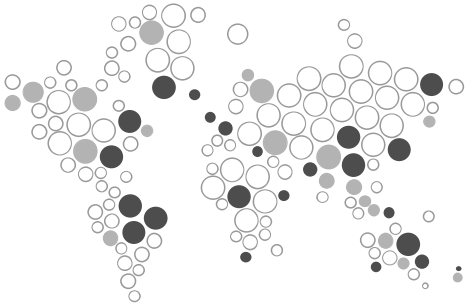
Small Circular DNA Viruses:
The muddy viral “playground” of recombinant, reassortant, and highly diverse viruses



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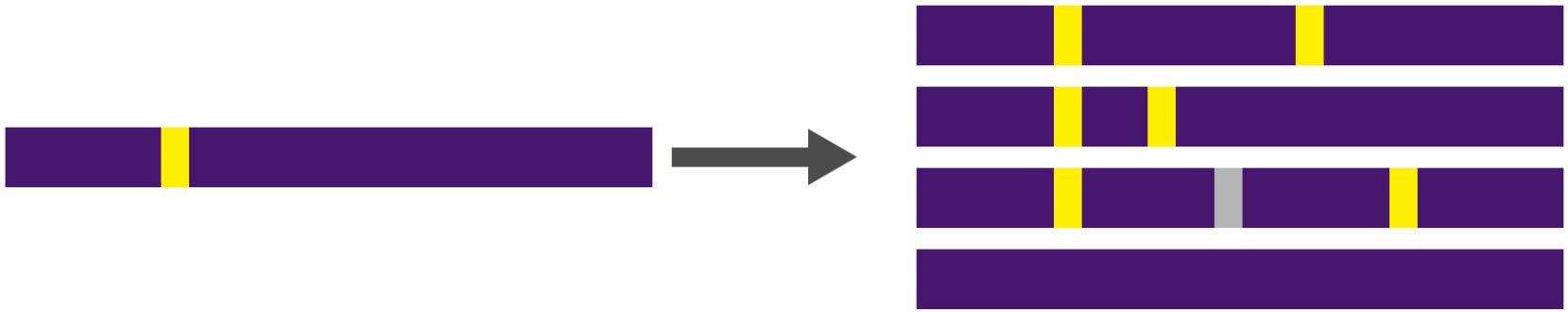
Arvind Varsani

Viral evolution

Nucleotide substitutions

Recombination

Reassortment



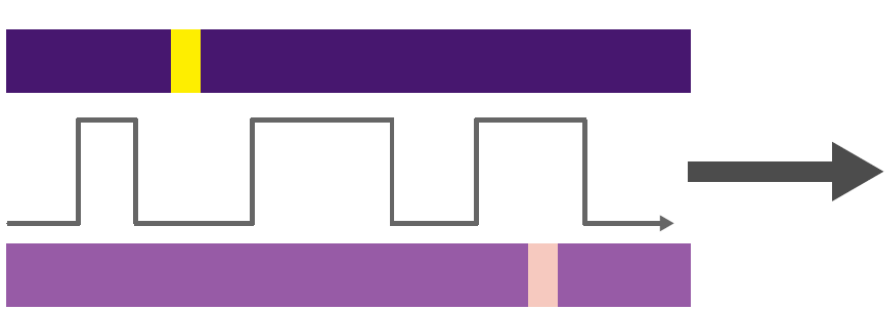
Low success rate to fix mutation by mutation

Viral evolution

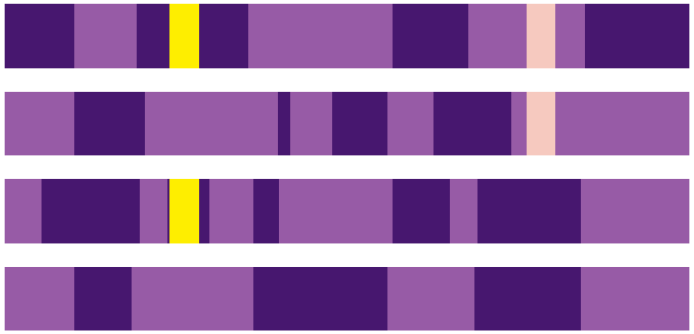
Nucleotide substitutions

Recombination

Reassortment



Switching between templates during replication



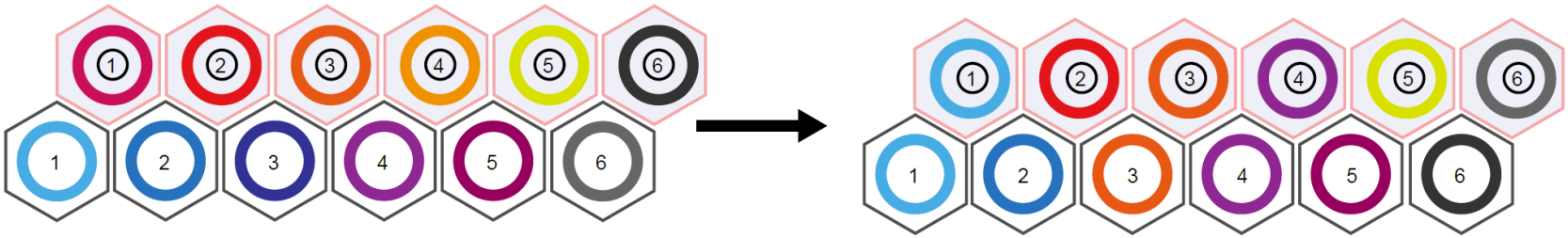
High success rate in fixing mutation by recombination

