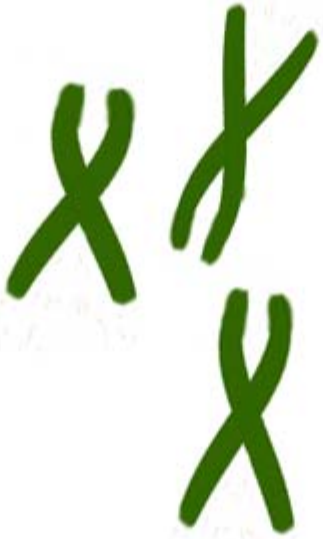
The wonderful world of chromosomes

Pat Heslop-Harrison
www.molcyt.com

Botanical Society of the British Isles



Botanical Society of the British Isles

DNA and botany

- Richard Gornall
- All you ever wanted to know about DNA and Plant Genetics, but didn't like to ask!
-
- Clive Stace
- Classification by molecules: what's in it for field botanists


EVOLUTION

Darwin: The final paragraph of "The Origin"

It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us..

Darwin: The final paragraph of “The Origin”

- It is interesting to contemplate … many plants of many kinds … and to reflect that these elaborately constructed forms, so different from each other … have all been produced by laws acting around us … from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved.

Crop plants

- Little interest to BSBI as few are native to UK

Major Crops 2007 million tons production

(sugar cane excluded)

item	ons) 2007
Maize	785
Rice, paddy	652
Wheat	607
Potatoes	322
Sugar beet	248
Cassava	228
Soybeans	216
Oil palm fruit	192
Barley	136
Sweet potatoes	126
Tomatoes	126
Watermelons	93
Bananas	81
Seed cotton	73
Cabbages and other br	69
Grapes	66
Sorghum	65
Onions, dry	64
Apples	64
Oranges	64
Coconuts	55
Yams	52

Crop plants

- Farmers have been getting better for 5000 years …
  - Weed control
  - Drainage/irrigation
  - Fertilization

Crop plants

- Great interest to BSBI as
  - Dominant in the landscape, particularly in England
  - Crop cultivation has the major impact on biodiversity
  - Wild collection of species (non-crops!) has an impact on diversity
- We can learn a lot about plant evolution and relationships from learning about the ‘laboratory’ of crops – intense selection over a few millennia, worldwide distribution, clear definition of genotypes

The Origin of Species begins with an example of how humans have domesticated certain species and used artificial selection, in contrast to natural selection, to produce extraoridnary variation in a short time. Darwin focused on "fancy" pigeons, but it is apparent in many dopmestic species, including dogs, cattle and crop plants like wheat (see below).

At that time, it was not known how such variation arose or was maintained. Now we know that this variation is due to genes and chromosomes, and a team here in Leicester investigate how the number and organisation of chromosomes varies across wheat varieties.

Dr Trude Schwarzacher and Prof Pat Heslop-Harrison investigate the evolution of cereals by examining their chromosomes. On the right are the chromosomes from a root cell of rye. The red and green spots are DNA sequences which can be used to trace the ancestry of different cereal species and varieties.

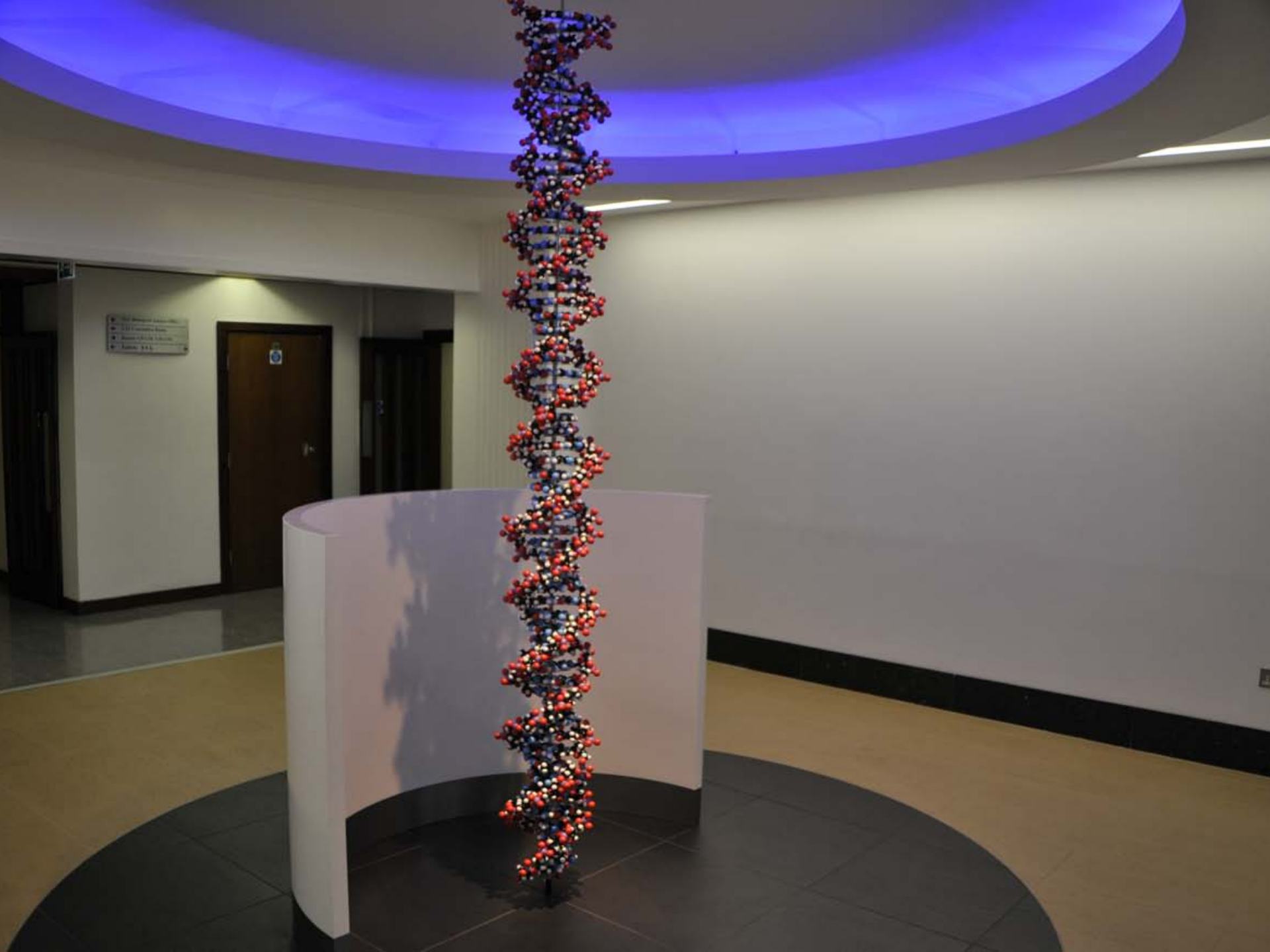
"Species are only strongly marked and permanent varieties"

Below are examples of wheat ears from different hybrids and wild varieties of wheat.

Crop plants

- Farmers have been getting better for 5000 years …

- They've kept up with pests and diseases
  - Choice of what to grow (species and cultivar: breeding)
  - Biosecurity
  - Chemical control



DNA: the Genome

- The entire complement of genetic material

Contains all the instructions encoded in the sequence of bases

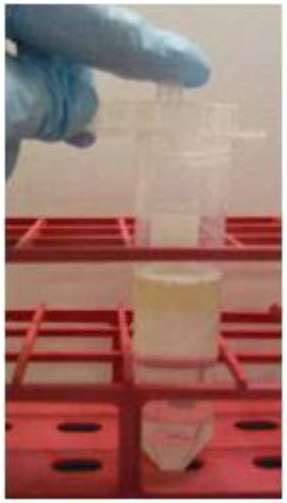
A T
T A
A T
C G
C G
G C
A T
T A
T A

1. Grind tissue, lyse cells

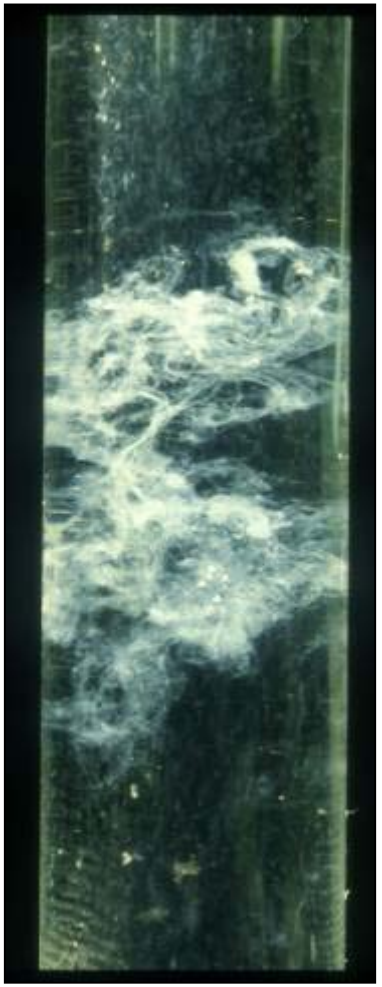


2. Ethanol precipitation, centrifugation, clean with phenol/chloroform



3. Precipitate in ethanol



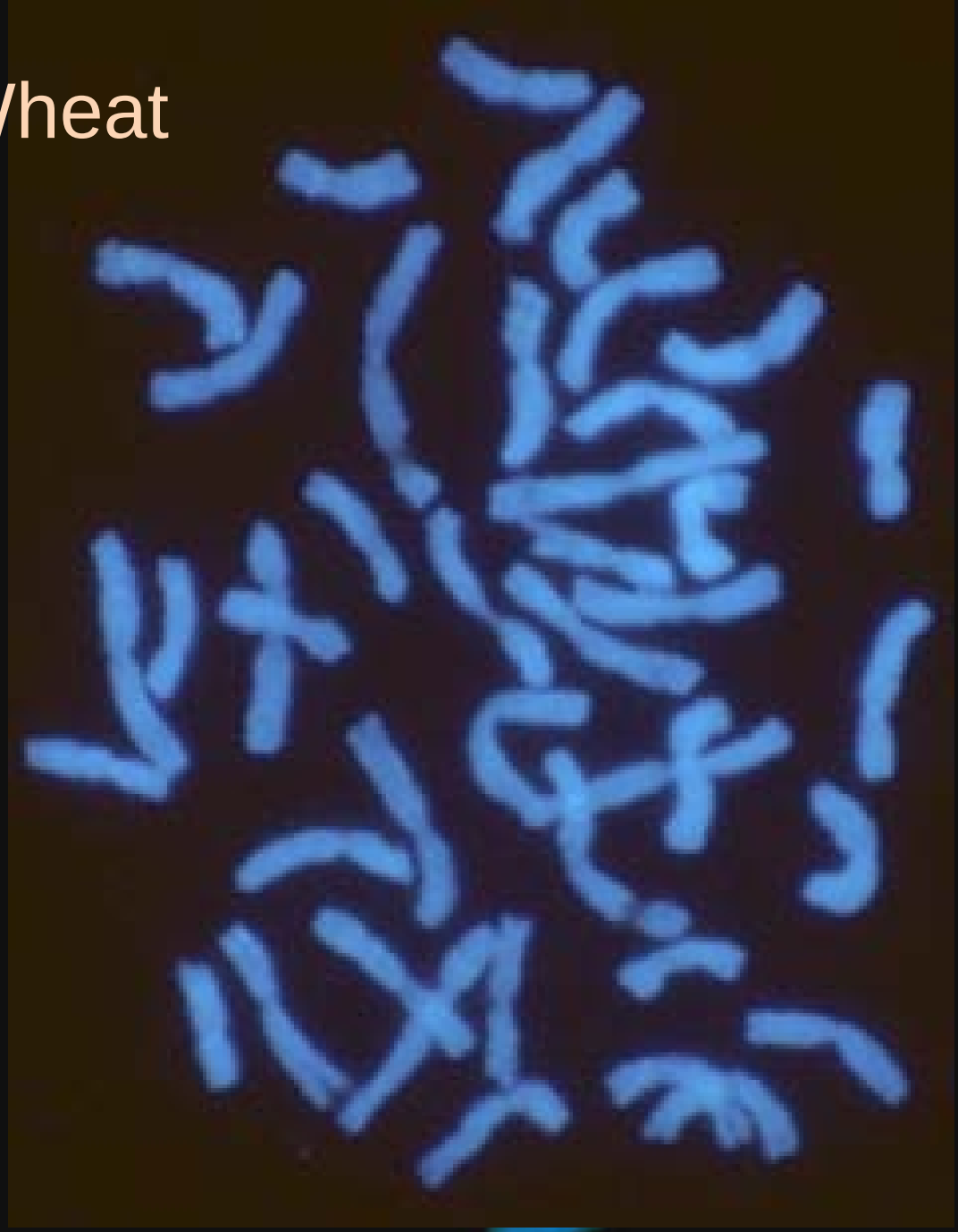
- Maybe DNA did the same for plants as Mendeleev did for chemistry
    - Framework for 4000 years
    - Linnaeus 1750s with flower characters
    - 1800-1900s increasingly natural taxonomy
    - DNA: all species can be classified based on natural relationships
- But
    - Still some hybrids are difficult
- Levels of evolution
    - DNA bases
    - Chromosomal and genome

