Lecture 10

Genome organization

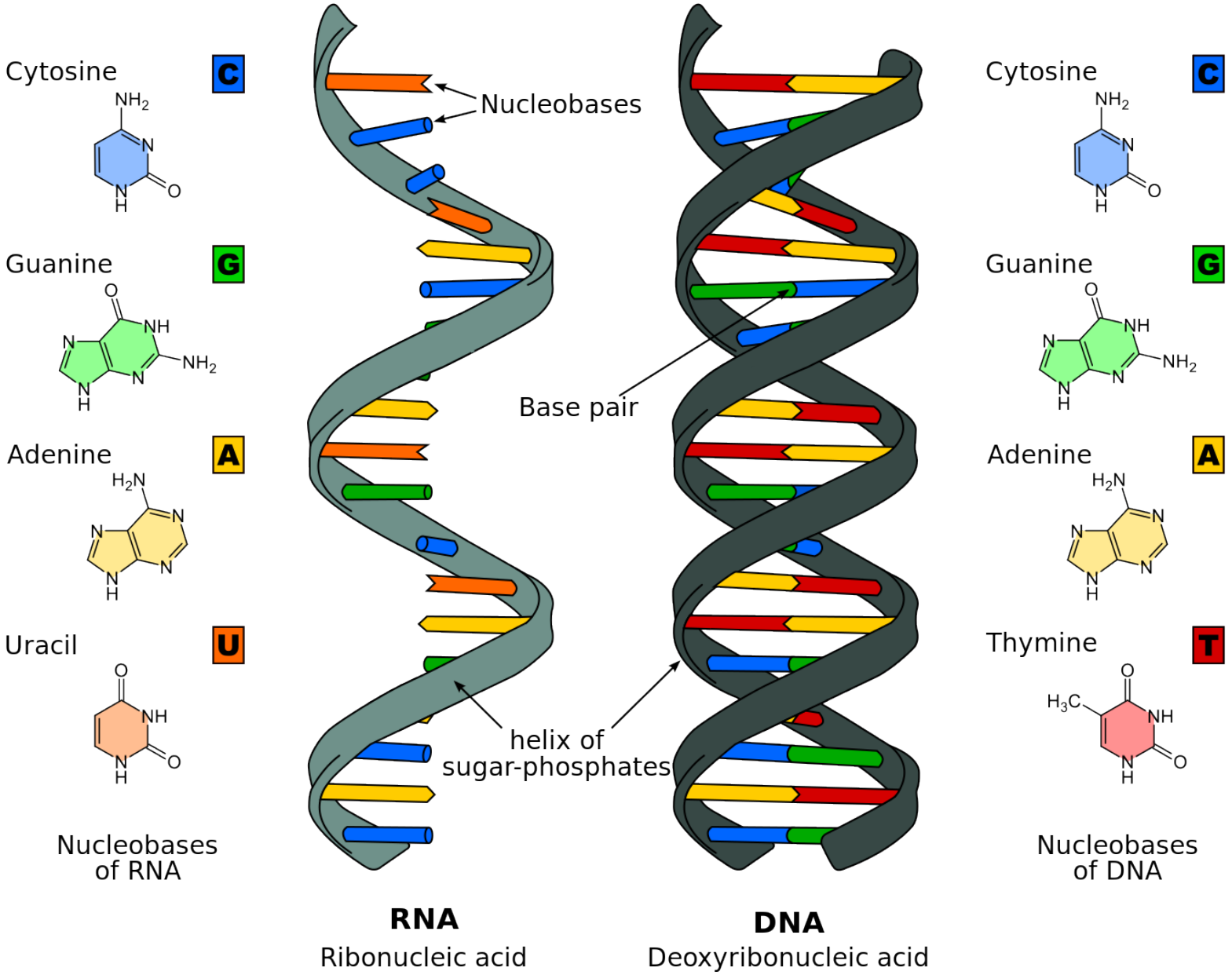
Readings (chapter 7)

Course 371

AIMS

- Introduce the genome as a concept.
- Introduce the variation in genomic structures across living forms.
- Introduce concepts related to the need of organizing genomes and biological significance.

Review


Cytosine
C
Guanine
G
Adenine
A
Uracil
U
Nucleobases of RNA
Nucleobases
Base pair
helix of sugar-phosphates
RNA
Ribonucleic acid
DNA
Deoxyribonucleic acid
Cytosine
C
Guanine
G
Adenine
A
Thymine
T
Nucleobases of DNA

Review

What are the differences between DNA and RNA?

	DNA	RNA
Sugar	deoxyribose	ribose
Bases	A, G, C, T	A, G, C, U
Strands	Double strands	Single strand
Genetic material	Most life	Some viruses
Enzymatic	None	Many with
Structure	Double helix	Linear or folded

Genome organization

What is a genome?

The entire genetic code of an organism

what does that mean?

Genome organization

How is the genetic code organized?

Thousands/ millions/ billions of nucleotide basepairs

How are they organized into a genome?

Genome organization

Genome organization differ depending on:

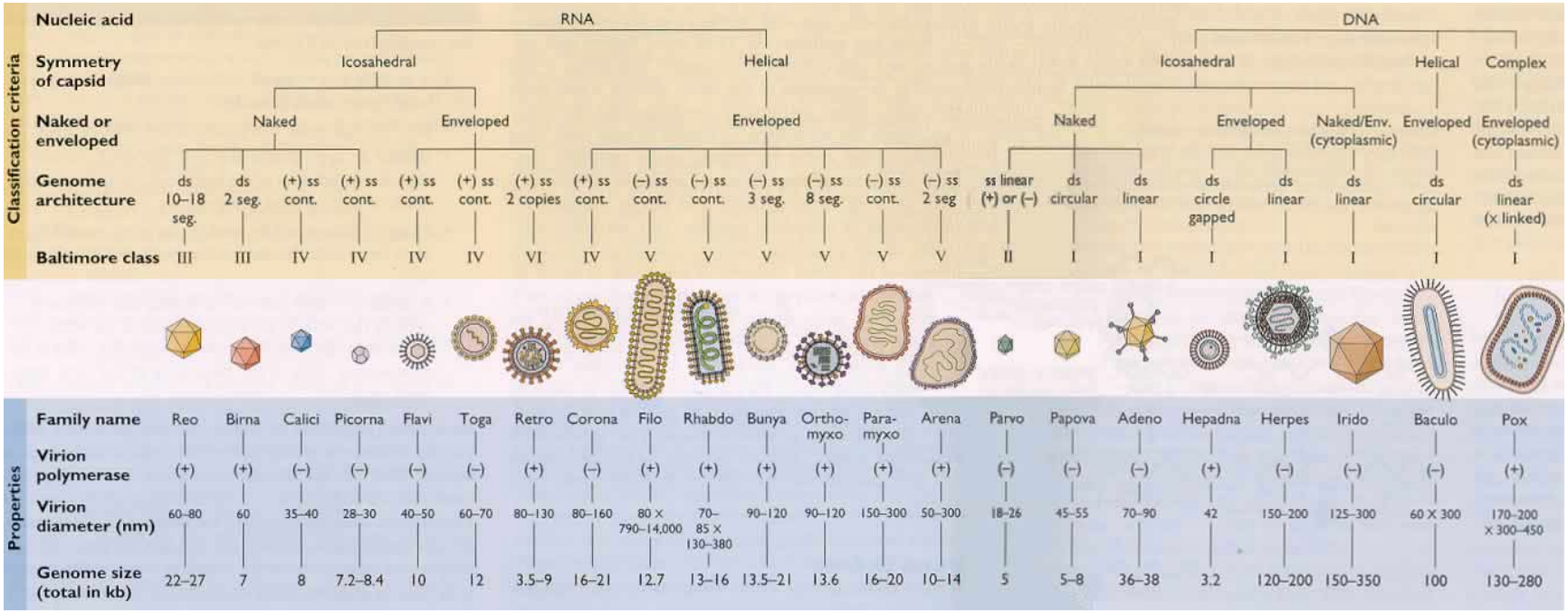
- Genome chemical identity
- Genome size
- Genome physical architecture
- Number of genome units
- Genome copy number
- taxonomic group (evolutionary history)

Genome chemical identity

The majority of life forms have a genetic material in the form of double stranded (ds) DNA.

Which organisms exhibit variation in the identity of their genomes?

