Microbial habitats

Microorganisms occur in practically every habitat on the planet, both terrestrial and aquatic/marine, upon and within the earth's surface. They colonize soils, rock, stone monuments, caves, mines, glaciers, river and oceans. Microorganisms may occur in extreme habitats hostile to human existence, such as deserts, ocean floors, hypersaline environments, acidic waters, and the upper strata of the atmosphere.

Indiano silver mine, Bustarviejo (Madrid)[1]

Jokulsarlon glacial lake (Iceland) [1]

Wadi Rum Desert (Jordan) [1]

Roman ruins at Jerash (Jordan)[1]

West coast of Monteagudo (Cíes Islands, Galicia, Spain))[2]

Atacama salt lake (Chile) [1]

Fish farm in Sardinia (Italy) [2]

Rio Tinto (Huelva)[3]

Kapalai Island (Borneo, Indonesia)[4]

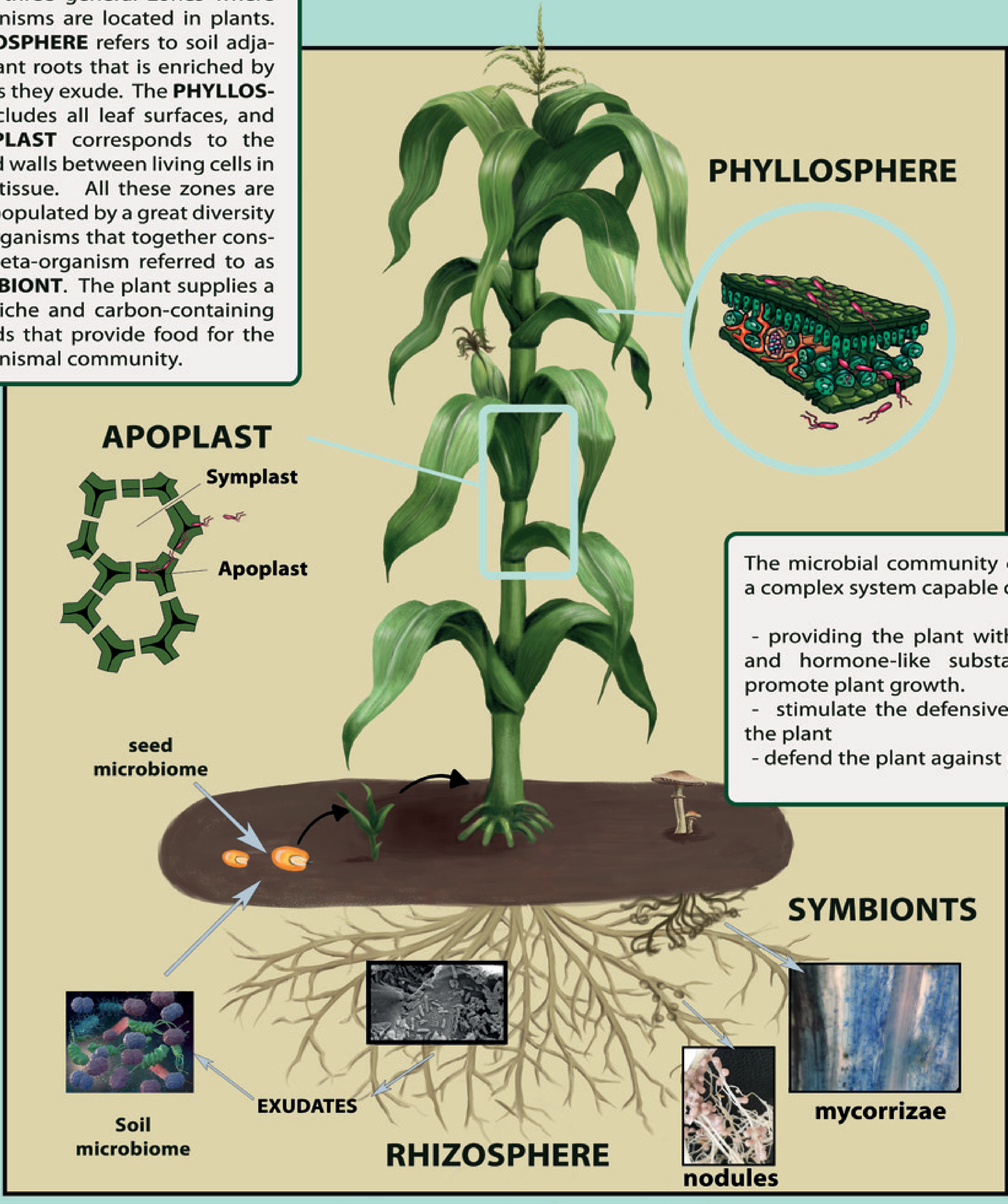
Mabul (Borneo, Indonesia)[4]

Image credits: [1]Asunción de los Ríos, [2] Jesús L. Romalde, [3]Julio Segura y Ricardo Amils, [4] Vicente Renovell

Plants and microorganisms:
a highly beneficial arrangement

Ever since their ancestors colonized the terrestrial environment 400 million years ago, plants have been closely associated with microorganisms that grow upon their surfaces and within their interior tissues. These microorganisms may interact symbiotically with the plant to the mutual benefit of both, as is the case with mycorrhizal fungi and nodule-forming bacteria. Others may be pathogens that cause harm to the plant.
All these organisms together constitute a complex microbiome that is essential for survival of plants in natural environments. The microbiome is fundamental to maintaining the ecological equilibrium of ecosystems and the productivity of crops in cultivation.

There are three general zones where microorganisms are located in plants. The **RHIZOSPHERE** refers to soil adjacent to plant roots that is enriched by substances they exude. The **PHYLLOSPHERE** includes all leaf surfaces, and the **APOPLAST** corresponds to the spaces and walls between living cells in the plant tissue. All these zones are naturally populated by a great diversity of microorganisms that together constitute a meta-organism referred to as the **HOLOBIONT**. The plant supplies a physical niche and carbon-containing compounds that provide food for the microorganismal community.

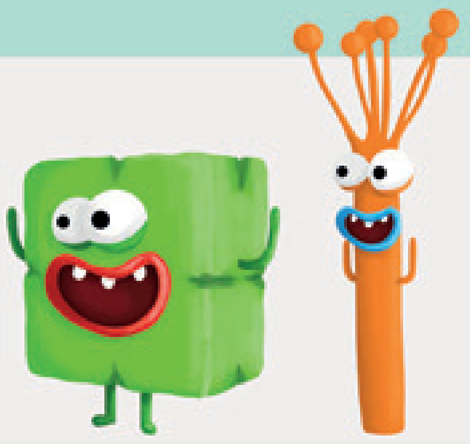


The microbial community constitutes a complex system capable of

- providing the plant with nutrients and hormone-like substances that promote plant growth.
- stimulate the defensive system of the plant
- defend the plant against pathogens

FUTURE DEVELOPMENTS: In recent years, increased understanding of plant microbiomes has enabled the development of sustainable strategies for biofertilization and crop protection against biological and abiotic threats, thereby allowing us to obtain healthier and safer foods.

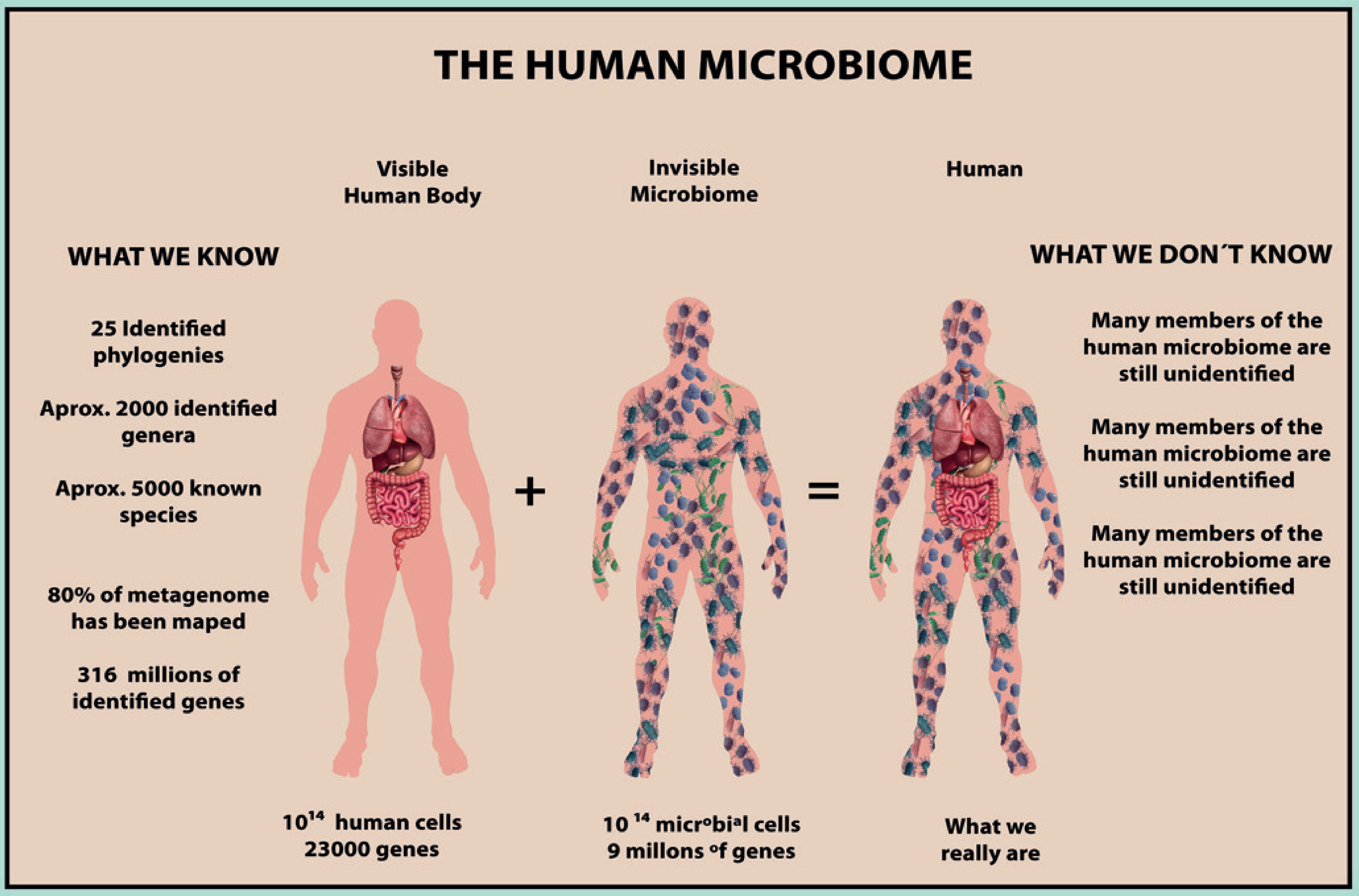
The Human Microbiome
Our Body is an Ecosystem



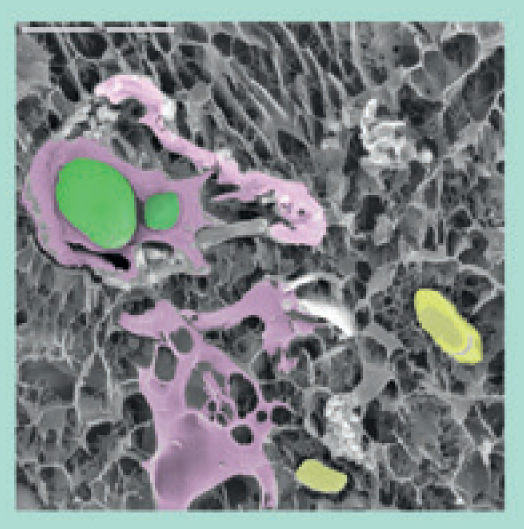
Our body contains an ecosystem distinct from others

Our relationship with microorganisms is much closer than people think. A diversity of microbial communities lives within and upon us, constituting the **HUMAN MICROBIOTA**. It includes specific microbes such as viruses, archaeans, bacteria, fungi and protozoa that live in symbiosis with humans.

Approximately **half of the cells in our body are not human, but microorganisms**. The intimate association of between microorganisms and humans (as well as other larger forms of life) is the result of co-evolution, as though a single organism were involved. Microorganisms cohabit and interact with us from the moment of birth. These microbiomes, like ourselves, are unique, although they change in composition during the course of our lives. This is true of all living things.



Microbiota on the hand of a 9-year-old boy

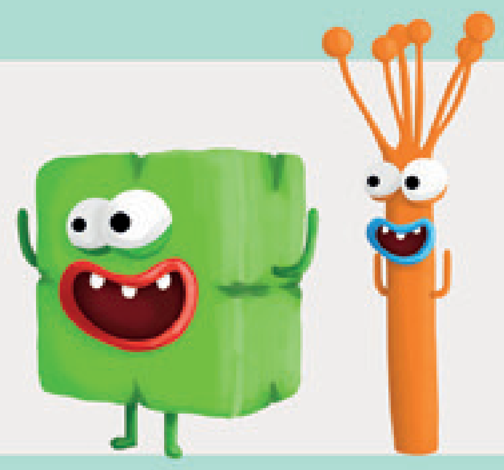


Bacteria under the scanning electron microscope

WHERE ARE THE MICROORGANISMS IN OUR BODY HIDING?

