Ecological Significance of Viruses

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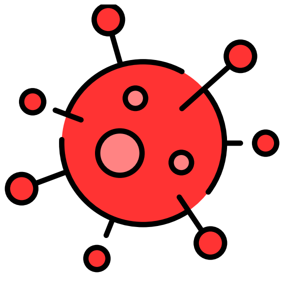
2020-12-11

DISCLAIM

This is **NOT** a lesson about Sars-Cov-2



Last lesson recap

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Last lesson recap

1. The plant-associated microbiome can provide benefits to the plant through various direct or indirect mechanisms
2. Disease-suppressive soils are exceptional ecosystems in which crop plants suffer less from specific soil-borne pathogens than expected owing to the activities of other soil microorganisms
3. Induced Systemic Resistance (ISR) is initiated in roots by plant-growth-promoting microbes (PGPM) and leads to resistance priming in distant parts of the plant
4. Correlation is not causation
5. Microorganisms have a role in cooperative or competitive interactions with other members of the microbiome

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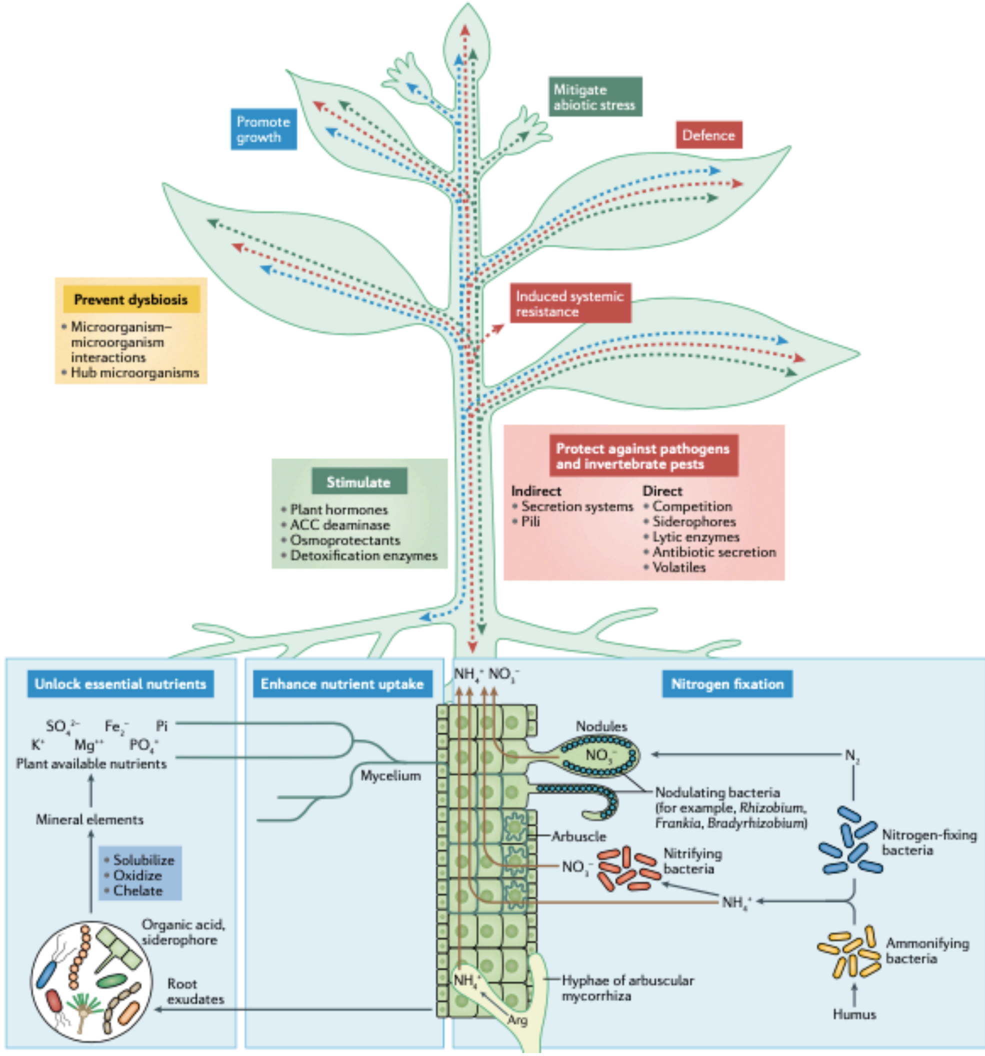

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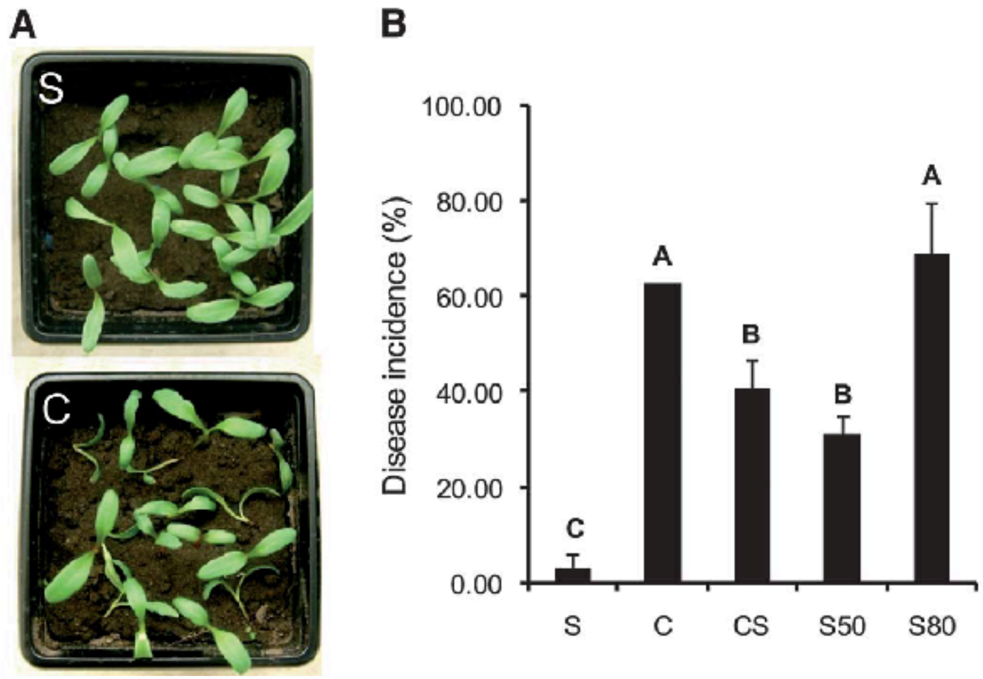

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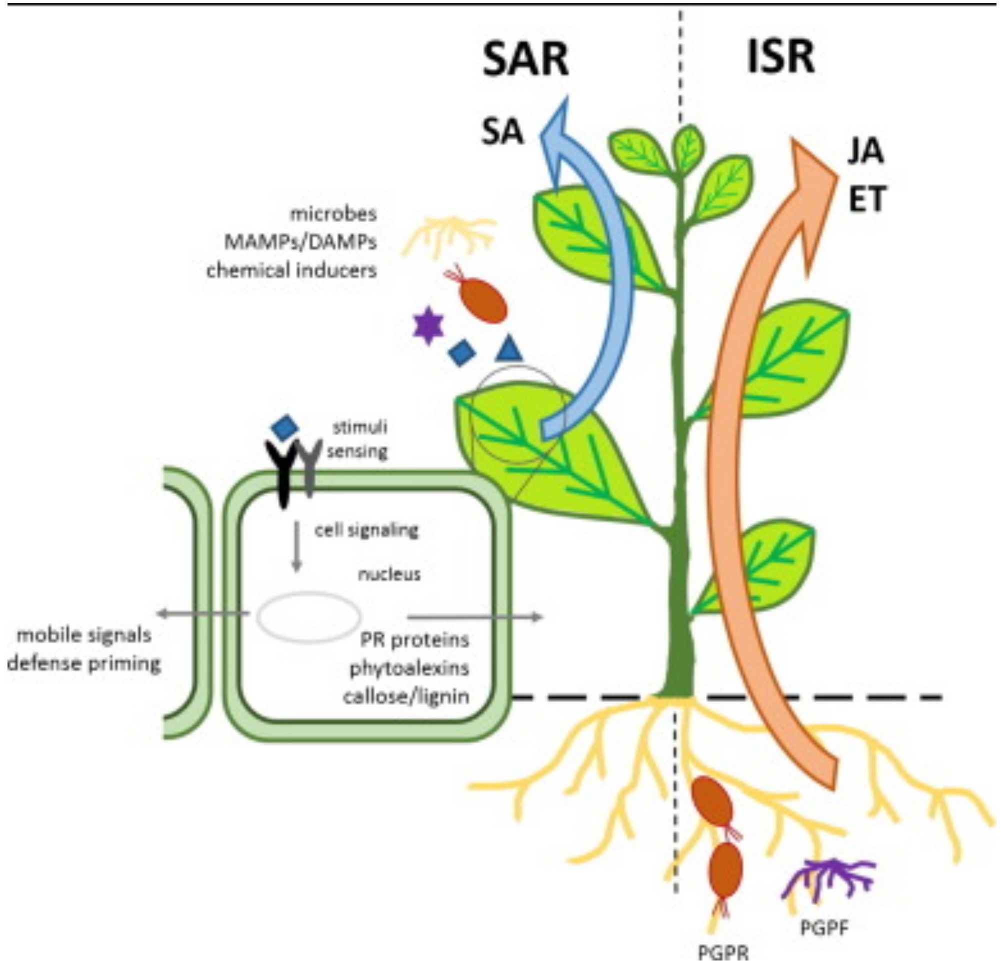

