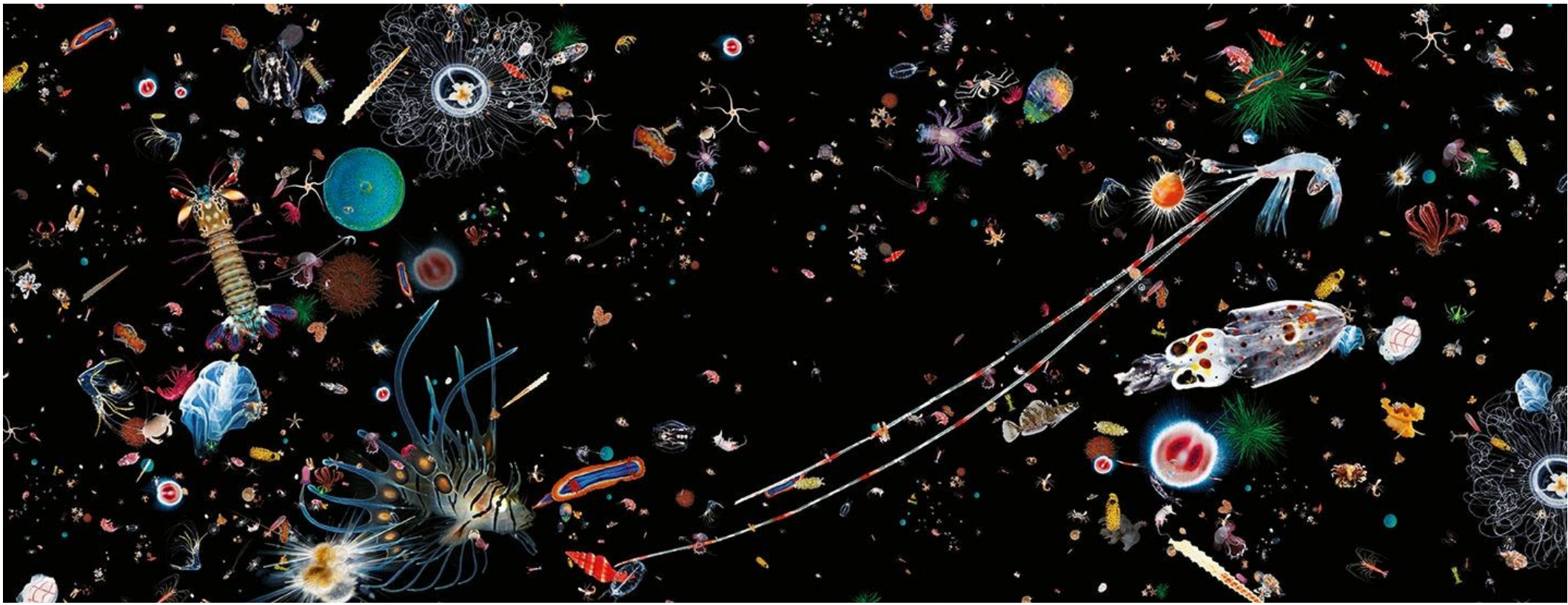
LS6 Immunity and Infection

LS7 Applied Medical Technologies, Diagnostics, Therapies, Public Health

LS8 Ecology, Evolution and Environmental Biology

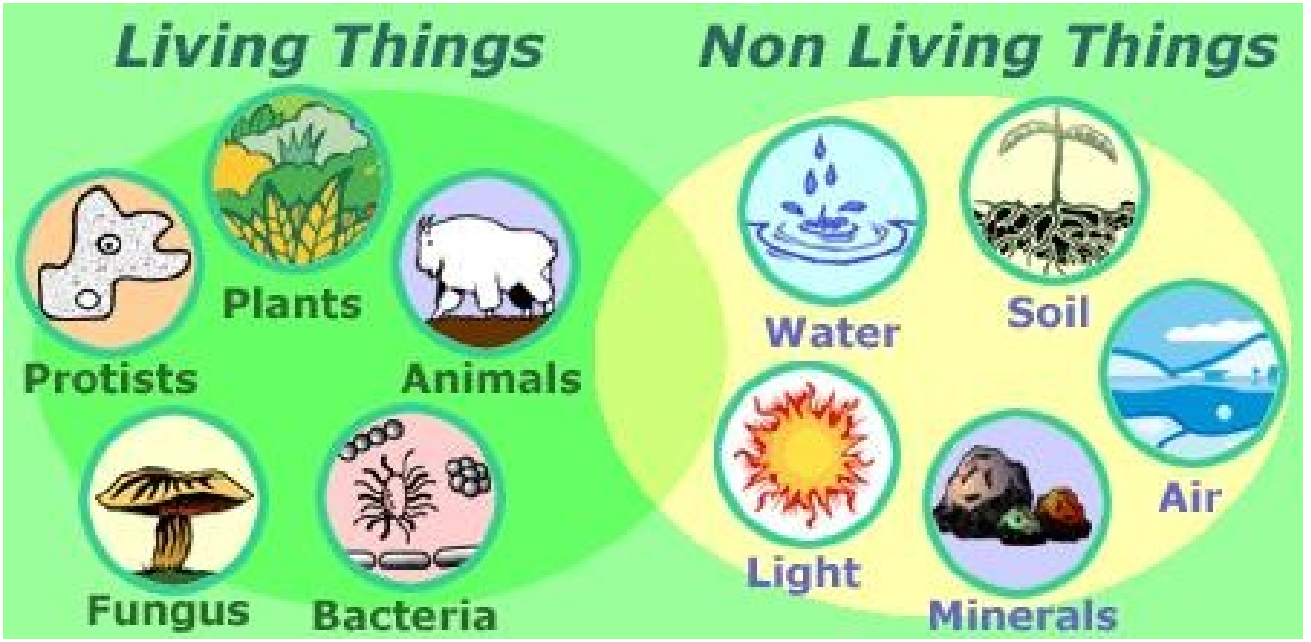
LS9 Applied Life Sciences, Biotechnology and Molecular and Biosystems Engineering

« La nature n’est jamais aussi grande que dans ses créatures les plus petites » (Pline l’Ancien)



What is life ?

What are the properties of the living world ?


Living Things
Non Living Things
Plants
Protists
Animals
Fungus
Bacteria
Water
Soil
Air
Light
Minerals

Fire
The sun
A virus
A computer virus
A mule (sterile hybrids)
A fœtus in the mother’s womb
A sperm cell
A spore that will never germinate
A sea urchin oocyte that will not be fertilized
The earth

Properties of the living world

Metabolism
Ability to reproduce
Auto-organization properties

Delimited by a membrane
Made of cells
Contains nucleic acids

What is the difference
between humans and other organisms ?

Humans versus other organisms

Several conceptions in different cultures

Our conception:
Naturalism (same physicality between humans and other organisms, all can be explained by this physicality)

Other views:
Animism (each living species has its own physicality and interiority and thus views the world in its own way)

Totemism (certain groups of humans have the same physicality and internality as certain groups of animals)
Ex: catcher (white cockato *cacatoès*) / watcher (raven)

Analogism (all types of physicalities and interiorities can be combined)

Descola 2005

Theodore Schwann, 1839

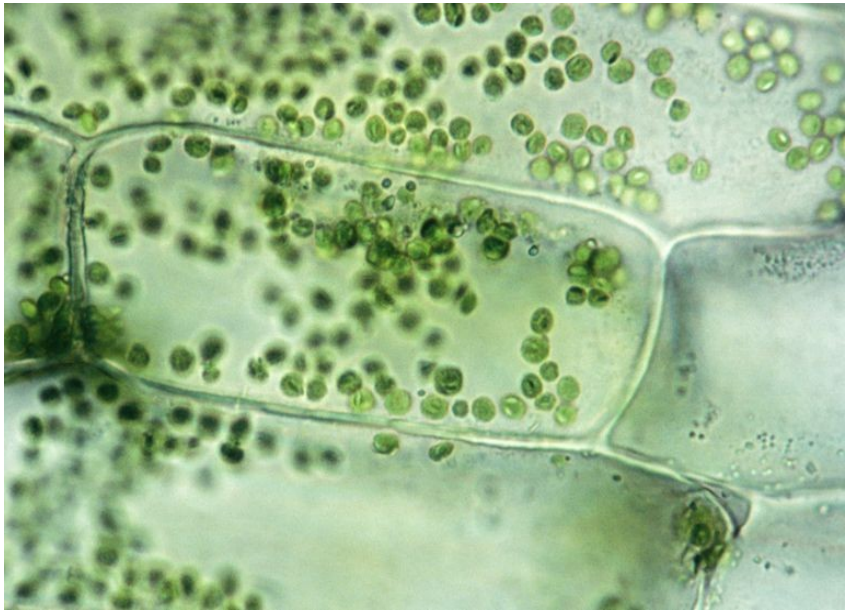
"*All living things are composed of cells and cell products*"

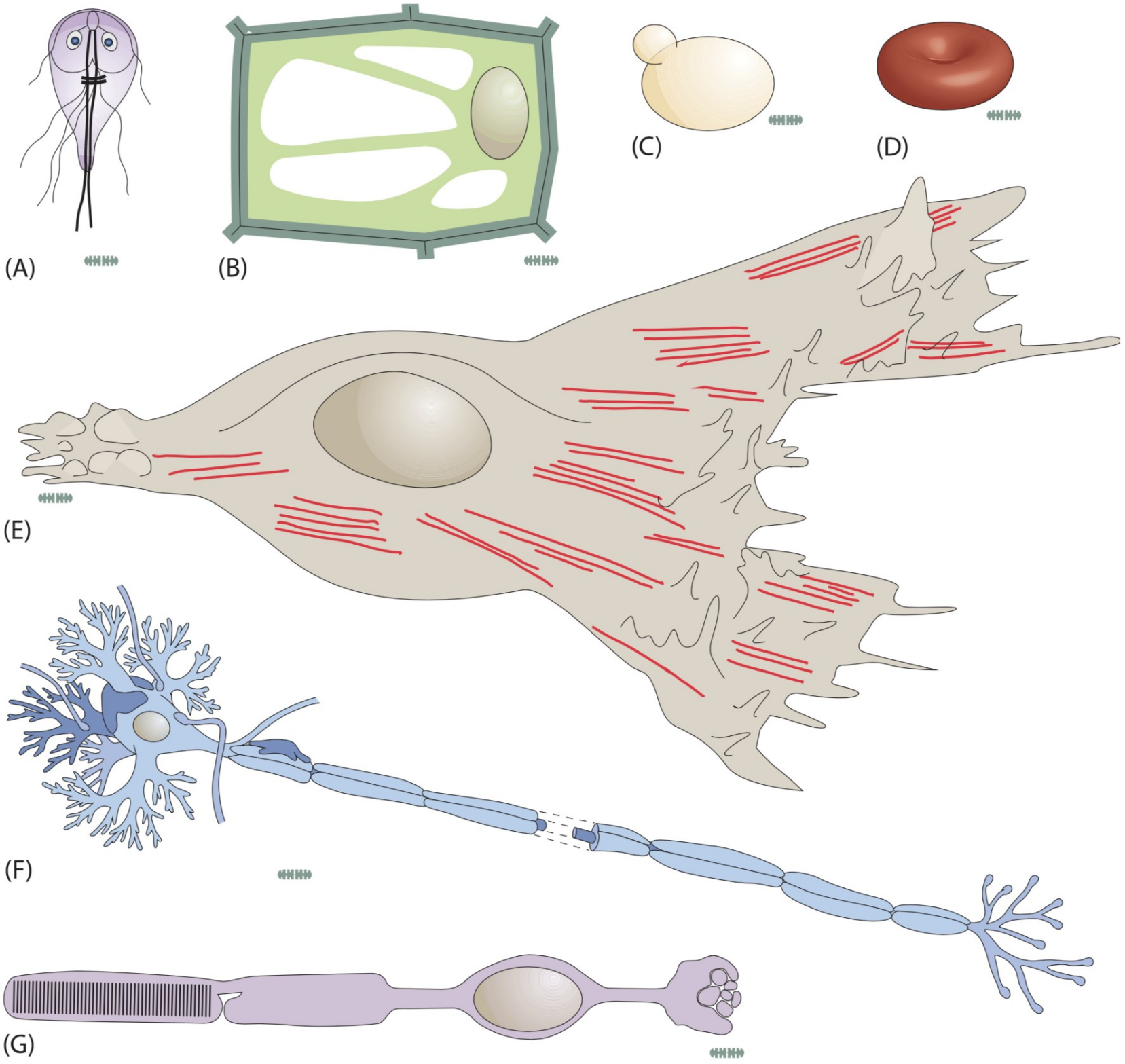
1) The cell is the unit of structure, physiology, and organization in living things.

2) The cell retains a dual existence as a distinct entity and a building block in the construction of organisms.

Rudolf Virchow, 1857

Every cell arises from another cell




(A)
(B)
(C)
(D)
(E)
(F)
(G)

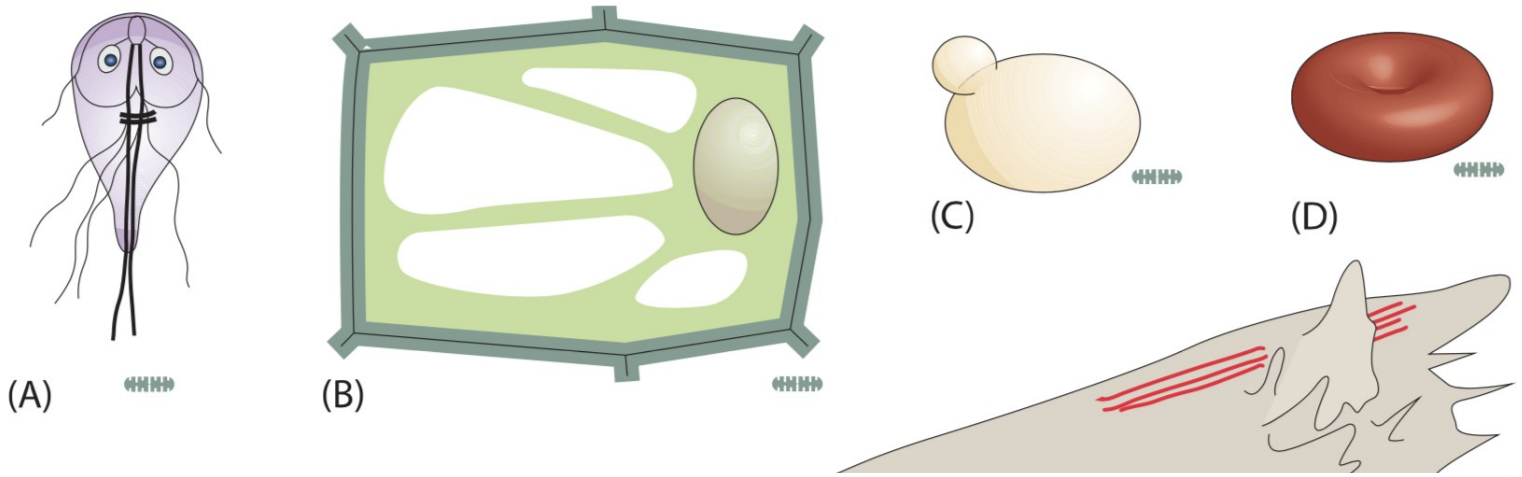
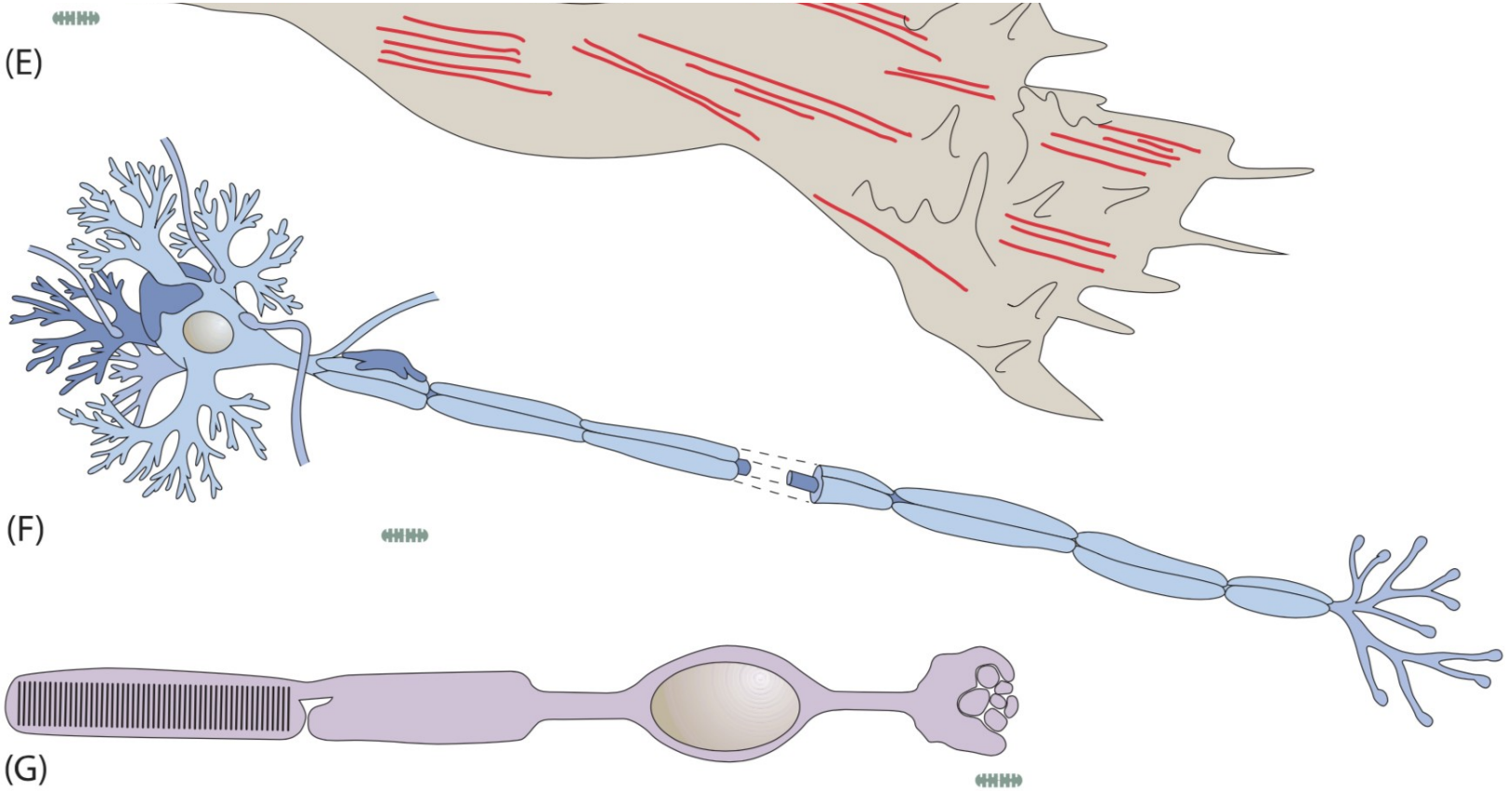
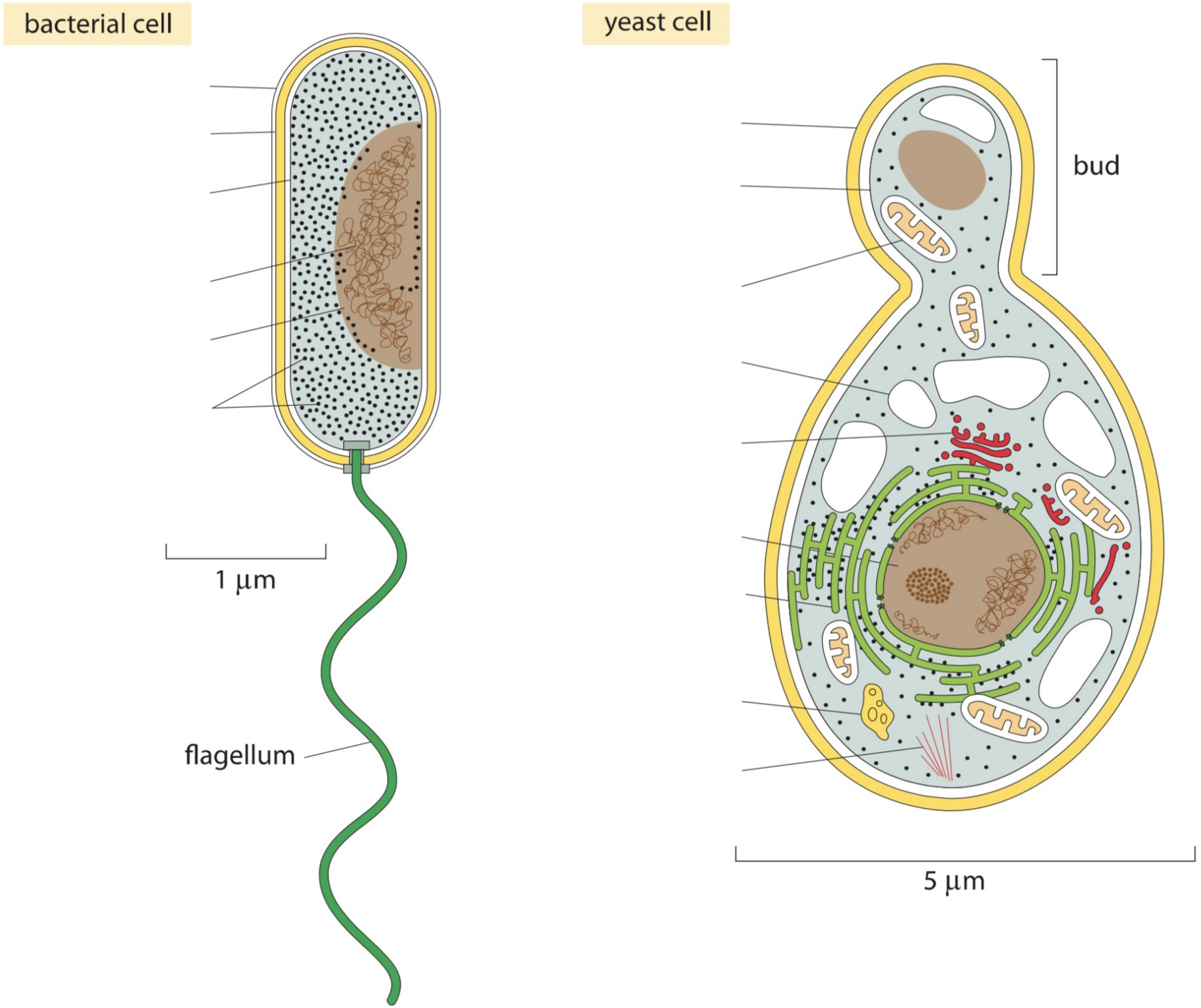
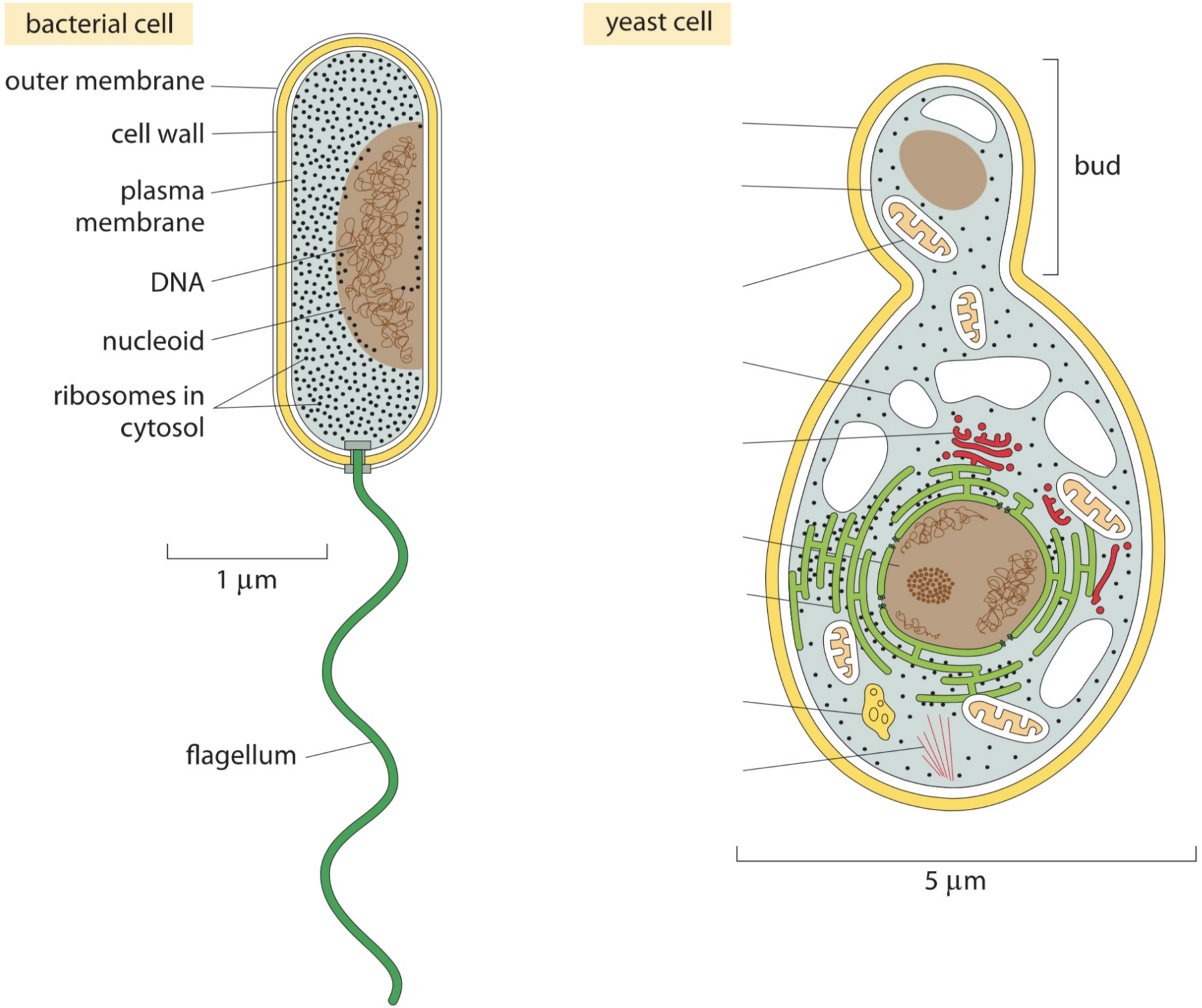


