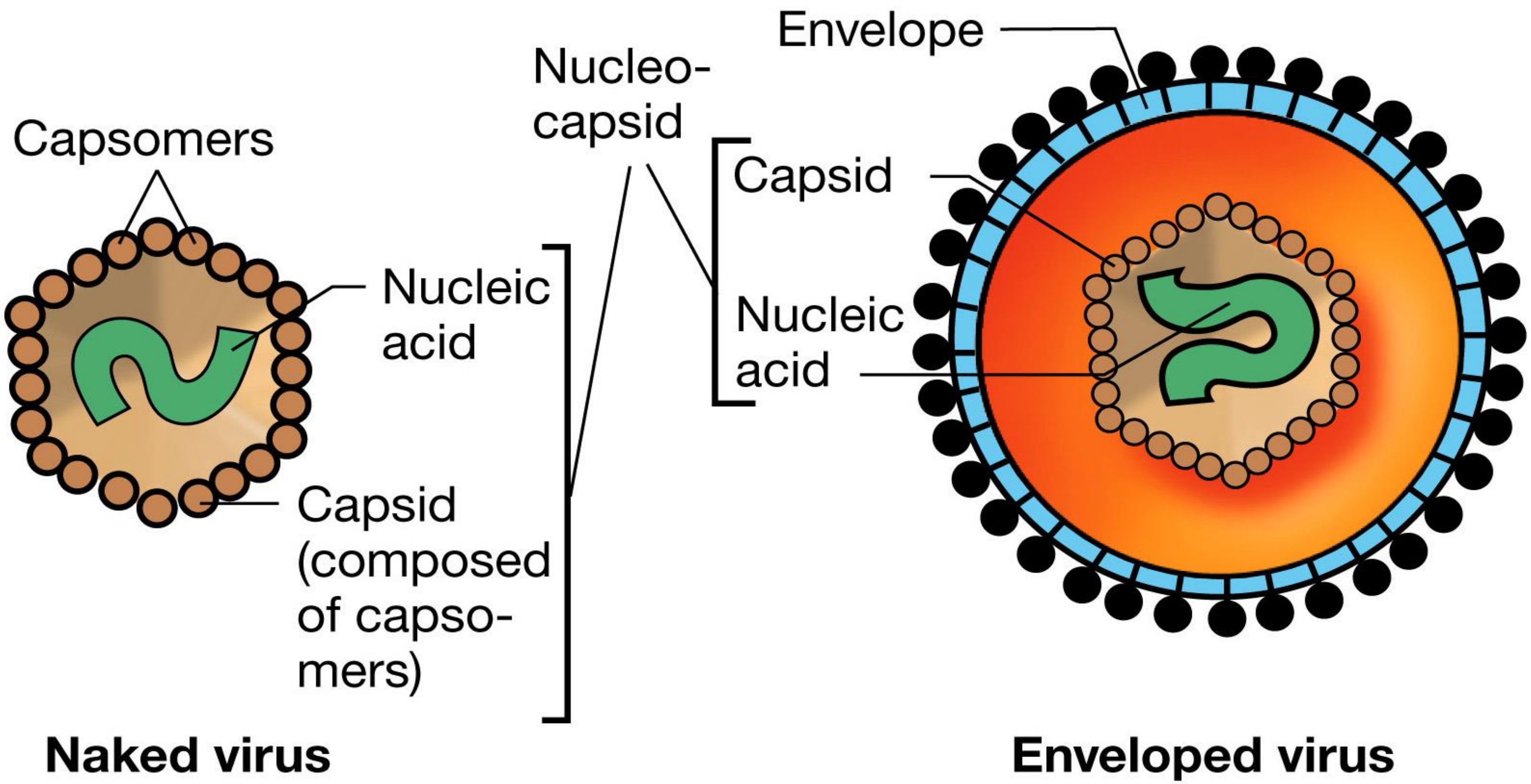
Parti del testo “Introduzione alla Virologia Moderna” da consultare per questa lezione

Capitolo 2 fino a pg. 14 e paragrafi 2.4, 2.5, 2.6 e 2.7

Capitolo 3

Struttura del virione



Struttura del virione

Funzioni delle proteine di rivestimento

Protezione del genoma **(soprattutto proteine del capside e nucleocapside)**

- Assemblaggio di un rivestimento proteico protettivo e stabile
- Riconoscimento specifico e impacchettamento del genoma
- In molti virus, interazione con la membrana dell'ospite per formare l'envelope

Trasporto del genoma

- Legame specifico con i recettori della cellula ospite
- Induzione della fusione dell'envelope con la membrana dell'ospite
- Segnali specifici che inducono la liberazione del genoma all'interno della cellula ospite (uncoating)
- Interazione con componenti cellulari che permettono il trasporto del genoma al sito appropriato per la replicazione

Capsidi virali: funzioni

Per proteggere gli acidi nucleici (genoma) che sono labile dal:

- **Danno fisico** - protezione meccanica.
- **Danno fisico** – Irradiazione UV (da luce solare) che porta alla modificazione chimica causando mutazioni anche letali
- **Danno enzimatico** – Nucleasi, esterasi, derivate da cellule morte o secrete deliberatamente come difesa contro le infezioni.

Protezione da variazioni di pH e Temperatura

Capsidi virali: funzioni

- **Packaging del genoma virale**

- **Interazione con cellule ospiti.** Proteine del capside di virus nudi mediano il legame e l'entrata dei virus.

- **Stimolazione della risposta immunitaria.** Le proteine del capside dei virus nudi sono spesso i maggiori antigeni del virus.

VIRAL CAPSID

- Protein coat surrounding the viral genome
- Made up of proteins encoded by the viral genome
- Capsid proteins form capsomeres
- Each capsomere = 1 or several aggregated capsid proteins
- 1 capsomere = morphological unit of the capsid

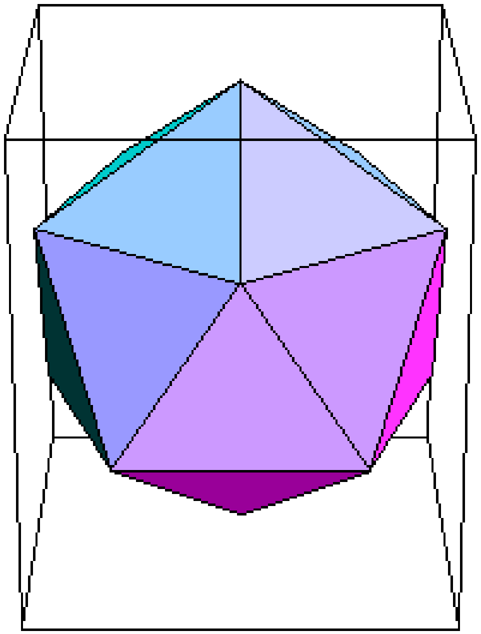
Capsid of most viruses

Icosahedral symmetry

Helical symmetry

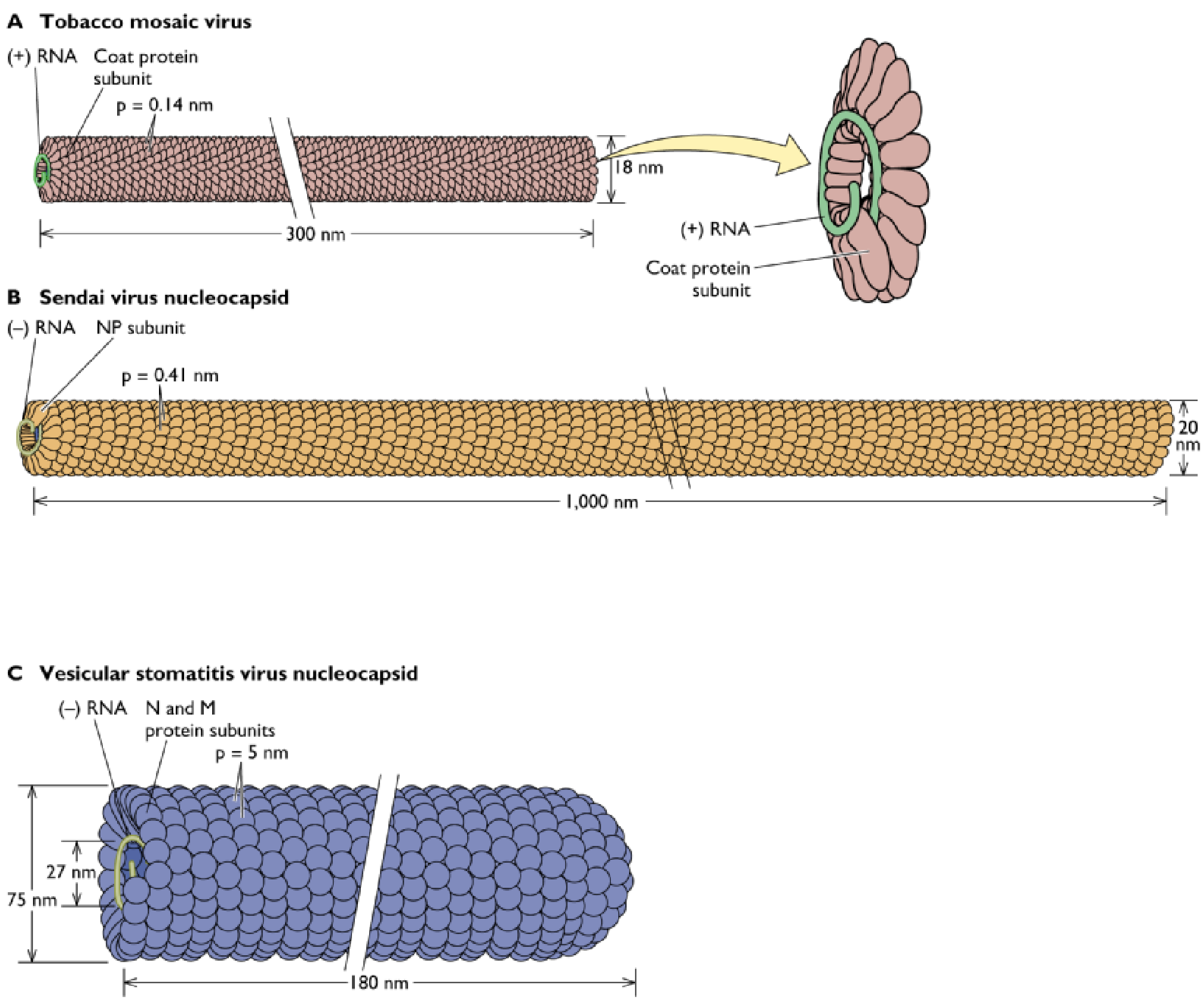
Struttura dei capsidi virali

Isometrici (quasi sferici)
Simmetria icosaedrica

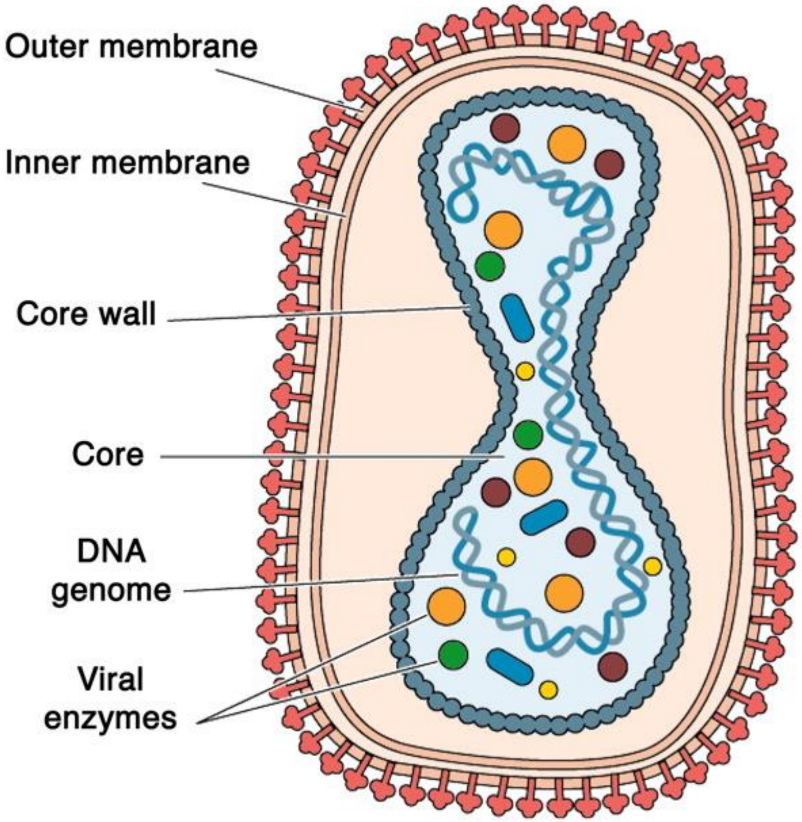


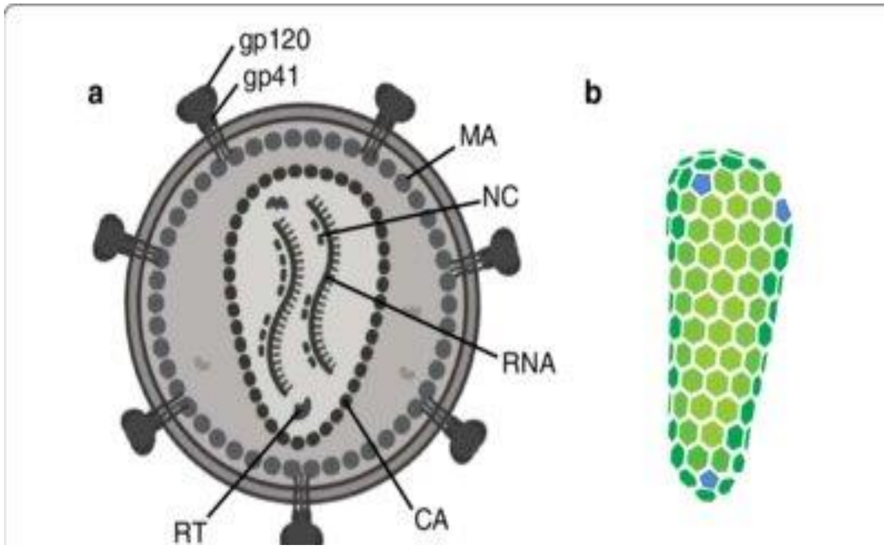
Struttura dei capsidi virali

Simmetria elicoidale



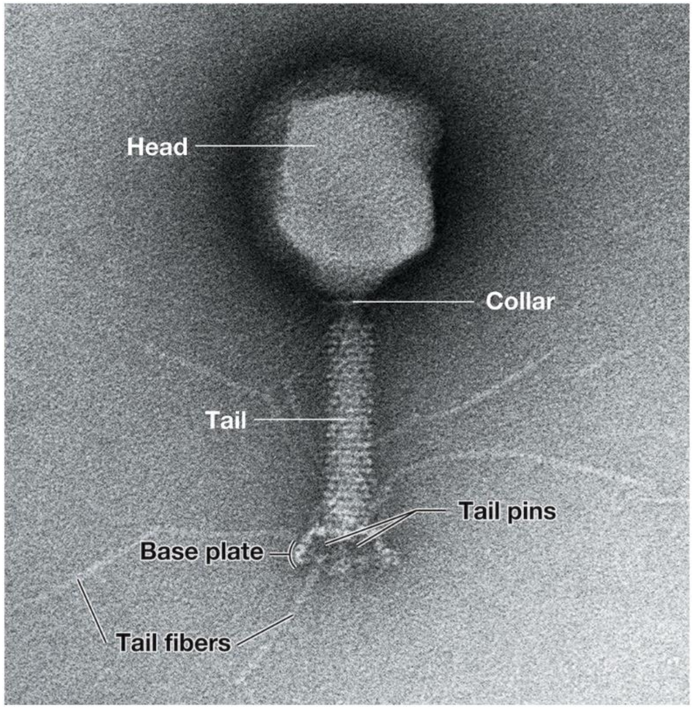
Struttura dei capsidi virali:
Complessi (es. poxvirus e HIV)

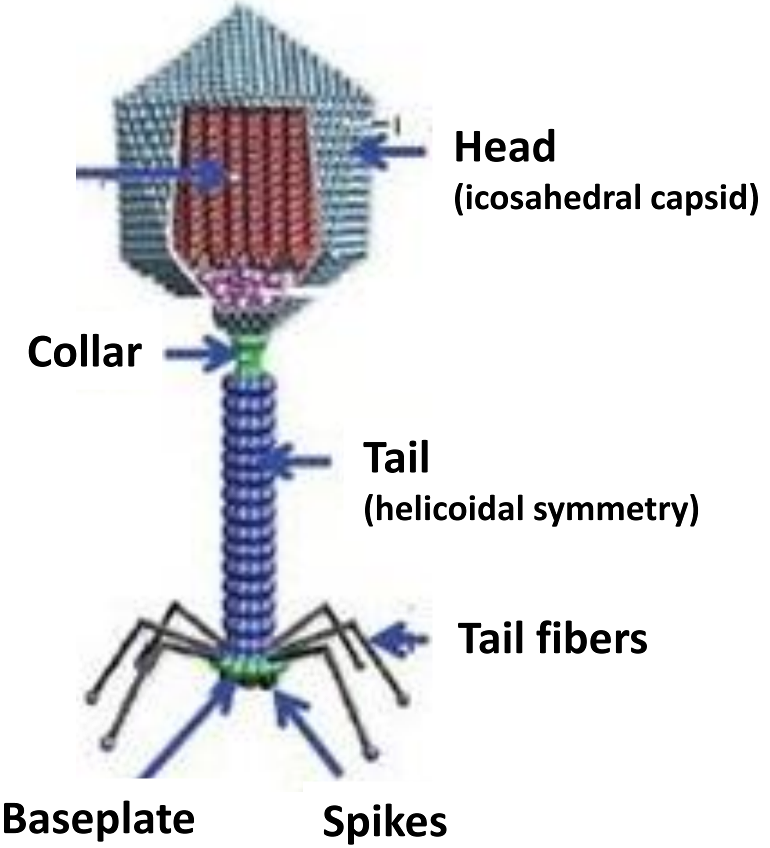




Structure of T4: a Complex Bacteriophage

The head possess an icosahedral structure, whereas the tail present a helical structure (mixed symmetry)





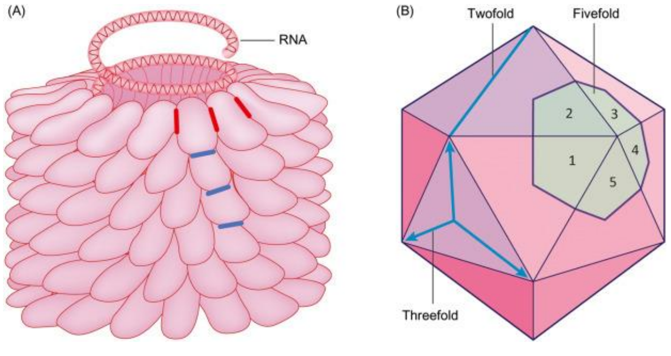
Simmetria del Capside virale

Elicoidale: quando l’acido nucleico si avvolge sulla struttura proteica di base, determinando, al microscopio elettronico, una forma oblunga. Spesso le subunità proteiche sono identiche tra loro

Icosaedrica: quando i capsomeri (unità base dell’icosaedro costituente il capside) sono organizzati a costituire una struttura poliedrica regolare con 20 facce costituite da triangoli equilateri. All’interno è situato il nucleocapside, aderente in alcuni punti ai capsomeri. E’ presente nella maggioranza dei virus

Complessa: struttura non classificabile secondo canoni ristretti: batteriofagi, poxvirus, ecc.

Troncoconica: tipica dei retrovirus



Struttura del virione

Capside virale

E' costituito da subunità proteiche assemblate a formare una struttura simmetrica ripetitiva.

Le dimensioni del capside determinano in qualche modo la quantità (quindi le dimensioni) del materiale genetico che può essere impacchettato nella particella virale.

Capside virale

I virus nudi di origine animale hanno una simmetria esclusivamente di tipo icosaedrico.

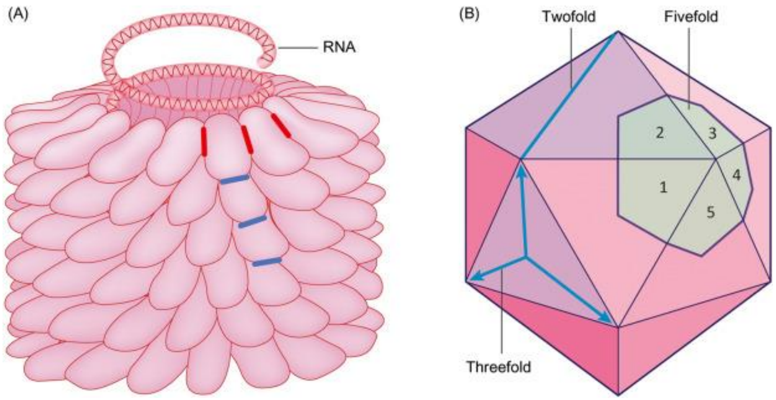
I virus con envelope (o rivestiti) possono avere il capside sia a simmetria elicoidale sia a struttura icosaedrica.

I virus più grandi (come i Poxvirus) possono avere una struttura morfologica più complessa.

Capside virale

E' proprio del virus, e' geneticamente determinato e costituito da subunità proteiche disposte in modo regolare, codificate dal genoma virale.

Dato il limitatissimo patrimonio genetico dei virus, le proteine costituenti i **capsomeri** (unità base del capside) sono molto poche, specifiche del virus, e, nei virus «nudi» in grado di interagire con i componenti sulla superficie cellulare fungendo da recettori.



Capside-Nomenclatura

Subunità strutturale (protomero): le singole proteine che costituiscono il capside

Unità morfologica (capsomero): la struttura più piccola visibile al microscopio elettronico, formata dall'interazione di più protomeri.

Nella simmetria icosaedrica

- **Pentoni:** capsomeri formati da cinque protomeri
- **Esoni:** capsomeri formati da sei protomeri

Capside virale

Some viruses only have one capsid protein because small size of viral genomes restricts number of proteins (**e.g.,** tobacco mosaic virus)

Capsids can be put together through **self-assembly** (spontaneous) or may require host cell folding assistance

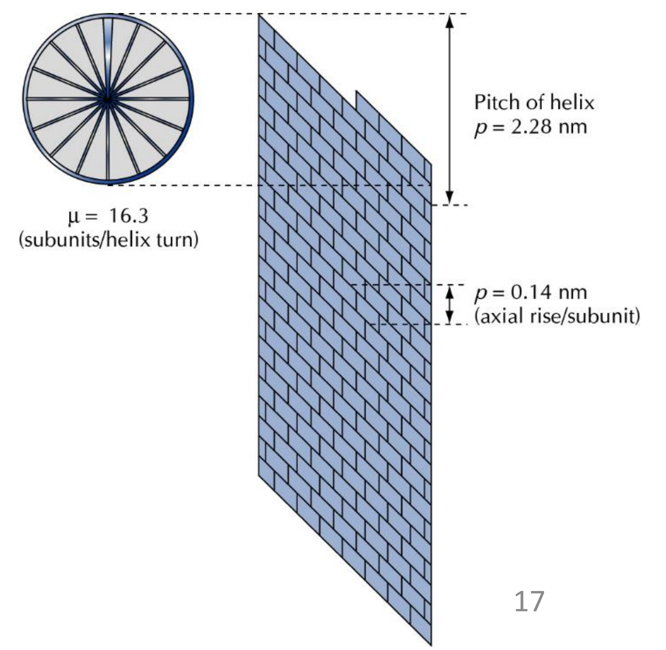
Capsidi virali: Simmetria elicoidale

Le dimensioni dei virioni con un capside a simmetria elicoidale sono date in termini di diametro, che dipende dalle caratteristiche dei protomeri, e di lunghezza, che dipende dalle dimensioni del genoma.