Crops and Chromosomes

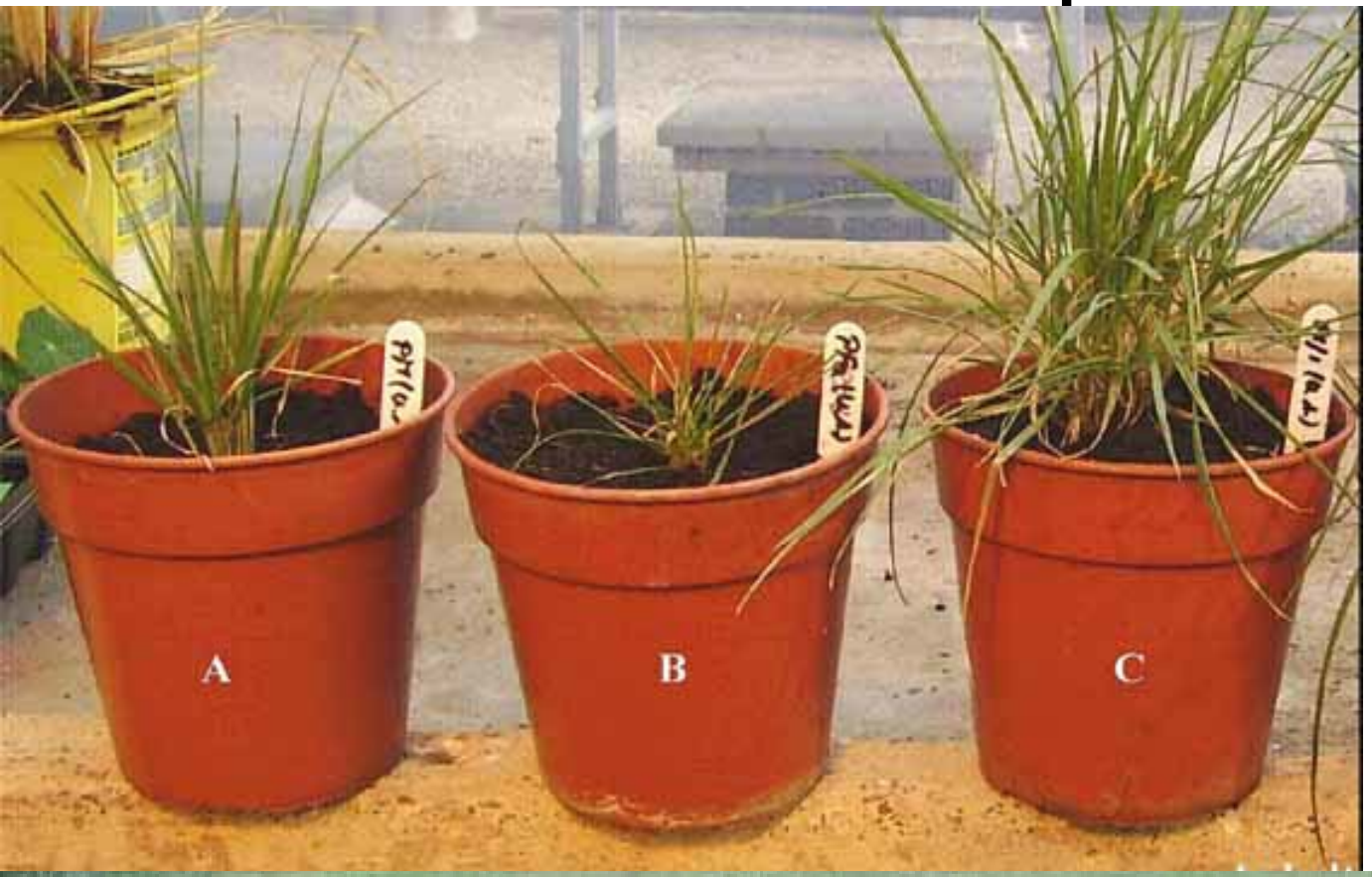
Arabidopsis

Human

Wheat

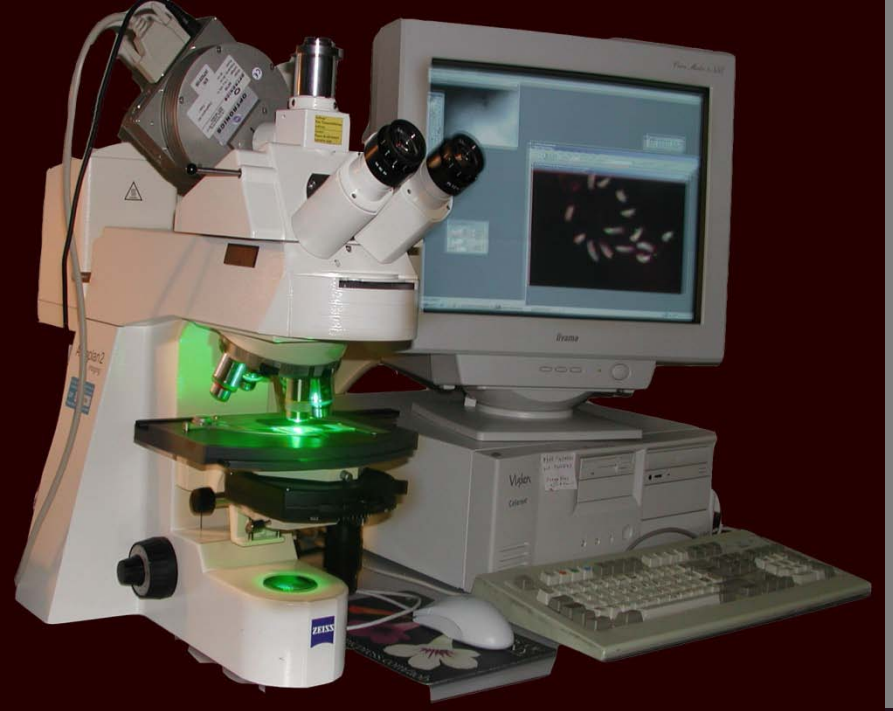


Lolium Biomass production

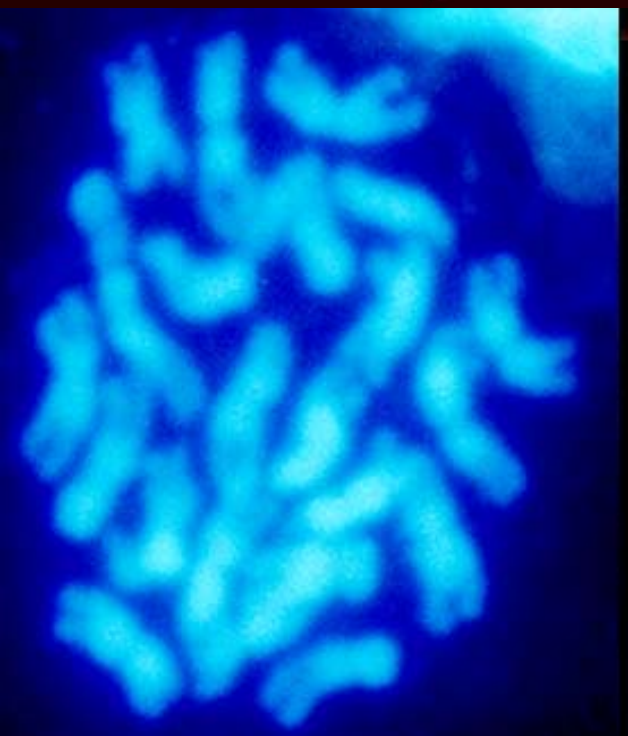


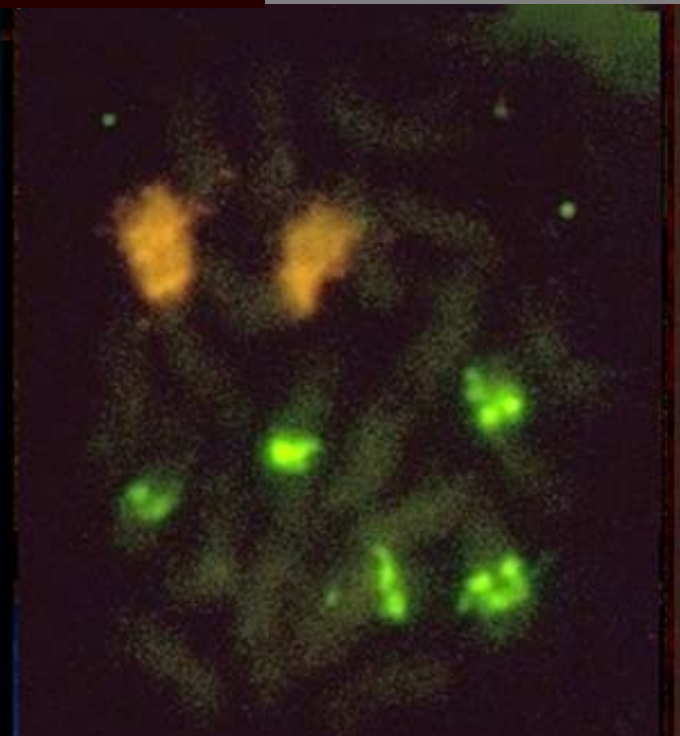
Susanne Barth, Ulrike Anhalt, Celine Tomaszewski


musa
genomics



Musa acuminata ‘Calcutta 4’
AA genomes, 2n=2x=22

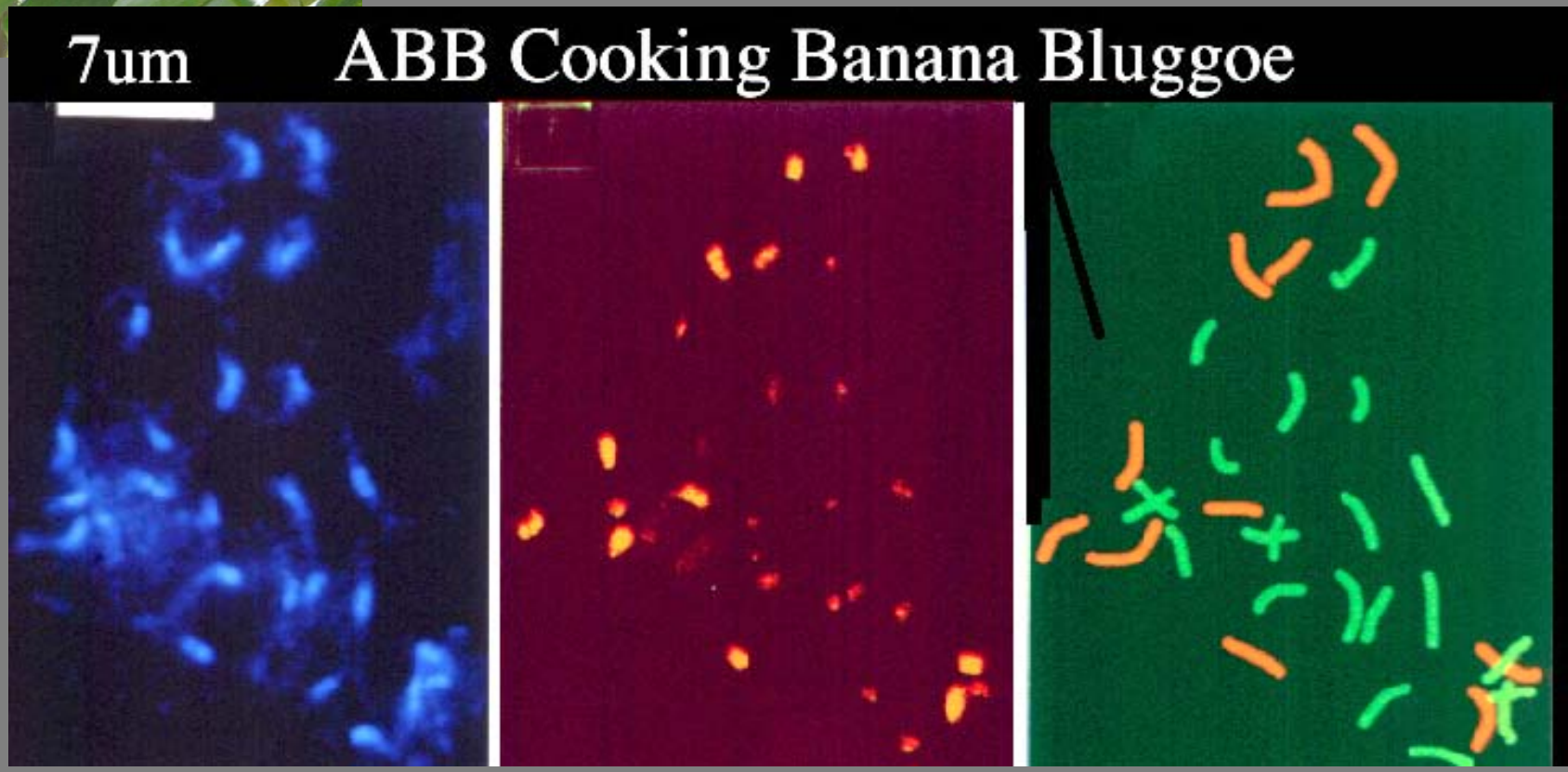




Musa/Banana Diversity

Cultivars are mostly parthenocarpic, sterile triploids, 2n=3x=33

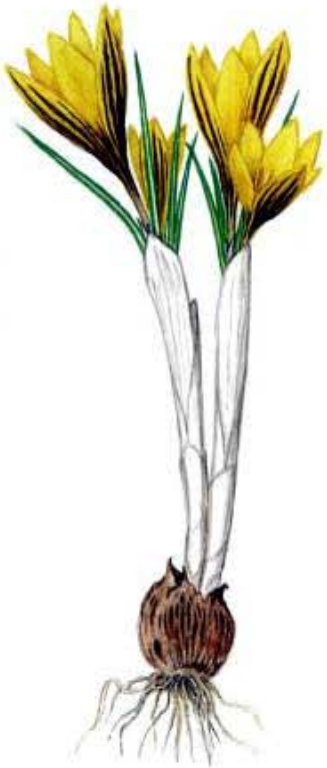
AAB and ABB hybrids: plantains, cooking bananas



