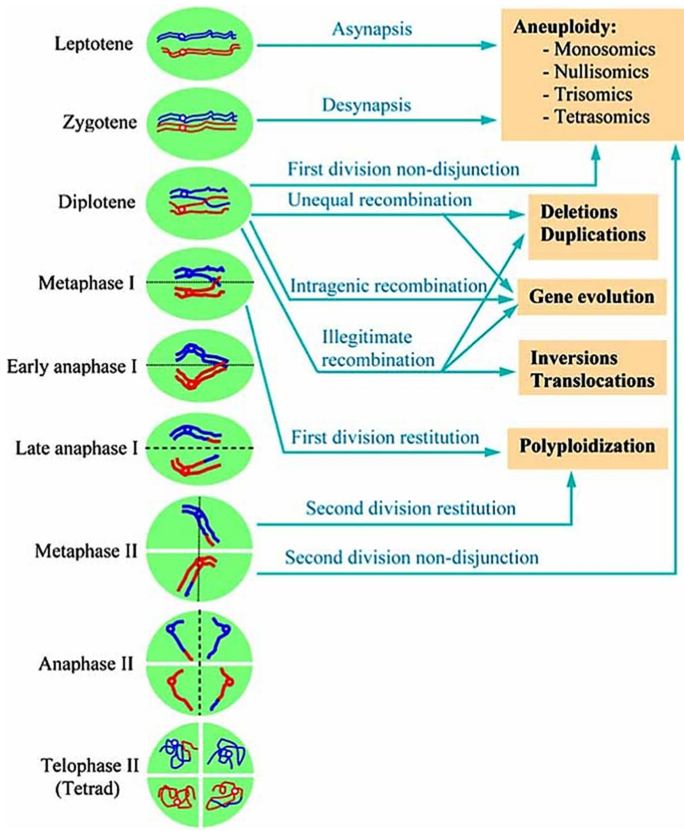
Meiotic alterations drive karyotype evolution

Cai & Xu, 2007
Review by **Heslop-Harrison and Schwarzacher, 2011**

"The genome is a metastable system, indeed an organelle, and not merely strings of DNA segments."

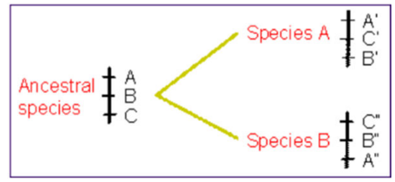
- von Sternberg, 1996 [Acta Biotheoretica 44:95-118]



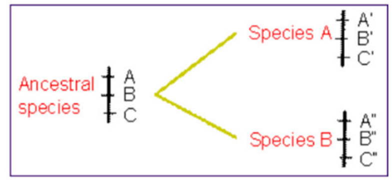
Synteny • Collinearity • Comparative mapping

Synteny

Tang et al, 2008 (Paterson lab)



Collinearity

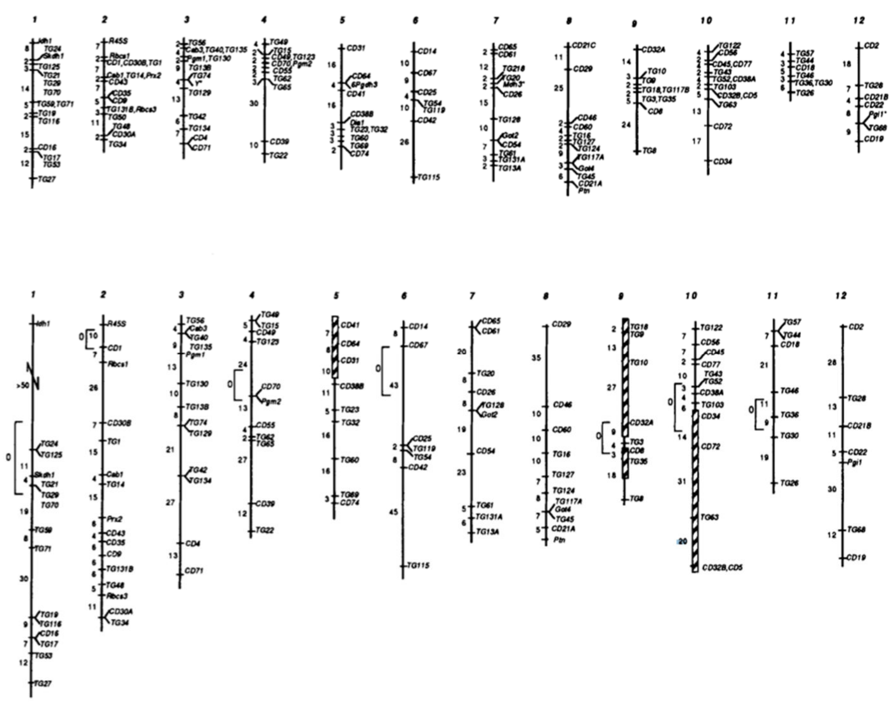


https://www.integratedbreeding.net/courses/genomics-and-comparative-genomics/www.generationcp.org/genomics/index42b0.html?page=1146

Macrosynteny

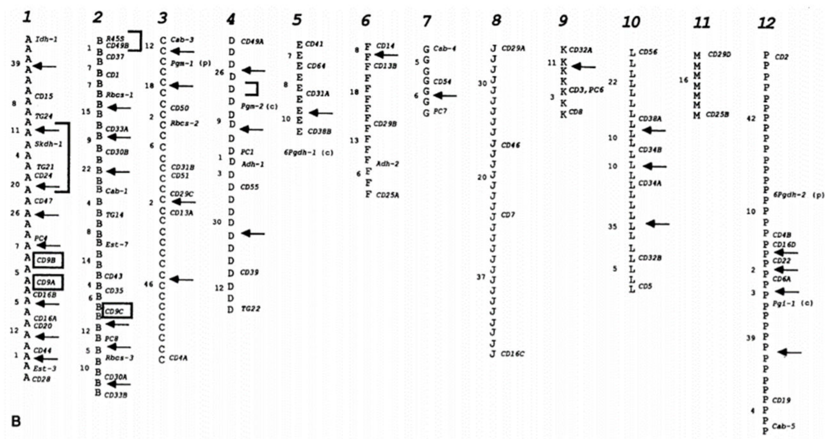
Bonierbale et al, 1988 (Tanksley lab)

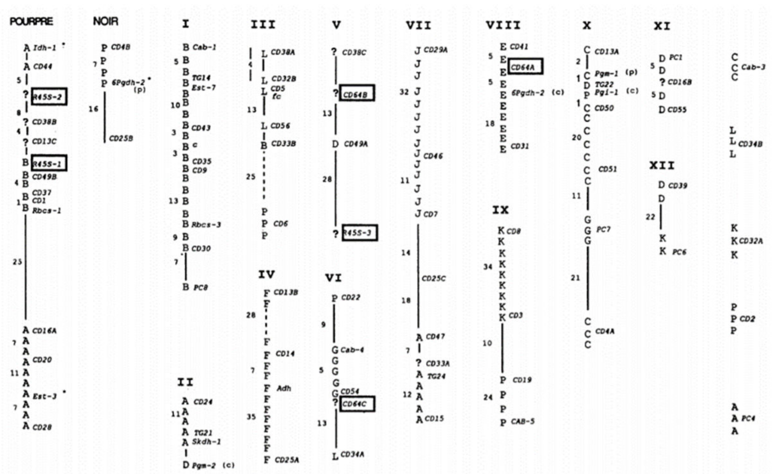
Chromosomes of potato (top) and tomato (bottom)



Tanksley et al, 1988

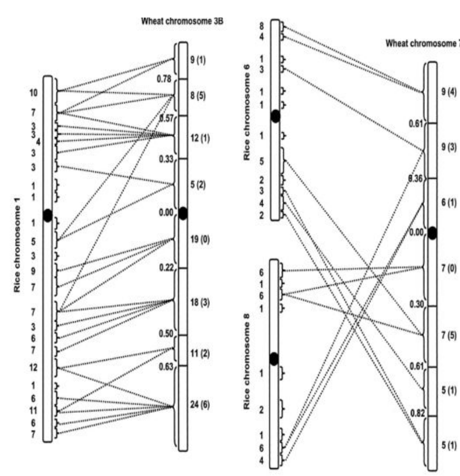
Tomato and bell pepper: A case of speciation with major chromosomal changes