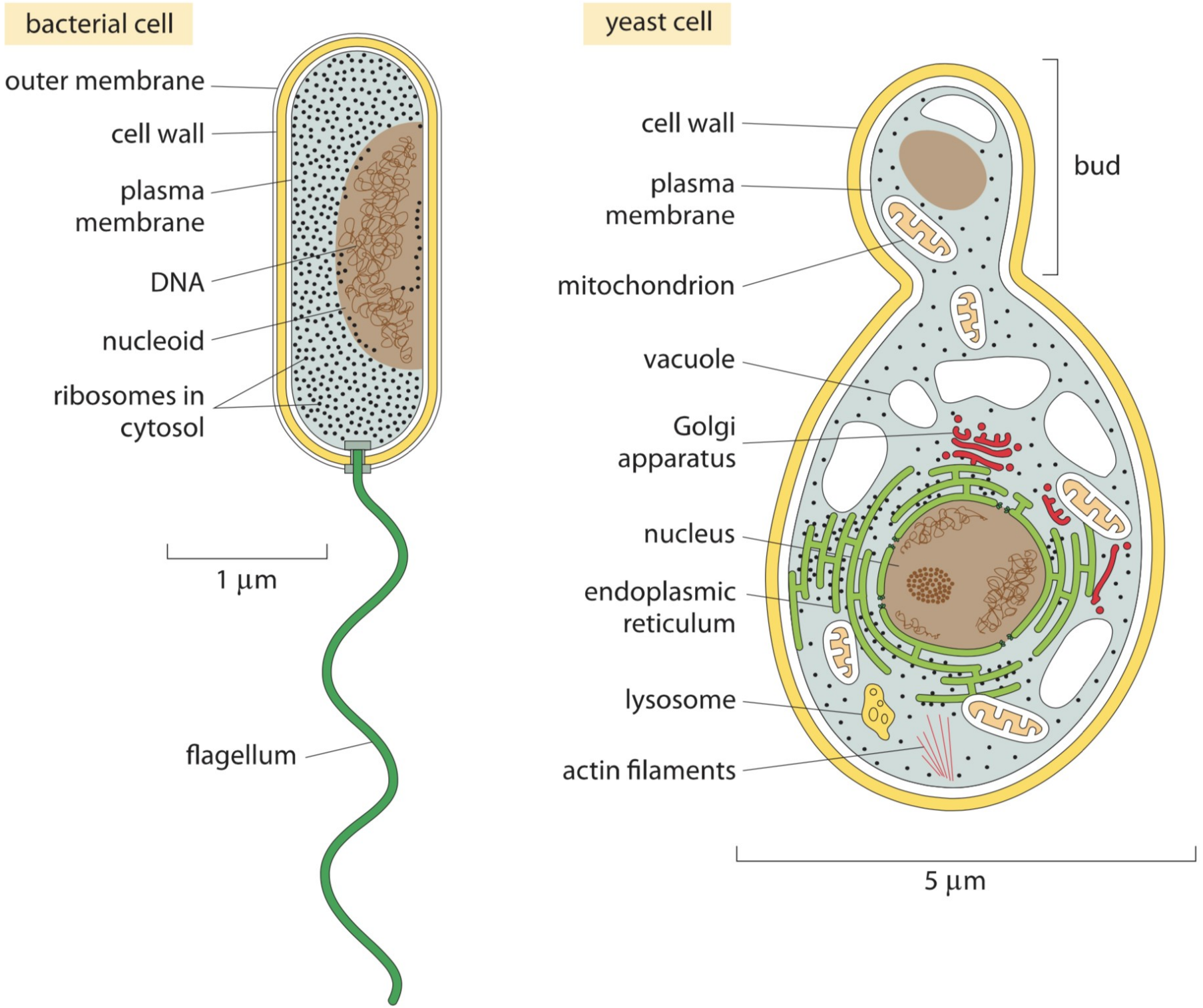
Figure 4: Cartoons of several different types of cells all referenced to a standard *E. coli* ruler of 1 micron width drawn in grey. (A) The protist Giardia lamblia, (B) a plant cell, (C) a budding yeast cell, (D) a red blood cell, (E) a fibroblast cell, (F) a eukaryotic nerve cell, and (G) a rod cell from the retina.

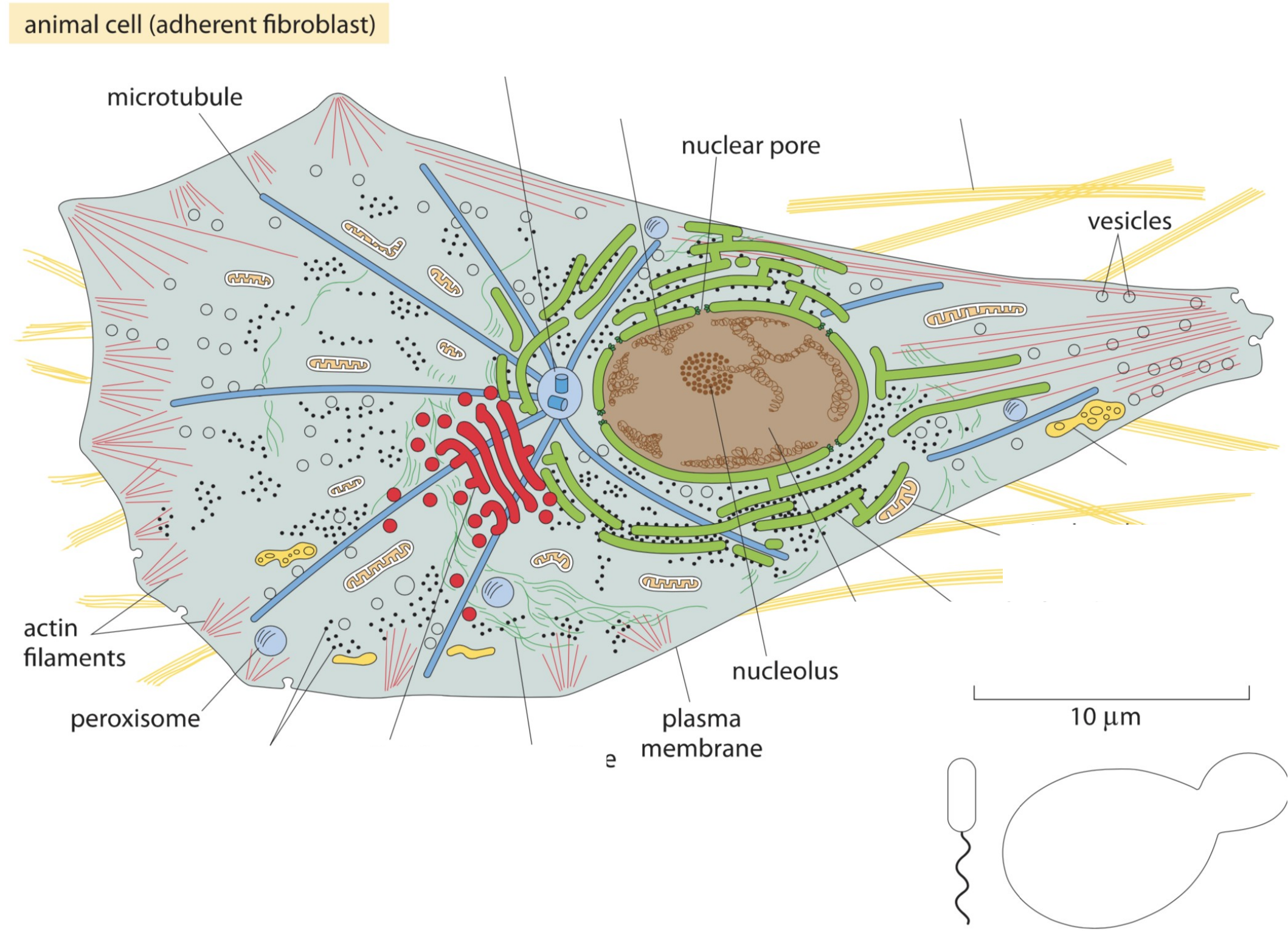


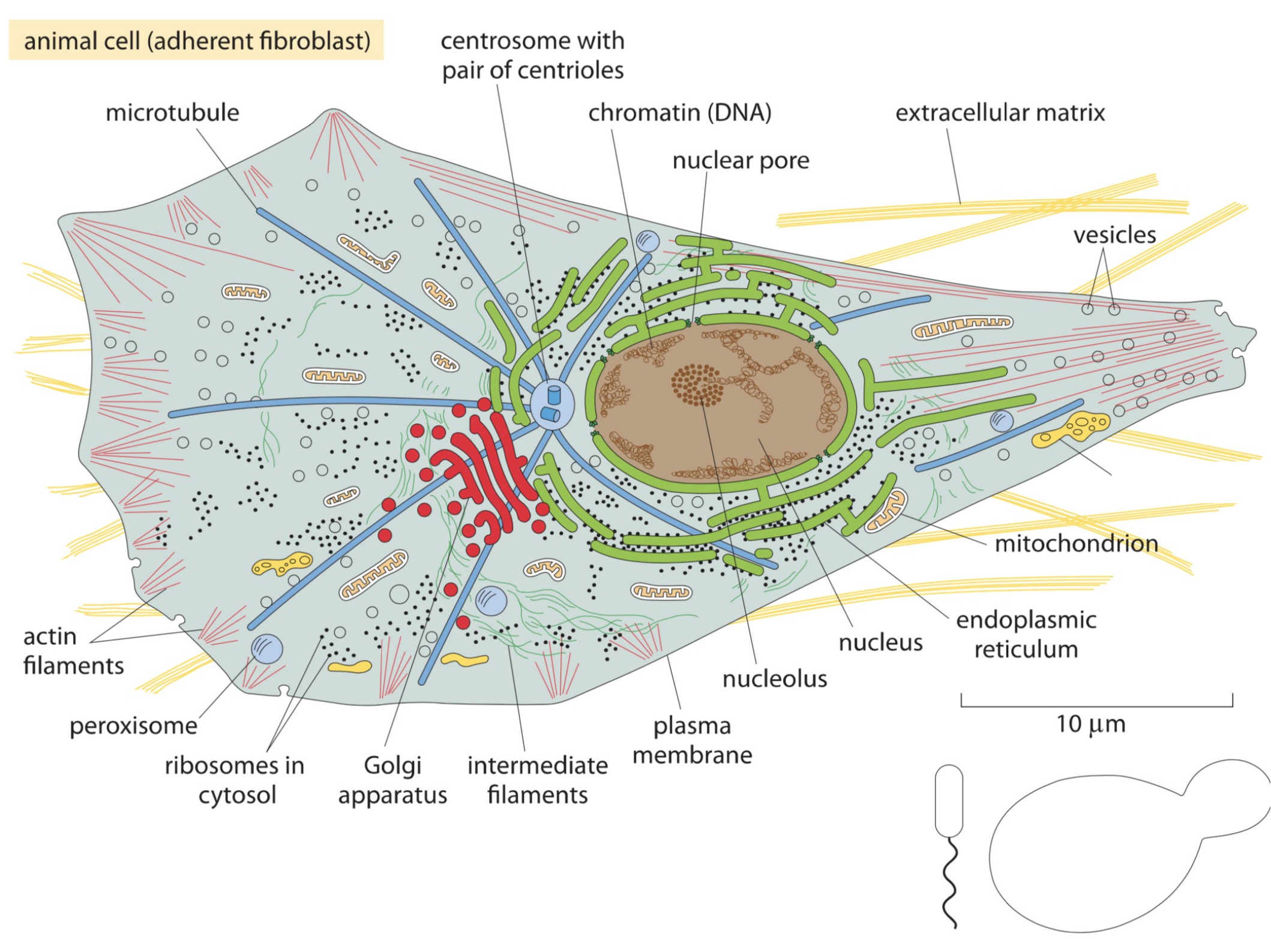
From cells to molecules


bacterial cell
1 µm
flagellum
yeast cell
bud
5 µm

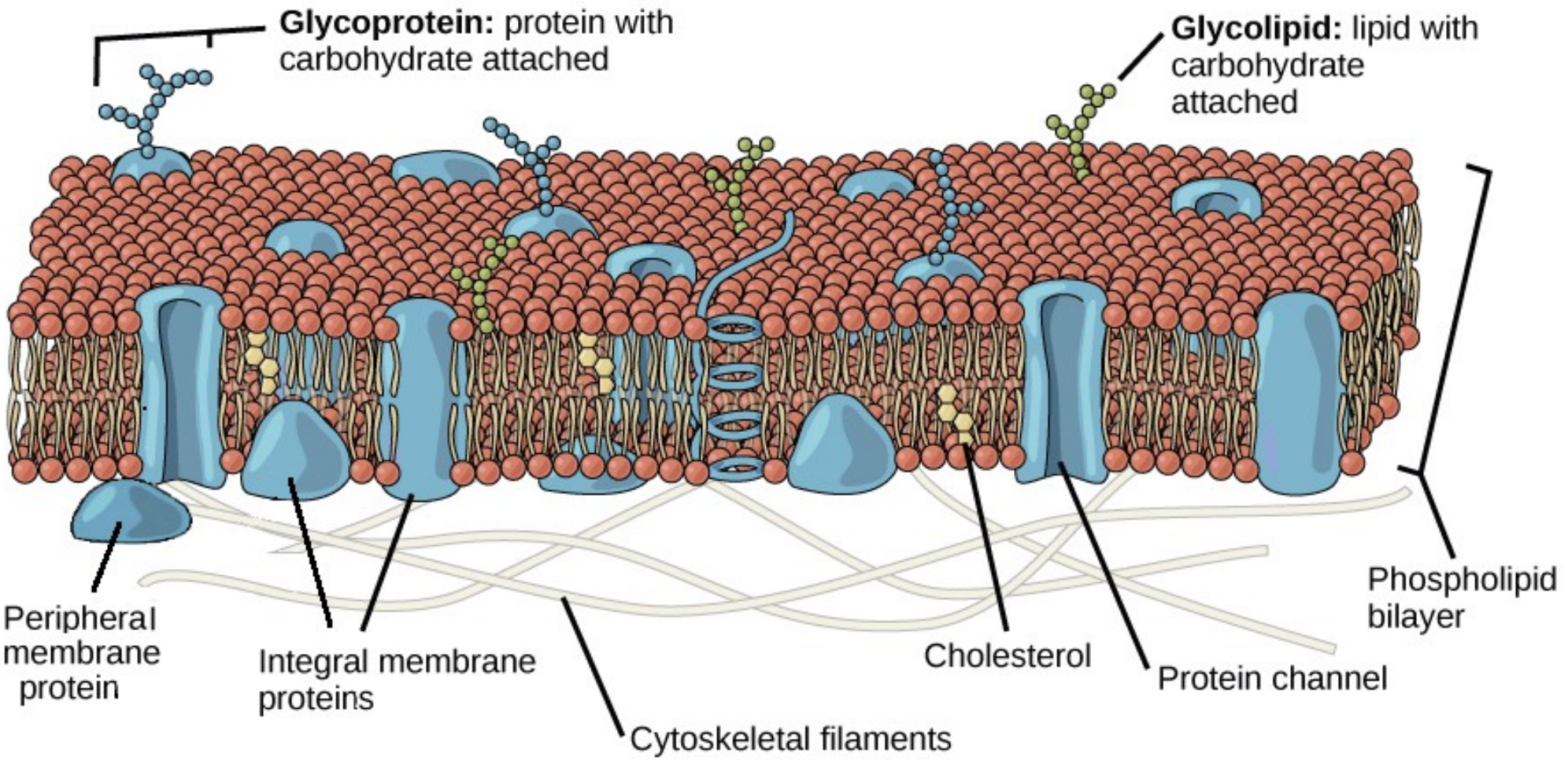

bacterial cell
outer membrane
cell wall
plasma membrane
DNA
nucleoid
ribosomes in cytosol
1 µm
flagellum
yeast cell
bud
5 µm


bacterial cell
outer membrane
cell wall
plasma membrane
DNA
nucleoid
ribosomes in cytosol
1 µm
flagellum
yeast cell
cell wall
plasma membrane
mitochondrion
vacuole
Golgi apparatus
nucleus
endoplasmic reticulum
lysosome
actin filaments
bud
5 µm


animal cell (adherent fibroblast)
microtubule
nuclear pore
vesicles
actin filaments
peroxisome
nucleolus
plasma membrane
10 µm


animal cell (adherent fibroblast)
centrosome with pair of centrioles
microtubule
chromatin (DNA)
extracellular matrix
nuclear pore
vesicles
mitochondrion
endoplasmic reticulum
nucleus
nucleolus
plasma membrane
actin filaments
peroxisome
ribosomes in cytosol
Golgi apparatus
intermediate filaments
10 µm

David Goodsell


Glycoprotein: protein with carbohydrate attached
Glycolipid: lipid with carbohydrate attached
Peripheral membrane protein
Integral membrane proteins
Cytoskeletal filaments
Cholesterol
Protein channel
Phospholipid bilayer

nucleic acid: biopolymer composed of nucleotides, which are the monomers made of three components: a 5-carbon sugar, a phosphate group and a nitrogenous base. If the sugar is a compound ribose, the polymer is RNA (ribonucleic acid); if the sugar is deoxyribose, the polymer is DNA (deoxyribonucleic acid).

protein: large biomolecule consisting of one or more long chains of amino acid residues.

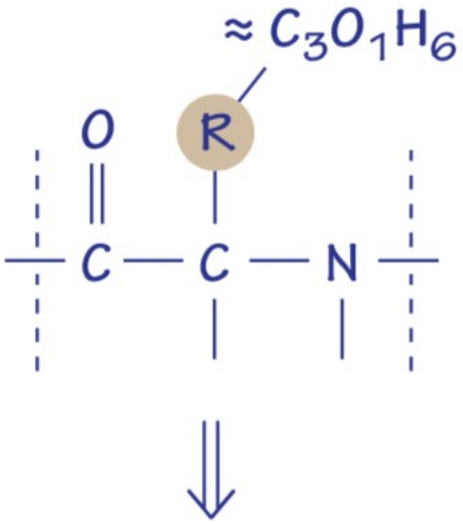
amino acid: organic molecule that contains amine (-NH2) and carboxyl (-COOH) functional groups, along with a side chain (R group) specific to each amino acid.

lipid: biomolecule soluble in nonpolar solvents. Functions of lipids include storing energy, signaling, and acting as structural components of cell membranes.

carbohydrate: biomolecule consisting of carbon (C), hydrogen (H) and oxygen (O) atoms, usually with the empirical formula Cm(H2O)n. Functions include storage of energy (e.g. starch and glycogen) and acting as structural components (e.g. cellulose in plants and chitin in arthropods).

