Morphodynamics ?

Control (*&*/or/of/*vs*) Dynamics…

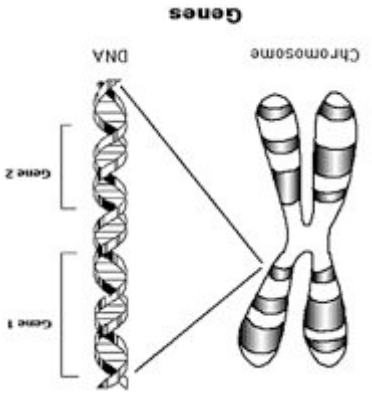
Growth *vs* Maintenance

Biology: shape (?) = classification

Genetic = reproduction of the shape

DNA as support of heredity

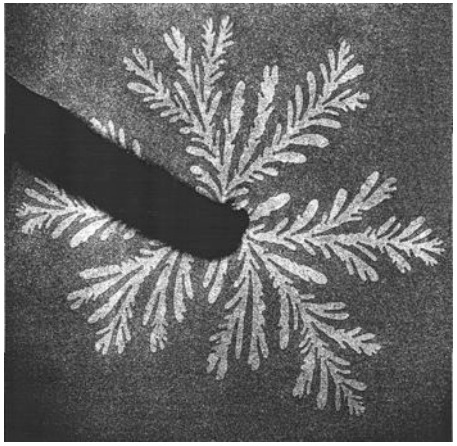
"The fixed part are the genes…
Hence the control comes from the genes"



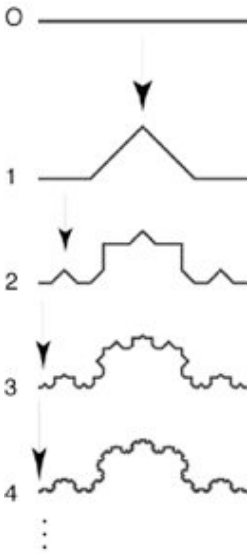
How does it work ?
Development…

In Physics

Where the stability comes from ?



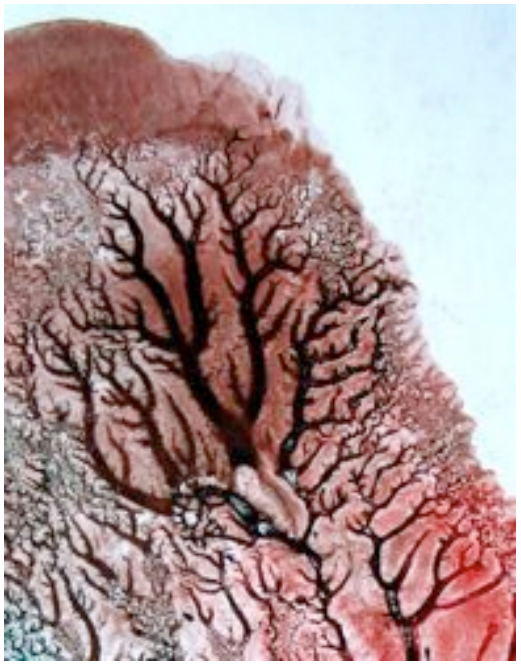
Instabilites → shapes



Formal description

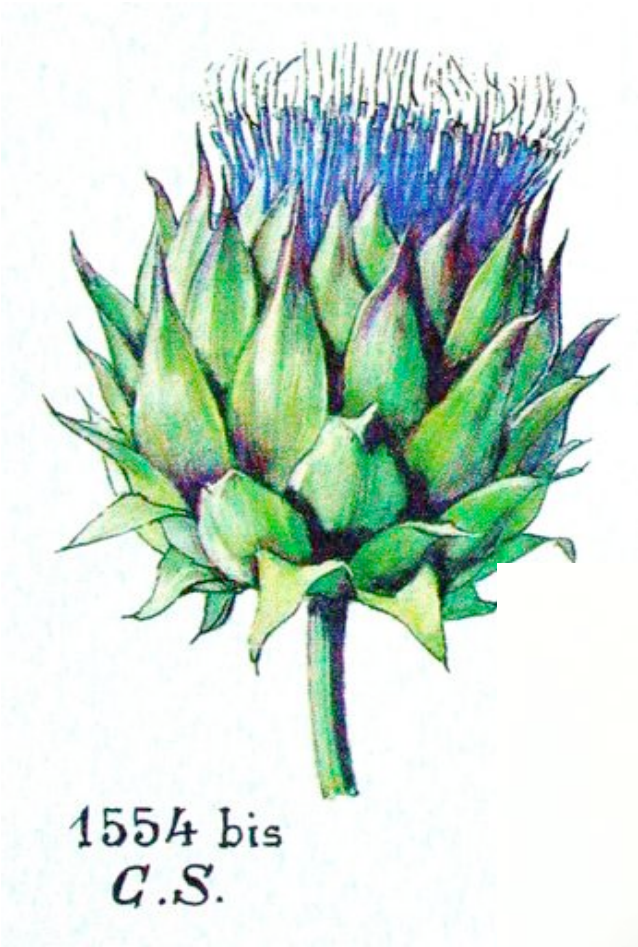
$$d = \lim_{l \to 0} \left(\frac{\ln N}{\ln l} \right)$$

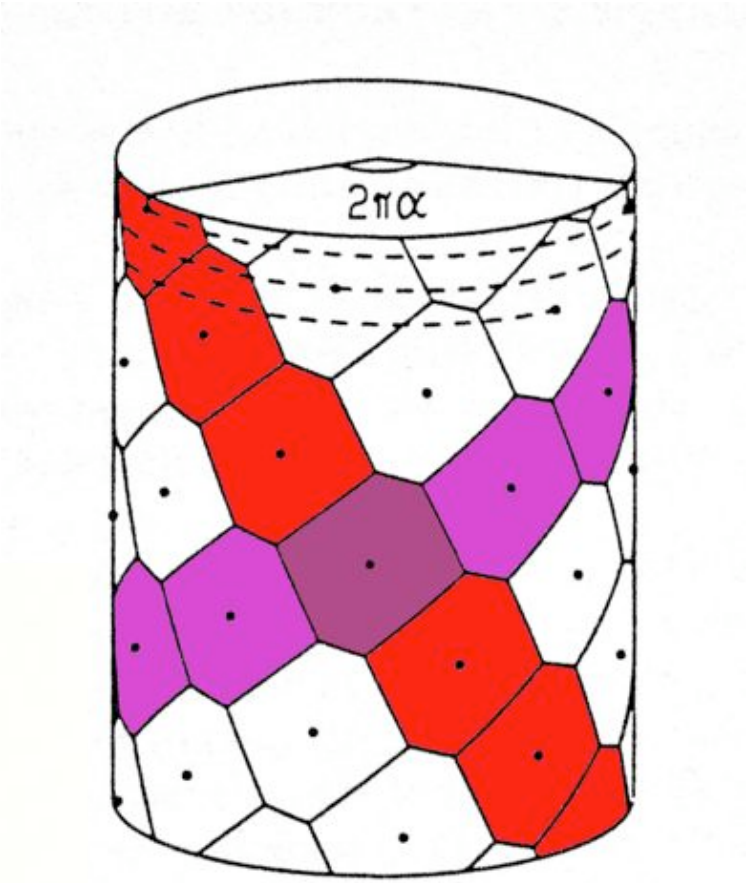
Fractals



Phyllo-Taxie

Leaf-Arrangement





Number of spirals
in each directions

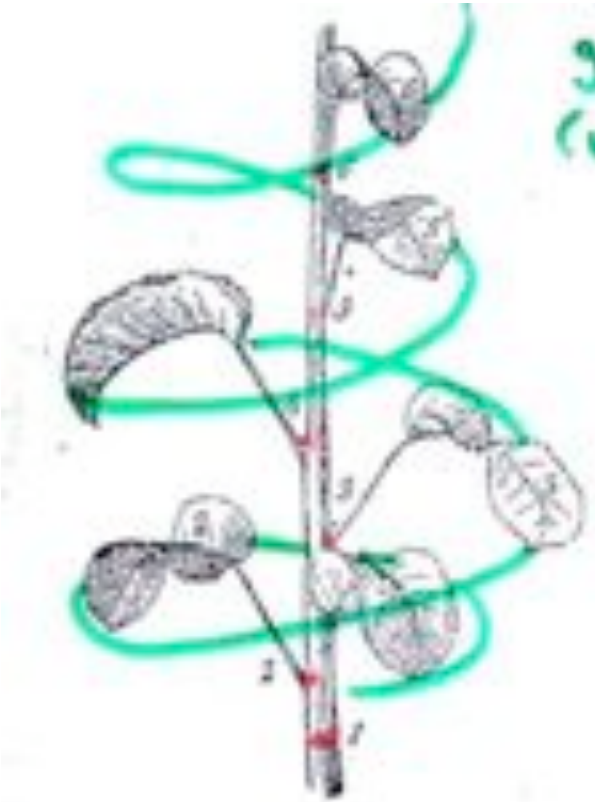
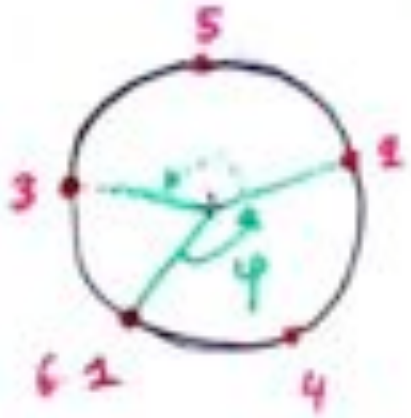


Fig. 3058. — Branche de Poirier portant 6 feuilles alternes à disposition quinconciale.

Fig. 3059. — Schéma de la disposition quinconciale.

génération spiral
(random direction)

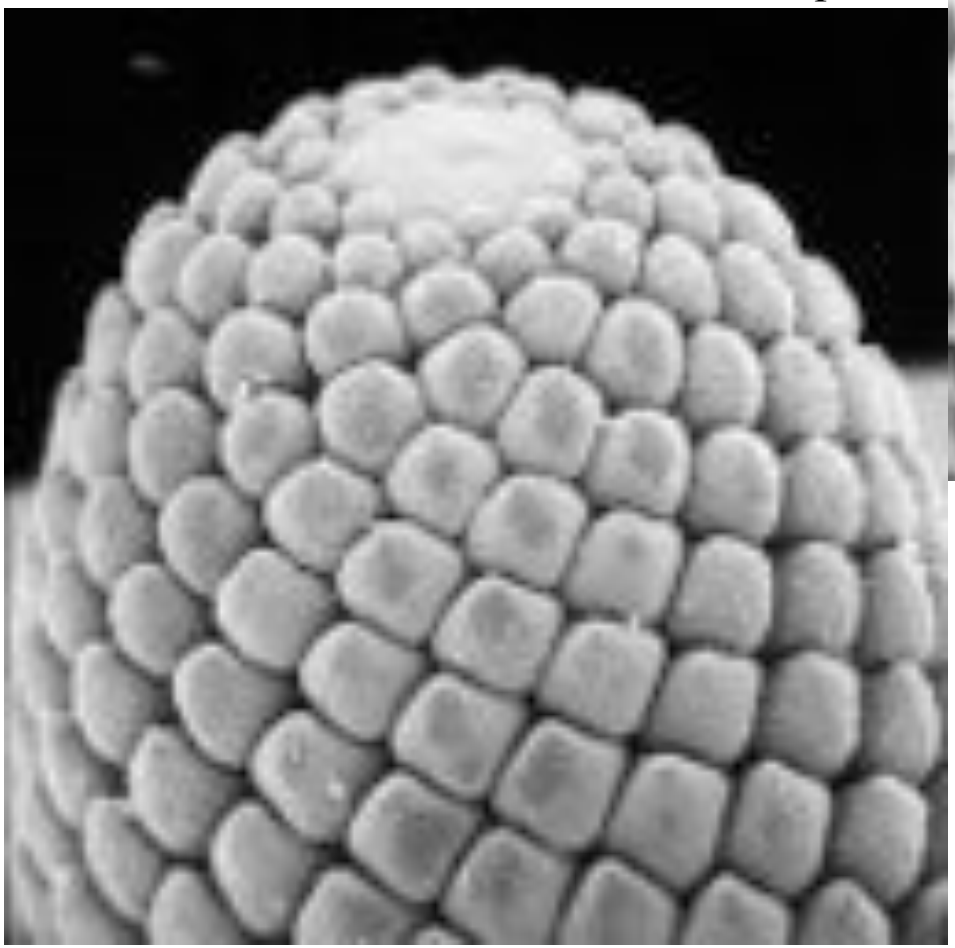


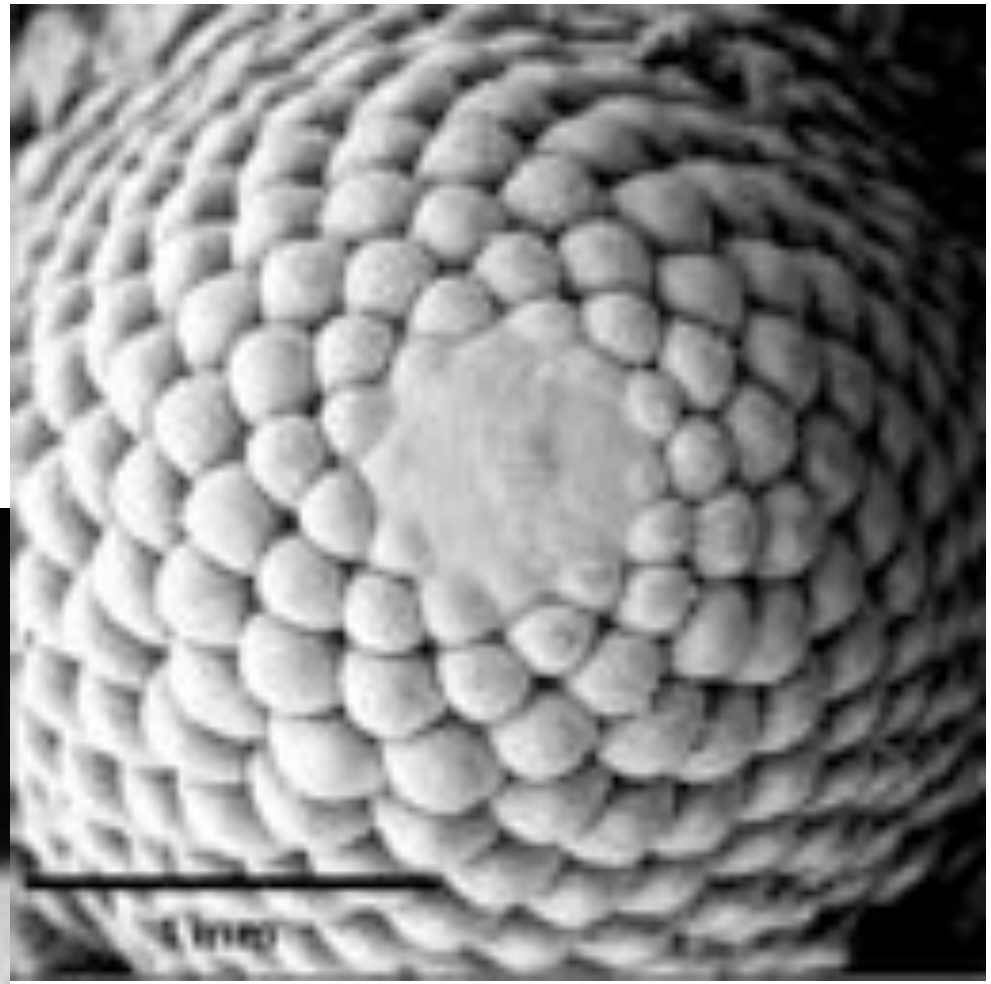
$\varphi = \frac{2}{5} \cdot (2\pi)$

divergence

Number of spirals:
two consecutive numbers
of the fibonacci series…

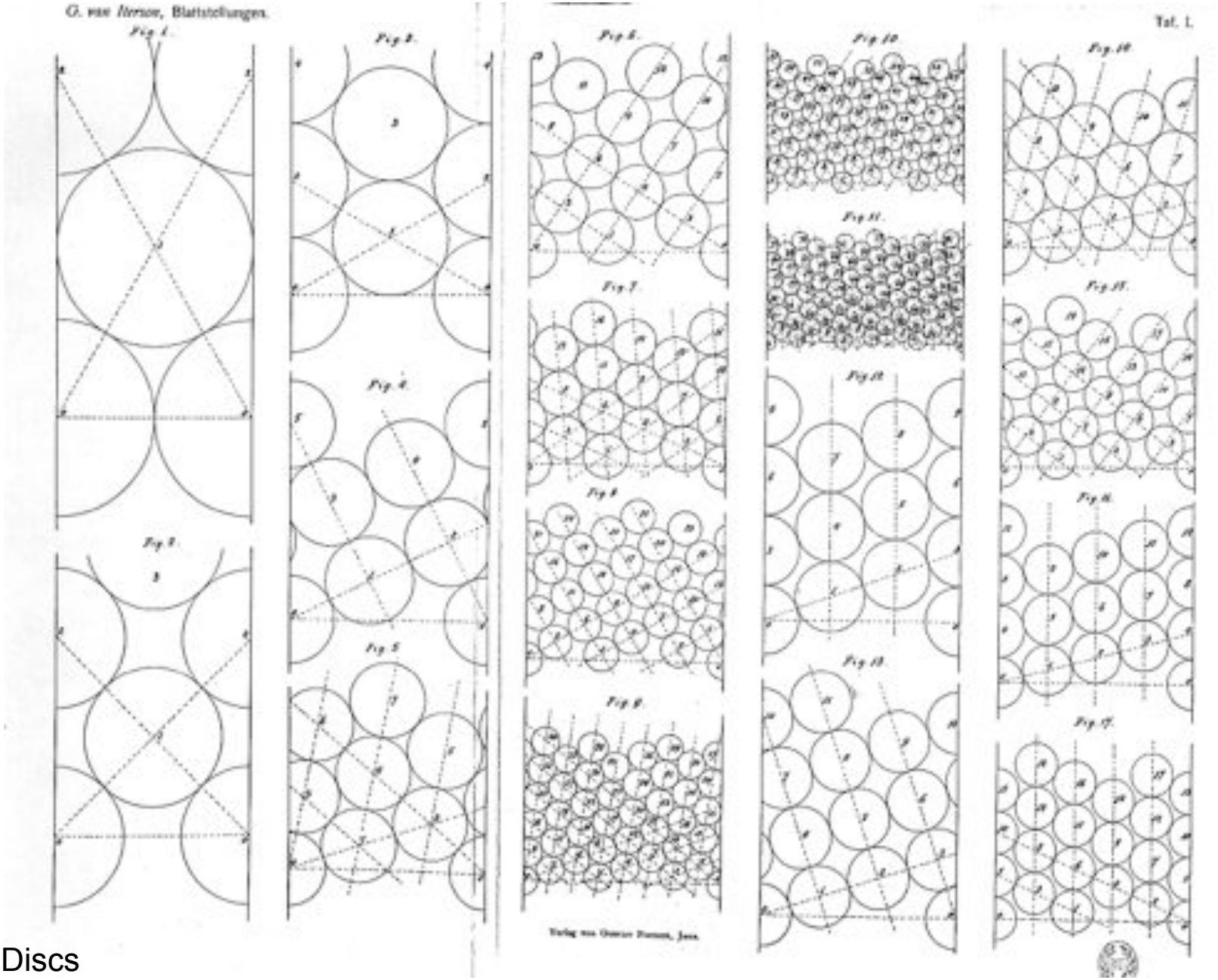
Epicea





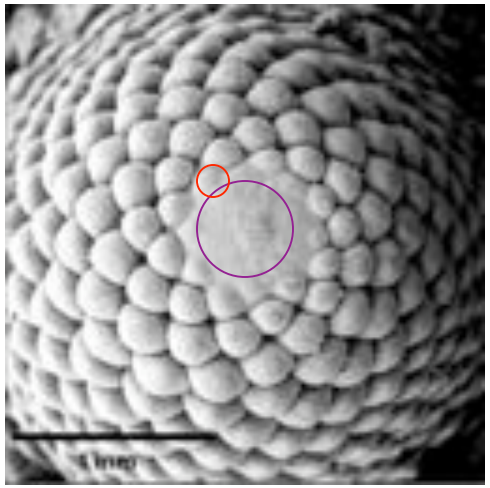
(Rutishauser)