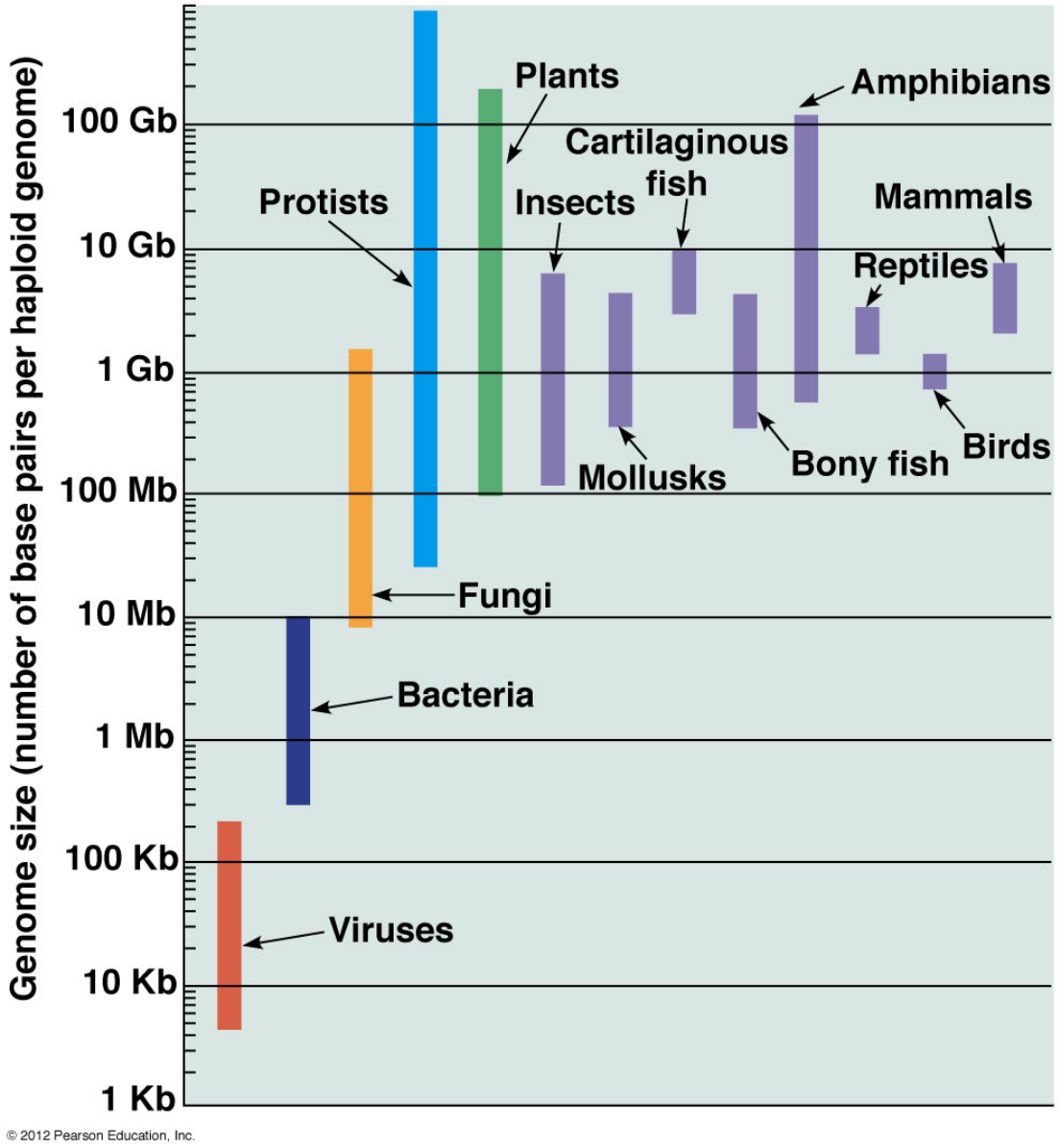
Genome chemical identity



Viruses have genomes in the form of:

- Single stranded DNA
- Single stranded RNA
- Double stranded DNA
- Double stranded RNA

Genome size



The simplicity of lower taxa is reflected in the genome size

BUT

in eukaryotes, the size of the genome is not related to organisms complexity

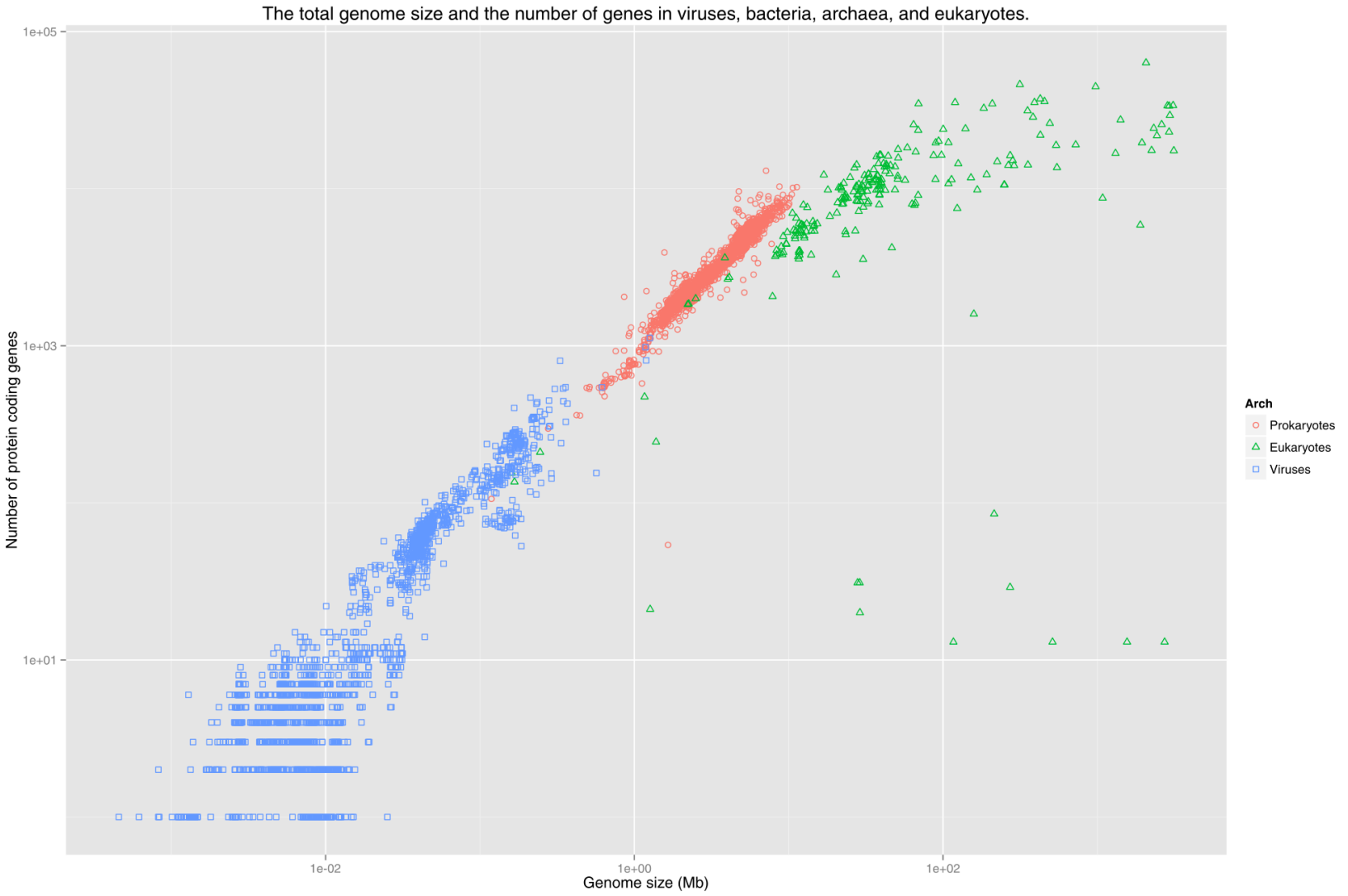
Genome size

Is the genome size a reflection of the complexity of the organism?

Do larger genomes have higher number of genes?

Genome size and gene number

Bigger genomes **do not** always have more genes



Genome size and gene number

How do calculate gene density?