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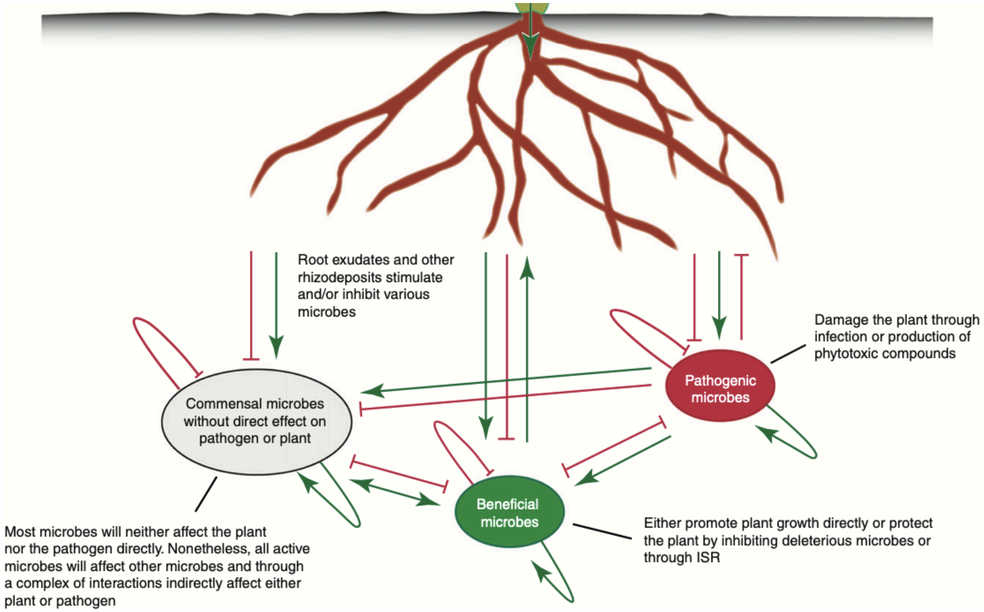

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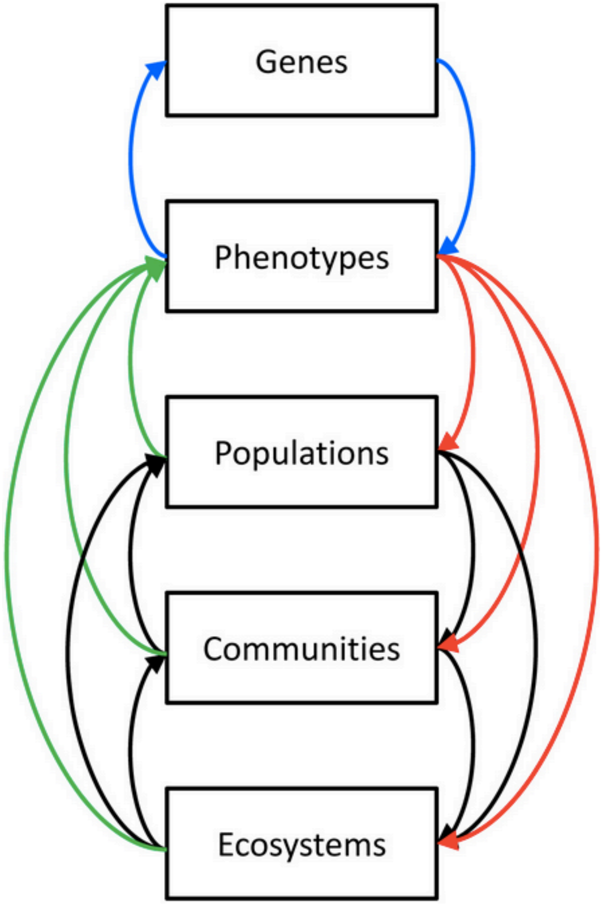

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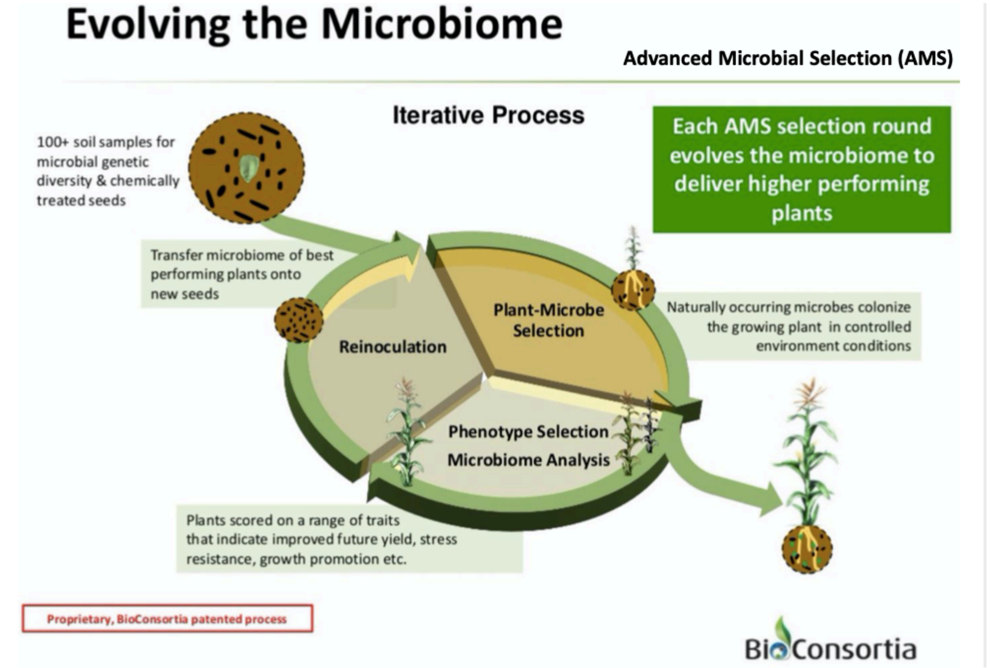


Virus short surveys

What is a Virus?

What is a Virus?

Who has

right now, among us

a viral infection?

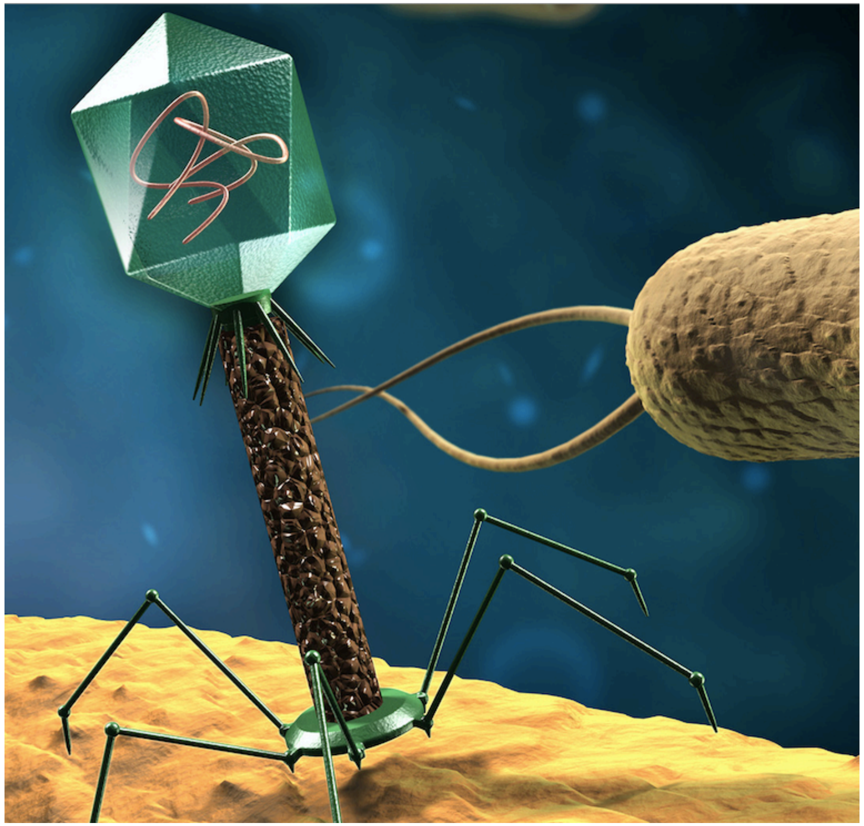
What is a Virus?

We live and prosper in a cloud of viruses

- Viruses infect all living things
- We regularly eat and breathe billions of viral particles
- We carry viral genomes as part of our own genetic material

How many viruses are out there?

- In the world's waters (salt water) there are 10^{30} bacteriophage (viruses that infect bacteria) particles
- 10'000'000'000'000'000'000'000'000'000'000
- A bacteriophage particle weight about a femtogram (10^{-15} grams)
- ❗ $10^{30} \times 10^{-15}$ = biomass on the oceans of the bacteriophages. This exceeds the biomass of elephants by more than 1000-fold!
- The length of a head to tail line of 10^{30}

