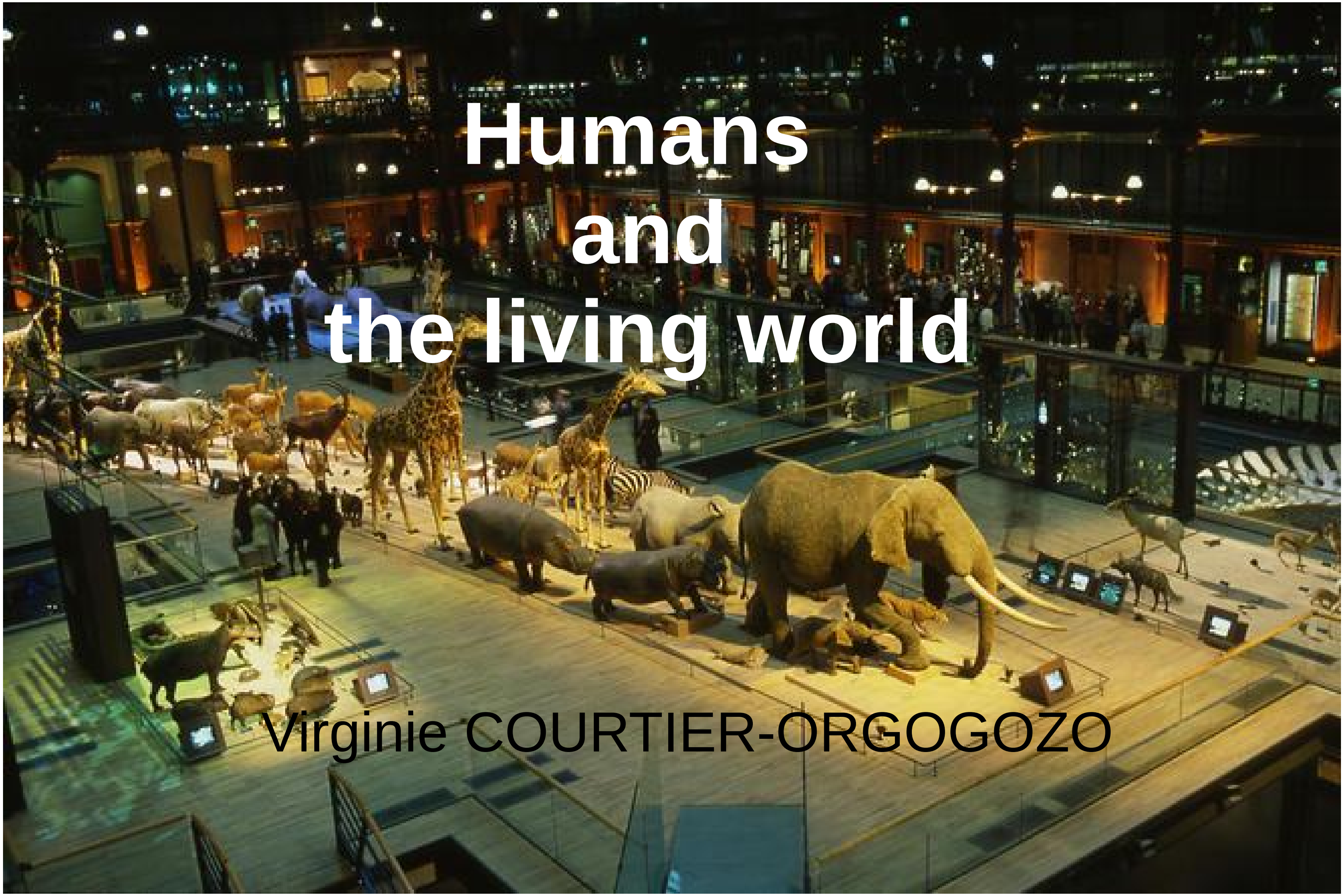


Humans and the living world

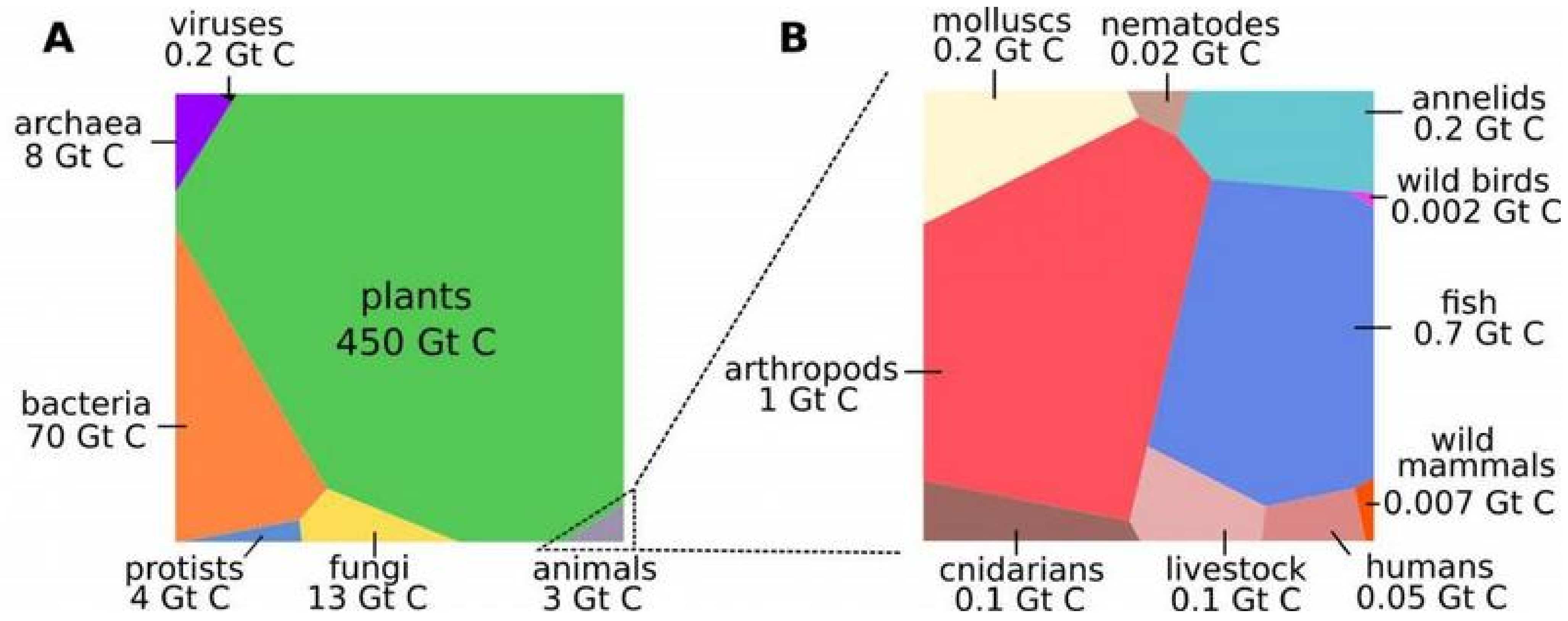
Virginie COURTIER-ORGOGOZO

Sept 2021

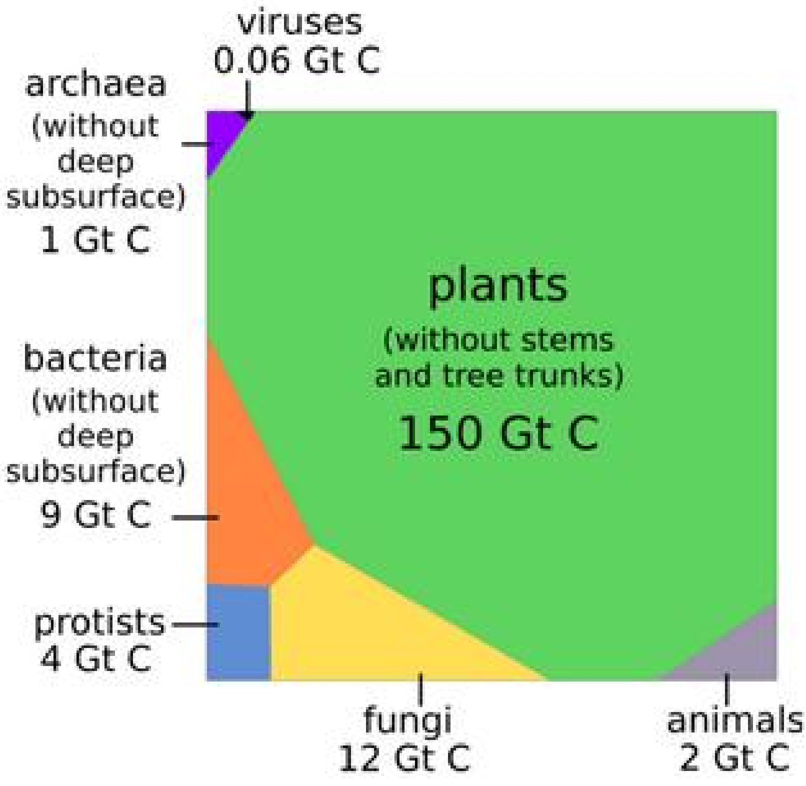
What is the largest biomass on earth ?

- ☐ **Insects**
- ☐ **Viruses**
- ☐ **Bacteria**
- ☐ **Green plants**

Biomass distribution on earth



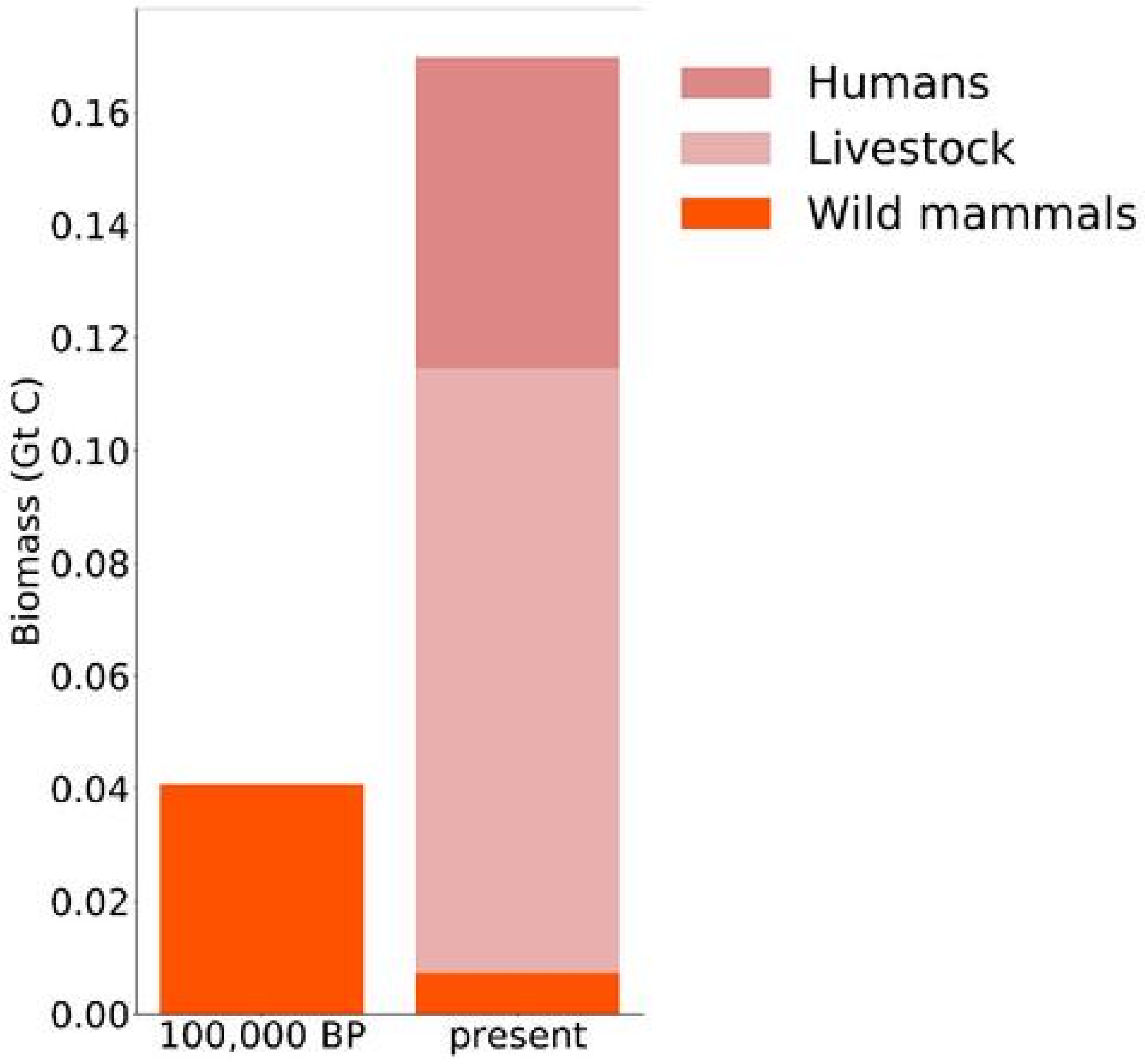
Bar-On 2018 PNAS



Bar-On 2018 PNAS

Which has the largest biomass ?

- ☐ humans
- ☐ livestock



Bar-On 2018 PNAS

What is life ?

From molecules to ecosystems

The tree of life
Individuals and interconnections

Anthropocene

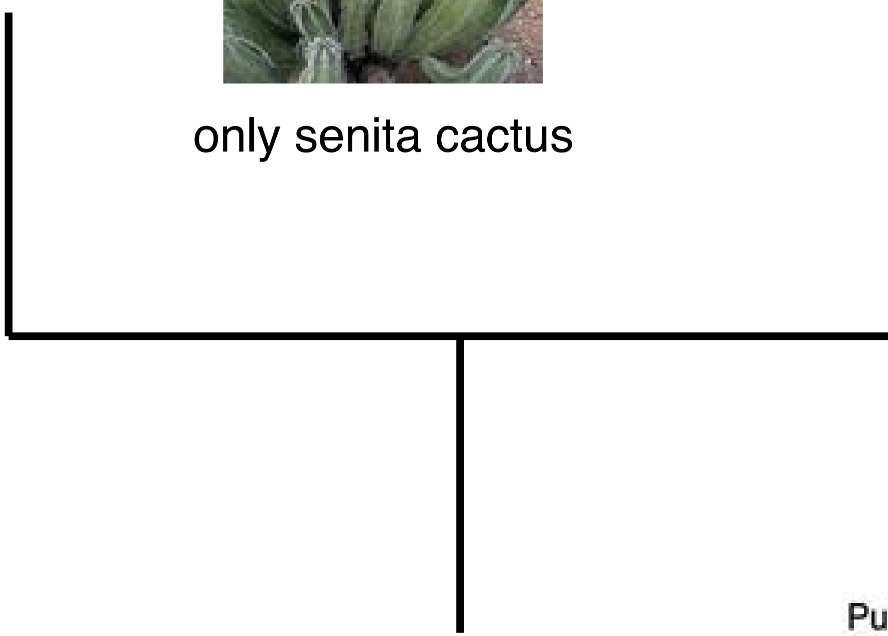
My lab topic: How do species diverge with time ?

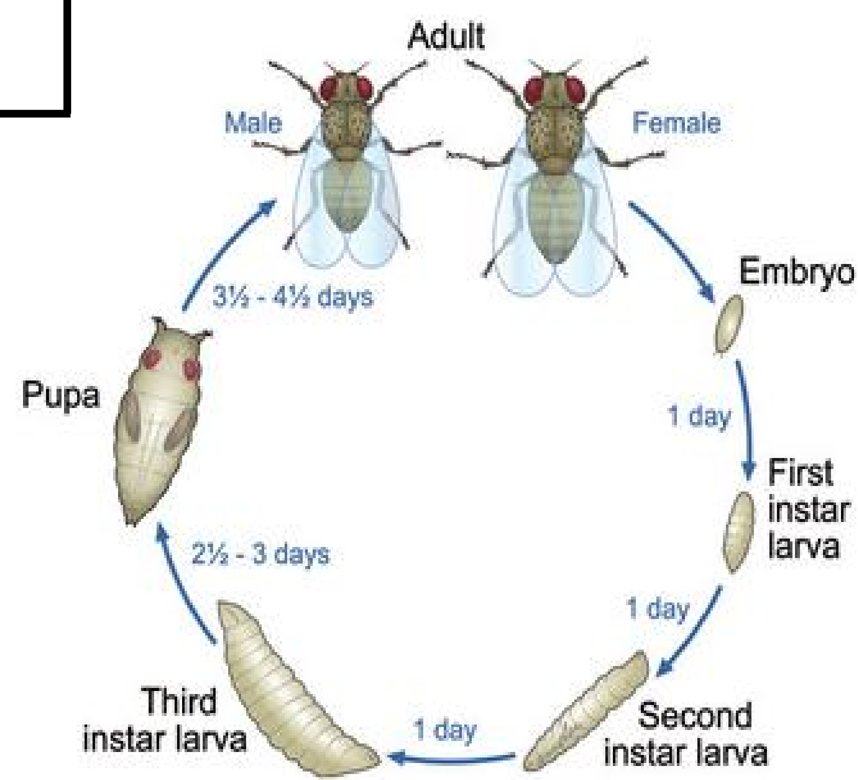
D. pachea

only senita cactus

D. nannoptera

many cactus species





Evolution of Drosophila glue

soil

. *grimshawi*

rotten strawberry

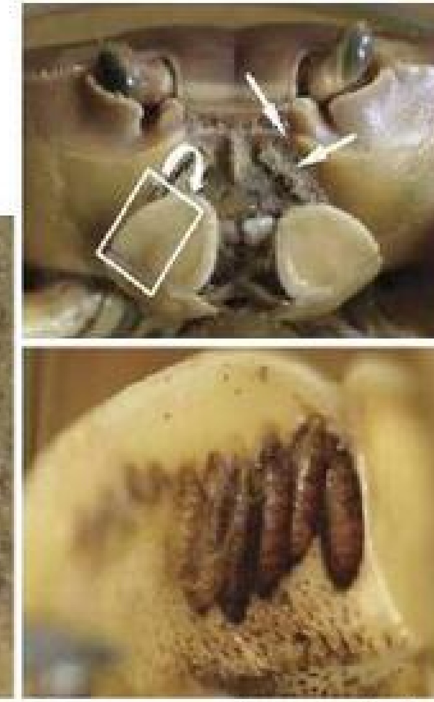
D. suzukii

grape

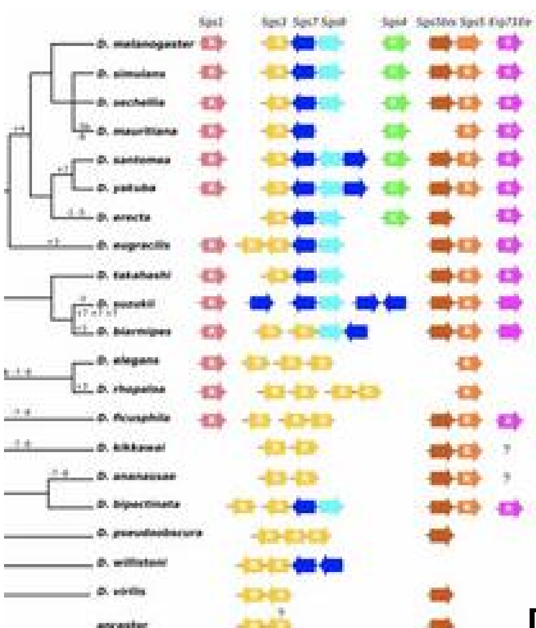
D. melanogaster

potato

D. repleta

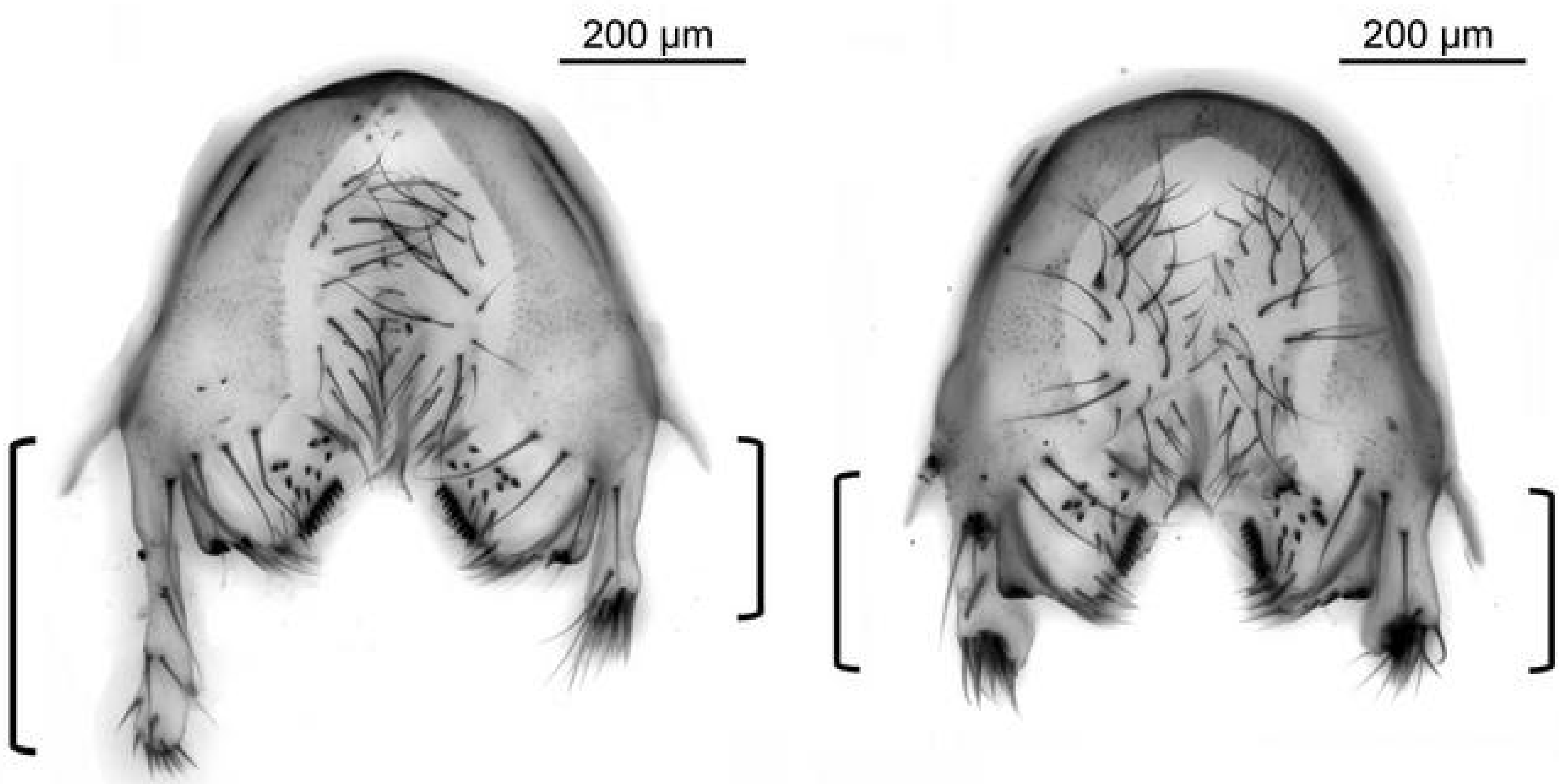


D. carcinophila



Da Lage et al. 2019 BMC Evol Biol

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



What is life ?

From molecules to ecosystems

The tree of life
Individuals and interconnections

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

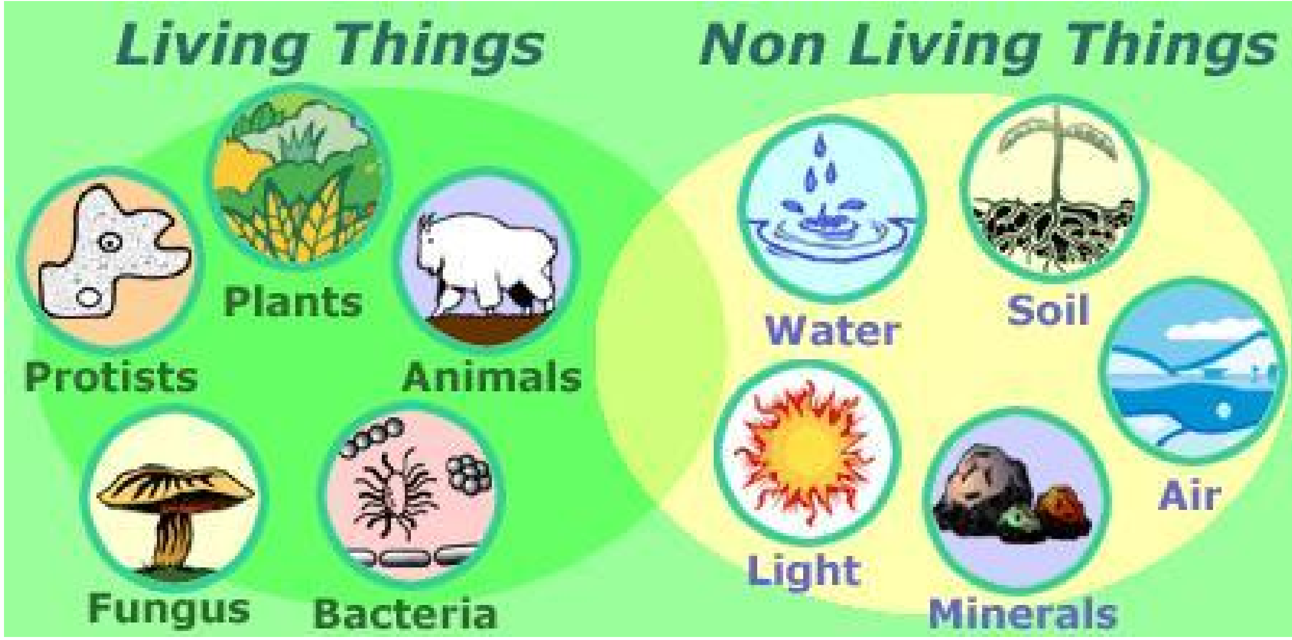
LS8 Ecology, Evolution and Environmental Biology

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
Can mutate
Derives from another living being

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

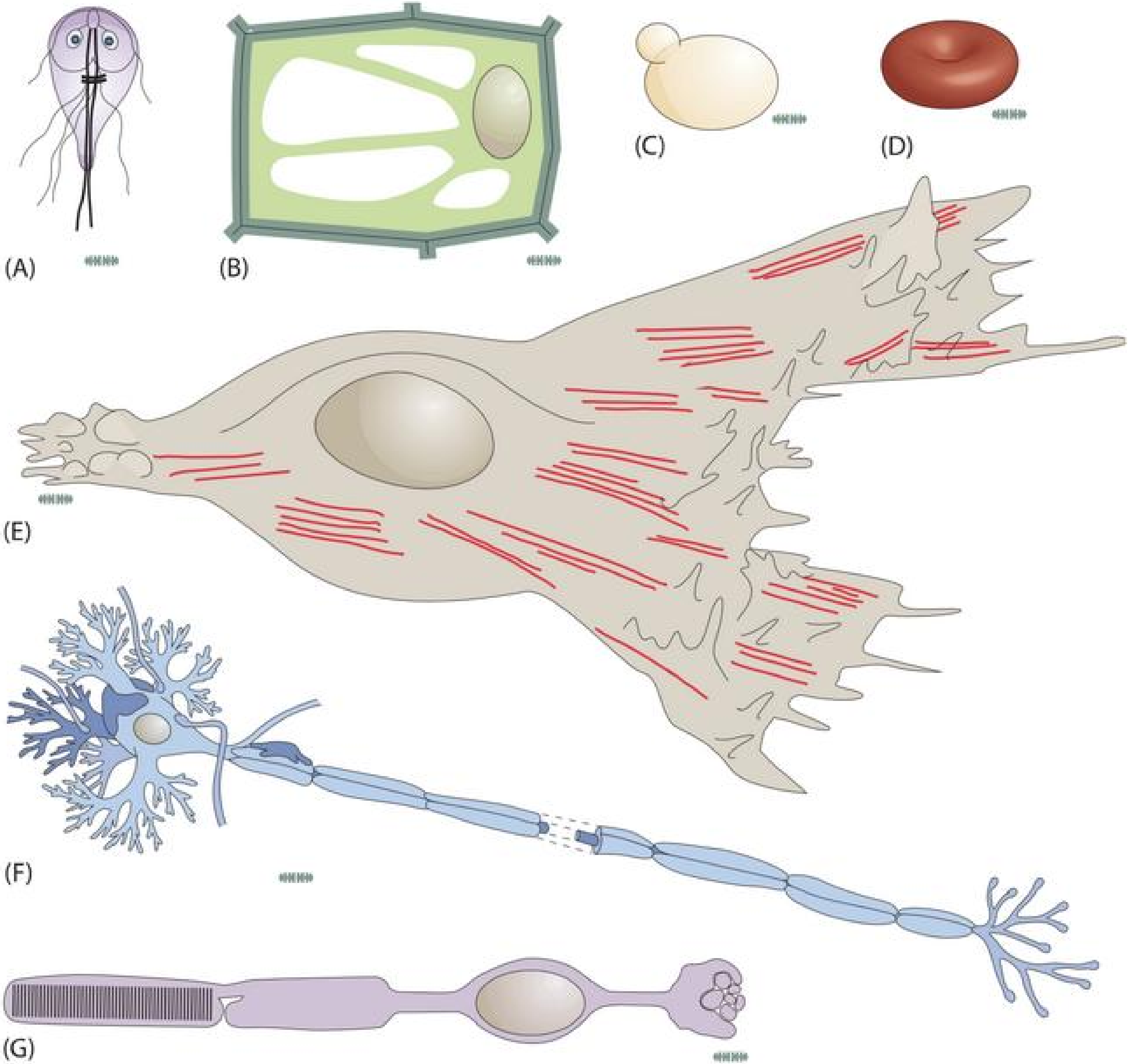
"*All living things are composed of cells and cell products*"

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)