Microorganisms are present in almost every part of the complex ecosystem that is the human body, and are adapted to live very specific zones. Our skin is covered with microorgansms, but a significant percentage of them also live within our bodies, from the oral and nasopharyngial cavities to the gastrointestinal tract, and the urogenital and respiratory systems. The normal microbiota of any living thing contributes toward maintaining the health of the tissue they inhabit, while a disruption of the equilibrium often leads to illness.

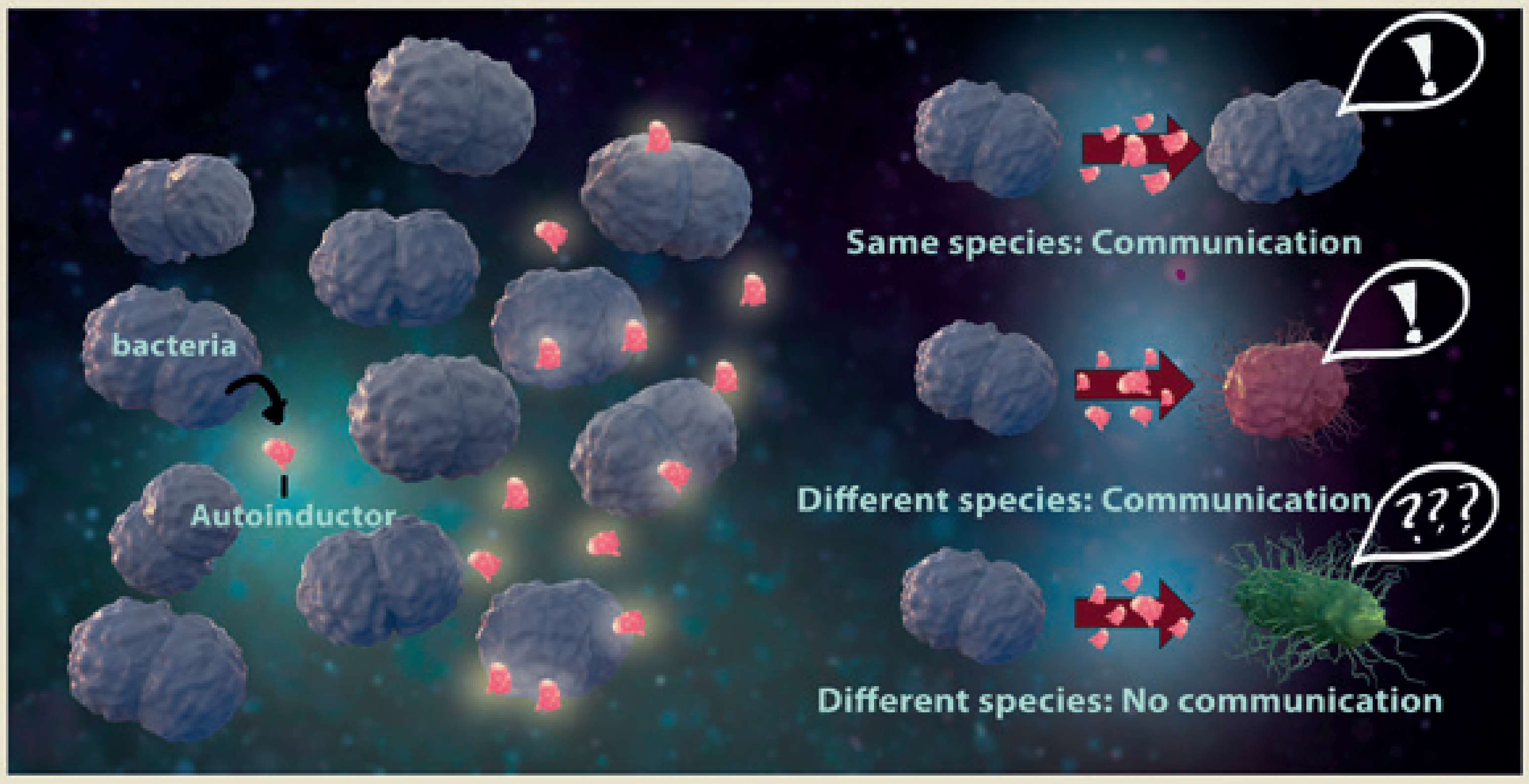
Microbial Social Relationships



MICROORGANISMS ARE "SOCIAL" Microorganisms communicate among themselves, permitting them to function in a coordinated manner.

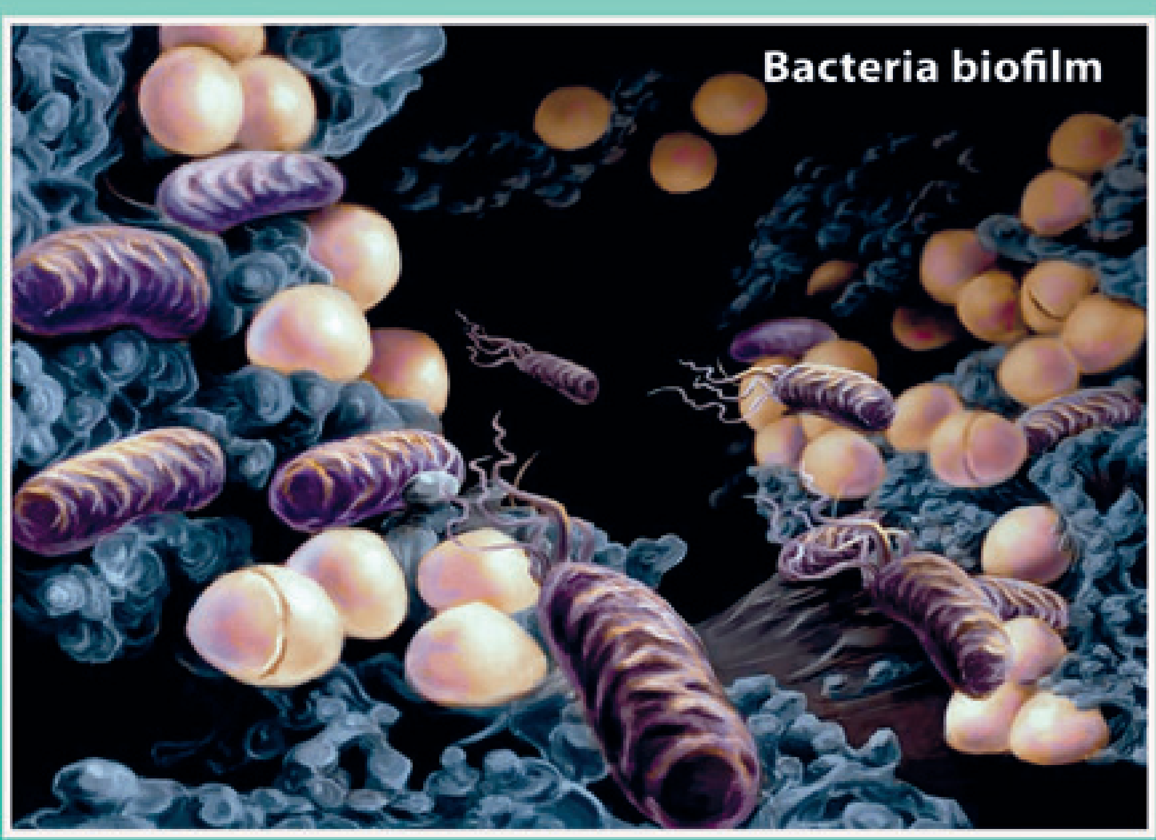
They communicate by means of chemical signals, called **autoinductors**. These are molecules that are secreted into the surrounding medium and are recognized by other cells, allowing them to respond as a group.

These communications can be established among cells of the same species (intraspecific) or those of different species (interspecific), if they respond to the same chemical "language."



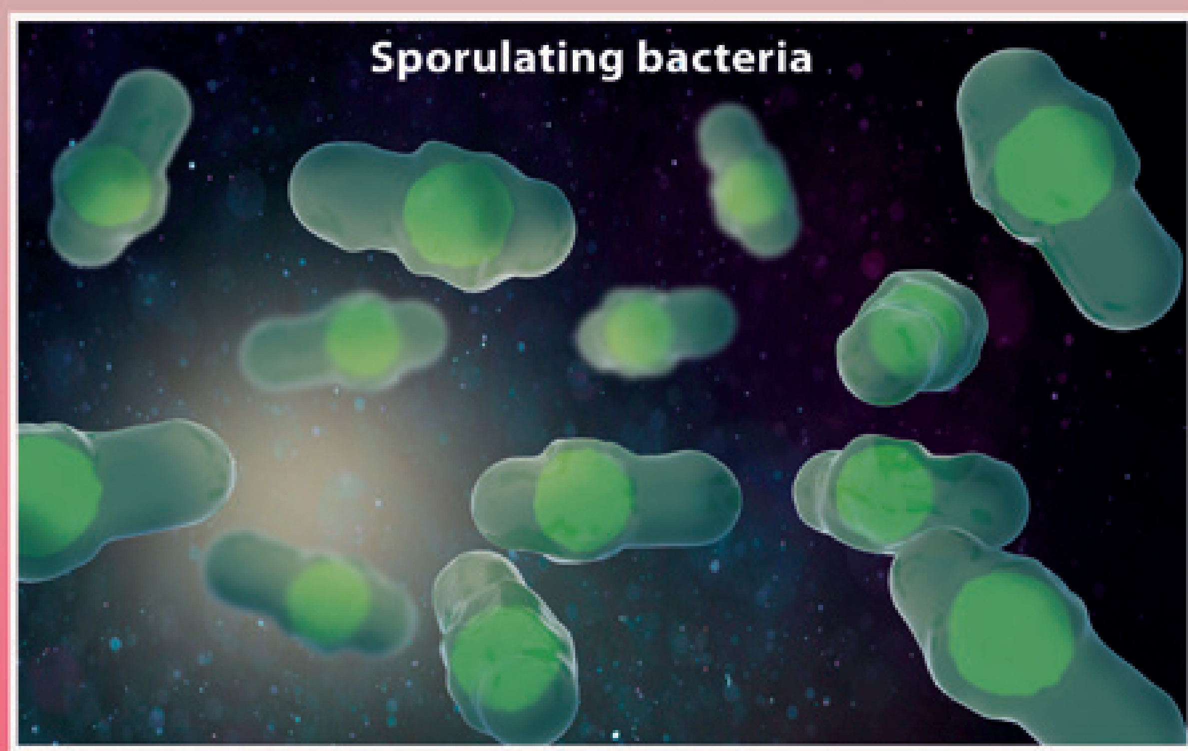
MICROORGANISMS ORGANIZE THEMSELVES IN COMPLEX STRUCTURES SUCH AS BIOFILMS AND, WHEN THEY BUILD LAYERED STRUCTURES, MICROBIAL MATS.

In both kinds of structures, different types of microorganisms live together, surrounded by a matrix of secreted extracellular polymers. This provides them with protection while facilitating interactions and acquisition of nutrients.


Bacteria biofilm

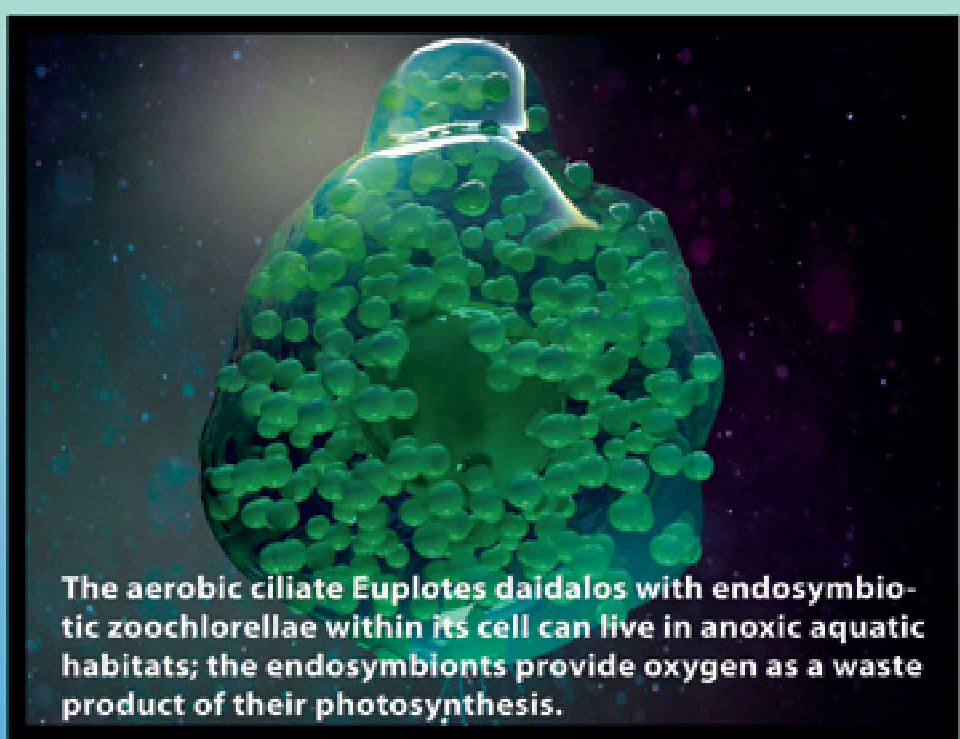
MICROORGANISMS PROTECT THEMSELVES BY FORMING RESISTANT STRUCTURES

Under unfavorable environmental conditions, such as lack of nutrients, some microorganisms for resistant structures, such as spores or cysts that are isolated from the exterior by thick walls or other coverings. These structures can endure long periods of time, even centuries. This process can occur individually (e.g., protists) or collectively (e.g., myxobacteria).


