Viruses that Infect Plants

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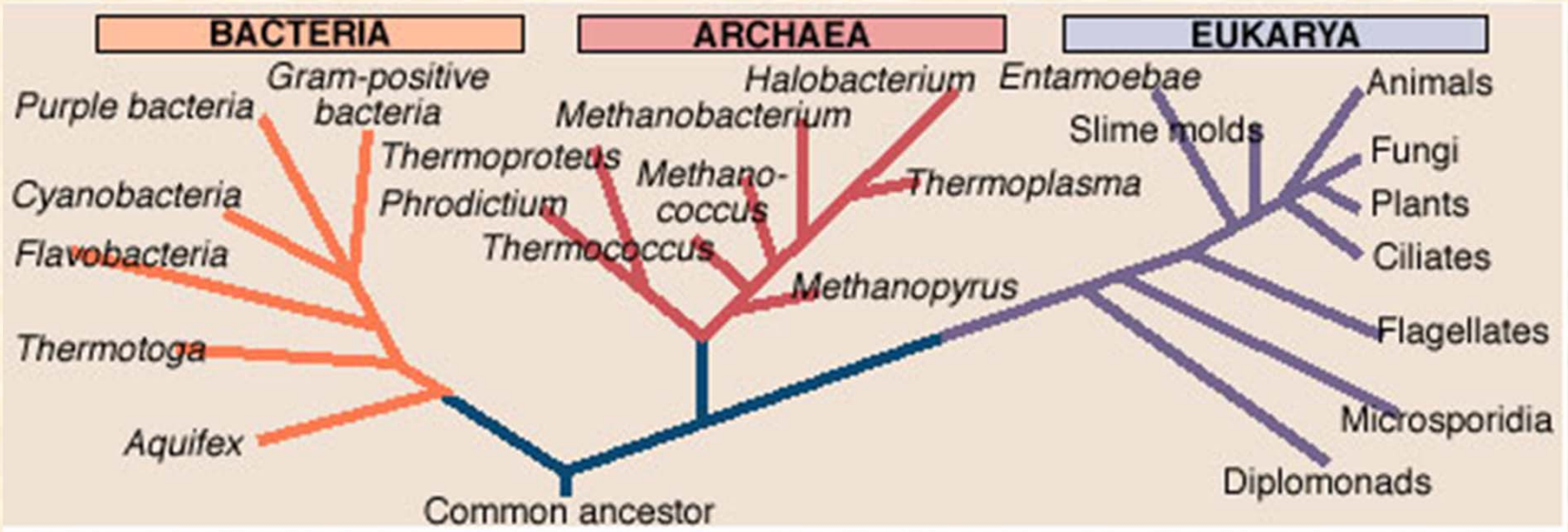
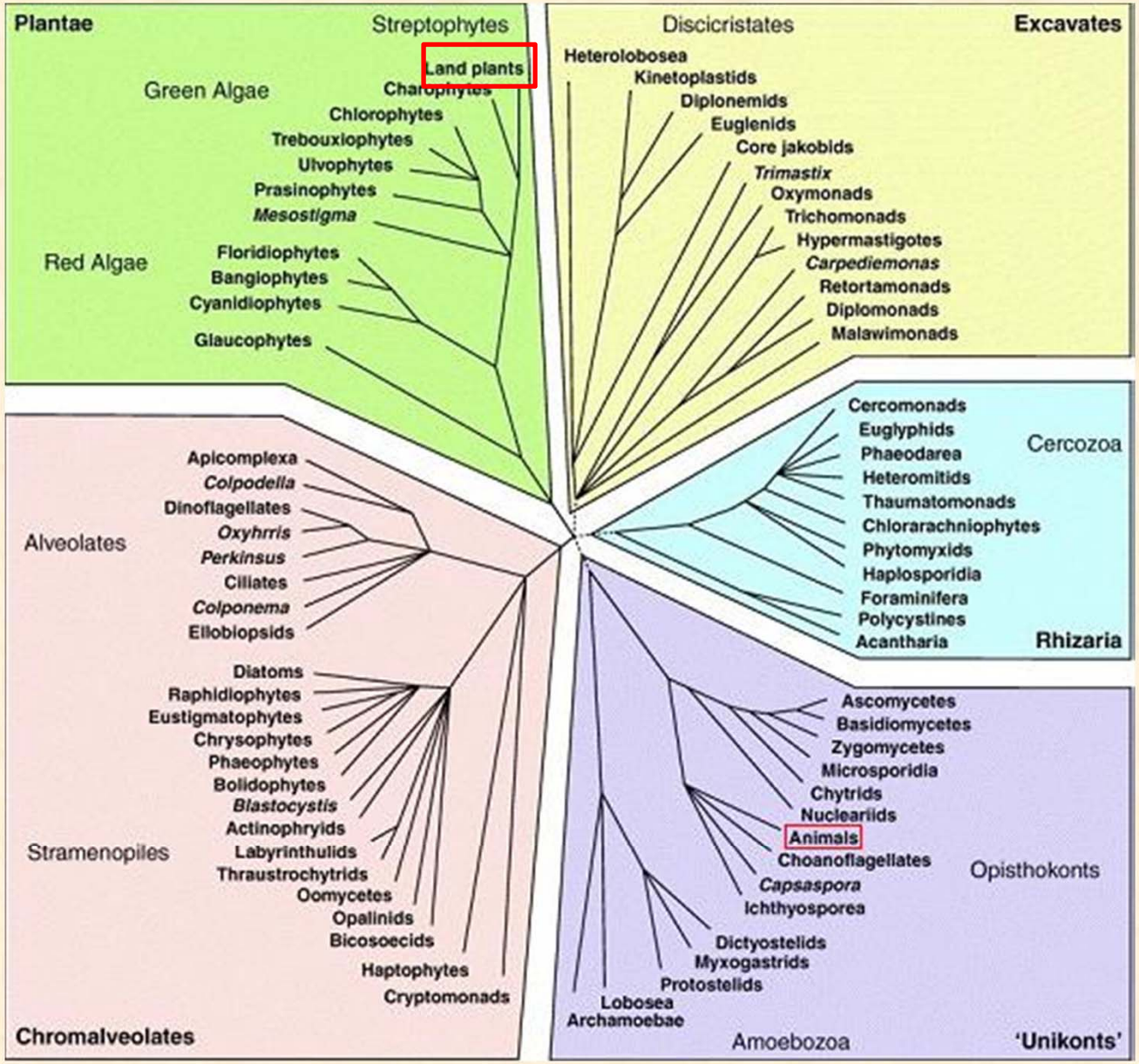
Viruses infect Organisms in All the Main Categories of Life



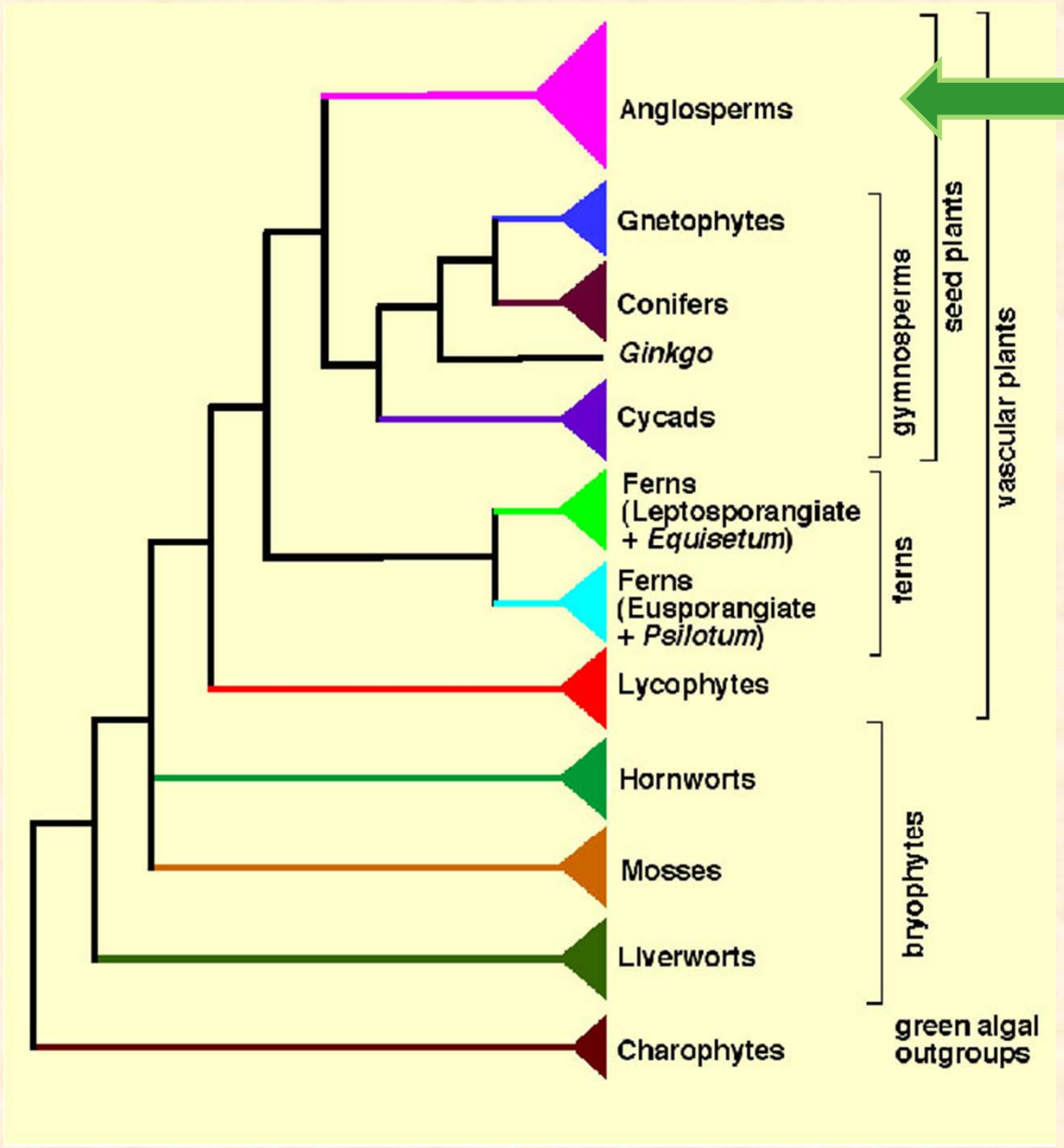
A tree of life. A phylogenetic tree of life based on comparative small subunit ribosomal RNA sequences.

Tree of Eukaryotic Life



Keeling, PJ, G Burger, DG Durnford, BF Lang, RW Lee, RE Pearlman, AJ Roger, MW Gray. 2005. The tree of eukaryotes. *Trends Ecol Evol* 20: 670-676. doi: 10.1016/j.tree.2005.09.005

Phylogeny of Vascular Plants (Embryophytes)

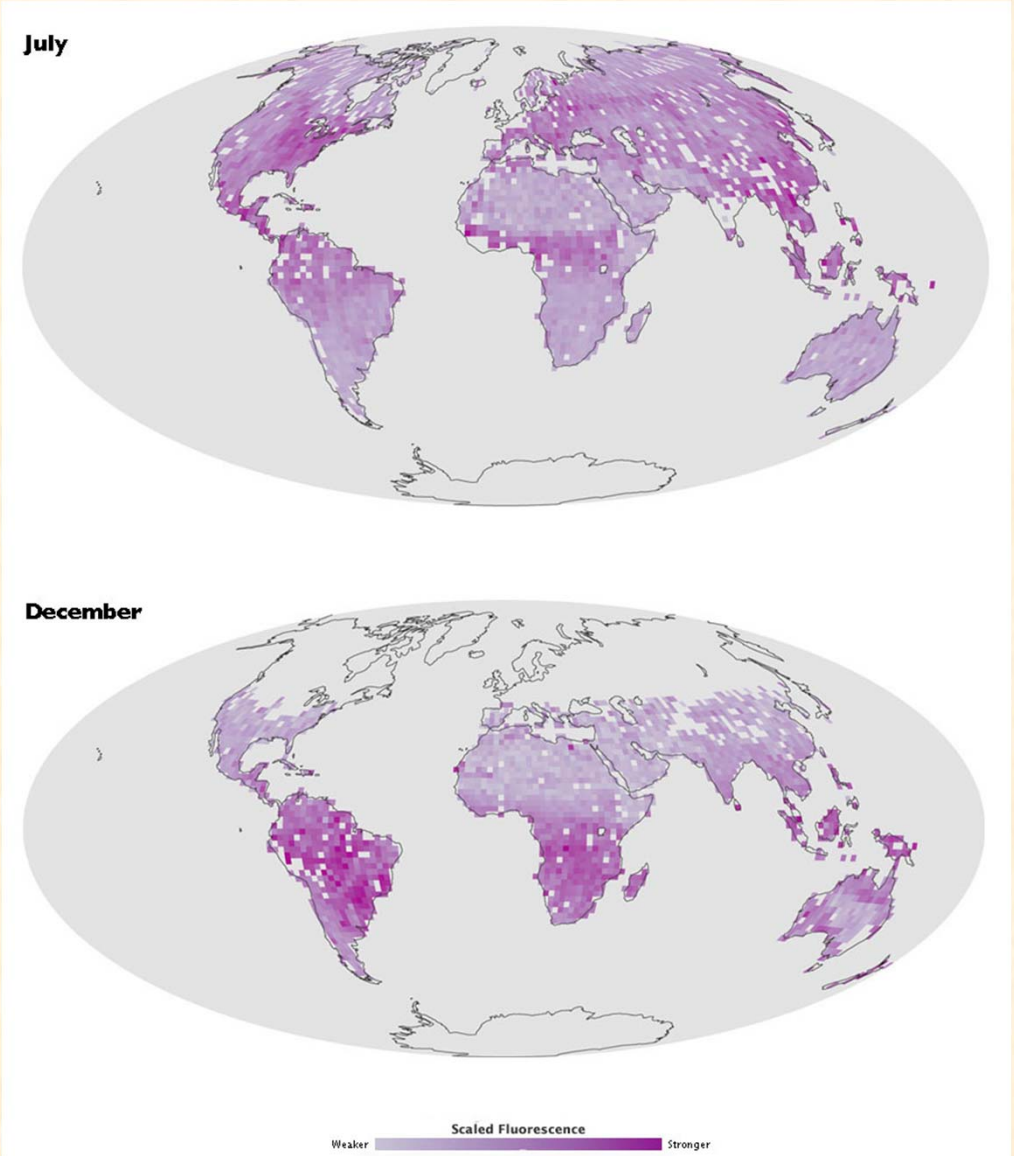


OUTLINE
Viruses of Vascular Plants

How are viruses that infect plants similar to viruses that infect other organisms?

