Genome evolution: extinction, continuation or explosion

Pat Heslop-Harrison
phh4@le.ac.uk
www.molcyt.com pw/user: 'visitor'

Social media
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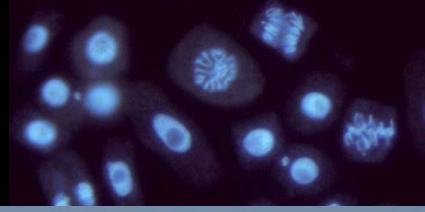
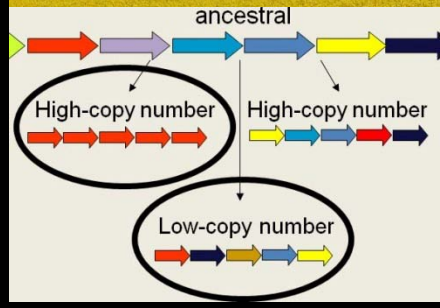
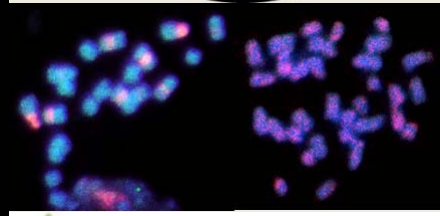
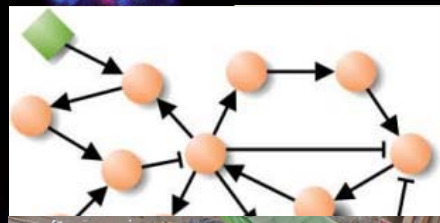
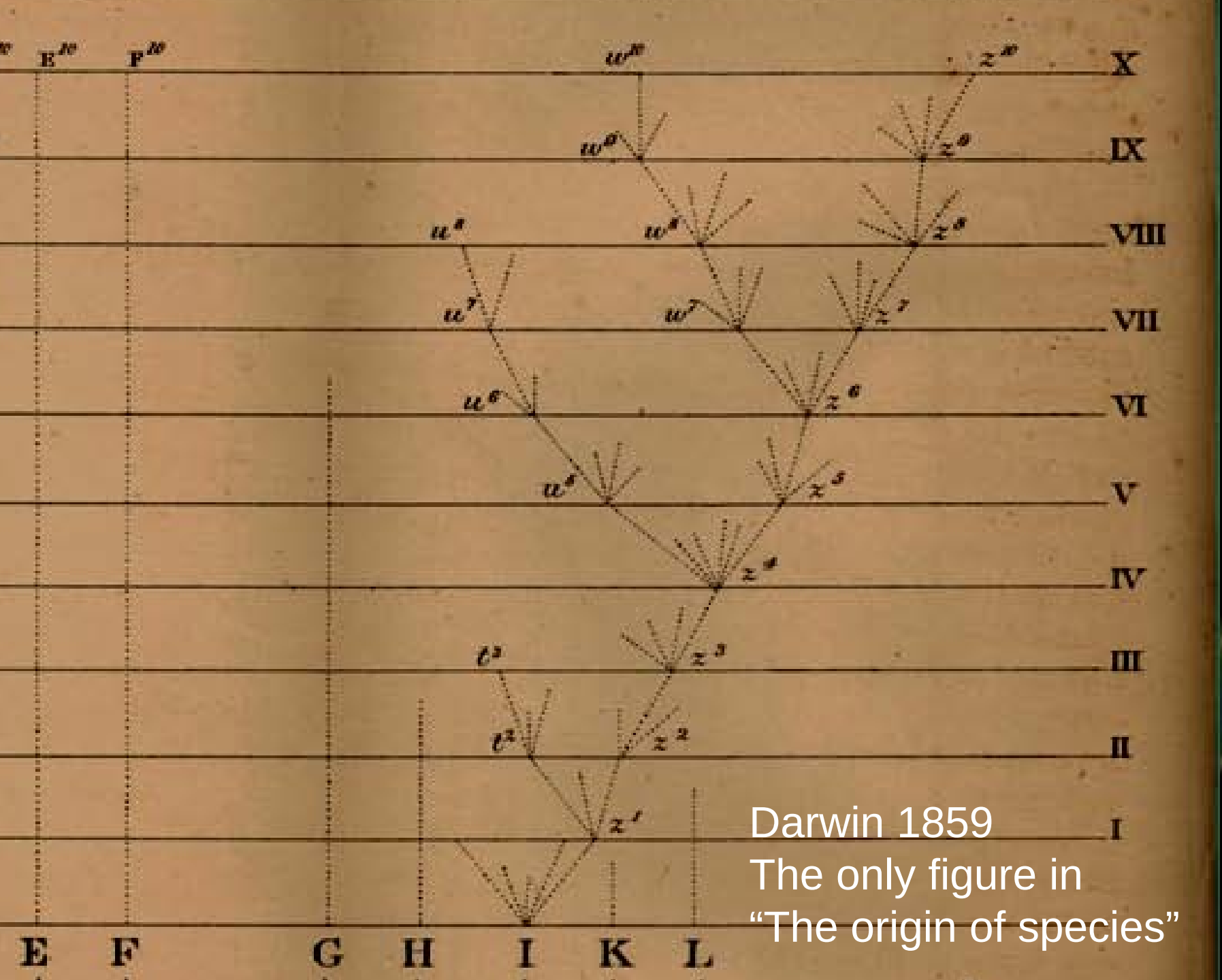




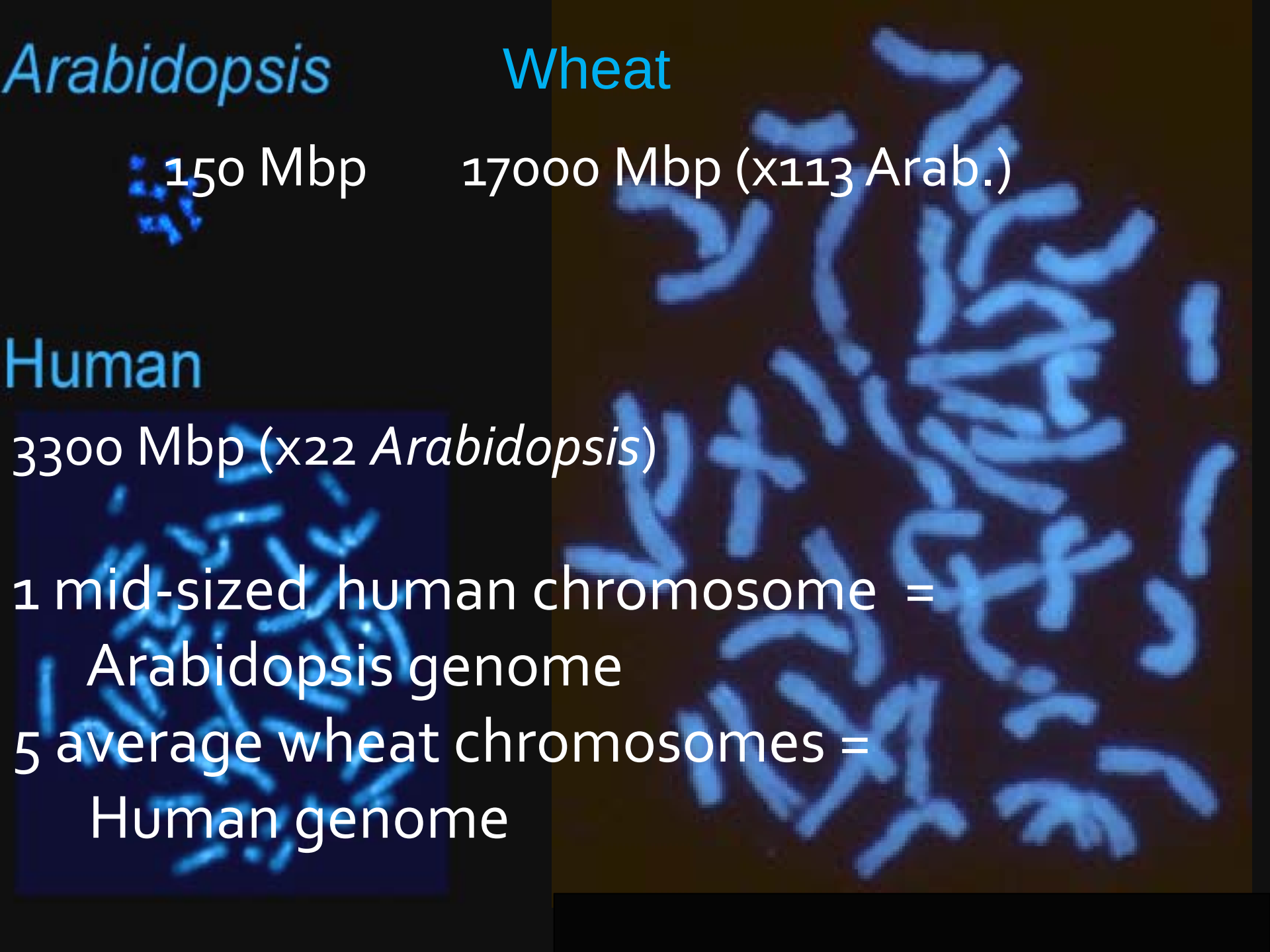


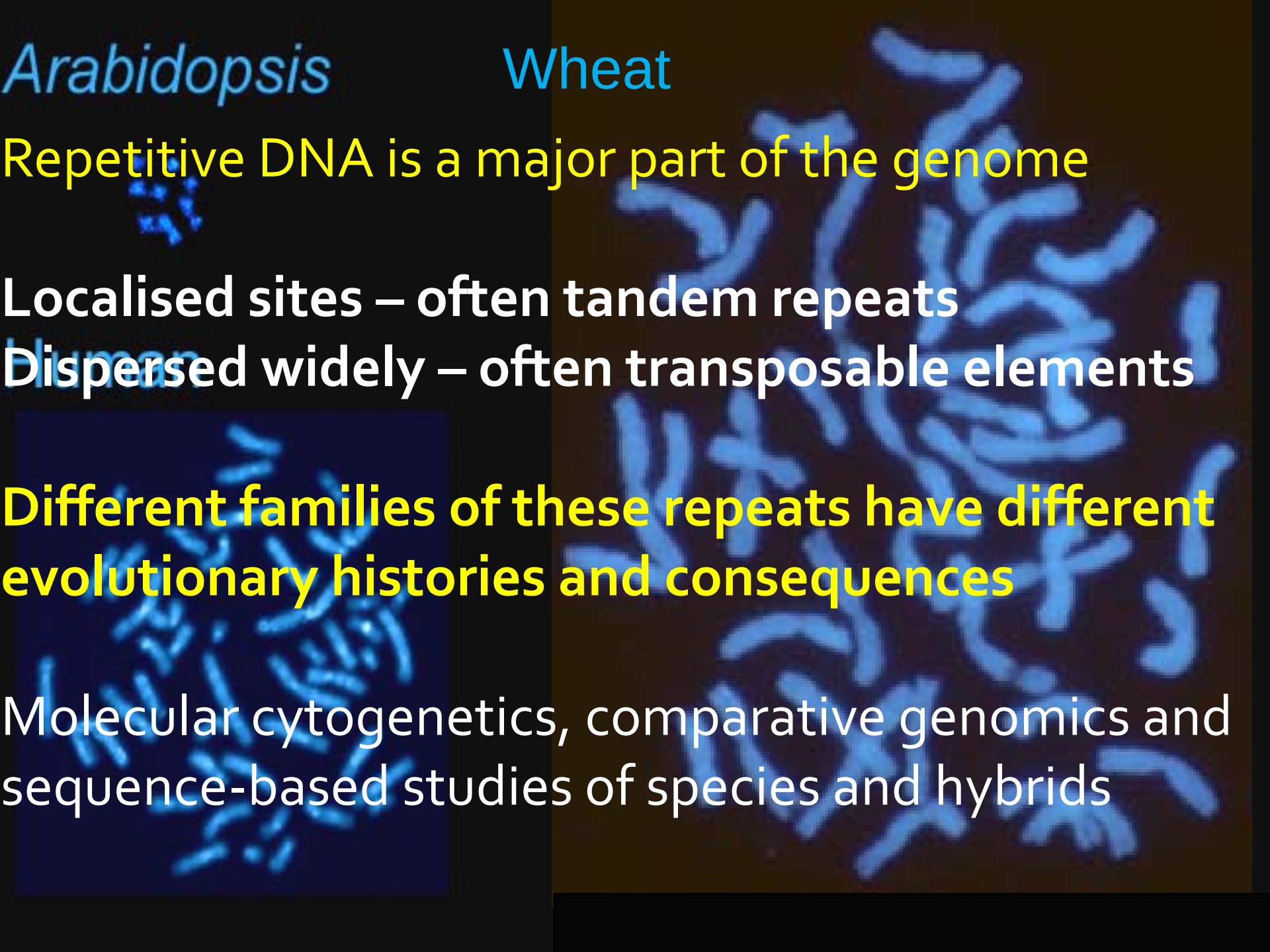


Current Opinion Conferences
Plant Genome Evolution
Amsterdam, The Netherlands • 4-6 September, 2011
A *Current Opinion* Conference



Darwin 1859
The only figure in
“The origin of species”


Arabidopsis
Wheat
150 Mbp
17000 Mbp (x113 Arab.)
Human
3300 Mbp (x22 Arabidopsis)
1 mid-sized human chromosome =
Arabidopsis genome
5 average wheat chromosomes =
Human genome



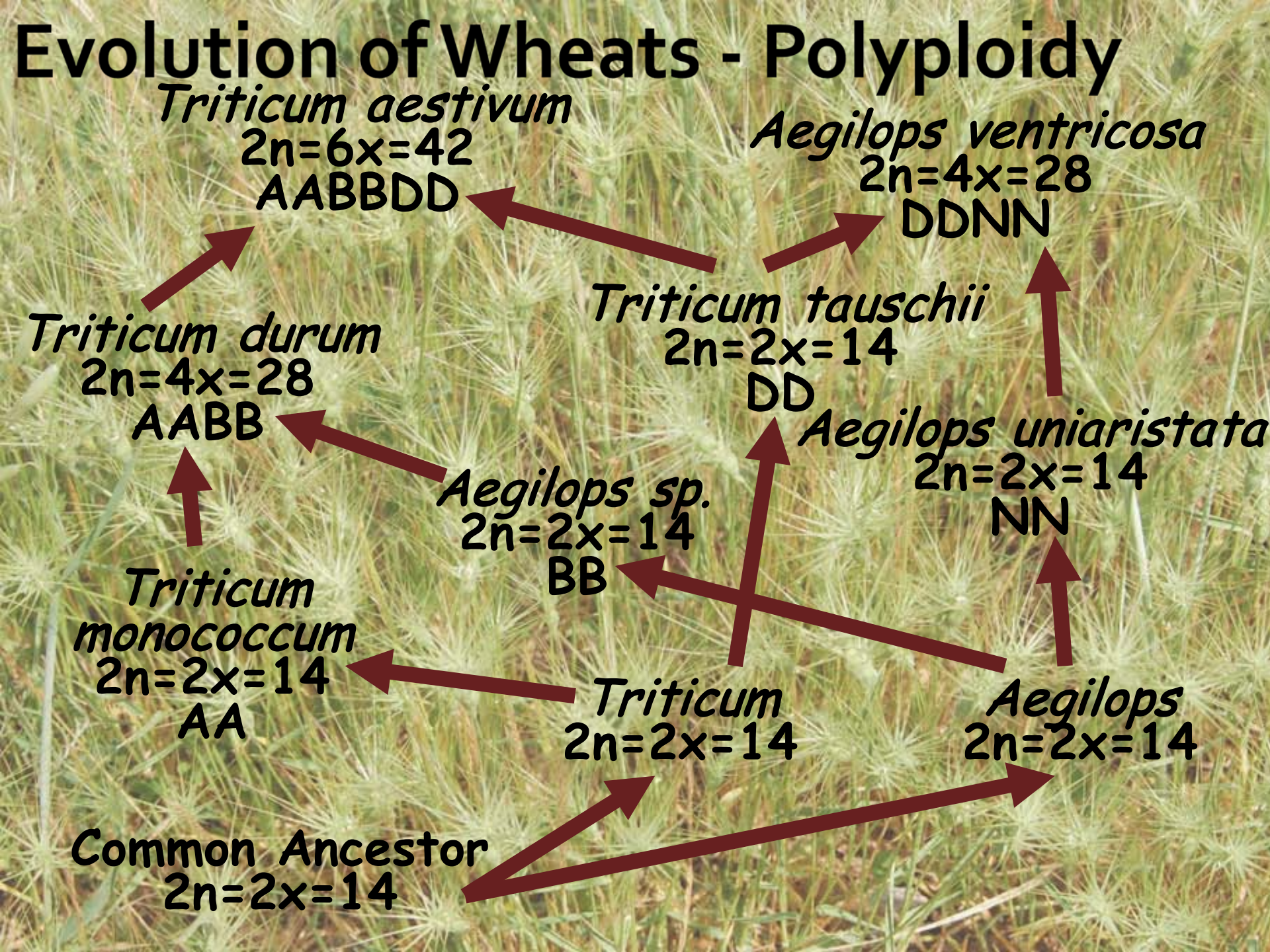
Repetitive DNA is a major part of the genome

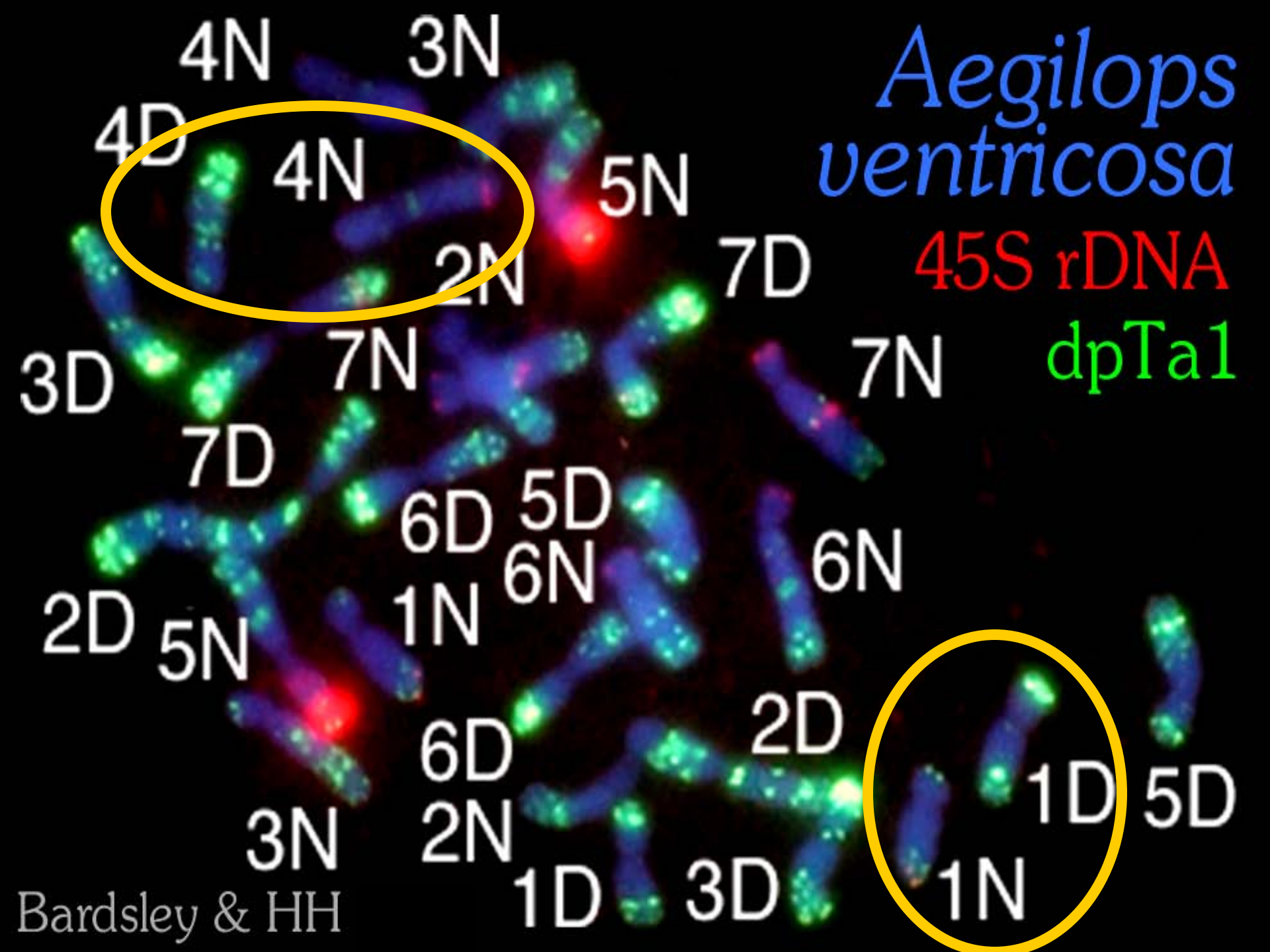
Localised sites – often tandem repeats
Dispersed widely – often transposable elements

