GIOVANNELLI LAB

University of Naples "Federico II"

Marine Microbial Diversity

donato.giovannelli@unina.it • @d_giovannelli • www.donatogiovannelli.com

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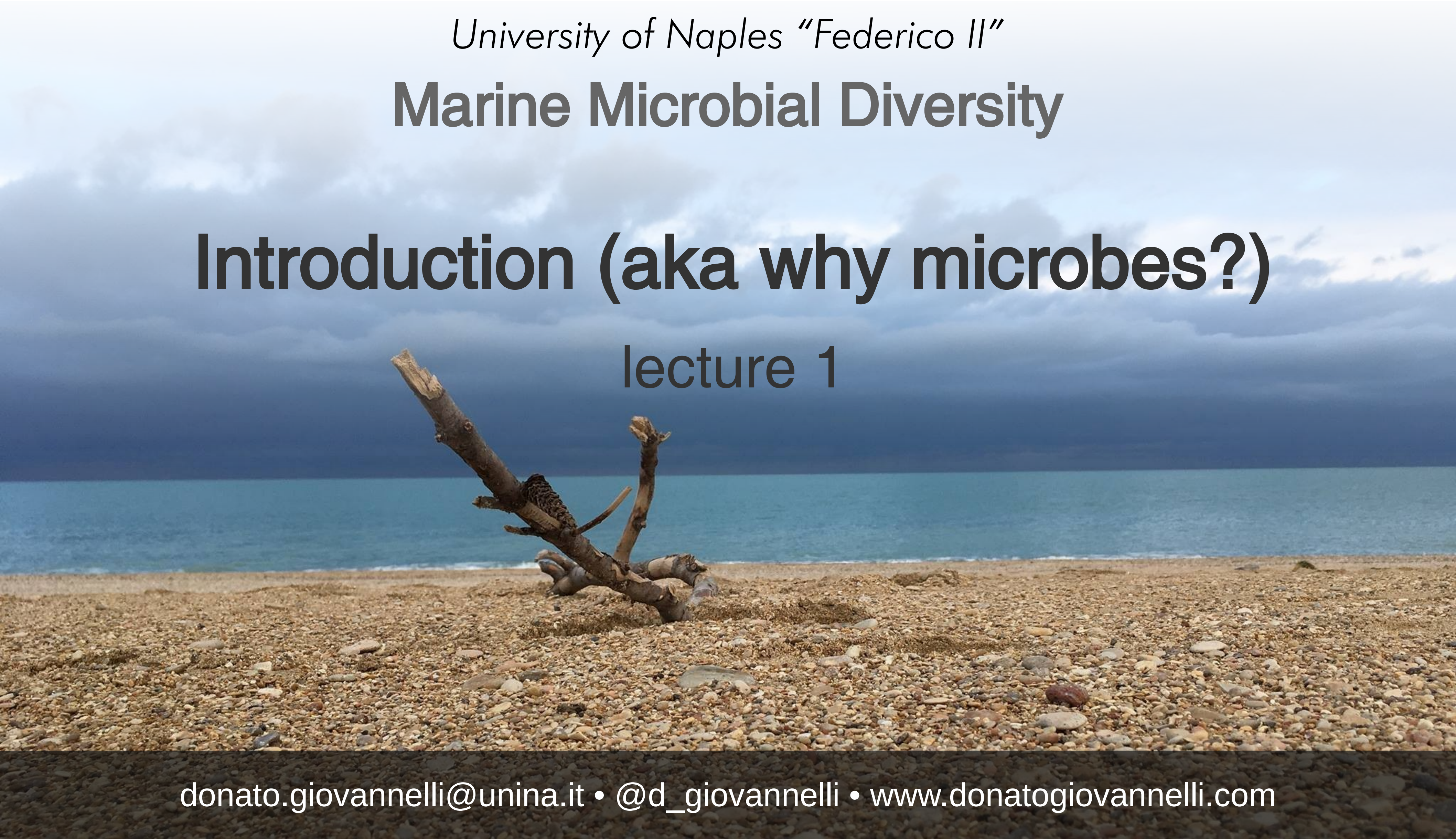
Introduction (aka why microbes?)

lecture 1



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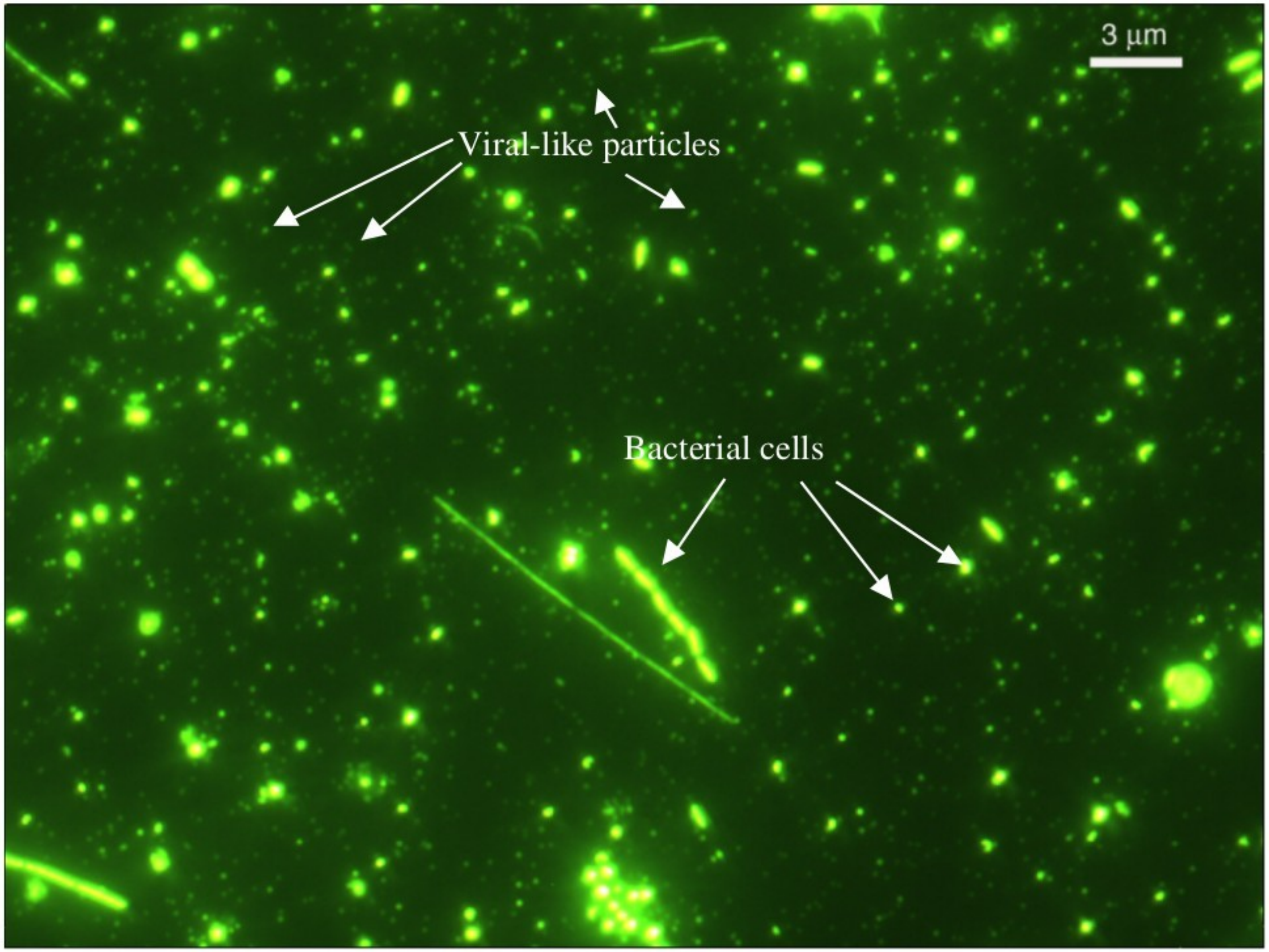
Why microbiology?

Bacteria not Whales!!

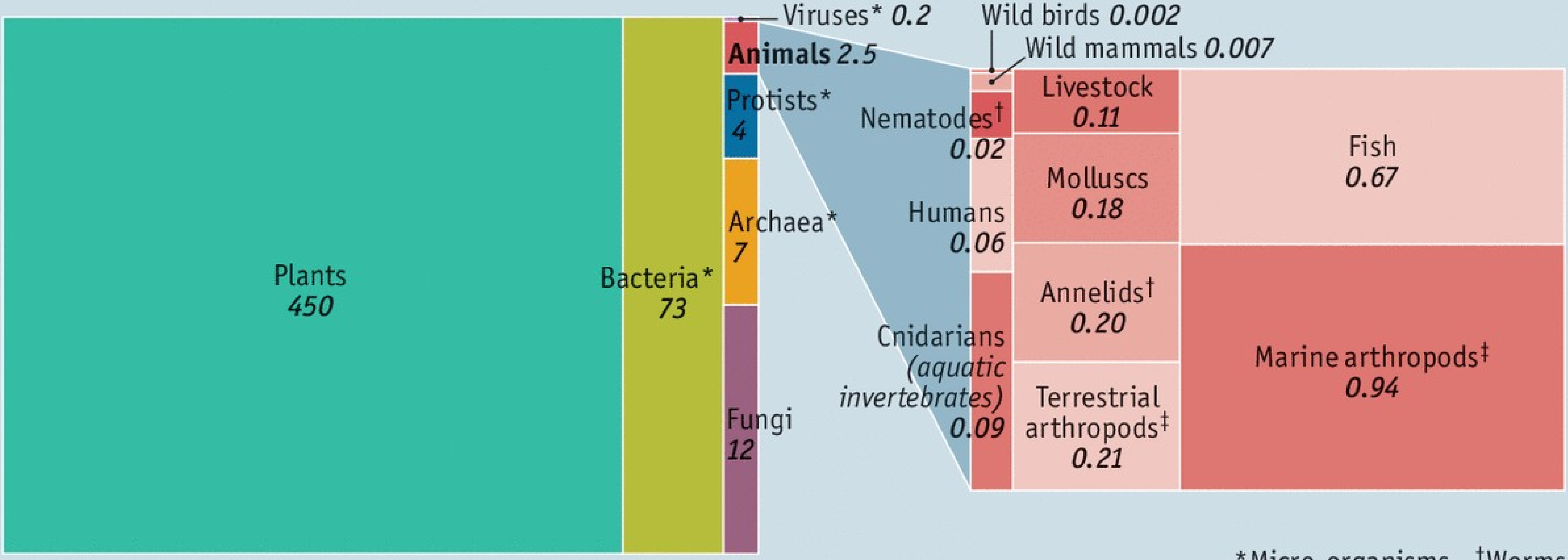
MICROORGANISMS - WHAT ARE THEY?



Although microorganisms are the smallest forms of life, collectively they constitute the bulk of biomass on Earth and carry out many necessary chemical reactions for higher organisms.

Life as we know it

Estimated global biomass of selected taxonomic groups, gigatonnes

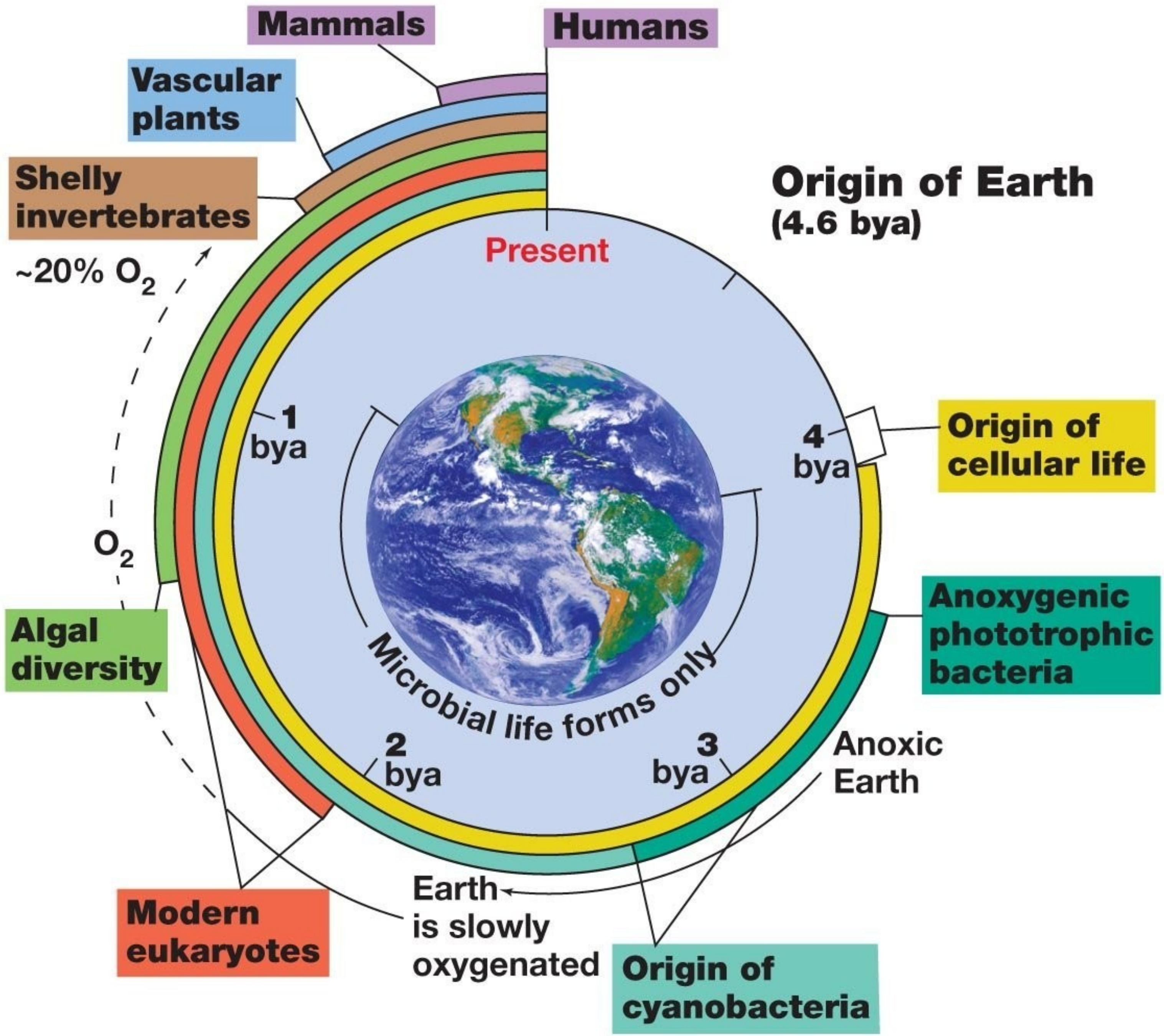


Source: "The biomass distribution on Earth" by Bar-On, Phillips & Milo, *PNAS*, 2018