La simmetria elicoidale è definita da due parametri:
Ampiezza = diametro
Passo dell'elica (P) = distanza coperta da un intero giro di elica

$$P = \mu \times \rho$$

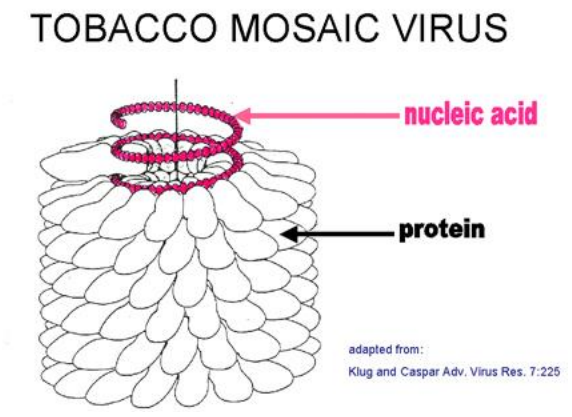
μ= numero di protomeri per giro d'elica
ρ= incremento assiale per subunità

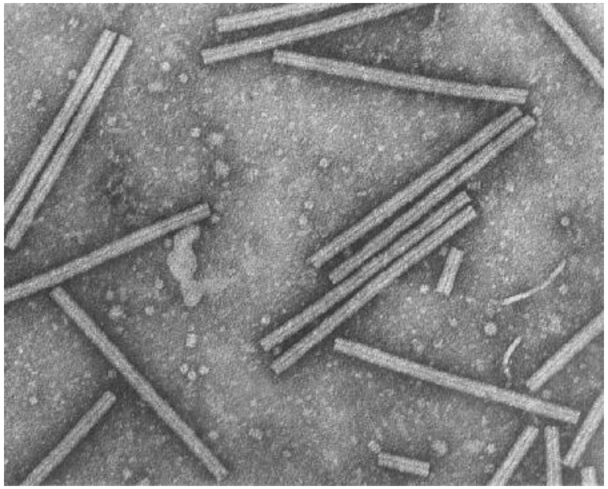


From Cann *Principles of molecular virology* (2001). Academic Press

Capsidi virali: Simmetria elicoidale

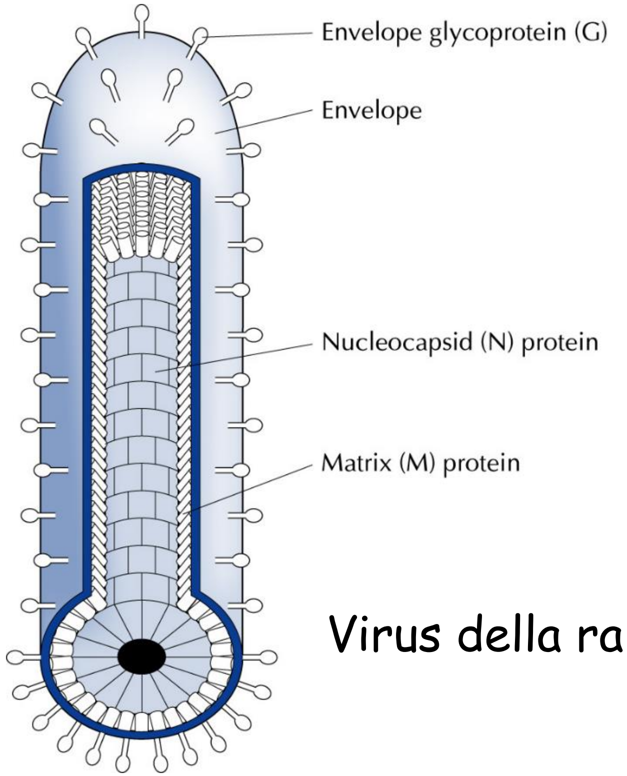
La simmetria elicoidale è molto frequente tra i virus vegetali



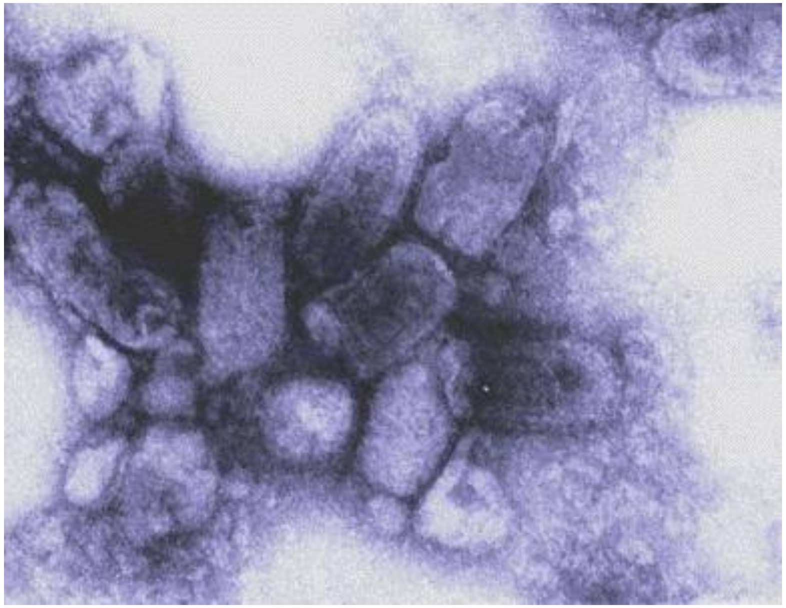


Capsidi virali: Simmetria elicoidale

I virus animali a simmetria elicoidale sono tutti provvisti di envelope
Numerosi virus patogeni per l'uomo sono caratterizzati da questa struttura: virus dell'influenza (orthomyxovirus), i virus che causano la parotite epidemica e il morbillo (paramyxovirus), il virus della rabbia (rabdovirus), i coronavirus.

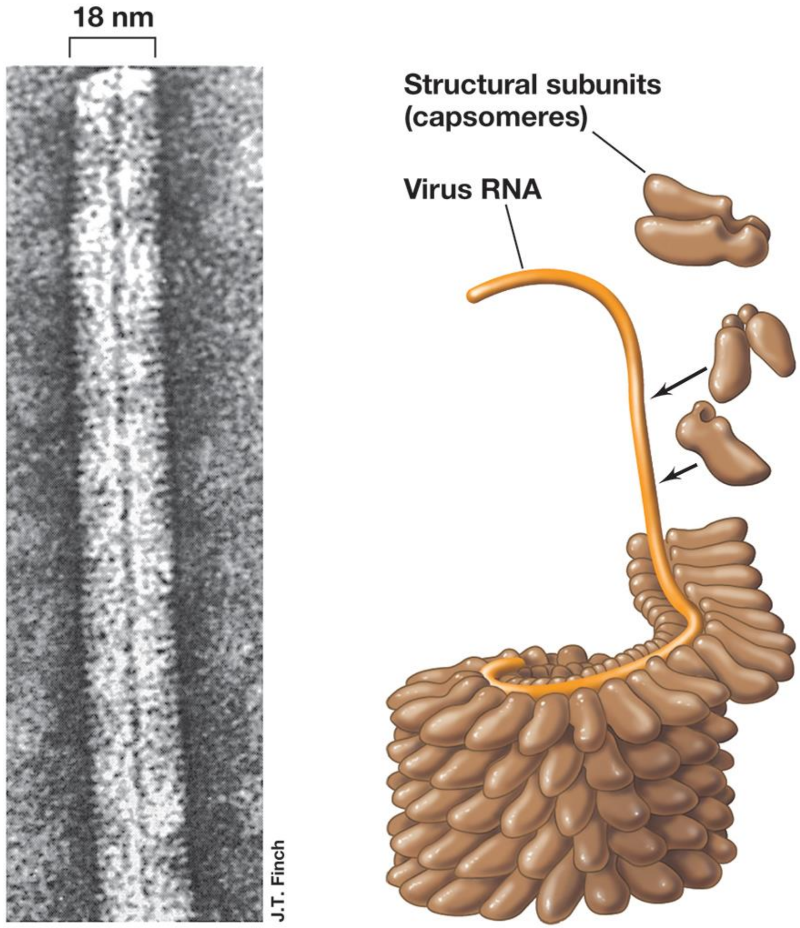


Virus della rabbia



From Cann *Principles of molecular virology* (2001). Academic Press

The Arrangement of RNA and Protein Coat in Tobacco Mosaic Virus, a Simple Naked Virus

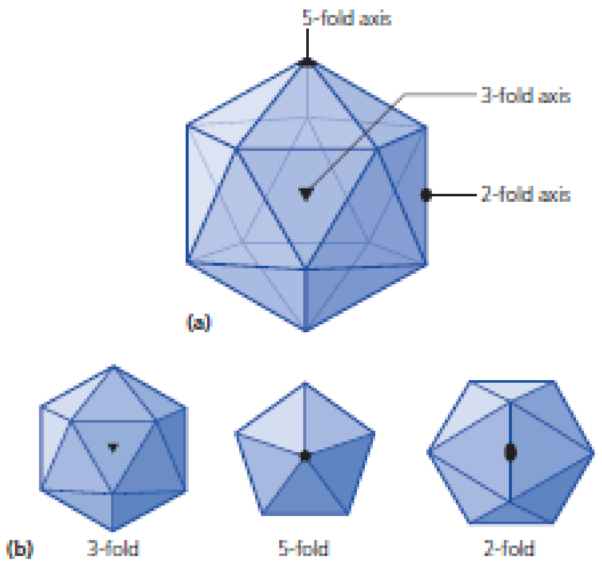


(a) (b)

Capsidi virali: Simmetria icosaedrica

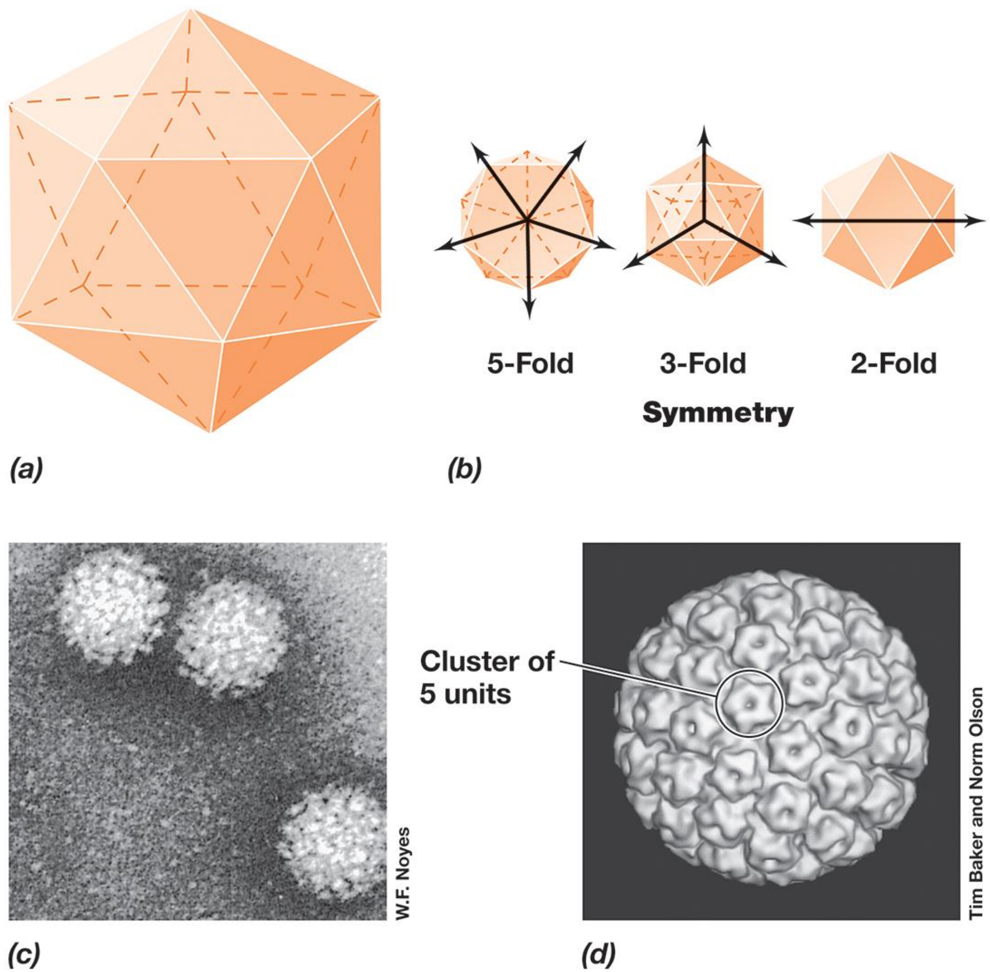
L' icosaedro è un solido con 20 facce triangolari e 12 vertici;
È un involucro **chiuso** (il capside elicoidale è una struttura **aperta**);
È caratterizzato da 3 assi di simmetria rotatoria:

- asse di simmetria 5 che passa attraverso ognuno dei dodici vertici, sono possibili 5 rotazioni di 72° , ciascuna delle quali produce una configurazione identica
- asse di simmetria 3, che passa per il centro di ciascuna delle venti facce, sono possibili tre rotazioni di 120° , ciascuna delle quali produce una configurazione identica
- Asse di simmetria 2, che passa per ciascuno dei trenta spigoli dell'icosaedro, sono possibili 2 rotazioni di 180° , ciascuna delle quali produce una configurazione identica



Introduction to Modern Virology, Seventh Edition. N. J. Dimmock, A. J. Easton and K. N. Leppard.

Icosahedral Symmetry

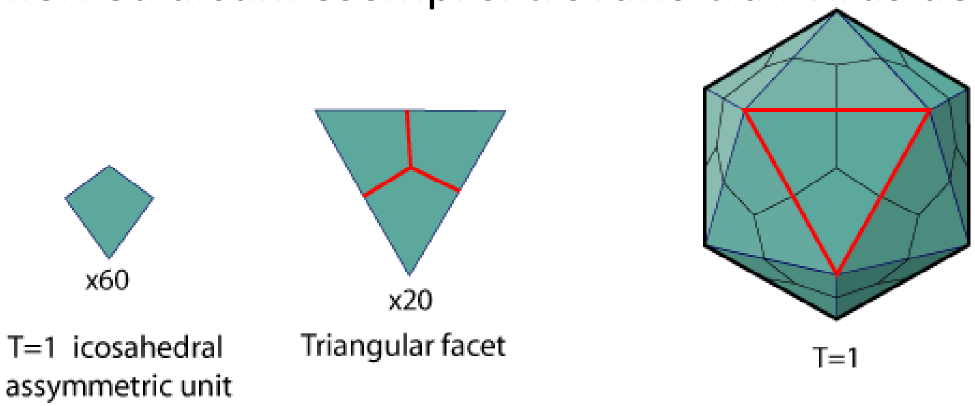


Capsidi virali: Simmetria icosaedrica

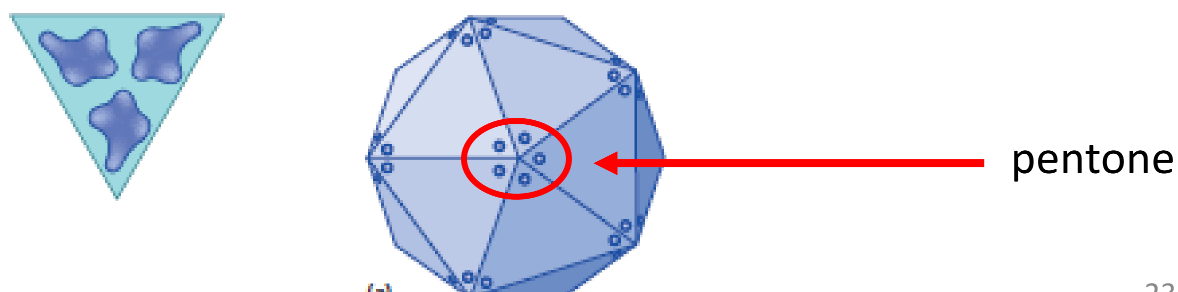
Gli involucri più semplici sono formati da 60 **protomeri**, tre per faccia, ognuno posto ad uno dei vertici.

L'insieme dei cinque protomeri attorno a ciascun vertice dell'icosaedro costituisce un **capsomero** (in questo caso un **pentone**)

Solo i virioni più piccoli e più semplici hanno un capside composto da 60 protomeri ed alcuni esempi si trovano tra i virus delle piante



Numero di triangolazione (T)
Numero di triangoli inscritti per faccia



Capsidi virali: Simmetria icosaedrica

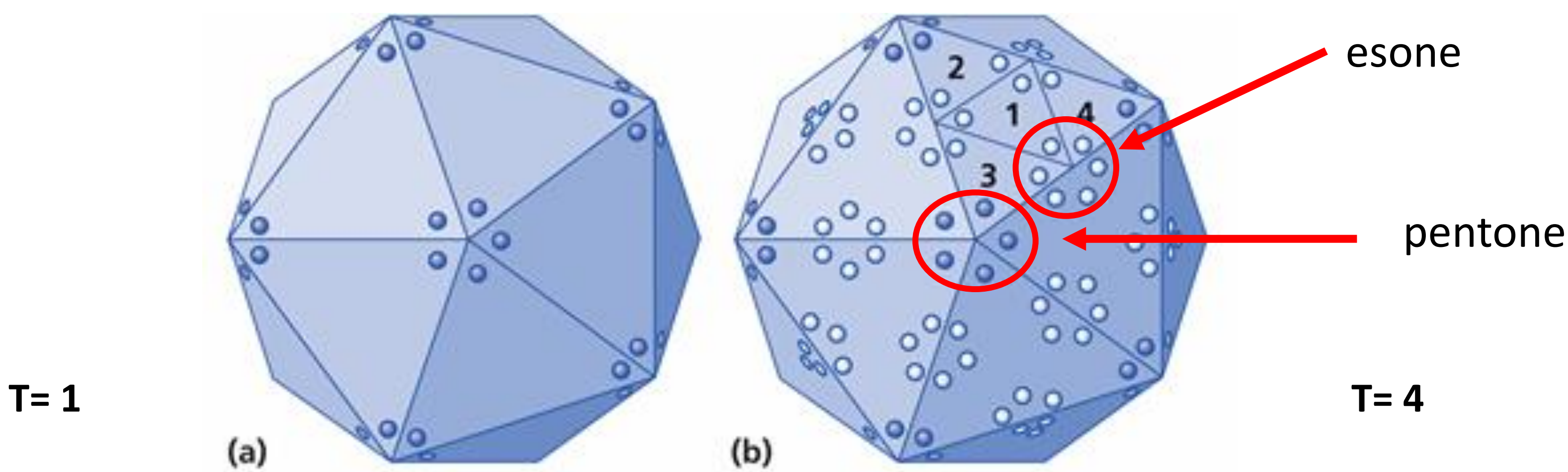
La maggior parte degli altri virus con capside a simmetria icosaedrica hanno più di 60 protomeri

Numero di triangolazione (T). Numero di triangoli inscritti per faccia. Il più piccolo numero possibile è1, poi 3, 4, 7, 9, 12 … quindi avremo

T=1 per l' icosaedro base (solo satelliti, dimensioni ridotte 18nm)

T=3 Tre triangoli inscritti per ciascuna faccia (sei emi-triangoli)

T=4 Quattro triangoli inscritti per ciascuna faccia etc…



Introduction to Modern Virology, Seventh Edition. N. J. Dimmock, A. J. Easton and K. N. Leppard. *…inciples of Virology* (2000), ASM Press

SMALL SIZE ICOSAHEDRAL CAPSID

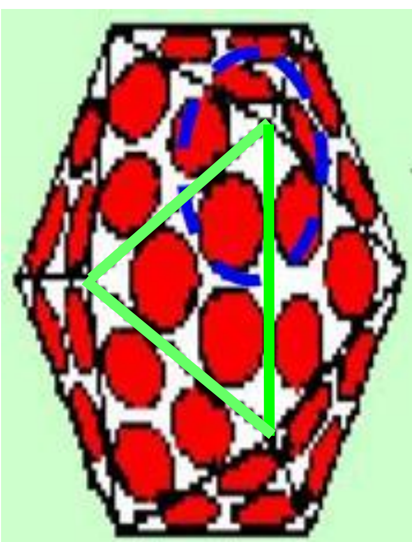
20 main faces with 3 capsid proteins per face

Total number of capsid proteins /capsid (N):

N = 20 x 3 = **60 capsid protein**

P = 12 pentamers

H = 0 hexamers



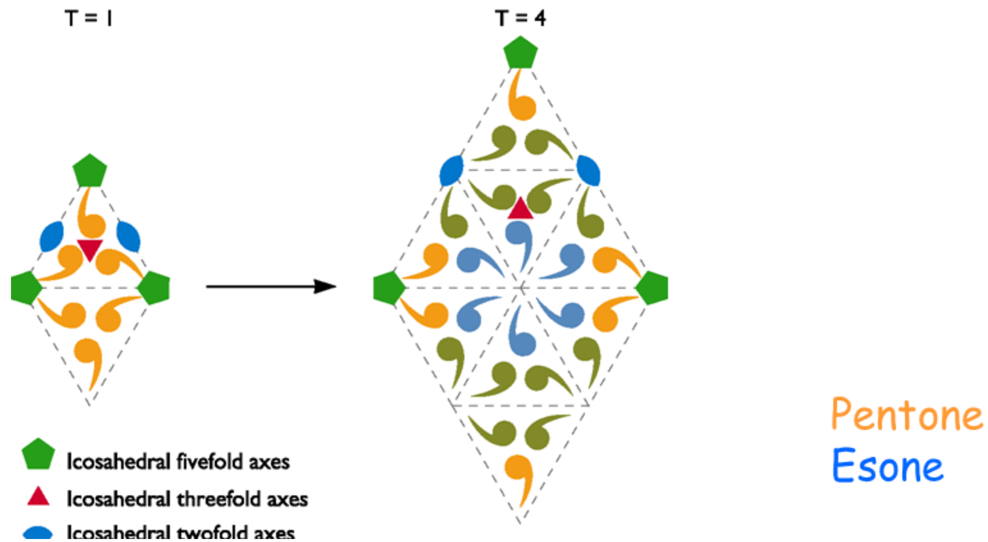
No subtriangulation

➔only 1 triangle per main face

➔ triangulation number **T = 1**

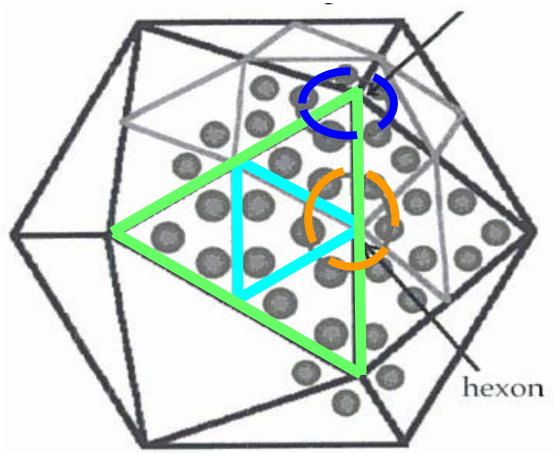
Capsidi virali: Simmetria icosaedrica

Principio di semi-equivalenza: quando la stessa unità strutturale o protomero si organizza a formare sia pentoni che esoni, le diverse interazioni stabilite nel formare i due tipi di capsomeri sono da attribuire e differenze di configurazione della stessa catena polipeptidica.
Poiché ciascun triangolo inscritto è formato da 3 protomeri, uno per vertice, nei capsidi icosaedrici con T>1 il numero di protomeri sarà 60xT



From Flint et al. *Principles of Virology* (2000), ASM Press

For **larger icosahedra capsids**, the **20 main faces** are larger and **subdivided in subtriangulations, containing each 3 capsid proteins**.