TABLE 7-2 Comparison of the Gene Density in Different Organisms' Genomes

Species	Genome Size (Mb)	Approximate Number of Genes	Gene Density (Genes/Mb)
Prokaryotes (bacteria)			
Mycoplasma genitalium	0.58	500	860
Streptococcus pneumoniae	2.2	2,300	1,060
Escherichia coli K-12	4.6	4,400	950
Agrobacterium tumefaciens	5.7	5,400	960
Sinorhizobium meliloti	6.7	6,200	930
Eukaryotes (animals)			
Fungi			
Saccharomyces cerevisiae	12	5,800	480
Schizosaccharomyces pombe	12	4,900	410
Protozoa			
Tetrahymena thermophila	125	27,000	220
Invertebrates			
Caenorhabditis elegans	103	20,000	190
Drosophila melanogaster	180	14,700	82
Ciona intestinalis	160	16,000	100
Locusta migratoria	5,000	nd	nd
Vertebrates			
Fugu rubripes (pufferfish)	393	22,000	56
Homo sapiens	3,200	20,000	6.25
Mus musculus (mouse)	2,600	22,000	8.5
Plants			
Arabidopsis thaliana	120	26,500	220
Oryza sativa (rice)	430	~45,000	~100
Zea mays (corn)	2,200	>45,000	>20
Triticum aestivum (wheat)	16,000	nd	nd
Fritillaria assyriaca (tulip)	~120,000	nd	nd

nd, not determined.

Genome size and gene number

Where is the size of eukaryotic genomes coming from?

TABLE 7-3 Contribution of Introns and Repeated Sequences to Different Genomes

Species	Gene Density (Genes/Mb)	Average Number of Introns per Gene	% of Repetitive DNA
Prokaryotes (bacteria)			
Escherichia coli K-12	950	0	<1
Eukaryotes (animals)			
Fungi			
Saccharomyces cerevisiae	480	0.04	3.4
Invertebrates			
Caenorhabditis elegans	190	5	6.3
Drosophila melanogaster	82	3	12
Vertebrates			
Fugu rubripes	56	5	2.7
Homo sapiens	6.25	6	46
Plants			
Arabidopsis thaliana	220	3	nd
Oryza sativa (rice)	~100	nd	42

nd, not determined.

Genome physical architecture

The genome physical architecture can be arranged in:

- Linear unit(s)
- Circular unit(s)

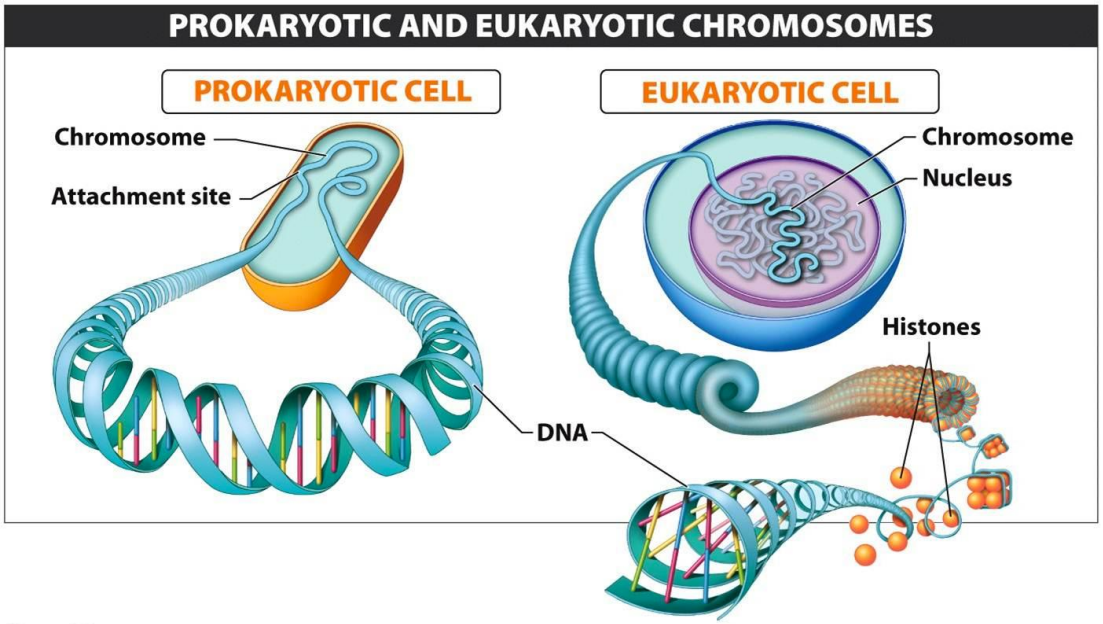


Figure 6-3
What Is Life? A Guide To Biology

Genome physical architecture

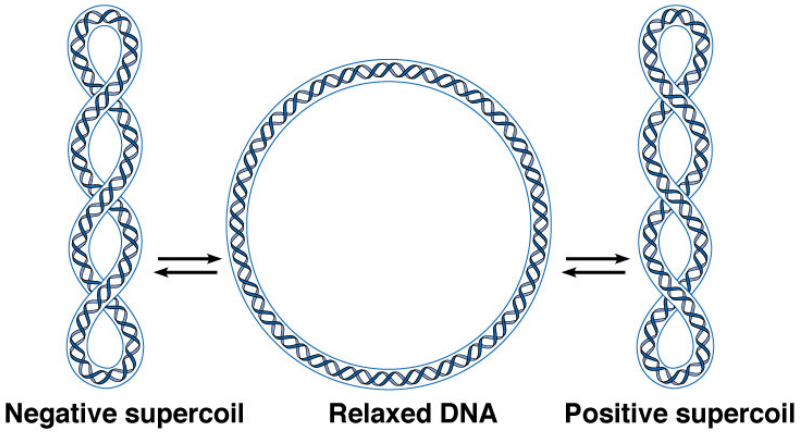
What is the advantage and disadvantages of having a circular genome?

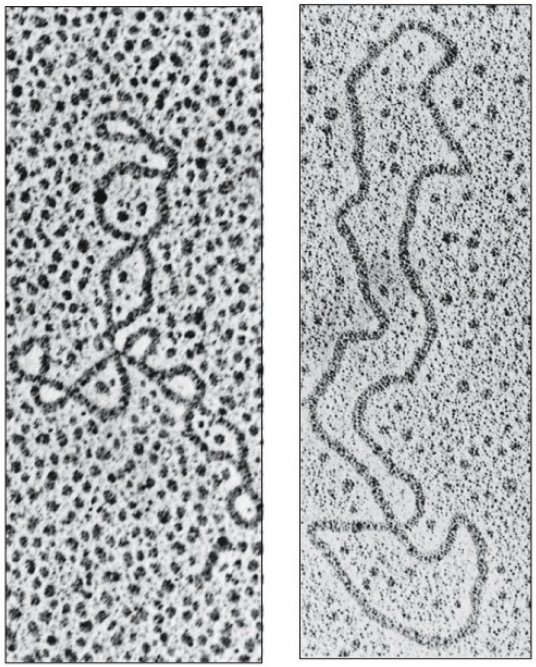
What are the advantages and disadvantages of having a linear genome?