main constituents of a cell

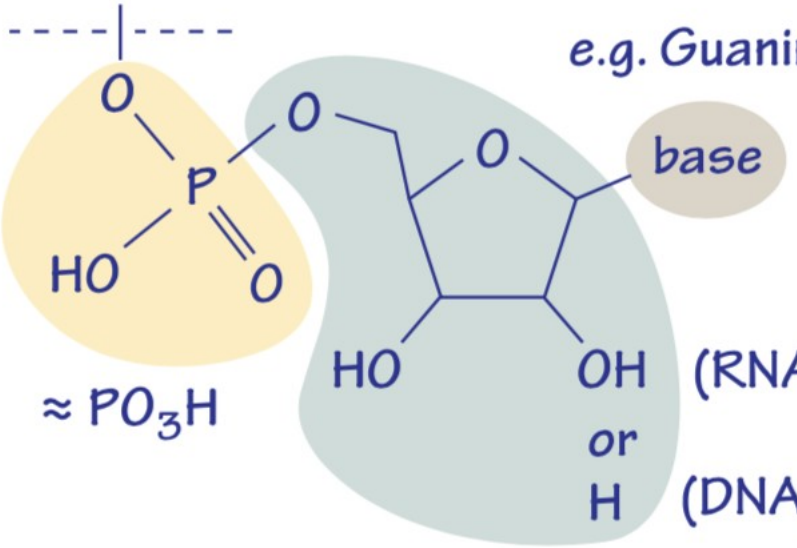
amino acids



≈ $N_1C_5O_2H_8$

≈ 110 Da

nucleotides



e.g. Guanine $N_5C_5O_1H_6$

≈ PO_3H

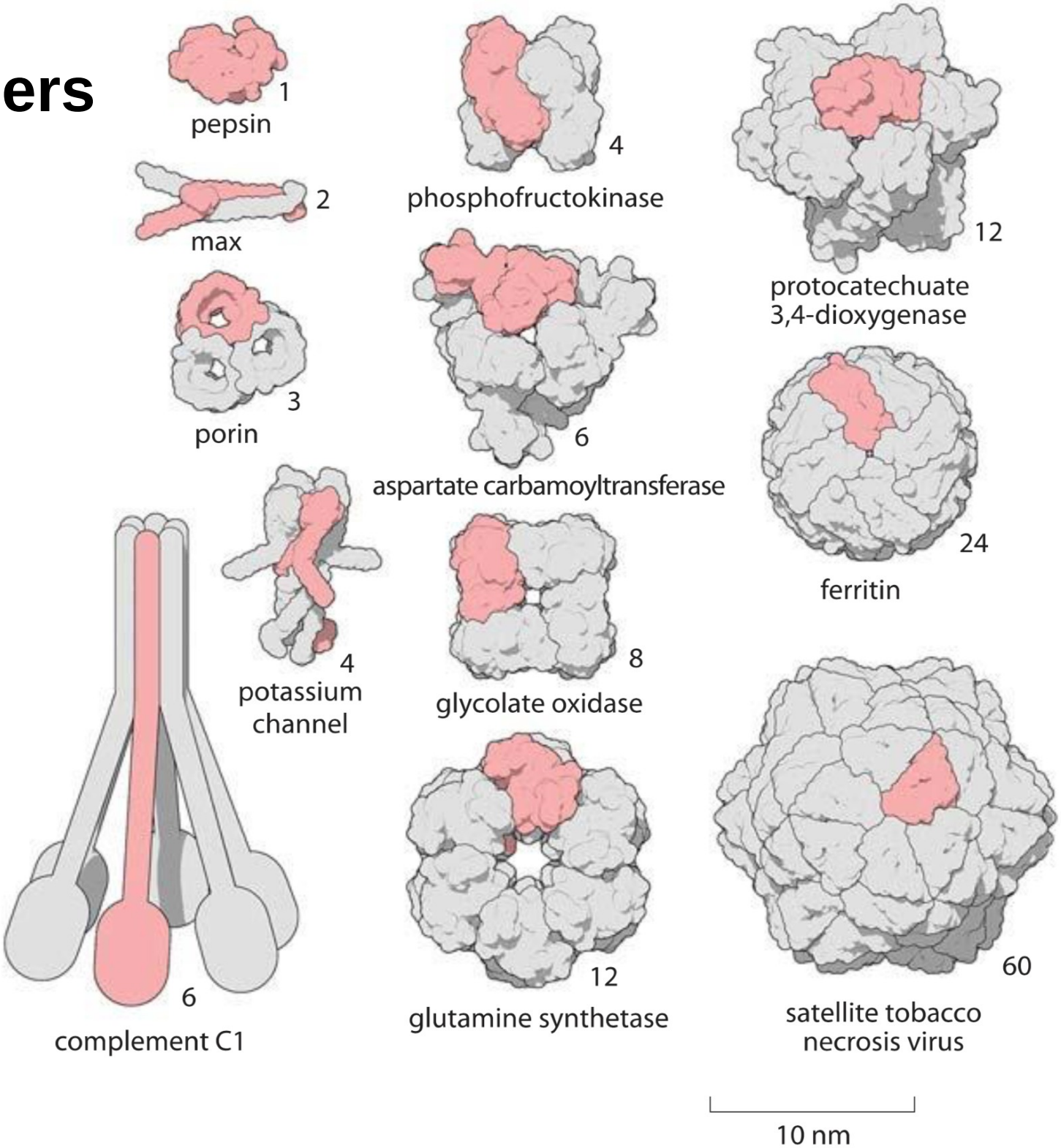
≈ $C_5H_8O_2$

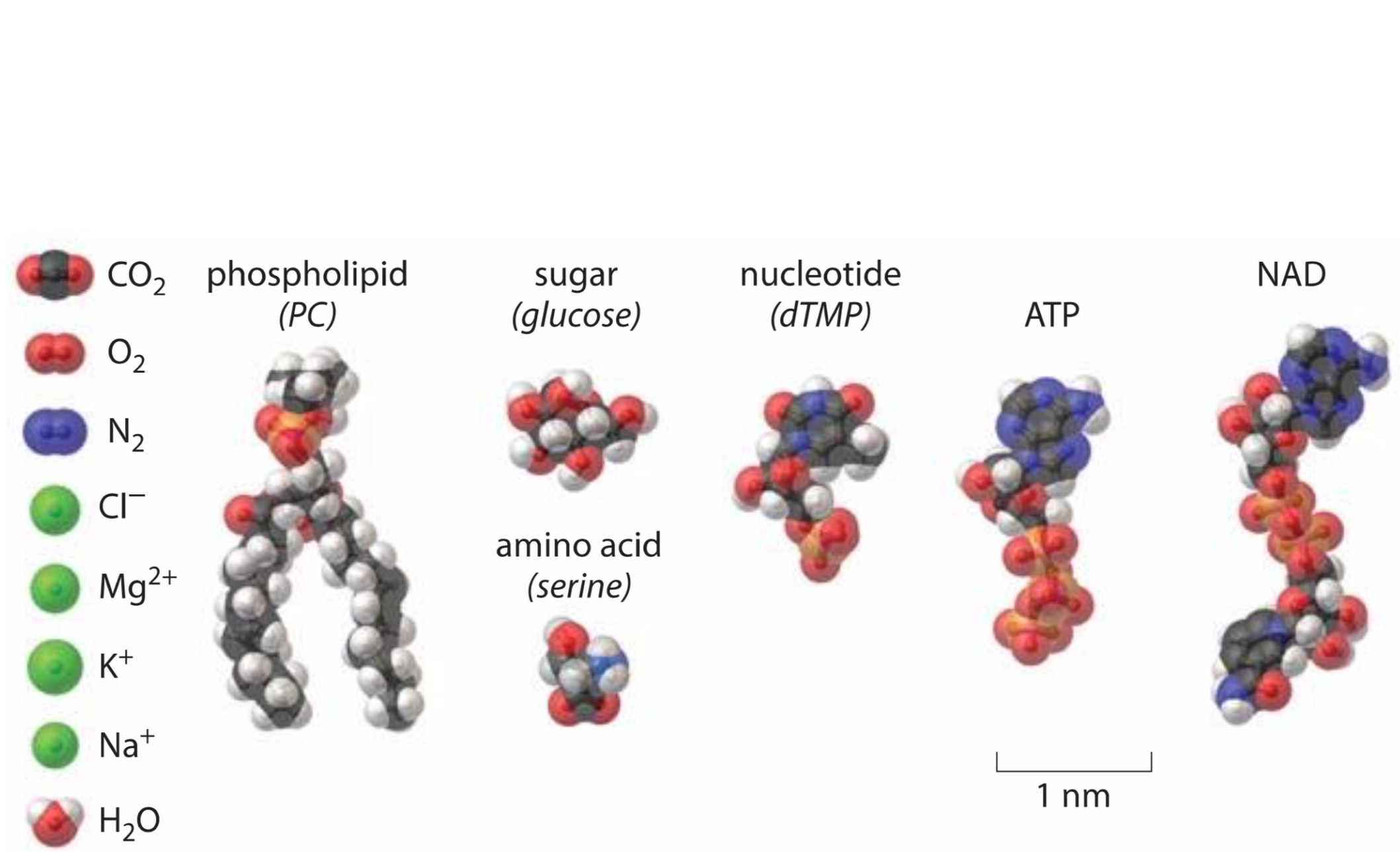
≈ $P_1N_5O_7C_{10}H_{14}$

≈ 350 Da

total protein mass in cell ≈ 3 times larger than RNA + DNA

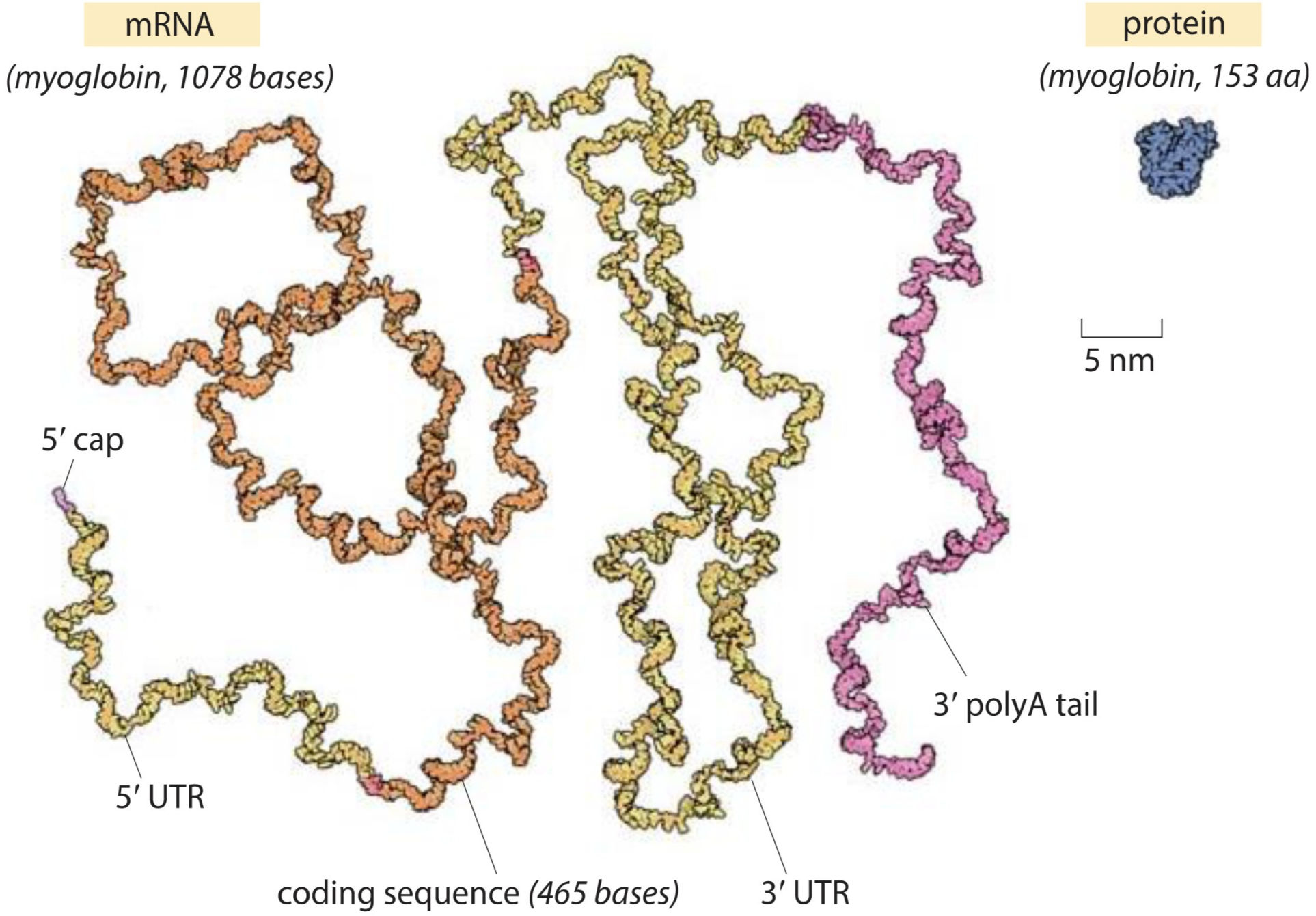
Homooligomers




CO_2
O_2
N_2
Cl^-
Mg^{2+}
K^+
Na^+
H_2O
phospholipid
(PC)
sugar
(glucose)
amino acid
(serine)
nucleotide
(dTMP)
ATP
NAD
1 nm

Which is larger:
mRNA or the protein it codes for?

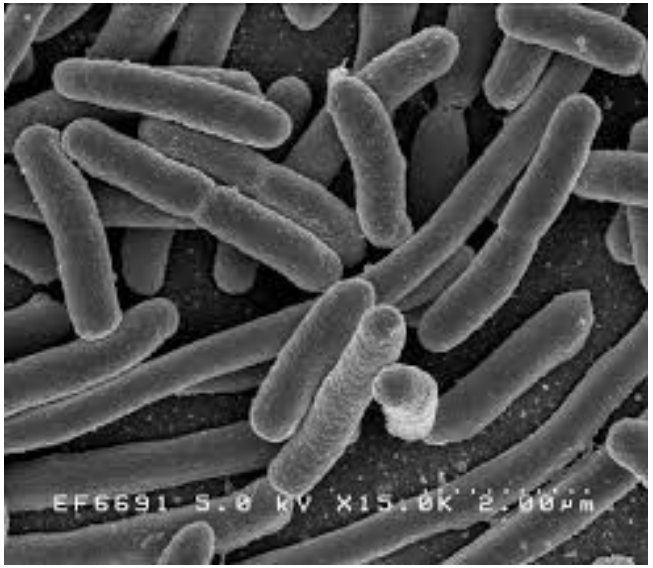
Which is larger: mRNA or the protein it codes for?



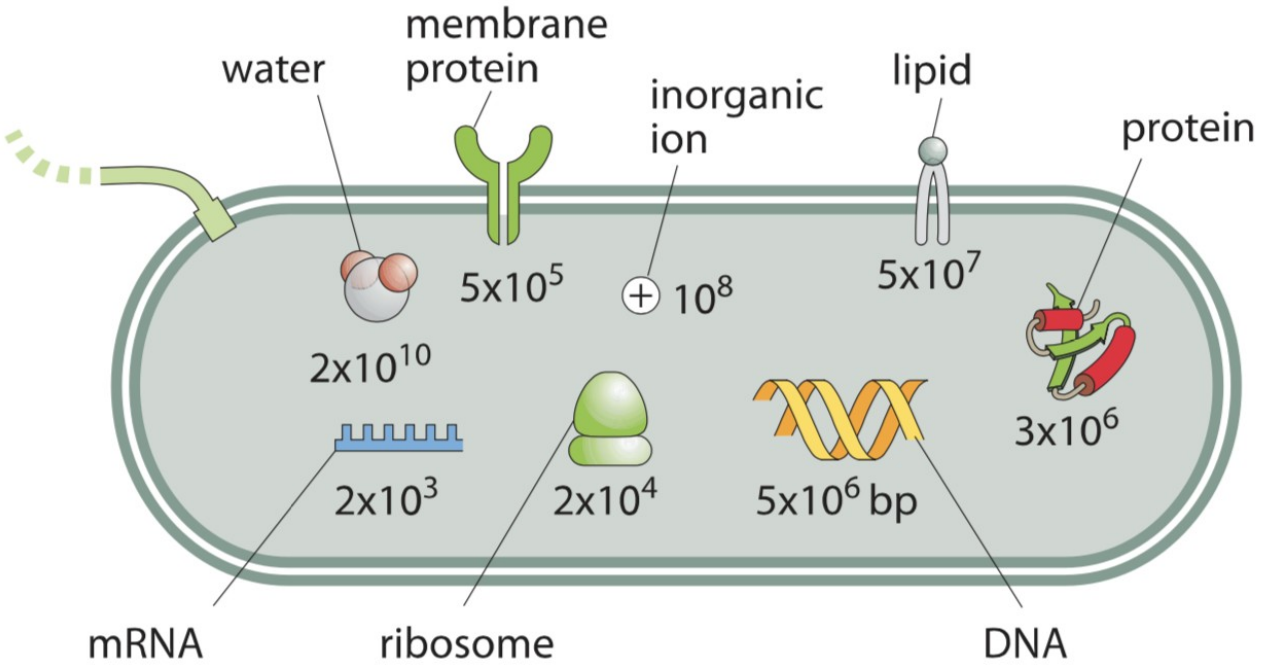
Median protein length

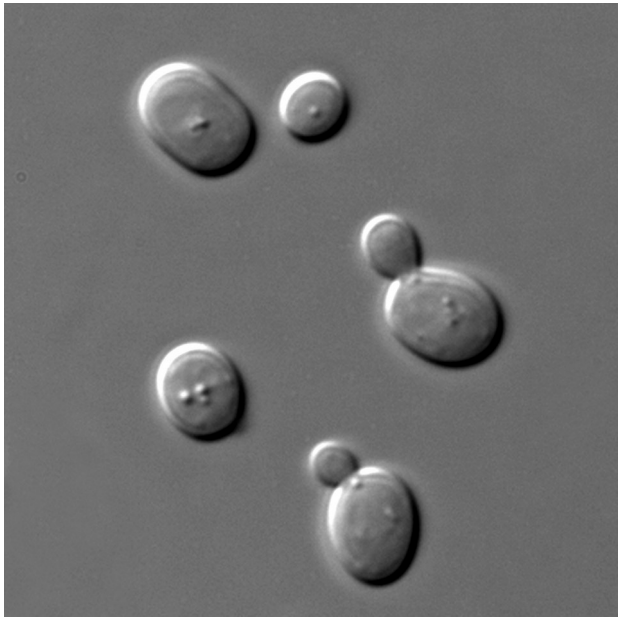
organism	median protein length (amino acids)
H. sapiens	375
D. melanogaster	373
C. elegans	344
S. cerevisiae	379
A. thaliana	356
5 eukaryotes (above)	361
67 bacteria	267
15 archaea	247

property	*E. coli*	budding yeast	mammalian (HeLa line)
cell volume	0.3–3 μm^3	30–100 μm^3	1,000–10,000 μm^3
proteins per μm^3 cell volume		$2–4\times10^6$	
mRNA per cell	10^3-10^4	10^4–10^5	10^5–10^6
proteins per cell	~10^6	~10^8	~10^{10}
mean diameter of protein		4–5 nm	
genome size	4.6 Mbp	12 Mbp	3.2 Gbp
number protein coding genes	4300	6600	21,000
regulator binding site length		10–20 bp	
promoter length	~100 bp	~1000 bp	~10^4–10^5 bp
gene length	~1000 bp	~1000 bp	~10^4–10^6 bp (with introns)
concentration of one protein per cell	~1 nM	~10 pM	~0.1–1 pM
diffusion time of protein across cell ($D \approx 10\ \mu m^2/s$)	~0.01 s	~0.2 s	~1–10 s
diffusion time of small molecule across cell ($D \approx 100\ \mu m^2/s$)	~0.001 s	~0.03 s	~0.1–1 s
time to transcribe a gene	<1 min (80 nts/s)	~1 min	~30 min (incl. mRNA processing)
time to translate a protein	<1 min (20 aa/s)	~1 min	~30 min (incl. mRNA export)
typical mRNA lifetime	2–5 min	~10 min to over 1 h	5-100 min to over 10 h
typical protein lifetime	1 h	0.3–3 h	10–100 h
minimal doubling time	20 min	1 h	20 h
ribosomes/cell	~10^4	~10^5	~10^6
transitions between protein states (active/inactive)		1–100 μs	
timescale for equilibrium binding of small molecule to protein (diffusion limited)		1–1000 ms (1 μM–1 nM affinity)	
timescale of transcription factor binding to DNA site		~1 s	
mutation rate		10^{-8}–10^{-10}/bp/replication	

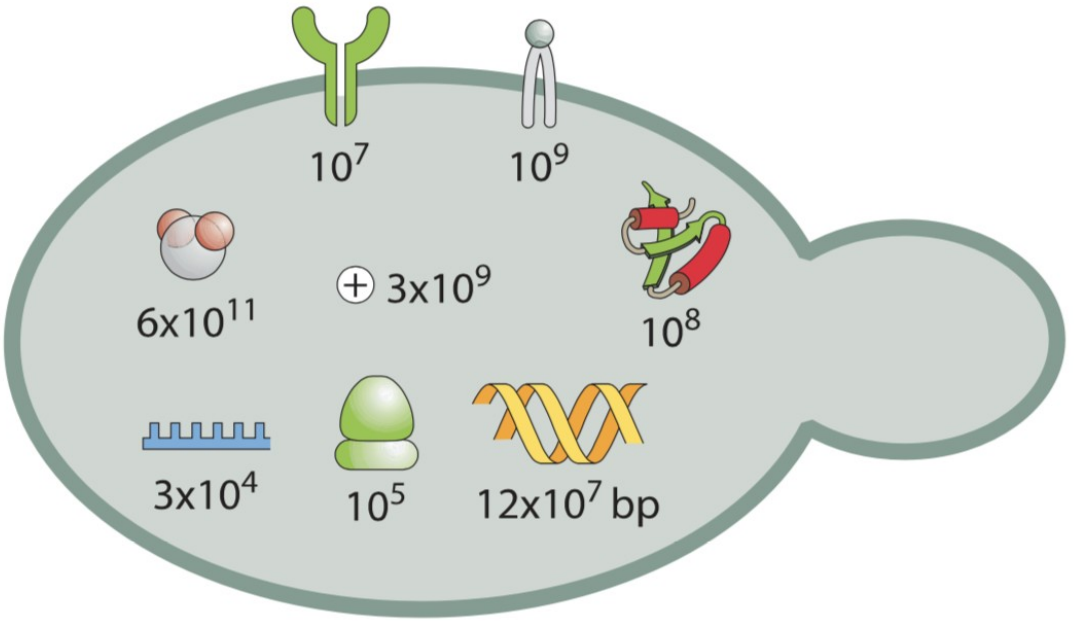


(A) bacterial cell (specifically, *E. coli:* $V \approx 1\ \mu m^3$; $L \approx 1\ \mu m$; $\tau \approx 1$ hour)

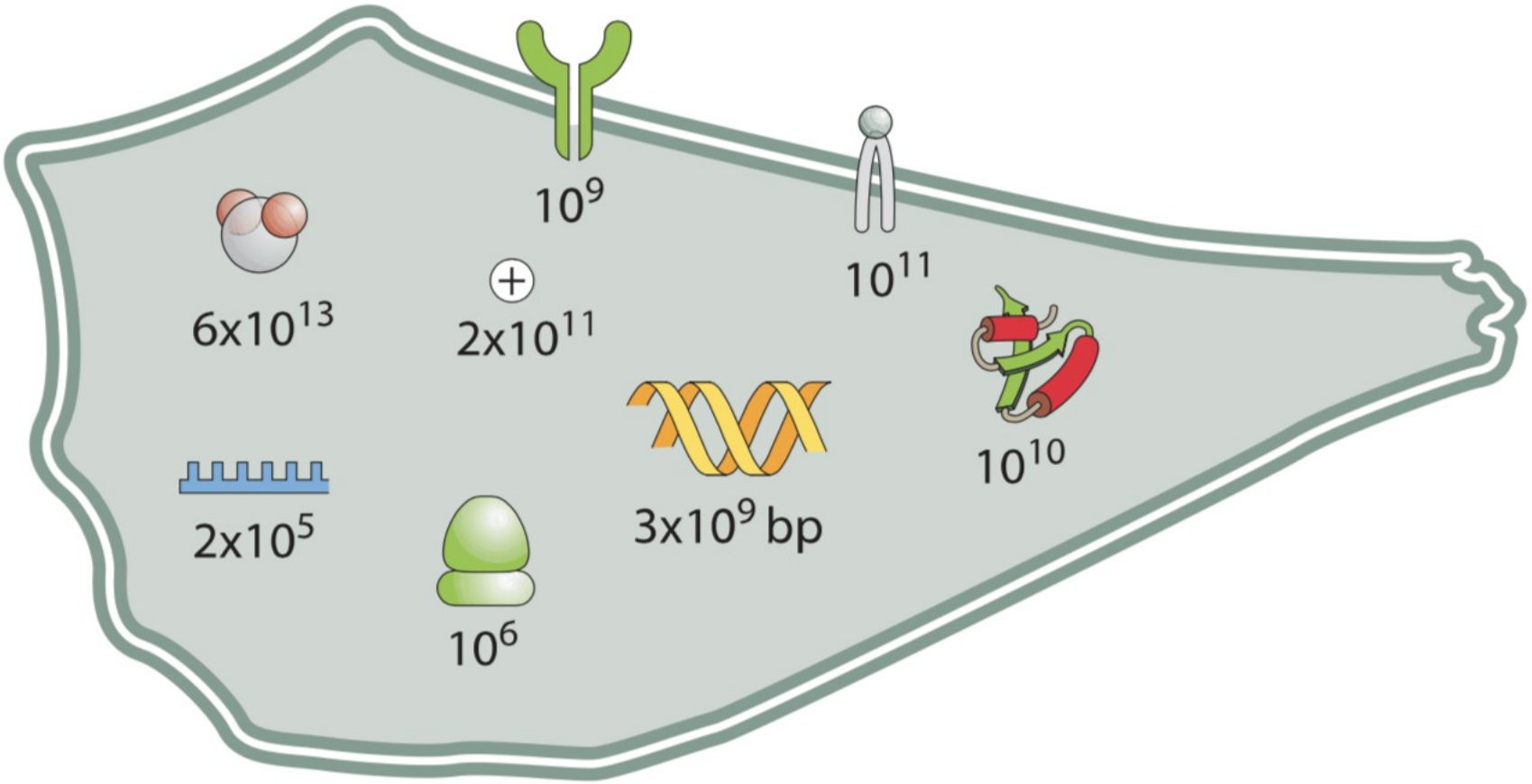




(B) yeast cell (specifically, *S. cerevisiae:* $V \approx 30\ \mu m^3$; $L \approx 5\ \mu m$; $\tau \approx 3$ hours)



(C) mammalian cell (specifically, HeLa: $V \approx 3000\ \mu m^3$; $L \approx 20\ \mu m$; $\tau \approx 1$ day)



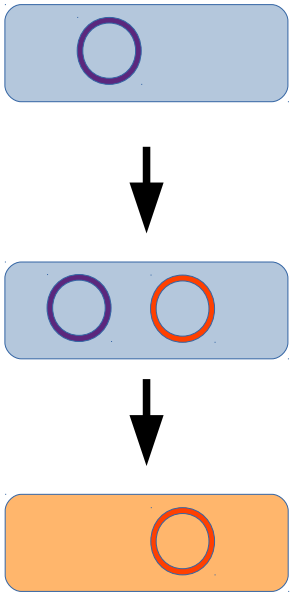
First “synthetic” cell developed by scientists

M. mycoides JCVI-syn1.0
1.08 million base pairs and 901 genes

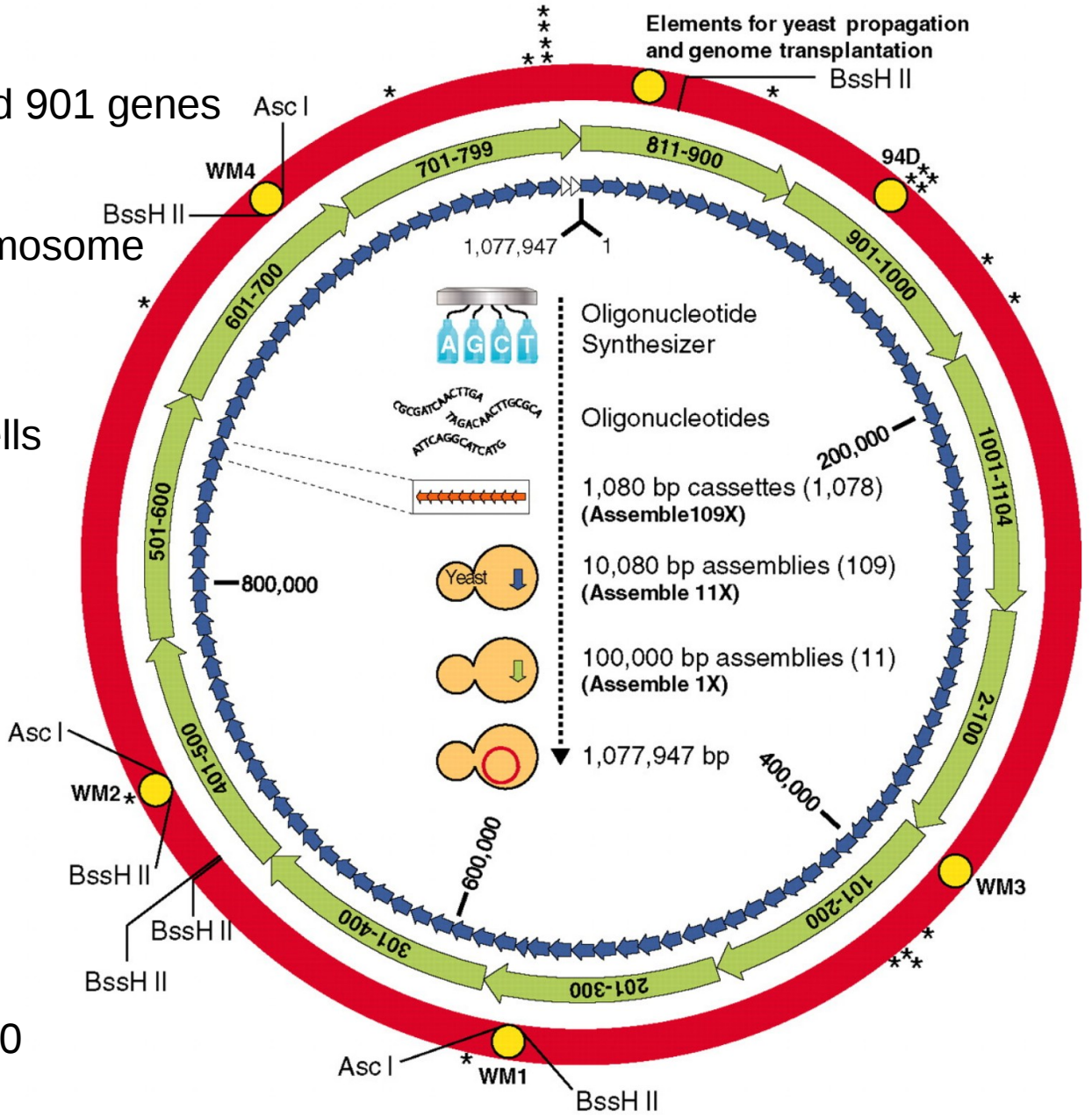
single yeast artificial chromosome

+

M. capricolum recipient cells



M. mycoides JCVI-syn1.0



Gibson et al. 2016

First “synthetic” cell developed by scientists

M. mycoides JCVI-syn1.0 contains strings of bases that, in code, spell out:

a web address to send emails to if you can successfully crack the new code,

the names of 46 authors and other key contributors,

three famous quotations. One of which by James Joyce, perfectly encapsulates the ups and downs of a the 15 year project—“To live, to err, to fall, to triumph, to recreate life out of life.”