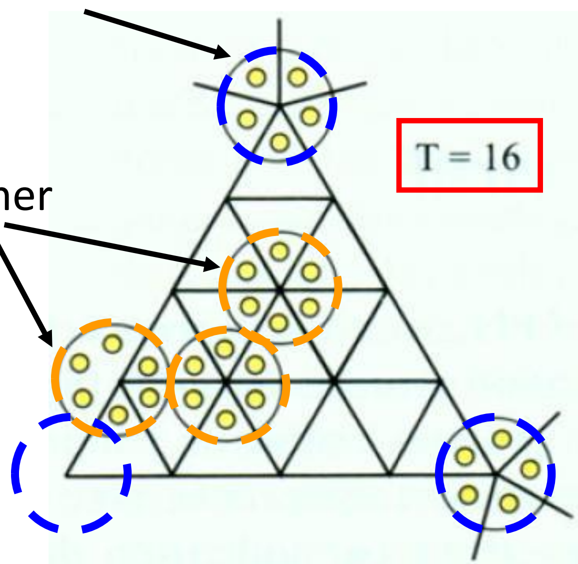
Triangulation number T = number of subtriangulations per main triangular face.

T = 4

number of pentameres will always be 12, the number of hexameres depend on the size of the capsid, so from T

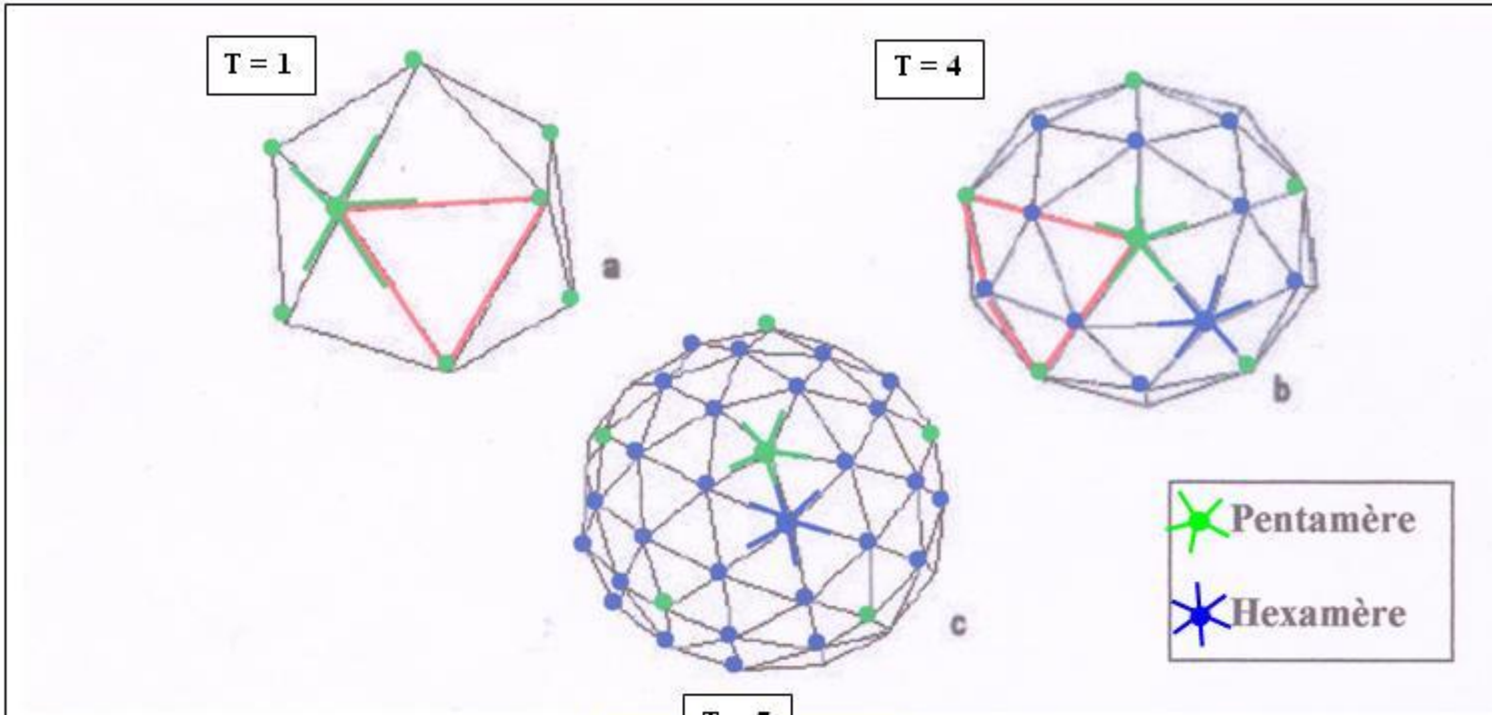
Pentamer

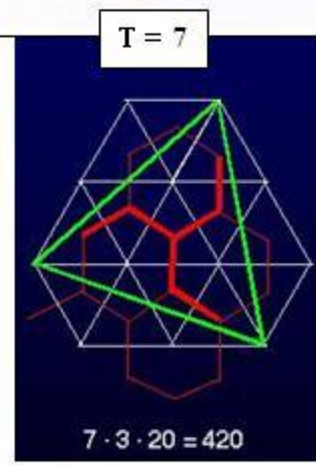
Hexamer



A capsid protein subunit is always engaged in a capsomere either pentamer or hexamer

Correlation between conformation and triangulation

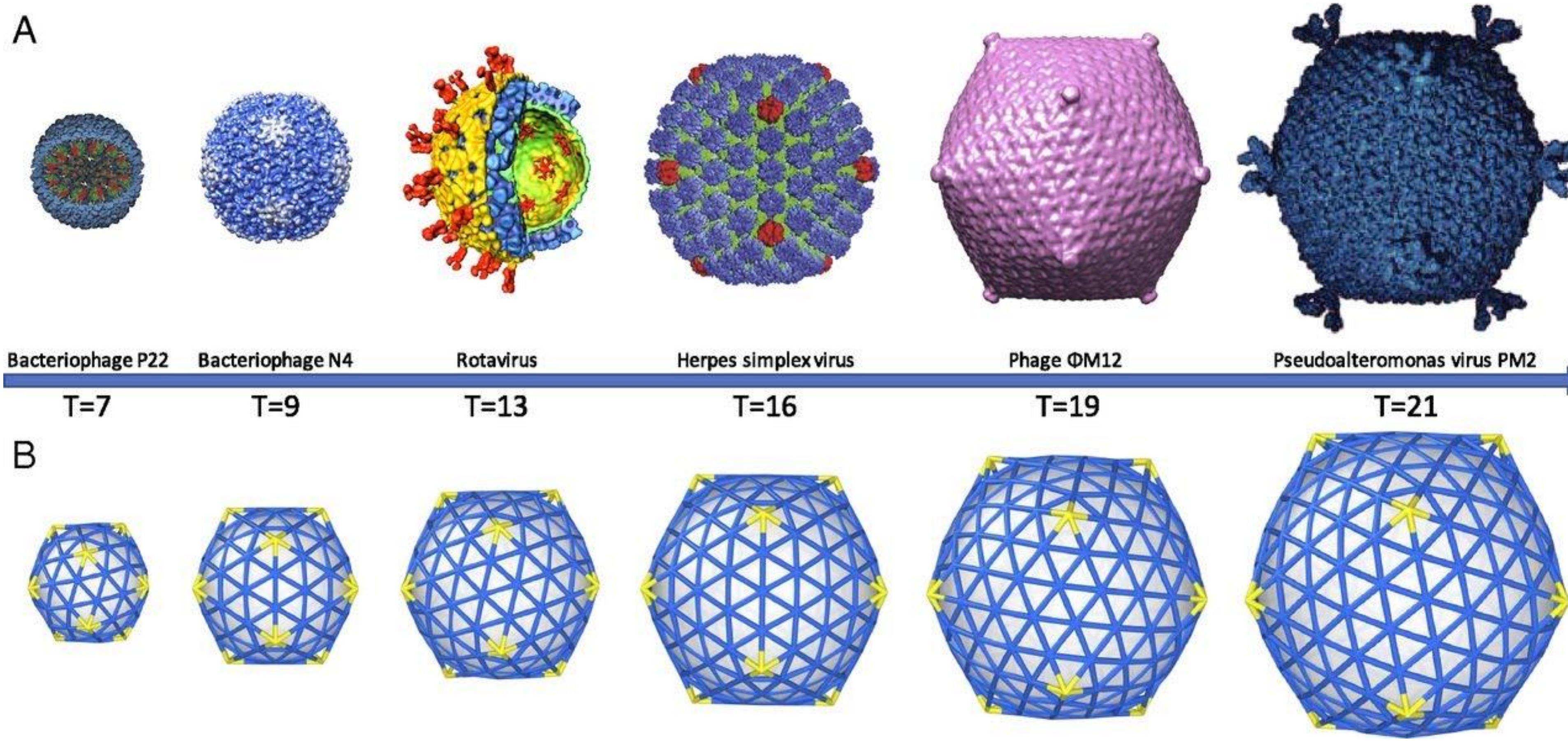




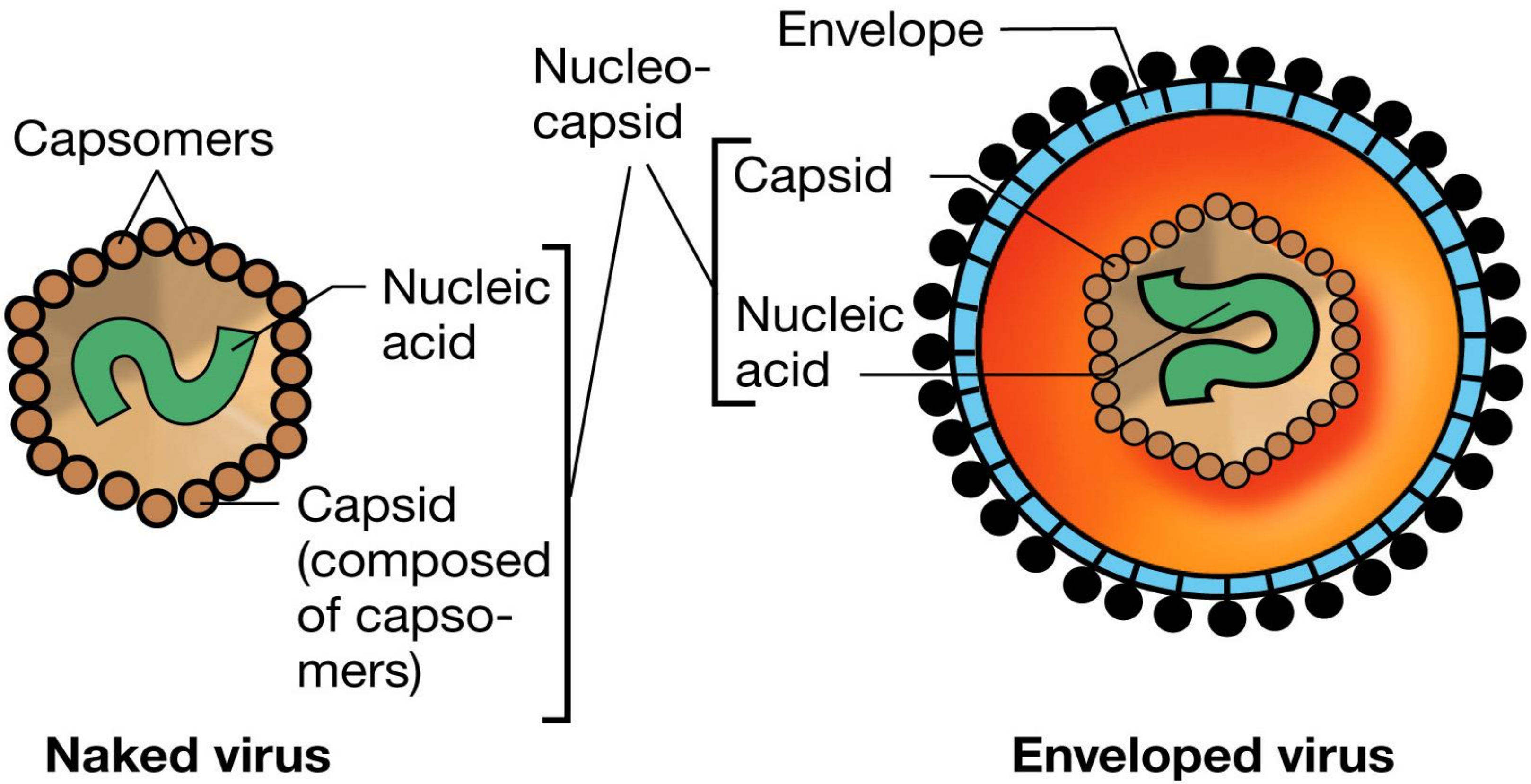
The number of capsomeres is dependent on the size and the shape of the viral particle.
The more the capsid possess subunit, the more the capsid look spherical.

Viral Capsid symmetry

Icosahedral symmetry



Struttura del virione



Struttura del virione

Pericapside (peplos, envelope)

Doppio strato lipidico che circonda il nucleocapside di molti virus animali. Deriva dalle membrane cellulari come risultato del processo di gemmazione della particella virale.

L'envelope contiene proteine, codificate dal genoma virale; spesso glicoproteine con un ruolo importante nel processo di attacco/adsorbimento e entrata del virus nella cellula ospite.

COMPOSITION OF THE VIRAL ENVELOPE

Derived from **an host cell membrane** :

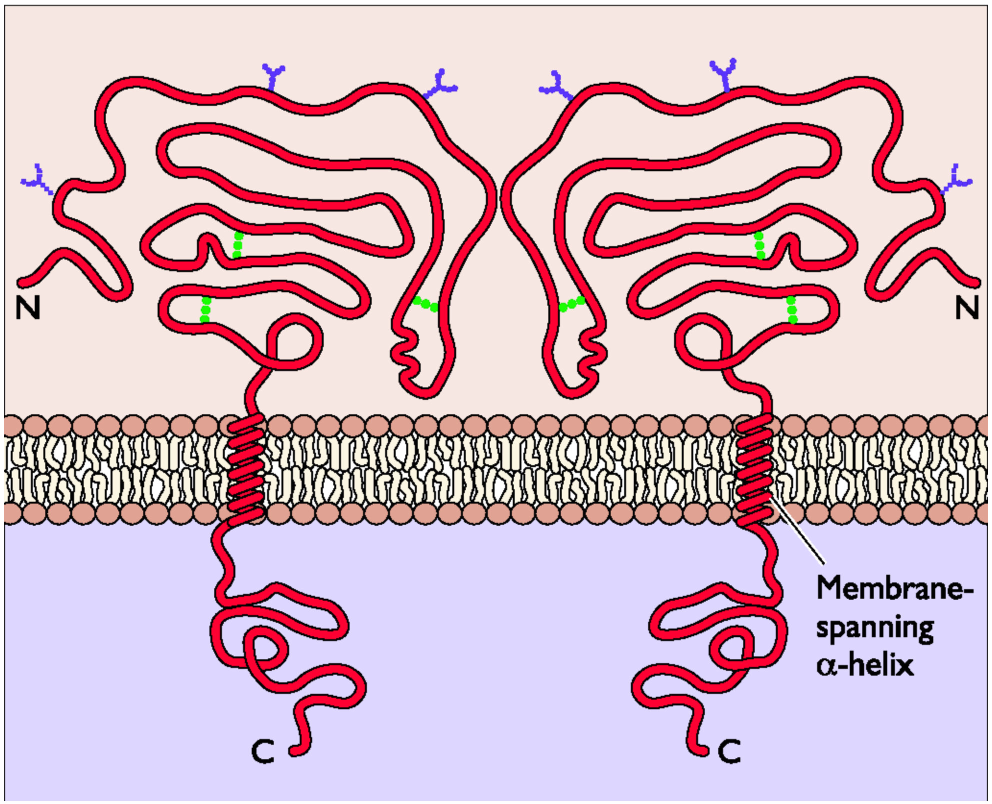
phospholipids bilayer

and

Viral glycoproteins encoded by the viral genome

examples : - receptor binding proteins
- Fusion proteins
etc.

COMPOSITION OF THE VIRAL ENVELOPE



La base di tutti gli involucri virali è una **membrana lipidica** acquisita dalla cellula ospite durante l'assemblaggio.

Proteine virali vengono inserite nella membrana lipidica.

La grande maggioranza di queste sono **glicoproteine** (oligomeri).

ORIGIN OF THE VIRAL ENVELOPE

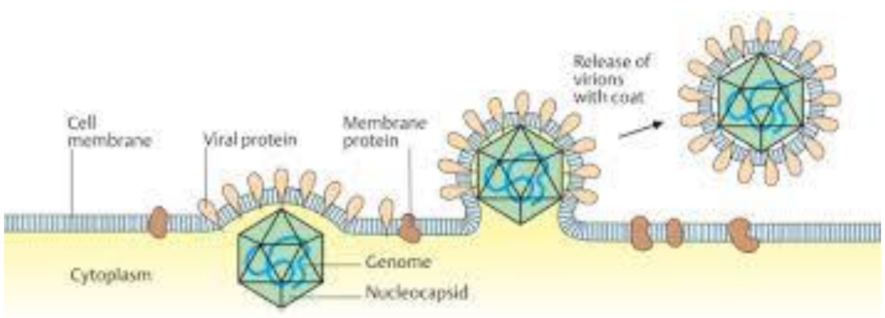
Derived from the host cell membranes

Plasma membrane (ORTHOMYXOVIRIDAE, RHABDOVIRIDAE, RETROVIRIDAE…)

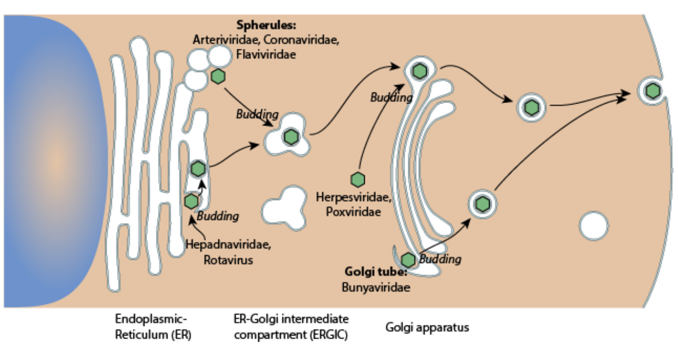
Or

Endomembrane system (FLAVIVIRIDAE, HERPESVIRIDAE…)

The lipid composition of the viral envelope depends on the cell membrane from which it emanates



D. Release of a virus by budding

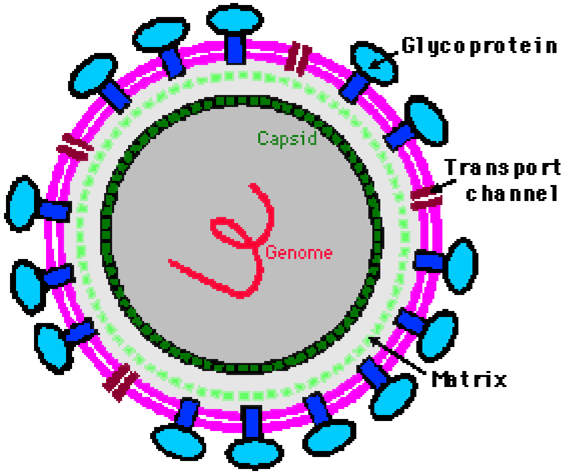


Pericapside (peplos, envelope)

Al doppio strato lipidico derivato dalle membrane cellulari sono associate proteine virus-specifiche quali:

•Glicoproteine, suddivise in base alla loro funzione in: glicoproteine esterne o di superficie, proteine transmembrana e canali di trasporto

•Proteine della matrice



Pericapside (peplos, envelope)

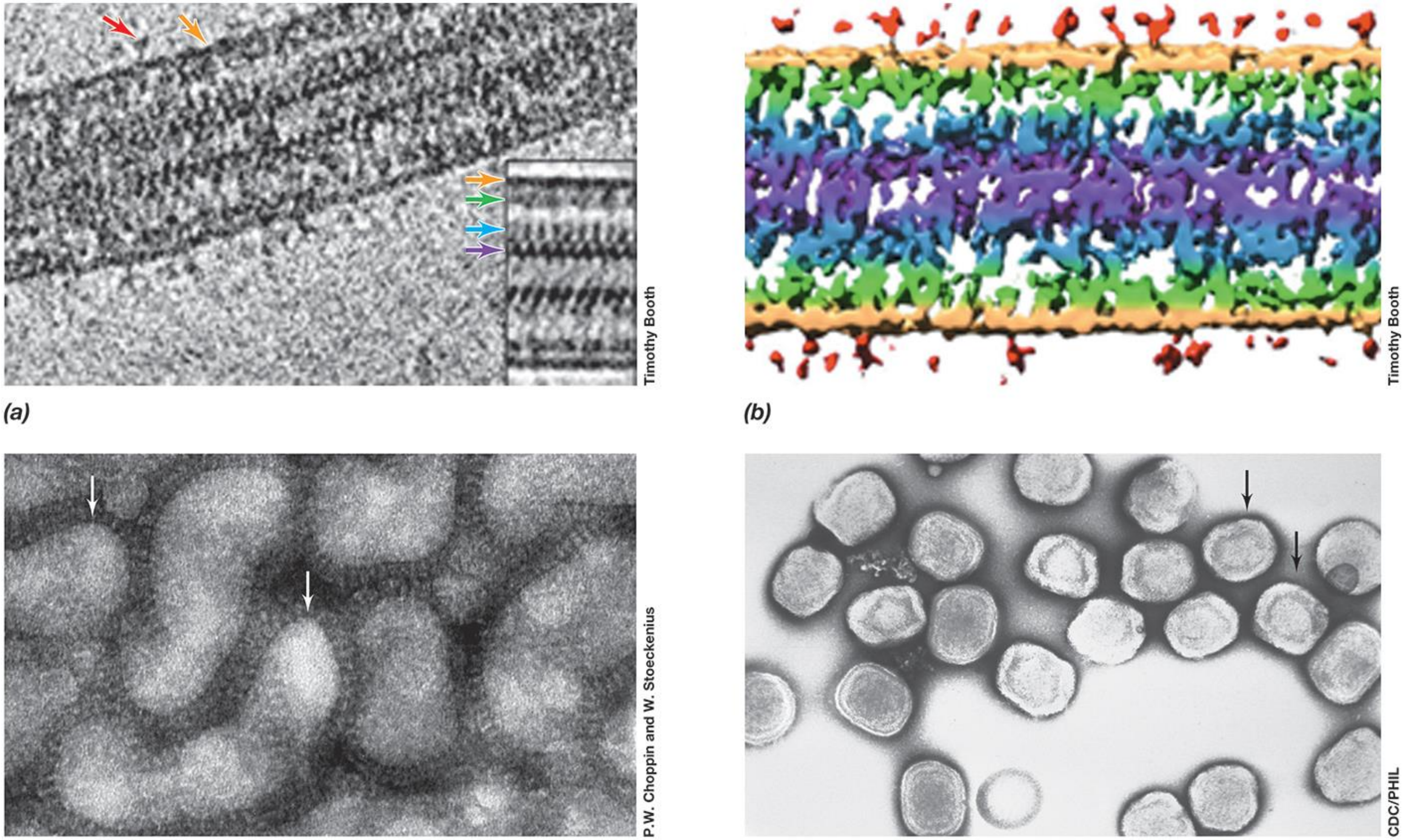
Presente solo in alcune famiglie di virus

(e.g. orthomyxovirus, herpesvirus, retrovirus, poxvirus, ecc.).