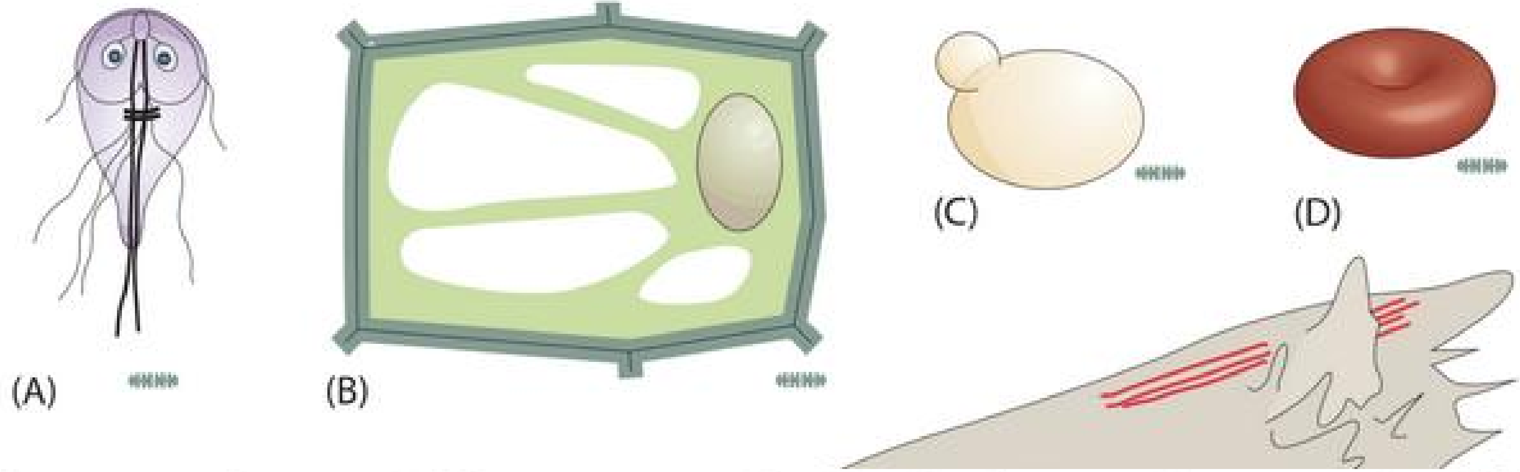
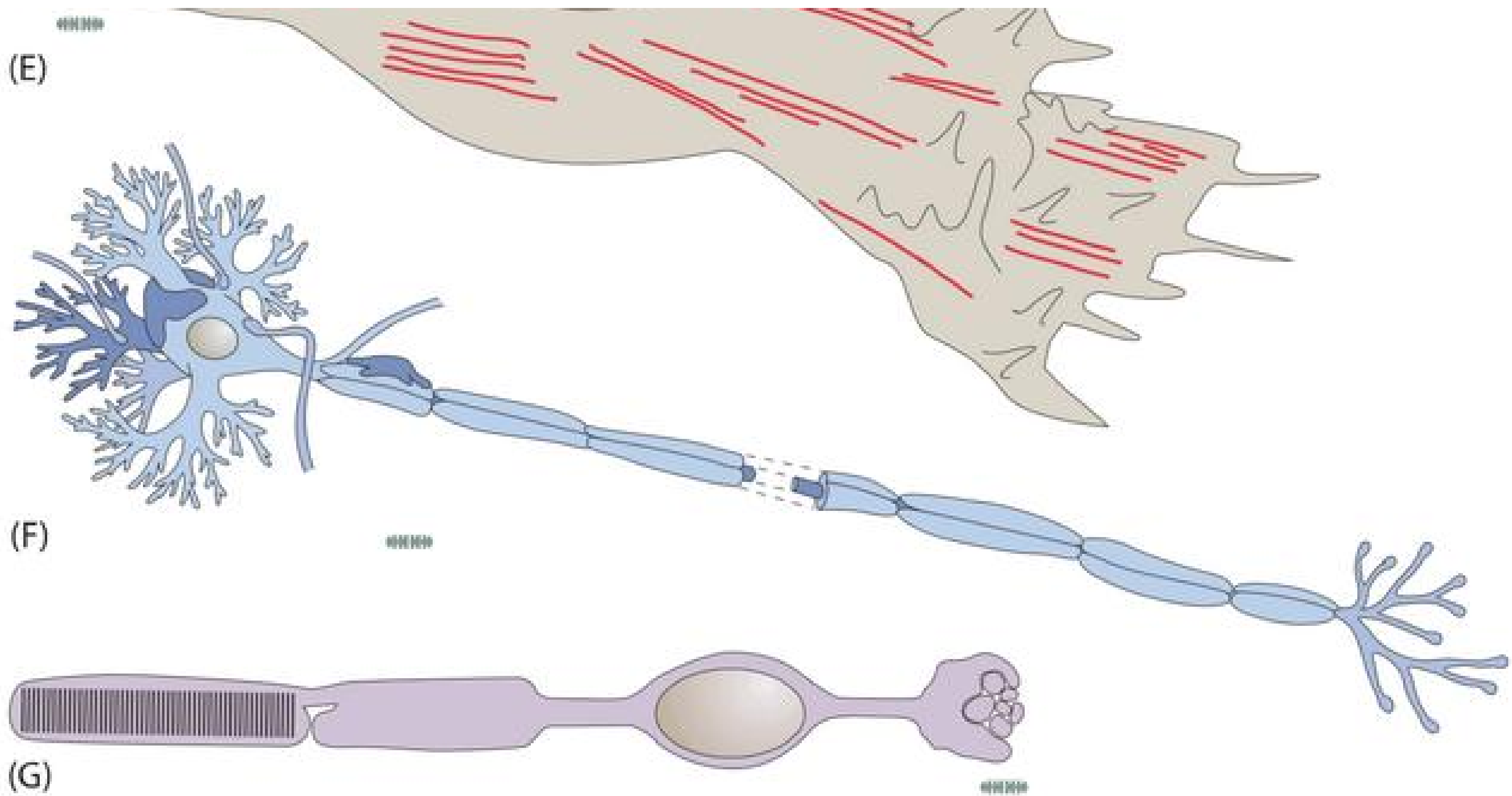
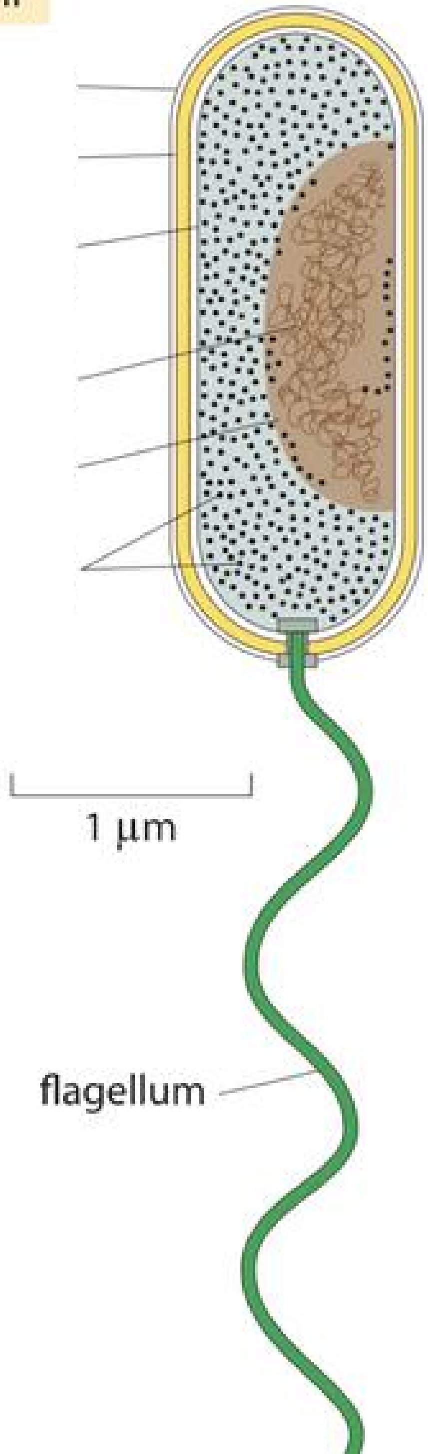


Figure 4: Cartoons of several different types of cells all referenced to a standard *E. coli* ruler of 1 micron width drawn in grey. (A) The protist Giardia lamblia, (B) a plant cell, (C) a budding yeast cell, (D) a red blood cell, (E) a fibroblast cell, (F) a eukaryotic nerve cell, and (G) a rod cell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

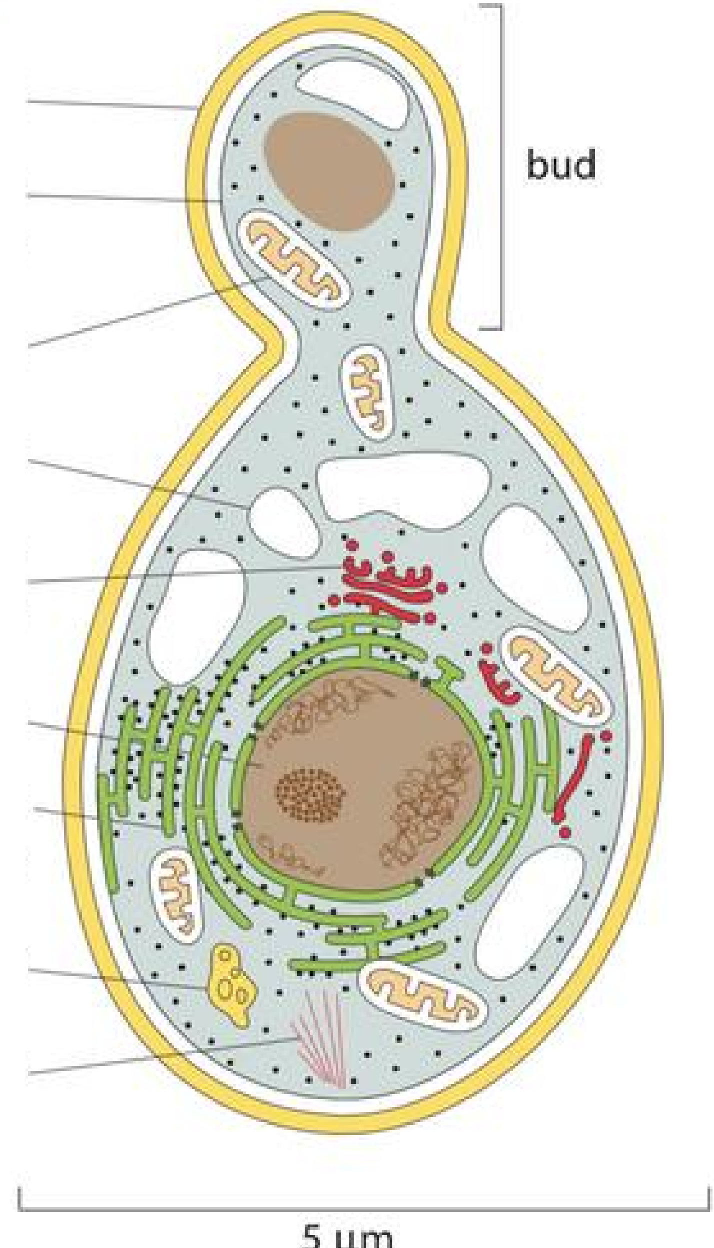


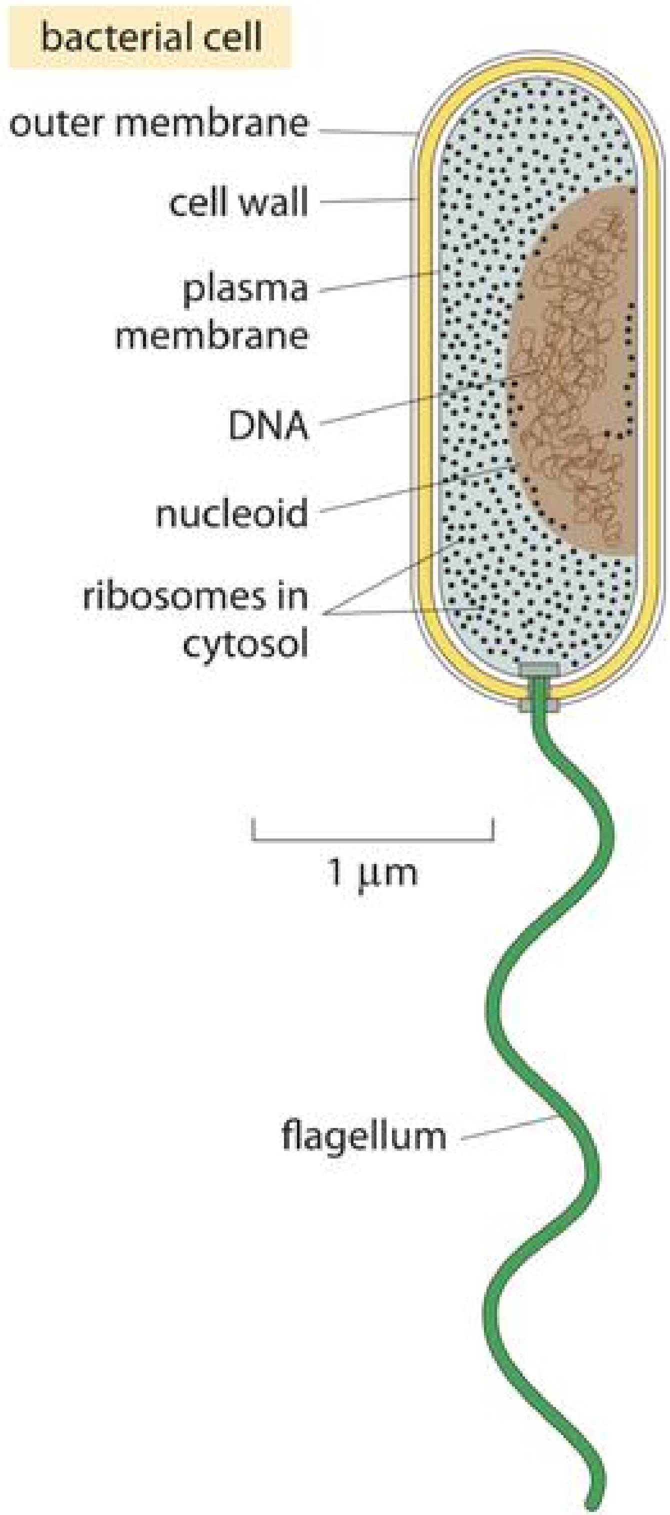
From cells to molecules

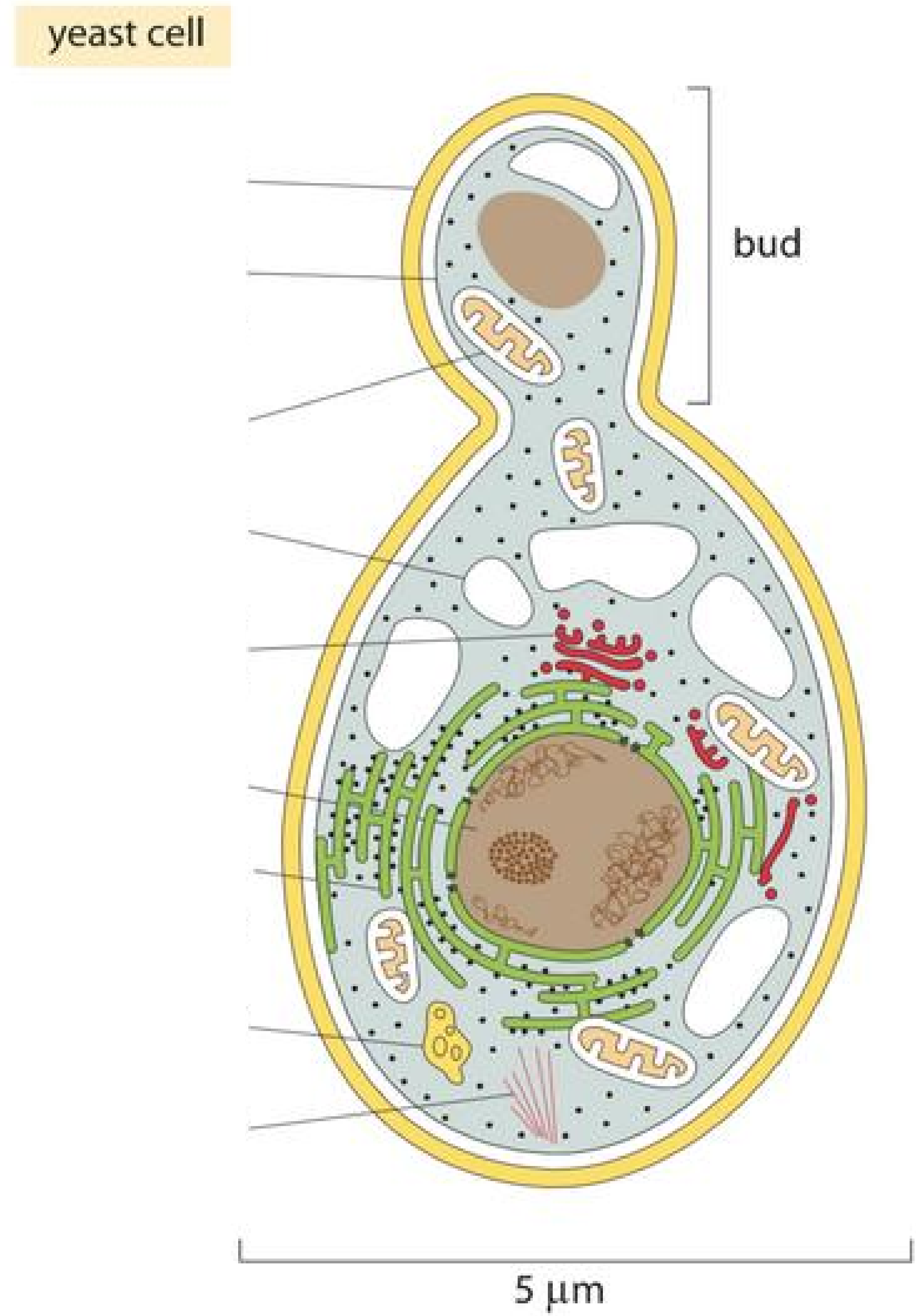
bacterial cell

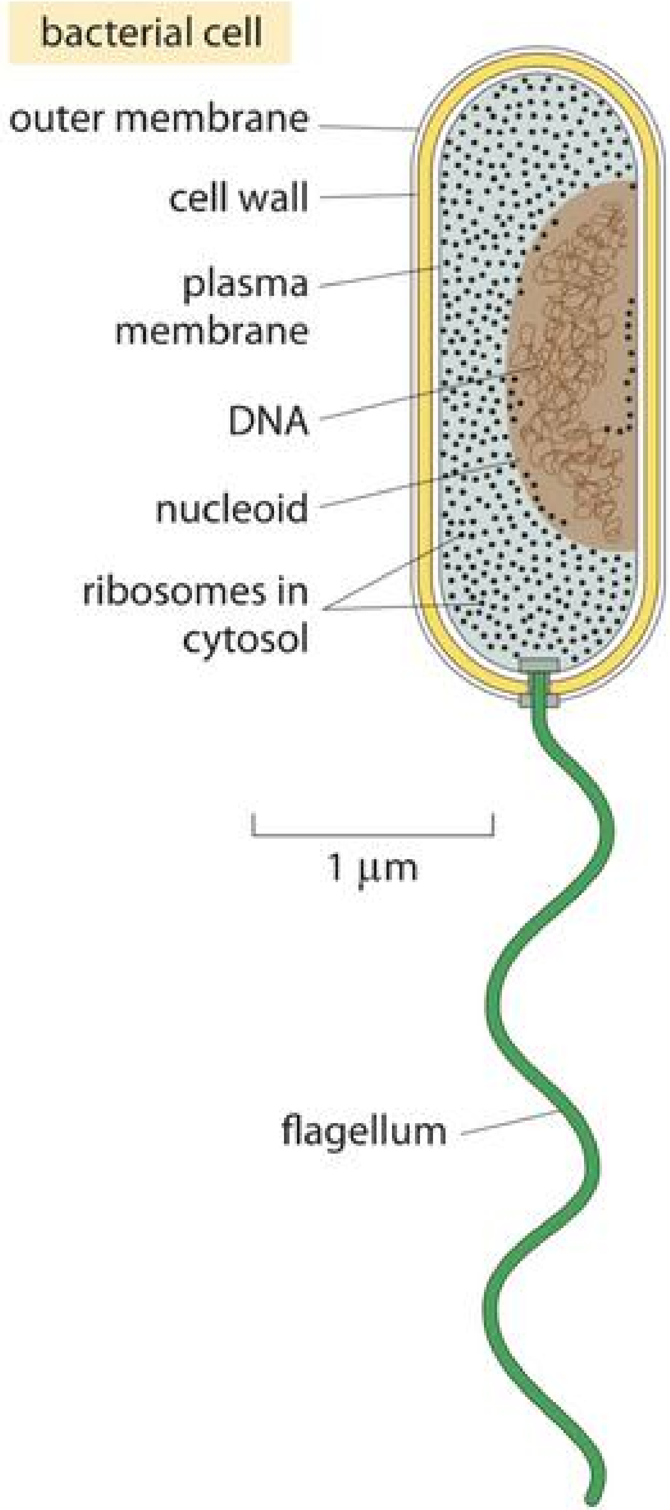


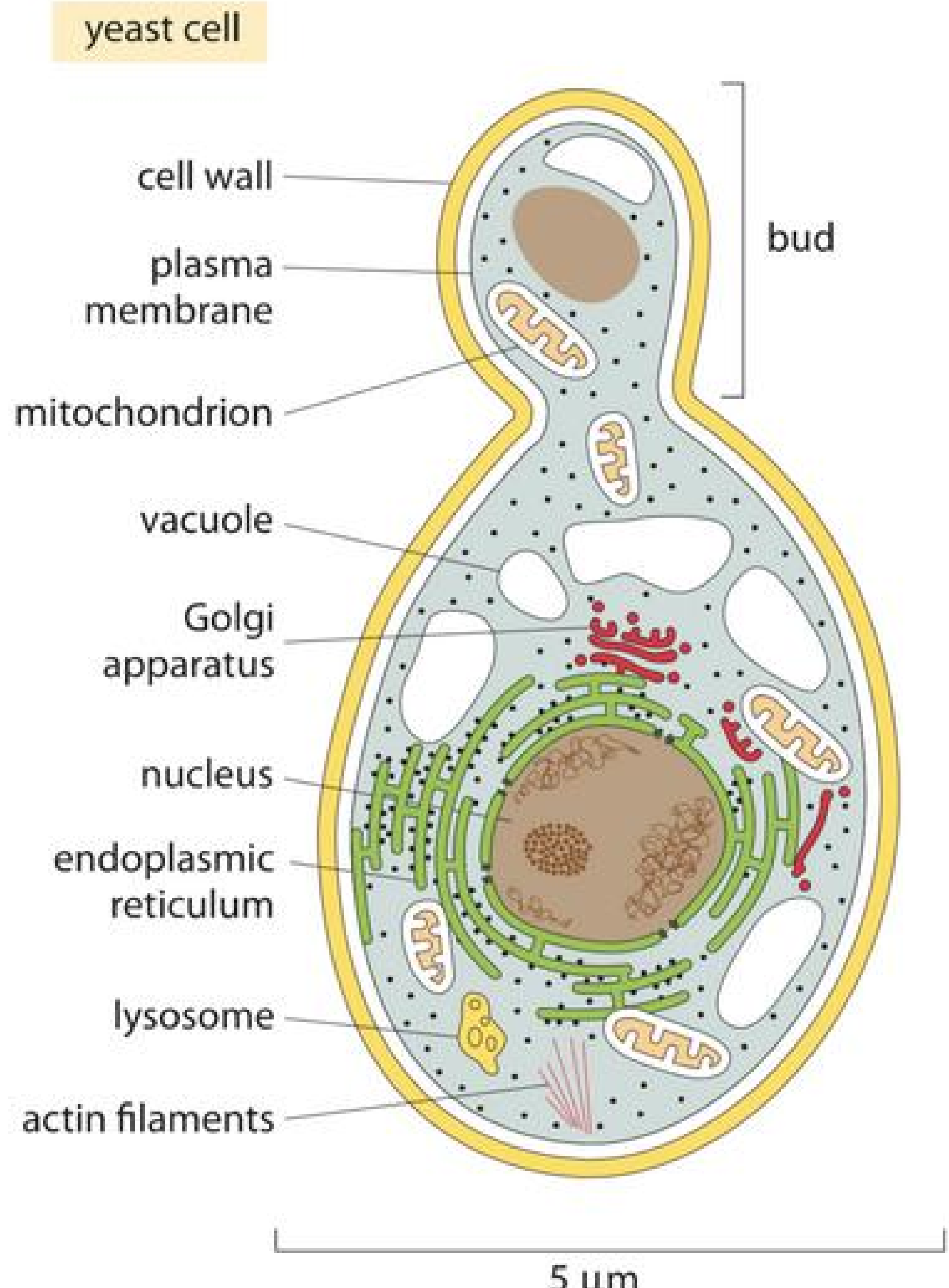
yeast cell



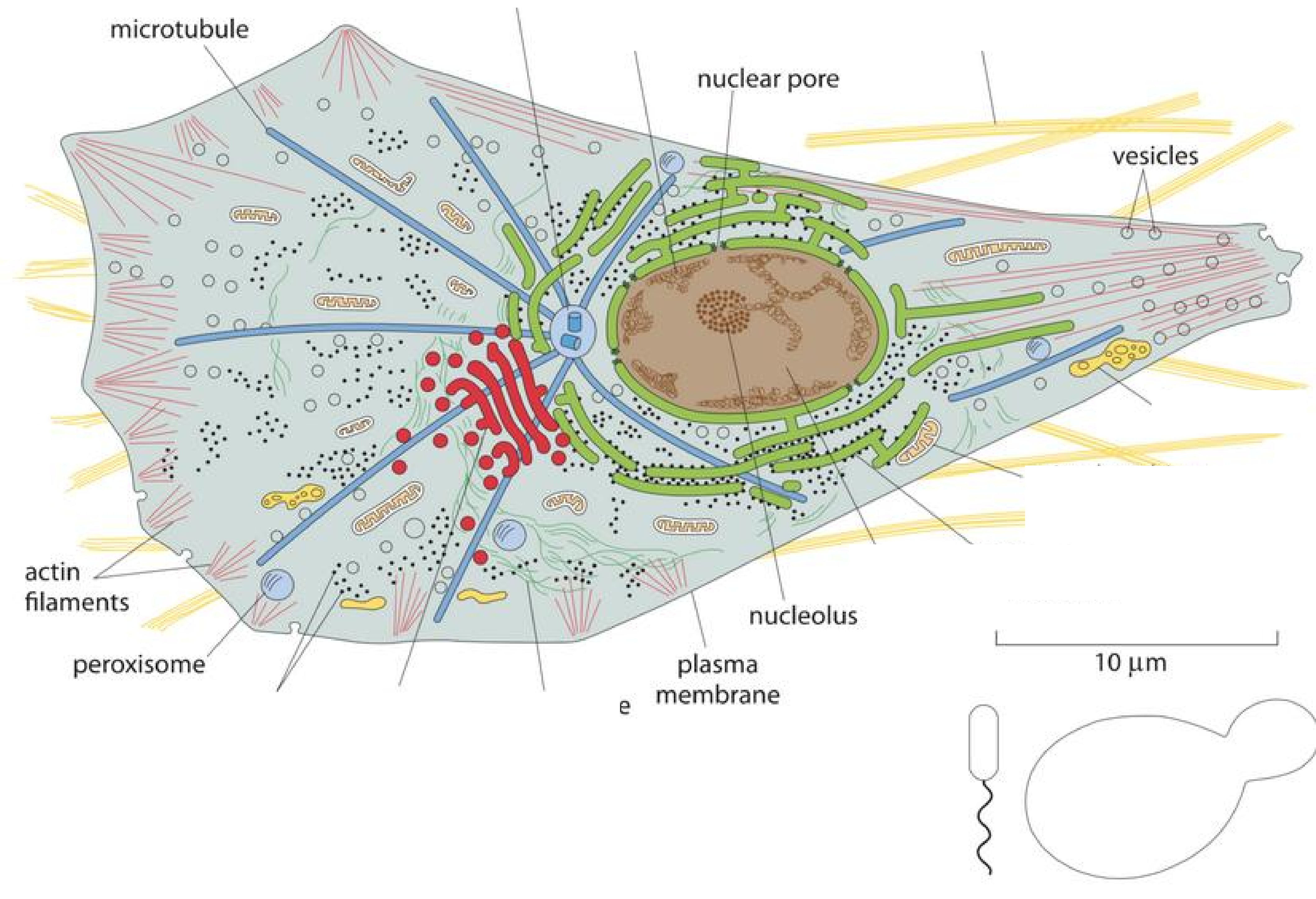

bacterial cell
outer membrane
cell wall
plasma membrane
DNA
nucleoid
ribosomes in cytosol
1 µm
flagellum

