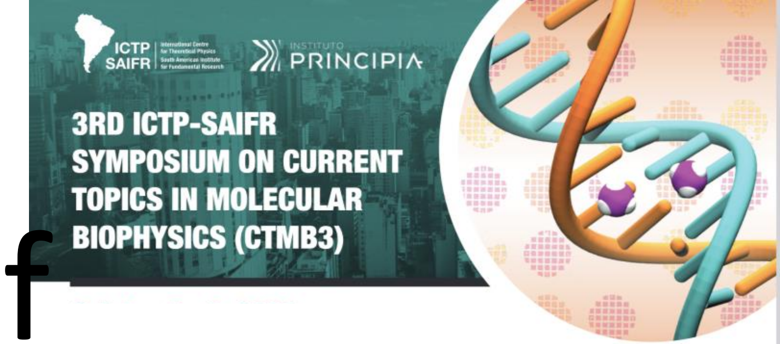


Different ways of compacting holocentric chromosomes

Amanda Souza Câmara

Leibniz Institute of Plant Genetics and Crop Plant Research

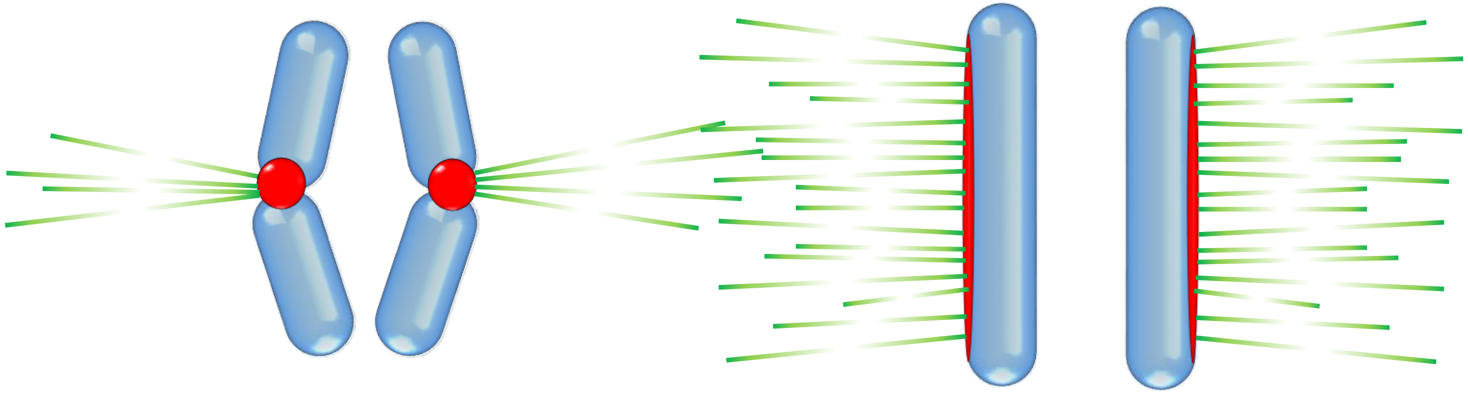
Gatersleben, Germany

8th October 2024

In Silico Genebank Proteomics

IPK LEIBNIZ-INSTITUT

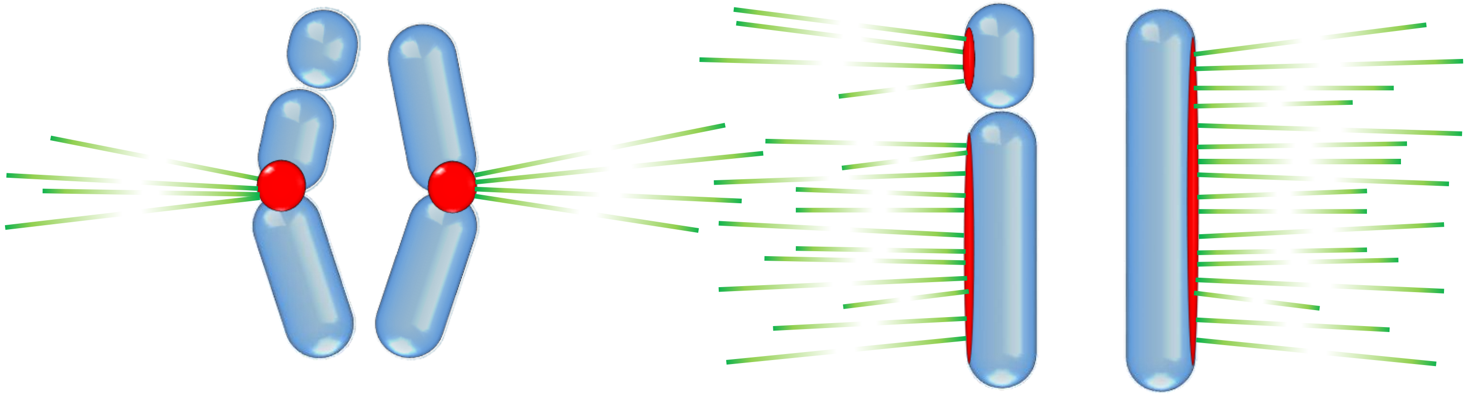
Centromere types



monocentric holocentric

centromere, chromosome, microtubule

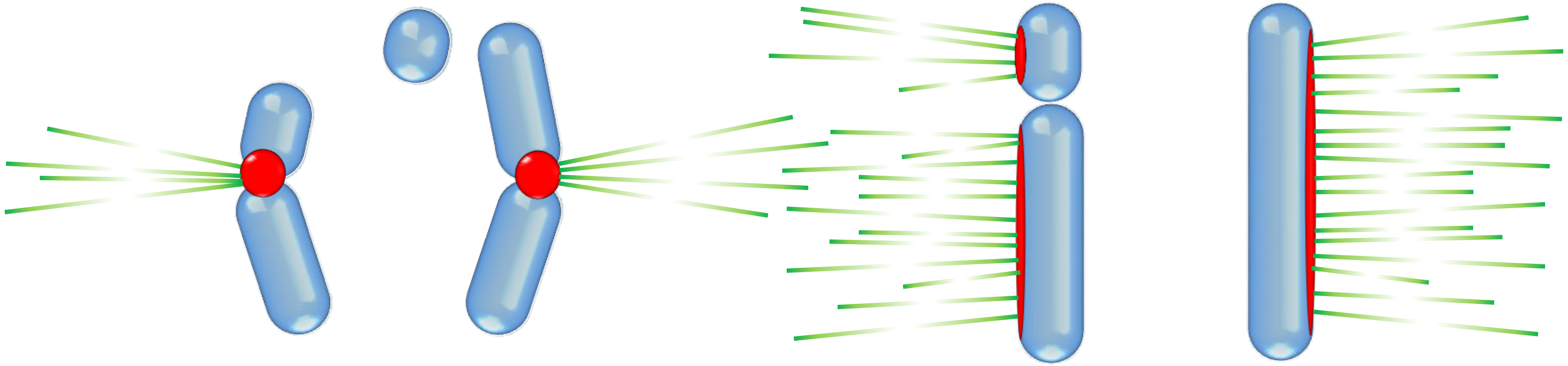
Centromere types



monocentric holocentric

centromere, chromosome, microtubule

Centromere types



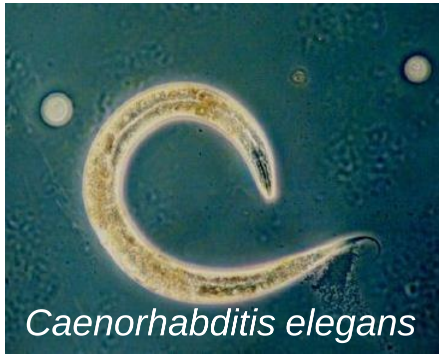
monocentric

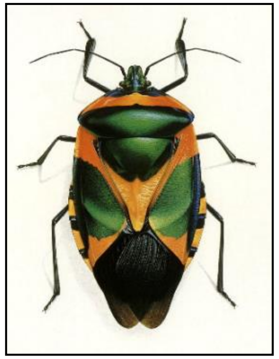
holocentric

centromere, chromosome, microtubule

Ocurrence and evolution of holocentricity

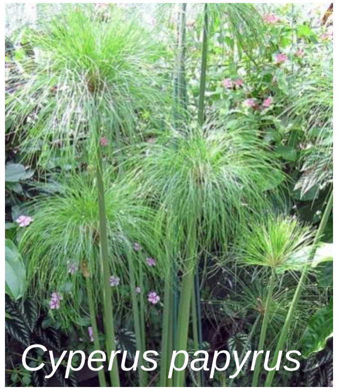
- evolved at least 13 times in animals and plants
- protozoan green algae, several invertebrates, monocot plant families, eudicot plant families.


Caenorhabditis elegans




Cuscuta

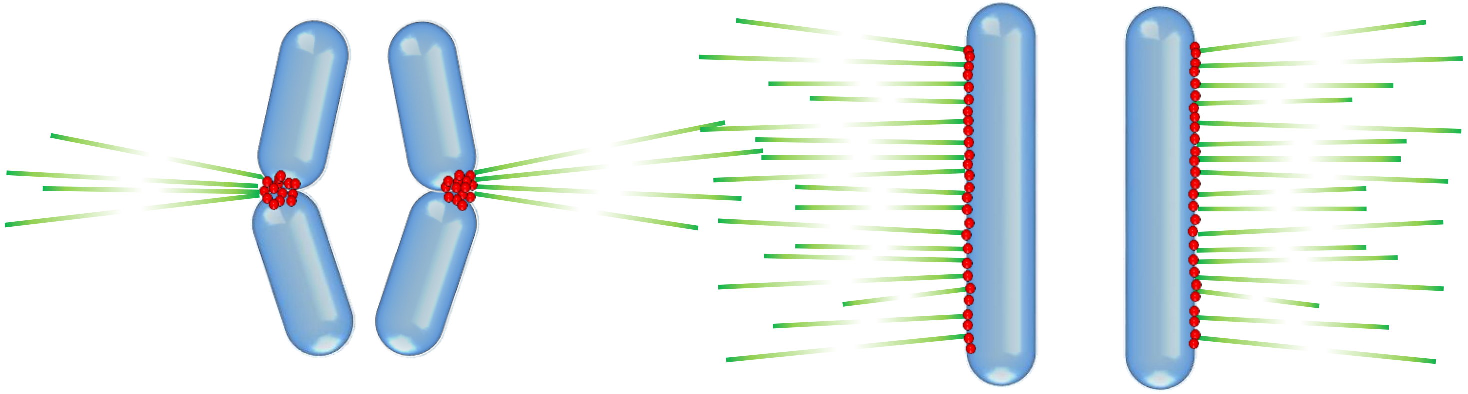

Rhynchospora nervosa


Cyperus papyrus


Luzula elegans

https://wikipedia.org

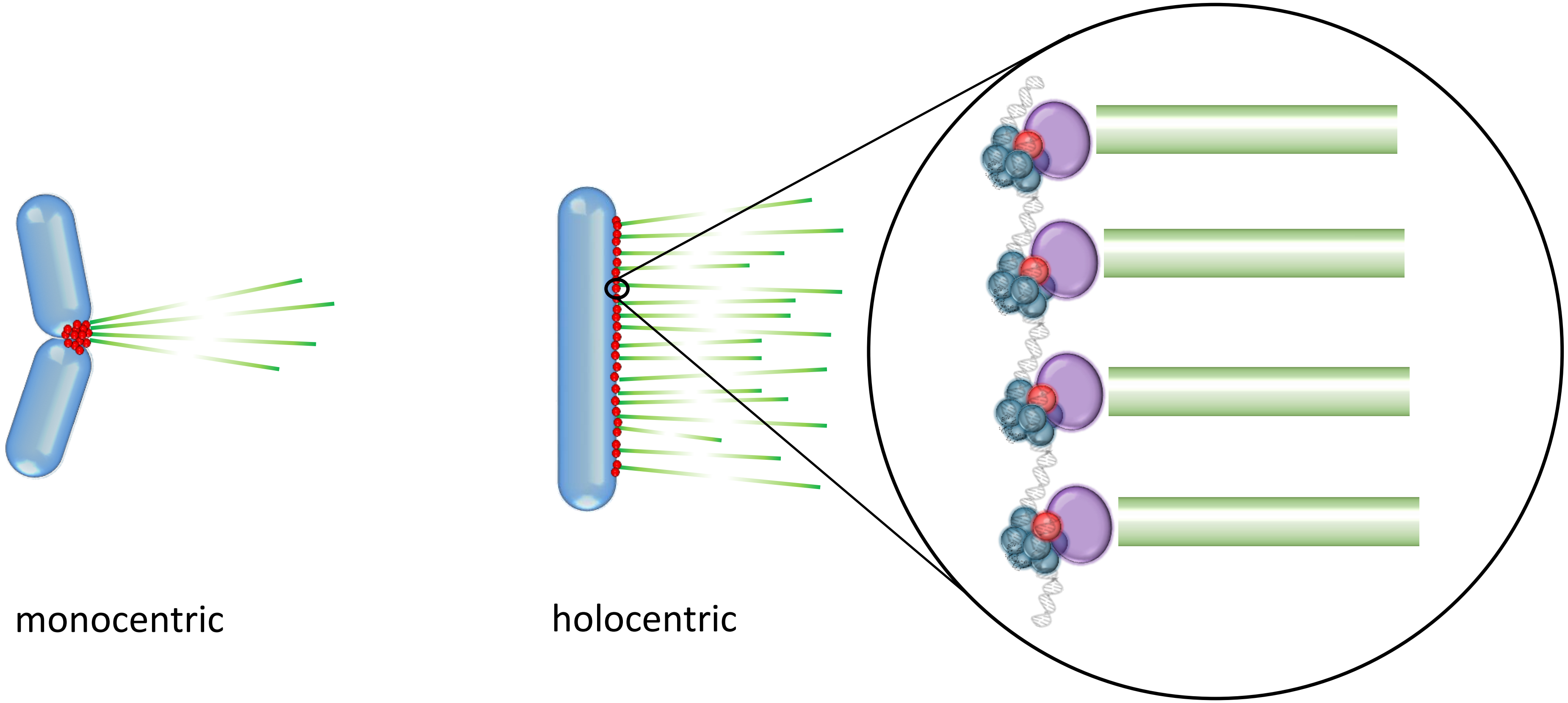
Centromeres are made of centromeric units



monocentric holocentric

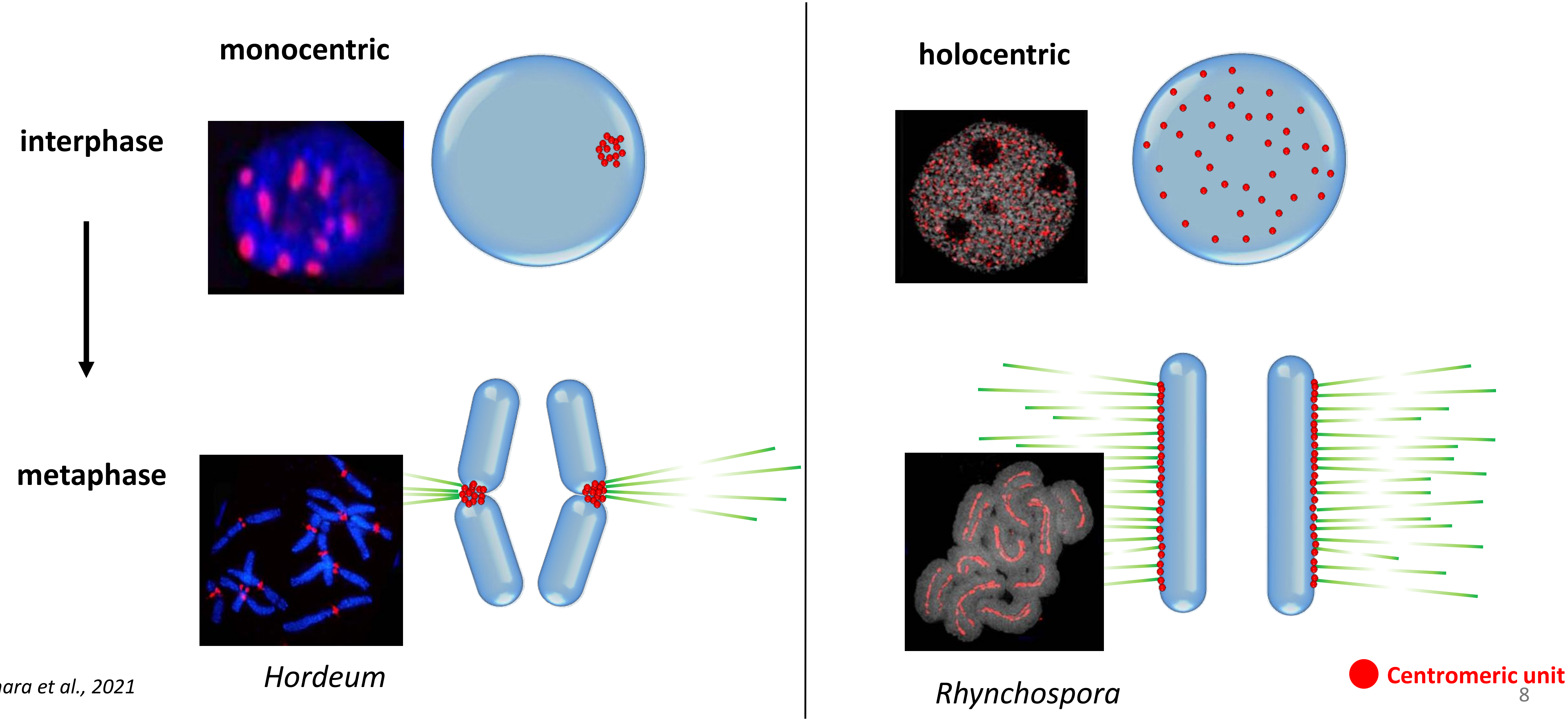
Centromere units, chromosome, microtubule

Centromeres are made of centromeric units



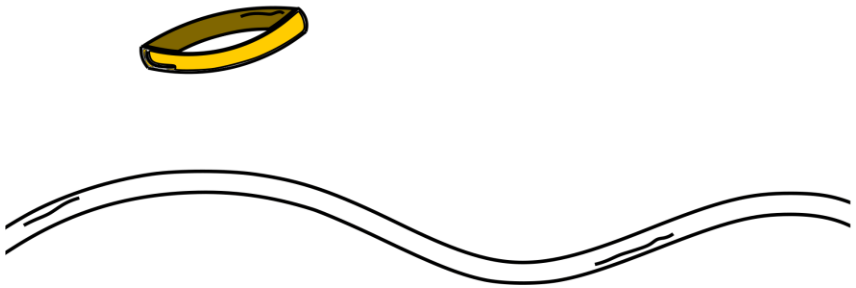
Centromere units, chromosome, kinetochore, microtubule