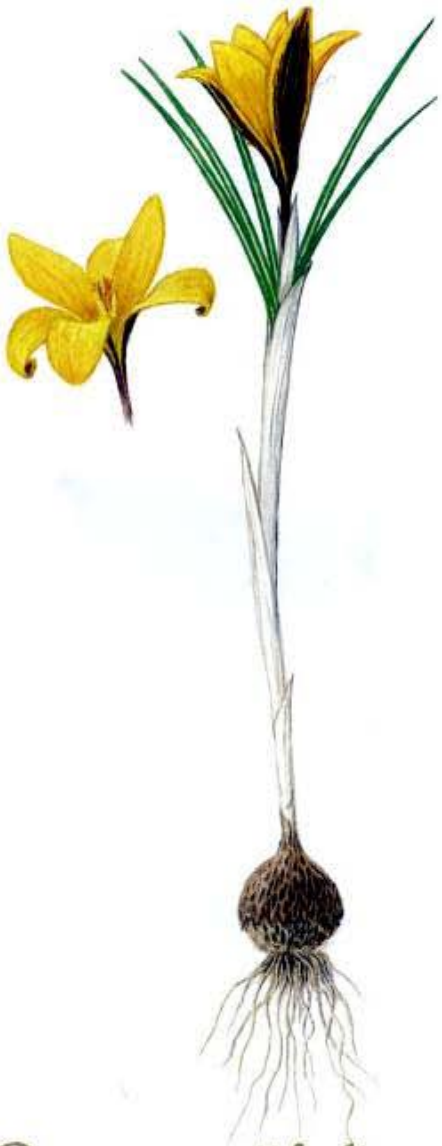
Osuji et al.
Annals of Botany

Crocus species and hybrids

C. flavus
2n=8



C. 'Stellaris'
2n=2x=10

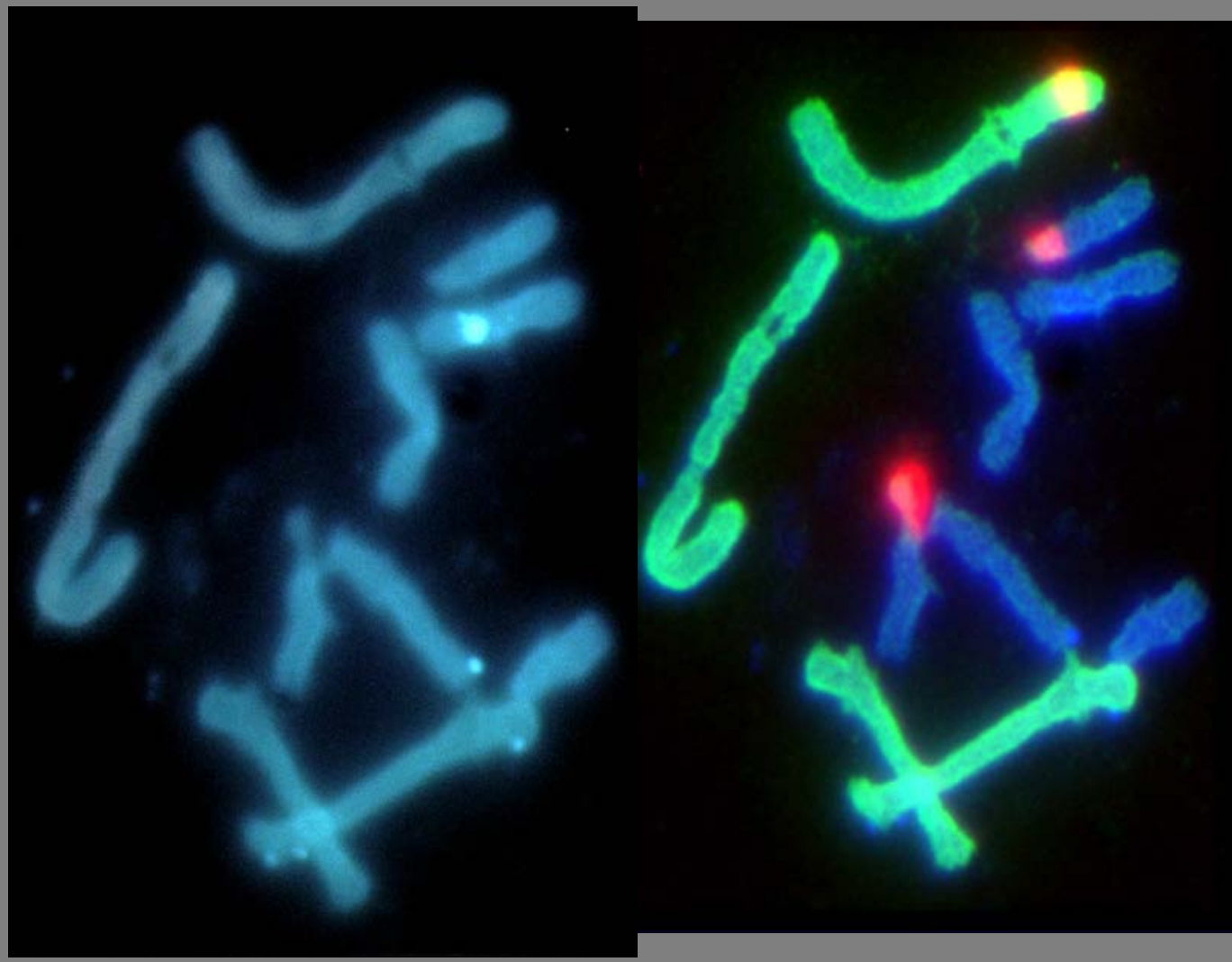


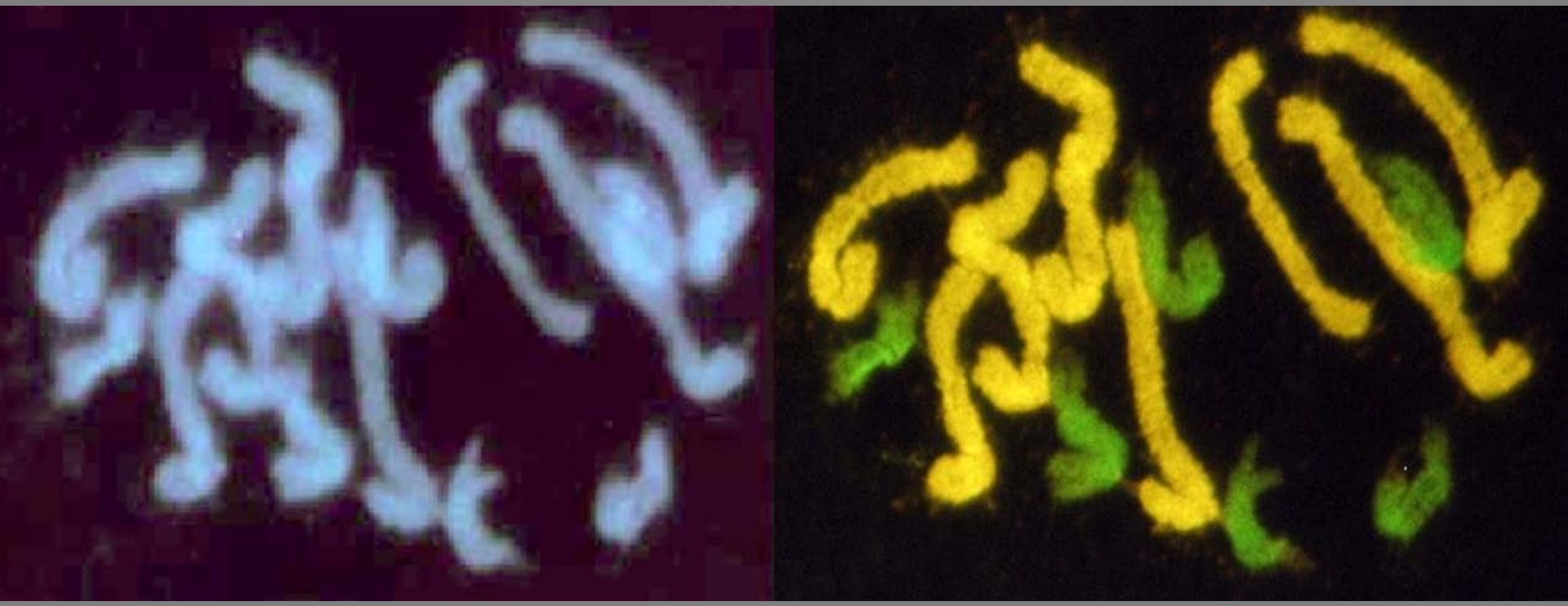
C. angustifolius
2n=12

C. 'Golden Yellow'
2n=3x=14

B.J.94

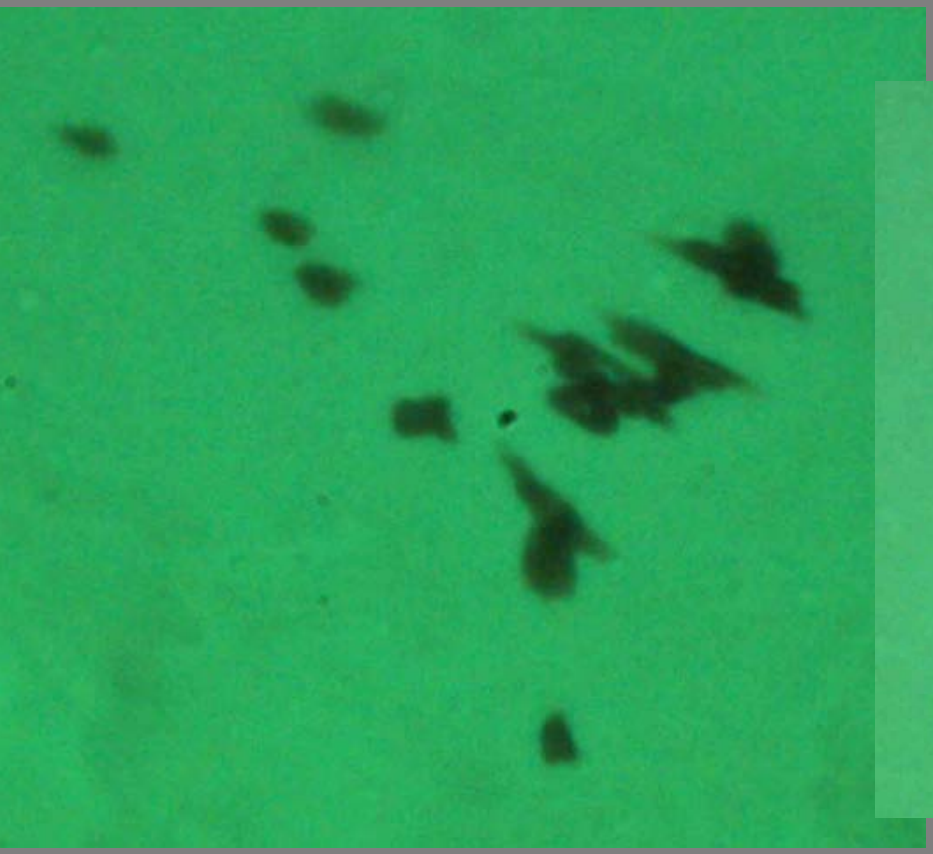
- The parents look similar, sharing many genes
- Total genomic DNA as a probe labels the parental genomes differentially





Orgaard et al. Annals of Botany

Metaphase I in triploid Golden Yellow Crocus



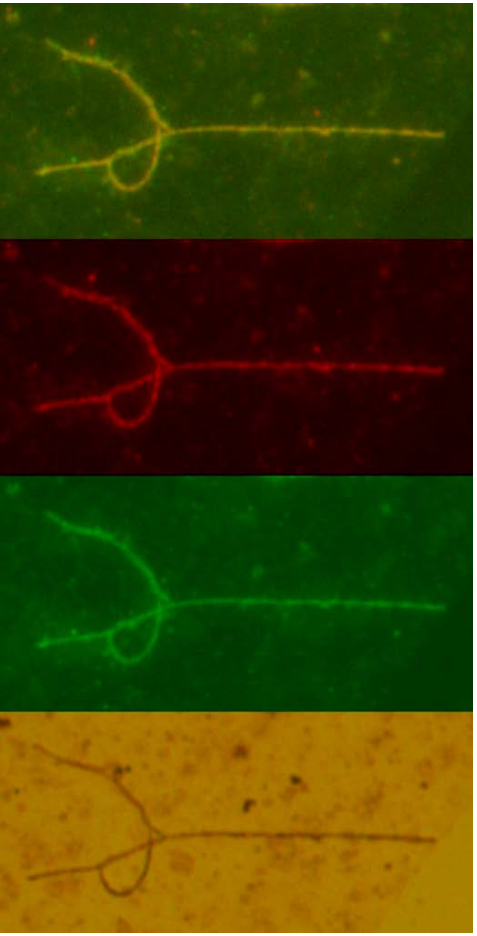
In many metaphase I cells of this triploid, we see four bivalents from pairing of the four pairs of *C. flavus* (2n=2x=8)-origin chromosomes, with the six chromosomes from *C. angustifolius* (2n=2x=12) present as univalents.

John Bailey, Farah Badakshi et al.

www.crocusbank.org

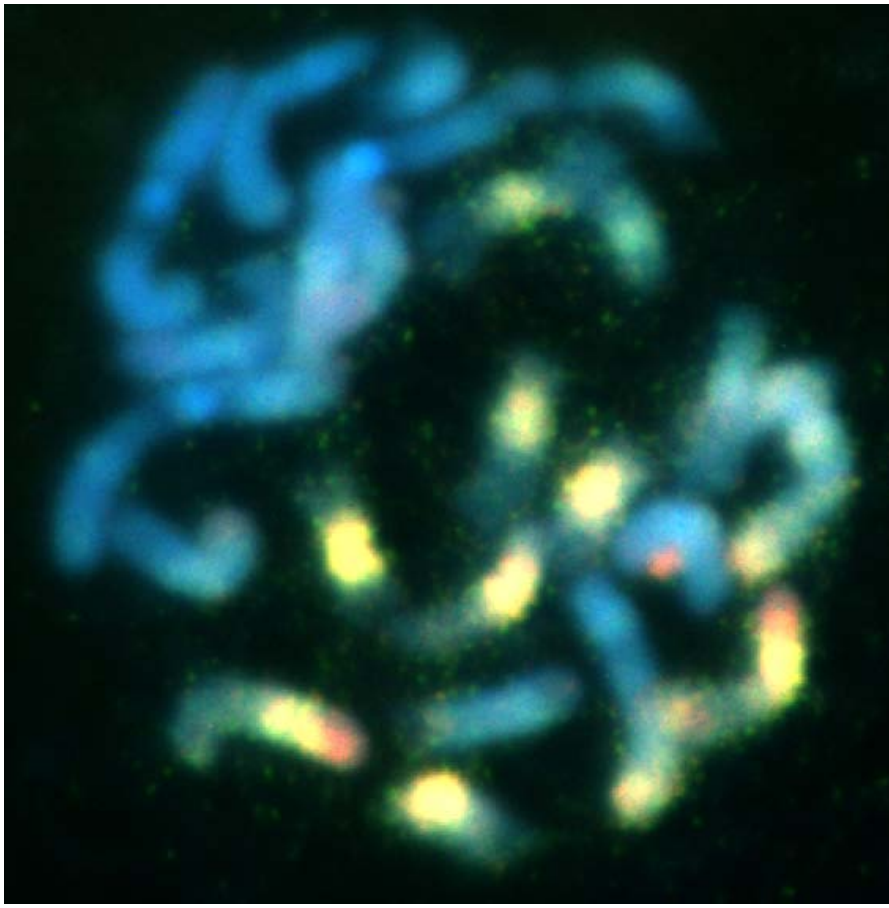
Saffron Diversity and Origins

The origins of triploid Saffron (*C. sativus*)



The three genomes present in saffron are much more closely related than those in Golden Yellow. *Crocus cartwrightianus* is likely to be the source of two of the genomes in saffron, but the third seems to be another, closely related, species.