Sporulating bacteria

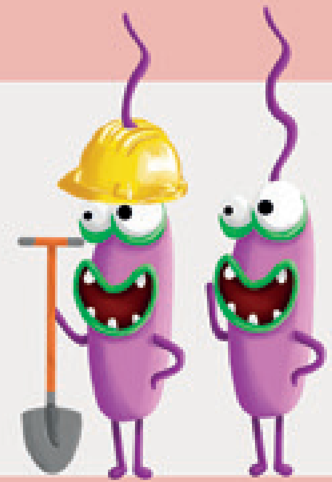
ASSOCIATION FOR SURVIVAL: MUTUALISTIC SYMBIOSIS

Microrganisms establish mutualistic associations with other microorganims or with plants, animals or humans. In these symbioses, all participants gain some benefit from the association, such as protection or facilitated acquisition of nutrients.


The aerobic ciliate Euplotes daidalos with endosymbiotic zoochlorellae within its cell can live in anoxic aquatic habitats; the endosymbionts provide oxygen as a waste product of their photosynthesis.


Fungi and algae associate in symbiosis, giving rise to lichens capable of resisting environmental extremes

Microbial biofactories.
Industrial microbiology and biotechnology



Humans have used microorganism to make fermented foods and beverages, enzymes, organic acids, and antibiotics.

This applied usage of microorganisms forms the basis of **microbial biotechnology**, or **industrial microbiology**, when carried out at large scale. Technical advances in molecular biology have permitted genetic manipulations of cultured microorganisms, **MOLECULAR BIOTECHNOLOGY** so that they produce desired products, such as human proteins (e.g., insulin).

Chemical and pharmaceutical biotechnology
Microorganisms are used for biosynthesis of chemical compounds for industry, particularly pharmaceuticals. For example, filamentous fungi and actinobacteria of the genus *Streptomyces* produce antibiotics. *Streptomyces* produces more than 50% of all known antibiotics and other pharmaceuticals, such as immune suppressors and anti-cancer drugs.

Enzymatic biotechnology
Microbial enzymes are used in industrial processes, such as production of fuels and chemical products, and in the breakdown and decontamination of industrial waste materials.

ANTIBIOTICS
PHARMACEUTICALS
BIOFUELS
CHEMICAL PRODUCTS
ENZYMES
ALCOHOLICS BEVERAGES
MONOMERS AND POLYMERS
FERMENTED FOODS

MICROORGANISMS
MICROBIAL ENZYMES

Agricultural biotechnology
Certain microorganisms increase crop yield by promoting plant growth and inhibiting pathogen development.

FIRSTS INDUSTRIAL MICROBIOLOGISTS

1854
Louis Pasteur
Beer

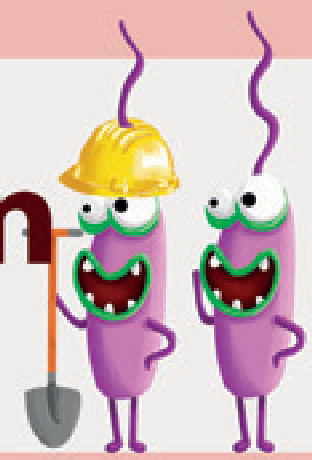
1914
Carls Neuberg
Glycerol

1917
james Currie
Citric acid

1928
Alexander Fleming
Penicilin

1945
Selman Waksman
Streptomycin

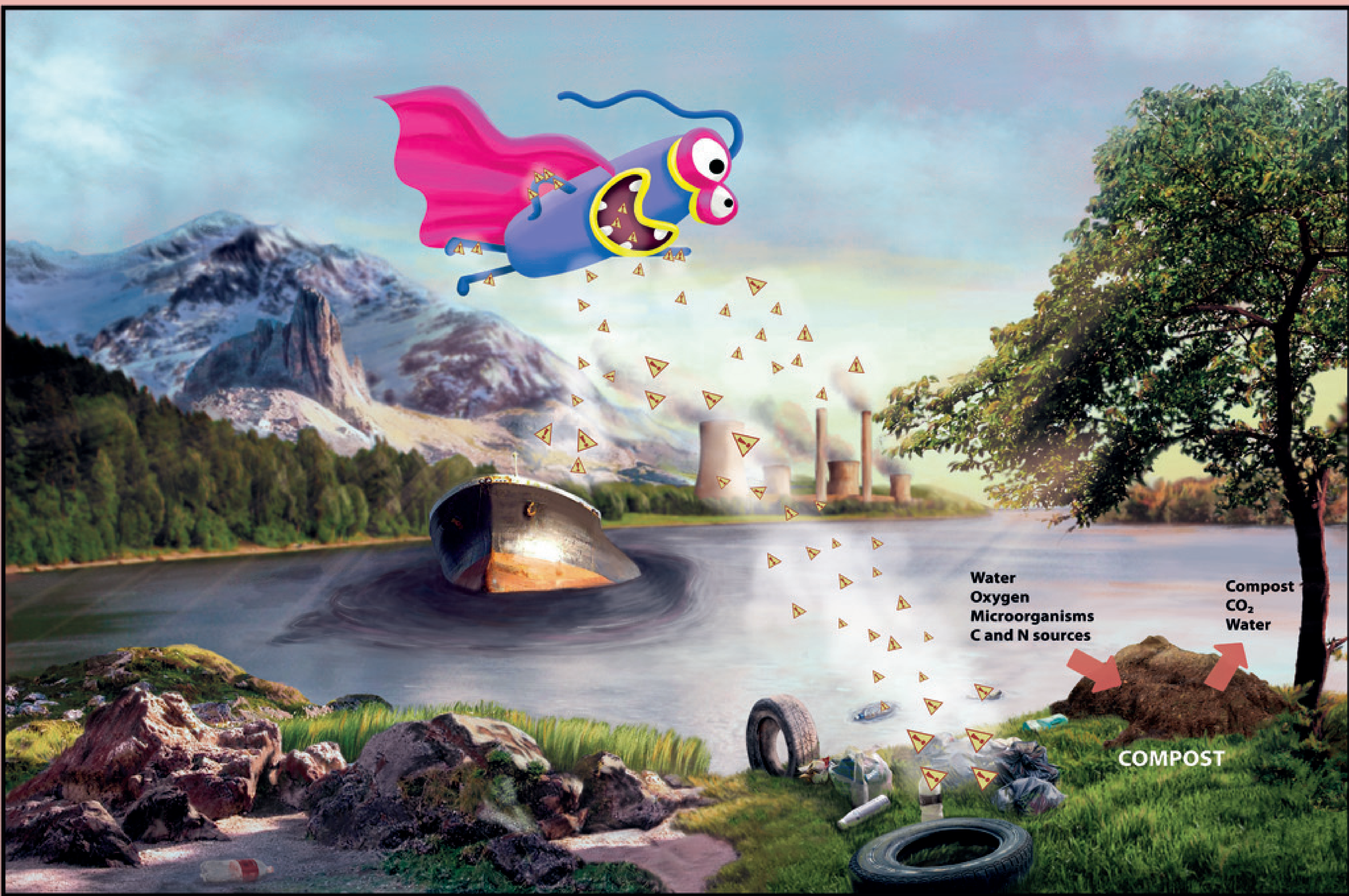
Bioremediation and biodegradation
microbial super-heroes that clean and recycle



Some microorganisms thrive in conditions that are deadly to other living things, and may also work to improve problematic environmental conditions through **bioremediation** and **biodegradatio**n.

Bioremediation: Microorganisms can help transform environments contaminated by pollutants, returning them to their natural state by binding to toxic substances or converting them into less toxic compounds.

Biodegradation: Some microorganisms can decompose organic material originating from plants, animals, and even industrial processes, facilitating its recycling.



MICROBIAL CLEANERS

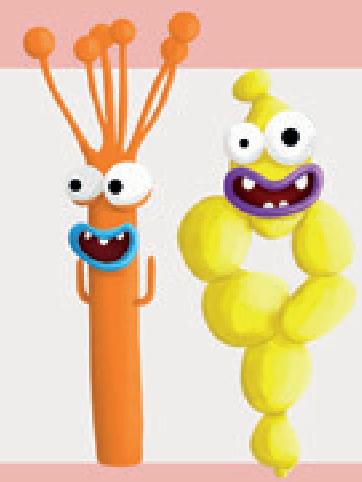
Petroleum spills and toxic wastes are serious hazards to which these **microbial super-heroes** come to the rescue, **removing the pollutants from the environment.** **Bioremediation** was employed after the **Prestige oil spil**l off the coast of Galicia, and also following the **Aznalcóllar accident** that dumped mud rich in toxic heavy metals into Doñana National Park. Certain microorganisms, such as *Deinococcus radiodurans*, can live under conditions of high radioactivity that would kill a human, **trapping the radioactive elements** and helping to detoxify contaminated zones such as nuclear power plants.

MICROBIAL RECYCLERS

Human activity generates an ever-increasing amount of organic waste. Microorganisms are capable of decomposing these wastes, producing natural fertilizers **(compost)** through **biodegradation**.