Cell cycle dynamics of centromeres

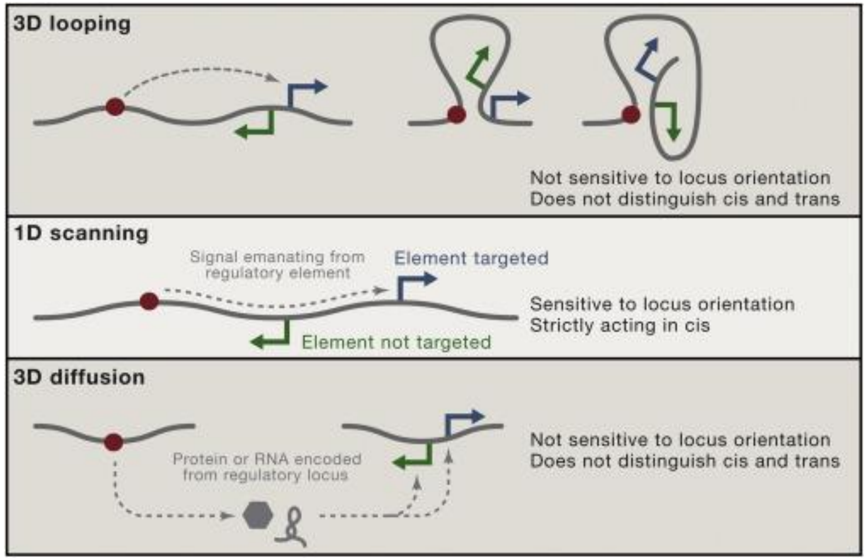


Câmara et al., 2021

Compaction by loop extrusion

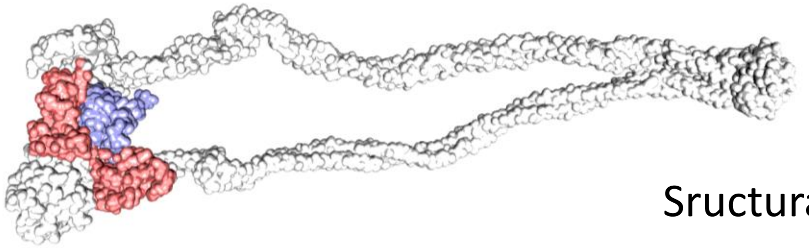


https://youtu.be/mi9WWSy-Nwo



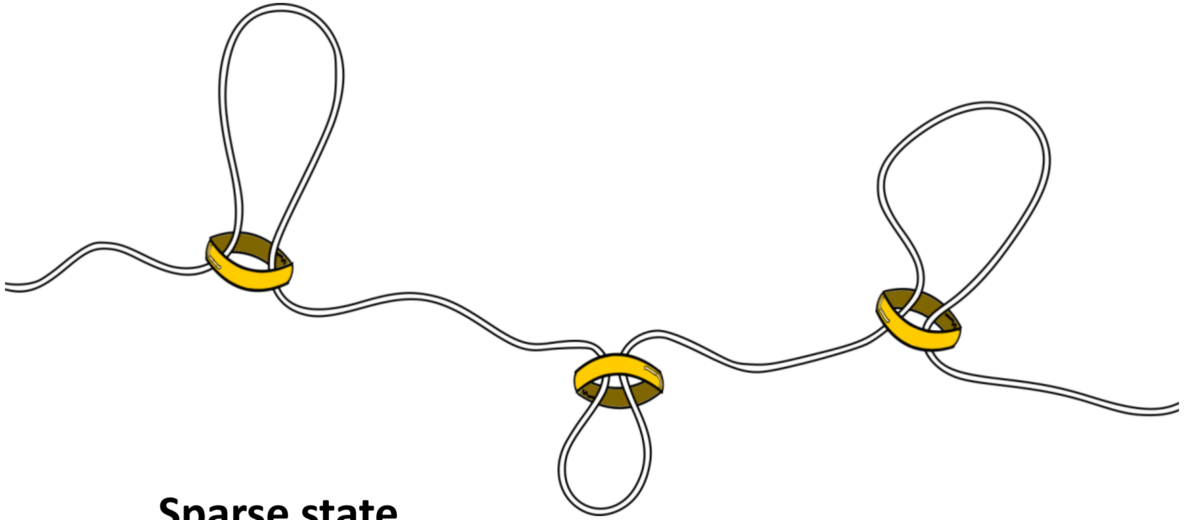
Dekker and Mirny, 2016

Subunities
SMC
HEAT
Kleisin

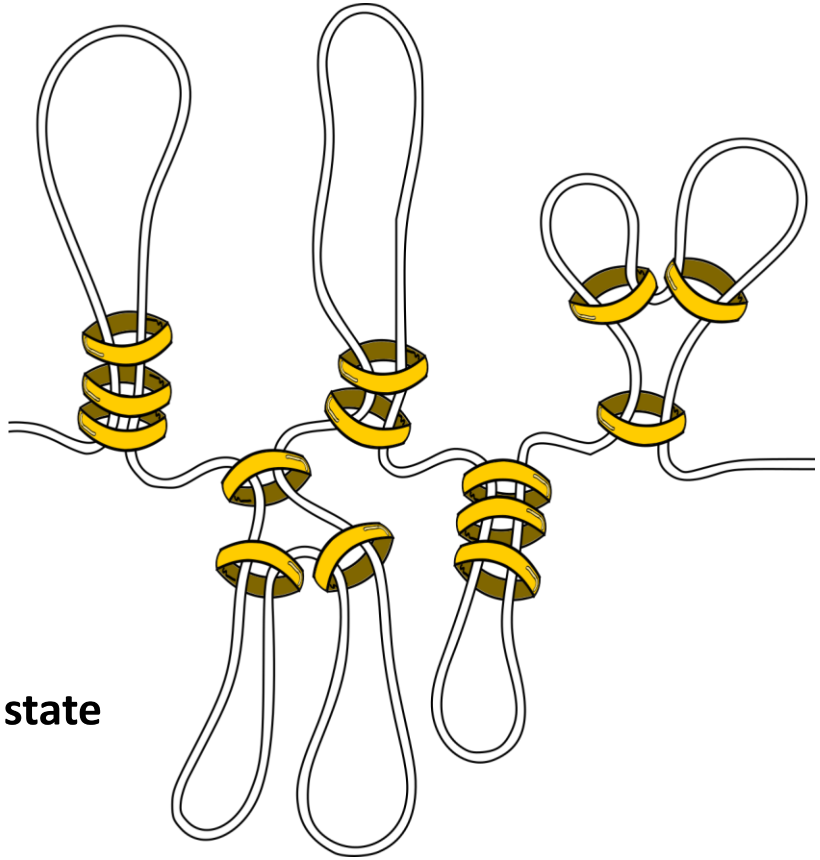


Sructural Maintenance of Chromosome (SMC) protein complex

Compaction by loop extrusion



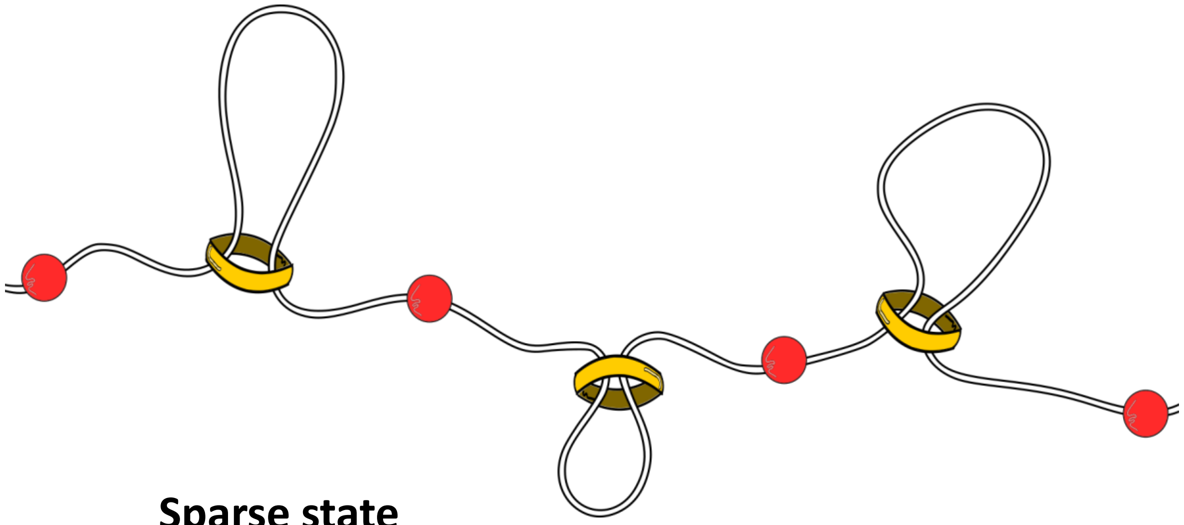
Sparse state



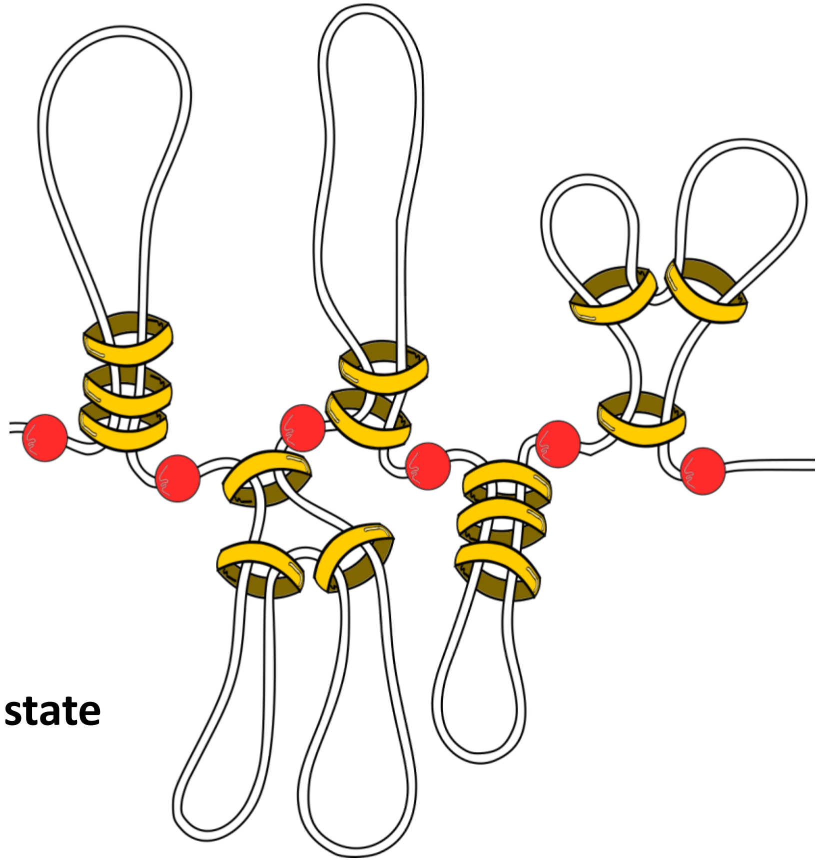
Compacted state

Centromeric units as anchors

Centromeric units may act as ANCHORS to the extrusion process of SMC proteins.

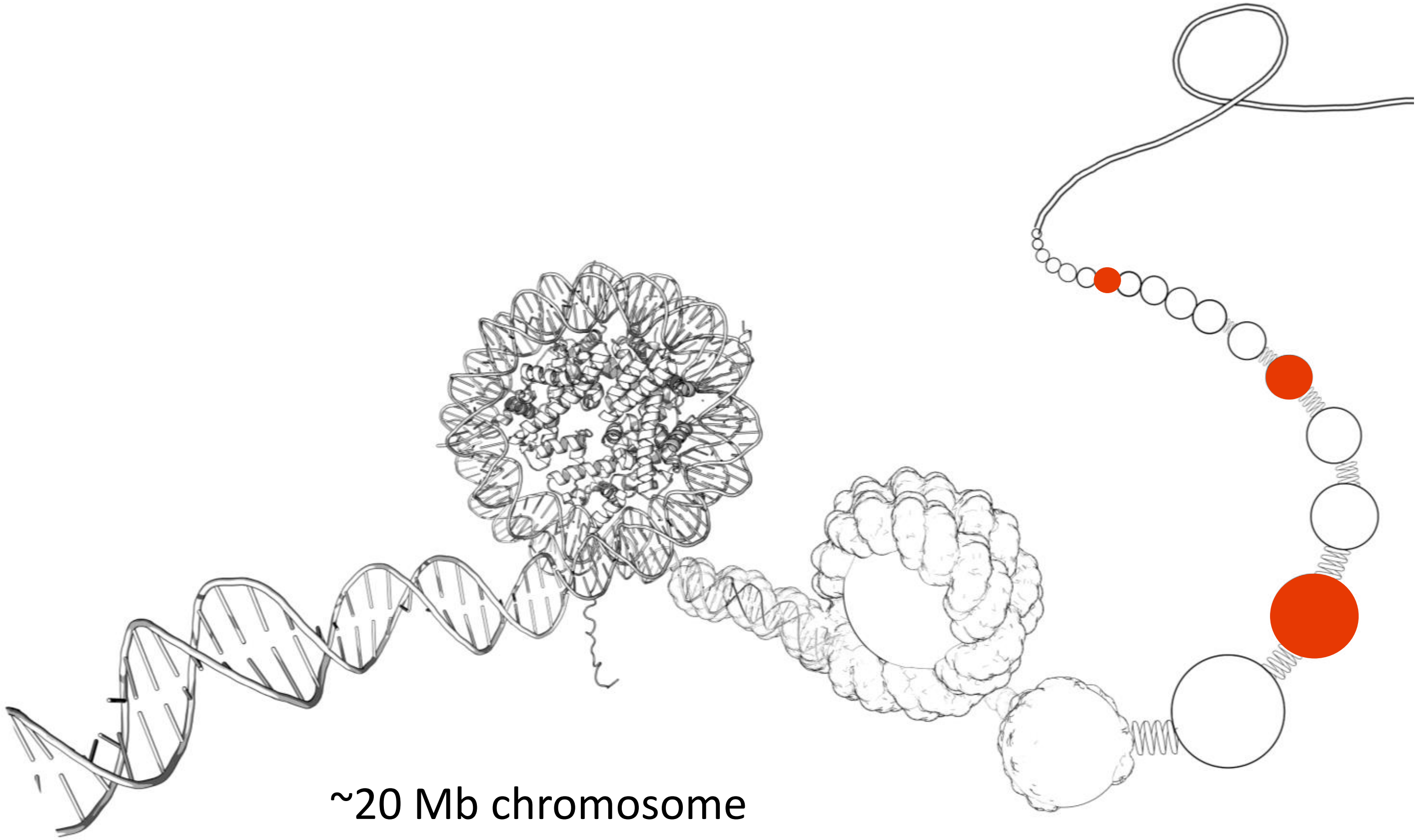


Sparse state

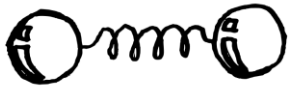


Compacted state

Coarse grain of chromatin fiber



~20 Mb chromosome
100,000 nucleosomes
1,000 centromeric nucleosomes

1. 

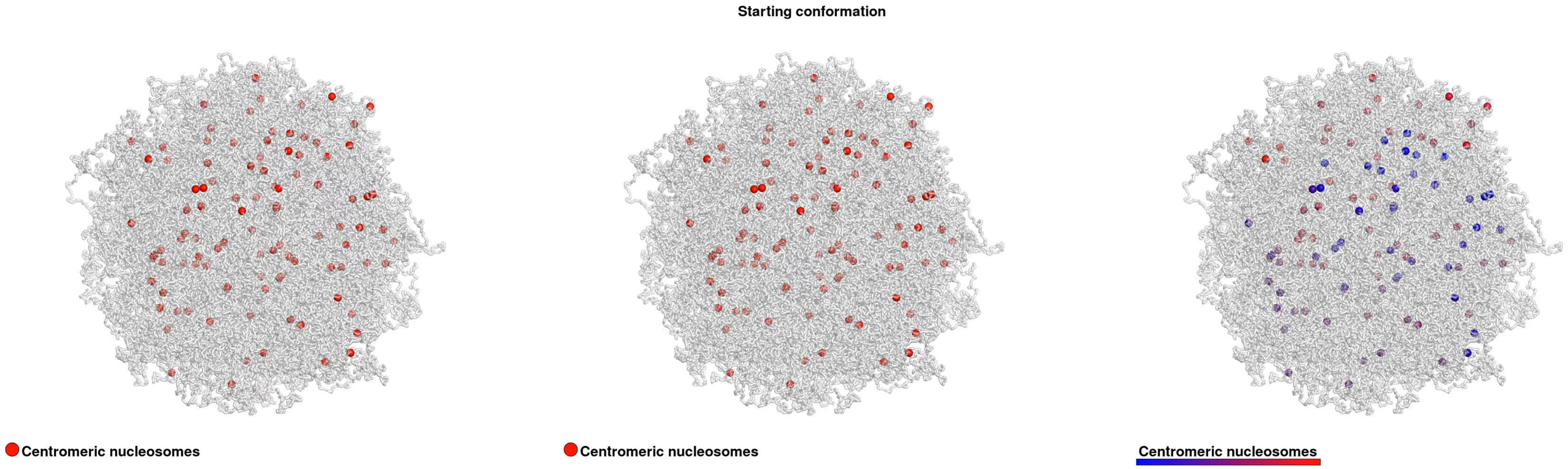
2. 

3. 