Detail of partner exchange in a trivalent (left)



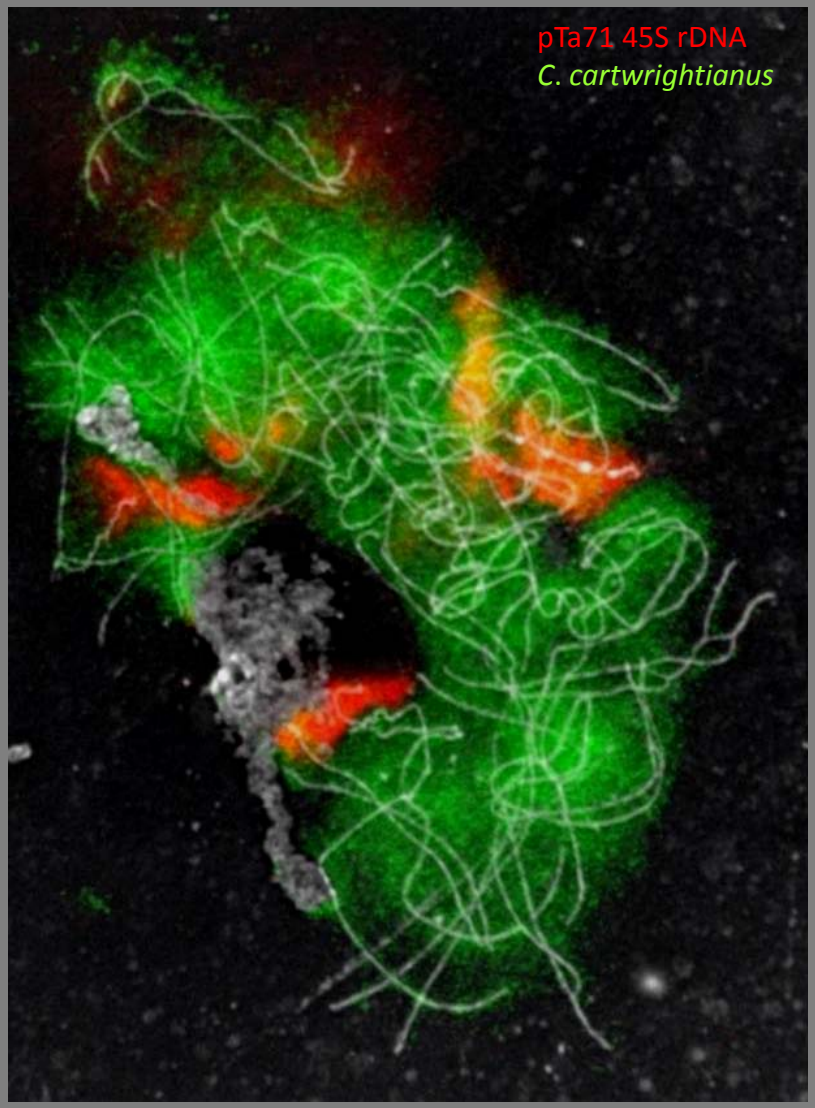
A suggestion of different genomes in saffron with 8 labelled chromosomes from a parent (right)

Action CROCUSBANK (AGRI GEN RES 018) is supported by the European Commission, Directorate General for Agriculture & Rural Development

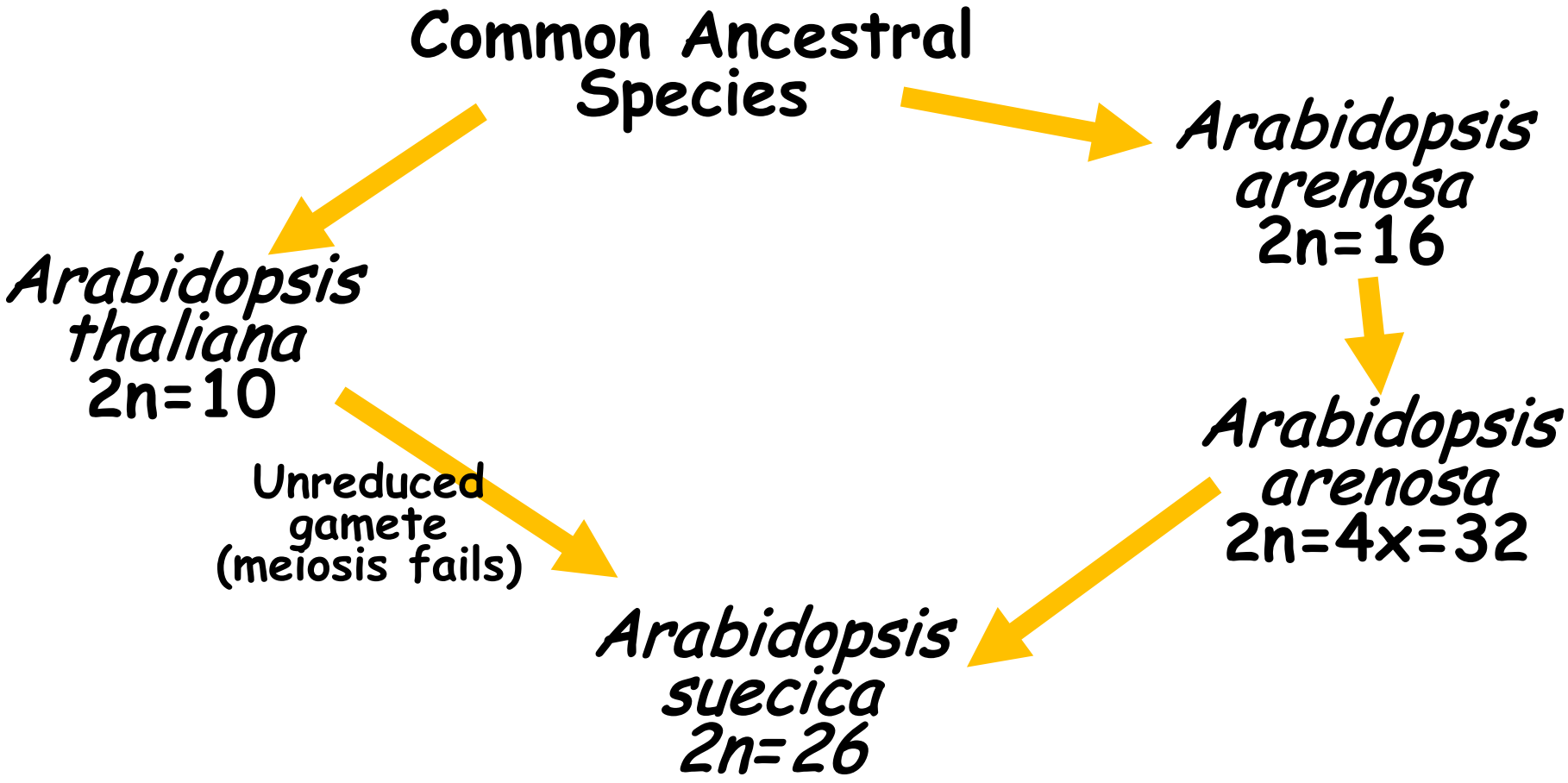
Chris Franklin and Sue Armstrong, Birmingham University, for the gift of ASY1 antibodies.
Work on the spring Crocus origin was in collaboration with Marian Orgaard and Niels Jacobsen, KVL, Copenhagen.

Work on Saffron is part of the EU CrocusBank project, www.crocusbank.org.

Meiotic prophase in triploid Saffron (*C. sativus*)