MICRORGANISMS ARE ACTIVE AGENTS OF SUSTAINABLE DEVELOPMENT

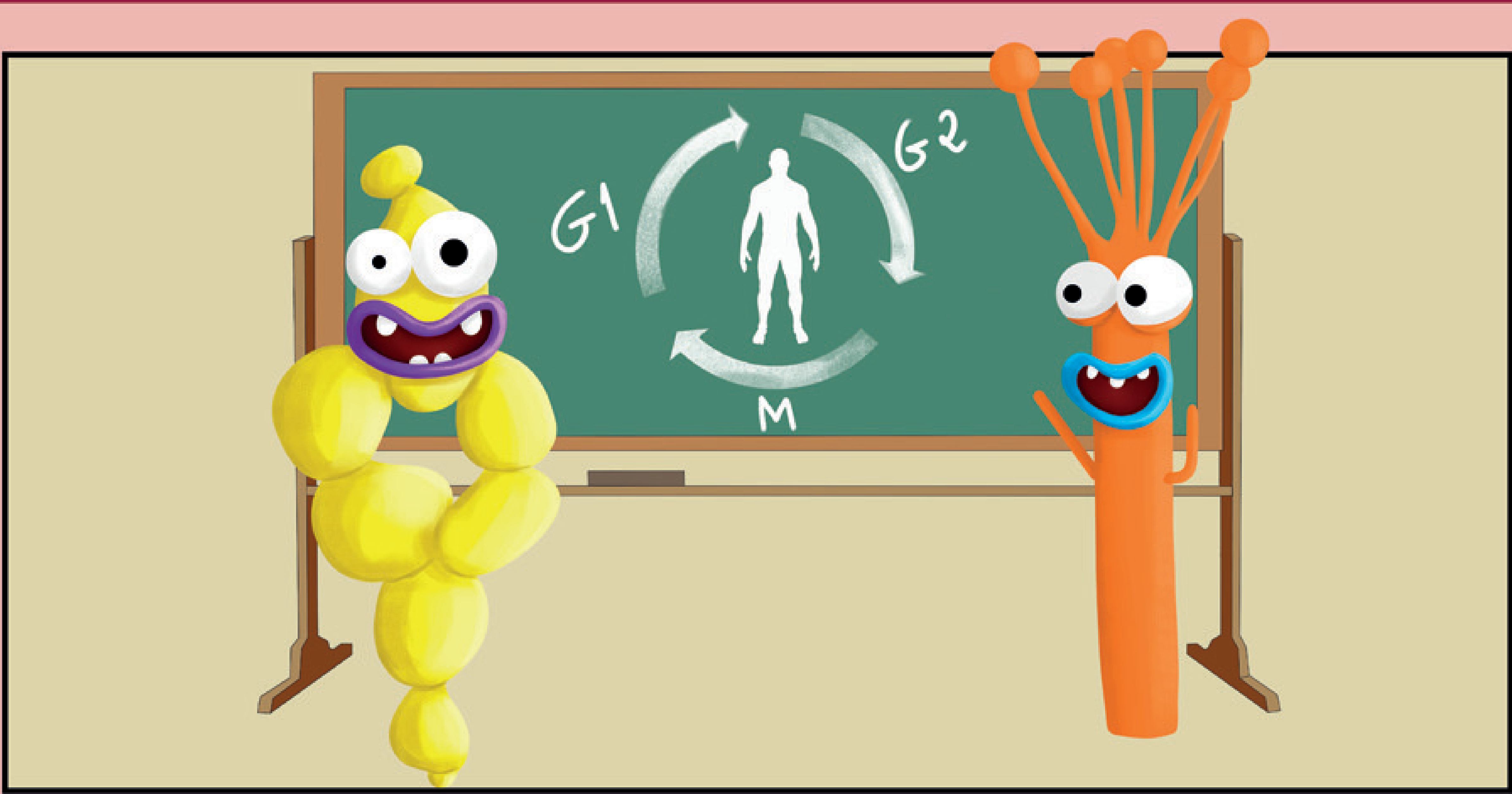
Our model microorganisms



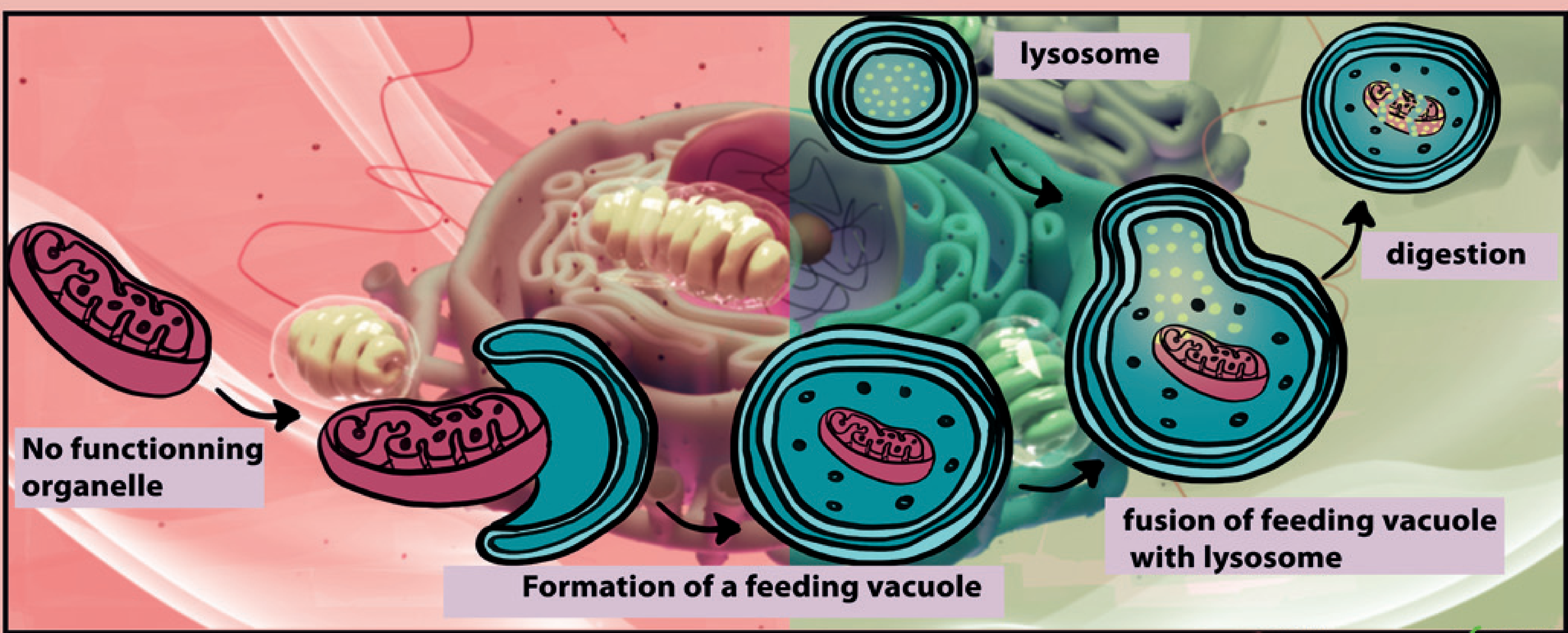
Filamentous fungi and yeasts can serve as **explicatory models** of different processes that occur within our cells, such as the cell cycle, autophagy, and cellular morphogenesis and development. The loss of regulatory control of these processes can lead to various human diseases, such as cancer, autoimmune and inflammatory illnesses, aging and deterioration.

WHY FILAMENTOUS FUNGI AND YEASTS ARE GOOD MODELS:

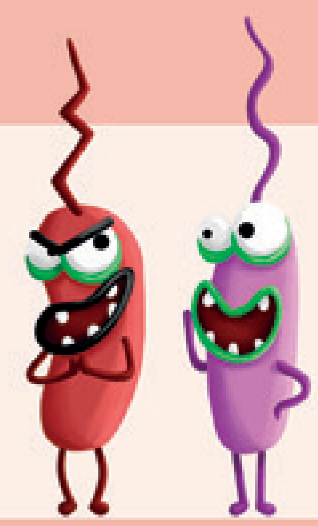
- **They are easy to cultivate in the laboratory**
- **They have eukaryotic cell organization, like us.**
- **We already know a lot about their genes and we have the ability to study their functions easily.**



Do you know that eukaryotic cells are constantly consuming parts of themselves?.
Autophagy refers to this self-digestion and recycling of parts of the cell that have become aged, no longer function, or have become toxic. The regulation of this process is very important for the correct functioning of neurons and cells of the immune system, and for protection against cancer, infectious diseases and the effects of cellular aging. We know about these mechanisms thanks to study of model microorganisms.



Microorganisms and our food



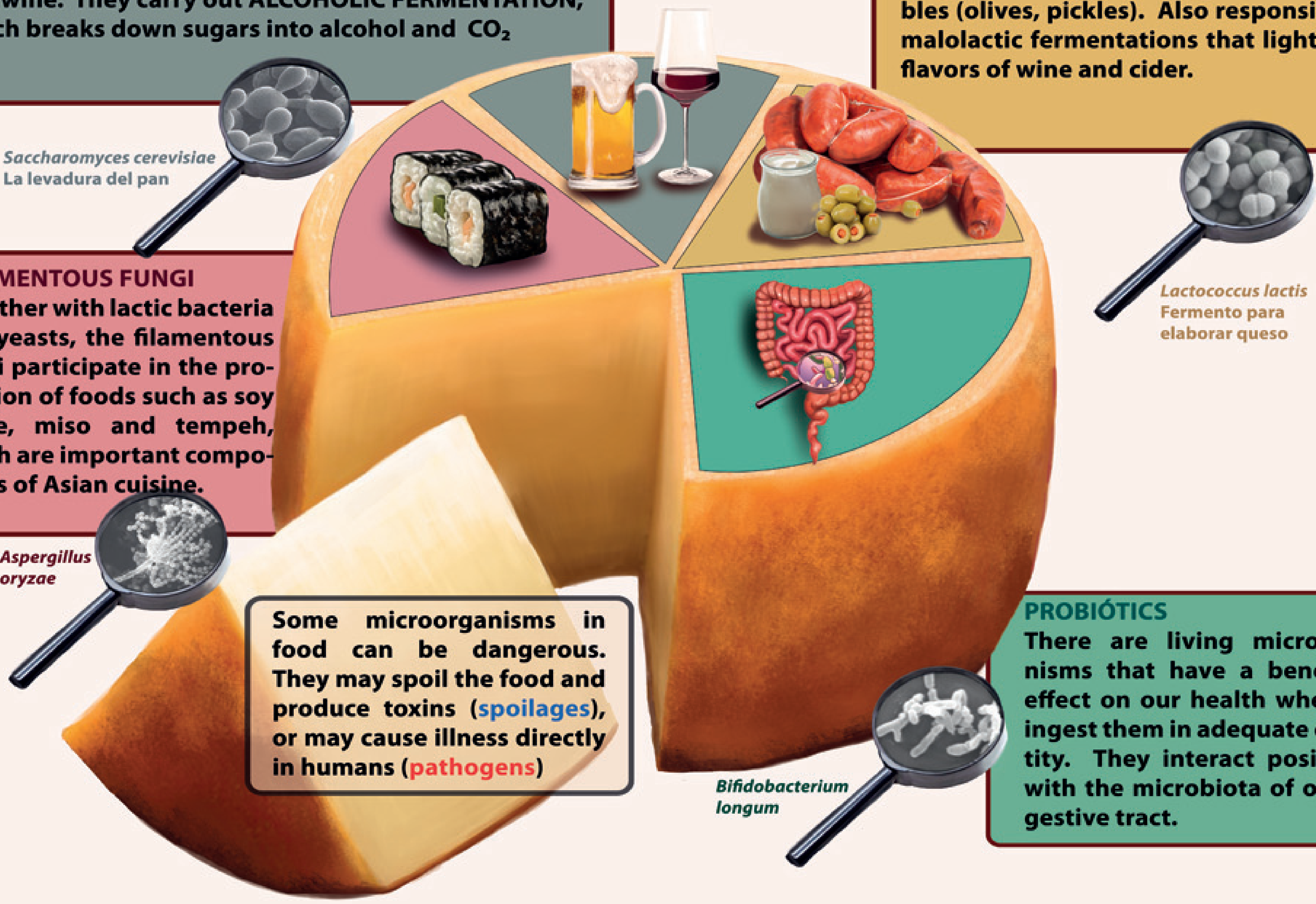
Since the Neolithic Age, prehistoric humans have used microorganisms to produce food by fermentation. Some examples:

LACTIC BACTERIAS

Produce lactic acid as a breakdown product in the fermentation of milk products (yogurts, cheeses), sausages, and vegetables (olives, pickles). Also responsible for malolactic fermentations that lighten the flavors of wine and cider.

YEASTS

These fungi are responsible for producing bread, beer and wine. They carry out ALCOHOLIC FERMENTATION, which breaks down sugars into alcohol and CO_2



FILAMENTOUS FUNGI

Together with lactic bacteria and yeasts, the filamentous fungi participate in the production of foods such as soy sauce, miso and tempeh, which are important components of Asian cuisine.

Some microorganisms in food can be dangerous. They may spoil the food and produce toxins (spoilages), or may cause illness directly in humans (pathogens)

PROBIÓTICS

There are living microorganisms that have a beneficial effect on our health when we ingest them in adequate quantity. They interact positively with the microbiota of our digestive tract.

PATOGENS MICROORGANISMS are responsible for infections and poisonings of the digestive system, such as gastroenteritis caused by *Salmonella* and *Listeria monocytogenes.*

SPOILAGE MICROORGANISMS reduce the useful life of foods, producing disagreeable odors and tastes. *Clostridium tyrobutyricum* causes the late swelling of mature cheeses.

But no cause for alarm. In the process of food production, rigid **measures for prevention and control** are followed to avoid spoilage microorganisms and consequent effects on consumers' health.

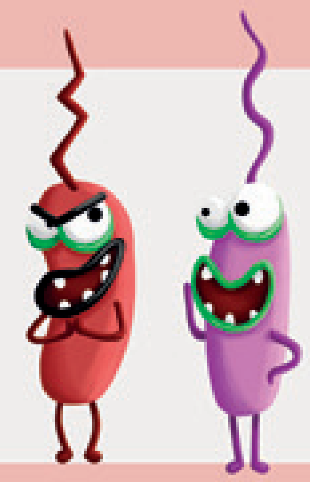
Many **strategies** are used to **conserve foods and guarantee their safety, nutritional value and taste**. Some are as old as our cave-dwelling ancestors who first applied them. Many are still employed today, although often in a technologically more sophisticated way.

High or low temperatures kill or inhibit the growth of microorganisms. For this reason, we cook, refrigerate or freeze foods.

High or low temperatures kill or inhibit the growth of microorganisms. For this reason, we cook, refrigerate or freeze foods.