Table 1.2 Distribution of microorganisms in and on Earth[a]

Habitat	*Percent of total*
Marine subsurface	66
Terrestrial subsurface	26
Surface soil	4.8
Oceans	2.2
All other habitats[b]	1.0

[a]Data compiled by William Whitman, University of Georgia, USA; refer to total numbers (estimated to be about 2.5×10^{30} cells) of *Bacteria* and *Archaea*. This enormous number of cells contains, collectively, about 5×10^{17} grams of carbon.
[b]Includes, in order of decreasing numbers: freshwater and salt lakes, domesticated animals, sea ice, termites, humans, and domesticated birds.



Mammals
Humans
Vascular plants
Shelly invertebrates
Origin of Earth
(4.6 bya)
Present
~20% O_2
O_2
1 bya
4 bya
Origin of cellular life
Microbial life forms only
Anoxygenic phototrophic bacteria
Algal diversity
2 bya
3 bya
Anoxic Earth
Earth is slowly oxygenated
Modern eukaryotes
Origin of cyanobacteria

(a)

MICROBIOLOGY: THE SCIENCE OF MICROORGANISMS

Microbiology is the ***study*** *and* ***classification*** *of microorganisms. Microbiology is also about* ***diversity*** *and* ***evolution*** *of microbial cells, about* ***how*** *different kinds of microorganisms arose and* ***why****. Microbiology embraces* ***ecology****, so it is also about where microorganisms live on Earth, how they associate and cooperate with each other, and what they do in the world at large, in soils and waters and in animals and plants.*

The science of microbiology revolves around two interconnected themes:

(1) understanding the nature and functioning of the microbial world;
(2) applying our understanding of the microbial world for the benefit of humankind and planet Earth.

Microbiology

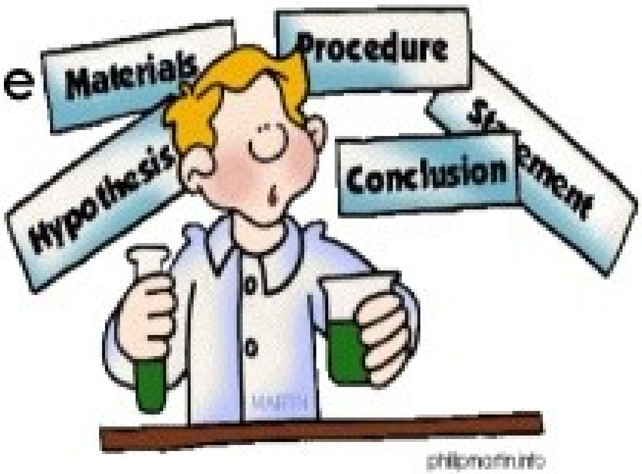
*As a **basic biological science**, microbiology uses microbial cells to probe the fundamental processes of life.*

*As an **applied biological science**, microbiology is at the forefront of many important breakthroughs in human and veterinary medicine, agriculture, and industry.*

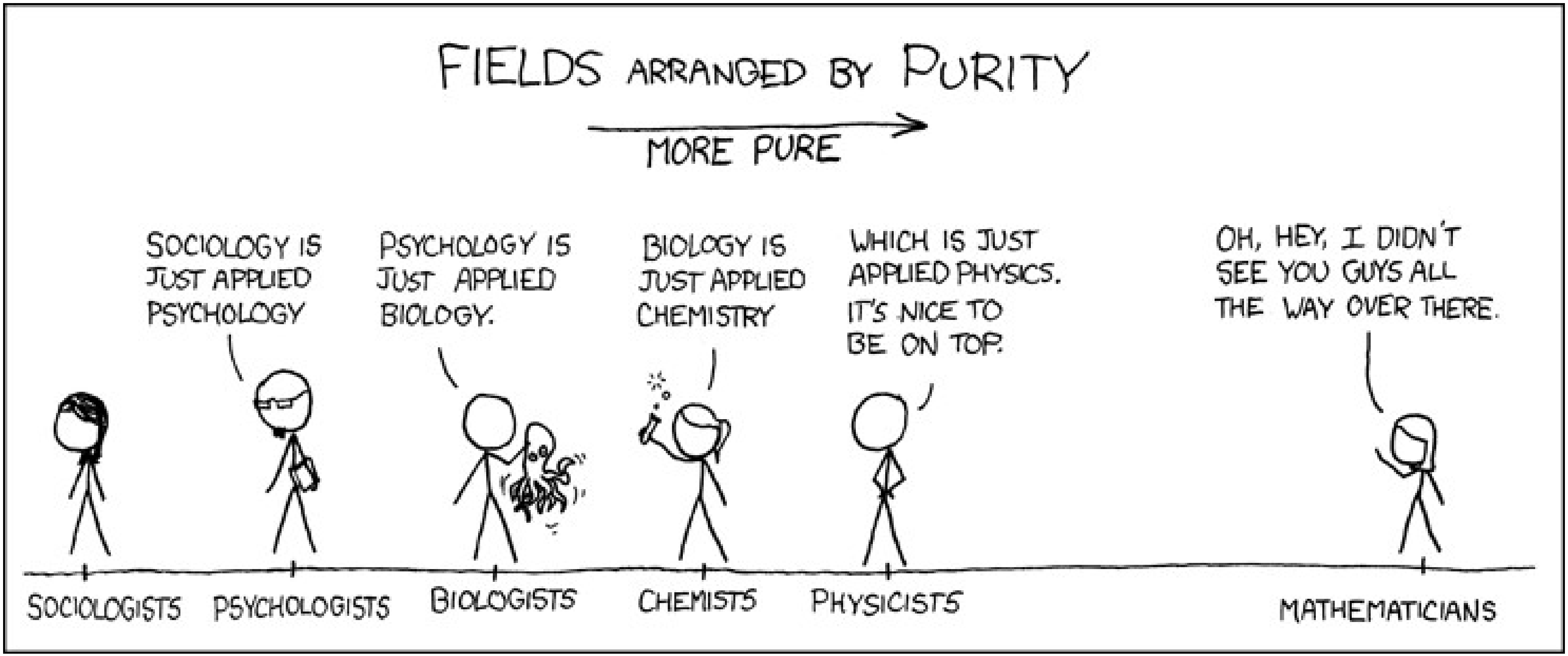
Basic or applied science?

BASIC AND APPLIED SCIENCE

- Basic Science seeks to expand knowledge
- Aim is to satisfy human thought



- Applied Science uses basic science to solve real-world problems.
- Researchers utilize widespread information – theories and hypothesis of basic science to arrive at a solution



https://xkcd.com/435/

The use of basic science

C.H. Llewellyn Smith

https://bit.ly/2CtWzvz

RIP: The Basic/Applied Research Dichotomy

Venkatesh Narayanamurti, Tolu Odumosu, Lee Vinsel

https://bit.ly/2TbNpcx

Why the distinction between basic (theoretical) and applied (practical) research is important in the politics of science

Nils Roll-Hansen

https://bit.ly/2CsvOb0

MICROBIOLOGY

*As a **basic biological science**, microbiology uses microbial cells to probe the fundamental processes of life*

MICROBIOLOGY

As a ***basic biological science****, microbiology uses microbial cells to probe the fundamental processes of life*

As an ***applied biological science****, microbiology is at the forefront of many important breakthroughs in human and veterinary medicine, agriculture, and industry*

Microbiology

Marine Microbiology

Environmental Microbiology

Microbial Ecology

Geomicrobiology

THE DISCOVERY OF MICROORGANISMS

The existence of creatures too small to be seen with the naked eye had been suspected and speculated for centuries.

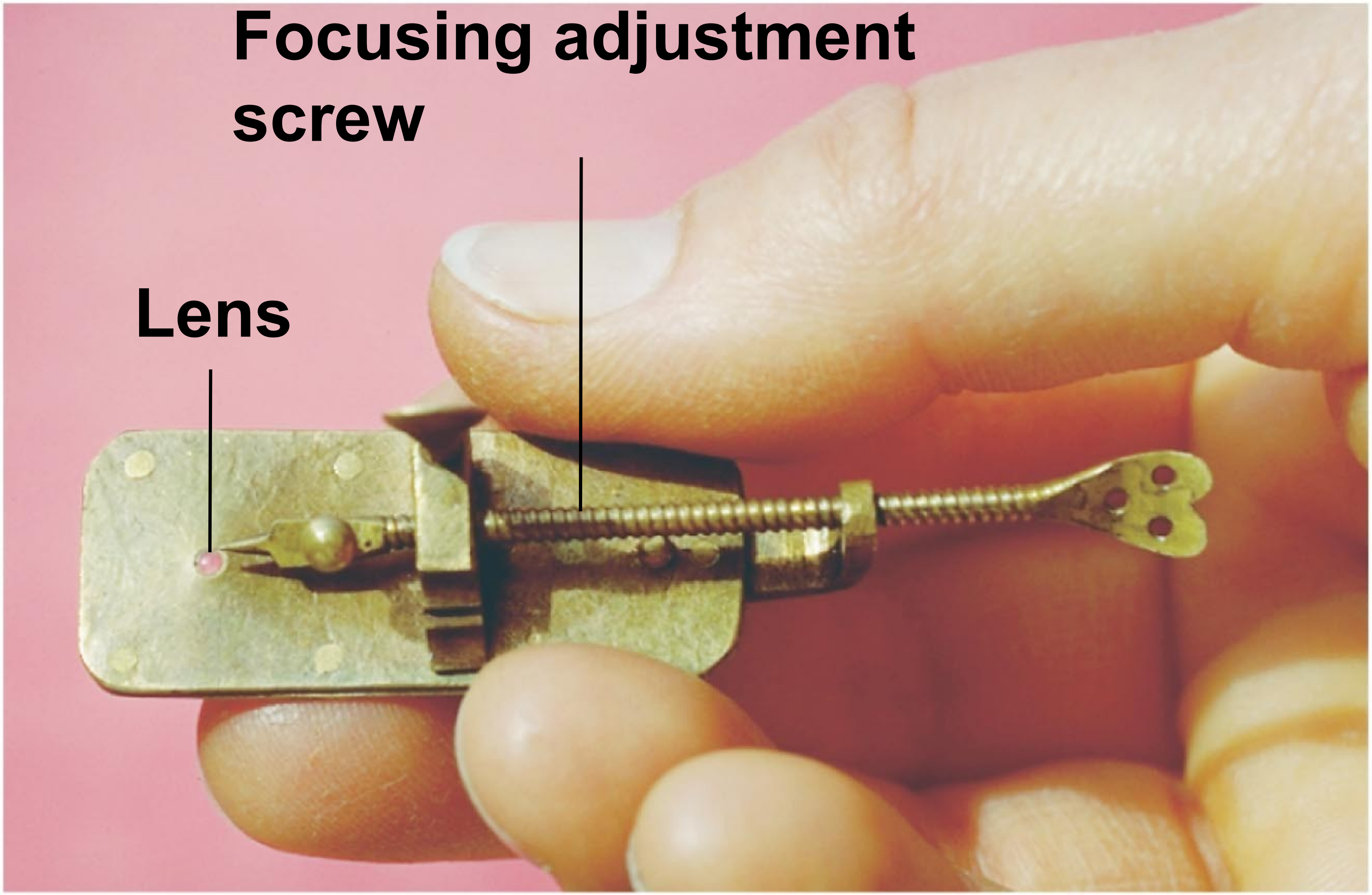
The English mathematician and natural historian Robert Hooke (1635–1703) described a series of microscopic observation in his famous book Micrographia (1665).

These included, among many other things, the fruiting structures of molds. This was the first known description of microorganisms.