Gibson et al. 2016

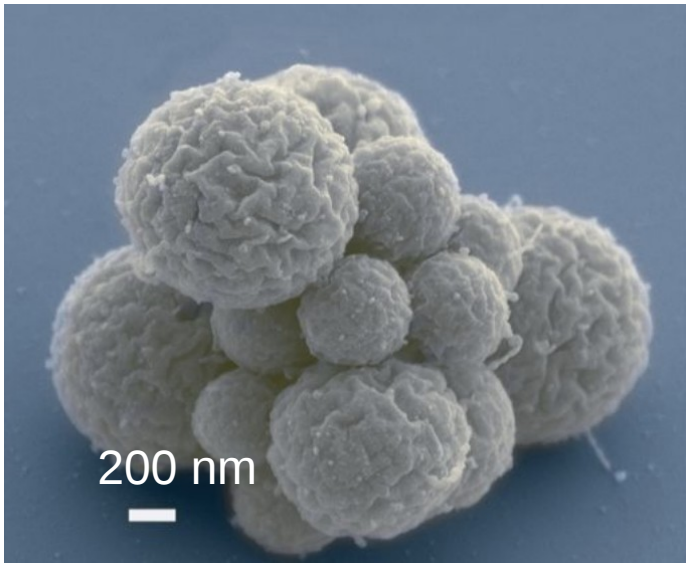
Smallest “synthetic” cell

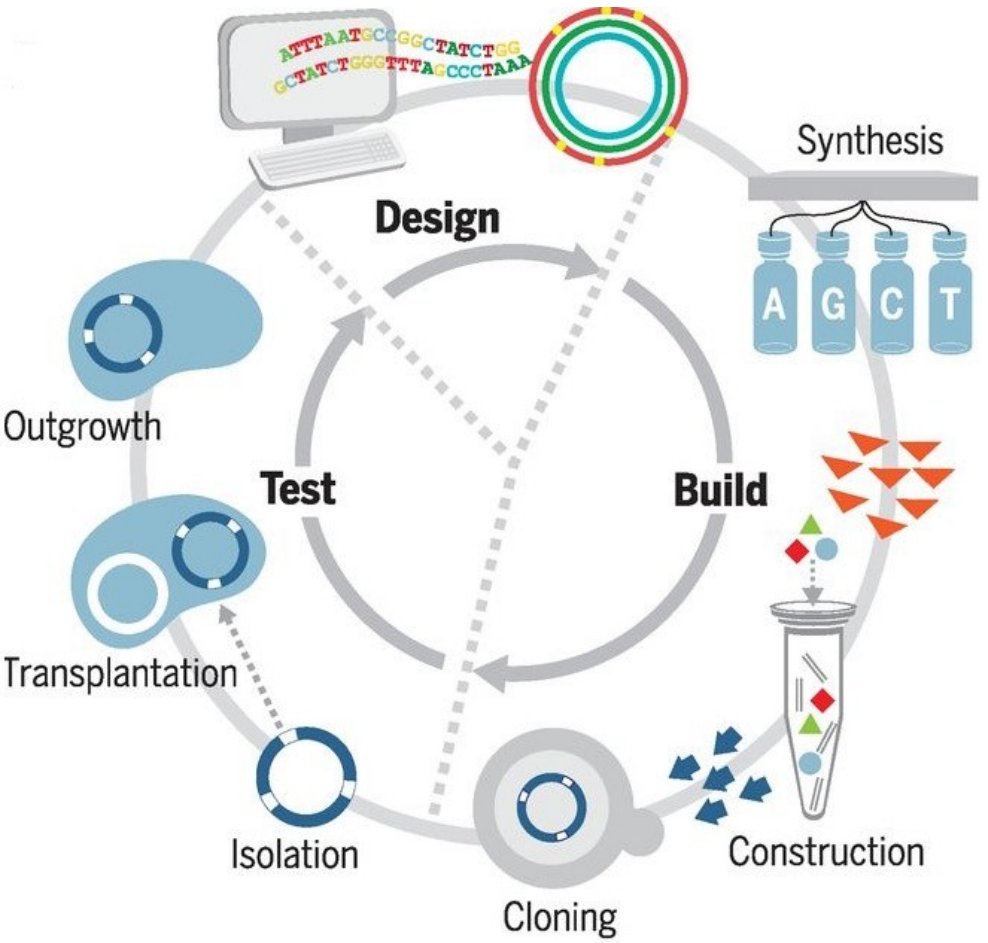
M. mycoides JCVI-syn3.0
531,560 base pairs and 473 genes

retains genes involved in key processes such as transcription and translation, but also contains 149 genes of unknown function

genome smaller than that of any autonomously replicating cell found in nature.

doubling time of ~180 min
colonies morphologically similar to those of JCVI-syn1.0

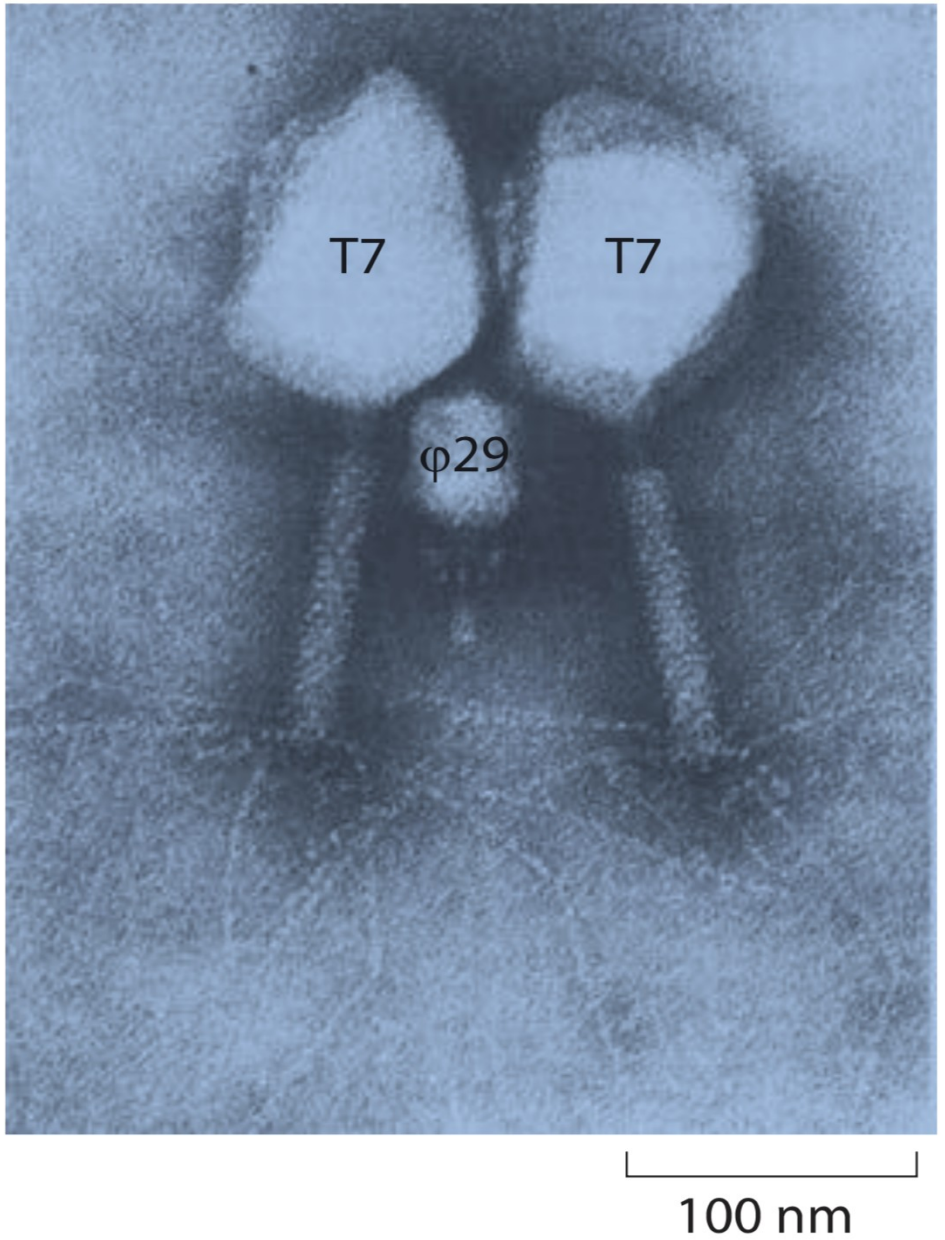


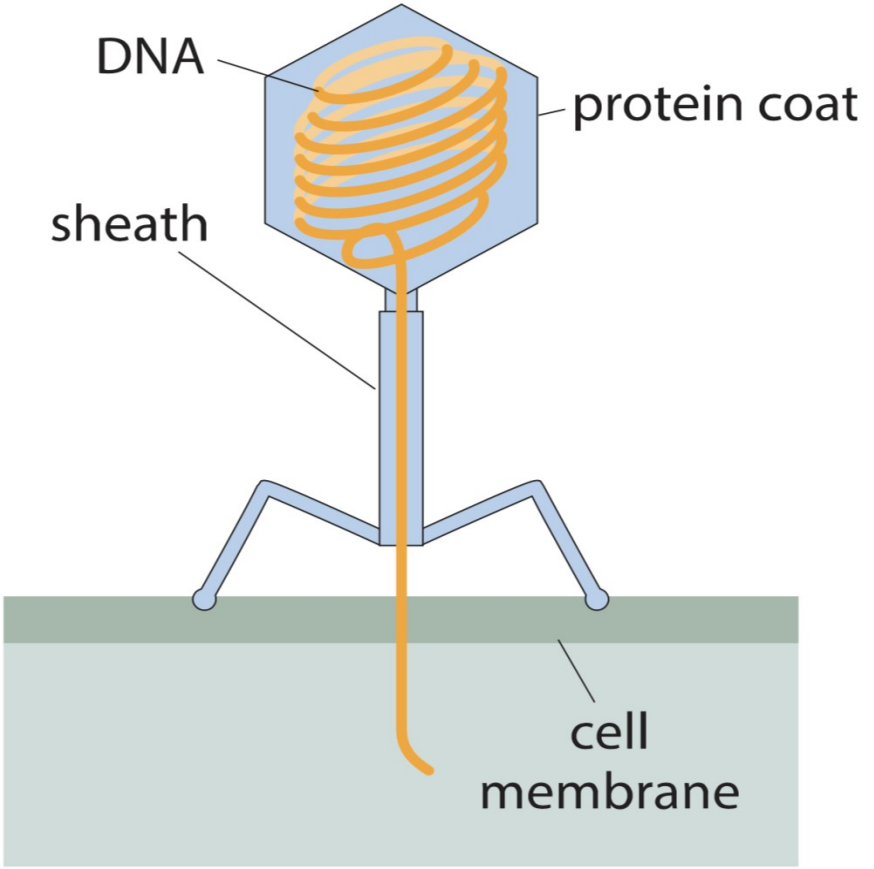


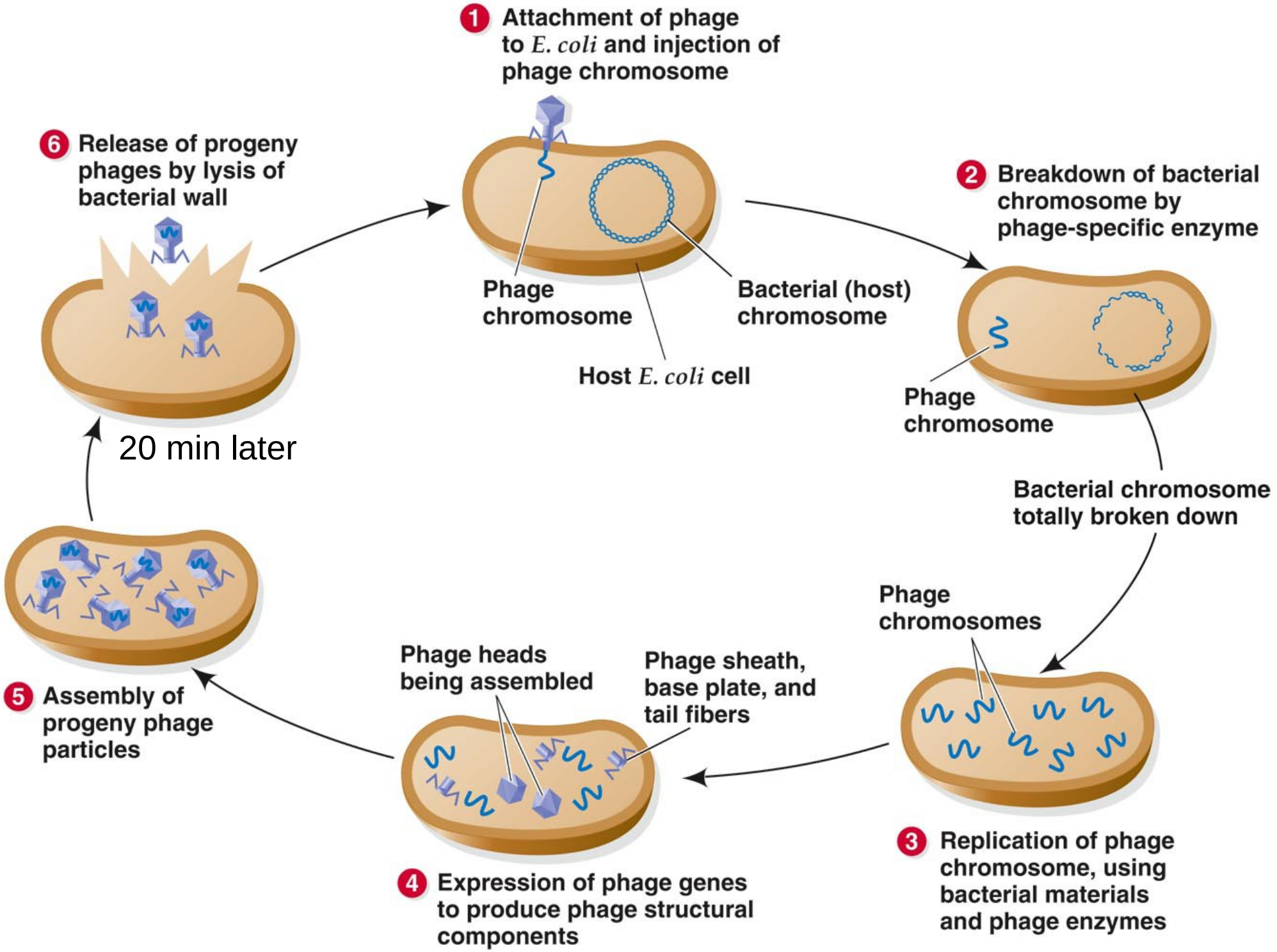
Hutchison III et al. 2016

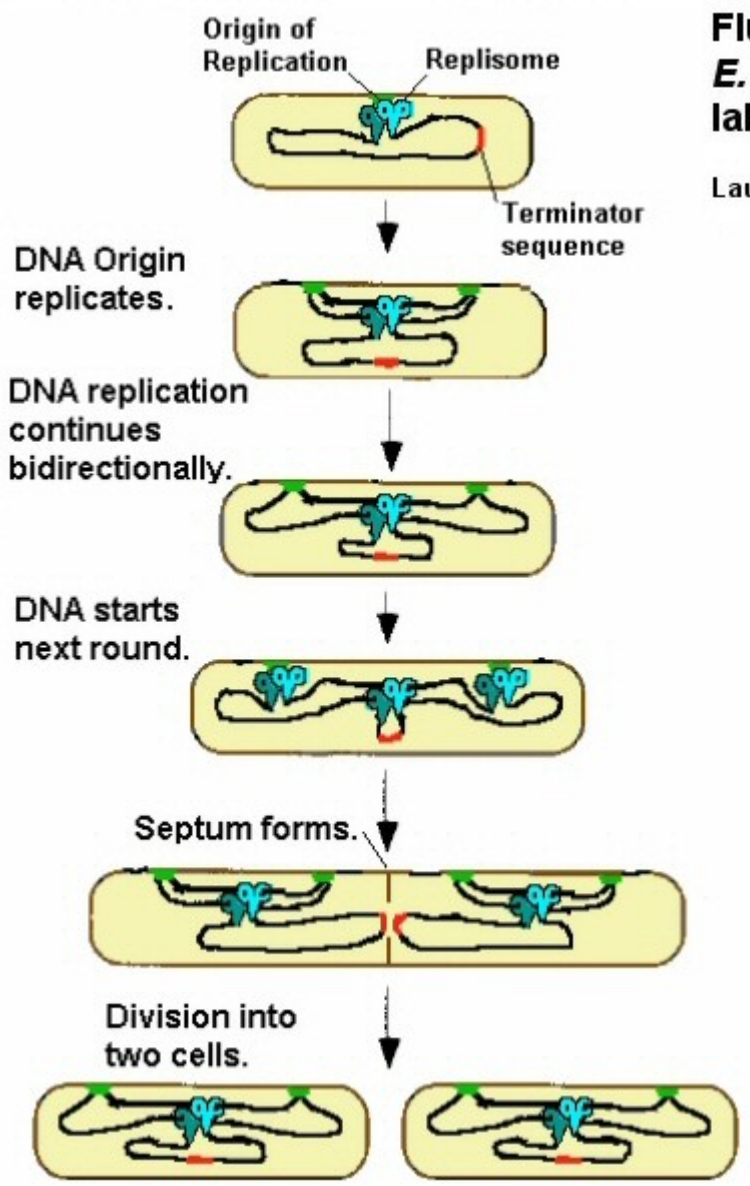
Viruses, cells, mitochondria, reproduction

Virus infecting bacteria = phages



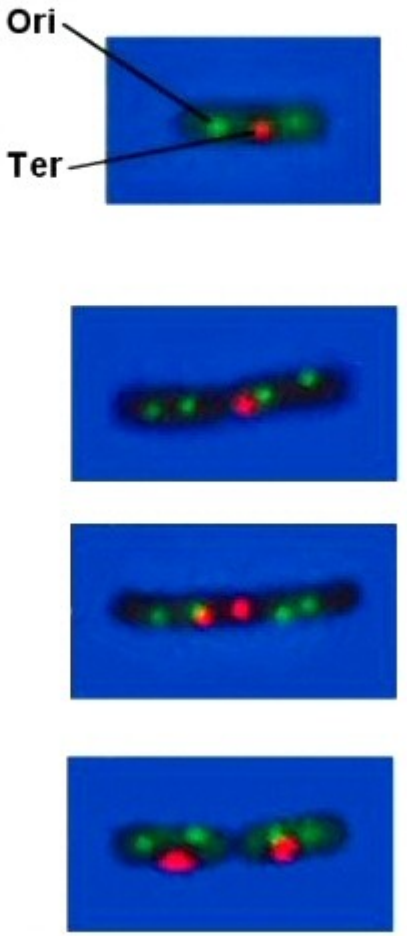




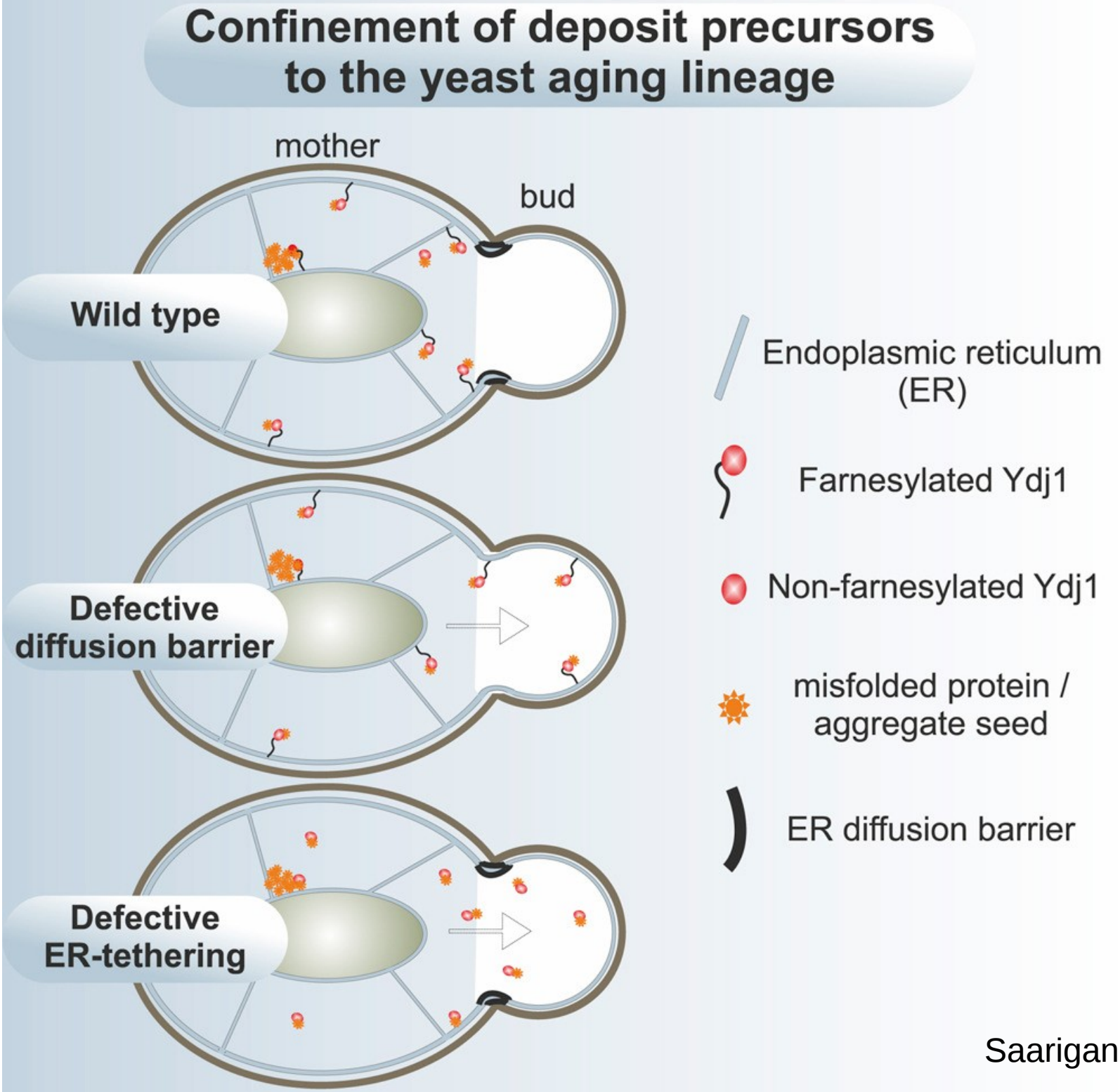


Fluorescence microscopy:
***E. coli* cells with fluorophores labeling Ori and Ter**