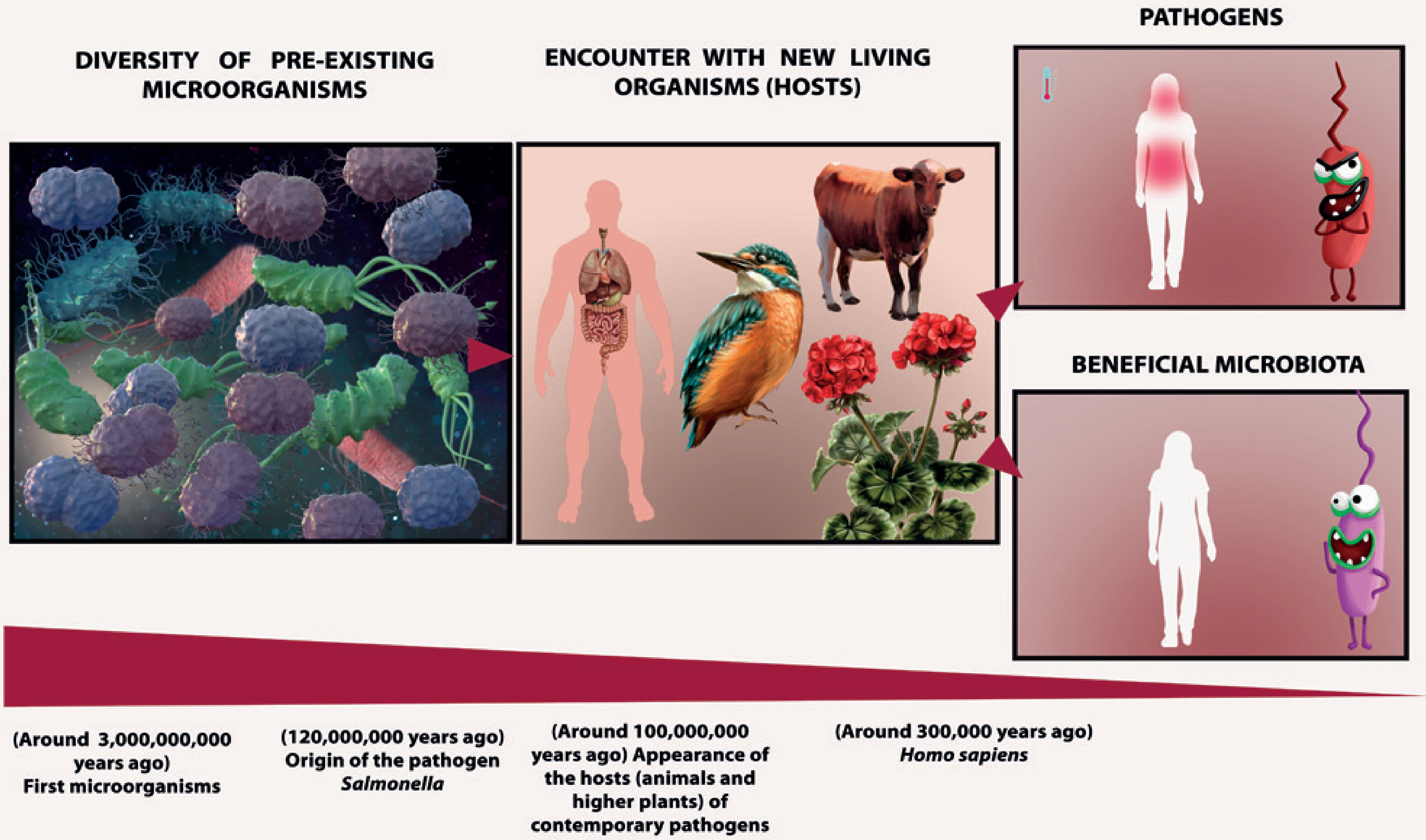
New preservation technologies are numerous, and make use of natural antimicrobial substances, high pressure, ultrasound and ozone treatment.

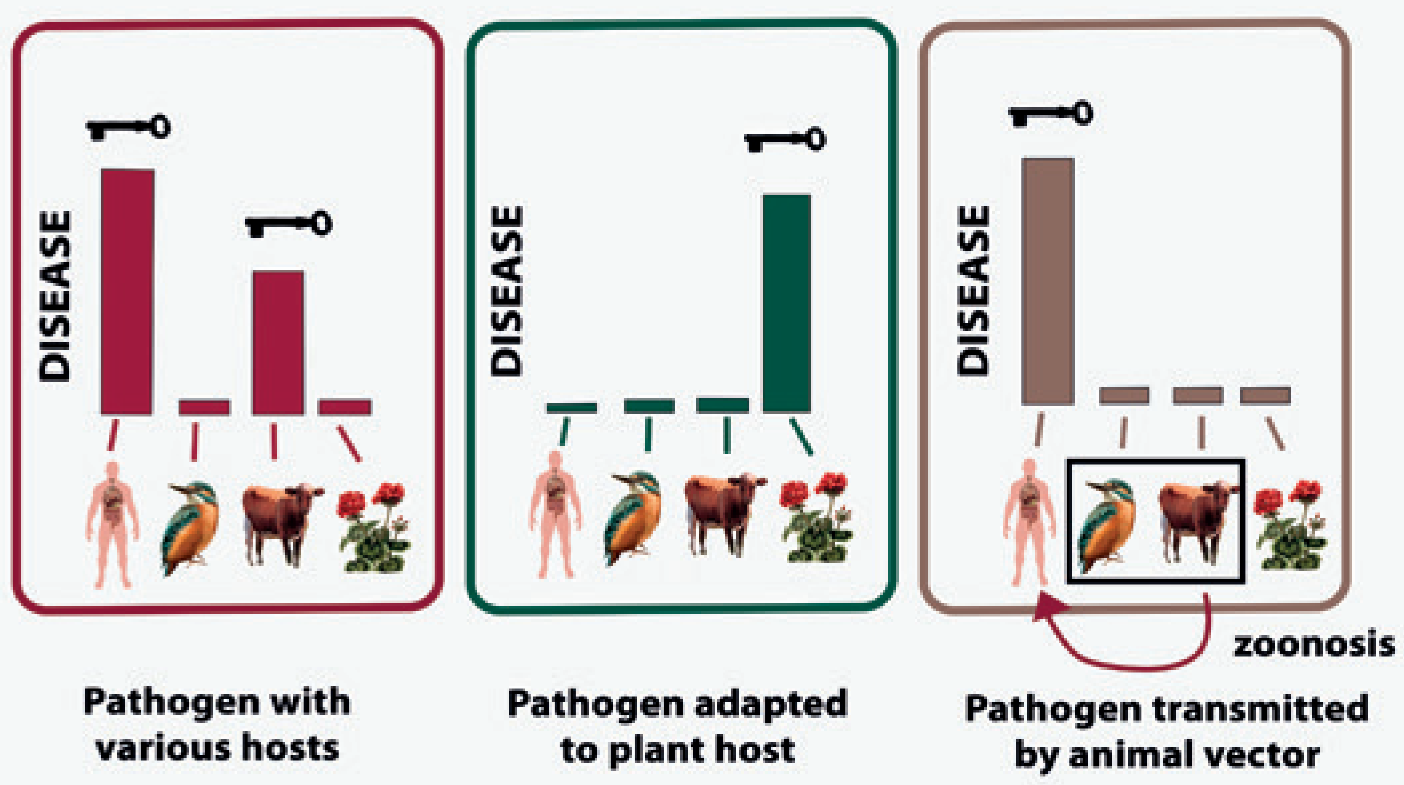
Microorganisms that threaten our health



We are in continuous contact with fungi, bacteria, viruses and protozoa in our environment and within our bodies (skin, mouth, digestive system, etc.). Sometimes, these interactions may affect us negatively and result in infectious illness. Such pathogenic (disease-causing) microbes may reside outside or inside living cells. Viruses are microbes that are strictly intracellular, since they require the machinery of the living cell they infect in order to proliferate.

The origins of pathogenic microorganisms and the diseases they cause:
Diverse microorganisms evolved on our planet long before humans and other complex organisms arose. Thus, **it appears that pathogenic microorganisms preceded their hosts**. When microorganisms encountered new forms of life, some established mutually beneficial relationships with their hosts, such as the **healthy microbiota** within our bodies. Other encounters generated negative confrontations, giving rise to **infectious diseases.** However, the study of these illnesses has shown that both the pathogen and the host evolve in response to one another, often towards establishment of a stable relationship. This produces what we know as **asymptomatic infections,** which are by far the most frequent.



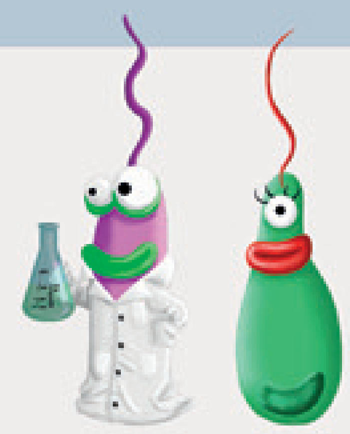


WHAT WE KNOW ABOUT PATHOGENIC MICROORGANISMS

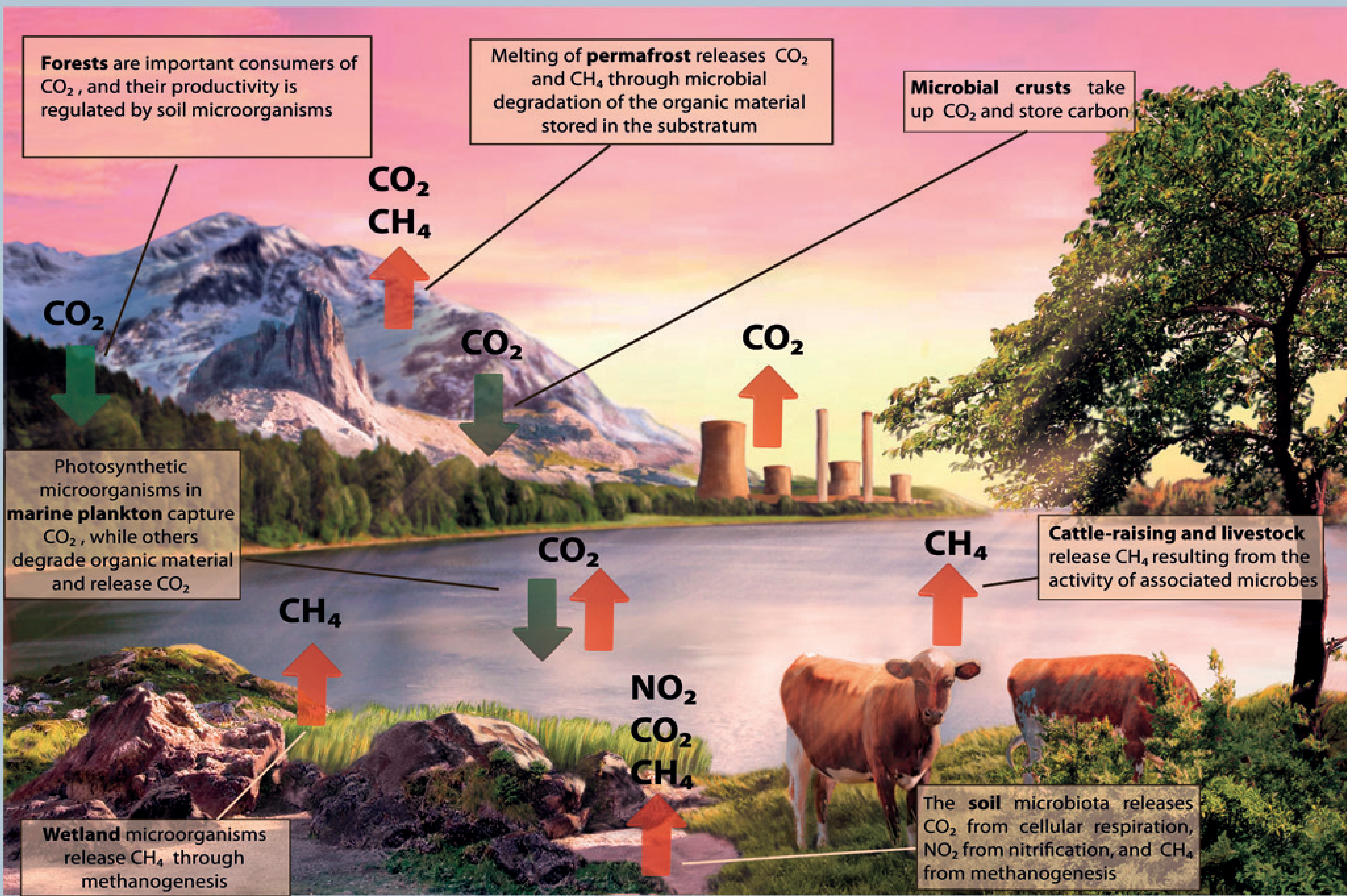
The most successful pathogens, in evolutionary terms, are those that cause the least damage to their host. Maintaining their host in good condition allows them to use it as a vehicle of transmission over a long period of time, as does the human herpes virus.

The pathogen-host interaction has been compared to a "lock and key" mechanism. The pathogenic microorganisms (key) will only produce disease in specific host organisms (lock); there are no "universal pathogens."
rsales".

Microorganisms and global change



Microorganisms REGULATE THE GLOBAL CLIMATE by generating or consuming greenhouse gases



In both terrestrial and aquatic ecosystems, microorganisms contribute to the regulation of global carbon cycles. Many of these microorganisms generate greenhouse gases (CO_2, CH_4 y NO_2), while others specialize in consuming them.

Microorganisms are vulnerable to climate change and human alterations of the environment*

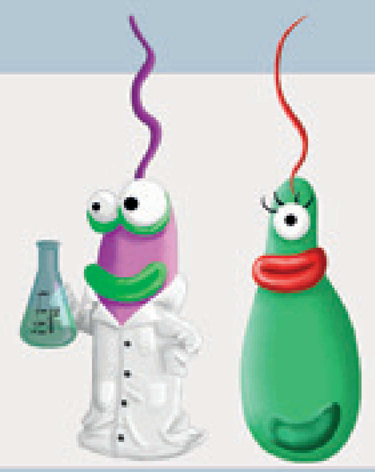
Biodiversity crisis: Many microbial species may disappear in the present Anthropocene

- Those microorganisms incapable of adapting to environmental changes will disappear or be displaced by those better adapted to the new environmental conditions.