Antoni van Leeuwenhoek

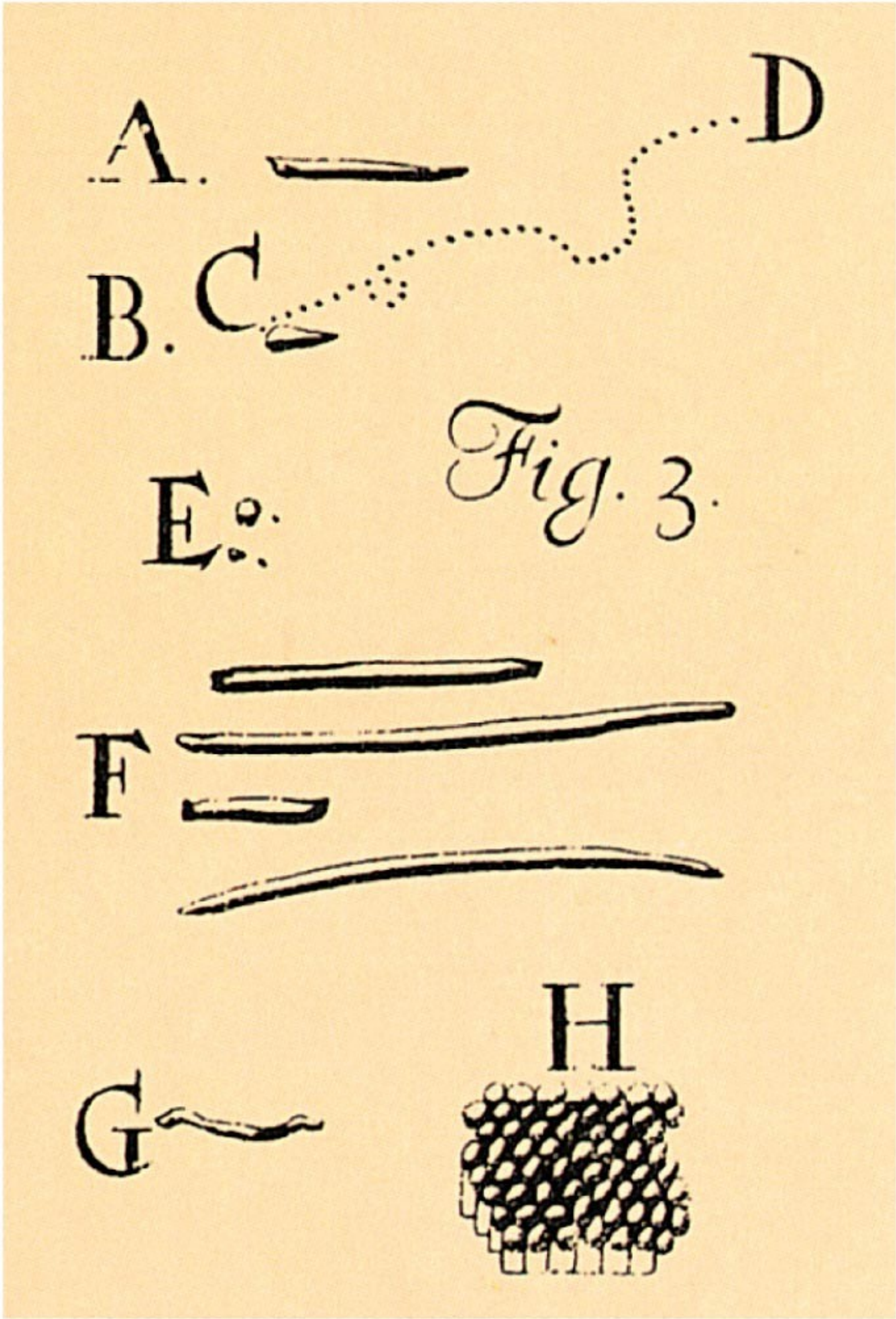
Antoni van Leeuwenhoek (1632–1723), a Dutch draper and amateur microscopist, discovered bacteria in 1676 while studying pepper–water infusions, and reported his observations in a series of letters to the prestigious Royal Society of London, which published them in English translation in 1684.

He referred to them as “wee animalcules”.



T. D. Brock

(a)



(b)

A (very) Brief History of Microbiology

1665 – Hooke – Discovery of microorganisms
1676 – Van Leeuwenhoek – First bacteria observation
1768 – Spallanzani – Disproved Spontaneous Generation
1866 – Cohn – Beggiatoa sulfur granules
1876 – Kock – Koch's postulates
1880 – Pasteur – The germ theory and first vaccine
1881 – Winogradsky – Chemolithoautotrophy
1884 – Gram – Gram Staining
1916 – Vernadsky – The Biosphere concept
1929 – Fleming – Pennicillin
1977 – Woese – Discover the Archaea
1977 – Ballard – Discovery of Hydrothermal Vent

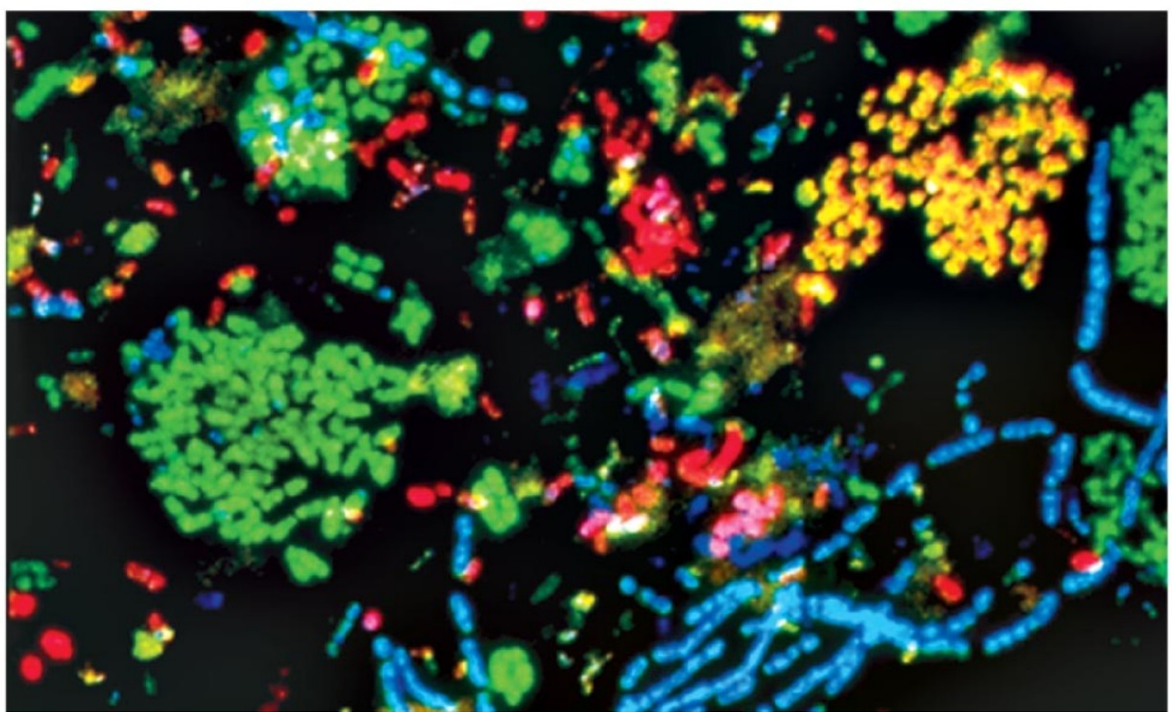
https://goo.gl/SMoyHc

PROKARYOTES: BACTERIA AND ARCHAEA

Prokaryotes include the Bacteria and the Archaea and consist of small and structurally rather simple cells.

The word "prokaryote" does not imply evolutionary relatedness. Archaea and Bacteria are two distinct domain of life, similarly to Bacteria and Eukarya

(b)



Bacteria: medical and environmental relevance

Not all bacteria are bad!

About >16,000 bacterial species are known today (>150,000 if we include uncultured).

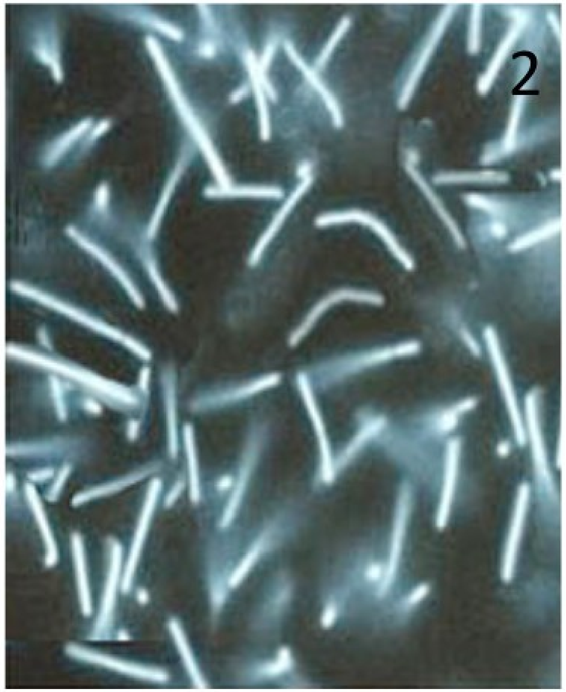
538 are known pathogens or facultative pathogens (~0.36%)

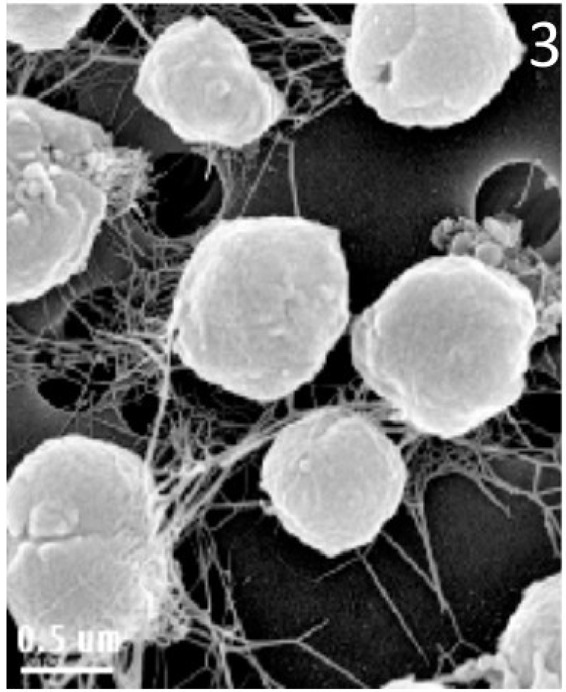
Table 28.4 Reportable infectious agents and diseases in the United States, 2013

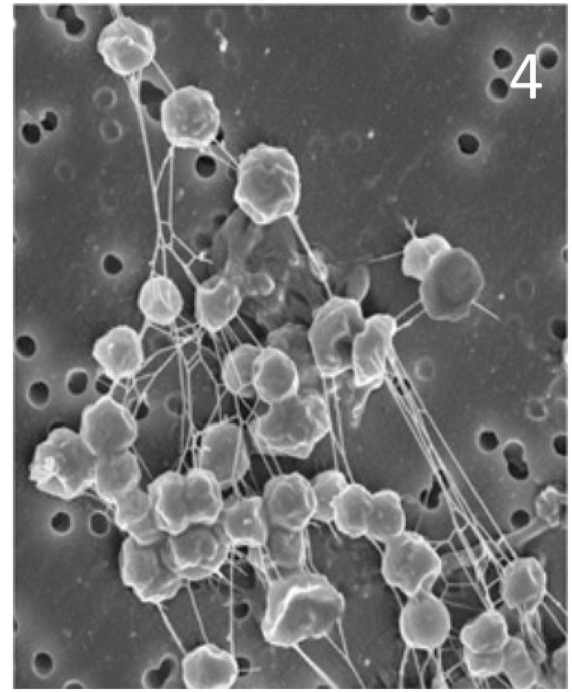
Diseases caused by *Bacteria*

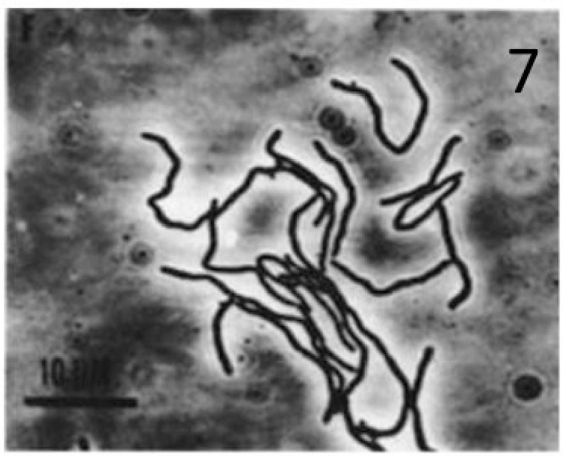
- Anthrax
- Botulism
- Brucellosis
- Chancroid
- *Chlamydia trachomatis* infection
- Cholera
- Diphtheria
- Ehrlichiosis/Anaplasmosis
- Gonorrhea
- *Haemophilus influenzae*, invasive disease
- Hansen's disease (leprosy)
- Hemolytic uremic syndrome
- Legionellosis
- Listeriosis
- Lyme disease
- Meningococcal disease (*Neisseria meningitidis*)
- Pertussis
- Plague
- Psittacosis
- Q fever
- Salmonellosis
- Shiga toxin–producing *Escherichia coli* (STEC)
- Shigellosis
- Spotted fever rickettsiosis
- Streptococcal toxic shock syndrome
- *Streptococcus pneumoniae*, invasive disease
- Syphilis, all stages
- Tetanus
- Toxic shock syndrome (staphylococcal)
- Tuberculosis
- Tularemia
- Typhoid fever
- Vancomycin-intermediate *Staphylococcus aureus* (VISA)
- Vancomycin-resistant *Staphylococcus aureus* (VRSA)
- Vibriosis (non-cholera *Vibrio* infections)