Viral evolution

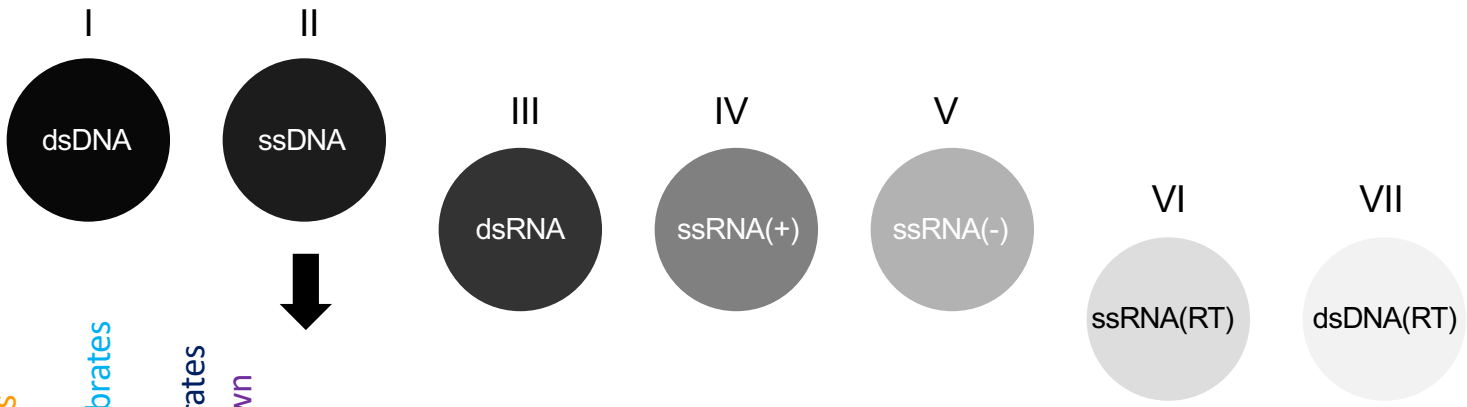
Nucleotide substitutions

Recombination

Reassortment



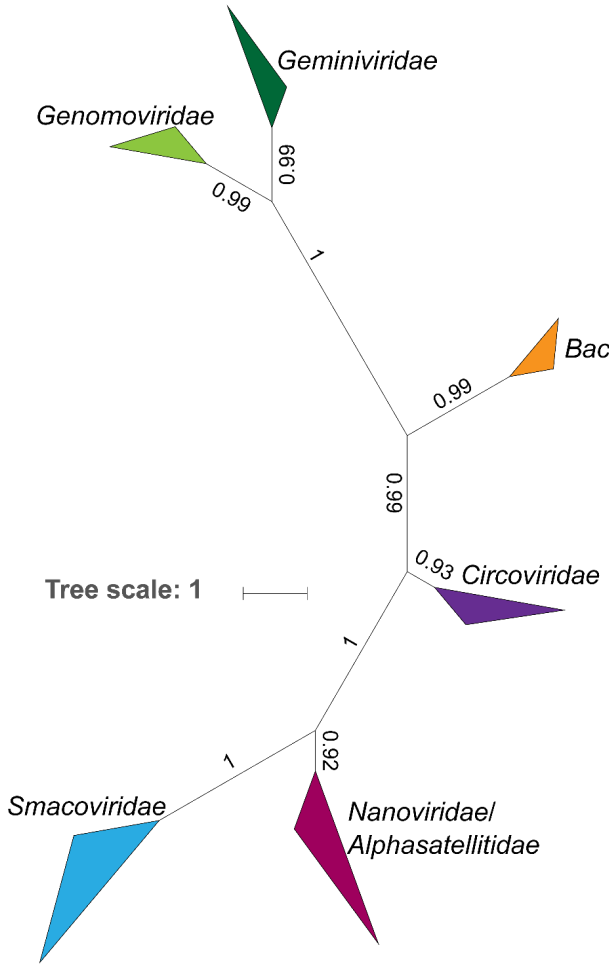
ssDNA viruses

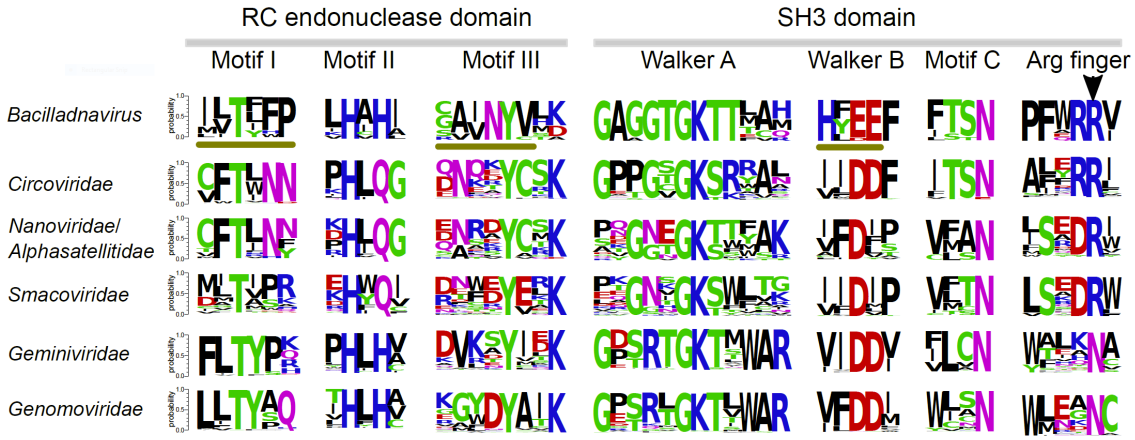


Archaea
Bacteria
Diatoms
Fungi
Invertebrates
Plants
Vertebrates
Unknown

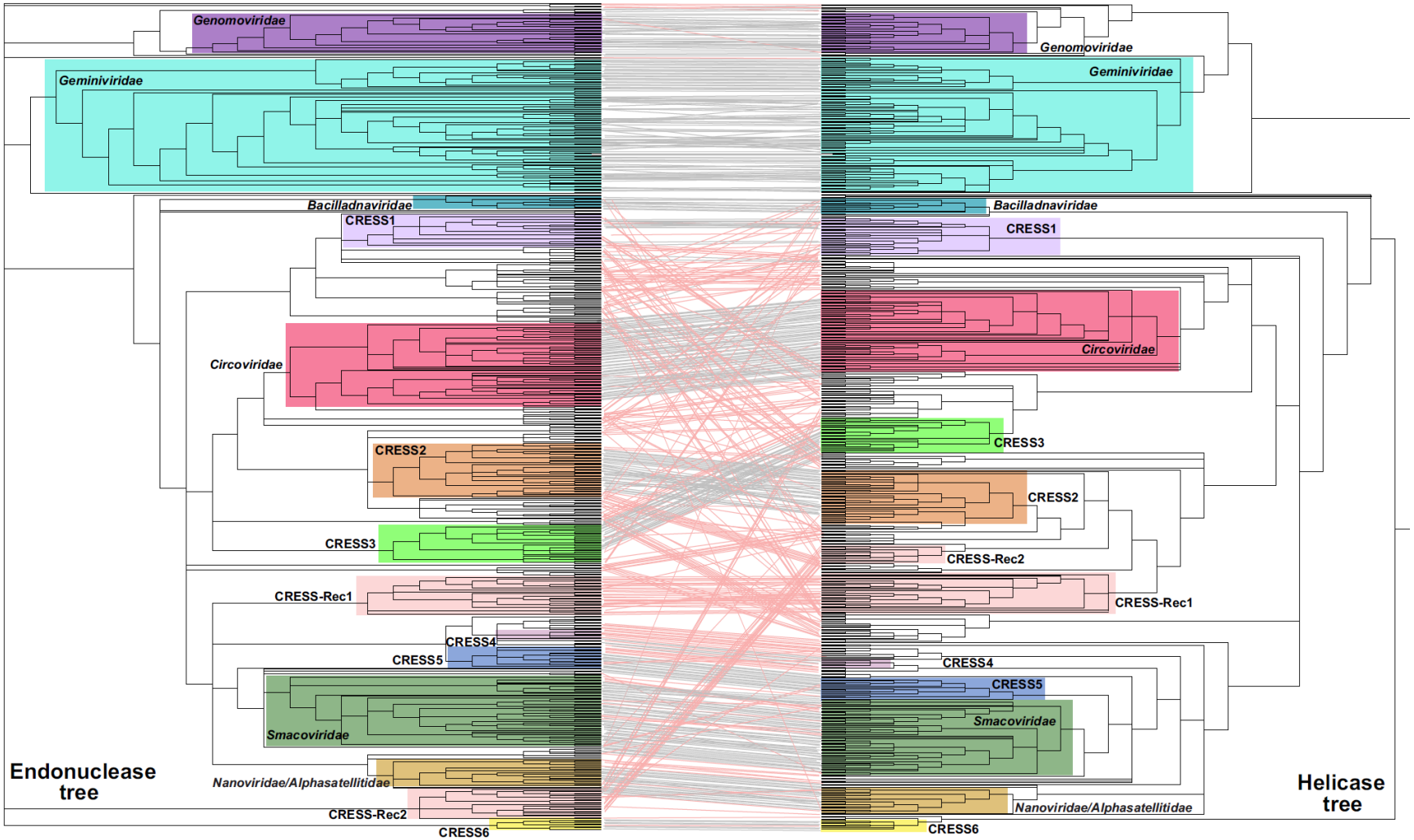
- *Anelloviridae* – circular (~2.1 - 3.8kb)
- *Bacillidnaviridae* - circular (~4.5 - 6kb)
- *Circoviridae* – circular (~1.6 - 2.3kb)
- *Geminiviridae* – circular (~2.7kb; monopartite, bipartite, associated with α/β satellites)
- *Genomovirdae* – circular (1.8 -2.3 kb)
- *Inoviridae* – circular (~5.8 - 8.7kb)
- *Microviridae* – circular (~4.5 - 6kb)
- *Nanoviridae* – circular (~1.2kb; multicomponent viruses; associated with satellites)
- *Parvoviridae* – linear (~3.7 - 6kb)
- *Pleolipoviridae** – circular ssDNA; circular dsDNA or liner dsDNA (7-16kb)
- *Smacoviridae** - circular (2.3 - 2.9kb)

ssDNA viruses





Chimerism in Rep



Nucleotide substitutions

Geminiviruses

MSV: ~2 x 10^{-4} subs/site/year
SSRV: ~3 x 10^{-4} subs/site/year
EACMV: ~1 x 10^{-3} subs/site/year
TYLCV: ~3 x 10^{-4} subs/site/year

Nanoviruses

FBNYV: ~1 x 10^{-3} subs/site/year
BBTV: ~3 x 10^{-4} subs/site/year

Circoviruses

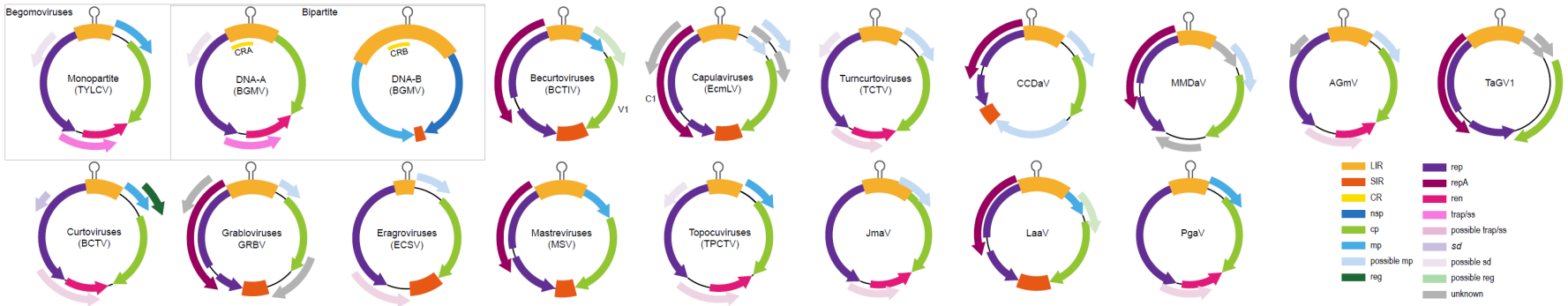
BFDV: ~2 x 10^{-3} subs/site/year
PCV-2: ~1 x 10^{-3} subs/site/year

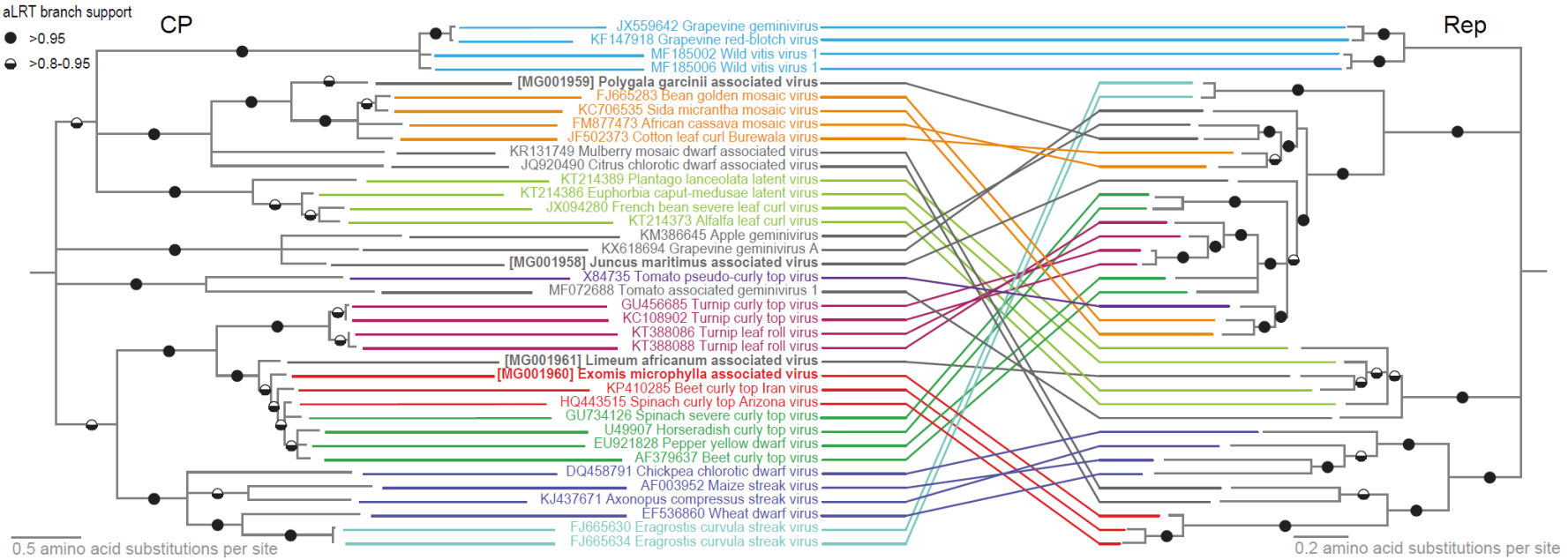
Parvoviruses

CPV: ~2 x 10^{-4} - 8 x 10-5 subs/site/year (VP1; NS1)
PPV: ~3 x 10^{-4} - 5 x 10-5 subs/site/year (VP1; NS1)