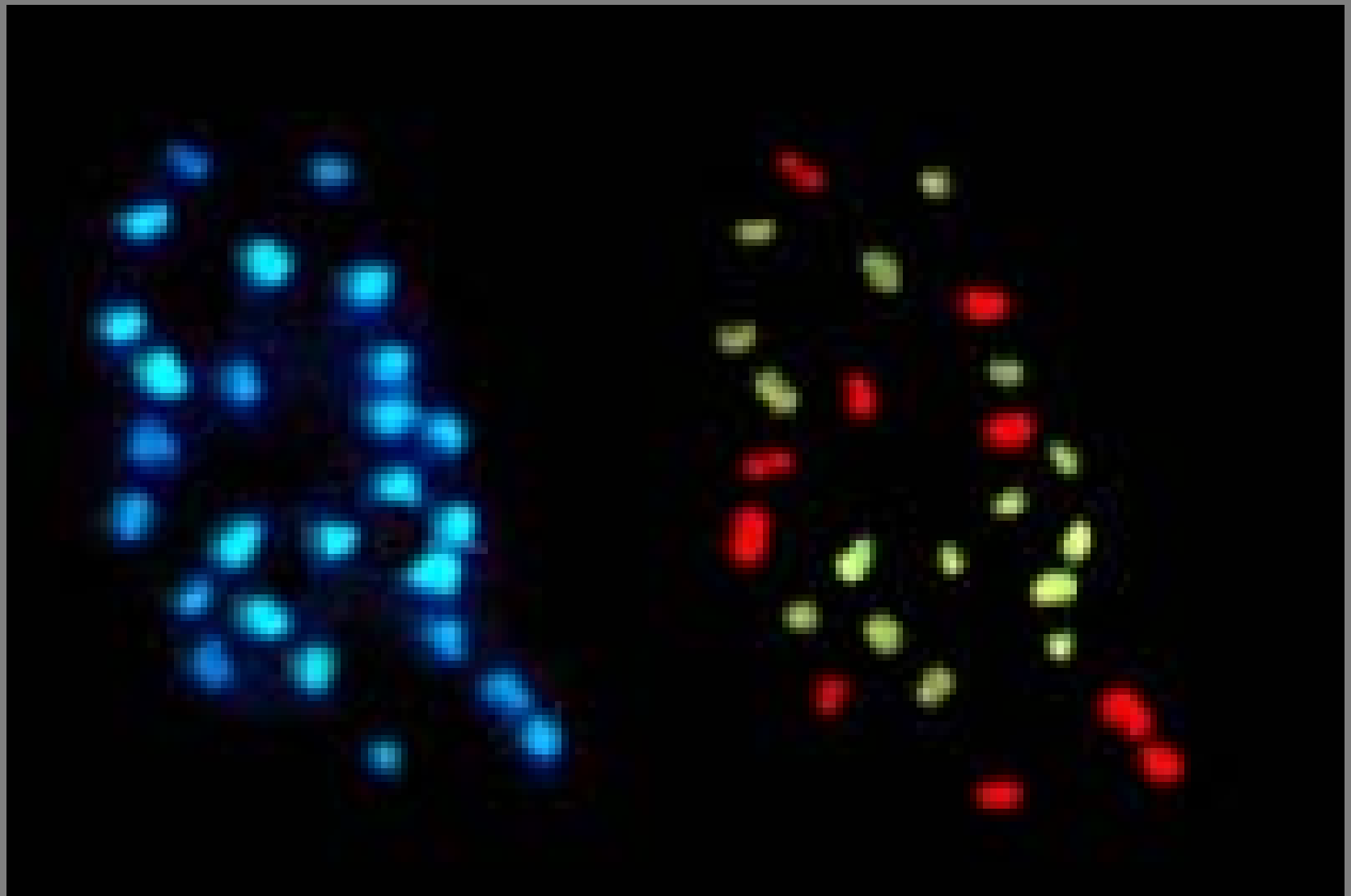


Arabidopsis polyploid species

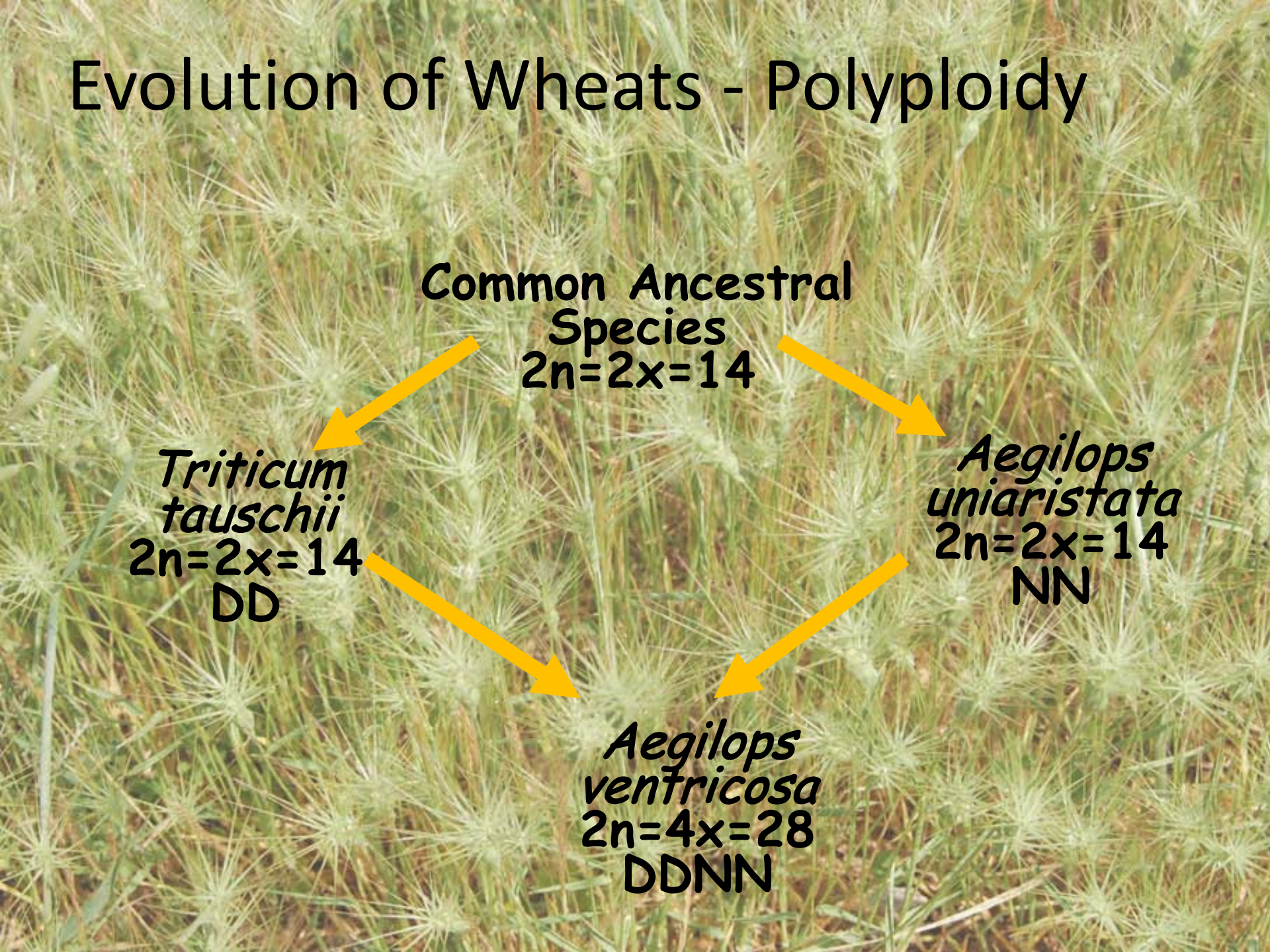


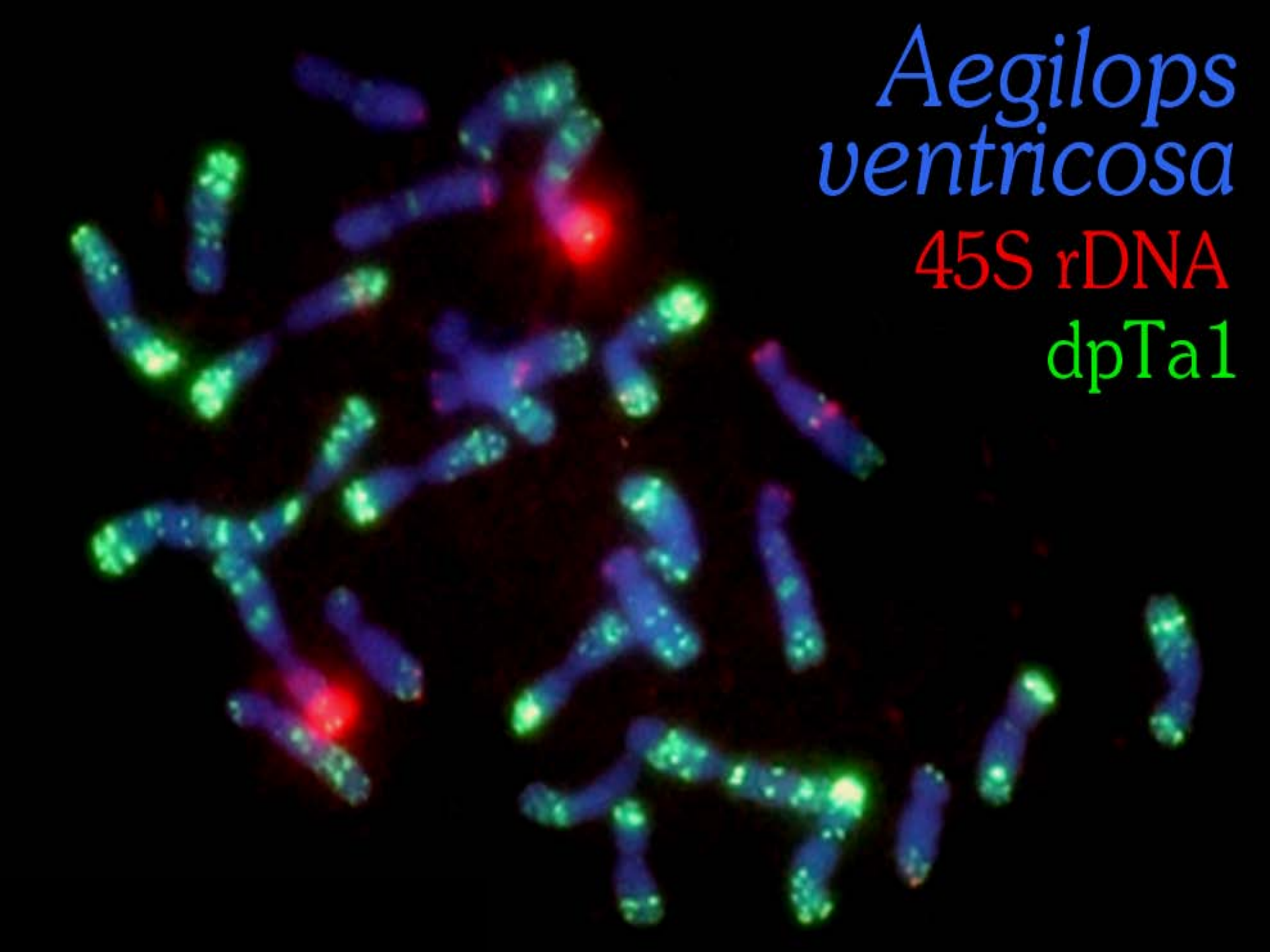
Arabidopis suecica

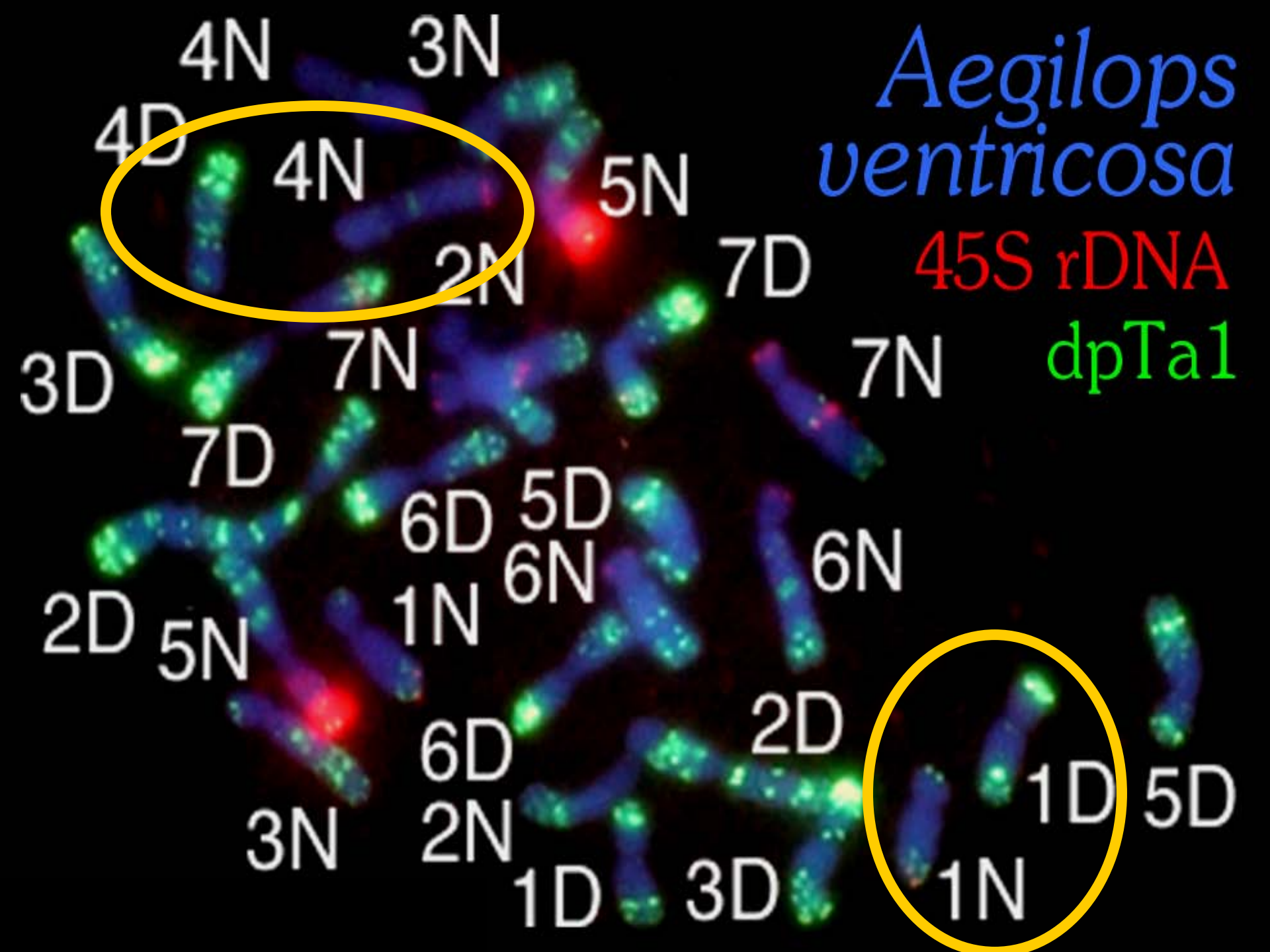
Hybrid of *A. arenosa* (pAa214 green)
and *A. thaliana* (180bp red)