Background on grasses

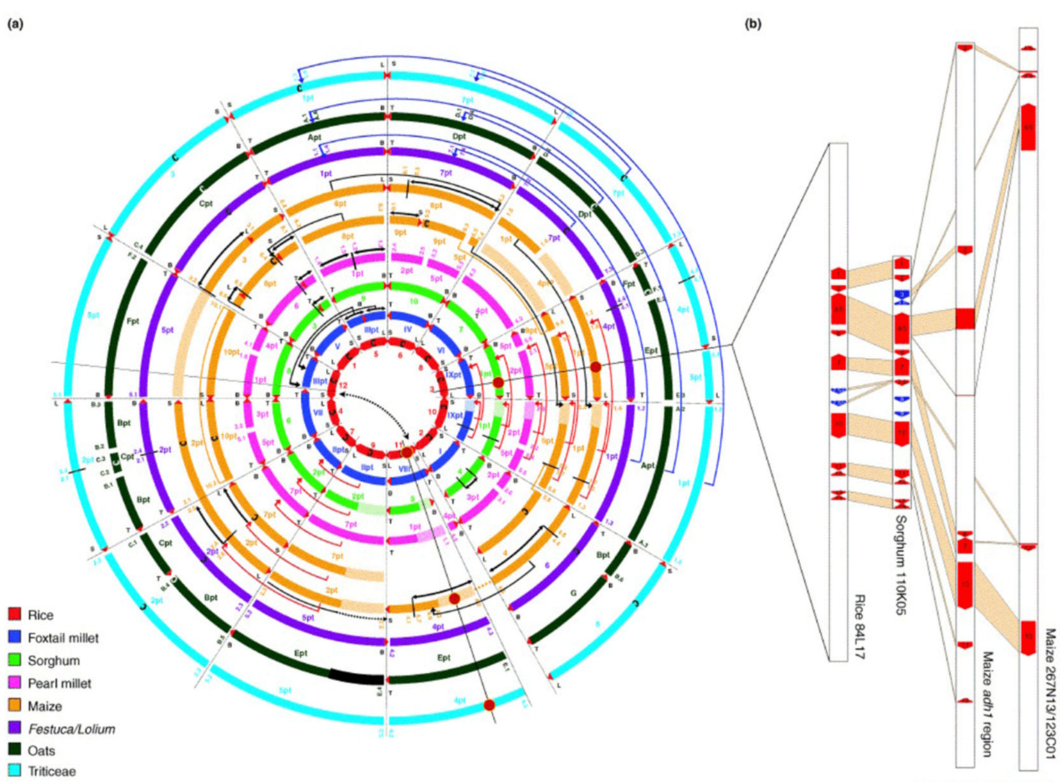
Wheat & rice synteny. Akhunov et al., 2003



Rice	430 million base pairs (Mbp)
Sorghum	760 Mbp
Maize	2,500 Mbp
Sugarcane	4,000 Mbp
Wheat	15,966 Mbp

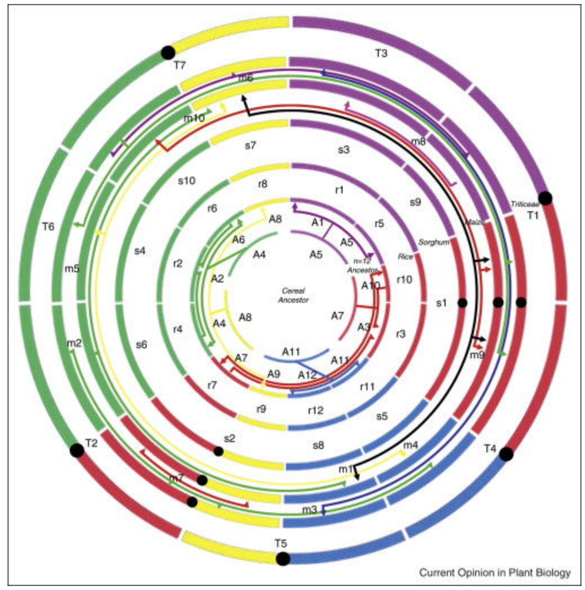
Crop circles

Devos, 2005

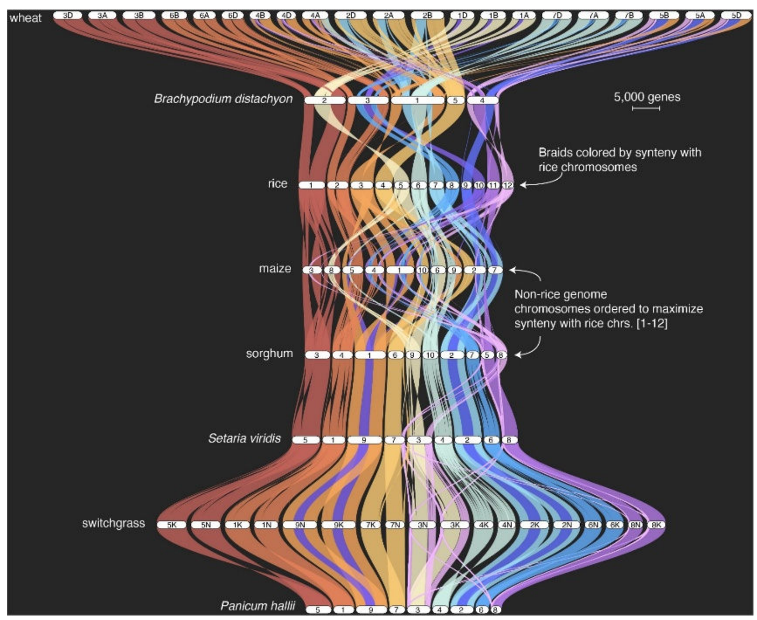


Cereal circle based on ancestral monocot chromosomes

Bolot et al., 2009



Lovell et al, 2022

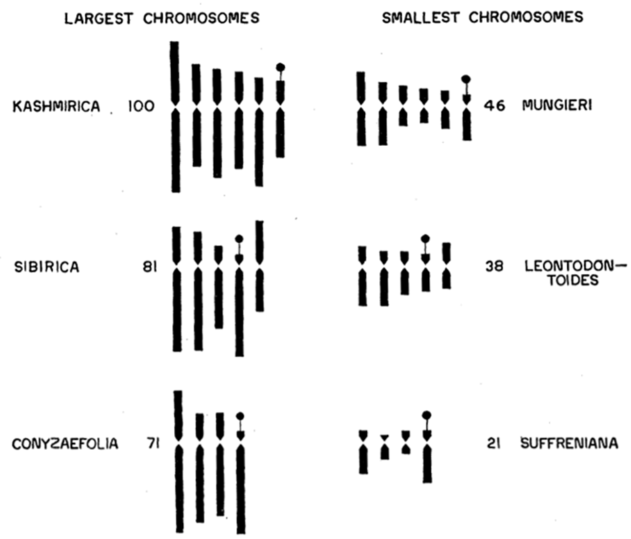


Evolution of chromosome number

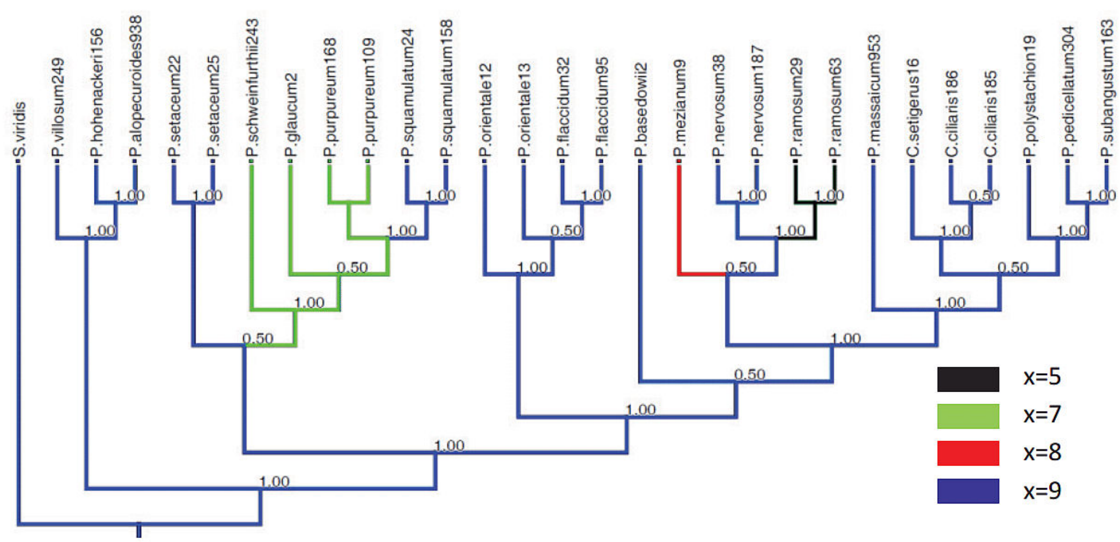
Review by Mandáková & Lysak, 2018; Mayrose & Lyasak, 2021