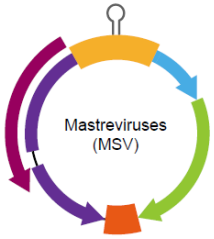
Recombination

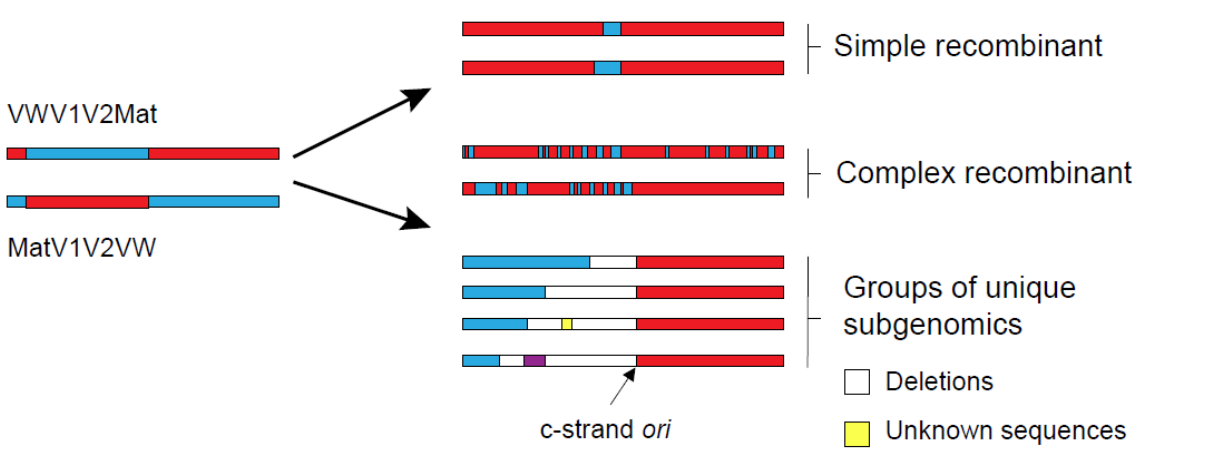
Geminiviruses

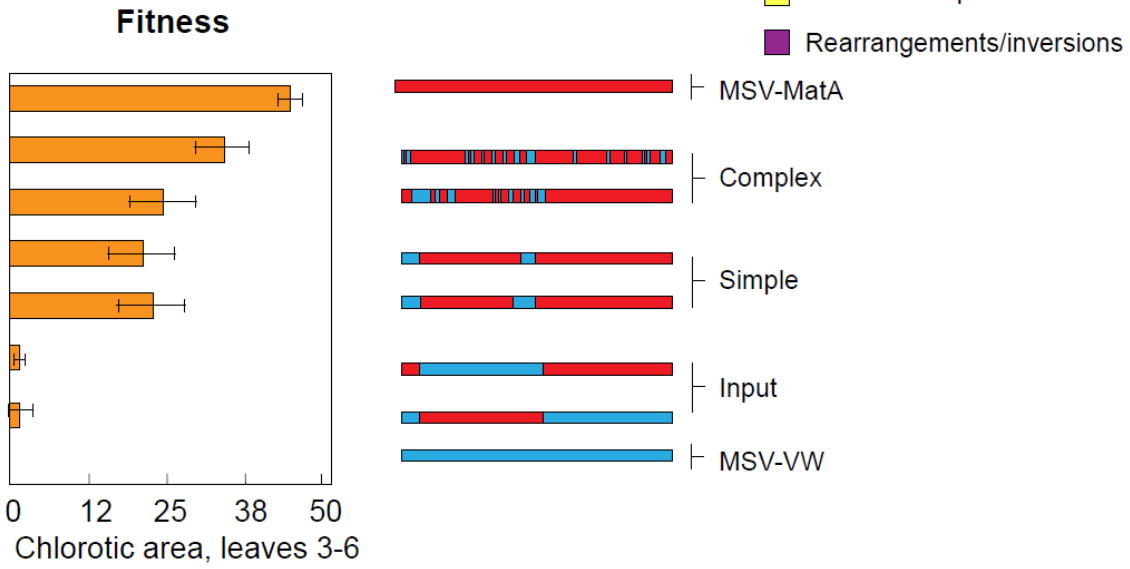




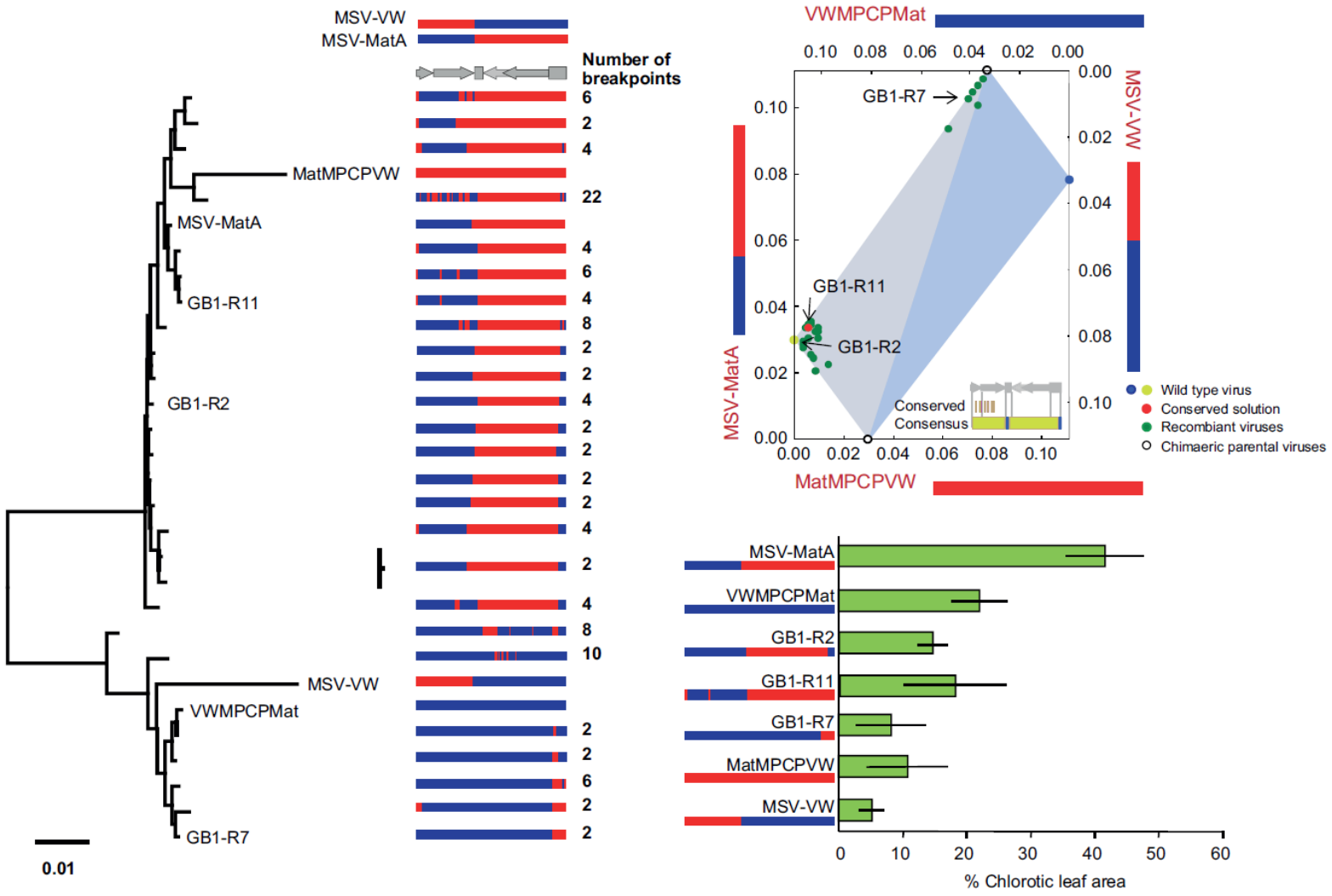
Recombination



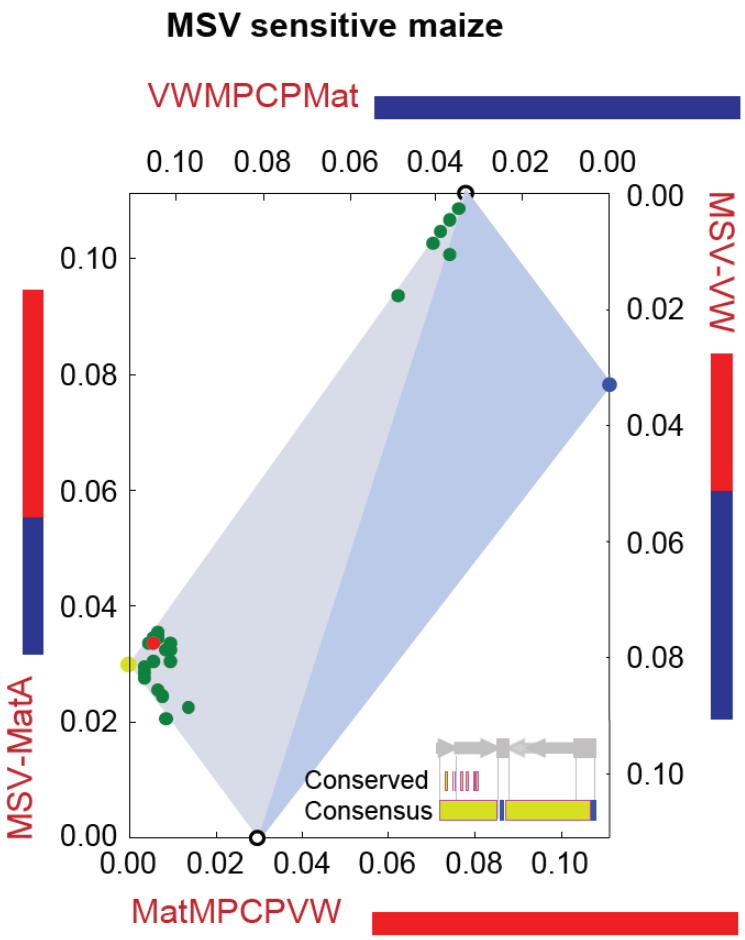


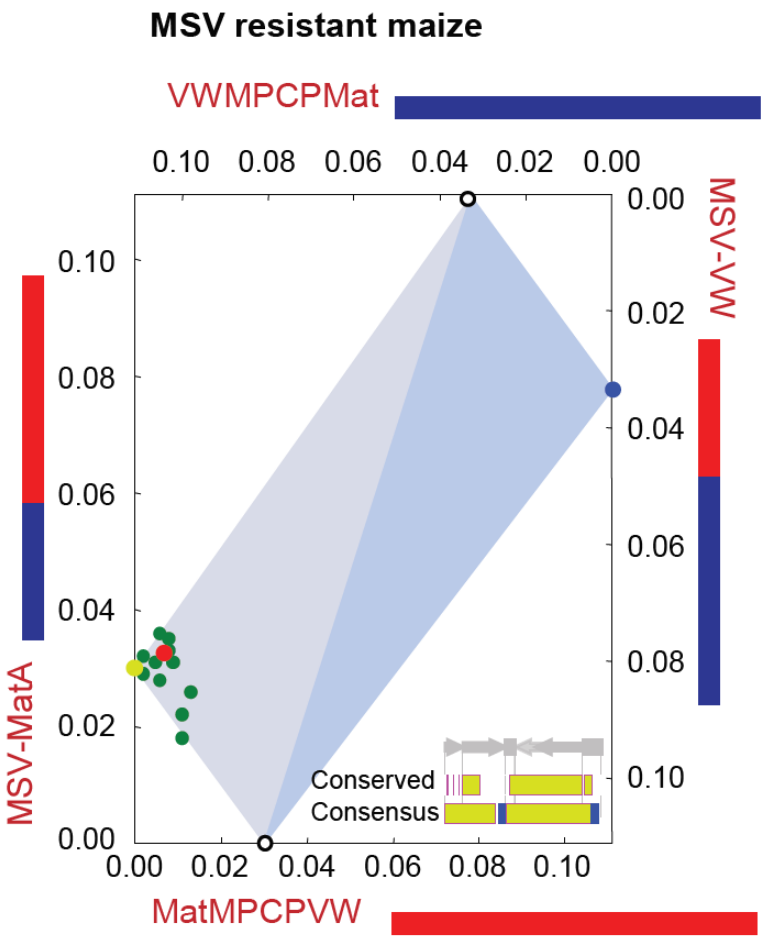


Recombination

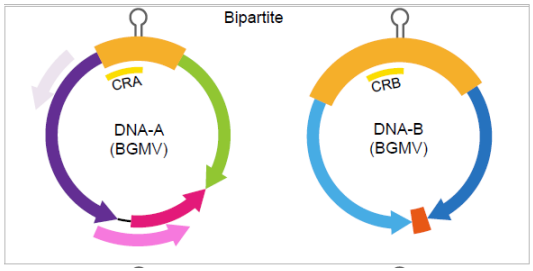


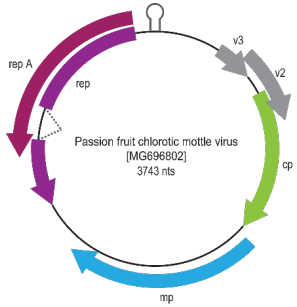
Recombination

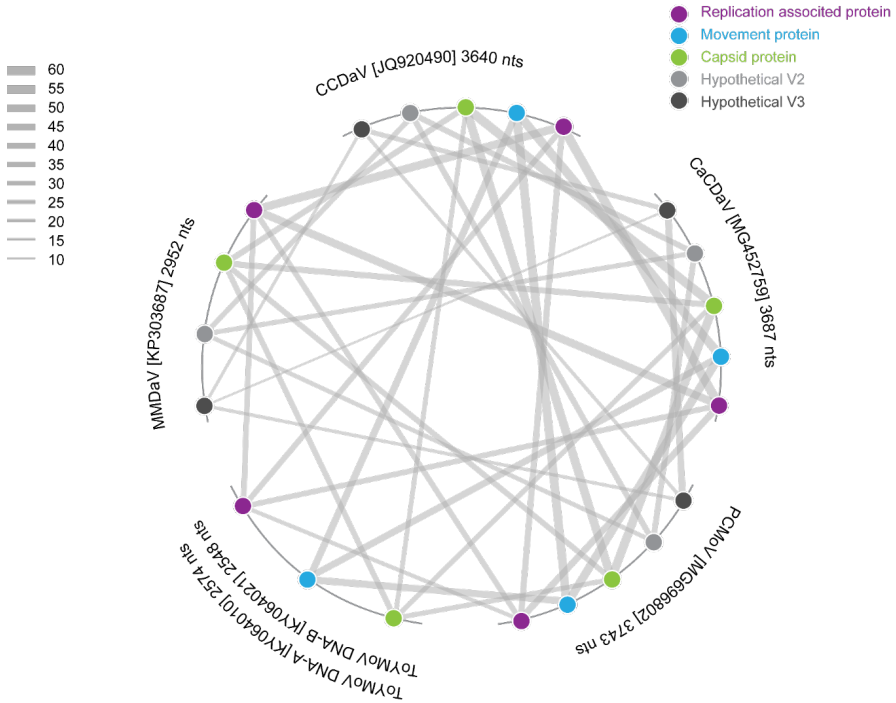




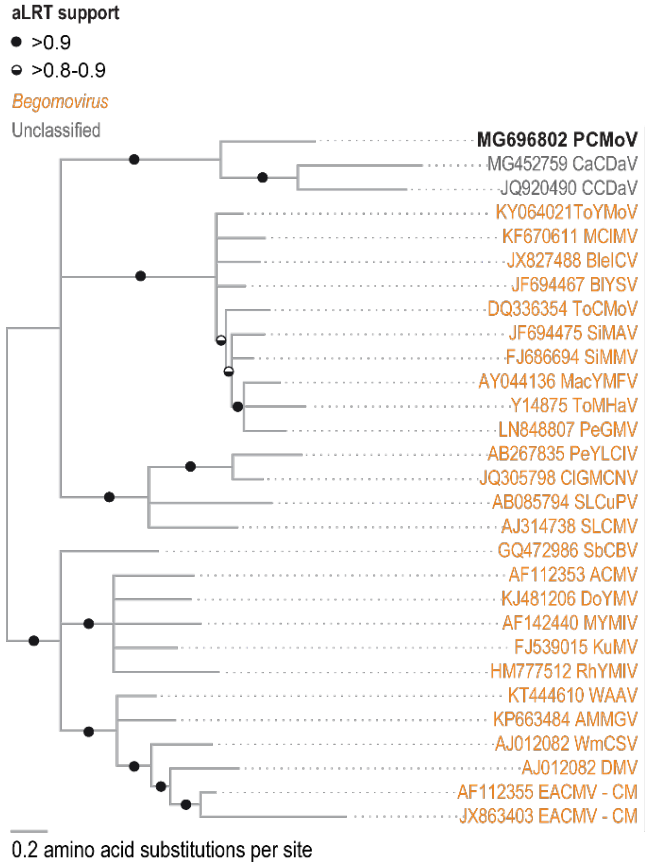
Genome plasticity



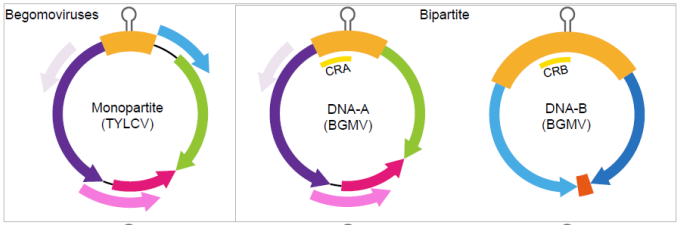


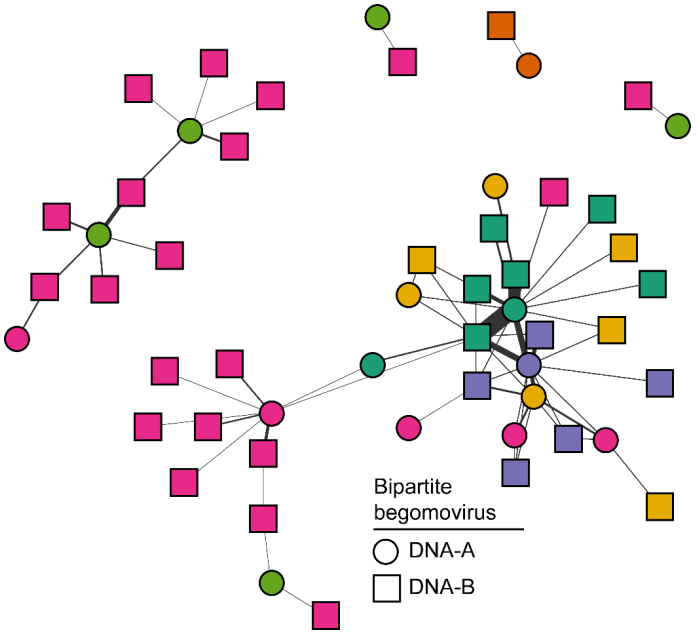


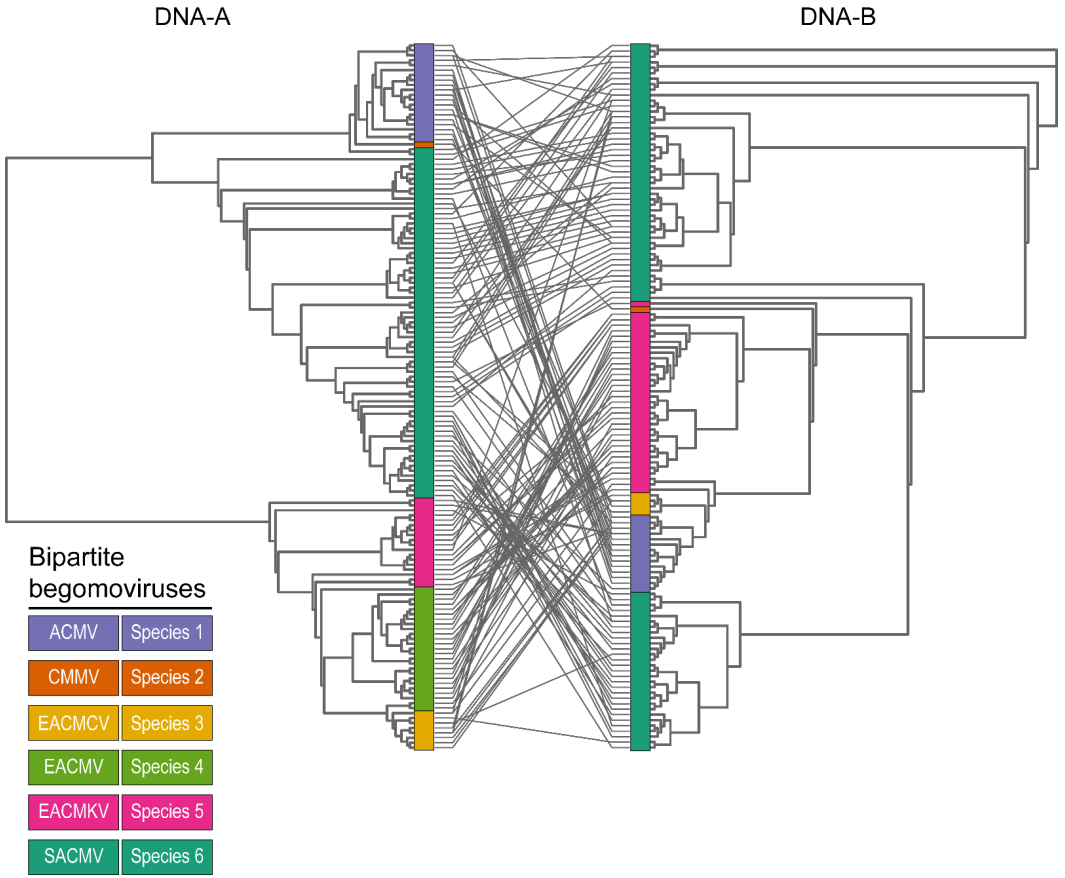
Gemimiviruses



Pseudo-recombination

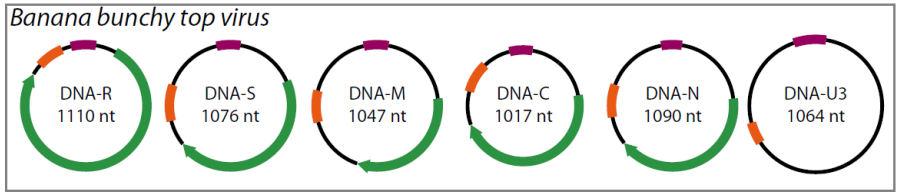