Genome physical architecture

Circular chromosomes:

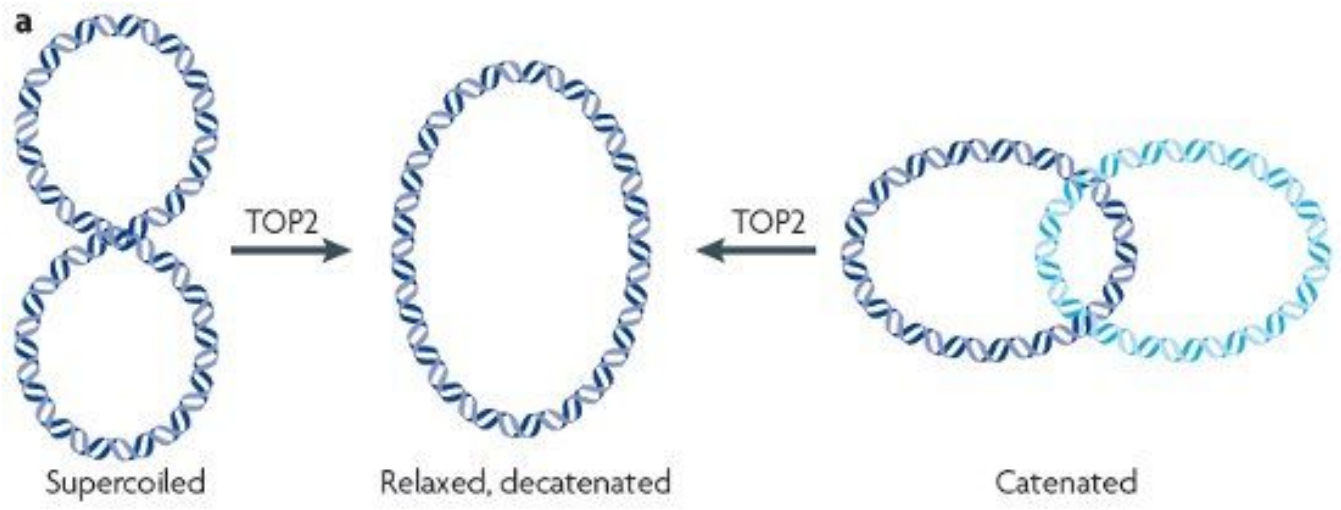
- No ends (telomeres)
- No fear of telomere shortening
- No need for end protection.
- Suitable for reproduction by cell division.





Genome physical architecture

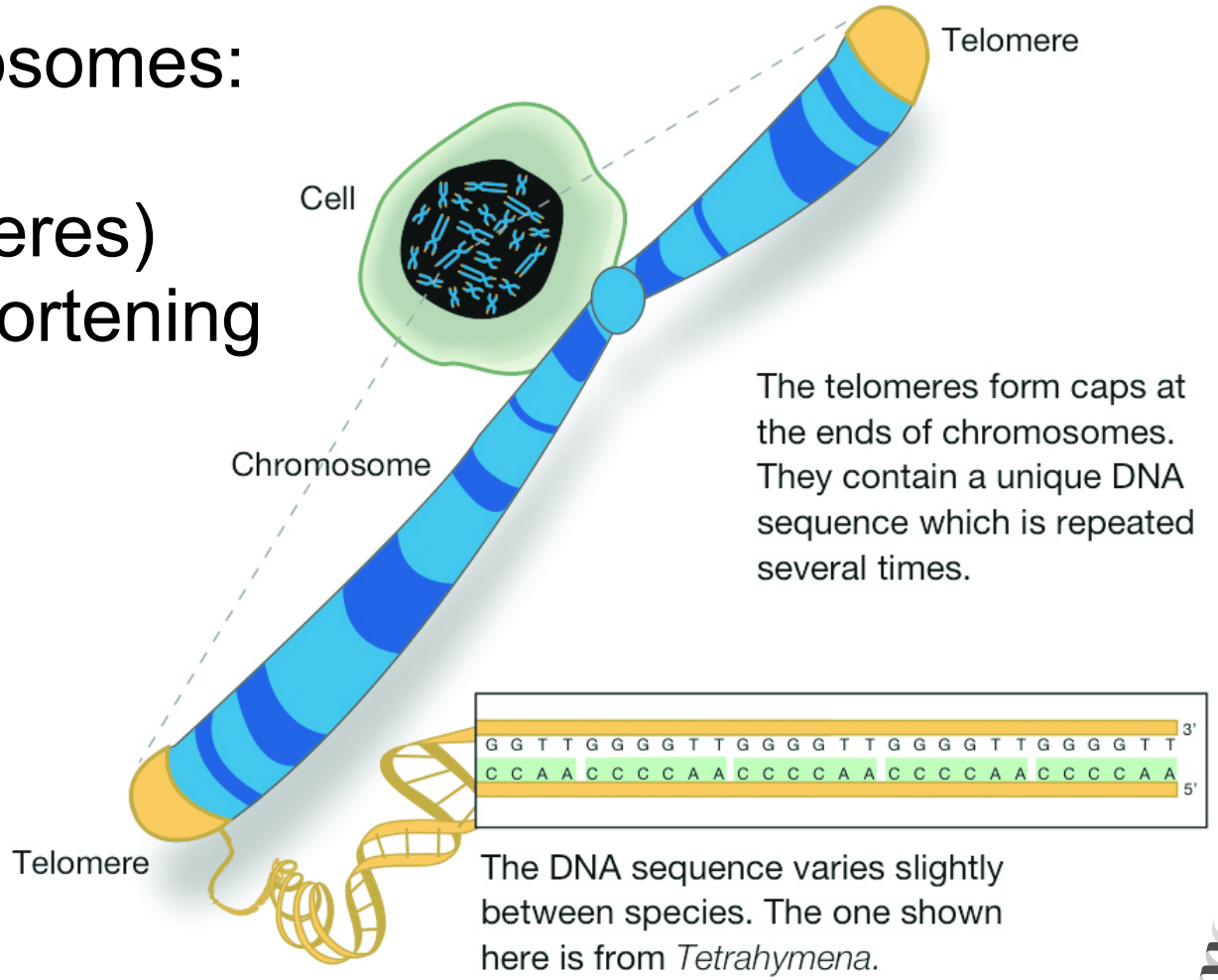
Product of circular chromosome replication needs to be resolved



Genome physical architecture

Linear chromosomes:

- Ends (telomeres)
- Telomere shortening
- Meiosis?



Genome physical architecture

The genome physical architecture can be arranged in:

- One unit (a single chromosome)
- Multiple units (multiple chromosomes)

Genome physical architecture

Bigger genomes are usually organized into multiple chromosomes

TABLE 7-1 Variation in Chromosome Makeup in Different Organisms

Species		Number of Chromosomes	Chromosome Copy Number	Form of Chromosome(s)	Genome Size (Mb)
Prokaryotes					
Mycoplasma genitalium		1	1	Circular	0.58
Escherichia coli K-12		1	1	Circular	4.6
Agrobacterium tumefaciens		4	1	3 circular 1 linear	5.67
Sinorhizobium meliloti		3	1	Circular	6.7
Eukaryotes					
Saccharomyces cerevisiae (budding yeast)		16	1 or 2	Linear	12.1
Schizosaccharomyces pombe (fission yeast)		3	1 or 2	Linear	12.5
Caenorhabditis elegans (roundworm)		6	2	Linear	97
Arabidopsis thaliana (weed)		5	2	Linear	125
Drosophila melanogaster (fruit fly)		4	2	Linear	180
Tetrahymena thermophilus (protozoa)	Micronucleus Macronucleus	5 225	2 10–10,000	Linear Linear	125
Fugu rubripes (fish)		22	2	Linear	393
Mus musculus (mouse)		19 + X and Y	2	Linear	2,600
Homo sapiens		22 + X and Y	2	Linear	3,200