- Those microorganism whose habitats are destroyed will disappear.

*** Human activities that affect diversity and function of microbial communities:**
- Change in soil usage and loss of natural habitats
- Eutrophication resulting from massive use of fertilizers
- Overexploitation of marine and terrestrial ecosystems
- Generation of pollutants
- Globalized movement of humans, plants, animals, and consequently microorganisms

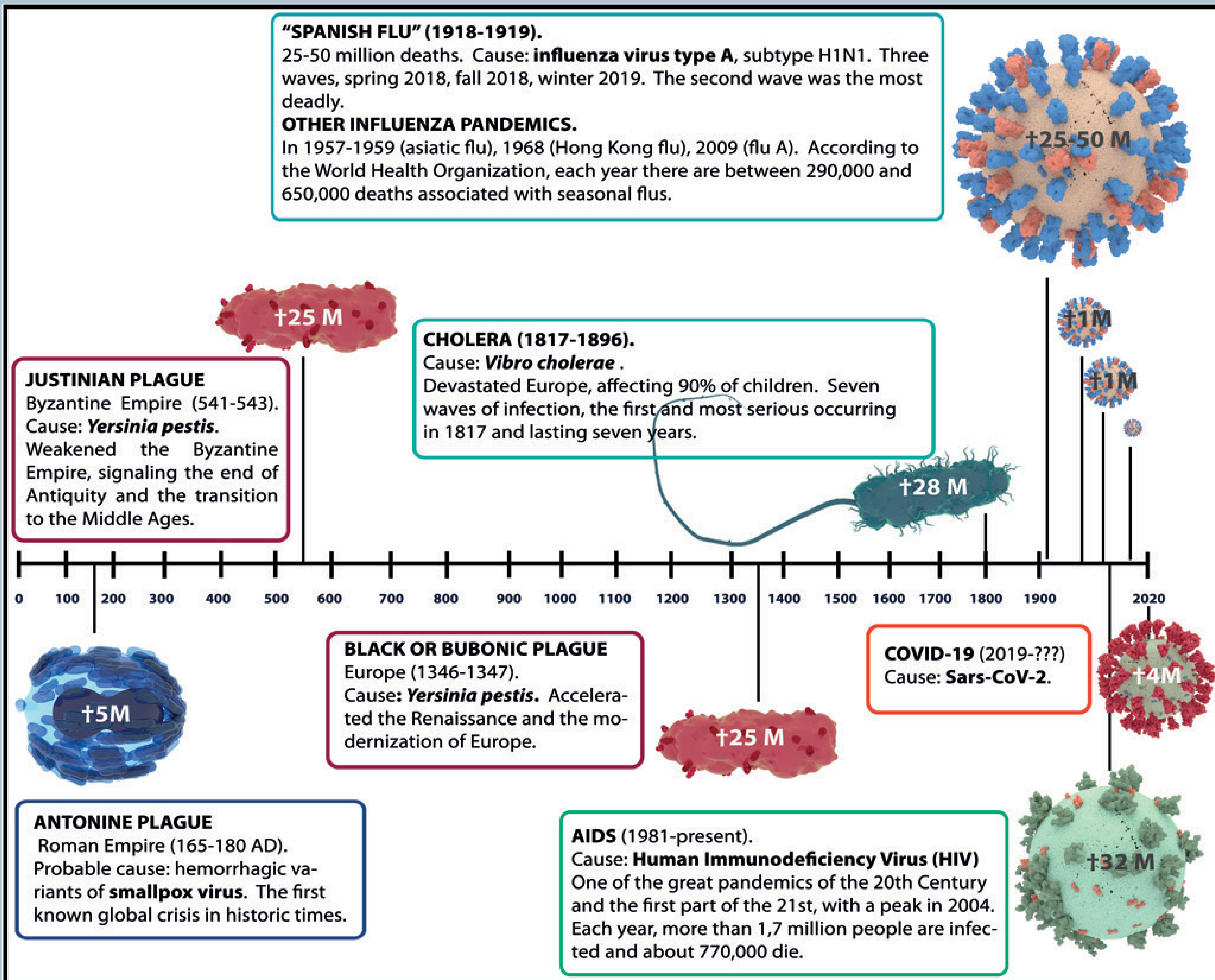
Pandemics throughout history



Breakout: sudden appearance of an infectious disease in a specific place at a given time.

Epidemic: the illness actively spreads and remains over time in a given geographic area.

Pandemic: the epidemic affects more than one continent, and is transmitted across communities.



"SPANISH FLU" (1918-1919).
25-50 million deaths. Cause: **influenza virus type A**, subtype H1N1. Three waves, spring 2018, fall 2018, winter 2019. The second wave was the most deadly.
OTHER INFLUENZA PANDEMICS.
In 1957-1959 (asiatic flu), 1968 (Hong Kong flu), 2009 (flu A). According to the World Health Organization, each year there are between 290,000 and 650,000 deaths associated with seasonal flus.

JUSTINIAN PLAGUE
Byzantine Empire (541-543). Cause: ***Yersinia pestis***. Weakened the Byzantine Empire, signaling the end of Antiquity and the transition to the Middle Ages.

CHOLERA (1817-1896).
Cause: ***Vibro cholerae*** .
Devastated Europe, affecting 90% of children. Seven waves of infection, the first and most serious occurring in 1817 and lasting seven years.

BLACK OR BUBONIC PLAGUE
Europe (1346-1347).
Cause: ***Yersinia pestis***. Accelerated the Renaissance and the modernization of Europe.

COVID-19 (2019-???)
Cause: **Sars-CoV-2.**

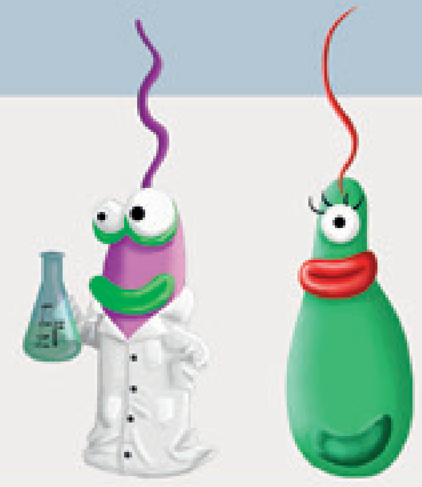
ANTONINE PLAGUE
Roman Empire (165-180 AD).
Probable cause: hemorrhagic variants of **smallpox virus**. The first known global crisis in historic times.

AIDS (1981-present).
Cause: **Human Immunodeficiency Virus (HIV)**
One of the great pandemics of the 20th Century and the first part of the 21st, with a peak in 2004. Each year, more than 1,7 million people are infected and about 770,000 die.

Throughout history, **microorganisms** have caused millions of deaths and been **responsible for economic crises and profound changes in human history**.

There have been many pandemics, including some more devastating than the current Covid-19.

Antibiotic Resistance
a silent pandemic

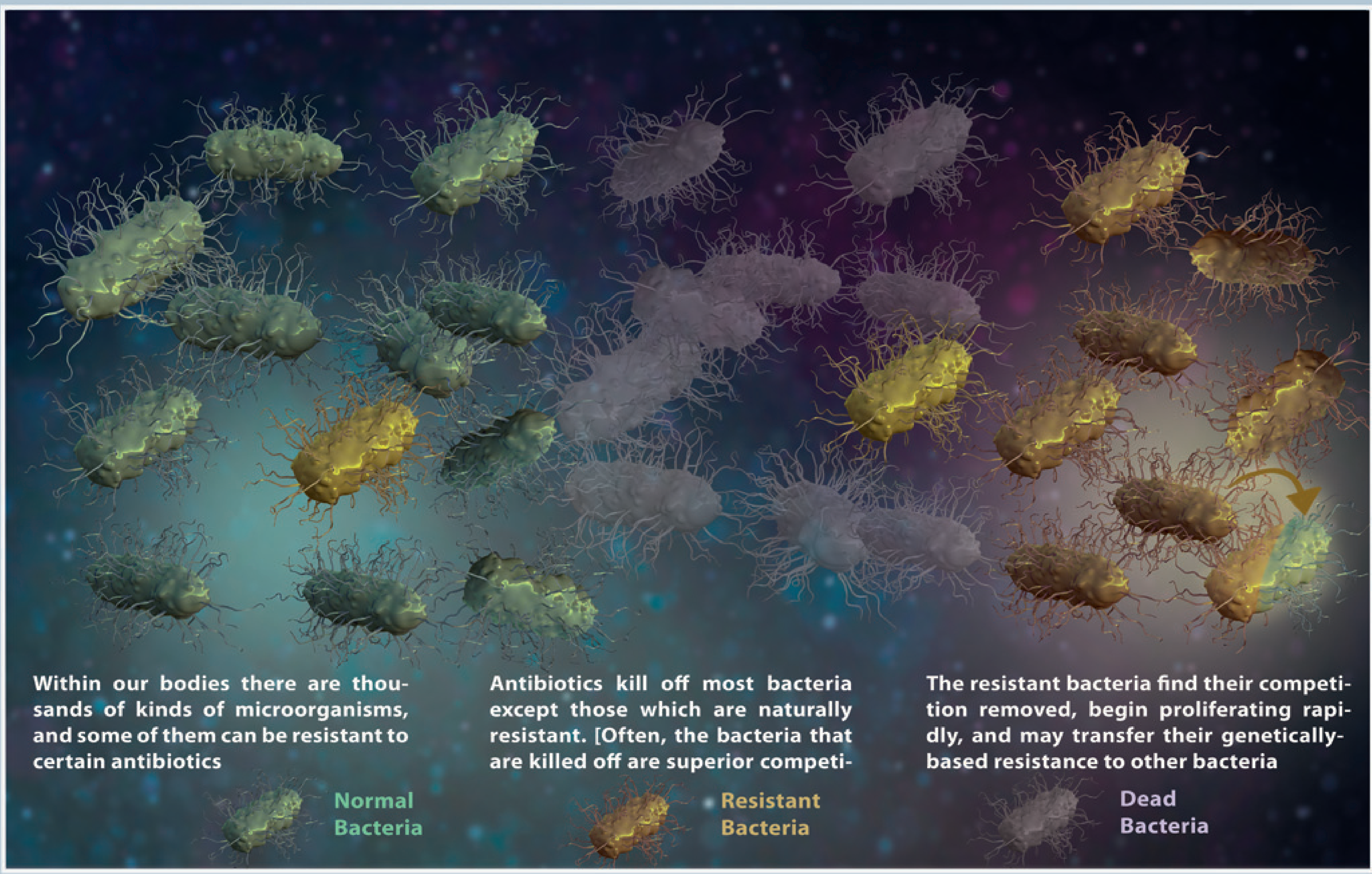


WHAT ANTIBIOTICS HAVE ACHIEVED

In 1928, Alexander Fleming discovered penicillin, which completely changed human history. Previously, people routinely died of infections and wounds, particularly from surgery. But with penicillin and other subsequently discovered antibiotics, surgical operations are successfully carried out worldwide, and we enjoy a level of human health greater than at any other time in our history.

WHERE DO ANTIBIOTICS COME FROM?

Most antibiotics are naturally produced by microorganisms, such as fungi and bacteria, as defensive and competitive weapons against each other, and as tools of communication. Microorganisms have been evolving these weapons, and also the means of resisting those of their competitors, for billions of years in a never-ending arms race.



HOW BACTERIA BECOME RESISTANT

Antibiotics act against bacteria by targeting specific cell processes, thereby inhibiting growth. Any adaptation on the part of the bacteria that interferes with this targeting results in **antibiotic resistance**.

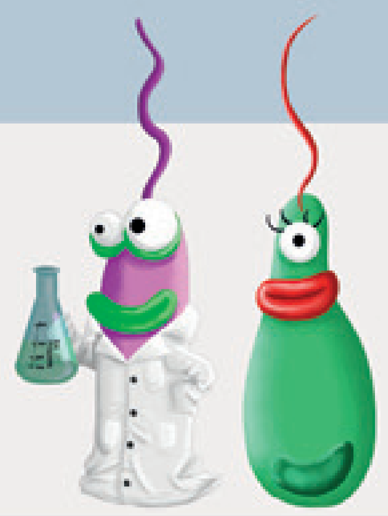
Antibiotic Resistance is the principal human health concern worldwide, and has become the **SILENT PANDEMIC**. Every year the number of deaths due to bacteria that resist all clinical antibiotics rises further.

In Spain, more people die every year of infection by antibiotic-resistant bacteria than of traffic accidents. If no action is taken, in the year 2050 more than 10 million people will die of such infections, equivalent to four Covid-19 pandemics per year. Resistance continues to rise, and the steps currently taken are not capable of slowing it down. **We need a One Health approach,** as recommended by the World Health Organization, such that all countries have a **strategy for fighting against antibiotic resistance**. In Spain, we have a program coordinated by the Spanish Agency for Medicines and Health Products (AEMPS).
More information at https://www.resistenciaantibioticos.es/en.