Different families of these repeats have different evolutionary histories and consequences

Molecular cytogenetics, comparative genomics and sequence-based studies of species and hybrids

Evolution of Wheats - Polyploidy

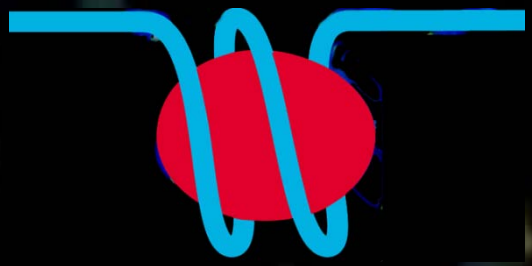



4N
3N
4D
4N
5N
2N
7D
45S rDNA
dpTa1
3D
7N
7N
7D
6D
5D
6N
6N
1N
2D
5N
6D
2D
1D
5D
3N
2N
1D
3D
1N
Aegilops ventricosa
Bardsley & HH

Tandem Repeats

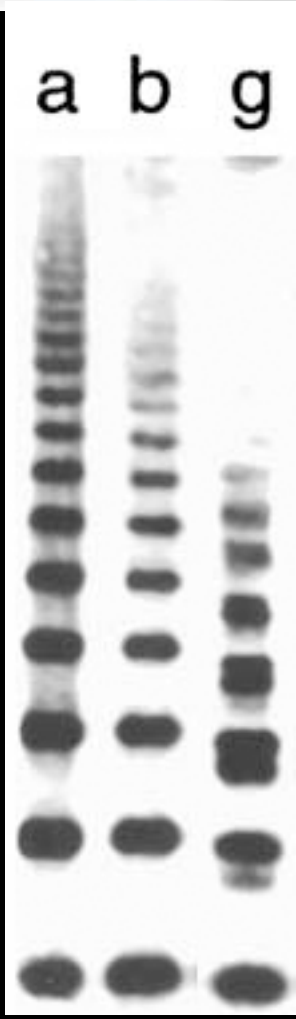
Where each arrow → is a single repeat unit

- - often a multiple of 180 bp but up to 10kb long



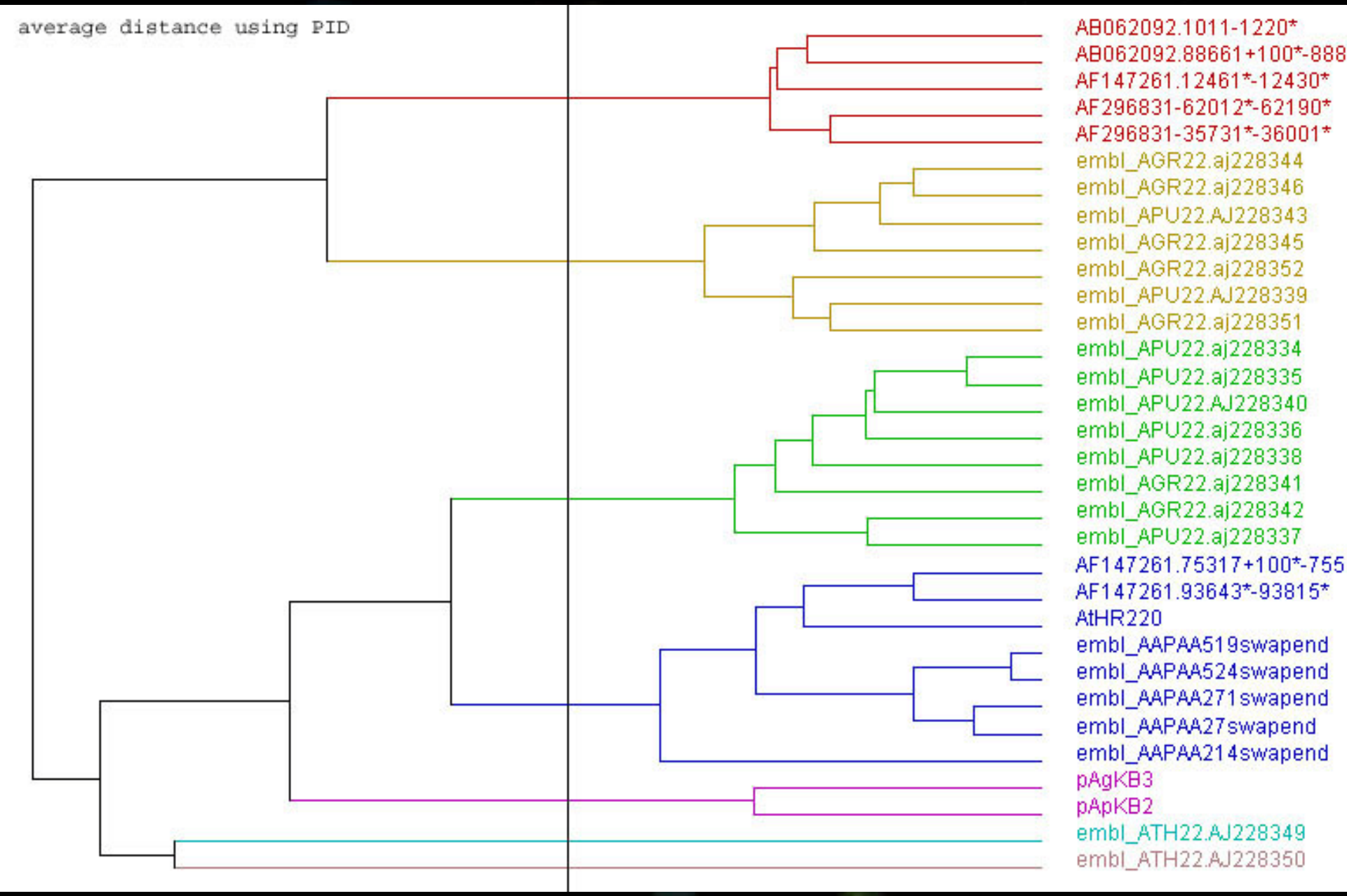
Head-to-tail organization

- CGACTAGT CGACTAGT
  CGACTAGT GGACTAGT
  CGACTAGT CGACTAGT



Crocus spp Probed pCvKB8 Frello, HH 2004

Arabidopsis species – species specific 178bp tandem repeat motif



HH et al. *Chromosome Research* 2003

Arabidopis suecica

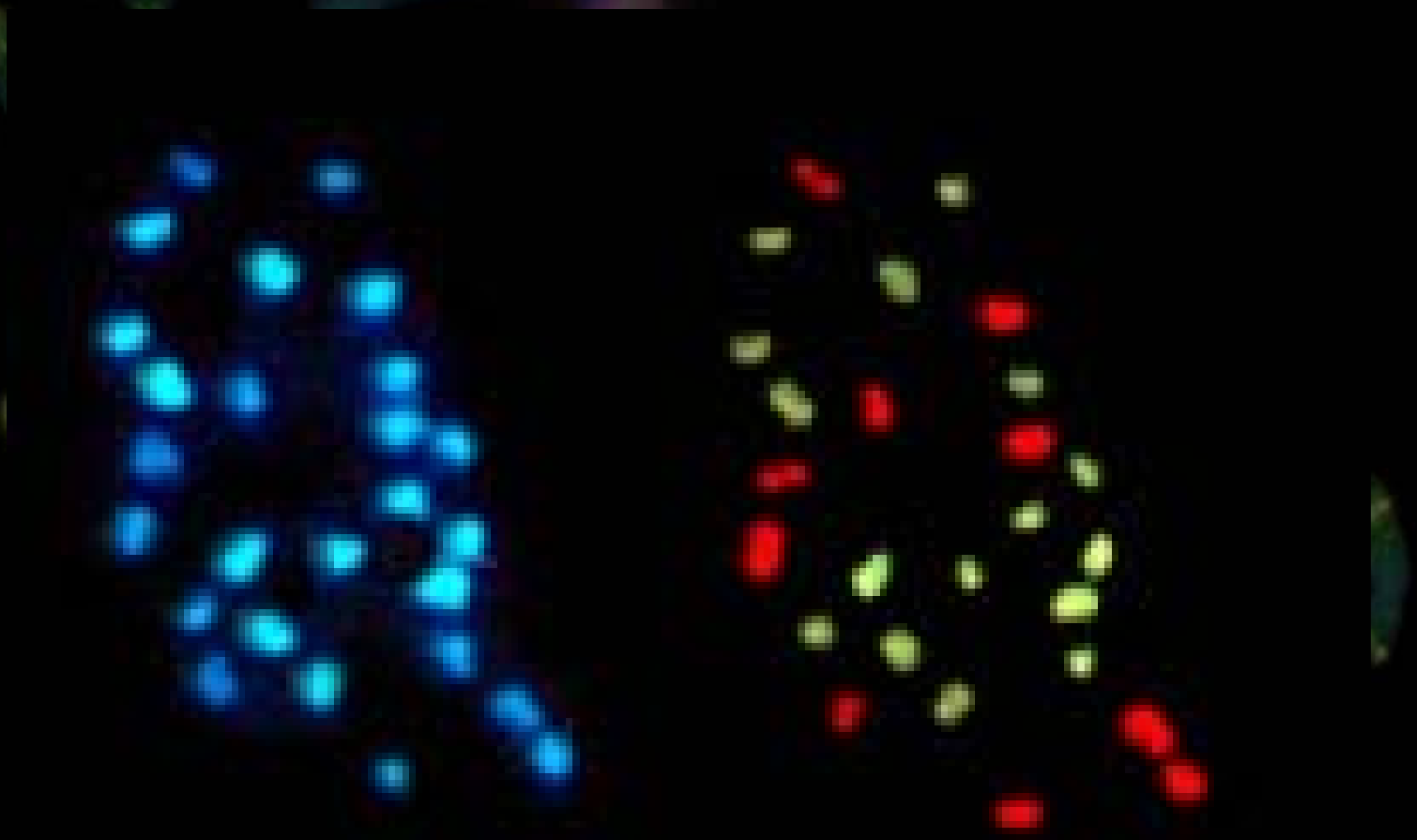
Hybrid of *A. arenosa* (pAa214 green) and *A. thaliana* (180bp red)

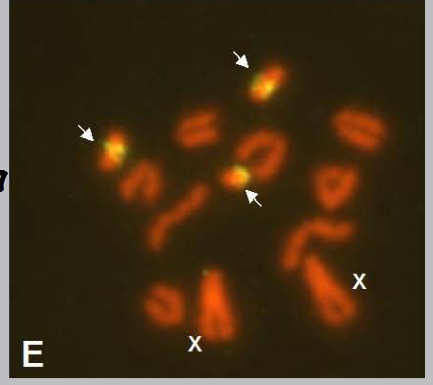
2n = 26

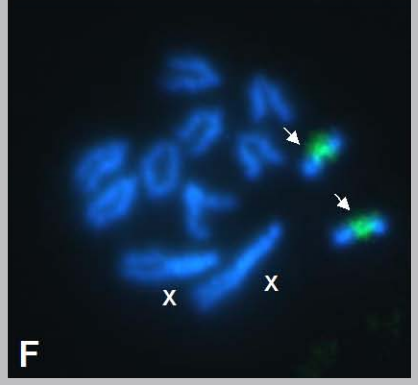
10 from *A. thaliana* 2n=2x=10

16 from *A. arenosa* 2n=2x=16

Kamm, HH et al.



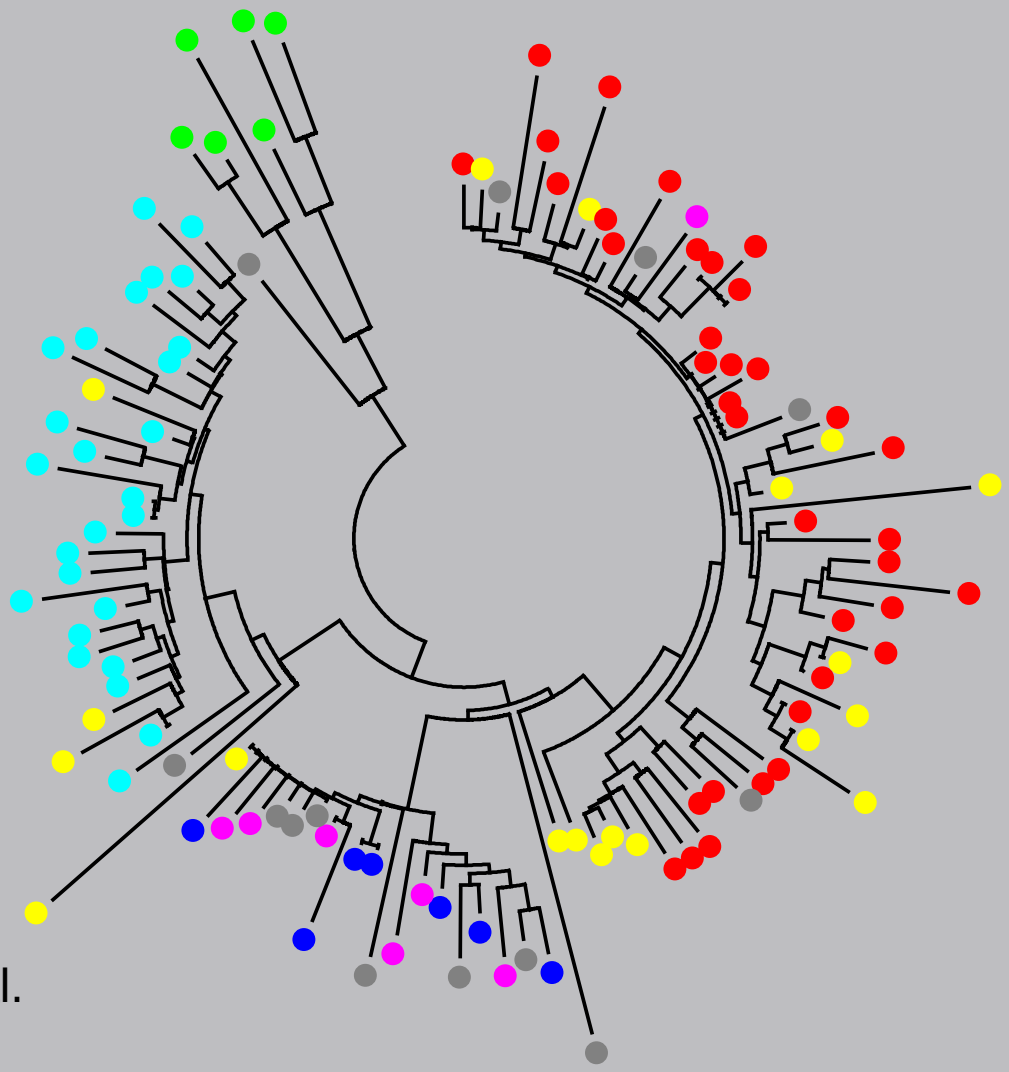




D. seriema

High copy species

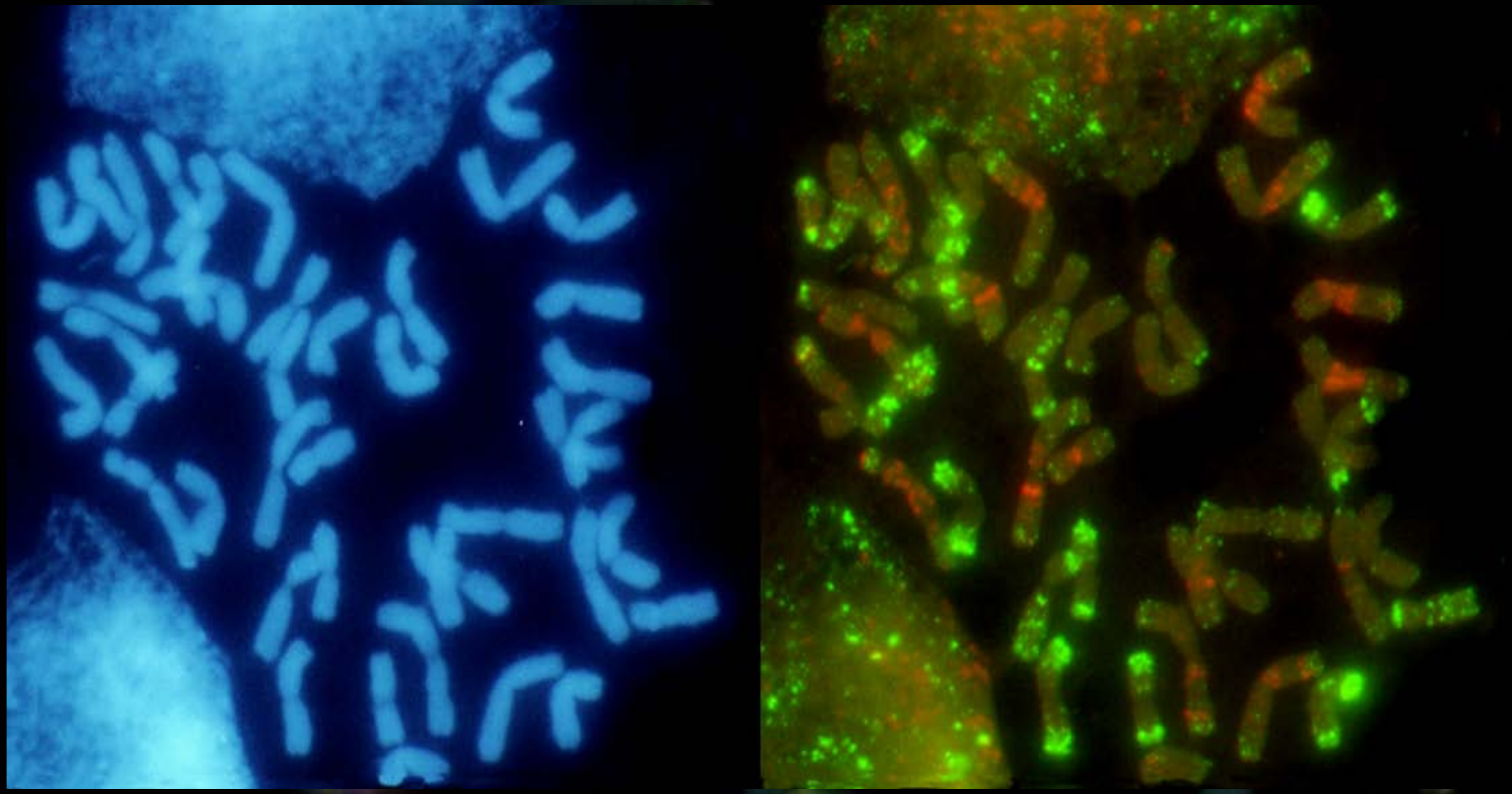
Low copy species



Dr119 repeats: showing homogenization and amplification of satellite tandem repeats

Drosophila spp: Kuhn, HH et al.
Mol Biol Evol 2011
Mol Gen Genet 2010
Chr Res 2008
Medicago: watch this space: Mondin et al.