With truncation

4. **Damping force as solvation**

Colocalization of condensin and general linear organization

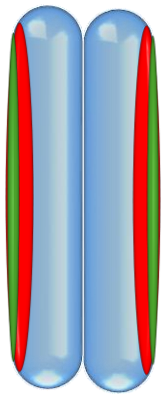


Câmara et al., 2021

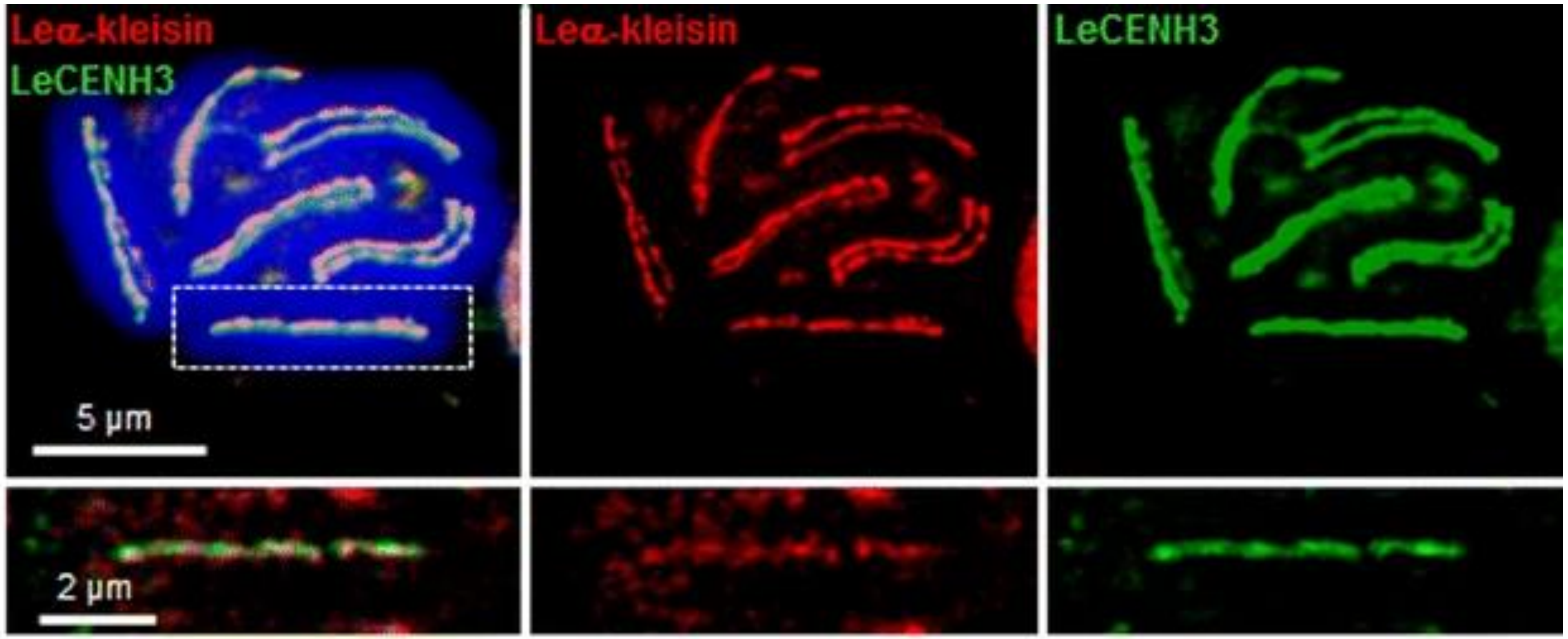
Beads-on-string model of one chromosome of 20 Mb.

https://youtu.be/kbVRhvzIexI

Colocalization of centromeres and condensins



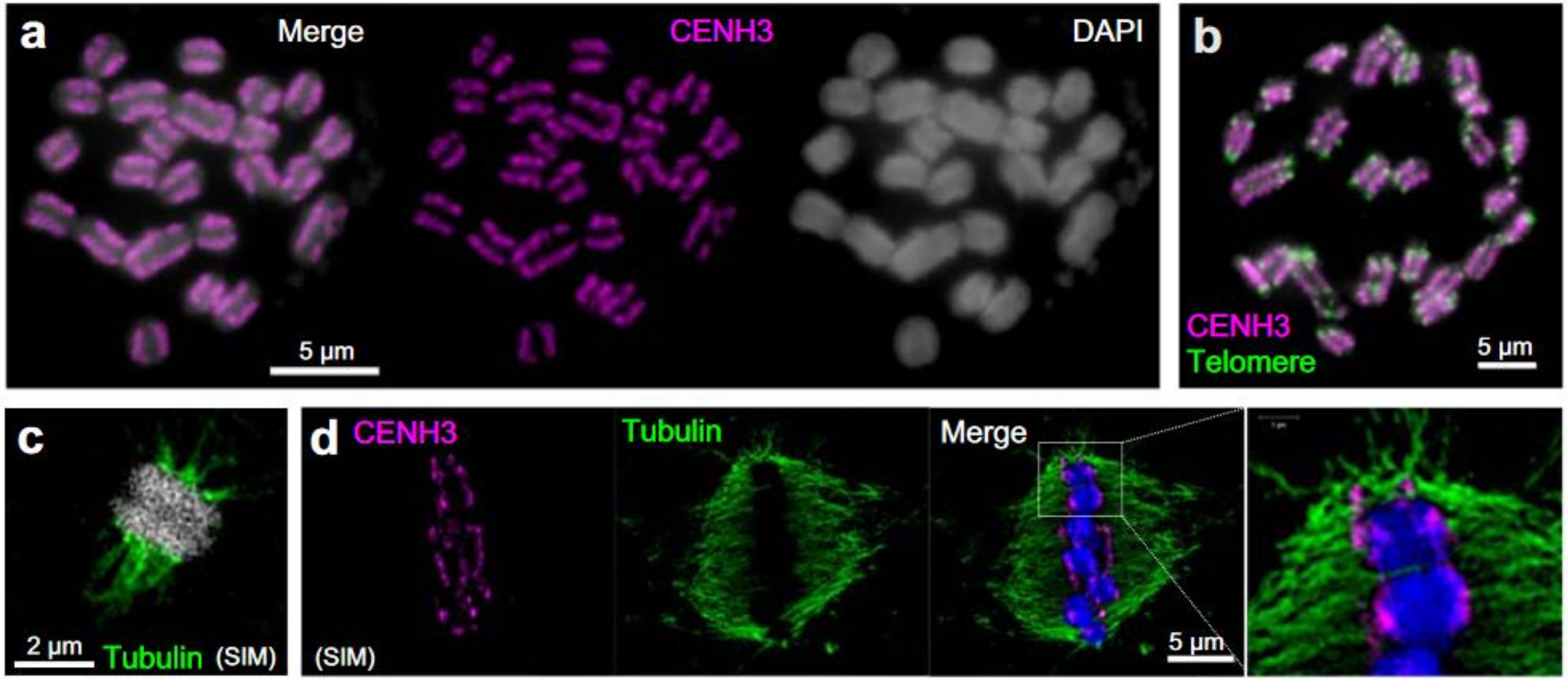
CenH3
Kleisin



Metaphase chromosomes of the holocentric species ***Luzula elegans***

Ma, W. et al., 2016.

Chionographis japonica

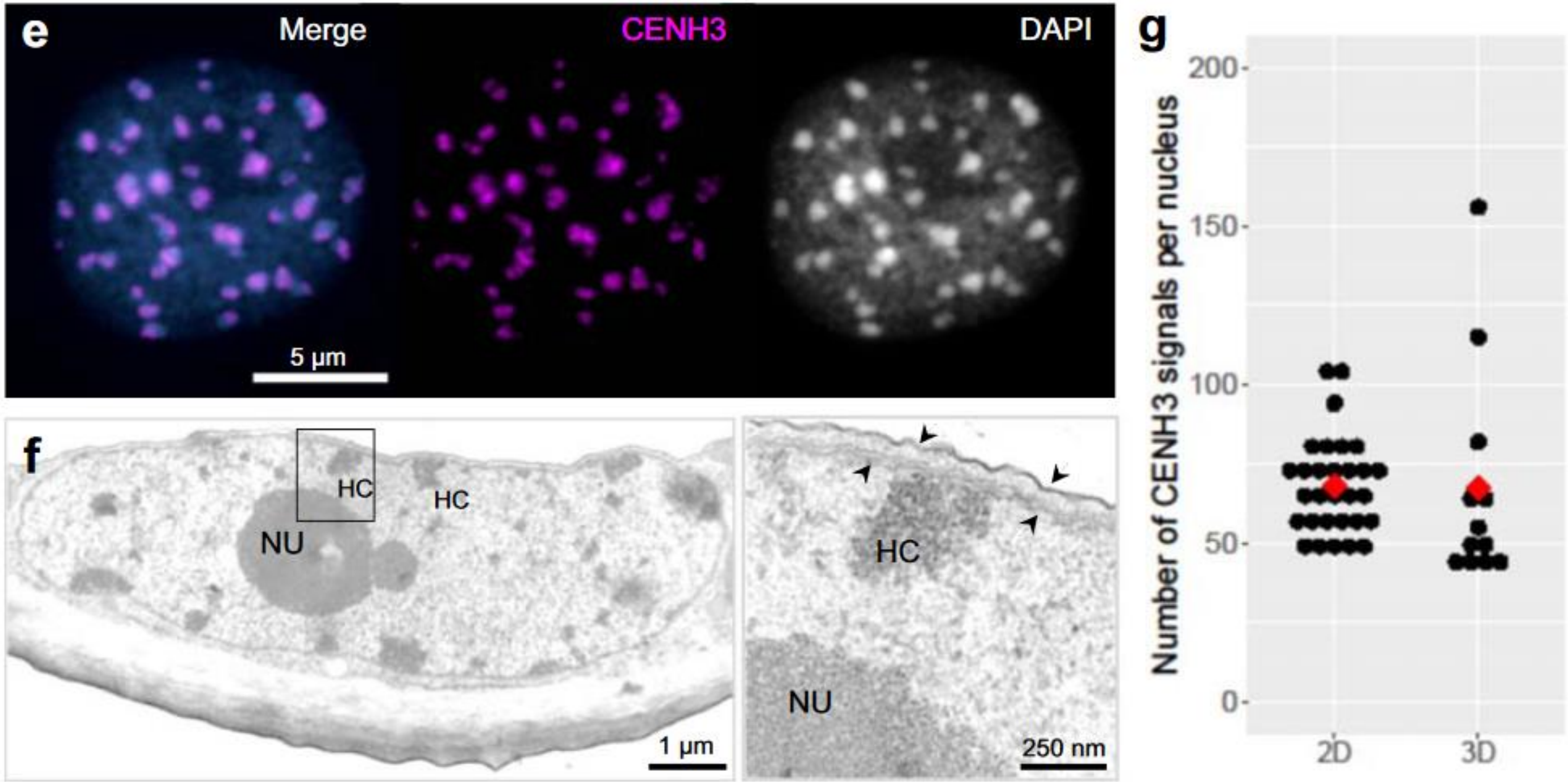


North American Rock Garden Society

Collaboration with Yi-Tzi Kuo and Andreas Houben, IPK

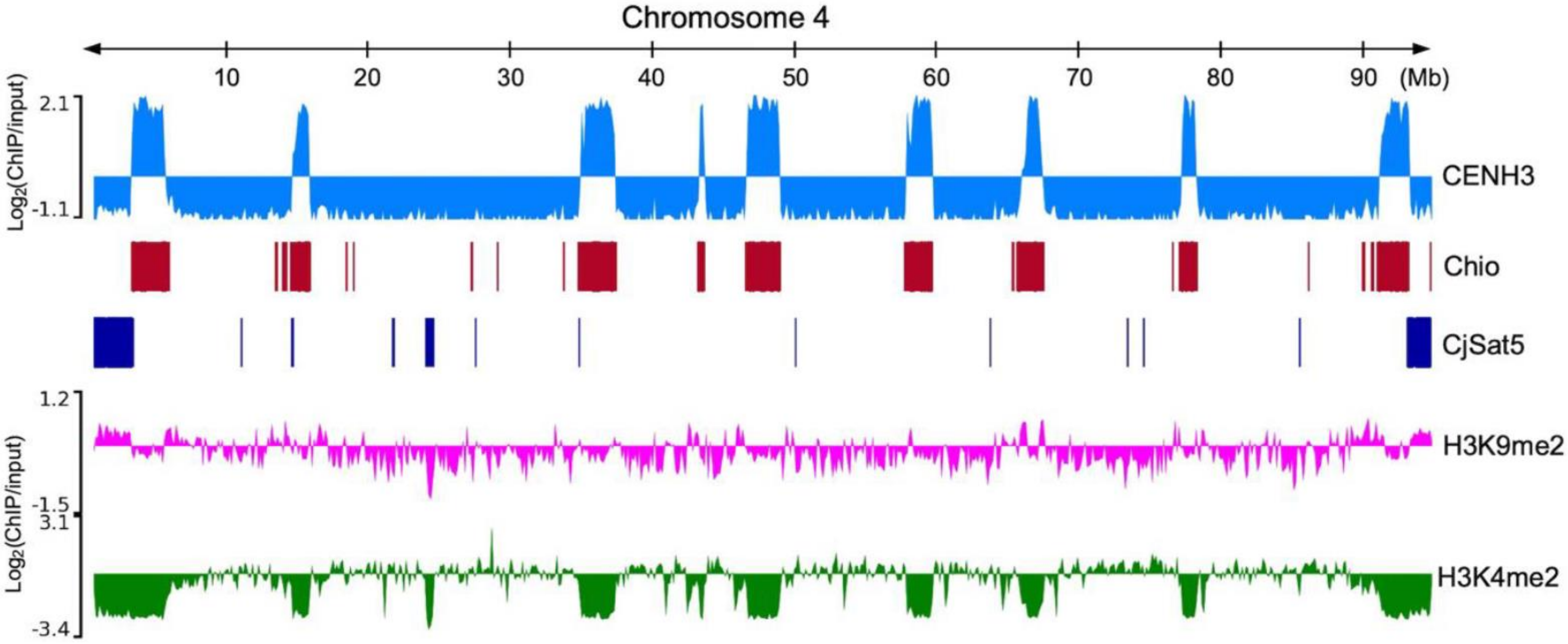
Kuo et al., 2023.

Holocentricity in clusters



Kuo et al., 2023.

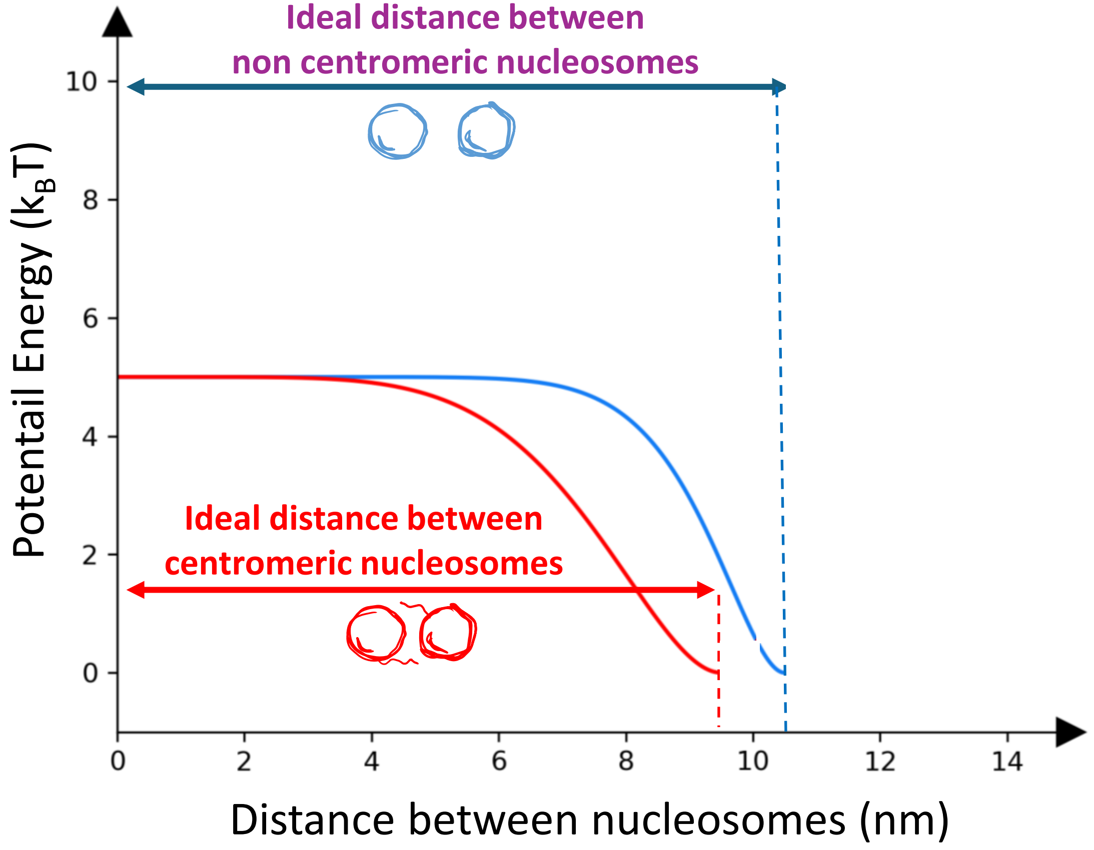
Centromeric units within heterochromatin and satellite repeats



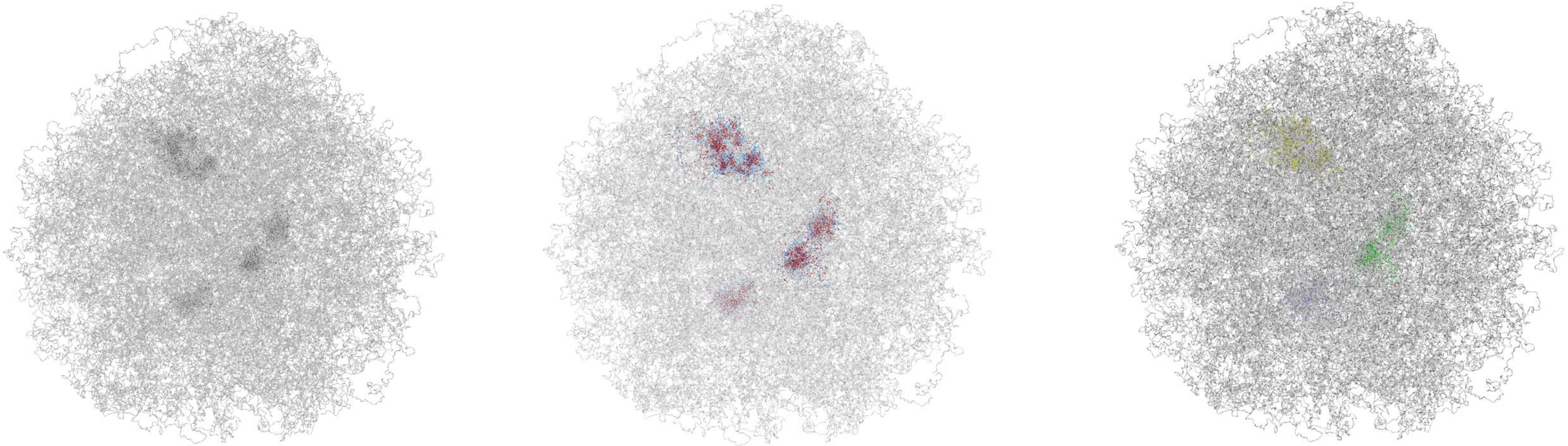
Kuo et al., 2023.