Dysploidy

Babcock, Stebbins, & Jenkins, 1942



. Dysploid series in Crepis; base × = 6. Babcock, Stebbins, & Jenkins, 1942



Dysploidy in the genus Pennisetum. Akiyama et al., 2011

Trends (and only trends within a genus)

Stebbins

Chromosome number vs linkage

Stucky & Jackson, 1975

n	gamete number
4	256
5	1024
6	4096
7	16,384
8	65,536
9	262,144
10	1,048,576

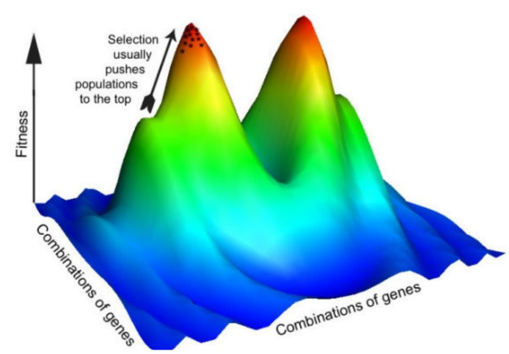


Figure 1. https://www.discovermagazine.com/health/a-thousand-little-adaptive-platoons *after Sewall Wright*

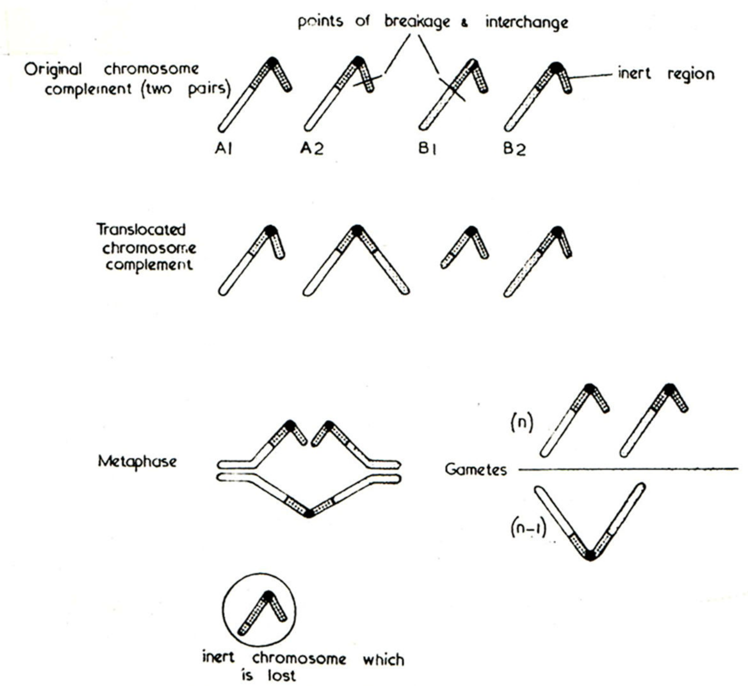
- If each II is heterozygous for 1 locus, then the number of gametes possible is 2^n
- If ∃ 1CO/II, then gametic number = 4^n (shown in table above)

Mechanisms of dysploidy

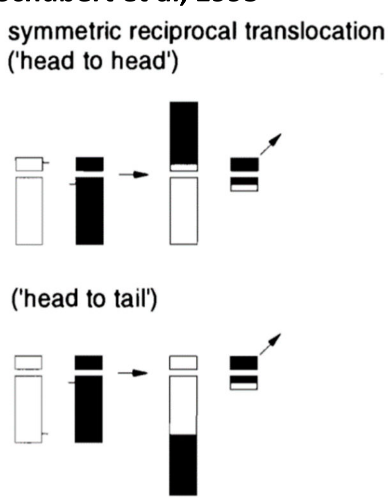
Darlington, 1937

1) Progressive reduction or descending basic aneuploidy

Darlington, 1937

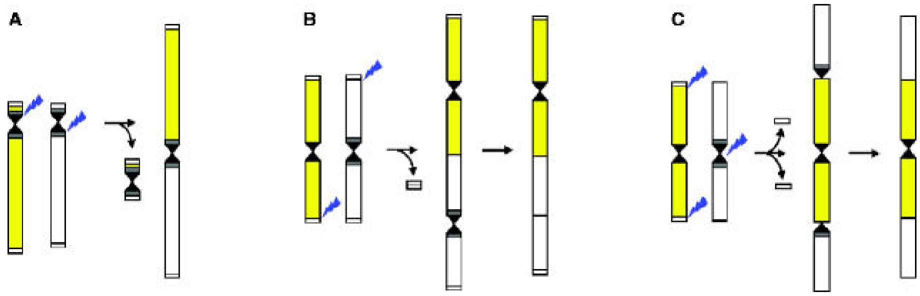


Schubert et al, 1995



End to end fusions

Mayrose & Lysak, 2021; Lysak, 2022



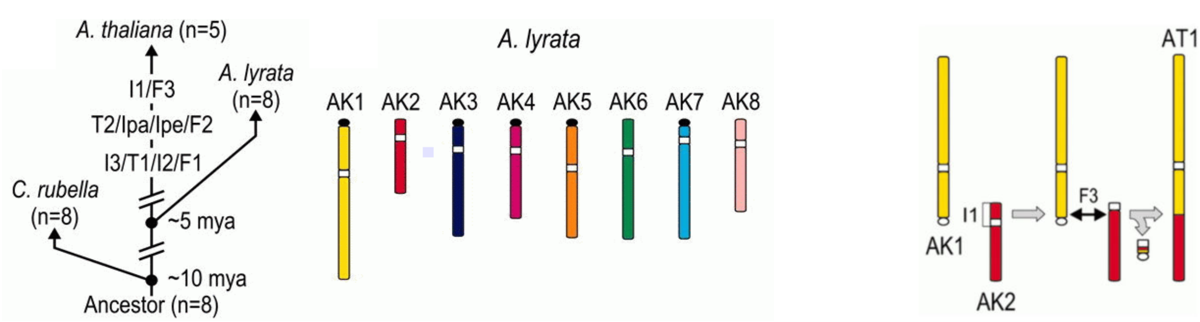
Schubert & Oud, 1997

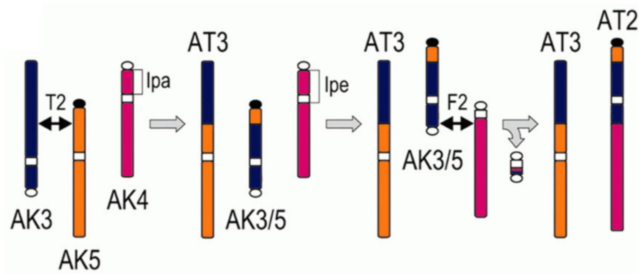
Example

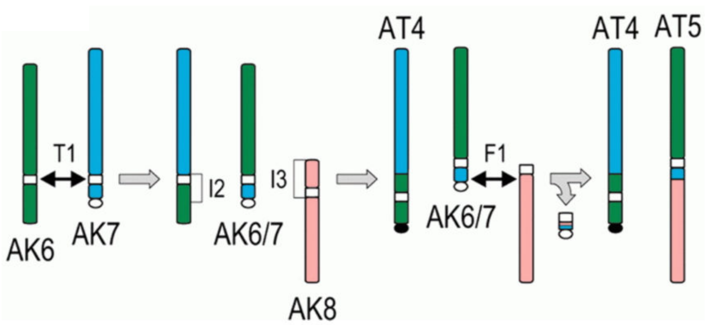
Lysak et al, 2006 (Shubert Lab)

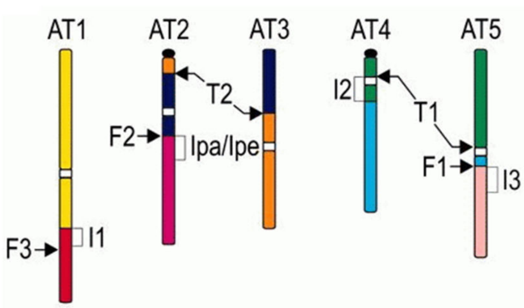
Arabidopsis ancestor had 2n = 8. *Arabidopsis is* 2n =5:

I = inversion; Ipa = paracentric inversion; Ipe = pericentric inversion; T = translocation; F = fusion