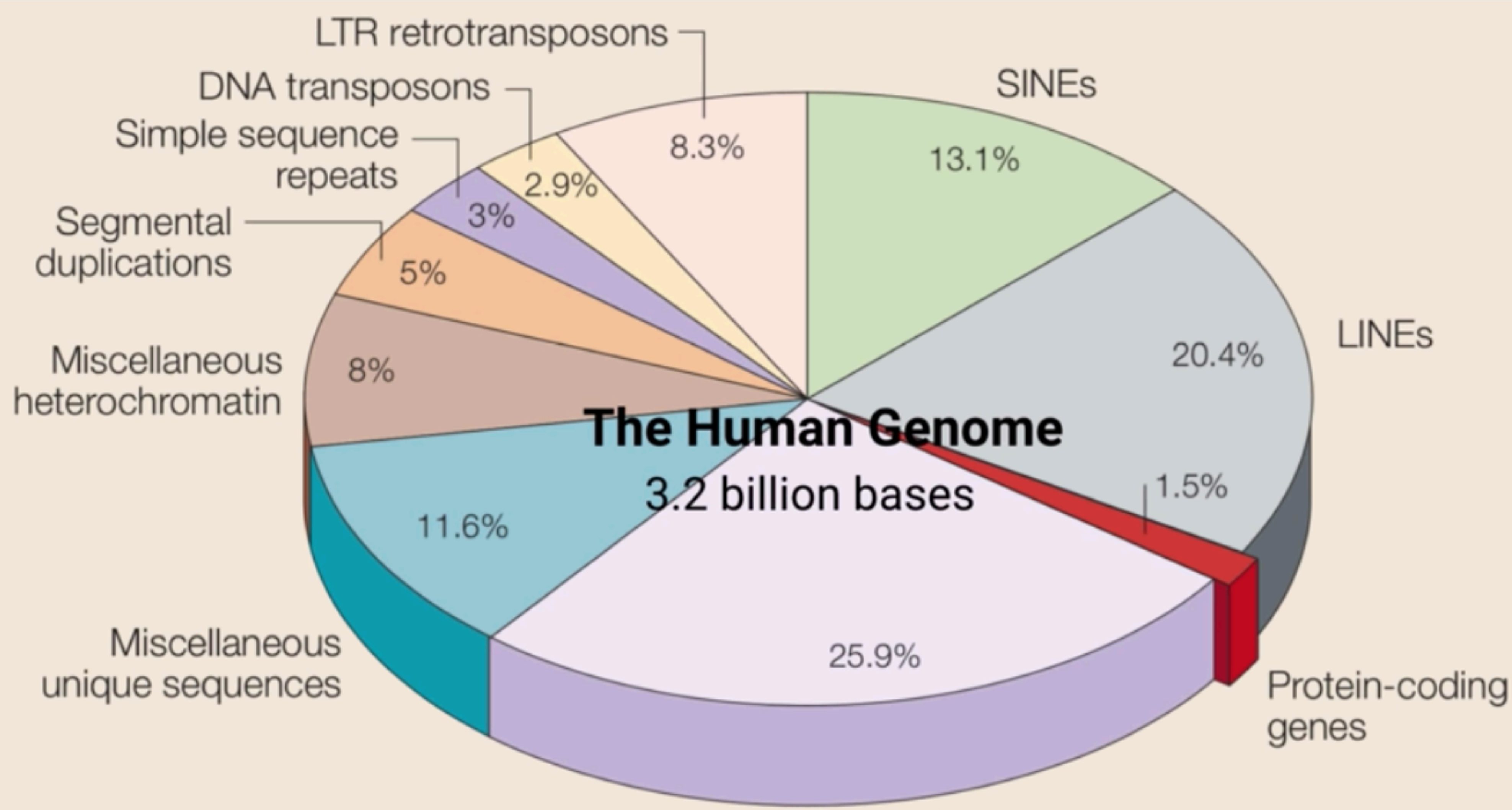


What is a Virus?

VIROME

- The human virome is the total collection of viruses in and on the human body
- Some viruses cause disease, while others may be asymptomatic or just pass by
- There are roughly 40 trillion bacteria in a typical human microbiome, and generally virions outnumber bacteria 10:1

What is a Virus?



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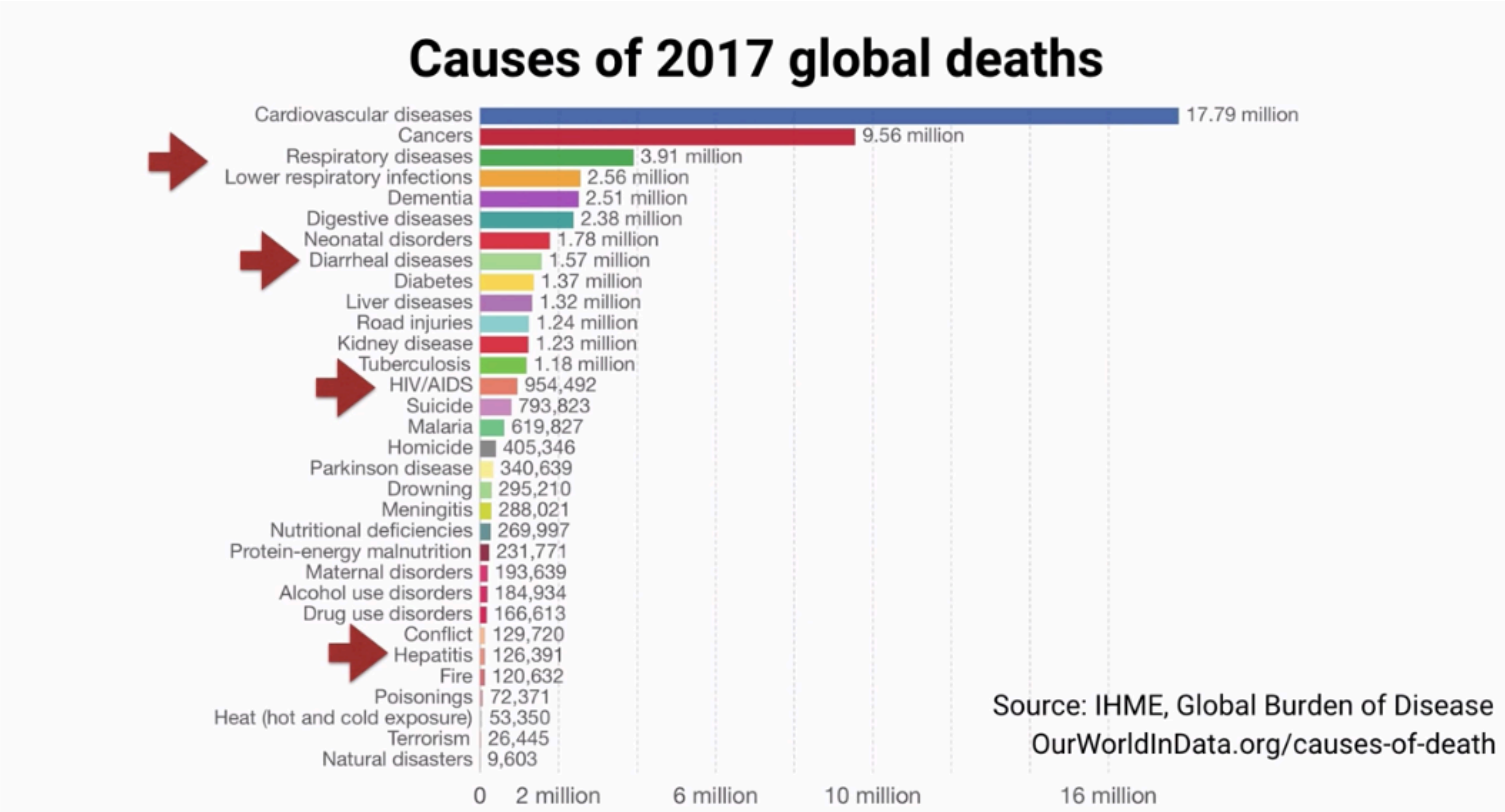
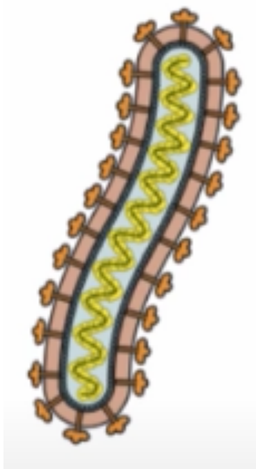


Most viruses just pass through us

- We ingest many non-animal viruses regularly with foods
    - Cabbage from 5 different supermarkets in Washington D.C.
    - Each serving (~100 cm^2 of leaf material) would contain up to 10^8 particles of virus pathogenic for the cabbage looper (caterpiller)
- Study on human feces:
    - Most RNA virus sequences (91%) were similar to plant virus
    - Most abundant human fecal virus:



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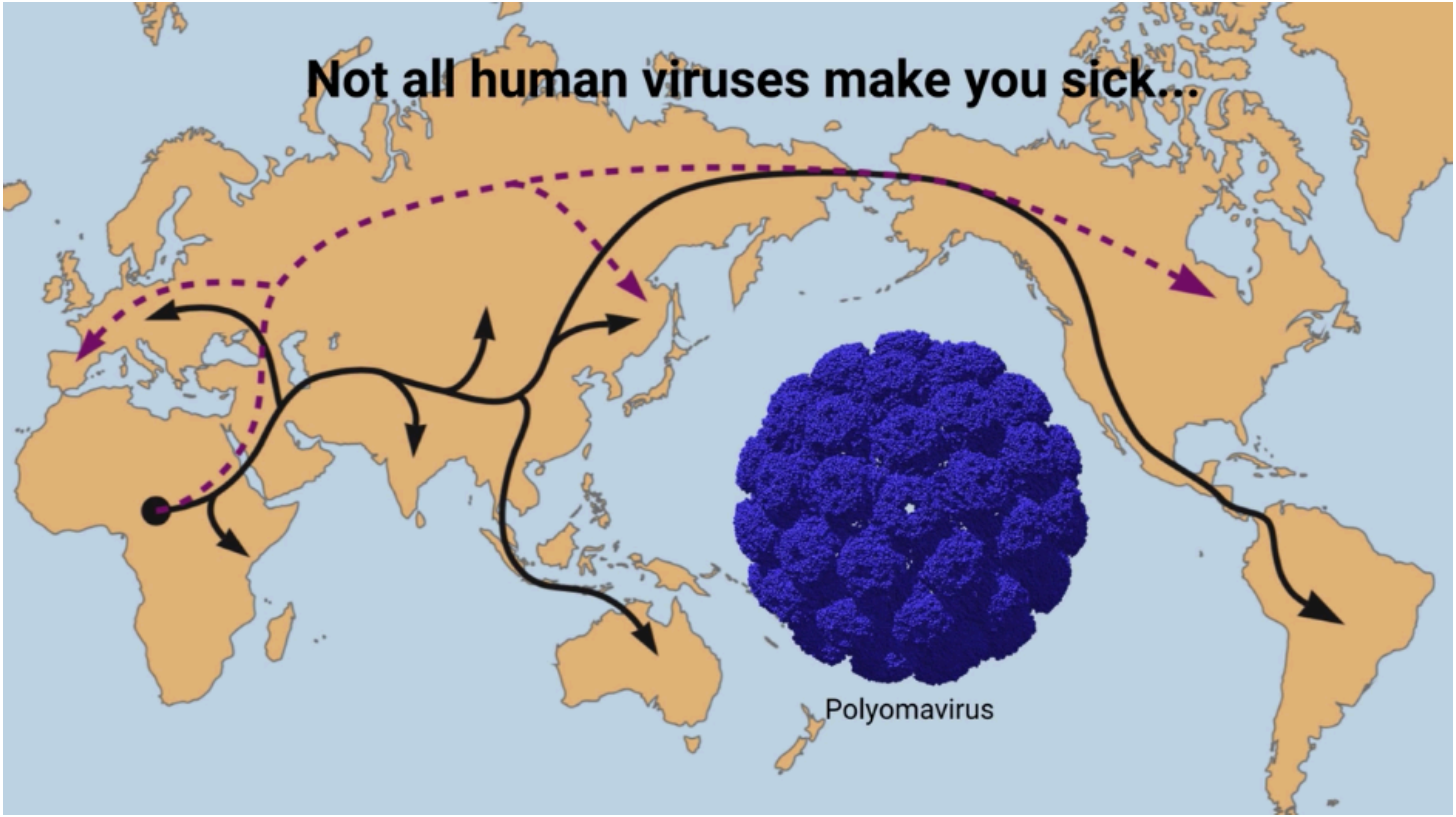


What is a Virus?