Reassortment

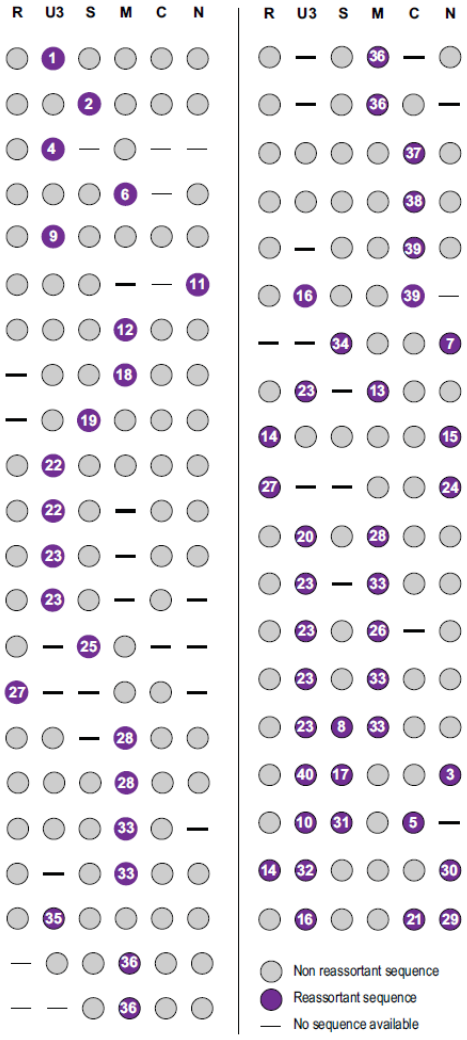
Reassortment



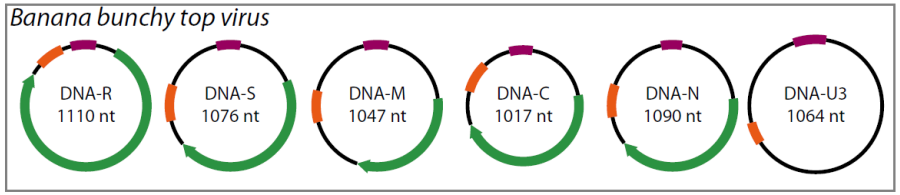
	Recombinant(s)	Sequence used to infer major parent(s)	Sequence used to infer minor parent(s)	Breakpoint Begin–End	Methods	P-value
DNA-R DNA-U3 DNA-S DNA-M DNA-C DNA-N	Tonga-Ha'apai Tonga-Vava'u	Tonga -Tonga'tapu Tonga-Ha'apai	India Pakistan	DNA-M 3393–4529	RGMCST	5.74×10^{-22}
DNA-R DNA-U3 DNA-S DNA-M DNA-C DNA-N	Australia	India Pakistan	Tonga -Tonga'tapu Tonga-Ha'apai	DNA-M DNA-C 3363–5388	RGBMCST	5.69×10^{-17}
DNA-R DNA-U3 DNA-S DNA-M DNA-C DNA-N	Tonga -Tonga'tapu	Tonga -Tonga'tapu	Tonga -Tonga'tapu	DNA-U3 1140–2346	RBST	6.94×10^{-9}

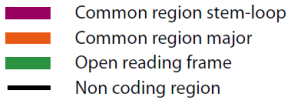
inferred major parent
inferred minor parent