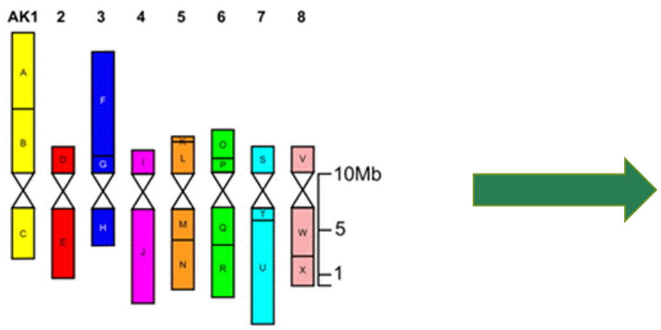


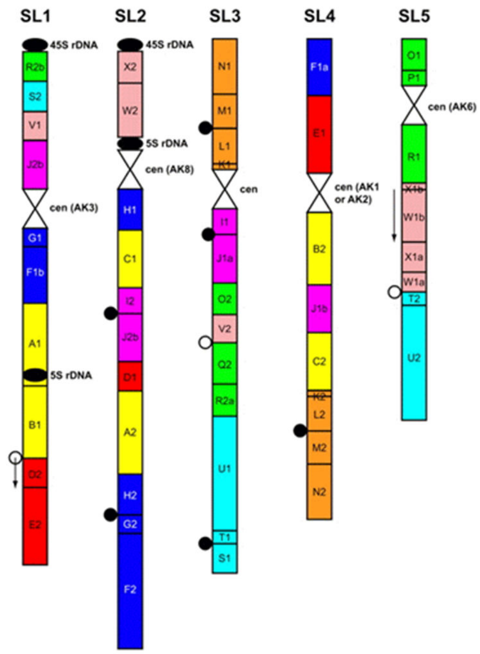


Centromere fate

Han et al, 2006;

Mandáková et al, 2010

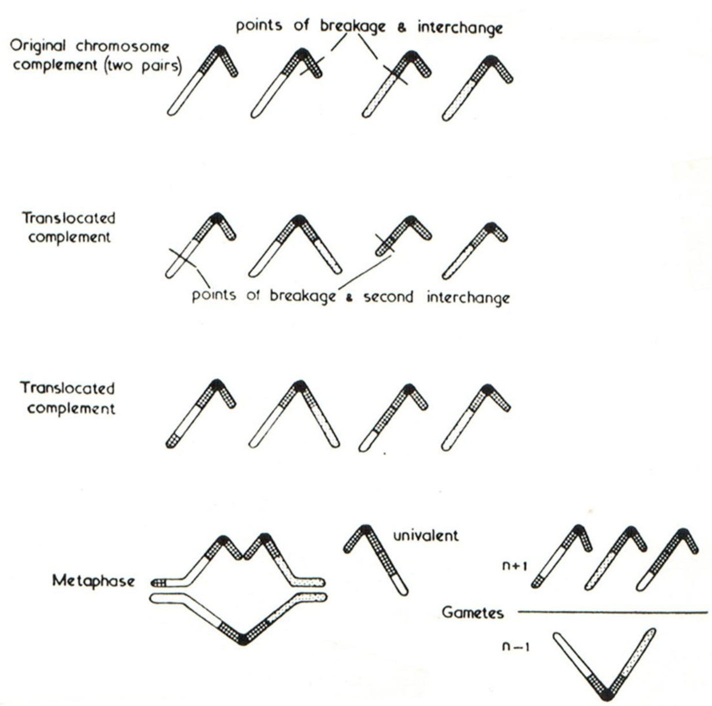




Stenopetalum lineare missing (empty circles) and silenced (filled circles) centromeres

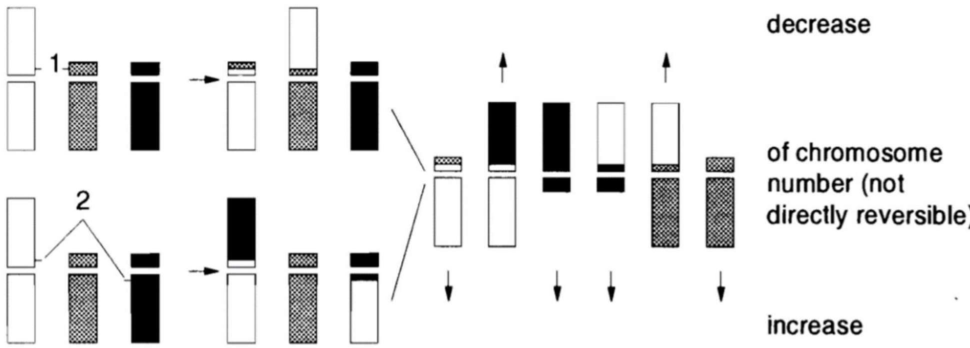
2) Progressive increase

Darlington, 1937



Multiple translocations

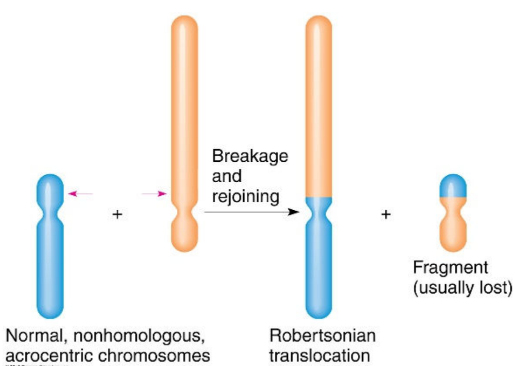
Schubert et al, 1995



3) Progressive reduction + polyploidy

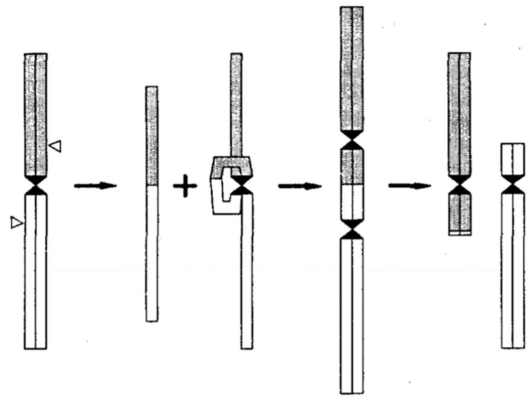
4) Polyploidy → progressive reduction

5) Robertsonian fusion/fission



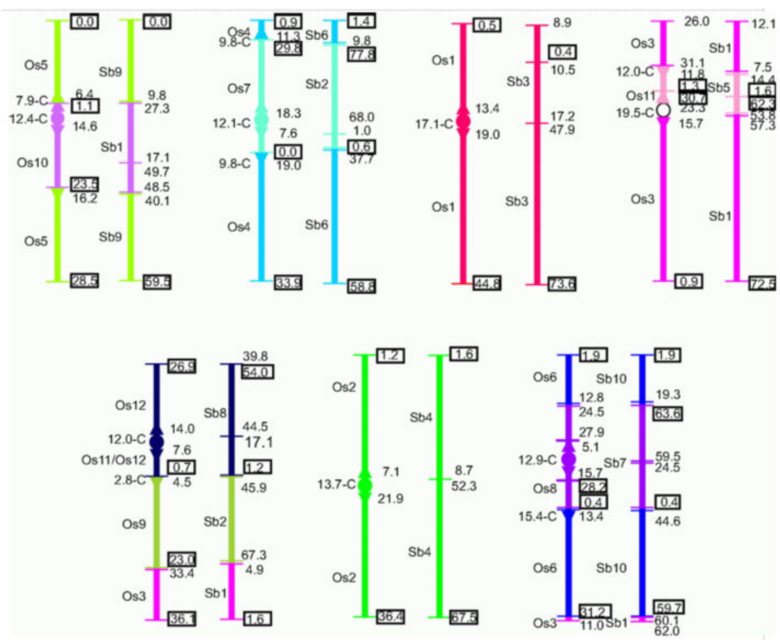
6) Number increase via a Breakage-Fusion-Bridge Cycle