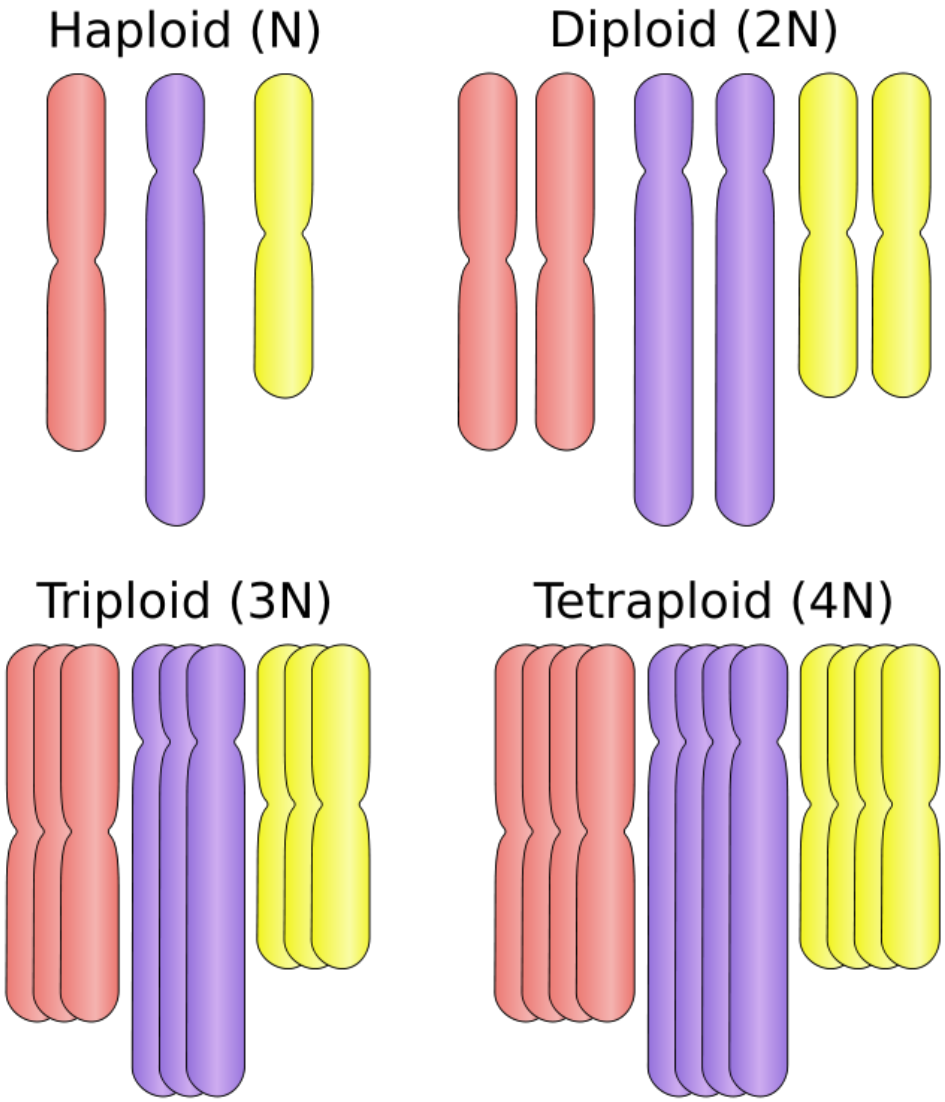
Genome physical architecture

What is the advantage and disadvantages of having a single unit (chromosomes) genome?

What is the advantage and disadvantages of having multiple units (chromosomes) genome?

Genome physical architecture

- The number of copies of the genome within cells varies across taxa.
- What is the advantage of having multiple copies of the genome?



Genome physical architecture

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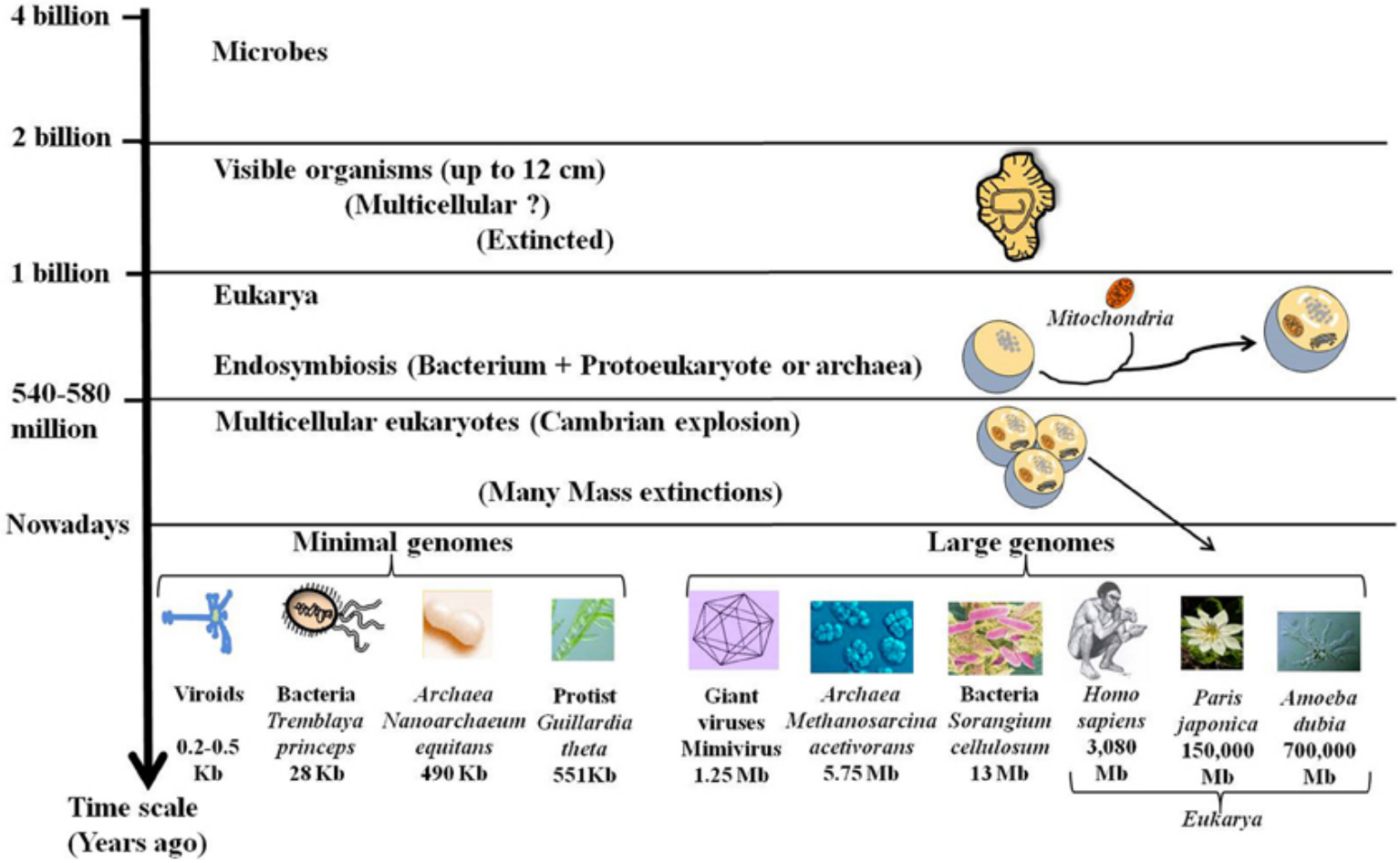
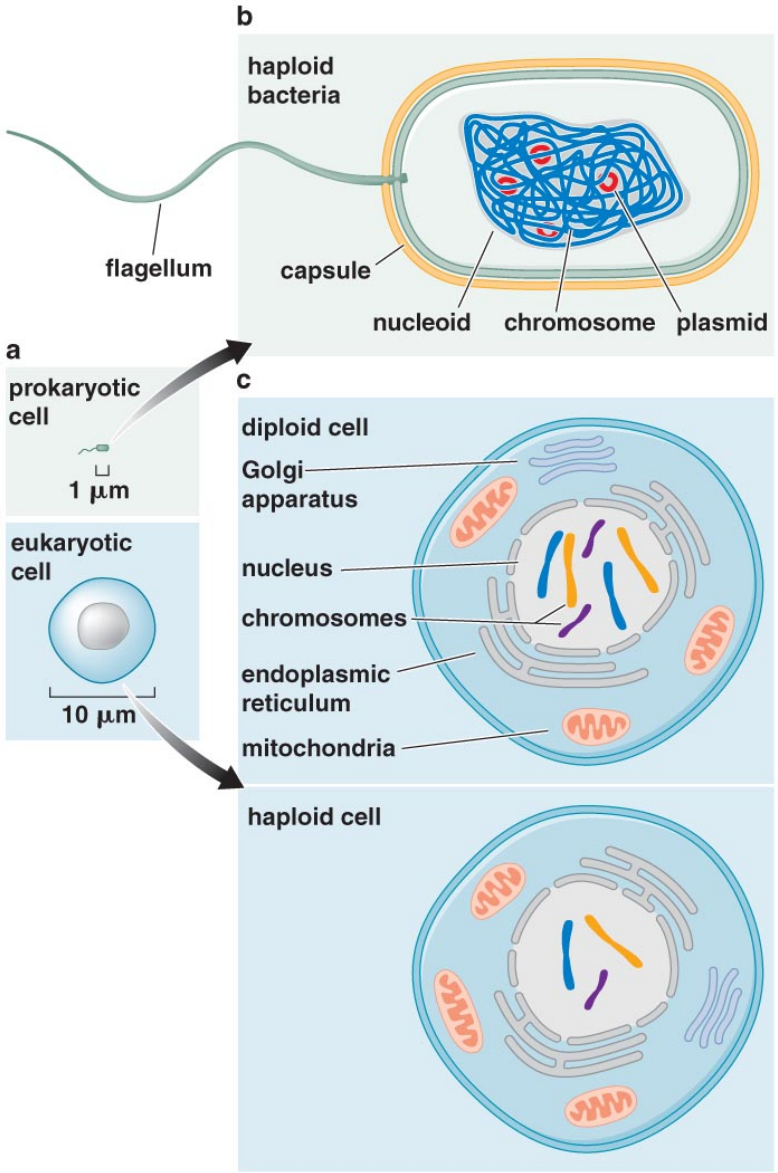
Genomes across taxa

Genomes evolved through time and genome organization evolved as well.