How are viruses that infect plants different from from viruses that infect other organisms?

Viruses of plants are found across the earth – wherever plants grow

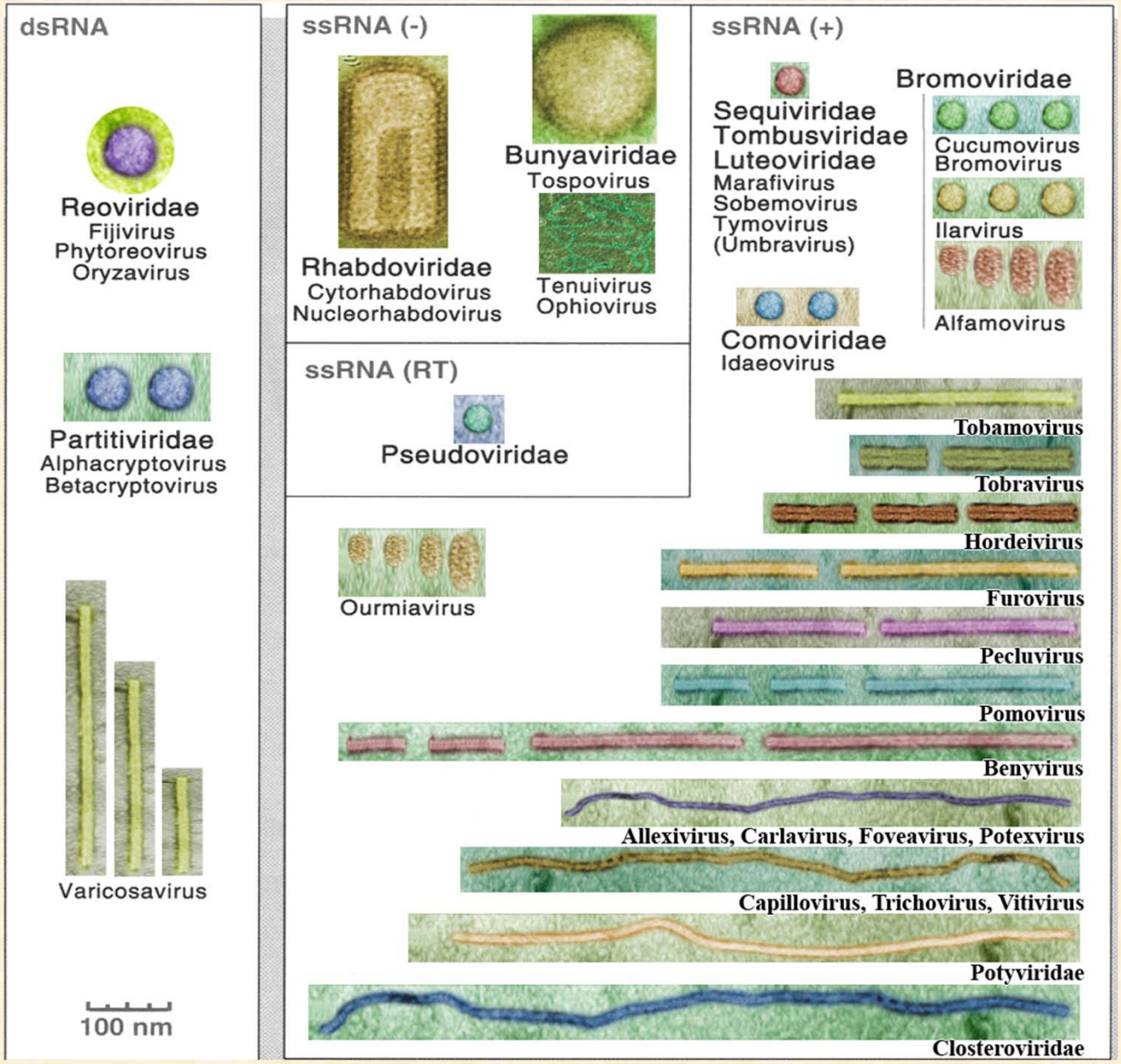


Map of fluorescence indicating the density of growing plants

http://www.nasa.gov/topics/earth/features/fluorescence-map.html

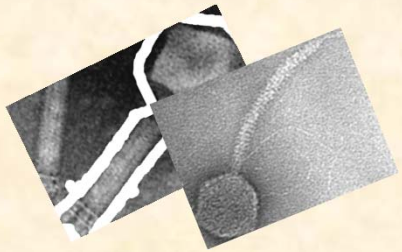
Viruses that infect Vascular Plants:

- Highly diverse
- Have a high degree of similarity with animal viruses
- Have evolved unique genes/ functions to facilitate infection



Number and Diversity of Plant Viruses

Estimated No. of Virus Species in the World	Total No. Viruses Characterized 2011	No. Species Known to Infect Land Plants 2011
millions	2,284	1,300



There are millions of diverse viral species in the world (65% of partial viral sequences found have no homologues in GenBank)

Edwards and Rohwer (2005) *Nat. Rev. Microbiol.* 3:504

Diversity of Viruses that Infect Vascular Plants

Approximately 1,300 distinct virus species classified as follows:

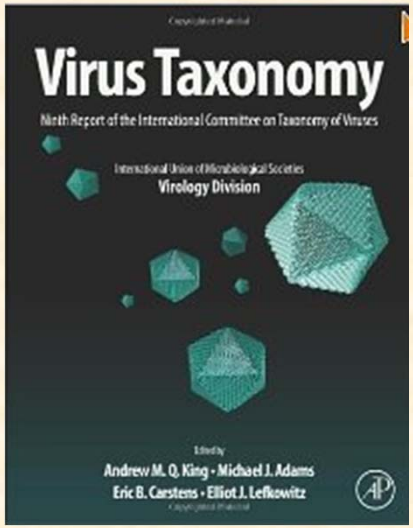
90 genera in 25 families
7 genera unassigned to family

4 families contain both plant and animal viruses

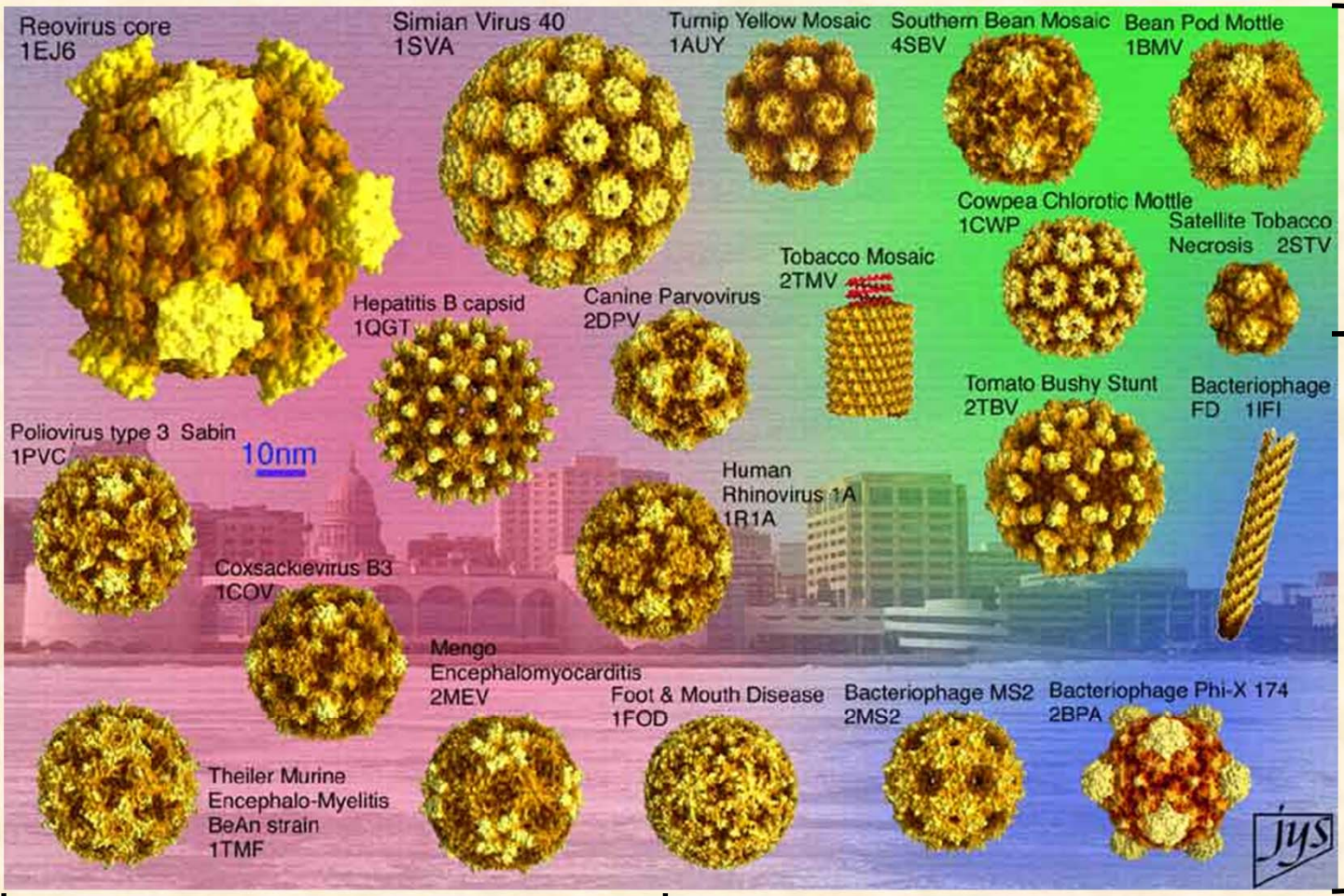
21 families contain only viruses that infect plants

Ninth Report of the International Committee on Taxonomy of Viruses

http://www.ictvonline.org/virusTaxonomy.asp?version=2011



Viruses that infect plants have characteristics similar to those of viruses that infect other organisms



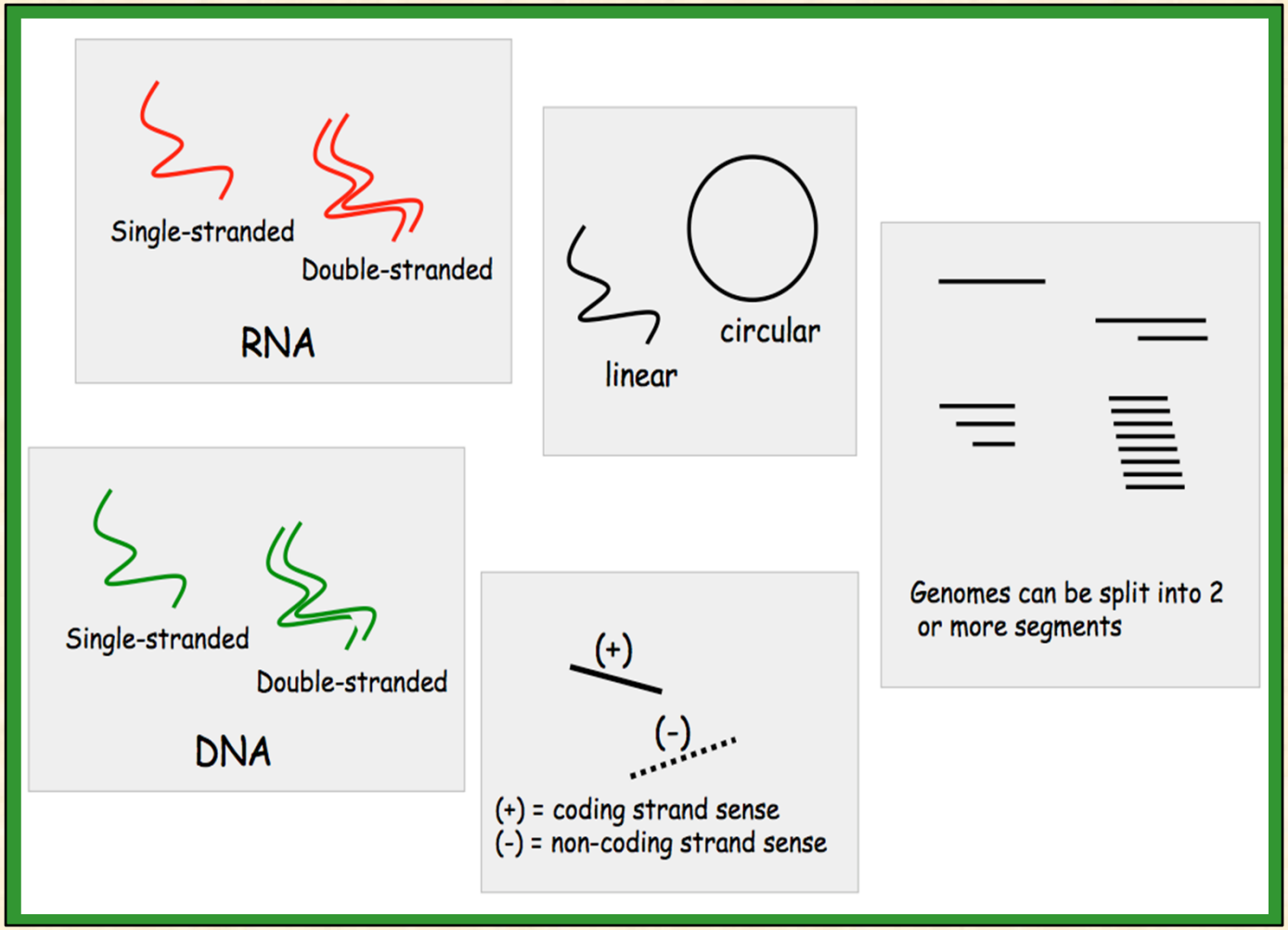
Angiosperm Hosts

Bacteria Hosts

Animal Hosts

Viruses that infect plants have characteristics similar to those of viruses that infect other organisms