Triticum aestivum 2n=6x=42



DAPI

pSc119.2 dpTa1

High copy number – low diversity in each of 3 genomes

Inheritance of Chromosome 5D

Aegilops ventricosa
DDNN

× *Triticum persicum* Ac.1510
AABB

ABDN

AABBDDNN × Marne
AABBDD

VPM1 × Hobbit

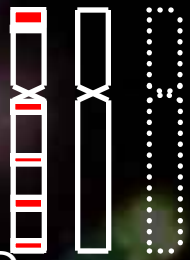
Dwarf A

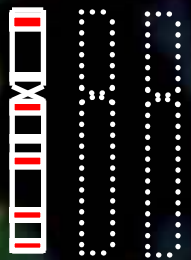
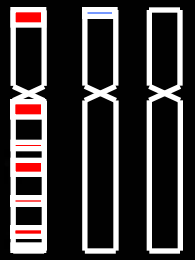
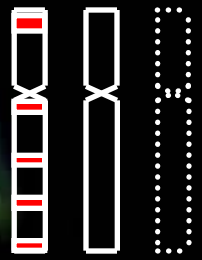
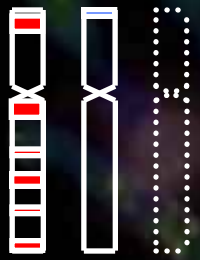
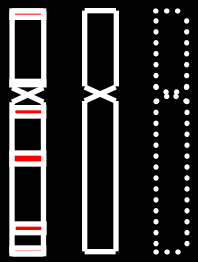
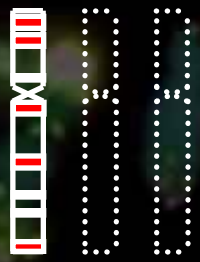
CWW1176-4 × Virtue

Rendezvous × {Kraka × (Huntsman × Fruhgold)}

Piko

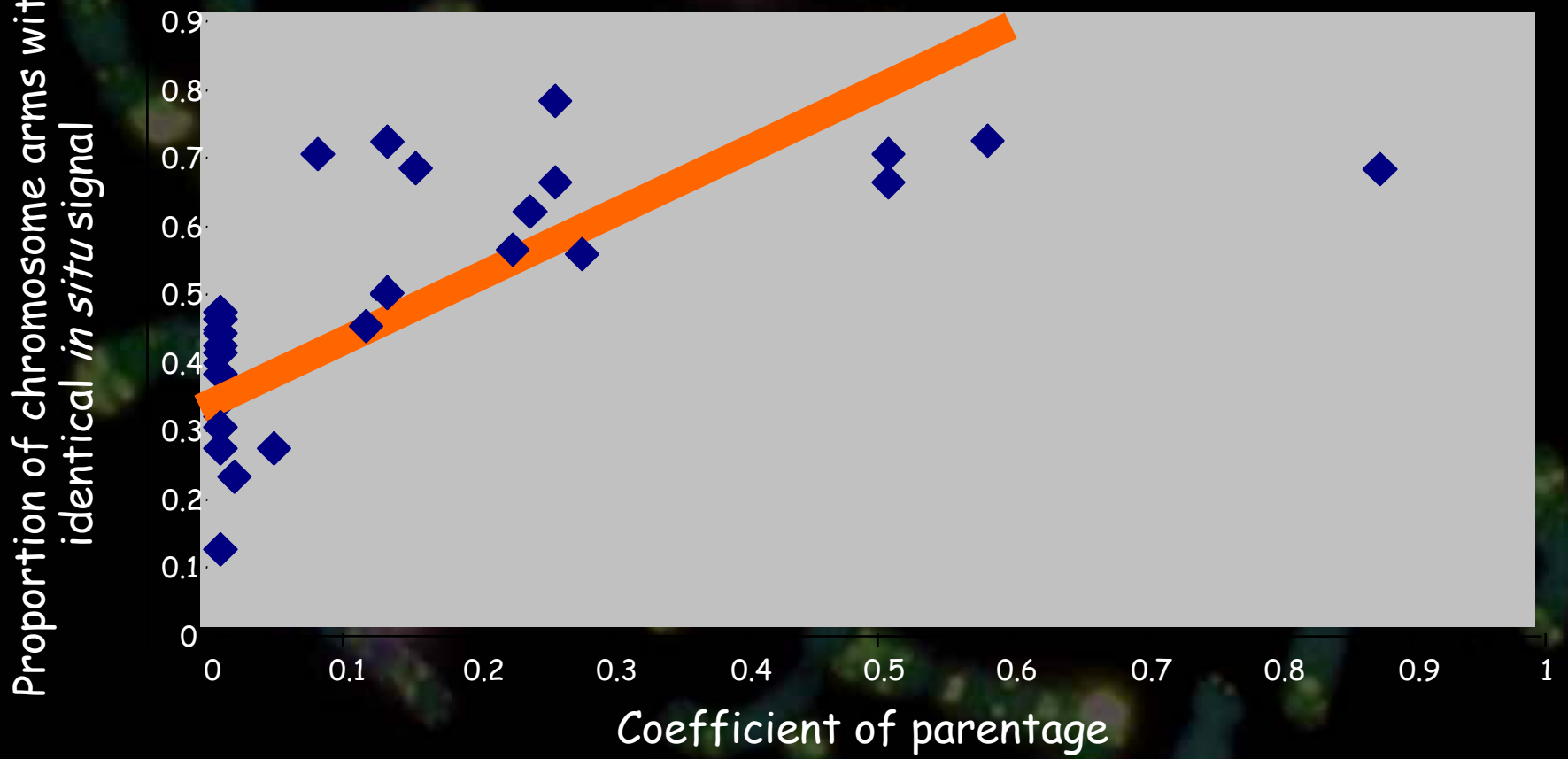
96ST61



dpTa1
pSc119.2
Genomic *Ae.ventricosa*

Correlation between genetic relationships and similarity of dpTa1 hybridization

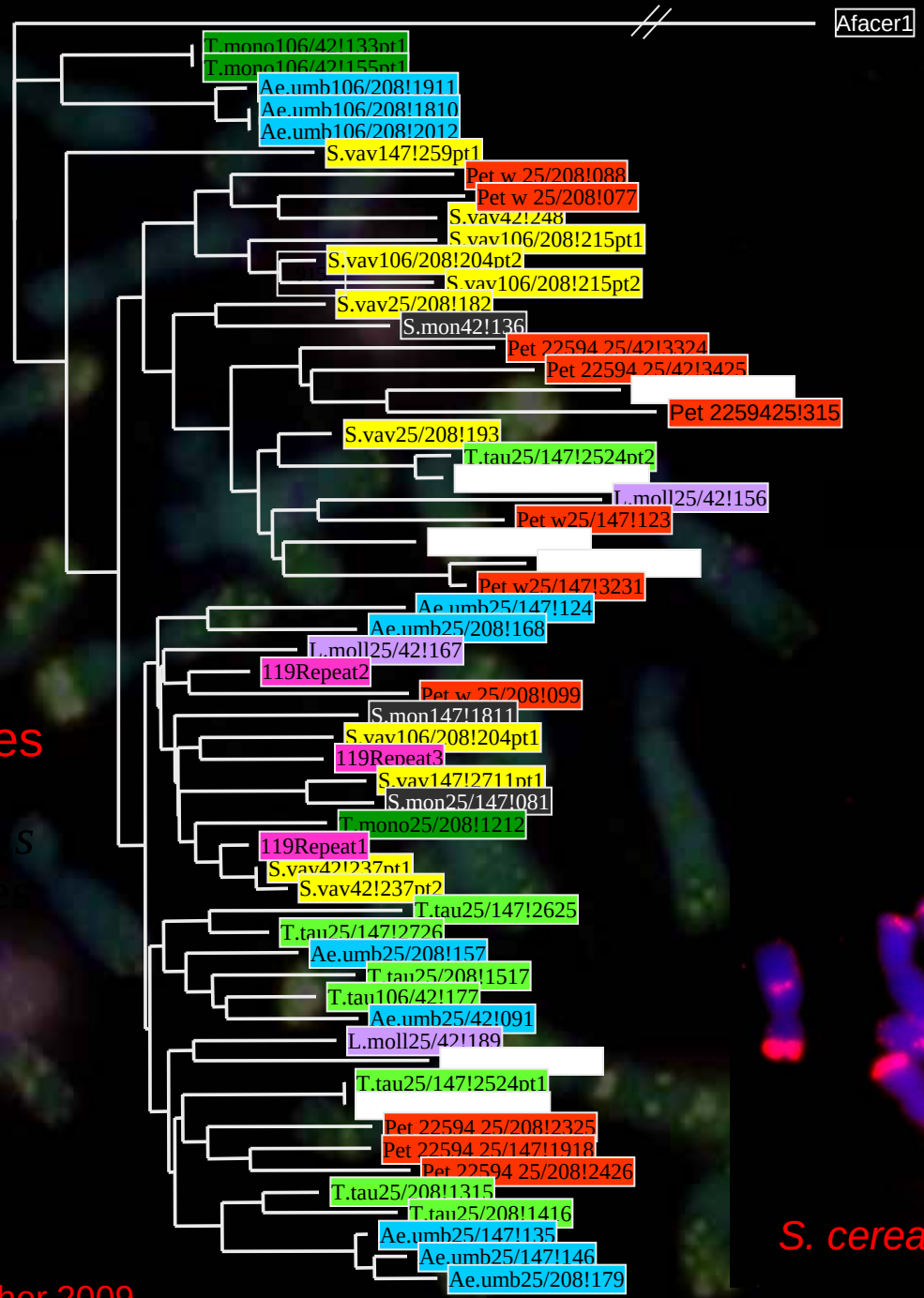


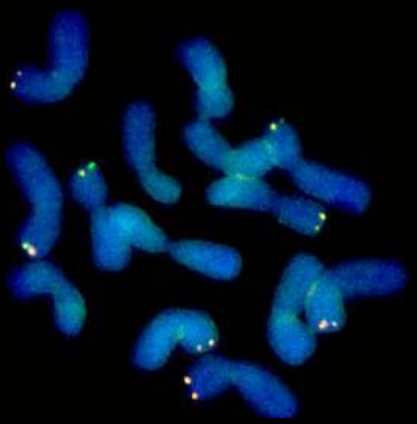
- Eyespot (fungus *Pseudocercosporella*) resistance from *Aegilops ventricosa* introduced to wheat by chromosome engineering
- Many diseases where *all* wheat varieties are highly susceptible

Crop standing
Lodging in cereals
Crop fallen

120bp repeat unit family

in *Triticum*, *Aegilops* and *Secale* species



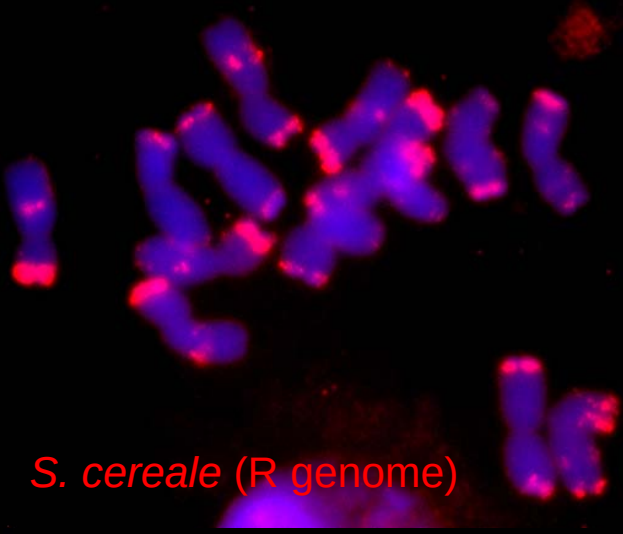


T.tauschii (D genome)

Colour blocks represent species

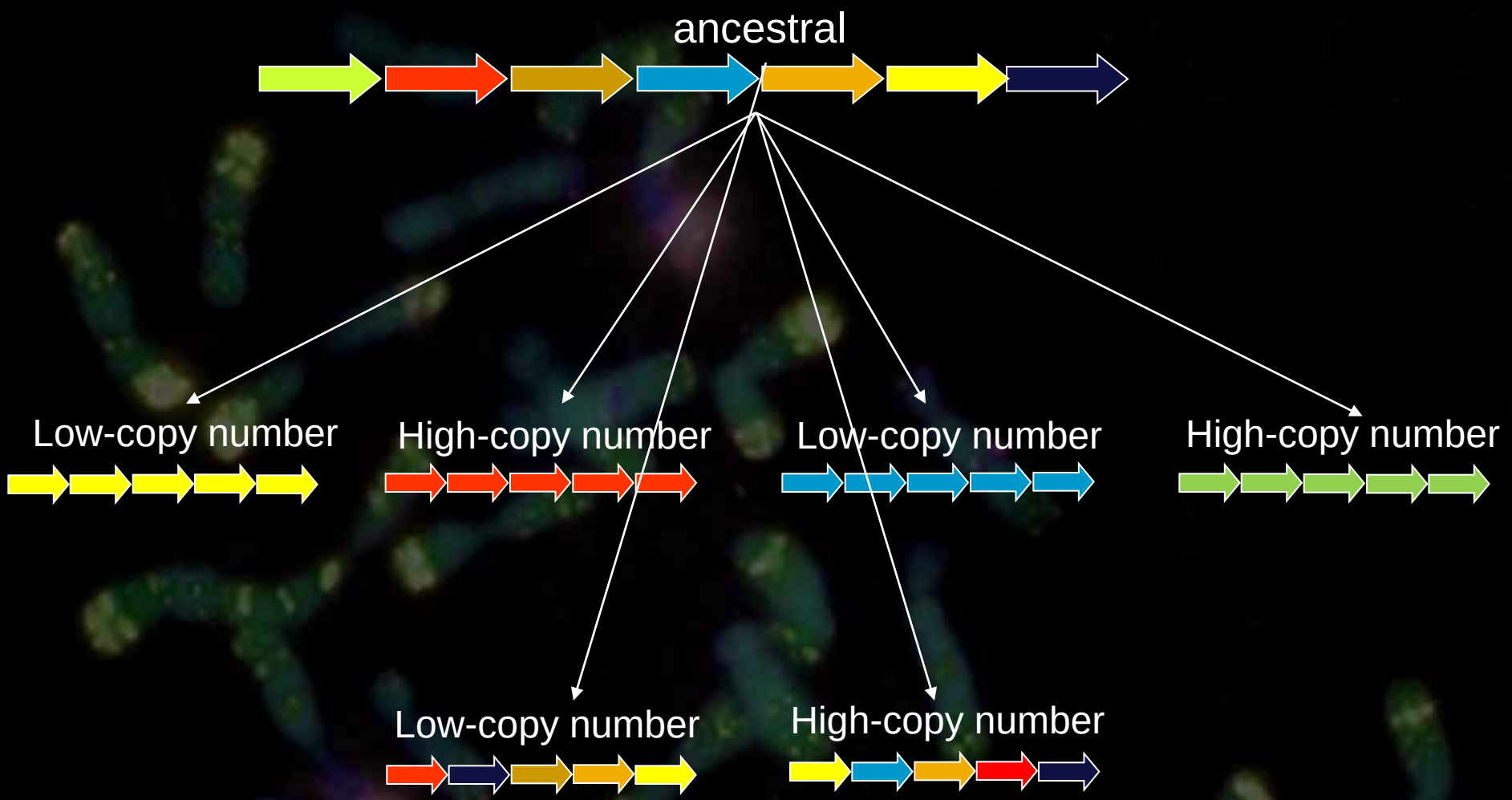
High copy,

High diversity



S. cereale (R genome)

Contento, HH, Schwarzacher 2009



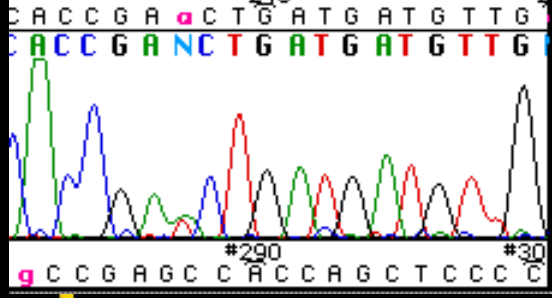
High copy spp: homogenized, amplification from a limited number of master copies

Low copy spp: much variation

Schwarzacher, Contento & HH 2009

Levels

- Sequences
- Genes / motifs
- Repetitive DNA
- Chromosomes
- Chromosome sets ('Genomes')
- Genotypes/CVs
- Species
- Genera and above