van Iterson 1907



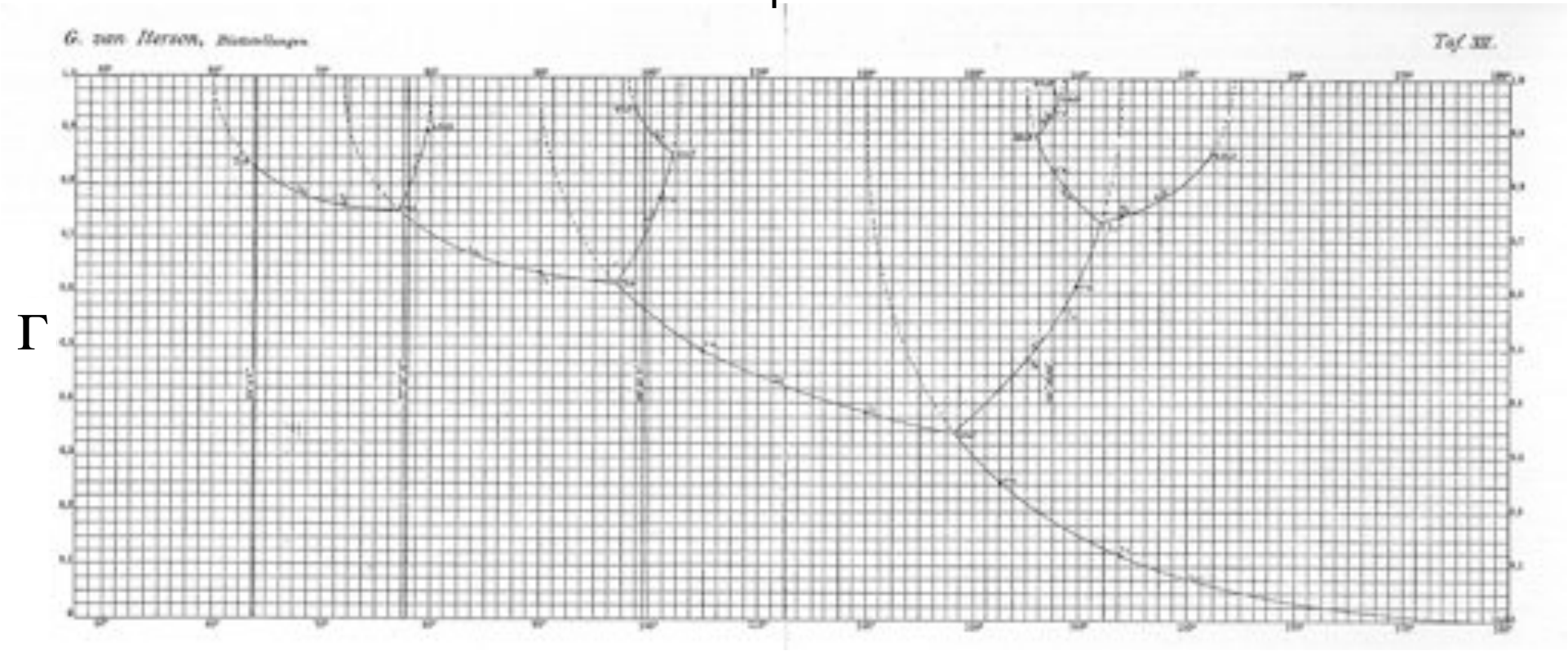
Tangent Discs

Parameter Γ=d/D



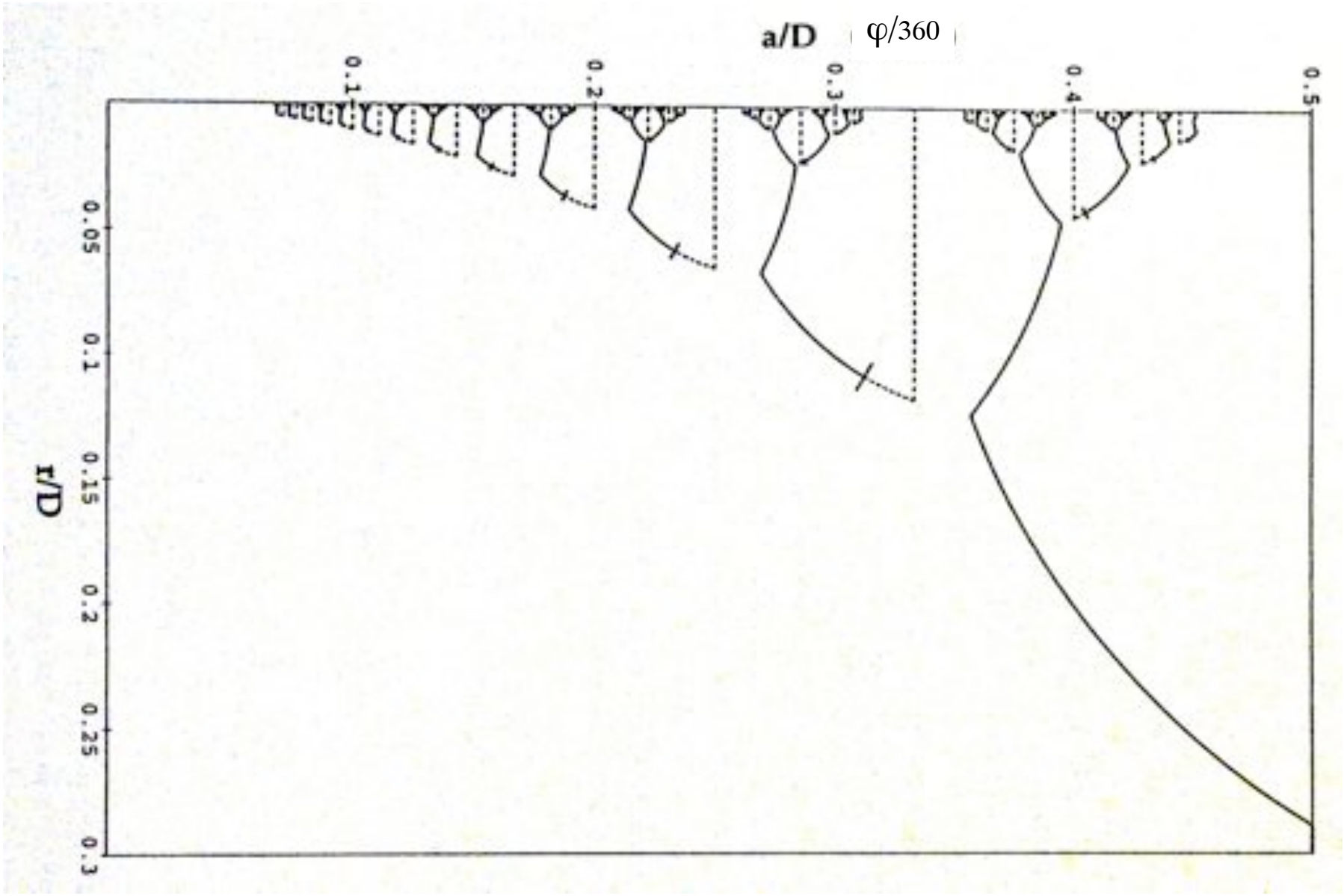
φ

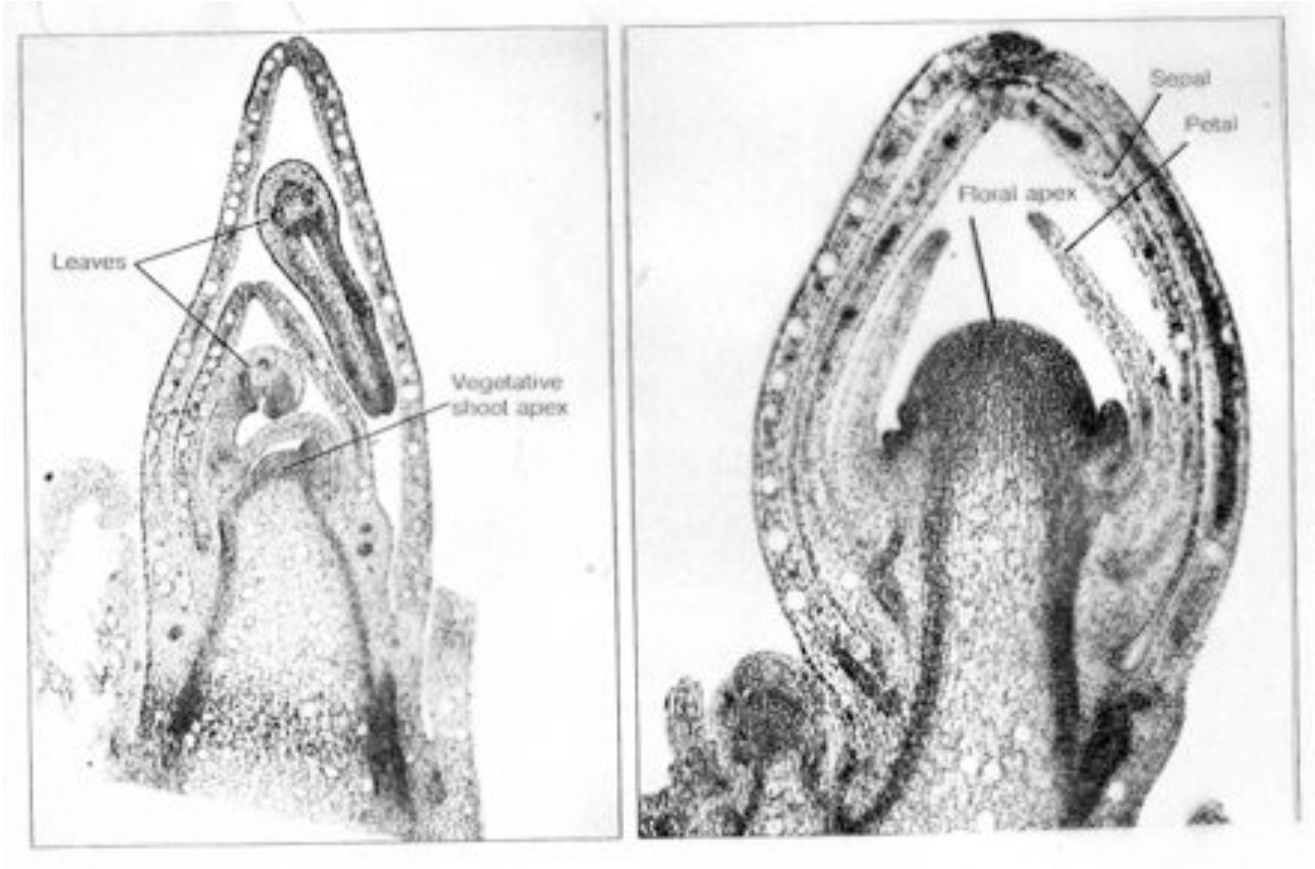
Γ



« imperfect »
bifurcations

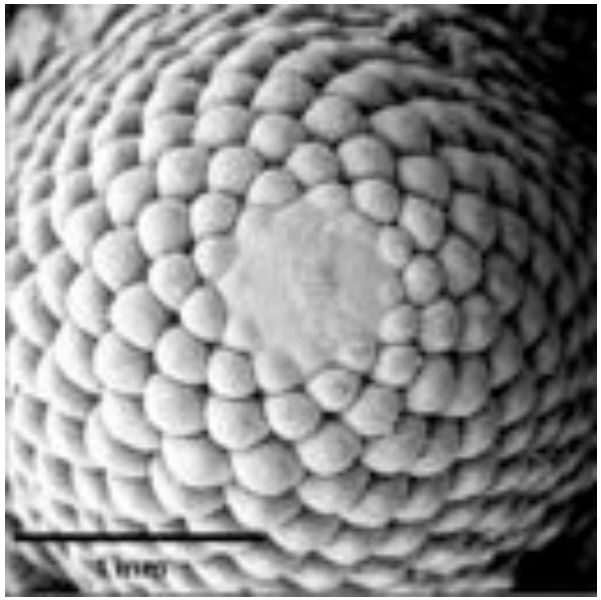
« dynamical »
threshold





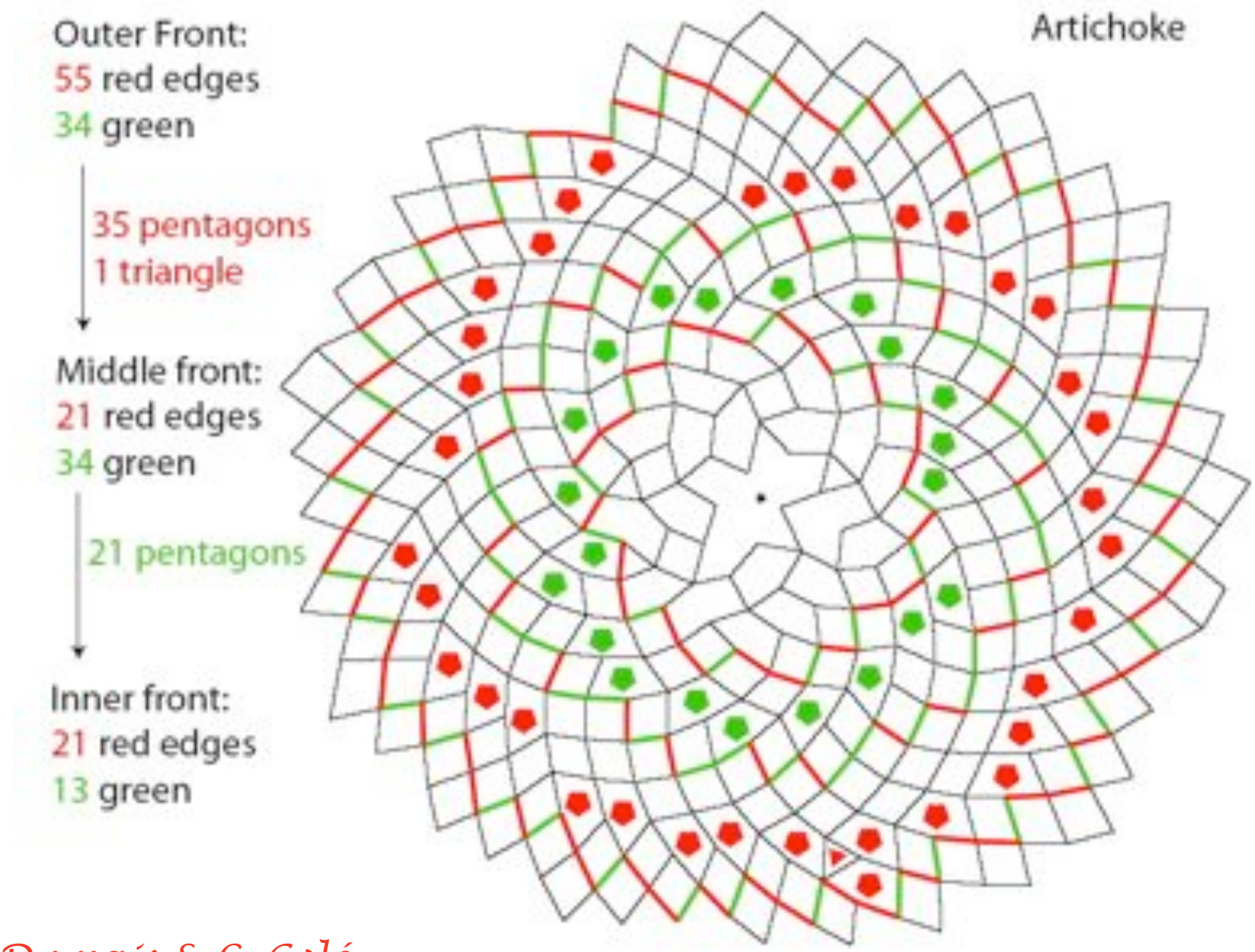
The real parameter is the History of $\Gamma(t)$

(and initial conditions)

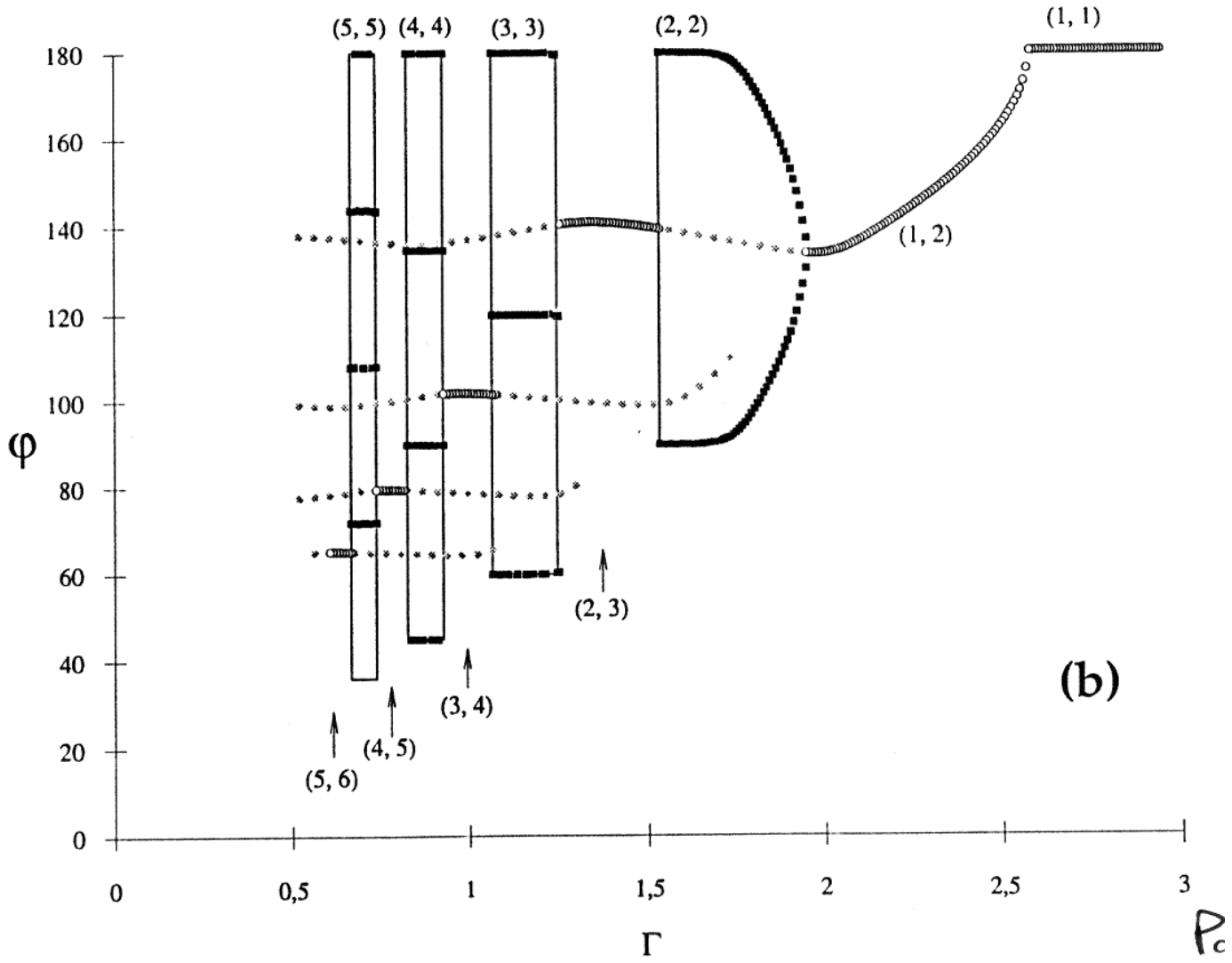


As long as successive appearance of closed packed primordia
With a forbiden central zone

Fall into the strong constraint of a mathematical object (2D regular cylindrical lattice)