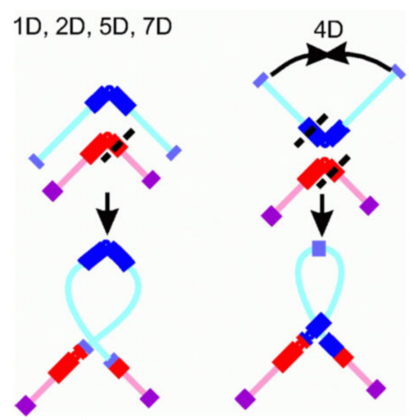
Fuchs et al, 1995



7) Chromosomal insertion into centromeres

Luo et al., 2009





Diploidization

Dysploidy + Fractionation → diploidization

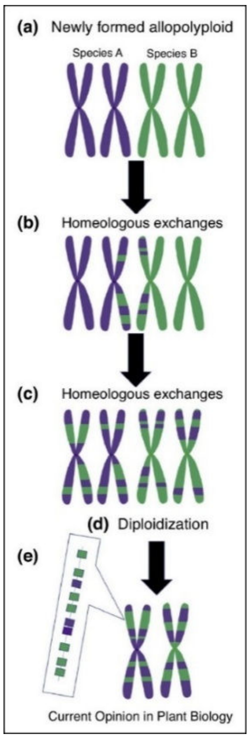


Figure 3. From Edger et al, 2018

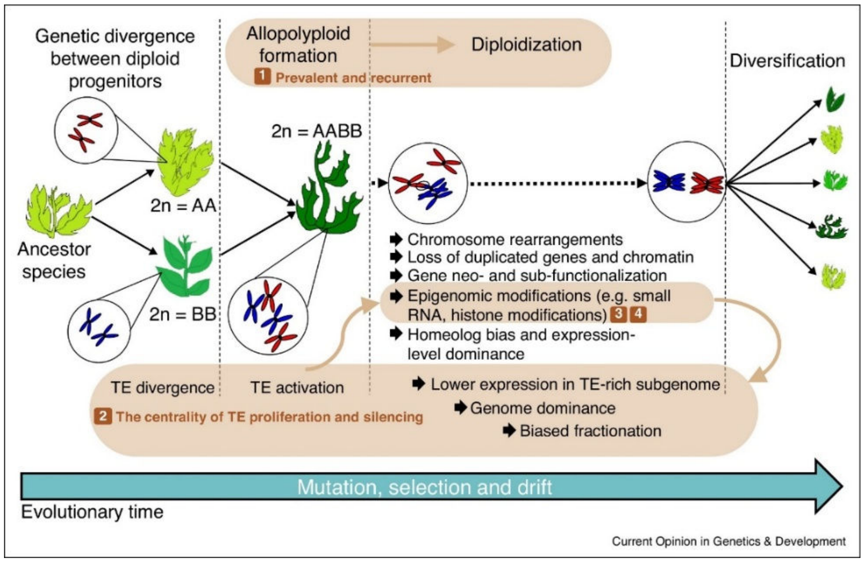
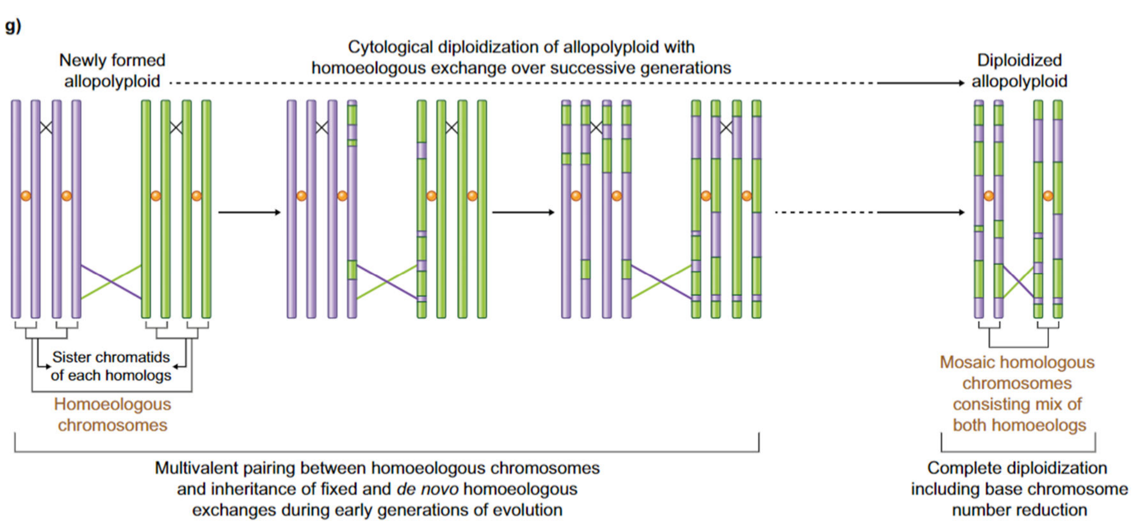


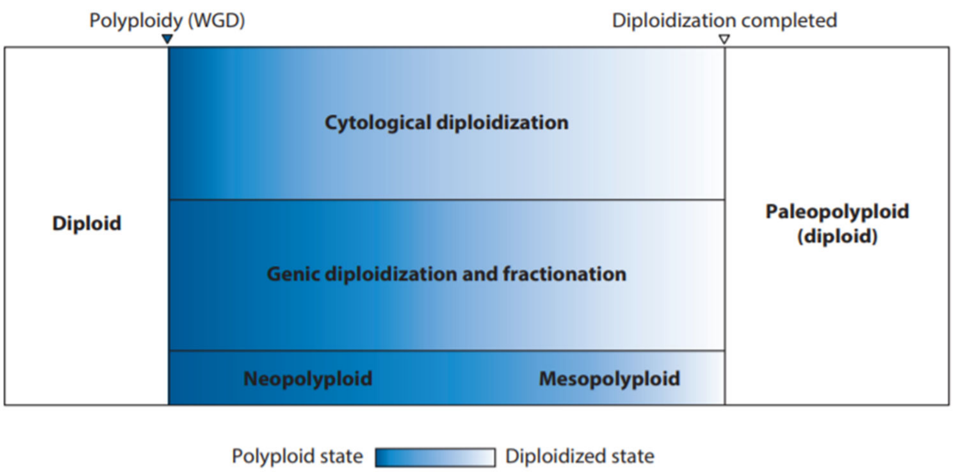
Figure 2. From Wendel et al, 2018

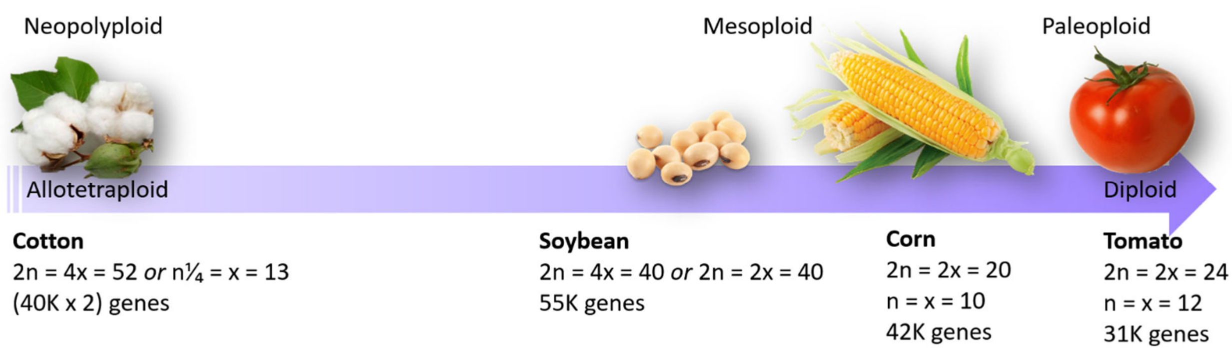
Deb et al, 2023



Diploidization is a gradual process

Li et al, 2021 (Barker lab)