Similar types of genomes – type of nucleic acid and strandedness

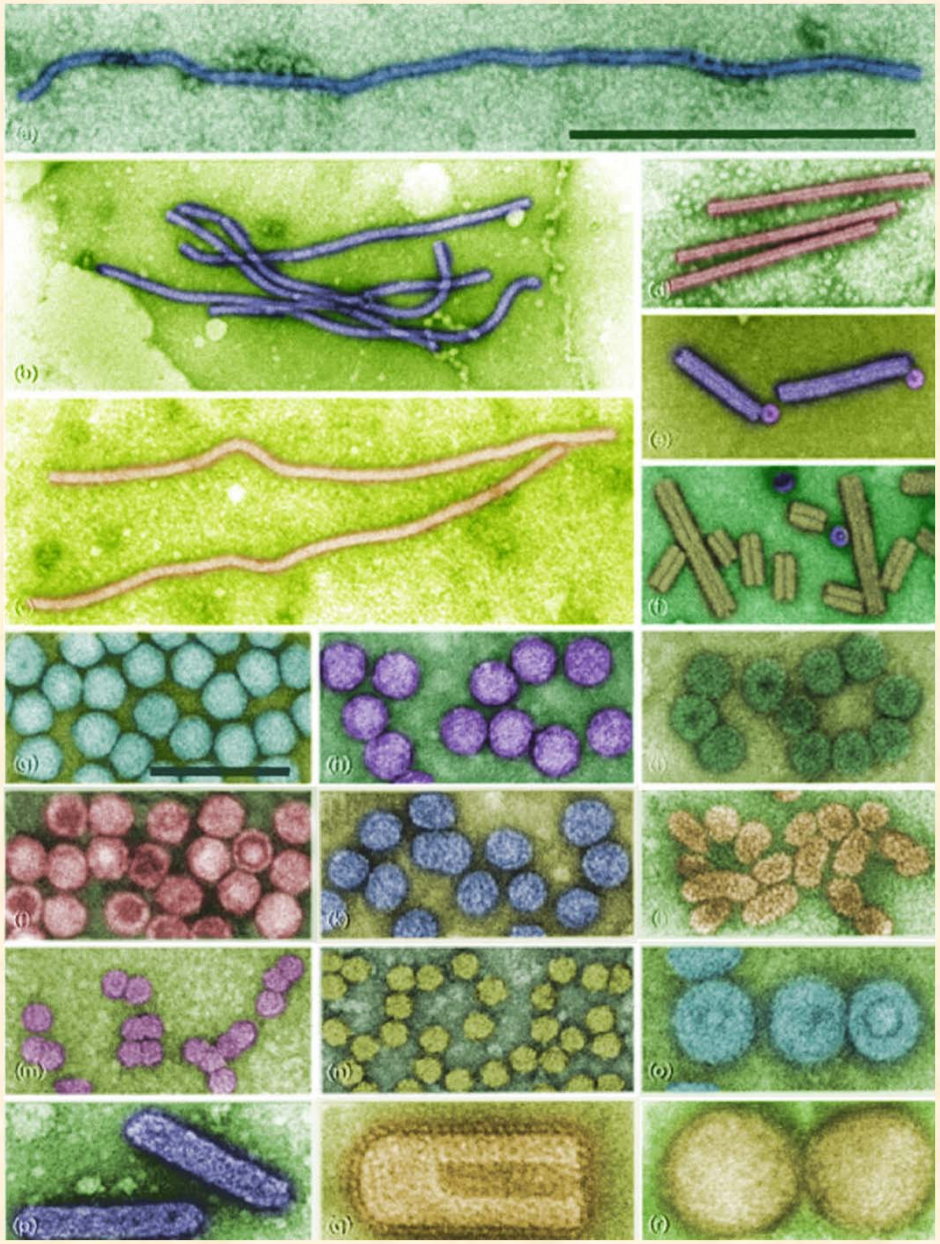


Three Main Differences Between Viruses that Infect Vascular Plants and Other Viruses:

1. **Overall, plant viruses have relatively small genomes and are streamlined in structure**

Particle Structure

Viruses that infect plants:
In general, simpler particle structure than viruses that infect other hosts

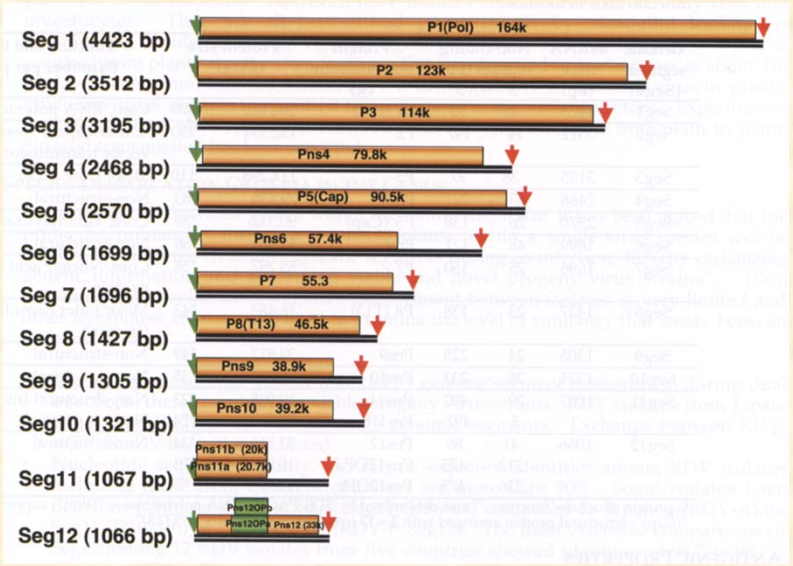


Viral Genome Structure

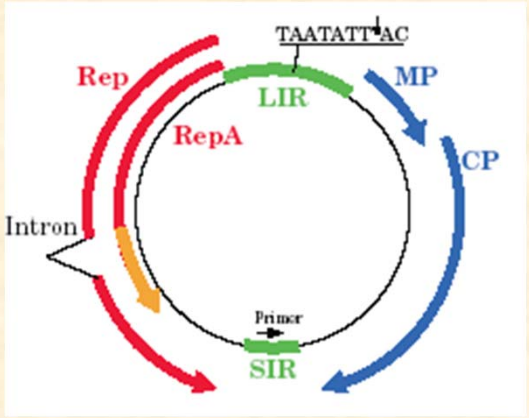
- Plant viral genomes are small in comparison to genomes of other viruses - only about 2,800 – 26,000 nucleotides

- Code for 1 to 12 proteins

Potyviridae



Reoviridae

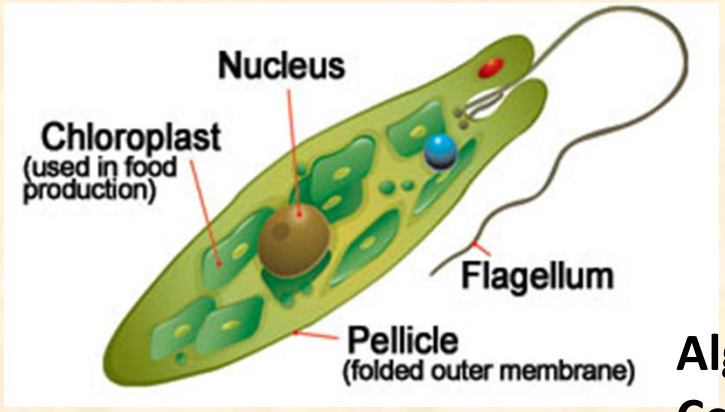


Geminiviridae

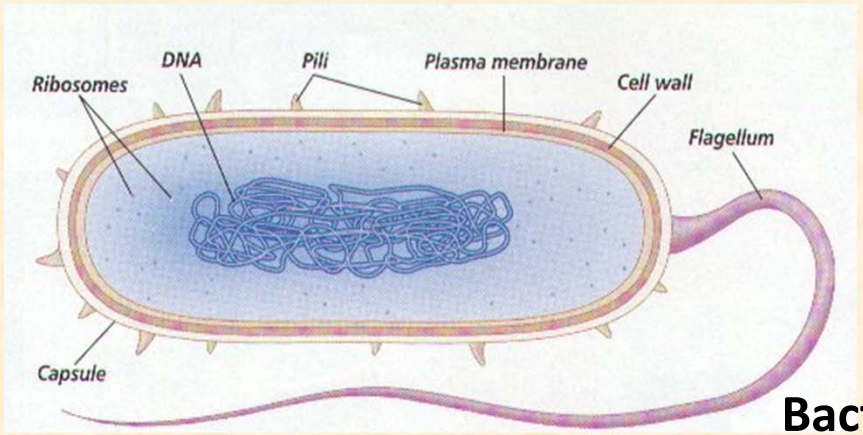
Three main differences between viruses that infect plants and other viruses:

1. Overall, plant viruses have relatively small genomes and are streamlined in structure

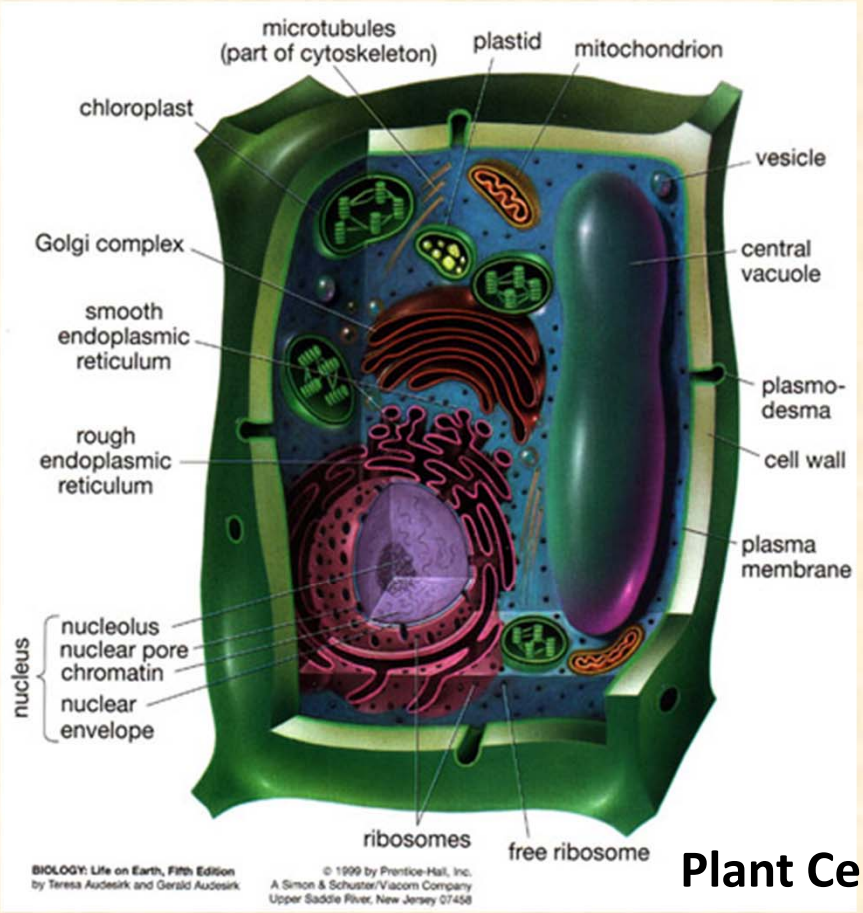
2. Plant viruses do not enter plant host cells through active mechanisms