Genome organization



Why organizing the genome?

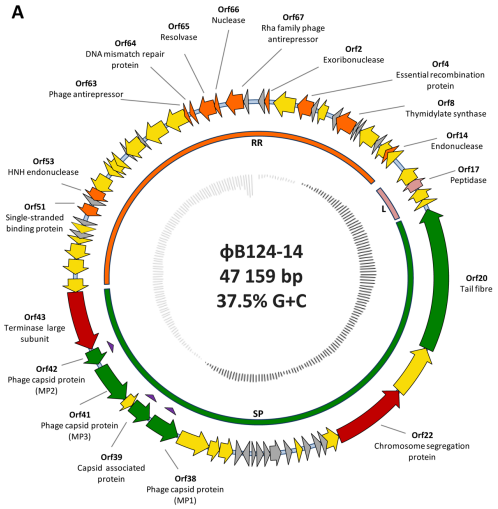
location location location! Space?

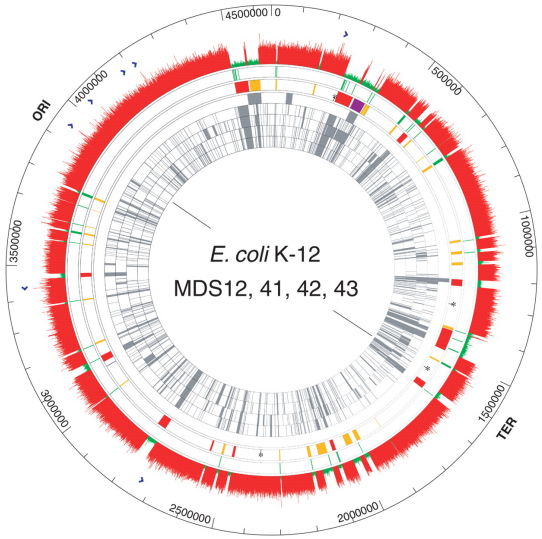
How can the genetic code in a small space?

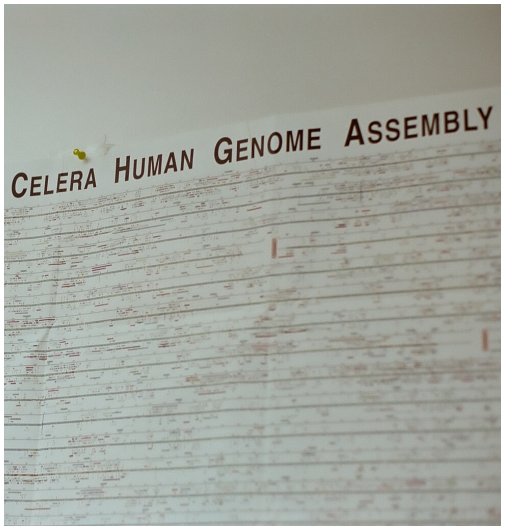
Genome organization

The characteristics of the genomes of different life forms

Viruses | Prokaryotes | Eukaryotes

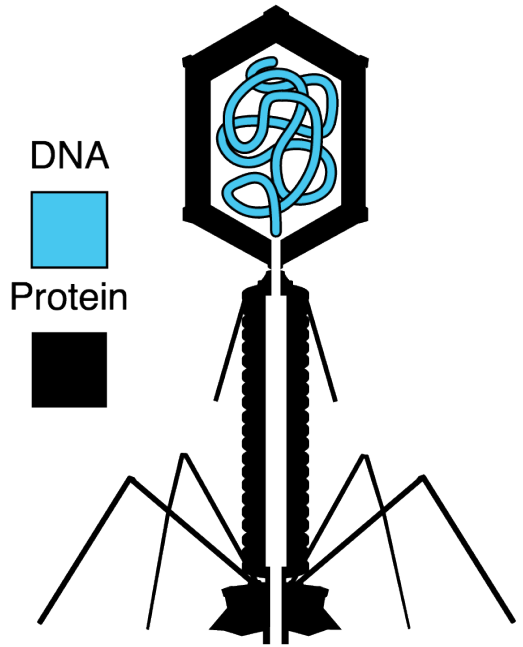






Viral genomes

- Genome can be:
    1. single stranded DNA.
    2. double stranded DNA.
    3. single stranded RNA.
    4. double stranded RNA.



- Genome can be linear or circular.

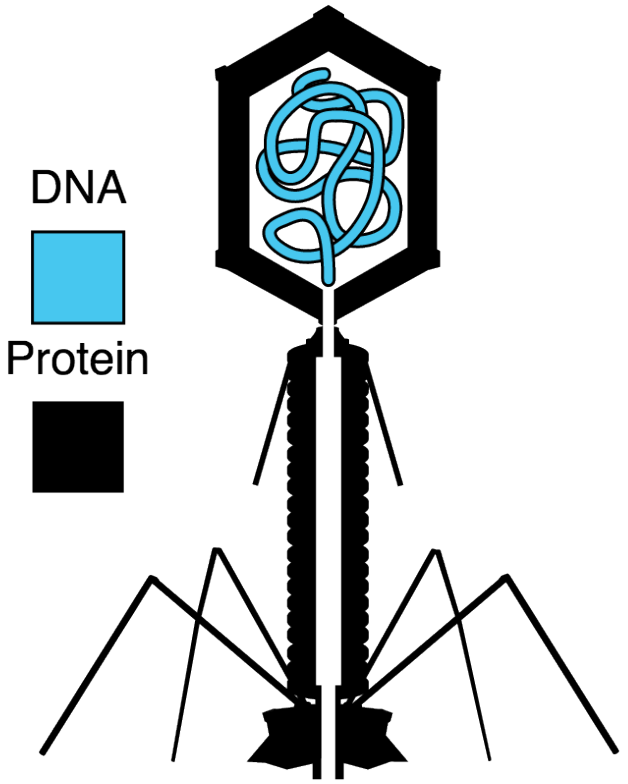
Viral genomes

- One molecule or segmented genome (many pieces).