Evolution of Wheats - Polyploidy



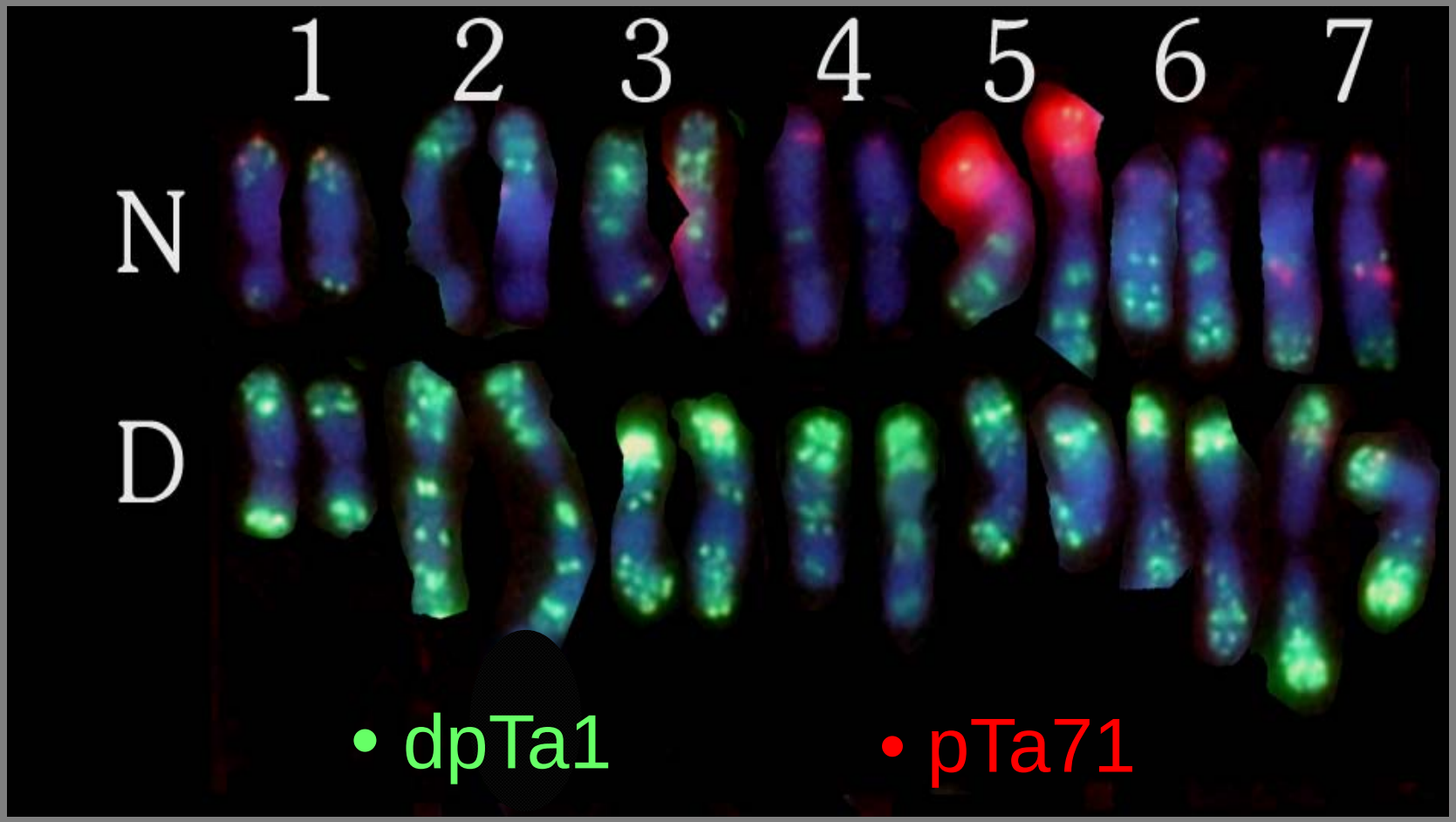

Aegilops
ventricosa
45S rDNA
dpTa1

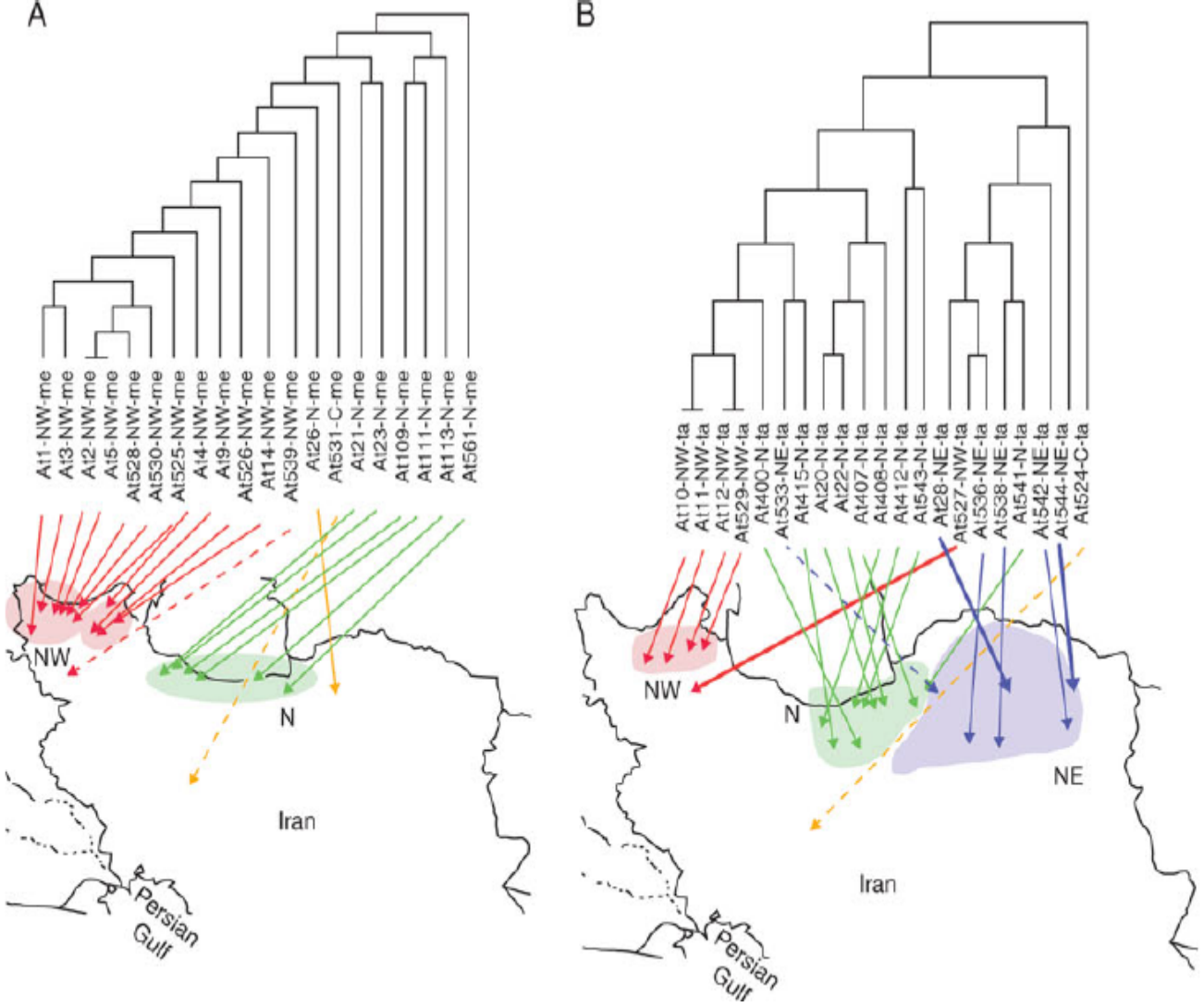


Aegilops ventricosa

Differences between genomes

Major differences in the nature and amount of repetitive DNA

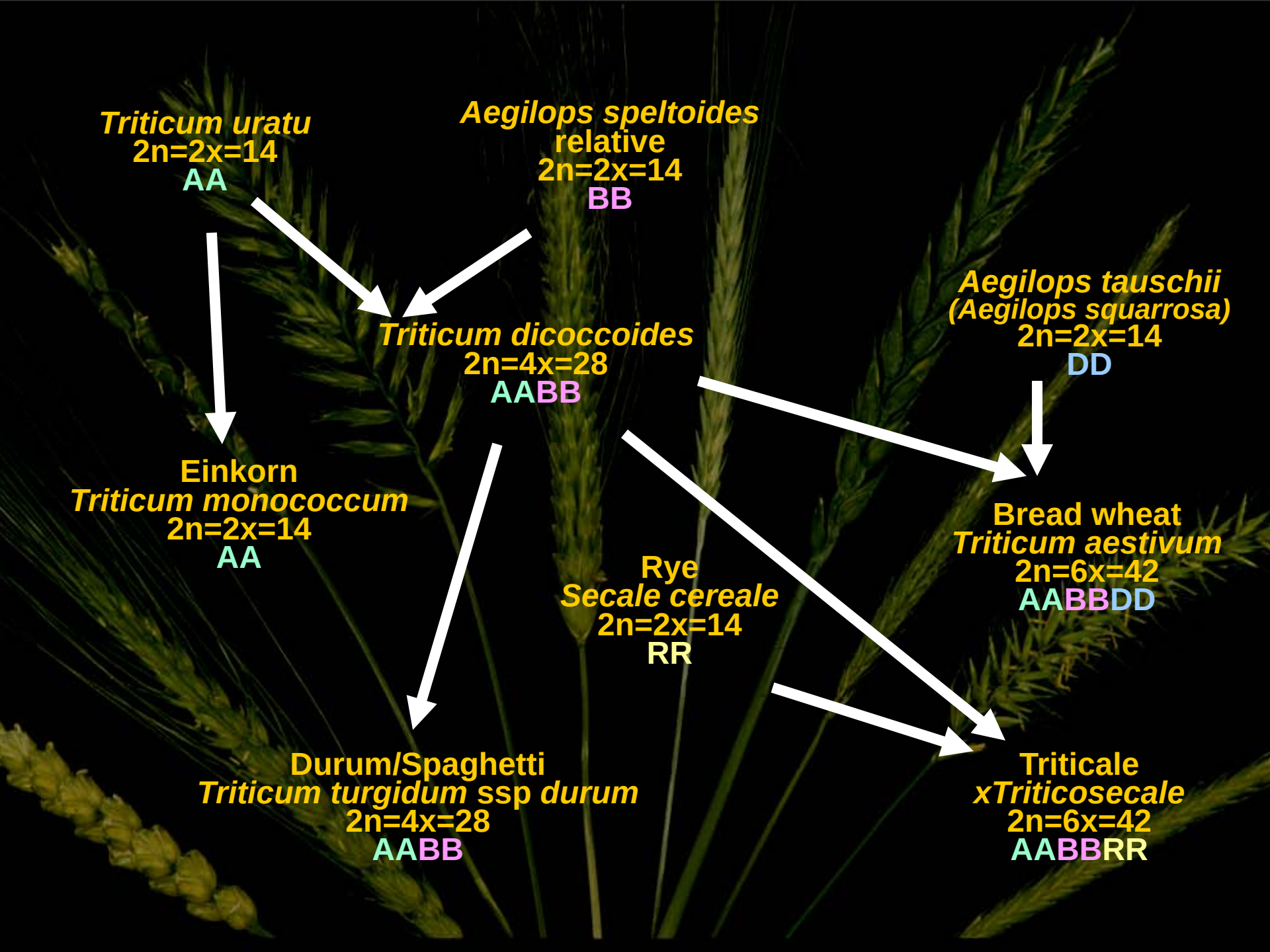




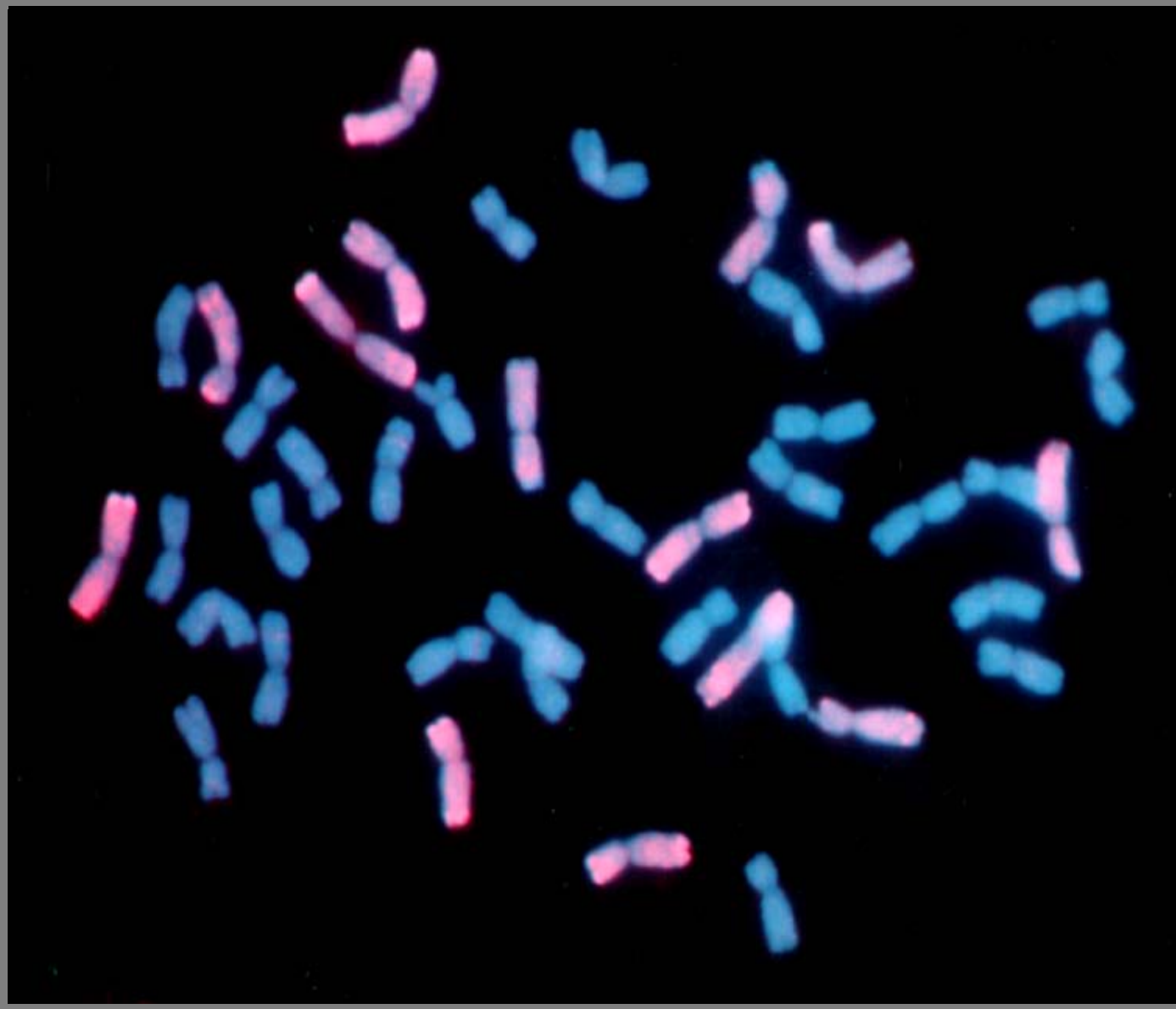
Ae. tauschii subsp. *tauschii* var. *meyeri*

Ae. tauschii subsp. *tauschii* var. *tauschii*

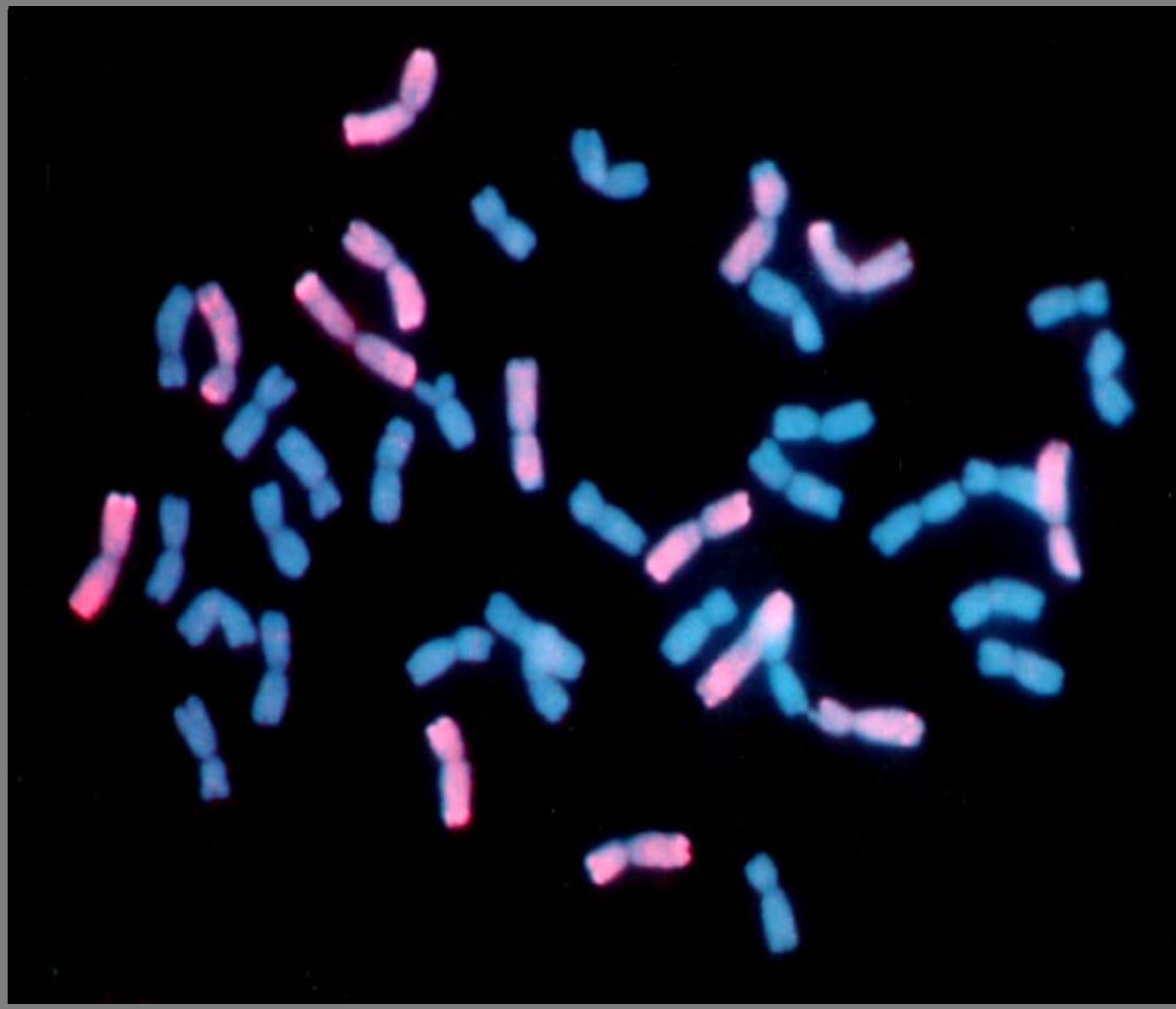
Retroelement insertional polymorphisms, diversity and phylogeography within diploid, d-genome Aegilops tauschii (Triticeae, Poaceae) sub-taxa in Iran. Saeidi, 2008. Annals of Botany


Triticum uratu
2n=2x=14
AA
Aegilops speltoides
relative
2n=2x=14
BB
Triticum dicoccoides
2n=4x=28
AABB
Aegilops tauschii
(Aegilops squarrosa)
2n=2x=14
DD
Einkorn
Triticum monococcum
2n=2x=14
AA
Rye
Secale cereale
2n=2x=14
RR
Bread wheat
Triticum aestivum
2n=6x=42
AABBDD
Durum/Spaghetti
Triticum turgidum ssp *durum*
2n=4x=28
AABB
Triticale
xTriticosecale
2n=6x=42
AABBRR