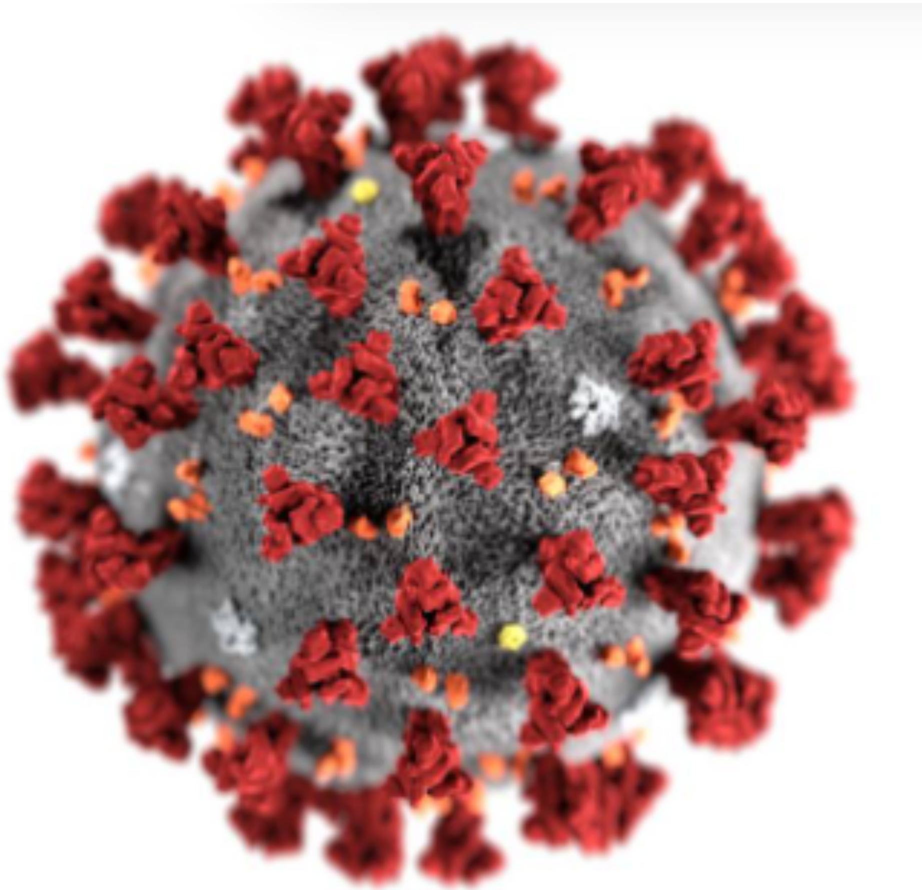
What is a VIRUS?

- A virus is a submicroscopic **infectious** agent that replicates its **genetic material** (DNA or **RNA**) only inside the living cells of an organism (**obligate intracellular parasites**)

- Viruses are often surrounded by a protein coat, somethime a membrane

- Viruses **use the host's cells to replicate** by forcing it to rapidly produce thousands of identical copies of the original virus

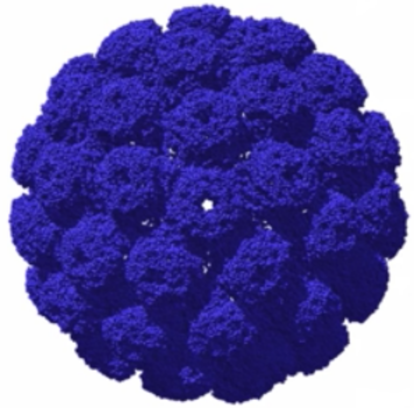
- When not inside the host, viruses



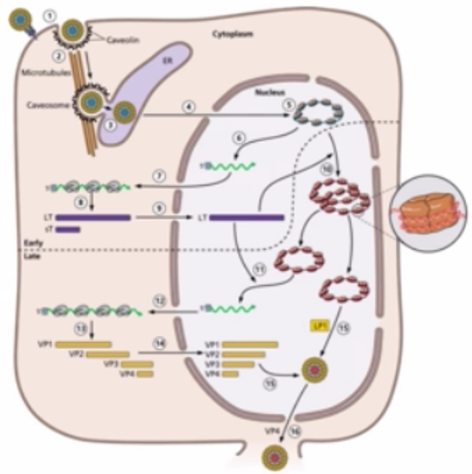
What is a Virus?

Are virus a life form?

- Viruses **can't capture or store any energy**, so they **rely on the cells of other organisms** to survive and reproduce
- They can not function outside a host organism! Owing on that they are often **regarded as non-living**
- On the other hand they **carry genetic material**, **reproduce**, and **evolve** through natural selection
- Viruses are considered by some biologists to be a life form
- Vviruses have been described as "**organisms at the edge of life**"



virion (infectious particle)



infected cell

Viruses do NOT think

They do not achieve their goal in a human-centered manner

Viruses are passive agents

Agenda

- Ecological Significance of Viruses 🦠
  - Ecological Importance of Viruses in the Oceans
  - Endogenous Virus Elements and Beneficial Infection in Vertebrates
  - Mycovirus involved in mutualistic symbiosis

Ecological Importance of Viruses in the Oceans

Ecological Importance of Viruses in the Oceans

- The oceans cover **more than 70%** of the Earth’s surface
- They control the **climate**, provide a significant amount of the **protein** that is consumed globally and produce approximately **half of the Earth’s oxygen**
- Microorganisms are a major force behind the **nutrient and energy cycles** in the world’s oceans
- It is estimated that **viruses kill approximately 20% of this biomass per day**
- As well as being agents of mortality,

Ecological Importance of Viruses in the Oceans

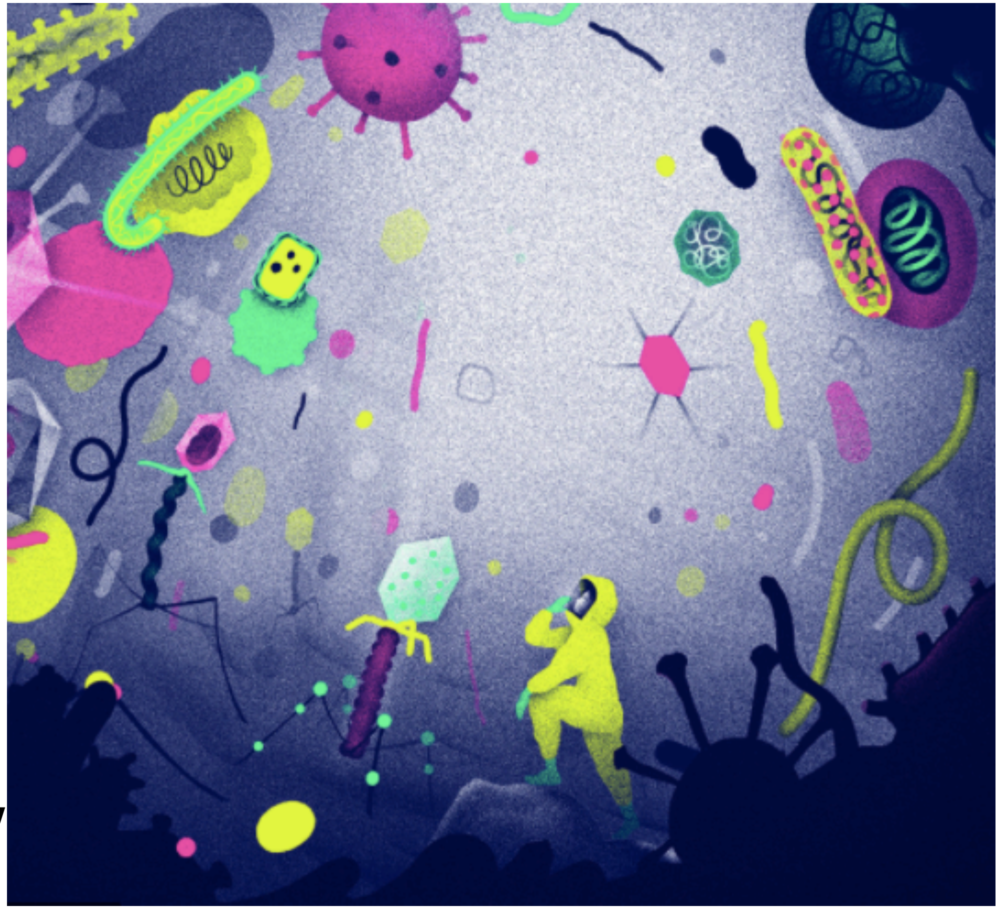
- **Virosphere** is the portion of the Earth in which viruses occur or which is affected by viruses

- The virosphere is inclusive of **every environment on the Earth**, from the atmosphere to the deep biosphere

- Nowhere is the importance of viruses more evident than in the world's oceans

- Viruses are substantial **agents of mortality** in heterotrophic and autotrophic plankton