Svolge funzione di protezione, di riconoscimento antigenico (emoagglutinina del virus influenzale) e di penetrazione nella cellula ospite tramite il meccanismo di fusione con la membrana cellulare.

La presenza del pericapside rende ragione della sensibilità di alcuni virus ai disinfettanti organici (eteri, alcooli) in grado di sciogliere i lipidi.

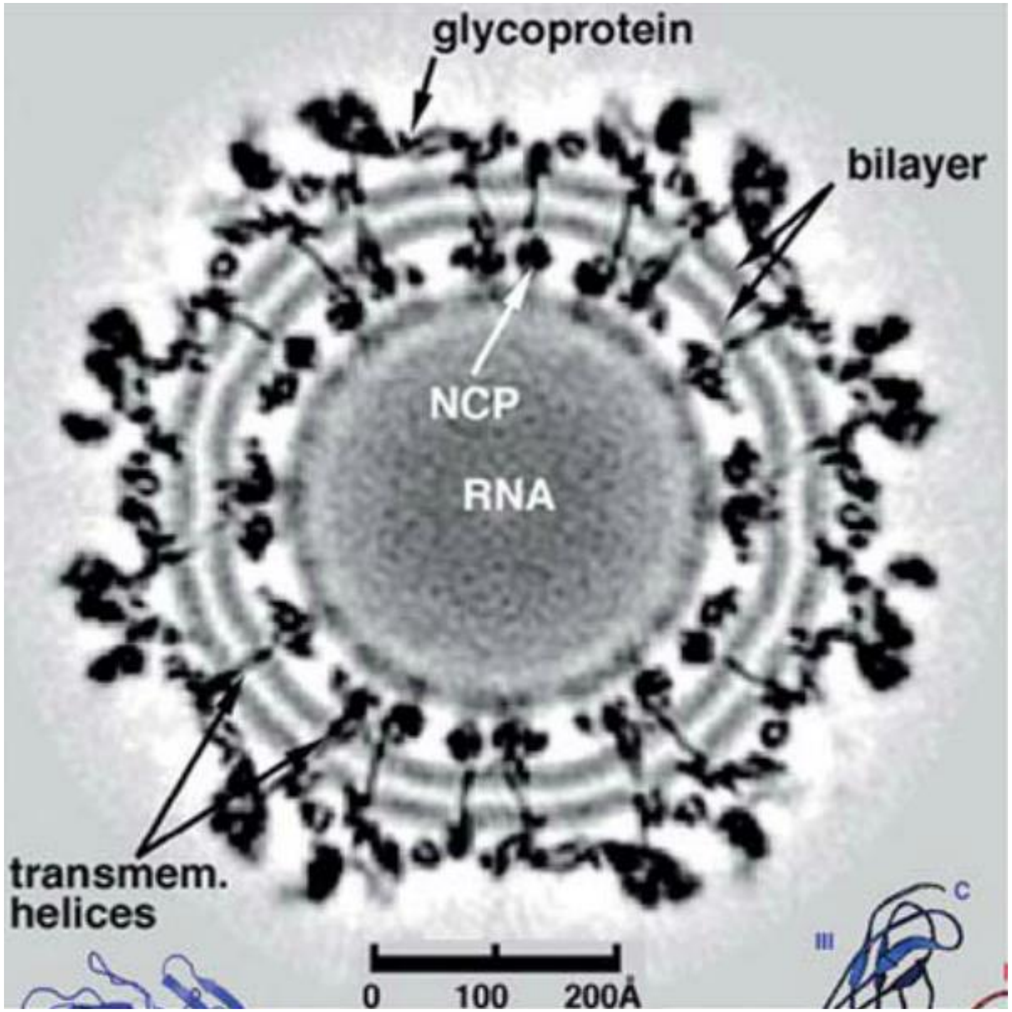
Enveloped Viruses



(a) (b) (c) (d)

Exemple of enveloped Virus : ALPHAVIRIDAE (Syndbis virus)

(CryoEM)

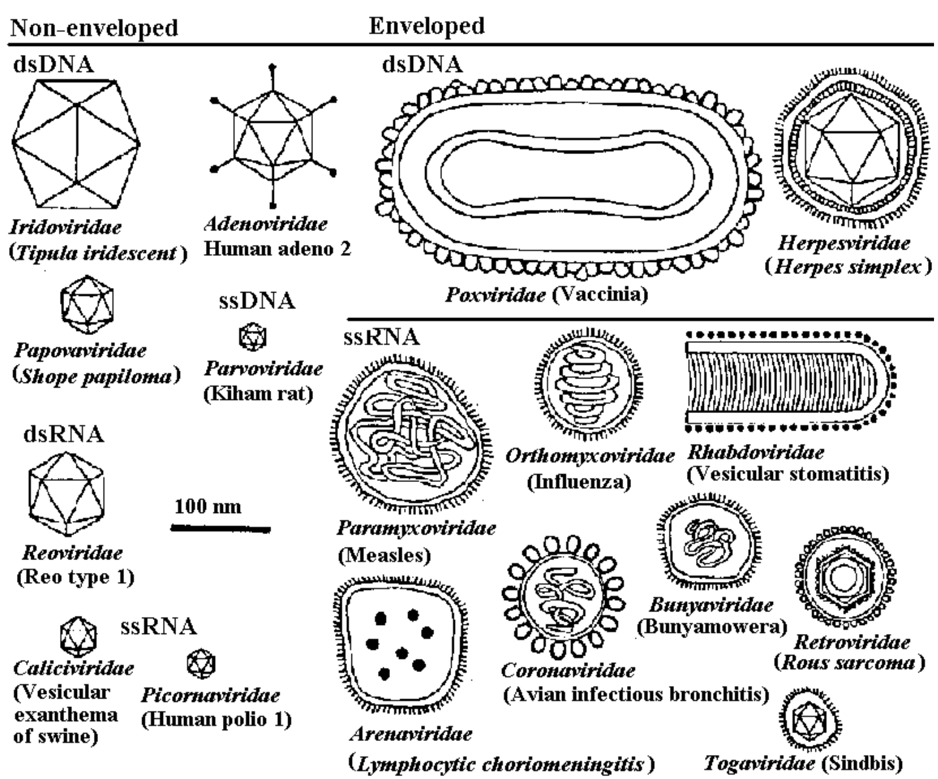


ENVELOPED VIRUSES

All animal RNA viruses with helical symmetry capsid

Some icosahedral RNA viruses : FLAVIVIRIDAE, RETROVIRIDAE…
and icosahedral DNA viruses : HERPESVIRIDAE...

Most plant viruses are non-enveloped viruses



FRAGILITY OF THE VIRAL ENVELOPE

- !!! Enveloped viruses are more fragile than naked viruses

- **Lipid bilayer sensitive to :** organic solvents, detergents, biliary salts, pH variations, temperature, dessication…

Not anymore infectious without envelope

Consequences of this fragility :

- Limited survival in the external environment and in the digestive tract

- With exceptions… as usual

BENEFIT OF VIRAL ENVELOPE

- Contrary to naked viruses, virus release does not require cell lysis.

-Possibility of persistent infection

- Great adaptability, variability of the viral envelope proteins.

Variability ➔ Evolutionary advantage :

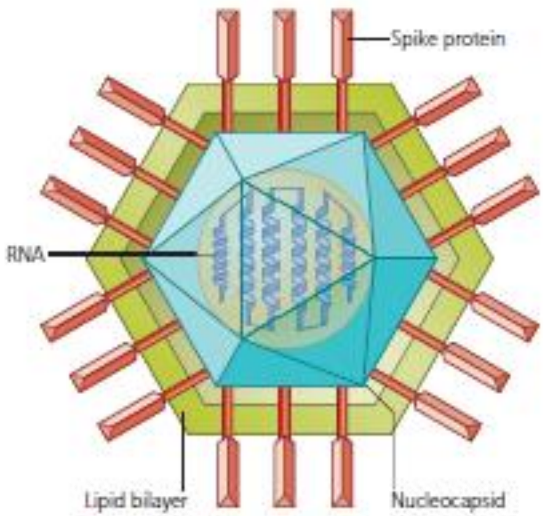
- help viruses to evade the host immune system
- to better adapt to a novel host (zoonose)

➔ numerous emerging virus in human

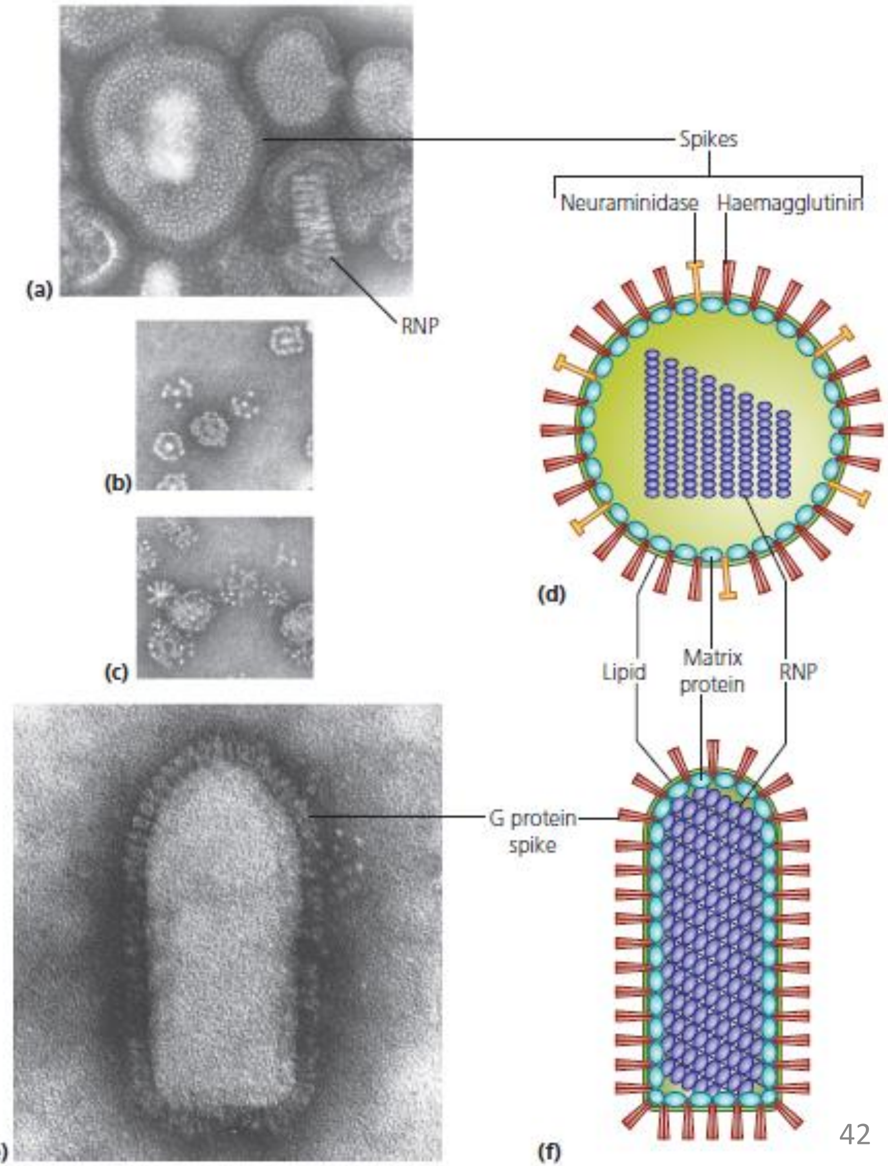
ex: HIV, SARS-CoV, Influenza virus, Ebola Virus, West Nile Virus, Zika virus, SARS-CoV2..

Struttura del virione

Involucro pericapsidico (envelope)



Sindbis virus:
an enveloped icosahedron

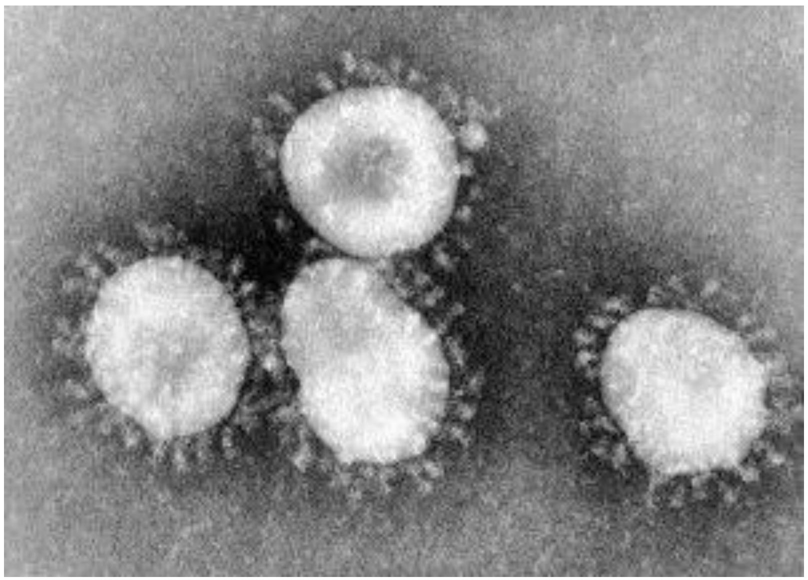


Viruses with enveloped helical structures.

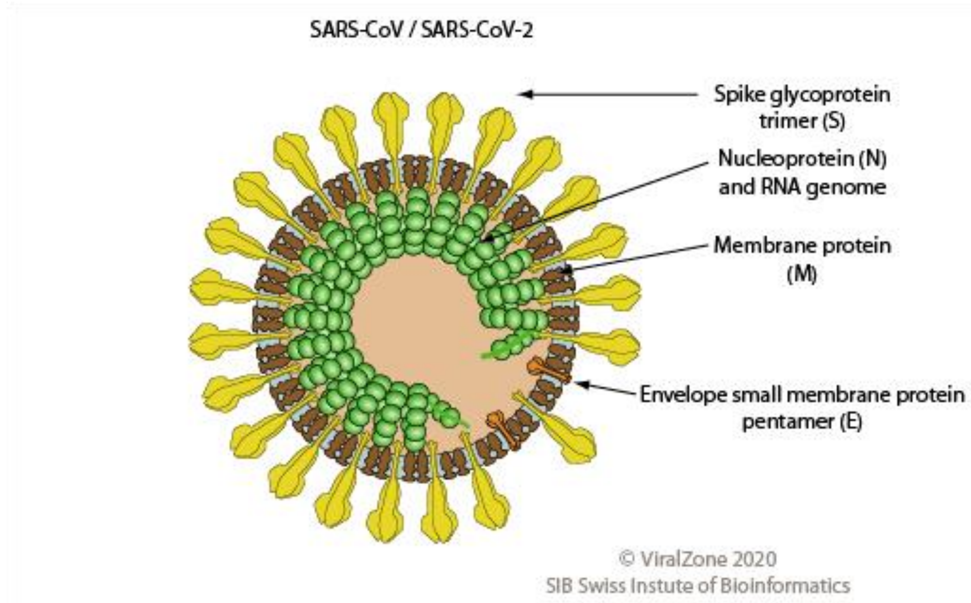
Introduction to Modern Virology, Seventh Edition. N. J. Dimmock, A. J. Easton and K. N. Leppard.

Viruses with enveloped helical structures

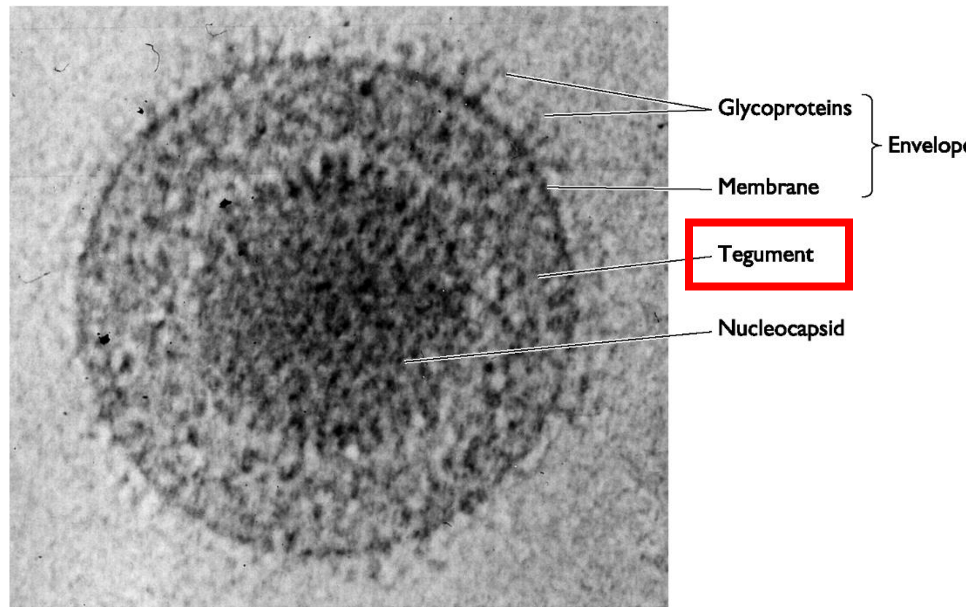
Coronavirus.



CDC/Dr Fred Murphy



Virus con involucro a livelli proteici addizionali



Struttura di un herpesvirus

Properties of naked capsid viruses

- Capsid is resistant to
  - Drying
  - Heat
  - Detergents
  - Acids
  - Proteases
- Consequences
  - Can survive in the gastrointestinal tract
  - Retain infectivity on drying
  - Survive well on environmental surfaces
  - Spread easily via fomites
  - Must kill host cells for release of mature virus particles
  - Humoral antibody response may be sufficient to neutralize infection

However, some naked virus types of the Picornaviridae and Hepeviridae families can also leave cells via an alternative route involving enclosure in fully host-derived lipid bilayers. The resulting particles resemble extracellular vesicles (EV), which are 50 nm–1 µm vesicles released by all cells.

Properties of enveloped viruses

- Envelope is sensitive to
  - Drying
  - Heat
  - Detergents
  - Acid
- Consequences
  - Must stay wet during transmission
  - Transmission in large droplets and secretions
  - Cannot survive in the gastrointestinal tract
  - Do not need to kill cells in order to spread
  - May require both a humoral and a cellular immune response

Adapted from Murray, P.R. Rosenthal K.S., Pfaller, M.A. (2005) Medical Microbiology, 5th edition, Elsevier Mosby, Philadelphia, PA Box 6-5

Viral Classification

Criteri di classificazione dei virus

- Nucleic acid nature: RNA vs DNA
- Capsid symmetry: Icosahedral, Helical, Complex
- Presence (enveloped) or absence (naked viruses) of the envelope
- Genome architecture: single strand or double strand, linear or circular, continous or segmented, genome polarity
- ICTV criteria: viral taxonomy
- mRNA production strategy: Baltimore classification
- Other (transmission route, pathology, tropism etc.)

Criteri di classificazione dei virus

2 main classifications for viruses

ICTV classification

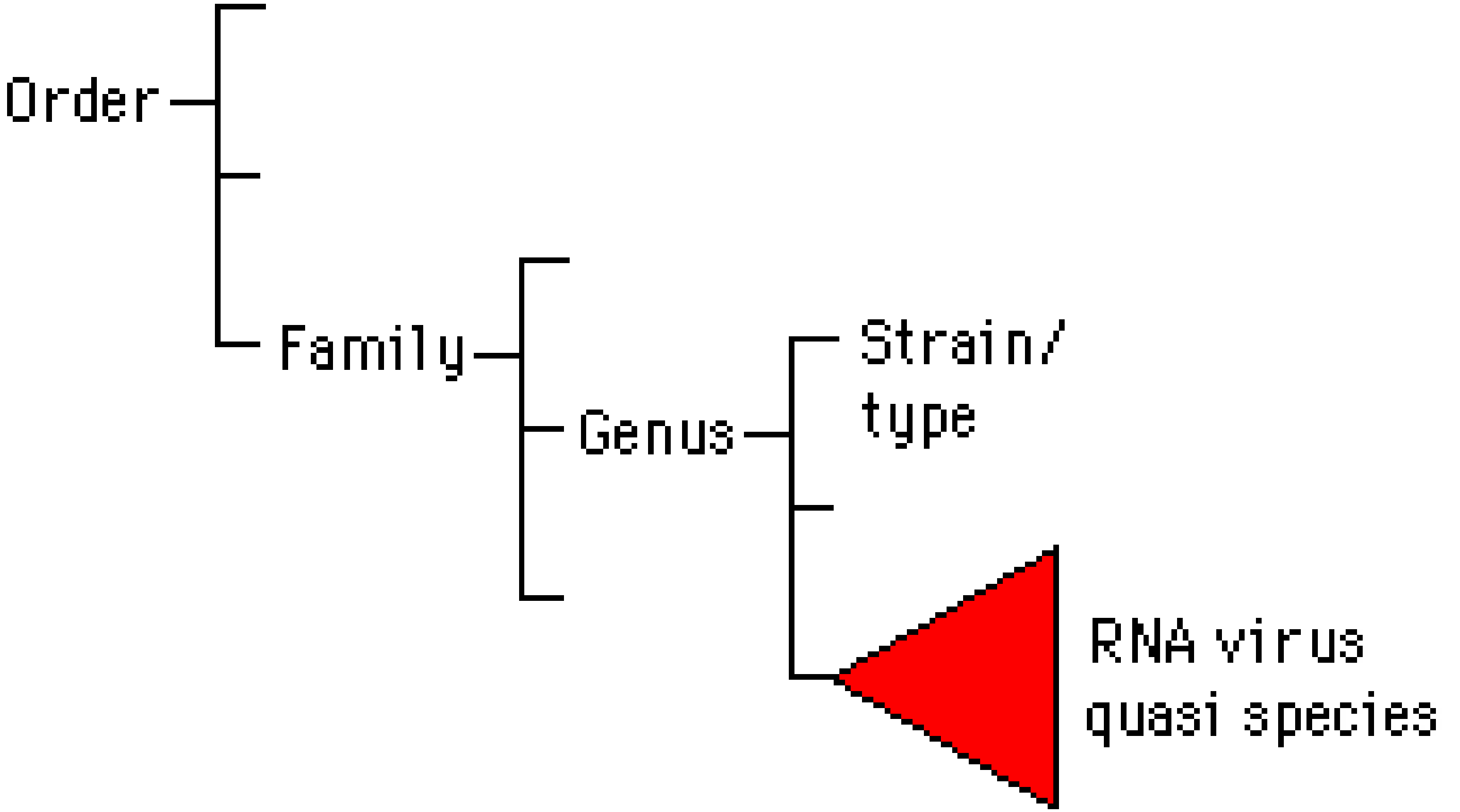
Baltimore classification

ICTV= International Committee on Taxonomy of Viruses

Baltimore classification was created in 1971 by virologist David Baltimore

Classificazione tassonomica
(ICTV fondato fine anni '60)

Gerarchia. L'ordine ha suffisso –virales. La famiglia ha suffisso -viridae. La sottofamiglia ha suffisso –virinae. Il genere ha suffisso virus.