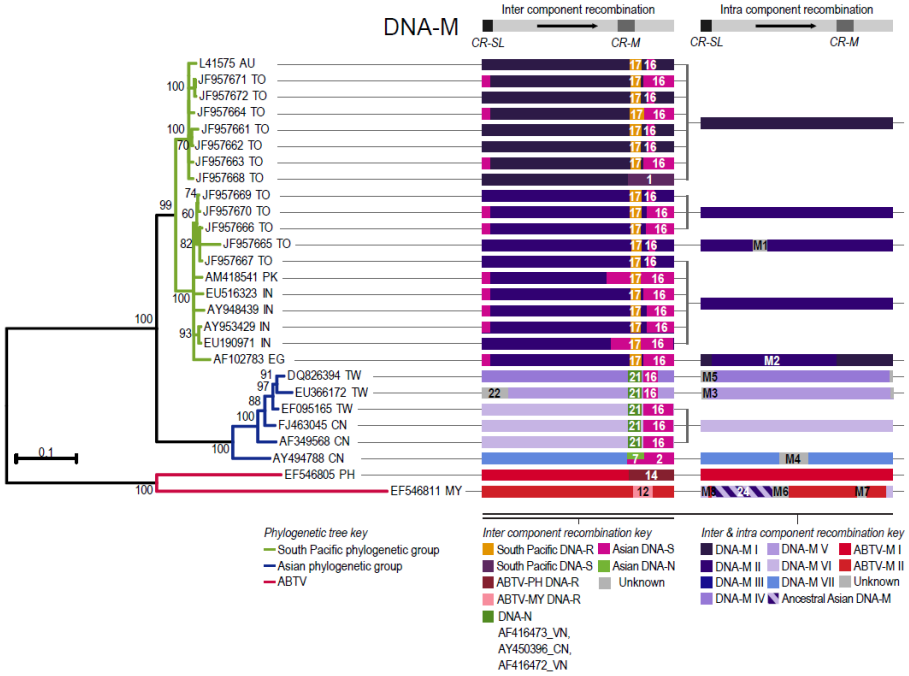
Methods R – RDP G – GENECONV B – Bootscan M – Maxchi C – Chimaera S – SiSscan T – 3Seq

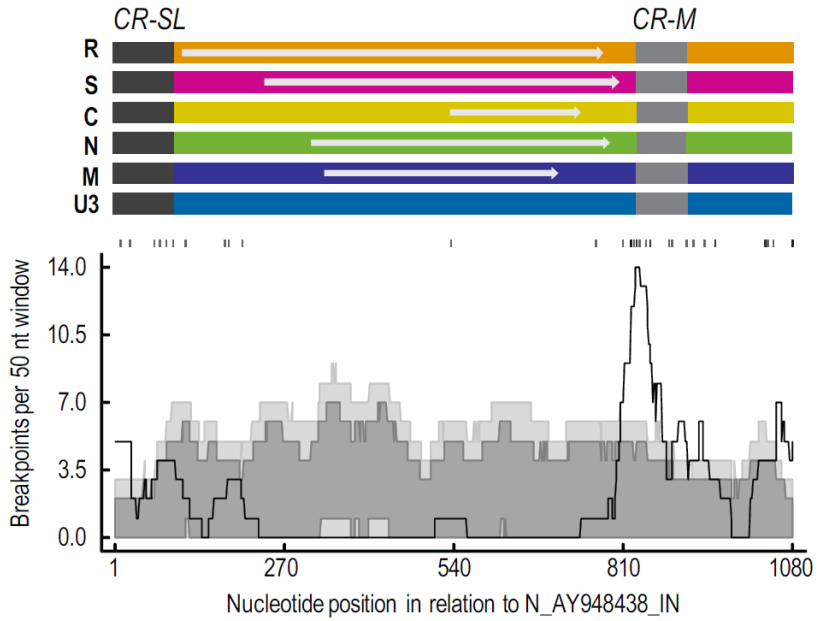


Recombination

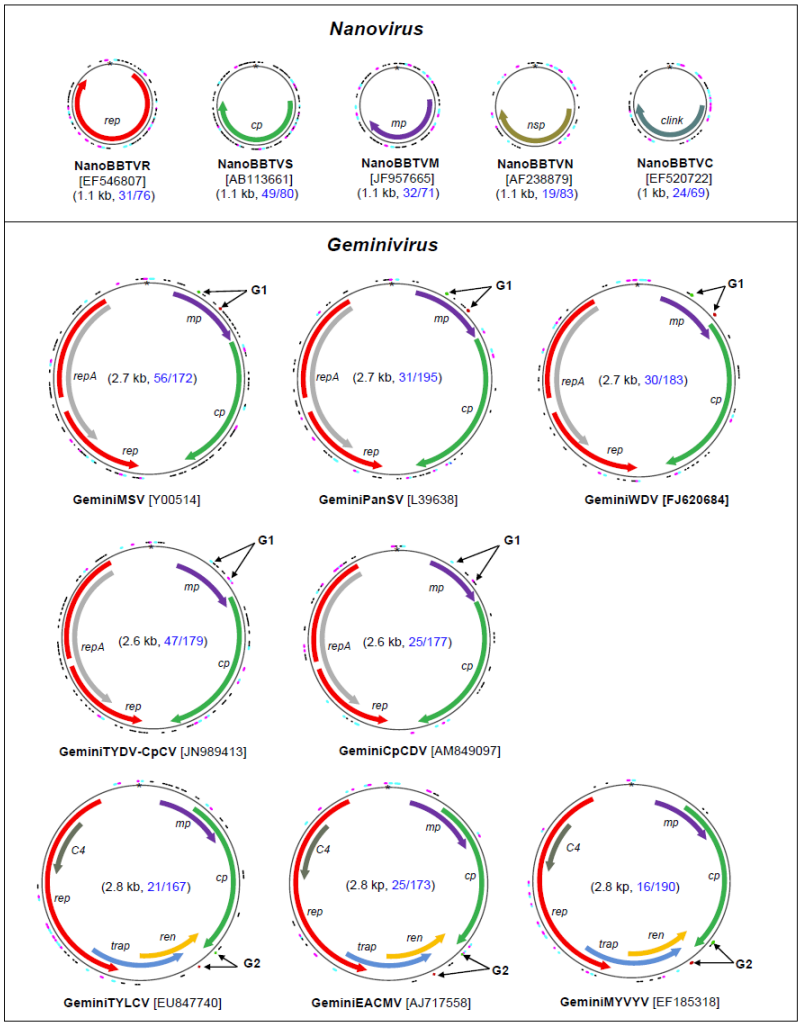


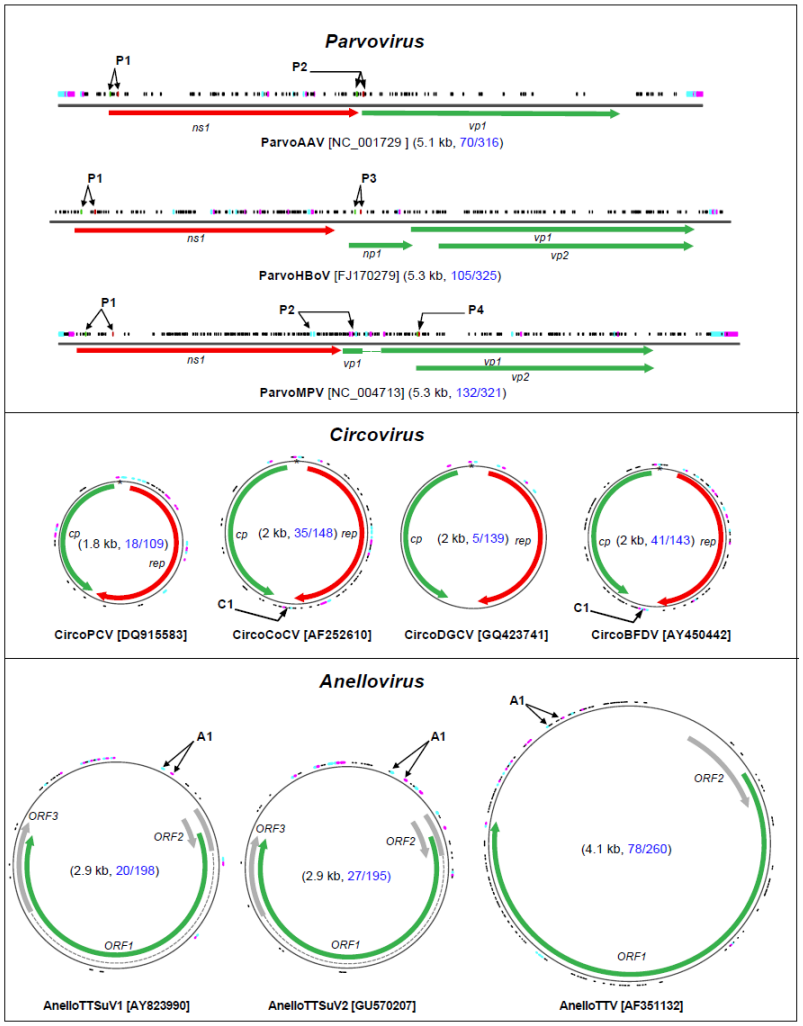






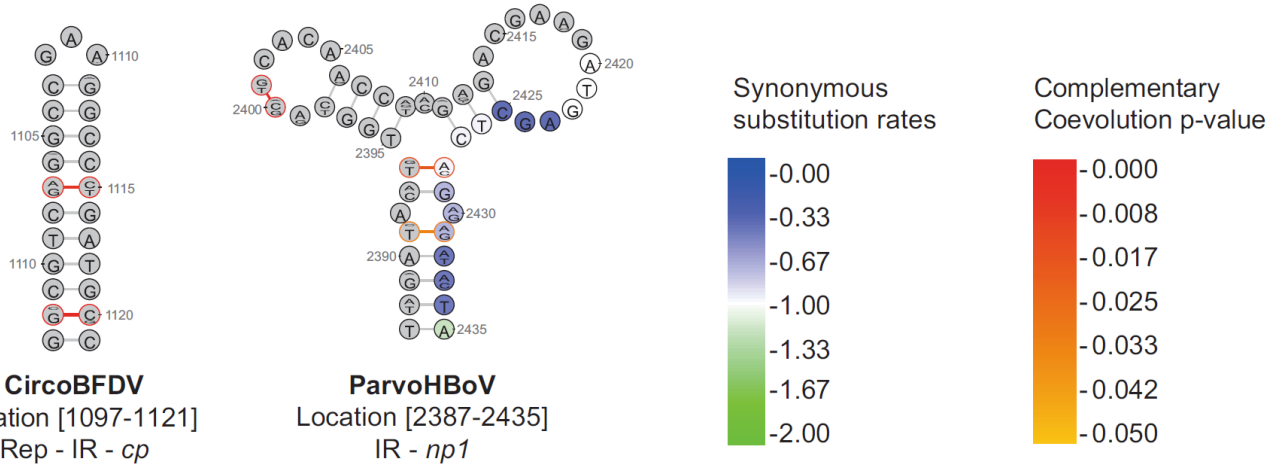
Secondary structure





Secondary structure

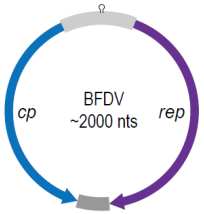
- Purifying selection is apparently strongest at paired-nucleotide sites
- Synonymous substitution rates are unusually low at paired genomic sites
- Short-term evolution experiments - mutations tend to preferentially accumulate at unpaired sites
- Base-paired sites tend to complementarily coevolve



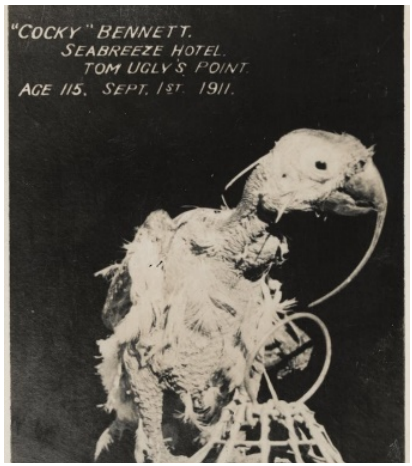
CircoBFDV
Location [1097-1121]
Rep - IR - *cp*