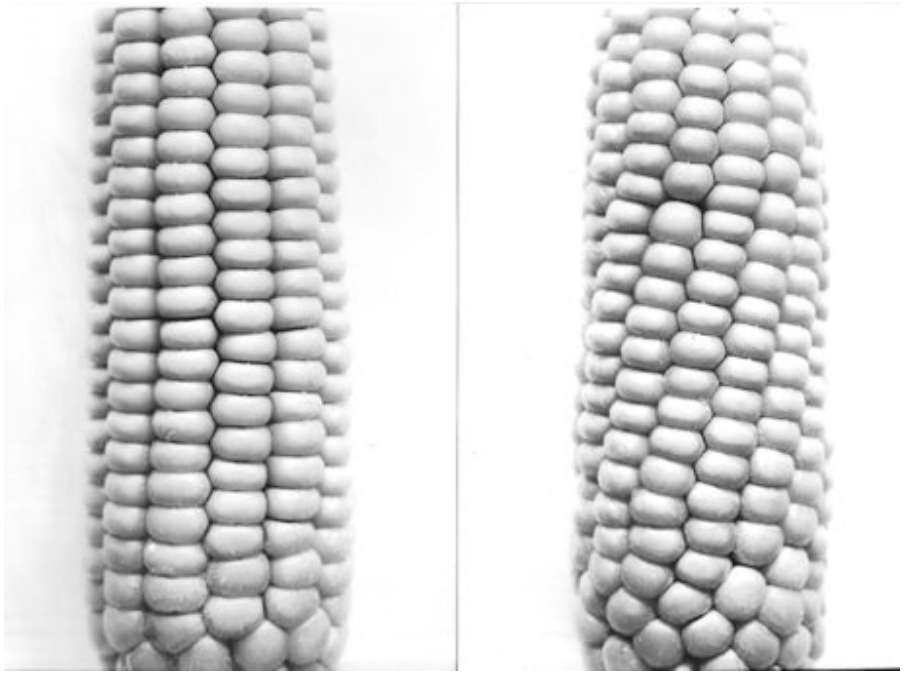


J. Dumais & C. Golé

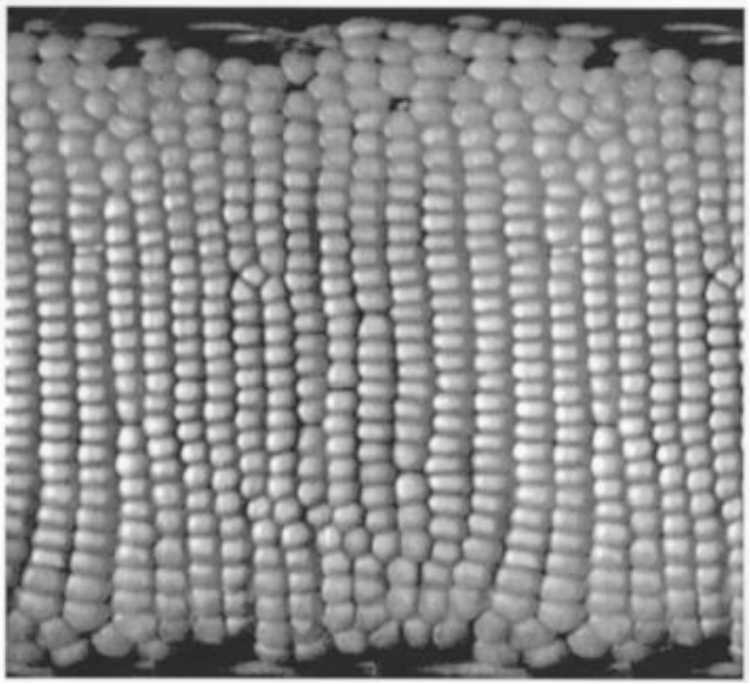

(5, 5)
(4, 4)
(3, 3)
(2, 2)
(1, 1)
(1, 2)
(2, 3)
(3, 4)
(4, 5)
(5, 6)
(b)
φ
Γ
180
160
140
120
100
80
60
40
20
0
0
0,5
1
1,5
2
2,5
3

whorled

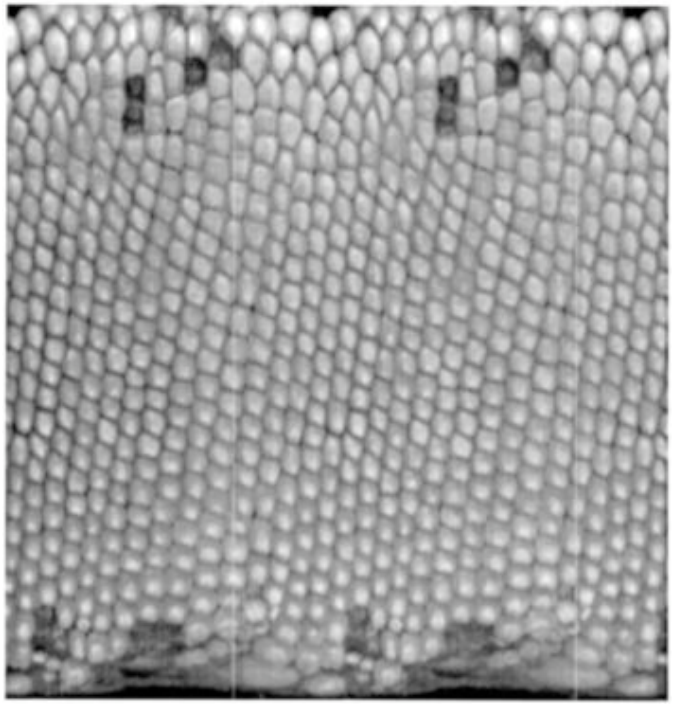
(i, i)



(i, i+1)



Corn:
i=3, 4, 5



Araucaria

Banksia

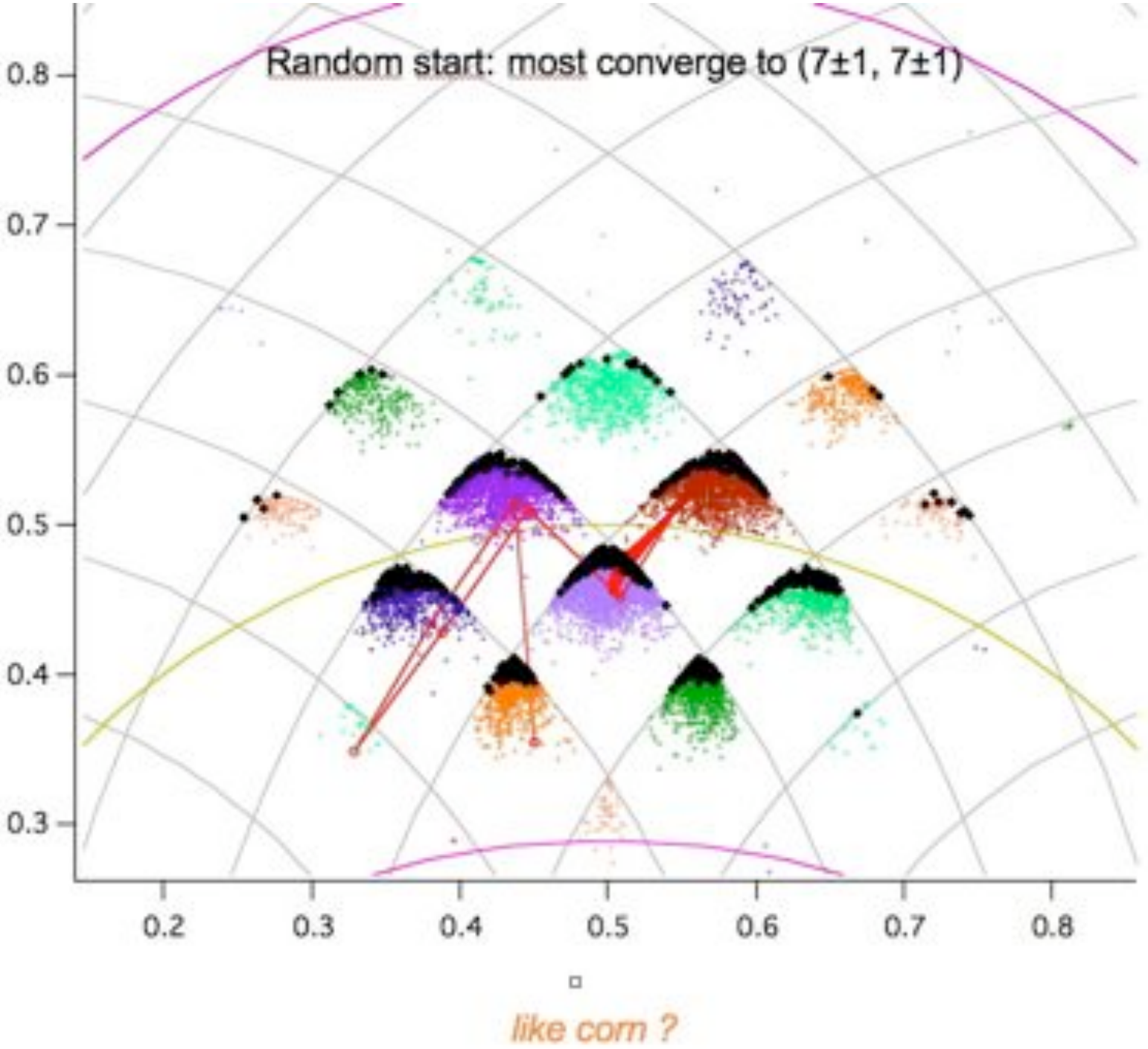
?

(3, 3)

(2, 3)

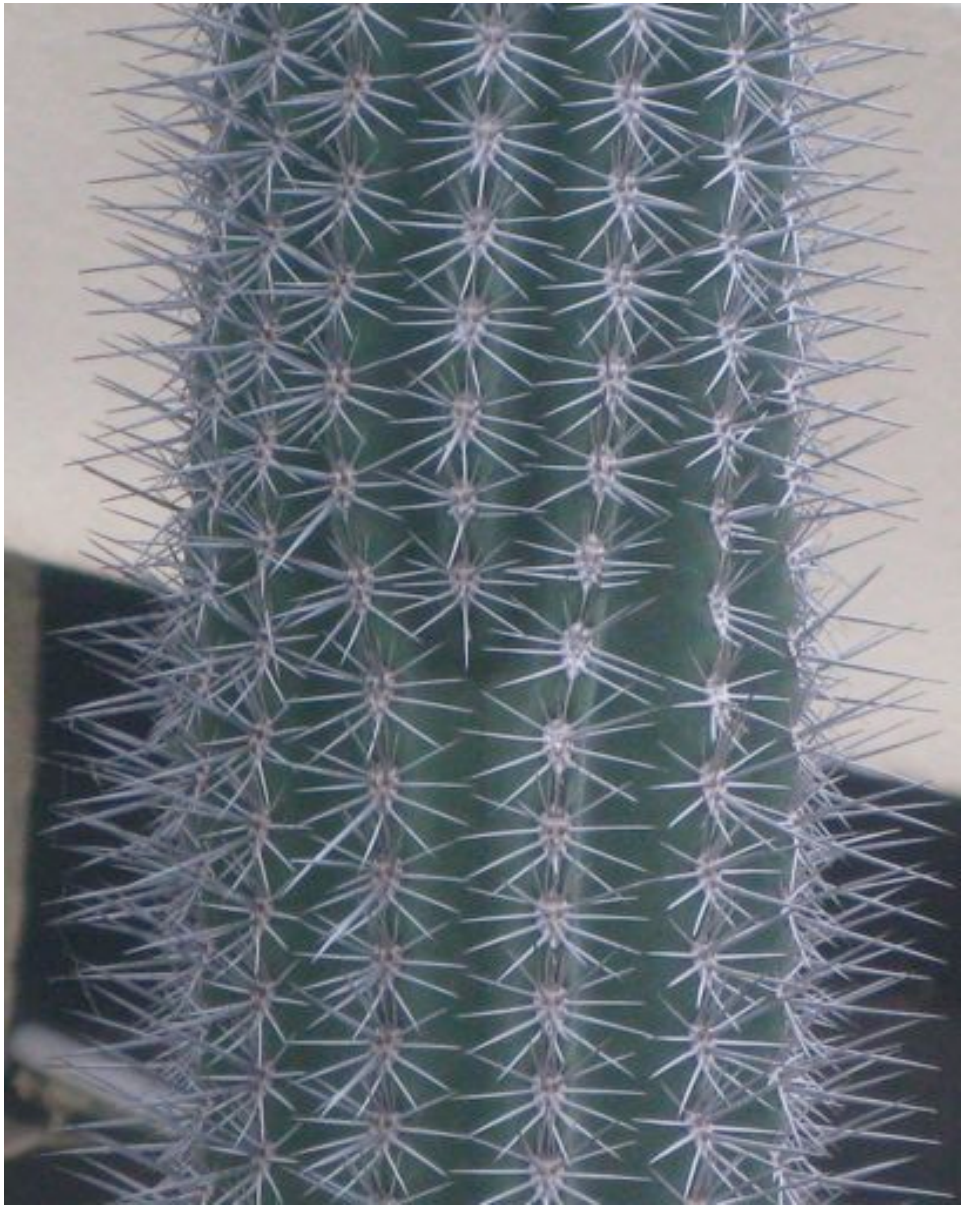
(2, 2)

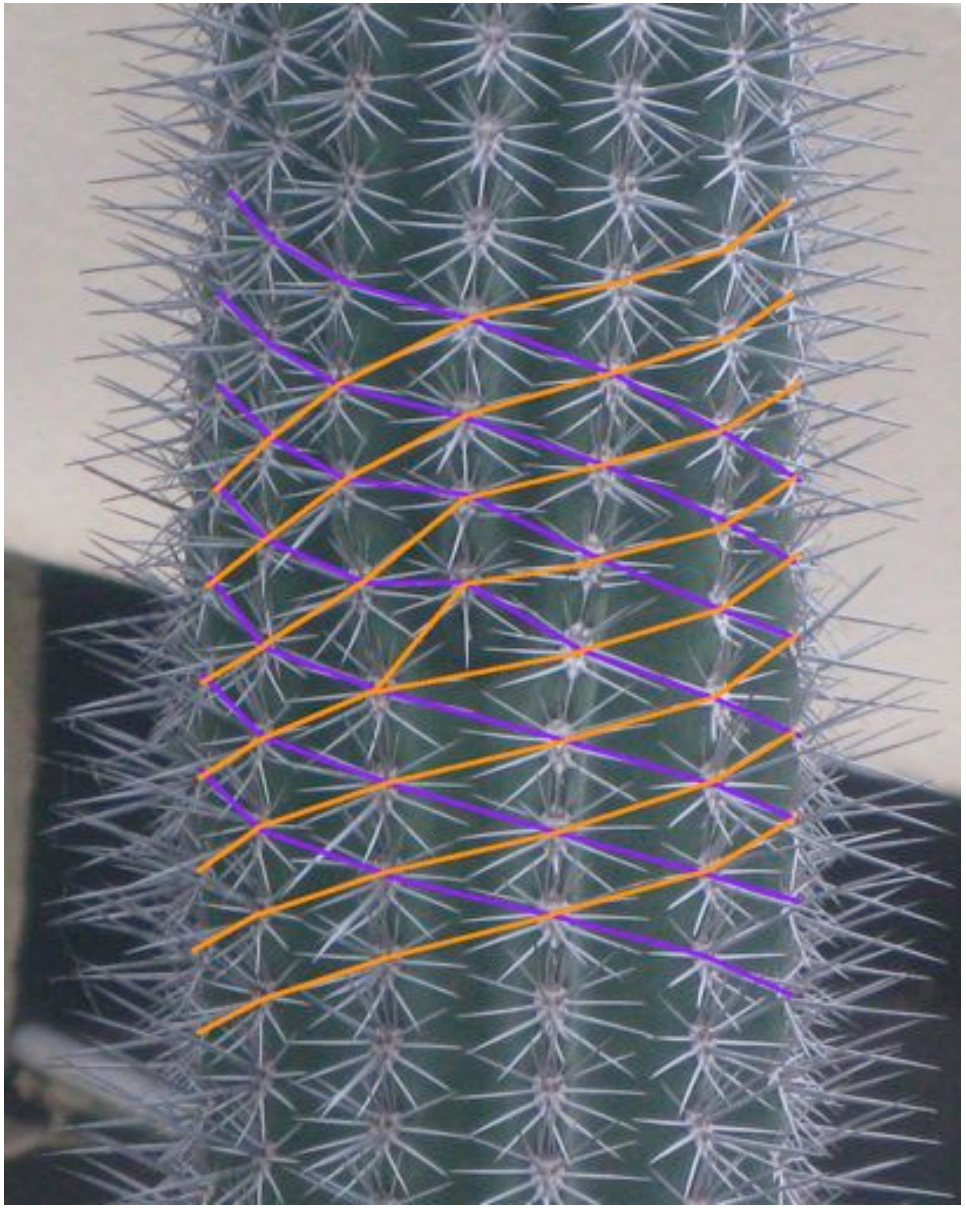
Acanthus


Random start: most converge to (7±1, 7±1)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.3
0.4
0.5
0.6
0.7
0.8

like corn ?

the number of diagonals is the sum of the two number of spirals

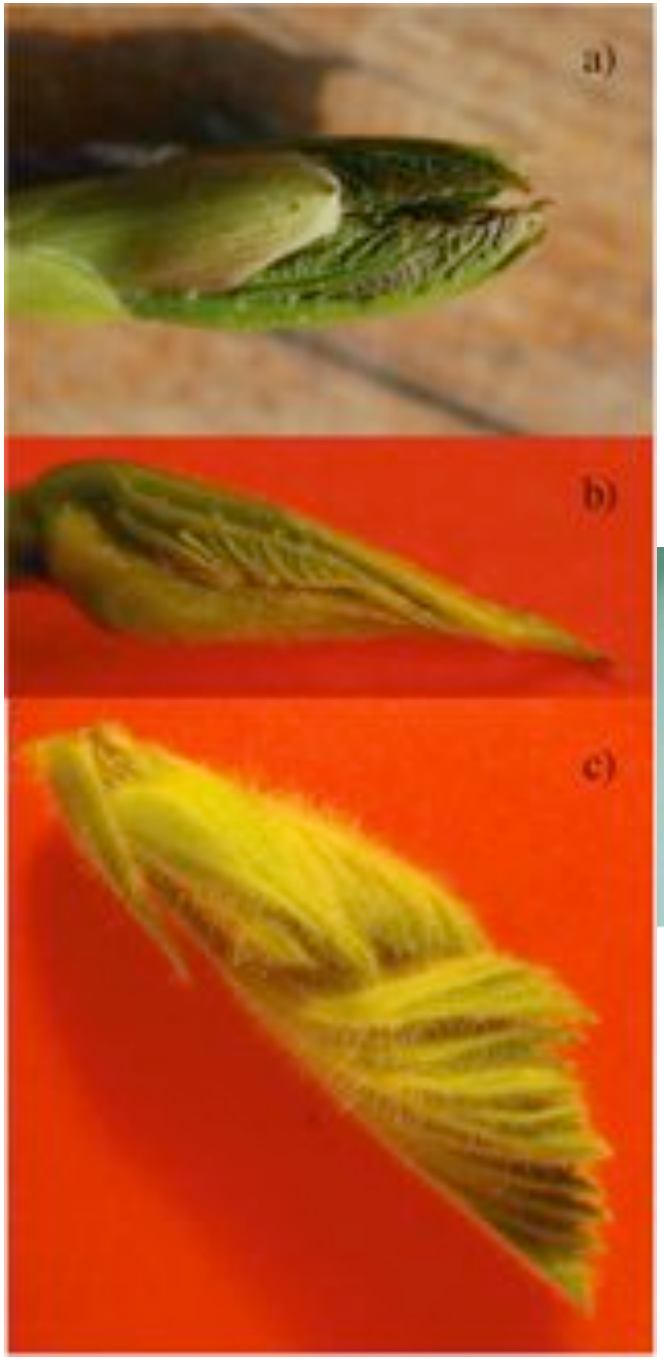




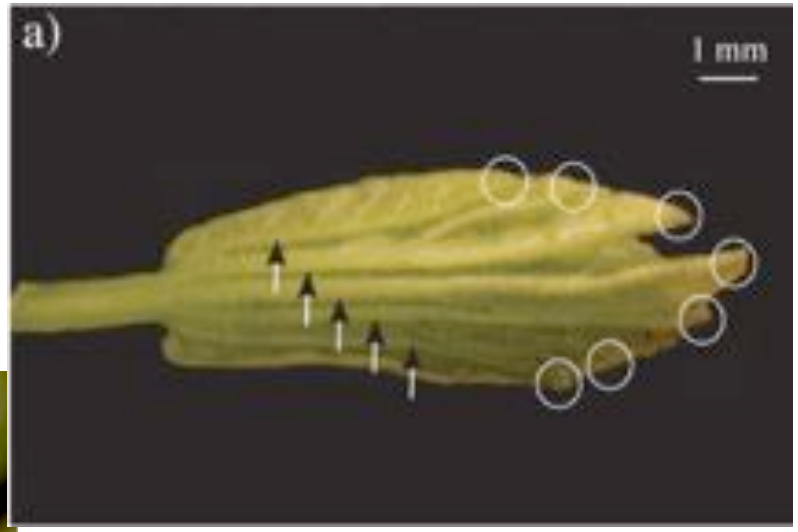
s = i+j -> i+j+1

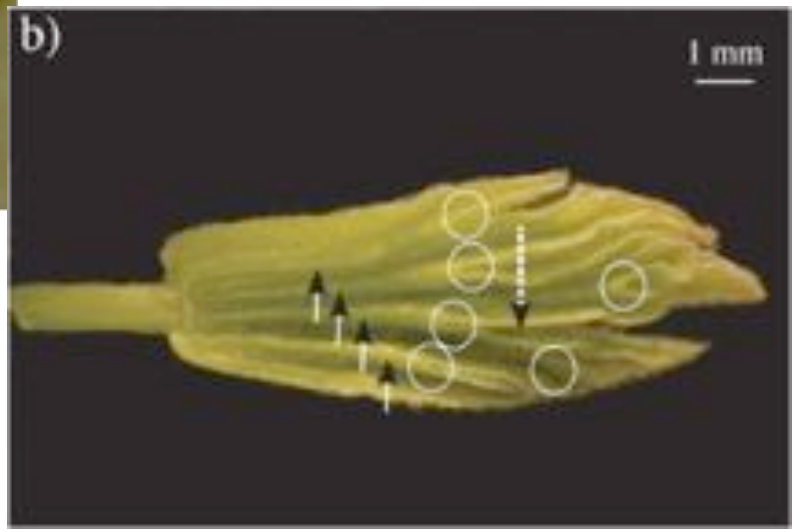
(i, j) -> (i+1, j)