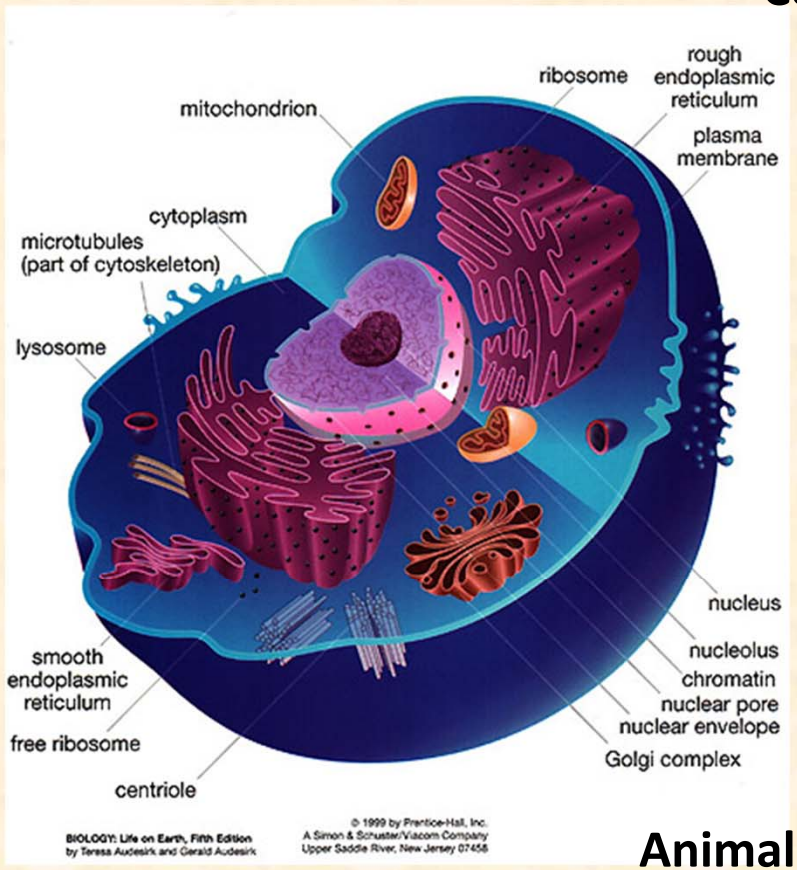
Algal Cell



Bacterial Cell



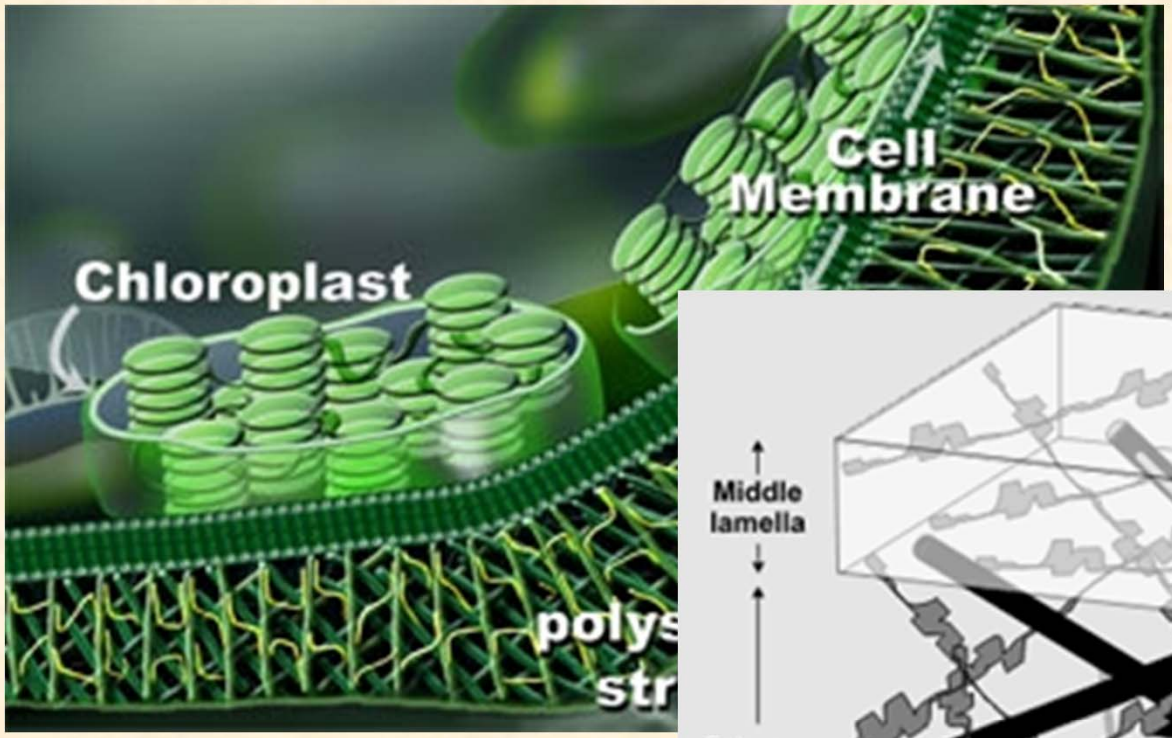
Plant Cell



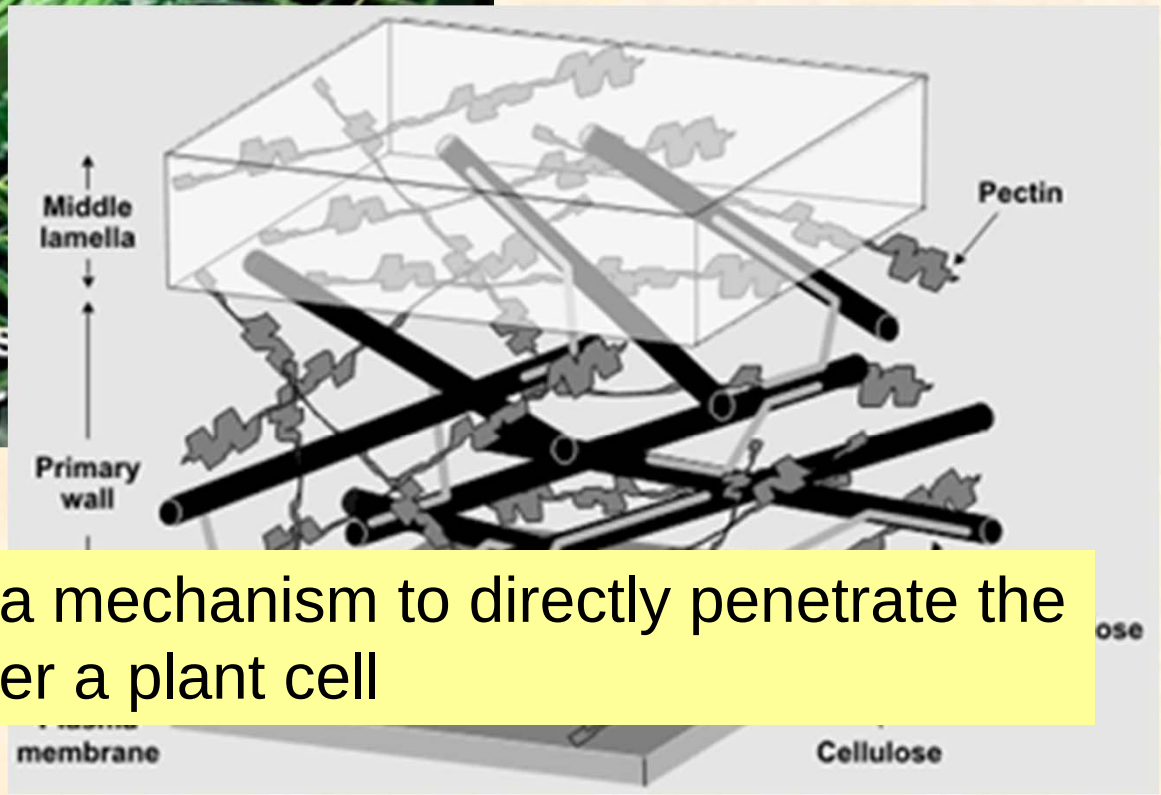
Animal Cell

Source: www.sirinet.net/~jgjohnso/ cell.html

Plant cell walls are thick compared with the sizes of the viruses infecting them (>10 µm versus <1 µm)



Outer surfaces of plants have layers of waxes and pectin



No virus has evolved a mechanism to directly penetrate the plant cell wall and enter a plant cell

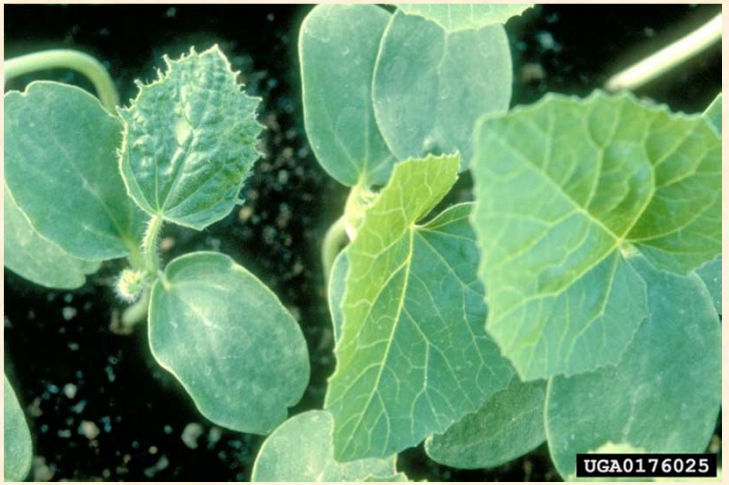
http://www.danforthcenter.org/newsmedia/feature/beachy/

How do viruses initiate infection in land plants?

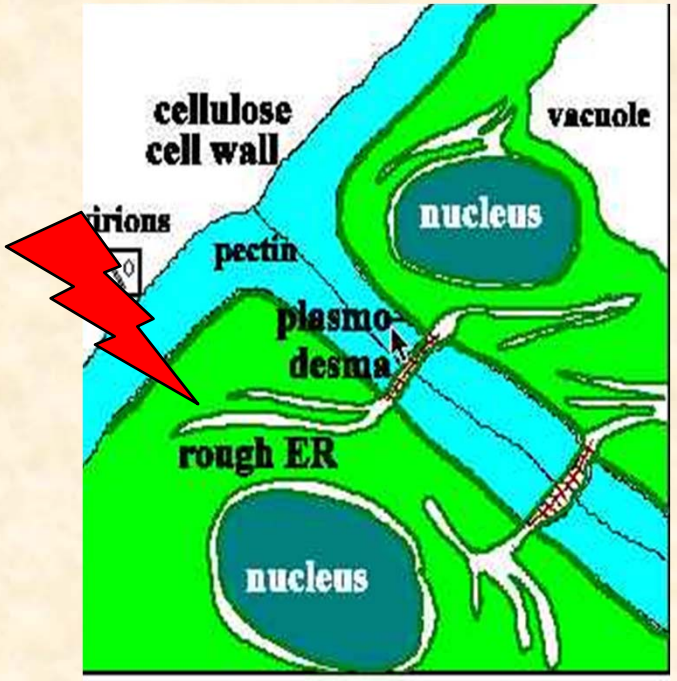
- Plant viruses lack an active mechanism for cell entry
- Host receptors are not known for plant viruses.
- NO entry via receptor-mediated endocytosis

How do plant viruses initiate infection?

- They can enter a plant by infection of the pollen or ovule so the plant begins life infected



- Viruses enter a mature plant cell via a wound that breaches the plant cell wall and cell membrane and allows the virus to enter into the cytoplasm.



http://www.microbiologybytes.com/virology/Plant.html

Wounding

A mechanical injury that breaches the cell wall and transiently breaches the plasma membrane of underlying cells

Sources of Wounds:

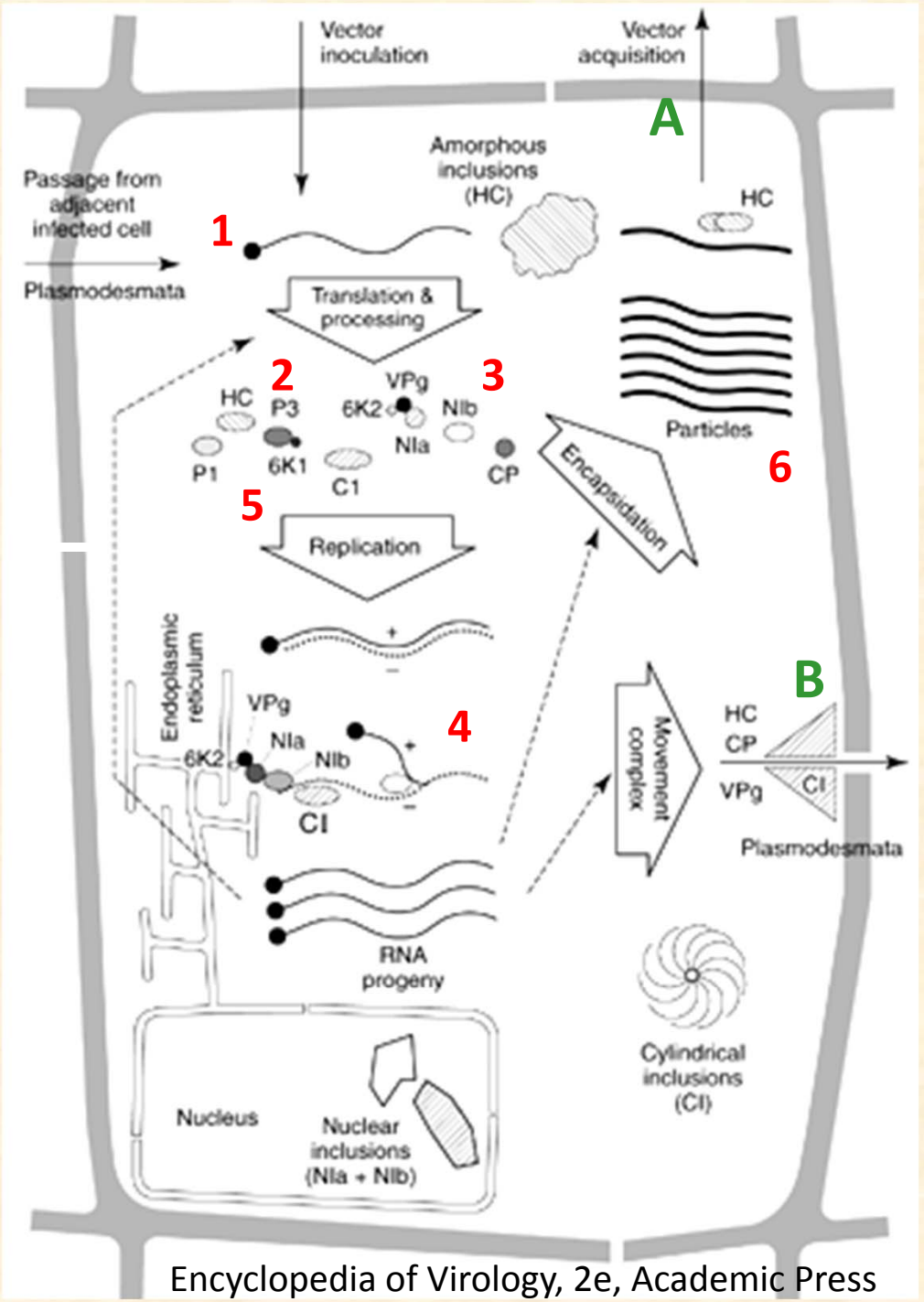
- **Tools, Equipment, Hands, Water, Soil**
- **Water**
- **Insects, Mites, Nematodes**
- **Virologists**

Once in the cell the virus replicates:

1. Uncoating
2. Primary Translation
3. Transcription
4. Replication
5. Secondary Translation
6. Encapsidation

Virus leaves the cell:

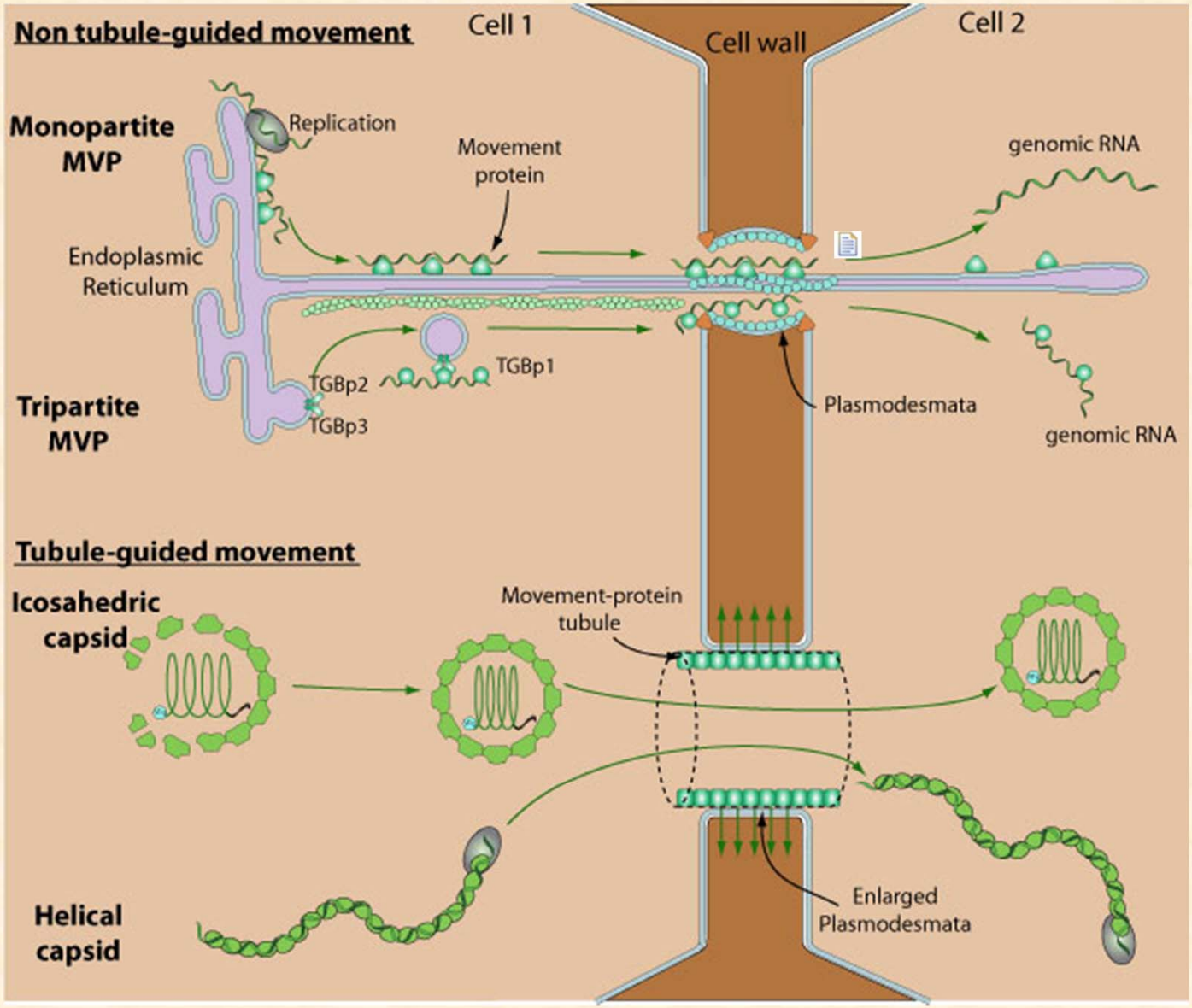
A. Encapsidated virus leaves with via a vector
B. Virus moves as a virion or a nucleoprotein complex into the next cell via plasmodesmata



Encyclopedia of Virology, 2e, Academic Press

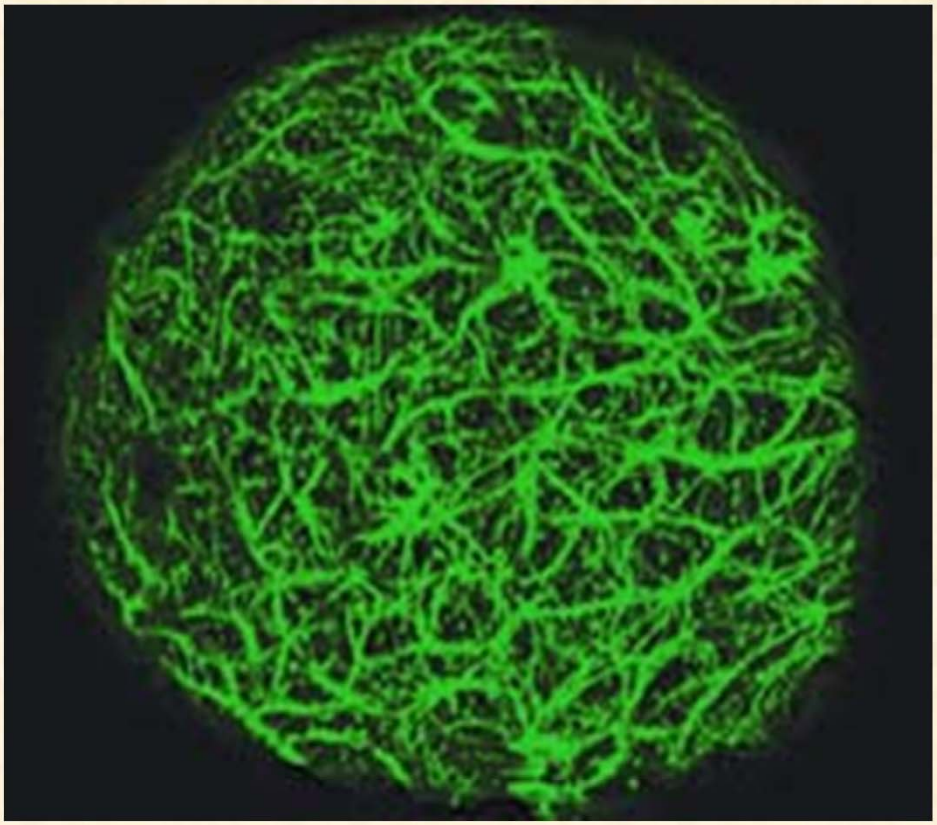
Movement of Viruses from Infected Plant Cells to New Cells

Viruses use complexes of viral encoded proteins (CP, HC-Pro, VPg) and RNA to modify plasmodesmata



http://viralzone.expasy.org/all_by_protein/1018.html

Example of a movement protein:

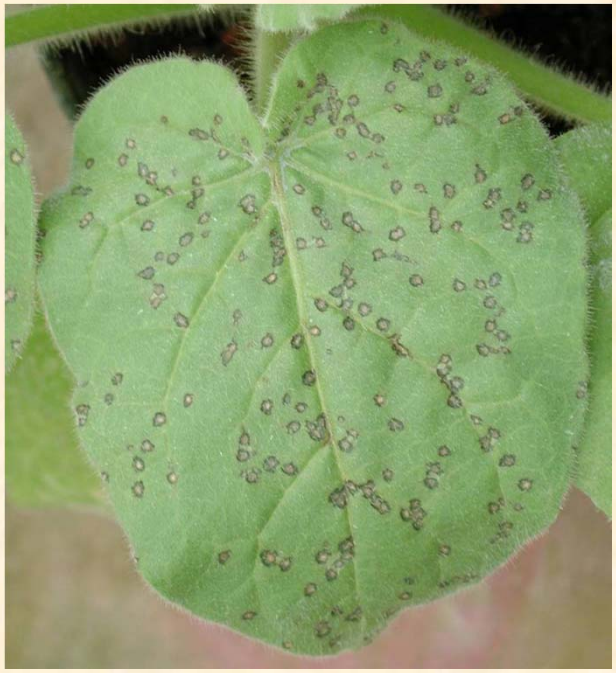


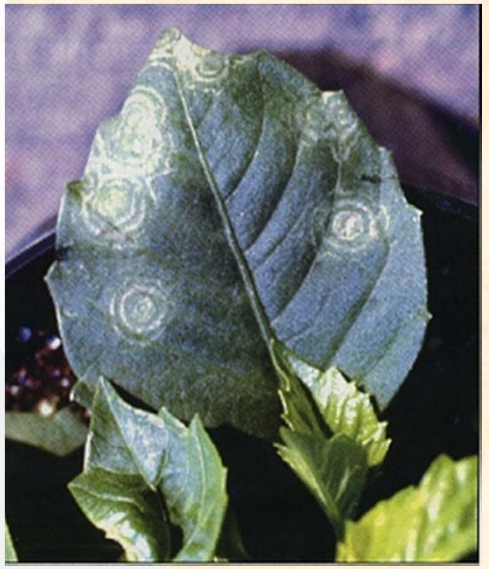
Tobacco mosaic virus
30 kDa movement protein (MP) in protoplasts following infection.

(Fluorescence microscopy was used to visualize MP:GFP fusion protein in association with microtubules and endoplasmic reticulum.)

Cell to Cell Movement Only (no systemic infection)

Symptoms Resulting from a Cell to Cell Movement Only



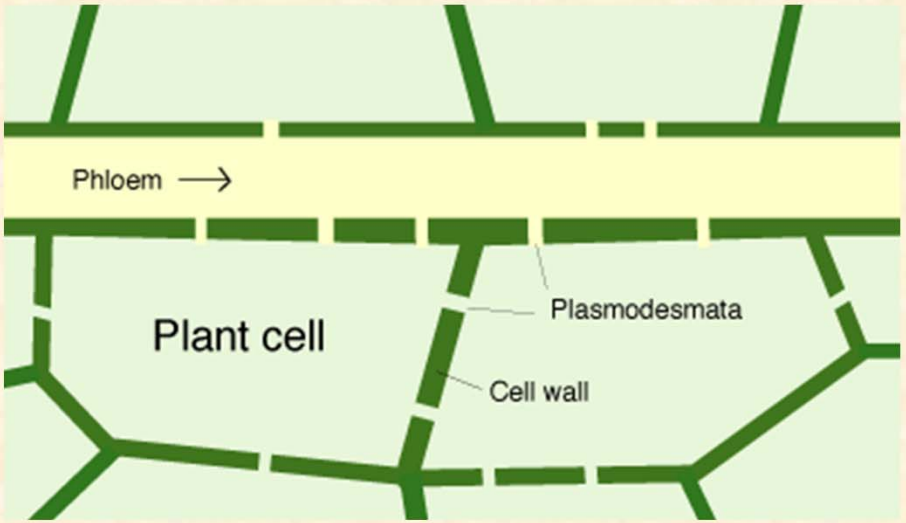


Ringspots

Cells within a short distance of the initially inoculated cell begin to undergo programmed cell death in advance of virus invasion.

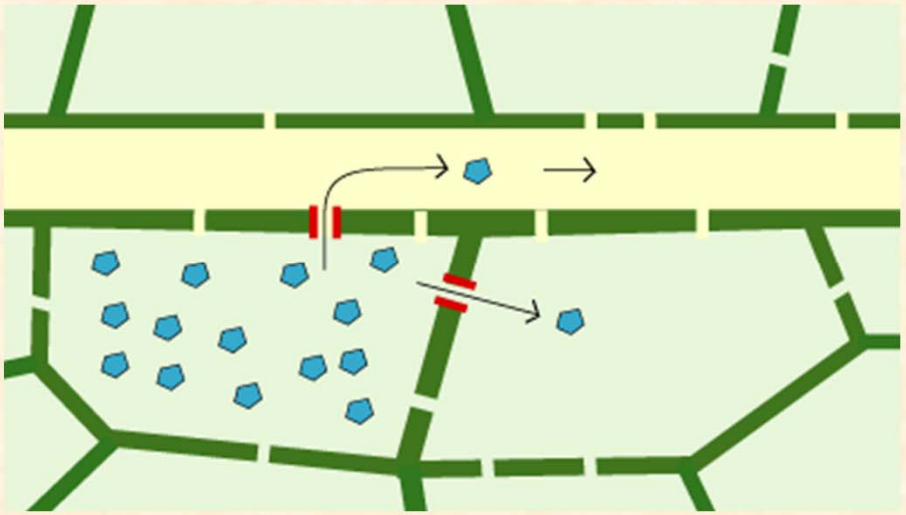
System Infection: viruses move from the site of inoculation to other parts of the plant

Plant viruses take advantage of the host plant's transport system - plasmodesmata which connects individual cells and phloem vessels - transport viruses to distant sites in the plant.