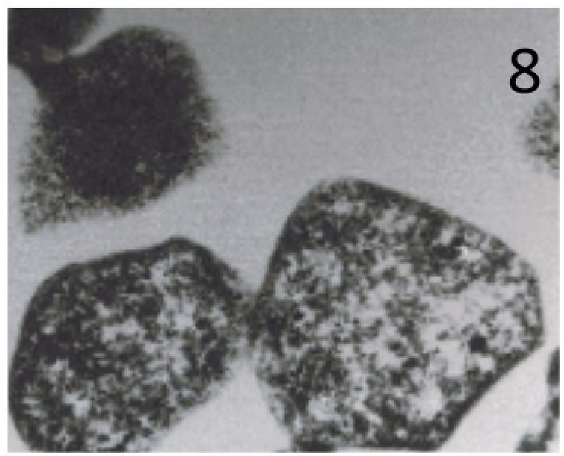
The discovery of Archaea

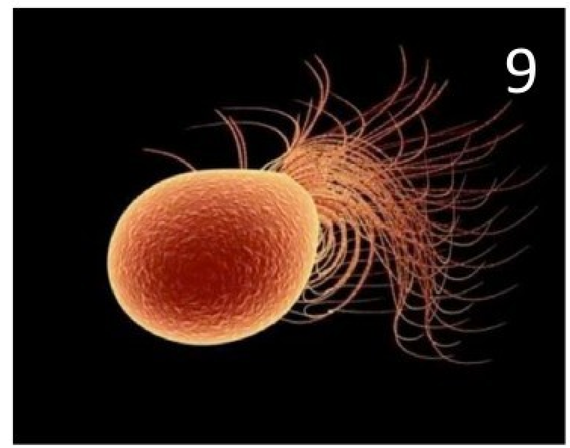












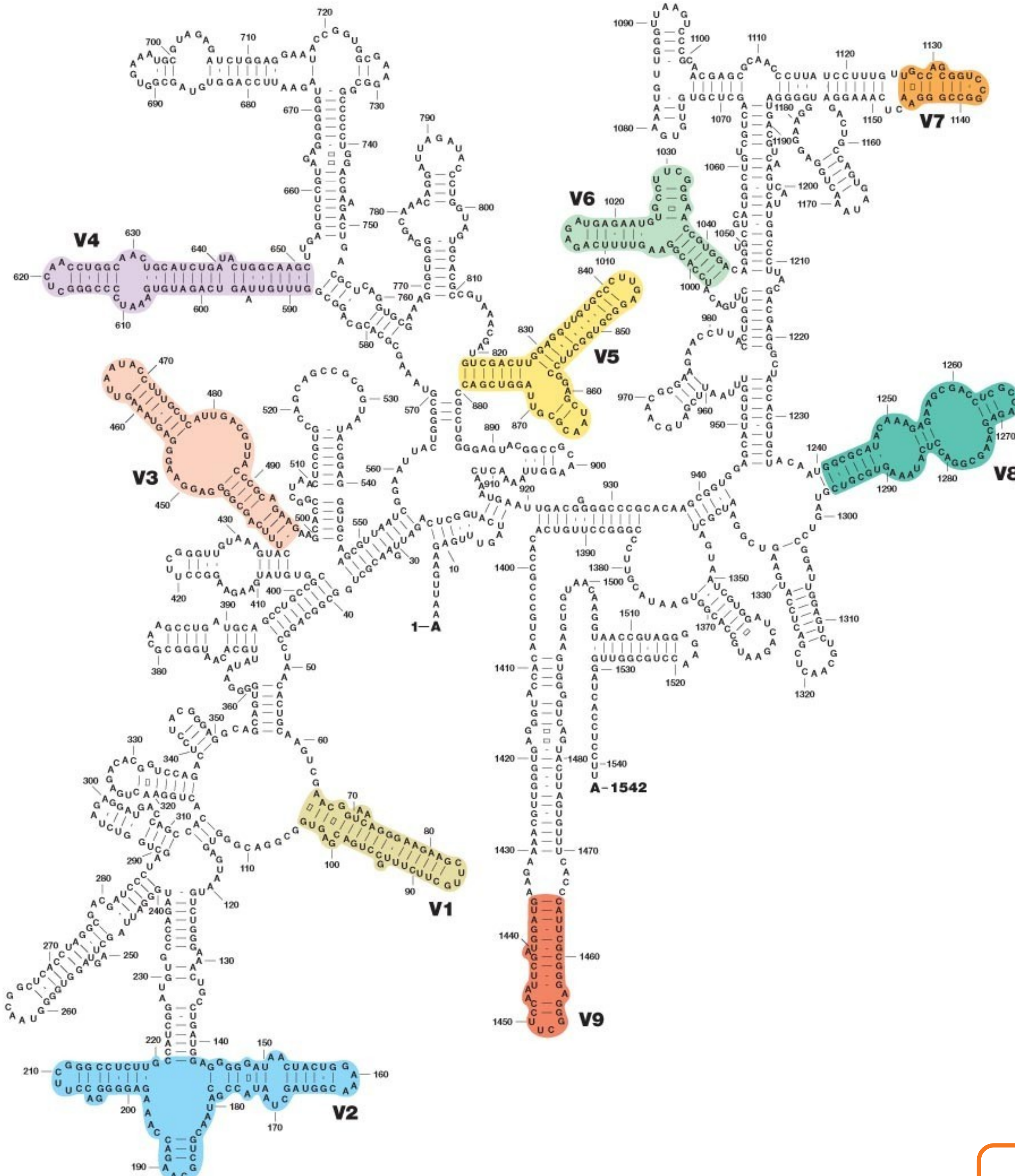
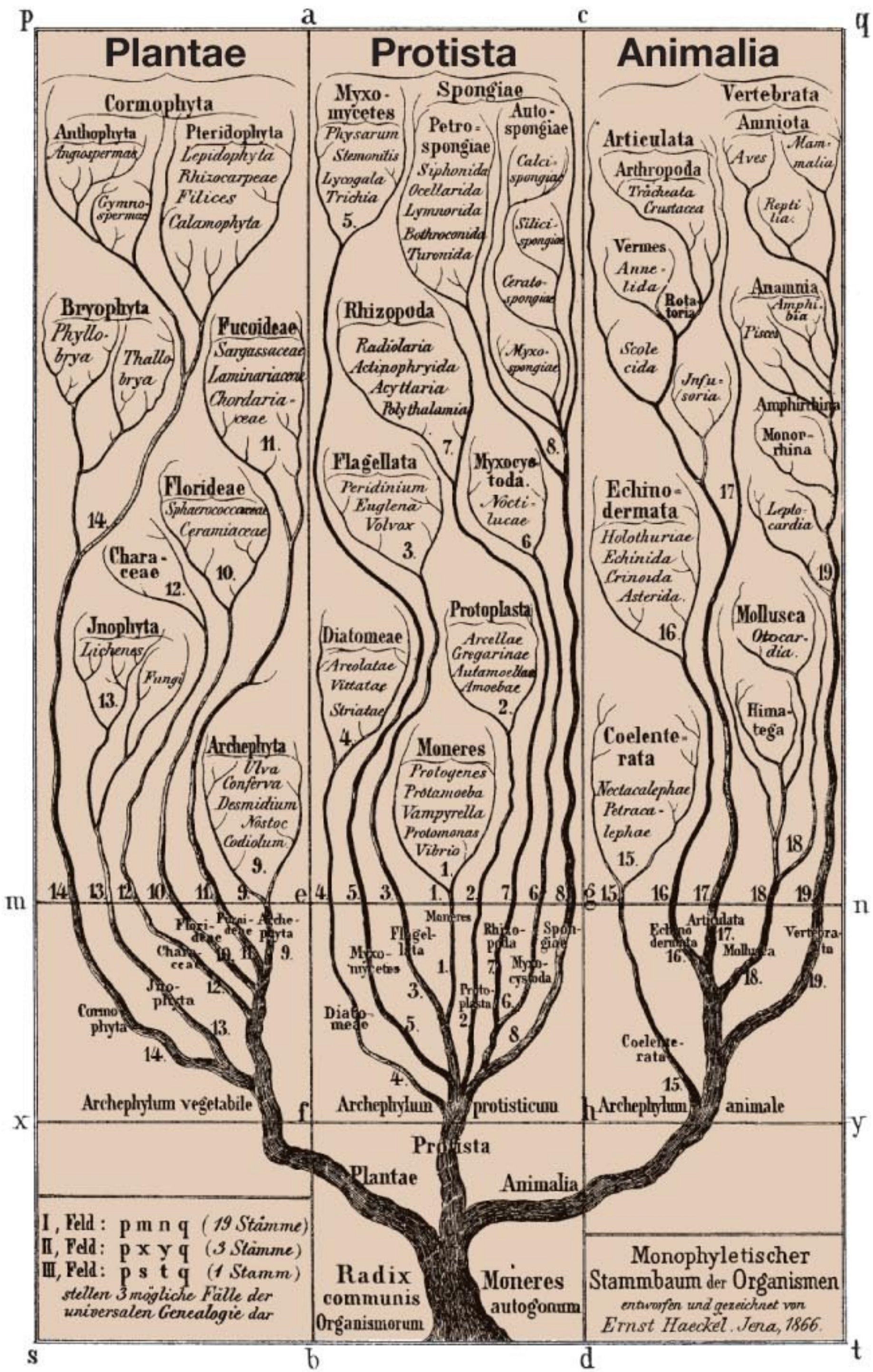
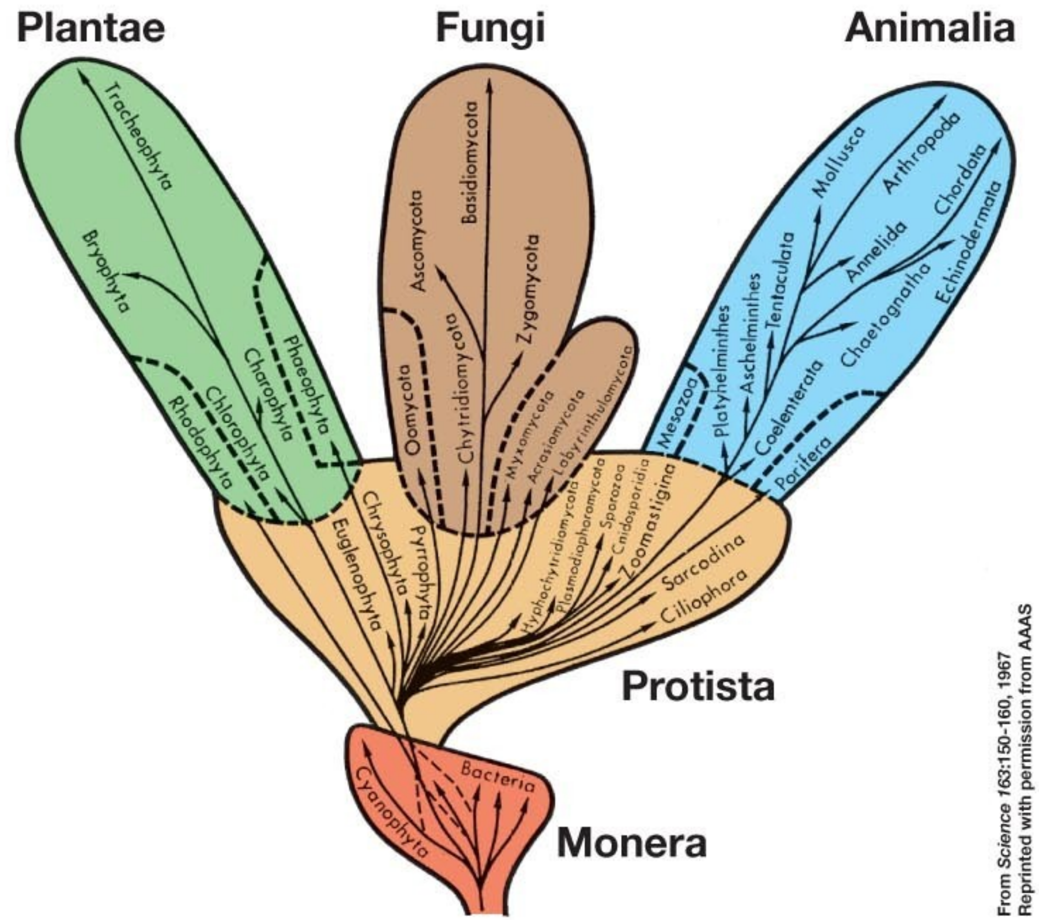