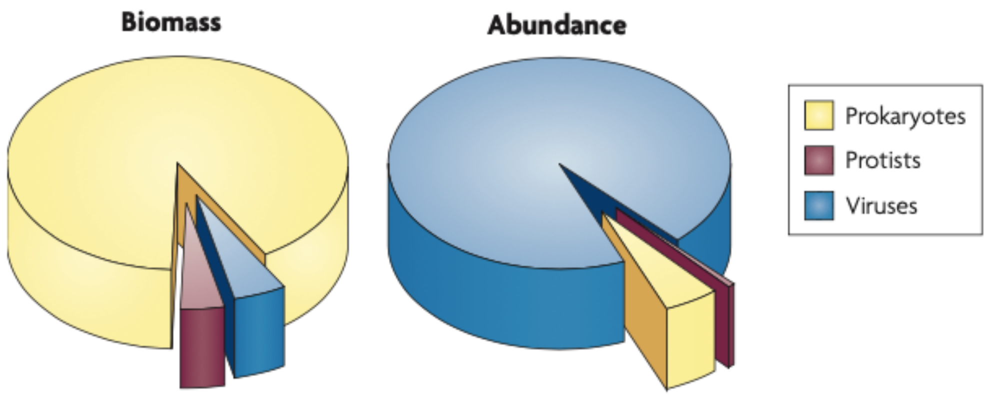
- Viruses are major players in the mortality of marine microorganisms and, consequently, **affect nutrient and energy cycles** as well as the structure of microbial communities



Ecological Importance of Viruses in the Oceans

The abundance of marine viruses

- The abundance of viruses in oceans exceeds that of bacteria and archaea by approximately 15-fold and comprising approximately **94% of the nucleic-acid-containing particles**
- However, because of their extremely small size, viruses represent only approximately **5% of the biomass**
- In the oceans, viral abundance decreases further offshore and deeper in the water column because

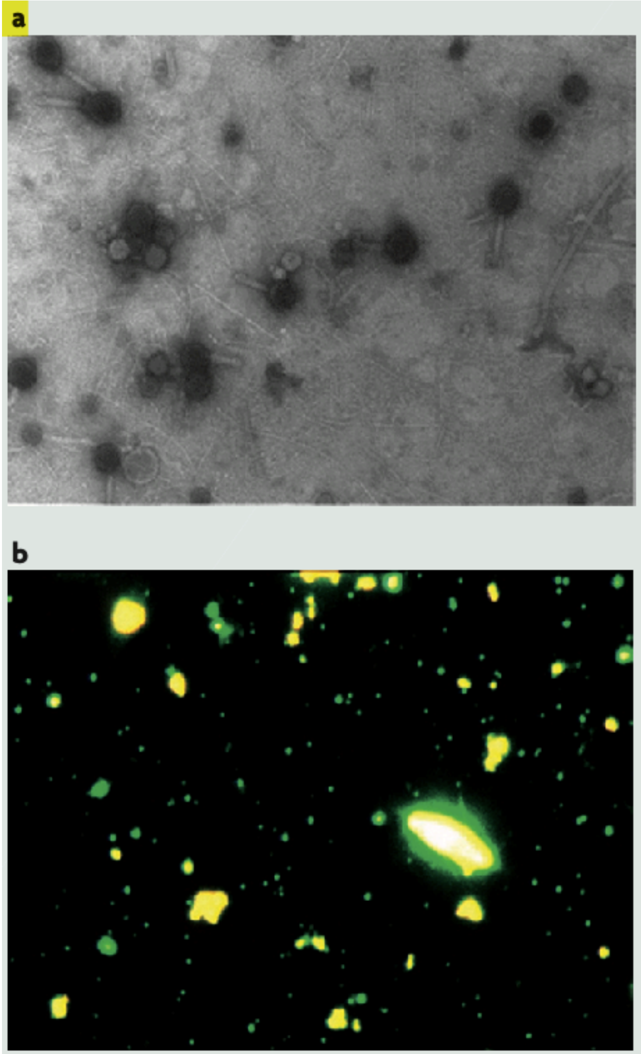


(Suttle, 2007)

Ecological Importance of Viruses in the Oceans

The abundance of marine viruses

- Six methods are used to estimate the abundance of viruses in aquatic samples
    - plaque assays (PAs) and most-probable-number assays (MPNs): are used to quantify the abundance of infectious units that cause the lysis of a particular host.
    - transmission electron microscopy (TEM): TEM is the only method that provides data on both the abundance and morphology of virus-like particles (fig a)
    - **epifluorescence microscopy** (EfM): the viruses are concentrated on a membrane filter, their nucleic acids are stained with a brightly fluorescent dye and the abundance of viruses is estimated (fig b)
    - flow cytometry (FC): accurate high-



Ecological Importance of Viruses in the Oceans

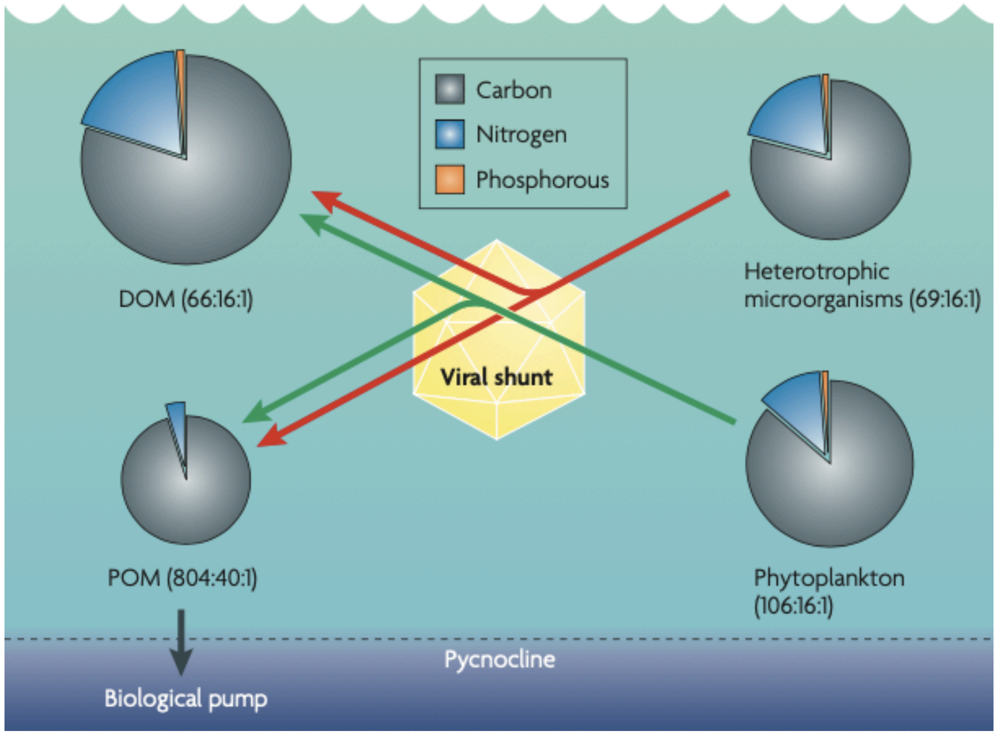
Viruses, mortality and elemental cycling

- As agents of mortality, viruses have a range of effects on the world's oceans, from altering geochemical cycles to structuring populations and communities.
- 20-40% of prokaryotes in surface water are removed by viruses every day (similar to the amount killed by grazing)
- Increase in the rate of viral reproduction in response to an increase in the growth rate of host cells is a strong feedback mechanism that would probably prevent dominance by the fastest growing taxa

Ecological Importance of Viruses in the Oceans

Viral shunt

- **Viral shunt**: the viral-mediated movement of nutrients from organisms to pools of dissolved and non-living particulate organic matter
- The viral shunt moves material from living organisms into **particulate organic matter** (POM) and **dissolved organic matter** (DOM)
- However, the effects can also be more profound and potentially include:
  - the **release of dimethyl sulphide**, a gas that affects the Earth's climate
  - the **remobilization of the organically complexed iron** that limits primary production in much of the world's oceans (for example, the viral lysis of prokaryotes liberates sufficient amounts of biologically available iron to support the needs of



(Suttle, 2007)

Ecological Importance of Viruses in the Oceans

Viral shunt in recycling DoM

- DOM, the **largest reservoir of carbon in the oceans**, is only available for uptake by bacteria
- There are **two main forms of bacterial mortality**: predation by unicellular eukaryotic grazers or lysis by phages
    - **Grazing** moves carbon up through the trophic levels from bacteria to protozoa to zooplankton to fish and larger organisms
    - When bacteria are **lysed by phages**, carbon and nutrients flow through the viral shunt and are remineralized by bacteria within the microbial loop, making the viral shunt function as the ocean's recycling system

Ecological Importance of Viruses in the Oceans

Viral shunt in recycling PoM

- The biological pump (BP) is a combination of processes that leads to the sequestration of carbon in the deep ocean as the result of the sinking of **PoM** from surface waters
- The amount of carbon that is exported by the BP has direct implications for the concentration of carbon dioxide in the atmosphere
- Carbon from cell lysis will sink more slowly and be retained to a greater extent in surface waters, where much of it will be converted to dissolved inorganic carbon by respiration or solar radiation

Ecological Importance of Viruses in the Oceans

Viruses manipulate the marine environment

- Until now we focused on two areas:
    - **viruses as pathogens** of aquatic organisms
    - **virus-driven dynamics** of the marine microbial food web
- Marine viruses can affect their hosts and environments in startling ways:
    - **Global transfer** of niche adaptation genes
    - Modifications of the **ontogeny and ecology** of marine organisms

Ecological Importance of Viruses in the Oceans

Virally encoded host genes

- Phage are known to carry and **transfer a variety of host genes**
- Most studies of this phenomenon have focused on the negative effects, but **viral infections can augment the metabolism, immunity, distribution and evolution of their hosts** in many unexpected and potentially positive ways

Ecological Importance of Viruses in the Oceans

Virally encoded host genes

Accessory gene expression

- Consider the **cyanobacteria**l which together account for about 25% of global photosynthesis
- Sequencing of the marine viral **cyanophage**s that infect these primary producers showed that **genes involved in photosynthesis** are commonly carried in phage genome
- During the lytic cycle, most of the host's transcription and translation is **shut down by phage**
- By expressing genes involved in photosynthesis, **phage generate the energy necessary for viral production**