Virus particles (blue) cannot spread through normal plasmodesmata –

Plant viruses express movement proteins (red) which alter the plasmodesmata. Several different mechanisms are possible.



www.bioinvision.dk/plantvir4.html

Systemic Infection of Plants

Virus enters a plant cell,

Replicates in the cell,

Moves to neighboring cells,

Moves into the phloem, then roots, and then spreads to cells in the apical dome of the plant,

Virus replicates in apical cells which may develop abnormally,

Cellular abnormalities give rise to foliar symptoms

- Symptoms develop in leaves days/ weeks after infection

- Symptoms develop in leaves distant from site of inoculation

Illustration showing the spread of TMV in a tomato plant

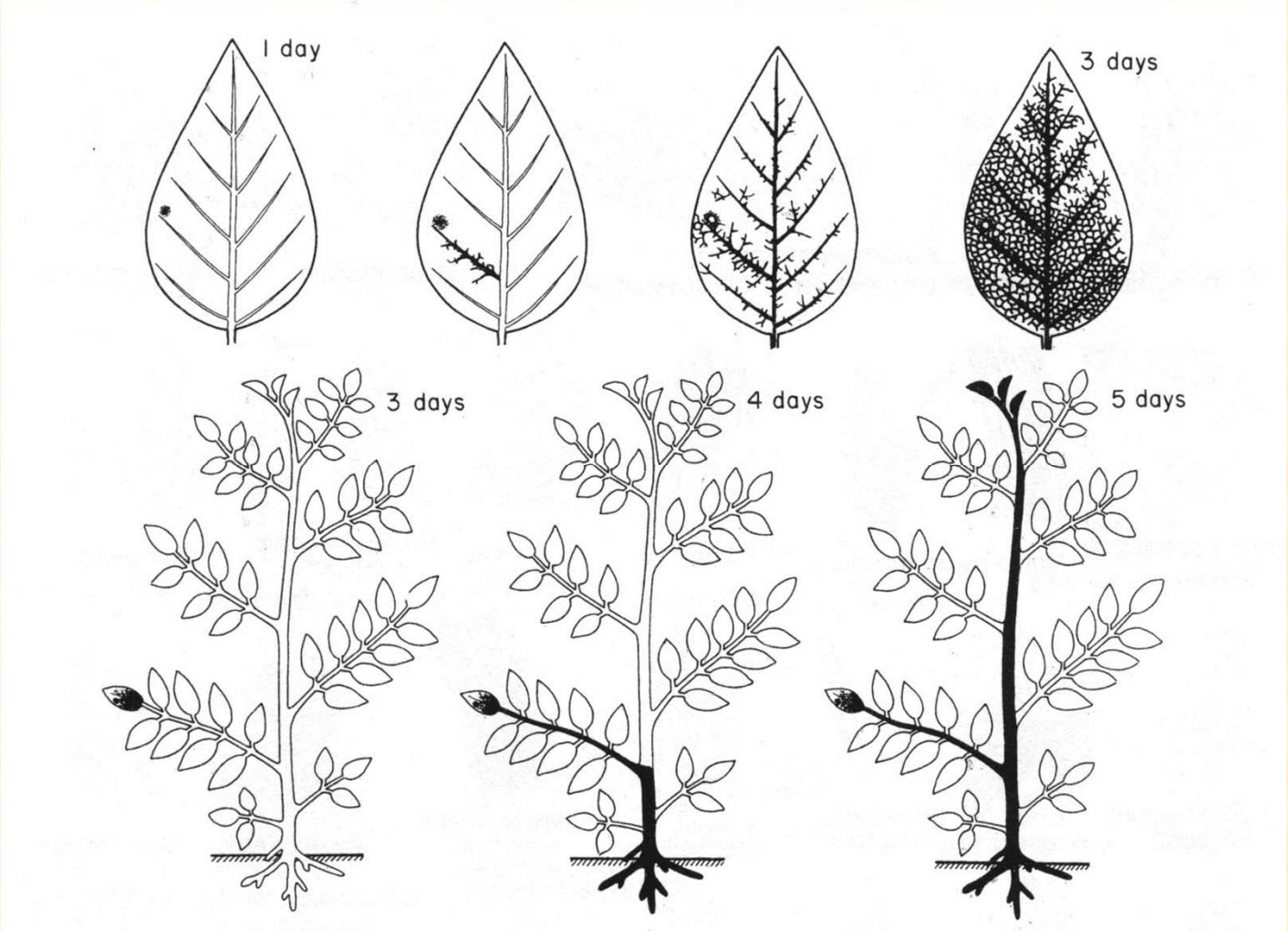


FIGURE 14-12 Schematic representation of the direction and rate of translocation of a virus in a plant. [Adapted from Samuel, G. (1934), *Ann. Appl. Biol.* **21**, 90–111.]

From: Agrios, G. N. Plant Pathology, 4e, Academic Press

Symptoms Resulting from a Systemic Infection:

Abnormal Growth and Development

Malformations - stunting, twisting of the growing tips,
leaf curling, leaf distortion,

Epinasty (unequal growth of two surfaces leading to curling of the whole leaf)

Enations (outgrowths from upper or lower surfaces of leaves)

Delayed senescence (plants remain vegetative)

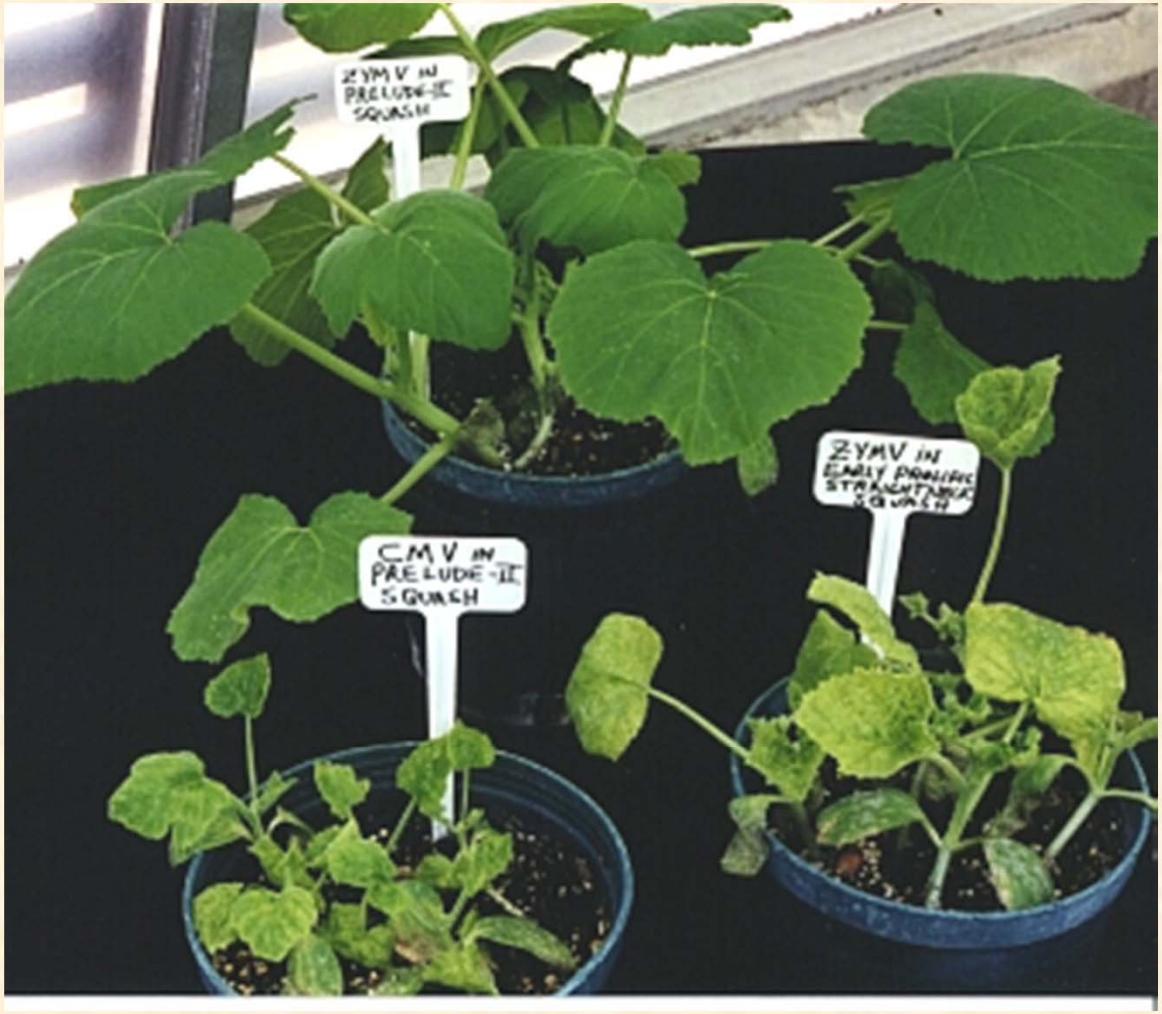
Mosaics - pattern of light and dark areas in dicots, **streaks or stripes** in monocots. Due to breakdown of chlorophyll in yellow (light) areas. Virus Infection may also interfere with normal chloroplast development

Mosaic in *Abutilon stratum* caused *Abutilon mosaic geminivirus*

Stripe mosaic in Johnson grass caused by *Sugarcane mosaic potyvirus*

Symptoms Resulting from a Systemic Infection:

Stunting and dwarfing symptoms



Symptoms Resulting from a Systemic Infection:

Programmed cell death resulting in necrosis

Healthy Plums

Symptoms Resulting from a Systemic Infection:

Programmed cell death resulting in necrosis

Localized necrotic flecks, **2 days** after inoculation.

Systemic necrosis and plant death, **2 weeks** after inoculation.

Symptoms Resulting from a Systemic Infection:

Leaf Mosaics

Mosaic: Due to breakdown of chlorophyll in yellow (chlorotic) areas.
Virus infection may also interfere with normal chloroplast development

Mosaic in *Abutilon stratum* caused *Abutilon mosaic virus (Geminiviridae)*

Stripe mosaic in Johnsongrass caused by *Sugarcane mosaic virus (Potyviridae)*

Symptoms Resulting from a Systemic Infection:

Mottle, Chlorosis/Yellowing: due to clearing or yellowing of the veins; general yellowing of any tissue

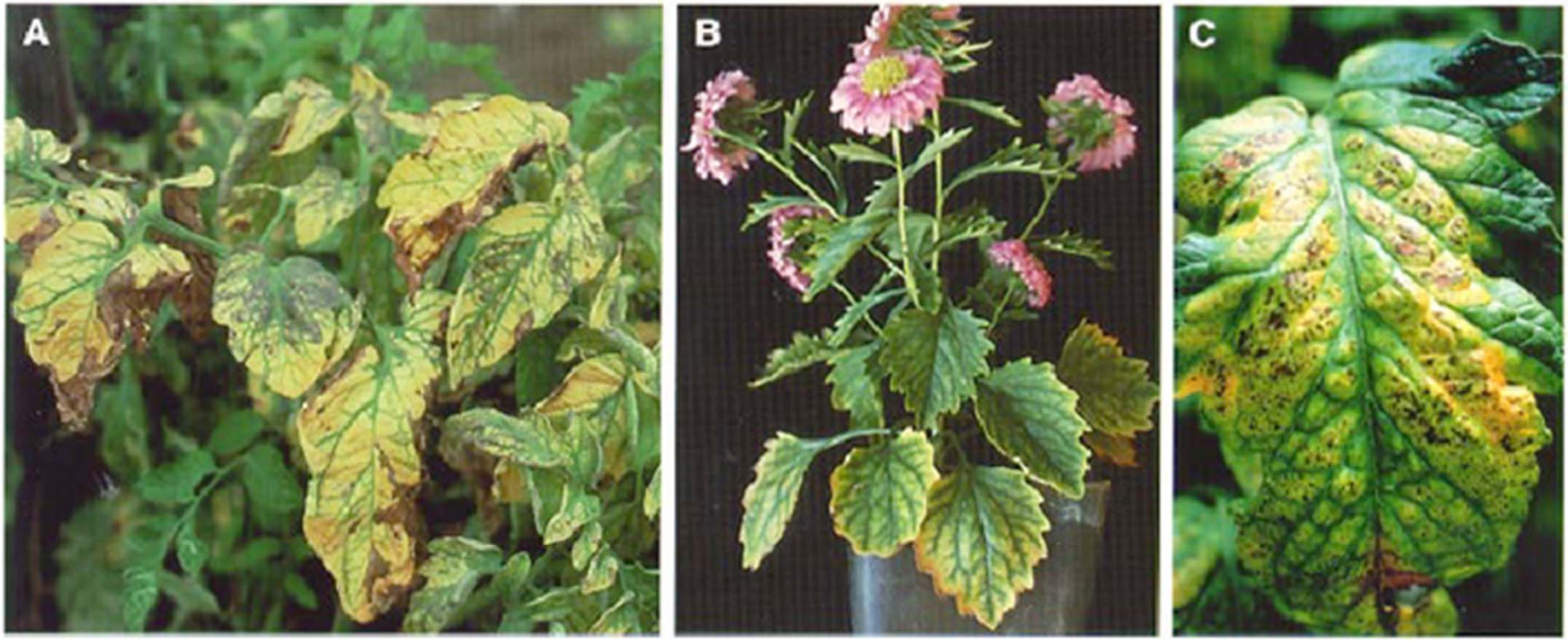
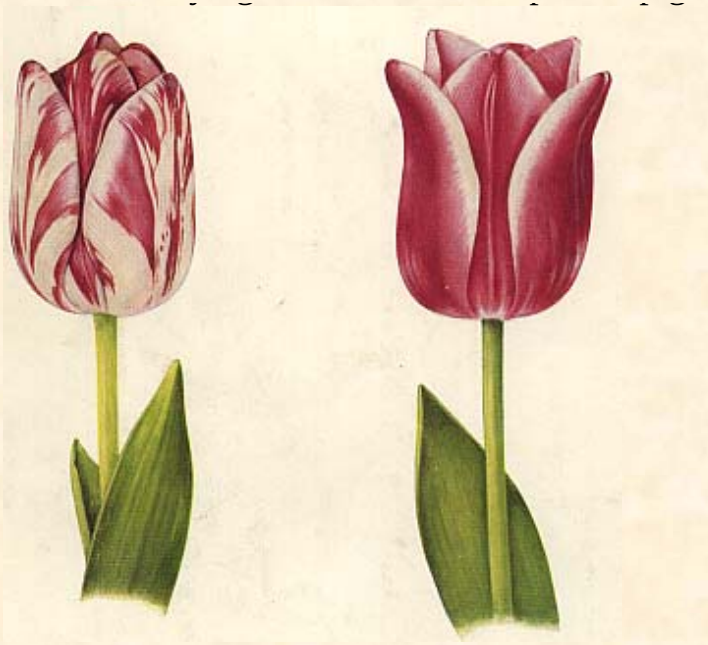


Fig. 9. (A) Leaf symptoms of tomato infectious chlorosis virus (TICV) infecting field-grown tomatoes in Orange County, California. (B) TICV infecting China aster showing typical interveinal yellowing. (C) Tomato chlorosis virus (ToCV) infecting greenhouse-grown tomatoes in north central Florida. (ToCV photo courtesy G. W. Simone).

Symptoms Resulting from a Systemic Infection:

Variegation of Flowers

Breaking of petal color, the result of anthocyanin pigment loss, revealing the underlying coloration due to plastid pigments.