TAKE-AWAY MESSAGE:
USE ANTIBIOTICS ONLY WHEN NECESSARY AND ACCORDING TO THE DOCTOR'S (OR VETERINARIAN'S) PRESCRIPTION.

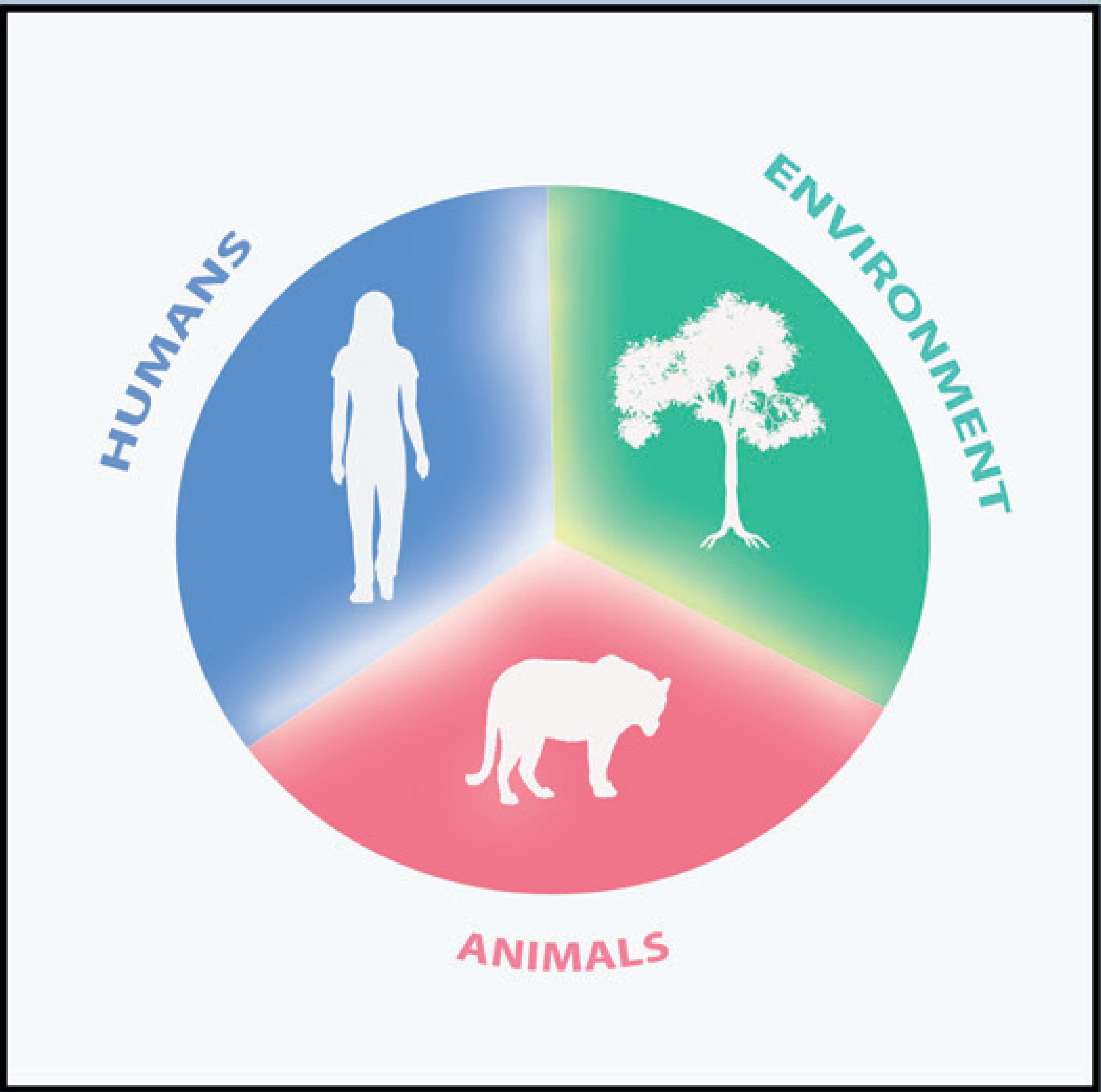
CSIC
250 museo nacional de ciencias naturales
SOCIEDAD ESPAÑOLA DE MICROBIOLOGÍA 75 ANIVERSARIO

One Health Strategy



The One Health Strategy is a new approach to dealing with human health issues that takes into account the health of animals and the environment as well as that of humans themselves.

To understand the movement of microorganisms among animals, humans and the environment and prevent future pandemics, we need collaboration among microbiologists and experts in environmental science, climate science, economics, psychology, medicine, veterinary science and engineering.



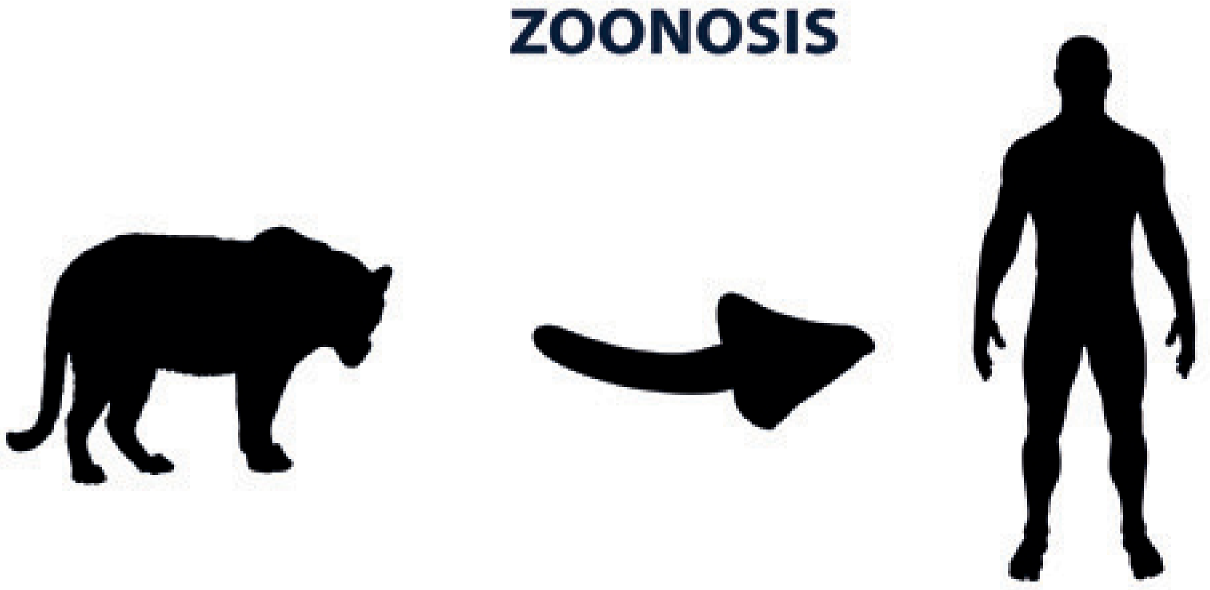
¿WHY IS THIS STRATEGY NEEDED?

We have to prevent **zoonosis**, which is the transmission of infectious diseases from animals to humans.

The **SARS II coronavirus**, cause of Covid-19, comes from very similar coronaviruses that normally infect bats. The virus has managed to jump to a different host species and infect humans, now millions of humans. This is an example of **zoonosis**, as has also occurred with Ebola, influenza, and rabies, among other diseases.

Global climate change and human alteration of the natural environment make microorganisms and their animal vectors (e.g., ticks, mosquitos) change habitat, favoring transmission of new viruses, bacteria and fungi that cause new diseases.

ZOONOSIS



5 new diseases appear each year, three of which originate from animal hosts.

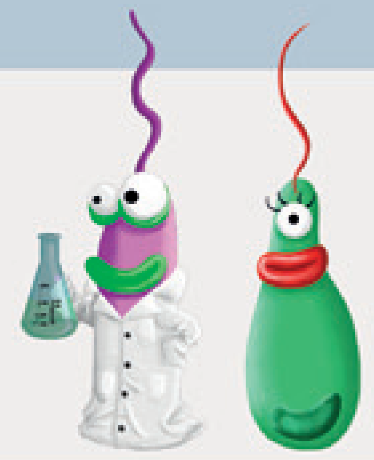
60% of infectious human diseases are zoonotic.

75% of pathogens causing emergent human diseases (Ebola virus, HIV...) originate in animal hosts.

80% of pathogenic agents that might be applied in terrorist attacks are zoonotic

To maintain our health, we need to take care of our planet as well as ourselves. For this we need specialists in different disciplines working together in the study and identification of the microorganisms and parasites that circulate through animal hosts and the environment. This ONE HEALTH strategy will allow us to evaluate and manage the risks of transmission.

Synthetic Microbiology



Microorganisms can be modified genetically to give them new properties or to strengthen their natural ones for use in biomedicine, biotechnology or environmental protection.

Scientists are now designing genomes of microorganims constructed like Lego blocks to carry out specific functions.

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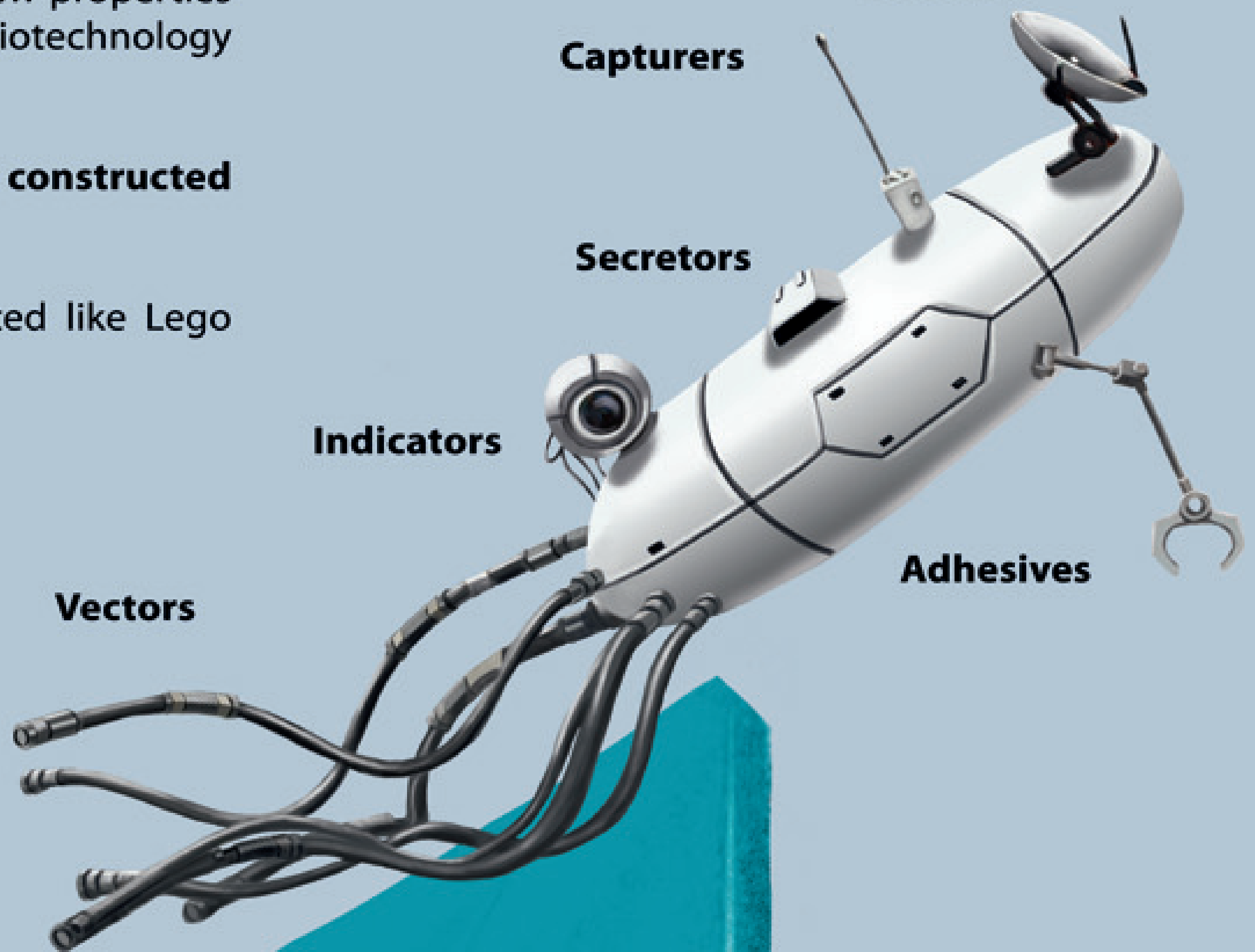
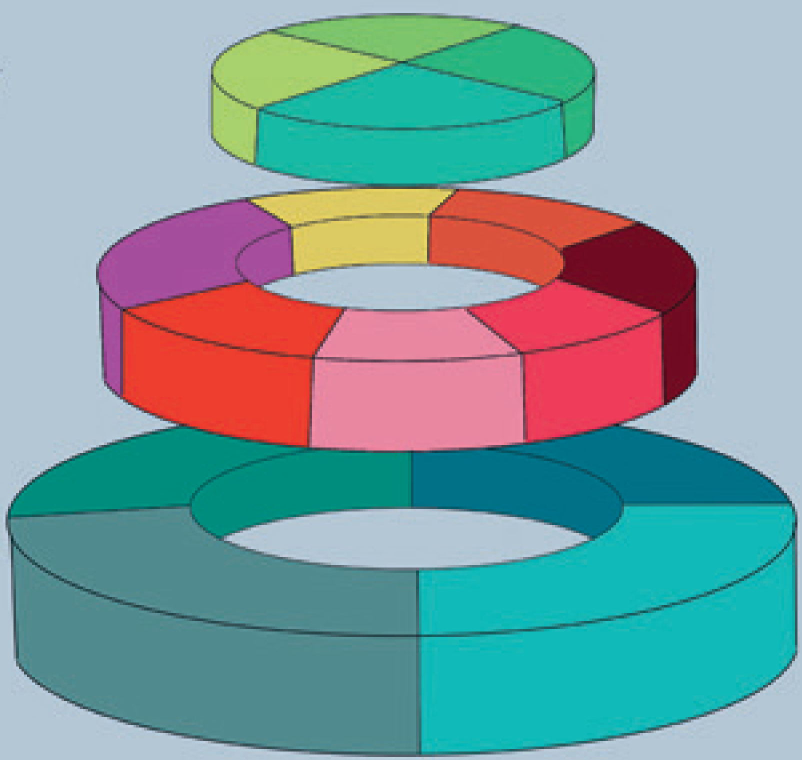