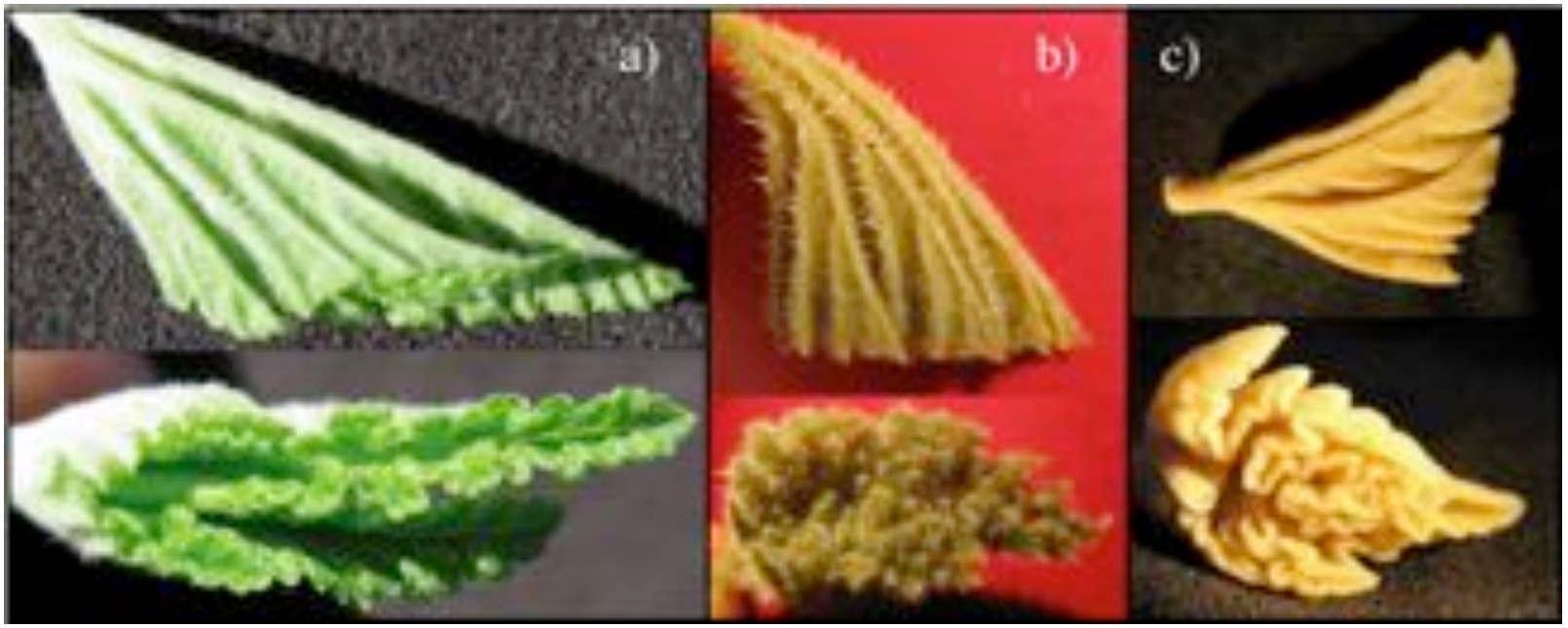
(happens often in corn too)

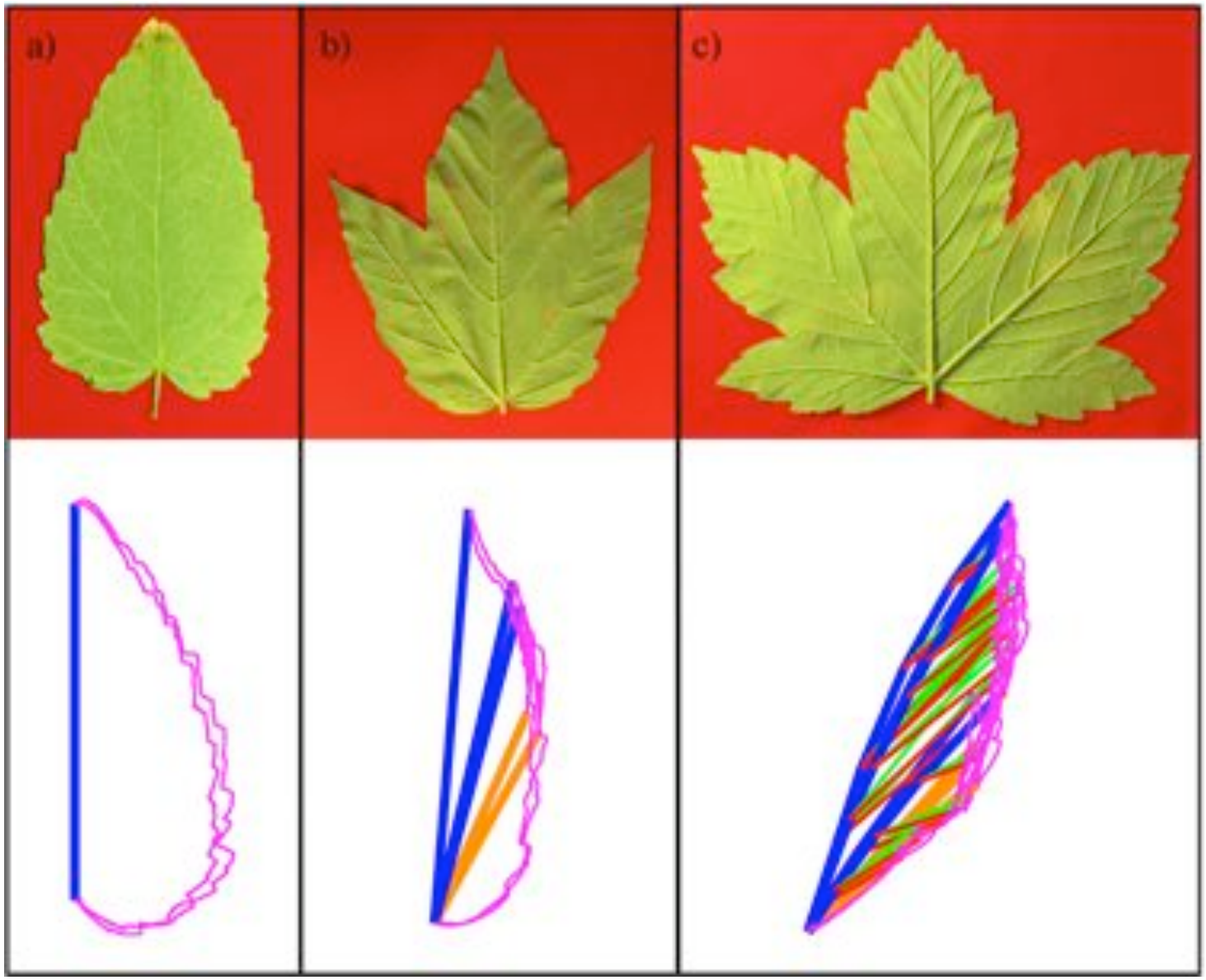

a)
b)
c)

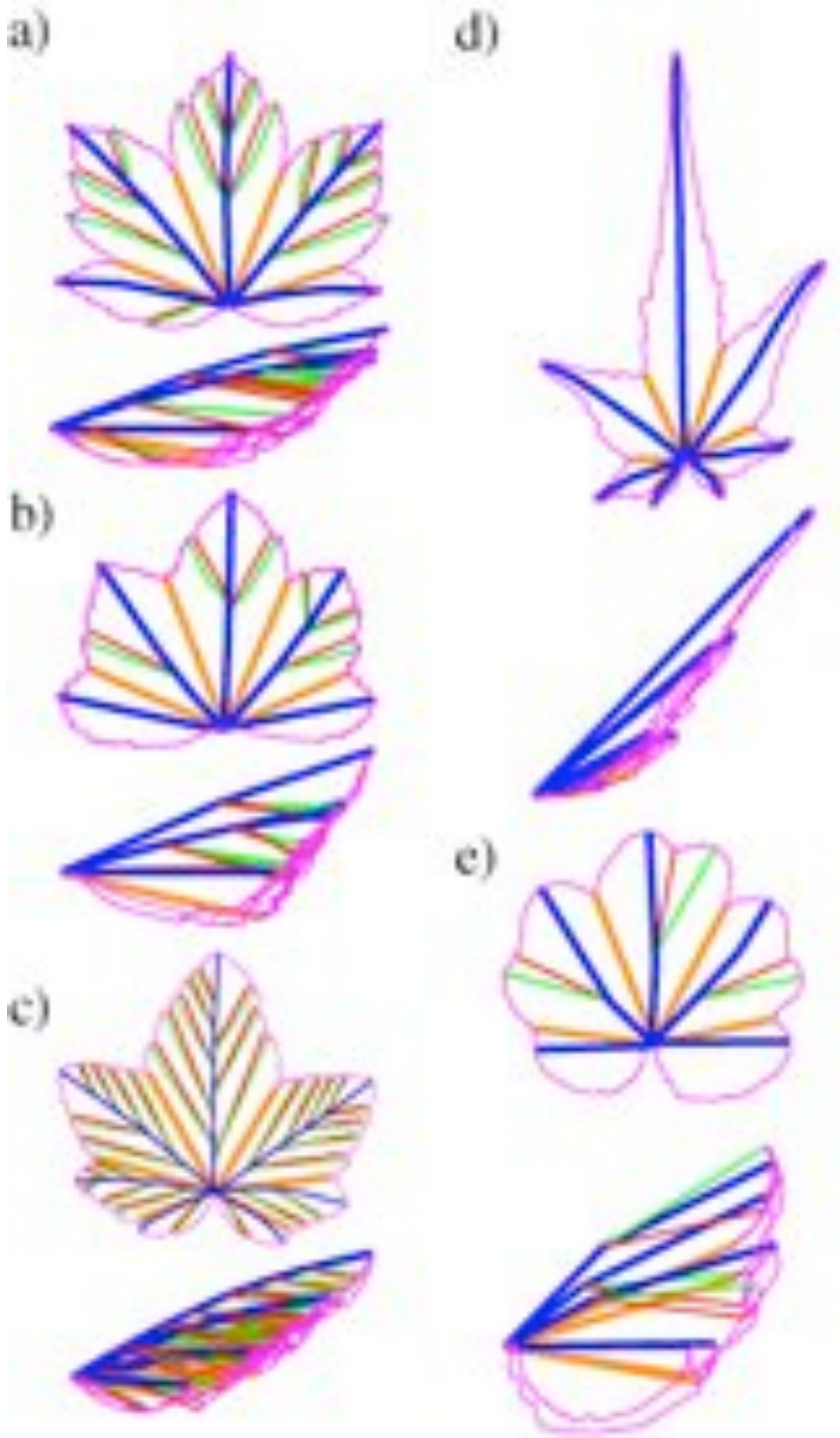

b.


a)
1 mm


b)
1 mm


a)
b)
c)


a)
b)
c)

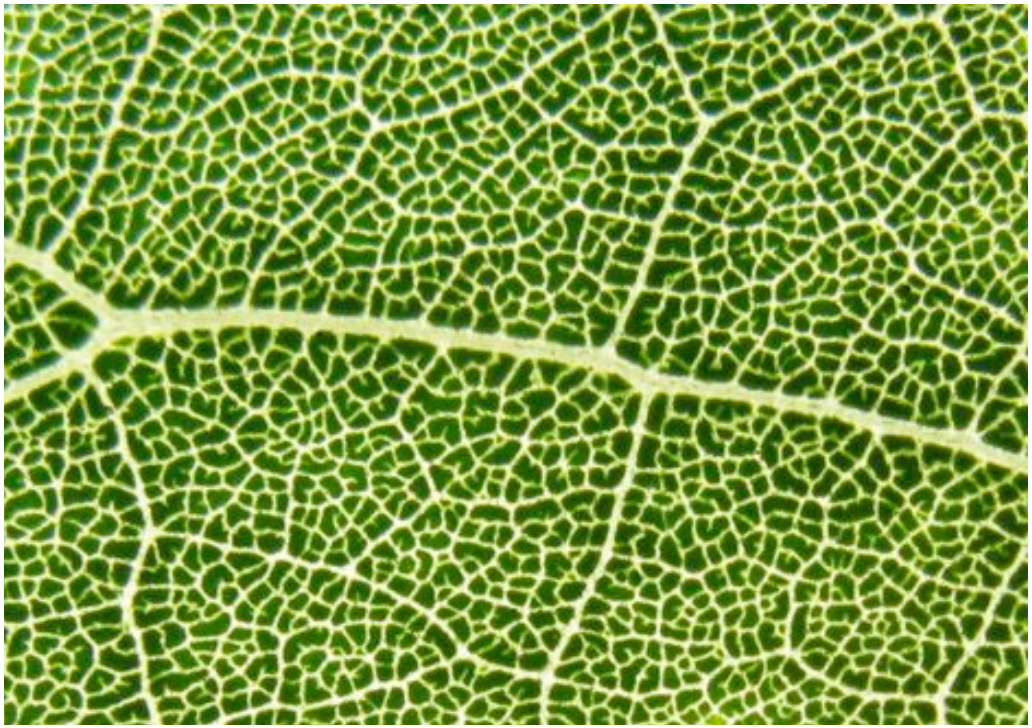


Etienne Couturier

No limitation of shape by the Kirigami (theorem)

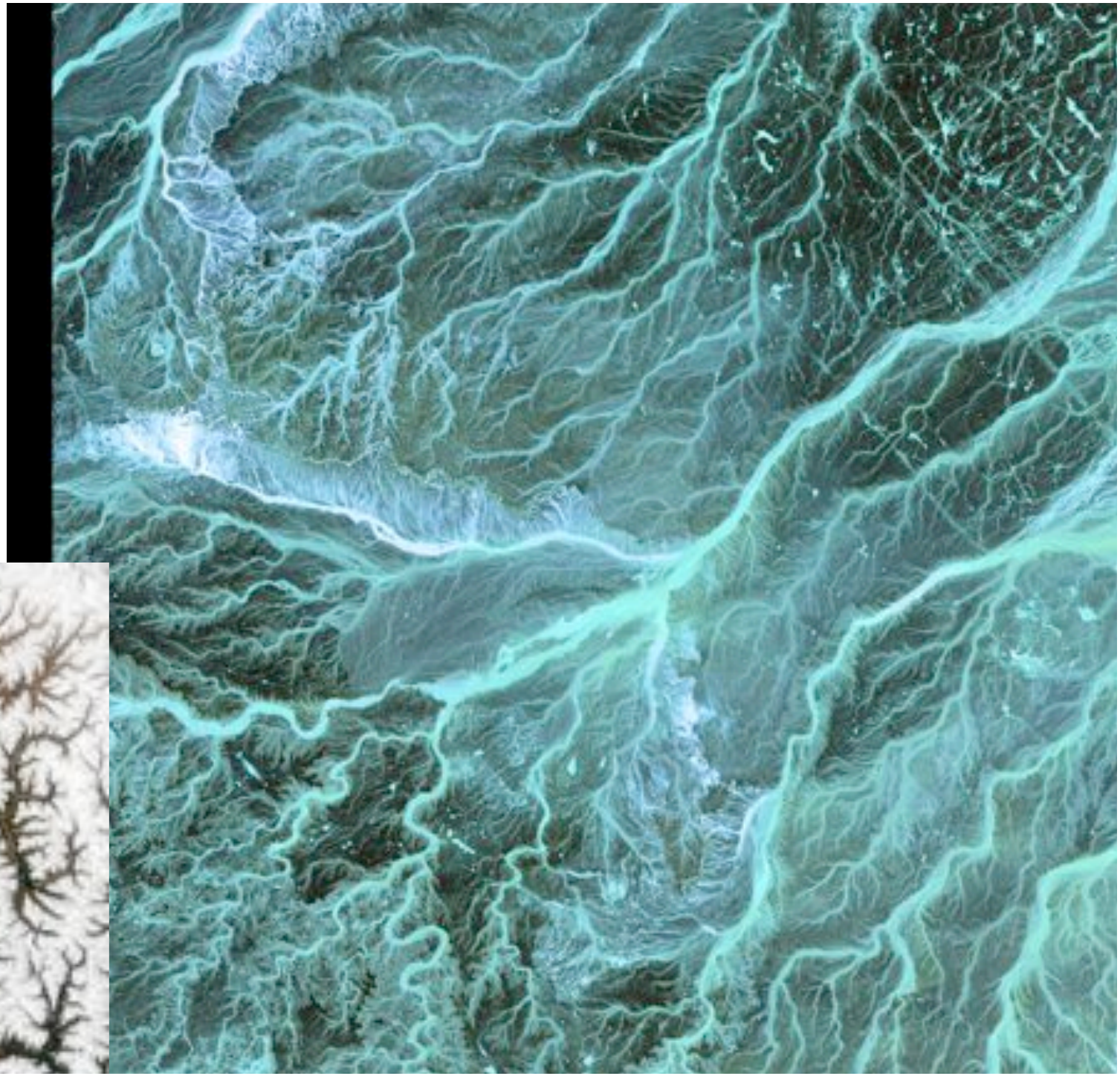
The limitation of shape comes from the particular folding,
Hence the develoement of the folds… (see Etienne)

Leaf Veination



Scalar models:
tree pattern,

no loops !