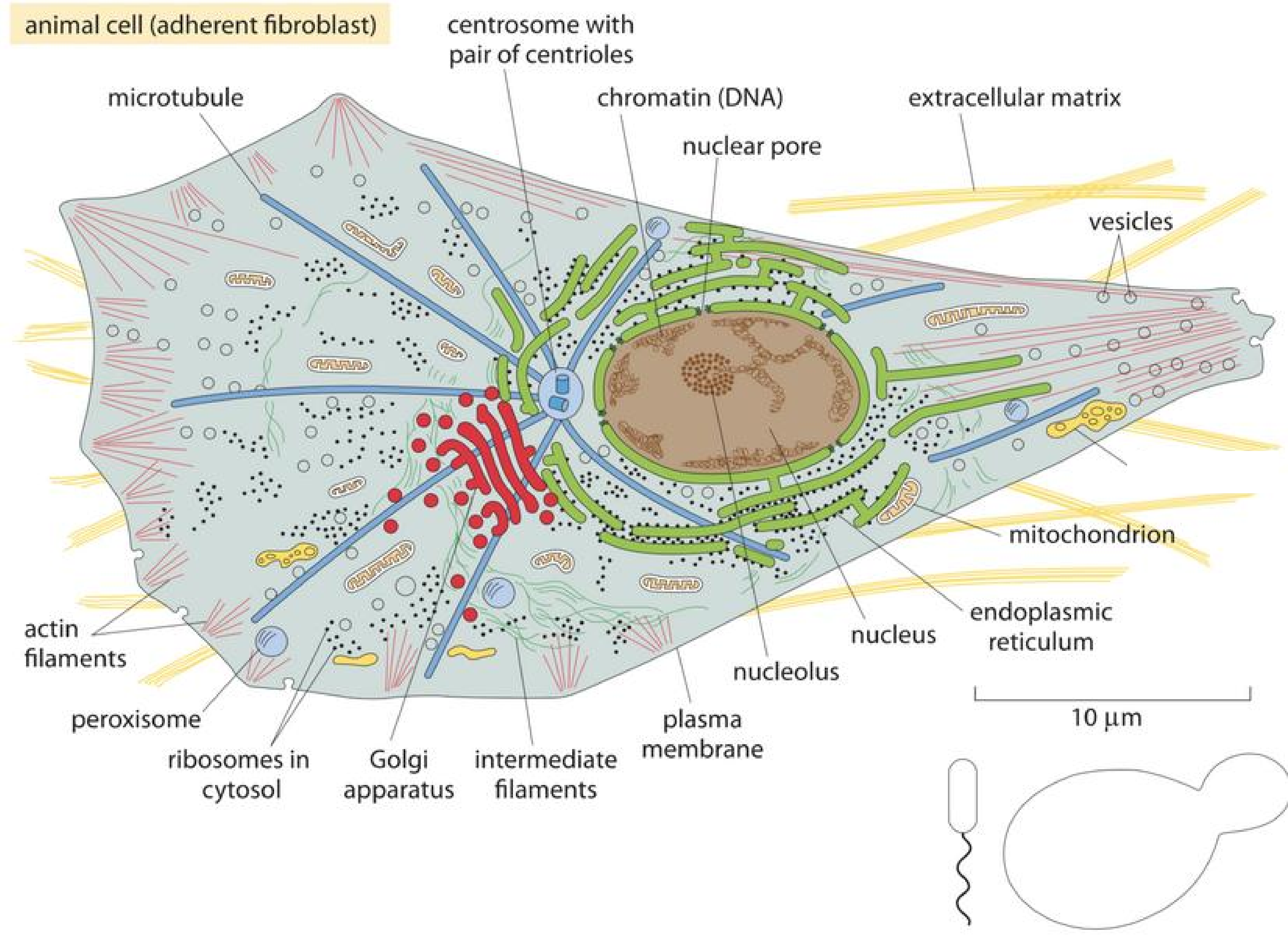

yeast cell
bud
5 µm

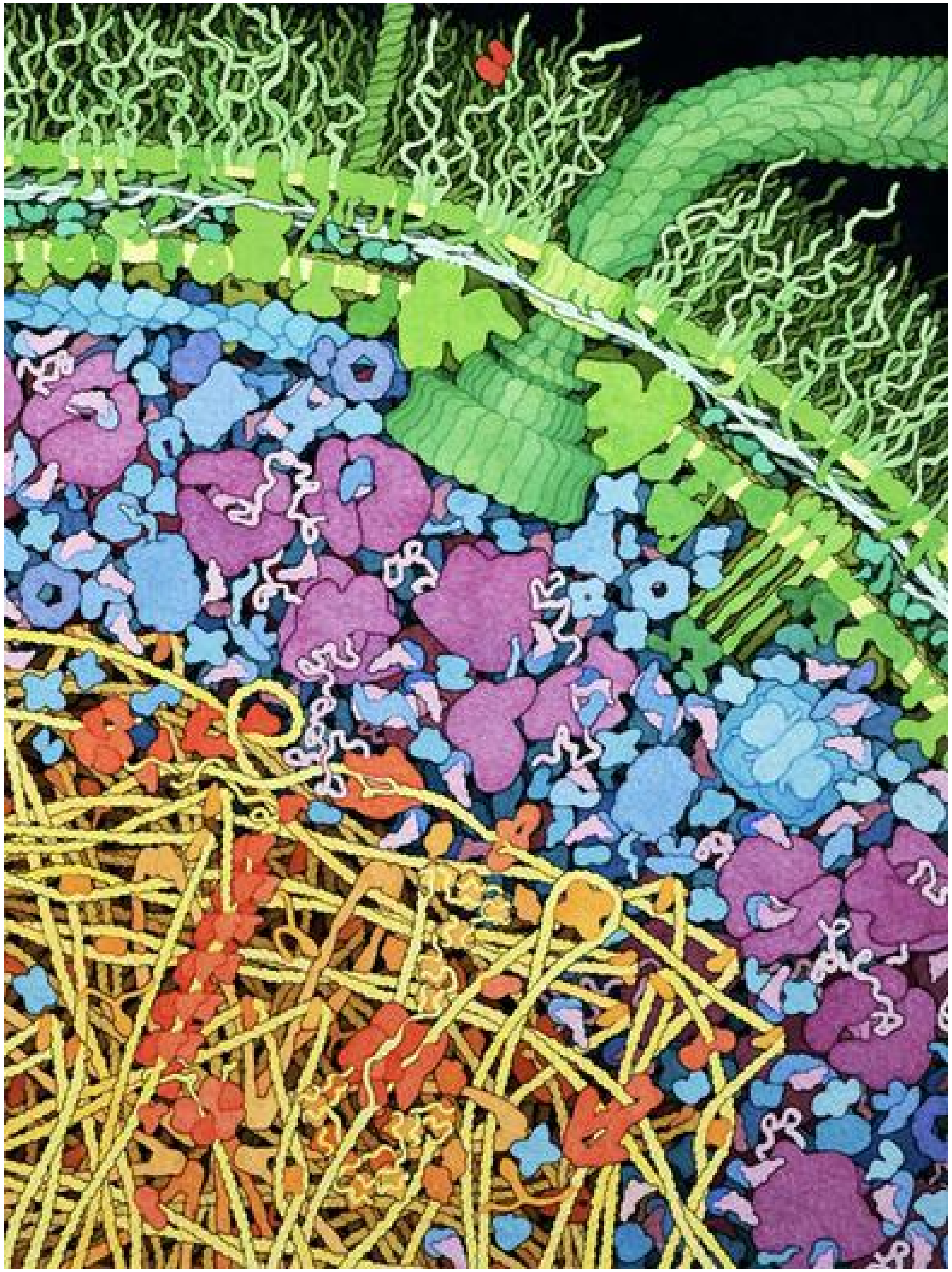

bacterial cell
outer membrane
cell wall
plasma membrane
DNA
nucleoid
ribosomes in cytosol
flagellum
1 μm


yeast cell
cell wall
plasma membrane
mitochondrion
vacuole
Golgi apparatus
nucleus
endoplasmic reticulum
lysosome
actin filaments
bud
5 μm

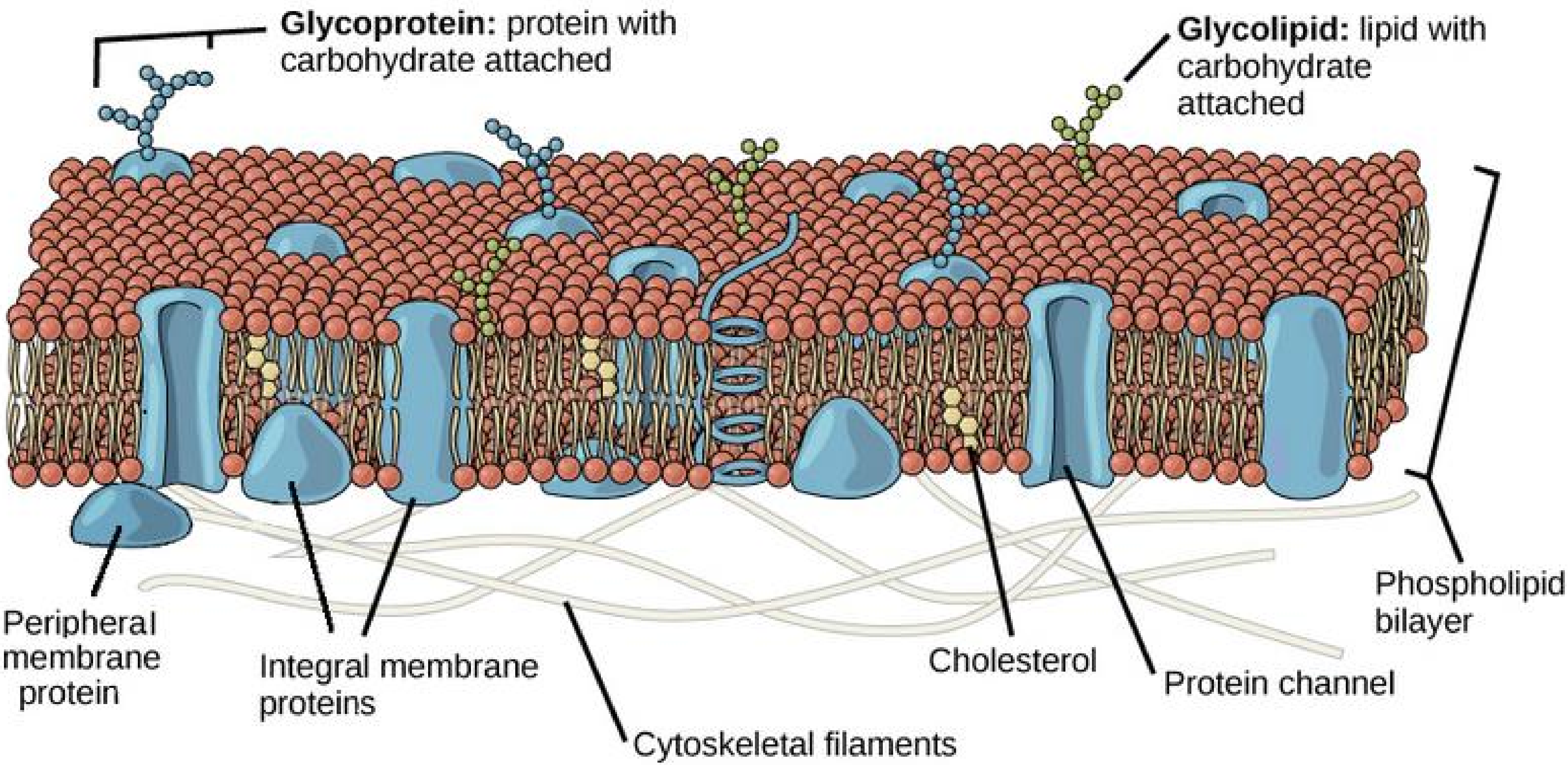
animal cell (adherent fibroblast)




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



David Goodsell


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

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.

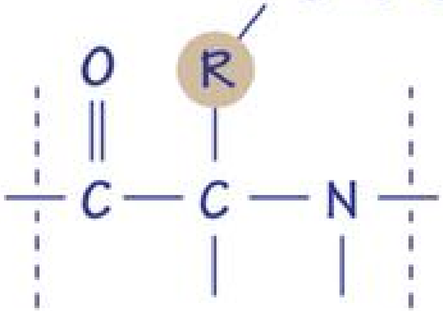
lipid: biomolecule soluble in nonpolar solvents. Functions of lipids include storing energy, signaling, and acting as structural components of cell membranes.

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

$\approx C_3O_1H_6$



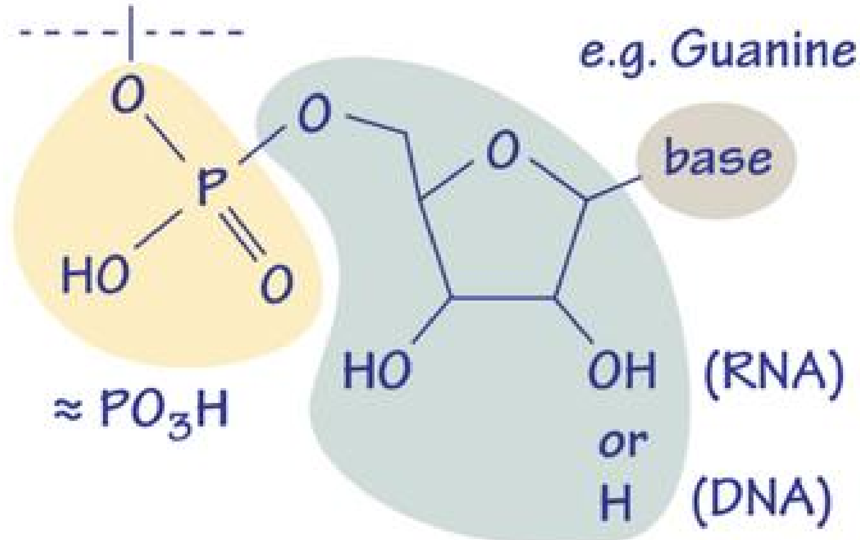
$\Downarrow$

$\approx N_1C_5O_2H_8$

≈ 110 Da

nucleotides

e.g. Guanine $N_5C_5O_1H_6$



$\approx PO_3H$

$\approx C_5H_8O_2$

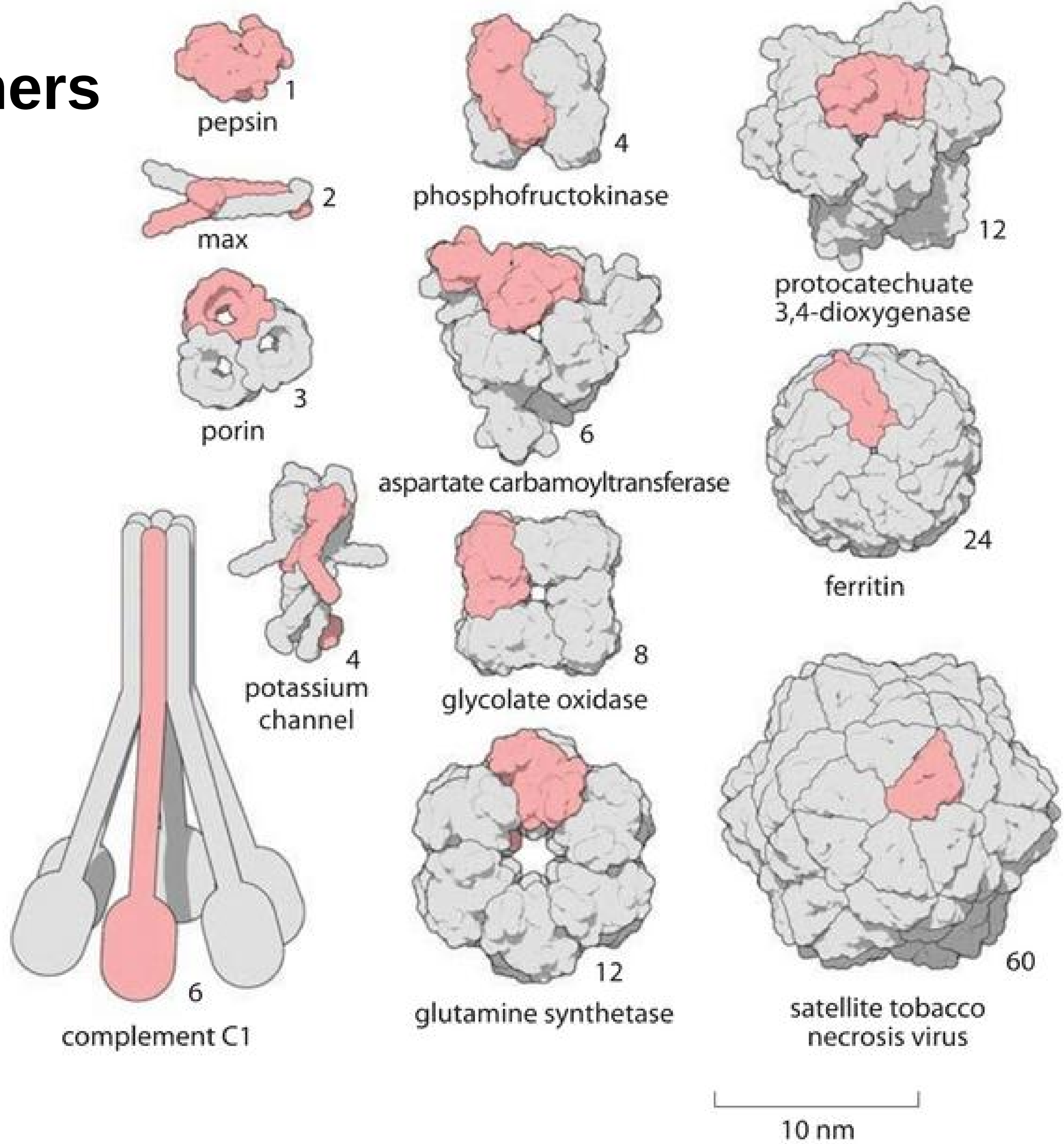
$\Downarrow$

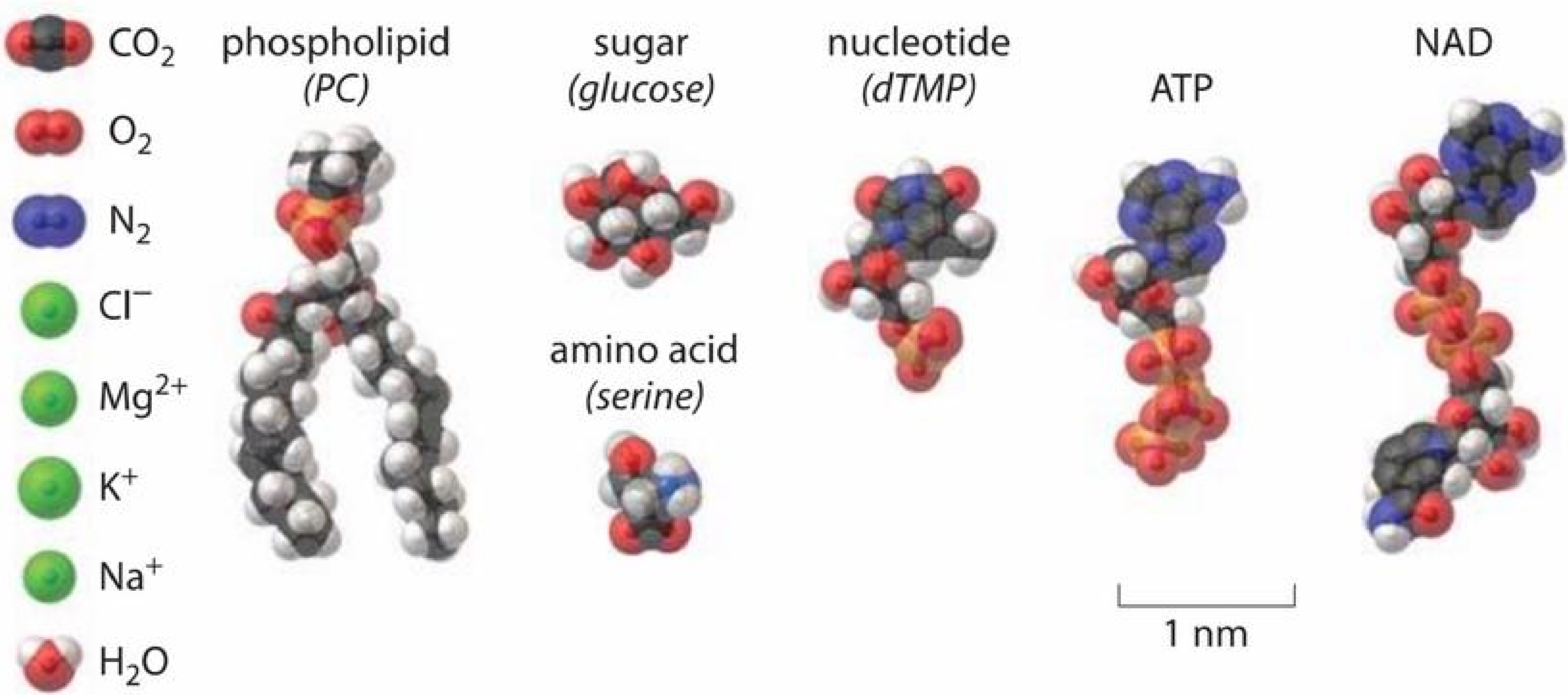
$\approx P_1N_5O_7C_{10}H_{14}$

≈ 350 Da

total protein mass in cell $\approx$ 3 times larger than RNA + DNA

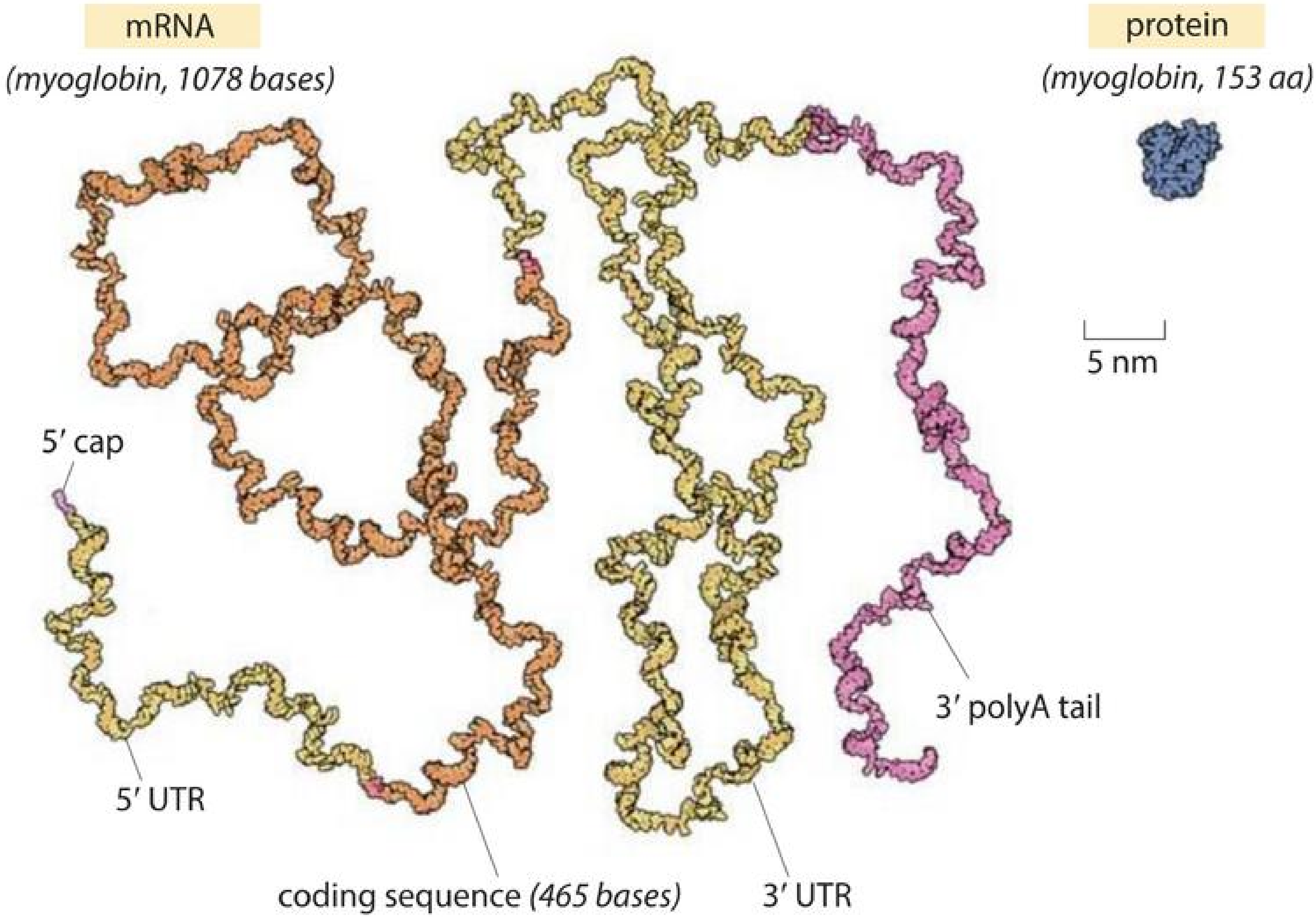
Homooligomers




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?

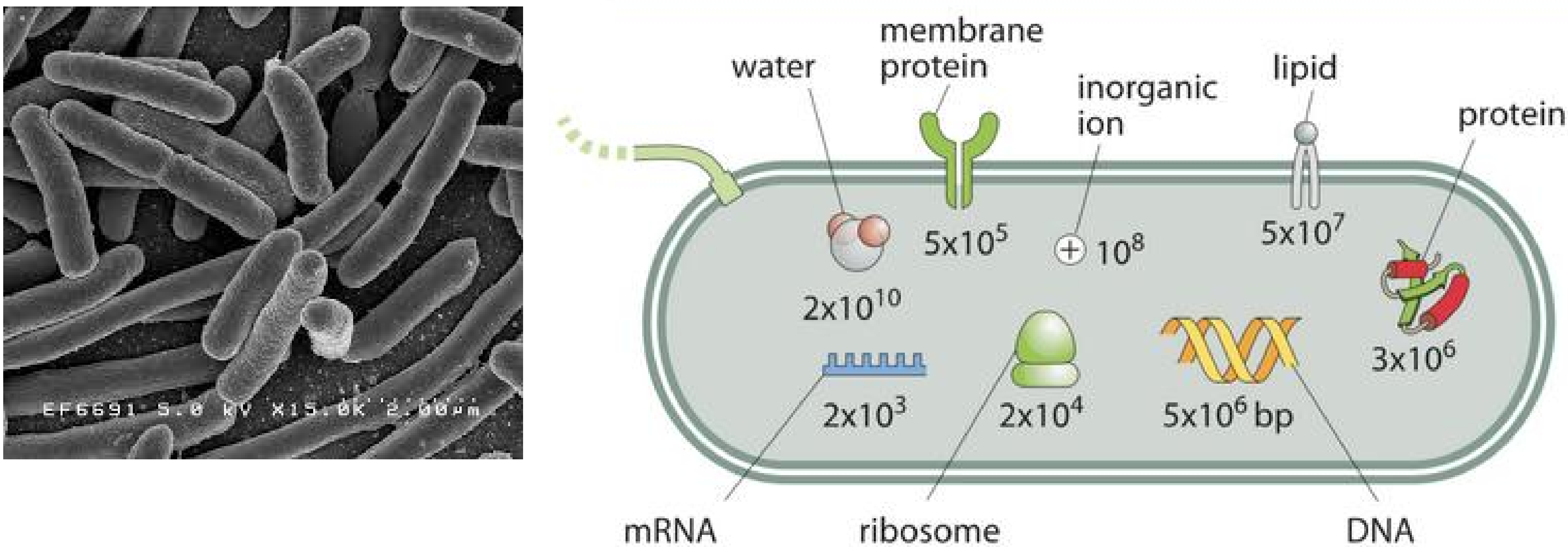


Median protein length

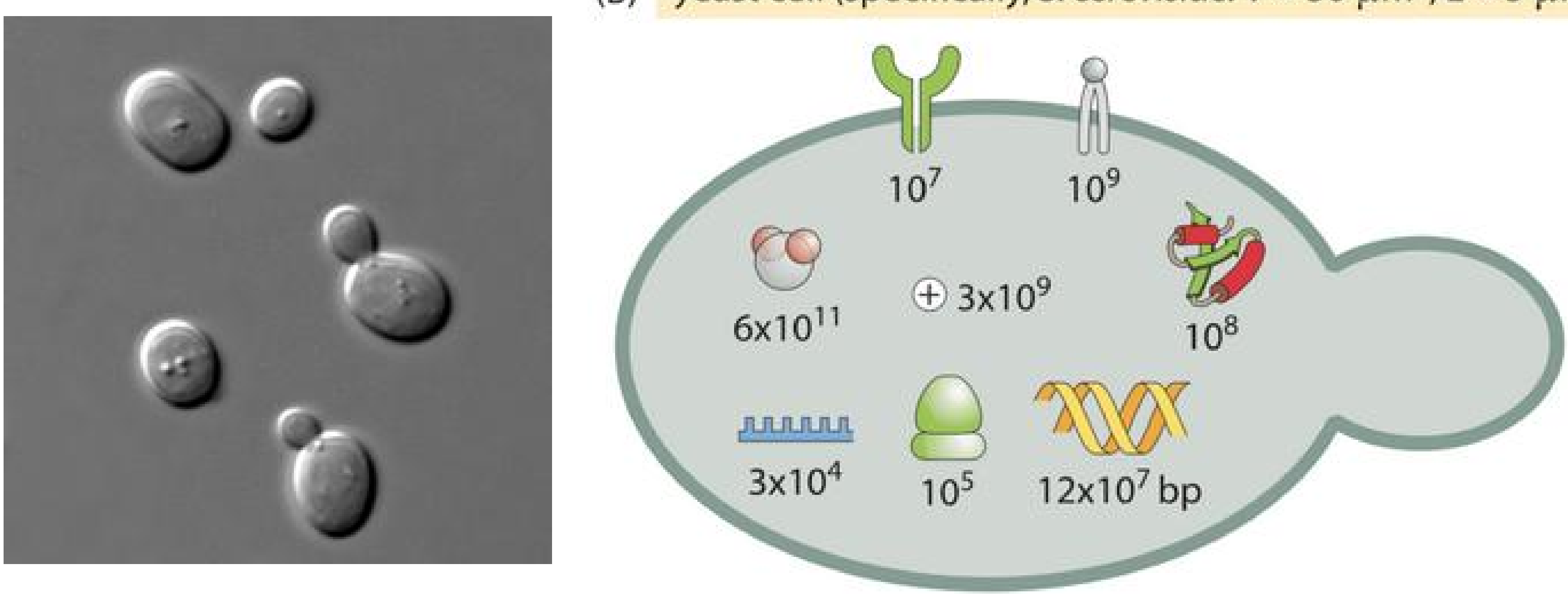
organism	median protein length (amino acids)
H. sapiens	375
D. melanogaster	373
C. elegans	344
S. cerevisiae	379
A. thaliana	356
5 eukaryotes (above)	361
67 bacteria	267
15 archaea	247

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	

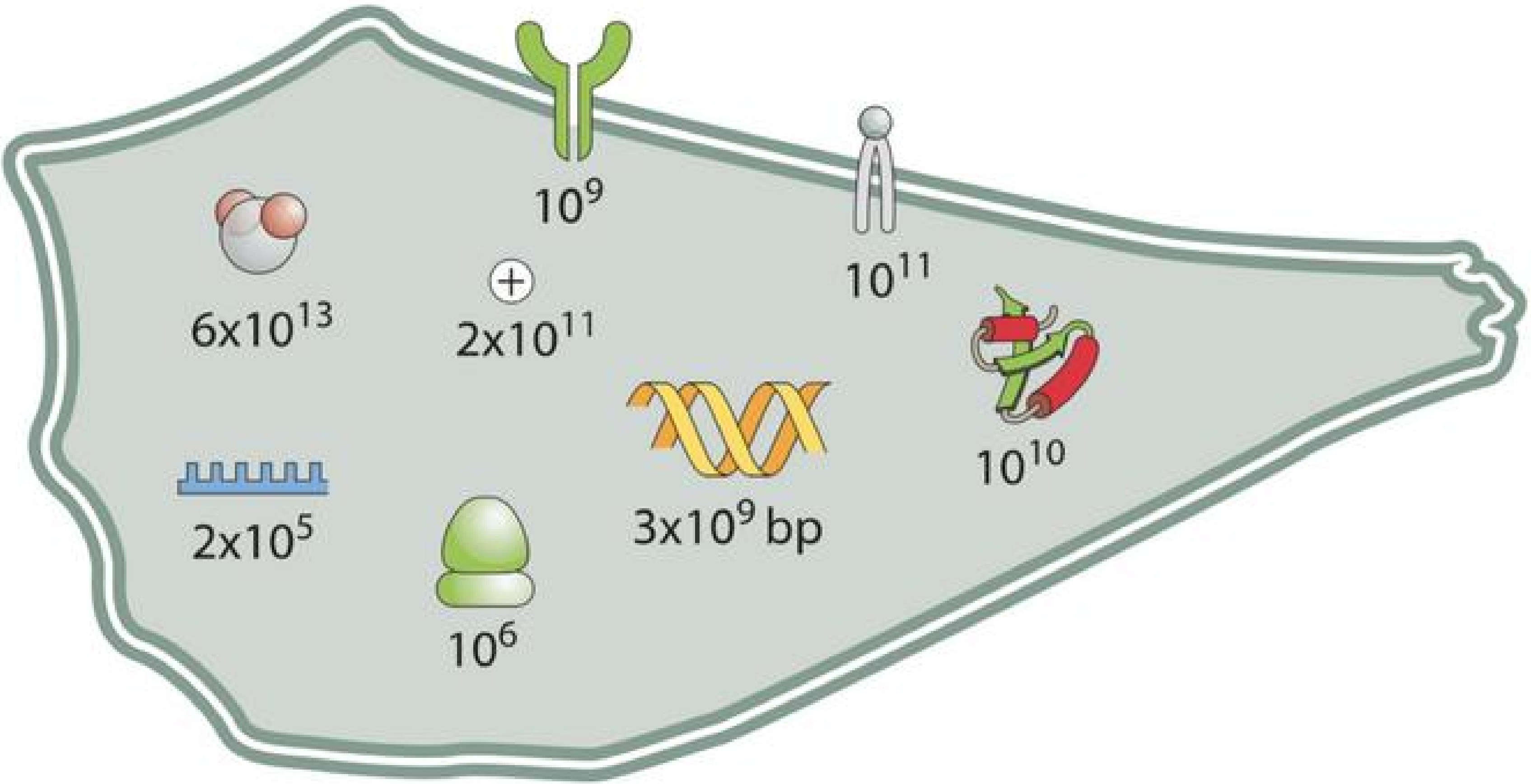
(A) bacterial cell (specifically, *E. coli:* $V \approx 1\ \mu m^3$; $L \approx 1\ \mu m$; $\tau \approx 1$ hour)