Lau et al (2003) Mol. Micro. 49:731

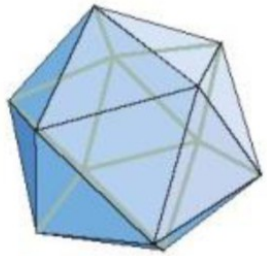


http://biology.kenyon.edu/courses/biol114/Chap01/cell.html



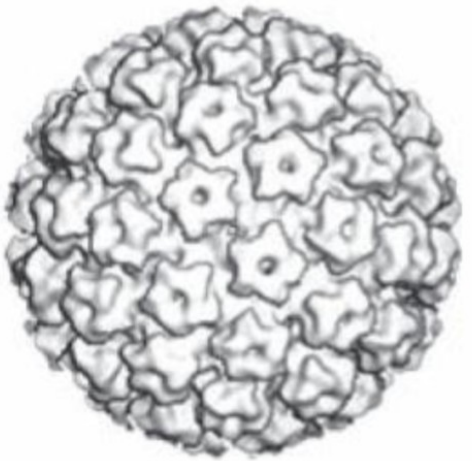
Saarigankas 2017

SYMMETRIC VIRUSES

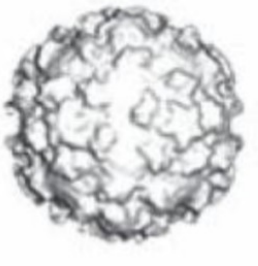


cowpea chlorotic mottle

human papilloma



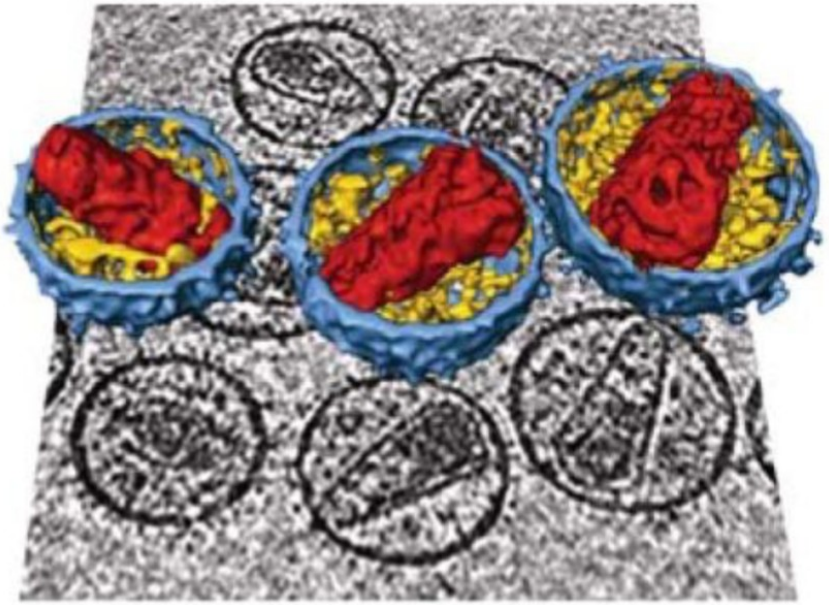
polio



30 nm

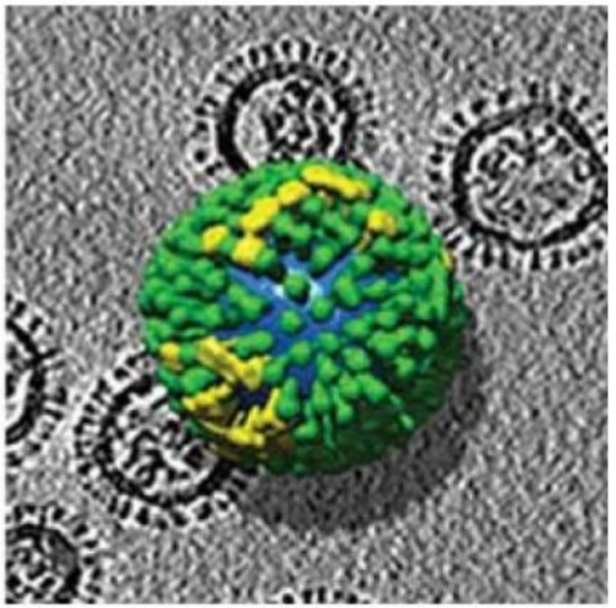
ASYMMETRIC VIRUSES

HIV



100 nm

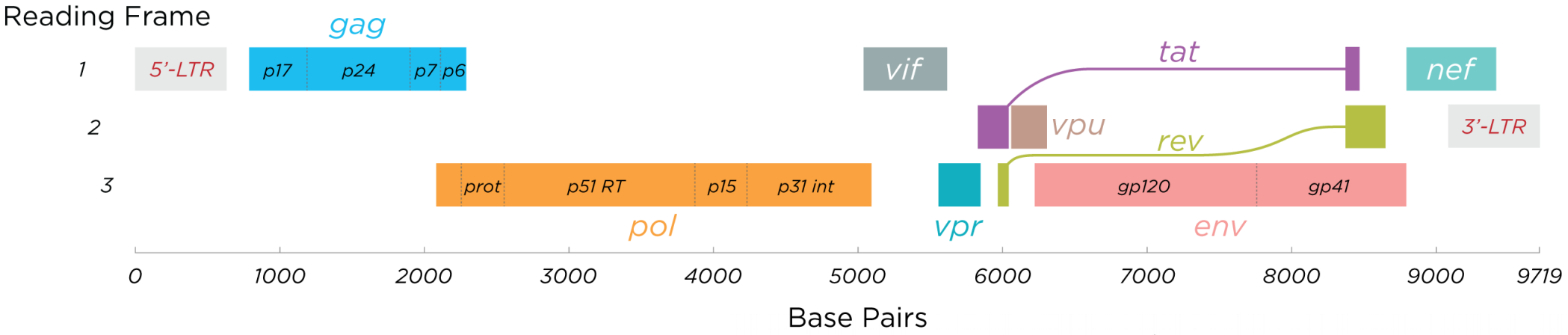
Influenza

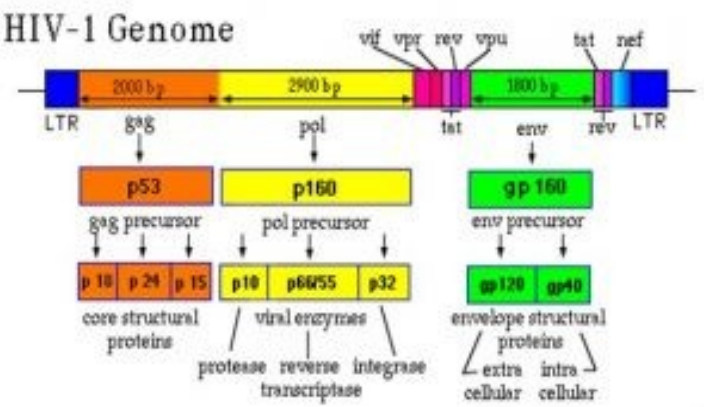


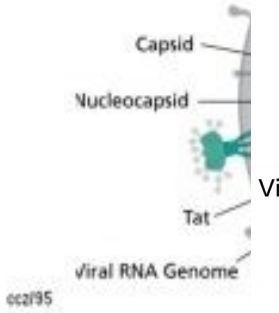
100 nm

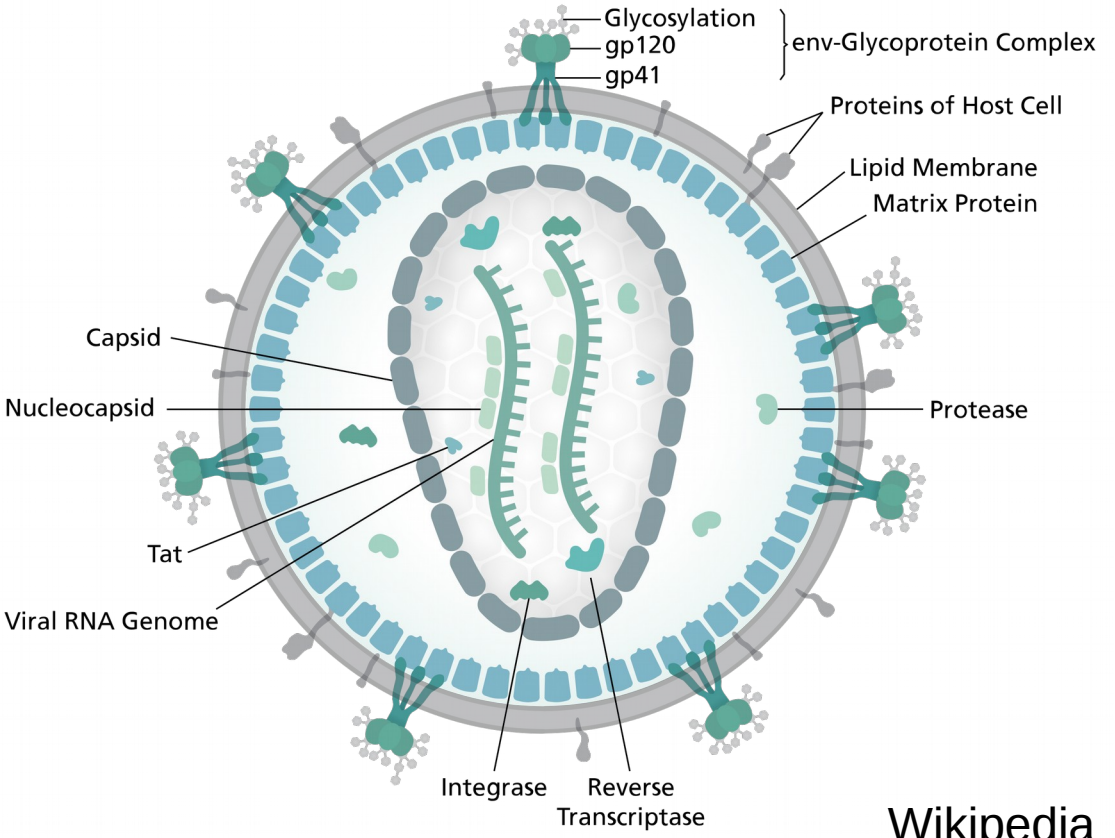
HIV genome

9 genes encoding 15 viral proteins









Wikipedia

virus	size (nm)	genome size (base pairs)
porcine circovirus (PCV)	17	1,760
cowpea mosaic virus (CPMV)	28	9,400
cowpea chlorotic mottle virus (CCMV)	28	7,900
φX174 (*E. coli* bacteriophage)	32	5,400
tobacco mosaic virus (TMV)	40×300	6,400
polio virus	30	7,500
φ29 (*Bacillus* phage)	45x54	19,000
lambda phage	58	49,000
T7 bacteriophage	58	40,000
adenovirus (linear DNA)	88-110	36,000
influenza A	80-120	14,000
HIV-1	120-150	9,700
herpes simplex virus 1	125	153,000
Epstein-Barr virus (EBV)	140	170,000
mimivirus	500	1,200,000
pandora virus	500x1000	2,800,000

Criteria to define viruses

Established by André Lwolff in 1957

1) does not contain ribosomes (needs the host machinery for replication)

2) cannot divide to produce 2 entities

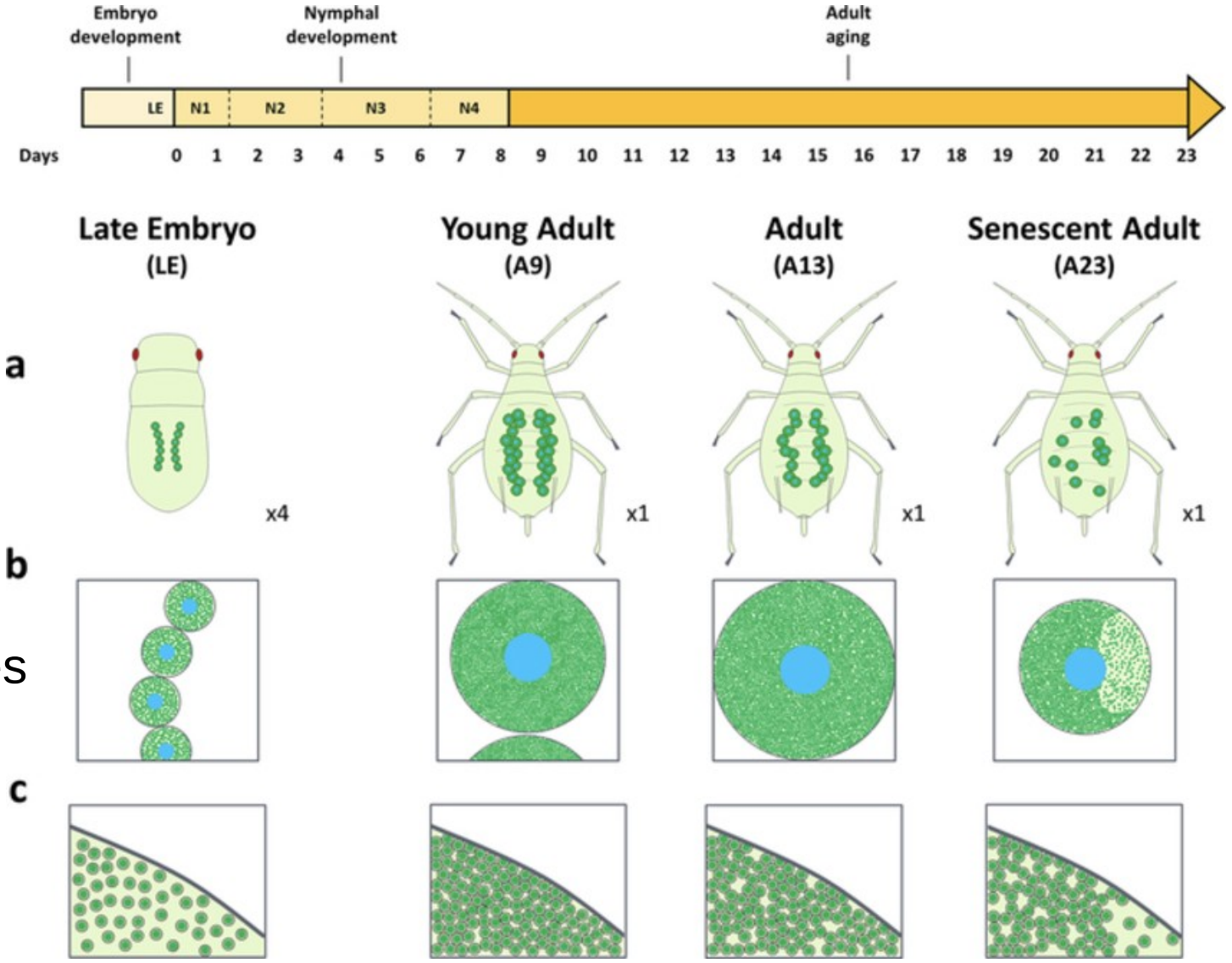
3) reproduce via only part of their constituents

4) does not harbour a minimal metabolism to reproduce

Points 3 and 4 were later refuted.

Buchnera : an obligate symbiont

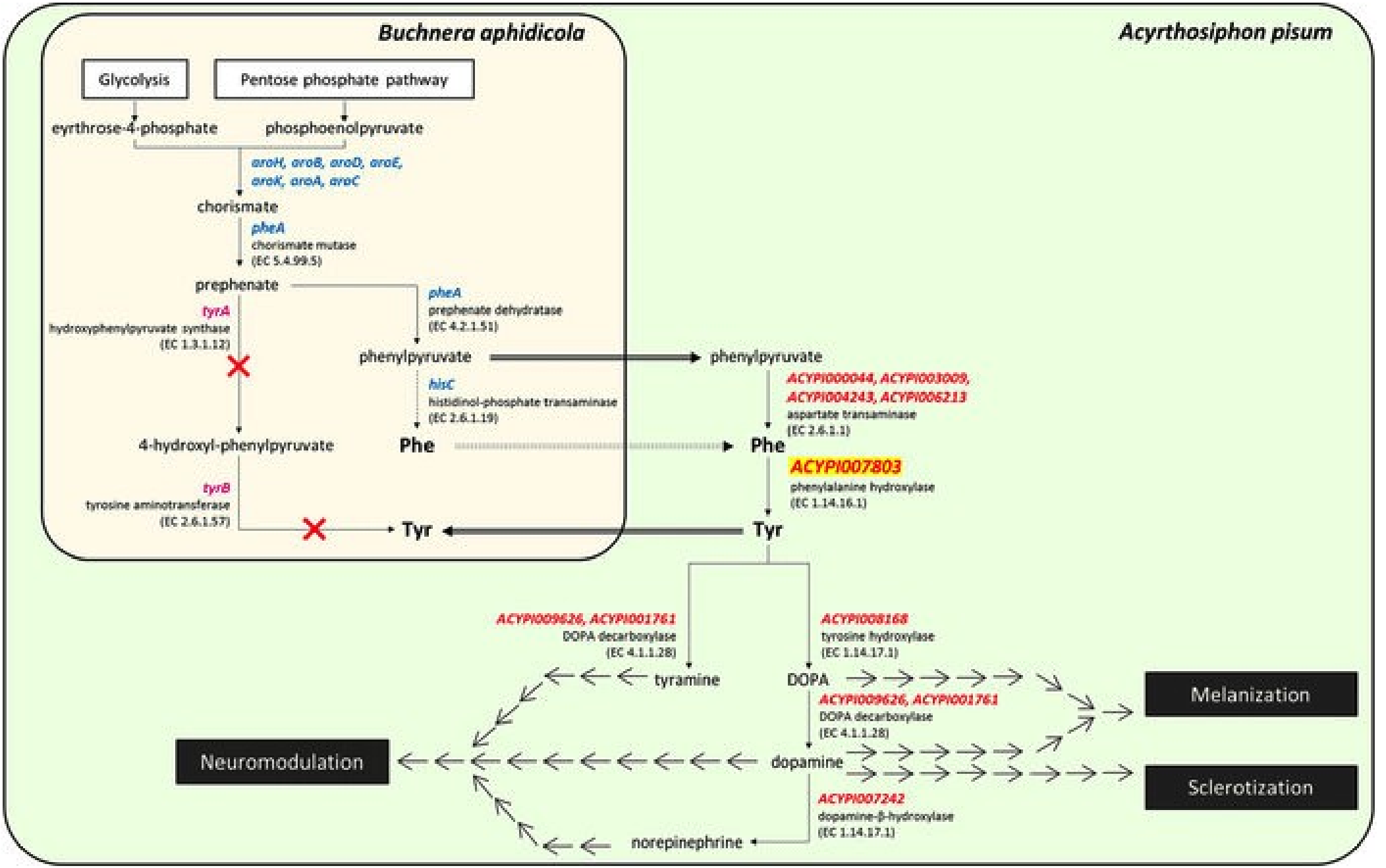
Phloem sap rich in carbohydrates but devoid of essential amino acids