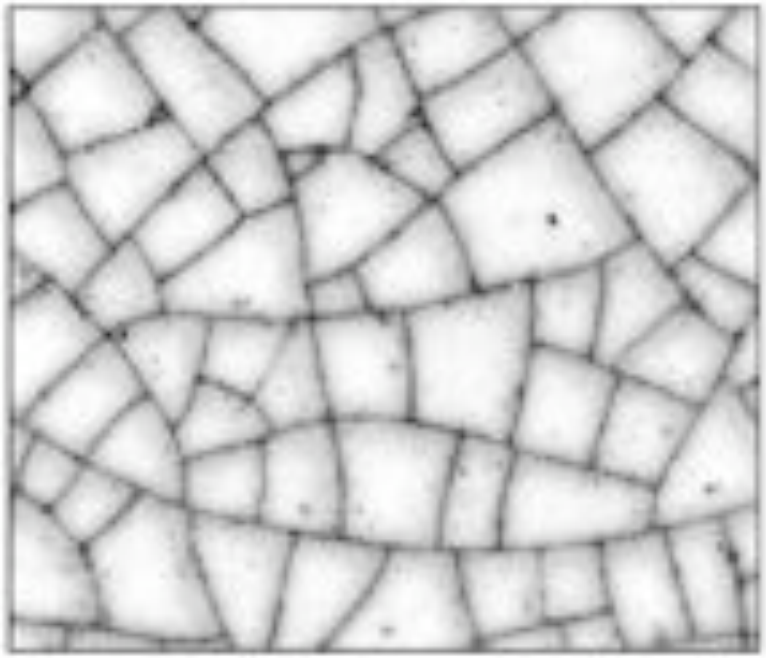
Mangroves

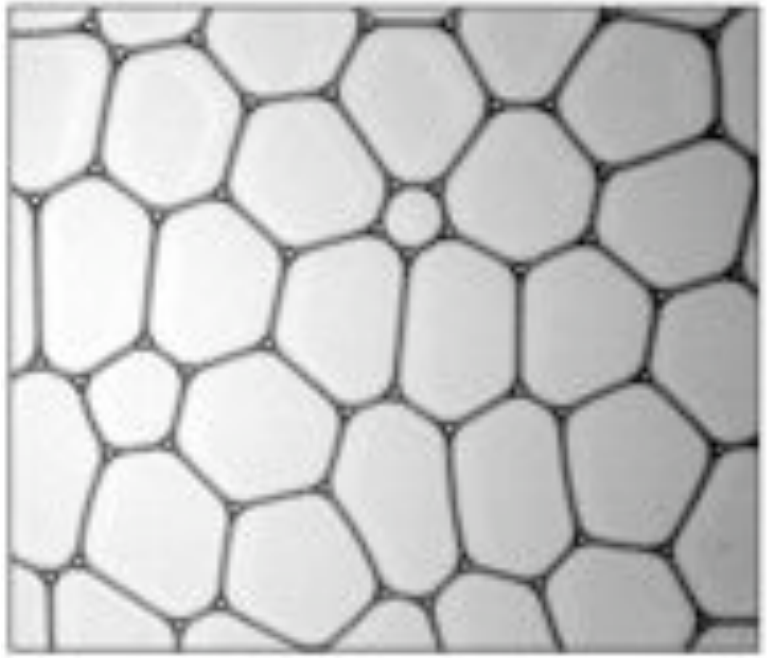
(inversion of flux direction: vector)

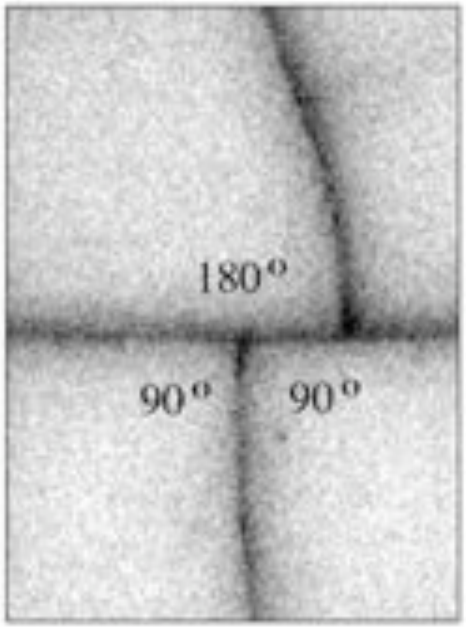
Intrinsic limitations from the type of model (dynamics)

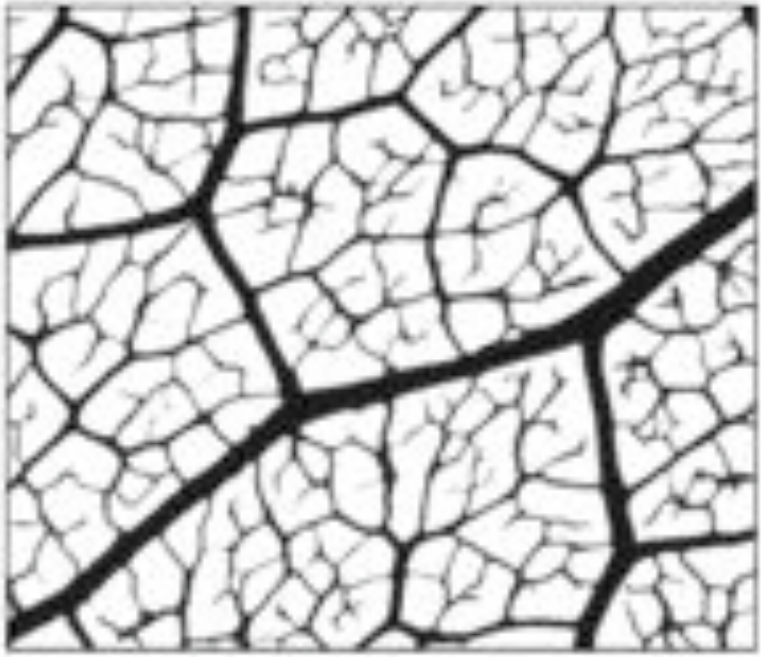


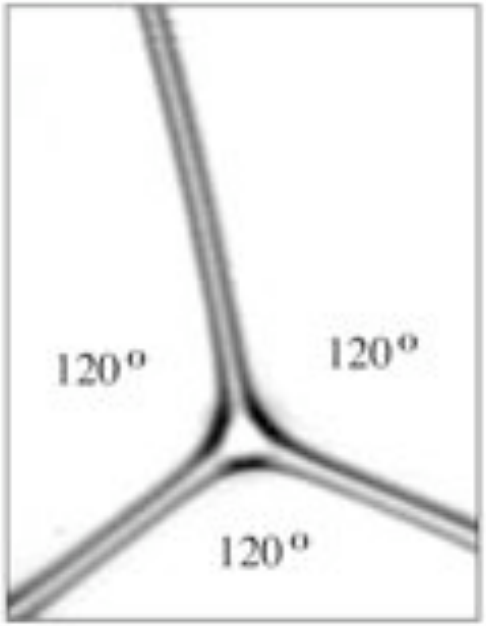
Ferns






180°
90°
90°

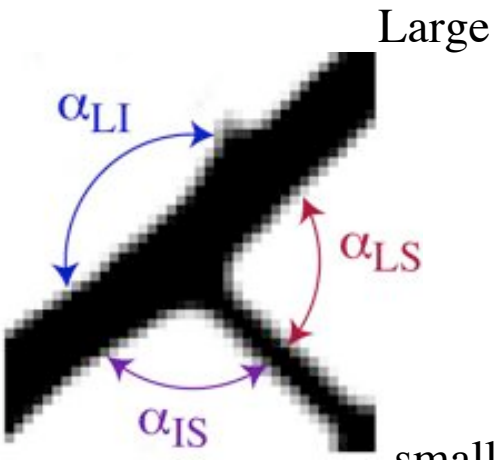


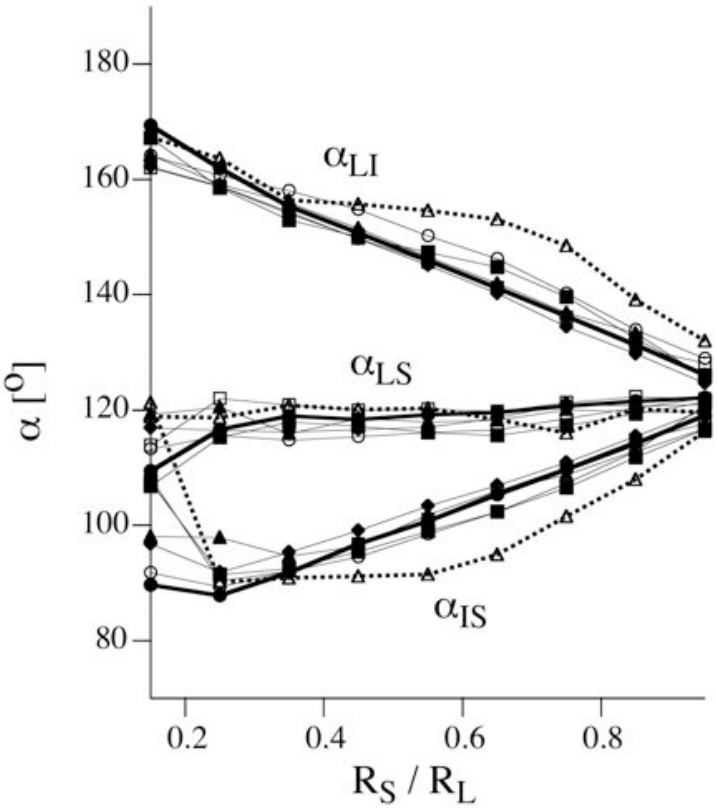

120°
120°
120°

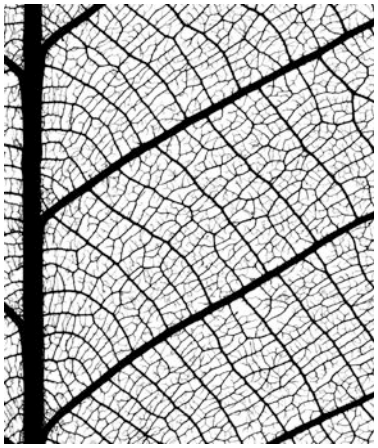
Hints on the mechanism from the shape…

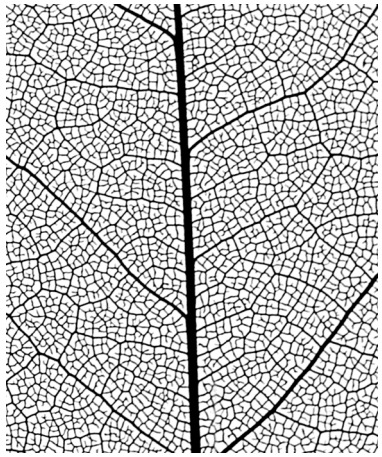
angles…

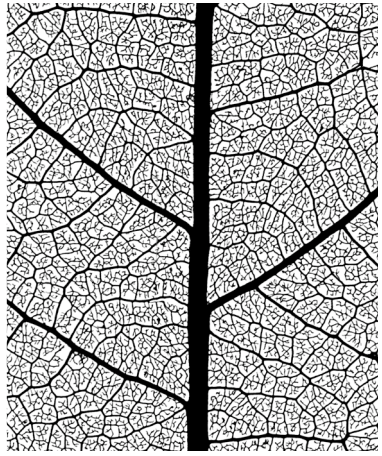
Angles depend on
the diameters of the veins !



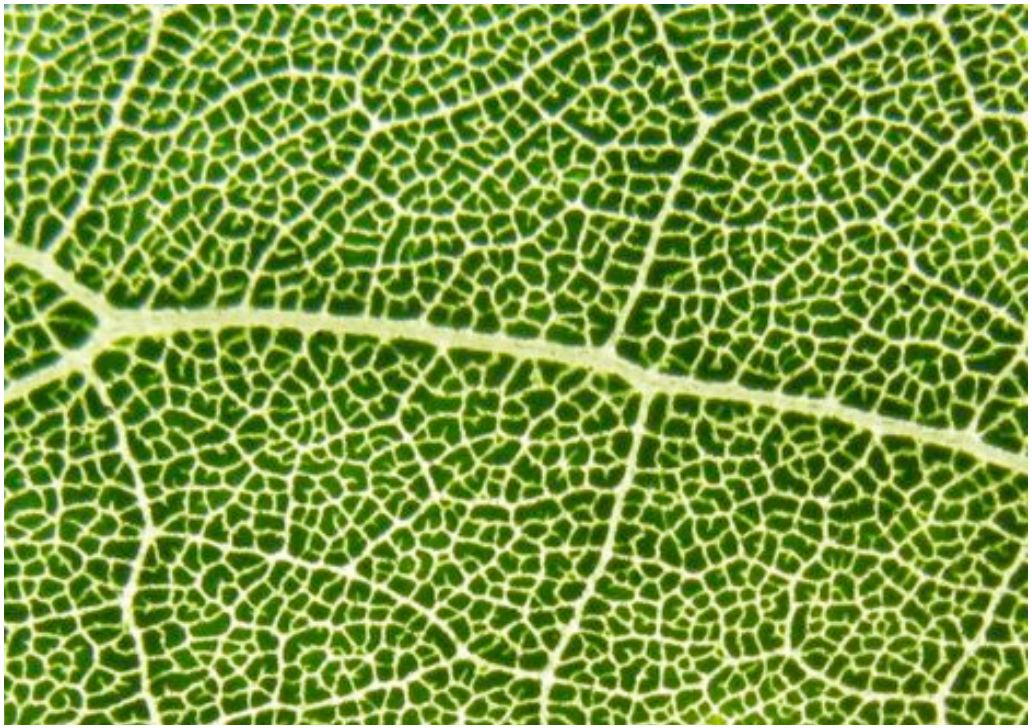


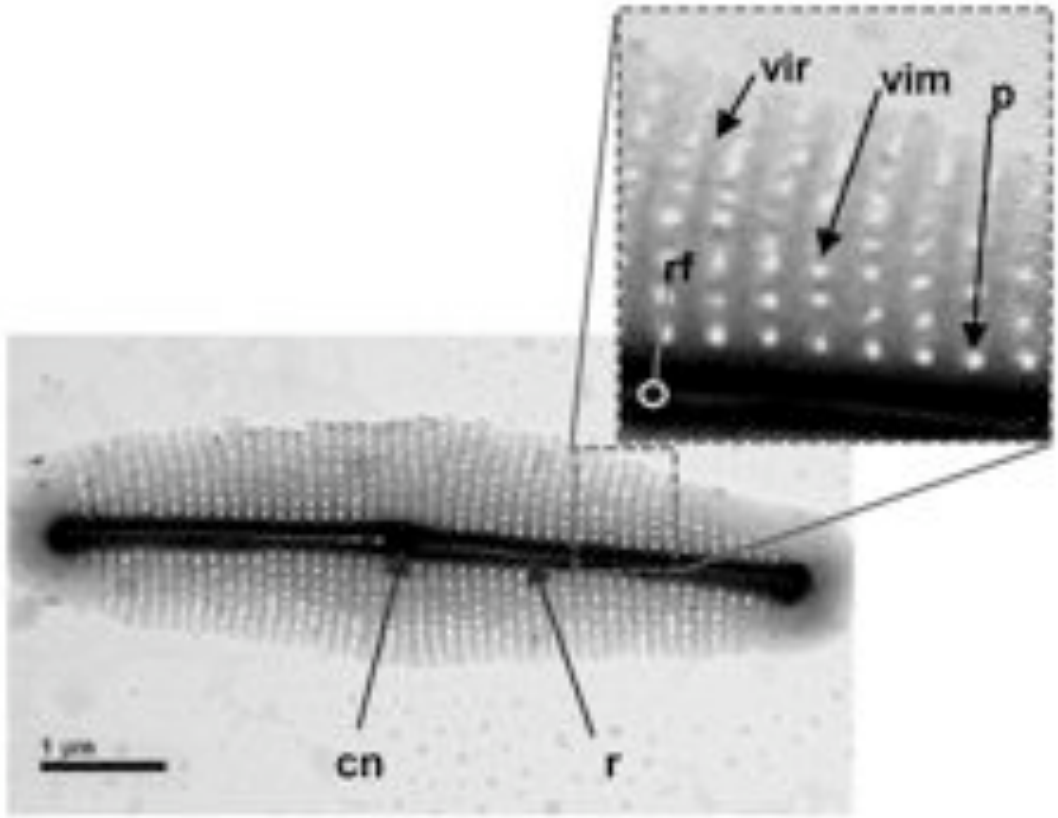




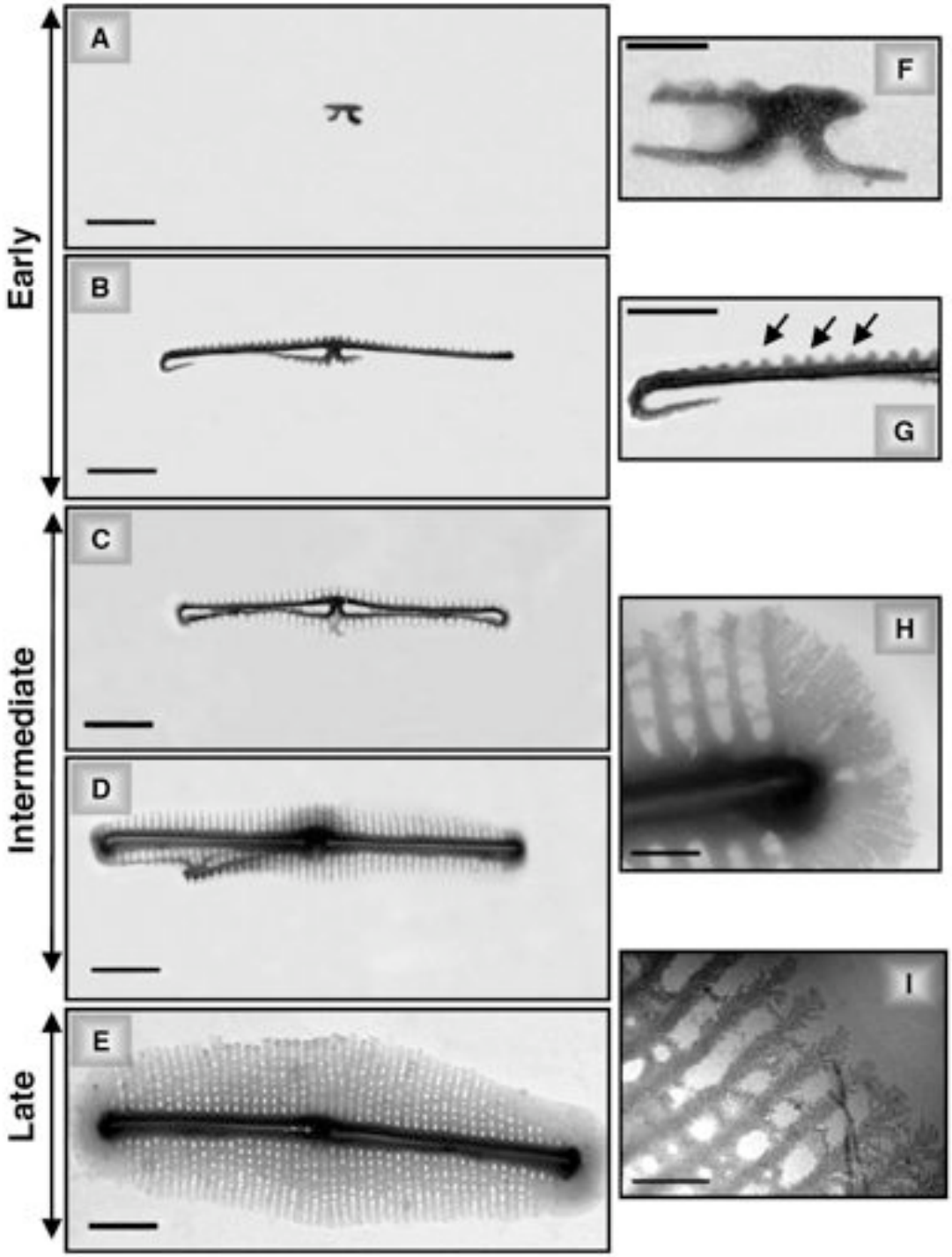


Leaf Veination *vs* Petal Veination

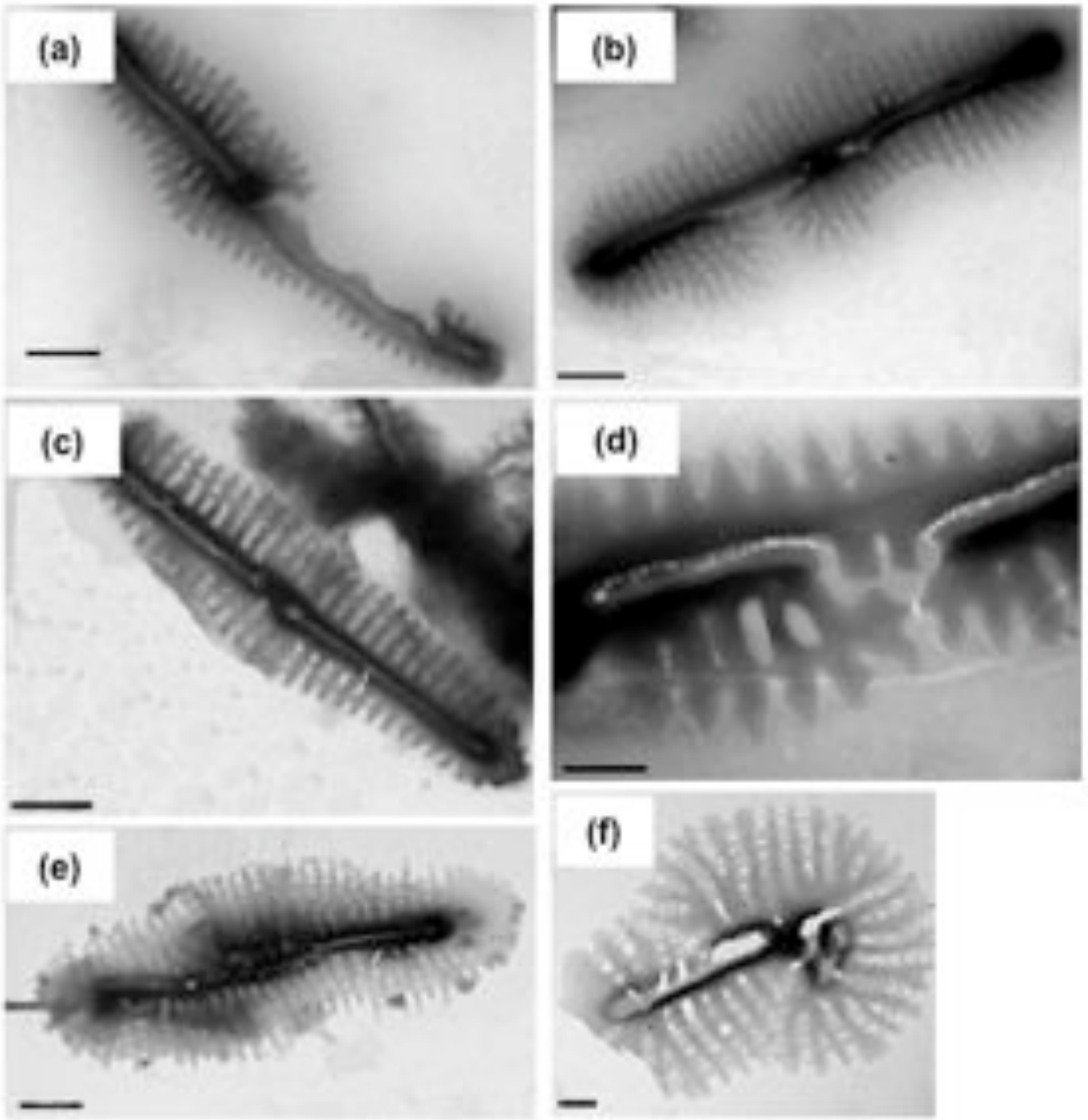



vir
vim
p
rf
1 µm
cn
r

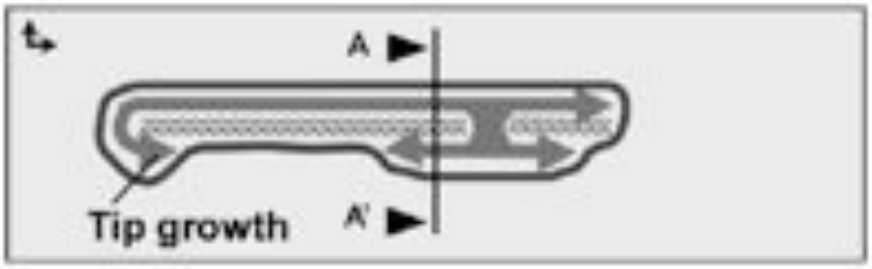
Where the stability
comes from ?