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



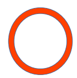
(C) mammalian cell (specifically, HeLa: $V \approx 3000\ \mu m^3$; $L \approx 20\ \mu m$; $\tau \approx 1$ day)



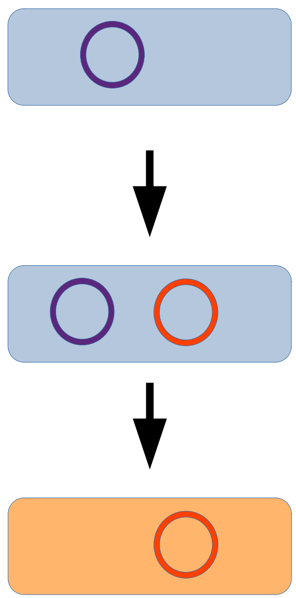
First “synthetic” cell developed by scientists

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

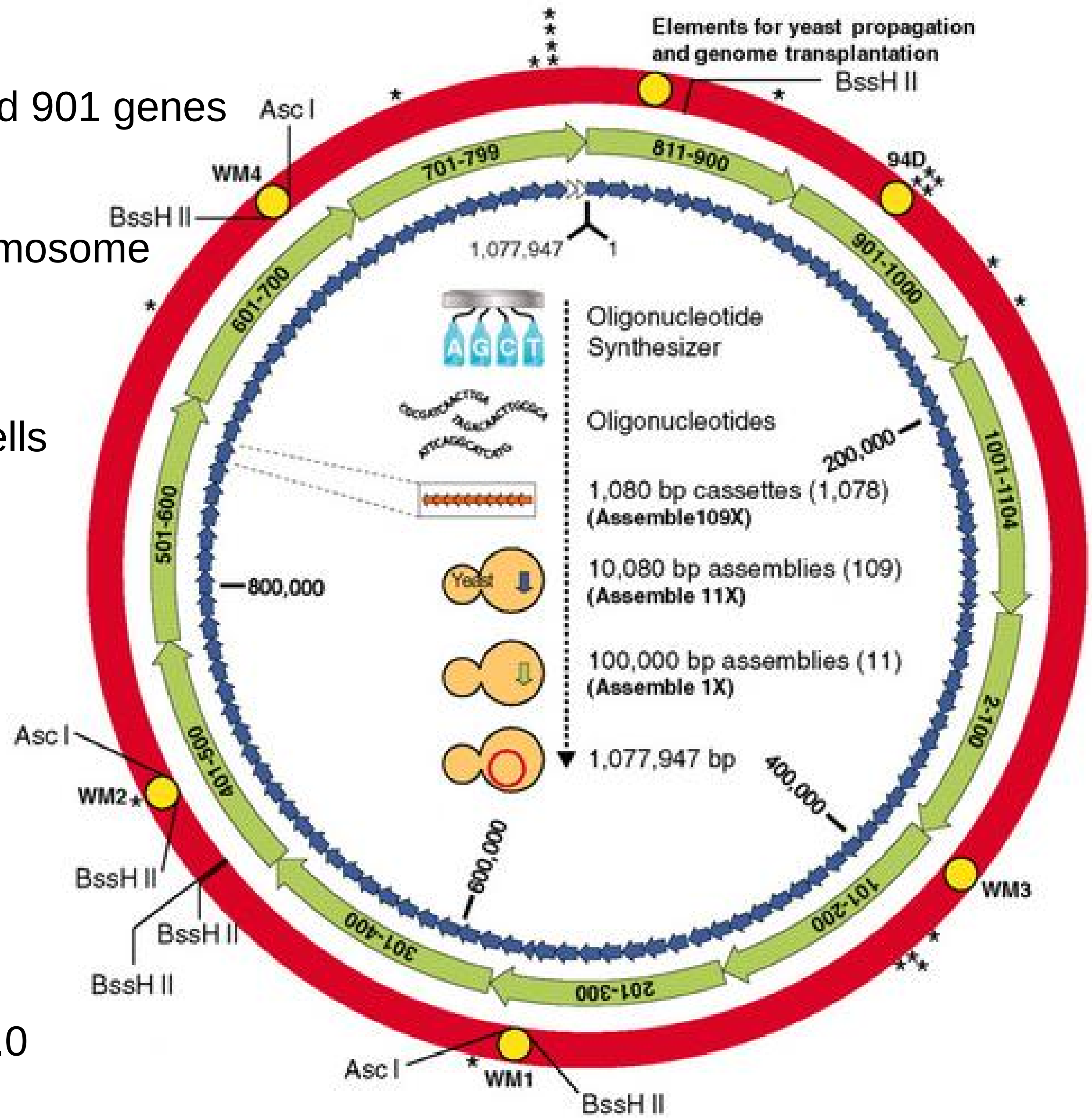
single yeast artificial chromosome



+
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. 2008

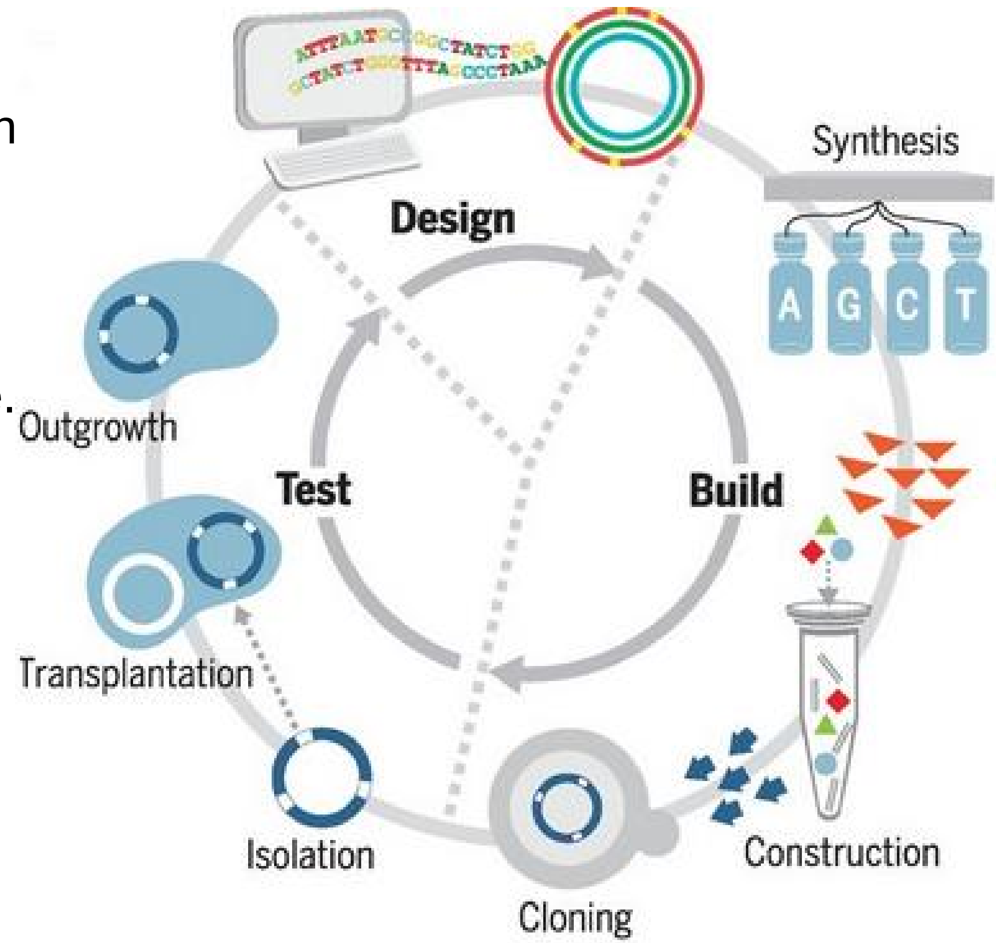
Smallest "synthetic" cell

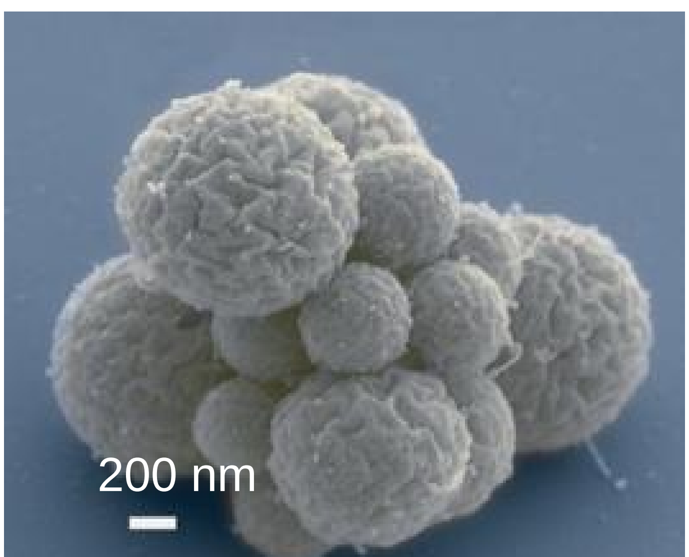
M. mycoides JCVI-syn3.0
531,560 base pairs and 473 genes

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

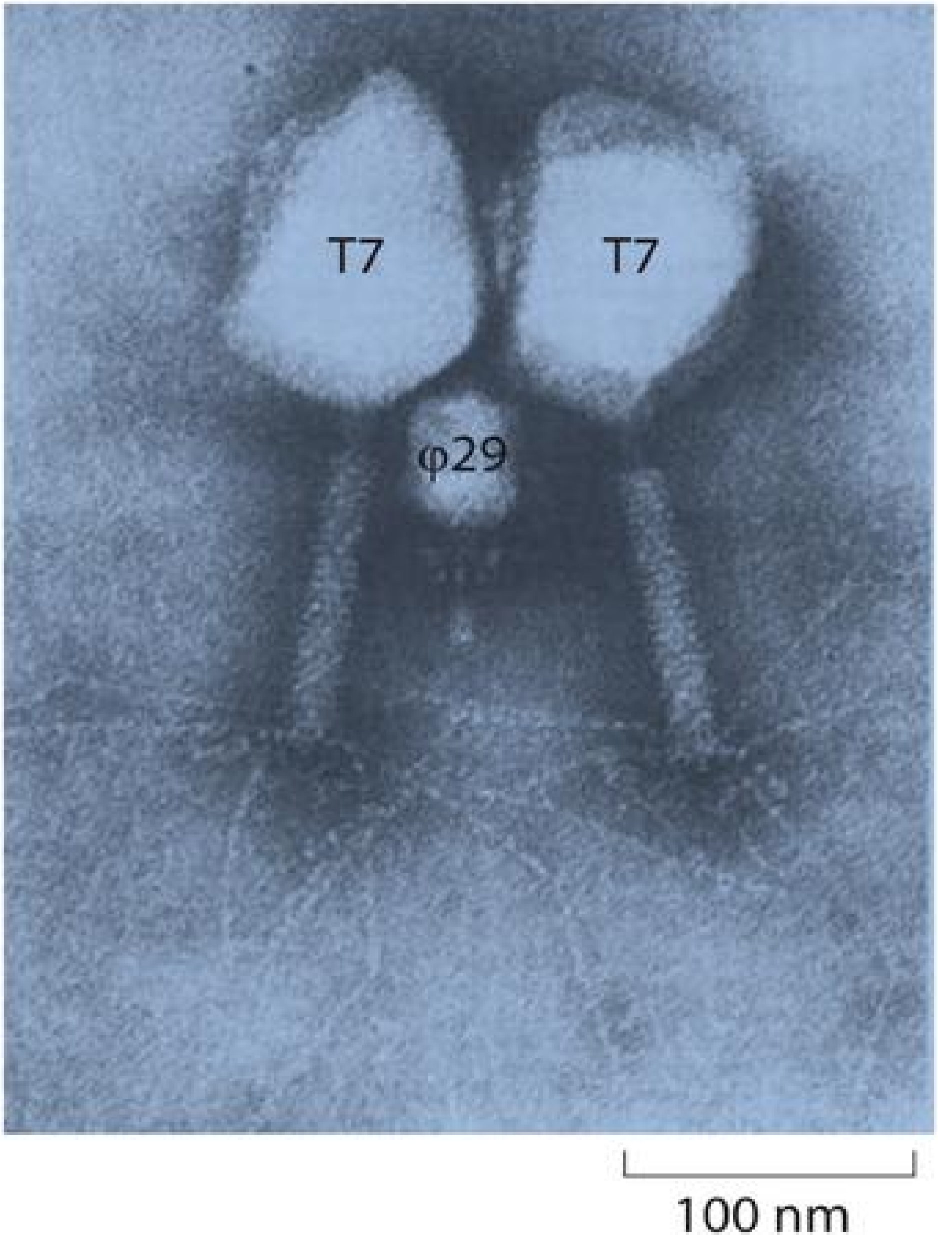


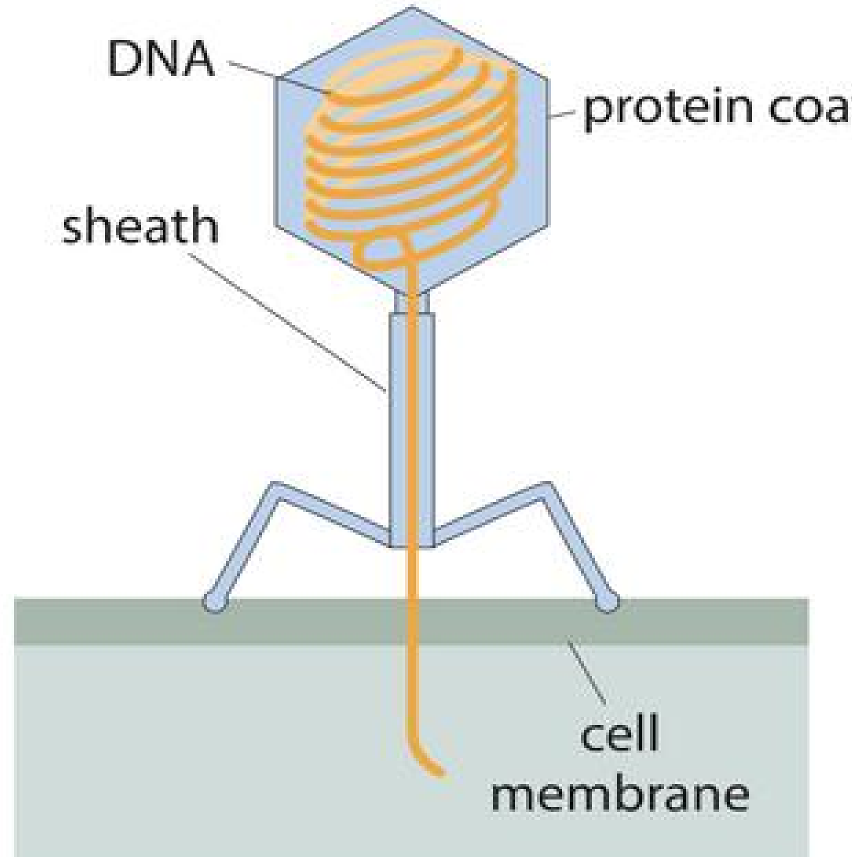


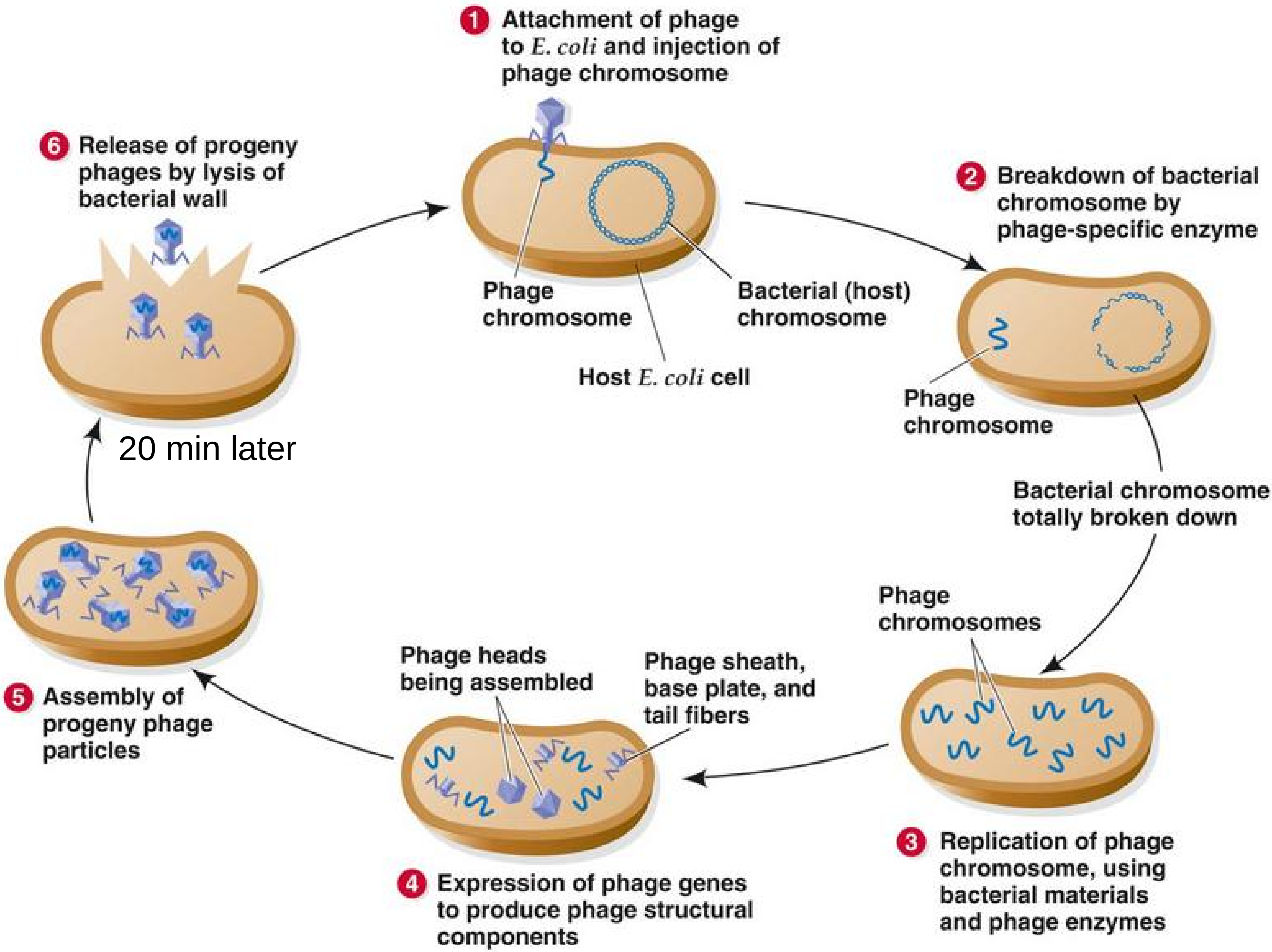
Hutchison III et al. 2016

Viruses, cells, mitochondria, reproduction

Virus infecting bacteria = phages







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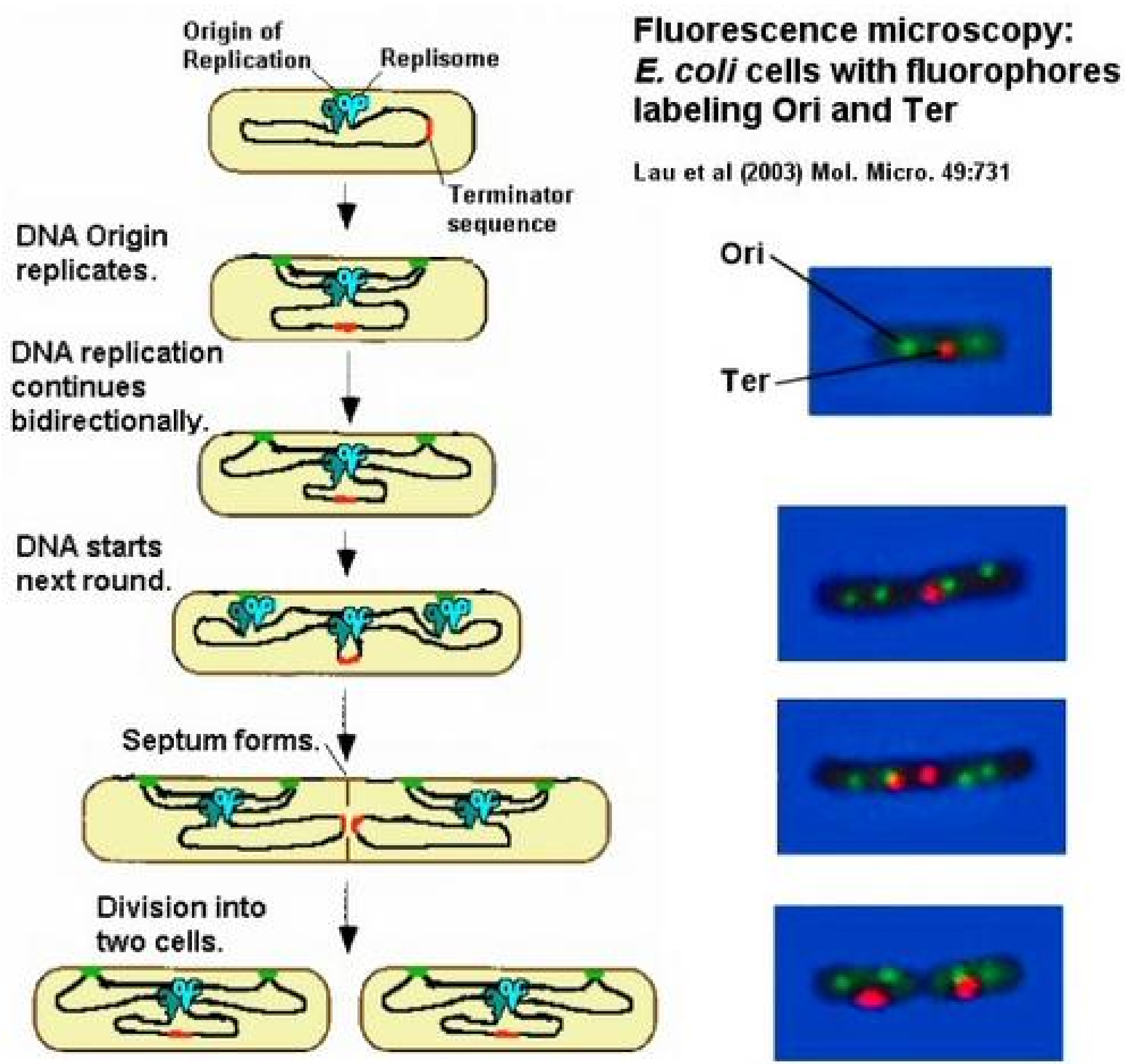
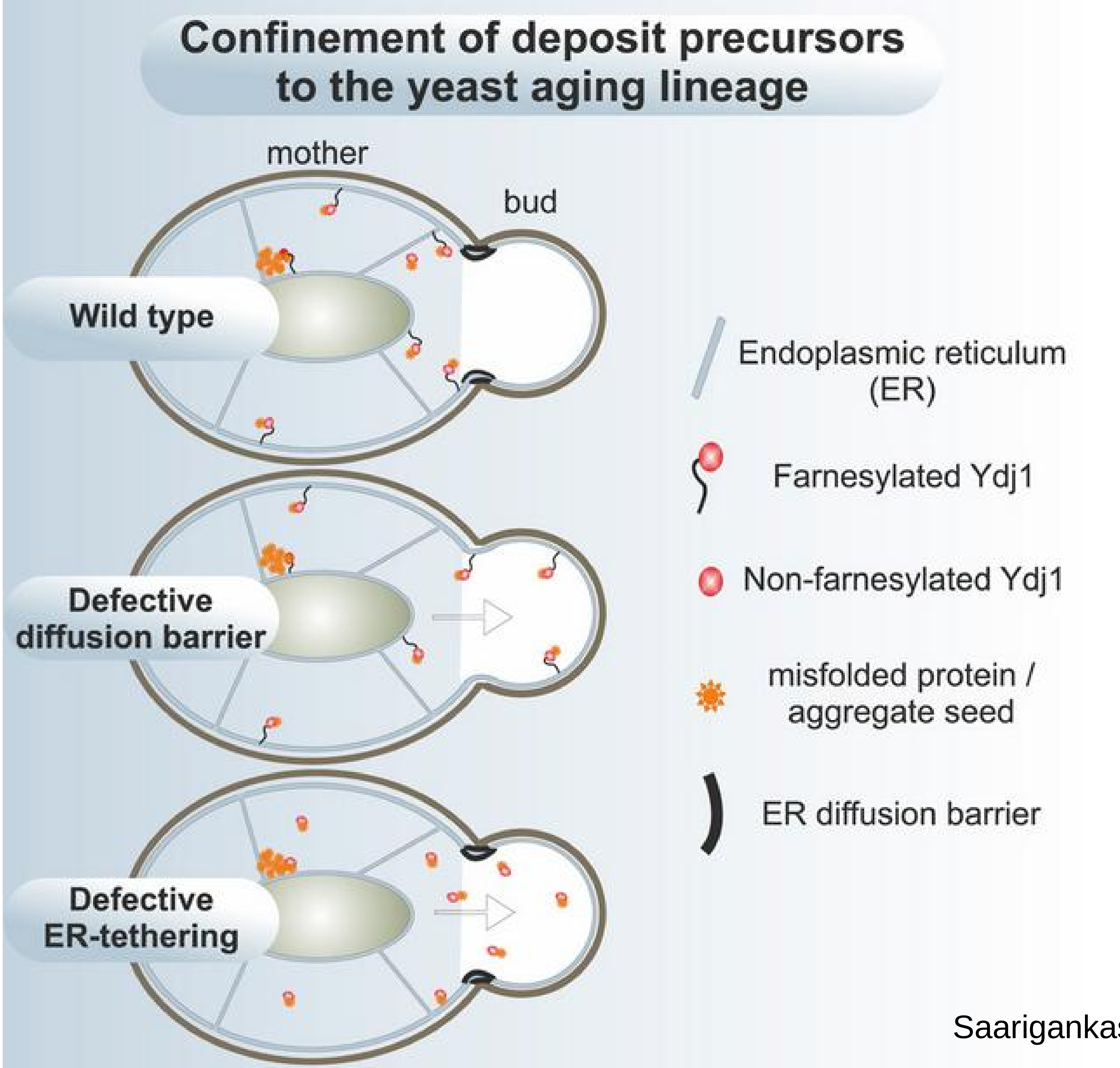
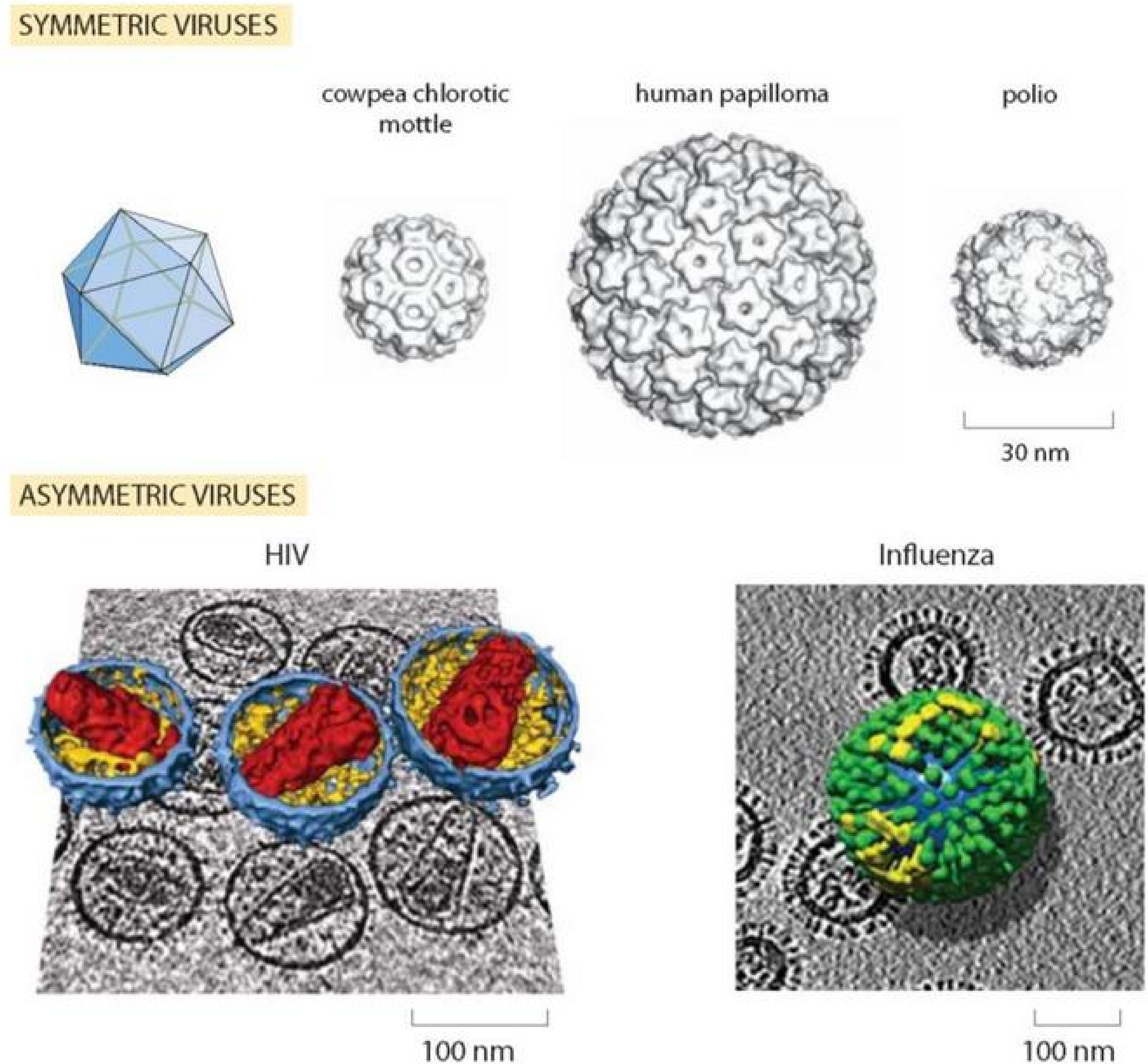