ParvoHBoV
Location [2387-2435]
IR - *np1*

Circoviruses

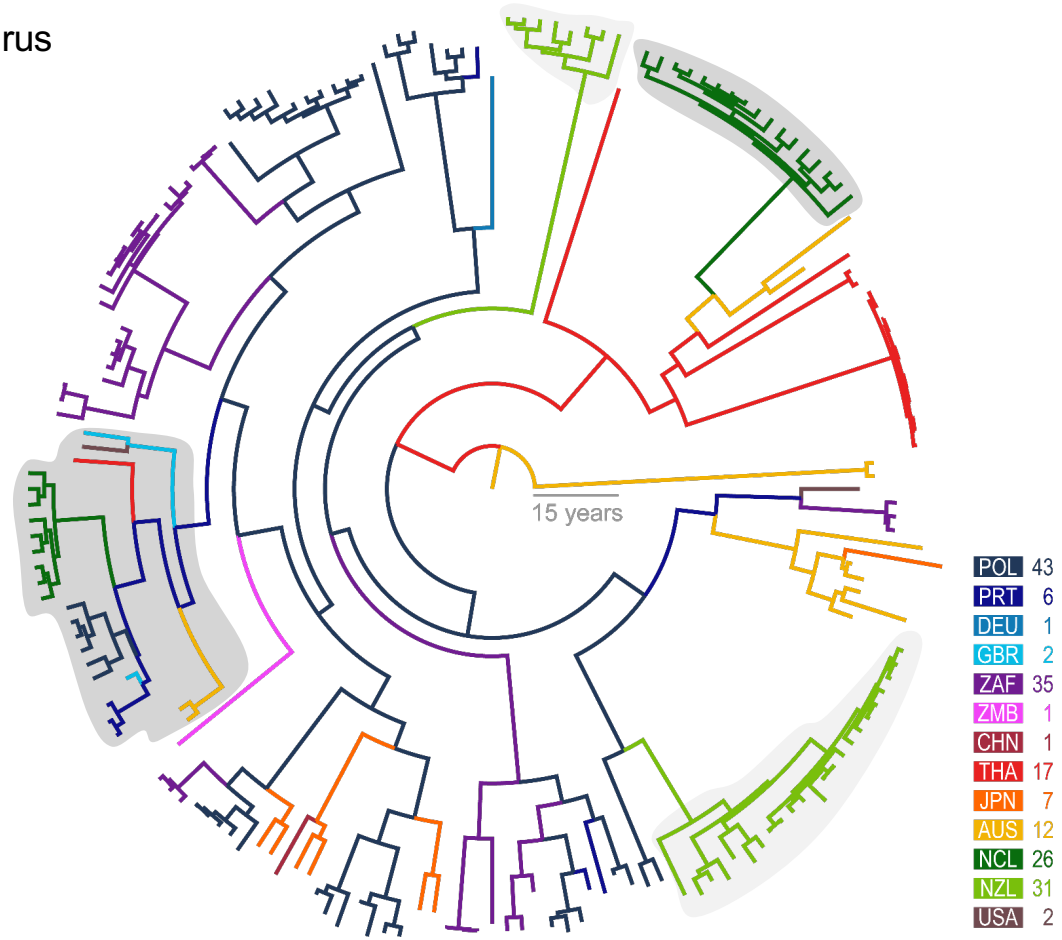


Circoviruses
Beak and feather disease virus

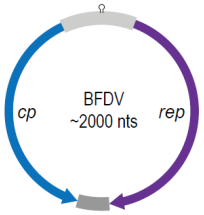


A VENERABLE COCKATOO.

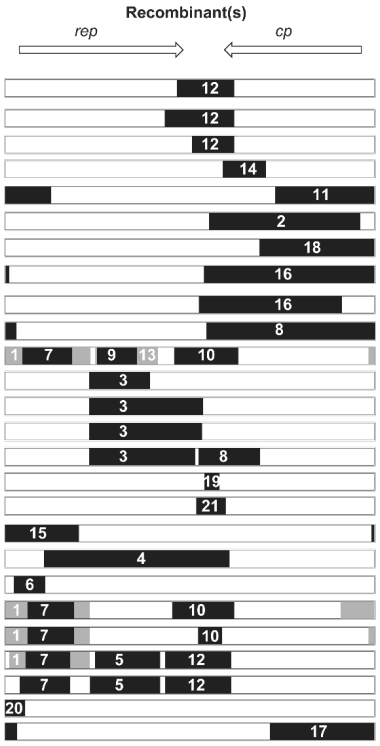
"Cocky Bennett," a sulphur-crested Australian cockatoo, died on Friday in his 120th year at Canterbury. This age is a record in longevity for an Australian parrot so far as the official records are concerned. For many years this bird was in the possession of Mrs. Sarah Bennett, the licensee of the Sea Breeze Hotel, at Tom Ugly's Point. When she left there, about 12 months ago, she transferred the parrot to her nephew, Mr. Murdoch Alexander Wagschall, at Woolpack Hotel, Canterbury. The old bird was absolutely featherless for the last 20 years, but it maintained its "patter" till the day before its death. "Cocky Bennett" was a great traveller, and is said to have journeyed seven times round the world. Mr. Wagschall has arranged to have the remains of this historic parrot preserved by a taxidermist.



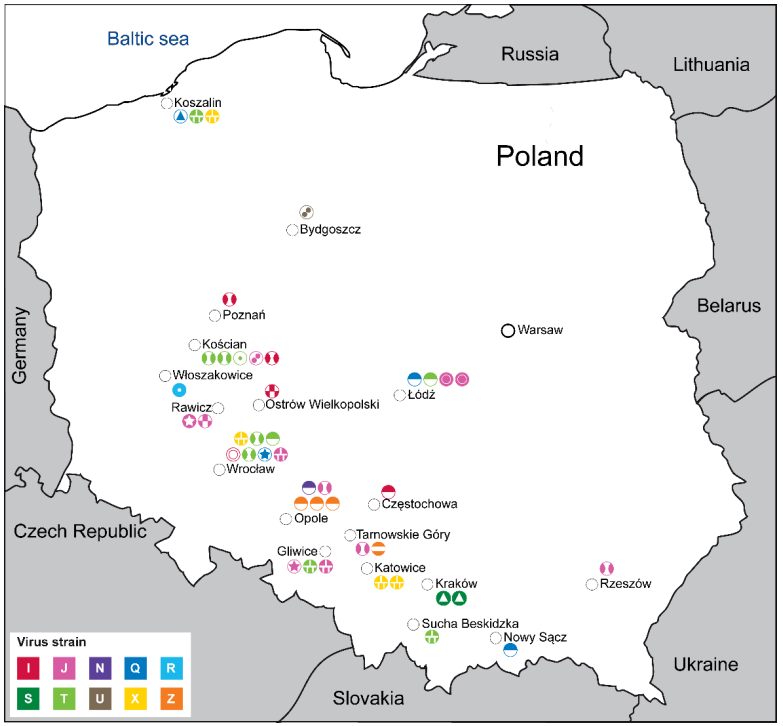
Trafficking and evolution



Beak and feather disease virus

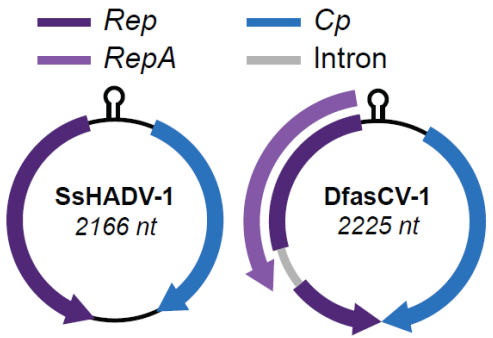


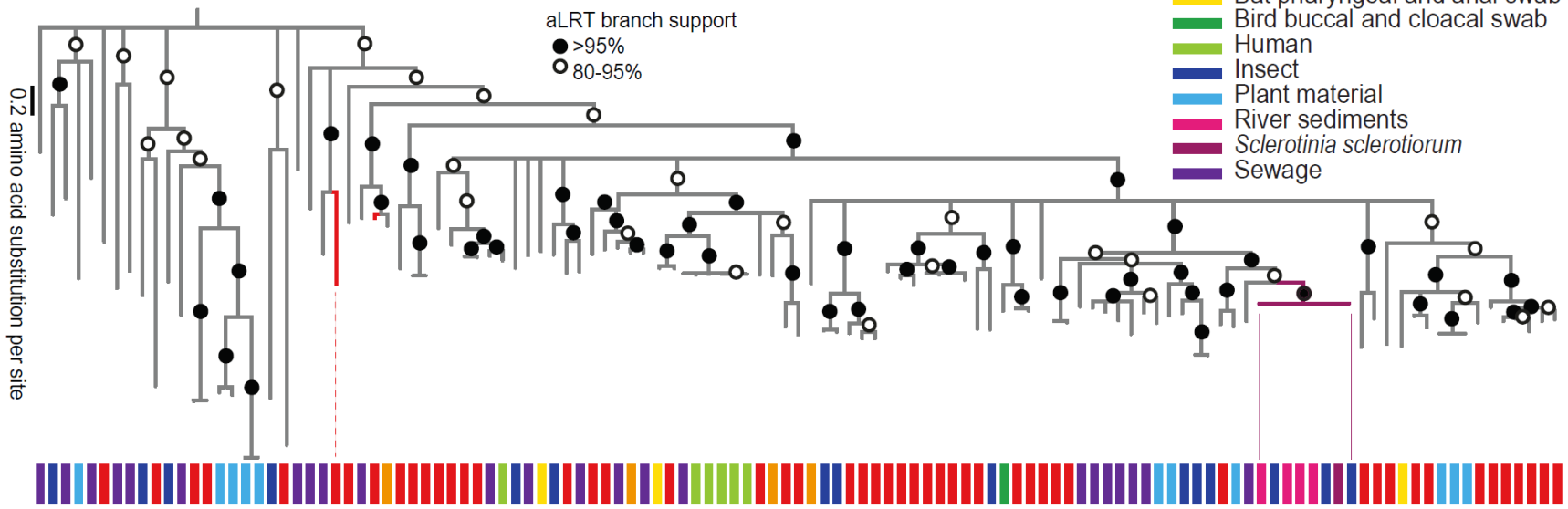
Scientific name	Common name	Number tested	Number positive	Virus strain
Agapornis sp.	Lovebirds	6	0	
Alisterus scapularis	Australian King Parrot	4	2	
Amazona aestiva	Blue-fronted Amazon	5	1	
Amazona amazonica	Orange-winged Amazon	2	1	
Amazona barbadensis	Yellow-shouldered Amazon	3	0	
Amazona ochrocephala	Yellow-fronted Amazon	2	0	
Amazona sp.	Amazon Parrot	2	0	
Aprosmictus erythropterus	Red-winged Parrot	4	2	
Ara ararauna	Blue and Yellow Macaw	17	0	
Ara chloroptera	Red and Green Macaw	8	0	
Ara macao	Scarlet Macaw	3	0	
Aratinga aculicaudata	Blue-crowned Conure	1	0	
Barnardius barnardi	Mallee Ring-necked Parrot	8	0	
Barnardius zonarius	Port Lincoln Parrot	2	0	
Cacatua alba	White Cockatoo	1	1	
Cyanoliseus patagonus	Patagonian Conure	1	0	
Diopsittaca nobilis	Red- shouldered Macaw	2	0	
Eclectus roratus	Eclectus Parrot	1	0	
Elophus roseicapillus	Galah	8	0	
Forpus coelestis	Pacific Parrotlet	1	1	
Melopsittacus undulatus	Budgerigar	13	9	
Pionites melanocephalus	Black-headed Caique	1	0	
Platycercus elegans	Crimson Rosella	4	2	
Platycercus eximius	Eastern Rosella	2	1	
Poicephalus robustus	Cape Parrot	1	1	
Poicephalus senegalus	Senegal Parrot	6	2	
Probosciger aterrimus	Palm Cockatoo	1	0	
Propyrrhura maracana	Blue-winged Macaw	2	0	
Psephotus sp.	Grass Parrots	2	0	
Psittacula alexandri	Red-breasted Parakeet	3	0	
Psittacula cyanocephala	Plum-headed Parakeet	2	0	
Psittacula derbiana	Lord Derby's Parakeet	1	0	
Psittacula eupatria	Alexandrine Parakeet	3	2	
Psittacula krameri	Ring-necked Parakeet	32	9	
Psittacus erithacus	African Grey Parrot	52	9	
Trichoglossus haematodus	Rainbow Lorikeet	3	0	
Total		209	43	