Sticky factor

Attraction and repulsion
of non bonded nucleosomes



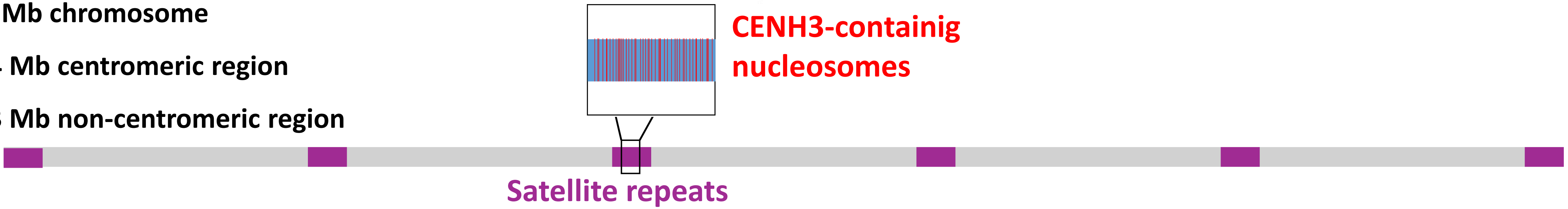
Model of chromocenters



20 Mb chromosome

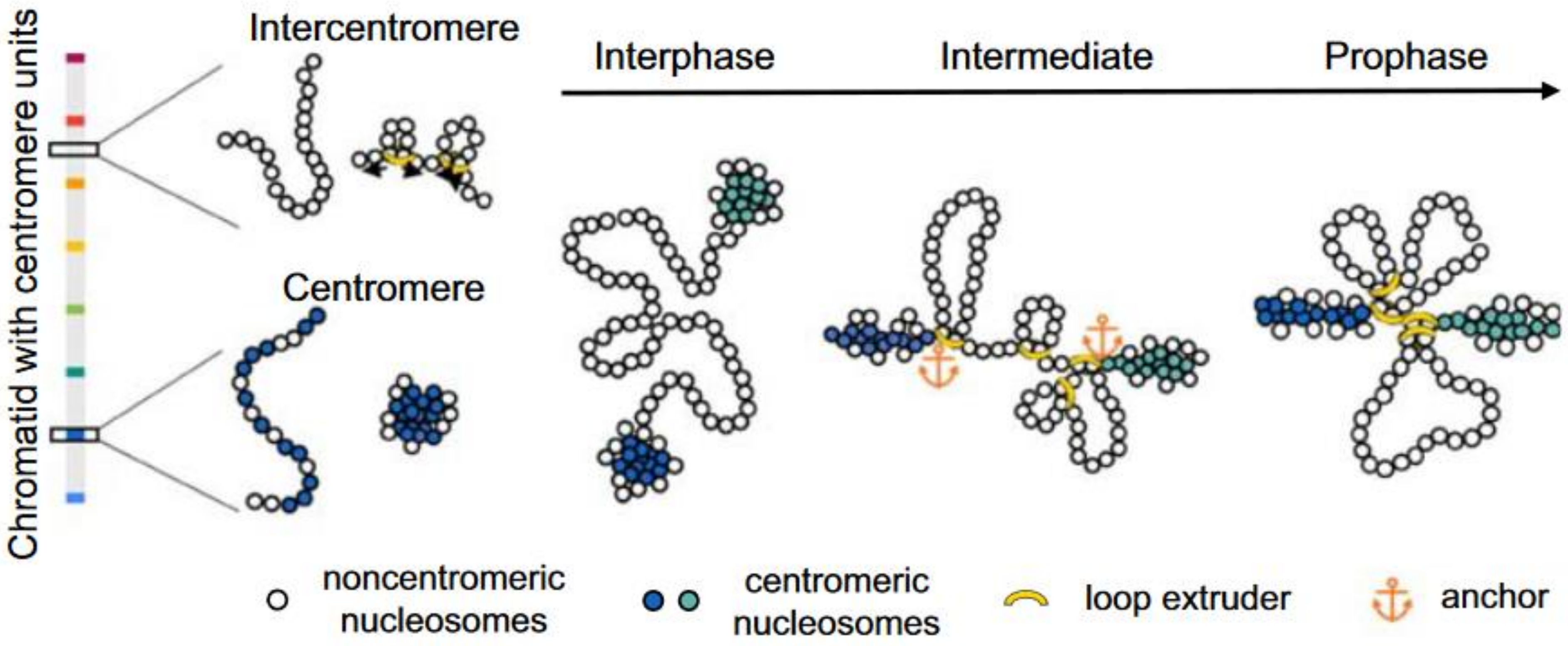
0.4 Mb centromeric region

2.3 Mb non-centromeric region

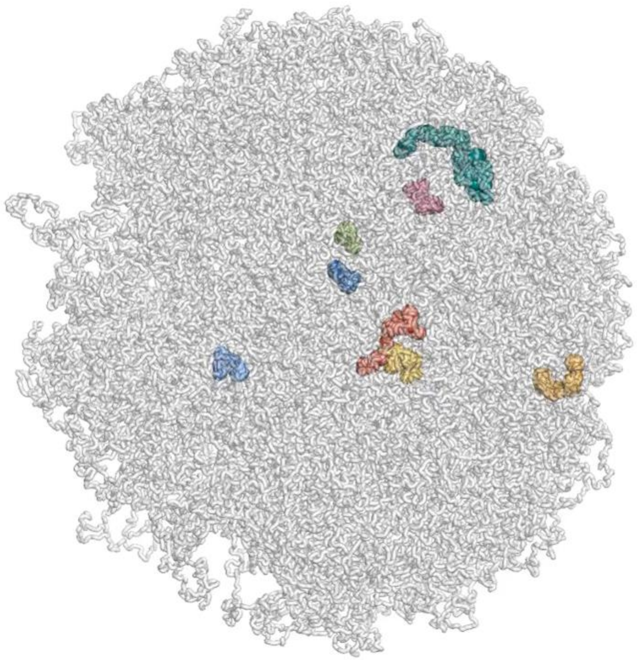


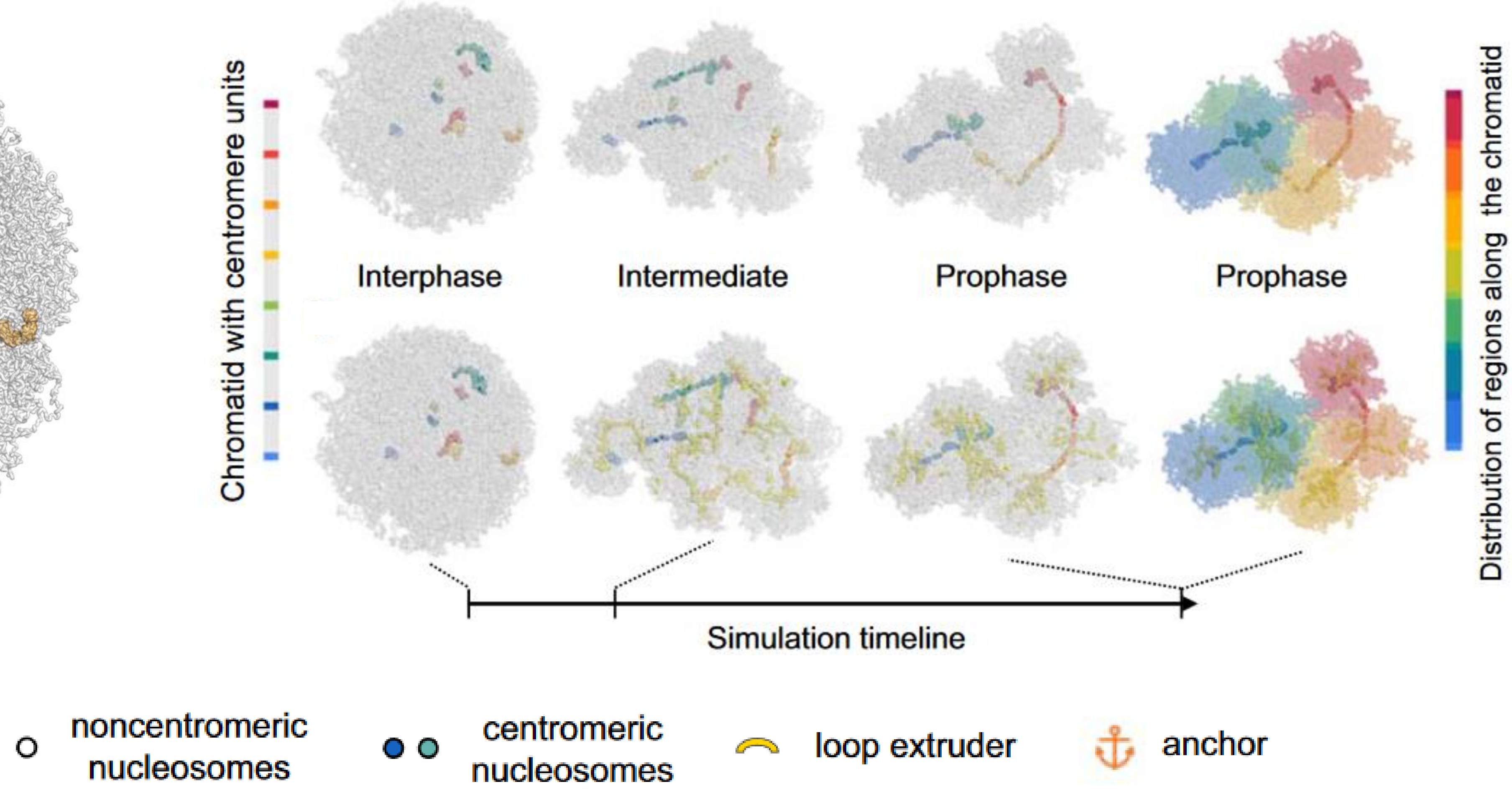
A *Chionographis* chromosome

Model of compaction with chromocenters

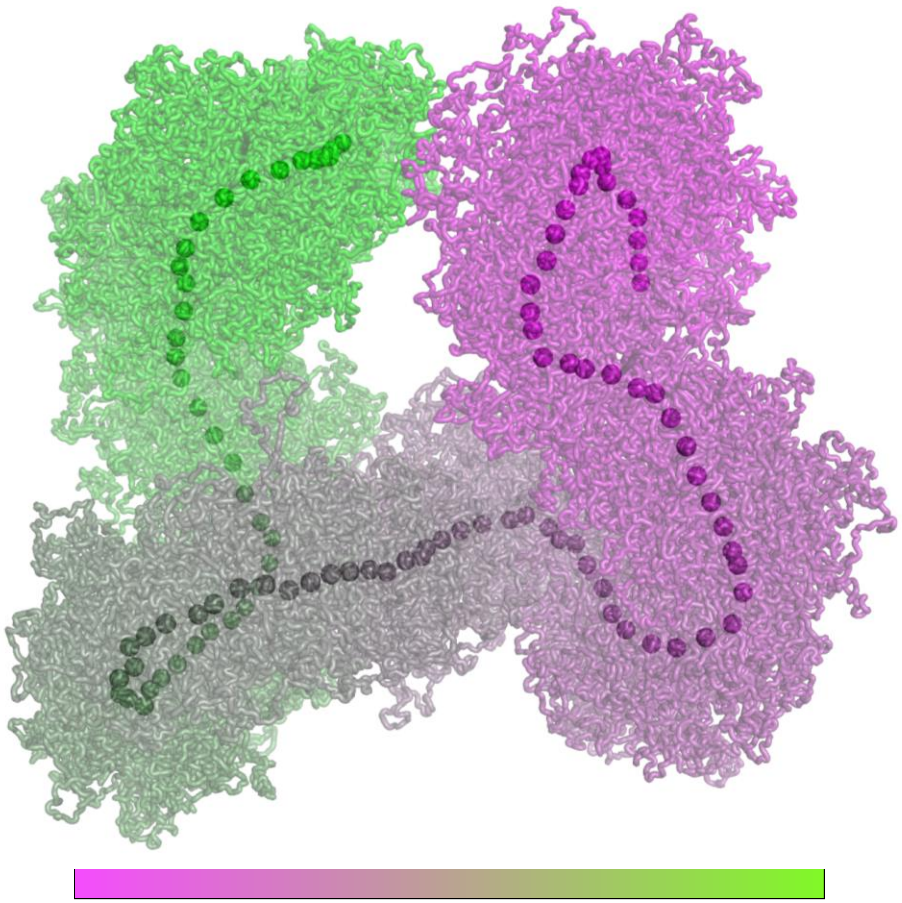


Model of compaction with chromocenters

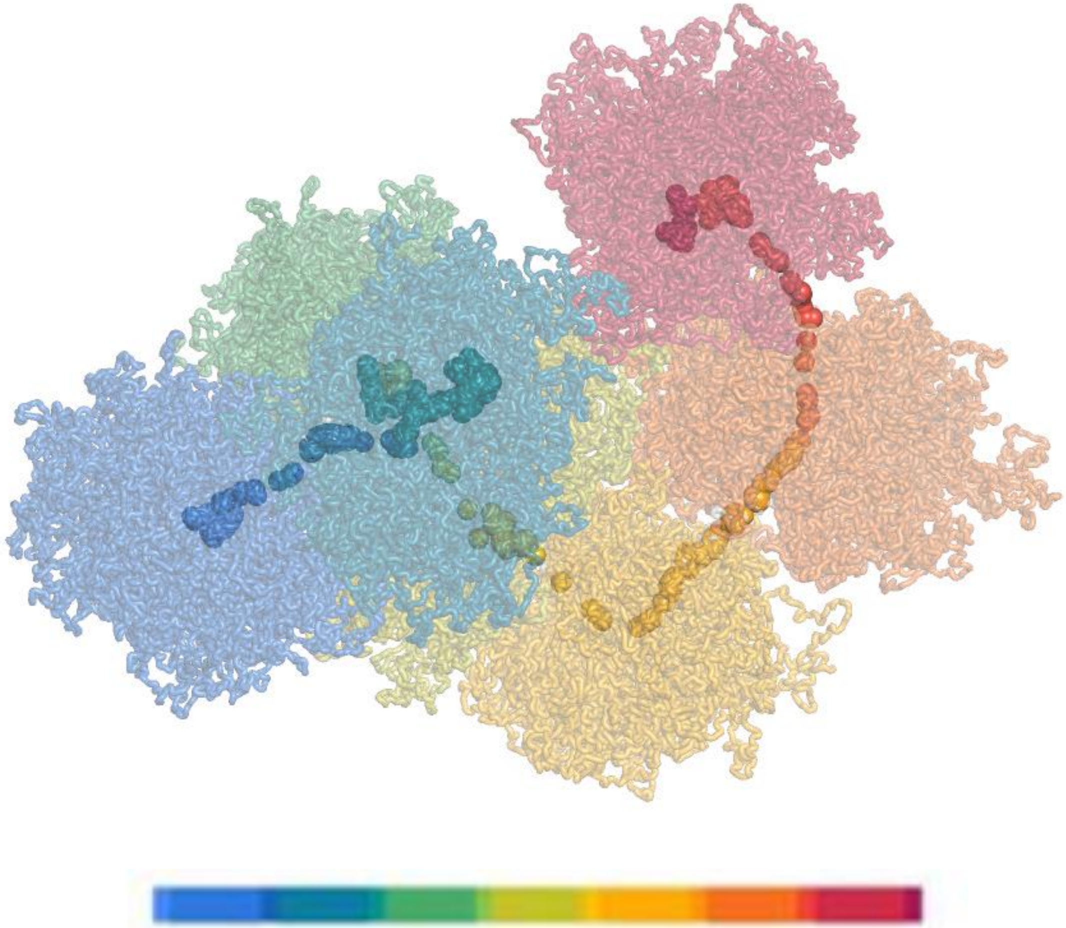




Chionographis chromosomes forms blobs



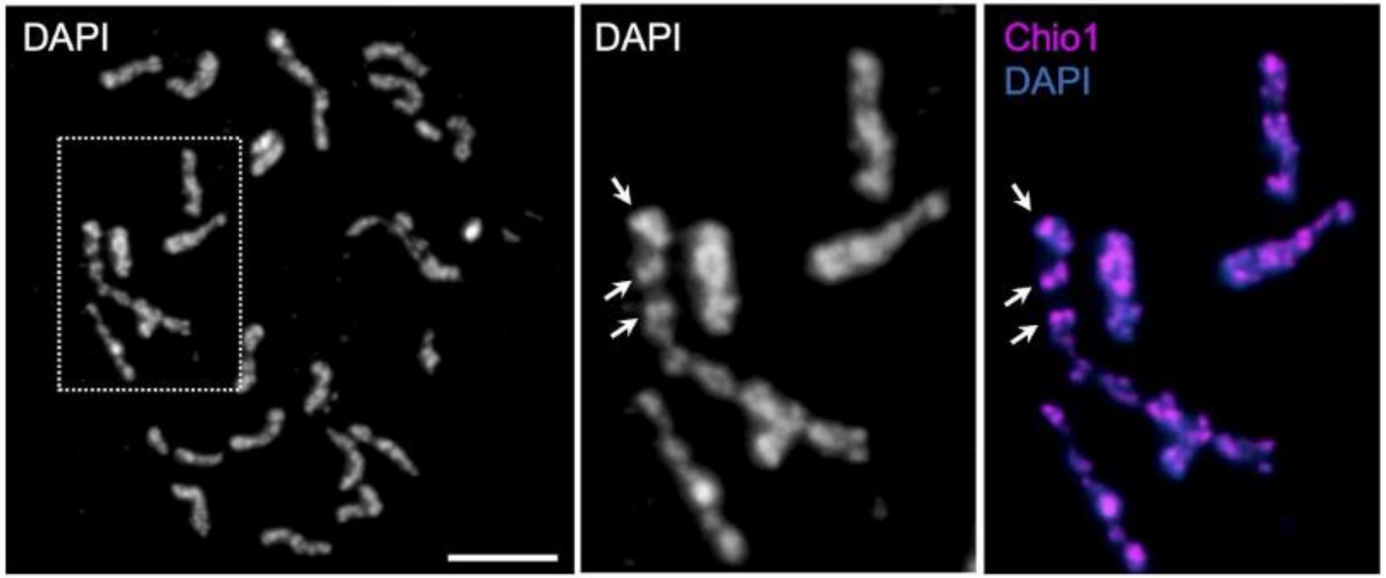
Genomic position



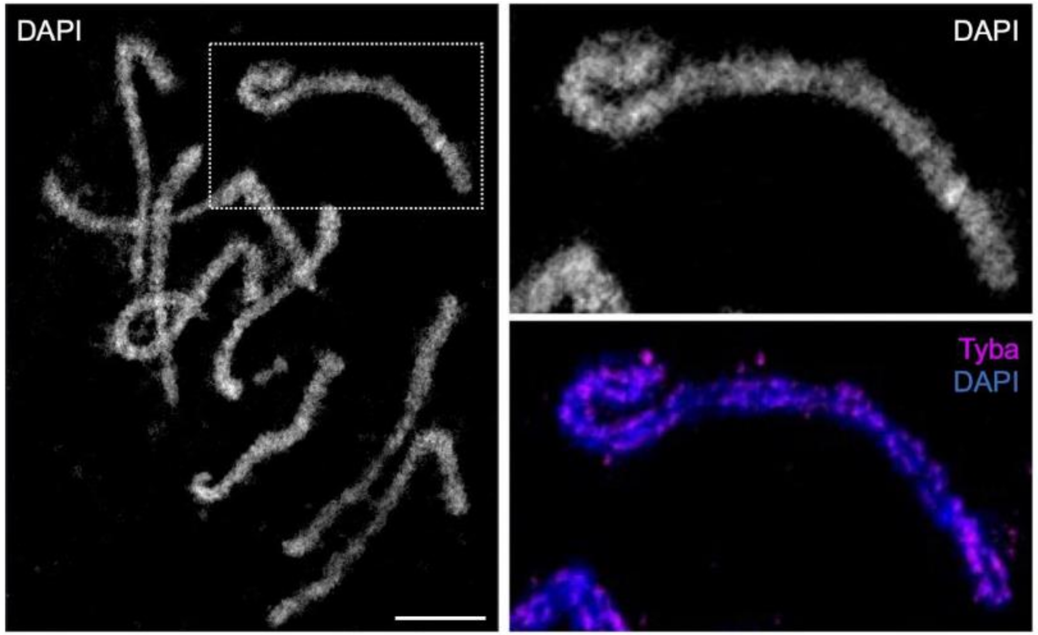
Genomic position