Tulip on the left infected with *Tulip breaking virus (Potyviridae);* Non-infected plant on the right

Three main differences between viruses that infect plants and other viruses:

1. Overall, plant viruses have relatively small genomes and are streamlined in structure

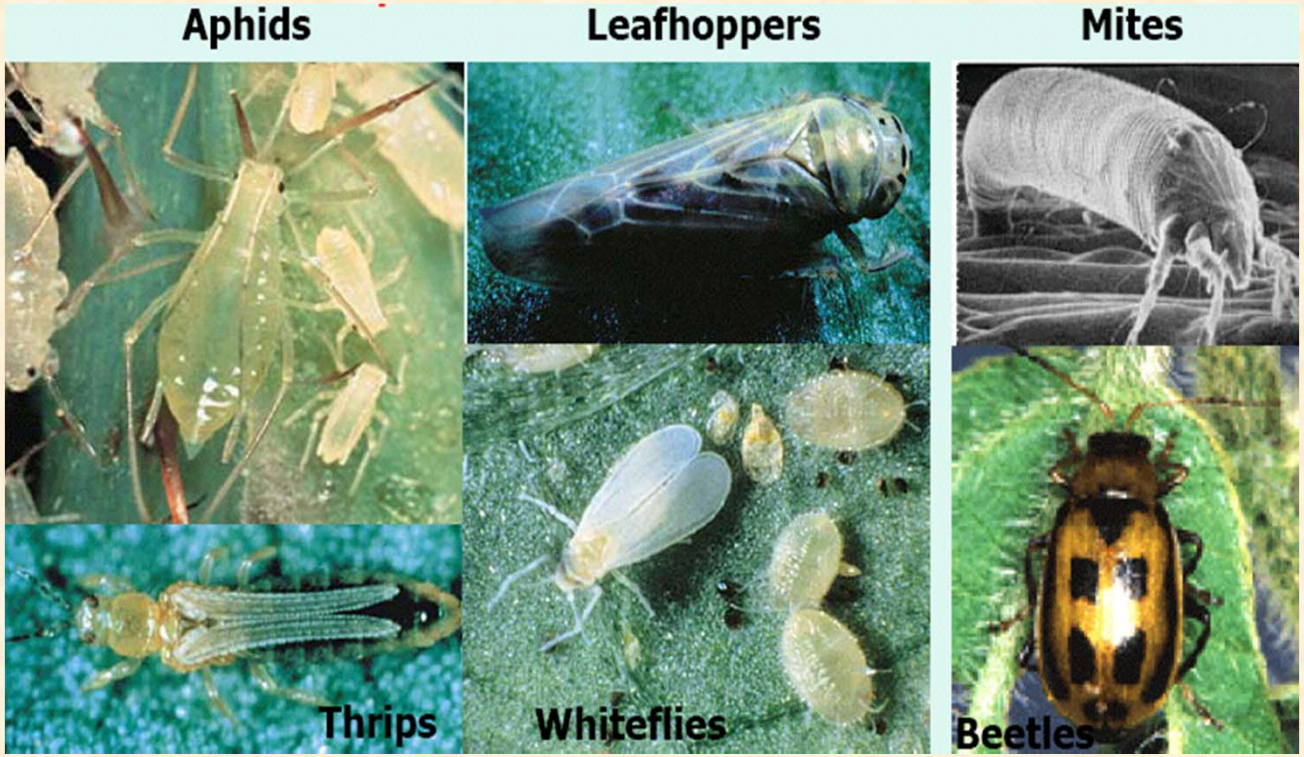
2. Plant viruses do not enter plant host cells through active mechanisms

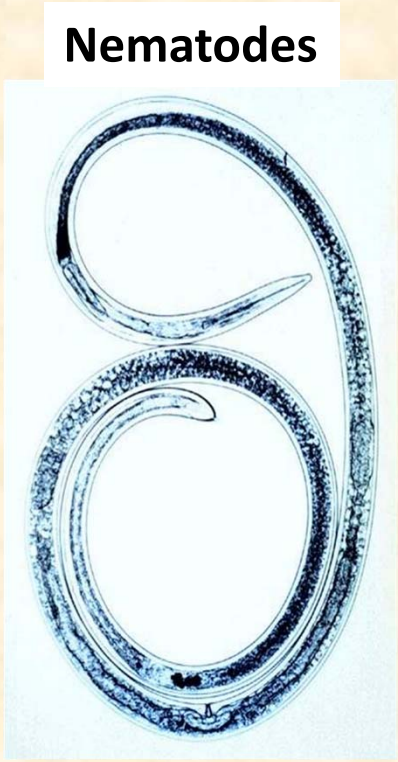
3. Most plant viruses have insect vectors but do not replicate in their vectors

3. Most plant viruses have insect vectors but do not replicate in their vectors

Most viruses that infect plants use insects to move from plant to plant

These viruses have highly evolved relationships with their vector in order to be transmitted without replication





Types of Vector-Virus Relationships

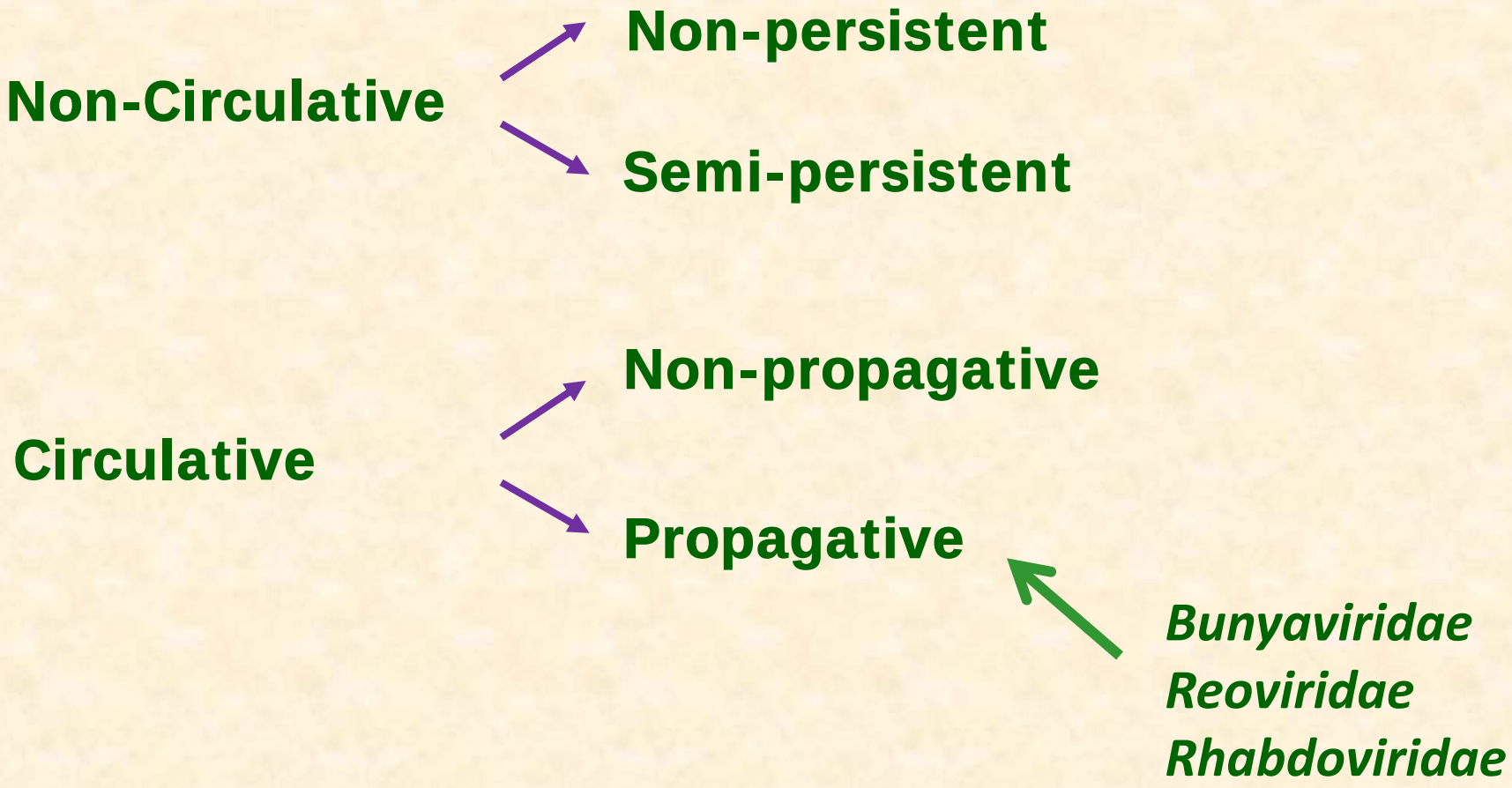
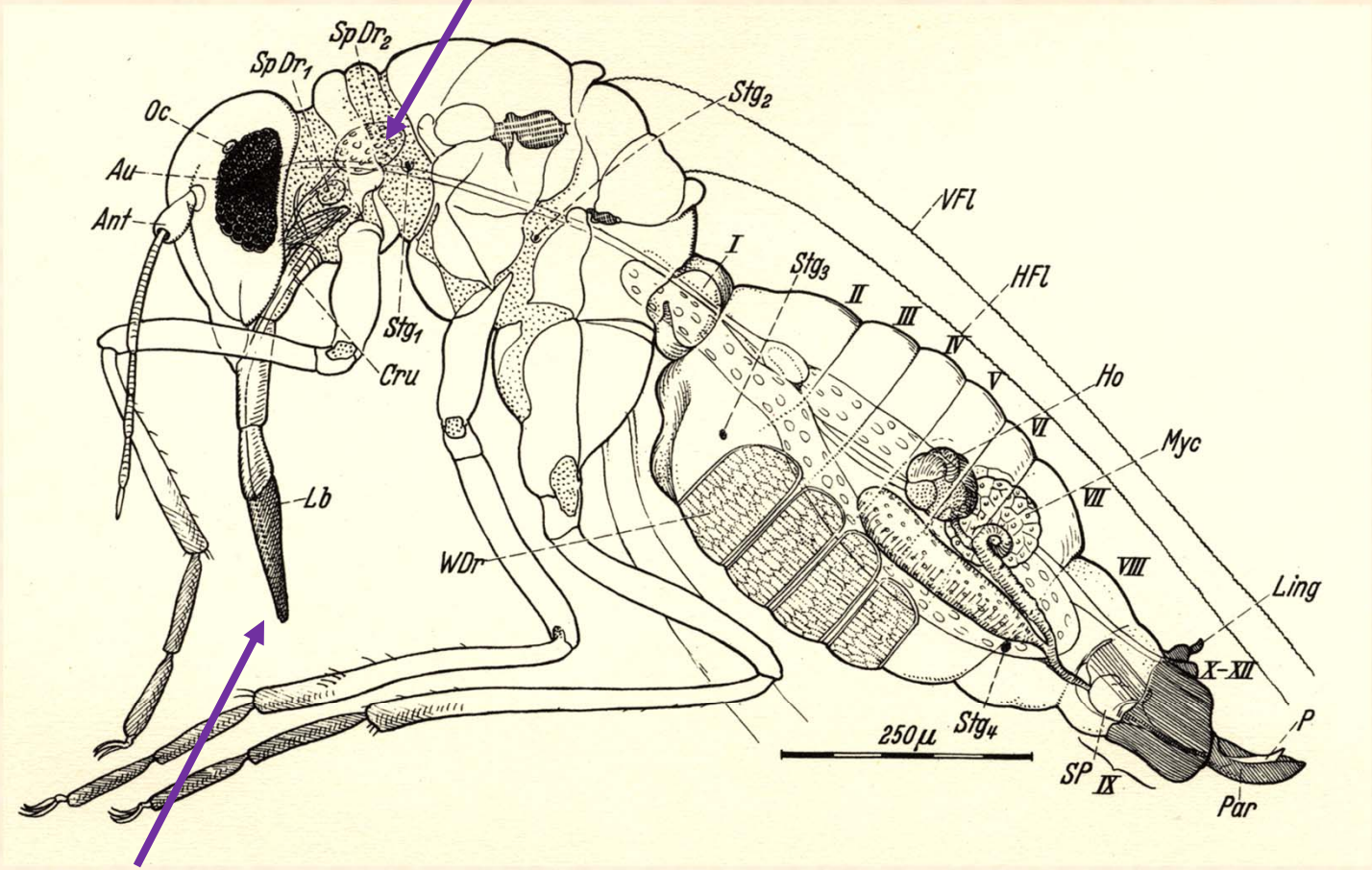


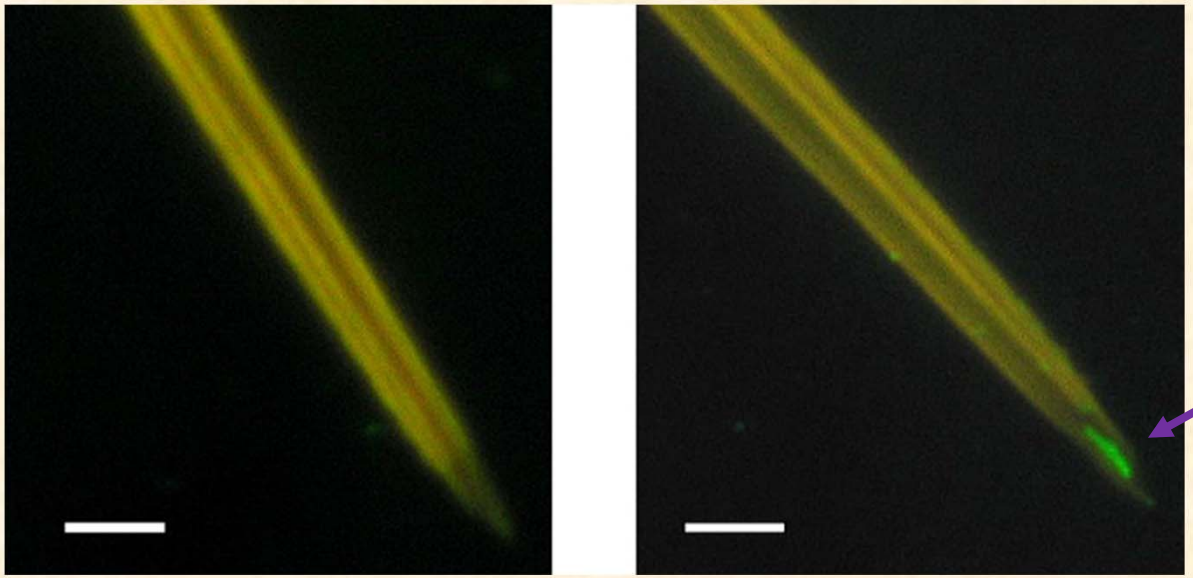
Diagram of an Insect Vector of Plant Viruses