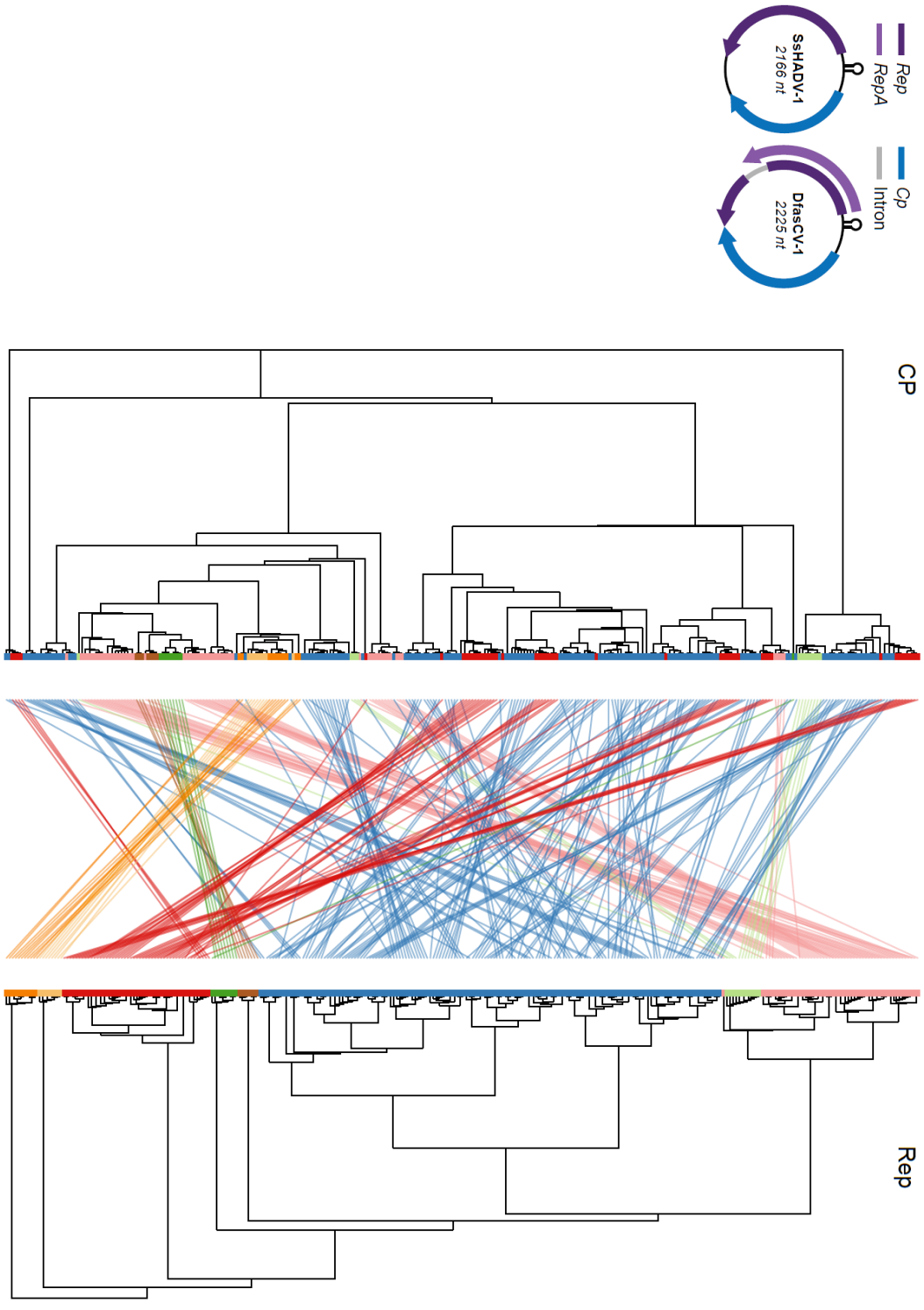
Genomoviruses

Animal faeces
Blood
Buccal and cloacal swab
Cerebrospinal fluid
Cervical sample
Insect abdomen
Leaf material
Mosquito samples
Mycelial samples
Pharyngeal & rectal swabs
Plasma
Rectal swab
River sediments
Serum
Sewage

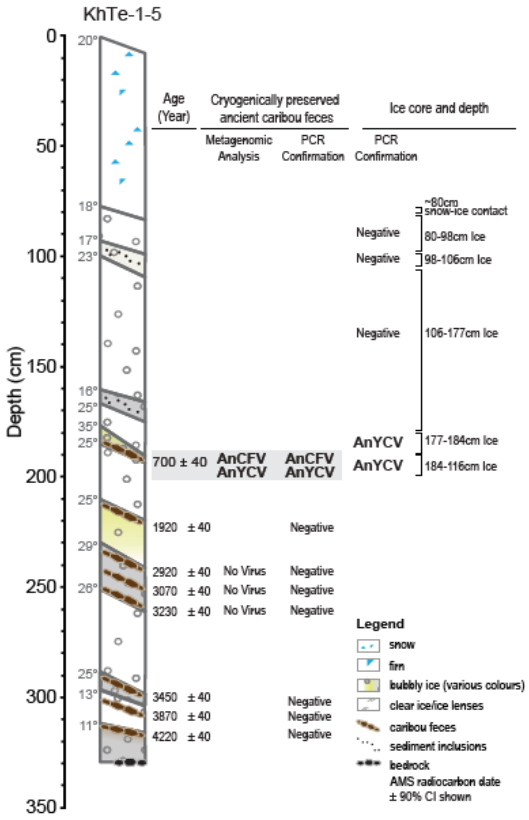




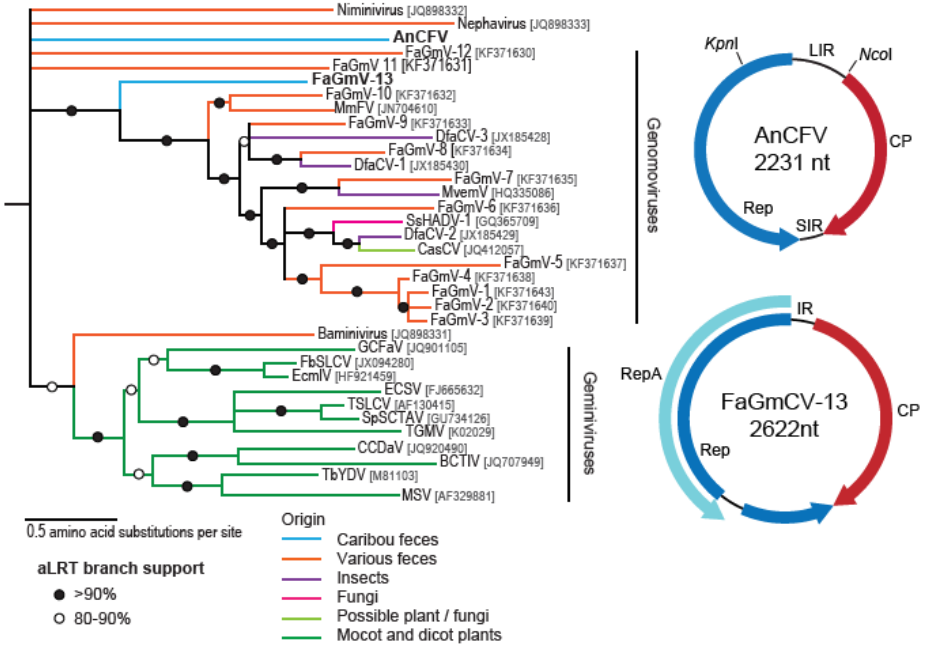
Genomoviruses

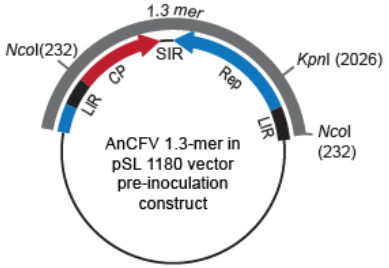


"Archived" viruses

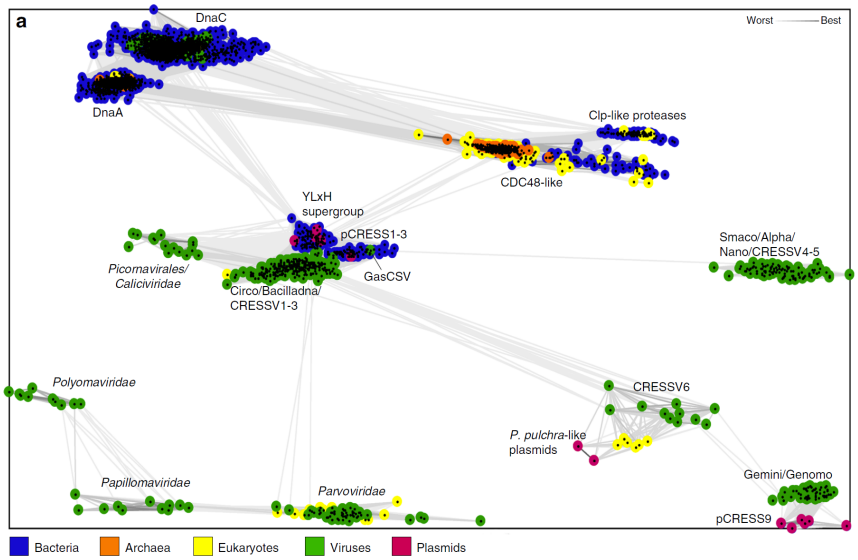


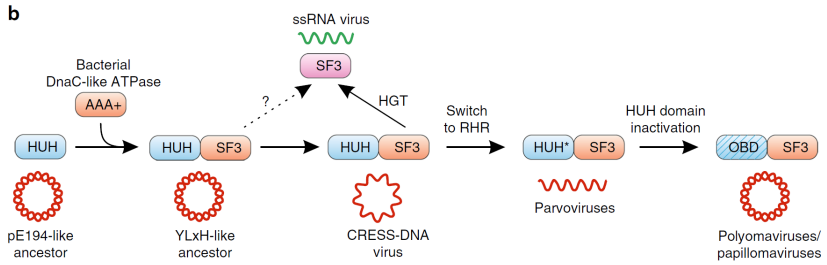
Virome	Virus detected	Expected host	Virus type
Frozen feces - 700 yr BP *R. tarandus*	Geminivirus/Gemycircularvirus -like - AnCFV	Plant/Fungi?	DNA non-enveloped
	Cripavirus - AnYCV	Insect	RNA non-enveloped
Present-day feces - 2012 *R. tarandus*	Tombusvirus	Plant	RNA non-enveloped
	Sobemovirus	Plant	RNA non-enveloped
	Gemycircularvirus - GmV-13	Plant/Fungi?	DNA non-enveloped