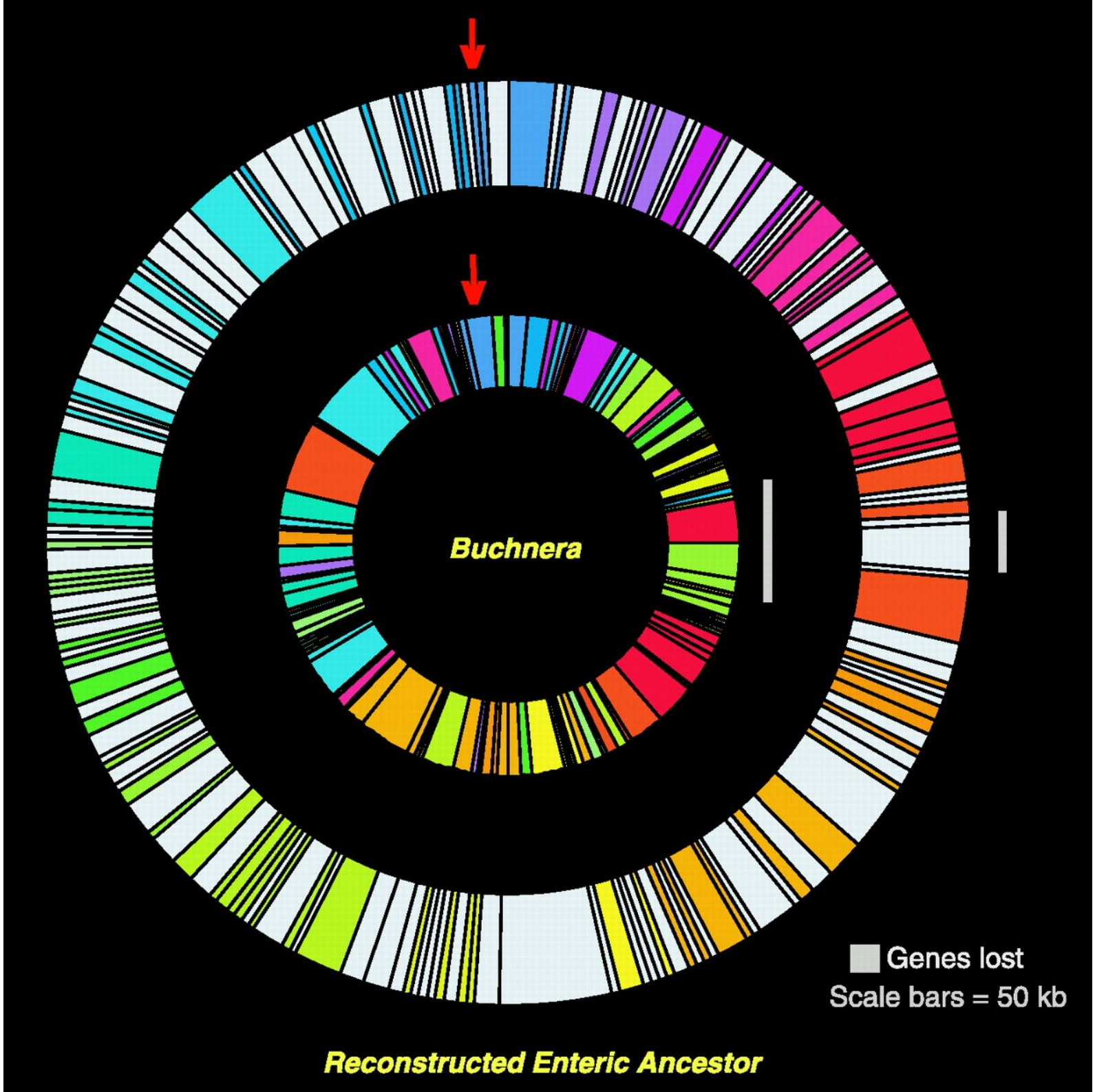


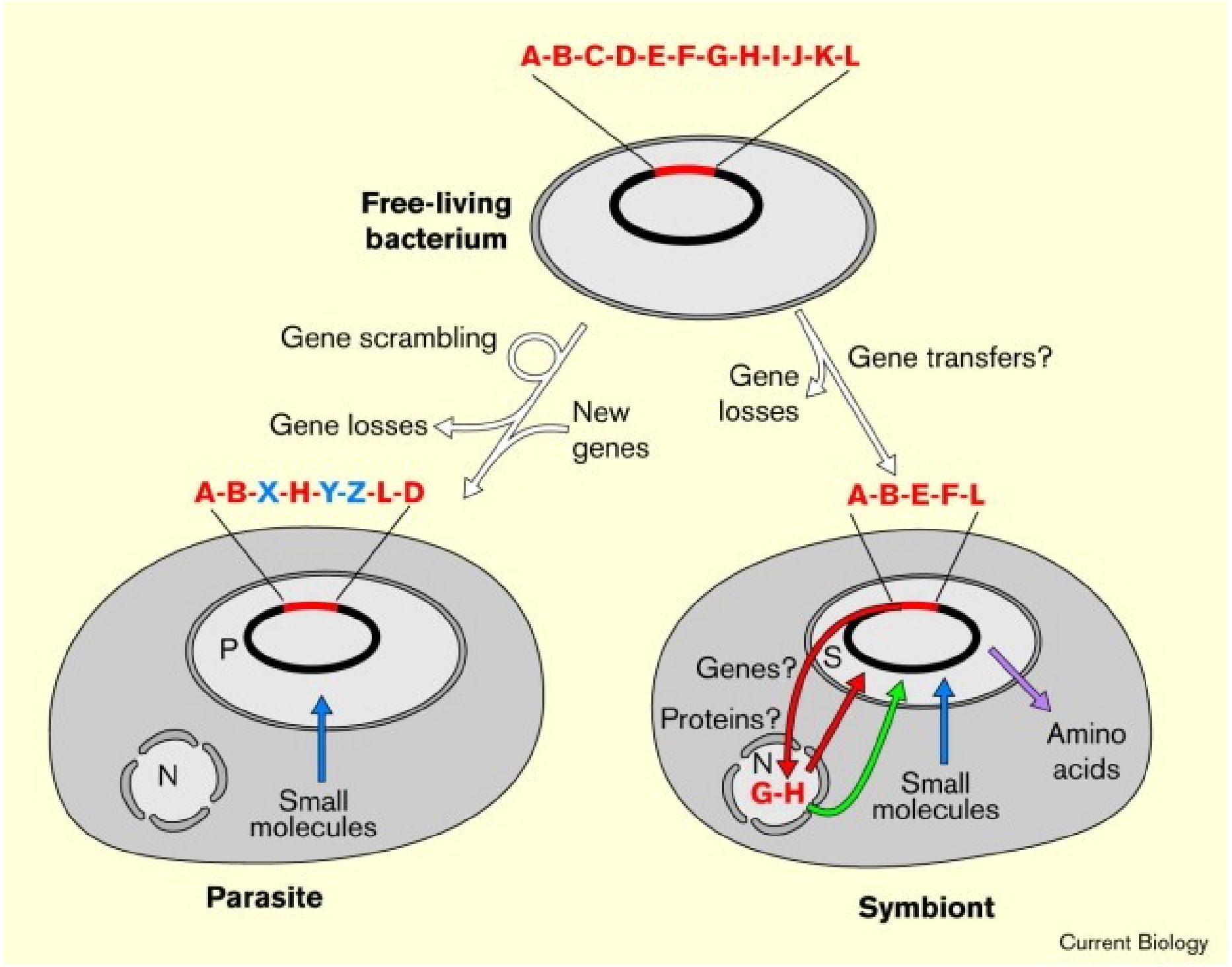
bacteriocytes

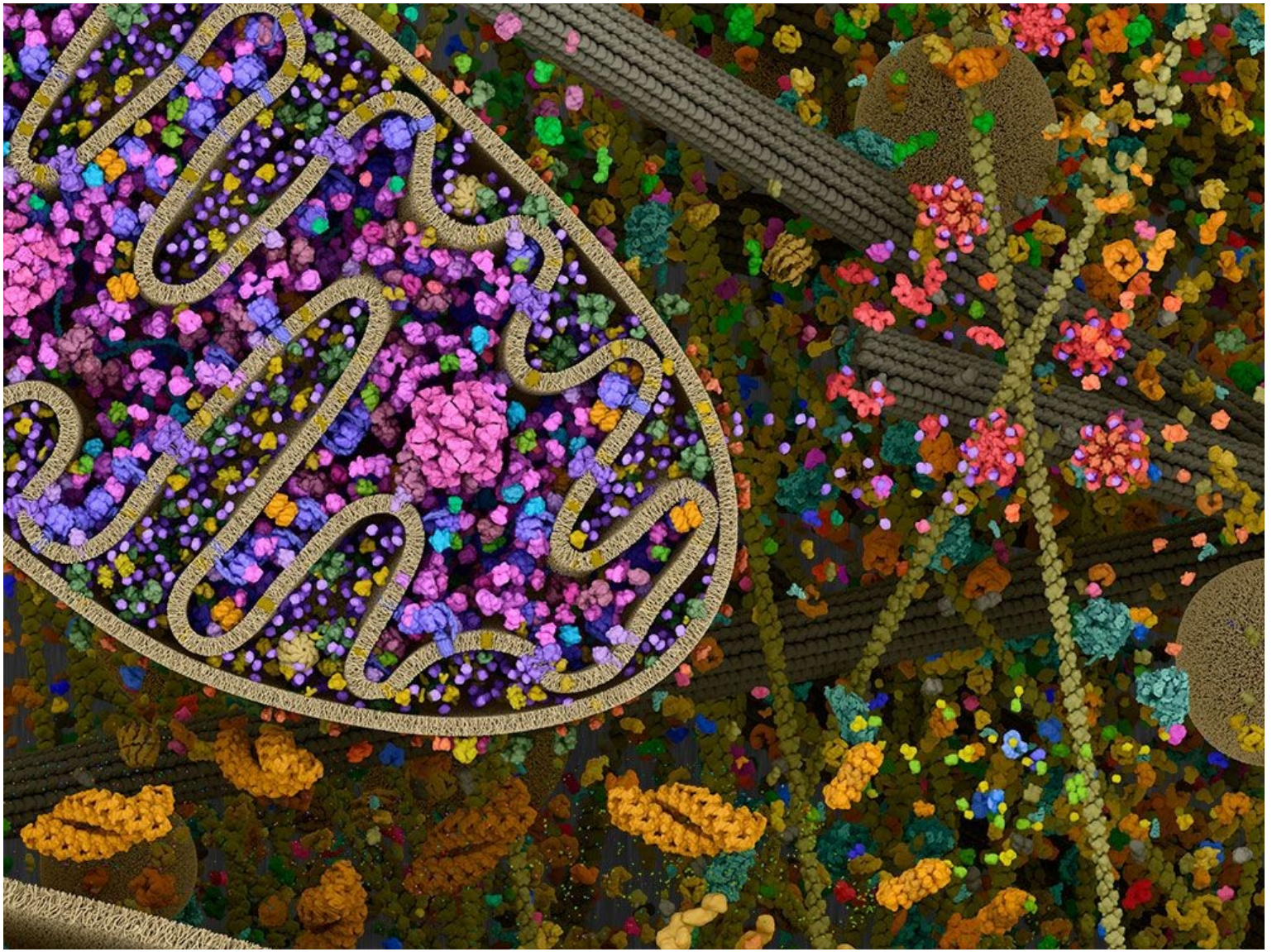
Buchnera bacteria

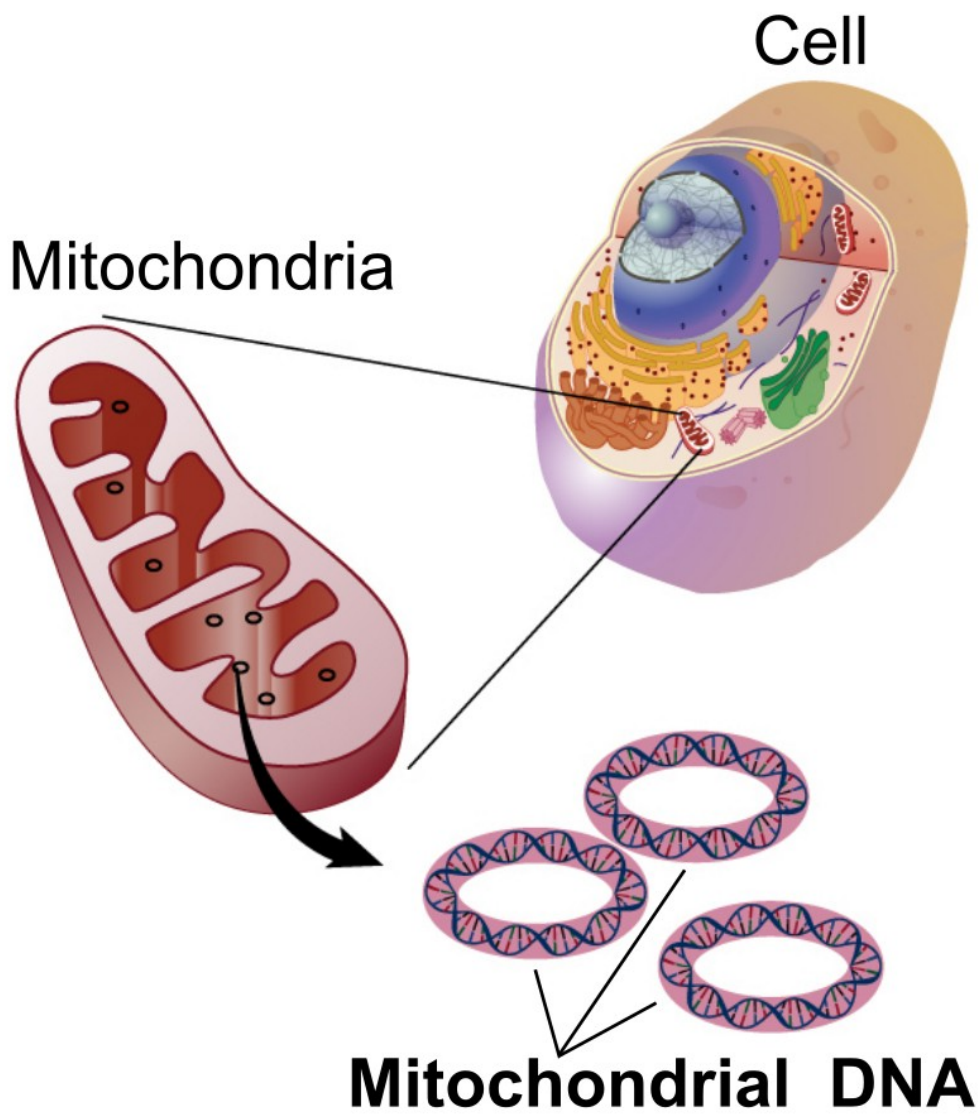
Simonet 2016

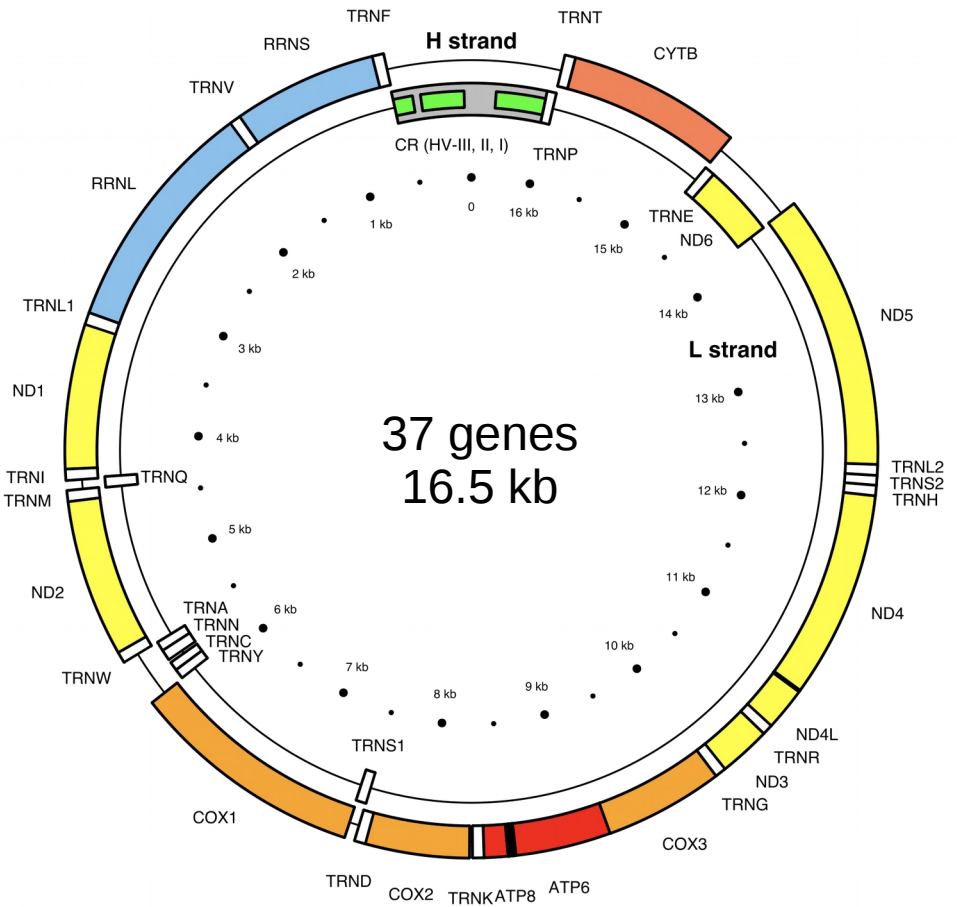

Buchnera aphidicola
Acyrthosiphon pisum
Glycolysis
Pentose phosphate pathway
eyrthrose-4-phosphate
phosphoenolpyruvate
aroH, aroB, aroD, aroE,
aroK, aroA, aroC
chorismate
pheA
chorismate mutase
(EC 5.4.99.5)
prephenate
tyrA
hydroxyphenylpyruvate synthase
(EC 1.3.1.12)
pheA
prephenate dehydratase
(EC 4.2.1.51)
phenylpyruvate
hisC
histidinol-phosphate transaminase
(EC 2.6.1.19)
4-hydroxyl-phenylpyruvate
Phe
tyrB
tyrosine aminotransferase
(EC 2.6.1.57)
Tyr
phenylpyruvate
ACYPI000044, ACYPI003009,
ACYPI004243, ACYPI006213
aspartate transaminase
(EC 2.6.1.1)
Phe
ACYPI007803
phenylalanine hydroxylase
(EC 1.14.16.1)
Tyr
ACYPI009626, ACYPI001761
DOPA decarboxylase
(EC 4.1.1.28)
tyramine
ACYPI008168
tyrosine hydroxylase
(EC 1.14.17.1)
DOPA
Melanization
ACYPI009626, ACYPI001761
DOPA decarboxylase
(EC 4.1.1.28)
Neuromodulation
dopamine
Sclerotization
ACYPI007242
dopamine-β-hydroxylase
(EC 1.14.17.1)
norepinephrine

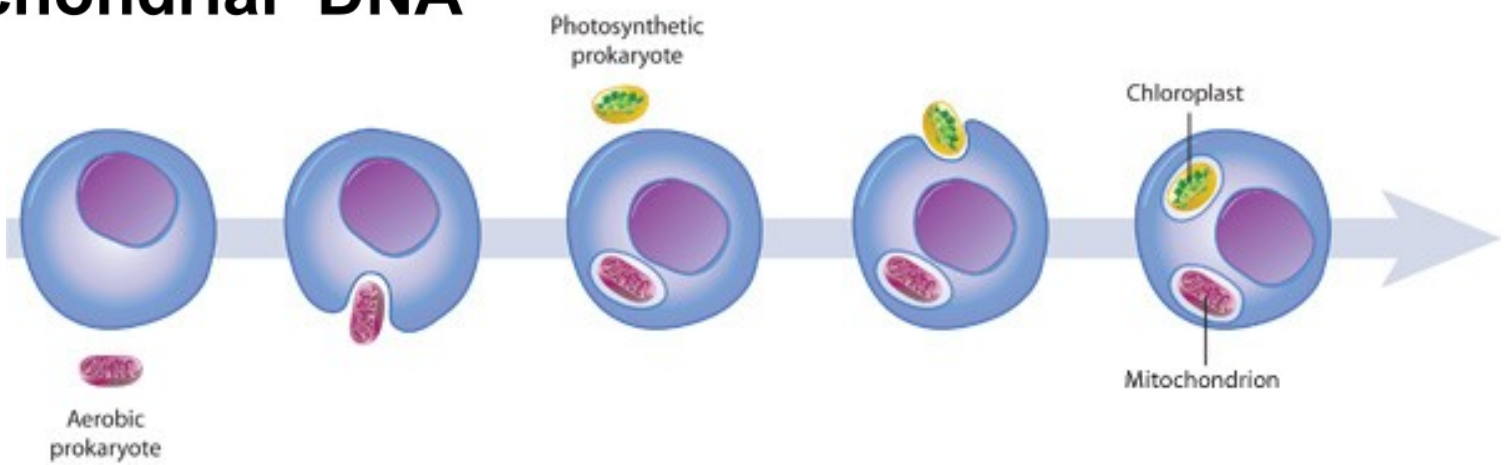

Buchnera
Genes lost
Scale bars = 50 kb
Reconstructed Enteric Ancestor


A-B-C-D-E-F-G-H-I-J-K-L
Free-living bacterium
Gene scrambling
Gene losses
New genes
Gene losses
Gene transfers?
A-B-X-H-Y-Z-L-D
A-B-E-F-L
P
N
Small molecules
Parasite
Genes?
Proteins?
S
N
G-H
Small molecules
Amino acids
Symbiont
Current Biology

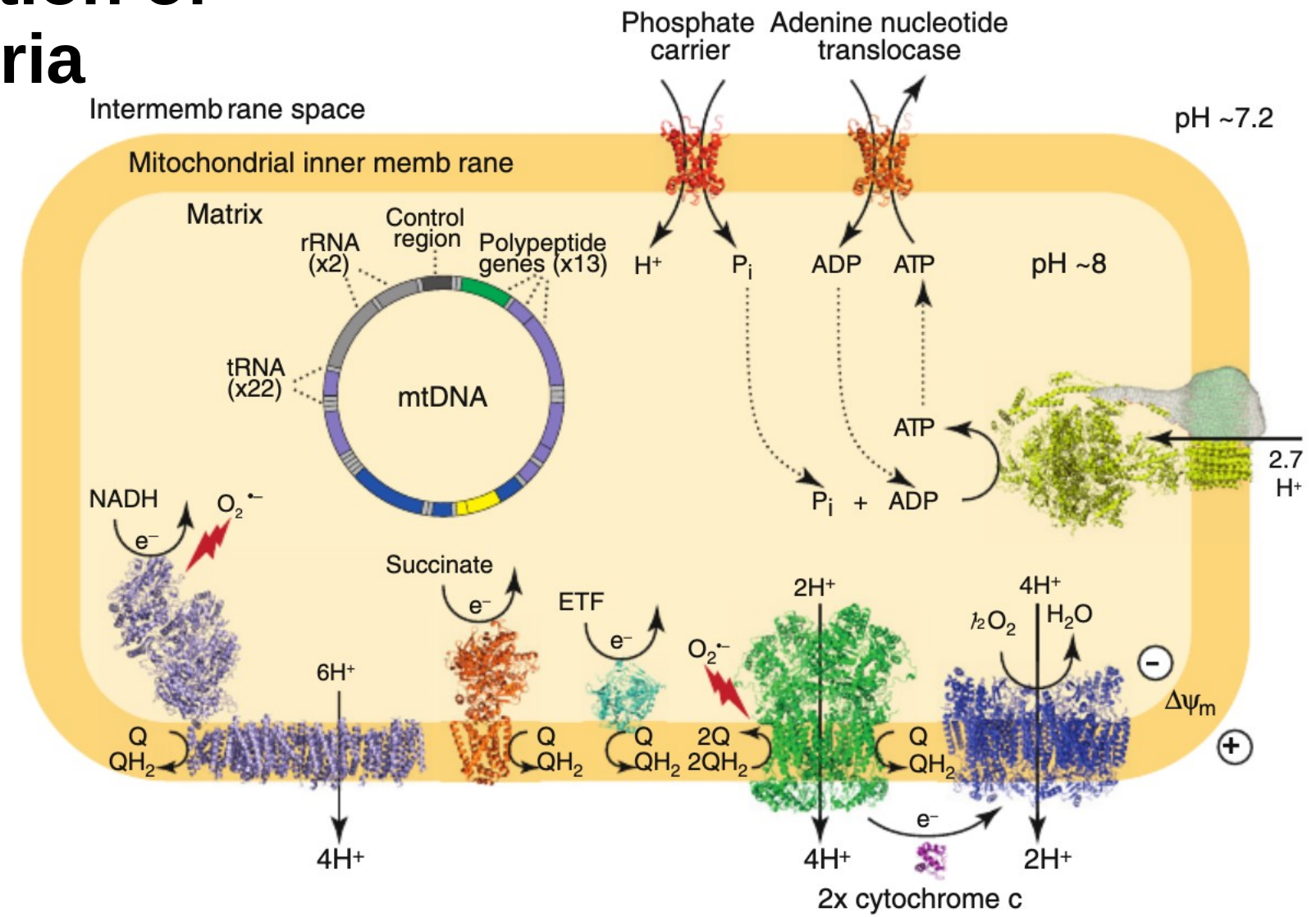



Cell
Mitochondria
Mitochondrial DNA


H strand
L strand
37 genes
16.5 kb
TRNF
TRNT
RRNS
CYTB
TRNV
CR (HV-III, II, I)
TRNP
RRNL
TRNE
ND6
TRNL1
ND5
ND1
TRNL2
TRNS2
TRNH
TRNI
TRNQ
TRNM
ND2
ND4
TRNA
TRNN
TRNC
TRNY
TRNW
ND4L
TRNR
ND3
TRNG
TRNS1
COX1
COX3
TRND
COX2
TRNK
ATP8
ATP6
0
1 kb
2 kb
3 kb
4 kb
5 kb
6 kb
7 kb
8 kb
9 kb
10 kb
11 kb
12 kb
13 kb
14 kb
15 kb
16 kb


Photosynthetic prokaryote
Chloroplast
Aerobic prokaryote
Mitochondrion

Major function of mitochondria is to produce ATP

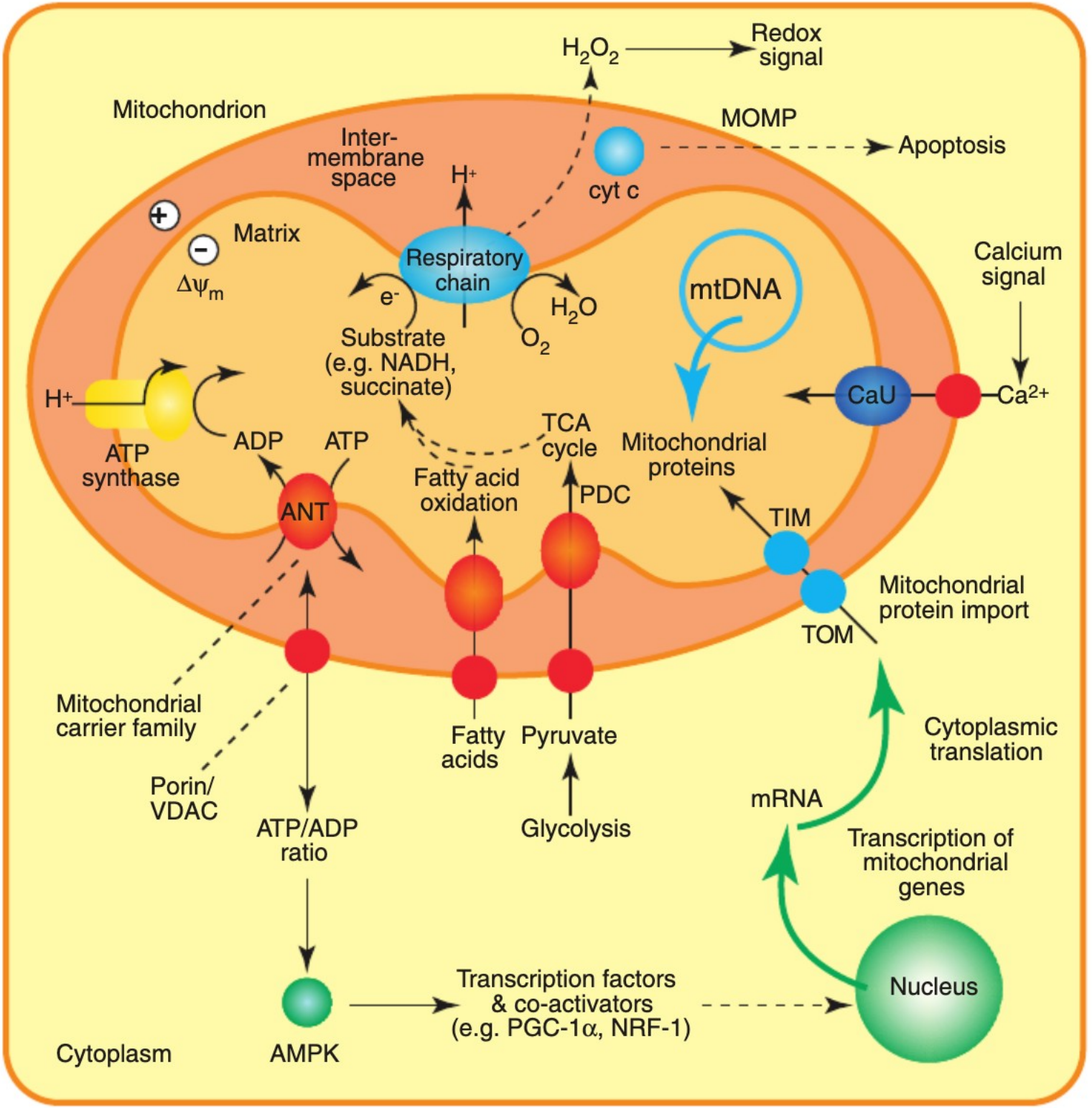


	Complex I	Complex II	ETF:Q oxido-reductase	Complex III	Complex IV	ATP synthase
Total number of subunits	45	4	1	11	13	16
Subunits encoded by mtDNA	7	0	0	1	3	2

Smith 2012

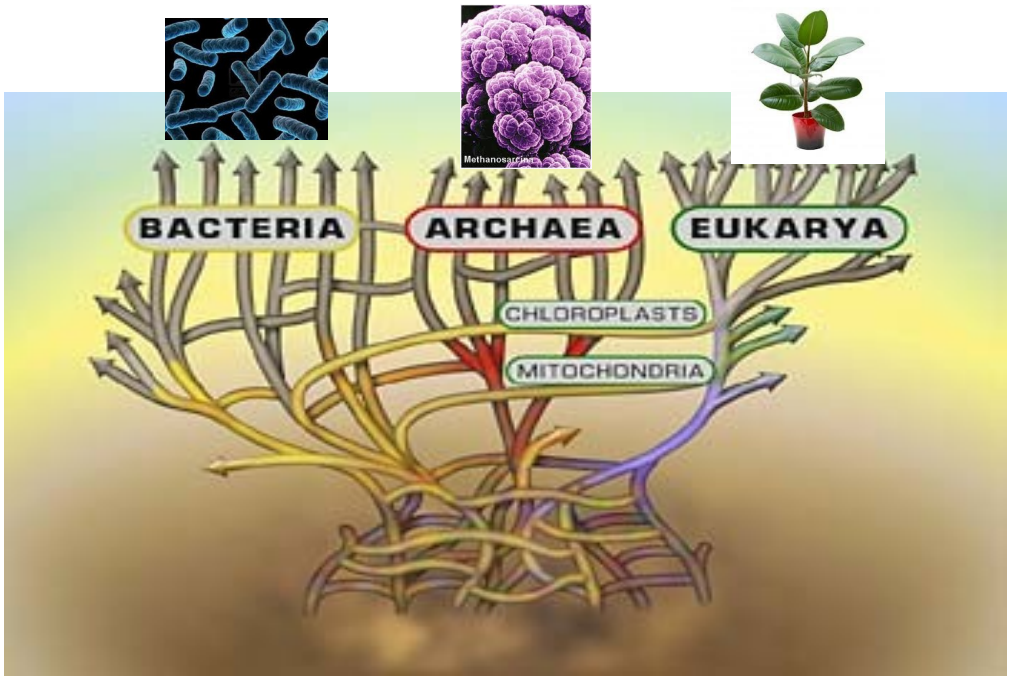
TRENDS in Pharmacological Sciences

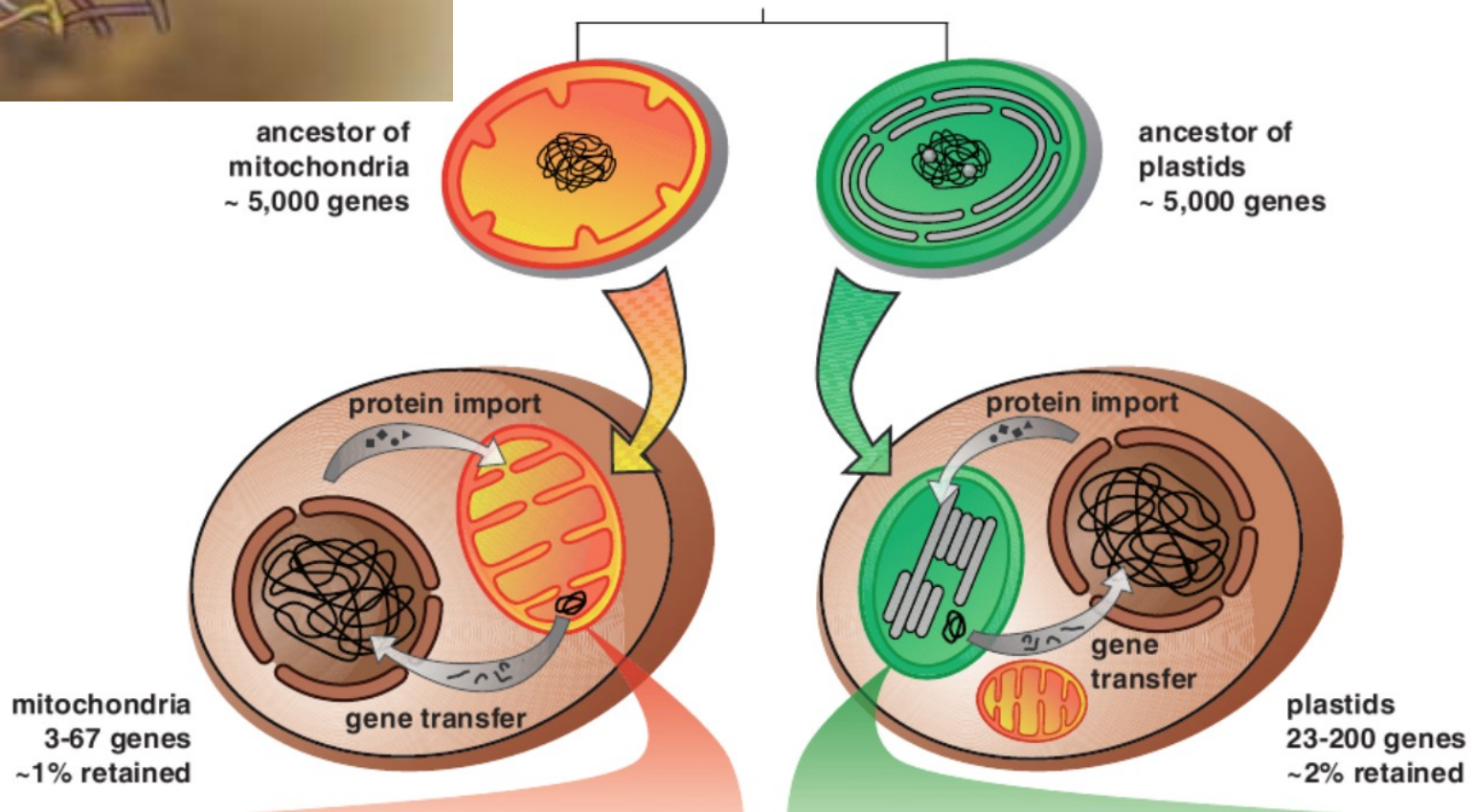
Functions And Biogenesis Of Mitochondria