ICTV= International Committee on Taxonomy of Viruses

Classificazione tassonomica: regole di base per la nomenclatura

- **Ordine** (- *virales*)
- **Famiglia** (- *viridae*)
- **Sottofamiglia** (-*virinae*)
- **Genere** (- *virus*)
- **Specie** e sottotipi/ceppi (*nome comune*)

ICTV TAXONOMY

International Committee on Taxonomy of Viruses : hierachical nomemclature, similarly to living beings

Order (-virales) → Family (-viridae) → Subfamily (-virinae) → Genus (-virus) → Type species → Strains

Order	Family	Subfamily	Genus	Type species
Mononegavirales	*Bornaviridae*		*Bornavirus*	*Borna disease virus*
	Rhabdoviridae		*Vesiculovirus*	*Vesicular stomatitis Indiana virus*
			Lyssavirus	*Rabies virus*
			Ephemerovirus	*Bovine ephemeral fever virus*
			Novirhabdovirus	*Infectious hematopoietic necrosis virus*
			Cytorhabdovirus	*Lettuce necrotic yellows virus*
			Nucleorhabdovirus	*Potato yellow dwarf virus*
	Filoviridae		*Marburgvirus*	*Lake Victoria marburgvirus*
			Ebolavirus	*Zaire ebolavirus*
	Paramyxoviridae	*Paramyxovirinae*	*Rubulavirus*	*Mumps virus*
			Avulavirus	*Newcastle disease virus*
			Respirovirus	*Sendai virus*
			Henipavirus	*Hendra virus*
			Morbillivirus	*Measles virus*
		Pneumovirinae	*Pneumovirus*	*Human respiratory syncytial virus*
			Metapneumovirus	*Avian metapneumovirus*

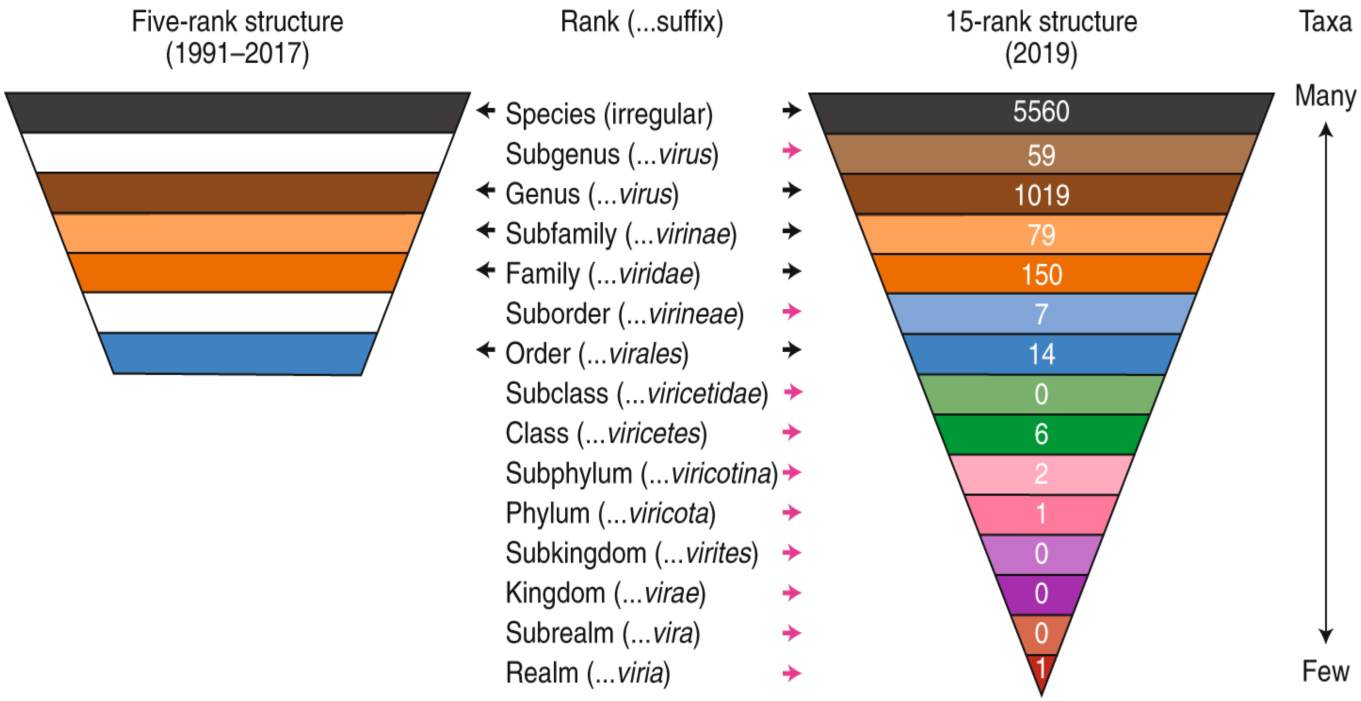
Replication and transcription in the nucleus

Rod-like shape

Linear, nonsegmented,
(-)ss RNA genome
6 to 10 genes
Enveloped viruses
Helical nucleocapsid
...

Filamentous virions
Highly contagious

F fusion protein

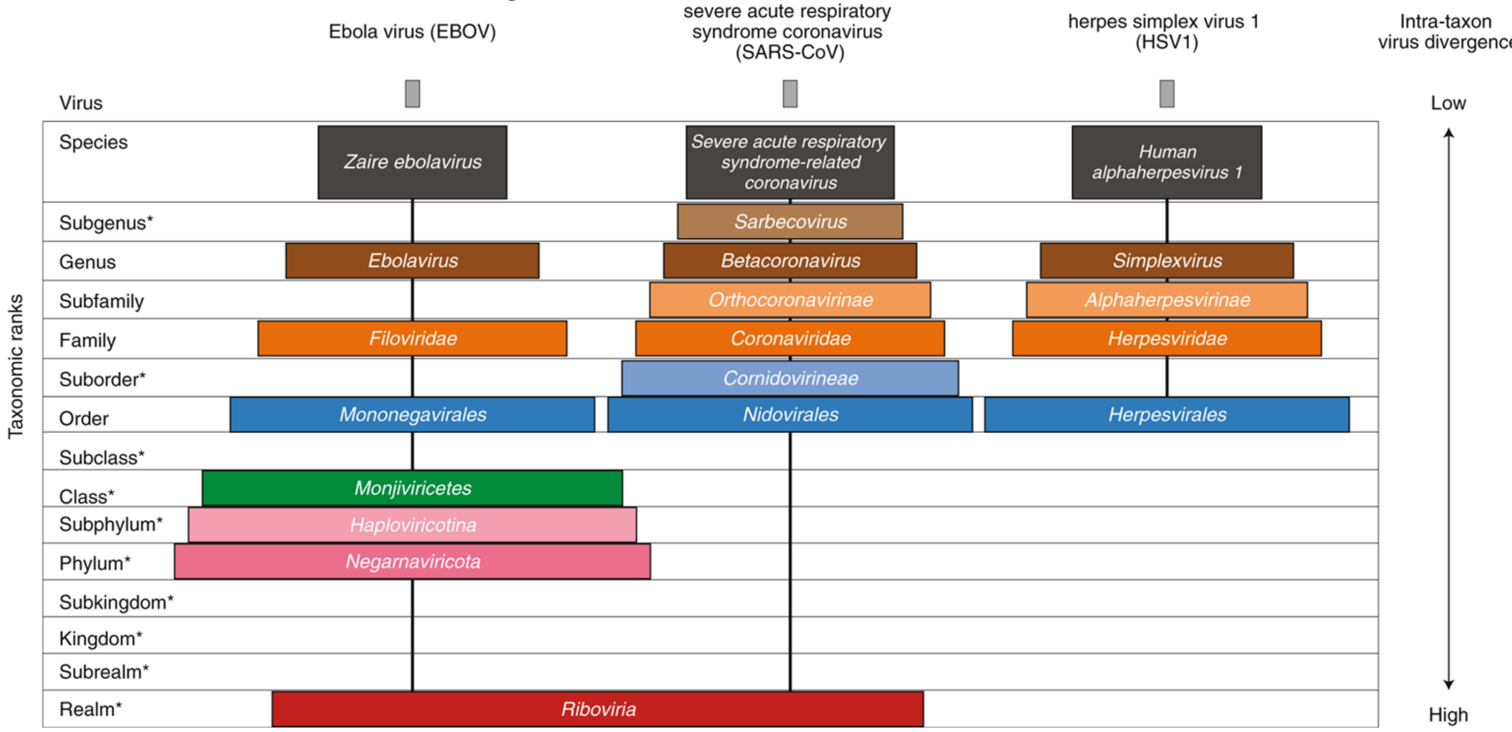


A comparison of the ICTV taxonomic rank hierarchy in 1991–2017 and 2019

Taxonomic ranks are shown in relation to the distribution pattern of taxa. The number of taxa assigned to each rank are shown in white font on the 15-rank structure. When the ranks are described as a hierarchy, the species rank is often referred to as the lowest rank and the realm rank as the highest rank. However, when the ranks are used as phylogenetic terms, the realm rank can be described as basal and the species rank as apical or terminal. Both conventions are used in this Consensus Statement. Black arrows, ranks common to the five- and 15-rank structure; pink arrows, ranks introduced in the 15-rank structure.

Nature Microbiology **volume 5**, pages 668–674 (2020)

Classification of EBOV, SARS-CoV and herpes simplex virus 1 in the 15-rank taxonomic hierarchy



Intra-cluster virus divergence, which increases from the virus to the species rank to the realm rank, is represented by the increasing width of the respective rectangles, which are not drawn to scale. EBOV is most closely related to, but distinct from, Bombali, Bundibugyo, Reston, Sudan and Taï Forest viruses, which belong to separate species included in the *Ebolavirus*genus. SARS-CoV is one of several closely related coronaviruses isolated from humans and animals, such as palm civets and bats, and are included in the species *Severe acute respiratory syndrome-related coronavirus*. Herpes simplex virus 1 is one of two human herpesviruses belonging to different species in the *Simplexvirus* genus. Ranks that were introduced with the extended rank structure are indicated by an asterisk.

Nature Microbiology **volume 5**, pages 668–674 (2020)

Baltimore Classification

(Division into replication classes)

All viruses must produce an mRNA that can be translated by the host cell's translational machinery.
In this classification system, the specific pathway from the viral genome to the production of mRNA defines a distinct viral class, based on the nature and polarity of the nucleic acid.

The New York Times

David Baltimore, Nobel-Winning Molecular Biologist, Dies at 87

He was only 37 when he made a discovery that challenged the existing tenets of biology and led to an understanding of retroviruses and viruses, including H.I.V.

https://www.science.org/content/article/remembering-david-baltimore-titan-who-transformed-biology-and-spoke-bluntly

Baltimore classification

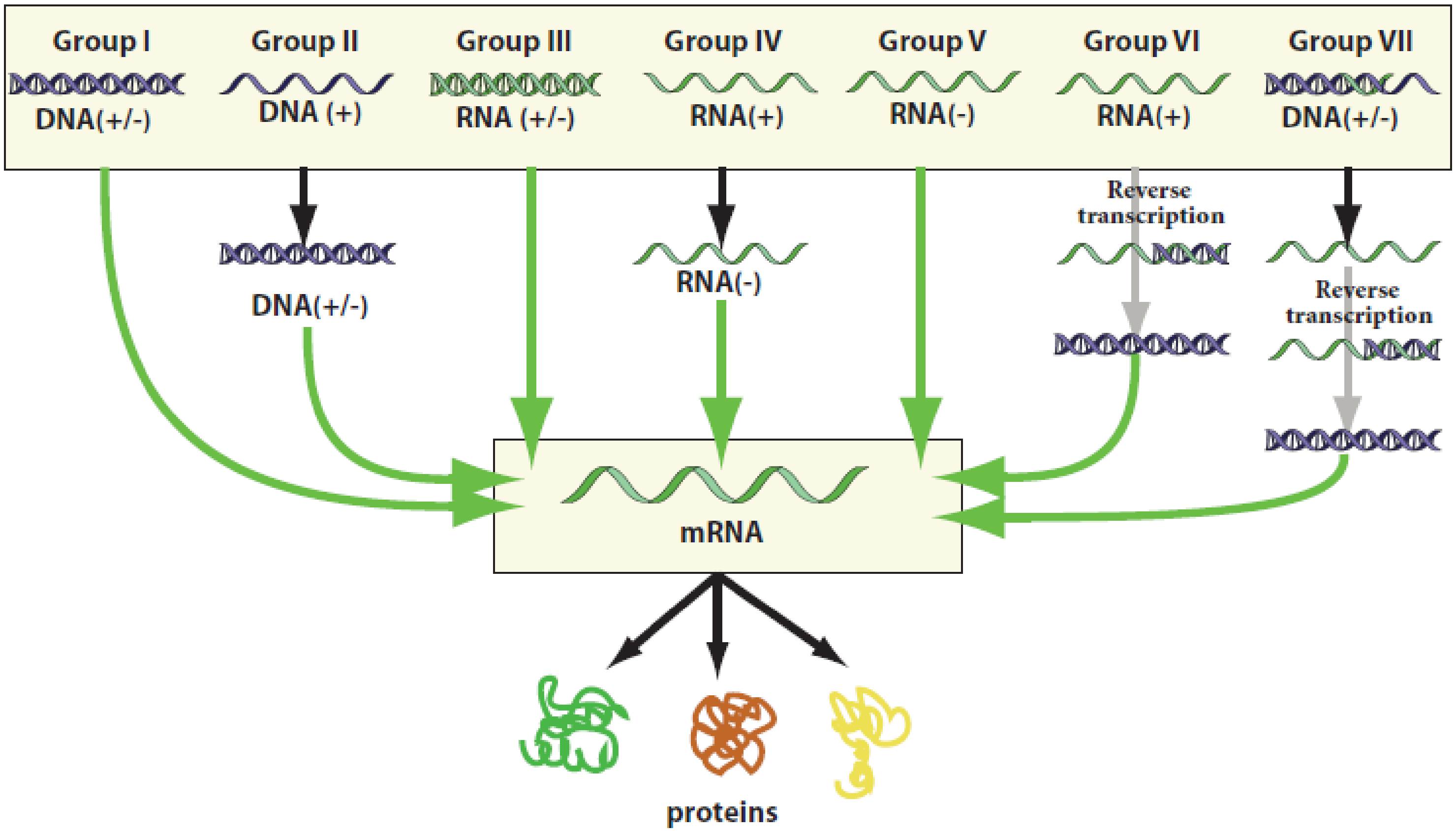


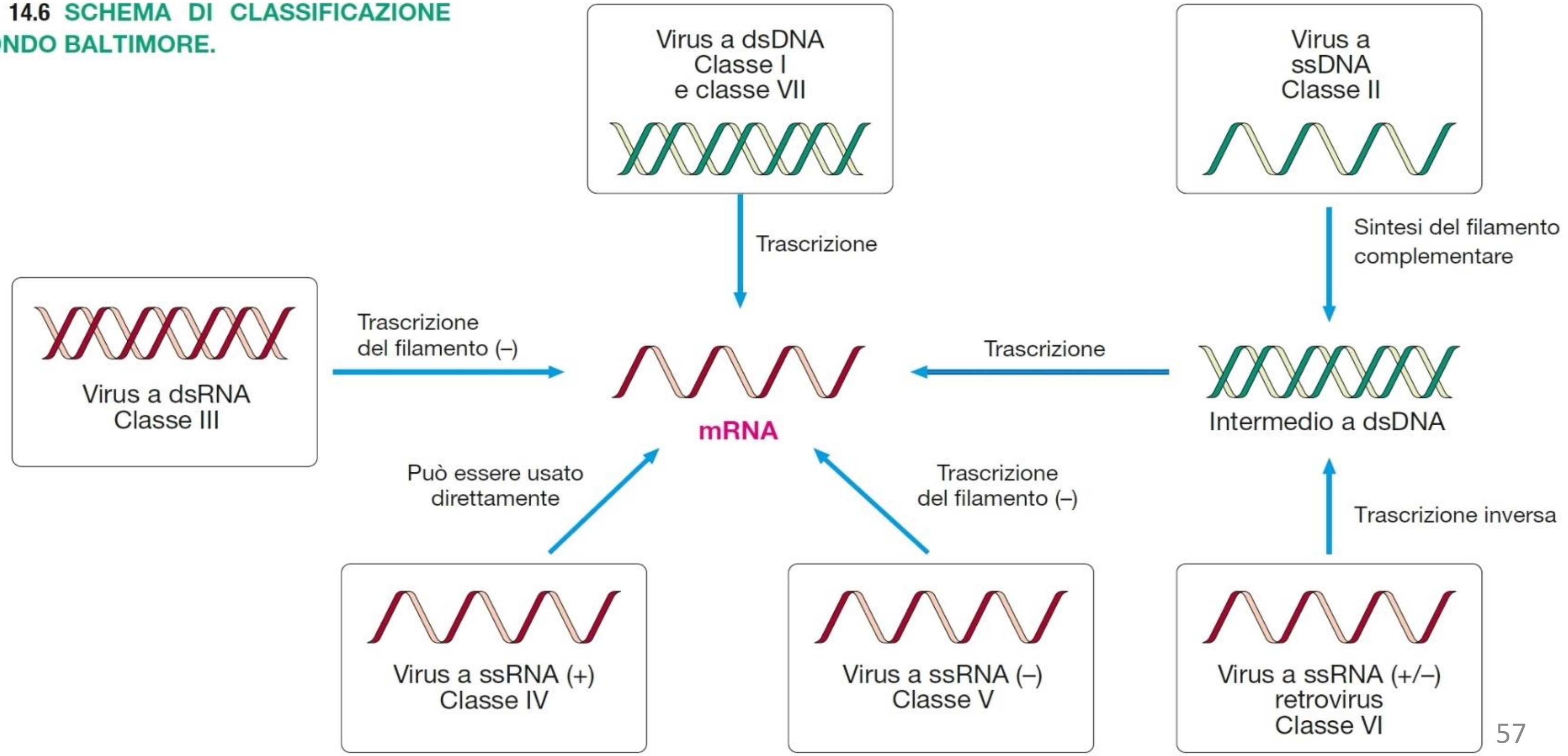
FIGURE 2.1. The Baltimore classification, a virus classification scheme based on the form of nucleic acid present in virion particles and the pathway for expression of the genetic material as messenger RNA.[1]

From Fields Virology

Baltimore classification

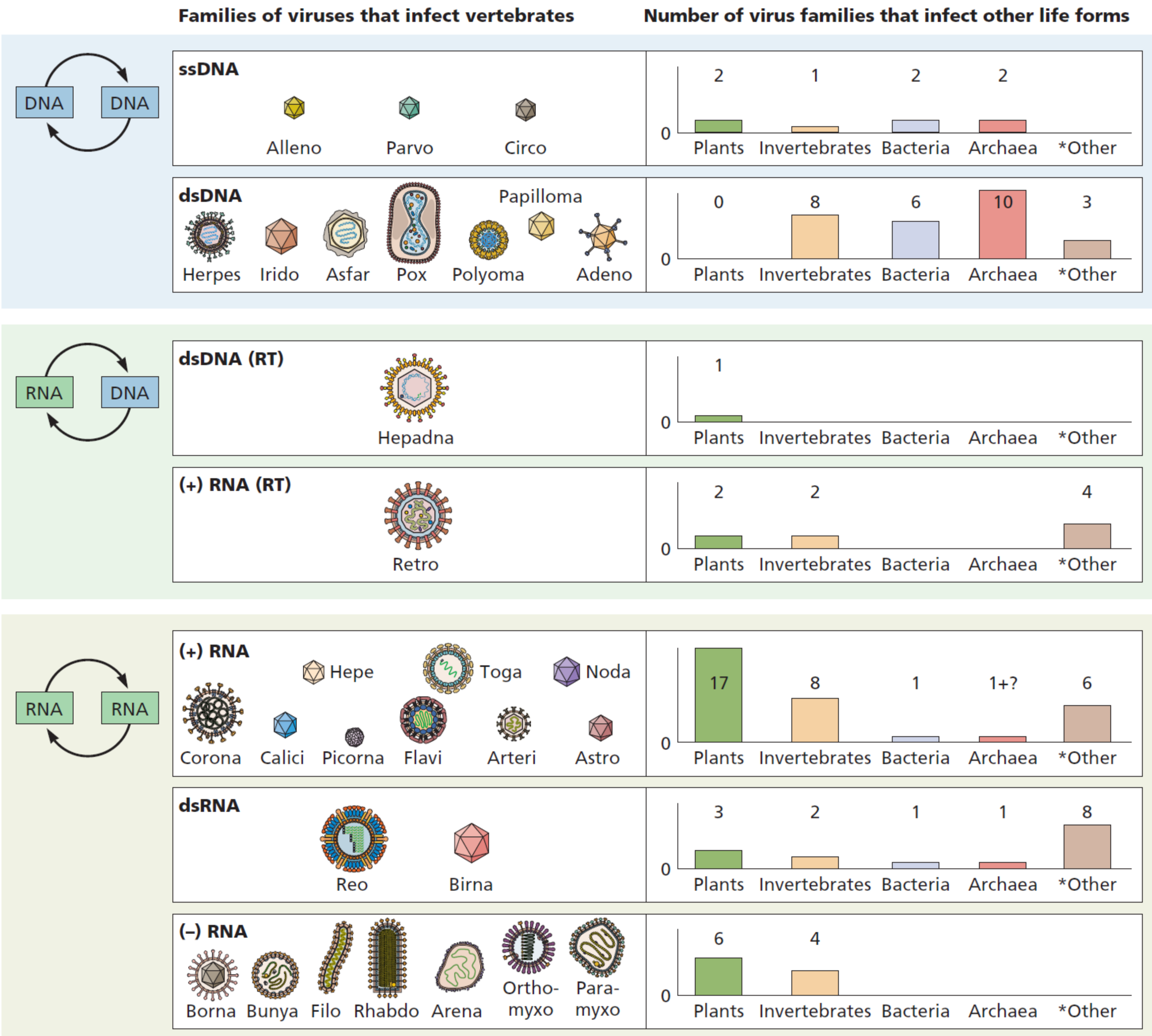
- **Basato sulla natura e polarità dei genomi virali**
- **Descrive le relazioni obbligatorie tra il genoma virale e il suo mRNA**

Figura 14.6 SCHEMA DI CLASSIFICAZIONE SECONDO BALTIMORE.