Figure 12.12

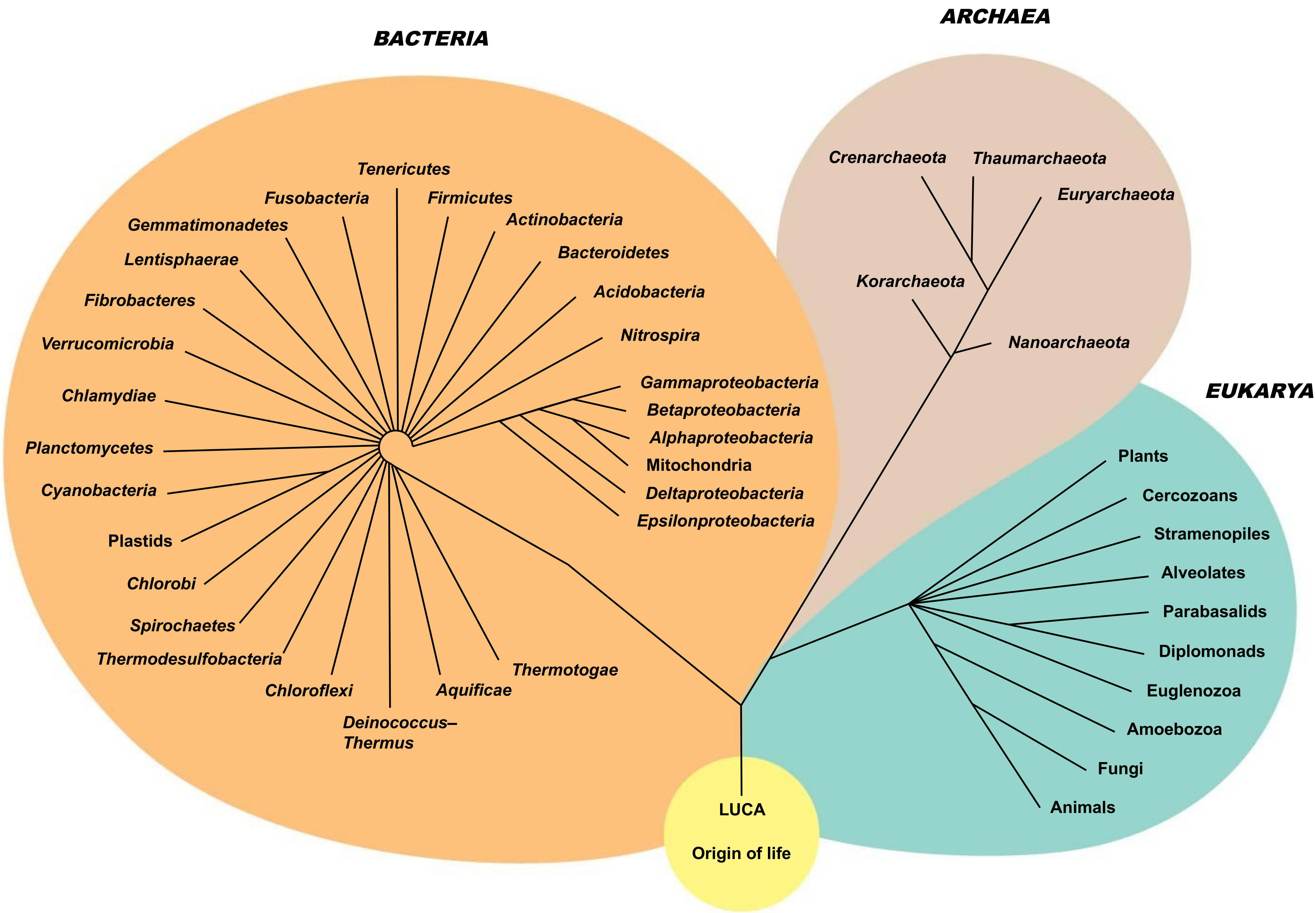


(a) **The Haeckel Tree**



(b) **The Whittaker Tree**

Early efforts to depict the universal tree of life. (a) Tree of life published in 1866 by Ernst Haeckel in Generelle Morphologie der Organismen. (b) Tree of life published by Robert H. Whittaker in 1969. The terms “Monera” and “Moneres” are antiquated terms used to refer to prokaryotic cells.



BACTERIA
ARCHAEA
EUKARYA
Tenericutes
Fusobacteria
Firmicutes
Gemmatimonadetes
Actinobacteria
Lentisphaerae
Bacteroidetes
Fibrobacteres
Acidobacteria
Verrucomicrobia
Nitrospira
Chlamydiae
Gammaproteobacteria
Betaproteobacteria
Alphaproteobacteria
Planctomycetes
Mitochondria
Cyanobacteria
Deltaproteobacteria
Epsilonproteobacteria
Plastids
Chlorobi
Spirochaetes
Thermodesulfobacteria
Thermotogae
Chloroflexi
Aquificae
Deinococcus–Thermus
Crenarchaeota
Thaumarchaeota
Euryarchaeota
Korarchaeota
Nanoarchaeota
Plants
Cercozoans
Stramenopiles
Alveolates
Parabasalids
Diplomonads
Euglenozoa
Amoebozoa
Fungi
Animals
LUCA
Origin of life

Shared Similarities

Table 12.1 Major structural and physiological characteristics of Bacteria, Archaea, and Eukarya[a]

Characteristic	Bacteria	Archaea	Eukarya
Morphological			
Prokaryotic cell structure	Yes	Yes	No
Cell wall	Peptidoglycan present	No peptidoglycan	No peptidoglycan
Membrane lipids	Ester-linked	Ether-linked	Ester-linked
Membrane-enclosed nucleus	Absent	Absent	Present
Flagella mechanism	Rotation	Rotation	Whiplike
Sensitivity to chloramphenicol, streptomycin, kanamycin, and penicillin	Yes	No	No
Physiological/special structures			
Dissimilative reduction of S^0 or SO_4^{2-} to H_2S, or Fe^{3+} to Fe^{2+}	Yes	Yes	No
Nitrification (ammonia oxidation)	Yes	Yes	No
Chlorophyll-based photosynthesis	Yes	No	Yes (in chloroplasts)
Denitrification	Yes	Yes	No
Nitrogen fixation	Yes	Yes	No
Rhodopsin-based energy metabolism	Yes	Yes	No
Chemolithotrophy (Fe^{2+}, NH_3, S^0, H_2)	Yes	Yes	No
Endospores	Yes	No	No
Gas vesicles	Yes	Yes	No
Storage granules of poly-β-hydroxyalkanoates	Yes	Yes	No
Growth above 70°C	Yes	Yes	No
Growth above 100°C	No	Yes	No

[a]Note that for many features, only particular representatives within a domain show the property.

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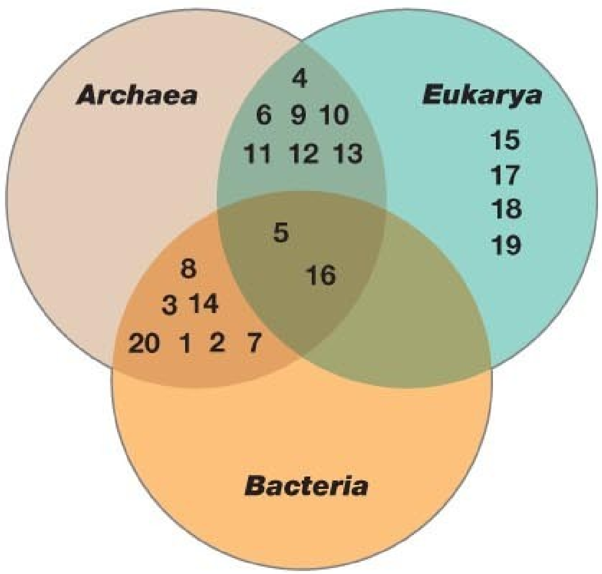
Shared Similarities

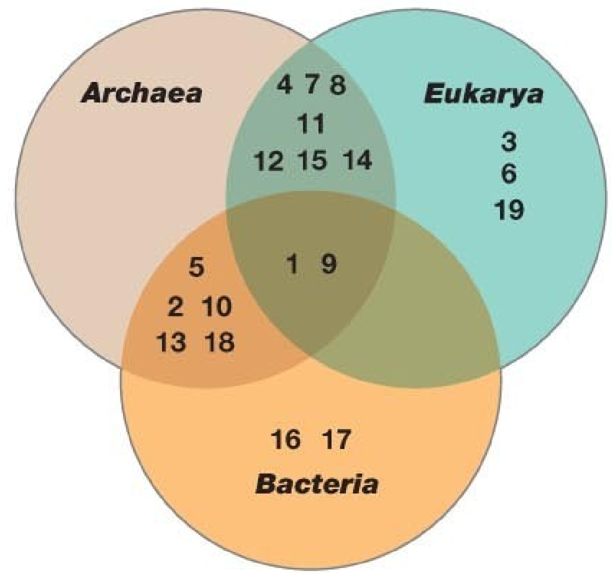
Genome



1 Chromosome circular versus linear
2 Single chromosome versus multiple chromosomes
3 Introns rare
4 Archaeal-type introns
5 Inteins
6 Histones
7 DNA gyrase
8 Reverse gyrase
9 Multiple chromosomal origins
10 Eukaryotic origin recognition complex
11 Eukaryotic-type helicase
12 B family DNA polymerase is major replicative enzyme
13 Eukaryotic-type sliding clamp
14 Restriction enzymes
15 RNAi
16 Genome of double-stranded DNA
17 Multiple retroelements in genome
18 Centromeres
19 Telomeres and telomerase
20 Genes organized into operons

(a)