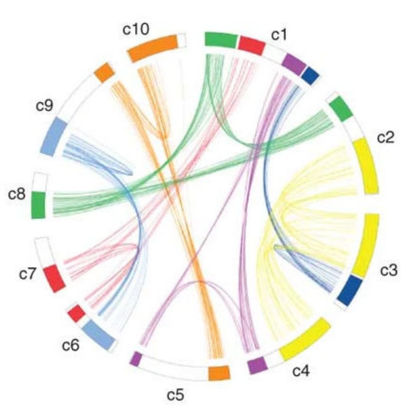


Evidence of polyploid ancestry in modern diploids

A diploidized polyploid

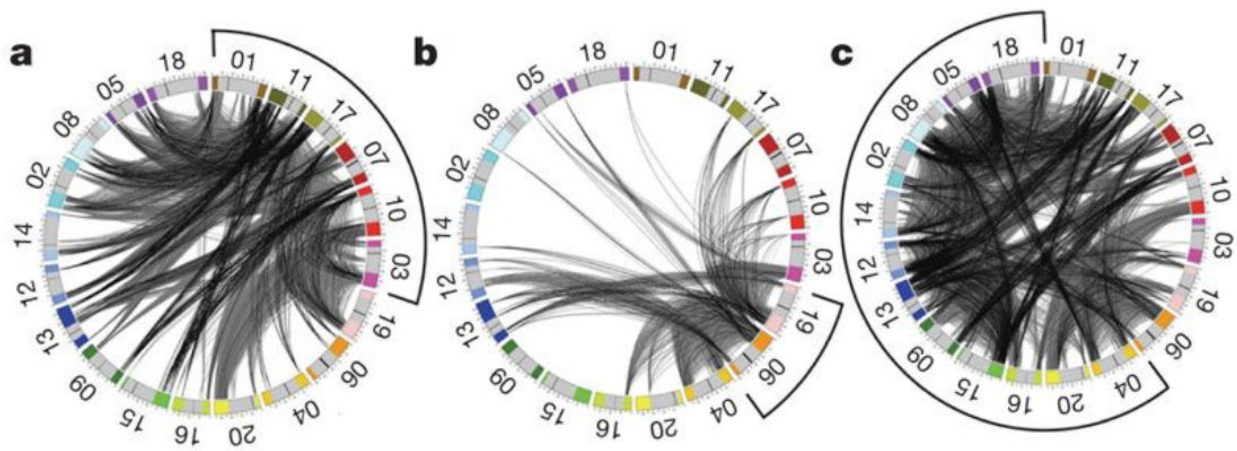
Cacao, 2n = 2x = 20

Argout et al, 2011



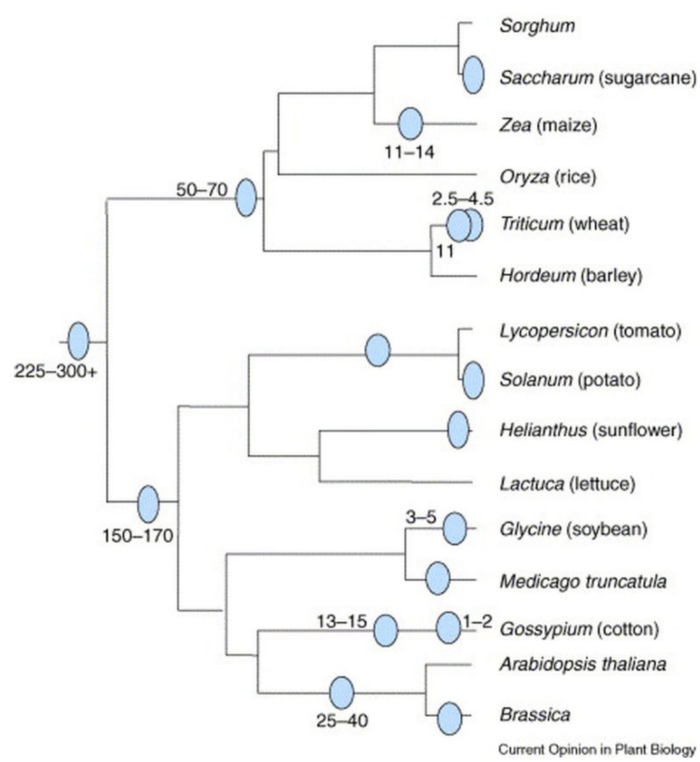
A mesopolyploid (in the process of becoming a diploid)