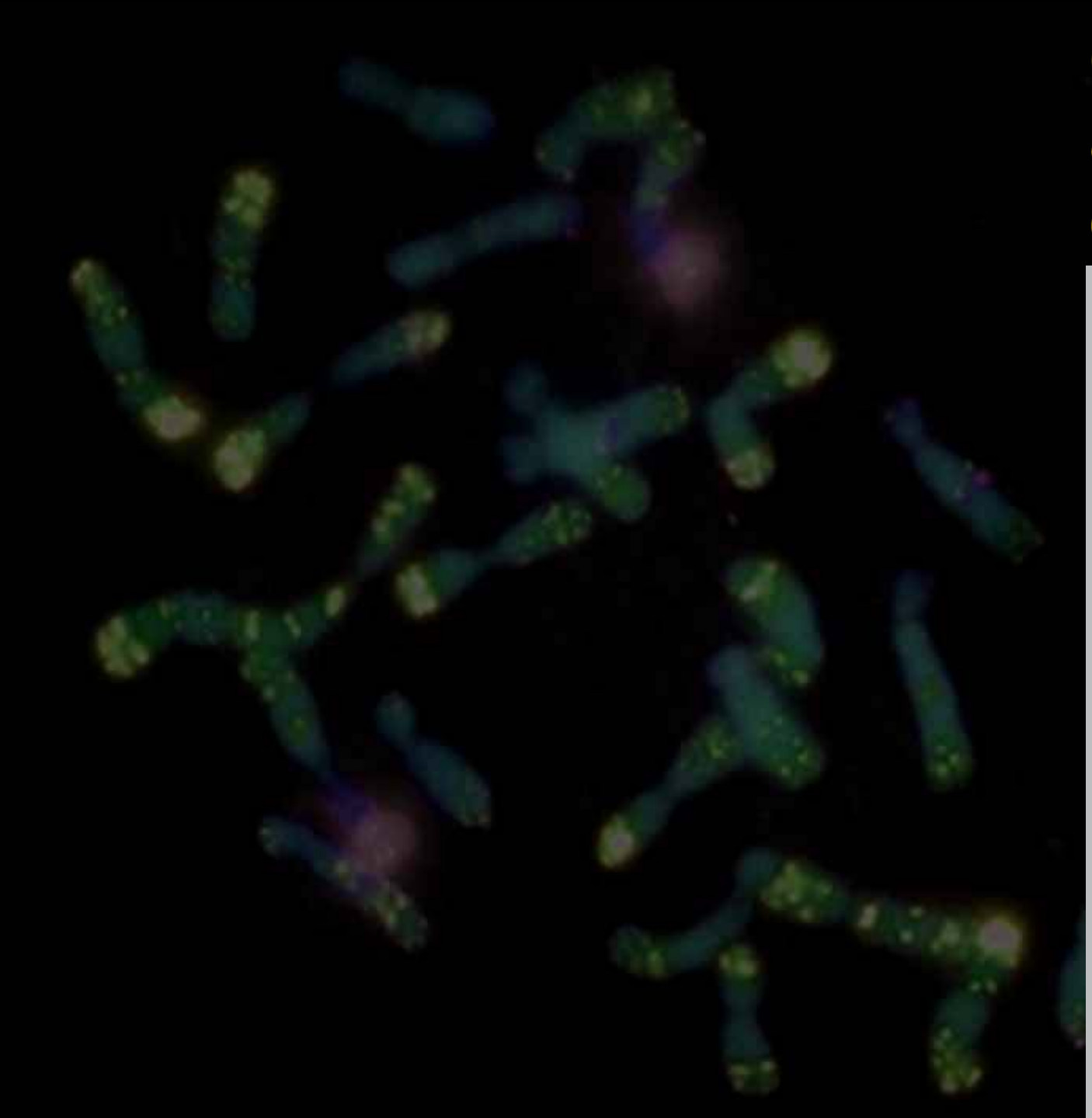


… involving

- Mutation
- Rearrangement
- Duplication
- Deletion
- Homogenization

… consequences for

- Crops / wild species
- Selection
- Speciation



Chromosome and genome engineering

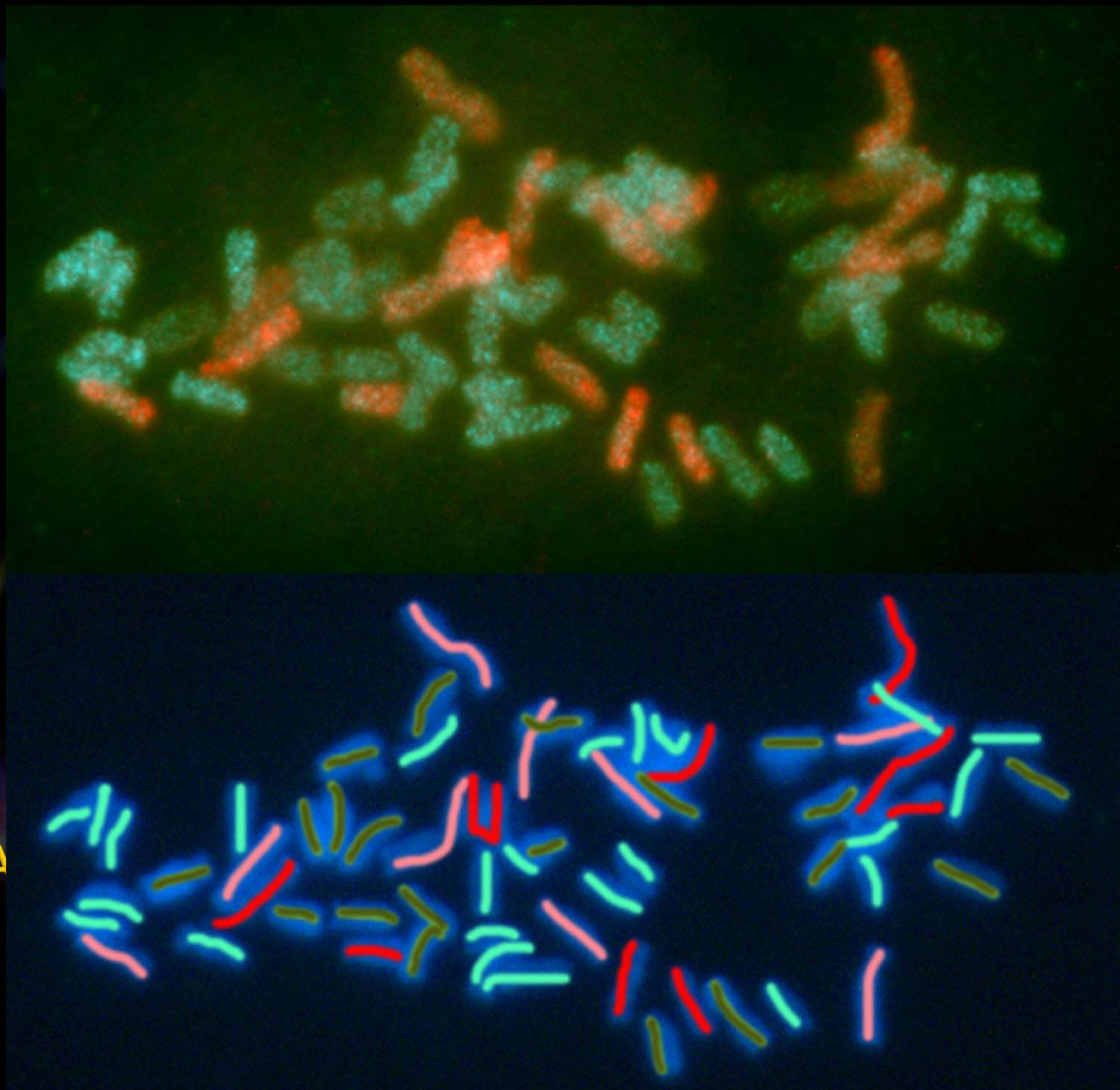
Cell fusion hybrid of two 4x tetraploid tobacco species

Patel, Badakshi, HH, Davey et al 2011 Annals of Botany

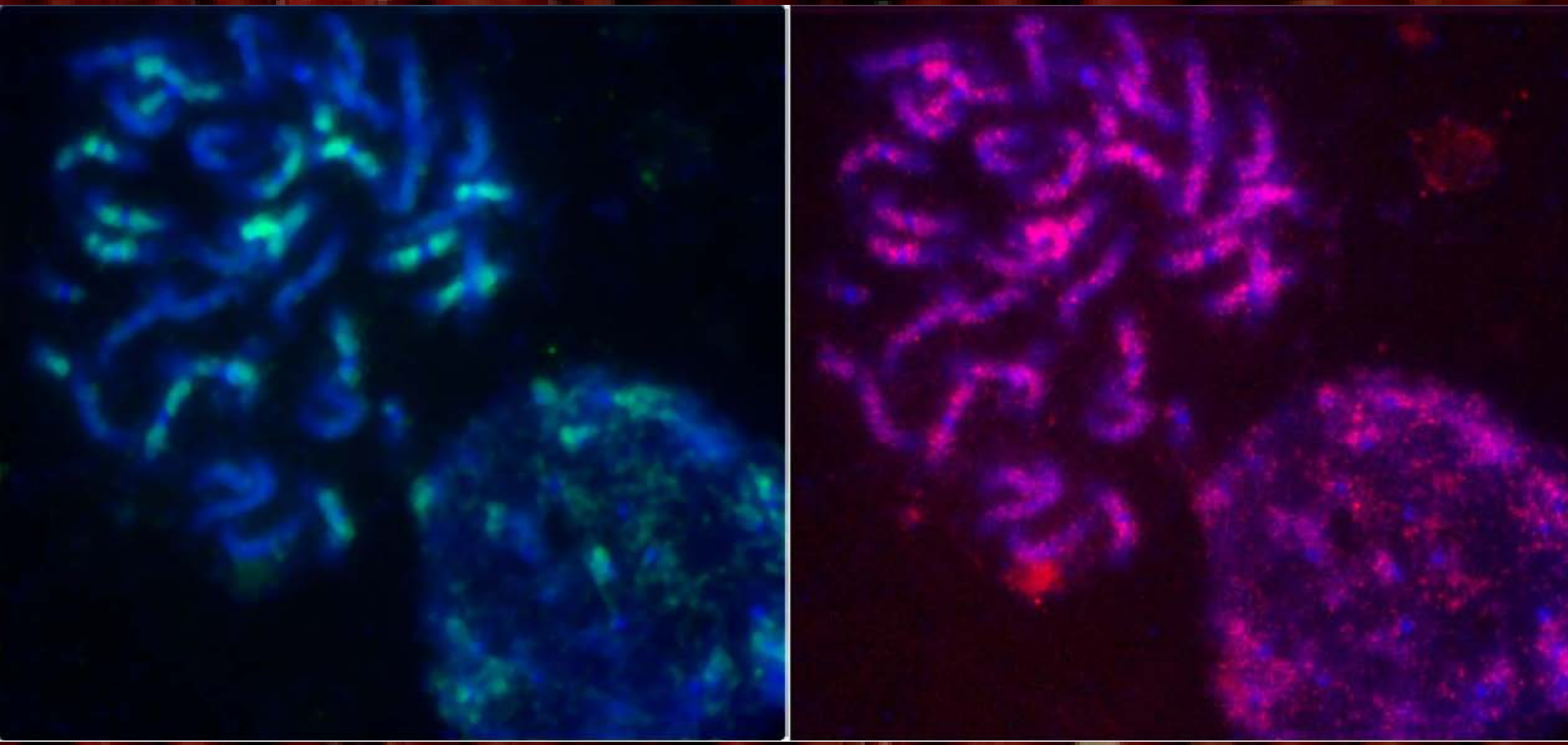
Nicotiana hybrid 4x + 4x cell fusions

Each of 4 chromosome sets has distinctive repetitive DNA when probed with genomic DNA

Patel et al Ann Bot 2011



Genome evolution



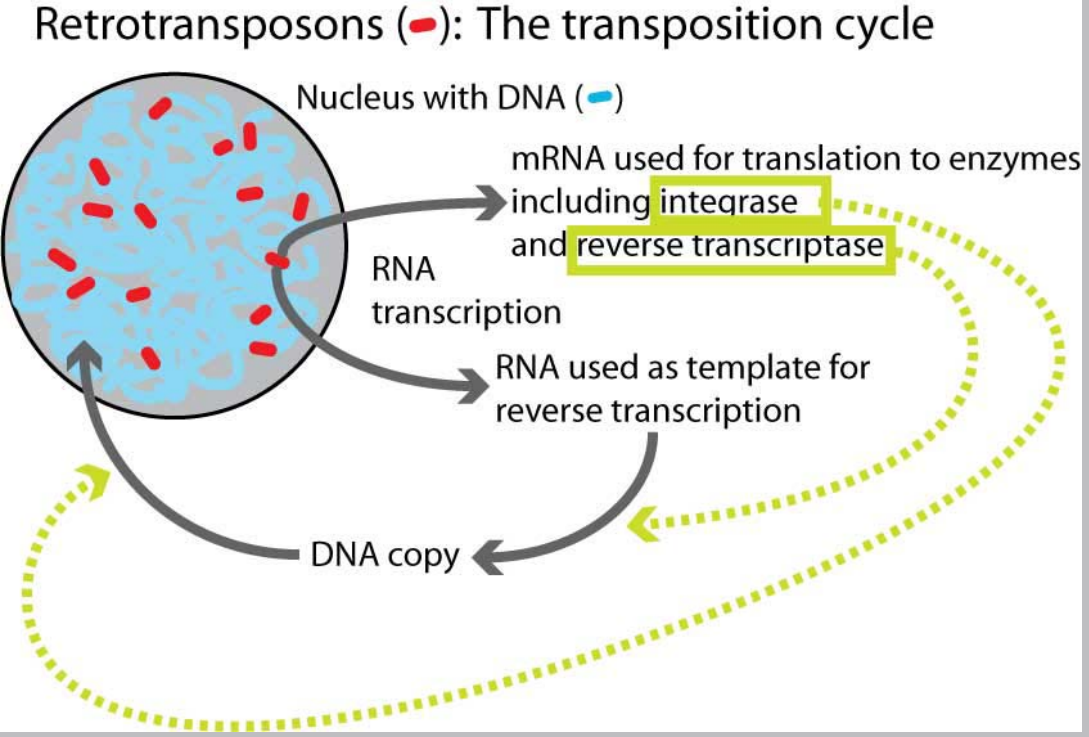
Arachis hypogaea – 2n=4x=40

In situ hybridization of two BACs including repeats

Contrasting distribution of their major repeat families

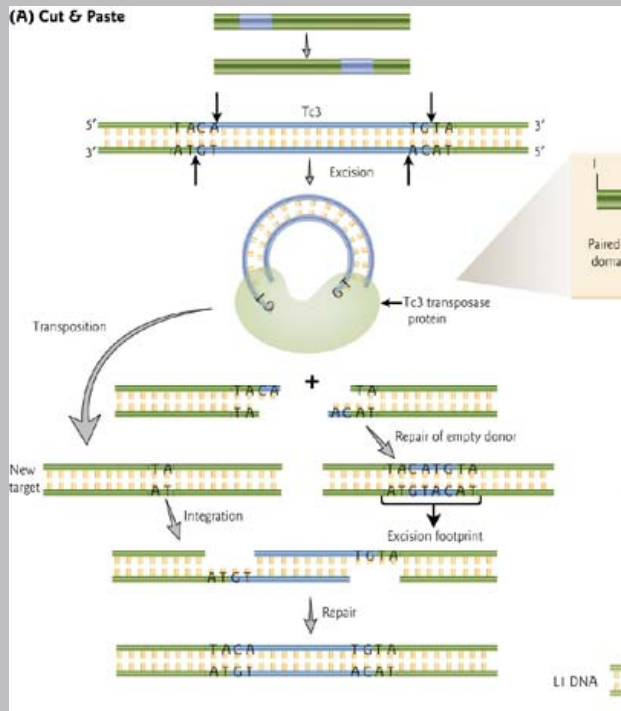
udia Guerra Araujo et al in prep 2011, EMBRAPA, Brazil

Arachis in situ 6 Slide 2 Meta 7
ADH167F07 red ADH129F24 green

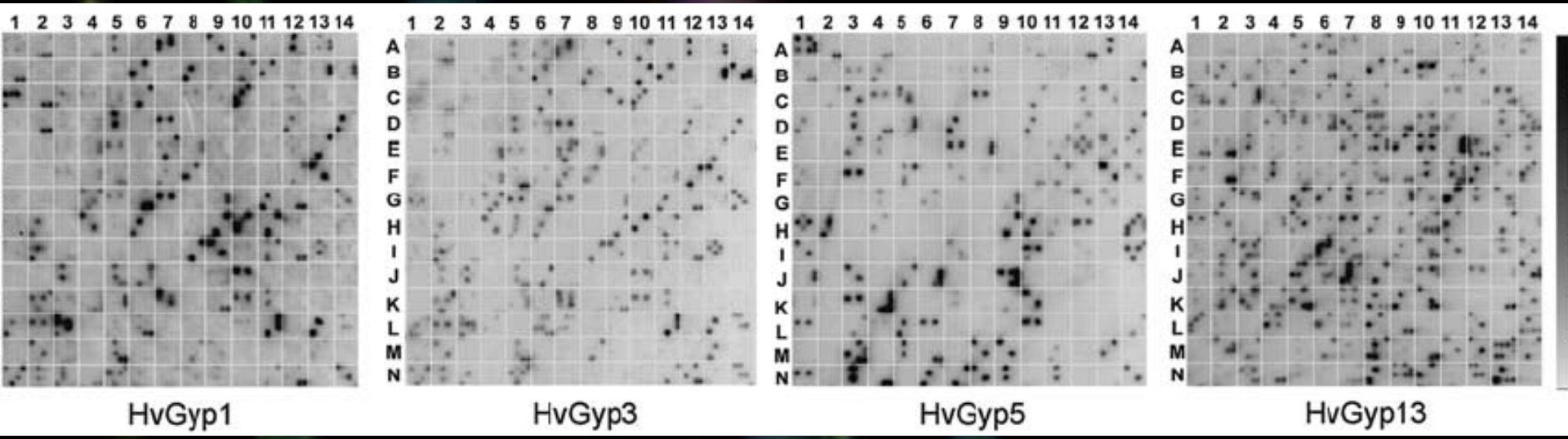


Retrotransposons
Class I transposable elements
RNA intermediate

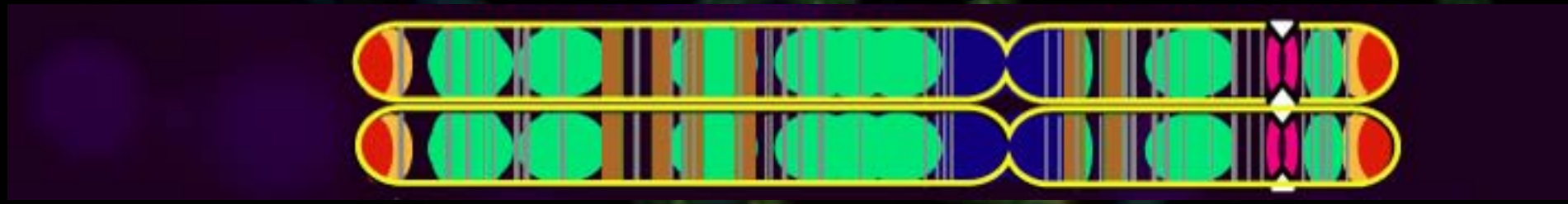
DNA transposons
Class II transposable elements
Cut-and-paste



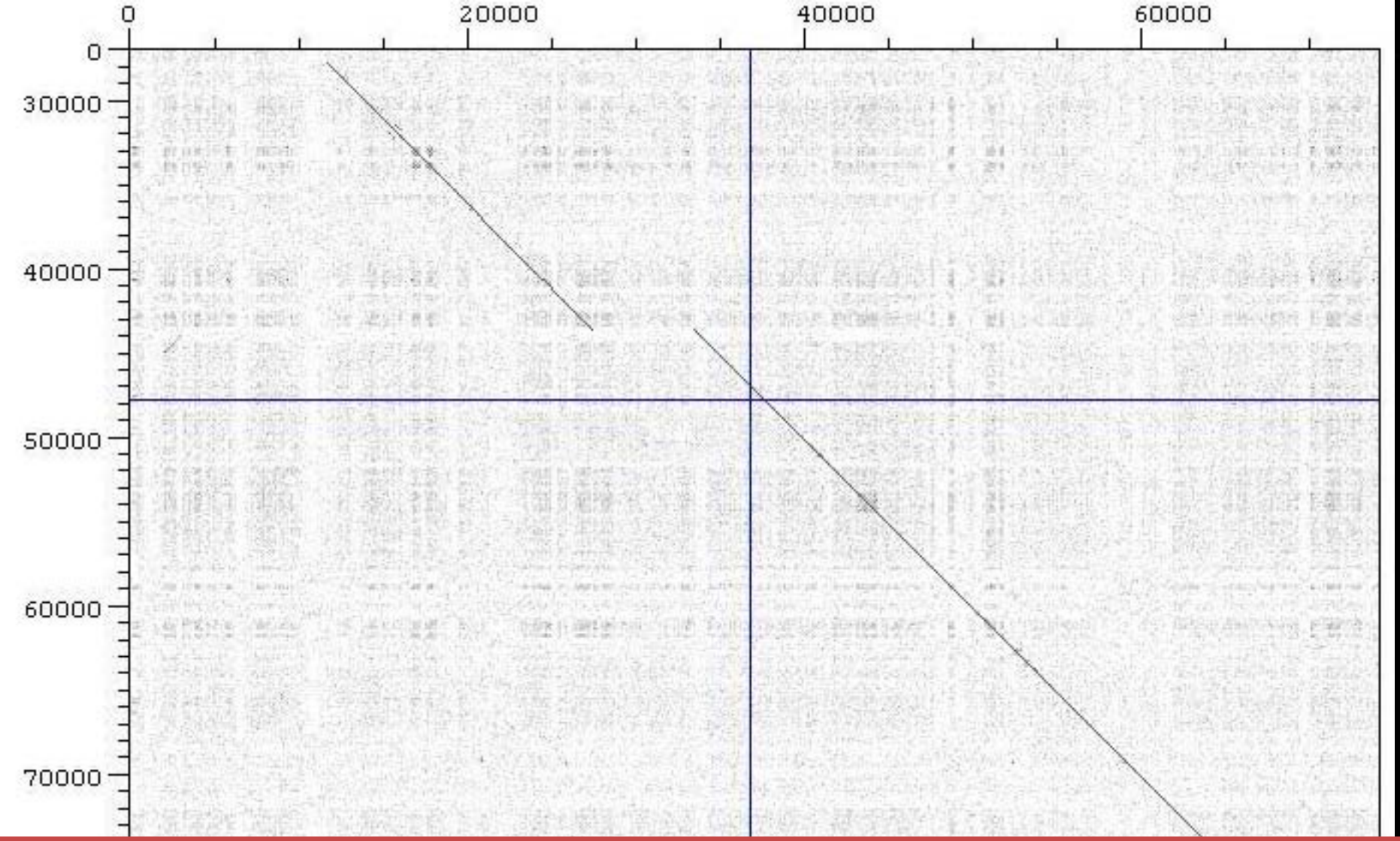
Retroelement abundance and diversity in barley