Smith 2012

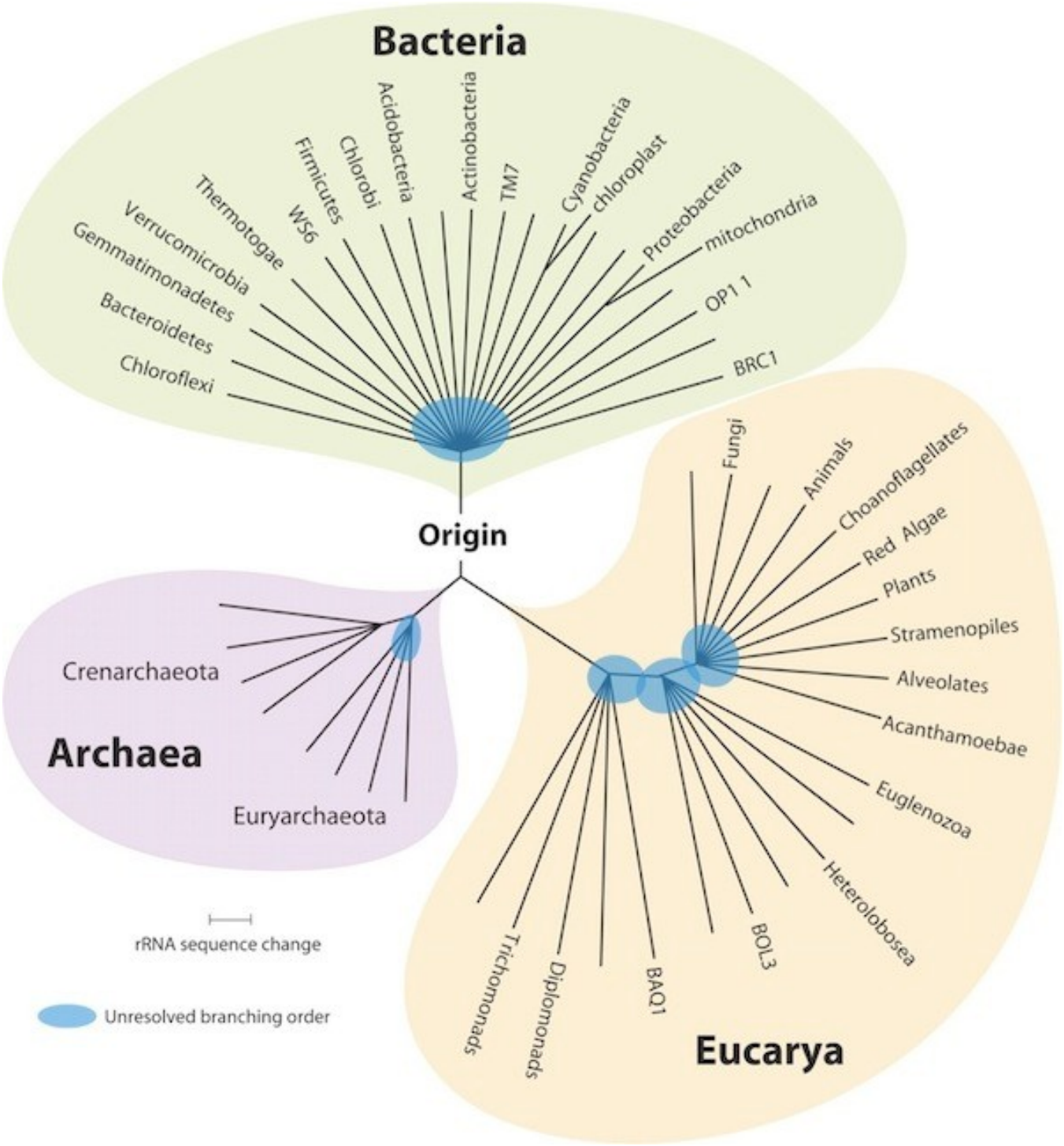
Mitochondria and chloroplasts



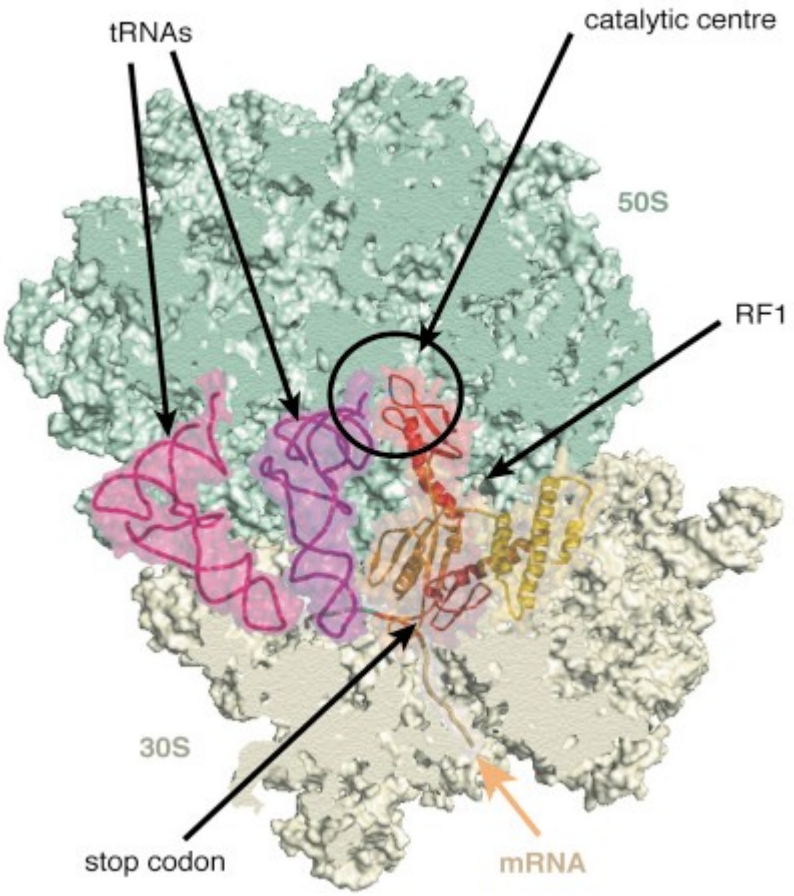


Maier 2013

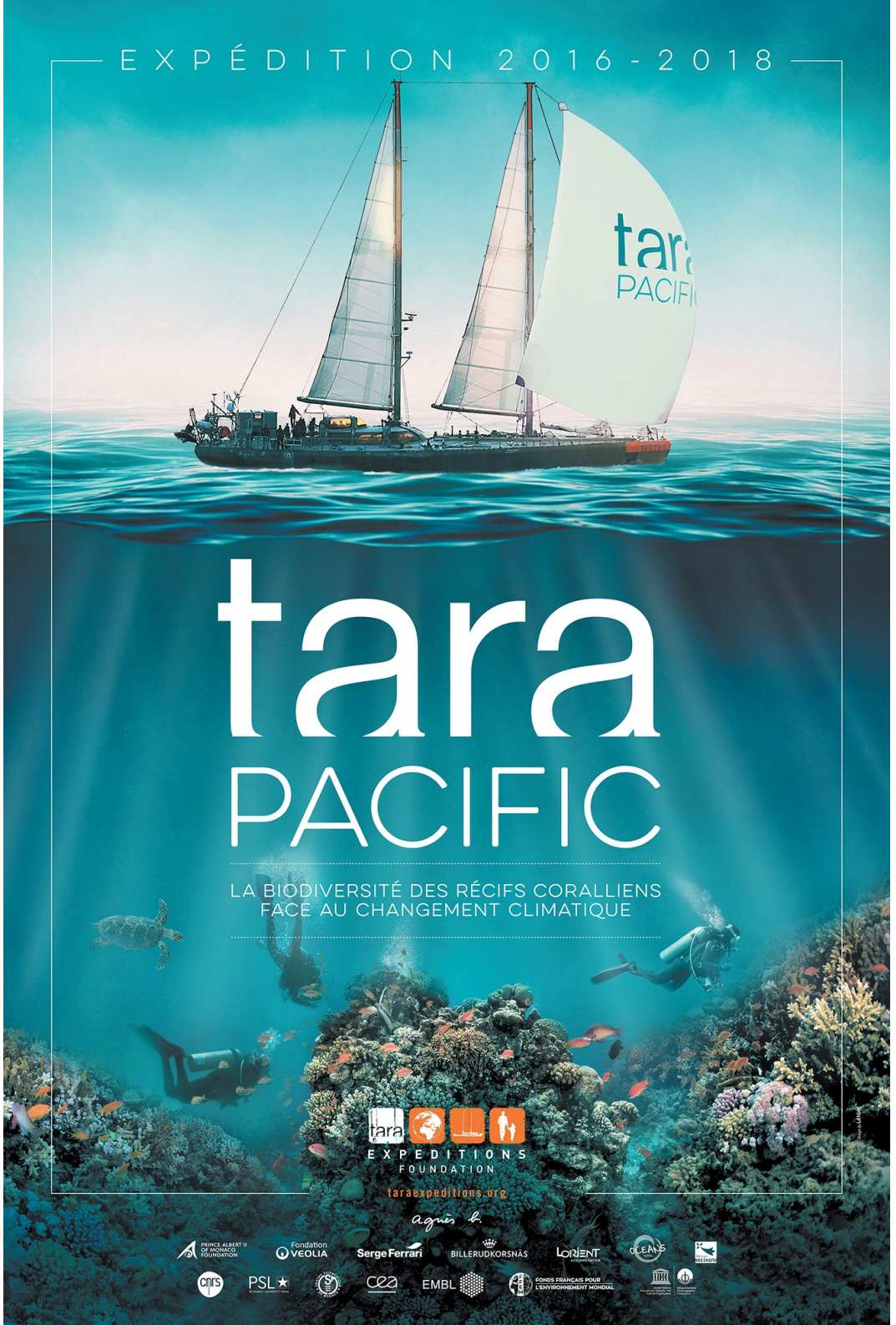
The tree of life, sampling the living world

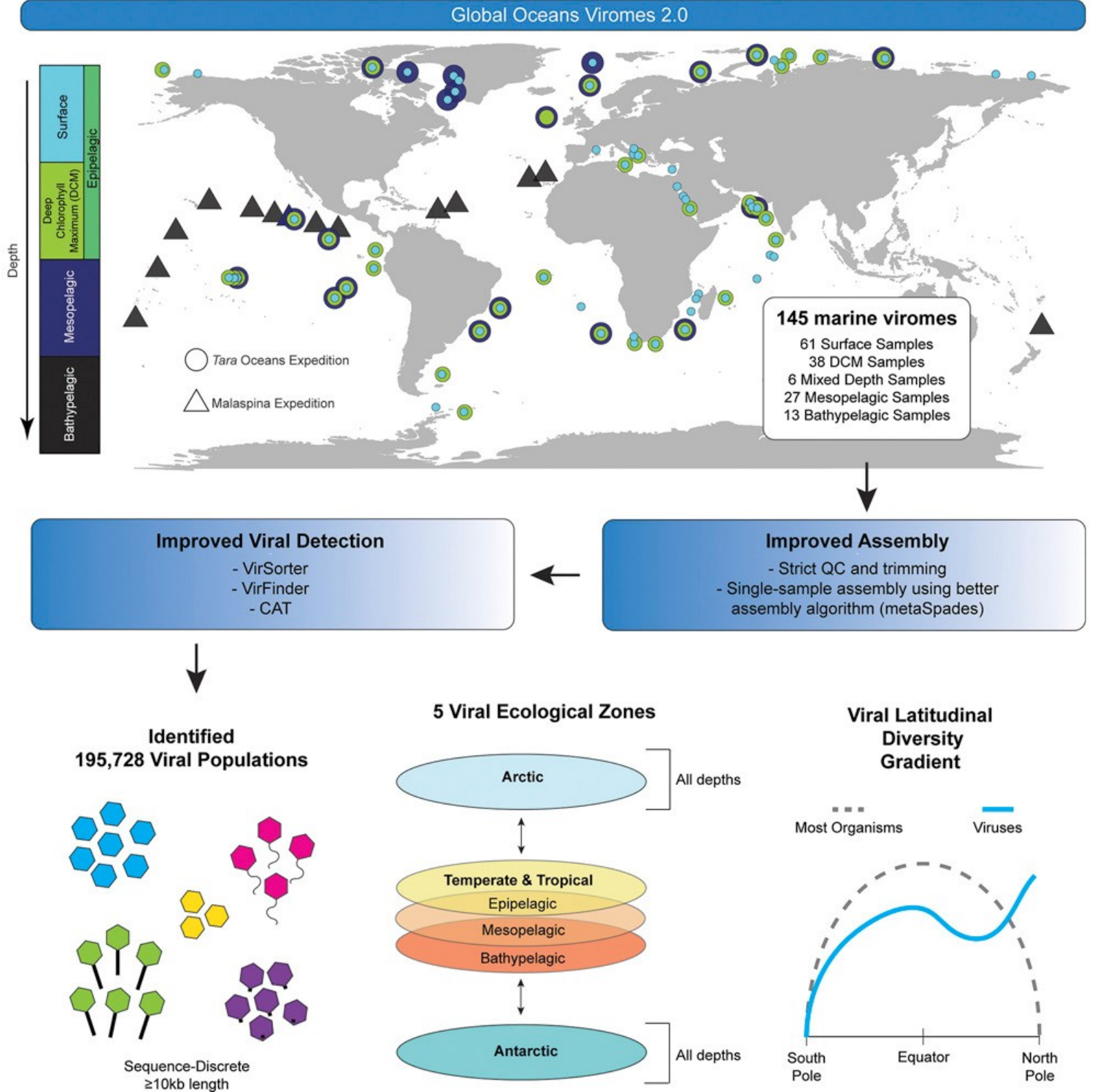

Bacteria
Acidobacteria
Actinobacteria
Chlorobi
Firmicutes
WS6
Thermotogae
Verrucomicrobia
Gemmatimonadetes
Bacteroidetes
Chloroflexi
TM7
Cyanobacteria
chloroplast
Proteobacteria
mitochondria
OP1 1
BRC1
Origin
Crenarchaeota
Archaea
Euryarchaeota
Fungi
Animals
Choanoflagellates
Red Algae
Plants
Stramenopiles
Alveolates
Acanthamoebae
Euglenozoa
Heterolobosea
BOL3
BAQ1
Diplomonads
Trichomonads
Eucarya
rRNA sequence change
Unresolved branching order

Ribosome on mRNA

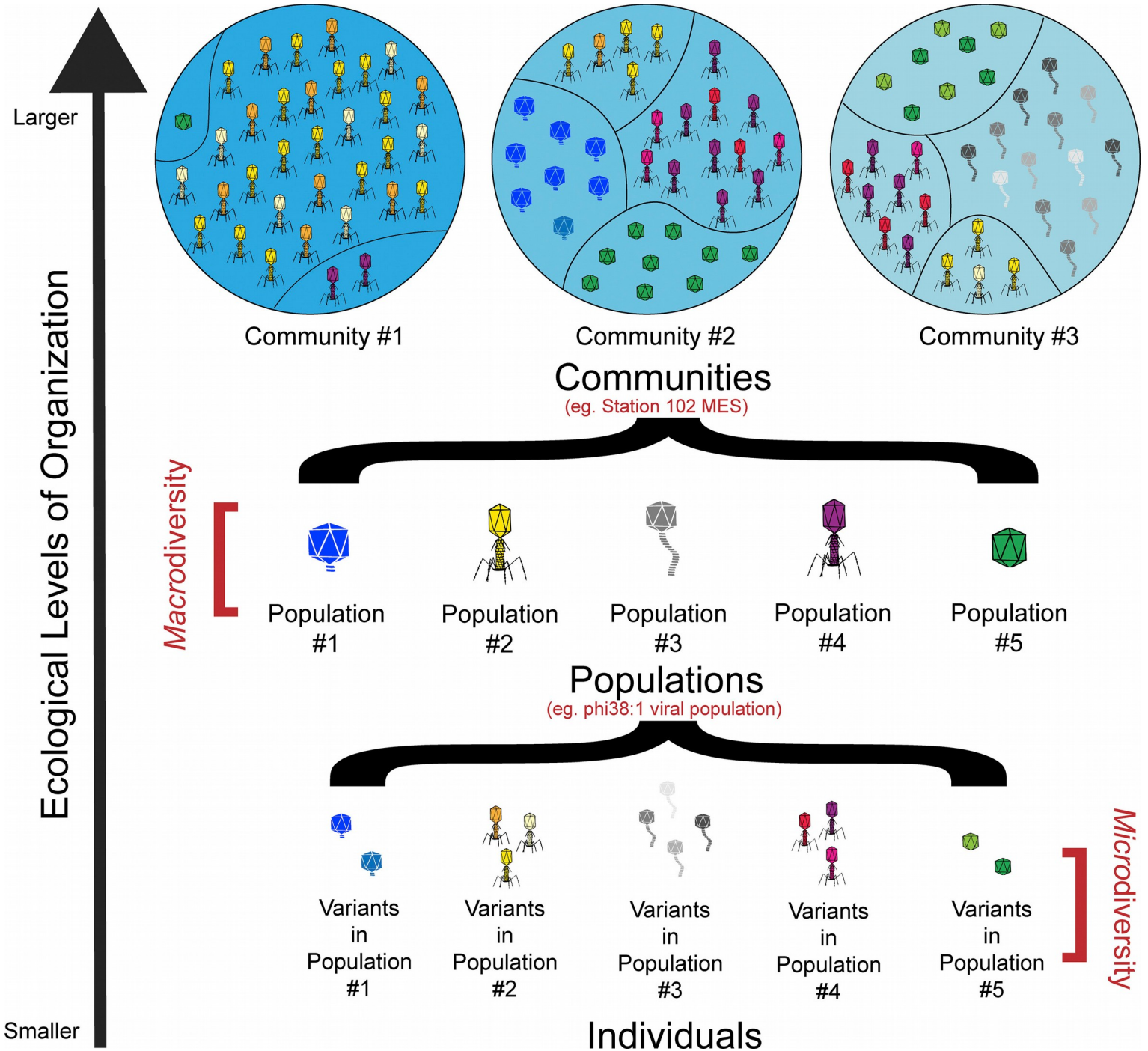


Eukaryote: 18S RNA, part of the 40S subunit
Bacteria, Mitochondria : 16S RNA, part of the 30S subunit

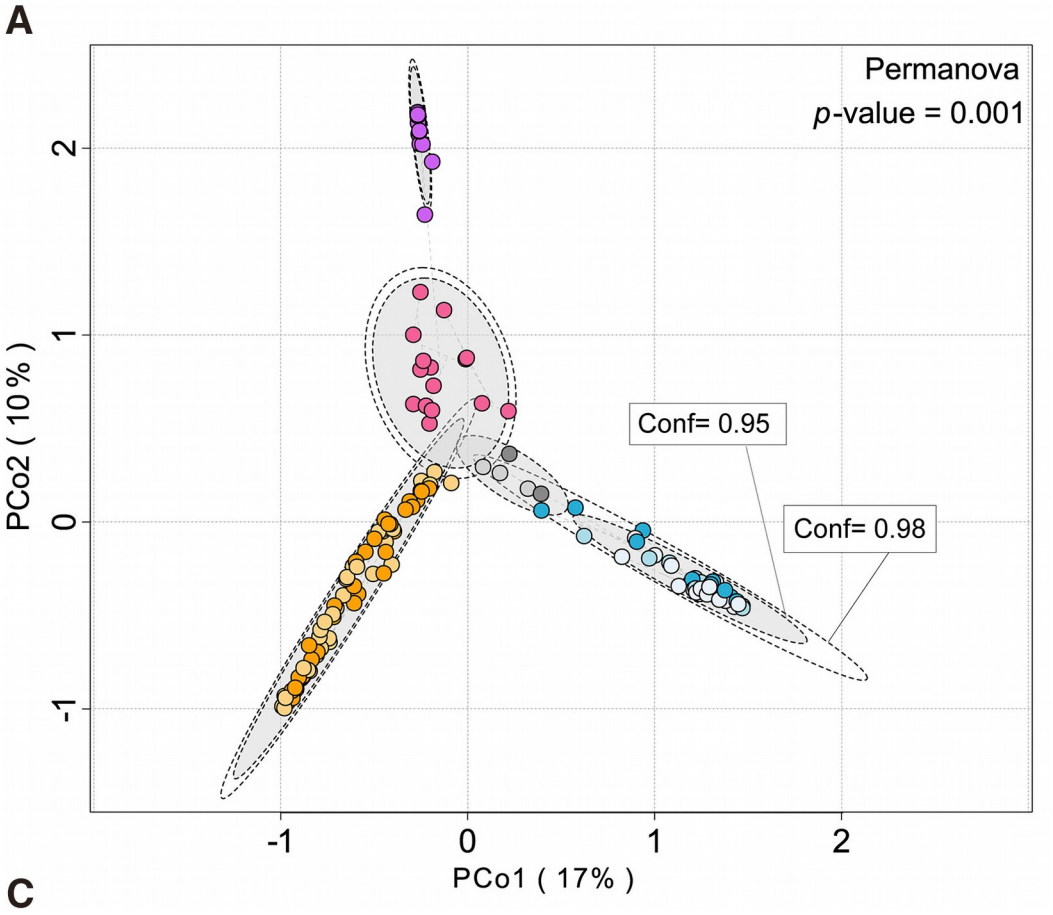

EXPÉDITION 2016-2018
tara
PACIFIC
LA BIODIVERSITÉ DES RÉCIFS CORALLIENS
FACE AU CHANGEMENT CLIMATIQUE
tara
EXPEDITIONS
FOUNDATION
taraexpeditions.org
agnès b.
PRINCE ALBERT II OF MONACO FOUNDATION
Fondation VEOLIA
Serge Ferrari
BILLERUDKORSNÄS
LORIENT
OCEANS
METAGEN
cnrs
PSL
cea
EMBL
FONDS FRANÇAIS POUR L'ENVIRONNEMENT MONDIAL



Gregory et al 2019

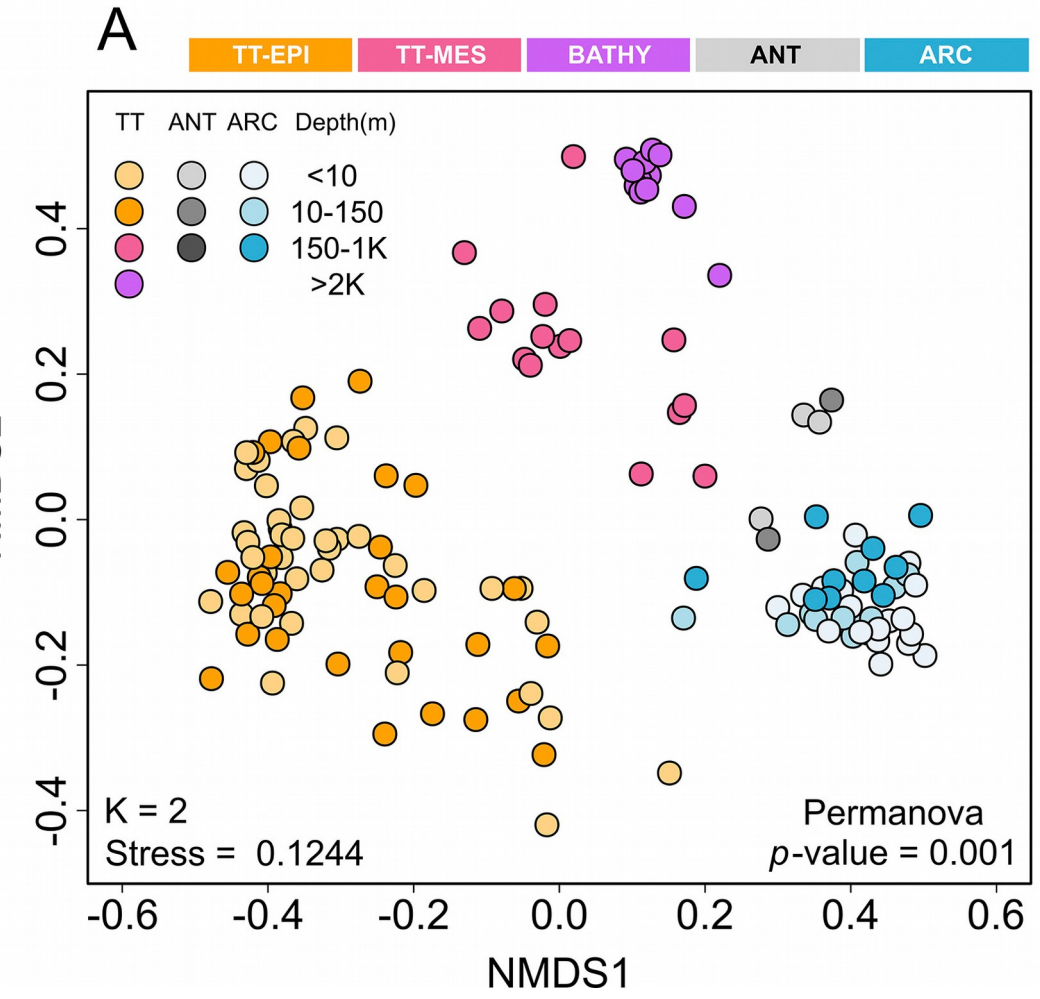

Ecological Levels of Organization
Larger
Smaller
Community #1
Community #2
Community #3
Communities
(eg. Station 102 MES)
Macrodiversity
Population #1
Population #2
Population #3
Population #4
Population #5
Populations
(eg. phi38:1 viral population)
Variants in Population #1
Variants in Population #2
Variants in Population #3
Variants in Population #4
Variants in Population #5
Microdiversity
Individuals