Prophase chromosomes are not uniform

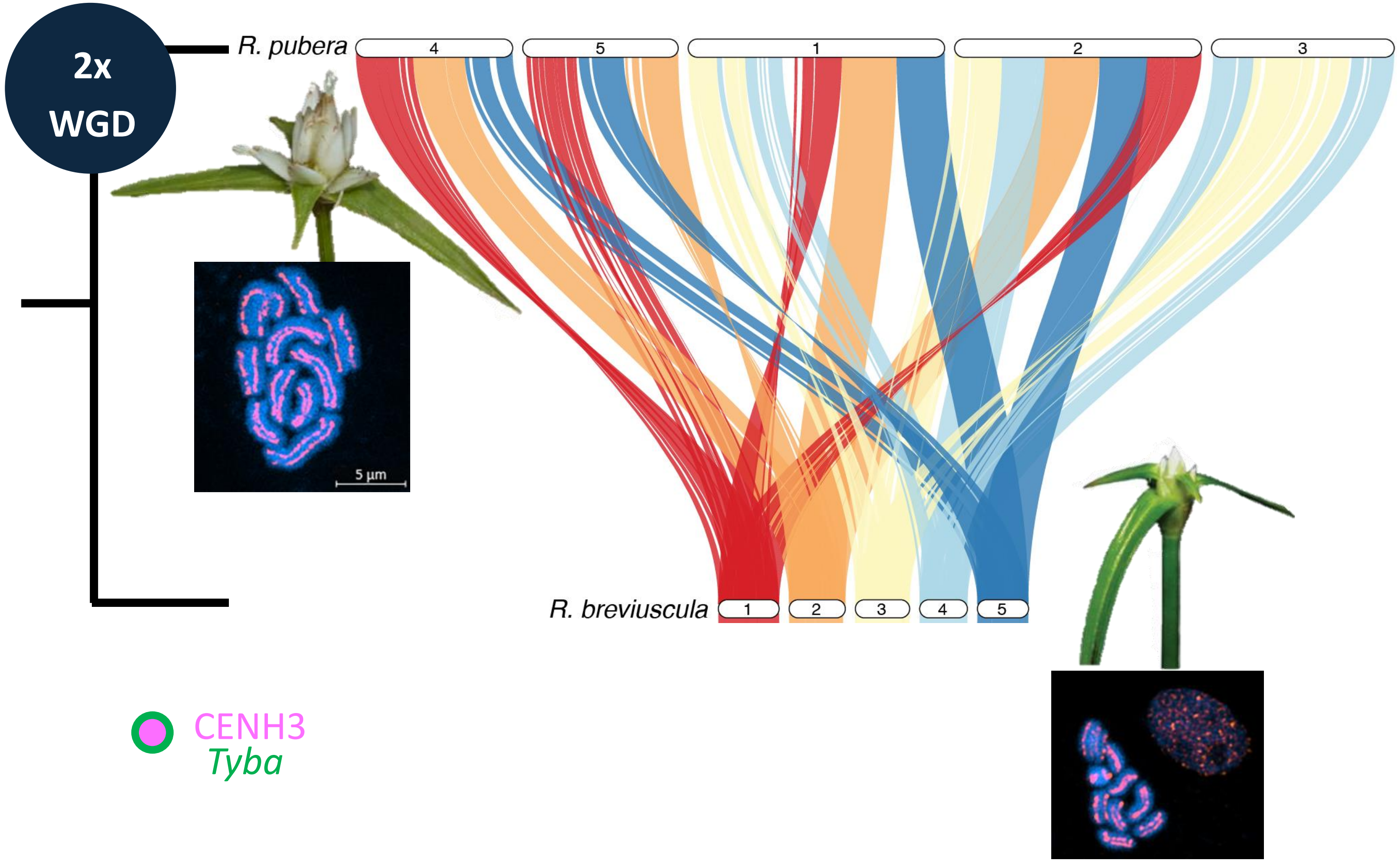
Chionographis japonica



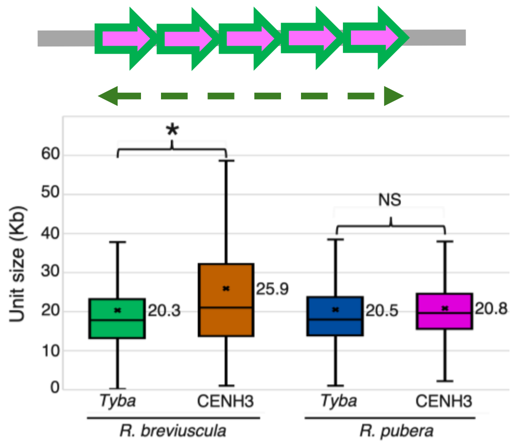
Rhynchospora pubera



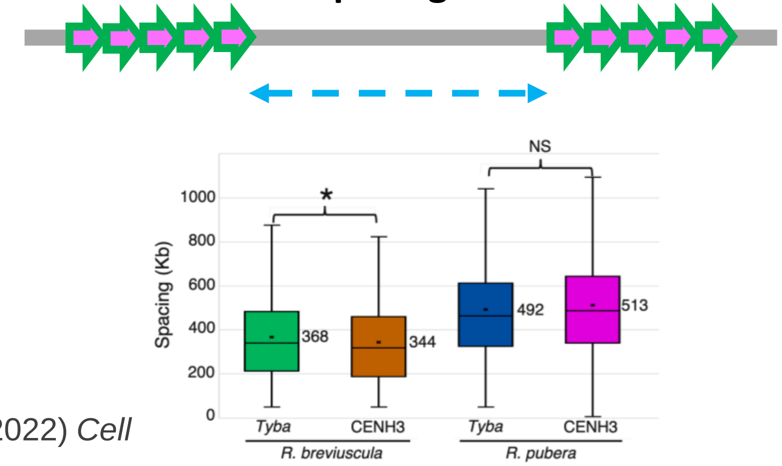
Centromere plasticity in the Rhynchospora genus



Size



Spacing

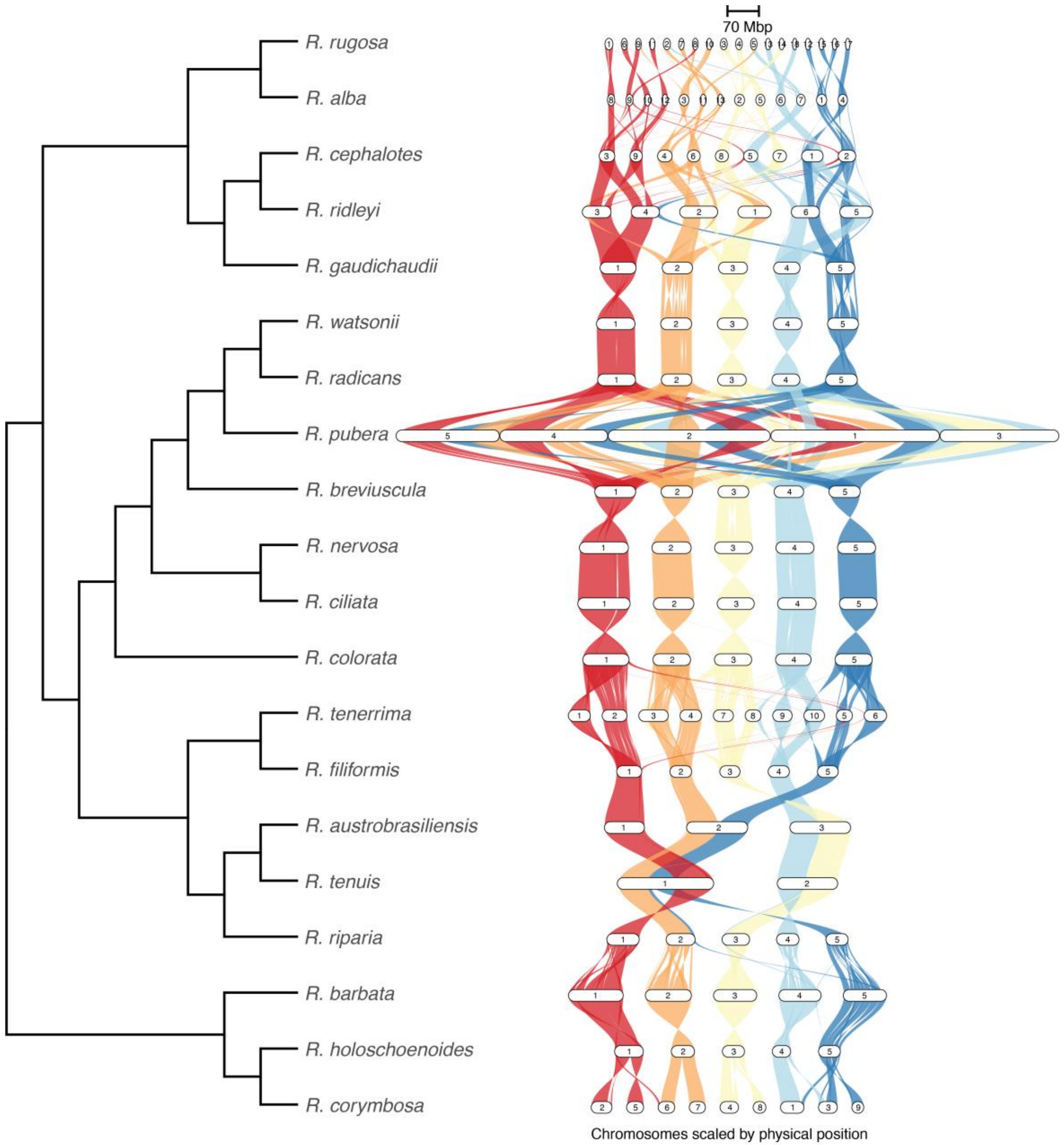


CENH3
Tyba

Collaboration with André Marques,
Max Planck Institute, Cologne

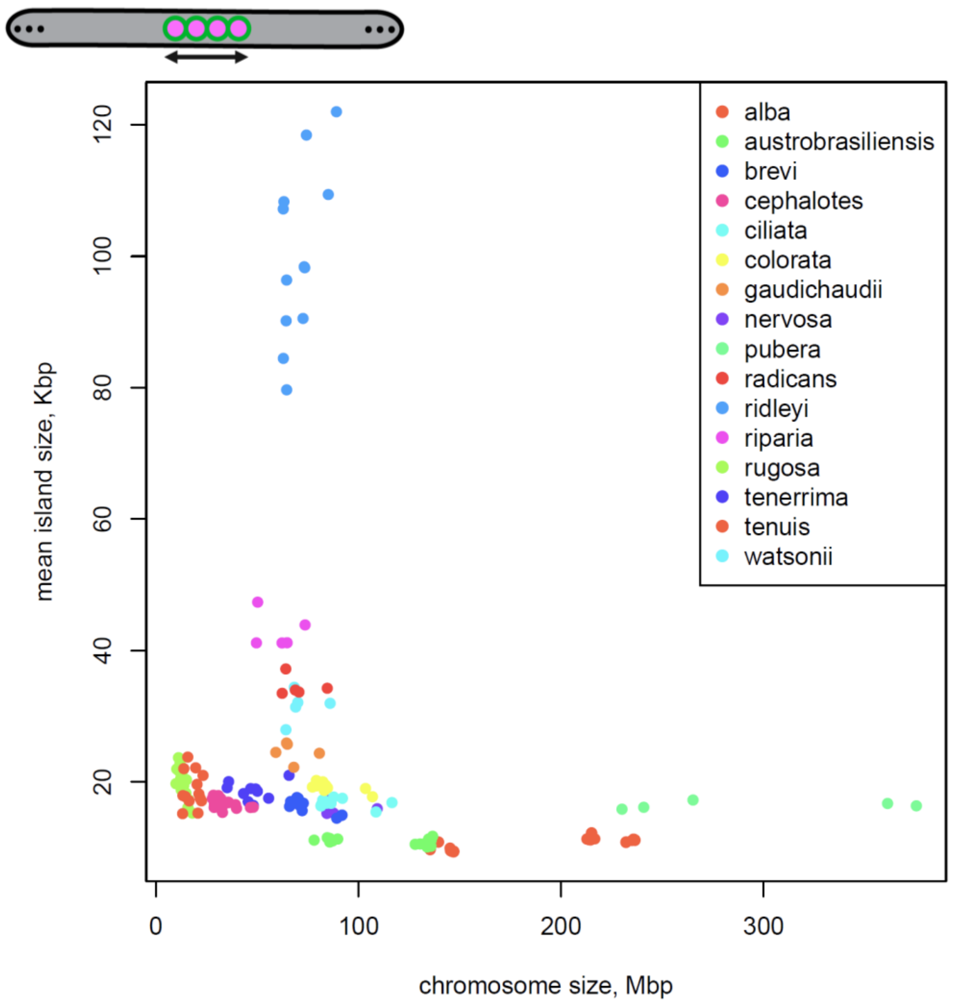
Hofstatter, Thangavel et al. (2022) *Cell*

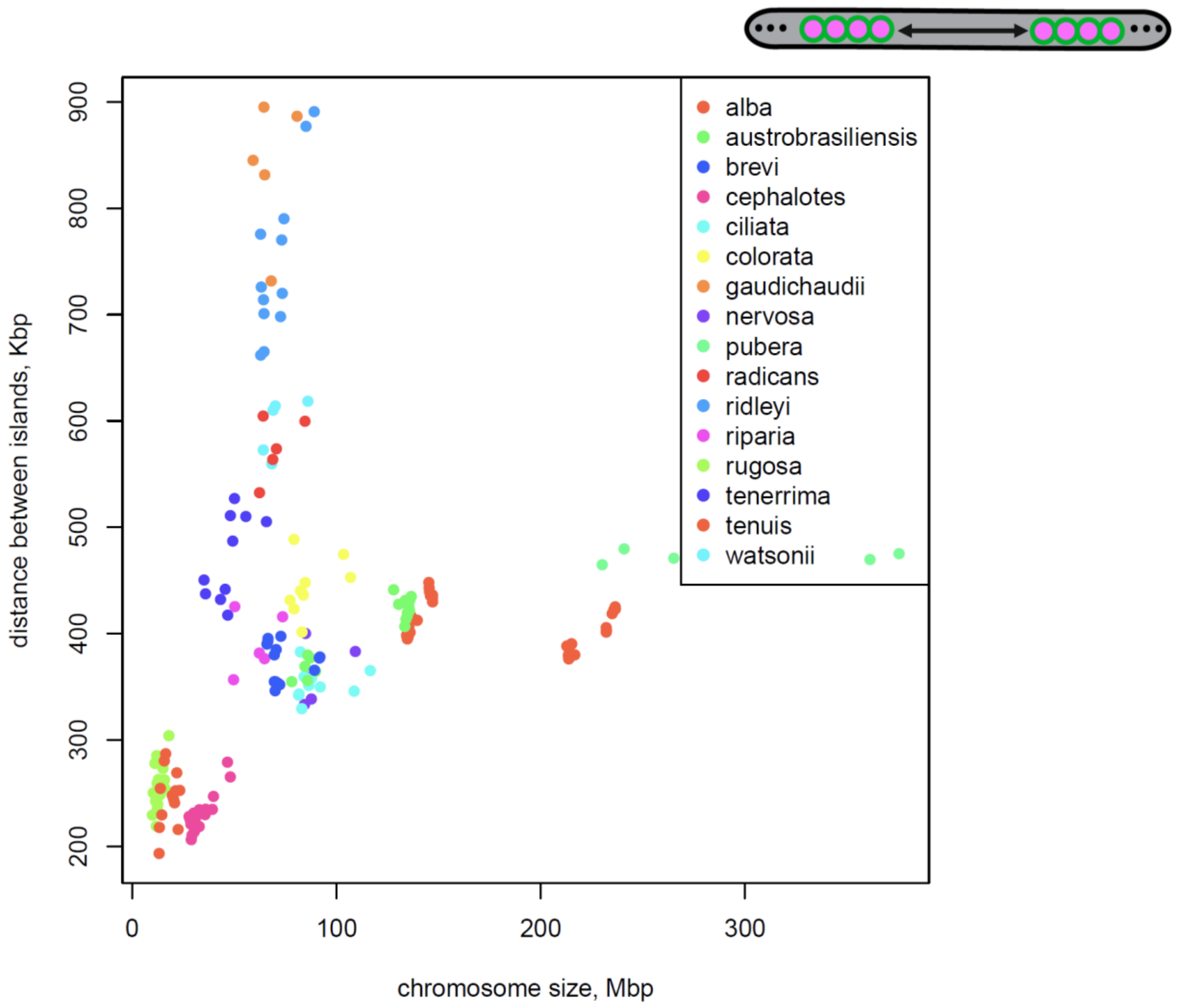
Chromosome plasticity in Rhynchospora



Unpublished

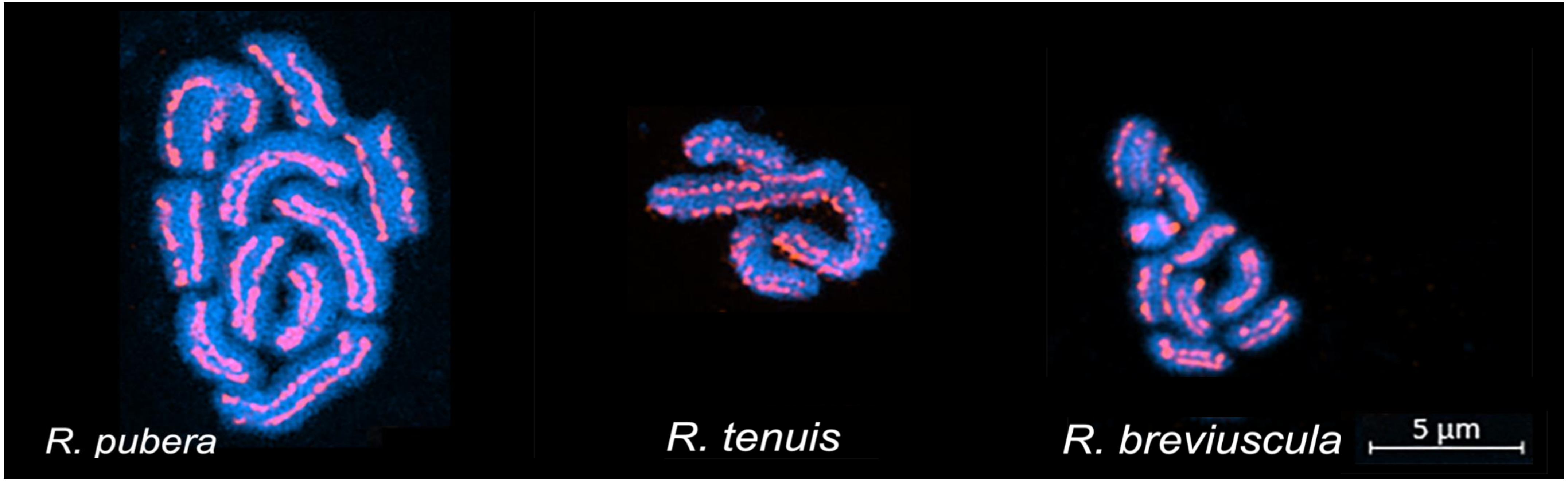
Centromere length is constant but spacings grow with chromosome length