le[illegible]esent [illegible]5% [illegible]on



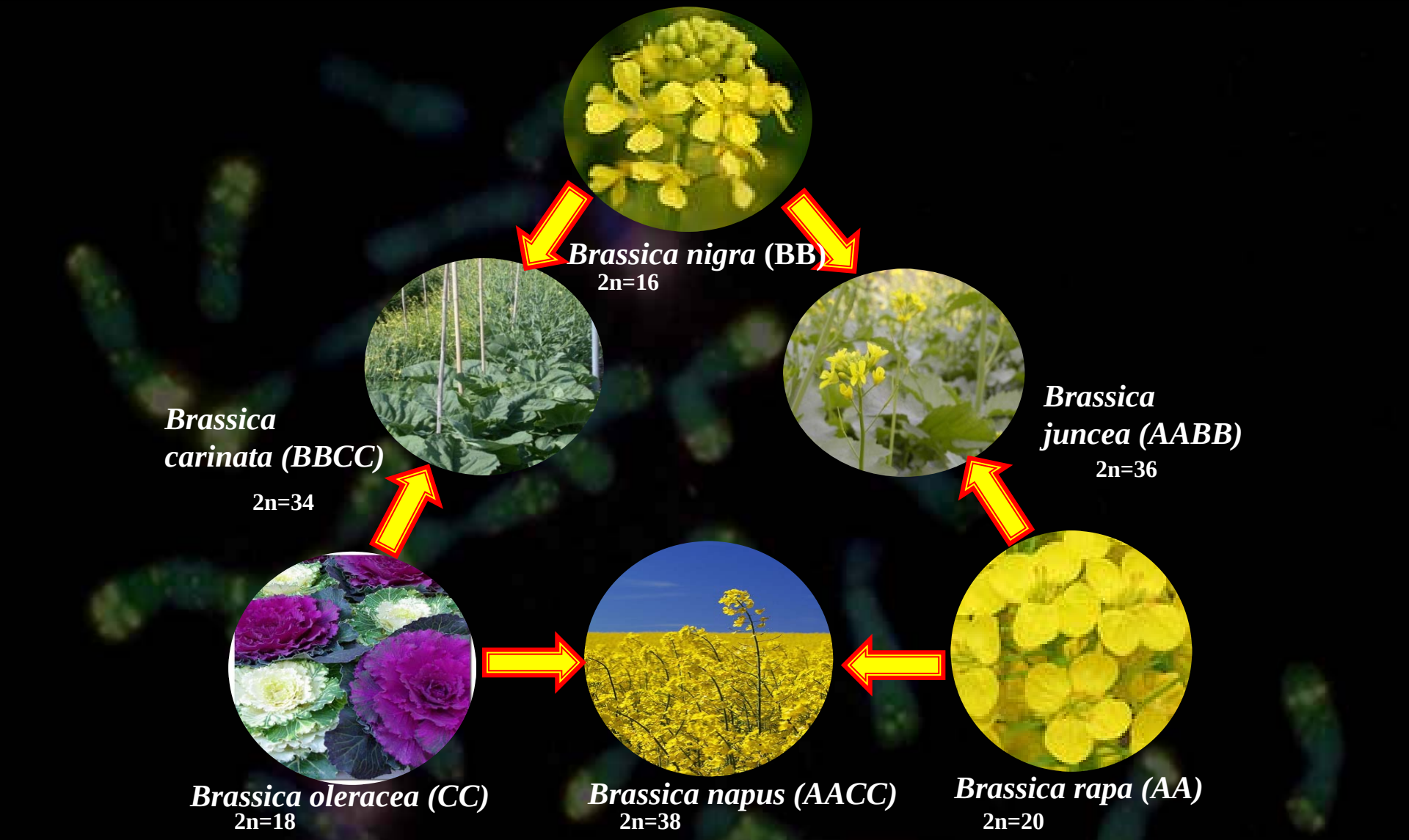
Barley gypsy: Vershinin, Druka, Kleinhofs, HH: Planf Mol Biol 2002;
cf Brassica Alix & HH Plant Mol Biol 2005



Dotplot comparisons at scale of 10,000s bp

Two *Musa* chromosomes are >95% homologous with gaps

Faisal Nouroz 2011

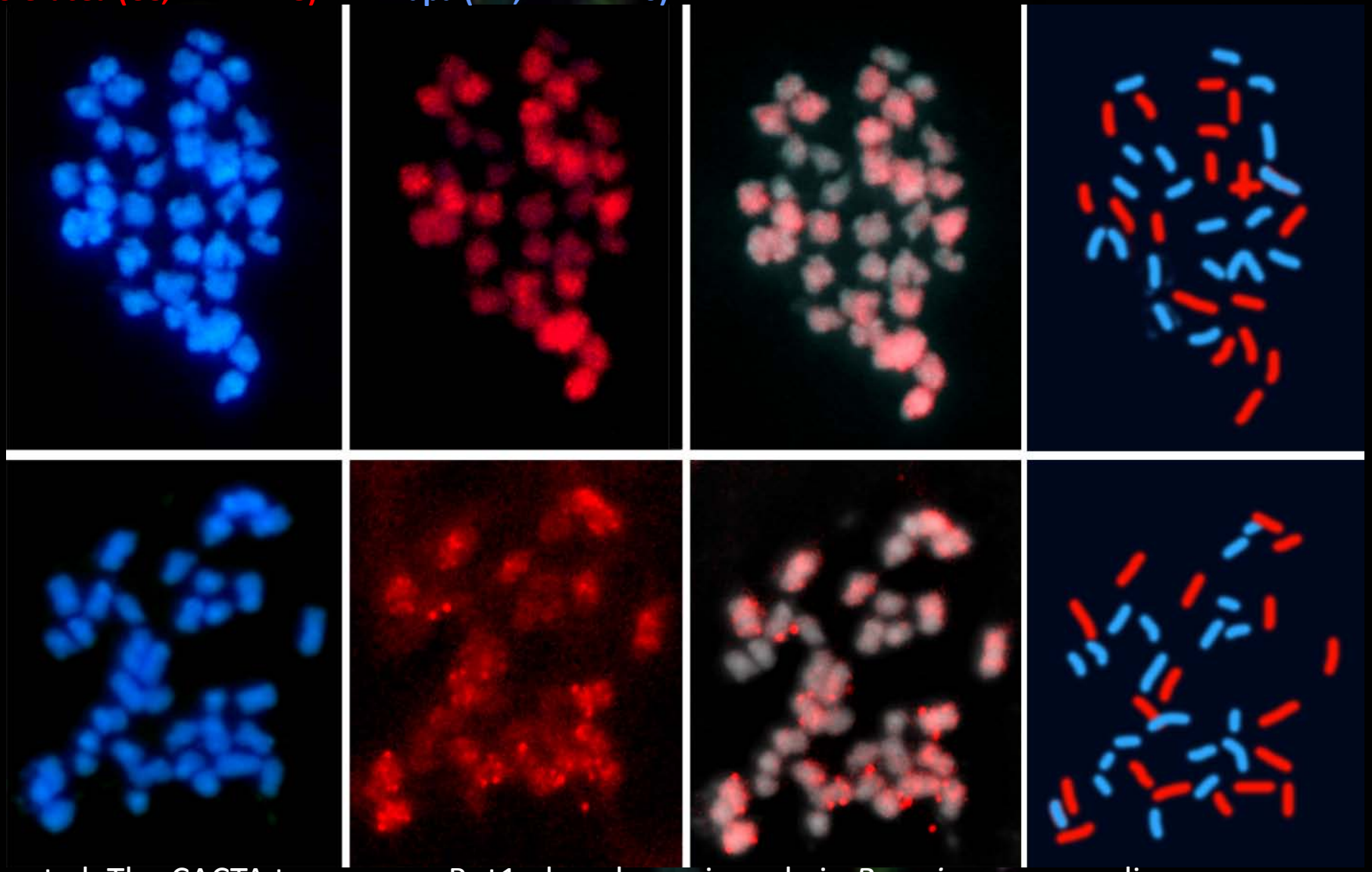


The *Brassica* genus is monophyletic, from single common ancestor. What has changed in the DNA sequences?

Genome Specificity of a CACTA Transposon

B. napus **(AACC, 2n=4x=38) – hybridized with C-genome CACTA element red**

B. oleracea (CC, 2n=2x=18) **B. rapa (AA, 2n=2x=20)**

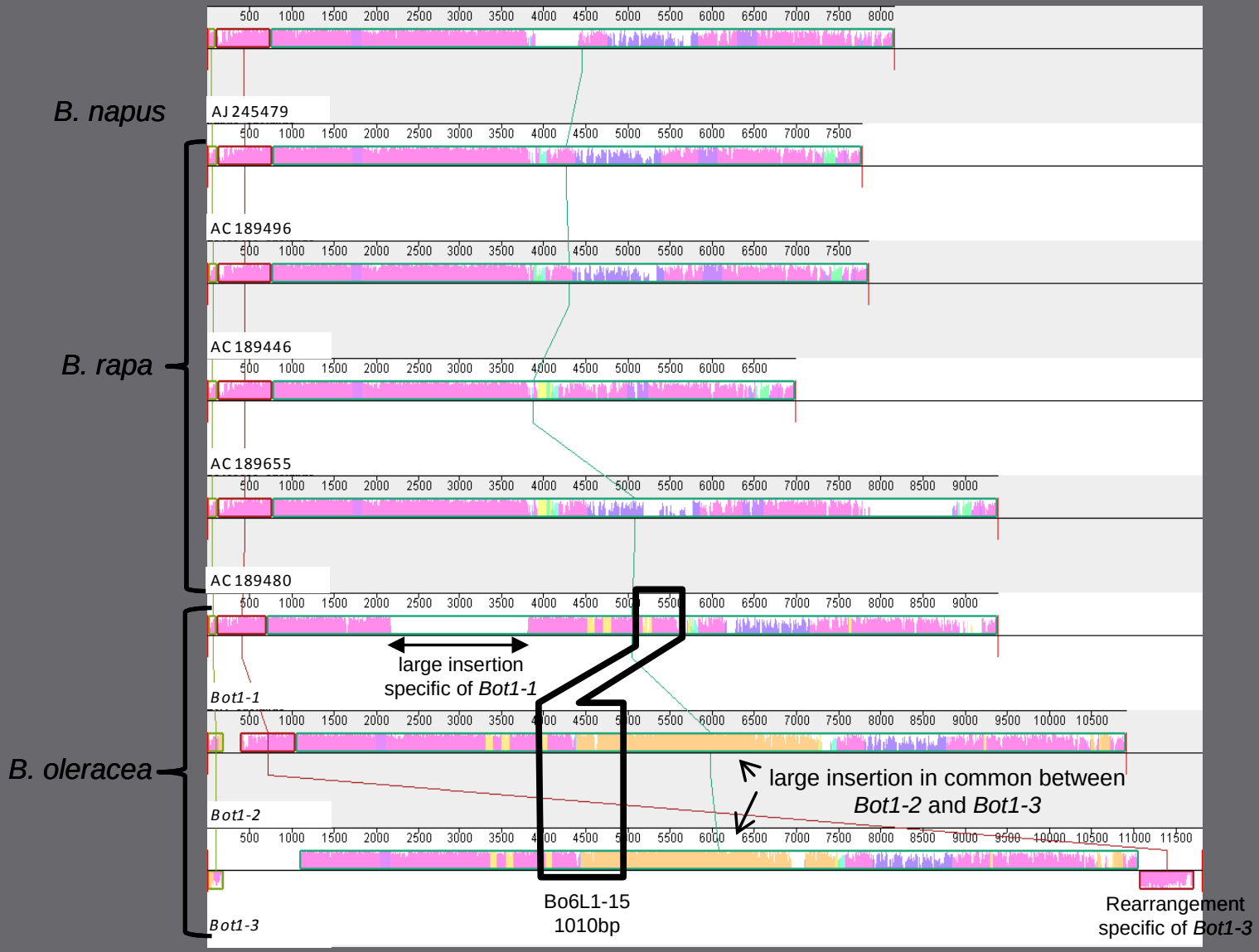


Alix et al. The CACTA transposon Bot1 played a major role in *Brassica* genome divergence and gene proliferation. Plant Journal

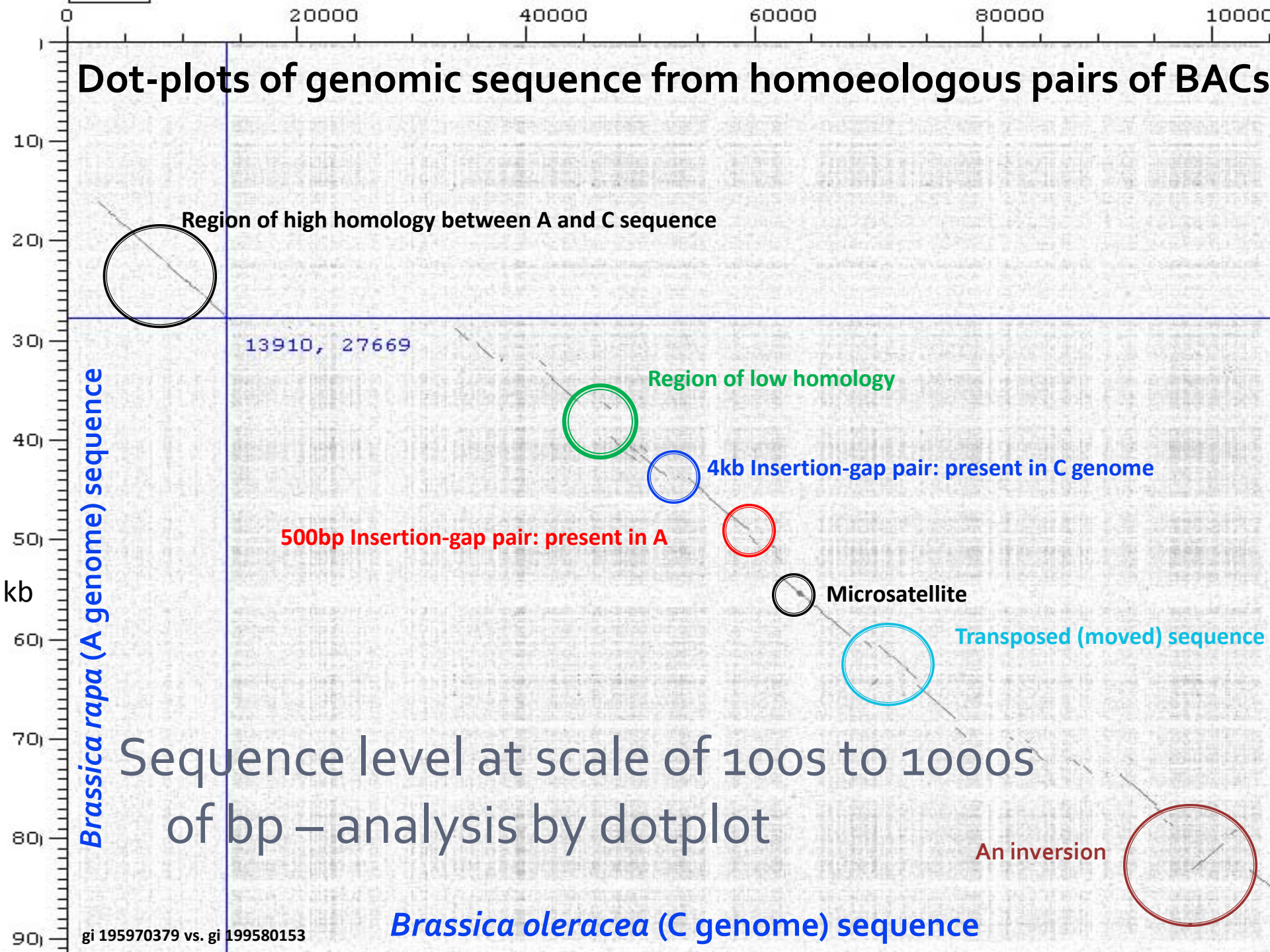
Genome Specificity of a CACTA (En/Spm) Transposon

Carries a S locus-associated SLL3 gene – involved in gene proliferation?

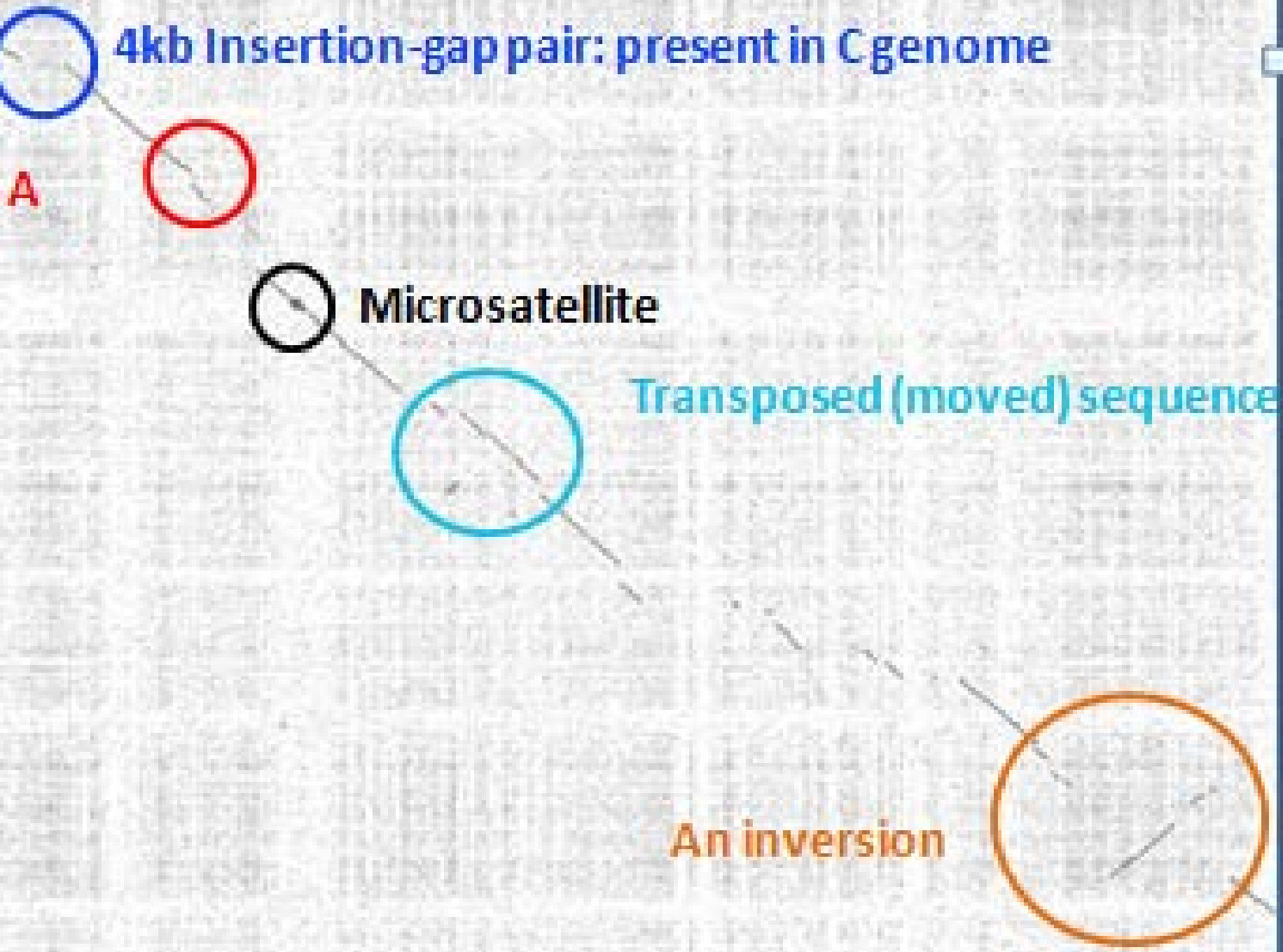
Transposons drive genome and gene evolution