http://biology.kenyon.edu/courses/biol114/Chap01/cell.html

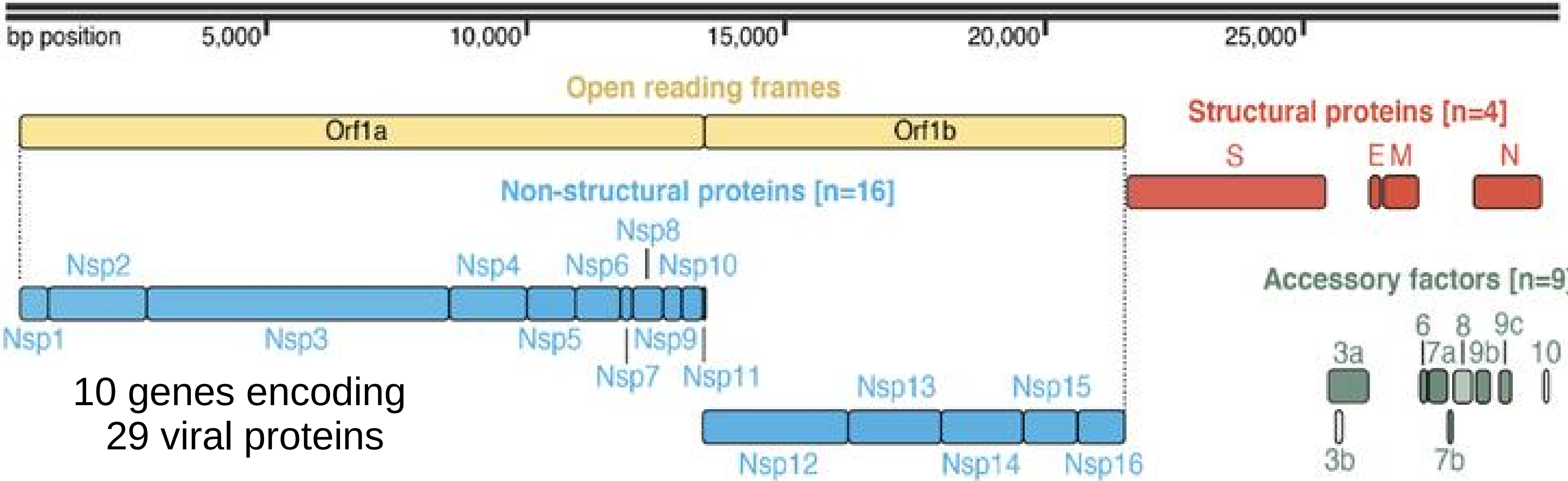


Saarigankas 2017

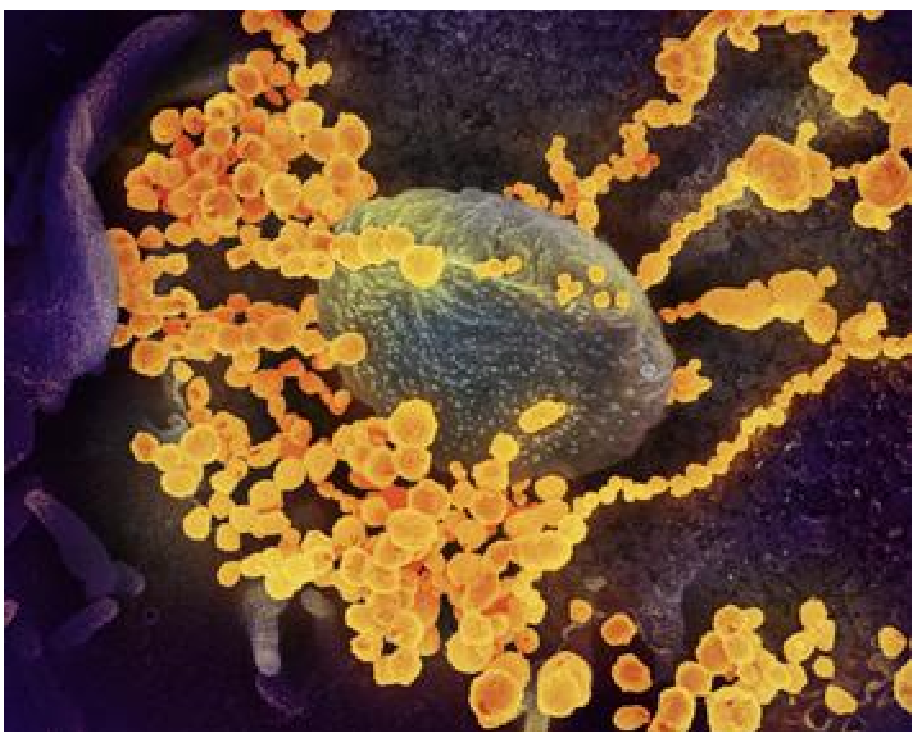


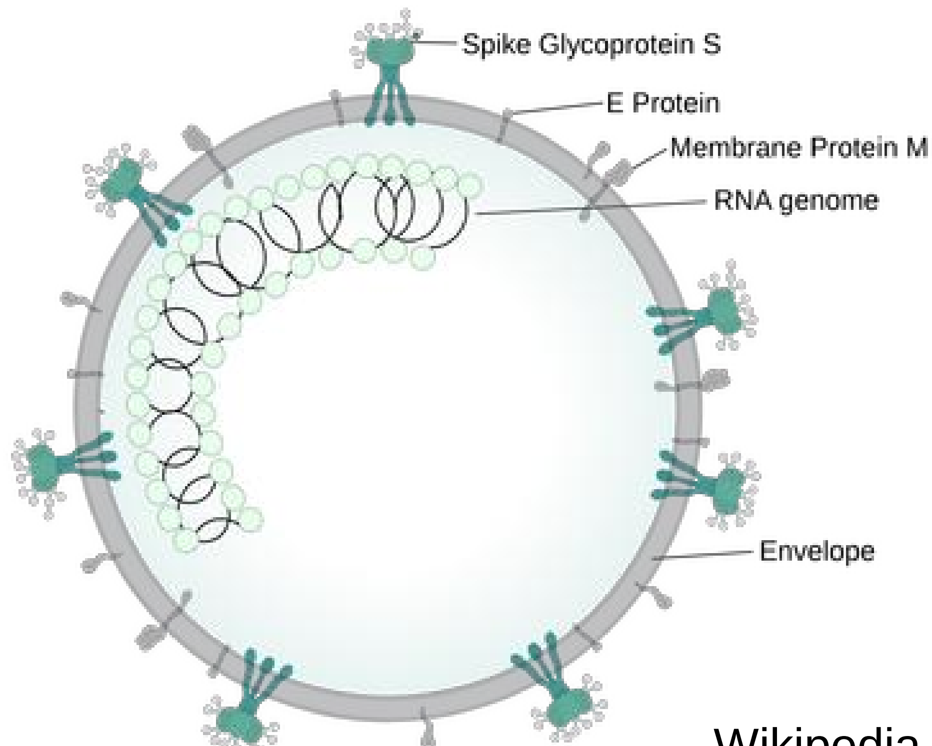
SYMMETRIC VIRUSES
cowpea chlorotic mottle
human papilloma
polio
30 nm
ASYMMETRIC VIRUSES
HIV
Influenza
100 nm
100 nm

SARS-CoV-2 genome



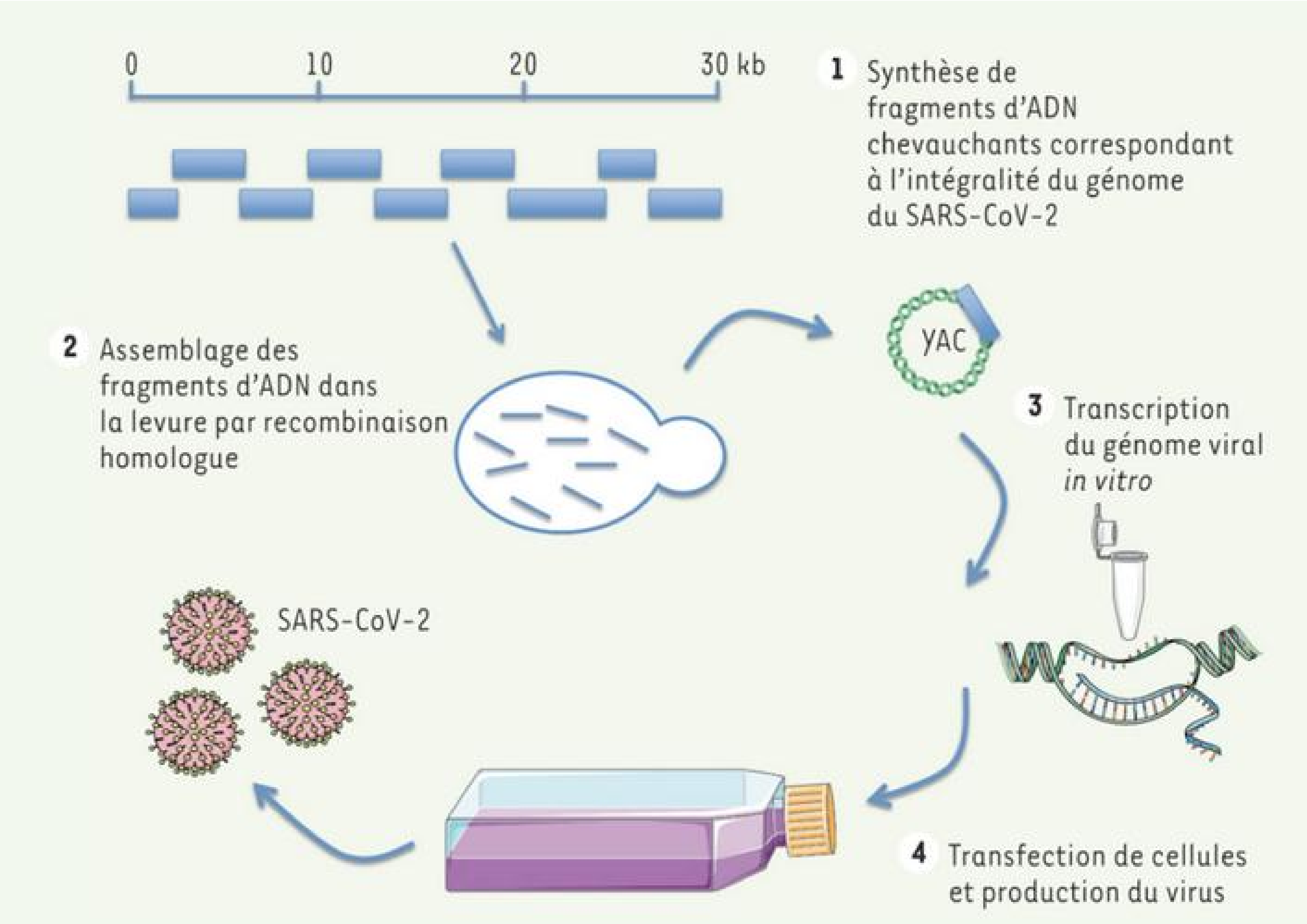
10 genes encoding
29 viral proteins





Wikipedia

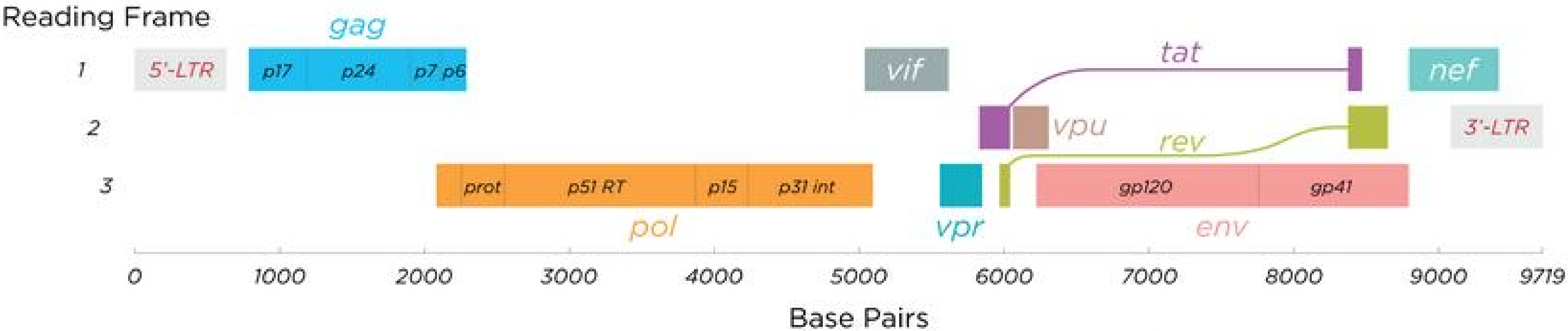
Synthesis of SARS-CoV-2 in a few weeks

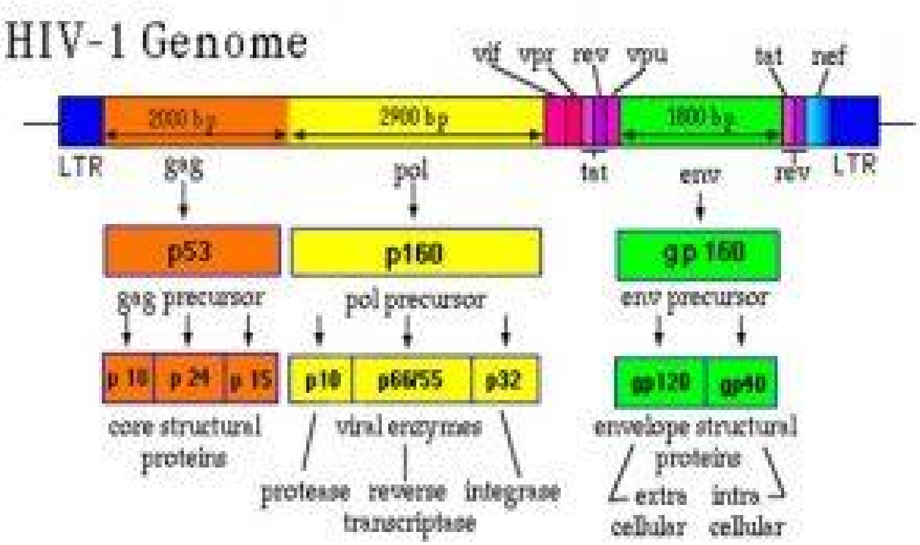


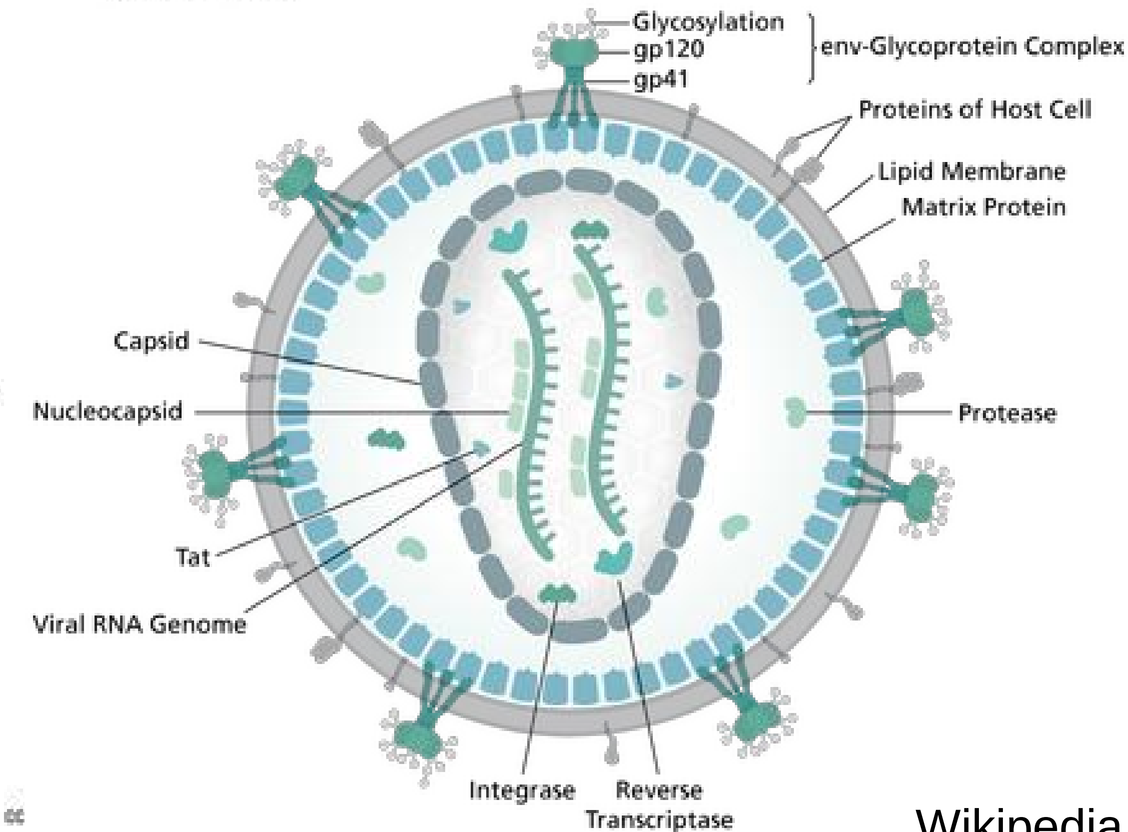
Iseni, Frédéric, and Jean-Nicolas Tournier. 2020. 'Une Course Contre La Montre-Création Du SARS-CoV-2 En Laboratoire, Un Mois Après Son Émergence !' Médecine/Sciences 36 (8–9): 797–802

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

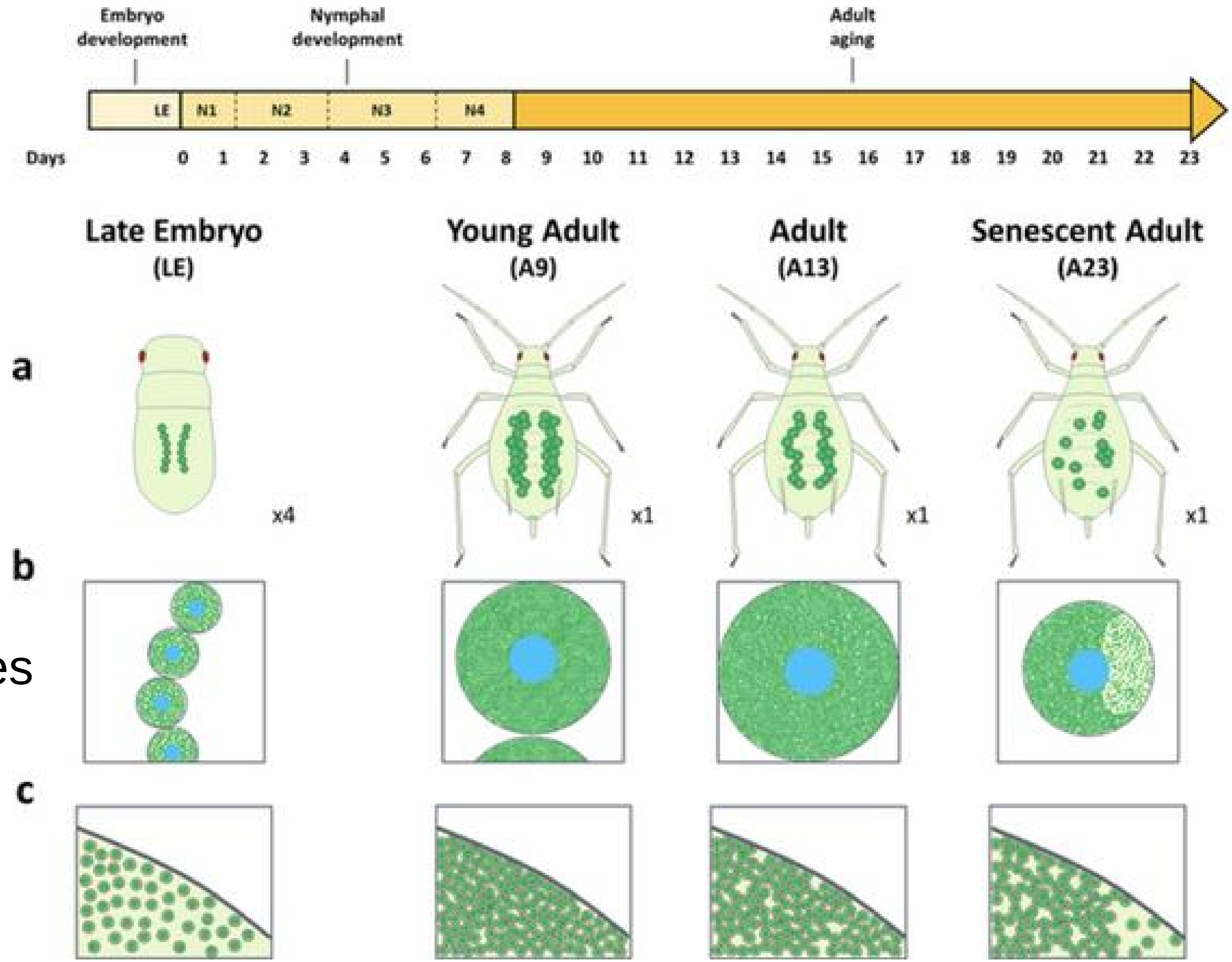
3) reproduce via only part of their constituents

4) does not harbour a minimal metabolism to reproduce

Points 3 and 4 were later refuted.

Buchnera : an obligate symbiont

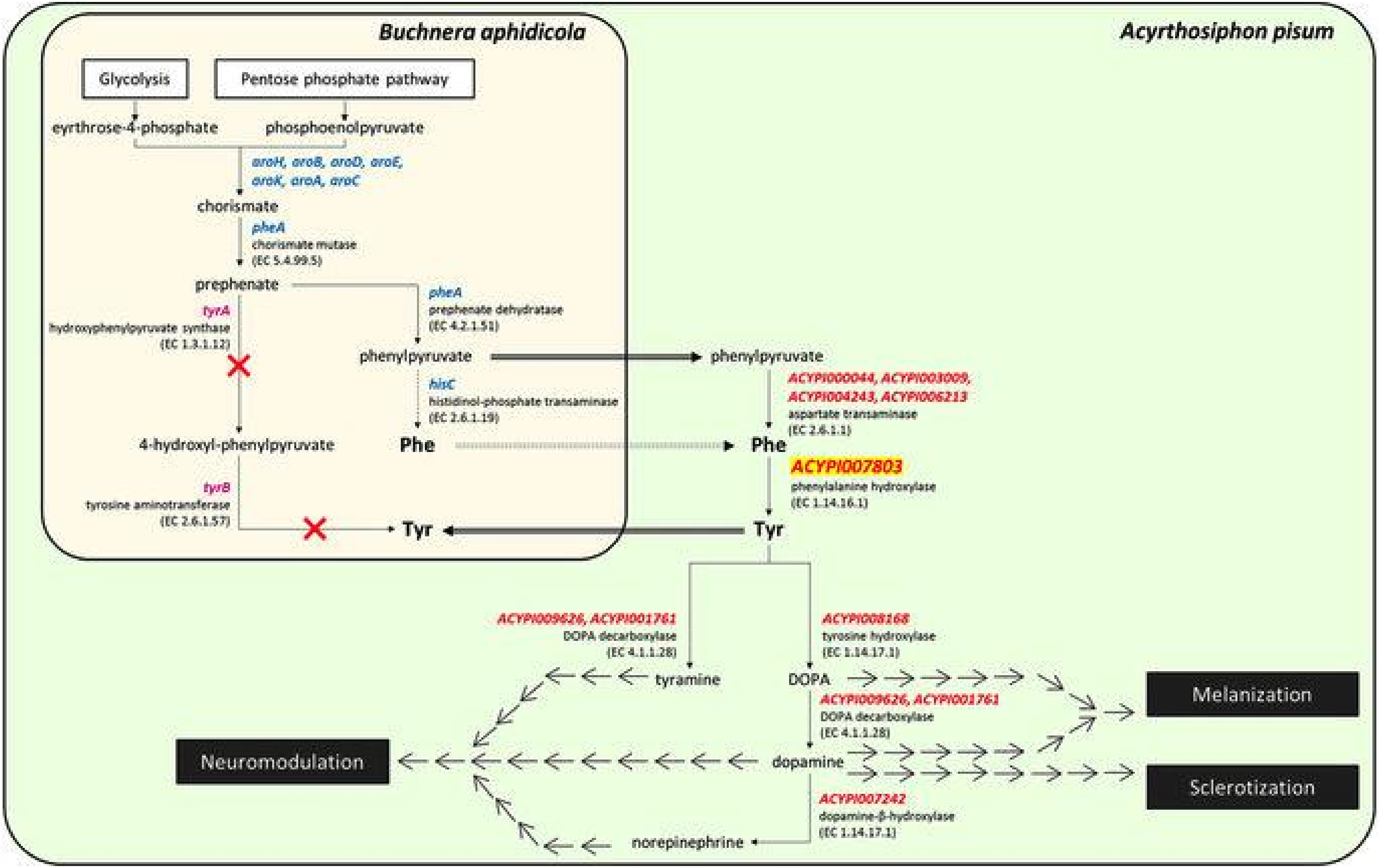
Phloem sap rich in carbohydrates but devoid of essential amino acids