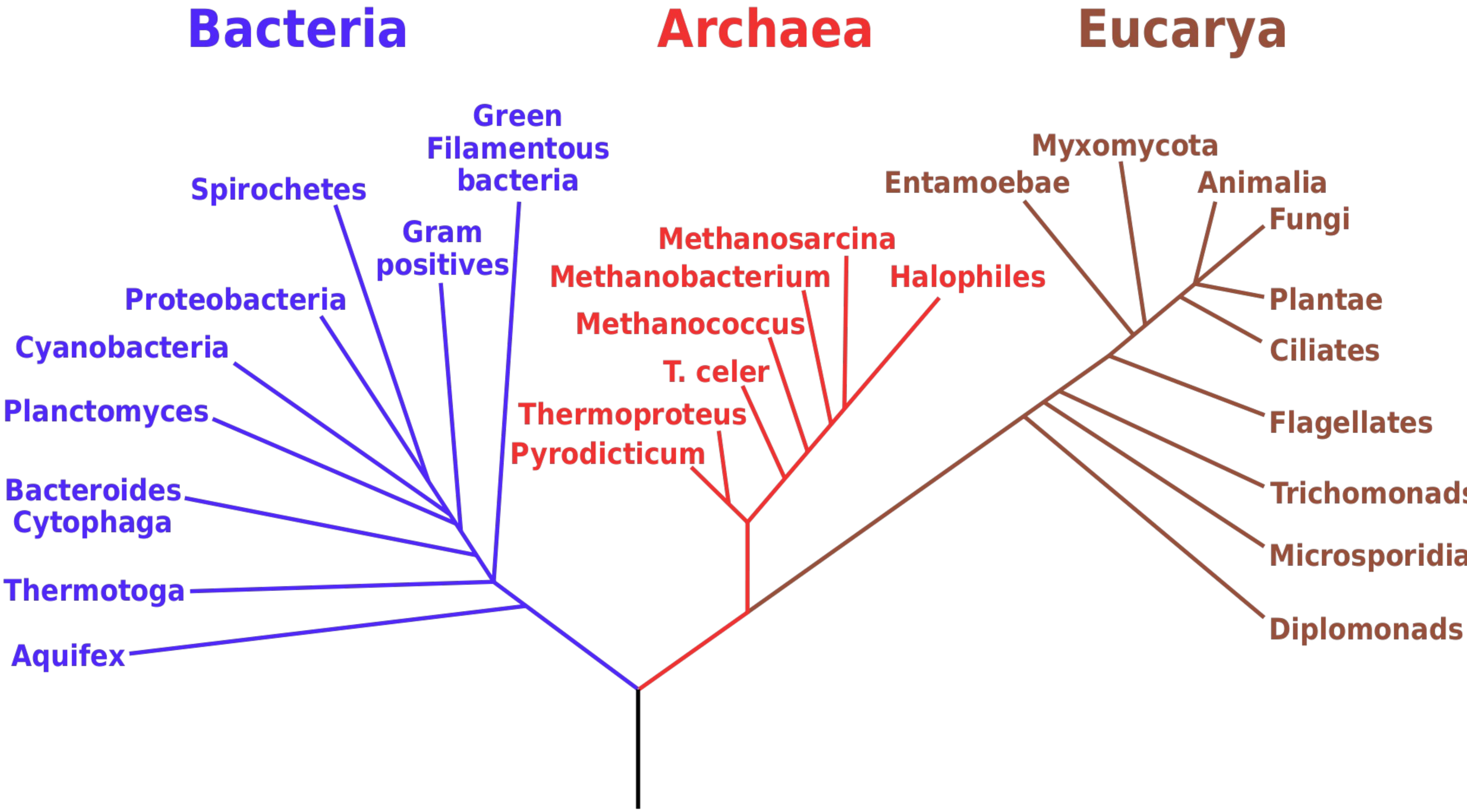
Transcription and Translation

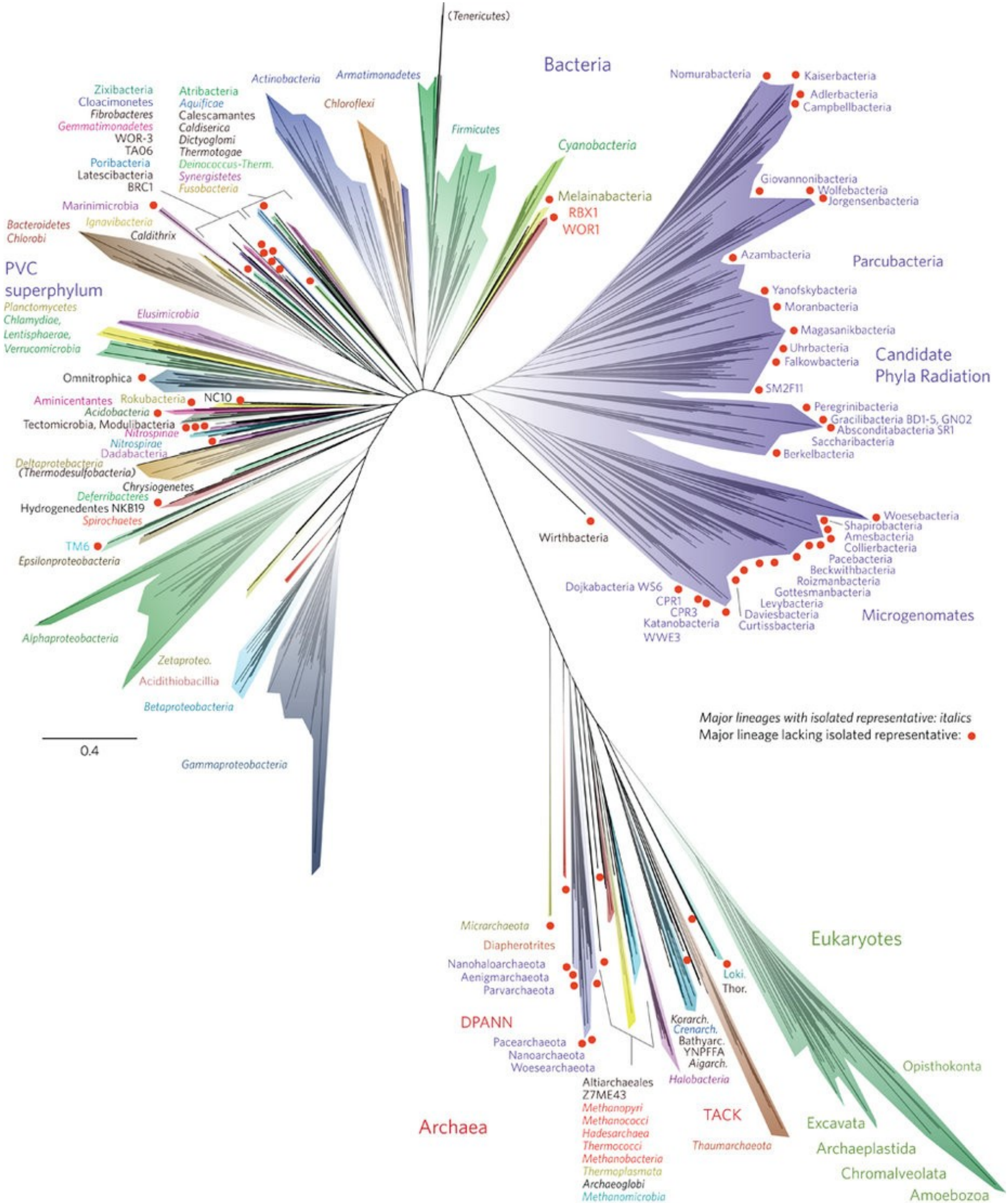


1 RNA used as a genetic messenger
2 Polycistronic mRNA
3 Cap and tail on mRNA
4 TATA box and BRE sequence in promoter
5 Repressors binding directly to DNA in promoter
6 Multiple RNA polymerases
7 RNA polymerase II with 8 or more subunits
8 Multiple transcription factors needed
9 Ribosomes synthesize proteins
10 70S versus 80S ribosomes
11 Ribosomal RNA sequence homologies
12 Ribosomal protein sequence homologies
13 Shine–Dalgarno sequences
14 Multiple translation factors
15 Elongation factor sensitive to diphtheria toxin
16 *N*-Formylmethionine versus methionine
17 tmRNA rescues stalled ribosomes
18 16S and 23S rRNA
19 18S, 28S, and 5.8S rRNA

(b)

Phylogenetic Tree of Life



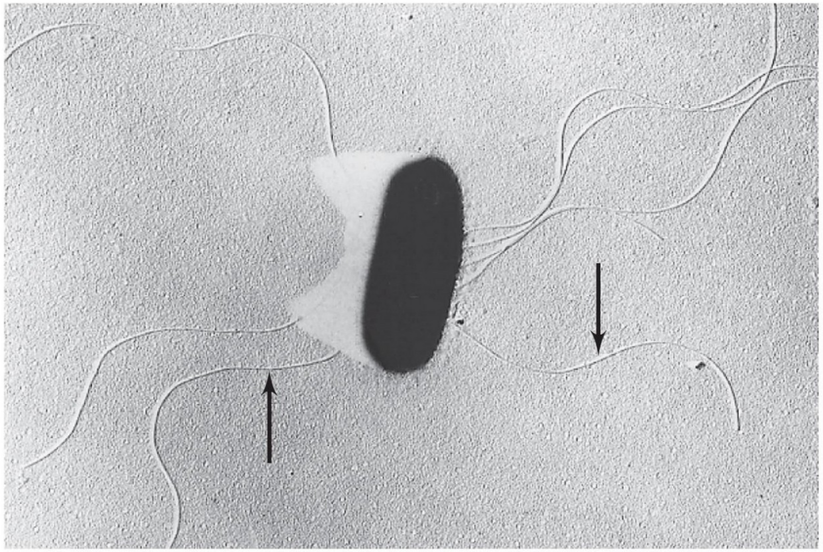


Hug et al 2016, Nat Microbiol

TAXONOMY

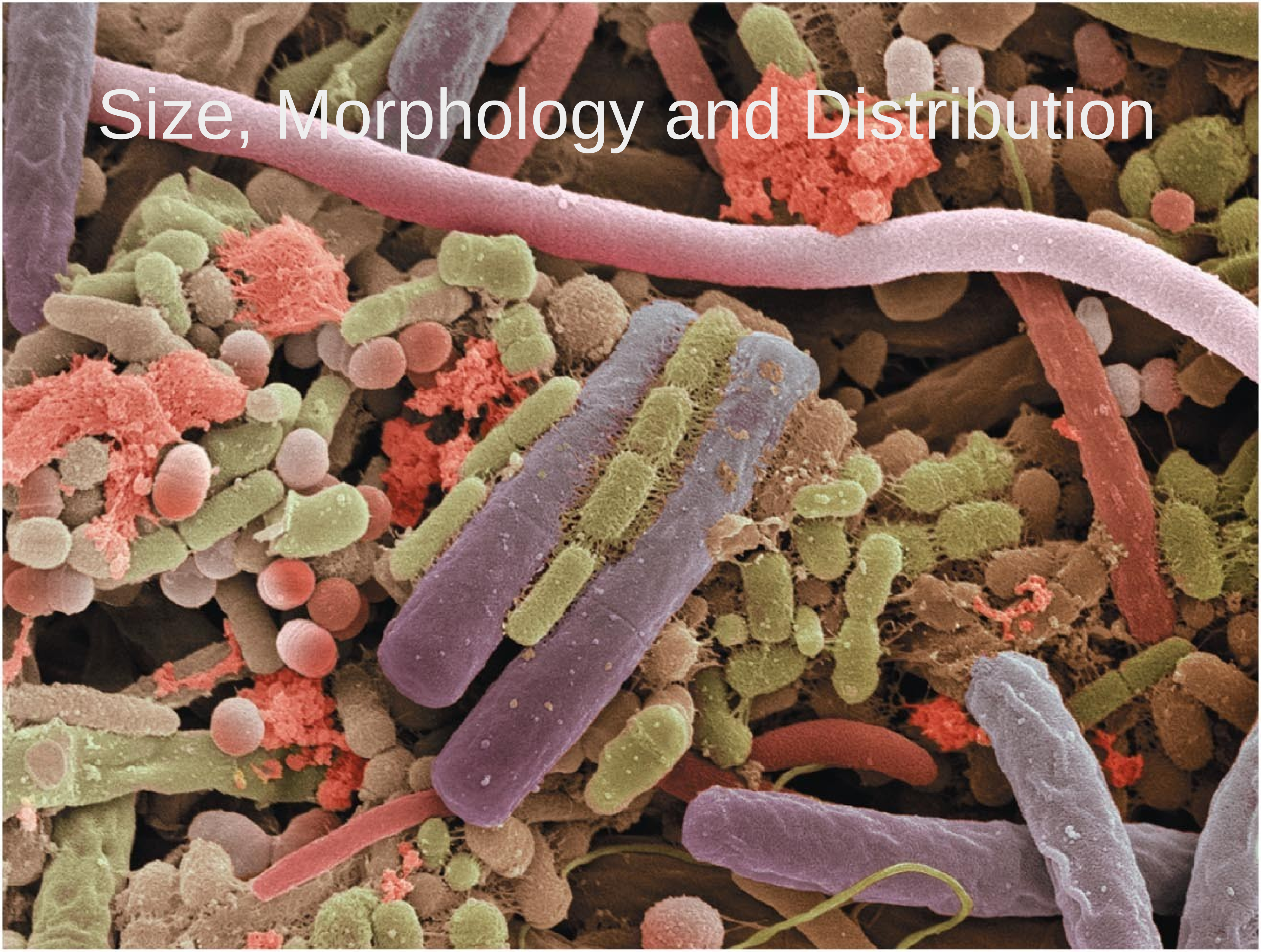
Taxonomic nomenclature follows the binomial systems. There are numerous rules and conventions, all established by the International Committee on the Systematics of Prokaryotes.

Domain:	*Bacteria*
Phylum:	*Proteobacteria*
Class:	*Gammaproteobacteria*
Order:	*Enterobacterales*
Family:	*Enterobacteraceae*
Genus:	*Escherichia*
Species:	*Escherichia coli*
Strain:	*K12*