Five ecological zones

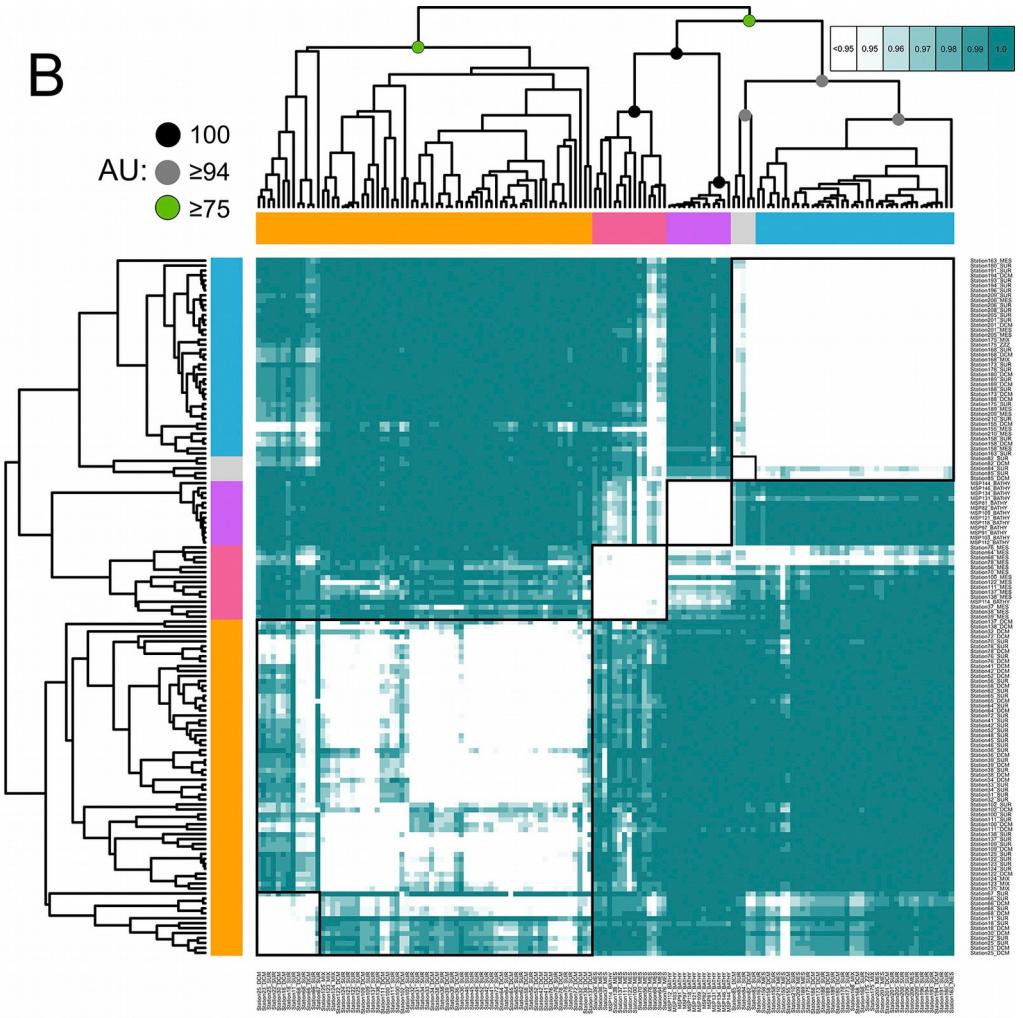


Principal Component Analysis

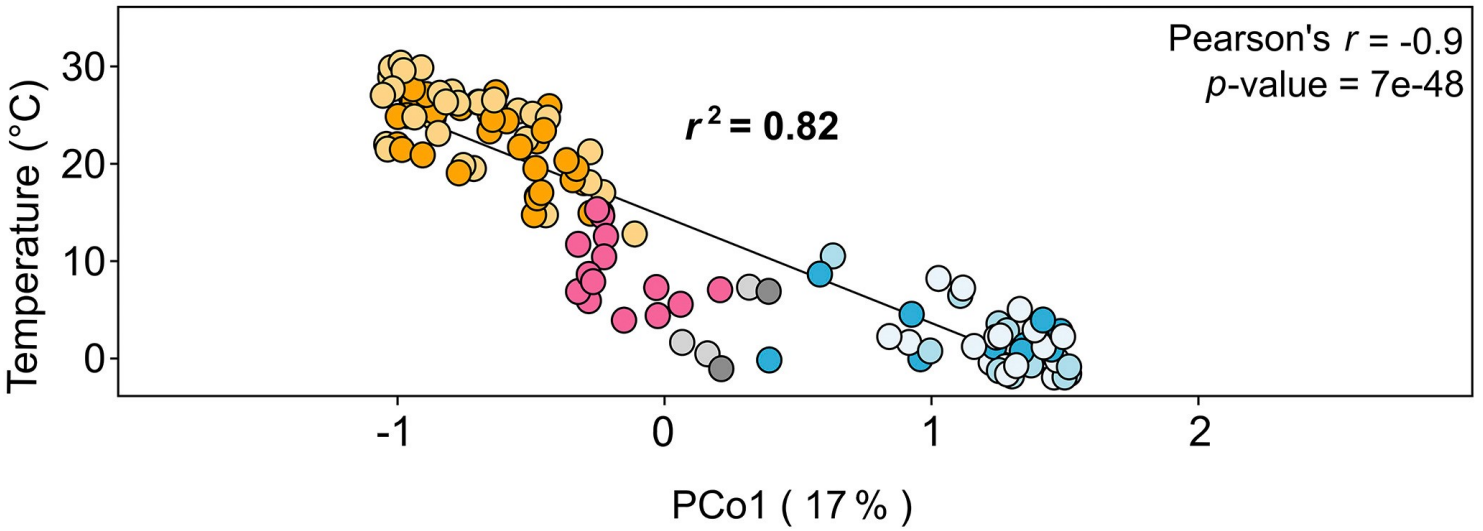
Five ecological zones



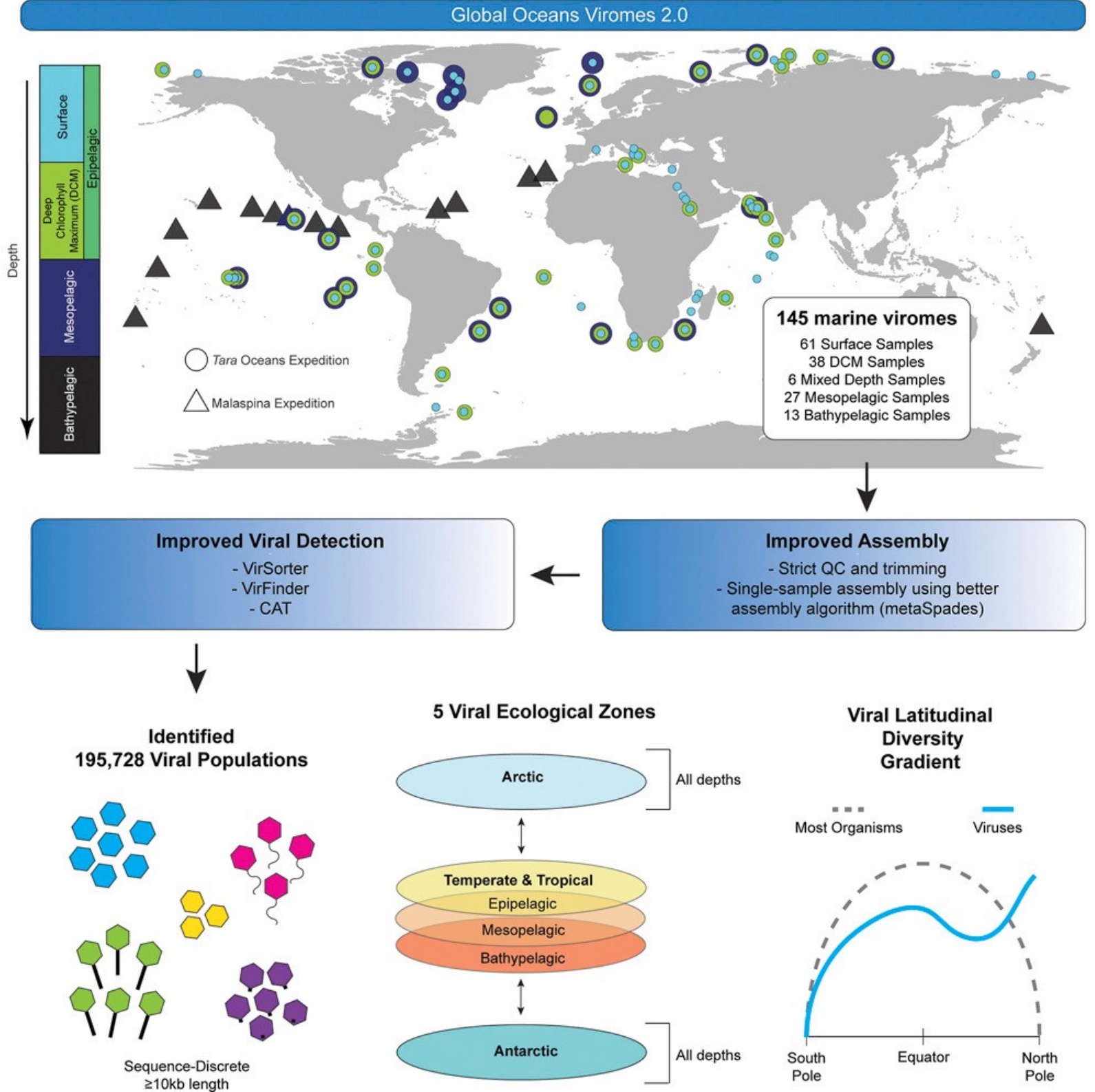
Non-metric Multidimensional Scaling



Hierarchical clustering



Regression analysis between the first coordinate of a PcoA and temperature
Samples are separated by their local temperatures with an r2 of 0.82.



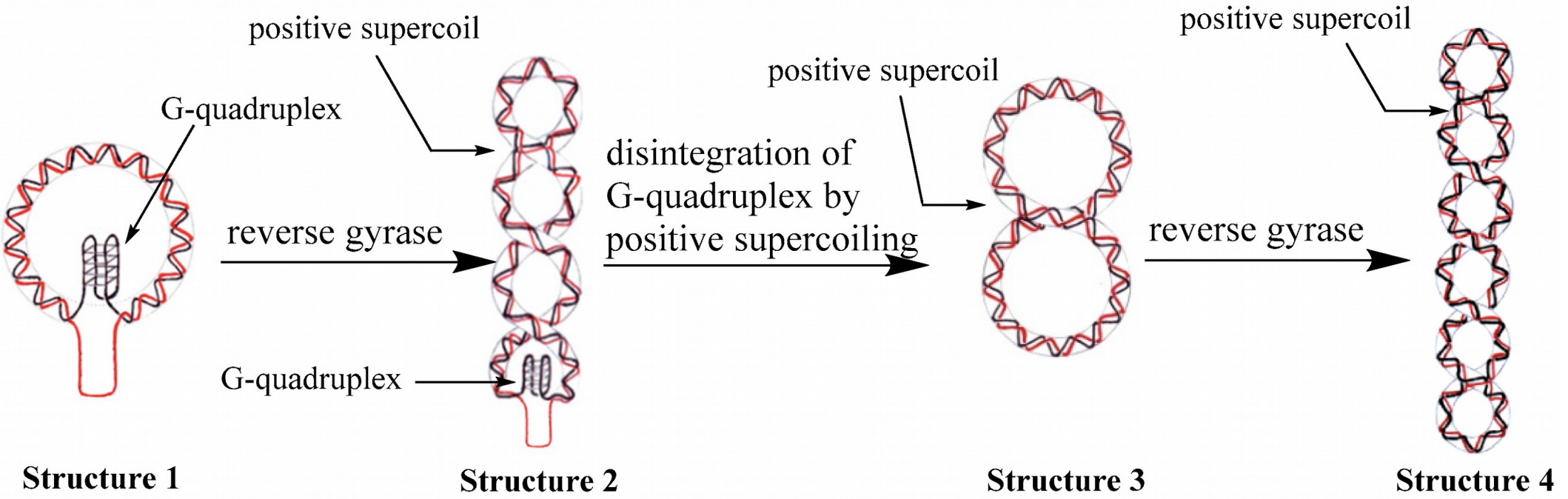
Gregory et al 2019

Living organisms in extreme conditions

Tardigrad: mountaintops, deep sea, mud volcanoes, tropical rain forests, Antarctic
Temperatures between −272 and +150 °C, pressure up to 6 000 atm, air deprivation, radiation, dehydration, starvation, outer space

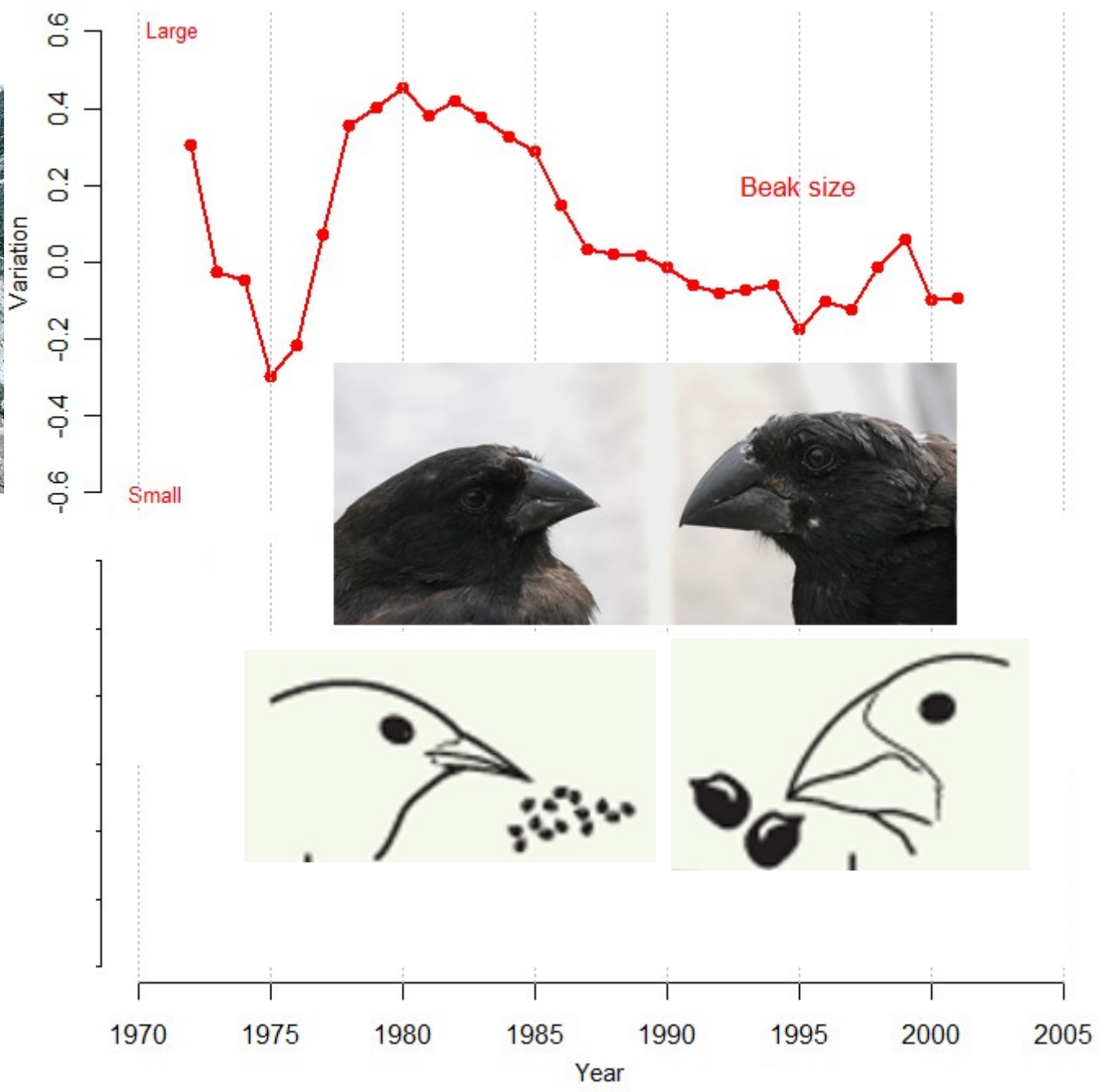
Hyperthermophile bacteria

All bacteria living at >80°C have a reverse gyrase enzyme
Maintains DNA stability

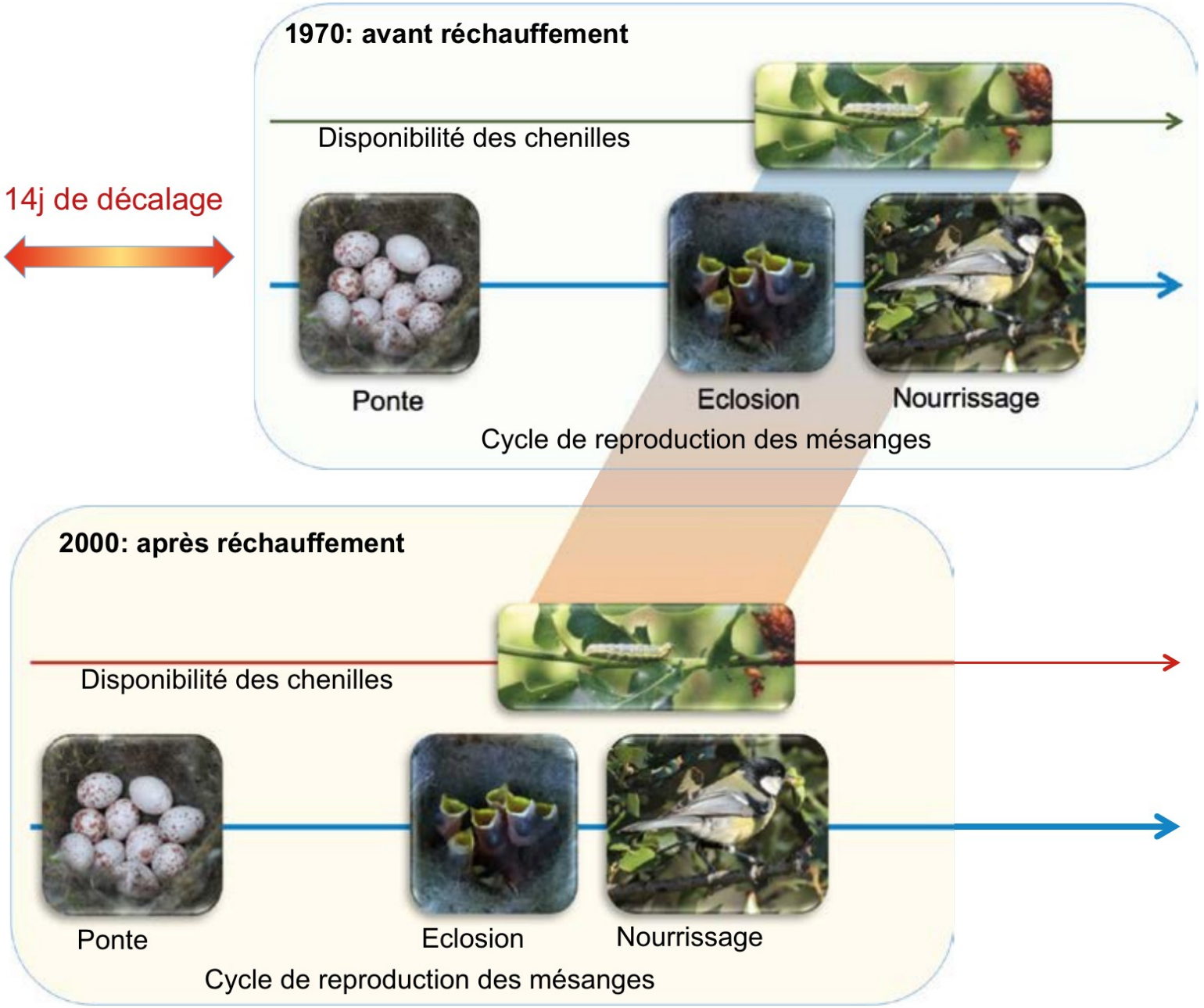


Monitoring birds

Peter and Rosemary Grant
in Galapagos



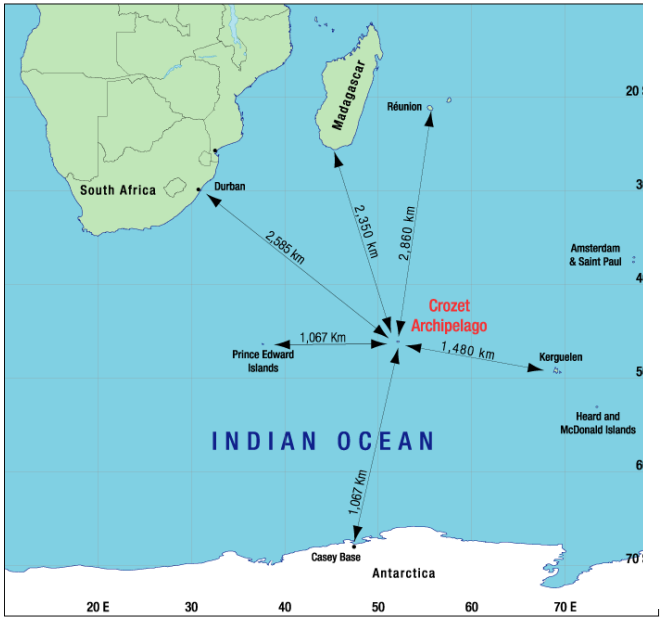
Rapid evolution of great tits

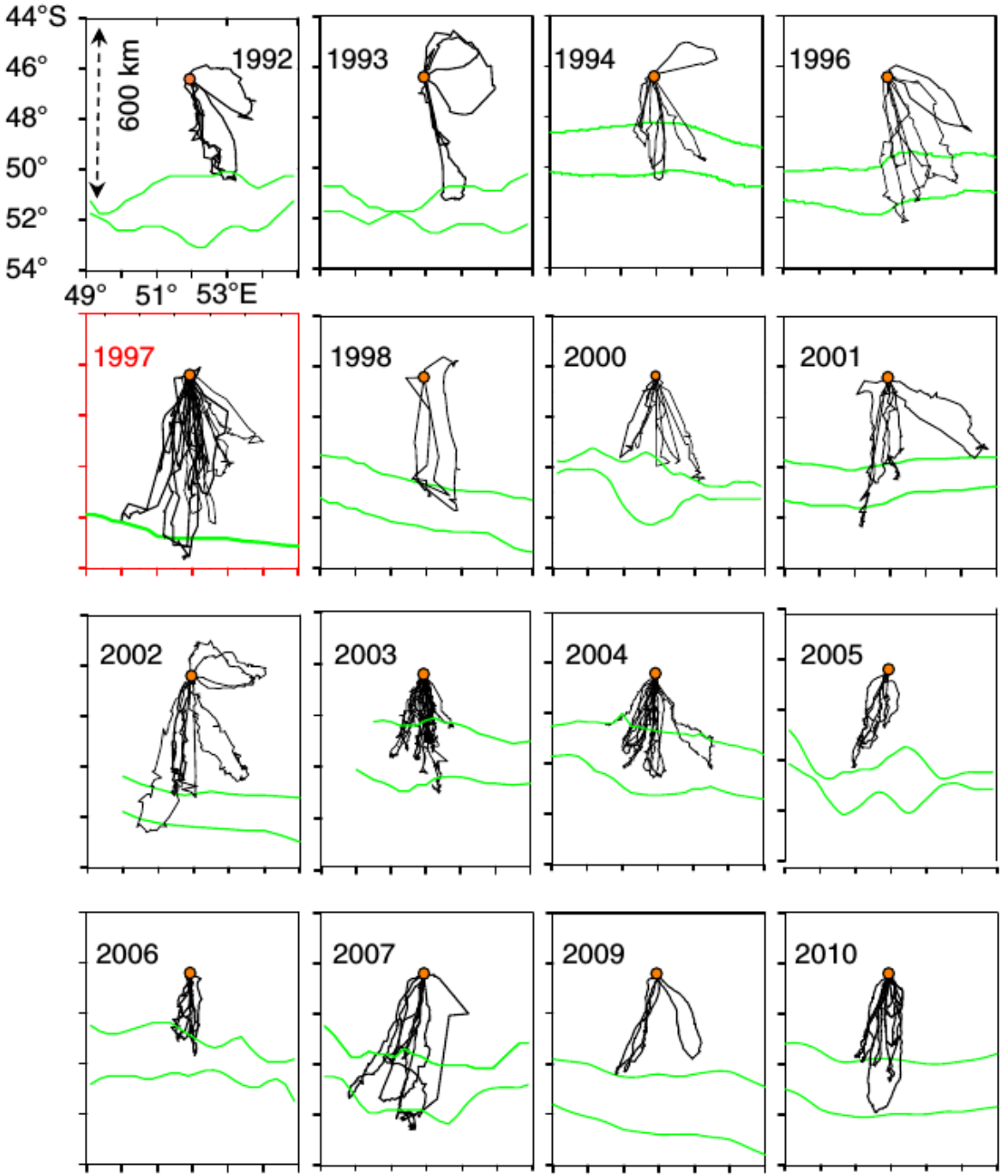


Etonnant vivant : découvertes et promesses du XXIe siècle (2017)

Tracking king penguins

Must go to the polar front
to capture fishes

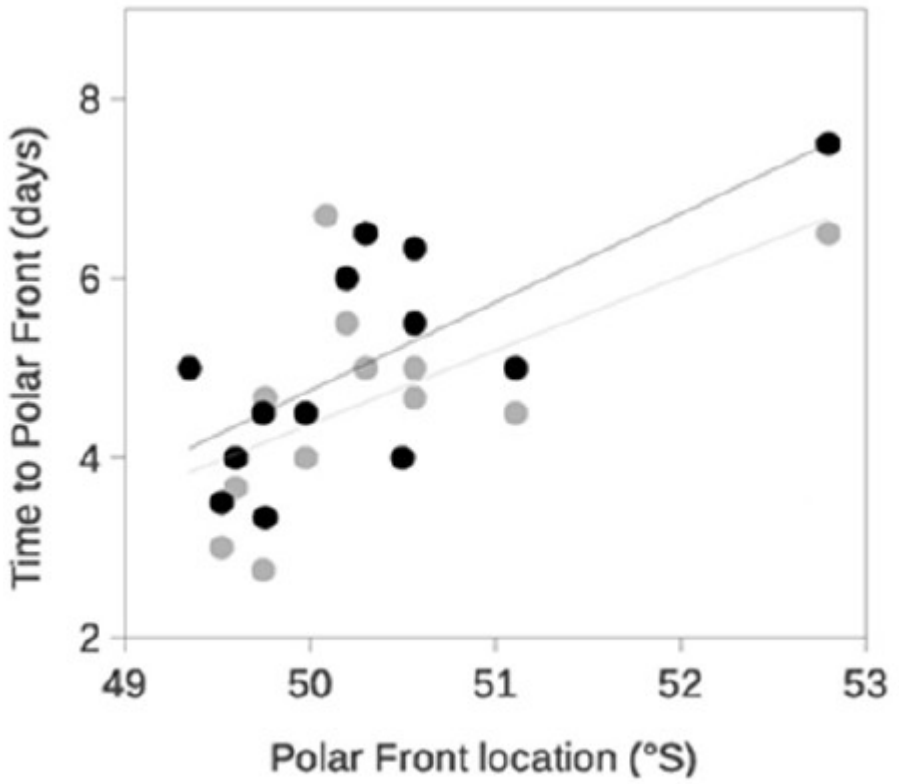




green lines; upper line: 5°C sea surface isotherm; bottom: 4°Csea surface isotherm

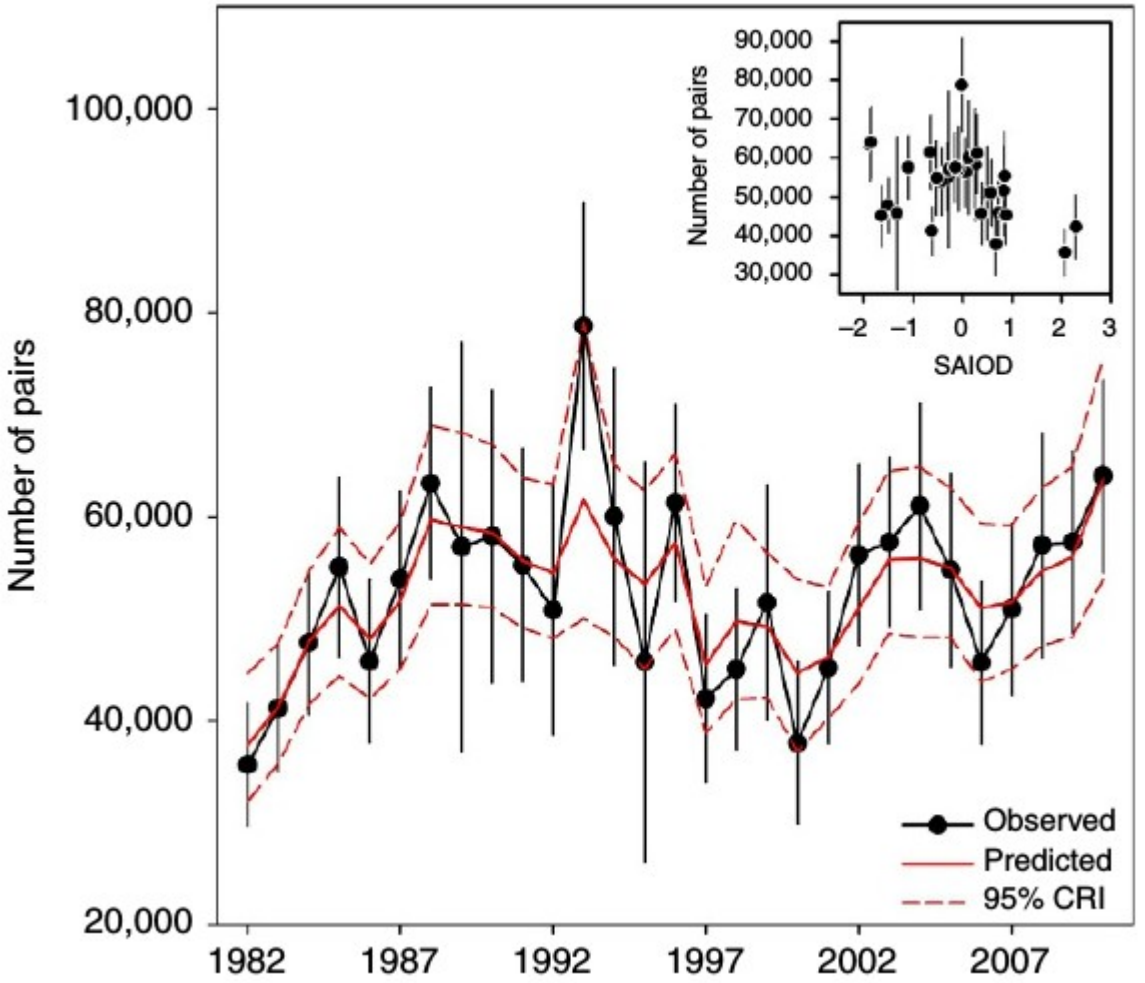
Bost
et al
2015

The further, the longer it takes



Bost et al 2015

Decrease in population numbers in 1997



Bost et al 2015