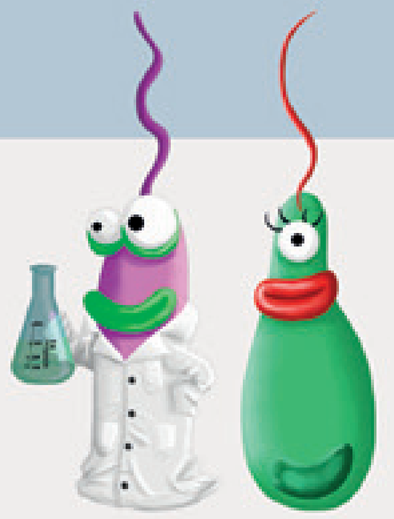


Bacteria and yeasts (fungi) can be converted into micro-vehicles that may one day travel through sick organisms to repair them, or form organized associations optimized to carry out complex tasks, from pharmaceutical synthesis to computation…

Synthetic biology will impact our lives for the better, influencing ecosystems, human and animal health, industrial production, etc., at the center of a circular and sustainable economy.

Synthetic microbiology in now being implemented in many laboratories, and its future development is in the hands of the next generation of scientists.

At the frontiers of knowledge

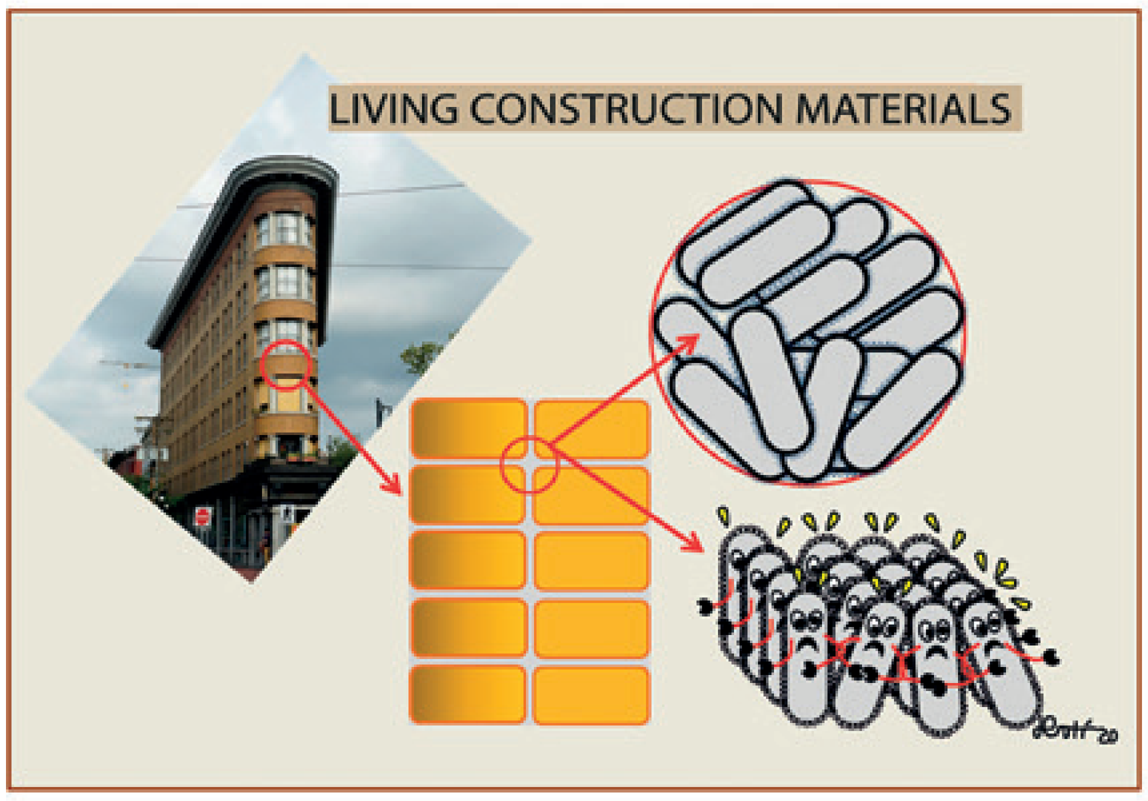


CONSTRUCTING AND RESTORING WITH THE HELP OF MICROORGANISMS

Some microorganisms can generate biominerals – minerals formed by the activity of living cells – and thereby act as biological engineers, creating a cement that protects and consolidates degraded stone. This helps support sustainable construction.

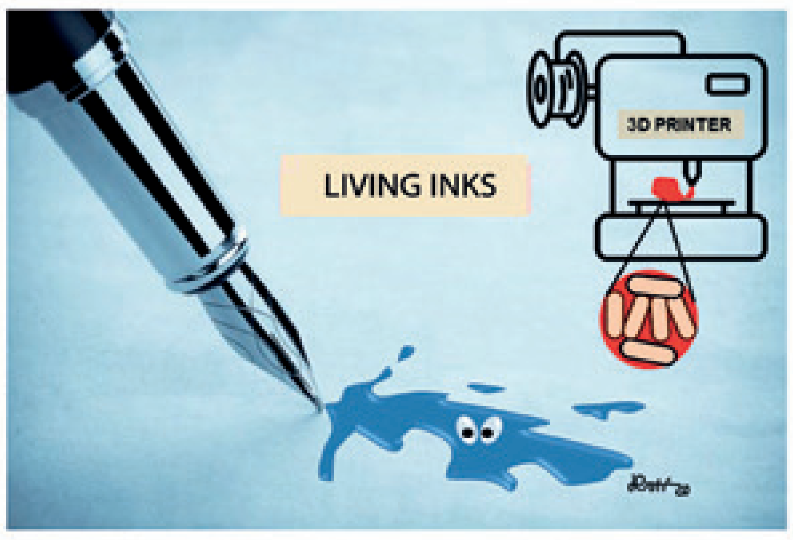
Bio-cement formed from sand, hydrogel and photosynthetic bacteria with durability similar to that of mortar*.

**C. M. Heveran CM, Williams SL, Qiu J, Artier J, Hubler MH, Cook SM, Cameron JC, Srubar III WV.*
Universidad de Boulder (Colorado, USA)

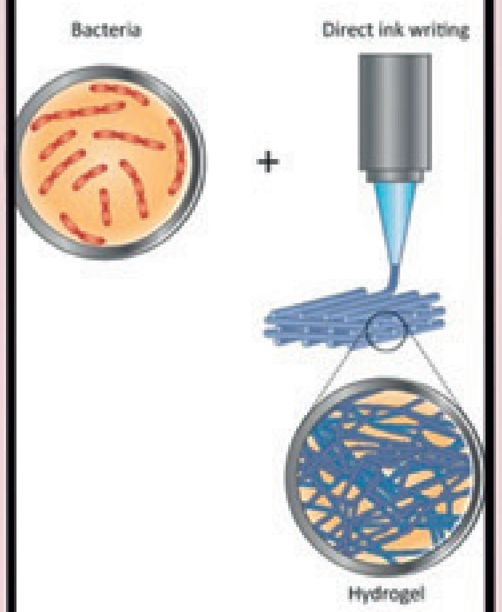


Credit:s Juan Carlos Gutiérrez

brick of reinforced bio-cement*



Credits: Juan Carlos Gutiérrez



Credits: Juan Carlos Gutiérrez

LIVING MICROBIAL INK IN BIOTECHNOLOGY

3-D bioprinting, with "inks" created by microorganisms embedded in a hygroscopic polymer, has applications with great potential.

Printed platforms can be applied to increase yield of certain biotechnological processes.

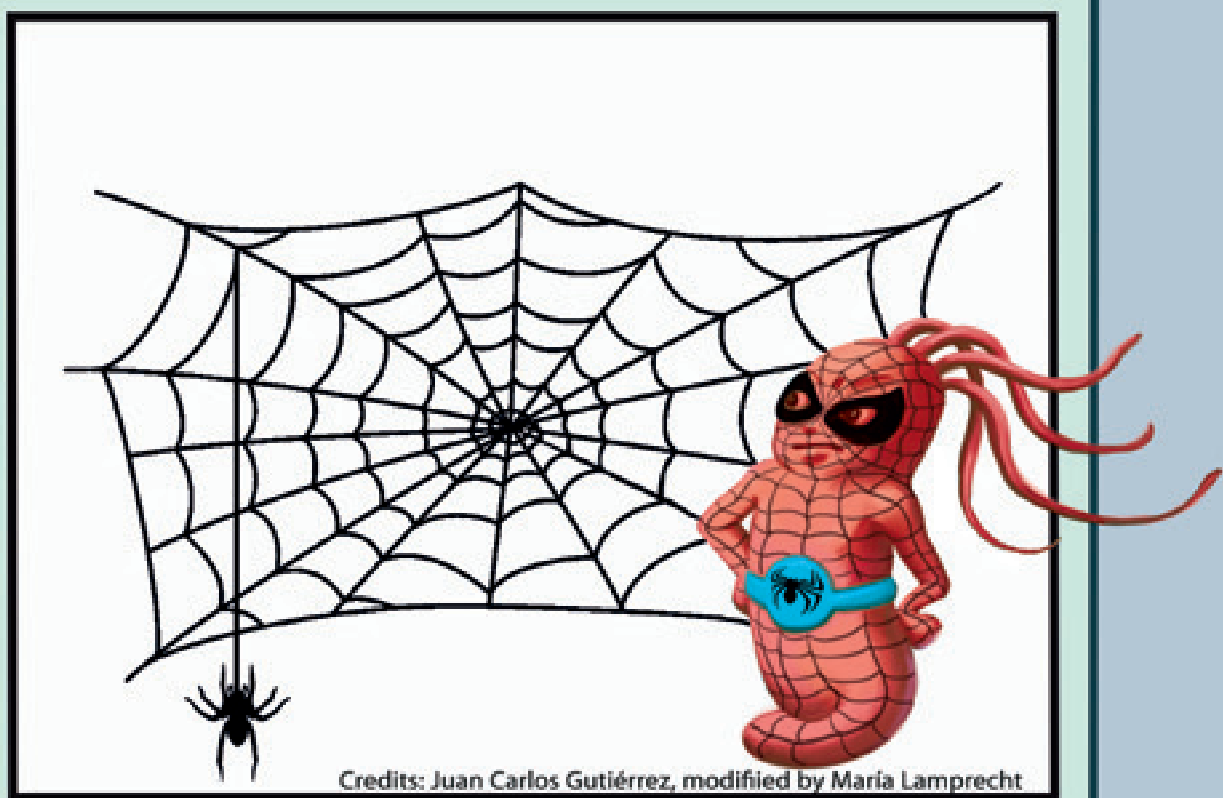
The systems become more robust and are better conserved when the ink is composed of bacterial spores rather than vegetative cells.

MICRO-MANUFACTURE OF TEXTILES TO ORDER

Spider silk is one of the most resistant and elastic fibers known. This bio-compatible, biodegradable and hypoallergenic material is five times stronger than steel and three times stringer than nylon, making it useful in the creation of materials such as surgical sutures, optical fibers, micro-conductors, or highly resilient military materials.

However, 1.2 million spiders would be needed to generate a single bullet-proof vest.

Nowadays, bacteria and yeasts may be modified genetically so that they produce spidroins (spider silk proteins) that can be used to make these products.



Credits: Juan Carlos Gutiérrez, modified by María Lamprecht