Arthur Kelman

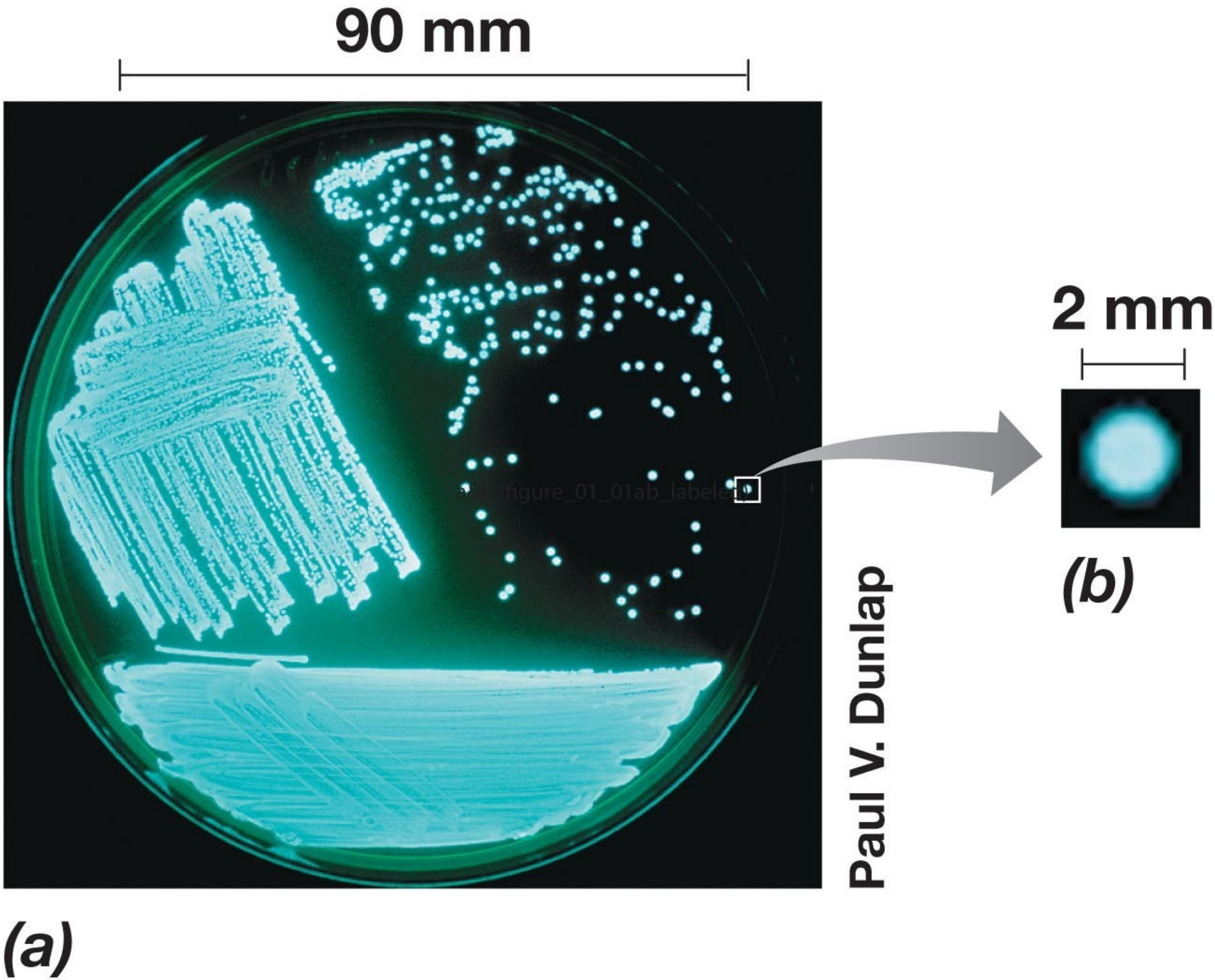
Size, Morphology and Distribution

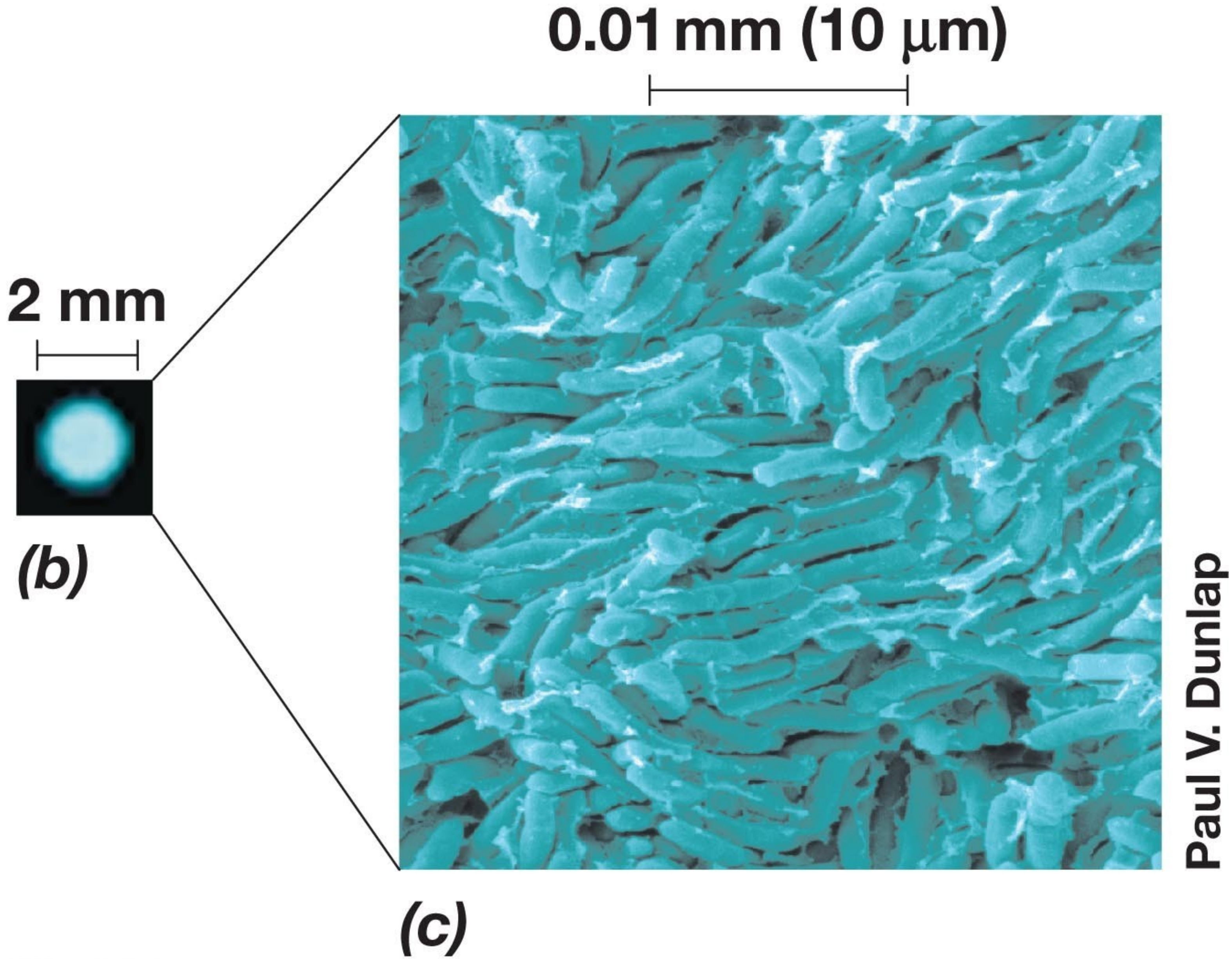


Size, Morphology and Distribution

Although cell morphology is easily determined, it is a poor predictor of other properties of a cell. For example, under the microscope many rod-shaped Archaea look identical to rod-shaped Bacteria, yet we know they are of different phylogenetic domains.

Prokaryotes vary in size from cells as small as about 0.2 µm in diameter to those more than 700 µm in diameter. The vast majority of rod-shaped prokaryotes that have been cultured are between 0.5 and 4 µm wide and less than 15 µm long.


90 mm
2 mm
(b)
Paul V. Dunlap
(a)



2 mm
(b)
0.01 mm (10 μm)
(c)
Paul V. Dunlap

Size Variation Among Bacteria

Table 2.1 Cell size and volume of some cells of *Bacteria*, from the largest to the smallest

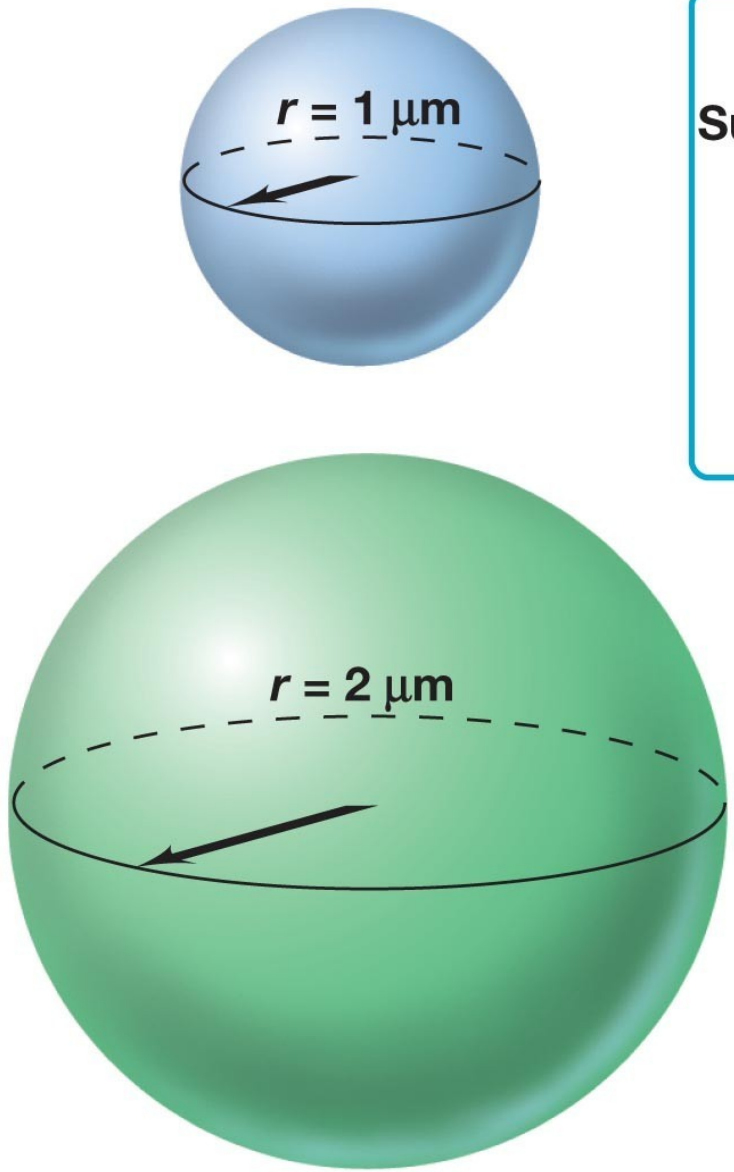
Organism	*Characteristics*	*Morphology*	*Size*[a] *(μm)*	*Cell volume (μm^3)*	E. coli *volumes*
Thiomargarita namibiensis	Sulfur chemolithotroph	Cocci in chains	750	200,000,000	100,000,000
Epulopiscium fishelsoni[a]	Chemoorganotroph	Rods with tapered ends	80 × 600	3,000,000	1,500,000
Beggiatoa species[a]	Sulfur chemolithotroph	Filaments	50 × 160	1,000,000	500,000
Achromatium oxaliferum	Sulfur chemolithotroph	Cocci	35 × 95	80,000	40,000
Lyngbya majuscula	Cyanobacterium	Filaments	8 × 80	40,000	20,000
Thiovulum majus	Sulfur chemolithotroph	Cocci	18	3,000	1,500
Staphylothermus marinus[a]	Hyperthermophile	Cocci in irregular clusters	15	1,800	900
Magnetobacterium bavaricum	Magnetotactic bacterium	Rods	2 × 10	30	15
Escherichia coli	Chemoorganotroph	Rods	1 × 2	2	1
Pelagibacter ubique[a]	Marine chemoorganotroph	Rods	0.2 × 0.5	0.014	0.007
Mycoplasma pneumoniae	Pathogenic bacterium	Pleomorphic[b]	0.2	0.005	0.0025

[a]Where only one number is given, this is the diameter of spherical cells. The values given are for the largest cell size observed in each species. For example, for *T. namibiensis*, an average cell is only about 200 μm in diameter. But on occasion, giant cells of 750 μm are observed. Likewise, an average cell of *S. marinus* is about 1 μm in diameter. The species of *Beggiatoa* here is unclear and *E. fishelsoni*, *Magnetobacterium bavaricum*, and *P. ubique* are not formally recognized names in taxonomy.

[b]*Mycoplasma* is a bacterium that lacks a cell wall and can thus take on many shapes (*pleomorphic* means "many shapes").

Source: Data obtained from Schulz, H.N., and B.B. Jørgensen. 2001. *Ann. Rev. Microbiol. 55*: 105–137.

Size Matters!