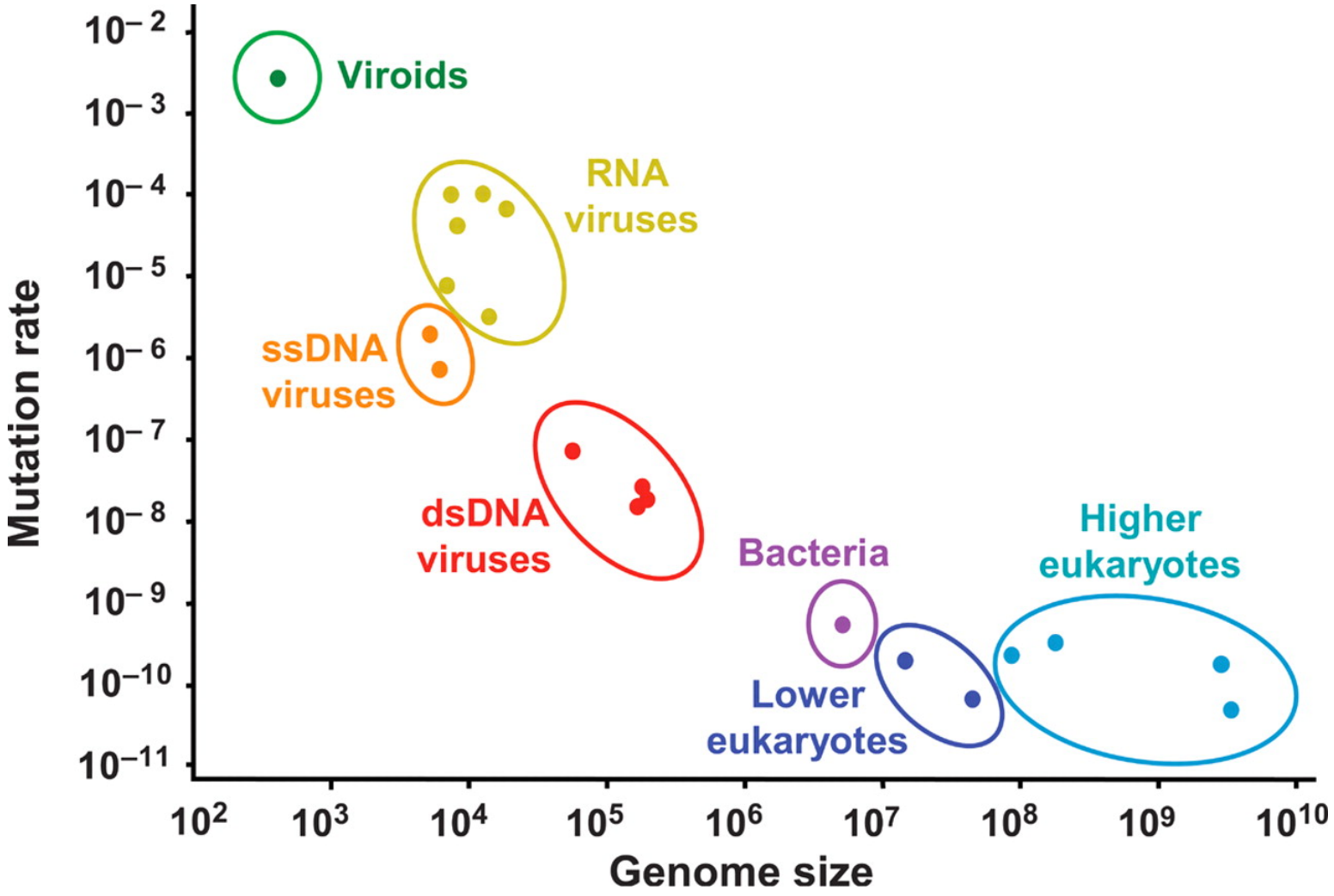
- Viruses with RNA genome are called retroviruses!

- Genome size 2 thousand basepairs (2Kb) – 2 million basepairs (2 Mb).

- No special organization of the genome.



Viral genomes



Gago S et. al., (2009). Extremely high mutation rate of a hammerhead viroid. Science 323 (5919):1308

Prokaryotic genomes

- Most genomes are:
    1. Single molecule (some multiple).
    2. One circular chromosome (some linear).
    3. Double stranded DNA.
    4. Some have small additional circular DNA that can replicate independently (**plasmid**).

- Genome is organized in a structure called (**Nucleoid**).

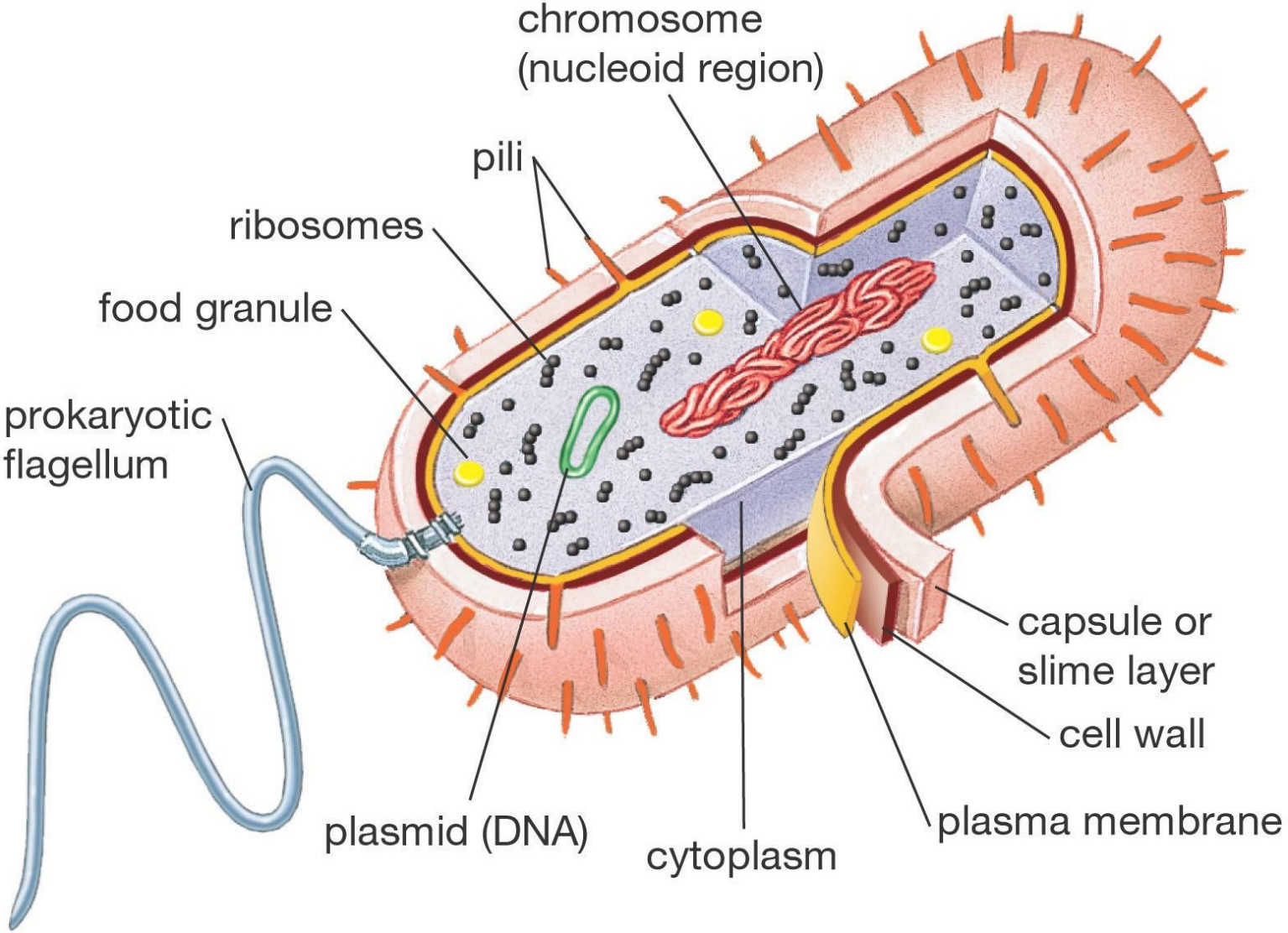
Prokaryotic genomes

•The genome is loose and not surrounded by a membrane (different than eukaryotes).

• **Loop domain** in bacterial genome contribute to the packaging.