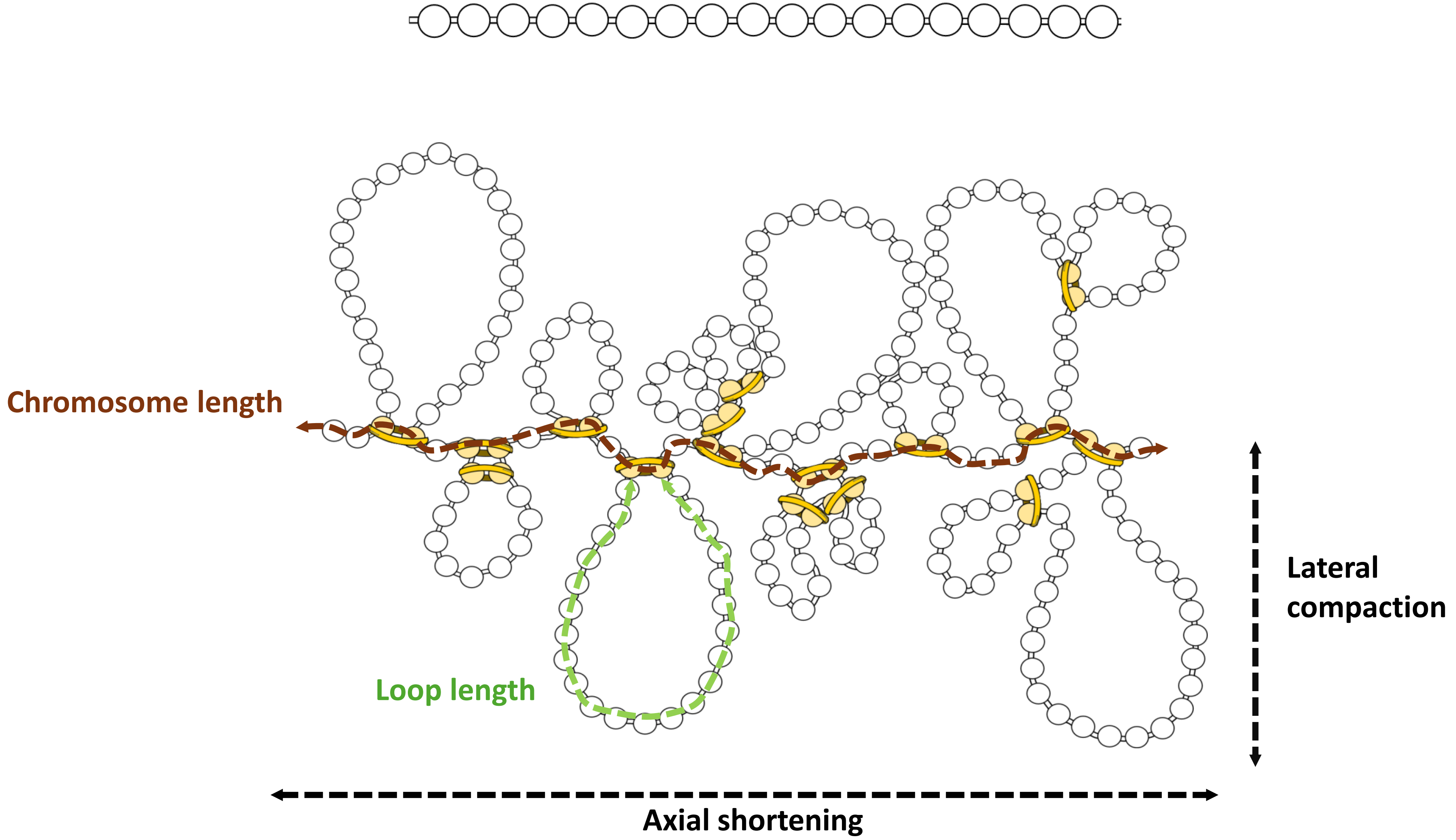
Unpublished

Varied length and width of mitotic chromosomes



Mean chromosome length: 300 Mb 150 Mb 75 Mb

Measuring compaction in the models

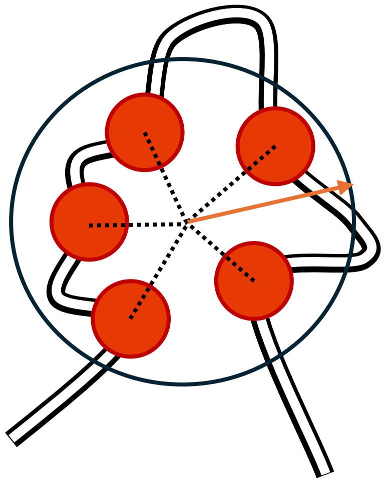


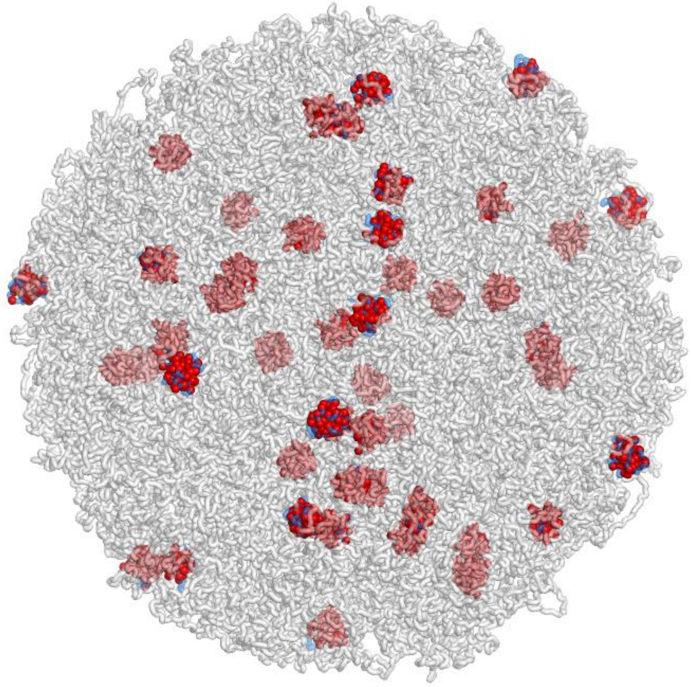
Simulated loop extrusion

	Rugosa	Breviuscula	Pubera
Chromosome length	14 Mb	75 Mb	300 Mb
Space between centromeric units	300 kb	450 kb	600 kb
Repeat length	20 kb	20 kb	20 kb
Percentage of centromeric nucleosomes	60 %	60 %	60 %
Simulated region	15 Mb	15 Mb	15 Mb
Number of centromeric units in the model	47	32	25
Number of simulated loop extruders (lifetime)	500 (500)	500 (500)	500 (500)
Mean loop length after equilibration	72.6 kb	75.8 kb	77.6 kb

Unpublished

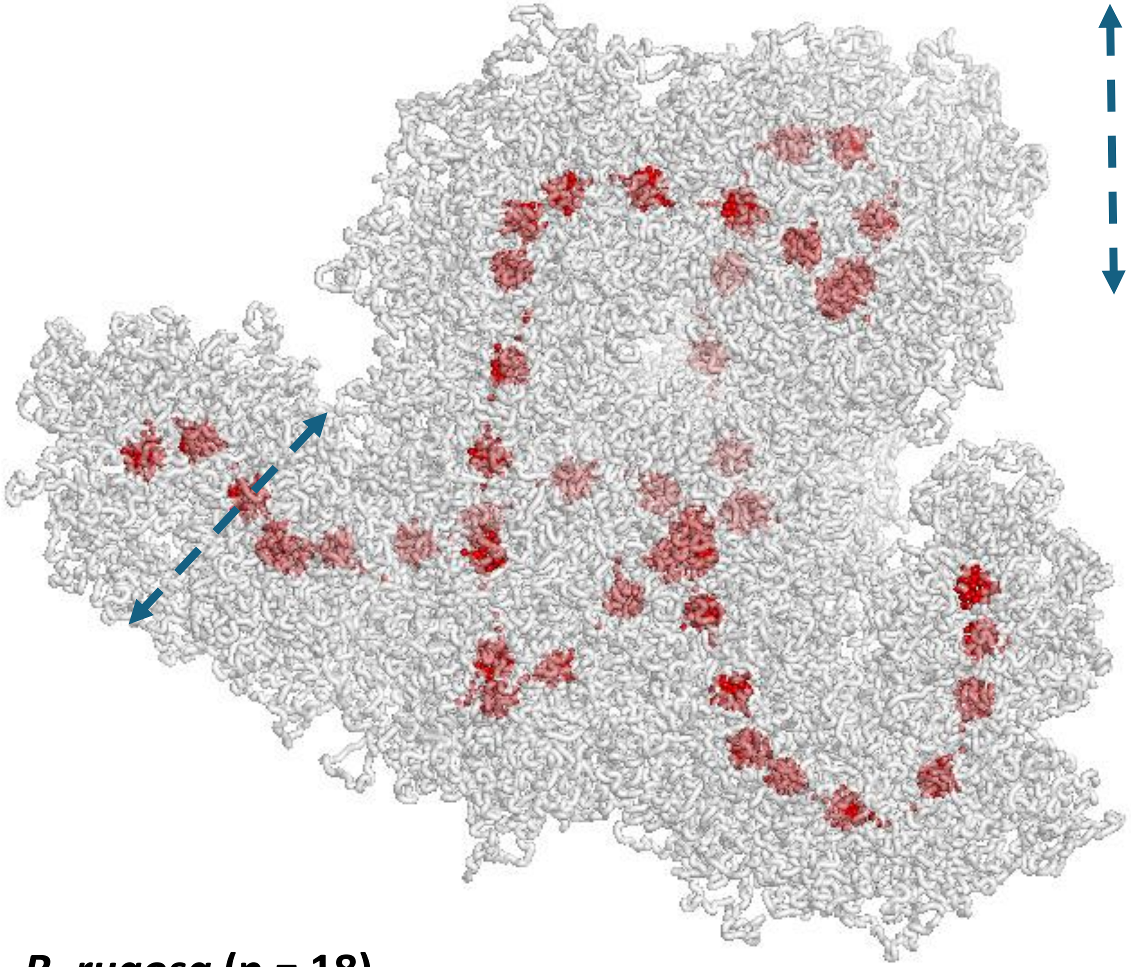
Update the centromeric unit model



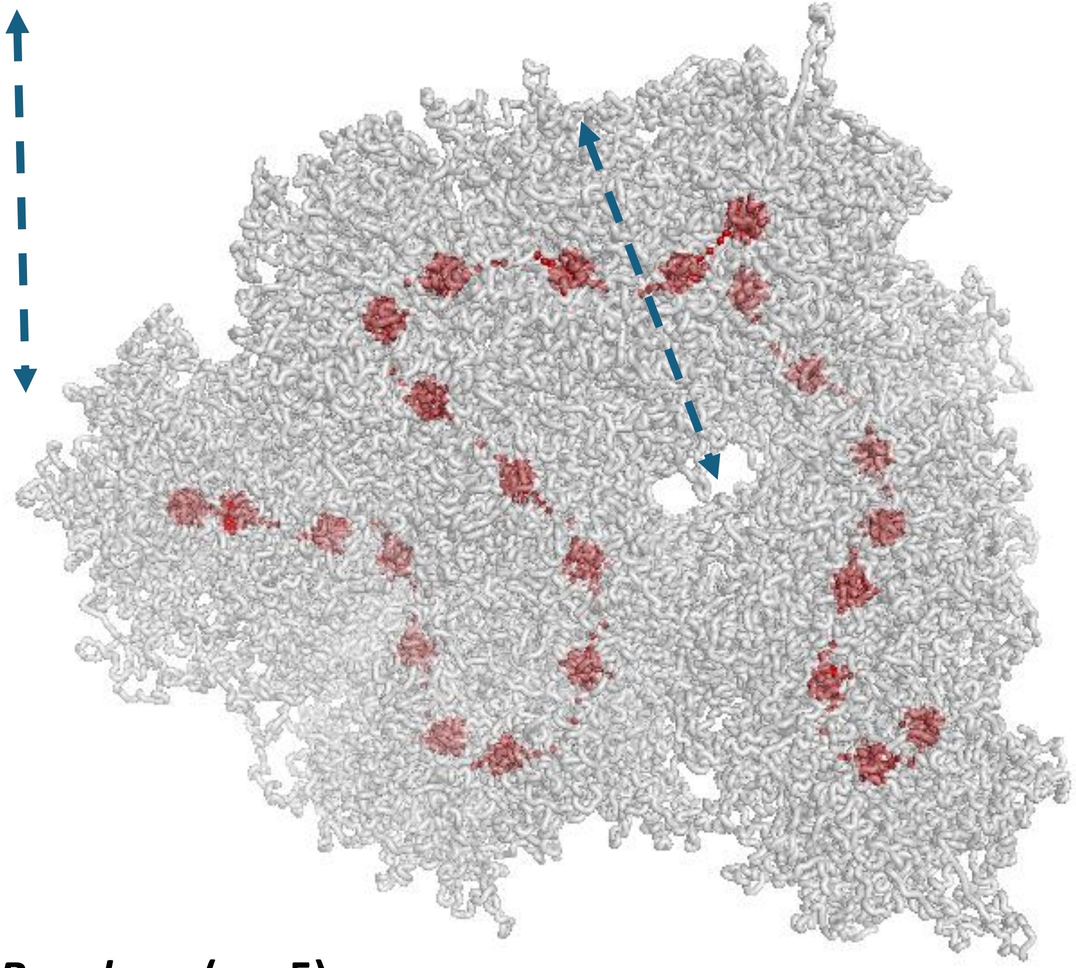


step 00000

Width measurement



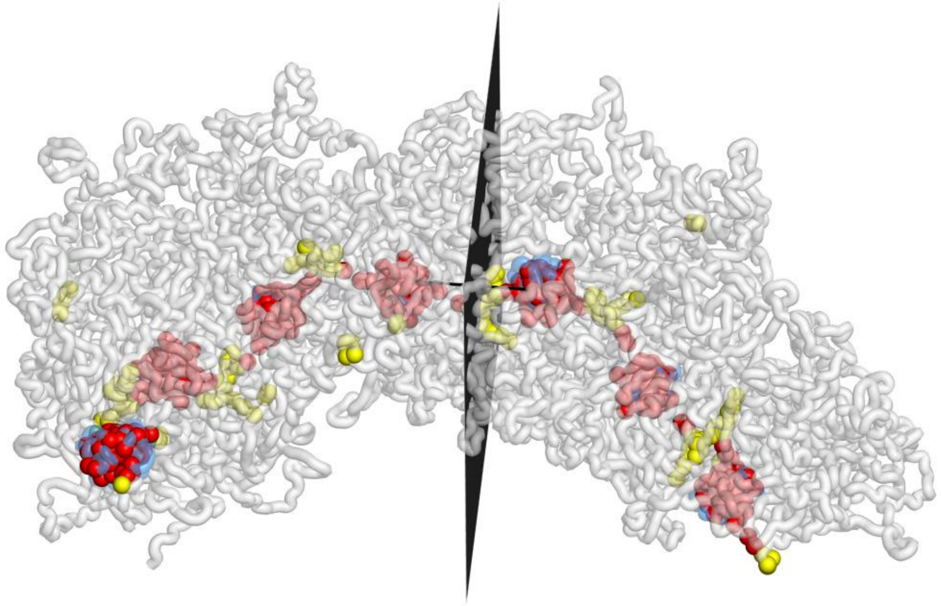
R. rugosa **(n = 18)**
median chromosome length = 14 Mb



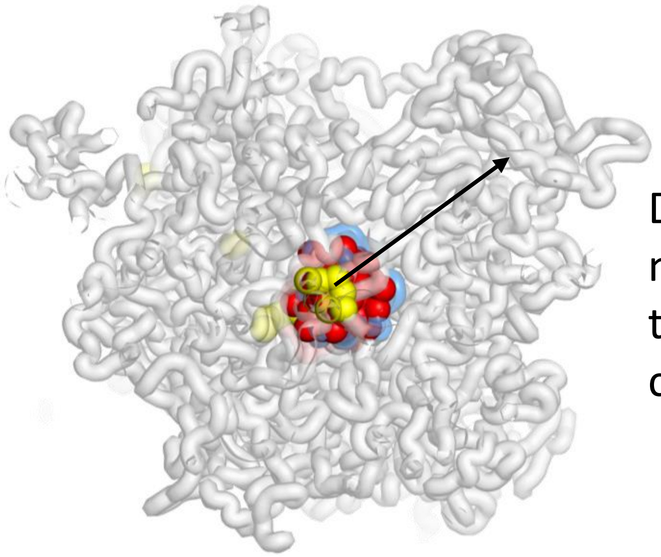
R. pubera **(n = 5)**
median chromosome length = 300 Mb