Alix, HH et al
Plant J 2008



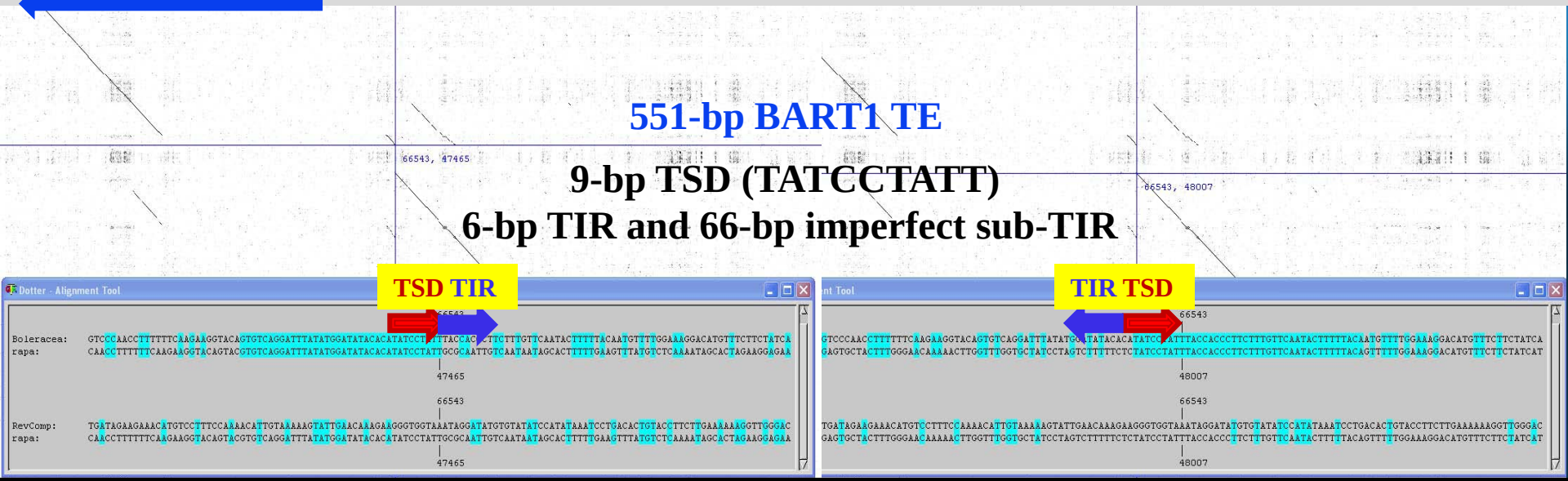
Sequence level at scale of 100s to 1000s of bp – analysis by dotplot


4kb Insertion-gap pair: present in C genome
A
Microsatellite
Transposed (moved) sequence
An inversion

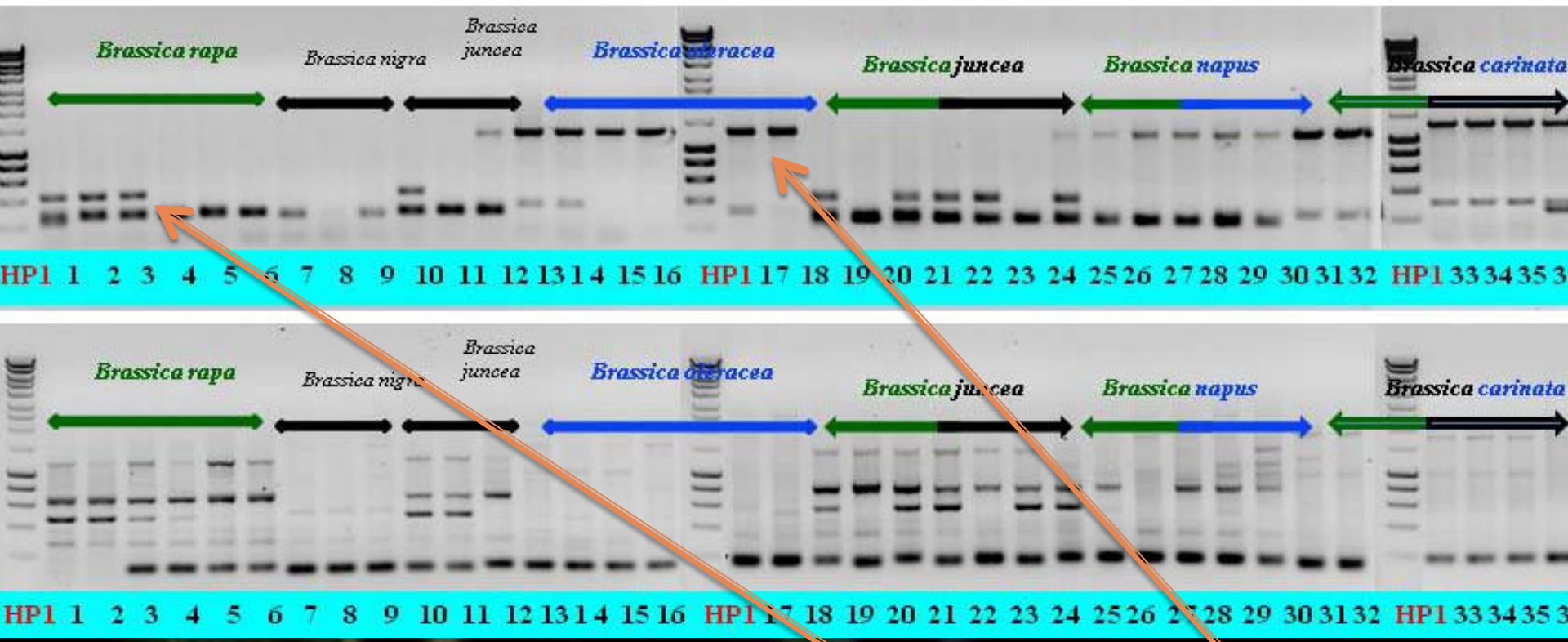
AAGTGAATGGATGCTCGCATTAGTTACTATGAGCCGATTCTCGCTCTTGCGAAAGCTAAAGAGGAAAAGGCCTTCGCATTGCAGAAG
AGCTGGCTGCCAGCGAGCAAGAGGTTTTCAATATTGGCTTGTGGAAAATTTGTTGCCACTTTTGCTTTACTAAGGAATGAAATAATAC
TTGTTTTTTTTTTTCATGGTTAATATTAGAAGATATAATTTCCTTTGAAGTTAGATTACGTTTCTTTATGTCGACGAAGTGAAGAAATATT
GTCTTGTTTATGGTTCCTTCTAGTCCCAACCTTTTTTCAAGAAGGTACAGTACGTGTCAGGATTTATATGGATATACACA

TATCCTATTG**C**G**C**A**A**TT**GTC**AATA*ATAGCAC***TTTTT**GAAG***TTTATGTCTCAAAATAGCACTAGAAGGAGAAAGTCACAAAAATGATATT***
CATTAAAGGGTAAAATATCTCTTATATCCTTGGTTTAAAATTAAATAAACAAACAAAAATAAATAAAAATAAATA*AAAAAAAA*TGAAAAAA
AAGAAAT*TTTTTTT*ATAGTTTCAGATTATATGTTTTCAGATTCG*ATTTTTTTTTT*ATTTTTTT*ATTTTTTT*CGAA*ATTTTTTTTT*T*ATTTTTTTT*CA
A*ATTTTCTTTTT*ATAATTT*AAAAA*TACTTTTTGAAACTG*TTTTTTT*A*ATTTTT*ATTTTTTATTTTAGTATTT*ATTTTTT*ATAAAATTTTAAACCCT
AATTCCTAAACCCCCACCCCTTAACTCTAAACCCTAAGGTTTGGATTAATTAACCCAATGGATATAAGTGT***ATATTTACCTCTTTAATGA***
AACCTATTTTTGTGACTTTGAATCTTGAGTGCTACTTTGGGAACAAAAAACTTGGTTTG*GTGCTAT*CCTA**GTC**TT***TTT***TC**TATCCTATT**

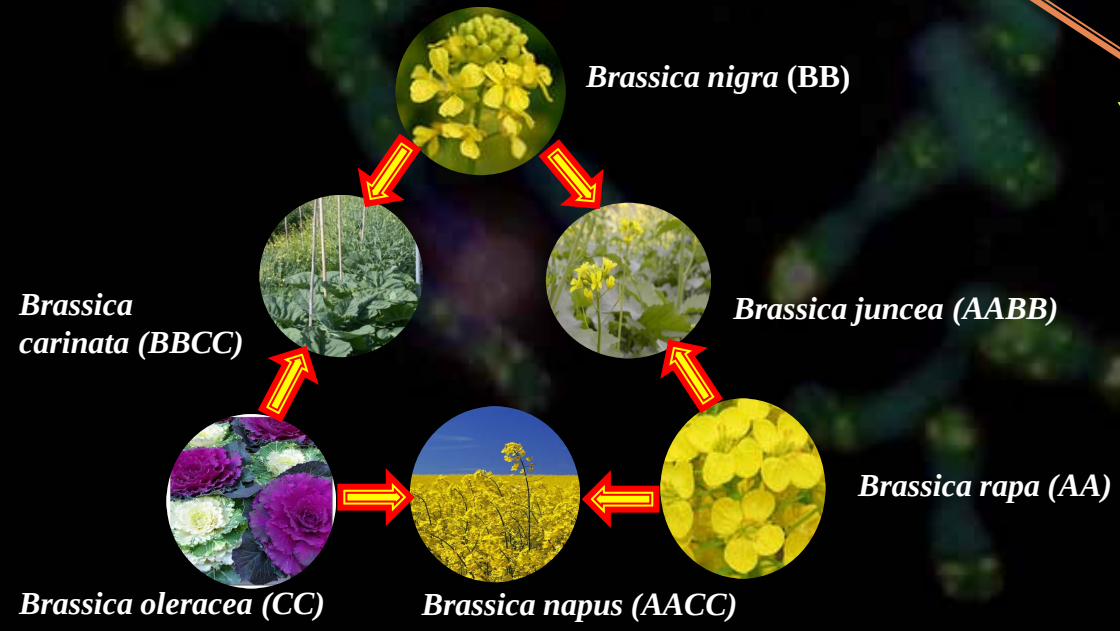
TACCACCCTTCTTTGTTCAATACTTTTTACAGTTTTTGGAAAGGACATGTTTCTTCTATCATCACTTAATGGTTATATATGTATGAGAAG
TTTGAAAGAGATTACACTGTTTTTGGAATATTAAAAAAAAAAAGATATTACAAGATCTGATTTTGTTTGTATTTTAAAATTCTACCAAATC
TCTCCTCAAAATCTTGGTCAAAGTCCAAAAATCCAAATATCTCAGTTAAATTCCACCAAATATGAAATCCTAAAACTTTTCCAAAATA
GTTCAATAAGCCCTTAGTGTTTGGTG

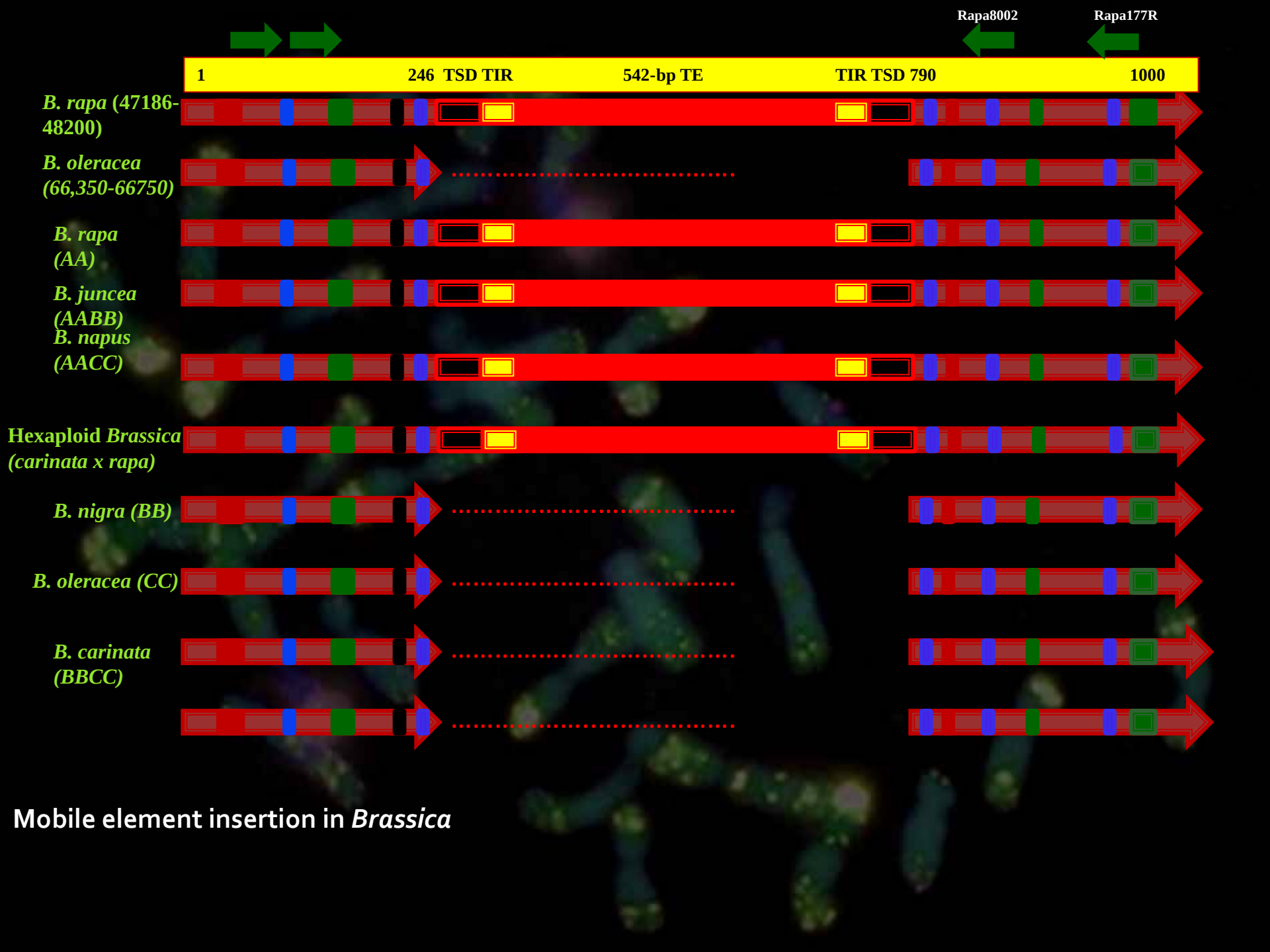


***Brassica rapa* with inserted 542bp sequence not present in *B. oleracea*. 9bp TSD (red letters and arr**
and TIR (blue). Flanking primers used in PCR (next slide) as blue arrows on sequence
Faisal Nouroz 2011

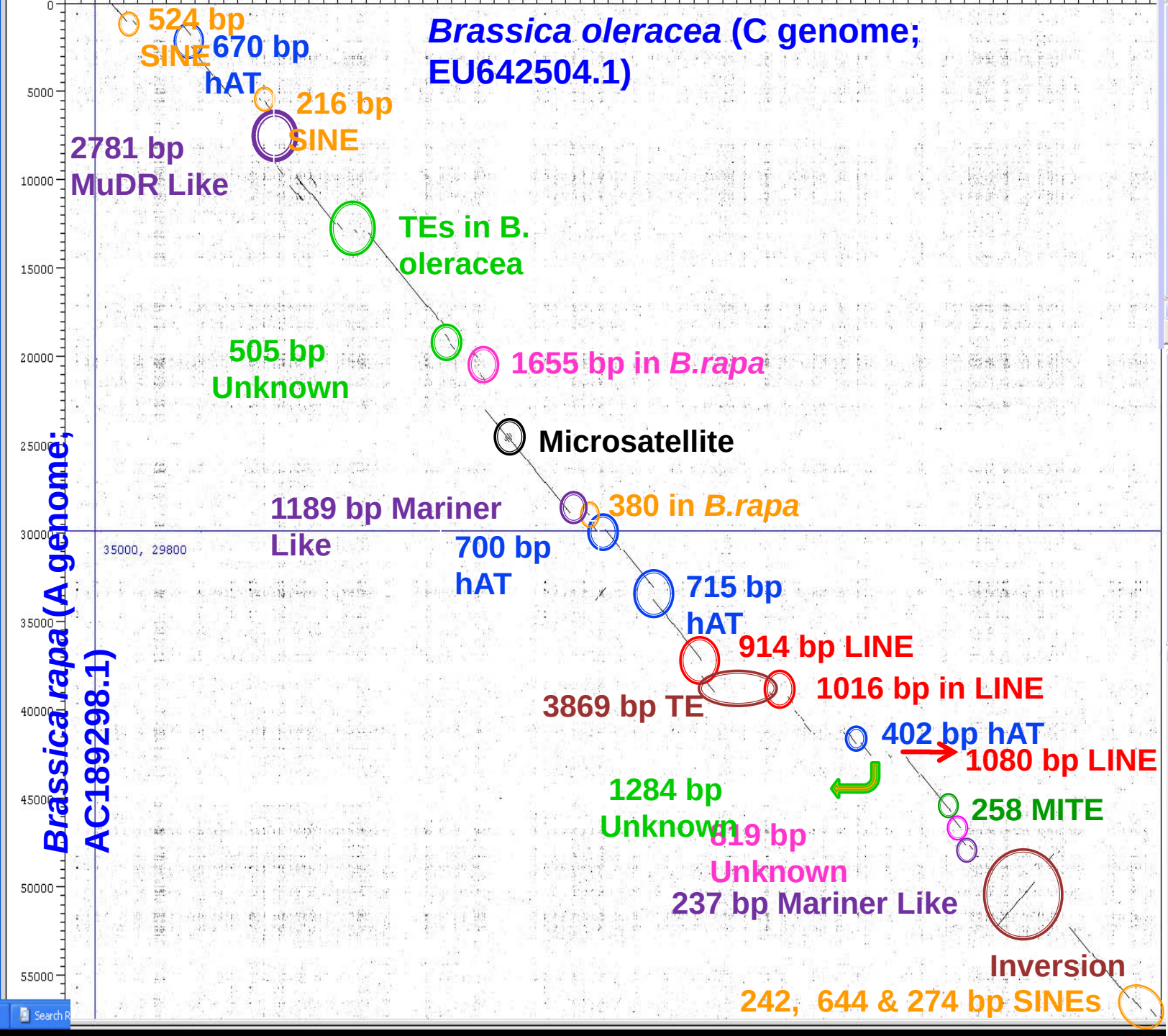

Brassica rapa
Brassica nigra
Brassica juncea
Brassica oleracea
Brassica juncea
Brassica napus
Brassica carinata
HP1 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 HP1 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 HP1 33 34 35
Brassica rapa
Brassica nigra
Brassica juncea
Brassica oleracea
Brassica juncea
Brassica napus
Brassica carinata
HP1 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 HP1 18 19 20 21 22 23 24 25 26 28 29 30 31 32 HP1 33 34 35

Young Old


Brassica nigra (BB)
Brassica juncea (AABB)
Brassica rapa (AA)
Brassica napus (AACC)
Brassica oleracea (CC)
Brassica carinata (BBCC)



Mobile element insertion in *Brassica*


Brassica oleracea (C genome; EU642504.1)
524 bp SINE
670 bp hAT
216 bp SINE
2781 bp MuDR Like
TEs in B. oleracea
505 bp Unknown
1655 bp in B.rapa
Microsatellite
1189 bp Mariner Like
380 in B.rapa
700 bp hAT
715 bp hAT
914 bp LINE
1016 bp in LINE
3869 bp TE
402 bp hAT
1080 bp LINE
1284 bp Unknown
258 MITE
819 bp Unknown
237 bp Mariner Like
Inversion
242, 644 & 274 bp SINEs
Brassica rapa (A genome; AC189298.1)
35000, 29800
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000