Ecological Importance of Viruses in the Oceans

Virally encoded host genes

Horizontal gene transfer

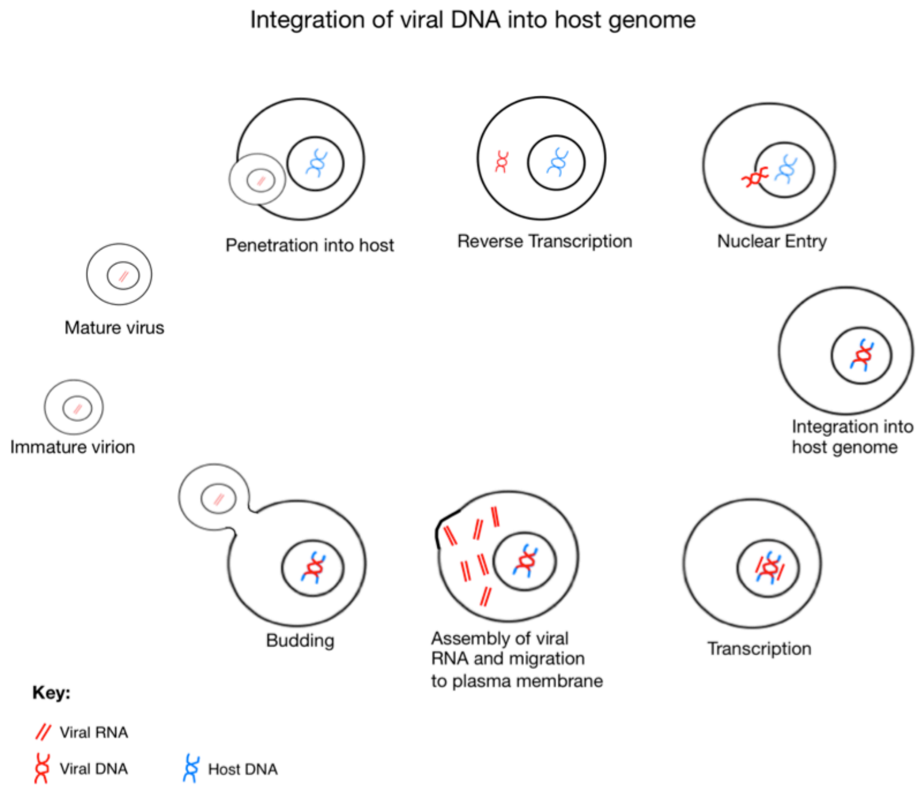
- One consequence of cyanophage carrying genes involved in the photosynthesis is the **horizontal gene transfer of photosynthetic genetic elements** between hosts
- Specific ecotypes that live in different parts of the water column and are **tuned to the different light and nutrient regimes**
- Given the prevalence of phage-encoded photosynthesis proteins and the occurrence of recombination between phage and host genes, phage populations are expected to **serve as gene reservoirs**

Endogenous Virus Elements

Endogenous Virus Elements

What is endogenization?

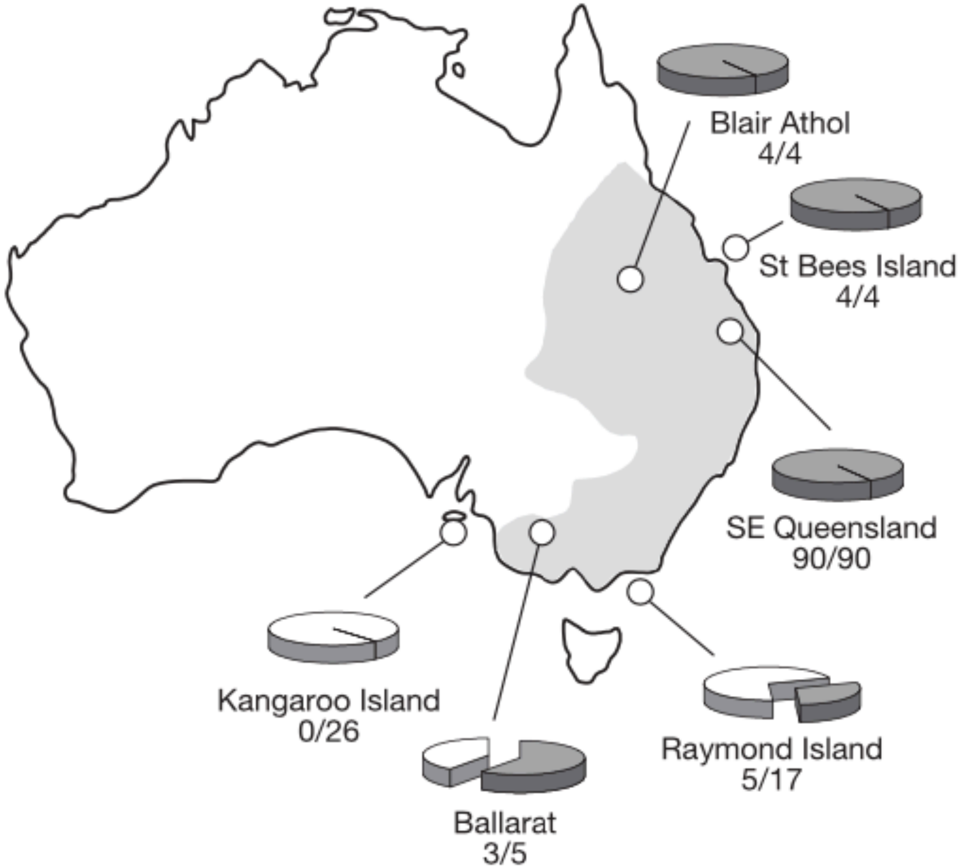
- An endogenous viral element (**EVE**) is a viral DNA sequence, present within the germline of a non-viral organism
- EVE may be entire viral genome or a fragment of viral genome
- EVEs are **usually eliminated** from the host gene pool within a small number of generations, but they can sometimes **reach fixation**
- EVEs that occur as **proviruses** can potentially remain capable of **producing infectious virus**



Endogenous Virus Elements

Retroviral invasion of the koala genome

- Endogenous retroviruses are a **common ancestral feature of mammalian genomes** with most having been inactivated over time through mutation and deletion
- Koala retrovirus (**KoRV**) is associated with koala neoplasia
- KoRV also shows features of a recently inserted endogenous retrovirus that is vertically transmitted
- **Isolated koala populations** have not yet incorporated KoRV into their genomes suggesting that KoRV is a **virus in transition** between an exogenous and endogenous element

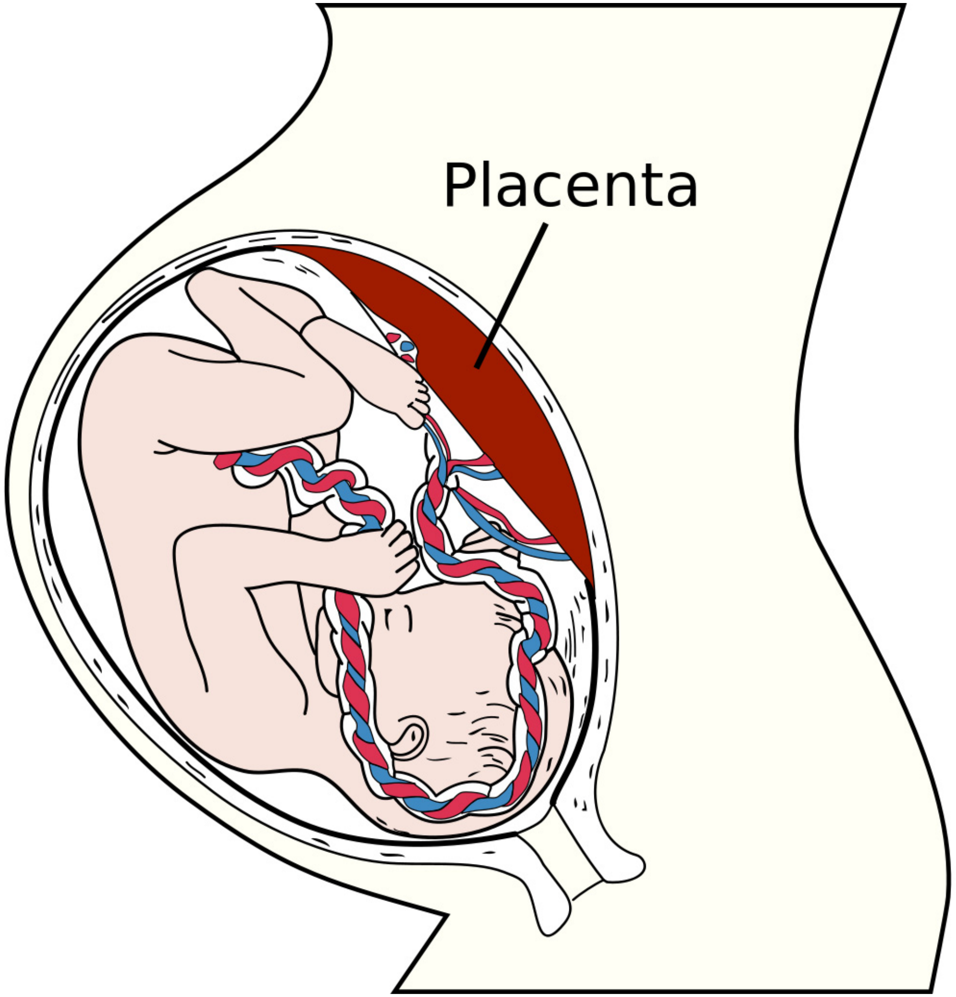


(Tarlinton, Meers, and Young, 2006)

Endogenous Virus Elements

Syncytin is a captive retroviral envelope protein involved in human placental morphogenesis

- Example of a viral gene that has been sequestered to serve an important function in the physiology of a mammalian host
- This gene, encoding a protein that we have called **syncytin**, is the envelope gene of a recently identified **human endogenous defective retrovirus**, HERV-W
- Data indicate that syncytin may be important in **human placental morphogenesis**
- **Syncytin disregulation or dysfunction** is



(Mi, Lee, Li, Veldman, Finnerty, Racie, LaVallie, Tang, Edouard,

Endogenous retroviral sequences are required for tissue-specific expression of a human salivary amylase gene

- The human genome contains three salivary and two pancreatic amylase genes
- The three **salivary amylase genes** are each associated with an **intact retroviral element**
- The two **pancreatic amylase genes** either lack retroviral sequences (AMY2B) or contain a solo LTR as a result of excision of the retrovirus (AMY2A).
- The gene structures are consistent with a sequence of events in which **insertion of the**

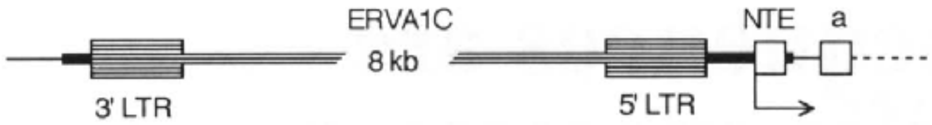


Figure 1. Structure of the human salivary amylase gene AMY1C. Insertions of the γ-actin pseudogene (solid bar) and the retrovirus ERVA1C occurred ~40 million years ago (Samuelson et al. 1990). (□)Exon a and the NTE; the rest of the gene is not shown. The major start site for transcription is indicated by an arrow. Insertion of the retrovirus apparently activated a cryptic promoter within the γ-actin pseudogene.