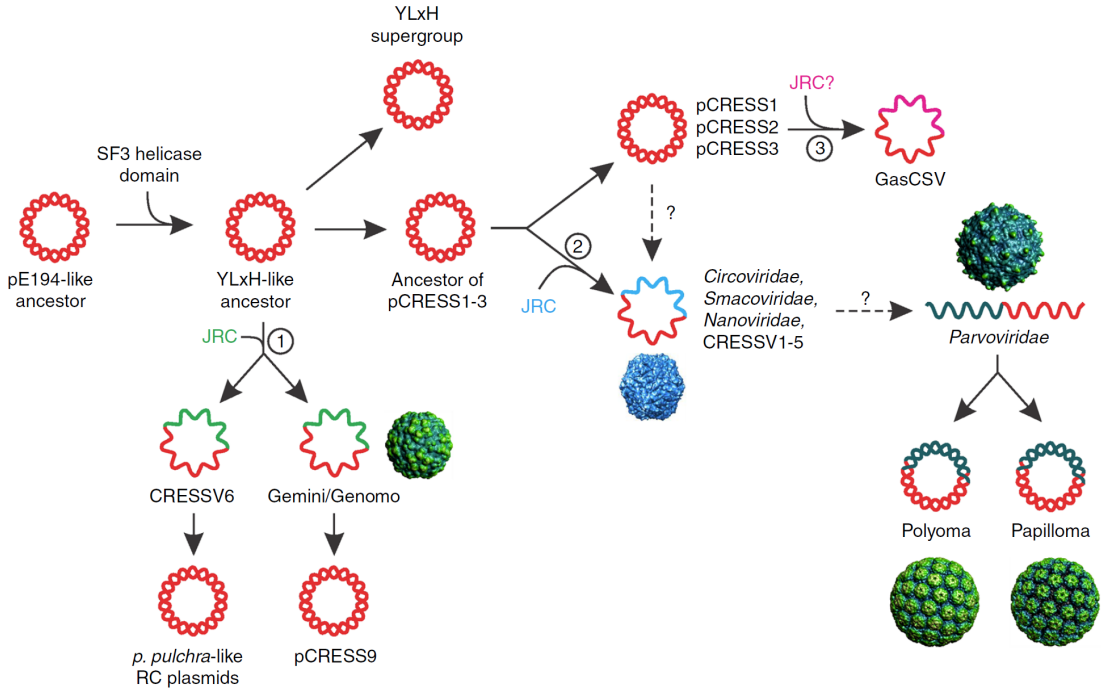


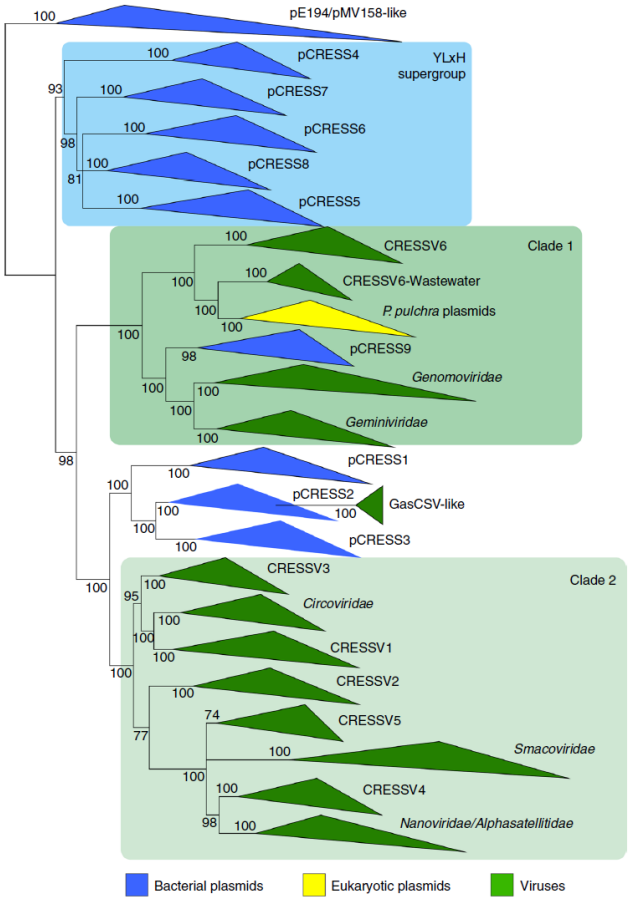
Reps of ssDNA viruses





Origin of ssDNA viruses





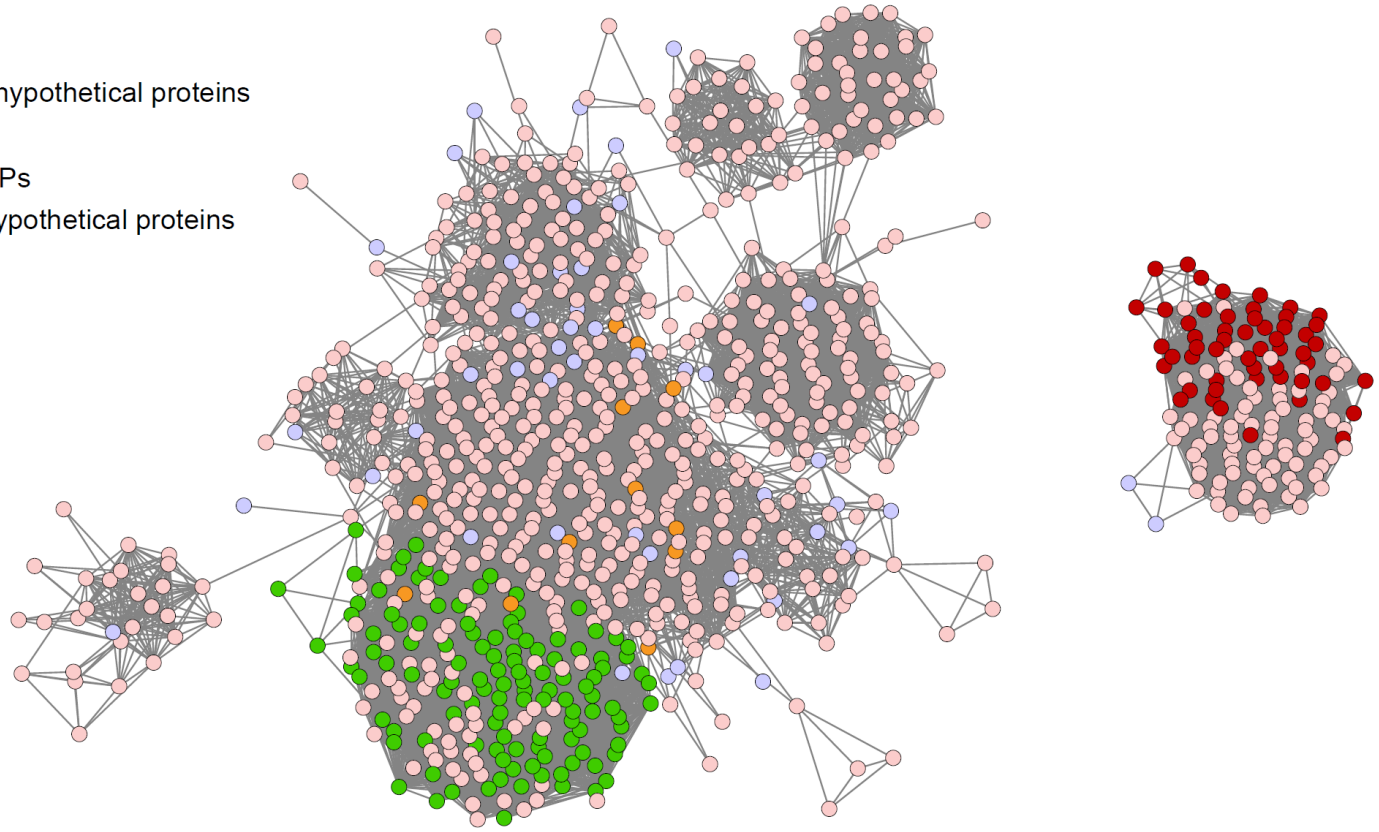
CRESS DNA virus CPs

CRESS DNA virus CPs / hypothetical proteins

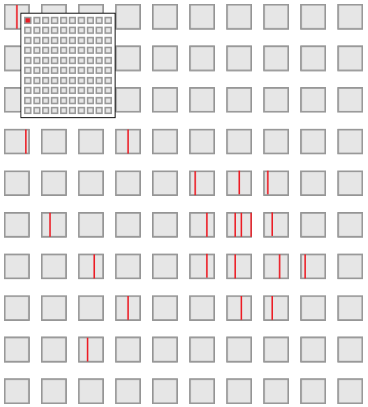
- Geminiviruses
- Unclassified CRESS CPs
- Unclassified CRESS hypothetical proteins

RNA virus CPs

- Tomusviruses
- Virtoviruses (STNV)



Sampling sequence space



LETTER

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Ecogenomics and potential biogeochemical impacts of globally abundant ocean viruses

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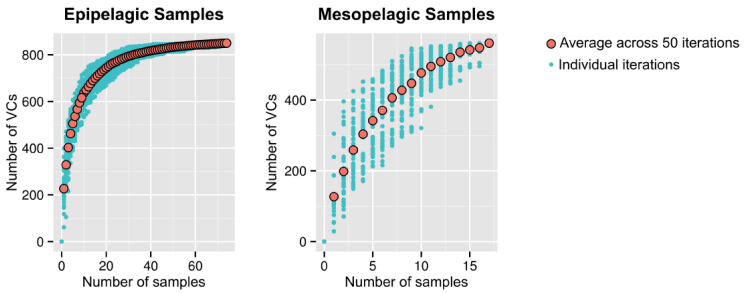
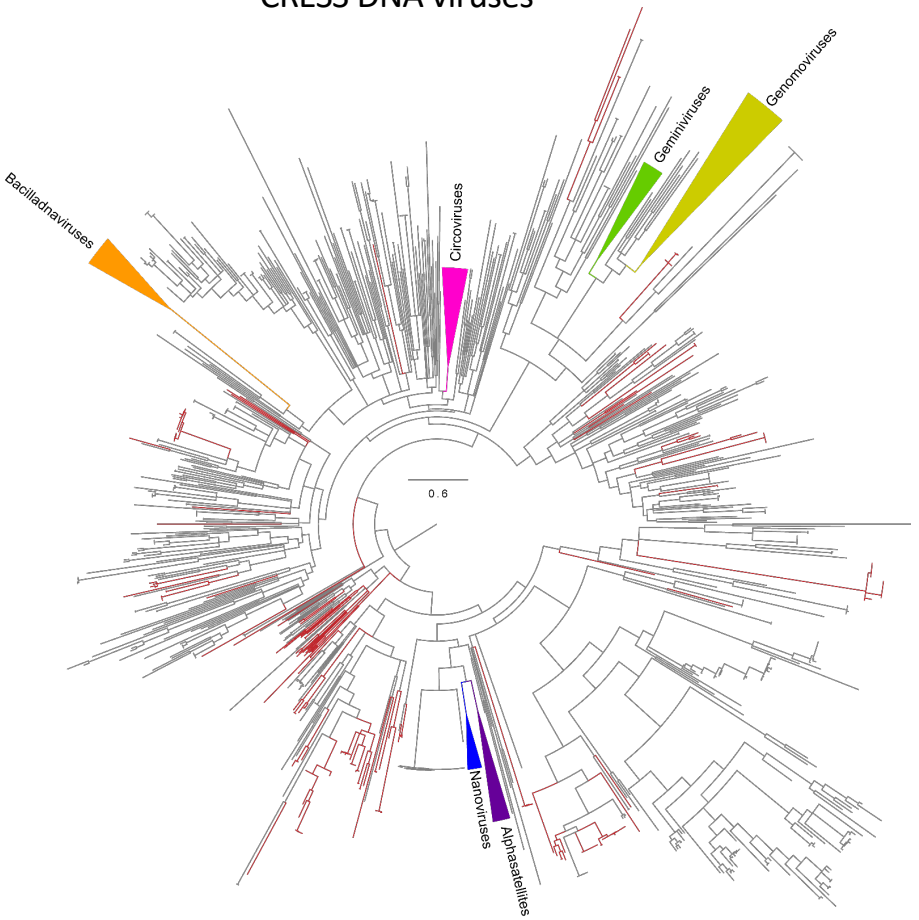


CRESS DNA viruses



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