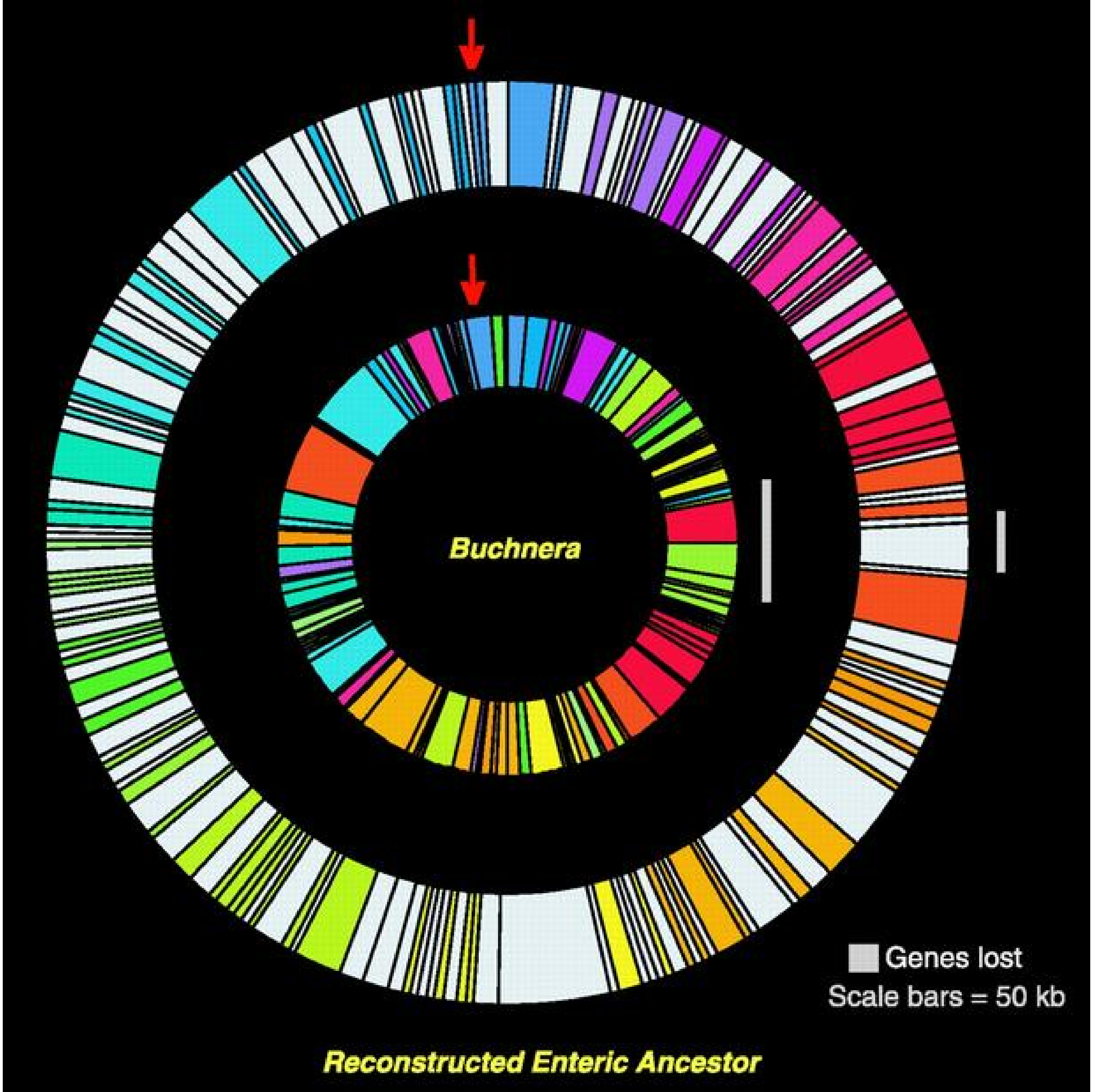
bacteriocytes

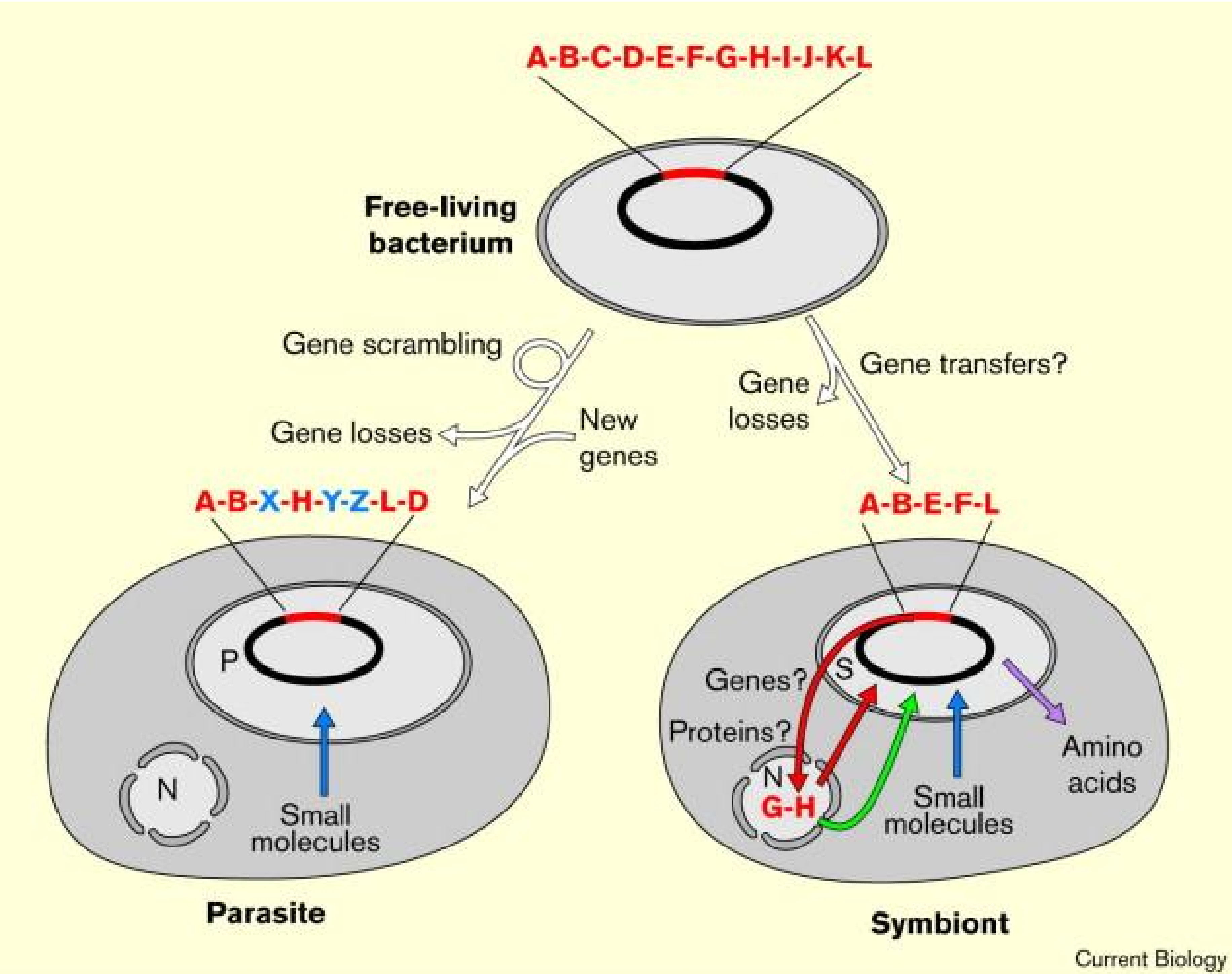
Buchnera bacteria

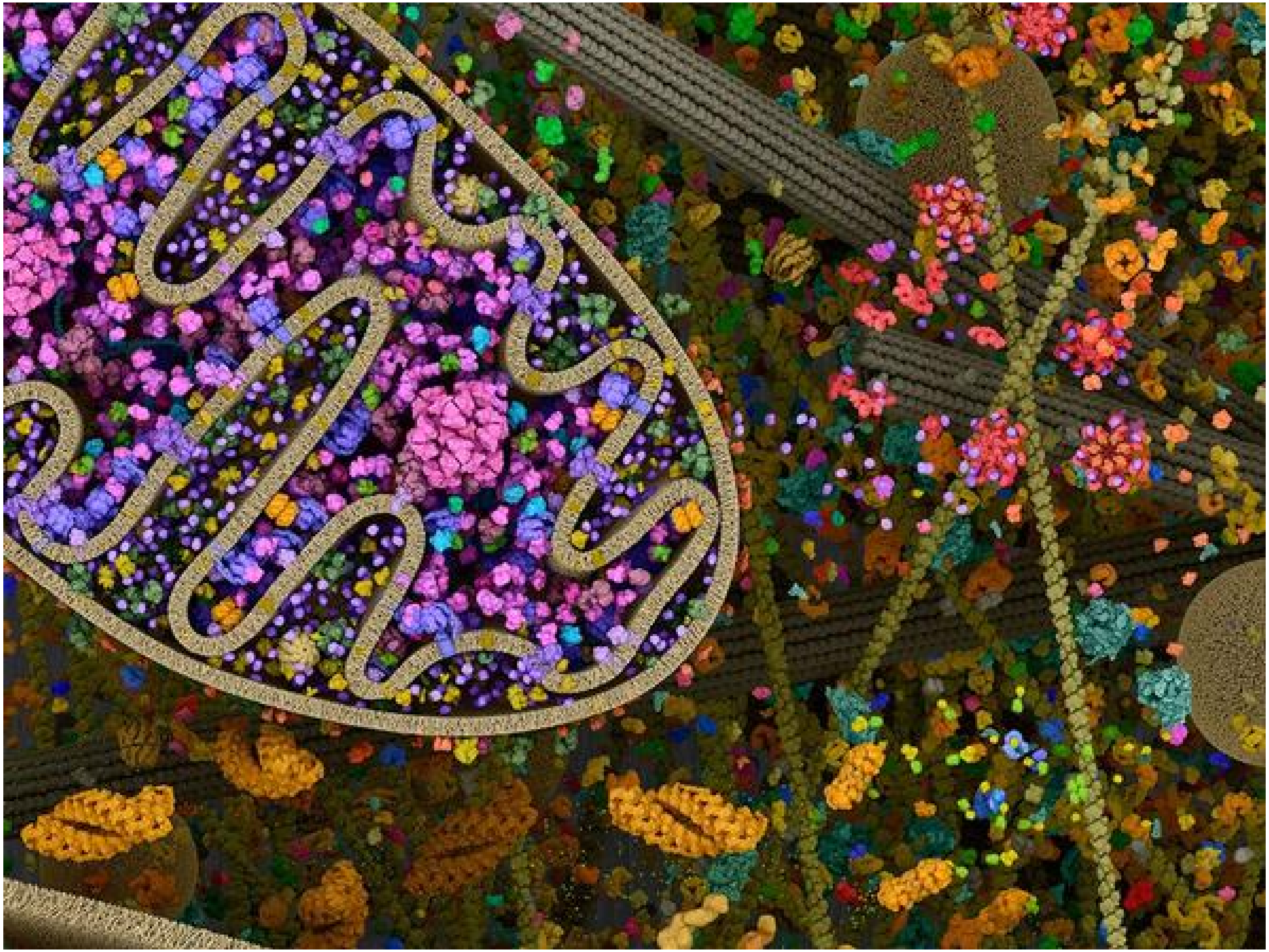
Simonet 2016

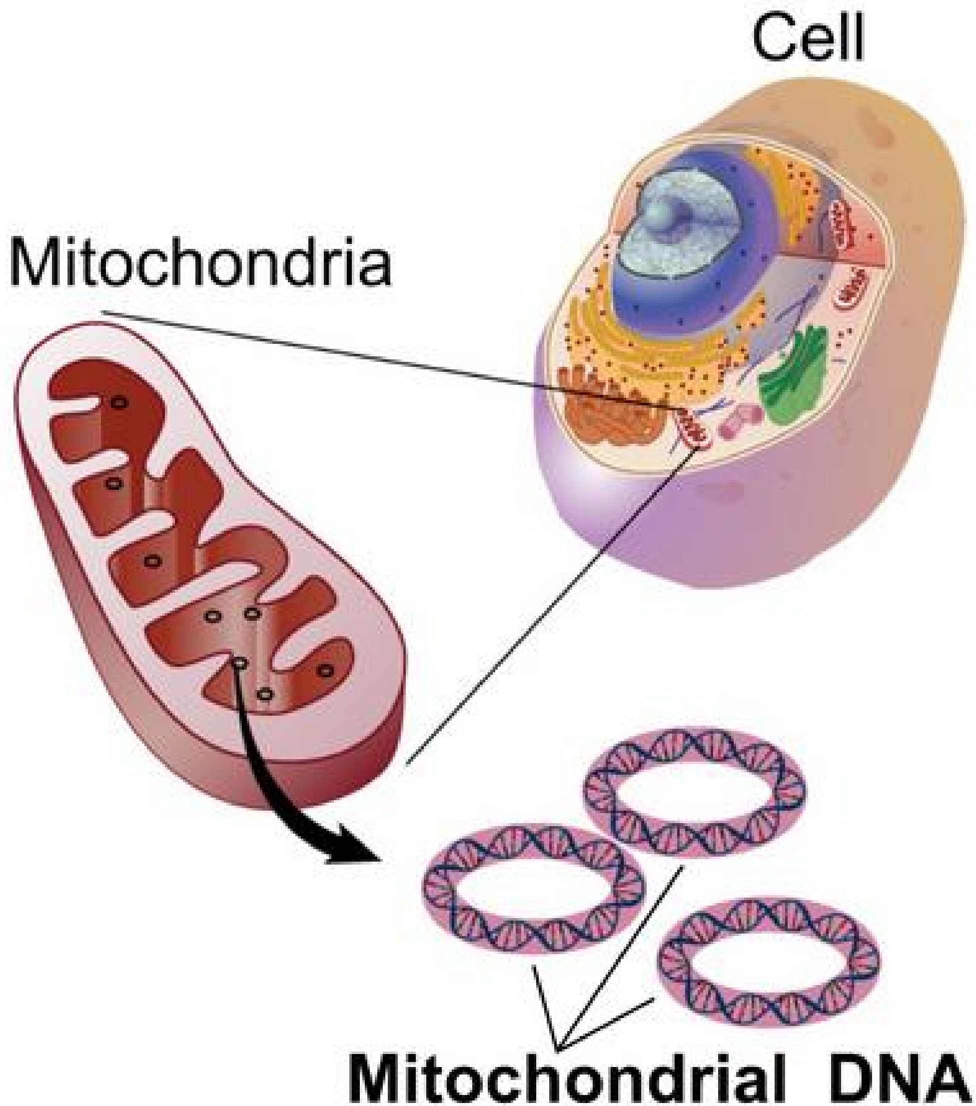


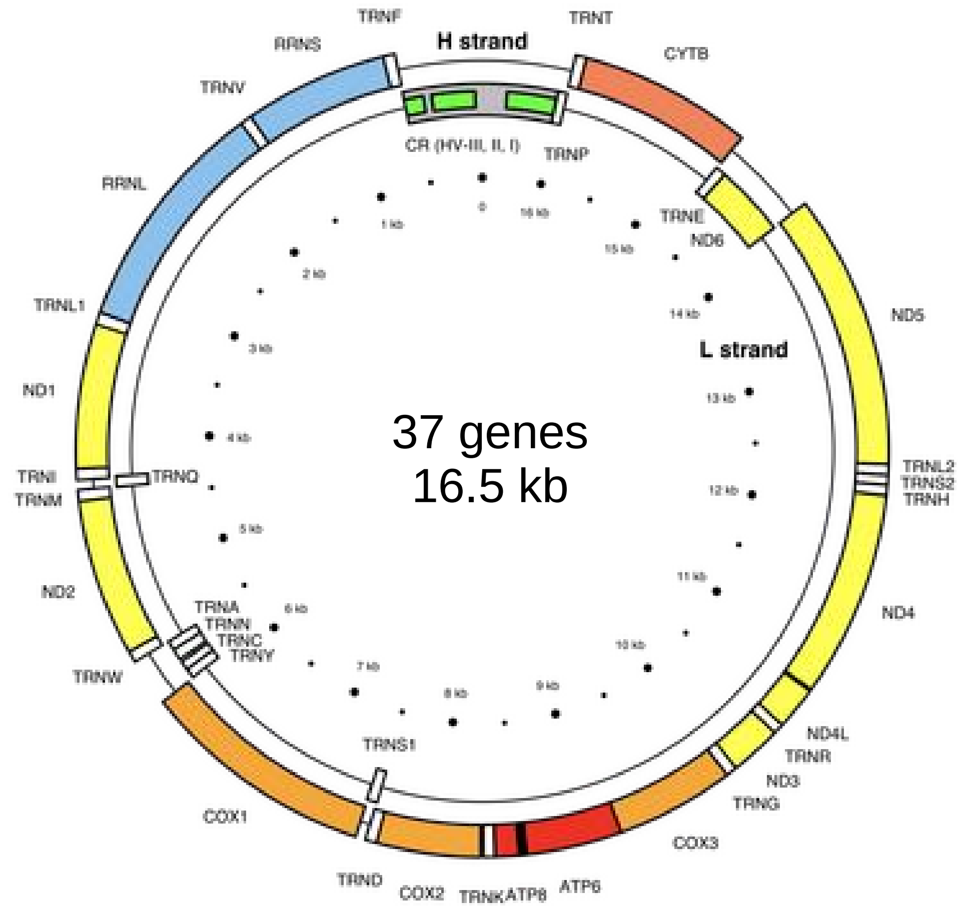
Buchnera aphidicola
Acyrthosiphon pisum
Glycolysis
Pentose phosphate pathway
eyrthrose-4-phosphate
phosphoenolpyruvate
aroH, aroB, aroD, aroE,
aroK, aroA, aroC
chorismate
pheA
chorismate mutase
(EC 5.4.99.5)
prephenate
pheA
prephenate dehydratase
(EC 4.2.1.51)
tyrA
hydroxyphenylpyruvate synthase
(EC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

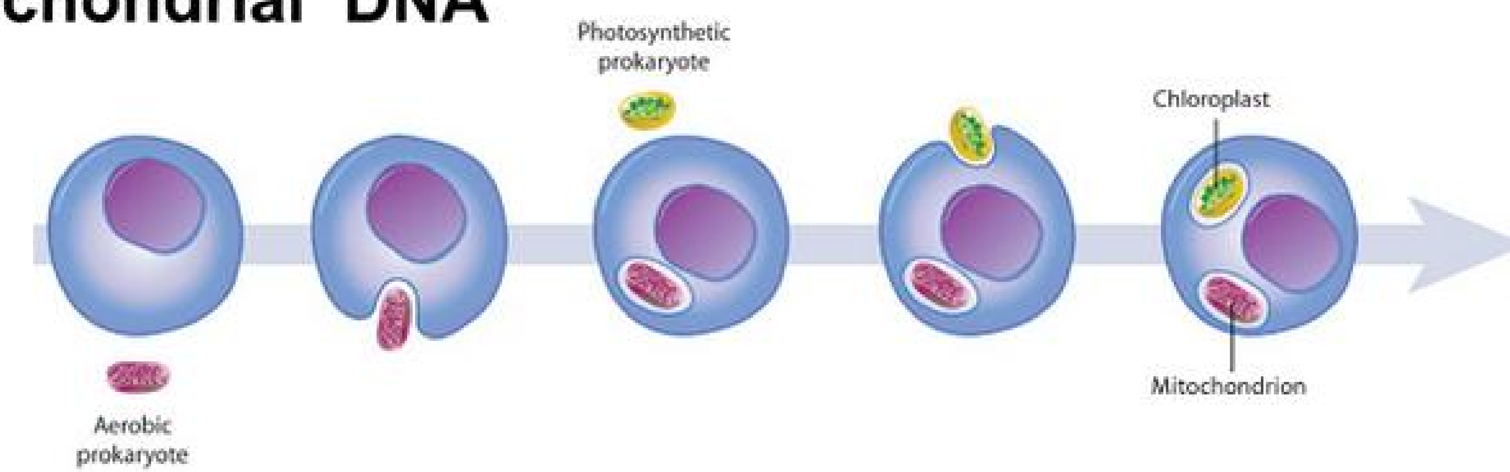

Buchnera
Genes lost
Scale bars = 50 kb
Reconstructed Enteric Ancestor


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

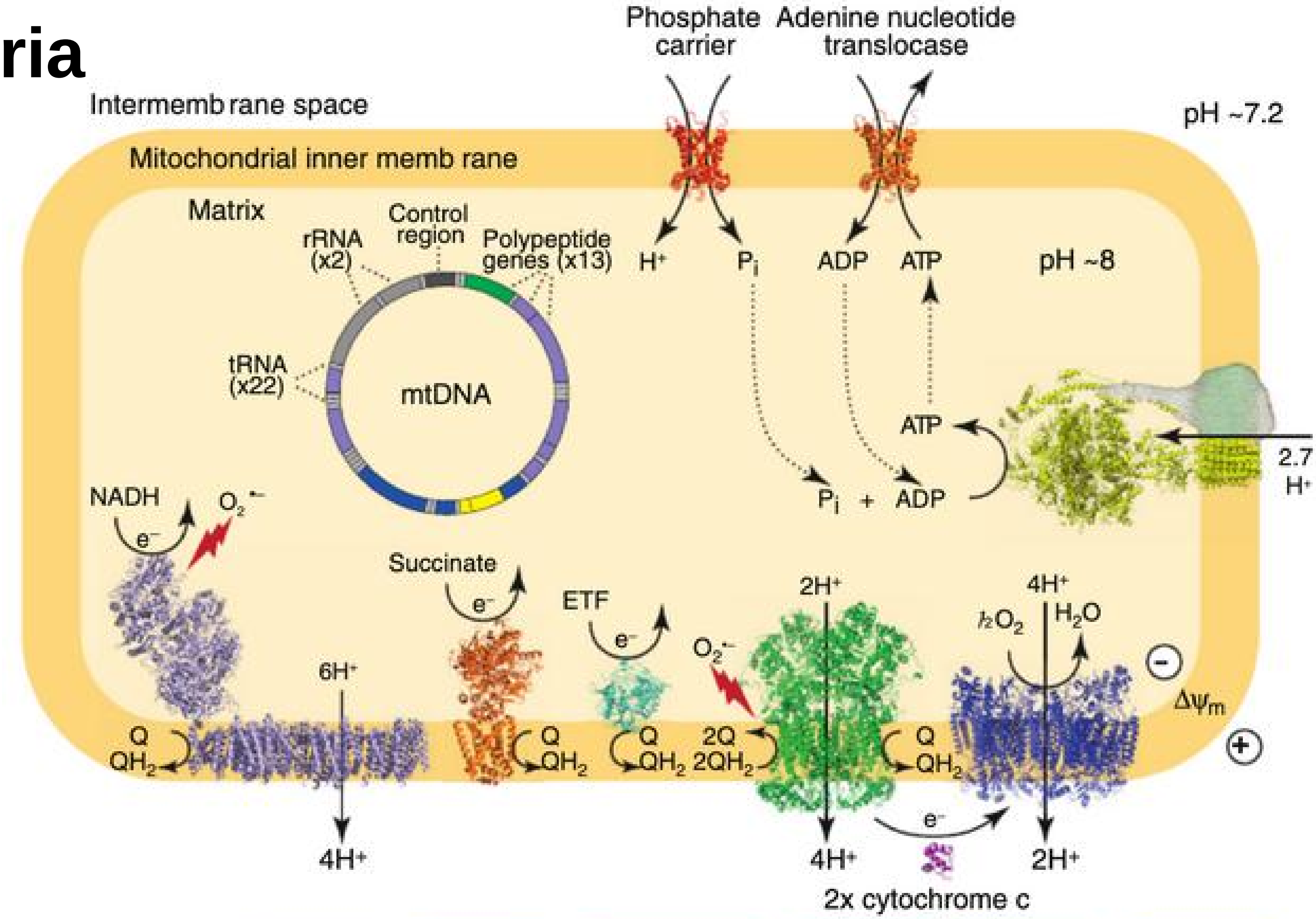



Cell
Mitochondria
Mitochondrial DNA


H strand
L strand
37 genes
16.5 kb
CR (HV-III, II, I)
TRNF
RRNS
TRNV
RRNL
TRNL1
ND1
TRNI
TRNQ
TRNM
ND2
TRNA
TRNN
TRNC
TRNY
TRNW
COX1
TRNS1
TRND
COX2
TRNK
ATP8
ATP6
COX3
TRNG
ND3
TRNR
ND4L
ND4
TRNL2
TRNS2
TRNH
ND5
ND6
TRNE
CYTB
TRNT
TRNP


Photosynthetic prokaryote
Chloroplast
Aerobic prokaryote
Mitochondrion

Major function of mitochondria is to produce ATP

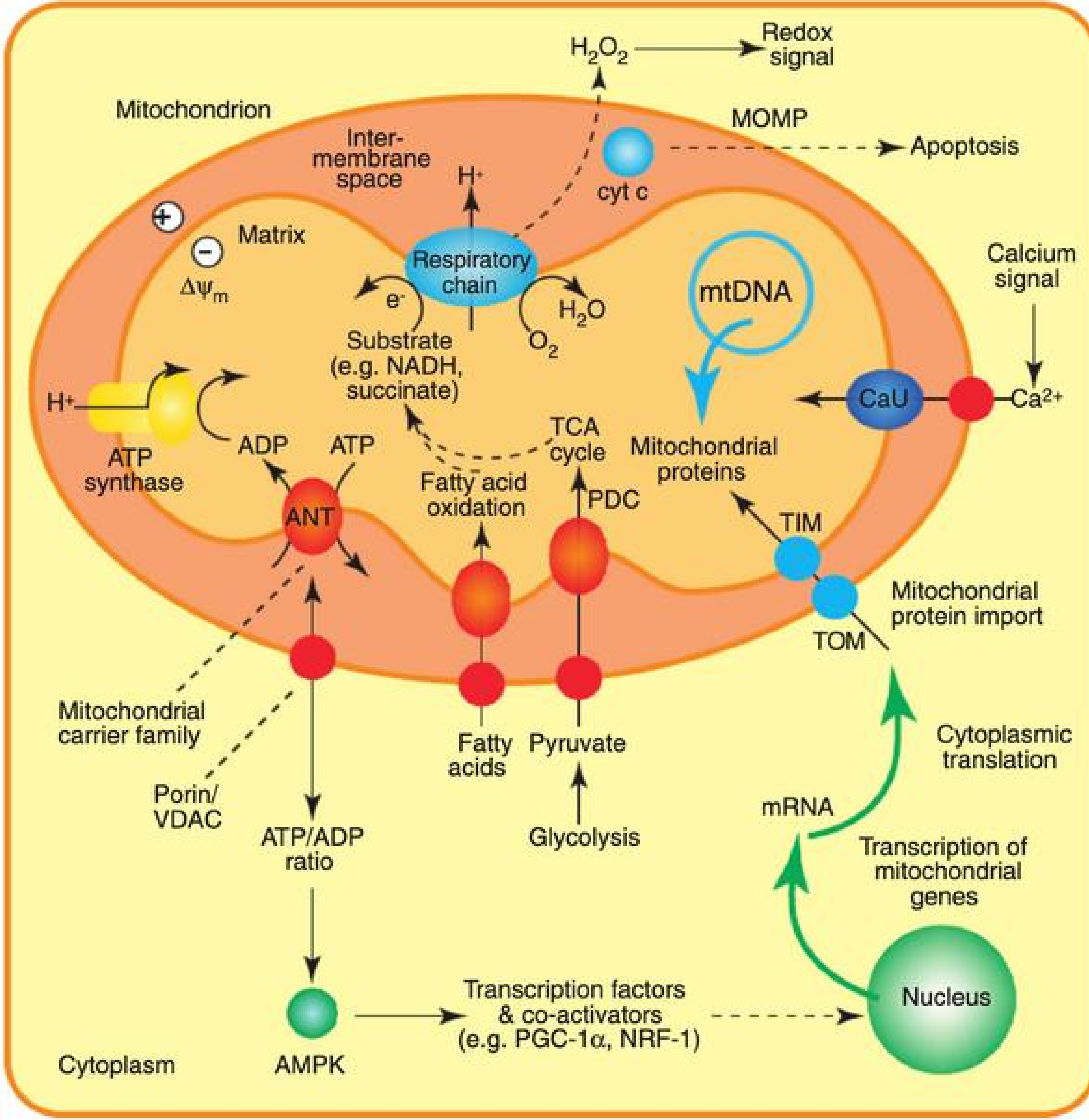


	Complex I	Complex II	ETF:Q oxido-reductase	Complex III	Complex IV	ATP synthase
Total number of subunits	45	4	1	11	13	16
Subunits encoded by mtDNA	7	0	0	1	3	2

Smith 2012

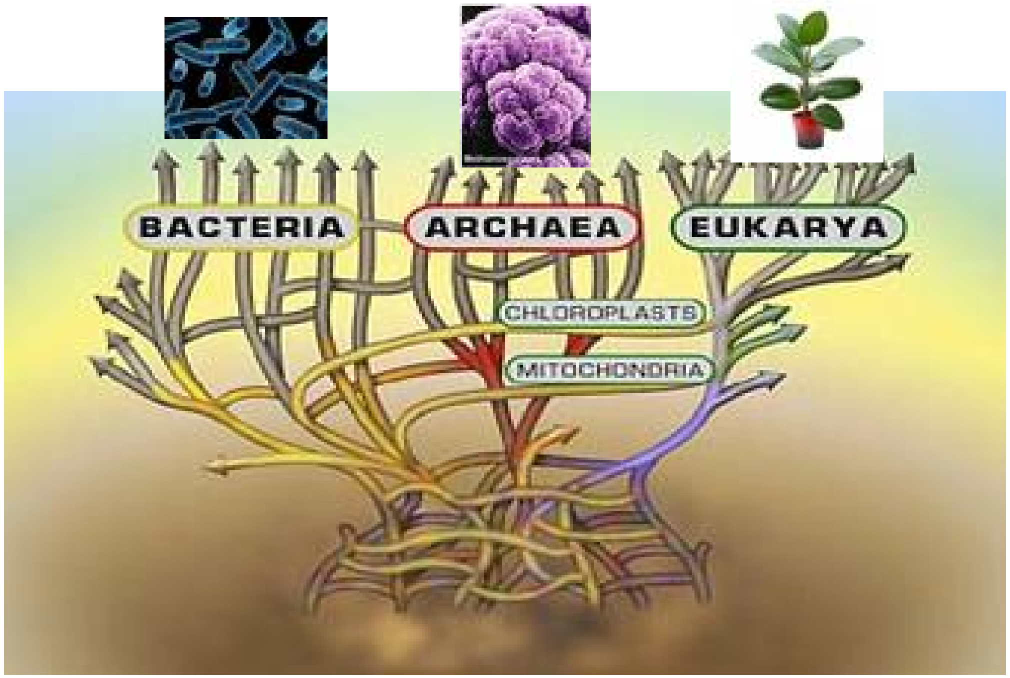
TRENDS in Pharmacological Sciences

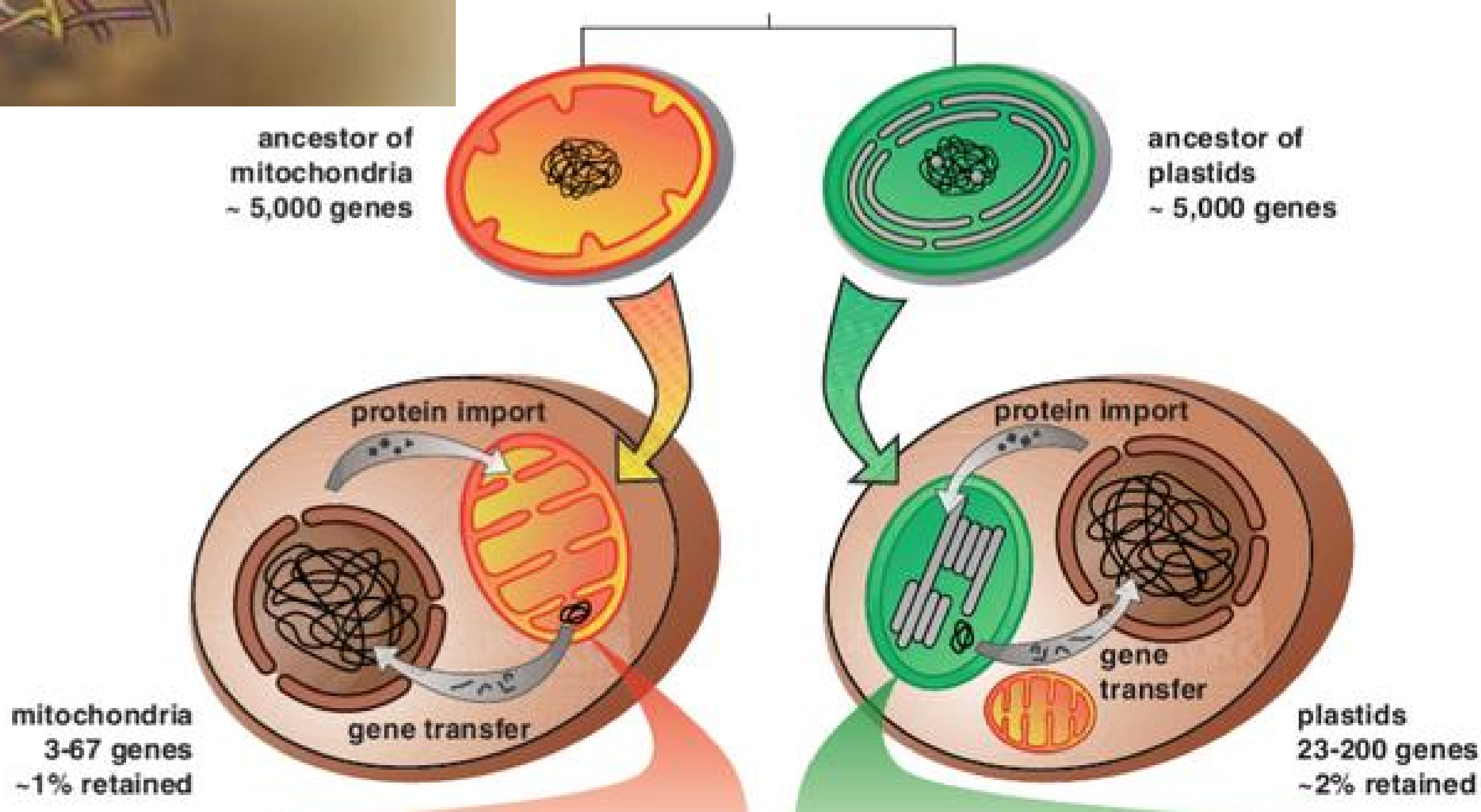
Functions And Biogenesis Of Mitochondria