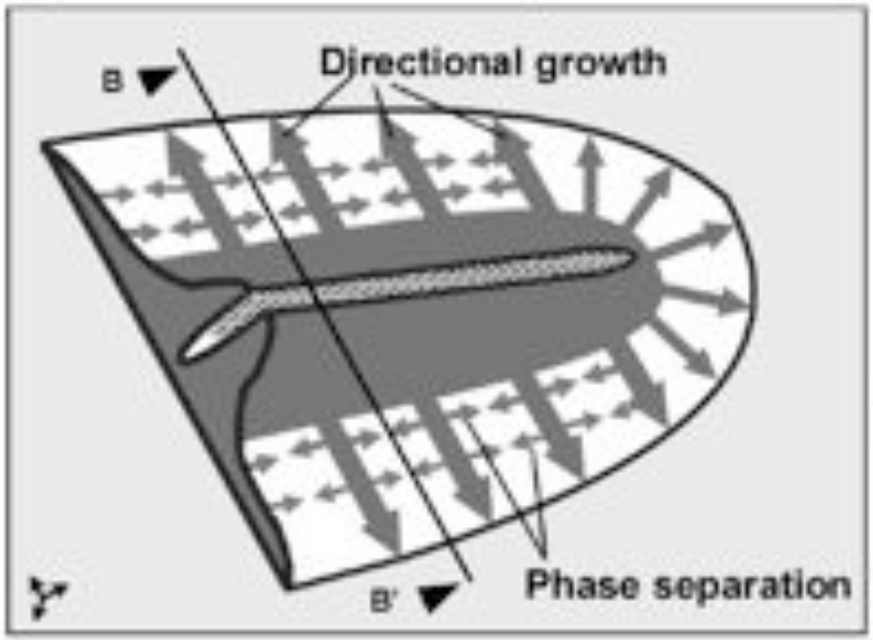
Vartanian & al.
New Phytol 2009

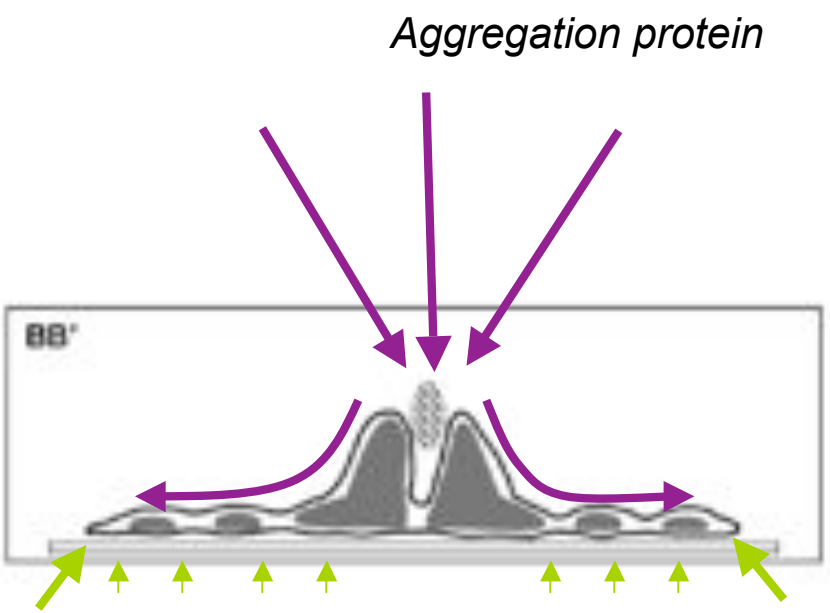

(a)
(b)
(c)
(d)
(e)
(f)

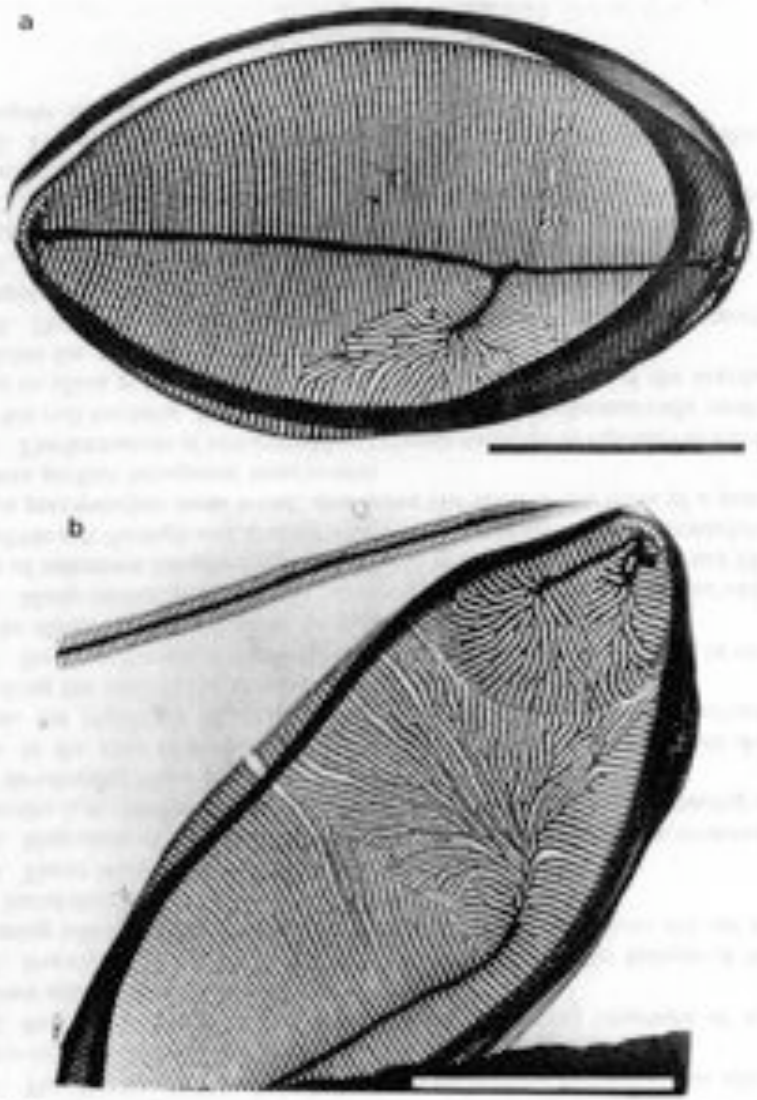
(a) Early Phases

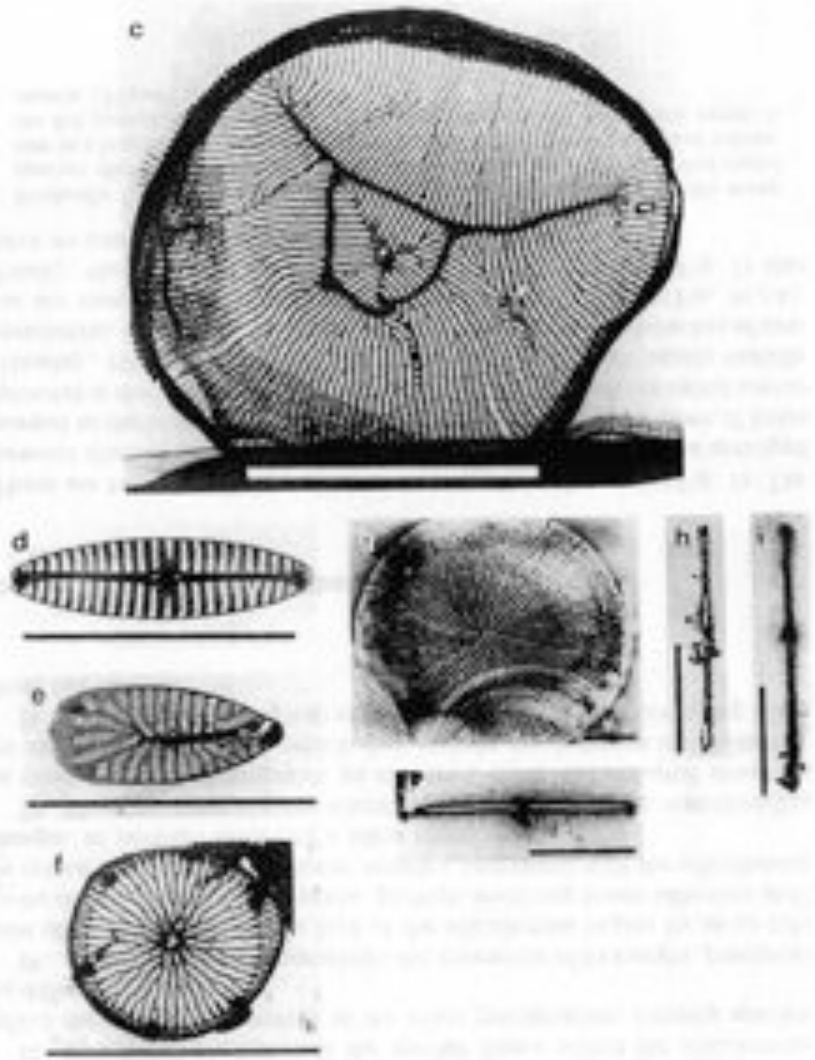


(b) Intermediate and late phases









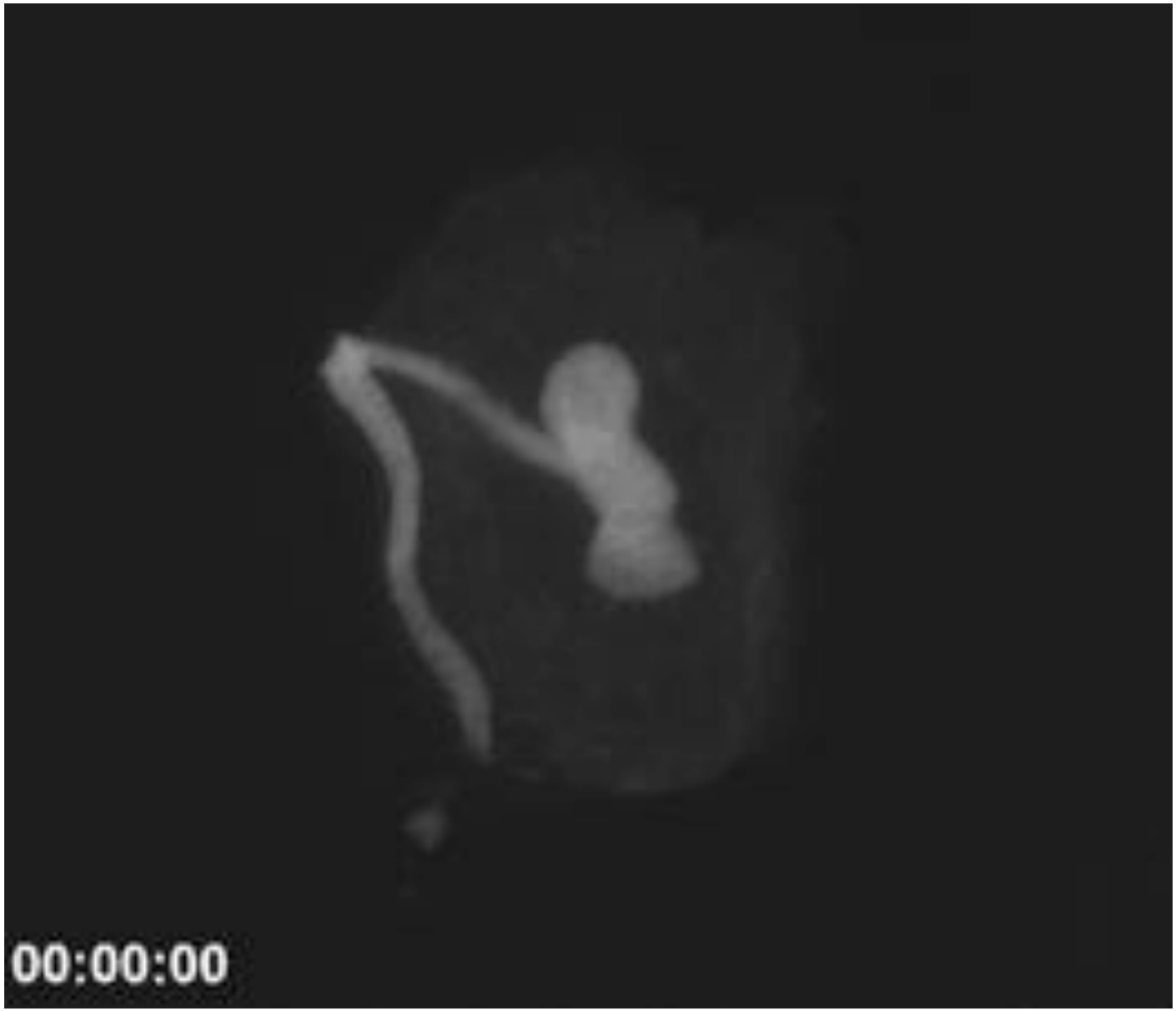
branching of the costae and the local nature of the alignment of the cross-costae to them

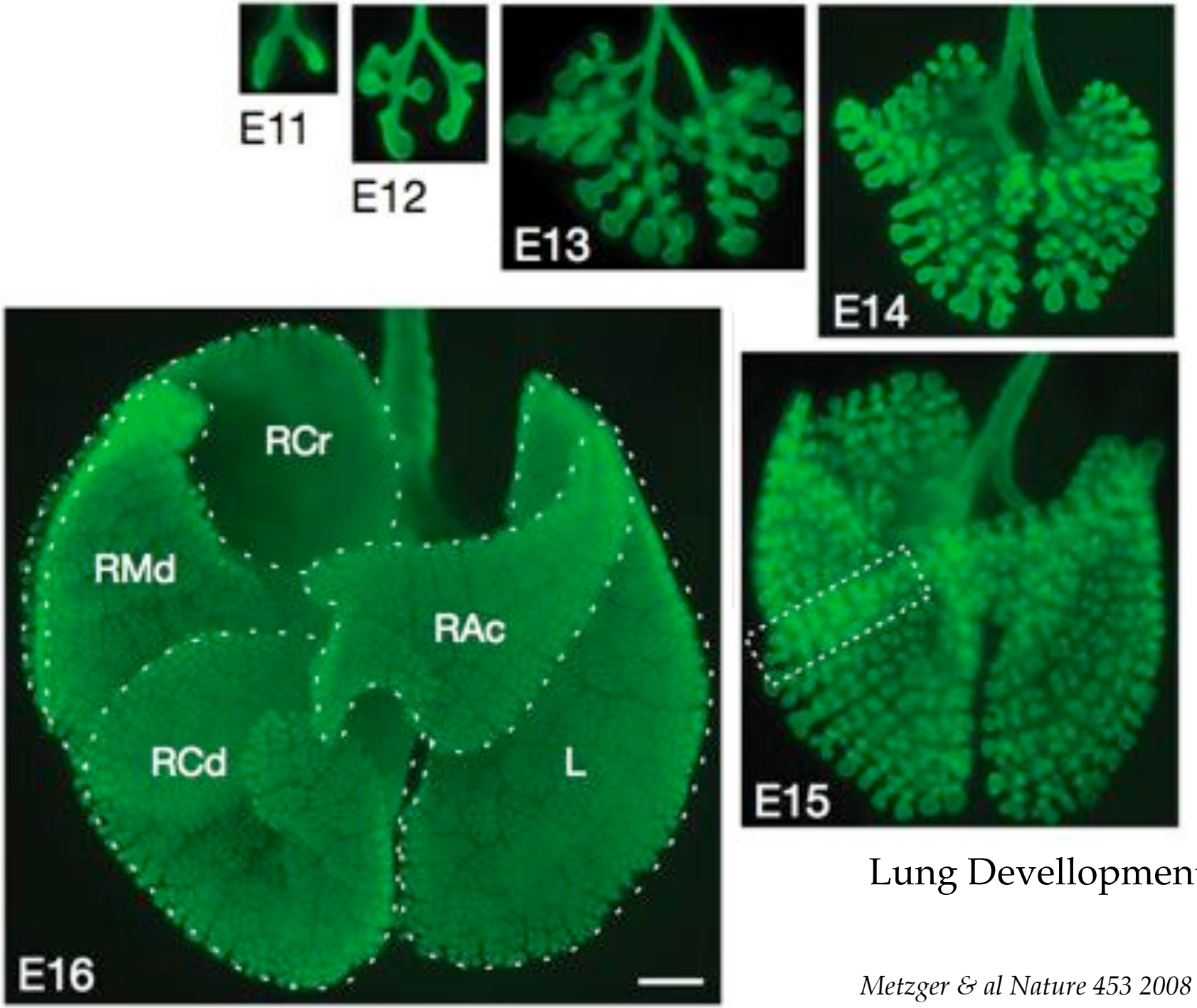
Creation of shape by a (physical/chemical) instability

But how to « control » the irregularity of the physical instability ?

Dynamical boundary conditions (e.g. directional growth) ?