Soybean 2n = 2x/4x = 40
Schmutz et al, 2010



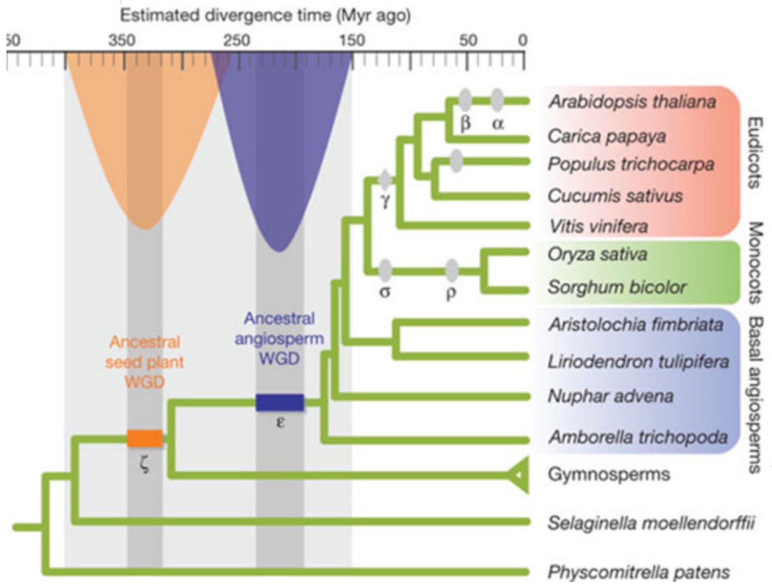
Cycles of whole genome doubling

Adams & Wendel, 2005

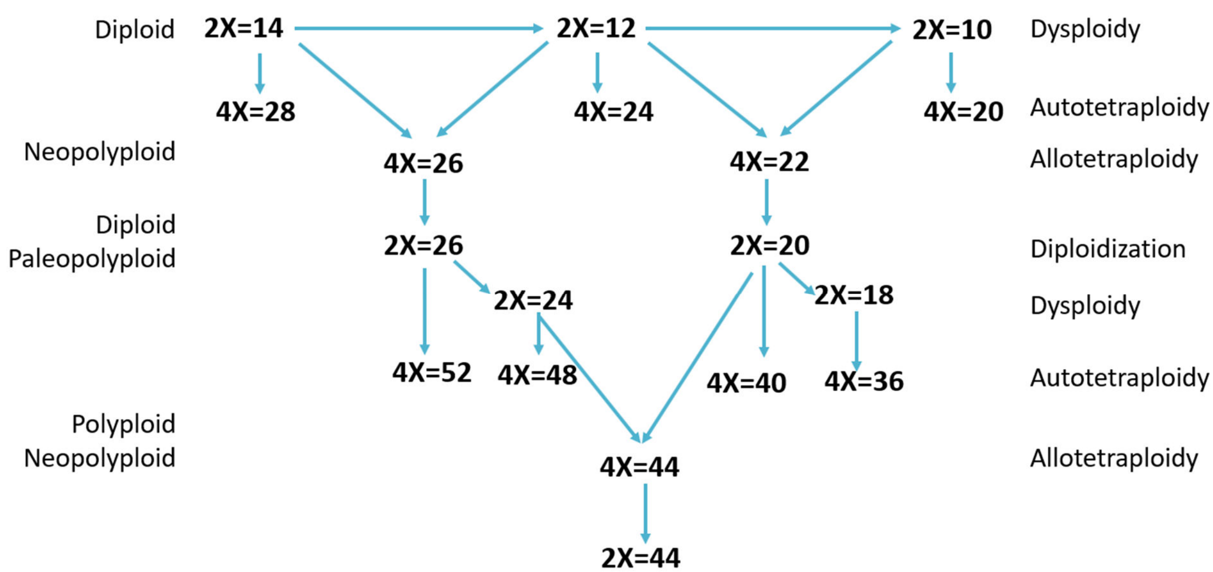


These WGDs have been given names

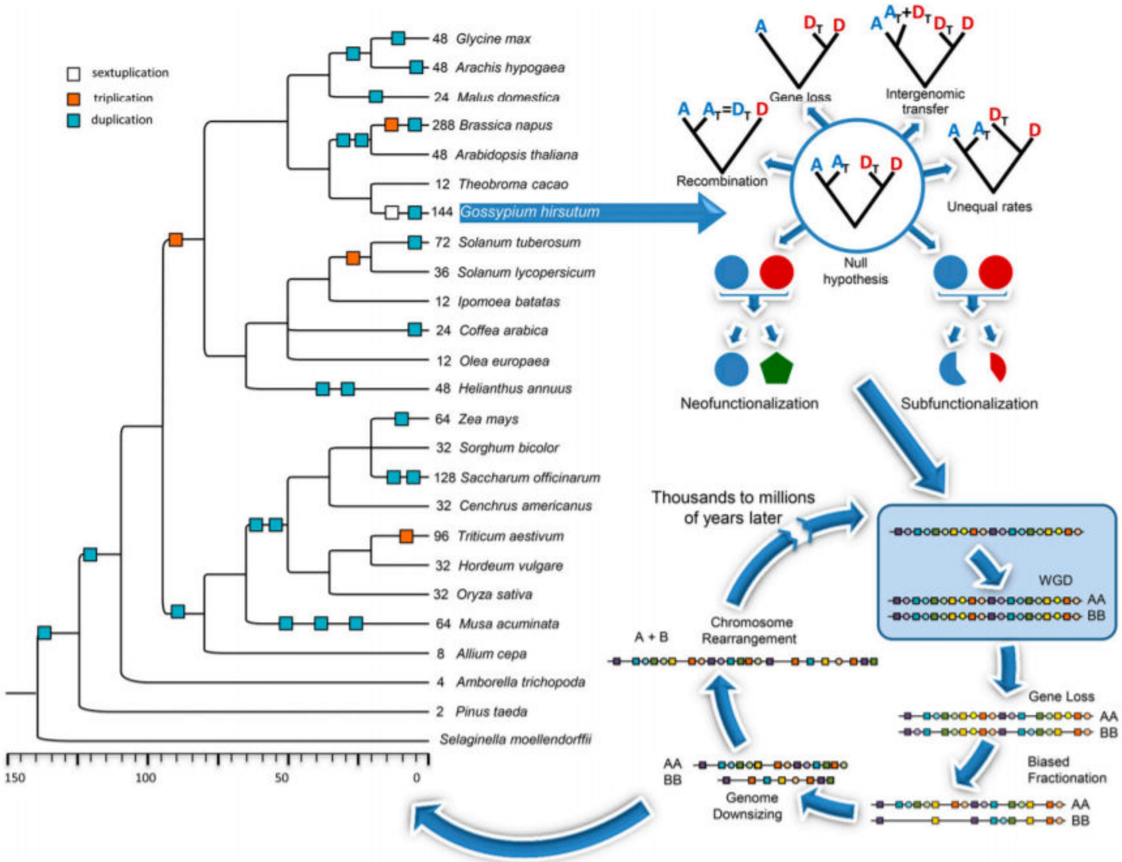
Jiao et al, 2011



Putting all the mechanisms into action

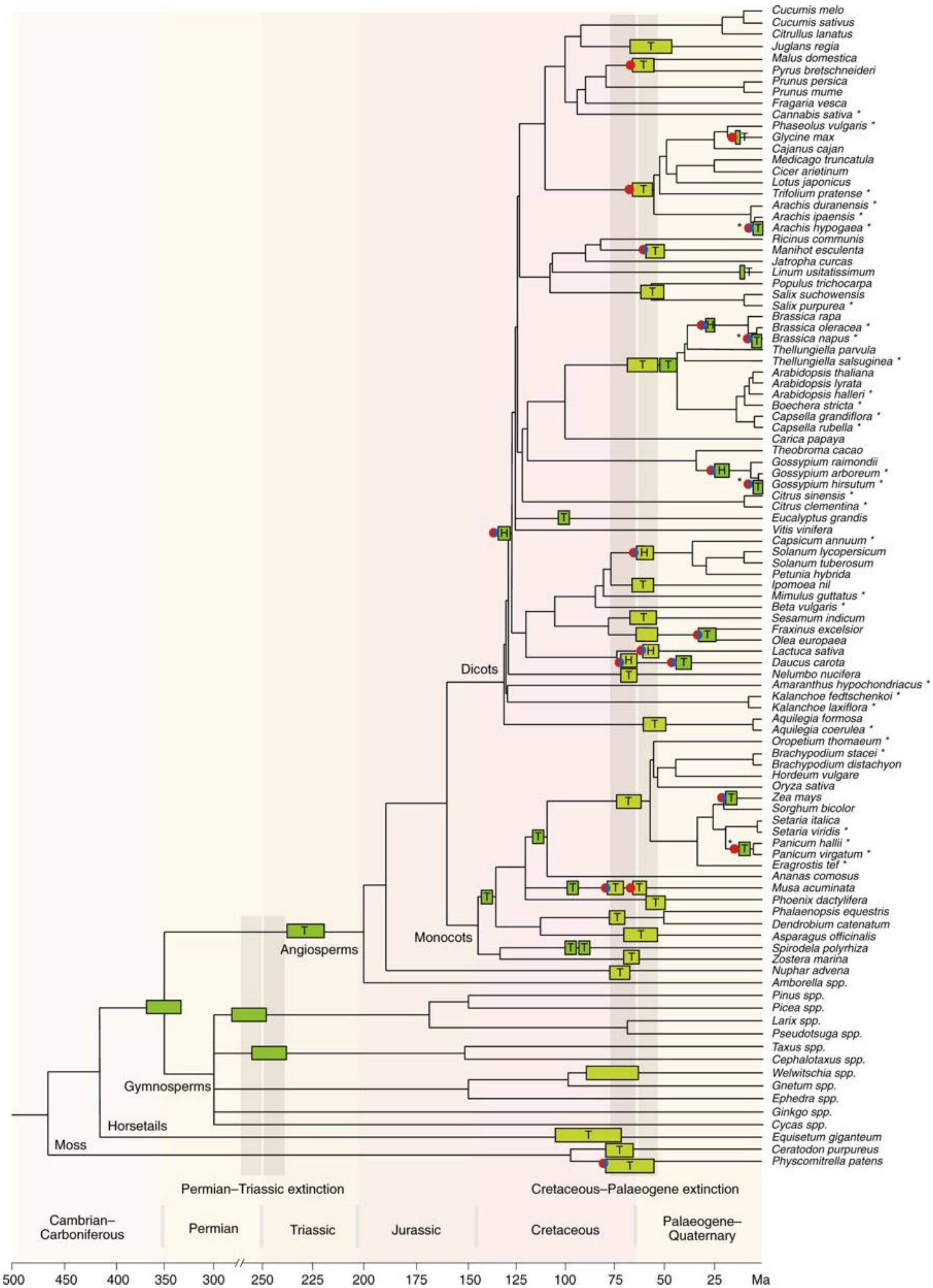


Wendel, 2015

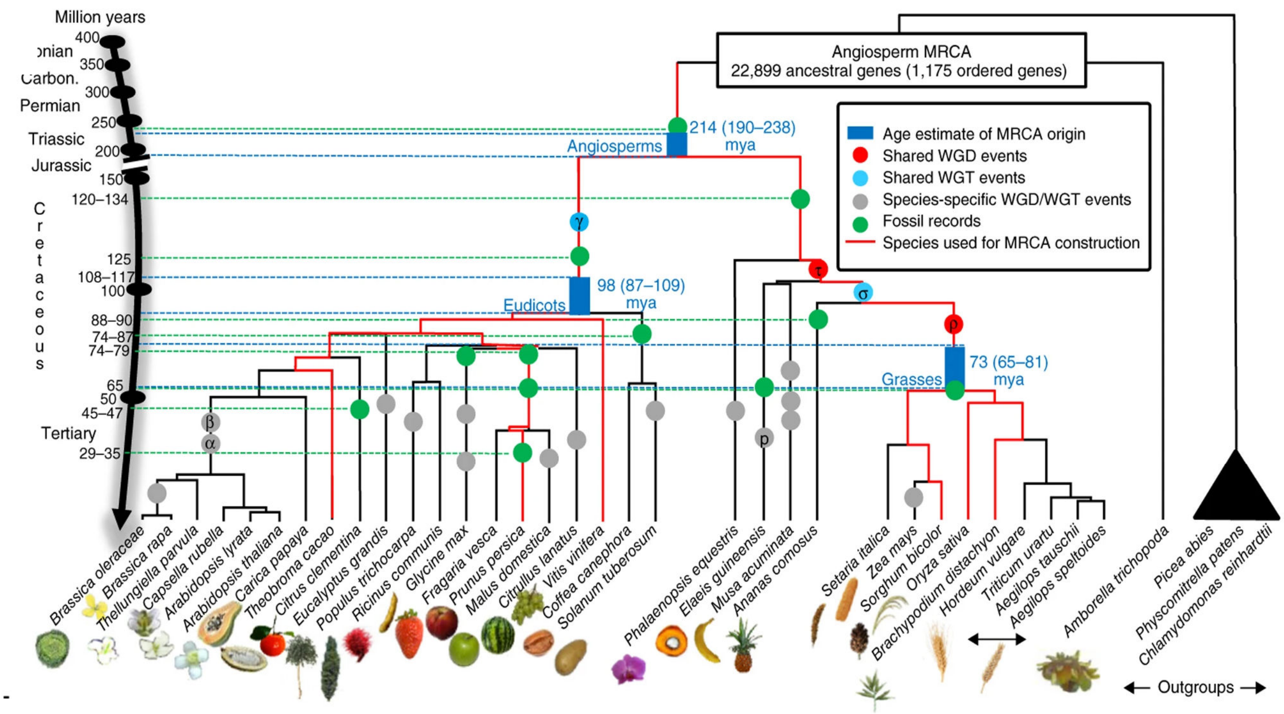

sextuplication
triplication
duplication
48 Glycine max
48 Arachis hypogaea
24 Malus domestica
288 Brassica napus
48 Arabidopsis thaliana
12 Theobroma cacao
144 Gossypium hirsutum
72 Solanum tuberosum
36 Solanum lycopersicum
12 Ipomoea batatas
24 Coffea arabica
12 Olea europaea
48 Helianthus annuus
64 Zea mays
32 Sorghum bicolor
128 Saccharum officinarum
32 Cenchrus americanus
96 Triticum aestivum
32 Hordeum vulgare
32 Oryza sativa
64 Musa acuminata
8 Allium cepa
4 Amborella trichopoda
2 Pinus taeda
Selaginella moellendorffii
150
100
50
0
Gene loss
Intergenomic transfer
Recombination
Unequal rates
Null hypothesis
Neofunctionalization
Subfunctionalization
Thousands to millions of years later
WGD
AA
BB
Gene Loss
Biased Fractionation
Genome Downsizing
Chromosome Rearrangement
A + B