Salivary Glands



Stylets: Specialized mouthparts

Non-persistent Transmission:
Virus binds to a particular location in the insect stylet



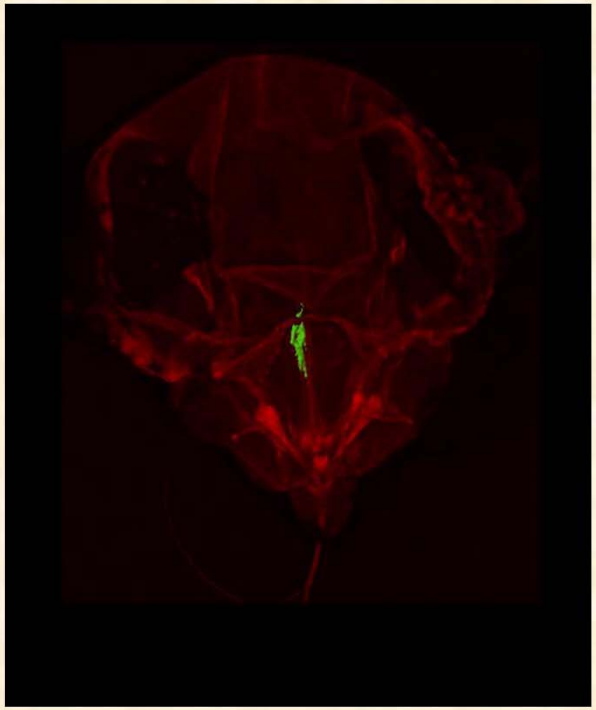
Virus bound to insect stylet

Virus produces a protein that binds to insect cuticle in a specific location on the stylet and binds to virus coat protein, released with saliva

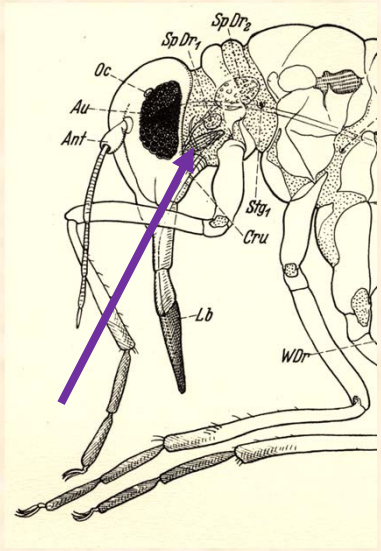
Insect probes infected plant – can transmit virus immediately, virus is retained for only a few minutes

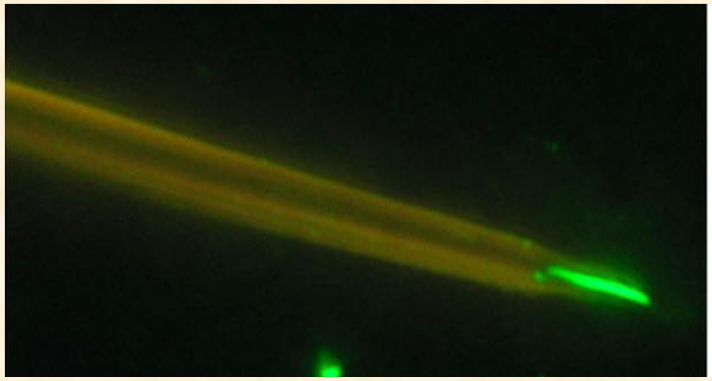
Uzest etal 2010 Arthropod Structure & Development 39:221-229

Semi-persistent Transmission:
Virus binds to a specific location in the stylet or foregut



Closteroviridae





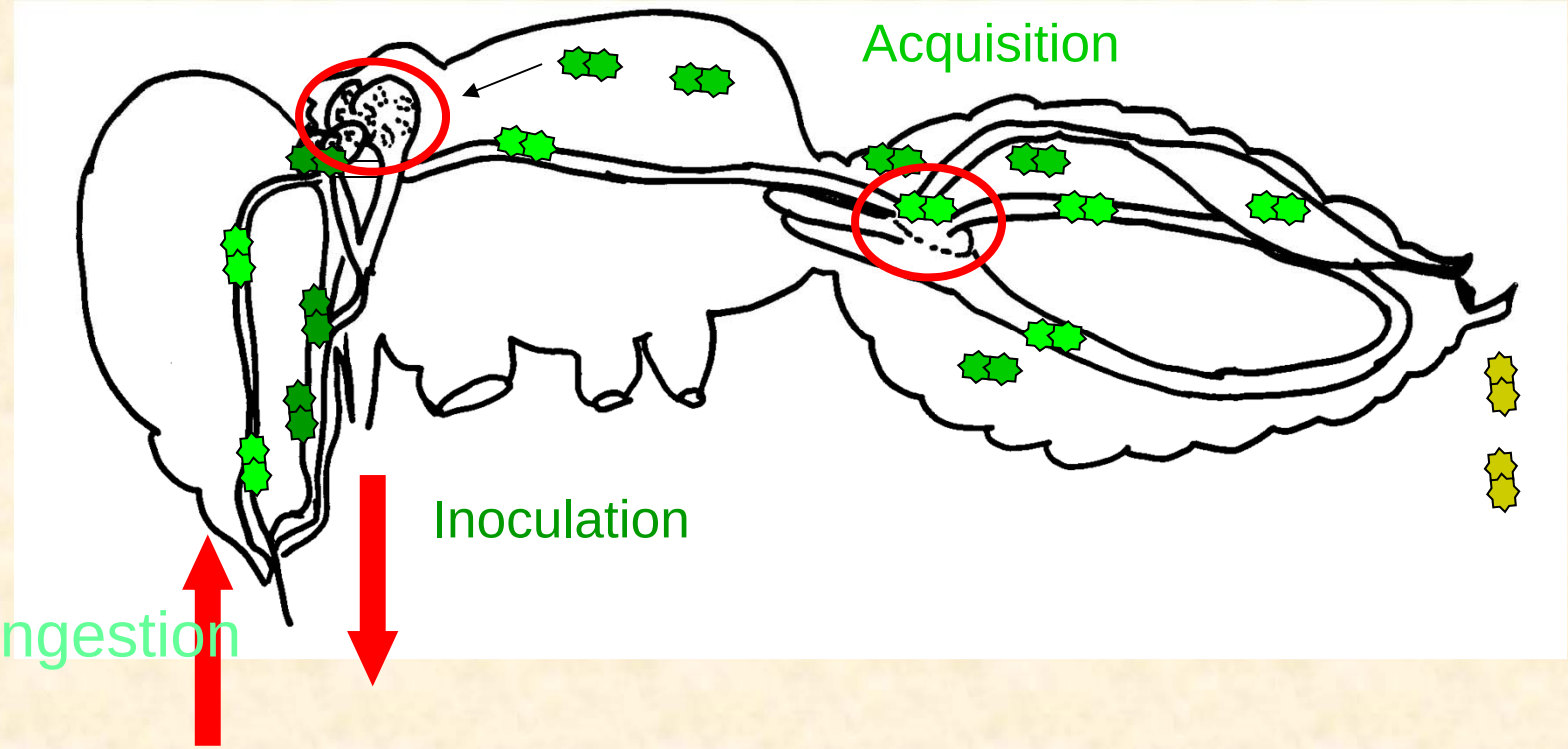
Caulimoviridae

Virus produces a protein that binds to vector cuticle in a specific location and binds to virus coat protein, released with saliva

Insect feeds on infected plant to acquire virus – can transmit virus immediately and up to 7 days later

Chen et al 2011 PNAS www.pnas.org/cgi/doi/10.1073/pnas.1109384108

Circulative, Non-Propagative Transmission:
Virus enters circulatory system of vector, enters salivary glands, and leaves the insect with the saliva



Insect feeds to acquire virus (15 min), latent period of 6-8 hours, transmission occurs by feeding, retention up to the life of the vector

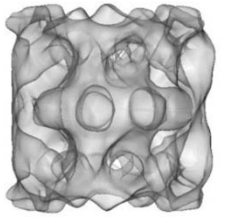
Circulative, Non-Propagative Transmission

How do viruses cross the midgut?
How do they survive in the haemolymph?
How do they get across the salivary gland cell membranes?

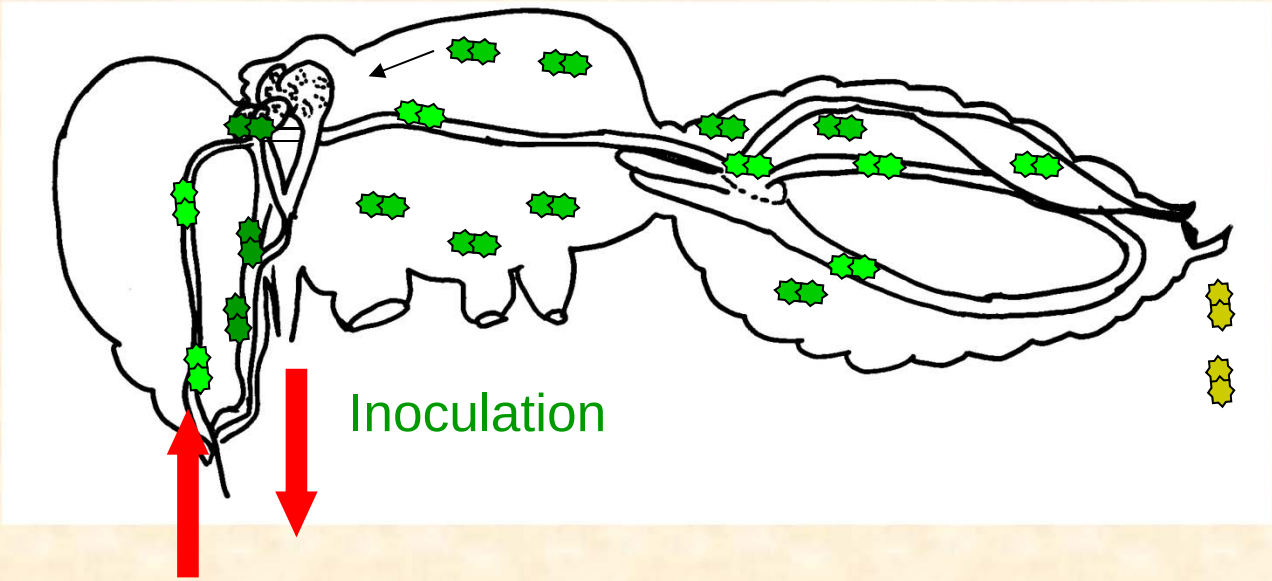
In some cases that have been studied:

Virus particles associate with a protein, not encoded by the virus or the insect... but by specific endosymbiotic bacteria living in the insect gut

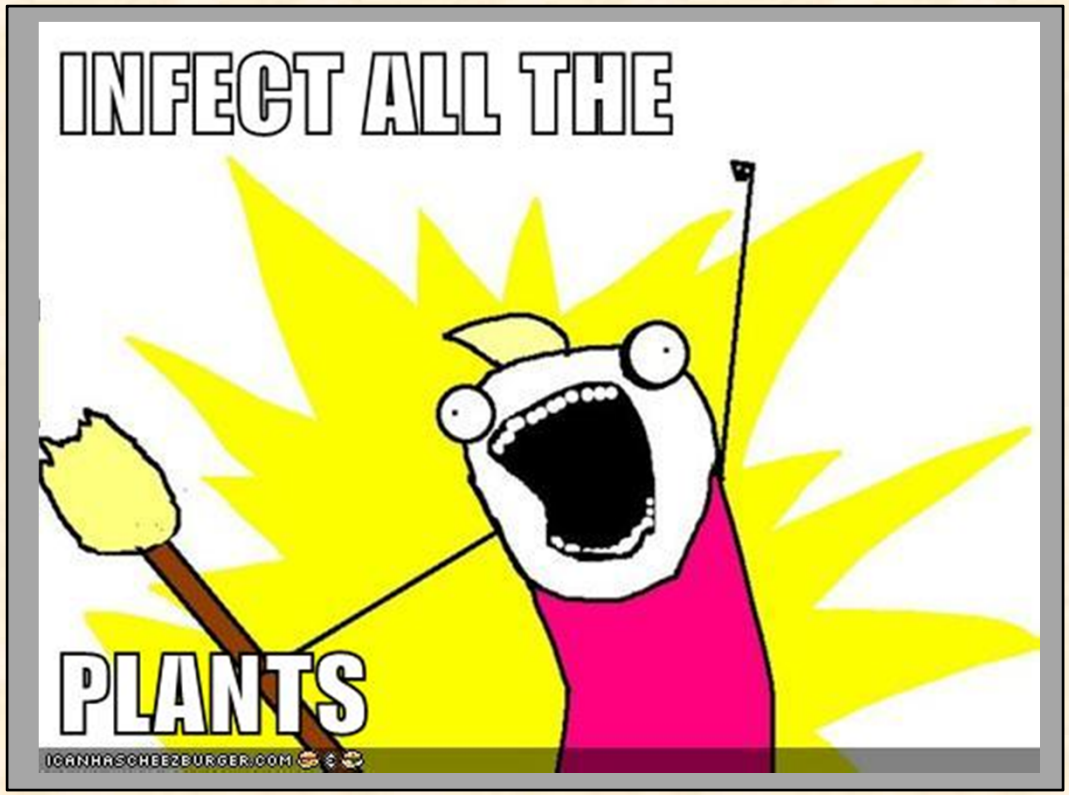
Protein known as GroEL, a chaperonin protein



Circulative, Propagative Transmission:
Virus enters insect cells, and replicates in various cells in the insect; virus enters salivary glands and leaves the insect with the saliva



Insect feeds to acquire virus (15 min), latent period of a few hours to days, transmission occurs by feeding, retention up to the life of the vector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