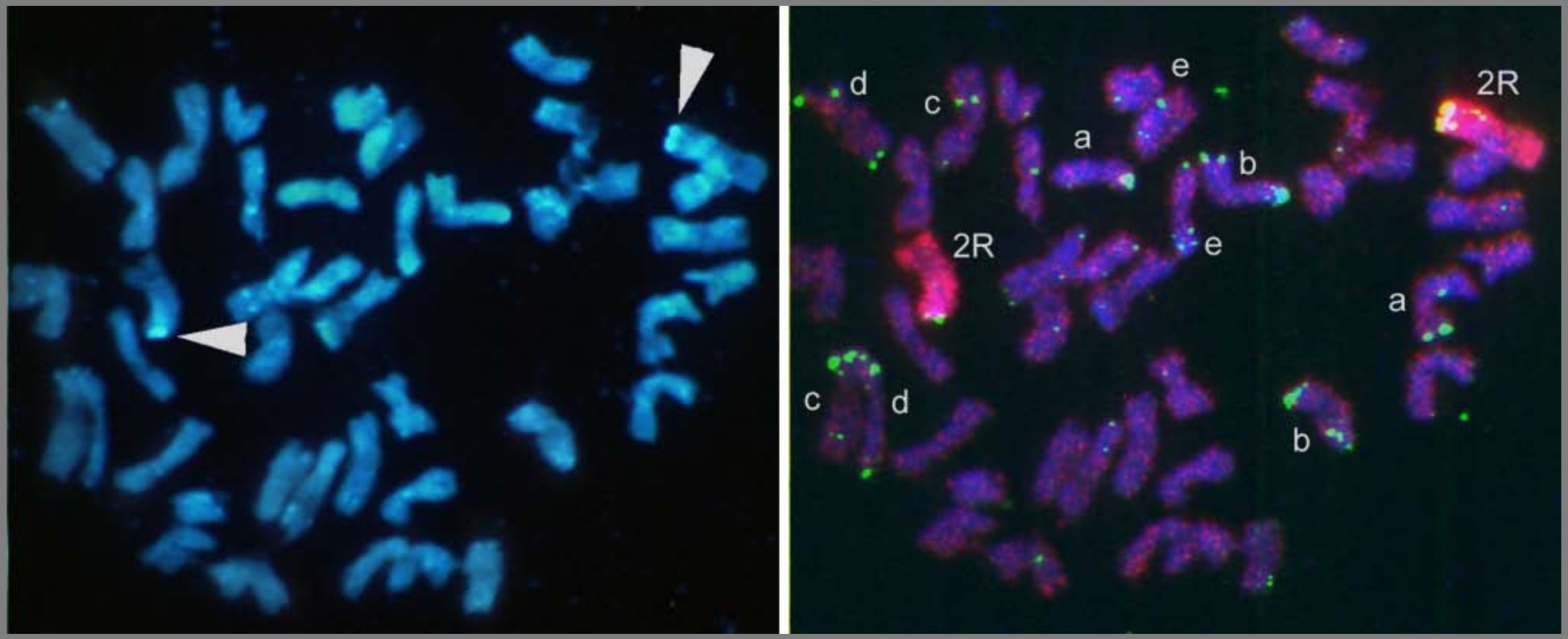
Triticale: wheat x rye hybrid



Triticale: wheat x rye hybrid



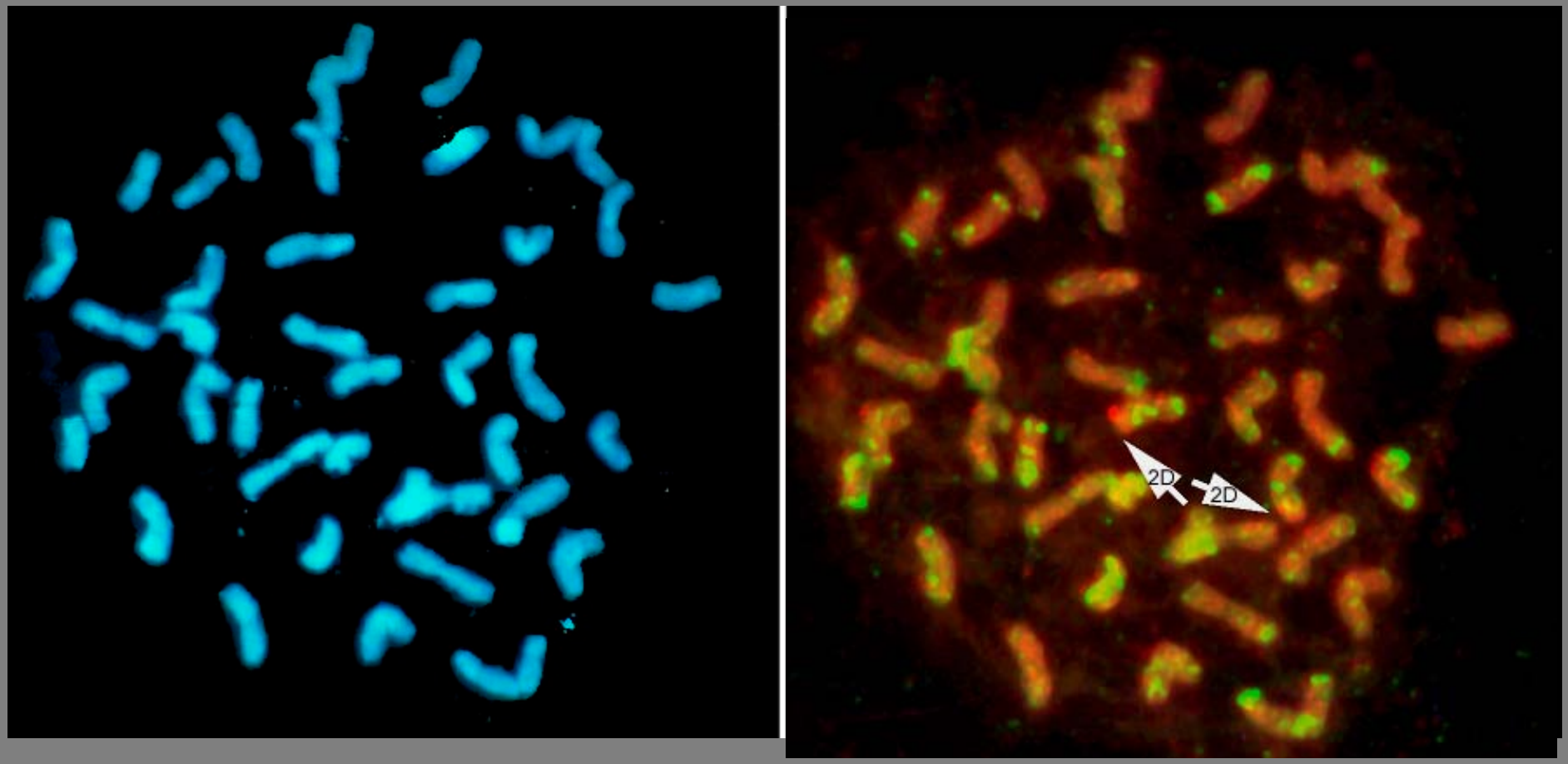
2D-2R substitution - *in situ* hybridization



Total genomic rye DNA shows rye-origin chromosomes

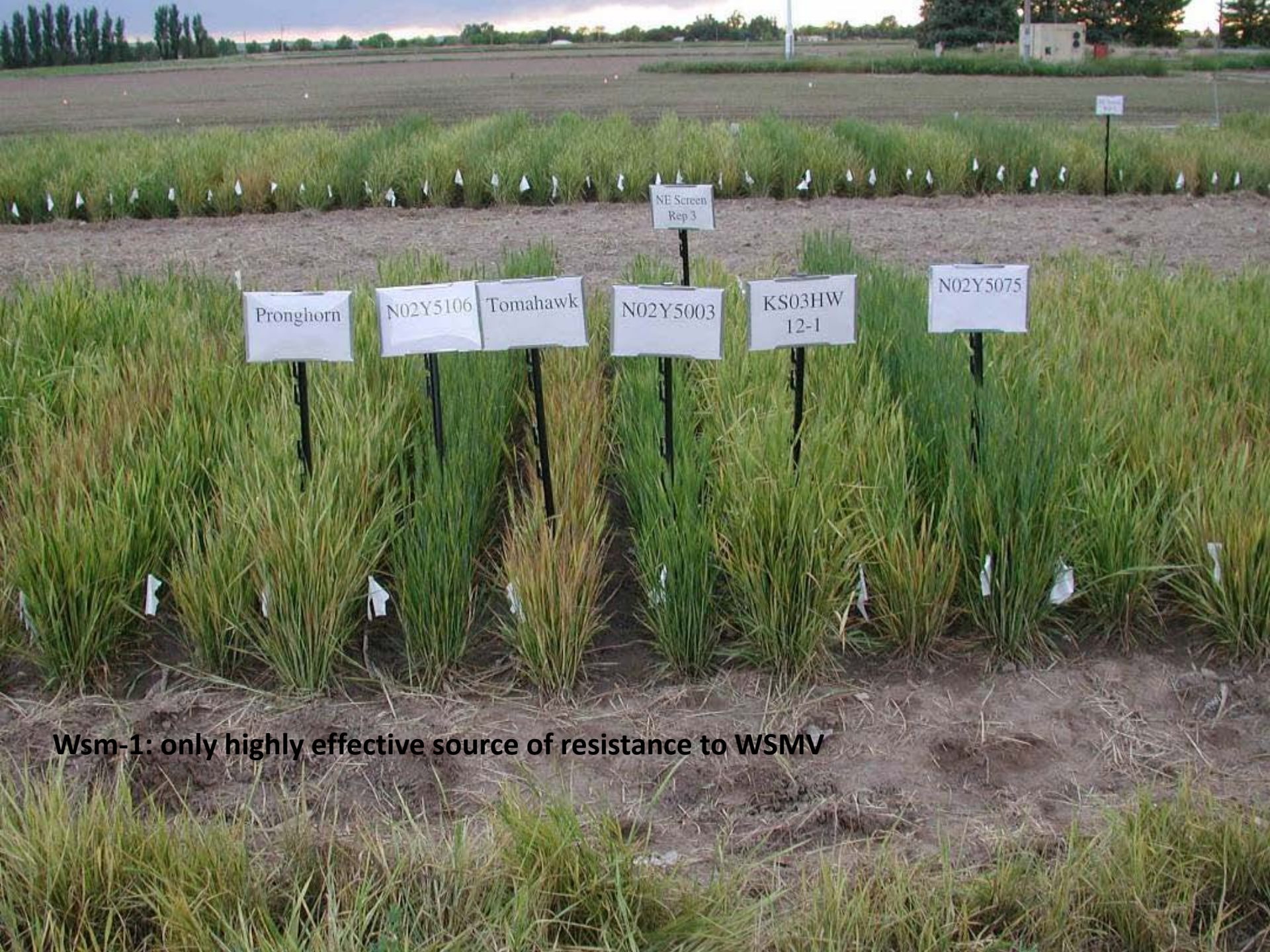
dpTa1 tandem repeat allows chromosome identification

In situ hybridization showing rye chromosome segment on chromosome 2DL



Total genomic rye DNA

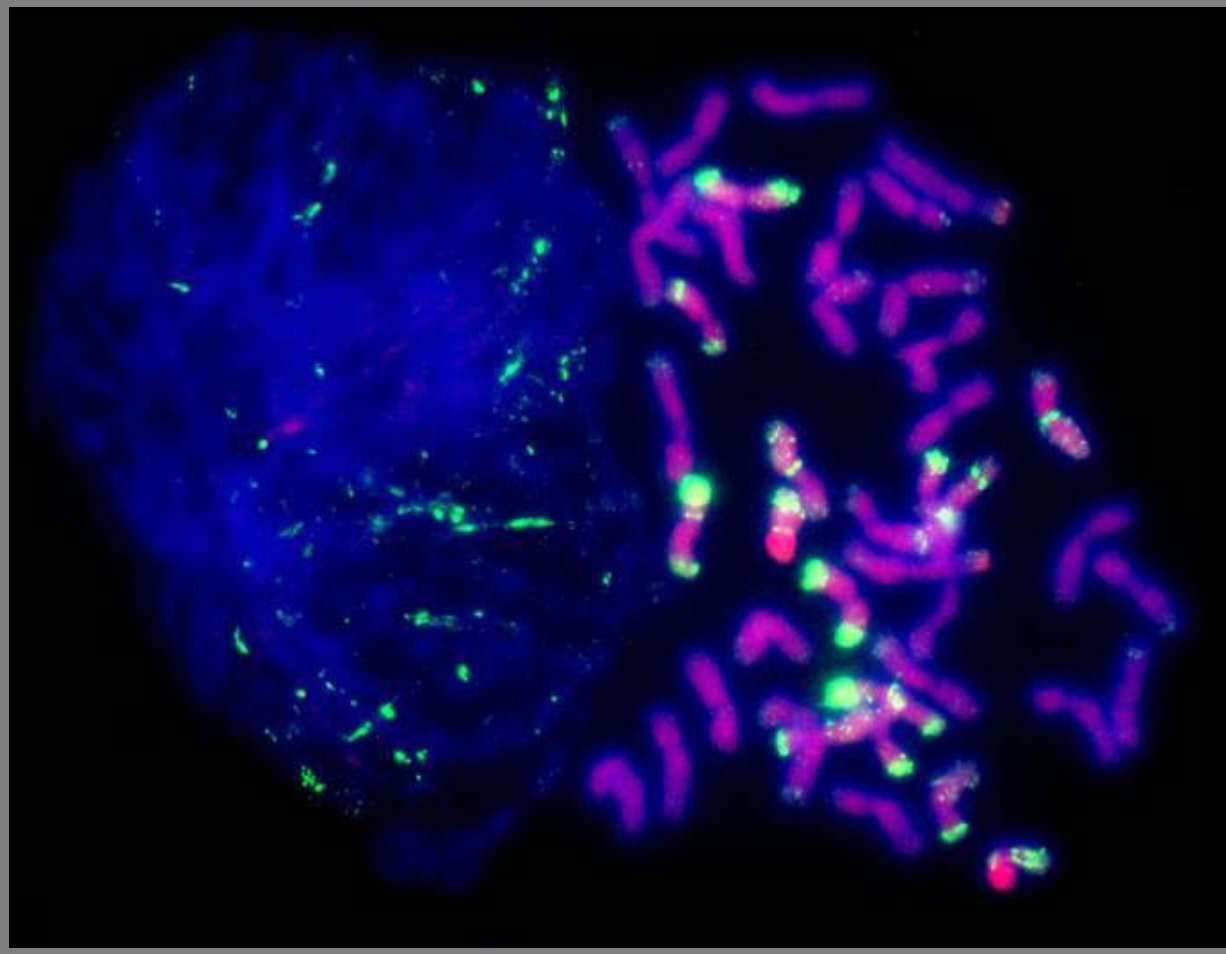
dpTa1 tandem repeat



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

Wsm1 Resistance Gene

- *Located on a small insert of chromatin from Agropyron intermedium* (Horst.) Beauv. (=*Thinopyrum intermedium) on wheat chromosome 4A or 4D.*
  - *–What chromosome arm is present in our advanced breeding lines.*
  - *–Can we develop procedures to rapidly screen & characterize hundreds of germplasm lines?*
- *Probes*
  - *–IWG genomic DNA – biotin*
  - *–dpTA1 (D-genome specific) digoxigenin*
- *Graybosch et al. 2009. Registration of Mace hard red winter wheat. Journal of Plant Registrations*



Registration of 'Mace' Hard Red Winter Wheat

R. A. Graybosch,* C. J. Peterson, P. S. Baenziger, D. D. Baltensperger, L. A. Nelson, Y. Jin, J. Kolmer, B. Seabourn, R. French, G. Hein, T. J. Martin, B. Beecher, T. Schwarzacher, and P. Heslop-Harrison

ABSTRACT

'Mace' (Reg. No. CV-1027, PI 651043) hard red winter wheat (*Triticum aestivum* L.) was developed by the USDA-ARS and the Nebraska Agricultural Experiment Station and released in December 2007. Mace was selected from the cross Yuma//PI 372129/3/CO850034/4/4*Yuma/5/(KS91H184/Arlin S//KS91HW29/3/NE89526). Mace primarily was released for its resistance to *Wheat streak mosaic virus* (WSMV) and adaptation to rainfed and irrigated wheat production systems in Nebraska and adjacent areas in the northern Great Plains. Mace was derived from a head selection made from a heterogeneous, in terms of field resistance to WSMV, F_5 line. Resistance to WSMV is conditioned by the *Wsm-1* gene, located on an introgressed chromosome arm from *Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey [*Agropyron intermedium* (Horst.) Beauv.] present as a 4DL.4AgS chromosomal translocation. Mace was tested under the experimental designation N02Y5117.