Unpublished

Measurement of the chromonema width



Plane between cetromeric units

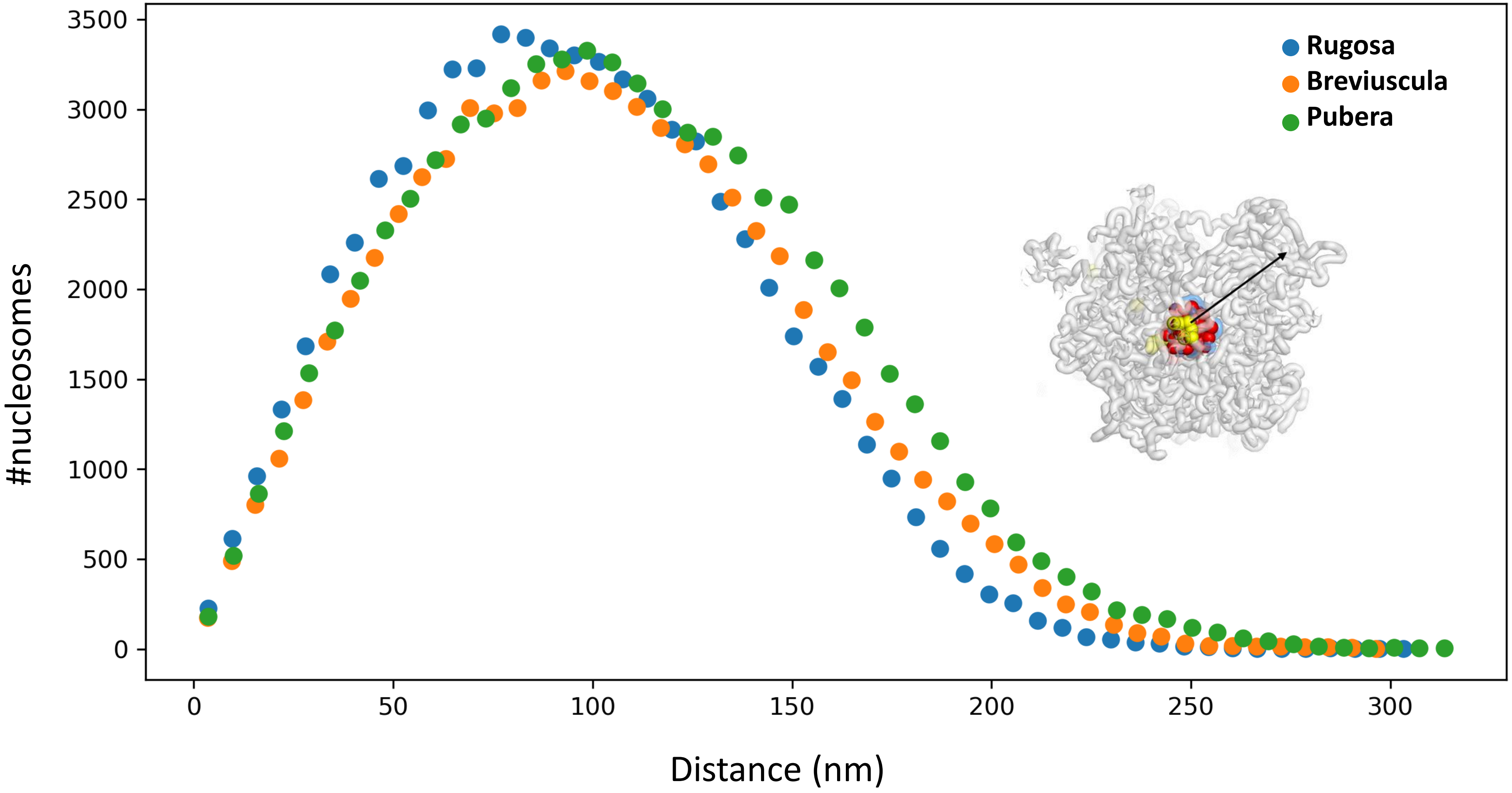


Distance of each nucleosome to the center of the plane, or the axis of the chromonema

Projection f the chromatin between centromeric units onto the plane

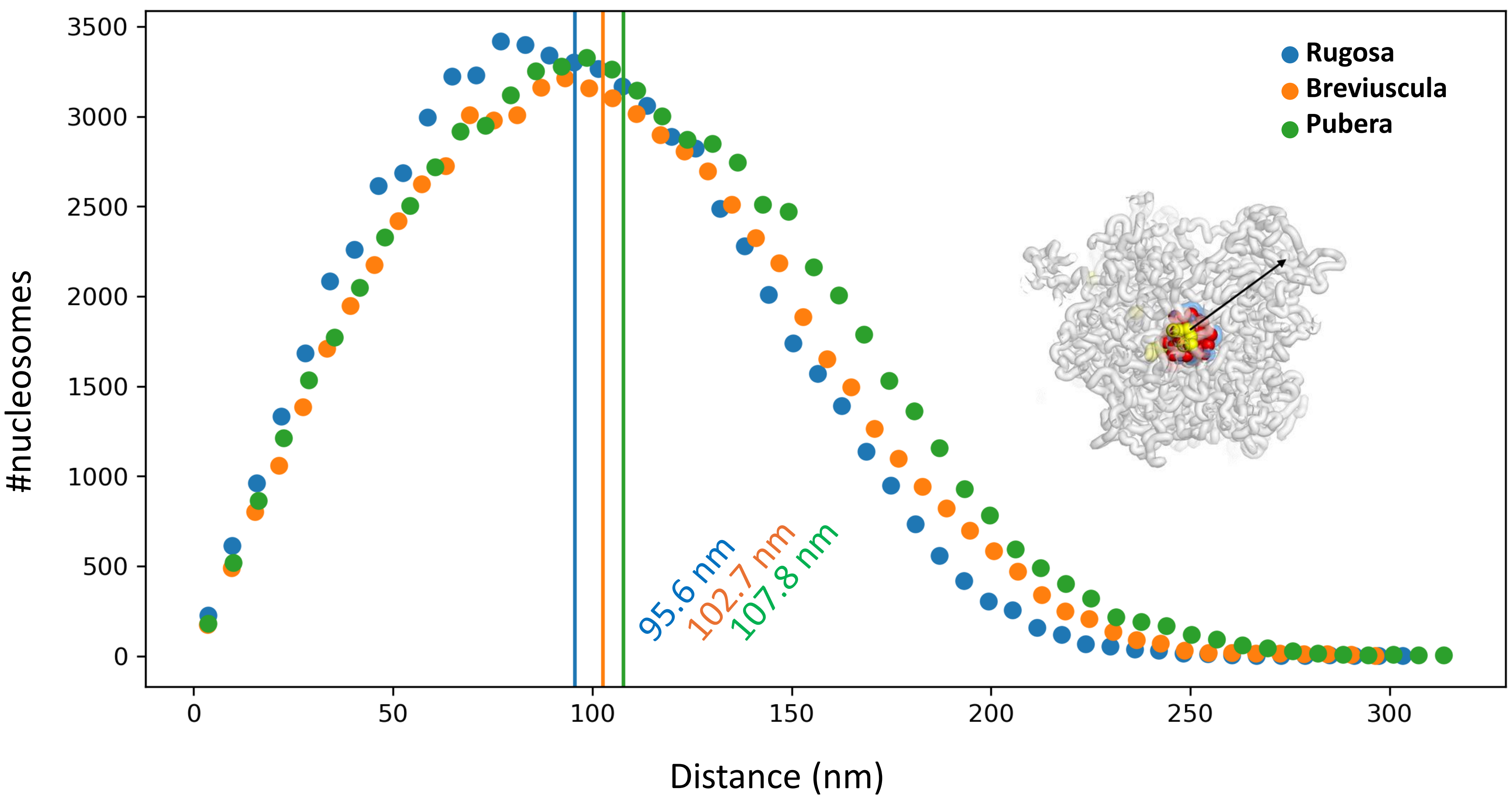
Unpublished

Measurement of the chromonema width



Unpublished

Measurement of the chromonema width



Unpublished

Take-home message

- Loop extrusion is a general compaction mechanism for all holocentric species, modulated by the distribution of centromeric units, which correlates with the mitotic chromosome shape

- Is the evolution of holocentric chromosomes affected by their mitotic shape?

Thank you!

- Andreas Houben
- Yi-Tzi Kuo (HeiHei)
- Veit Schubert
- Martin Mascher

- André Marques

MAX PLANCK INSTITUTE FOR PLANT BREEDING RESEARCH

DFG Deutsche Forschungsgemeinschaft

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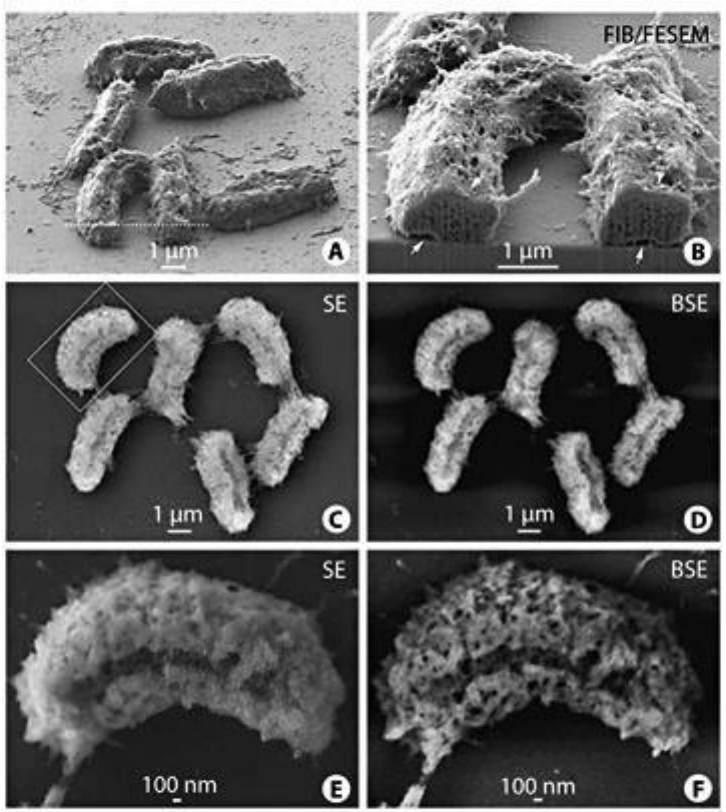
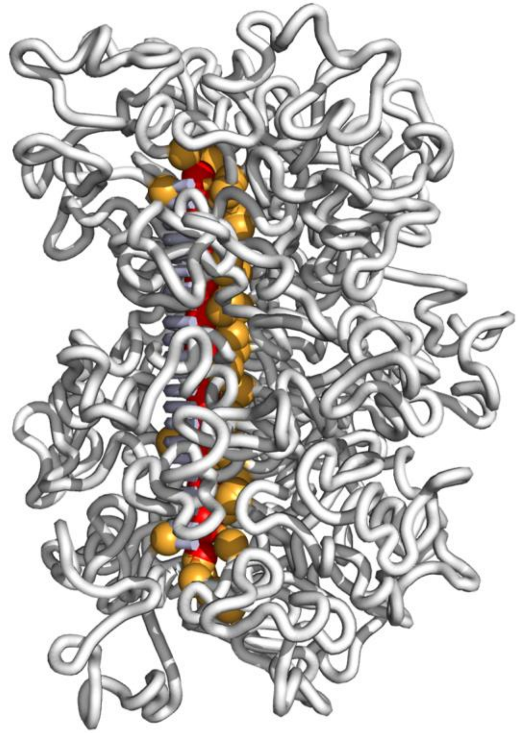
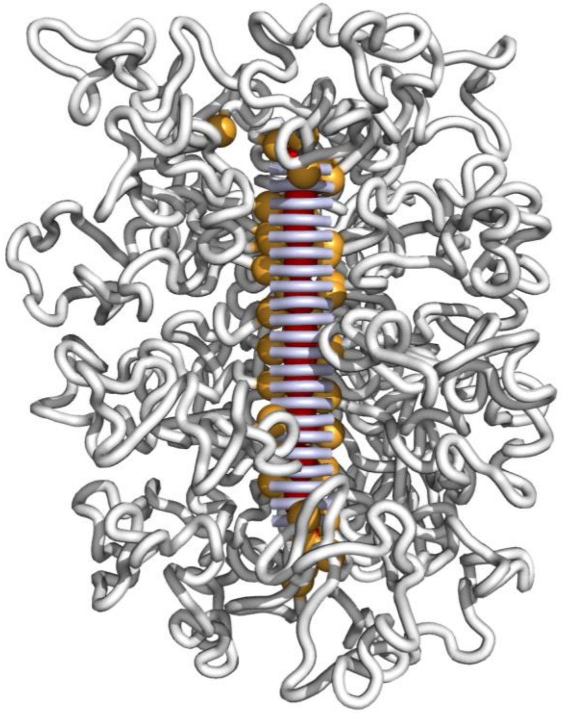
Groove formation

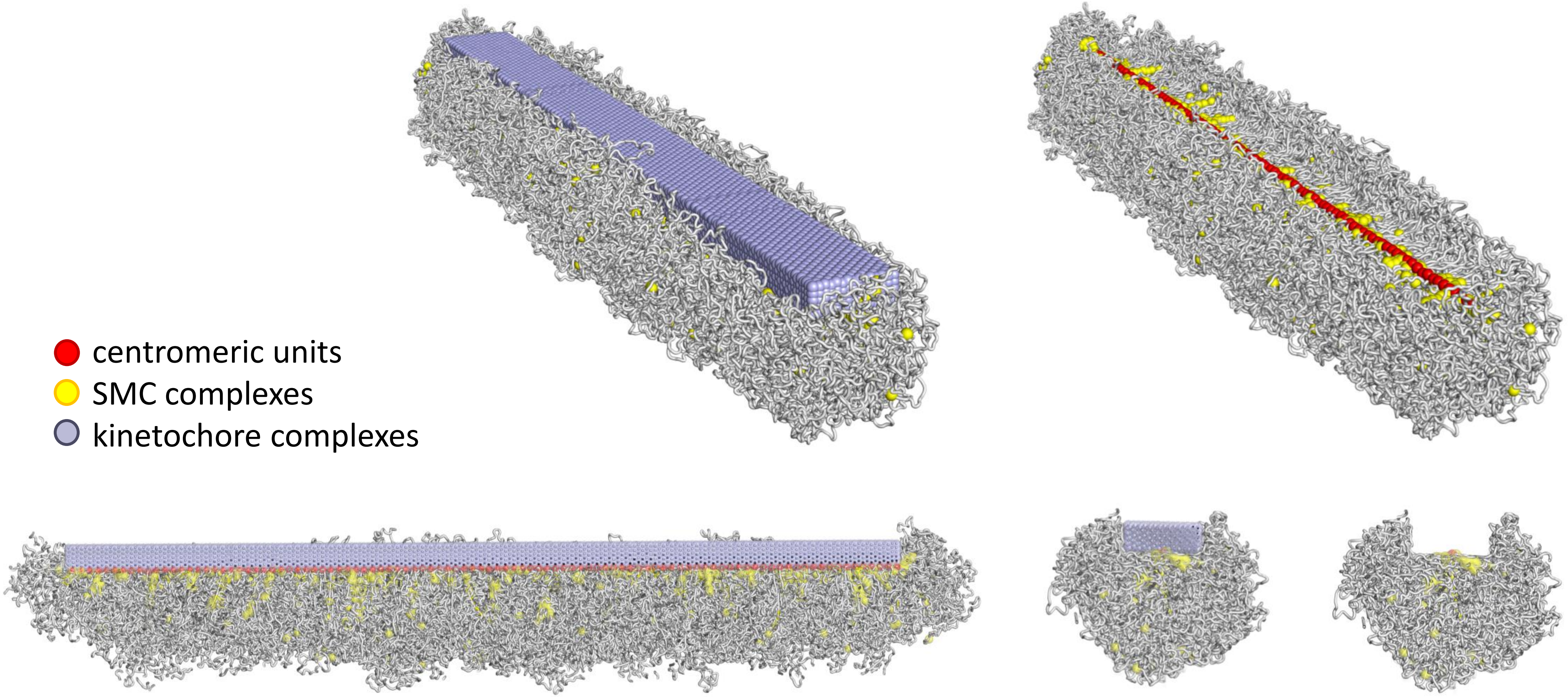






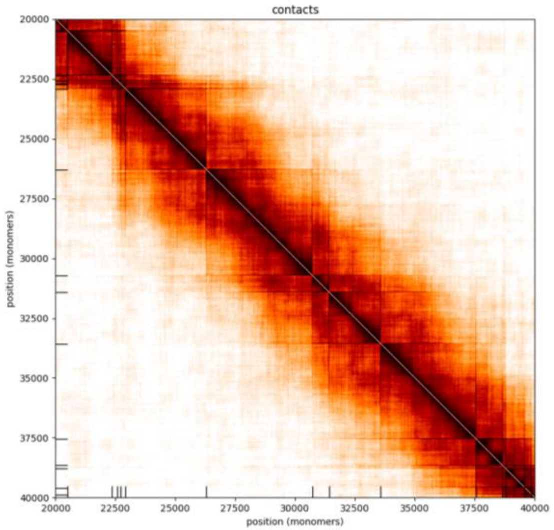
Heckmann S. et al., 2011.