• To fit the genome in a bacterial cell the DNA undergoes **supercoiling.**

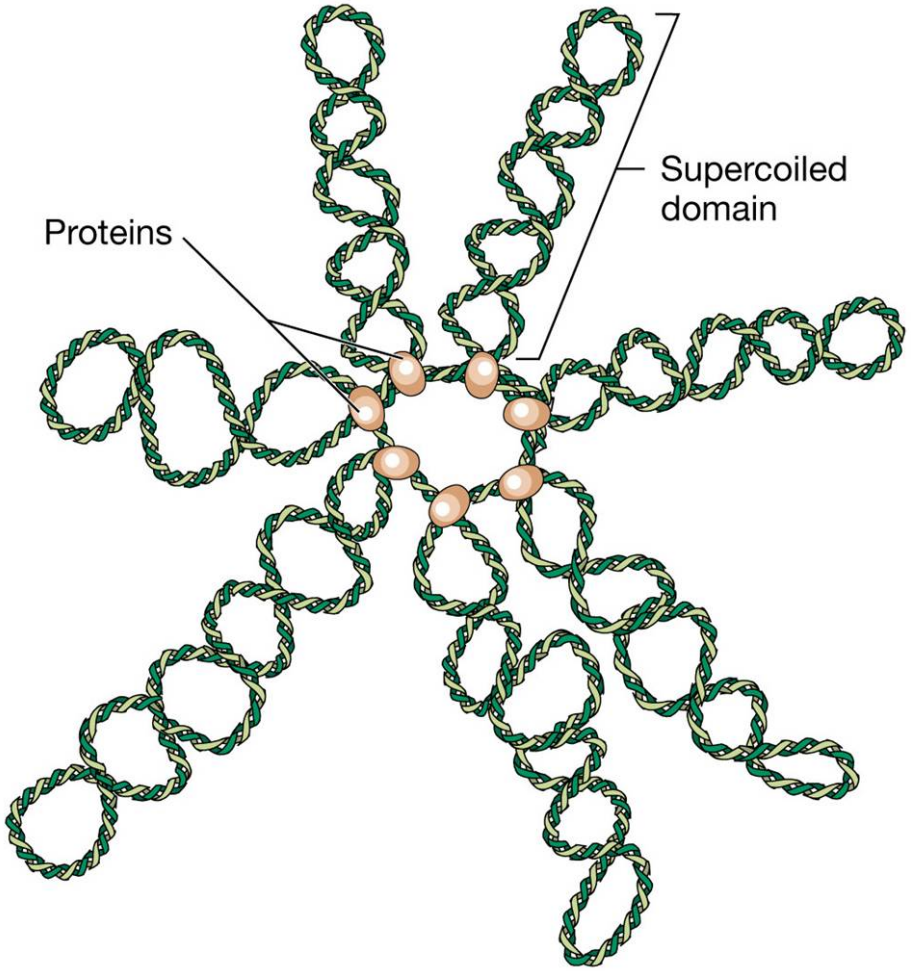
Prokaryotic genomes



Prokaryotic genomes organization

Prokaryote genome organization through:

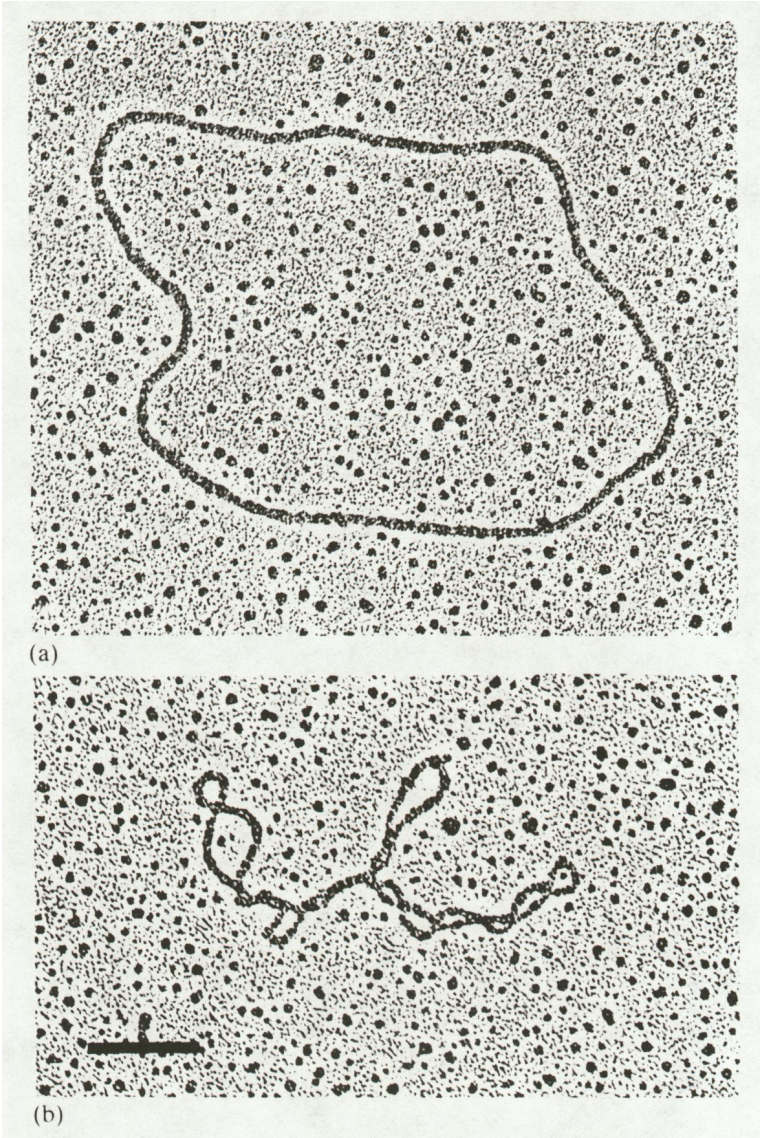
1. Nucleoid (protein DNA interaction).
2. Supercoiling.
3. DNA loops



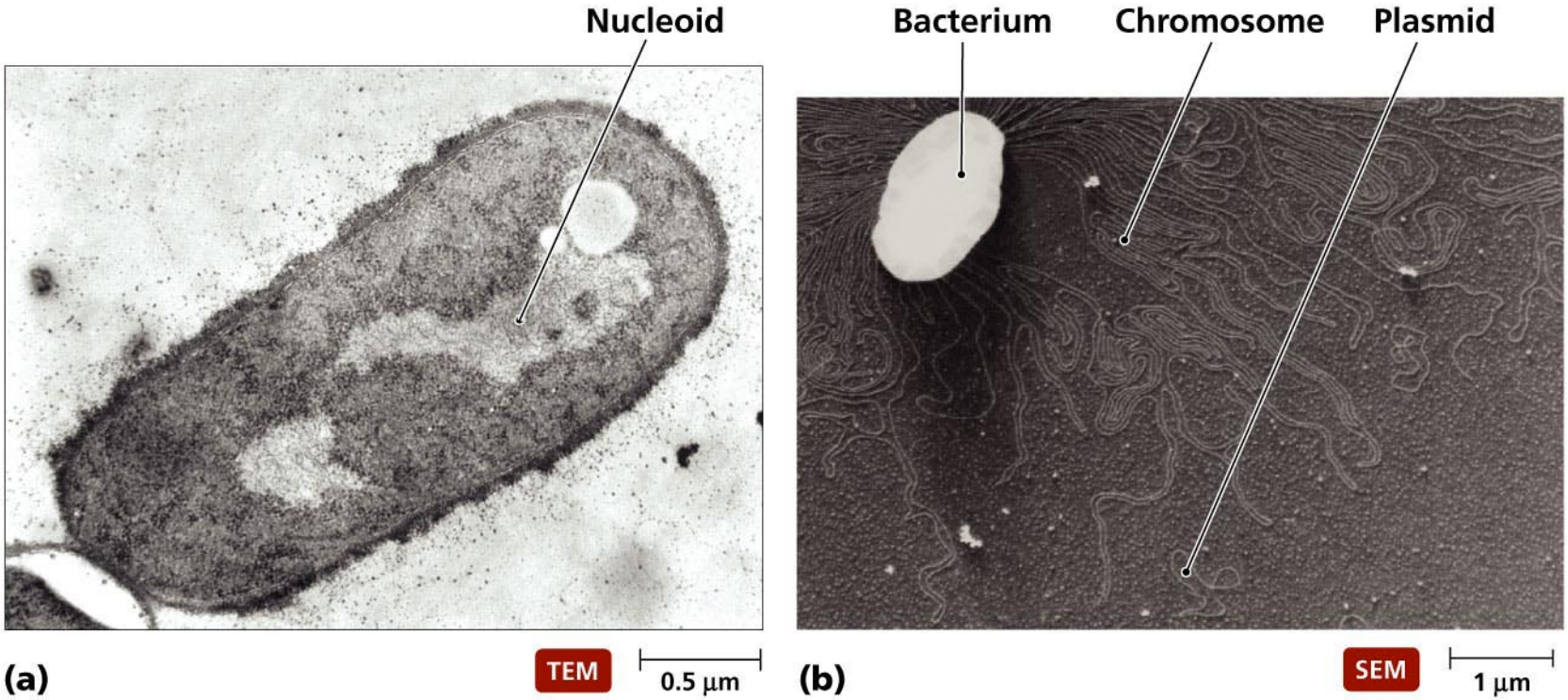
Prokaryotic genomes organization

Relaxed circular chromosome

Supercoiled circular chromosome



Prokaryotic genomes organization



Expectations

- You know how to define the genome.
- You know how genomes are generally organized.
- You know the genome organization across taxa and the biological significance.