Abbreviations: NRPN, Northern Regional Performance Nursery; PCR, polymerase chain reaction; WSBMV, *Wheat soilborne mosaic virus*; WSMV, *Wheat streak mosaic virus*.

Published in the Journal of Plant Registrations 3:51–56 (2009).
doi: 10.3198/jpr2008.06.0345crc

677 S. Segoe Rd., Madison, WI 53711 USA

such line, subsequently named 'Mace' (Reg. No. CV-1027, PI 651043), was deemed suitable for cultivar release. Mace is a hard red winter wheat cultivar developed cooperatively by the USDA-ARS and the Nebraska Agricultural Experiment Station and released in 2007 by the developing institutions. Mace was released primarily for its field resistance to *Wheat streak mosaic virus* (WSMV) and adaptation to rainfed and irrigated wheat production systems in Nebraska and adjacent areas in the northern Great Plains. Resistance to WSMV is conditioned by the *Wsm-1* gene (Seifers et al., 1995), situated on an introgressed chromosome arm from

Lodging in cereals
UK July 2007

- Eyespot (fungus *Pseudocercosporella*) resistance from *Aegilops ventricosa* introduced to wheat by chromosome engineering

- Many diseases where *all* wheat varieties are highly susceptible

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*

Crop plants

- There is little new about the challenges faced by the environment from people
  - Population expansion
  - Overexploitation
  - Degradation
  - Climate change

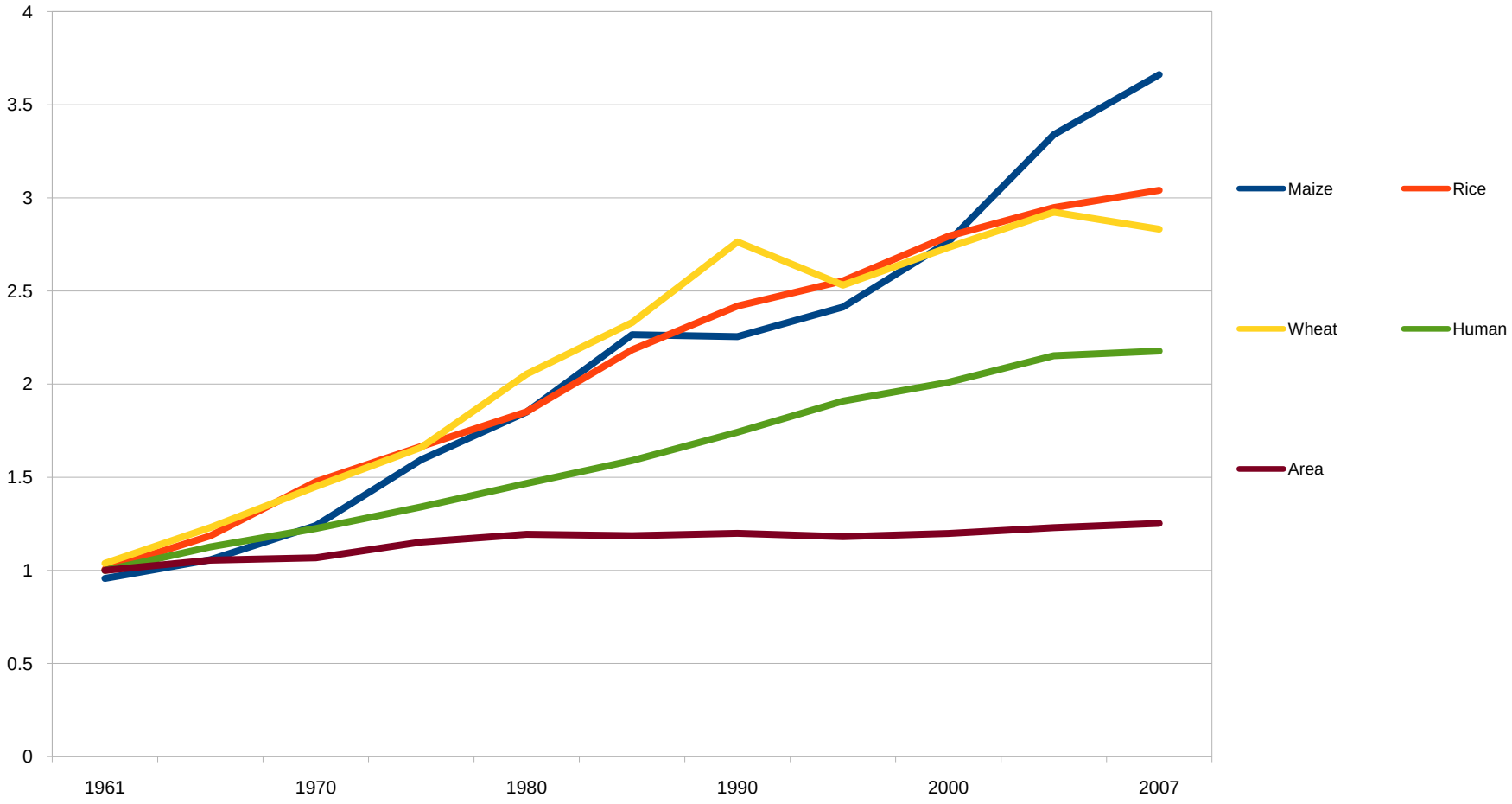
Threats to sustainability: no different for 10,000 years

- Increased need (population expansion)
- Habitat destruction
- Climate change (abiotic stresses)
- Diseases (biotic stresses)
- Overexploitation
- Less effort in agriculture

	year (millions)		
item	1961	2007	2007/1961
People	3,090	6,602	2.1
Maize	205	785	3.8
Rice, paddy	216	652	3.0
Wheat	222	607	2.7
Potatoes	271	322	1.2
Sugar beet	161	248	1.5
Cassava	71	228	3.2
Soybeans	27	216	8.0
Oil palm fruit	14	192	13.7
Barley	72	136	1.9
Sweet potatoes	98	126	1.3
Tomatoes	28	126	4.5
Watermelons	18	93	5.2
Bananas	21	81	3.9
Seed cotton	27	73	2.7
Cabbages and other bra	23	69	3.0
Grapes	43	66	1.5
Sorghum	41	65	1.6
Onions, dry	14	64	4.6
Apples	17	64	3.8
Oranges	16	64	4.0
Coconuts	24	55	2.3
Yams	8	52	6.5
Rapeseed	4	49	12.3
Cucumbers and gherkin	10	45	4.5
Groundnuts, with shell	14	35	2.5
Plantains	13	34	2.6
Mangoes, mangosteens	11	33	3.0
Eggplants (aubergines)	7	32	4.6
Millet	26	32	1.2

	year (millions)		
item	1961	2007	2007/1961
Oil palm fruit	14	192	13.7
Rapeseed	4	49	12.3
Soybeans	27	216	8.0
Yams	8	52	6.5
Watermelons	18	93	5.2
Onions, dry	14	64	4.6
Eggplants (aubergines)	7	32	4.6
Tomatoes	28	126	4.5
Cucumbers and gherkin	10	45	4.5
Oranges	16	64	4.0
Bananas	21	81	3.9
Maize	205	785	3.8
Apples	17	64	3.8
Cassava	71	228	3.2
Rice, paddy	216	652	3.0
Cabbages and other bra	23	69	3.0
Mangoes, mangosteens	11	33	3.0
Wheat	222	607	2.7
Seed cotton	27	73	2.7
Plantains	13	34	2.6
Groundnuts, with shell	14	35	2.5
Coconuts	24	55	2.3
People	3,090	6,602	2.1
Barley	72	136	1.9
Sorghum	41	65	1.6
Sugar beet	161	248	1.5
Grapes	43	66	1.5
Sweet potatoes	98	126	1.3
Millet	26	32	1.2
Potatoes	271	322	1.2

50 years of plant breeding progress



Progress

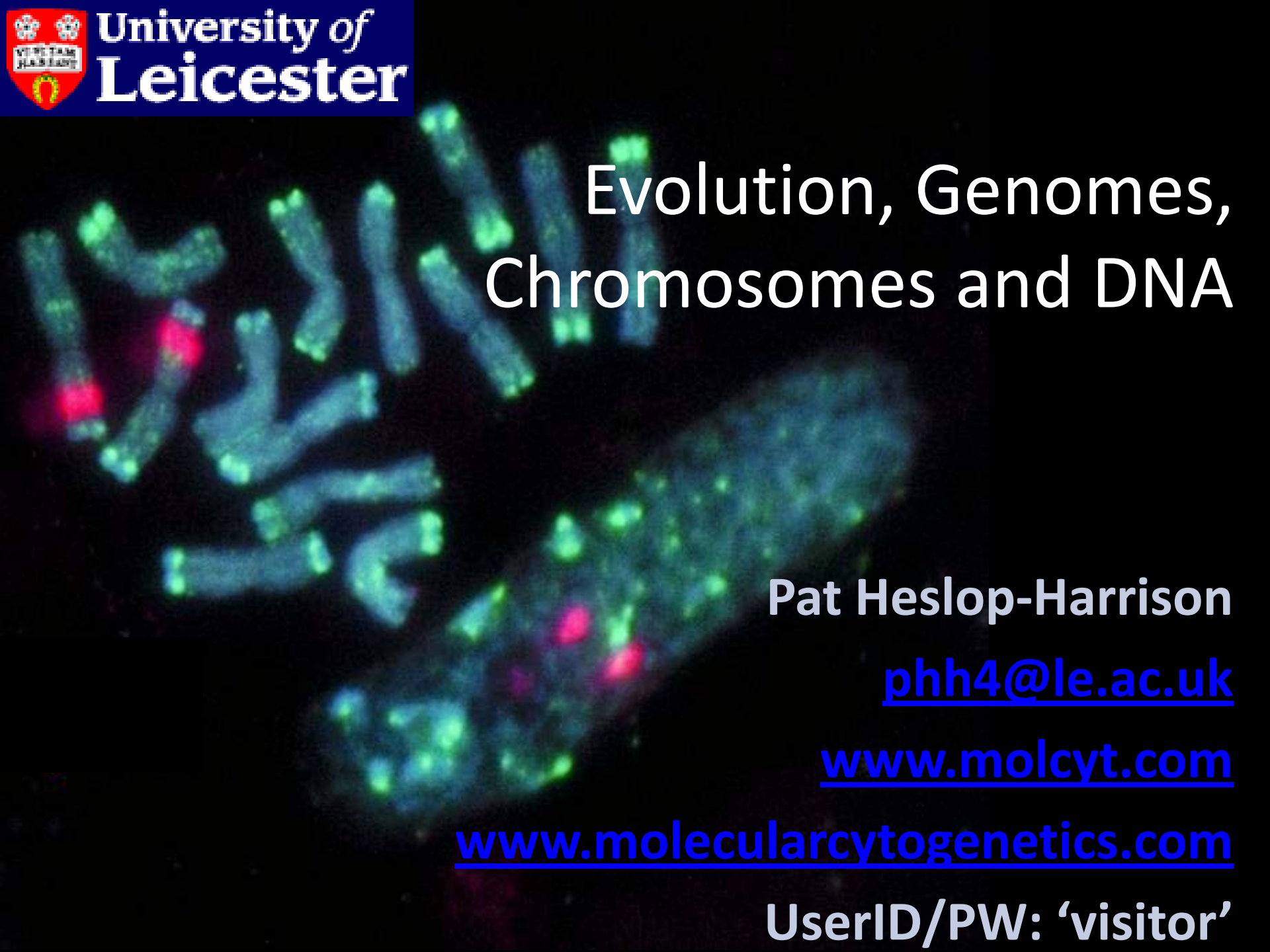
- Computers and Moore's Law – doubling every two years since 1970s
- Crops: punctuated
  - Selection of varieties
  - Mechanisation
  - Dwarfs, fertilization

Past, present and future

- Where were we and which option did we choose?
- Malthus 1740s / Ehrlich 1990s
  - First increasing productivity of agriculture
  - Second importing food

- London – horse food and dung

	year (millions)		
item	1961	2007	2007/1961
People	3,090	6,602	2.1
Maize	205	785	3.8
Rice, paddy	216	652	3.0
Wheat	222	607	2.7
Potatoes	271	322	1.2
Sugar beet	161	248	1.5
Cassava	71	228	3.2
Soybeans	27	216	8.0
Oil palm fruit	14	192	13.7
Barley	72	136	1.9
Sweet potatoes	98	126	1.3
Tomatoes	28	126	4.5
Watermelons	18	93	5.2
Bananas	21	81	3.9
Seed cotton	27	73	2.7
Cabbages and other bra	23	69	3.0
Grapes	43	66	1.5
Sorghum	41	65	1.6
Onions, dry	14	64	4.6
Apples	17	64	3.8
Oranges	16	64	4.0
Coconuts	24	55	2.3
Yams	8	52	6.5
Rapeseed	4	49	12.3
Cucumbers and gherkin	10	45	4.5
Groundnuts, with shell	14	35	2.5
Plantains	13	34	2.6
Mangoes, mangosteens	11	33	3.0
Eggplants (aubergines)	7	32	4.6
Millet	26	32	1.2



University of Leicester

Evolution, Genomes, Chromosomes and DNA

Pat Heslop-Harrison

phh4@le.ac.uk

www.molcyt.com

www.molecularcytogenetics.com

UserID/PW: 'visitor'