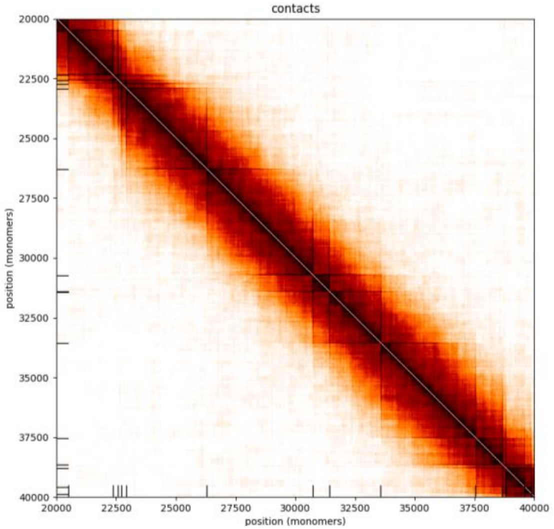
A 20 Mb example



Contact matrices

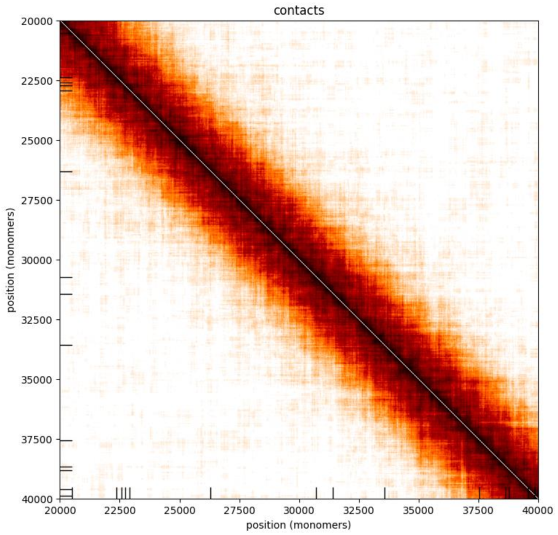
Anchoring effect

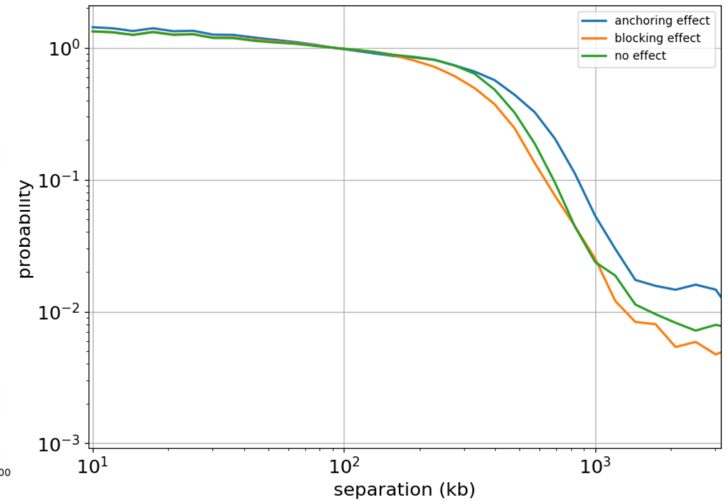




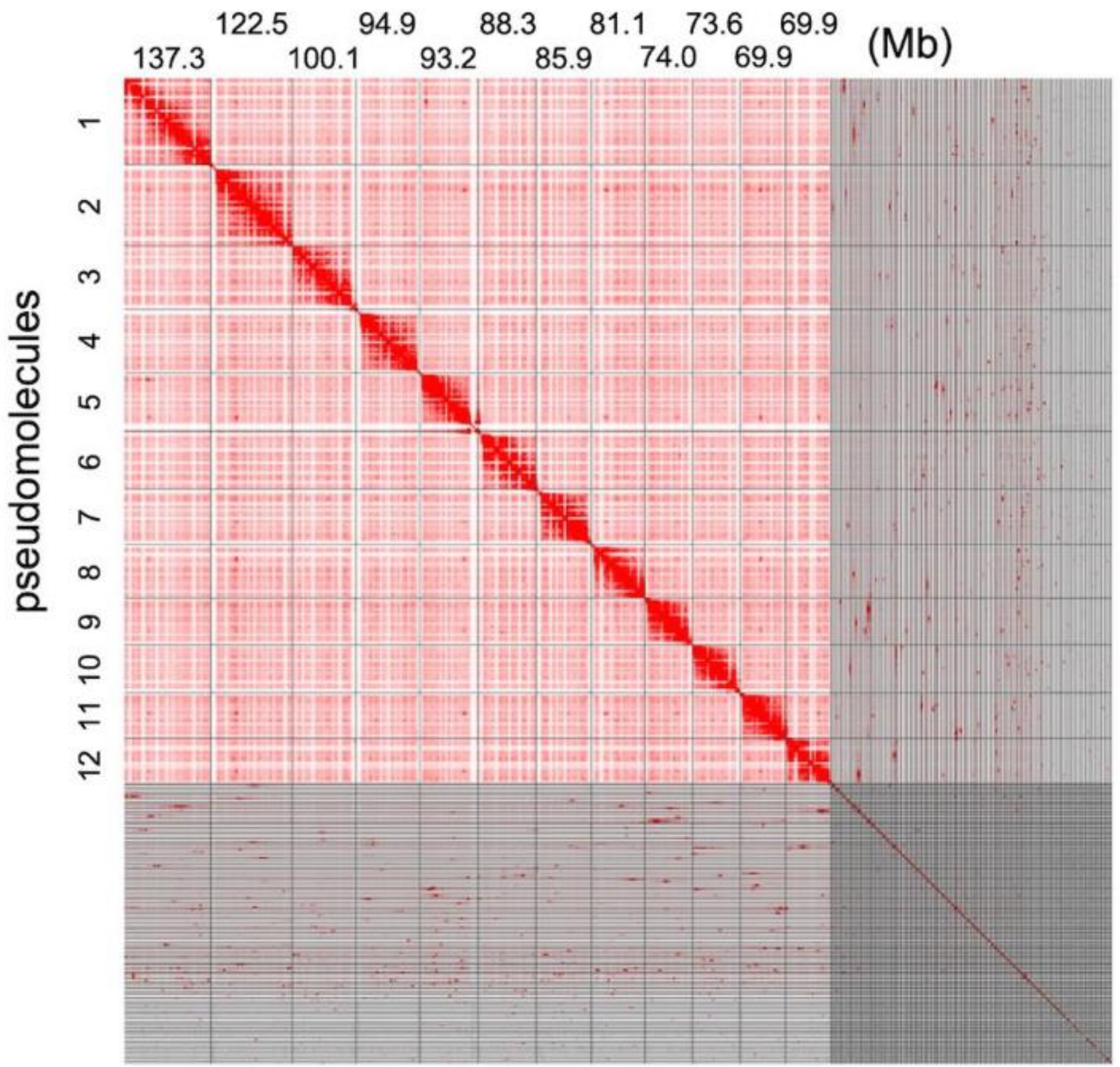
Blocking effect

No effect

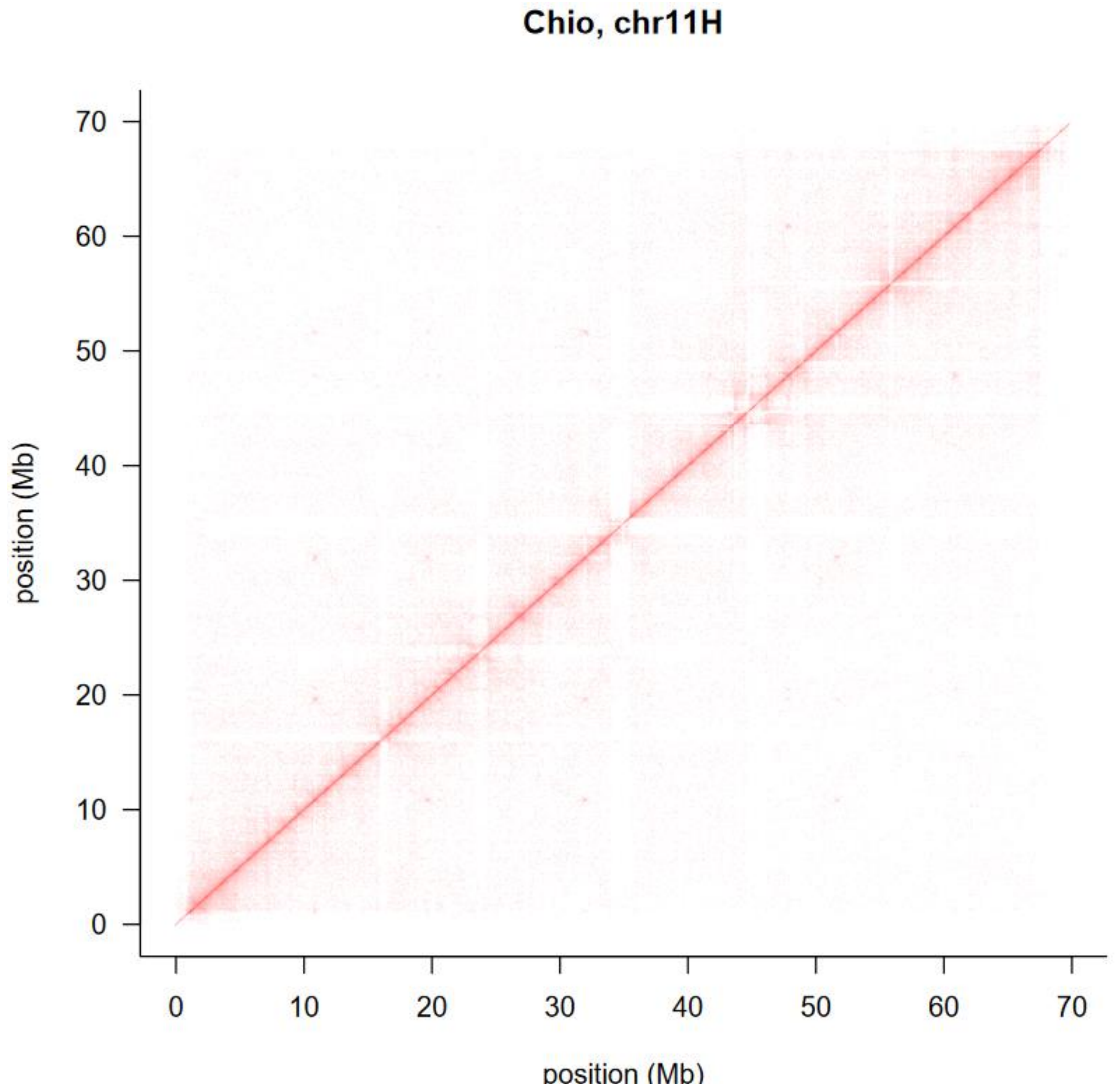




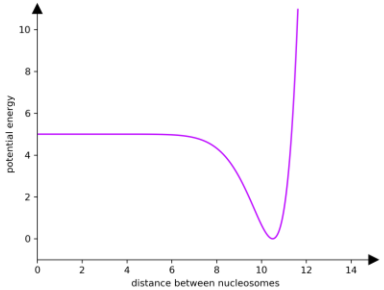
Contact probability



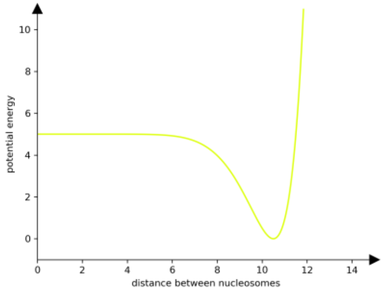
137.3
122.5
100.1
94.9
93.2
88.3
85.9
81.1
74.0
73.6
69.9
69.9
(Mb)
pseudomolecules
1
2
3
4
5
6
7
8
9
10
11
12



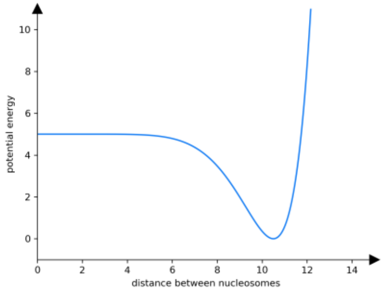
Chio, chr11H
position (Mb)
0
10
20
30
40
50
60
70
position (Mb)



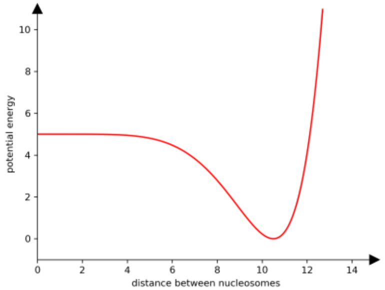
$$E_p(r) = 5 + 30\left(\frac{r}{10.5}\right)^{14} - 35\left(\frac{r}{10.5}\right)^{12}$$



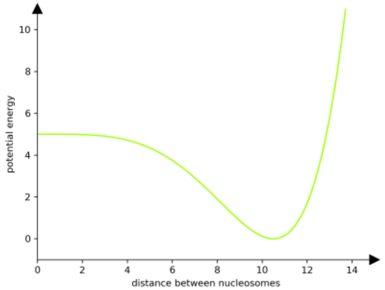
$$E_p(r) = 5 + 25\left(\frac{r}{10.5}\right)^{12} - 30\left(\frac{r}{10.5}\right)^{10}$$



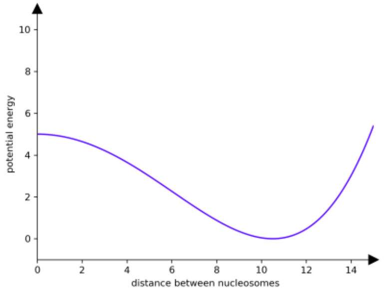
$$E_p(r) = 5 + 20\left(\frac{r}{10.5}\right)^{10} - 25\left(\frac{r}{10.5}\right)^{8}$$



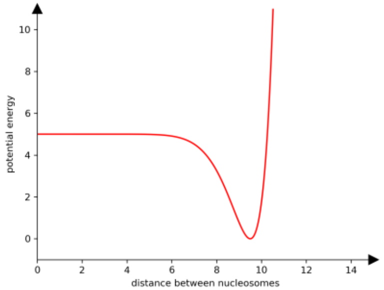
$$E_p(r) = 5 + 15\left(\frac{r}{10.5}\right)^{8} - 20\left(\frac{r}{10.5}\right)^{6}$$



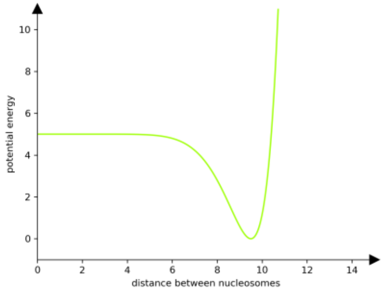
$$E_p(r) = 5 + 10\left(\frac{r}{10.5}\right)^{6} - 15\left(\frac{r}{10.5}\right)^{4}$$



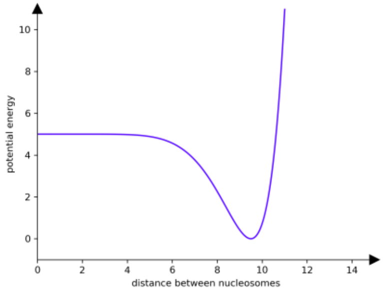
$$E_p(r) = 5 + 5\left(\frac{r}{10.5}\right)^{4} - 10\left(\frac{r}{10.5}\right)^{2}$$



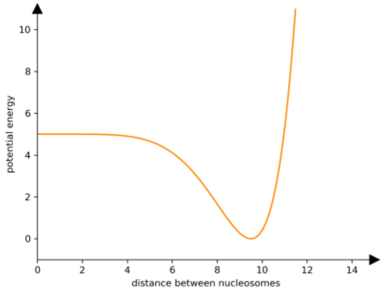
$$E_p(r) = 5 + 30\left(\frac{r}{9.5}\right)^{14} - 35\left(\frac{r}{9.5}\right)^{12}$$



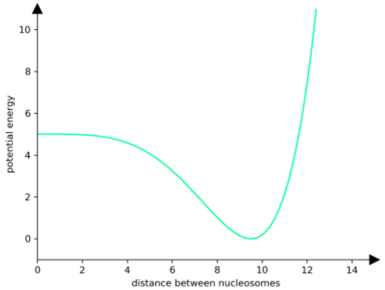
$$E_p(r) = 5 + 25\left(\frac{r}{9.5}\right)^{12} - 30\left(\frac{r}{9.5}\right)^{10}$$



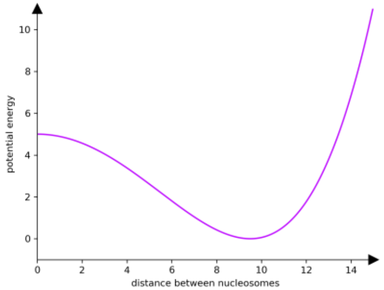
$$E_p(r) = 5 + 20\left(\frac{r}{9.5}\right)^{10} - 25\left(\frac{r}{9.5}\right)^{8}$$



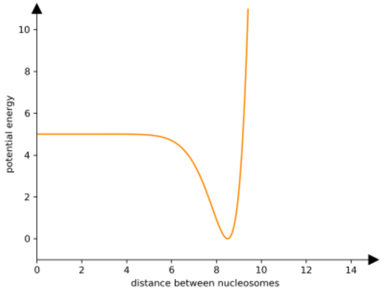
$$E_p(r) = 5 + 15\left(\frac{r}{9.5}\right)^{8} - 20\left(\frac{r}{9.5}\right)^{6}$$



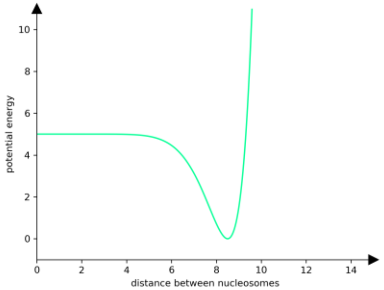
$$E_p(r) = 5 + 10\left(\frac{r}{9.5}\right)^{6} - 15\left(\frac{r}{9.5}\right)^{4}$$



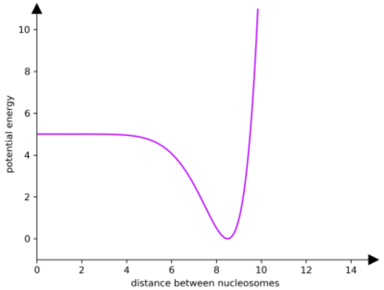
$$E_p(r) = 5 + 5\left(\frac{r}{9.5}\right)^{4} - 10\left(\frac{r}{9.5}\right)^{2}$$



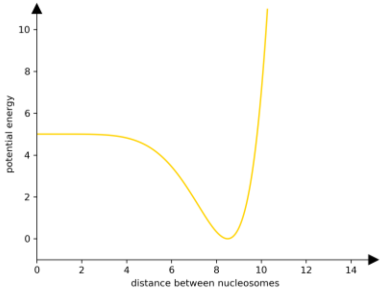
$$E_p(r) = 5 + 30\left(\frac{r}{8.5}\right)^{14} - 35\left(\frac{r}{8.5}\right)^{12}$$



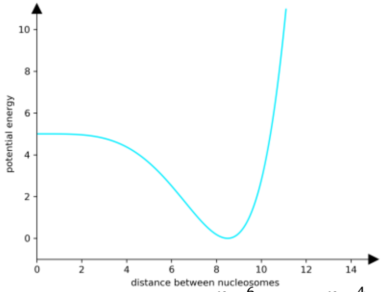
$$E_p(r) = 5 + 25\left(\frac{r}{8.5}\right)^{12} - 30\left(\frac{r}{8.5}\right)^{10}$$



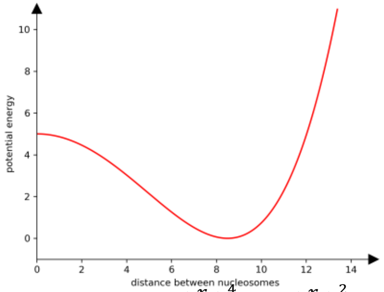
$$E_p(r) = 5 + 20\left(\frac{r}{8.5}\right)^{10} - 25\left(\frac{r}{8.5}\right)^{8}$$



$$E_p(r) = 5 + 15\left(\frac{r}{8.5}\right)^{8} - 20\left(\frac{r}{8.5}\right)^{6}$$



$$E_p(r) = 5 + 10\left(\frac{r}{8.5}\right)^{6} - 15\left(\frac{r}{8.5}\right)^{4}$$



$$E_p(r) = 5 + 5\left(\frac{r}{8.5}\right)^{4} - 10\left(\frac{r}{8.5}\right)^{2}$$