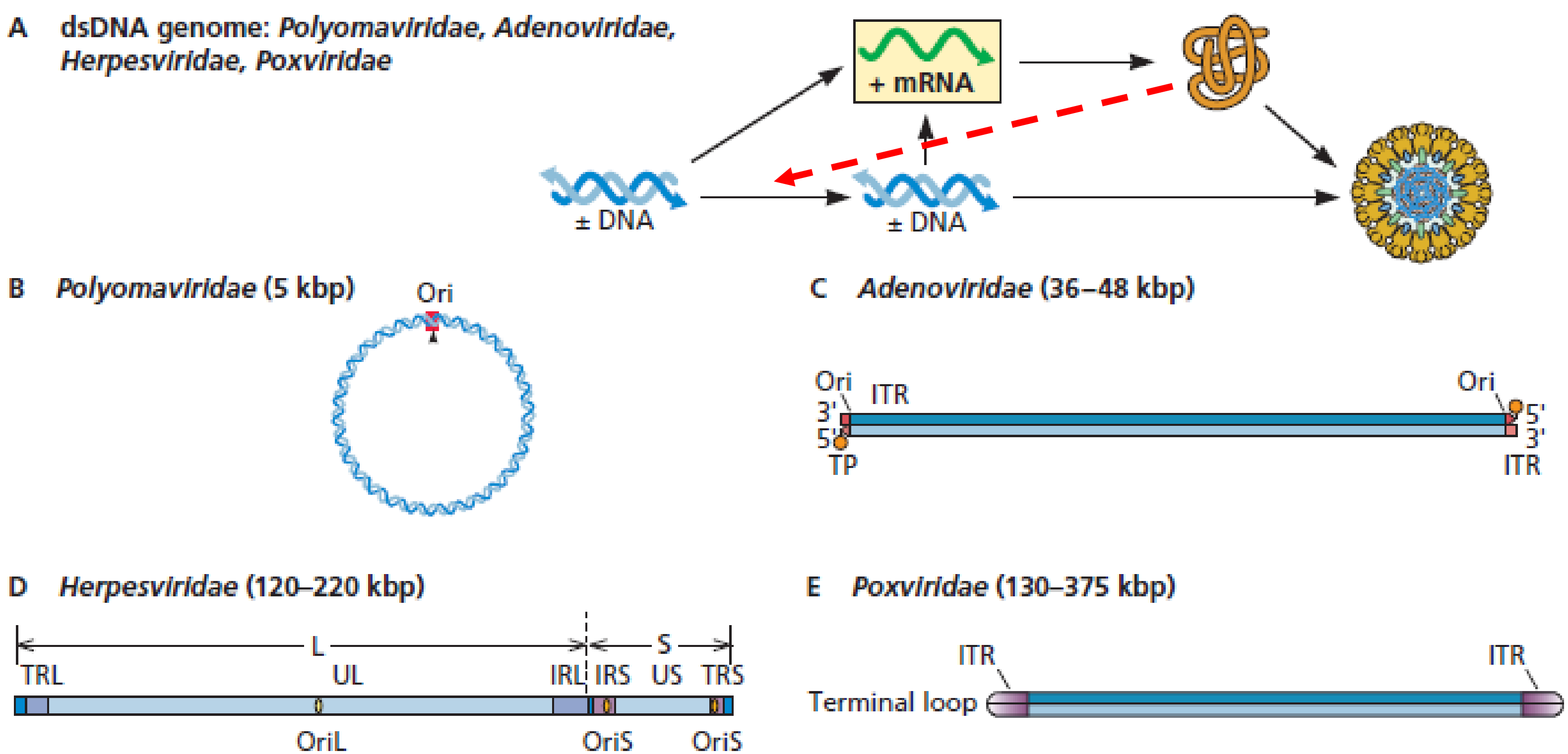
Cellular and Viral Polymerases

Type	Template → Product	Function
DNA-dependent DNA-Polymerase	DNA → DNA	Replication
DNA-dependent RNA-Polymerase	DNA → RNA	Transcription
RNA-dependent RNA-Polymerase	RNA → RNA	Replication and transcription of RNA-viruses
RNA-dependent DNA-Polymerase	RNA → DNA	Reverse transcription



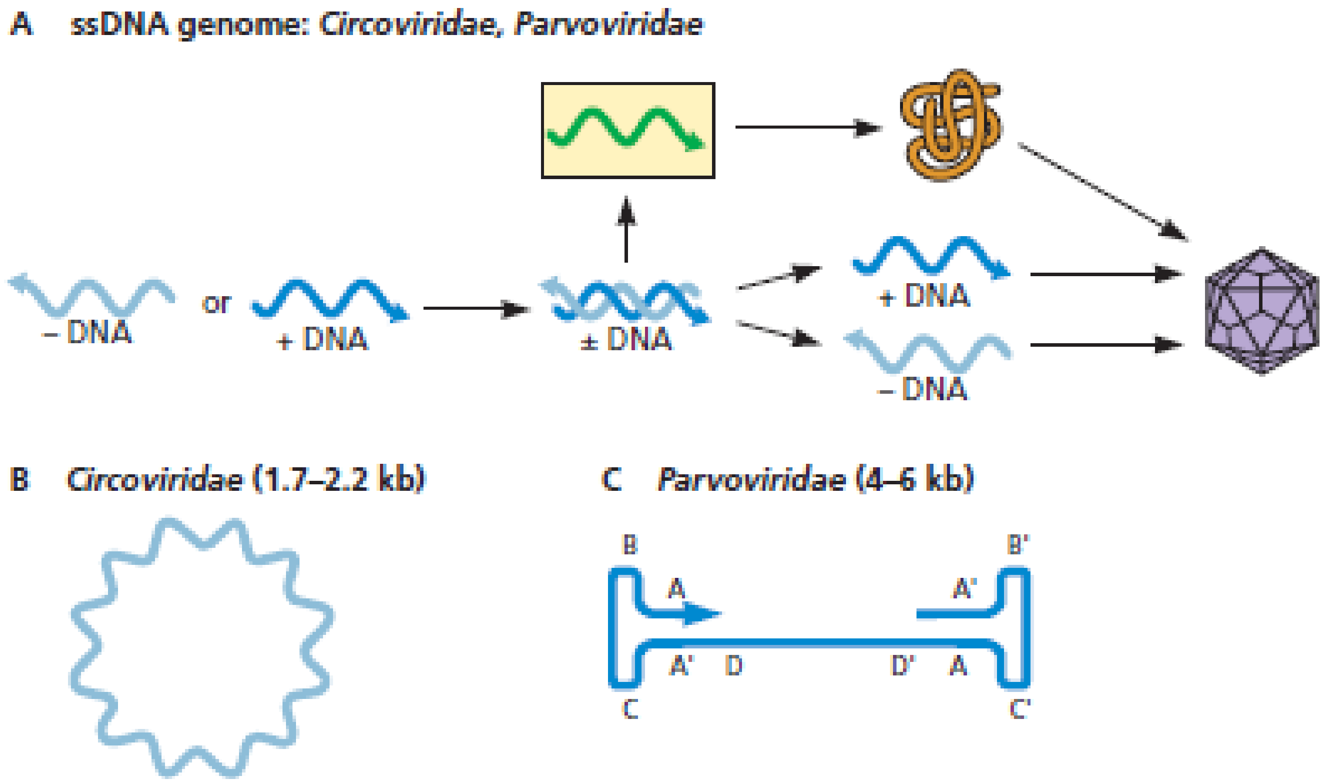
*Algae, fungi, yeasts, and protozoa

CLASSE 1 (dsDNA)



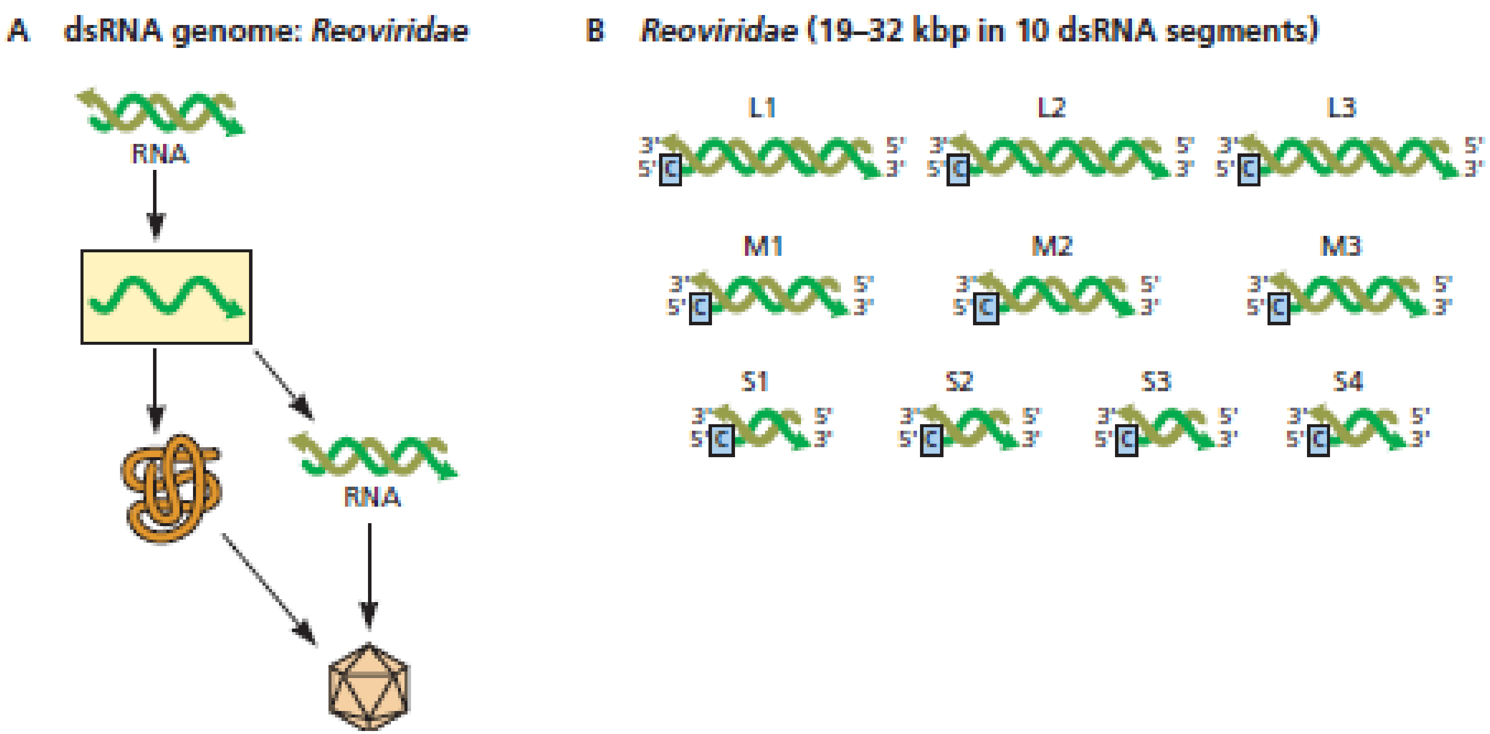
From Flint et al. *Principles of Virology* (2015), ASM Press

CLASSE 2 (ssDNA)



From Flint et al. *Principles of Virology* (2015), ASM Press

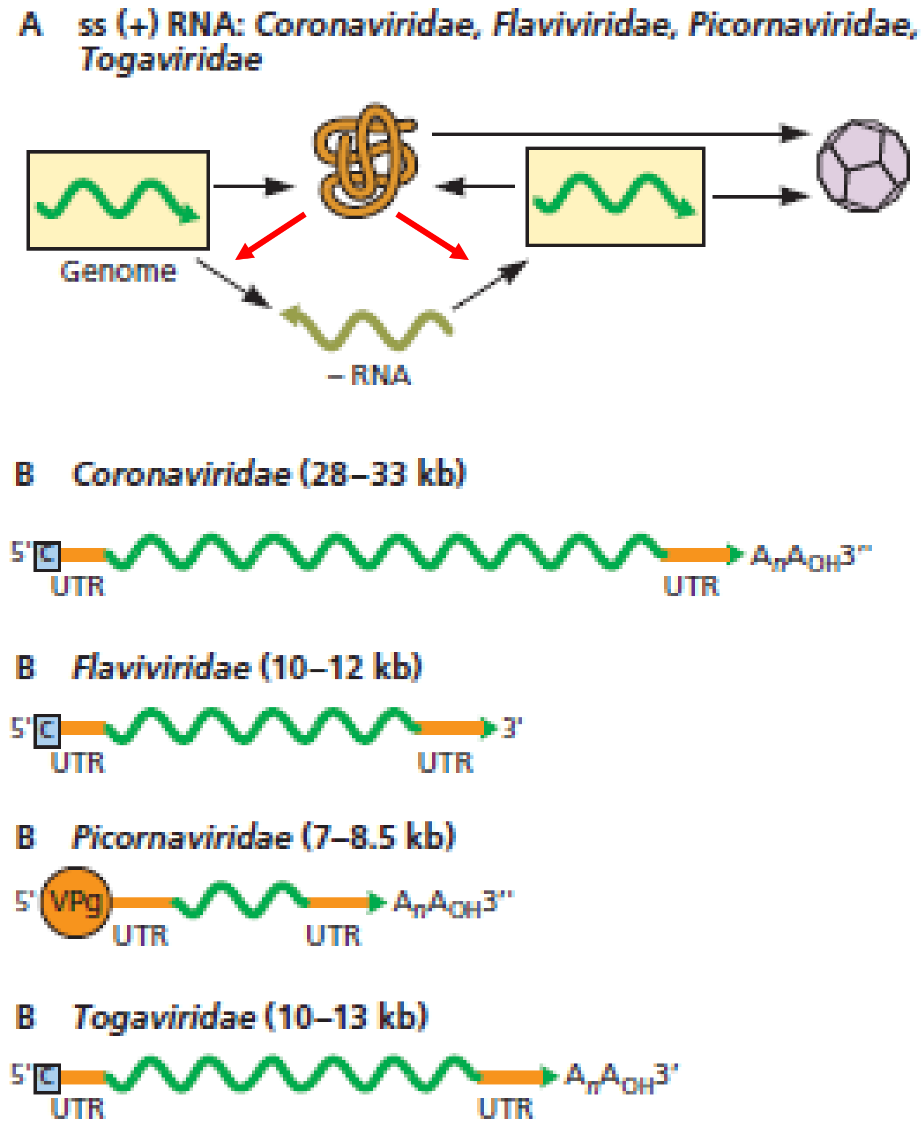
CLASSE 3 (dsRNA)



Schema di classificazione di Baltimore

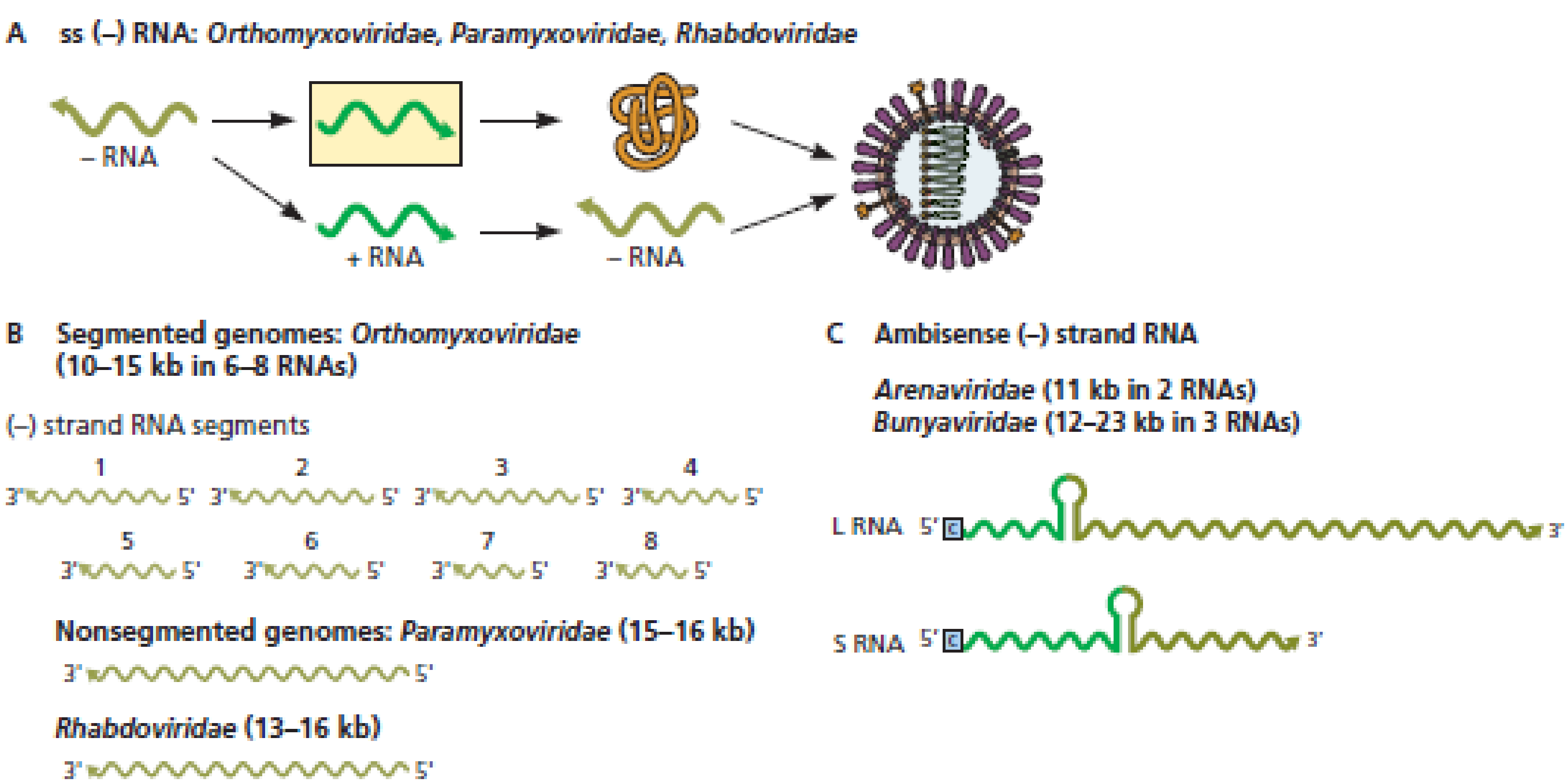
From Flint et al. *Principles of Virology* (2015), ASM Press

CLASSE 4 (ssRNA positive sense)



From Flint et al. *Principles of Virology* (2015), ASM Press

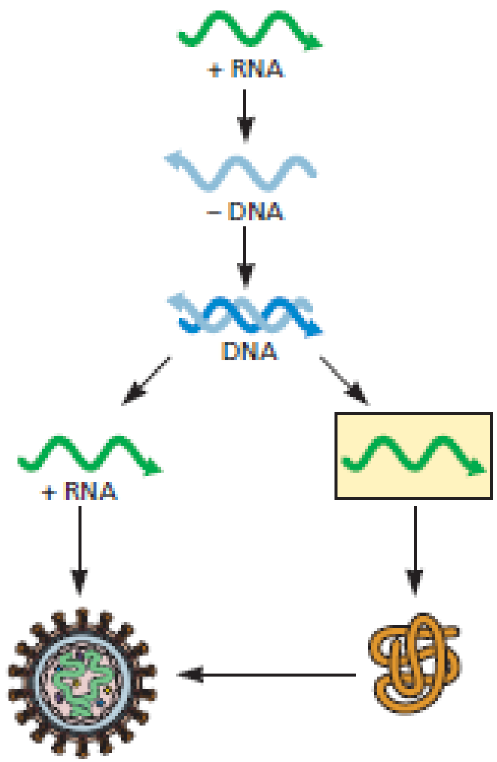
CLASSE 5 (ssRNA negative sense)



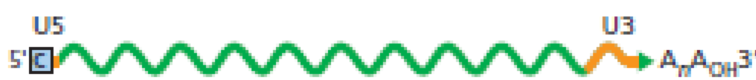
From Flint et al. *Principles of Virology* (2015), ASM Press

CLASSE 6 (ssRNA with DNA intermediate)

A ss (+) RNA with DNA intermediate: *Retroviridae*

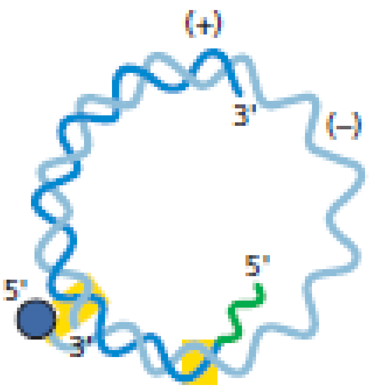


B *Retroviridae* (7–10 kb)

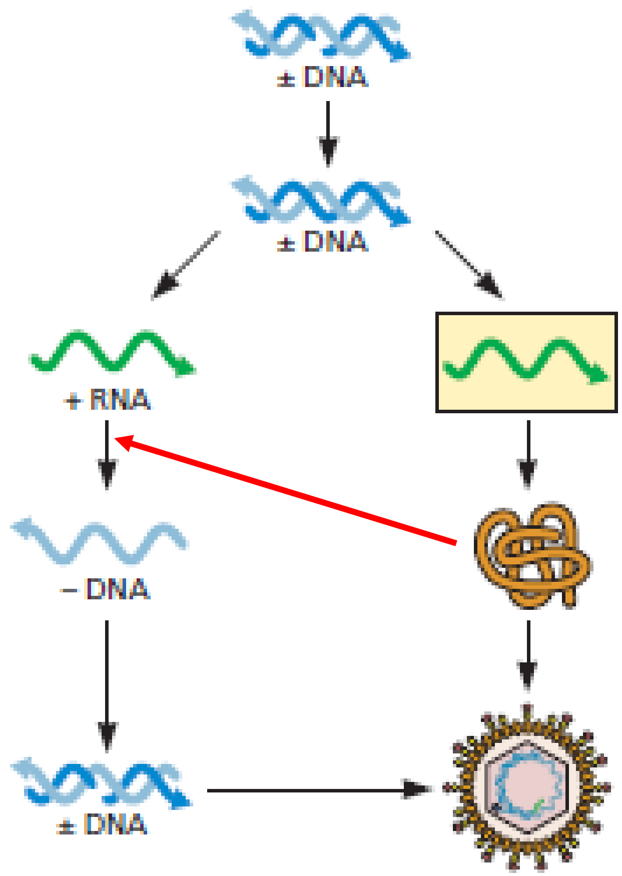


From Flint et al. *Principles of Virology* (2015), ASM Press

CLASSE 7 (dsDNA with RNA intermediate)

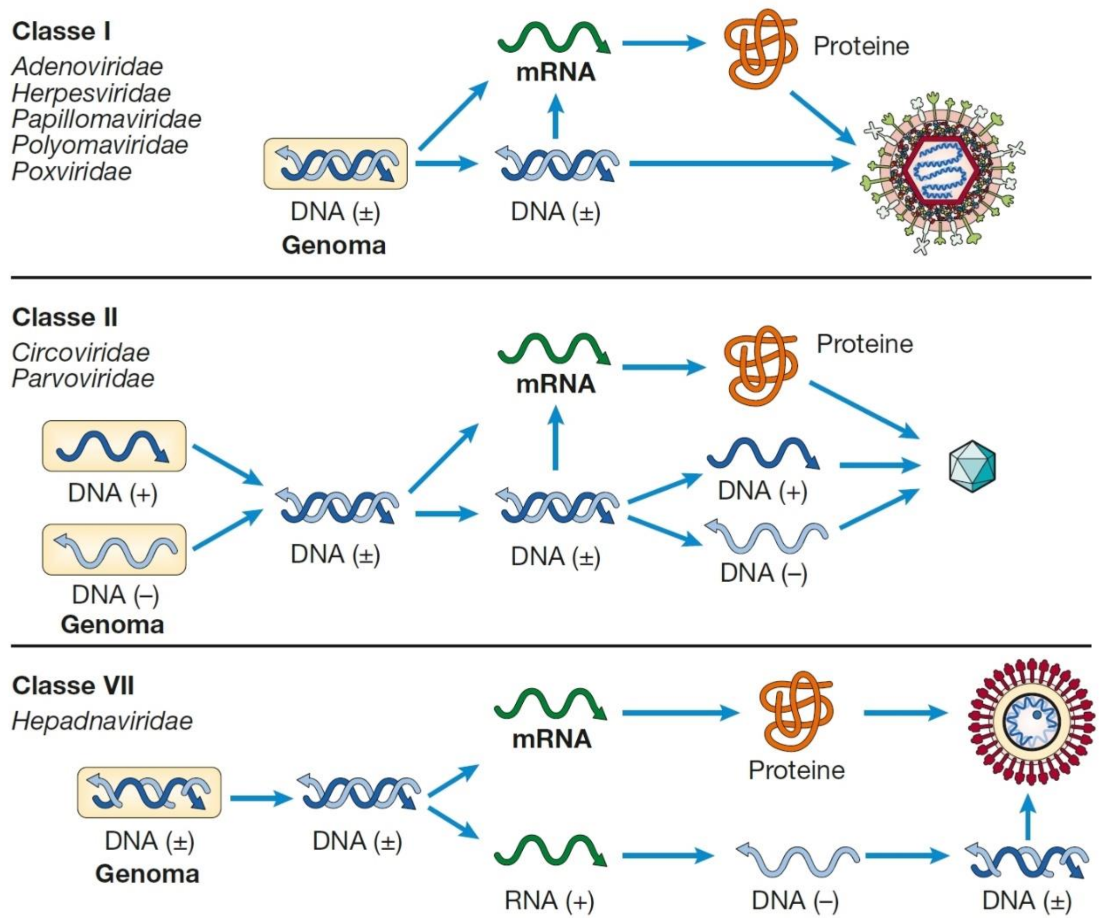


A Gapped, circular, dsDNA genome: *Hepadnaviridae*



From Flint et al. *Principles of Virology* (2015), ASM Press

Figura 14.8 RAPPRESENTAZIONE SCHEMATICA DEL FLUSSO DEGLI EVENTI NELLA REPLICAZIONE DEI VIRUS ANIMALI A DNA DELLE CLASSI I, II E VII SECONDO LA CLASSIFICAZIONE DI BALTIMORE.