Smith 2012

Mitochondria and chloroplasts

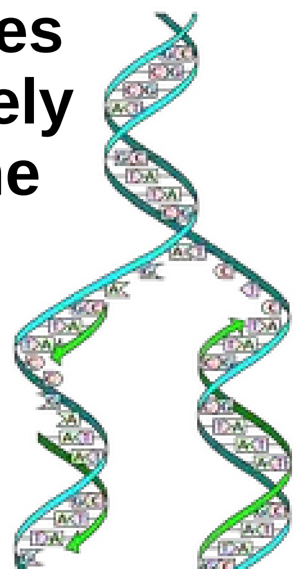




Maier 2013

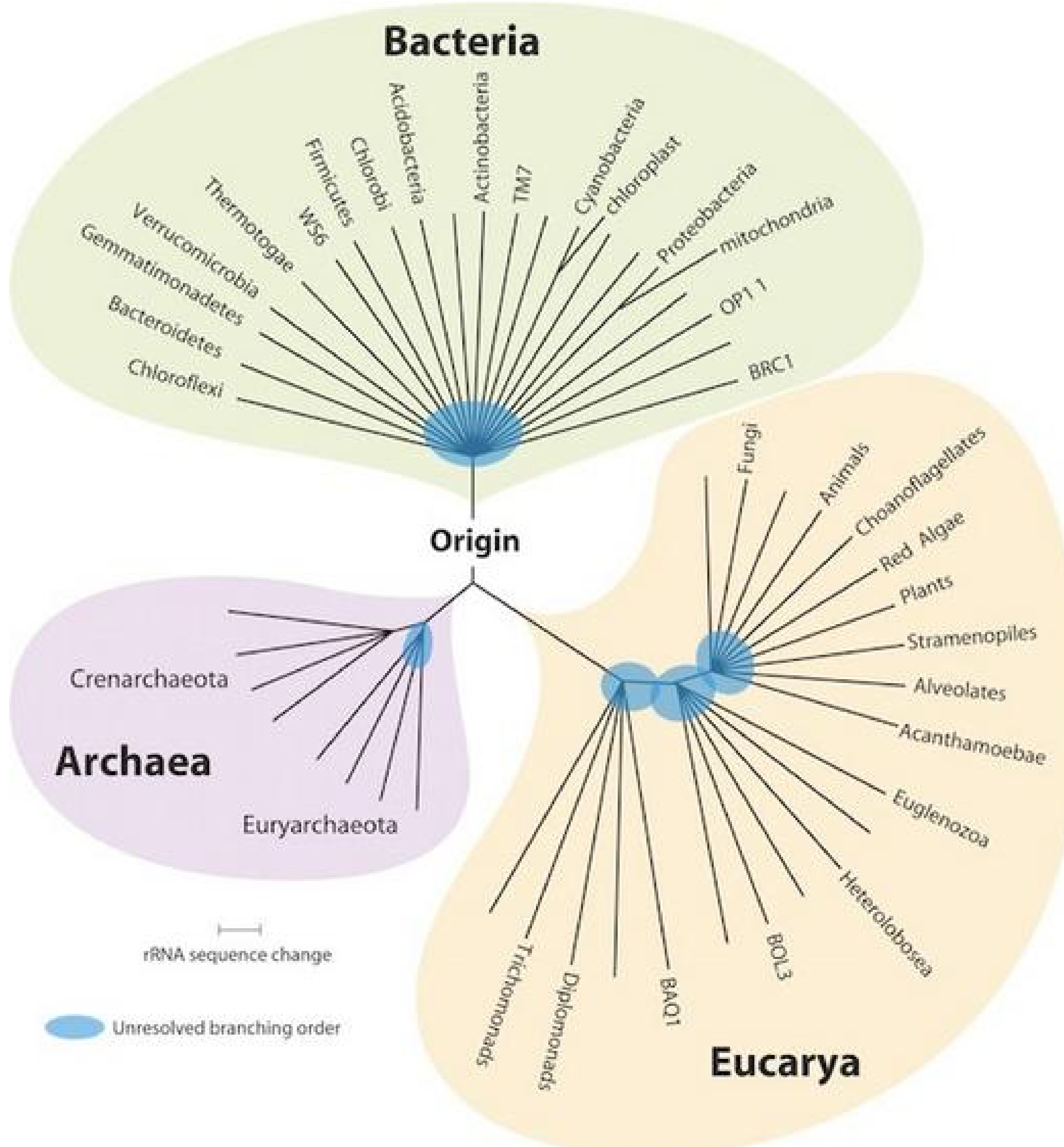
A living organism is not made by assembling pieces together

..but results from changes that occurred successively across evolutionary time



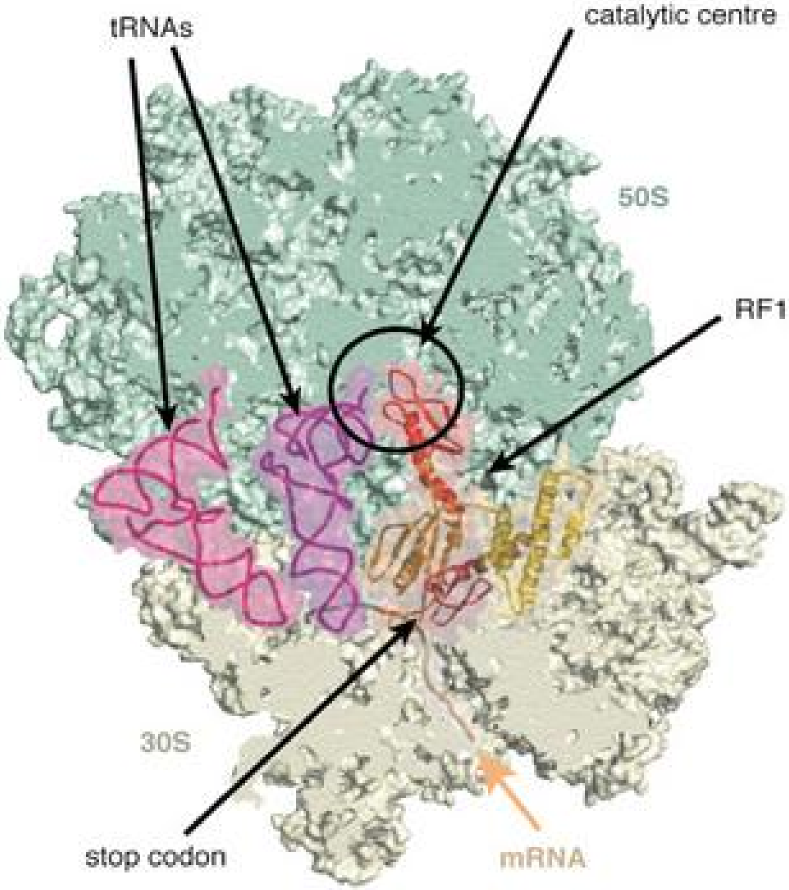
Orgogozo et al 2015 Frontiers Genetics

The tree of life, sampling the living world

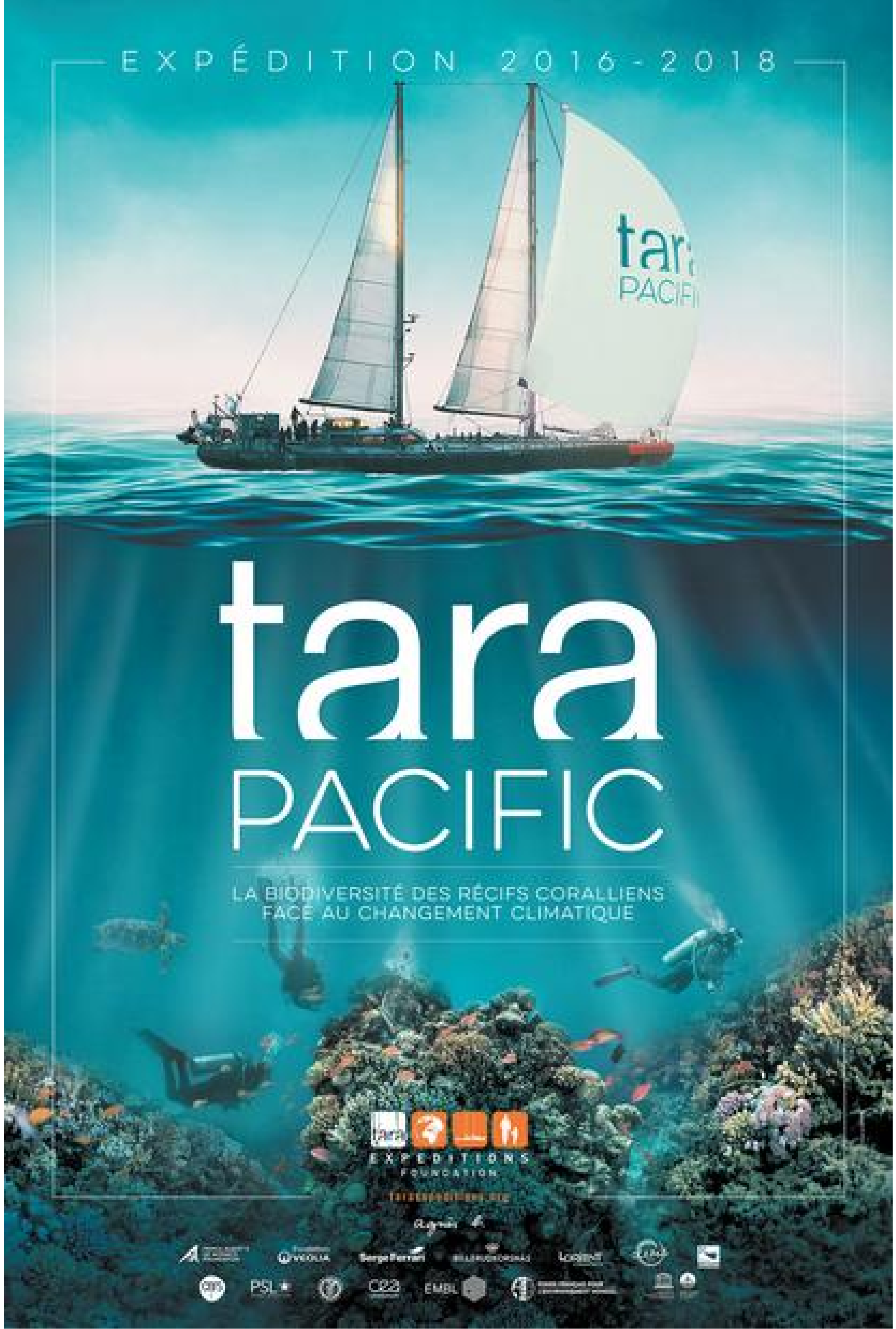


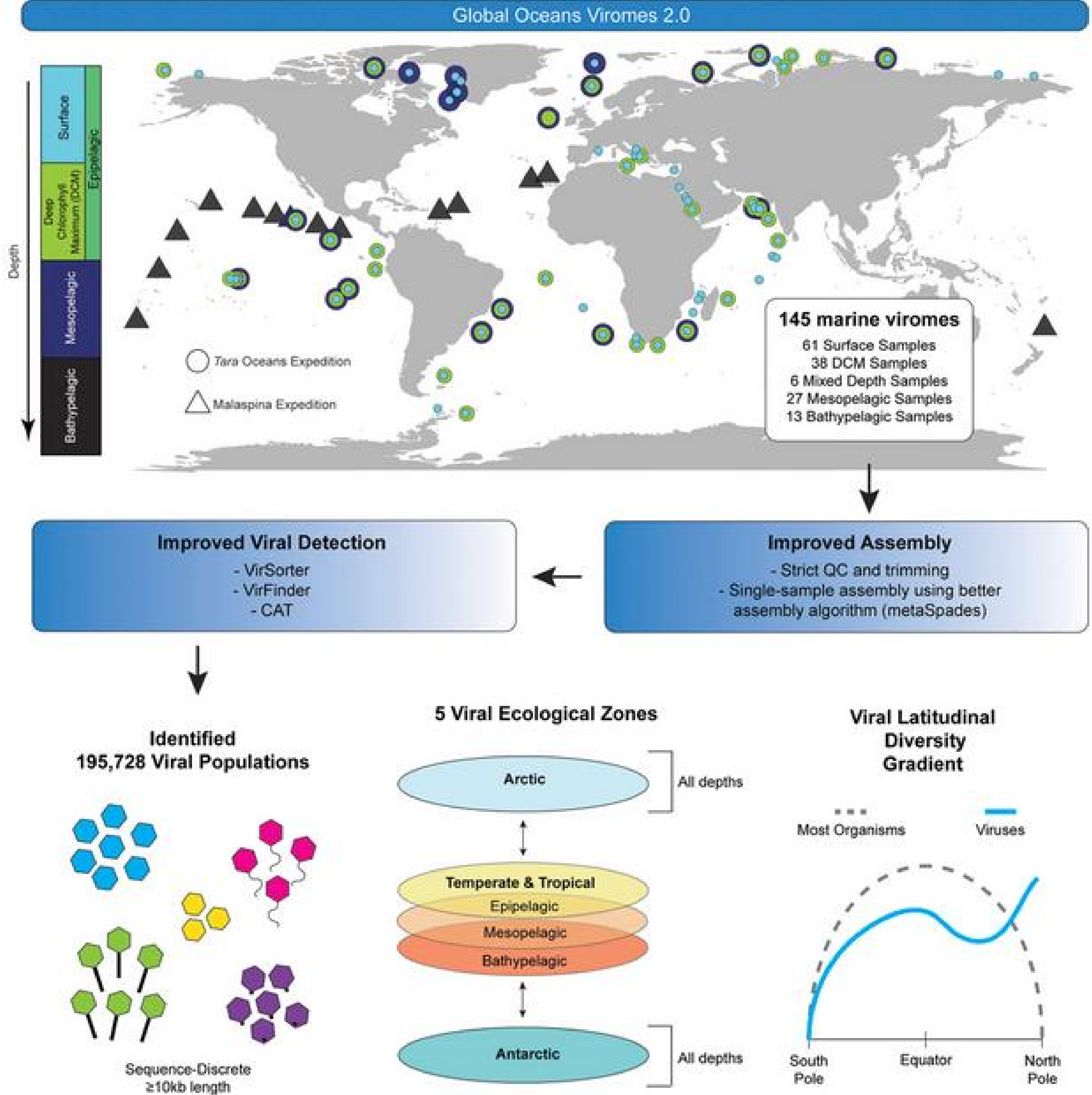
Bacteria
Chloroflexi
Bacteroidetes
Gemmatimonadetes
Verrucomicrobia
Thermotogae
WS6
Firmicutes
Chlorobi
Acidobacteria
Actinobacteria
TM7
Cyanobacteria
chloroplast
Proteobacteria
mitochondria
OP11
BRC1
Origin
Crenarchaeota
Archaea
Euryarchaeota
Fungi
Animals
Choanoflagellates
Red Algae
Plants
Stramenopiles
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
tara
PACIFIC
LA BIODIVERSITÉ DES RÉCIFS CORALLIENS
FACE AU CHANGEMENT CLIMATIQUE
EXPEDITIONS
FOUNDATION



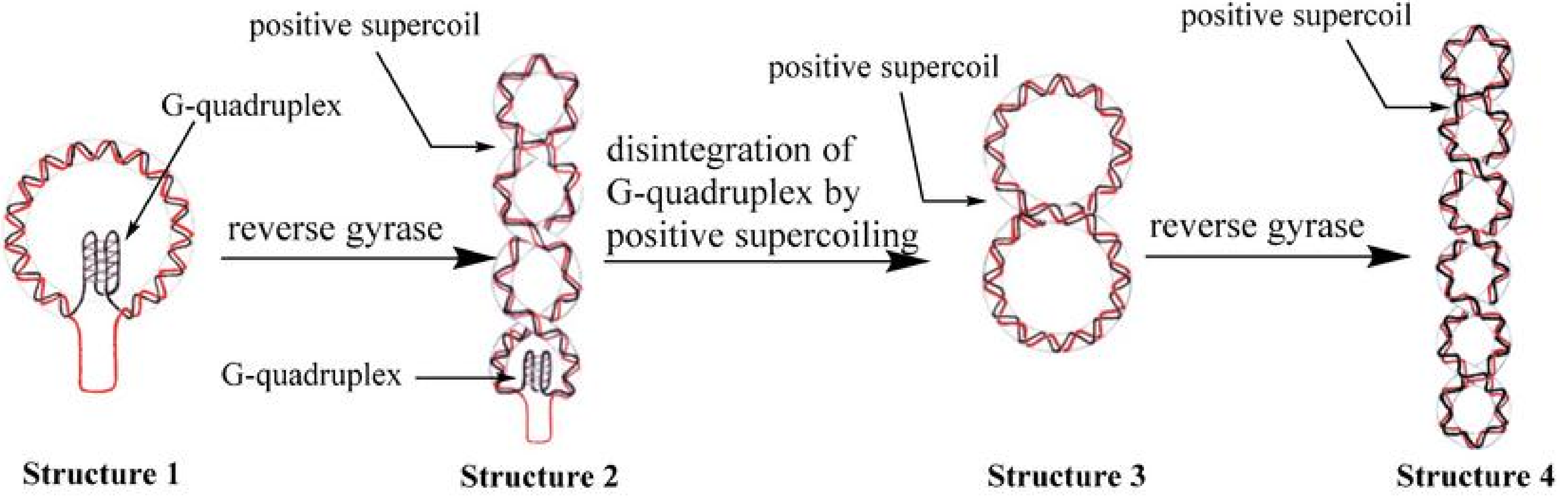
Gregory et al 2019

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

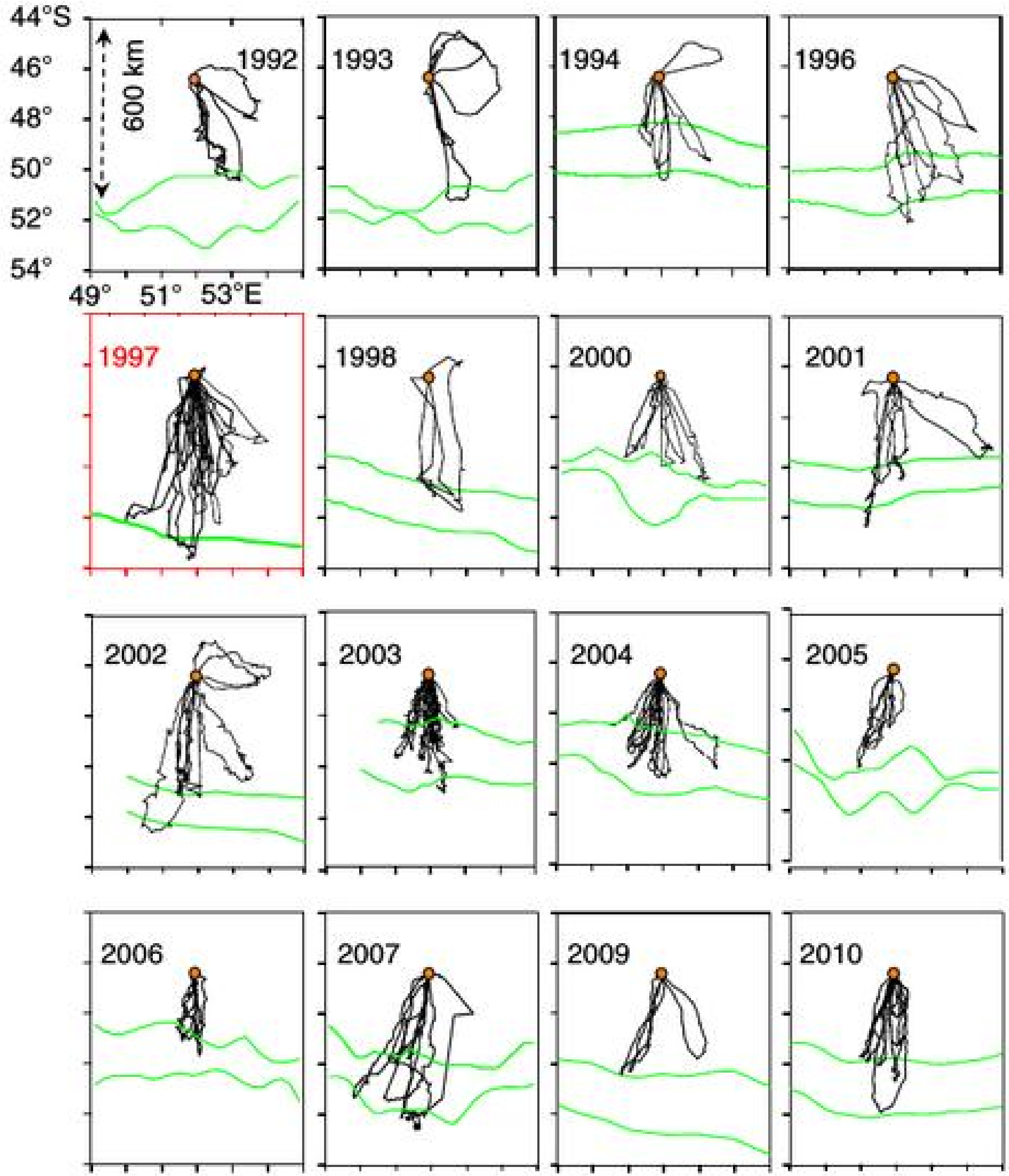
All bacteria living at >80°C have a reverse gyrase enzyme
Maintains DNA stability



Ecology

Tracking king penguins

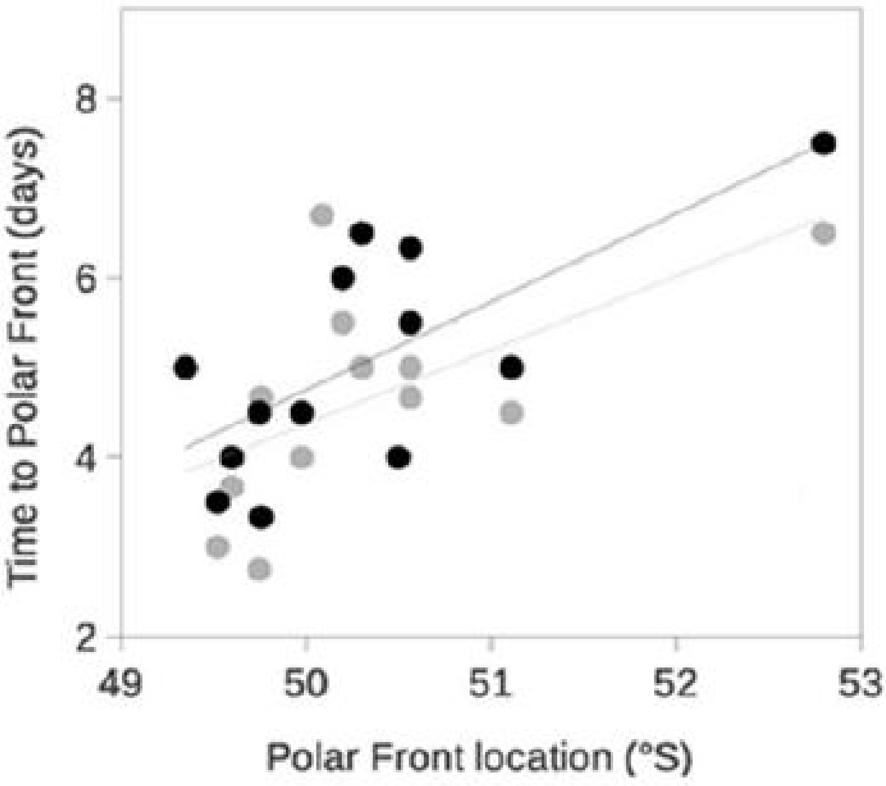
Must go to the polar front to capture fishes



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

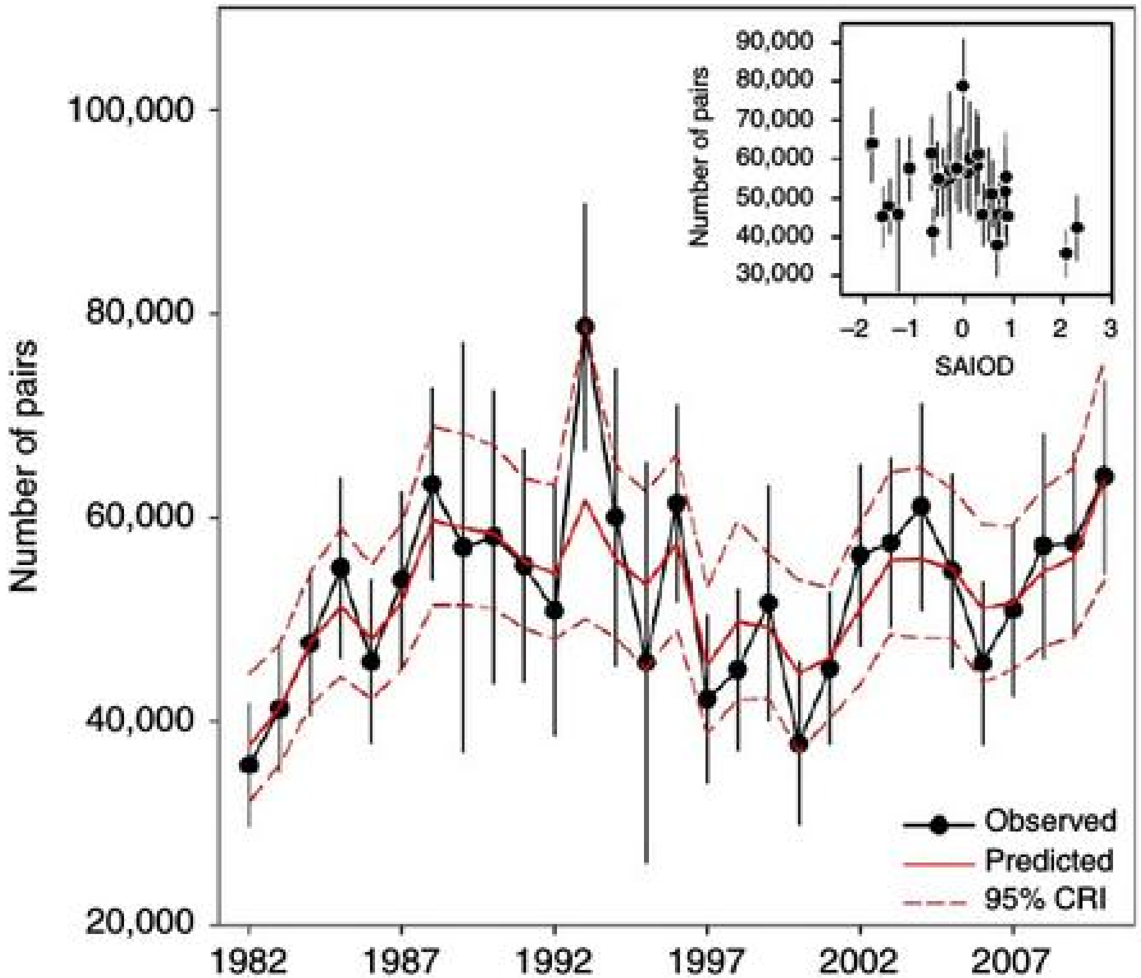
Bost et al 2015

The further, the longer it takes



Bost
et al
2015

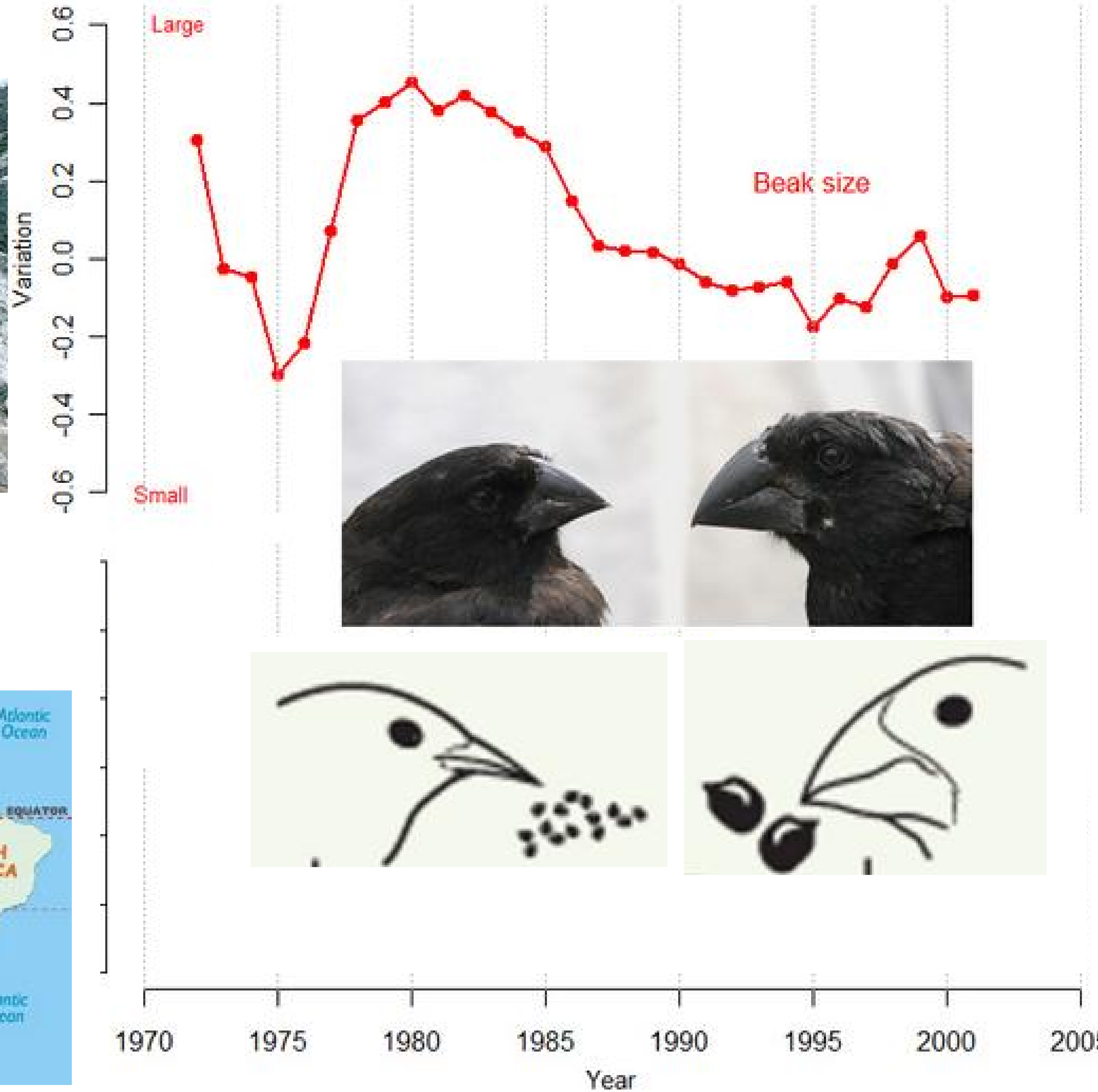
Decrease in population numbers in 1997



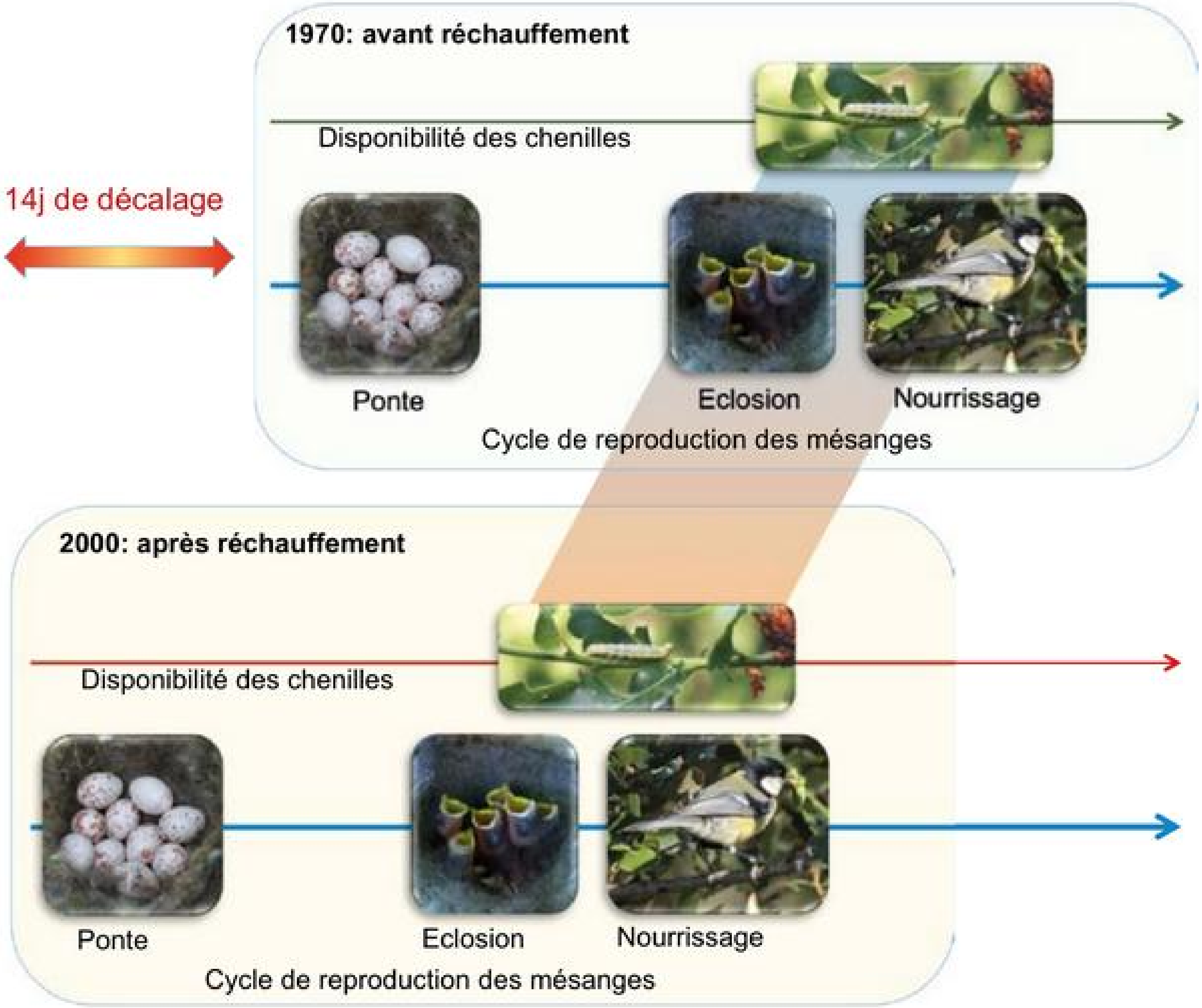
Bost et al 2015

Monitoring birds

Peter and Rosemary Grant
in Galapagos



Rapid evolution of great tits



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

Anthropocene

Anthropocene

proposed geologic timescale dating from the commencement of significant human impact on Earth's geology and ecosystems, including anthropogenic climate change