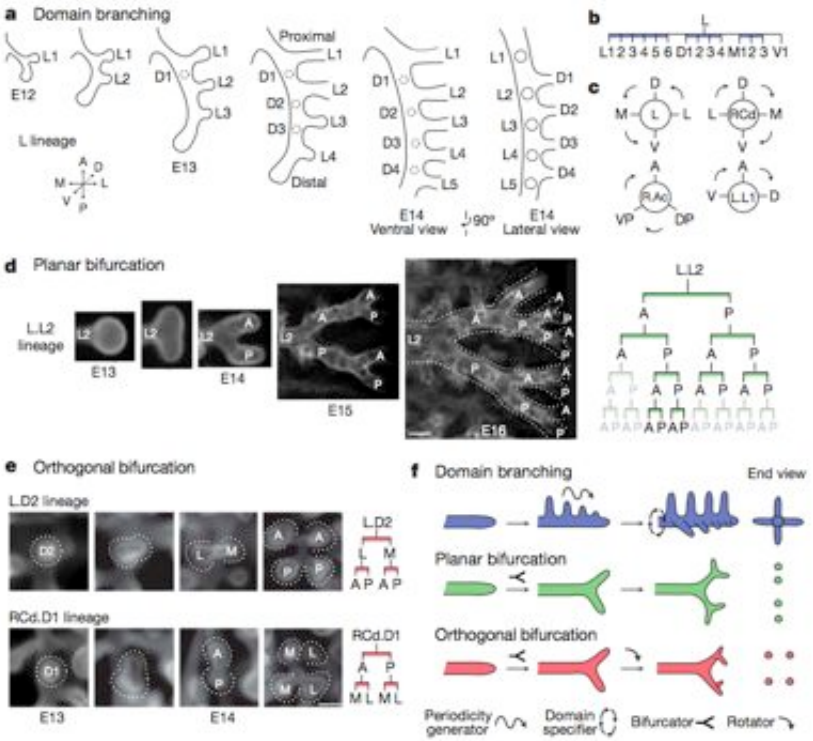
Lung/Kidney growth



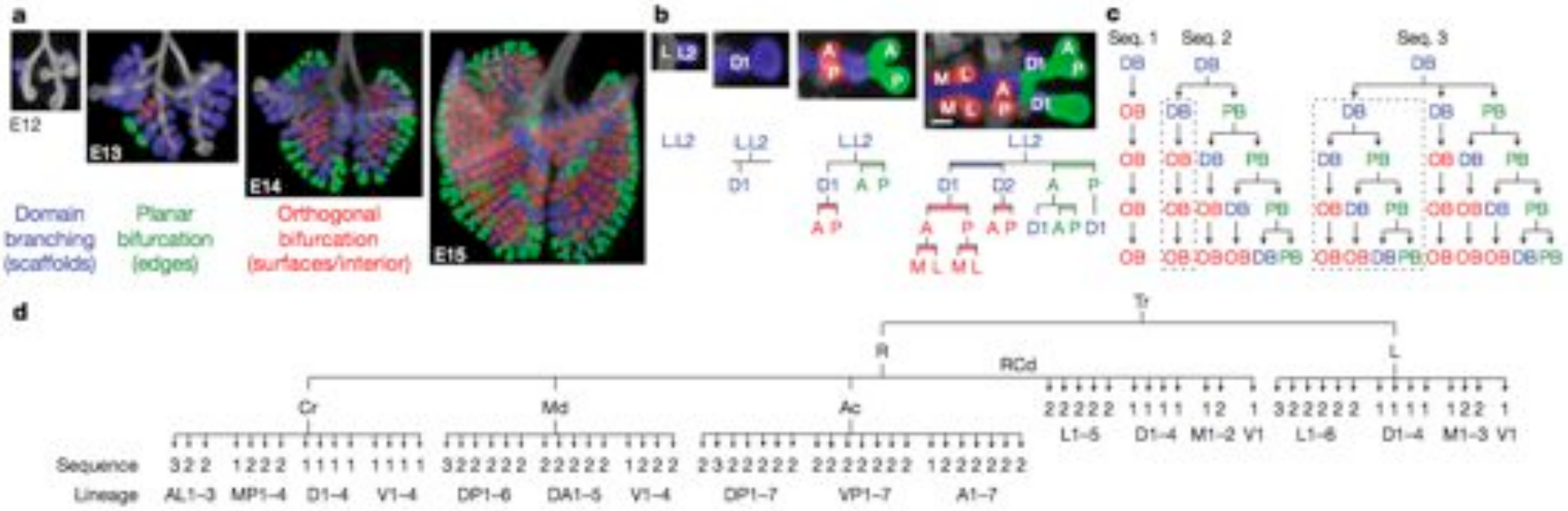


Lung Devellopment

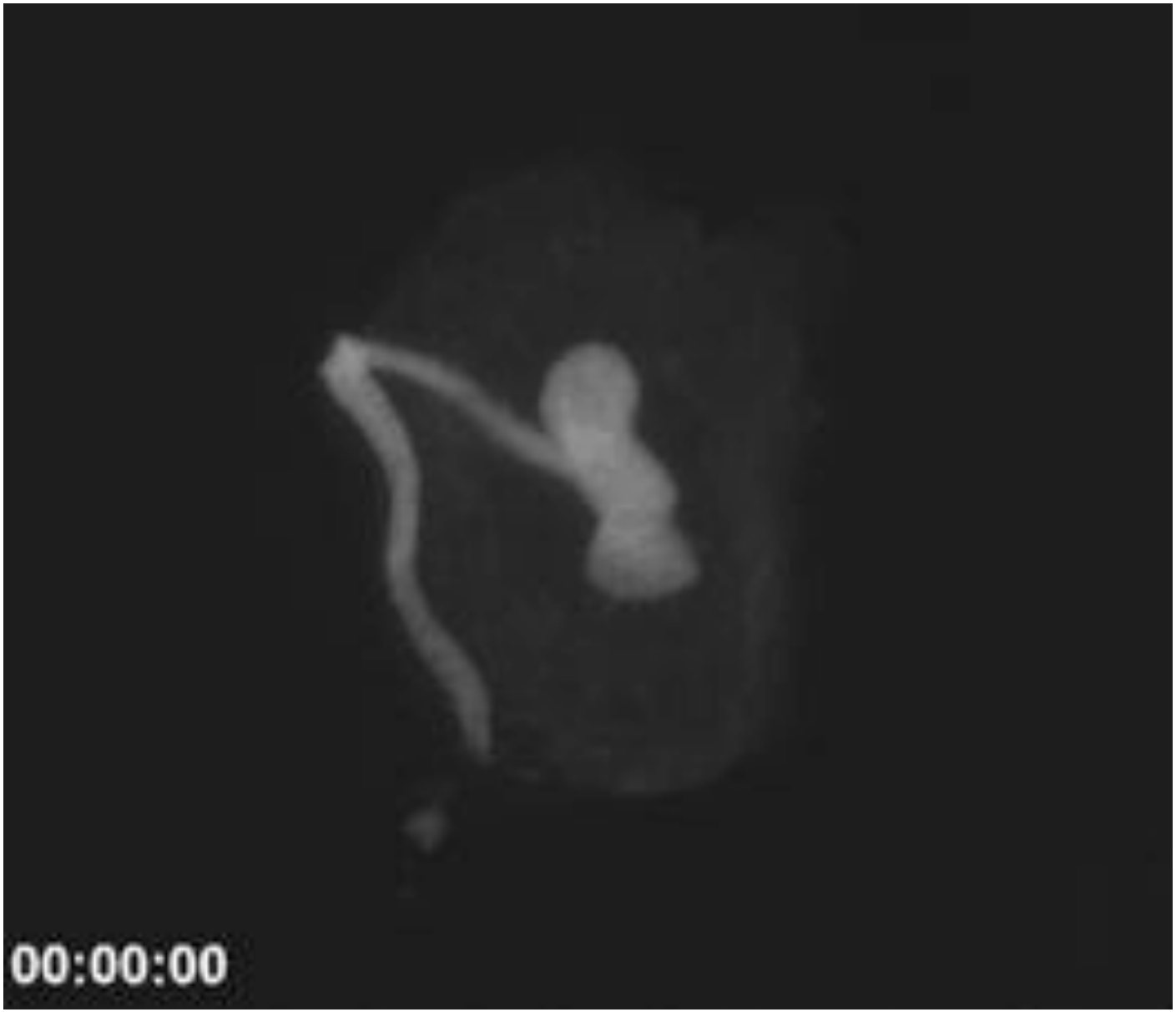
Metzger & al Nature 453 2008

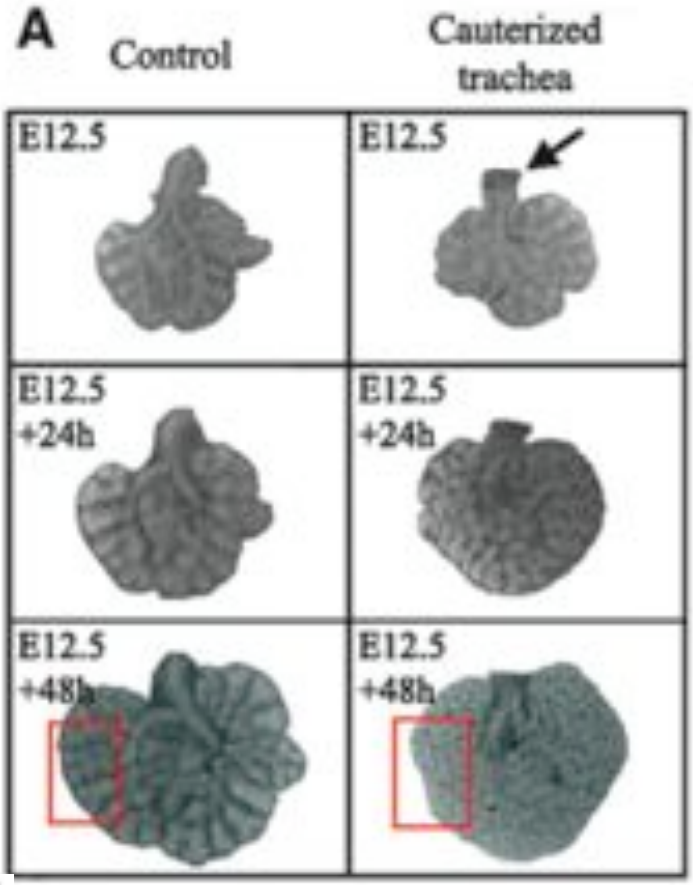


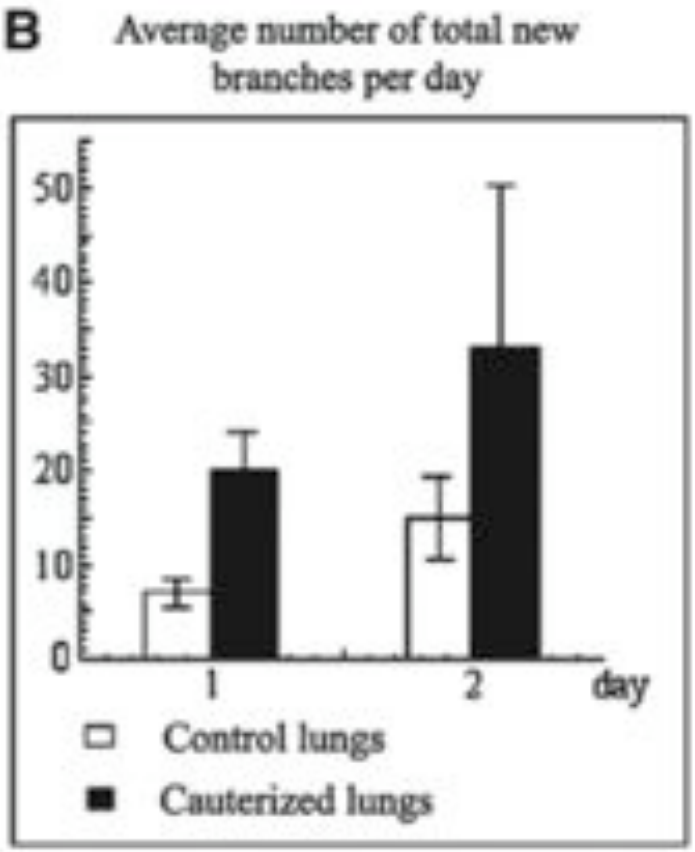
The branching programme of mouse lung development

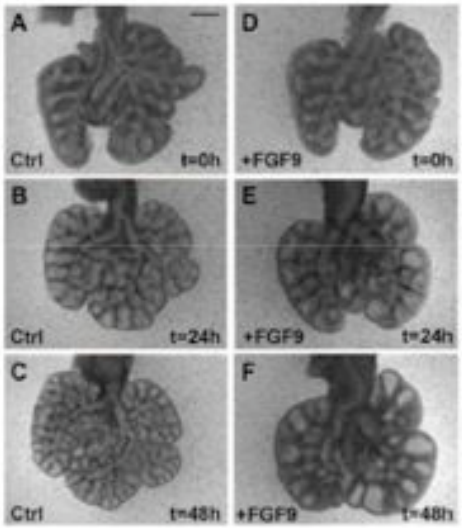


Globally stable but always different… need a regulation !