Polyploidy in plant lineages

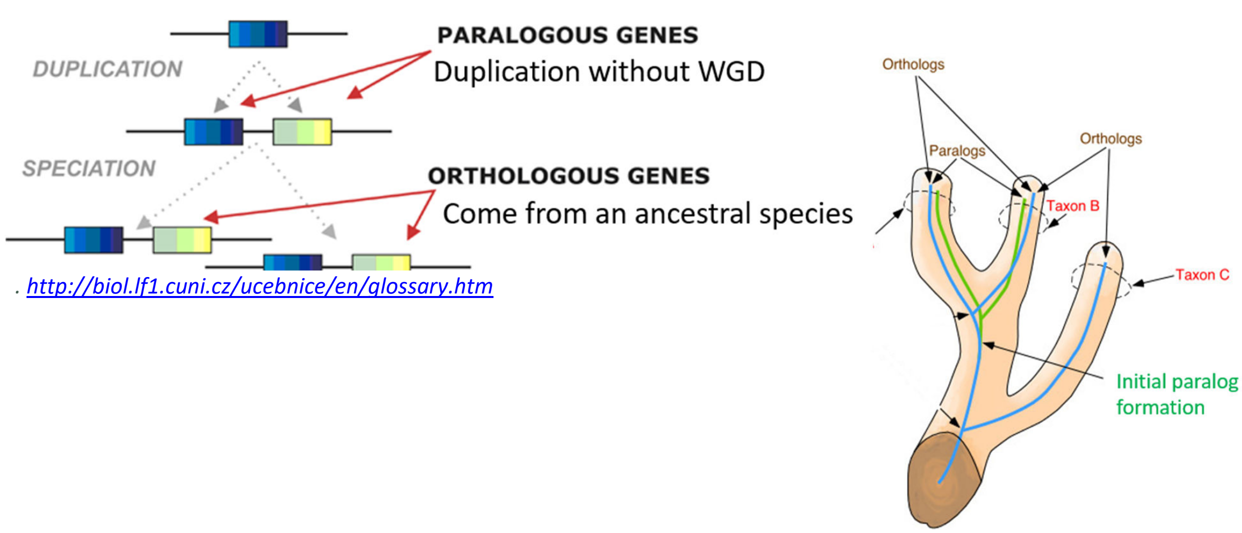
Cheng et al, 2018



Murat et al., 2017



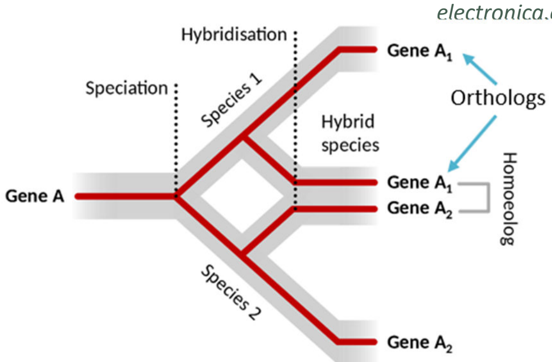
Terminology



. http://biol.lf1.cuni.cz/ucebnice/en/glossary.htm

Genes that started out as paralogs in an ancestral species remain paralogs.

electronica.org/2000_1/retinal/fig17.htm

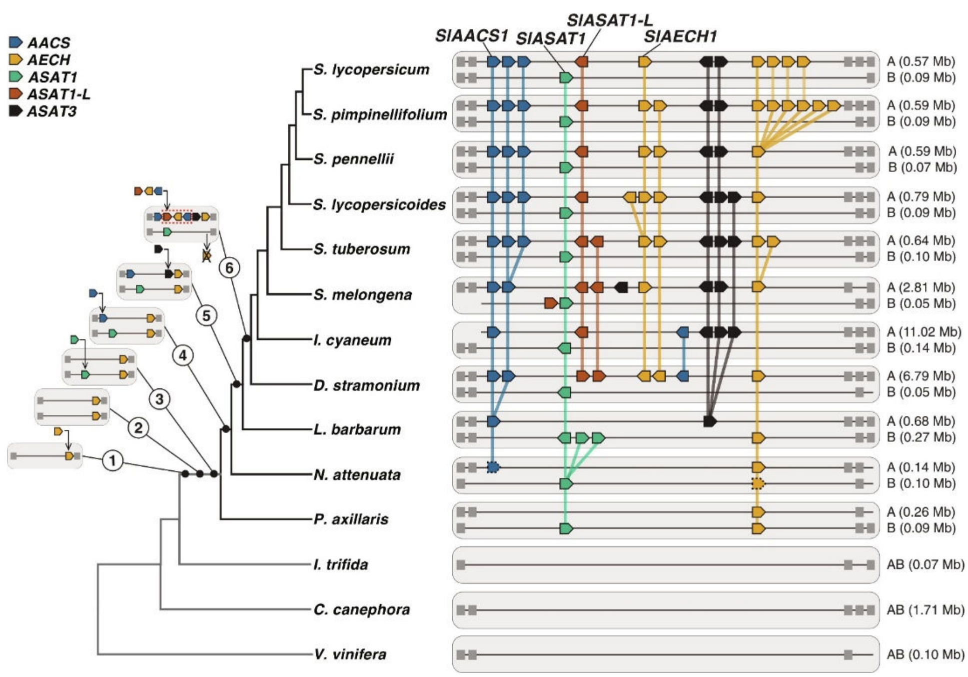


Orthologs become homoeologs upon allopolyploidization

https://en.wikipedia.org/wiki/Sequence_homology#/media/File:Homoeology.svg

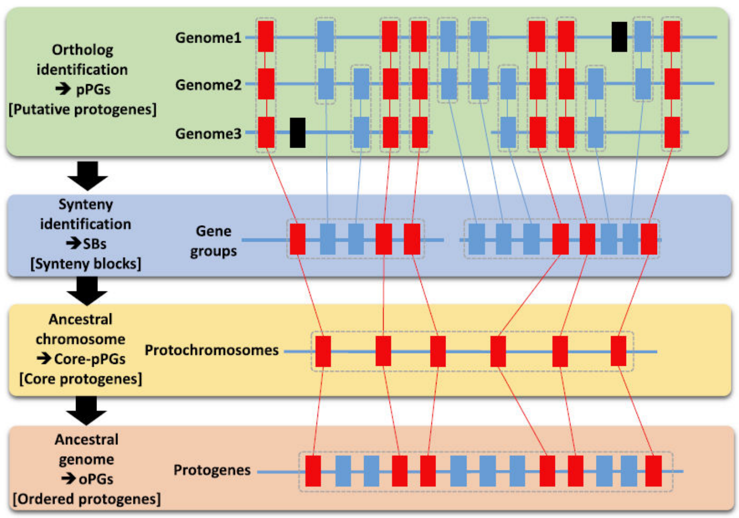
Role of paralogues

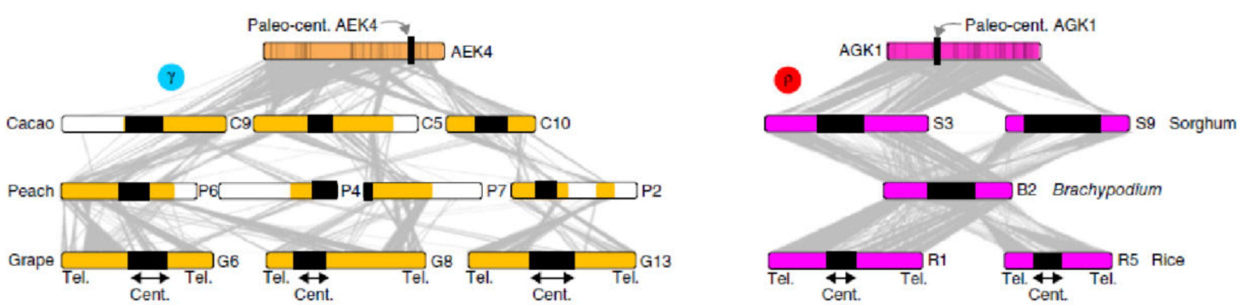
Kerwin et al, 2024



Paleogenomics

Murat et al., 2017; Pont et al., 2019





Pont et al., 2019