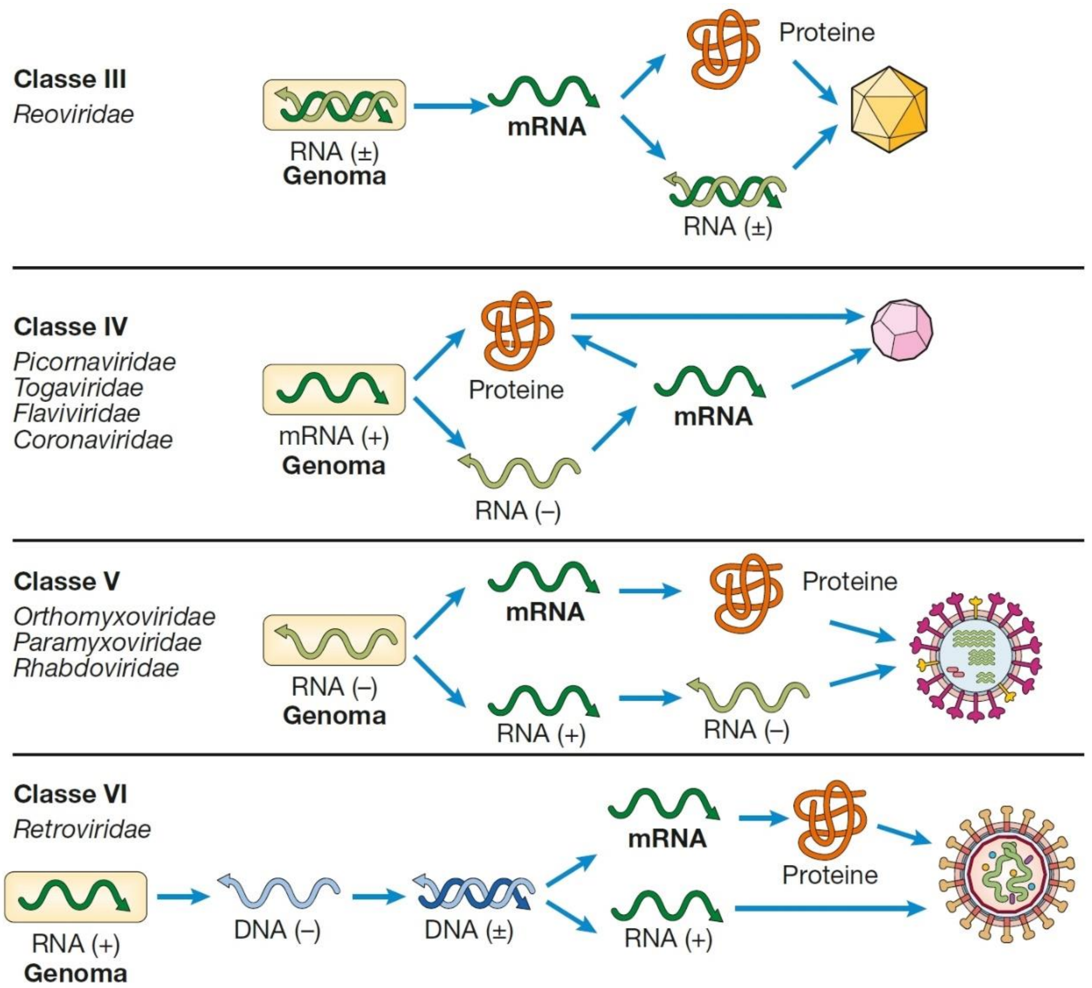
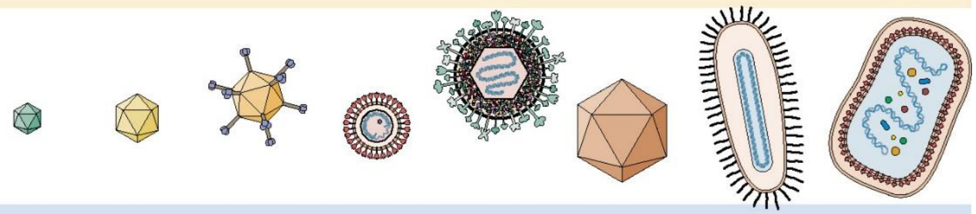


Figura 14.9 RAPPRESENTAZIONE SCHEMATICA DEL FLUSSO DEGLI EVENTI NELLA REPLICAZIONE DEI VIRUS ANIMALI A RNA DELLE CLASSI III, IV, V E VI SECONDO LA CLASSIFICAZIONE DI BALTIMORE.

DNA viruses

Classification criteria

Nucleic acid	DNA							
Symmetry of capsid	Icosahedral						Helical	Complex
Naked or enveloped	Naked			Enveloped		Naked/Env. (cytoplasmic)	Enveloped	Enveloped (cytoplasmic)
Genome architecture	ss linear (+) or (–)	ds circular	ds linear	ds circle gapped	ds linear	ds linear	ds circular	ds linear (x linked)
Baltimore class	II	I	I	VII	I	I	I	I



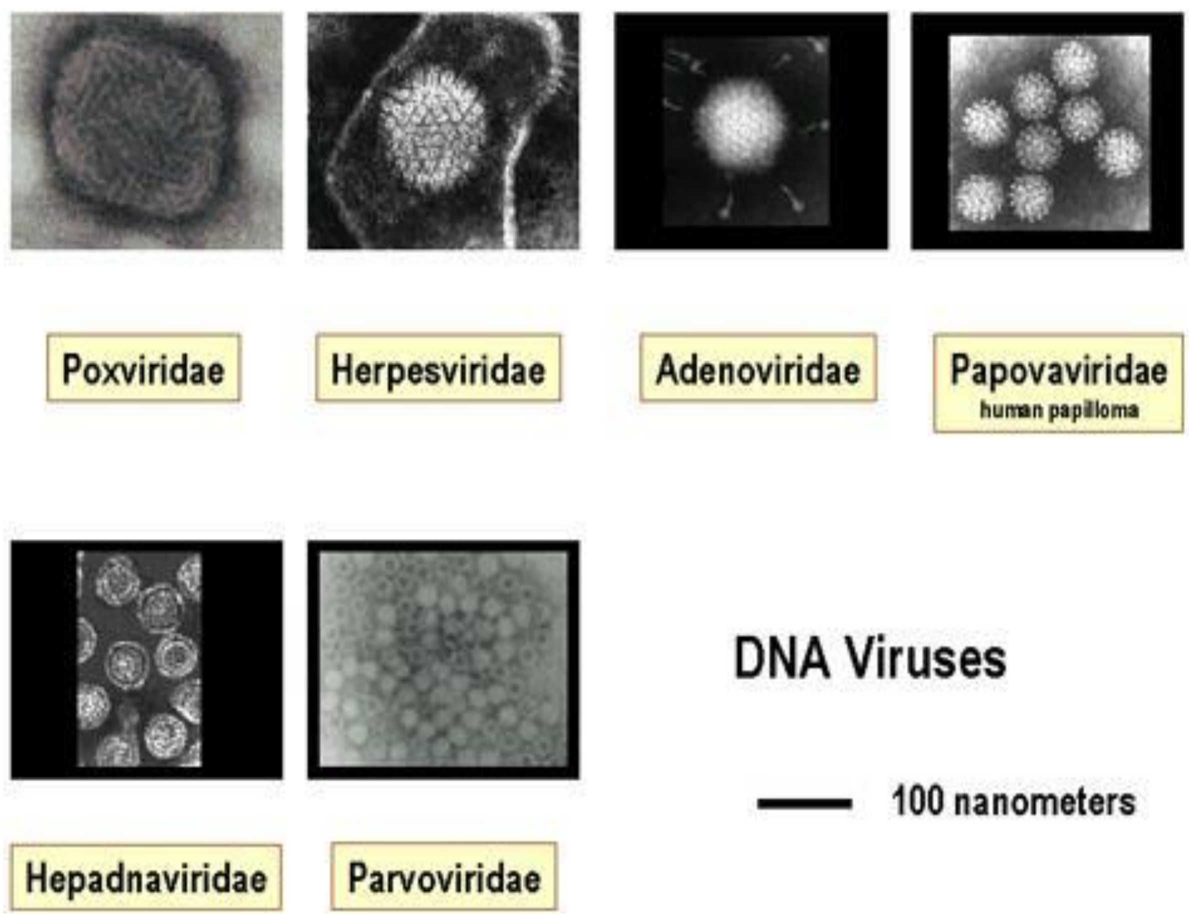
Properties

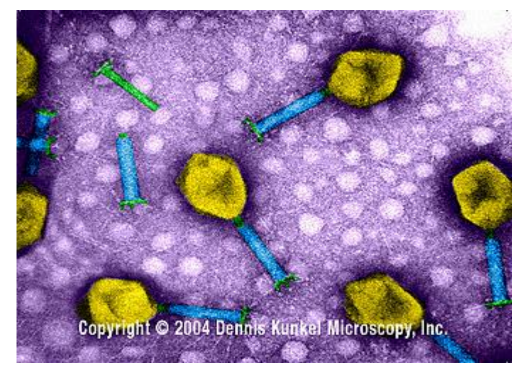
Family name	Parvo	Papova	Adeno	Hepadna	Herpes	Irido	Baculo	Pox
Virion polymerase	(–)	(–)	(–)	(+)	(–)	(–)	(–)	(+)
Virion diameter (nm)	18–26	45–55	70–90	42	150–200	125–300	60 X 300	170–200 x 300–450
Genome size (total in kb)	5	5–8	36–38	3.2	120–200	150–350	100	130–280

The size of the genome reflects the complexity of the virus and its replication, which is more evident in DNA viruses than in RNA viruses.

From Flint et al. *Principles of Virology* (2000), ASM Press

DNA viruses

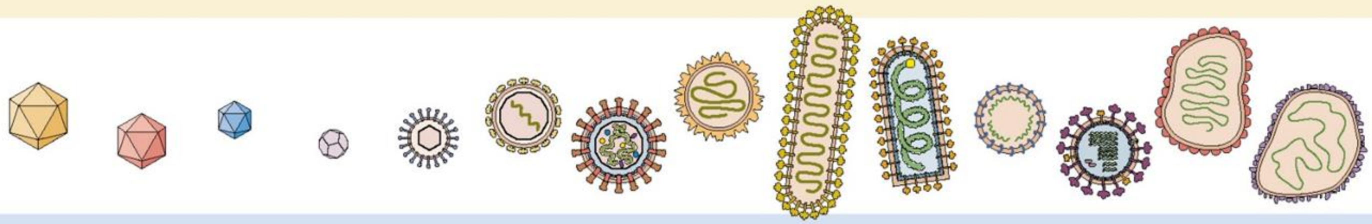

Poxviridae
Herpesviridae
Adenoviridae
Papovaviridae
human papilloma
Hepadnaviridae
Parvoviridae
DNA Viruses
100 nanometers


Copyright © 2004 Dennis Kunkel Microscopy, Inc.

RNA viruses

Classification criteria

Nucleic acid	RNA													
Symmetry of capsid	Icosahedral							Helical						
Naked or enveloped	Naked				Enveloped			Enveloped						
Genome architecture	ds 10–18 seg.	ds 2 seg.	(+) ss cont.	(+) ss cont.	(+) ss cont.	(+) ss cont.	(+) ss 2 copies	(+) ss cont.	(–) ss cont.	(–) ss cont.	(–) ss 3 seg.	(–) ss 8 seg.	(–) ss cont.	(–) ss 2 seg.
Baltimore class	III	III	IV	IV	IV	IV	VI	IV	V	V	V	V	V	V

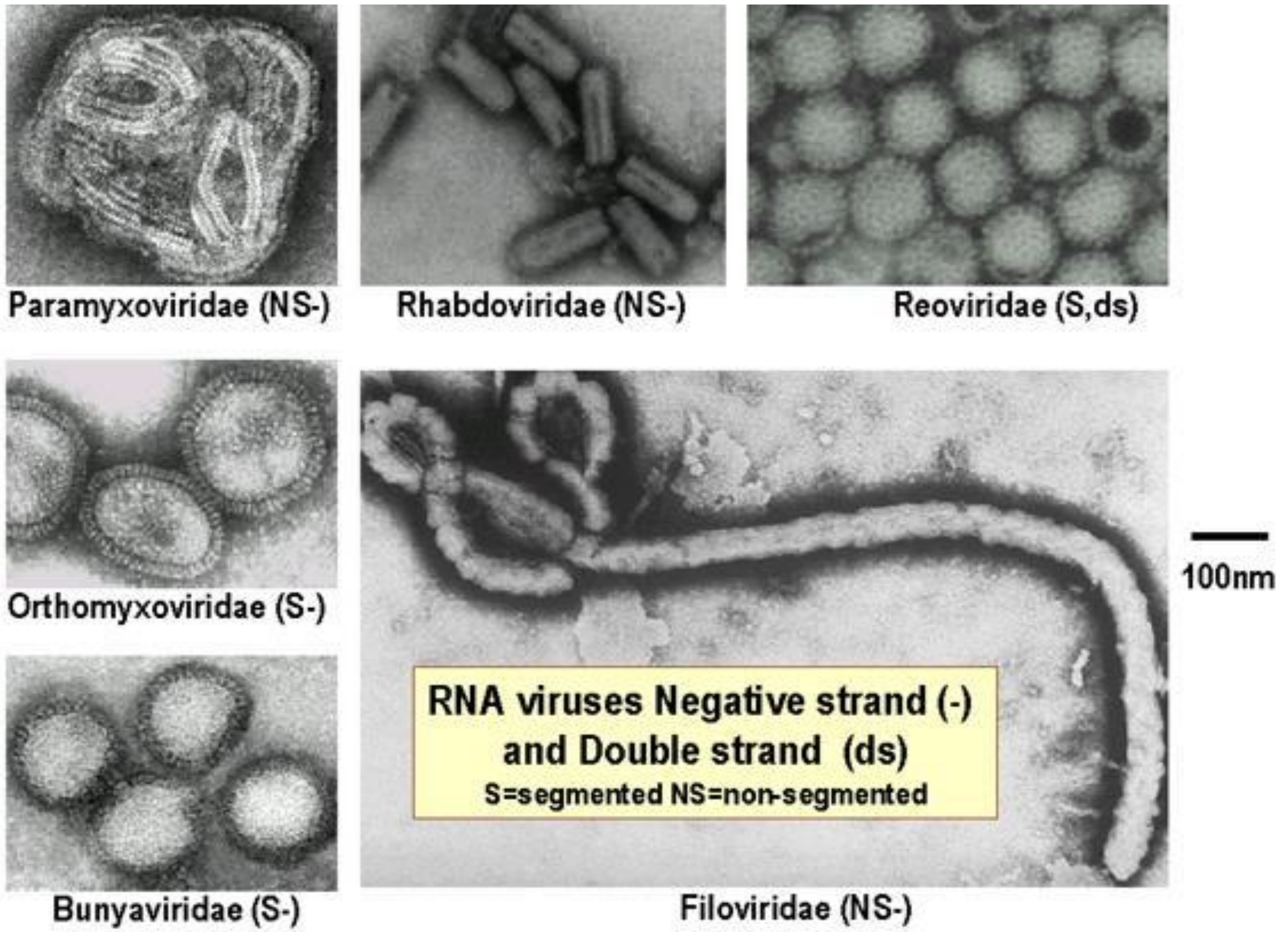


Properties

Family name	Reo	Birna	Calici	Picorna	Flavi	Toga	Retro	Corona	Filo	Rhabdo	Bunya	Ortho-myxo	Para-myxo	Arena
Virion polymerase	(+)	(+)	(–)	(–)	(–)	(–)	(+)	(–)	(+)	(+)	(+)	(+)	(+)	(+)
Virion diameter (nm)	60–80	60	35–40	28–30	40–50	60–70	80–130	80–160	80 × 790–14,000	70–85 × 130–380	90–120	90–120	150–300	50–300
Genome size (total in kb)	22–27	7	8	7.2–8.4	10	12	3.5–9	16–21	12.7	13–16	13.5–21	13.6	16–20	10–14

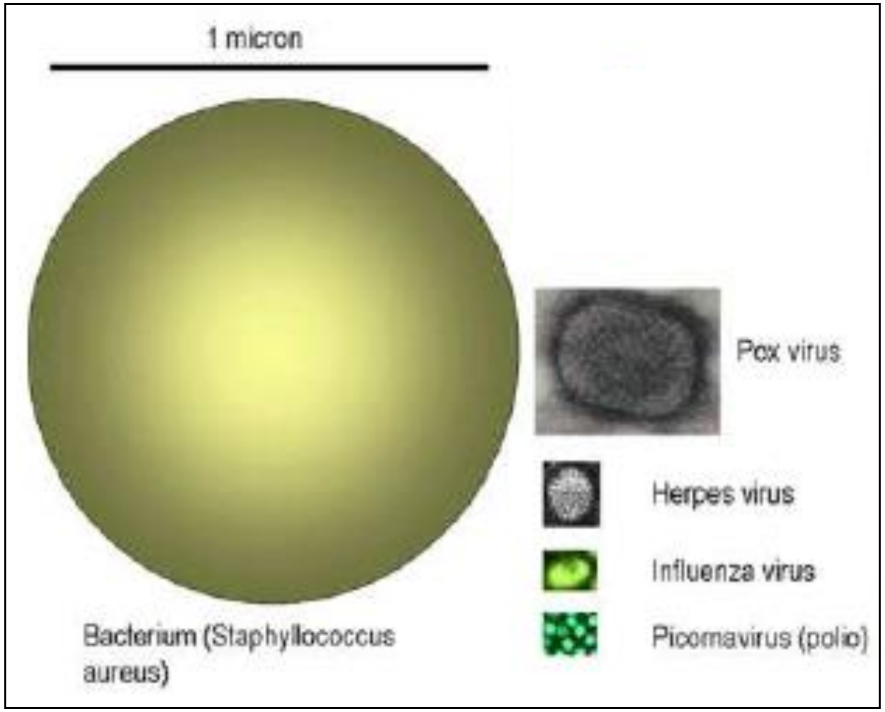
From Flint et al. *Principles of Virology* (2000), ASM Press

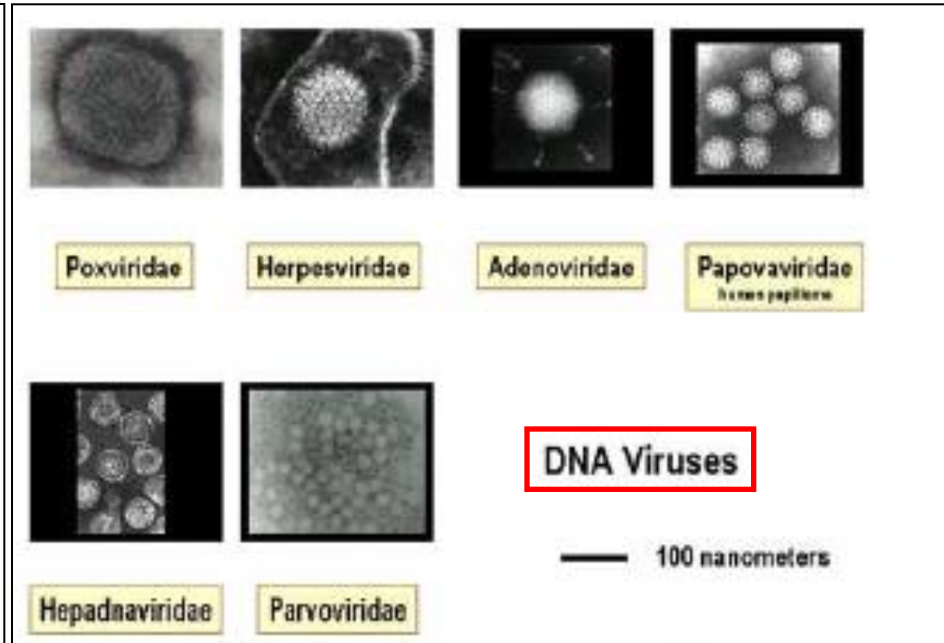
RNA viruses

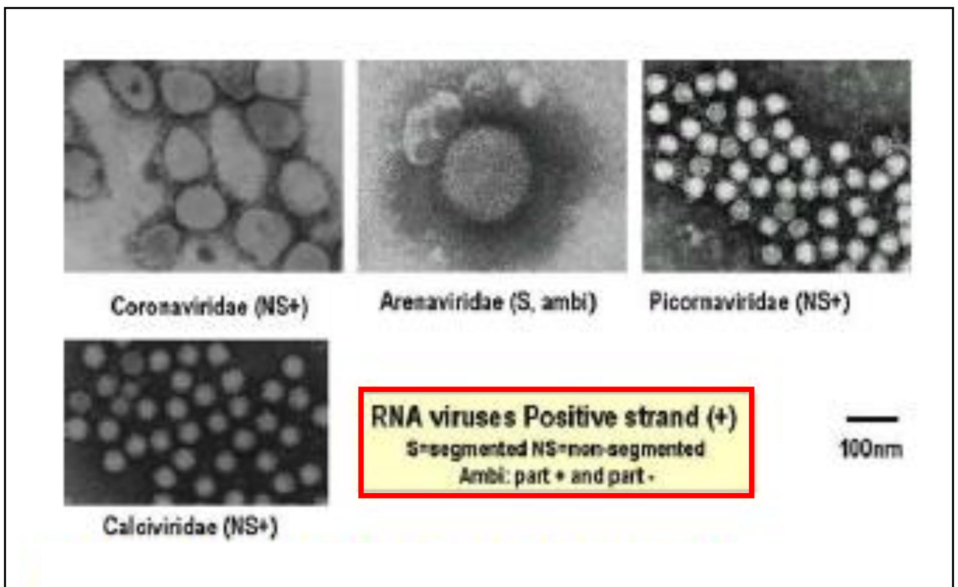


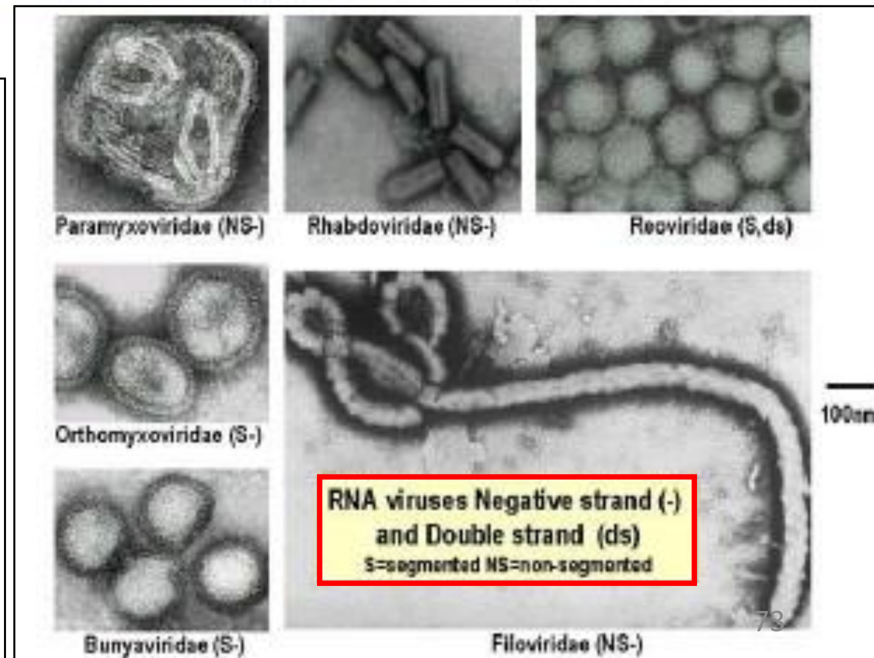
Paramyxoviridae (NS-)
Rhabdoviridae (NS-)
Reoviridae (S,ds)
Orthomyxoviridae (S-)
100nm
RNA viruses Negative strand (-)
and Double strand (ds)
S=segmented NS=non-segmented
Bunyaviridae (S-)
Filoviridae (NS-)