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proposed geologic timescale dating from the commencement of significant human impact on Earth's geology and ecosystems, including anthropogenic climate change

Plastic

Pollution

Transports

Humans move sediments at rates higher than all rivers together (mines, constructions)

Extensive Agriculture (deforestation)

Climate change

Biodiversity crisis

Anthropocene

proposed geologic timescale dating from the commencement of significant human impact on Earth's geology and ecosystems, including anthropogenic climate change

Plastic

Pollution

Transports

Humans move sediments at rates higher than all rivers together (mines, constructions)

Extensive Agriculture (deforestation)

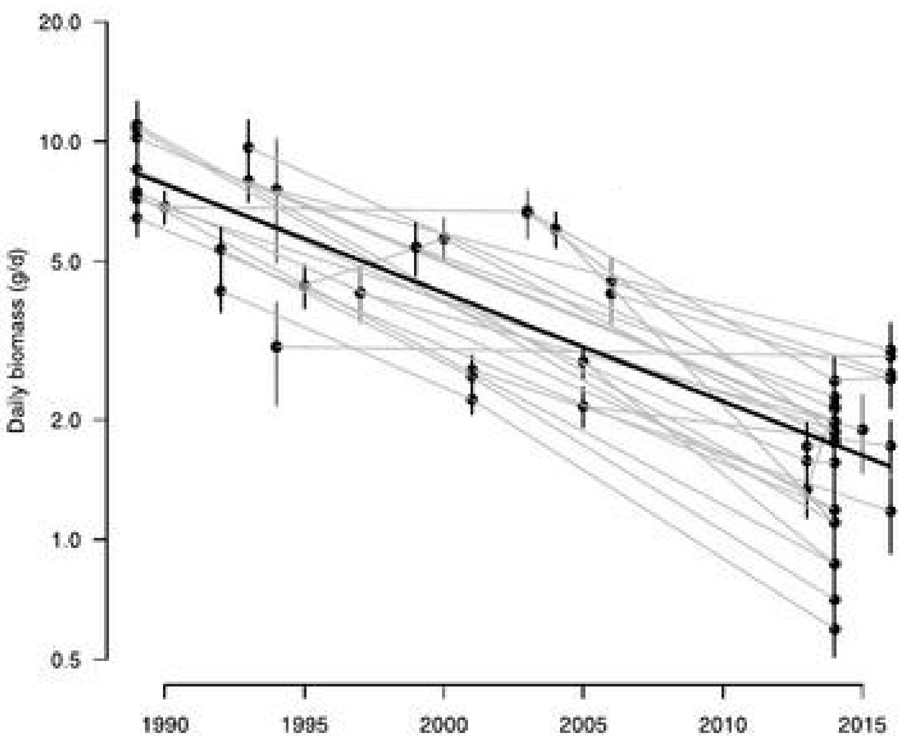
Climate change

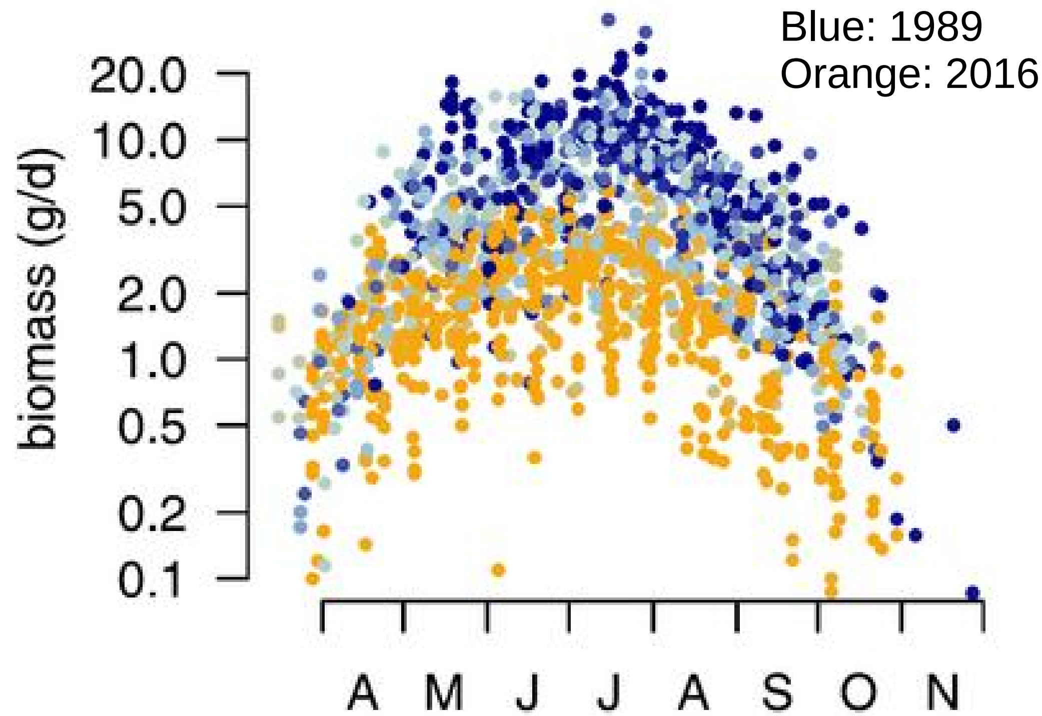
Biodiversity crisis

Not all human, certain human activities - ***Capitalocene*** *(D. Haraway, J. Moore)*

75% decline of flying insect biomass in 27 years

Malaise trap
96 unique location-year samplings
in Germany from 1989 to 2016 (27 years)
~50 kg of insects collected





Hallmann 2017

Finding causes for the decline

Check various parameters: climate (T, precipitations, frost days, light...), habitat (plants, pH...), land use

Decline = evident throughout the growing season
irrespective of habitat type or landscape configuration

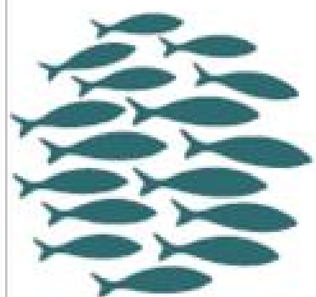
Temperature: increase in 0.5ºC, should have increased insect biomass

Pesticide usage not tested

Hallmann 2017

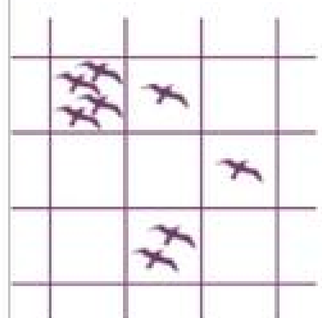
DIFFÉRENTS INDICATEURS, MÊME CONCLUSION

La biodiversité : un concept à multiples facettes qui nécessite de multiples indicateurs



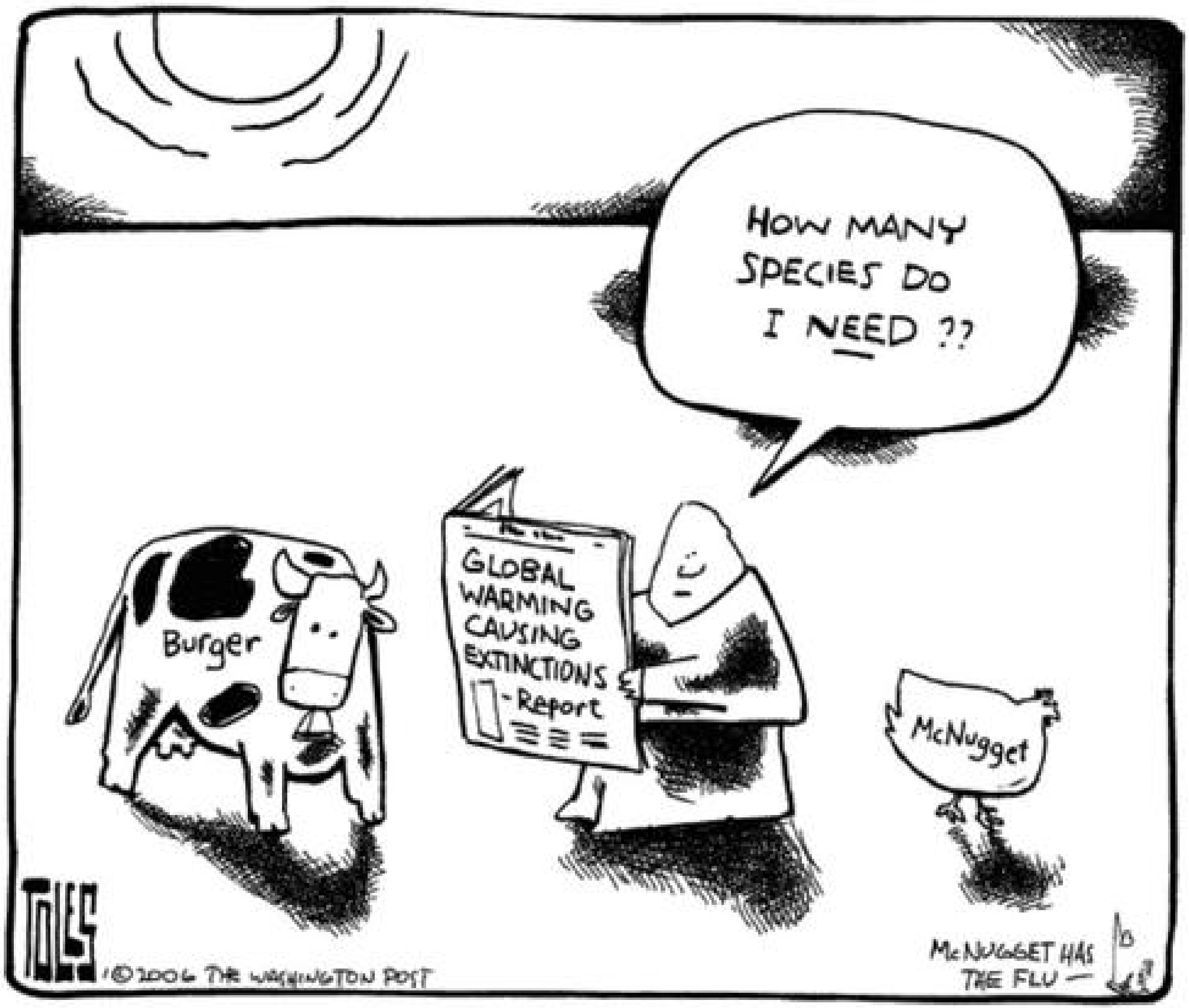
ABONDANCE

COMPOSITION



RÉPARTITION

RISQUE D'EXTINCTION



HOW MANY SPECIES DO I NEED ??
GLOBAL WARMING CAUSING EXTINCTIONS -Report
Burger
McNugget
TOLES
©2006 THE WASHINGTON POST
McNUGGET HAS THE FLU —

Services ecosystémiques (valeurs extrinsèques)

Support

Production primaire
Recyclage des éléments
Fertilité des sols
Pollinisation
Habitat pour les espèces

Culture

Ecotourisme
Loisirs
Ethique
Esthétique
Education

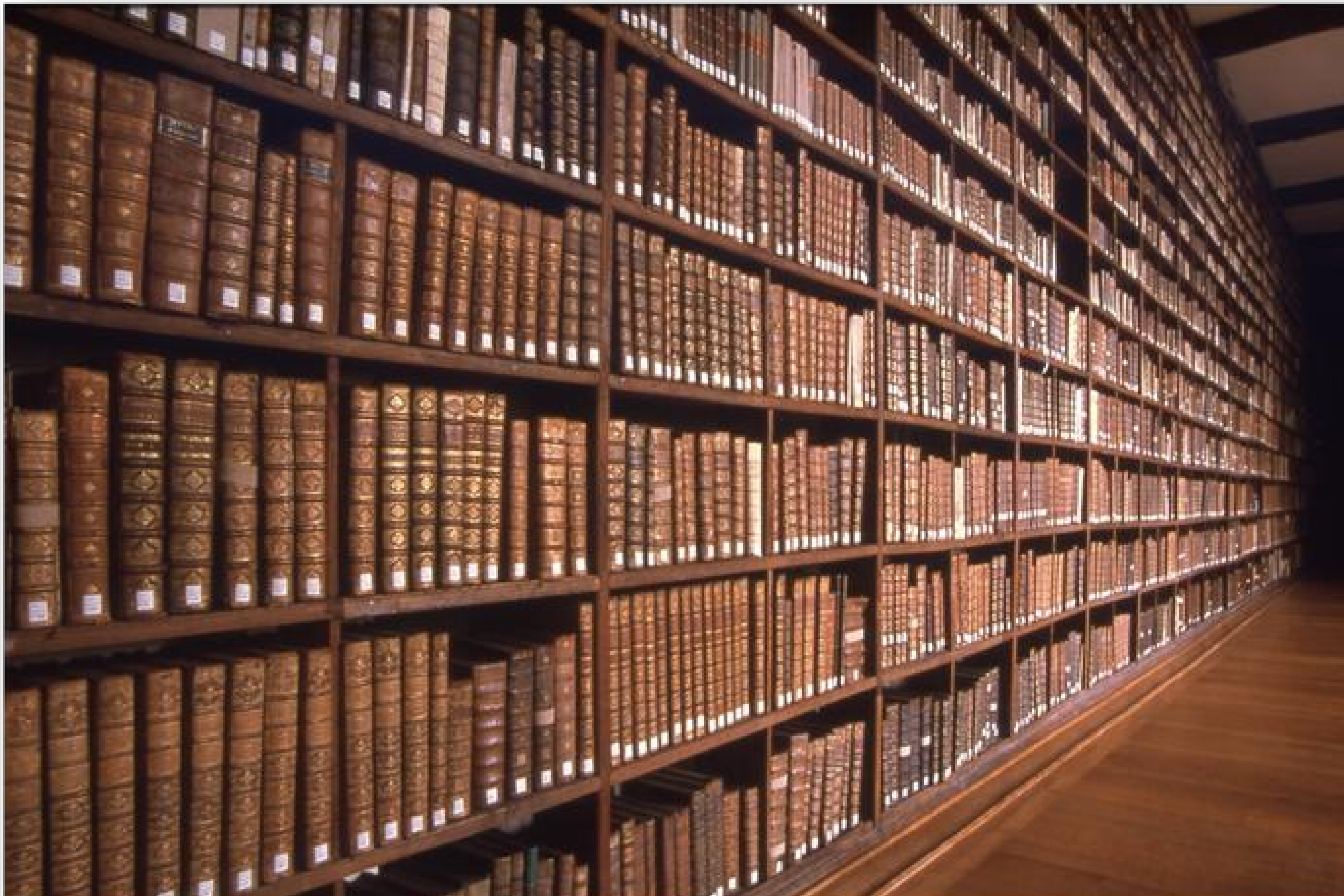
Approvisionnement

Cultures
Elevage
Pêche
Aquaculture
Gibier, Cueillette
Bois
Ressources génétiques
Eau potable

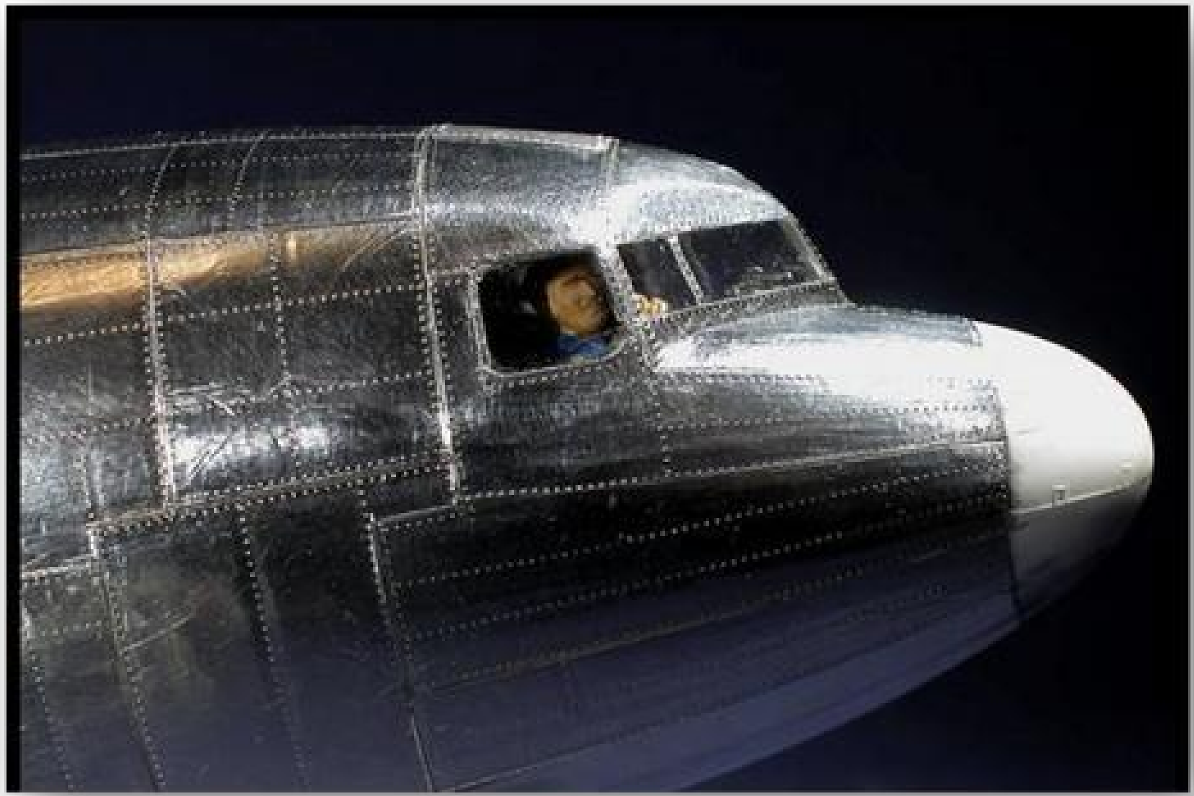
Régulation Environnementale

Régulation du climat
Purification des eaux et de l'air
Régulation des flux hydriques
Atténuation des perturbations
Contrôle de l'érosion
Contrôle biologique
Prévention des épidémies

La perte d’une espèce n’est pas comme la perte d’un livre

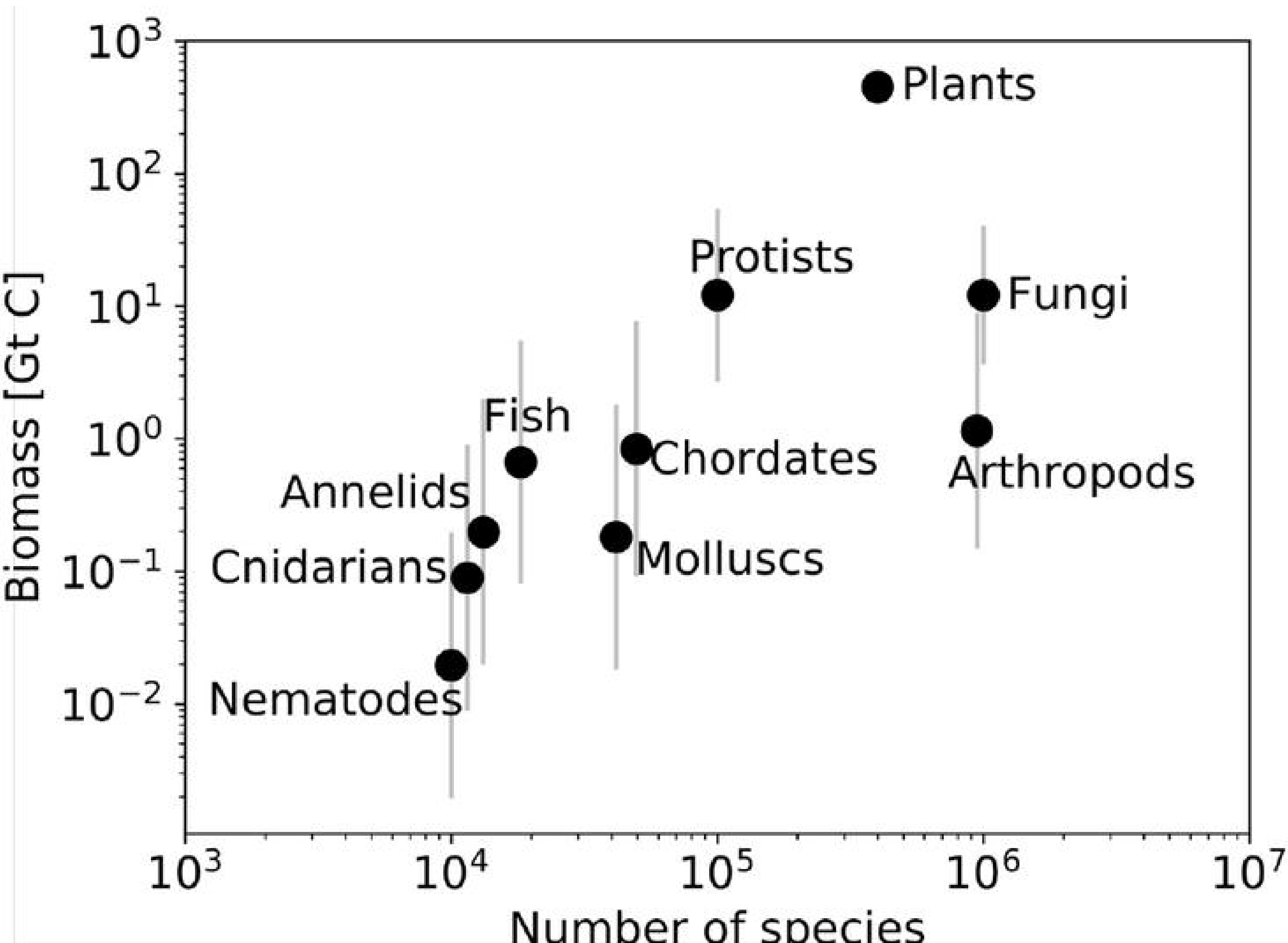


La perte des rivets d’un avion



Le tissu vivant de la planète

http://sogeco31.blogspot.com/2019/08/non-lamazonie-nest-pas-le-poumon-de-la.html



Bar-On 2018 PNAS

From molecules to ecosystems

Characteristics of living organisms

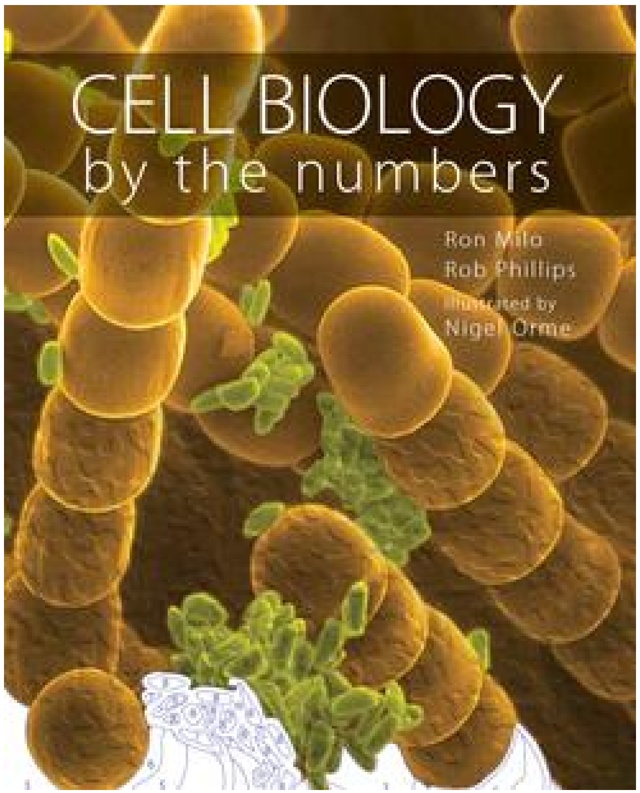
Main molecules in living organisms

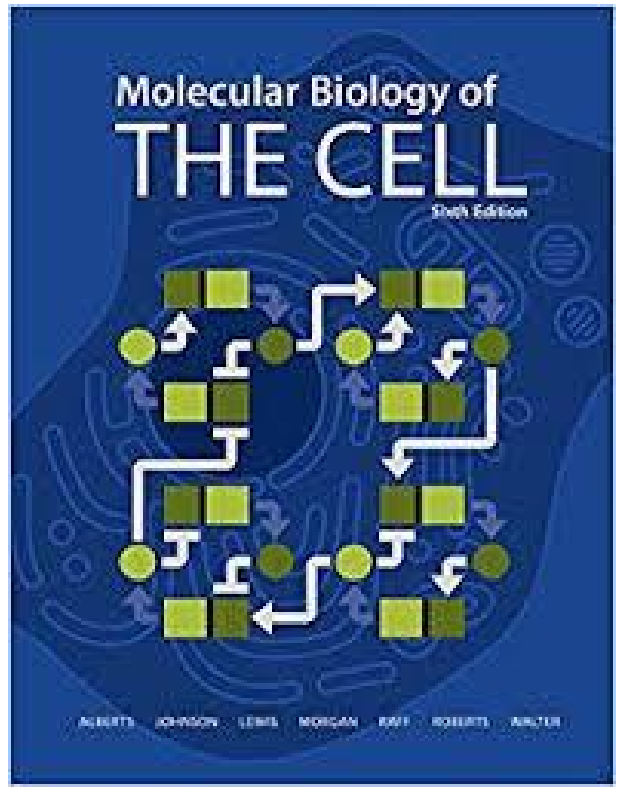
Virus, Bacteria, Eucaryote, Archaea

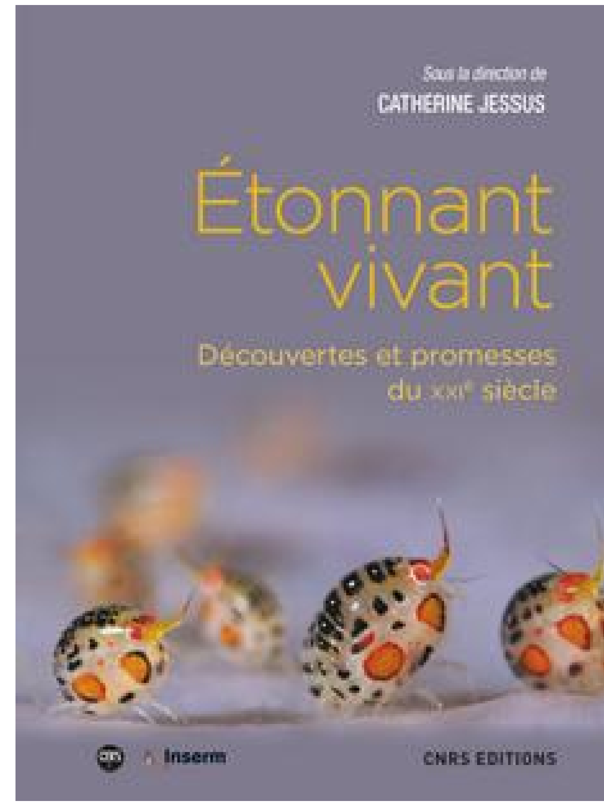
Cell division, Virus amplification

Ecological observations

Anthropocene







Bionumbers.org