(Ting, Rosenberg, Snow, Samuelson, and Meisler, 1992)

Endogenous Virus Elements

An enteric virus can replace the beneficial function of commensal bacteria

- The symbiotic contribution on host physiology of **commensal bacteria is well established**
- The **role of eukaryotic viruses** that are present in the gastrointestinal tract under homeostatic conditions is undefined
- Researched demonstrate that a common enteric RNA **virus can replace the beneficial function of commensal bacteria** in the intetine
- Murine norovirus (MNV) infection of germ-free or antibiotic- treated mice **restored intestinal morphology** and **lymphocyte function** without inducing overt inflammation and disease

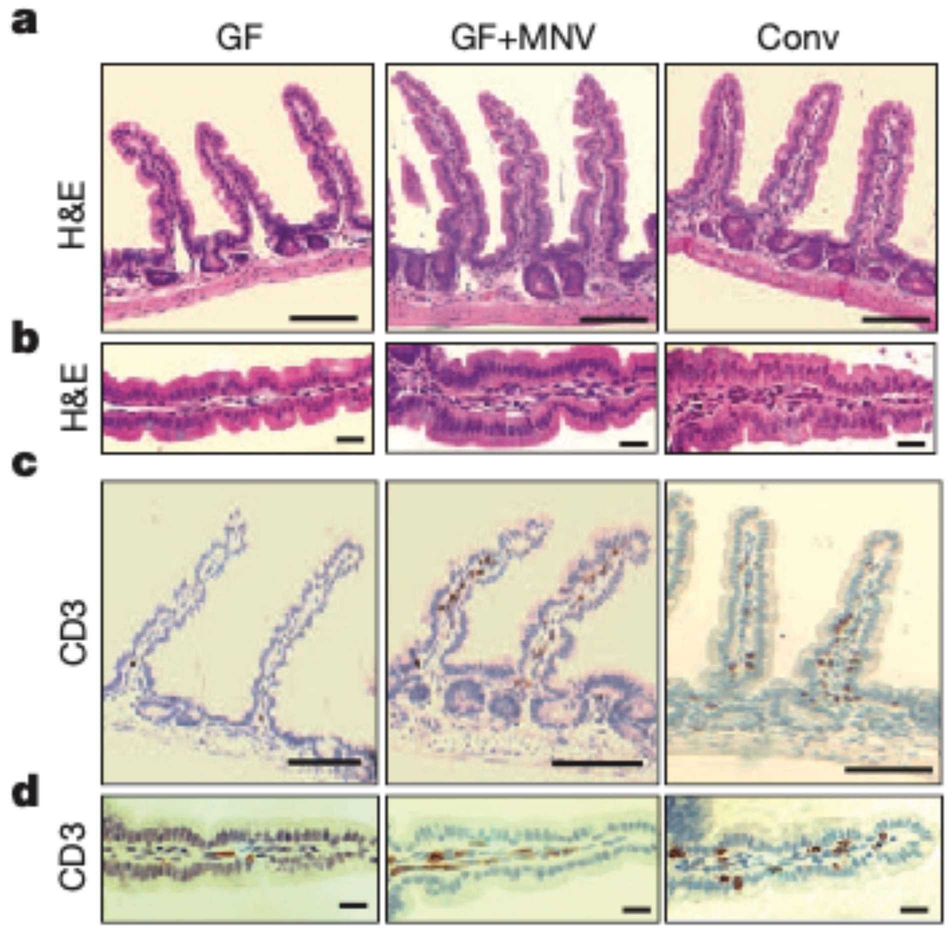


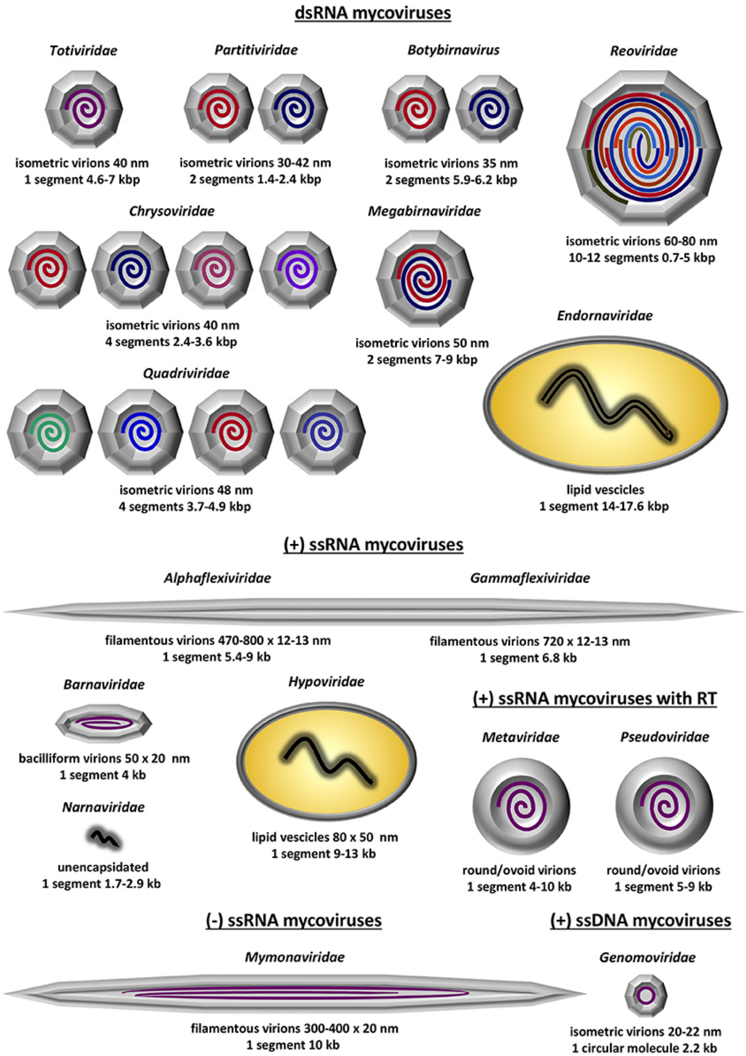
Figure 1 | MNV reverses intestinal abnormalities in GF mice. **a–d**, Representative small intestinal sections from GF, GF+MNV or conventional (Conv) mice stained with haematoxylin and eosin (H&E) (**a**, **b**) or anti-CD3 antibody (**c**, **d**). Scale bars, 100 μm (**a**, **d**); 10 μm (**c**, **d**).

Mycovirus involved in mutualistic symbiosis

Mycovirus involved in mutualistic symbiosis

Mycovirus: General features

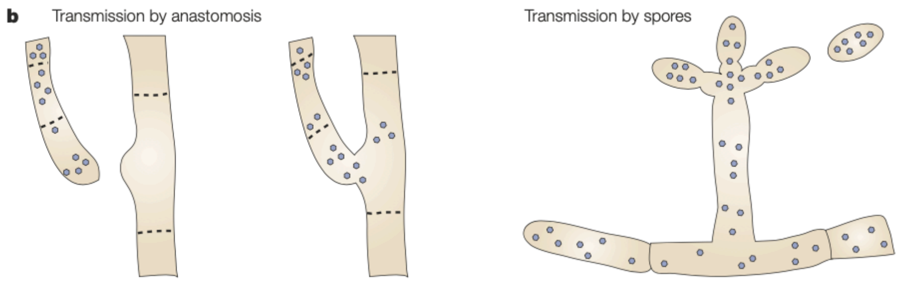
- Discovered in 1962
- As most viruses not phylogenetically homogeneous. Different evolutionary trajectories
- Mostly dsRNA…but also ssRNA, and recently -ssDNA
- Often the result of long co-evolution. Neutral or beneficial symbiosis