SIZE OF VIRUSES









Morfologie

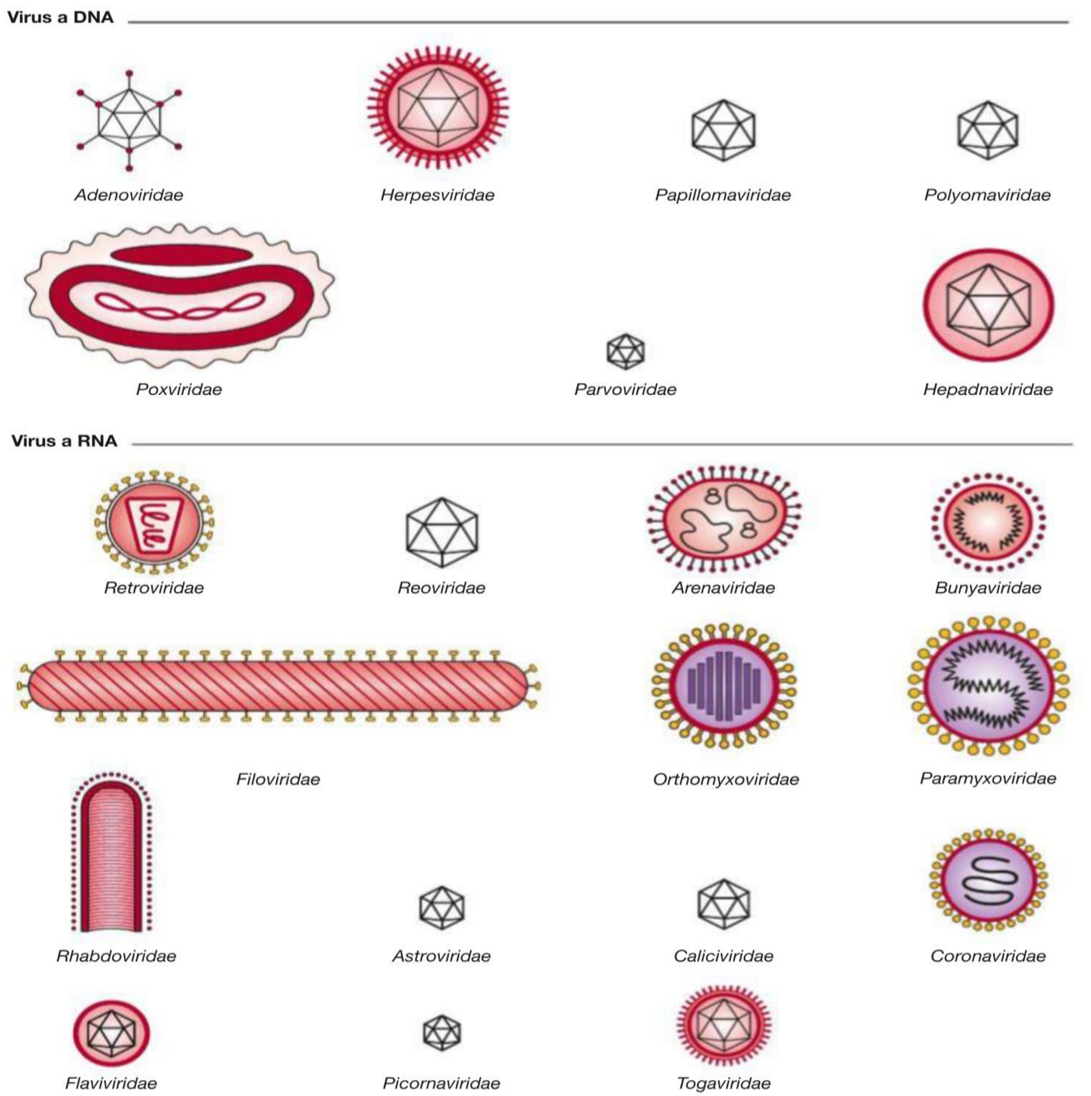
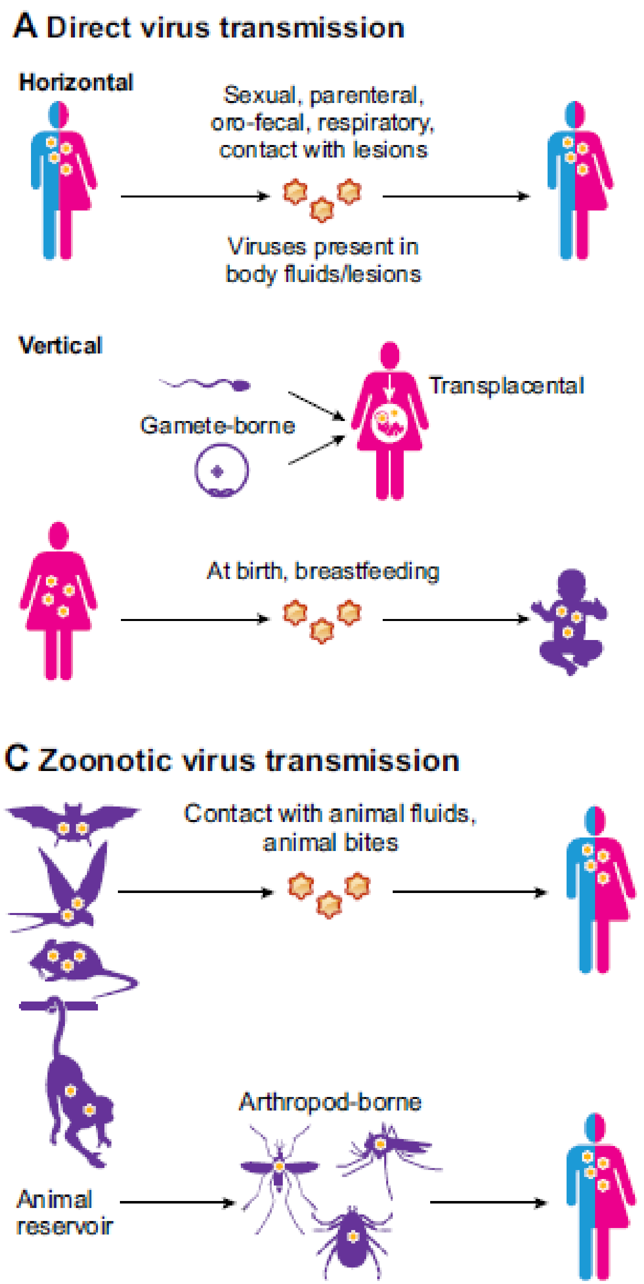


Figura 35.1 **Rappresentazione schematica delle diverse famiglie di virus animali.**

Criteri di classificazione dei virus

- Nucleic acid nature: RNA vs DNA
- Capsid symmetry: Icosahedral, Helical, Complex
- Presence (enveloped) or absence (naked viruses) of the envelope
- Genome architecture: single strand or double strand, linear or circular, continous or segmented, genome polarity
- mRNA production strategy: Baltimore classification
- ICTV criteria: viral taxonomy
- Other (transmission route, pathology, tropism etc.)



Another way to describe/classify viruses is through their route of infection

Horizontal transmission: from one individual to another

Vertical transmission: from parents to offspring

HORIZONTAL TRANSMISSION OF ANIMAL VIRUSES
infected individual ➔ healthy individual

- ❑ **Via aerosolized air droplets** (respiratory transmission)
  ➔ coughing, sneezing… : ***Influenza virus, Rhinovirus, SARSCoV2…***

- ❑ **Via food and water contaminated by excrements** (faecal-oral transmission)
  ➔ poor hygiene conditions, water contamination, unwashed hands… : ***Rotavirus (gastroenteritis), Hepatitis A virus, Poliomyelitis virus…***

- ❑ **Via direct contact**
  - **sexual contact** (Sexual transmission): ***HIV, Herpes Simplex Virus, Papillomavirus…***
  - **kissing** (Salivary transmission): ***Epstein-Barr virus***
  - **animal bite:** ***Rabies virus***
  - **unsafe injections** (toxicomen) ***HIV, Hepatitis B and C virus…***

- ❑ **Iatrogenic:** blood transfusion, transplants and contaminated medical instruments: ***HIV, Hepatitis B, CMV…***

- ❑ **Vector-borne**

  - arthropods: **Yellow fever virus, Zika virus, Chikungunya virus, Dengue virus (mosquitos), encephalitis viruses *(tick)…*** *ARthropod BOrne VIRUS* : ***ARBOVIRUS***

VERTICAL TRANSMISSION OF ANIMAL VIRUSES
parents ➔ offspring

❑ **Hereditary transmission, via contaminated germ cells:**

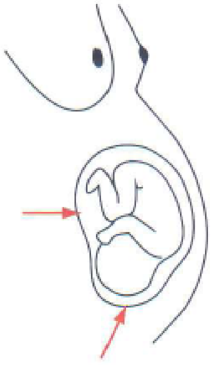
viral genome inserted into host cell genome → transmission of the viral genome to daughter cells

Endogenous retroviruses > viral sequences fixed in our gene pool

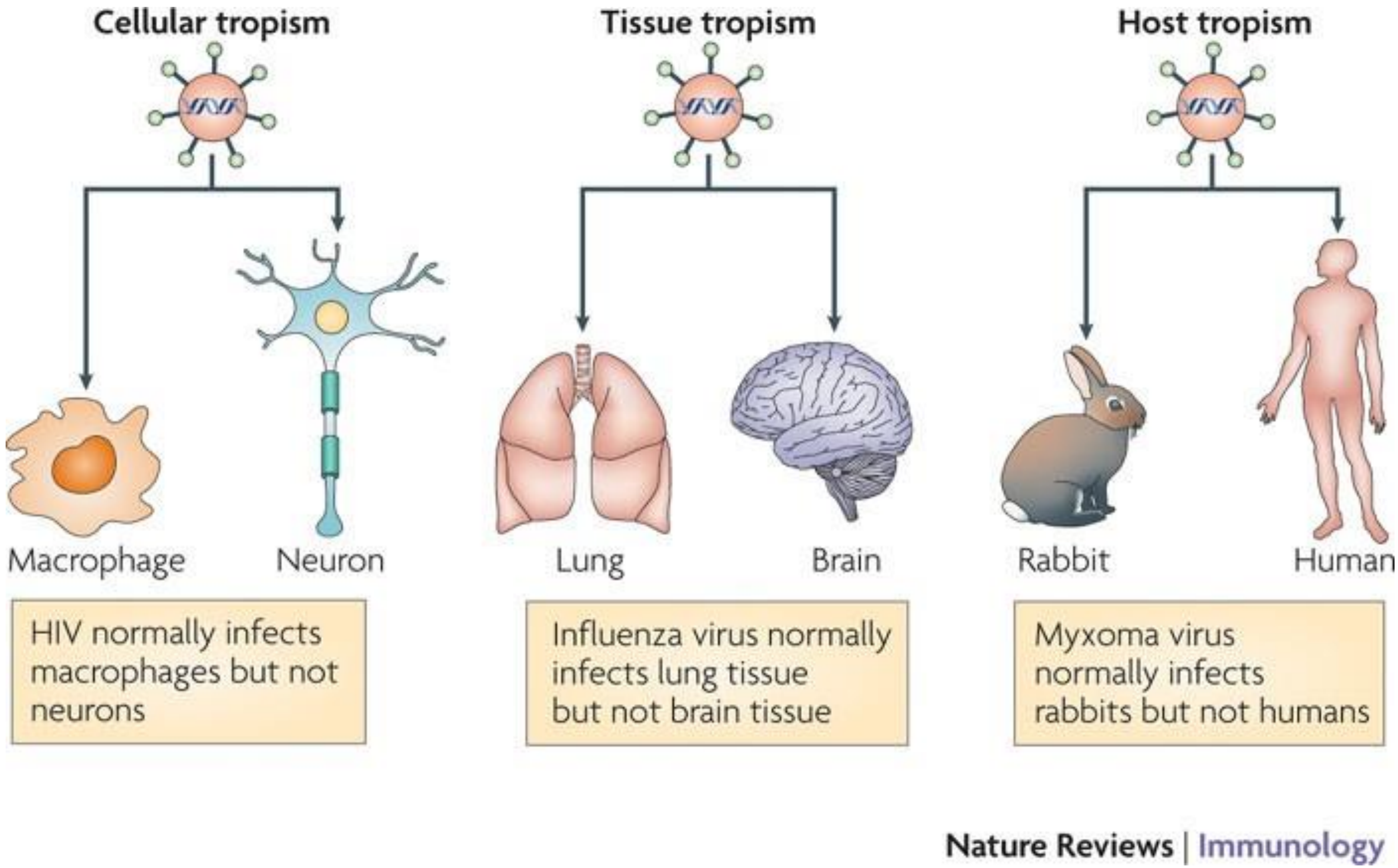
Herpes virus 6 HHV-6

❑ **Mother to child transmission:**

- **Transplacental transmission** : *HIV, Cytomegalovirus, Rubeola virus, ZIKA virus…*
- **Perinatal transmission** (during childbirth, breastfeeding) : *HIV…*

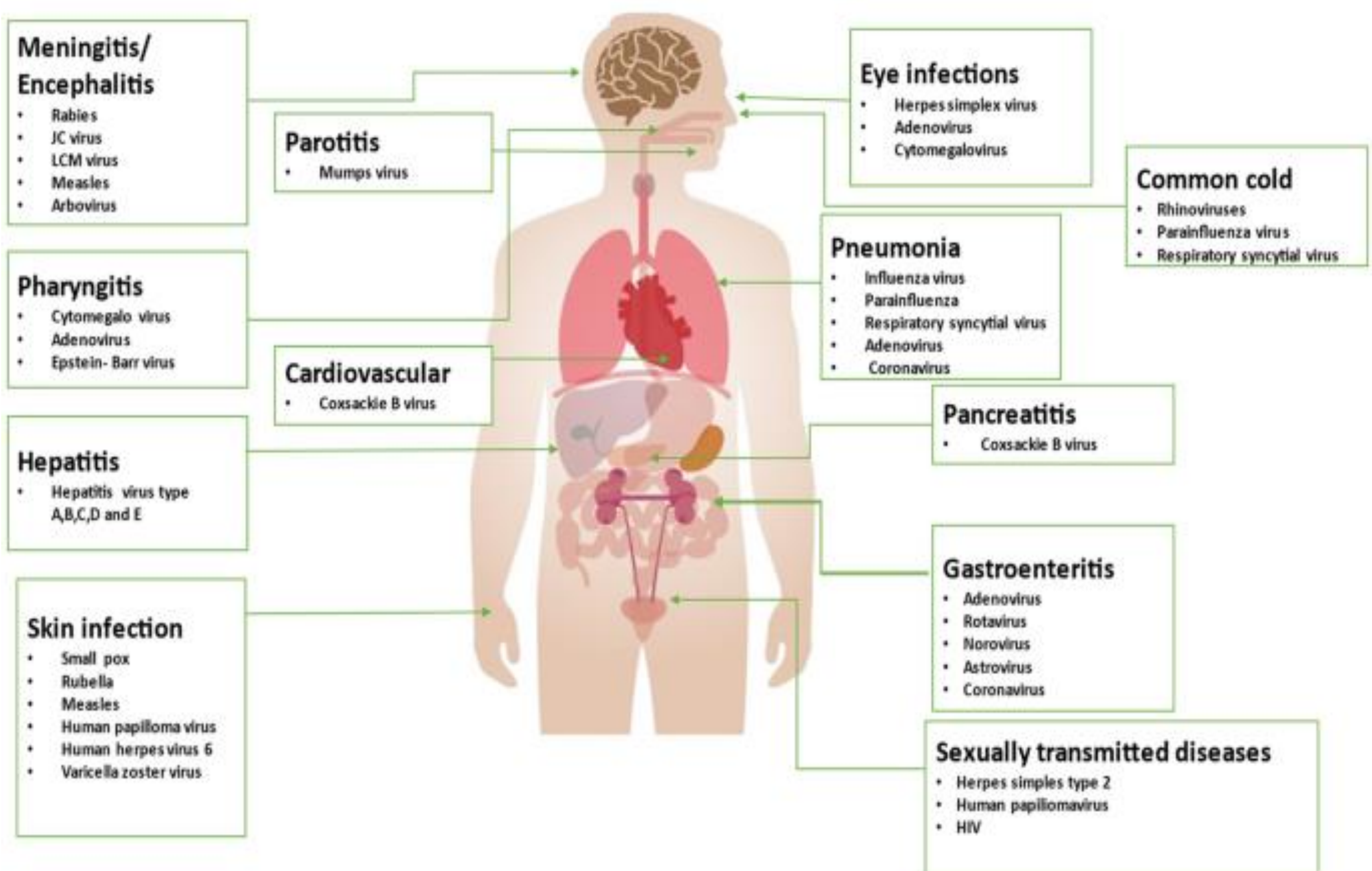


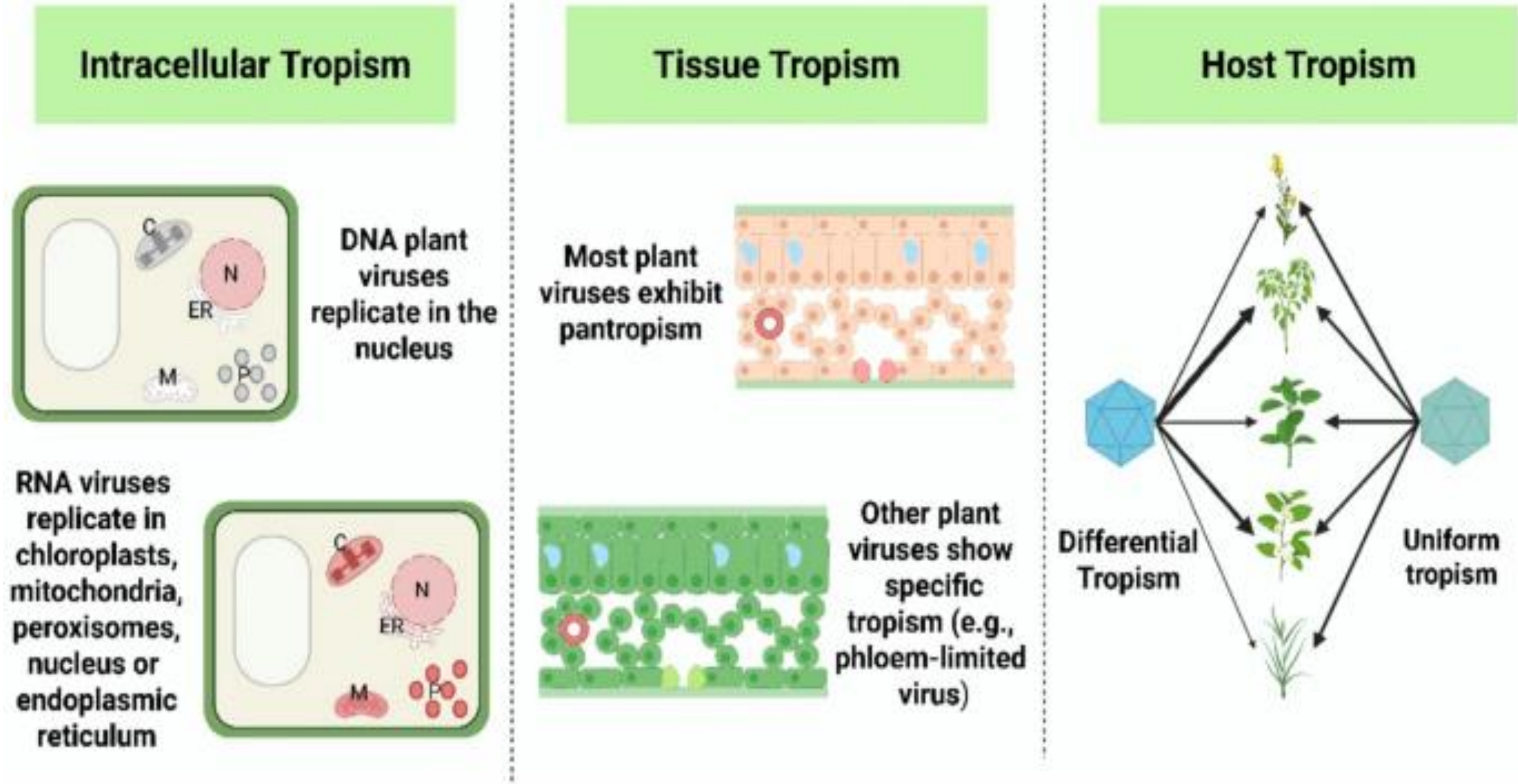
Viral tropism



McFadden, G., *et al. Nat Rev Immunol* **9**, 645–655 (2009).

Viral pathology





Tropism in plant viruses can be categorized into intracellular tropism, tissue tropism, and host tropism. Intracellularly, DNA plant viruses replicate in the nucleus. RNA viruses replicate in chloroplasts (C), mitochondria (M), peroxisomes (P), nucleus (N) or endoplasmic reticulum (ER). At the tissue level, most plant viruses exhibit pantropism, infecting multiple tissue types, although some are restricted to specific tissues (e.g. phloem-limited viruses). Host tropism refers to the virus differential ability to infect and replicate in distinct plant hosts. Some viruses exhibit differential host tropism, accumulating to different levels across hosts within their range, while others show uniform tropism with comparable infection efficiency across hosts.

Núñez-Muñoz, L.A., *et al.* . *Arch Microbiol* **207**, 152 (2025)

HORIZONTAL TRANSMISSION OF PLANT VIRUSES (PHYTOVIRUS)

Plants are motionless

Physical barriers surrounding plant cells (cell wall; cuticle)

→ Viral transmission mainly through vectors

These vectors are :

- certain **insects** (aphids, cochineal…) : contaminate aerial plant organs
- Roots **nematodes** : contaminate roots
- **Zoospores of telluric fungi :** contaminate roots

Insects and nematodes are infected and transmit the infection when feeding on the plant.

infection +++ when plants damaged (weather, pruning, fire…)

VERTICAL TRANSMISSION OF PLANT VIRUSES
More frequent than for animal viruses

- **During sexual reproduction** : though contaminated seed or pollen (more rarely)

- **During asexual reproduction (vegetative propagation)** :
  - natural: through tubercles, bulbs, rhizomes…
  - horticultural methods: grafting, slip…