Repetitive DNA

rapid evolution in copy number, location and sequence, with diverse turnover mechanisms

often marks the major differences between closely related species

it is hard to analyse by next generation or whole-genome sequencing methods

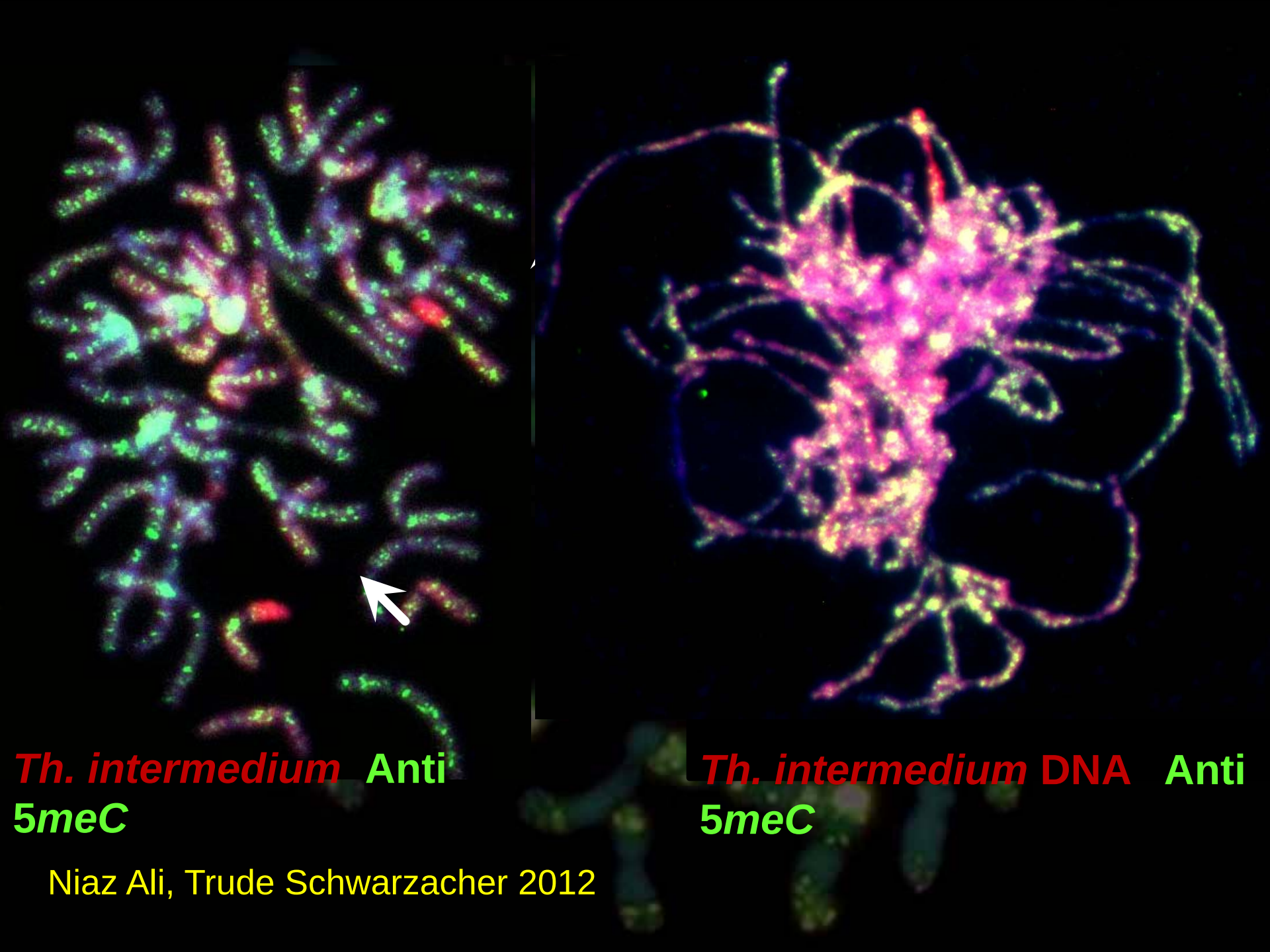
Many of the repetitive sequences are retrotransposons and DNA transposons

Some are microsatellite motifs

Some are satellites – including the most rapidly evolving sequences

Mace wheat
Graybosch et al. 2009
In situ: Niaz Ali & Schwarzacher

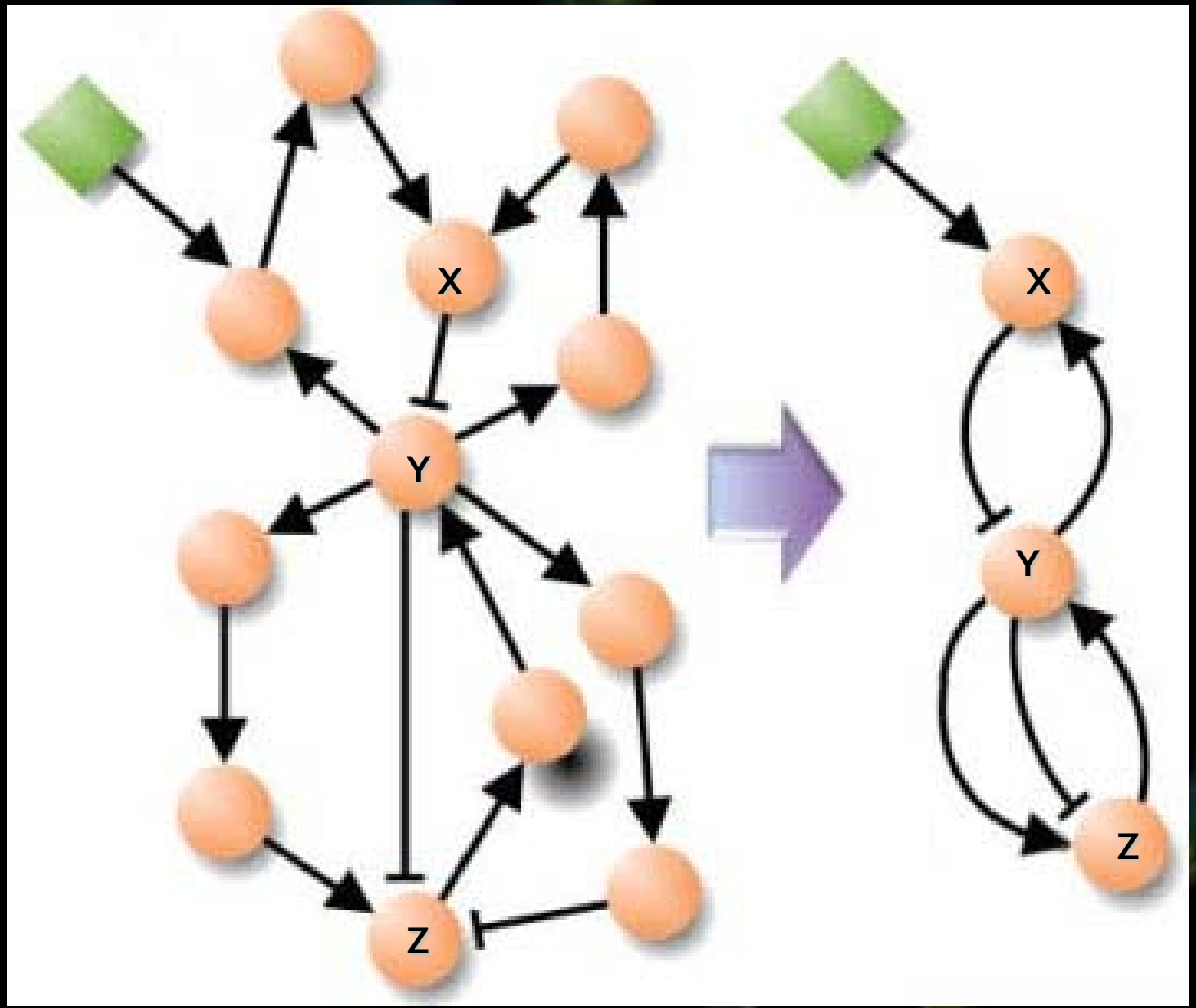
Wsm-1: only highly effective source of resistance to WSMV



Niaz Ali, Trude Schwarzacher 2012

Network reduction

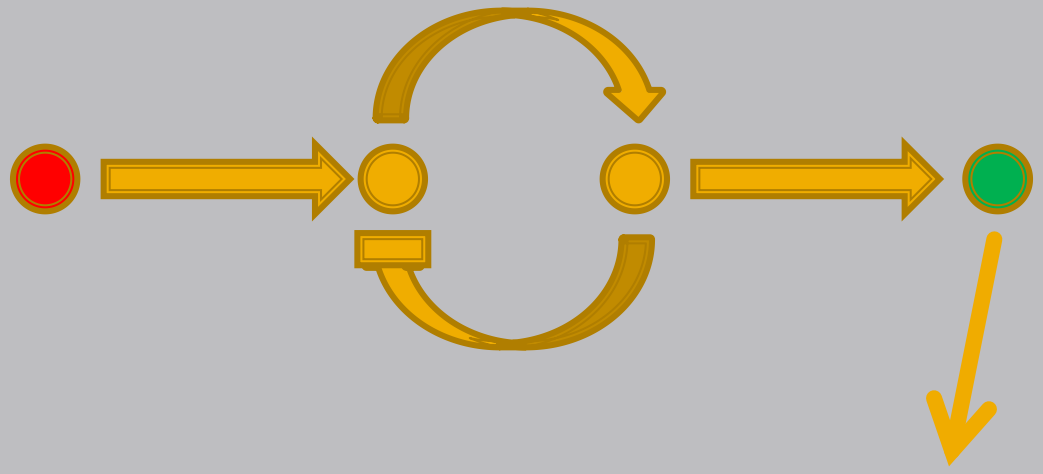
Circadian Clock regulation
after Leloup & Goldbeter
cf Andrew Millar
in Arabidopsis

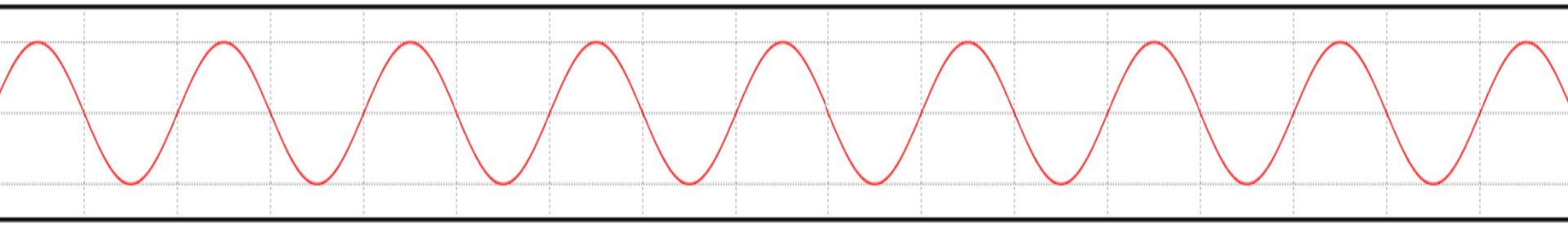


Kim, HH, Cho et al. 2011 Science Signaling

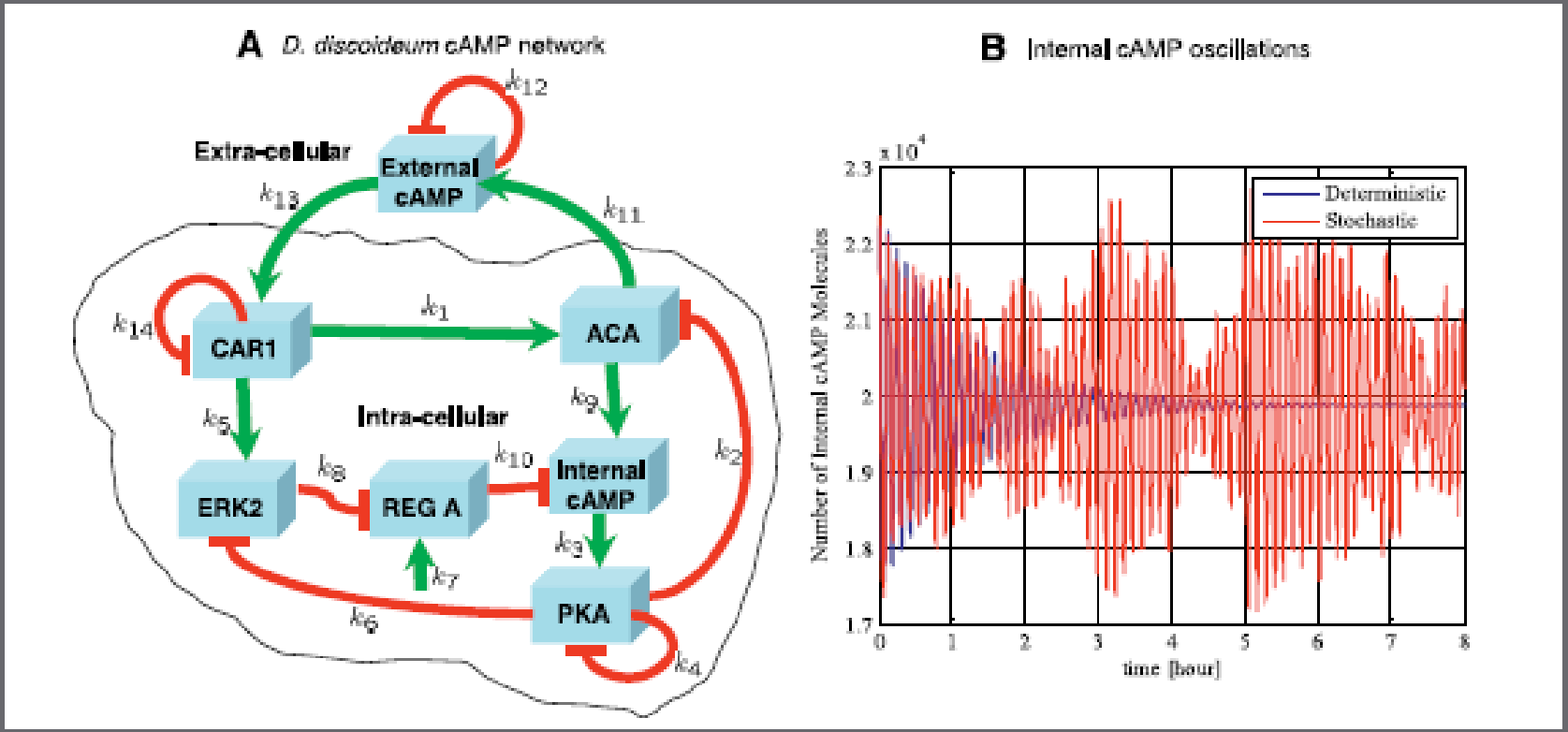
Regulation of oscillations

- Robustness
- Synchronization without external regulators



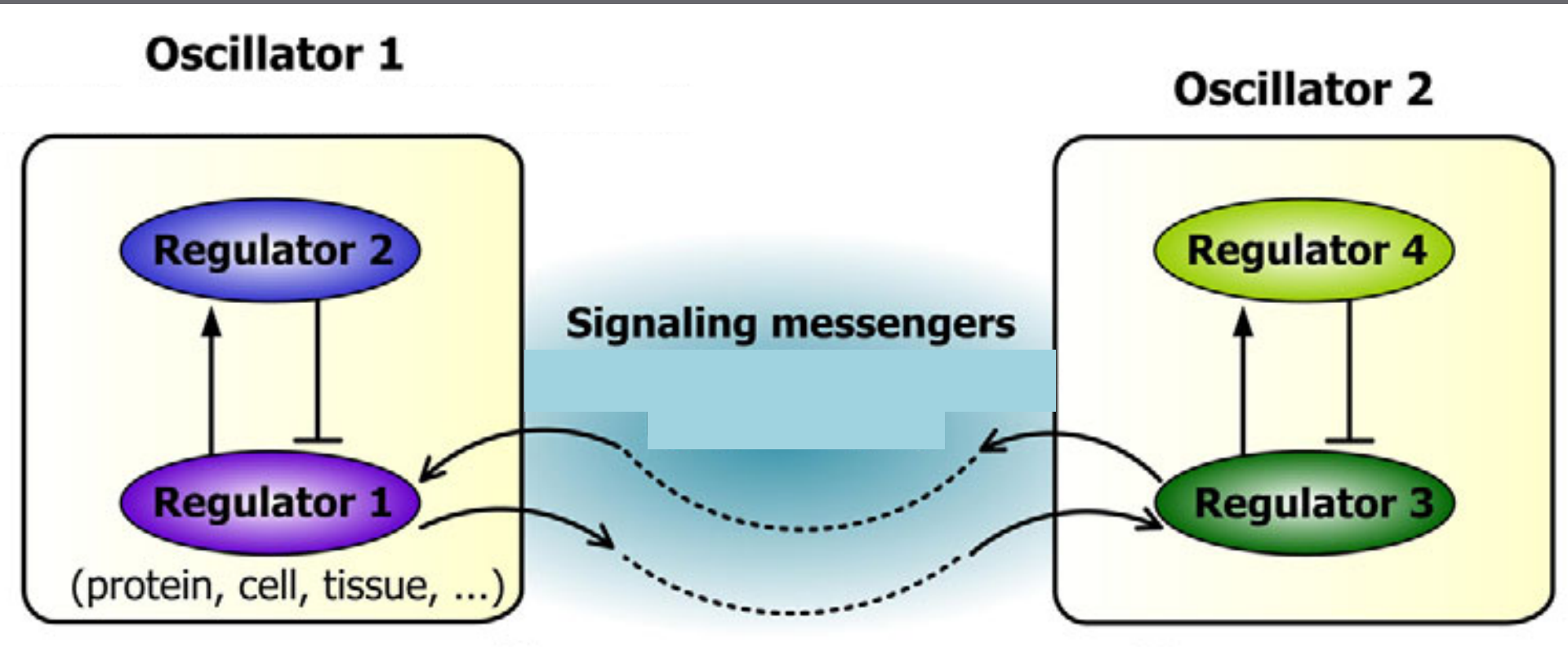


Oscillations: noise and stability



- Stochastic fluctuations
  - preserve stable oscillations
  - ensure robustness of the oscillations to cell-to-cell variations
- Robustness analysis requires stochastic simulation

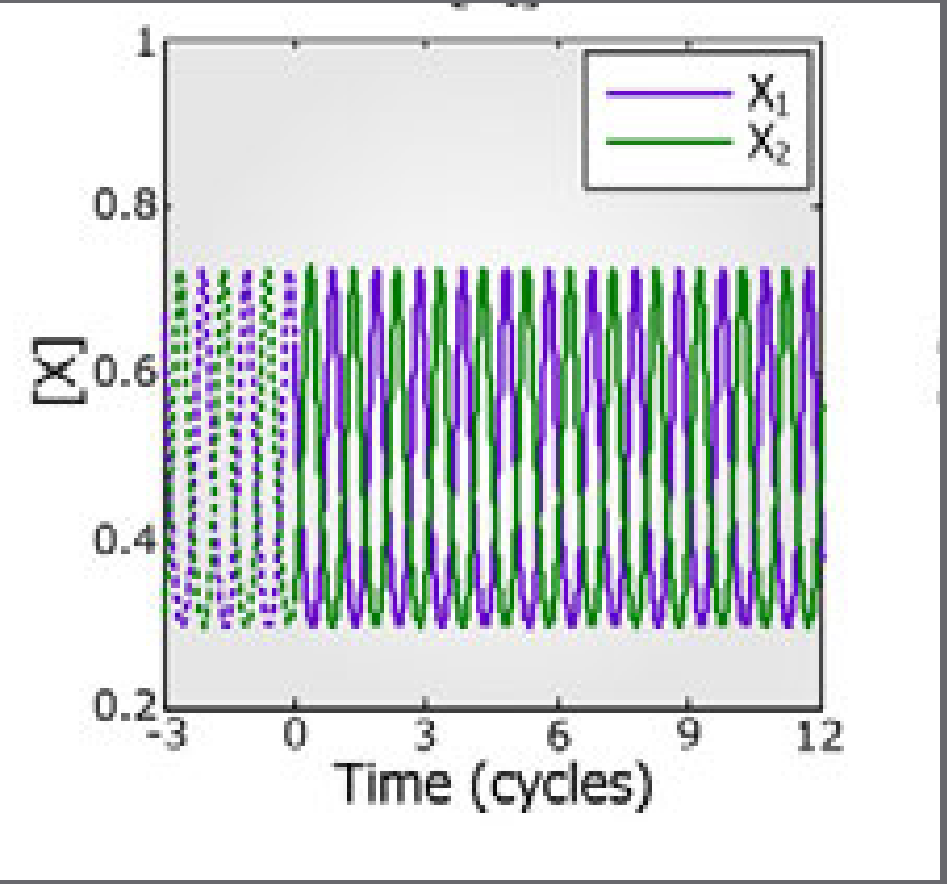
JongRae Kim et al. Stochastic noise and synchronisation during *Dictyostelium* aggregation make cAMP oscillations robust. PLoS Computational Biology 2007