Mycovirus involved in mutualistic symbiosis

Mycovirus: Transmission

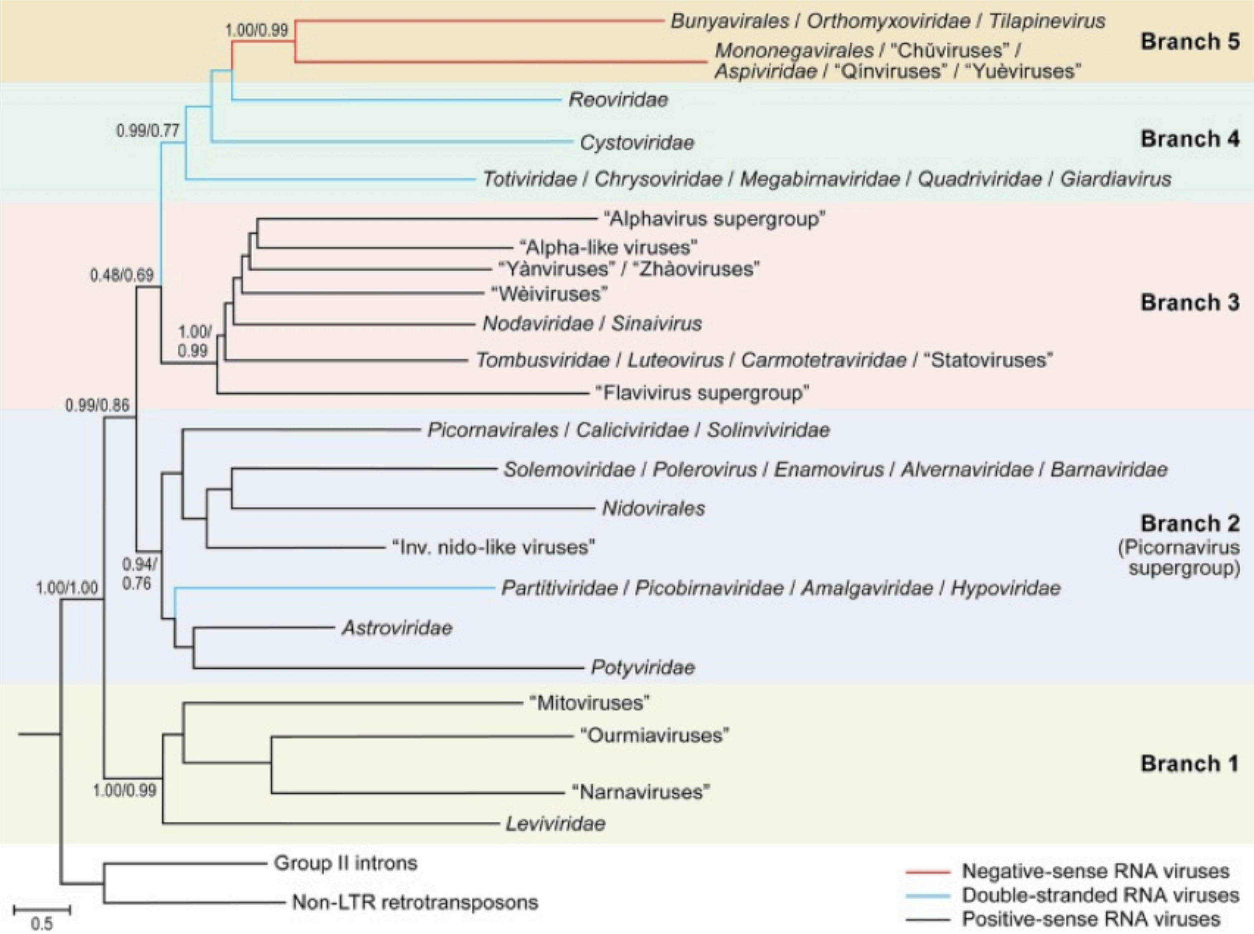
- Extracellular transmission was excluded until recent years
- **Vertically**: during sporogenesis: asco, basidio, and conidio spores have different efficiency of transmission according to the specific virus-host interaction
- **Horizontally**: regulated by vegetative compatibility groups (VC)



(Nuss, 2005)

Mycovirus involved in mutualistic symbiosis

Mycovirus biodiversity

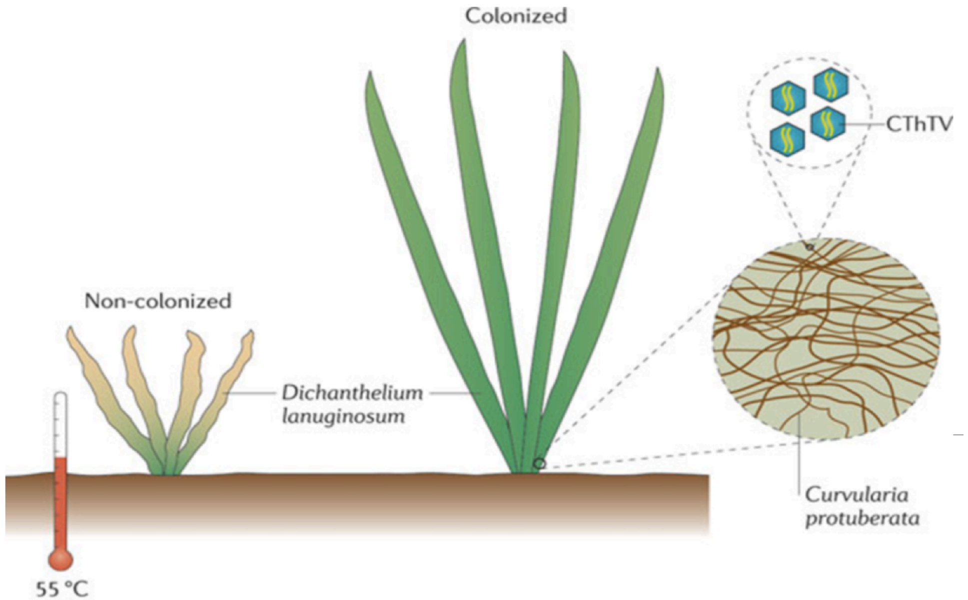


- Negarnaviricota
- Duplornaviricota
- Kitrinoviricota
- Pisuviricota
- Lenarviricota

Mycovirus involved in mutualistic symbiosis

A Virus in a Fungus in a Plant: Three-Way Symbiosis Required for Thermal Tolerance

- A mutualistic association between a fungal endophyte and a tropical panic grass allows both organisms to grow at high soil temperatures
- **Fungal isolates cured of the virus are unable to confer heat tolerance**, but heat tolerance is restored after the virus is reintroduced
- The virus-infected fungus **confers heat tolerance not only to its native monocot host but also to a eudicot host**, which suggests that the underlying mechanism involves pathways conserved between these two groups of plants



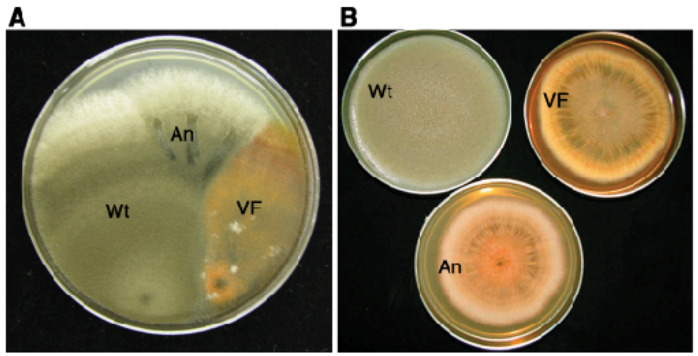


Fig. 3. (**A**) Anastomosis of the wild-type virus-infected isolate of *C. protuberata* (Wt) and the virus-free hygromycin-resistant isolate (VF) to produce a virus-infected hygromycin-resistant isolate (An). (**B**) After single-spore isolation to produce pure cultures, the isolate newly infected with the virus (An) retained the hygromycin-resistance and the morphology of the VF isolate.

Mycovirus involved in mutualistic symbiosis

A Virus in a Fungus in a Plant: Three-Way Symbiosis Required for Thermal Tolerance

Fig. 2. (**Top**) Representative *D. lanuginosum* plants after the heat-stress experiment with thermal soil simulators. Rhizosphere temperature was maintained at 65°C for 10 hours and 37°C for 14 hours/day for 14 days under greenhouse conditions. Plants were nonsymbiotic (NS) and symbiotic with the wild-type virus-infected isolate of *C. protuberata* (Wt), the hygromycin-resistant isolate newly infected with the virus through hyphal anastomosis (An), or the virus-free hygromycin-resistant isolate (VF). (**Bottom**) The histogram presents the number of plants chlorotic, dead, and alive at the end of the experiment. The small letters on top of the bars indicate statistical differences or similarities (chi-square test, $P < 0.01$).

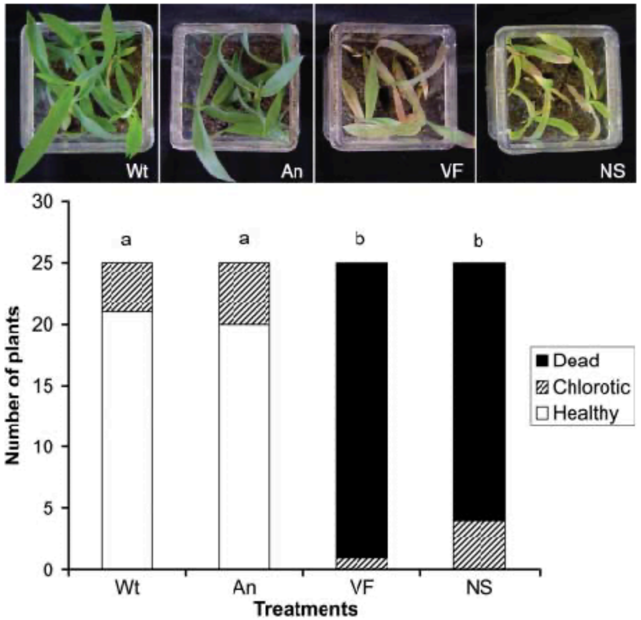
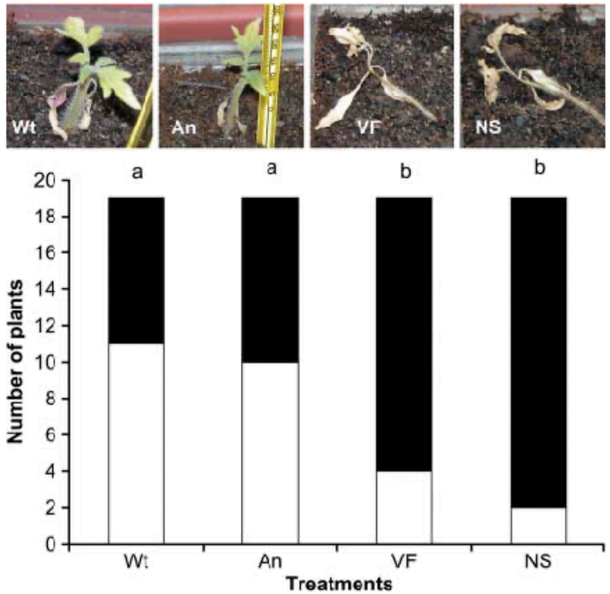


Fig. 4. (**Top**) Representative tomato (*Solanum lycopersicon*, var. Rutgers) plants after the heat-stress experiment. Plants were nonsymbiotic (NS) and symbiotic with the wild-type virus-infected isolate of *C. protuberata* (Wt), the hygromycin-resistant isolate newly infected with the virus through hyphal anastomosis (An) or the virus-free hygromycin-resistant isolate (VF). Rhizosphere temperature was maintained at 65°C for 10 hours and ambient temperature (26°C) for 14 hours/day for 14 days under greenhouse conditions. (**Bottom**) The histogram presents the number of plants dead (white) and alive (black) at the end of the experiment. The small letters on top of the bars indicate statistical differences or similarities (Fisher's exact test, $P < 0.05$).



(Márquez Redman, et al., 2007)

Questions about the lesson

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