$r = 1\ \mu m$

Surface area ($4\pi r^2$) = 12.6 μm^2

Volume ($\frac{4}{3}\pi r^3$) = 4.2 μm^3

$$\frac{\textbf{Surface}}{\textbf{Volume}} = 3$$

$r = 2\ \mu m$

Surface area = 50.3 μm^2

Volume = 33.5 μm^3

$$\frac{\textbf{Surface}}{\textbf{Volume}} = 1.5$$

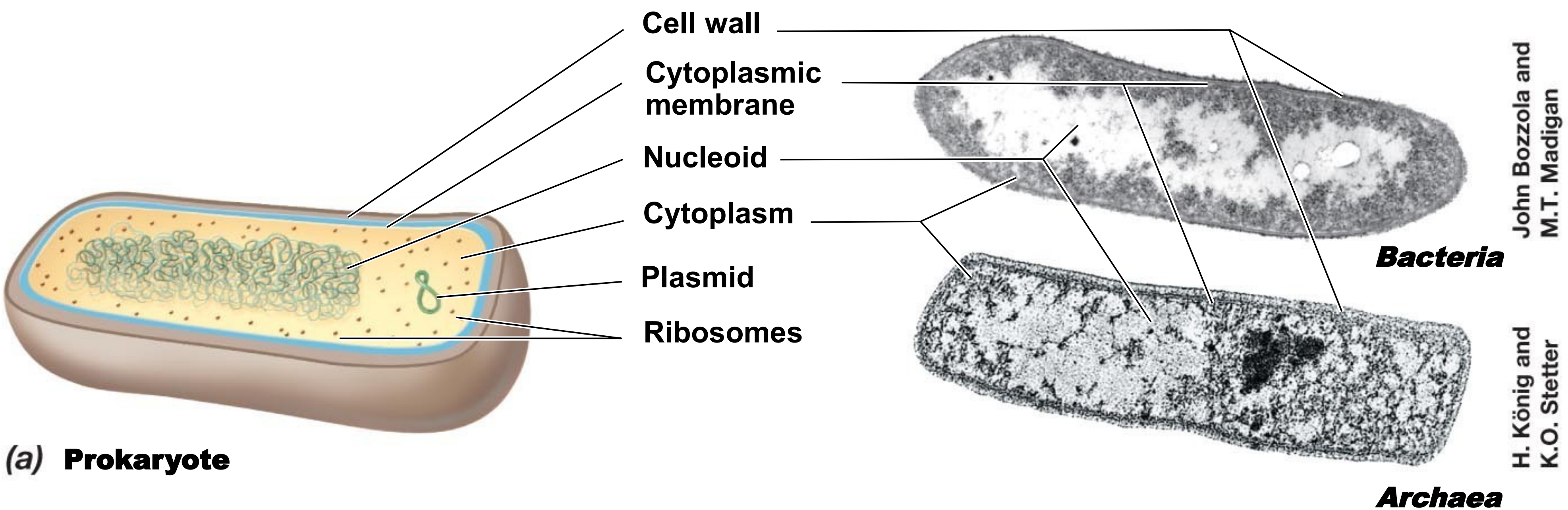
Lower Limits of Cell Size

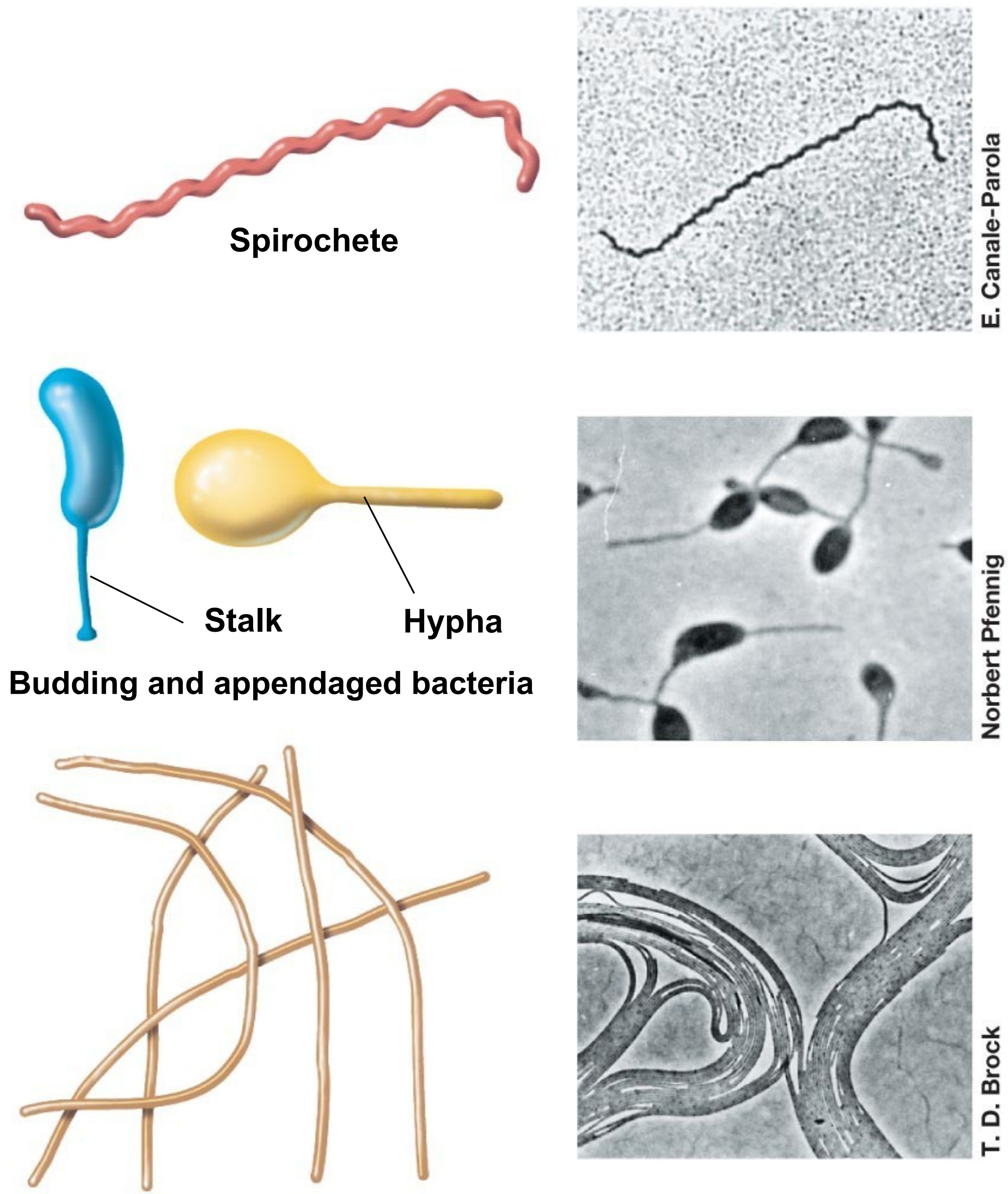
If one considers the volume needed to house the essential components of a free-living cell—proteins, nucleic acids, ribosomes, and so on—a structure 0.1 µm in diameter or less is insufficient to do the job, and structures 0.15 µm in diameter are marginal.

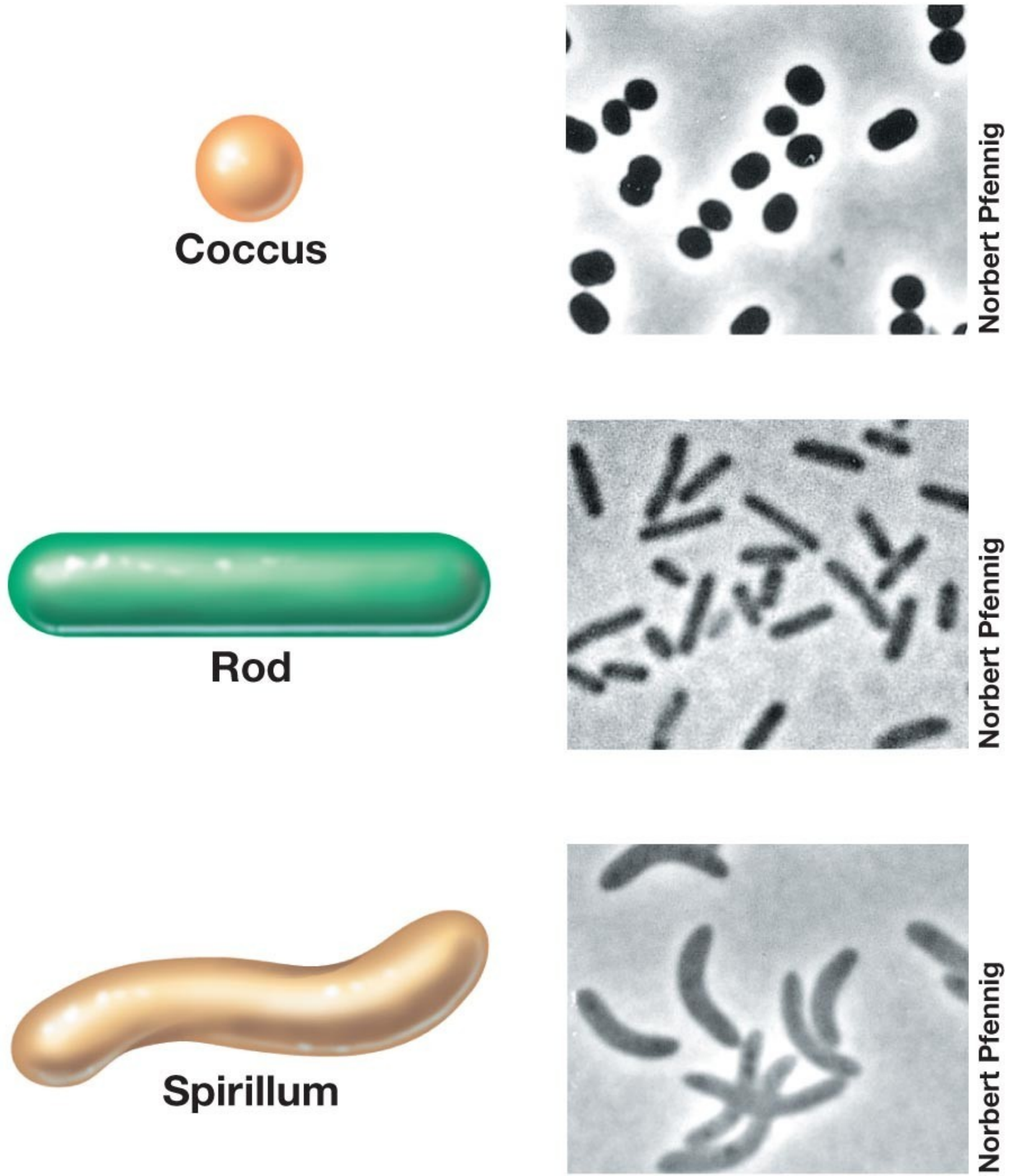
(a)

D. E. Caldwell

Prokaryotic cell structures




Spirochete
Stalk
Hypha
Budding and appendaged bacteria
E. Canale-Parola
Norbert Pfennig
T. D. Brock


Coccus
Rod
Spirillum
Norbert Pfennig
Norbert Pfennig
Norbert Pfennig

Abundance and Size

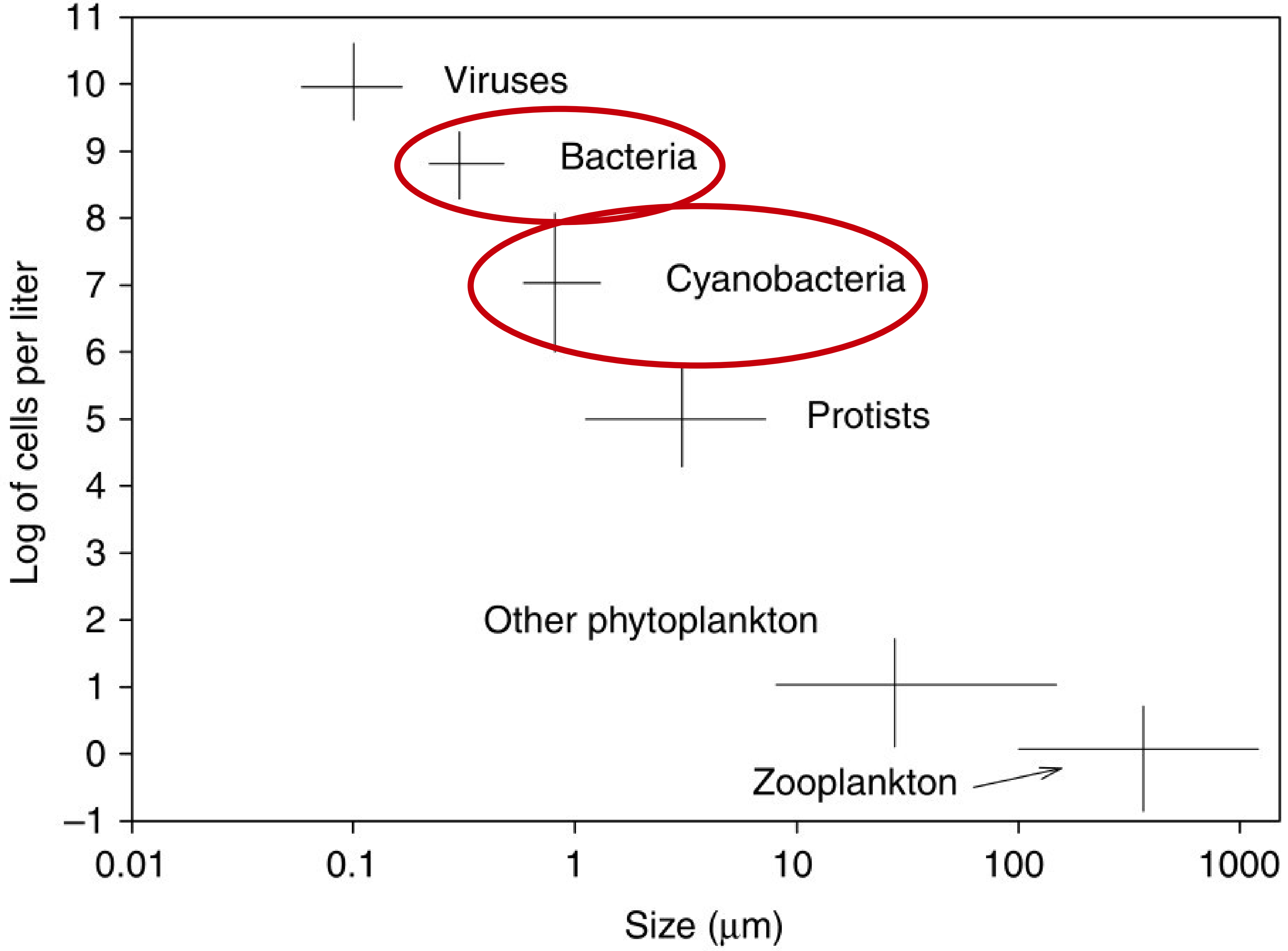


Table 1.2 Distribution of microorganisms in and on Earth[a]

Habitat	*Percent of total*
Marine subsurface	66
Terrestrial subsurface	26
Surface soil	4.8
Oceans	2.2
All other habitats[b]	1.0

[a]Data compiled by William Whitman, University of Georgia, USA; refer to total numbers (estimated to be about 2.5×10^{30} cells) of *Bacteria* and *Archaea*. This enormous number of cells contains, collectively, about 5×10^{17} grams of carbon.
[b]Includes, in order of decreasing numbers: freshwater and salt lakes, domesticated animals, sea ice, termites, humans, and domesticated birds.

This week read

All reading material and slides will be available for download on the course website provided you have registered for the class.

Llewellyn Smith, CH. 1997. **The use of basic science.** CERN Public Archive, https://bit.ly/2CtWzvz