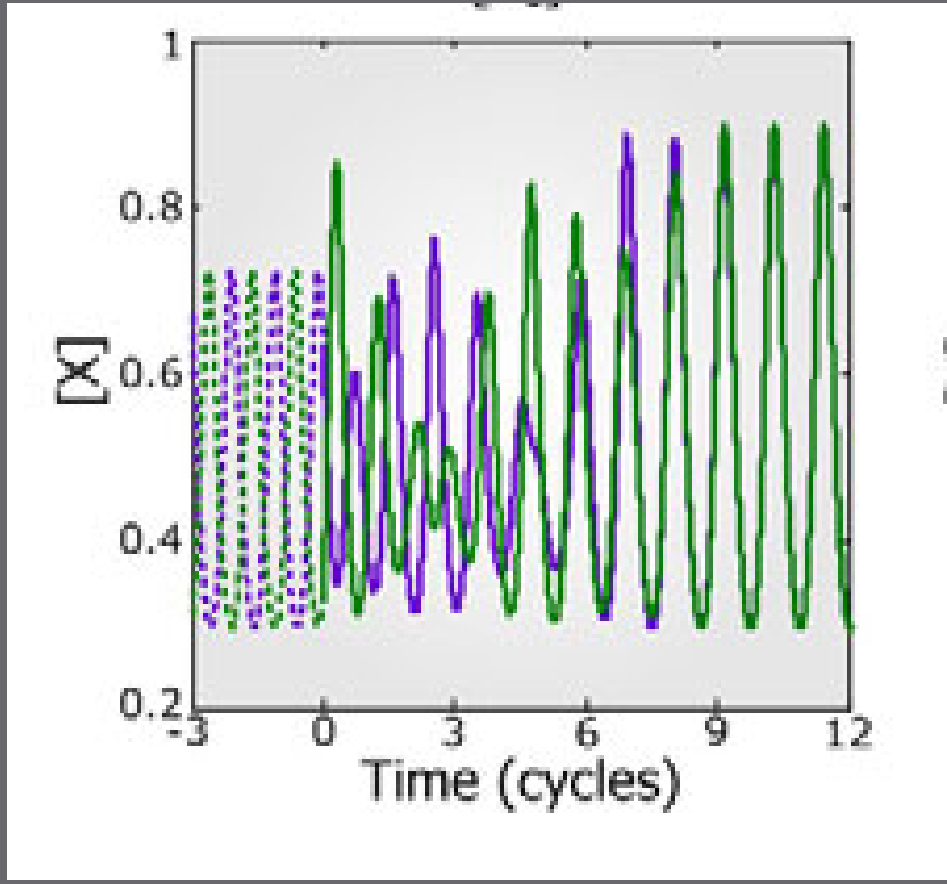


Jeong-Rae Kim, HH & Kwang-Hyun Cho. J Cell Sci 2010

Weak Stronger

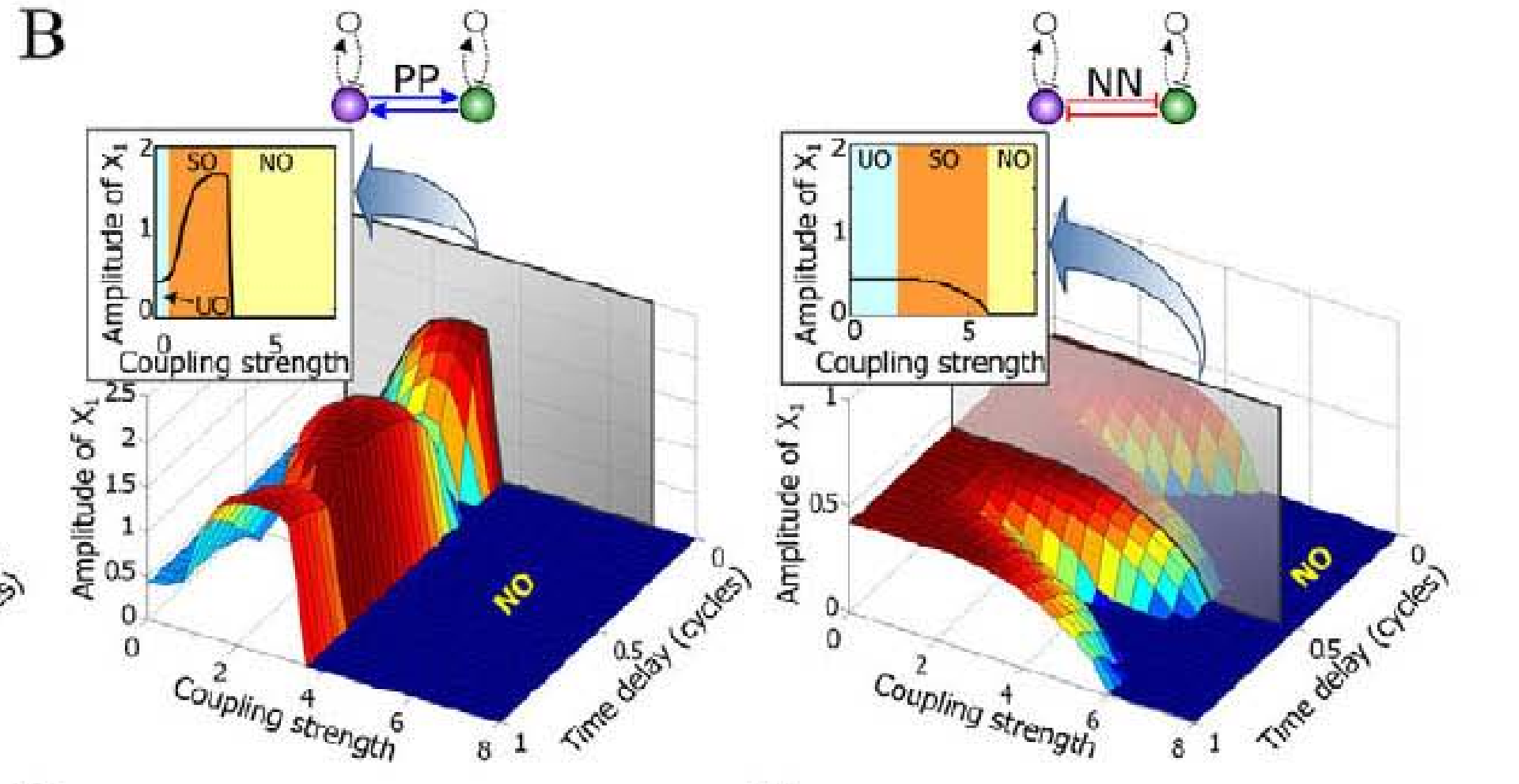
Coupling





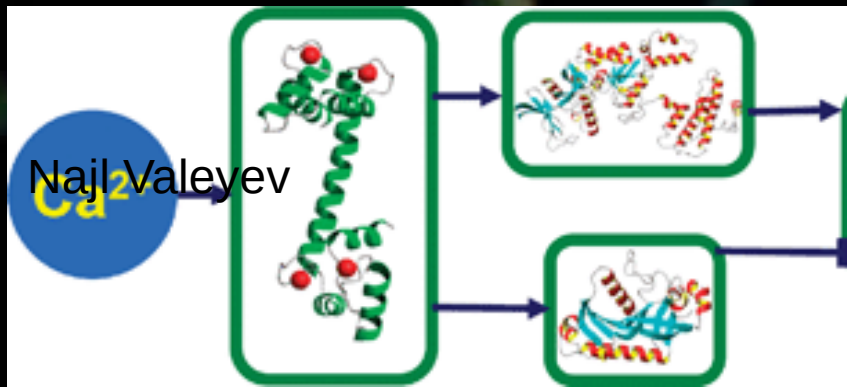
Live version: YouTube – pathh1 channel phaseportrait.avi

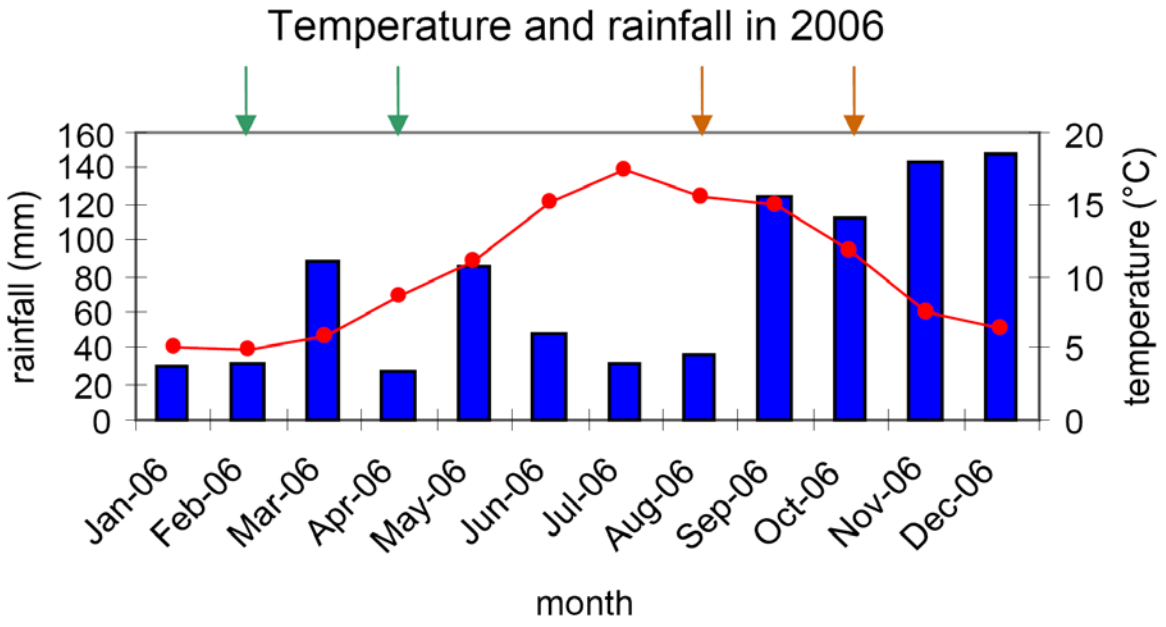
Jeong-Rae Kim, HH & Kwang-Hyun Cho. J Cell Sci 2010

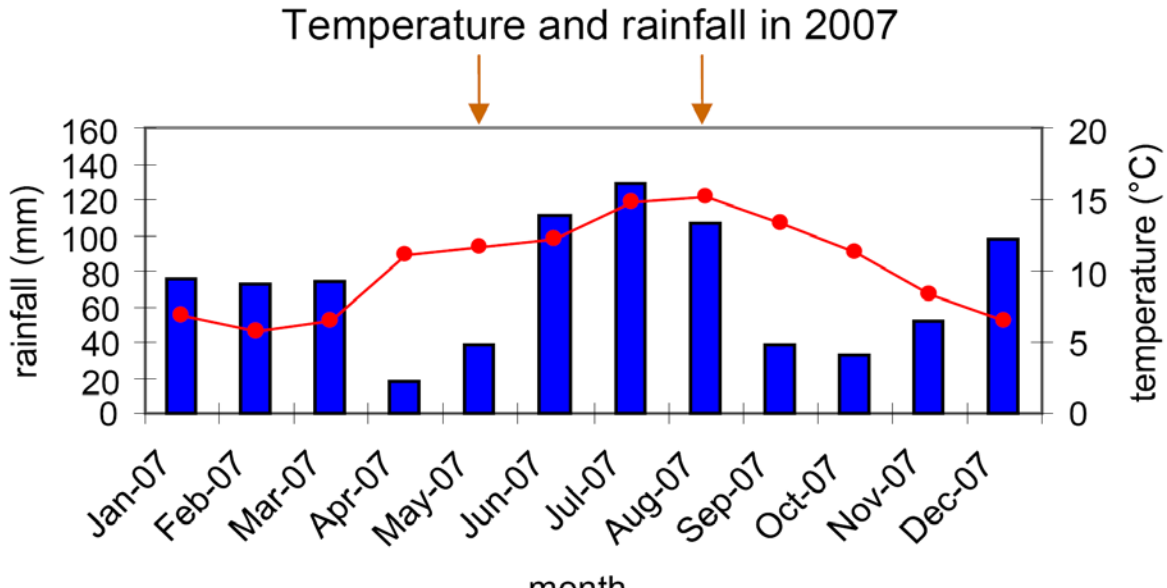

B
PP
NN
SO
NO
UO
Amplitude of X_1
Coupling strength
Time delay (cycles)
NO

Function and multifunction

- How many genes are there?
- 1990s: perhaps 100,000
- 2000: 25,000
- How does this give the range of functions and control?







- Formidable genetic and environmental interactions

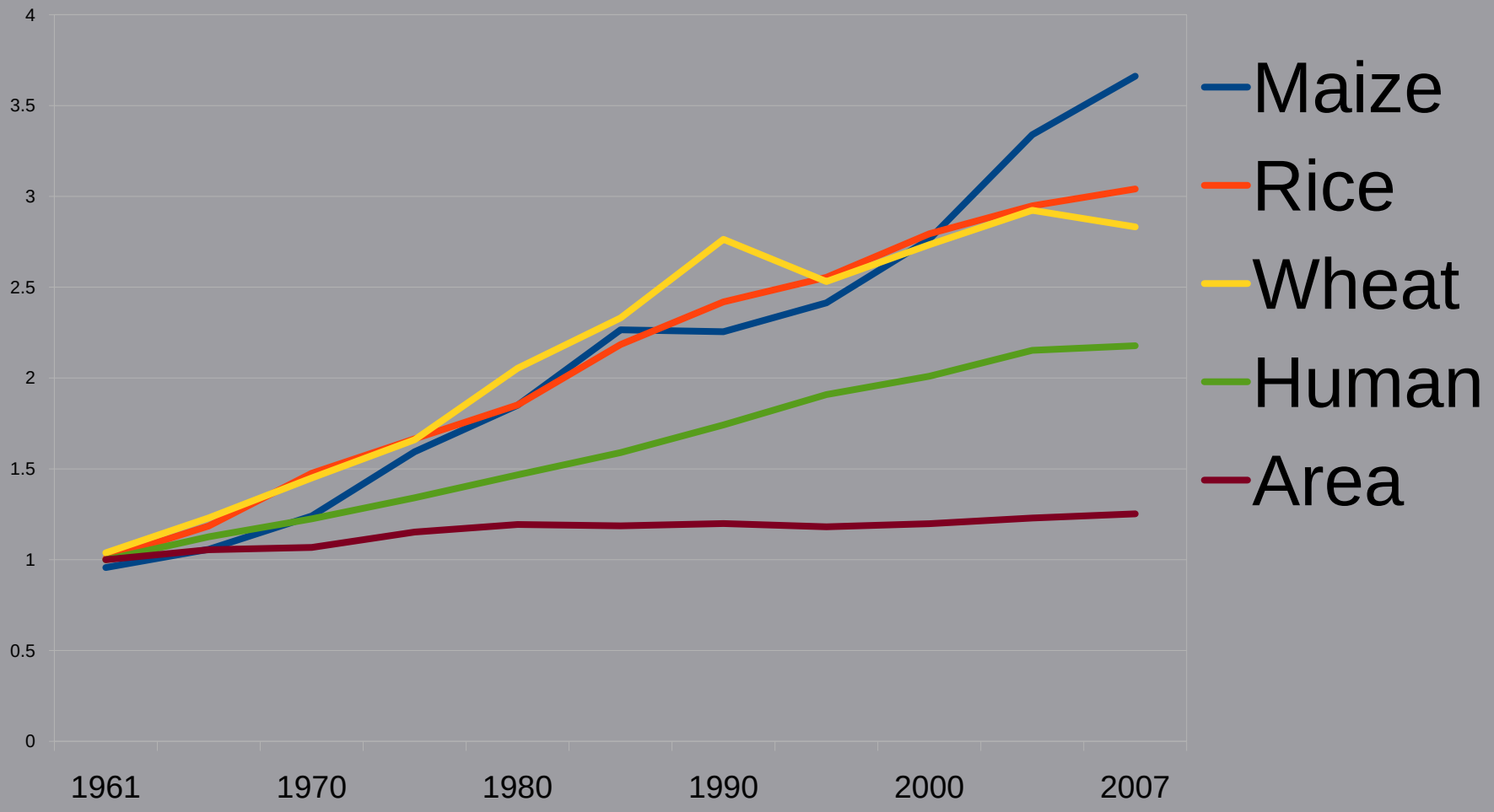
Anhalt, Barth, HH
Euphytica 2009
Theor App Gen 2008

Nothing special about crop genomes?

Crop	Genome size	2n	Ploidy	Food
Rice	400 Mb	24	2	3x endosperm
Wheat	17,000 Mbp	42	6	3x endosperm
Maize	950 Mbp	10	4 (palaeo-tetraploid)	3x endosperm
Potato	900 Mbp	48	4	Modifed leaf
Sugar beet	758 Mbp	18	2	Modified root
Cassava	770 Mbp	36	2	Tuber
Soybean	1,100 Mbp	40	4	Seed cotyledon
Oil palm	3,400 Mbp	32	2	Fruit mesocarp
Banana	500 Mbp	33	3	Fruit mesocarp

Heslop-Harrison & Schwarzacher 2012. Genetics and genomics of crop domestication. In Altman & Hasegawa Plant Biotech & Agriculture. 10.1016/B978-0-12-381466-1.00001-8

50 years of plant breeding progress



United Nations
Millennium Development Goals- MDGs

Goal 1 – Eradicate extreme poverty and hunger

Goal 2 – Achieve universal primary education

Goal 3 – Promote gender equity and empower women

Goal 4 – Reduce child mortality

Goal 5 – Improve maternal health

Goal 6- Combat HIV/AIDS, malaria and other diseases

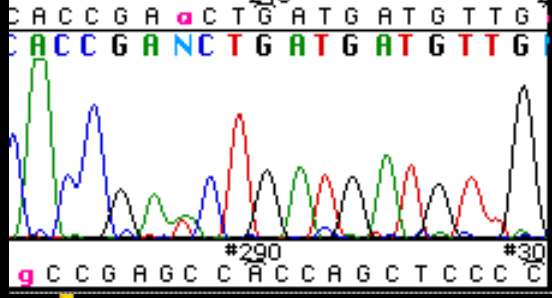
Goal 7 - Ensure environmental sustainability

Goal 8 - Develop a global partnership for development

Thank You For
Shopping

Levels

- Sequences
- Genes / motifs
- Repetitive DNA
- Chromosomes
- Chromosome sets ('Genomes')
- Genotypes/CVs
- Species
- Genera and above



… involving

- Mutation
- Rearrangement
- Duplication
- Deletion
- Homogenization

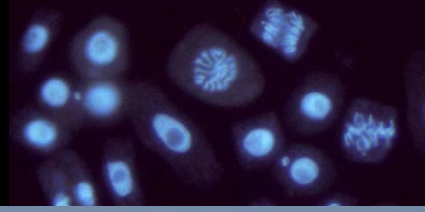
… consequences for

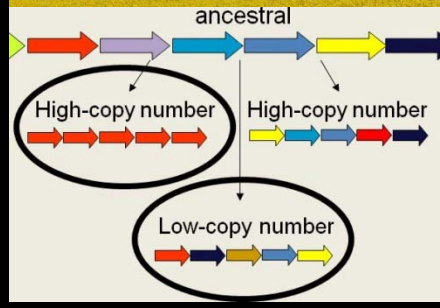
- Crops / wild species
- Selection
- Speciation

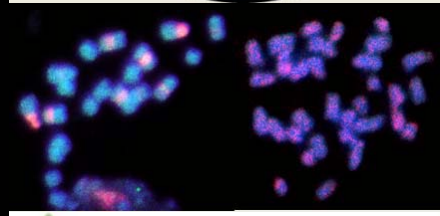
Genome evolution: extinction, continuation or explosion

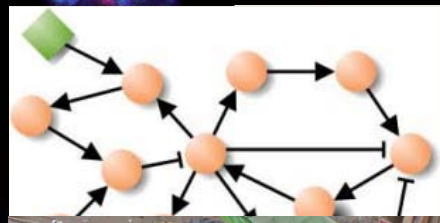
Pat Heslop-Harrison
phh4@le.ac.uk
www.molcyt.com pw/user: 'visitor'

Social media
Follow #PGE11 and Pathh1 on Twitter and AoBBlog.com









Current Opinion Conferences
Plant Genome Evolution
Amsterdam, The Netherlands • 4-6 September, 2011
A *Current Opinion* Conference