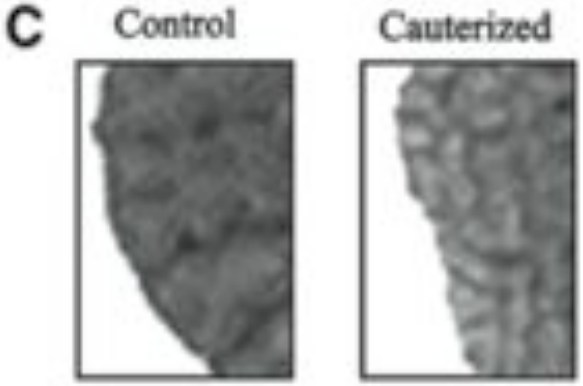




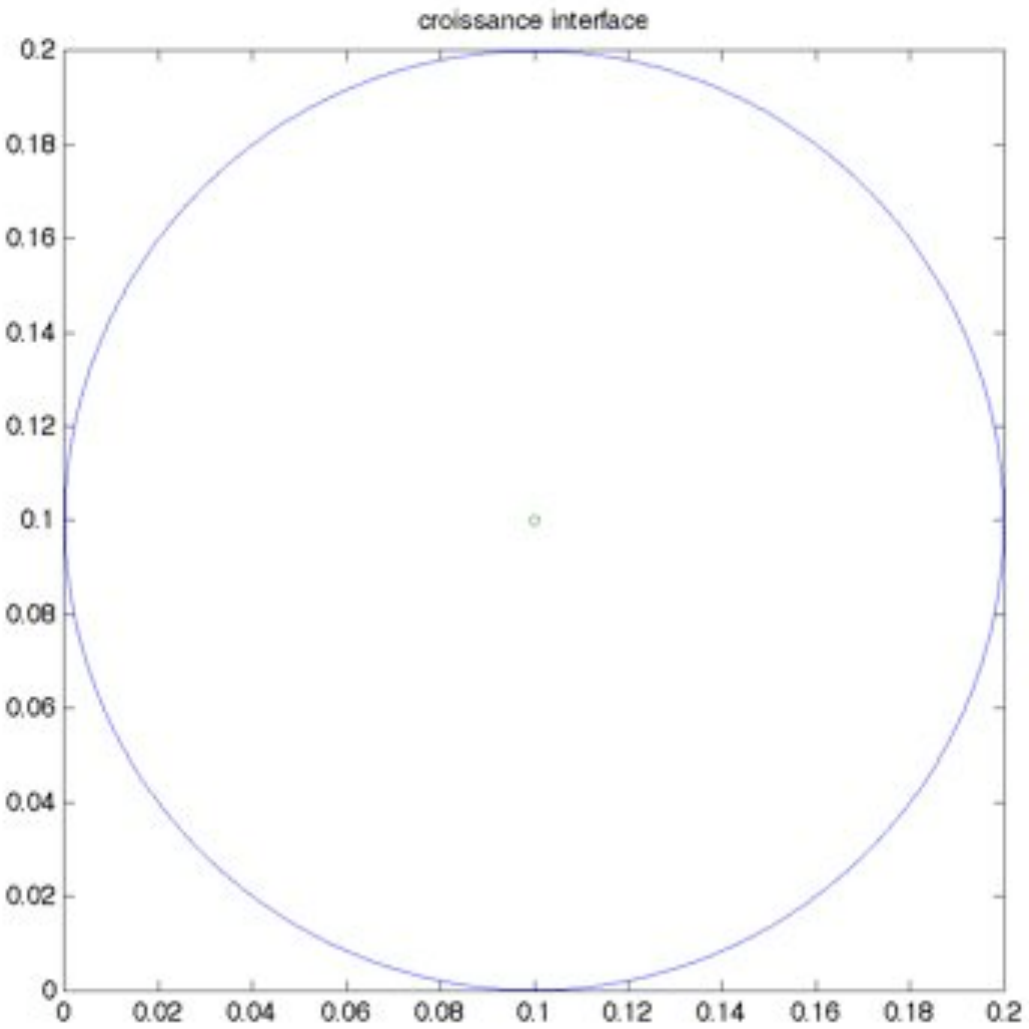


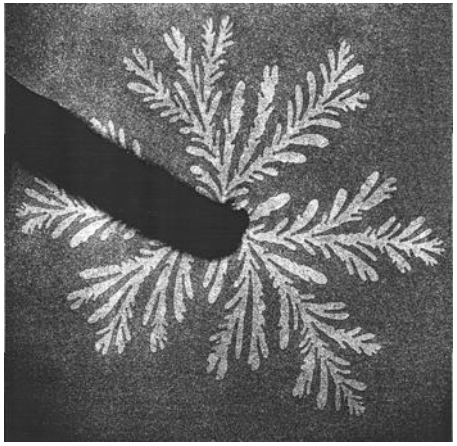


Mechanical effect

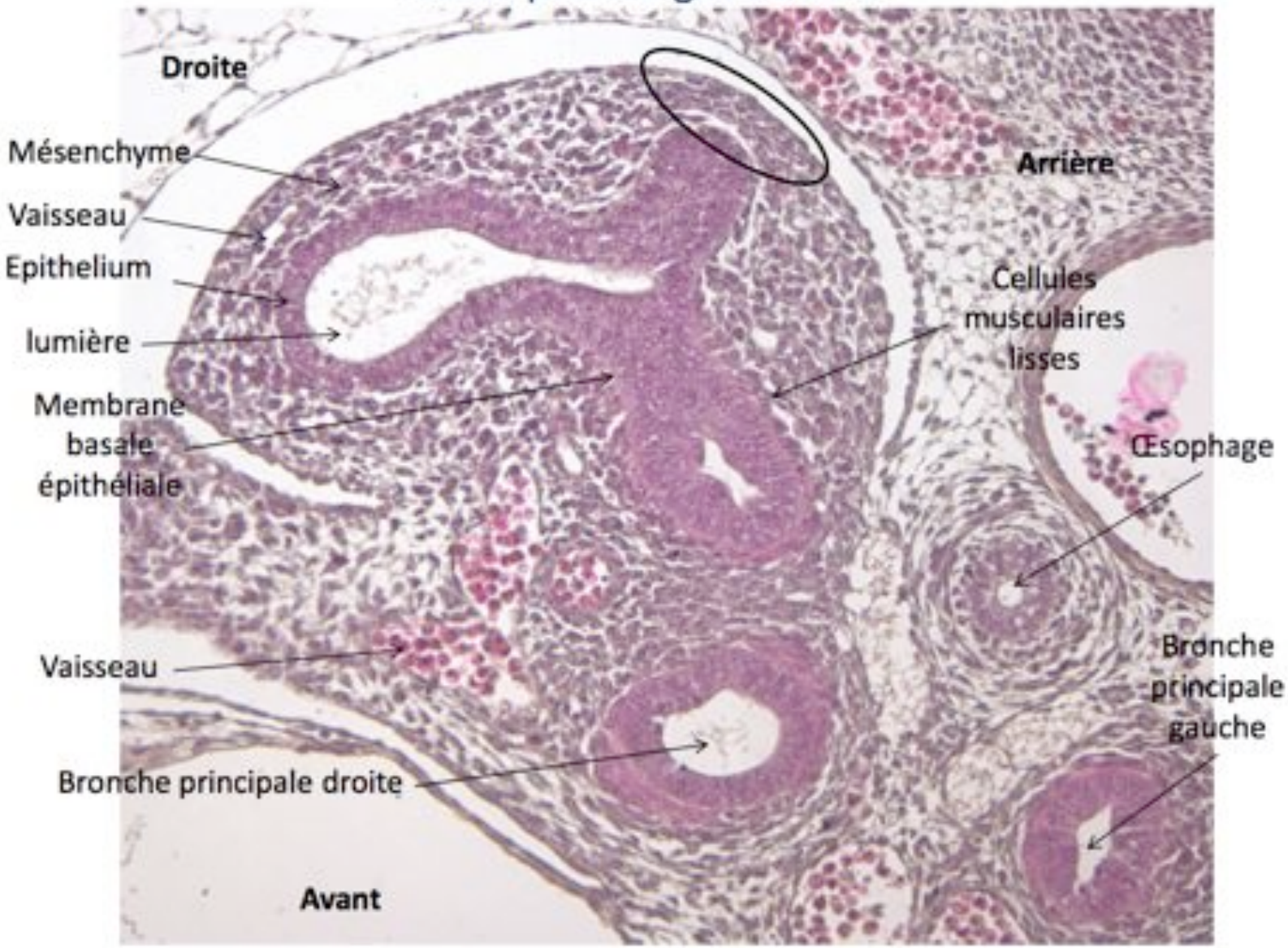


Saffman-Taylor

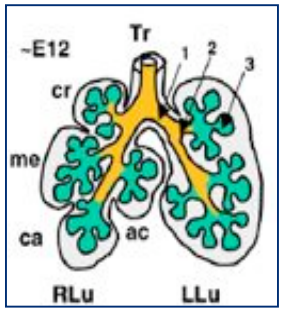


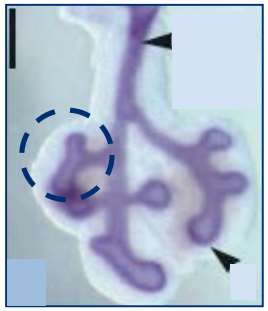


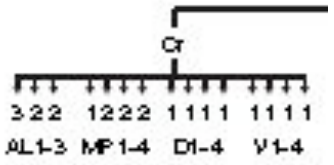
Stade pseudo-glandulaire

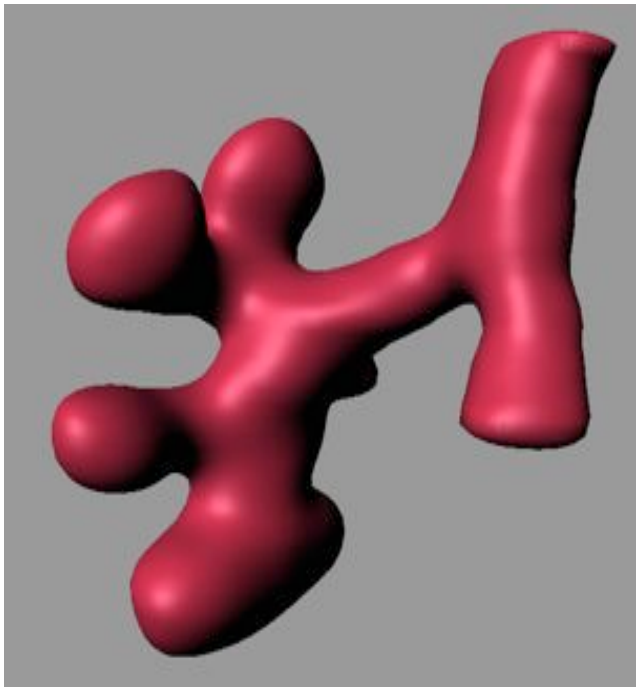


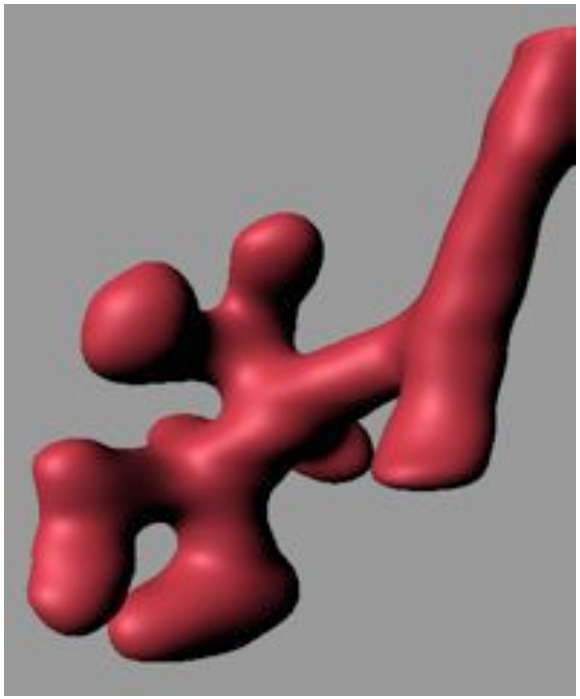
Lobe crânial – E12.5 – vue antérieure

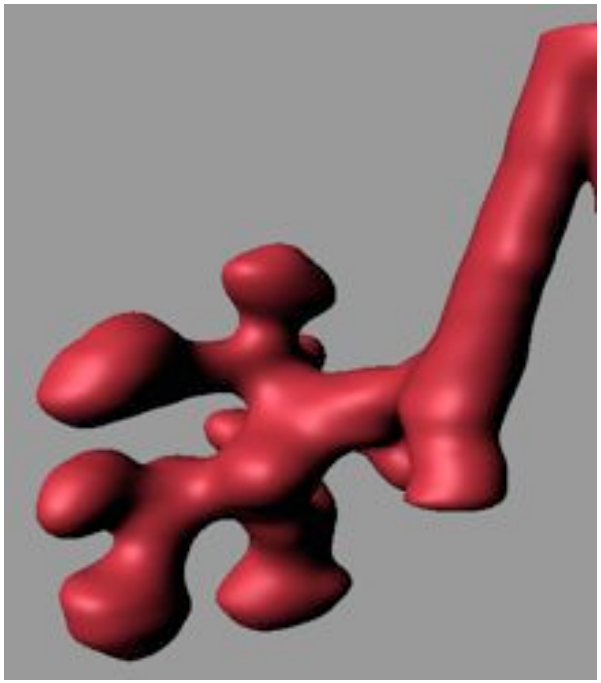






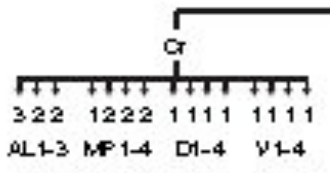


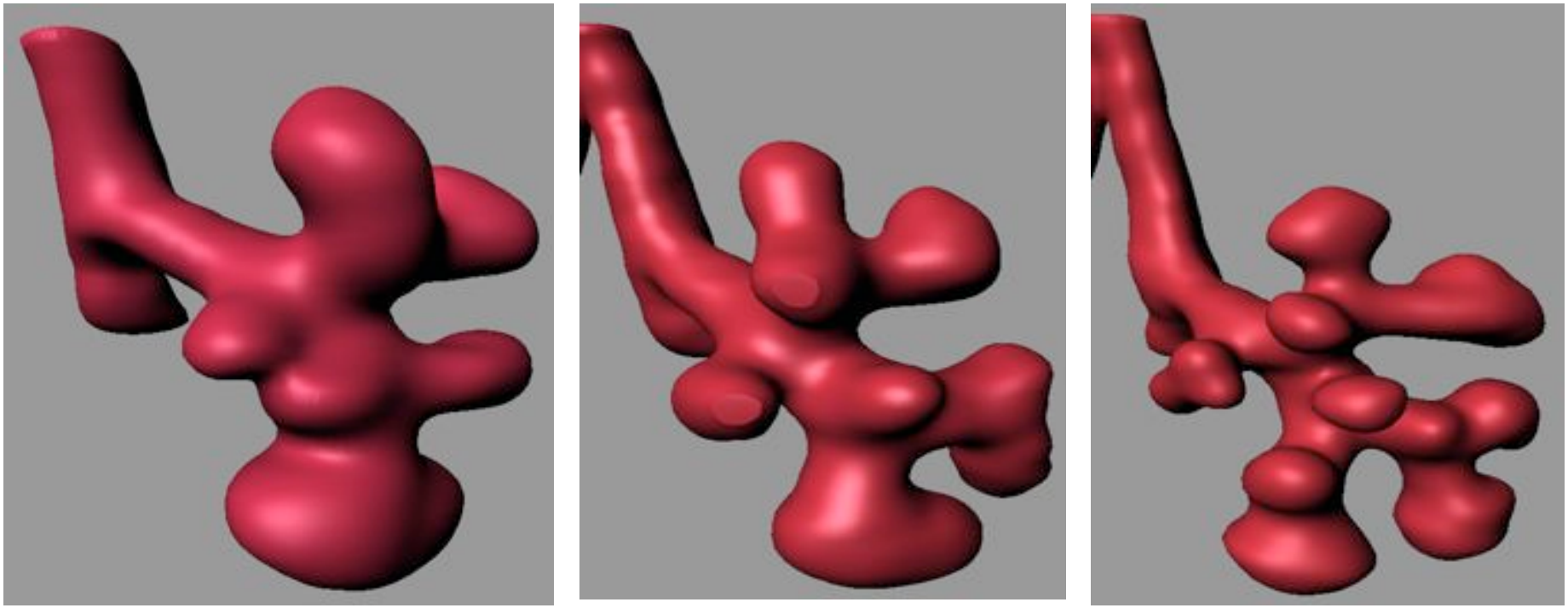




Lobe crânial – E12.5 – vue postérieure

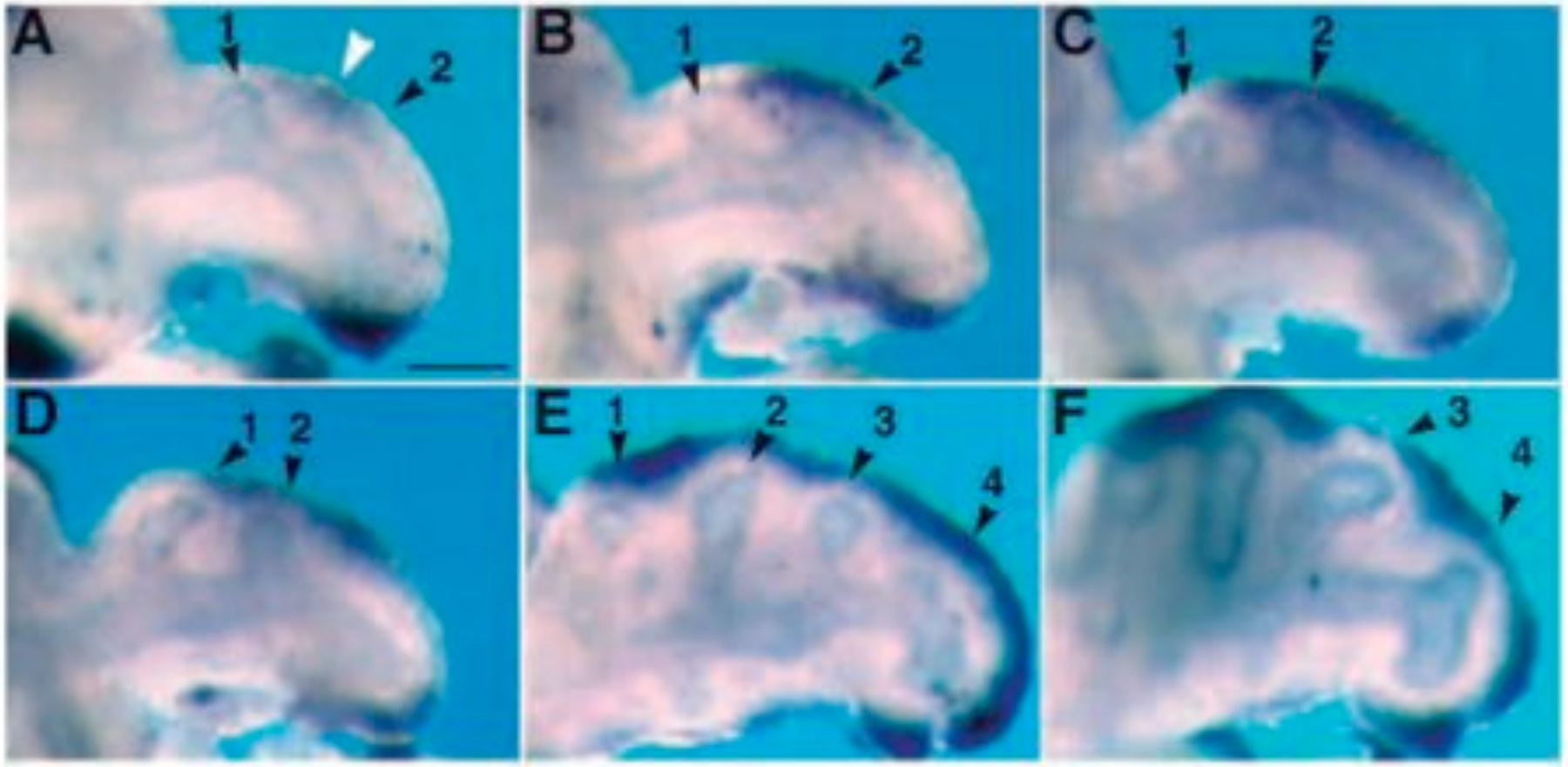
“One possibility is that the process is not precisely controlled; for example, if branching occurs randomly to fill available space.”





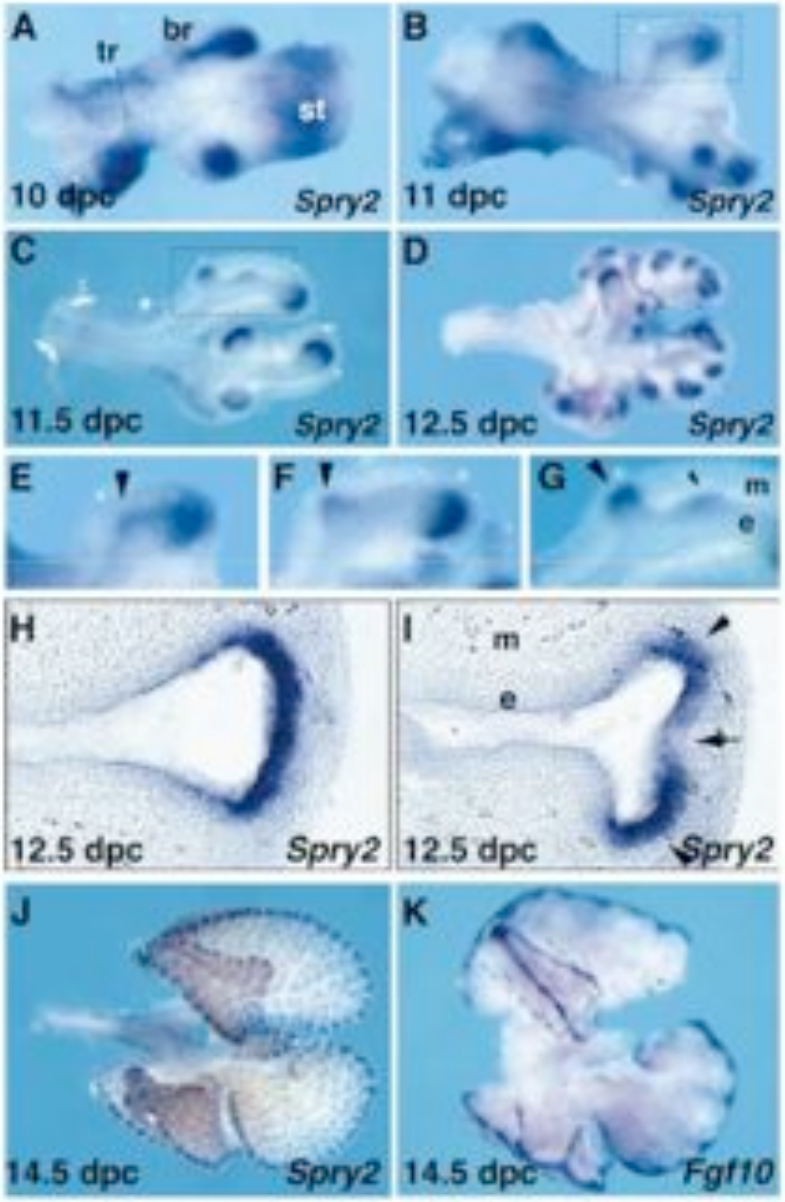
Part d’auto-organisation dans la morphogénèse bronchique?

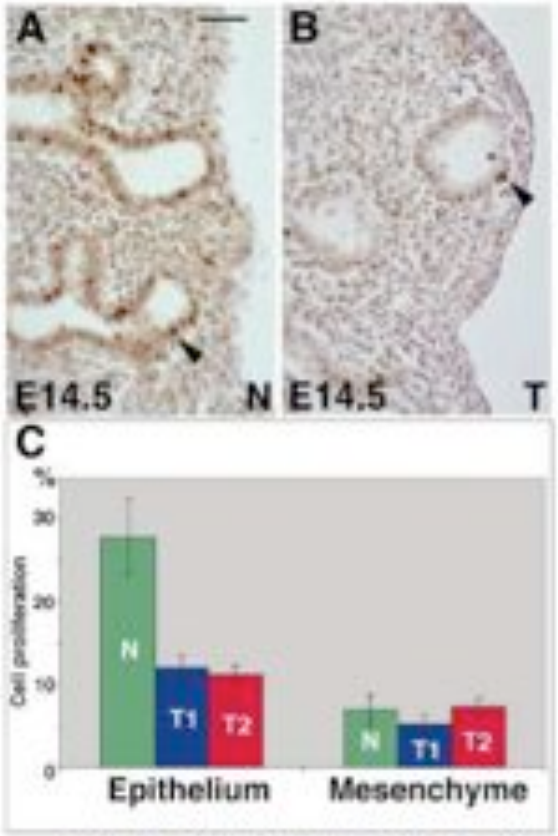
Expression of Fgf10 (growth factor 10)



Bellusci et al., Dev. 1997

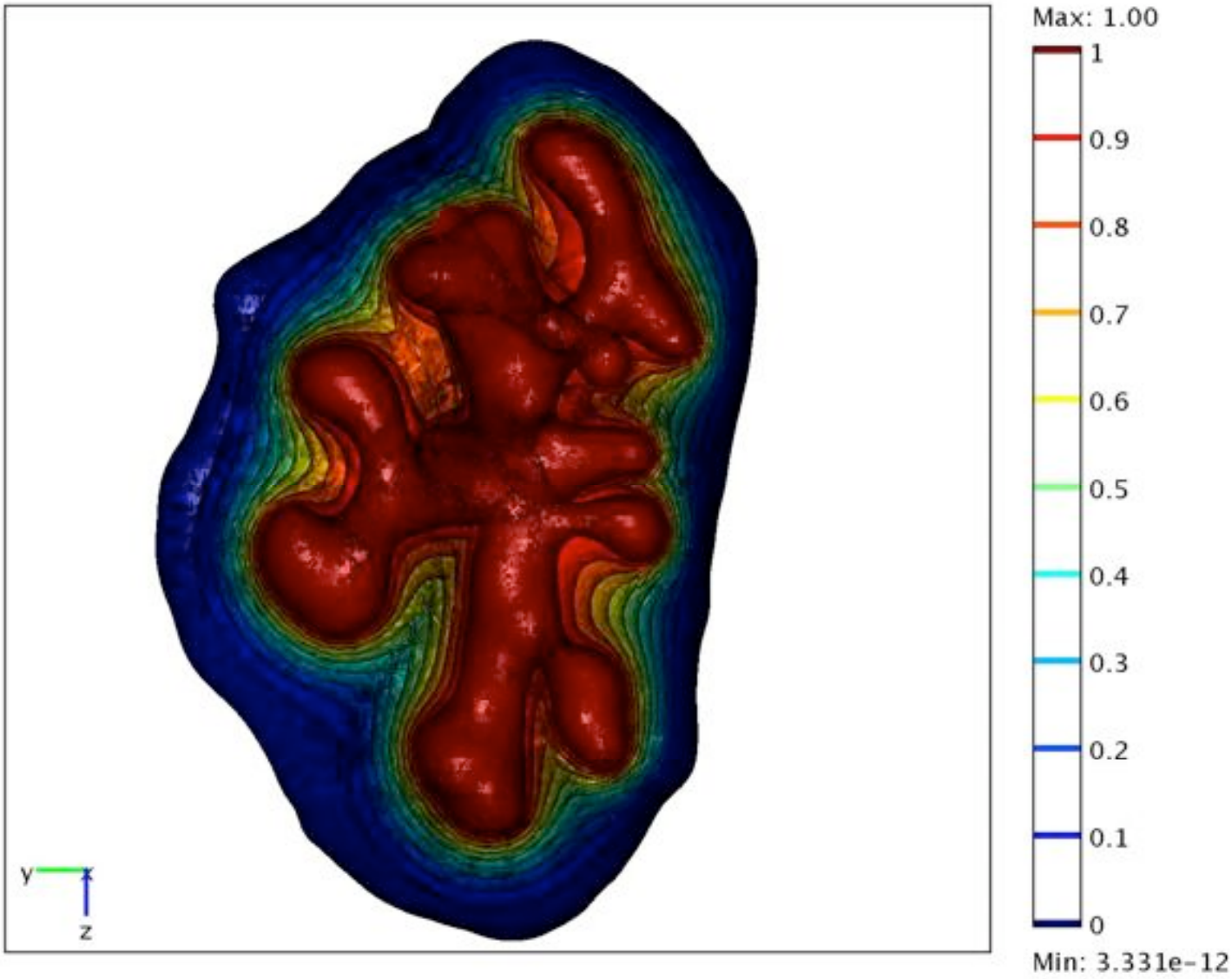
Sprouty 2: Spry 2



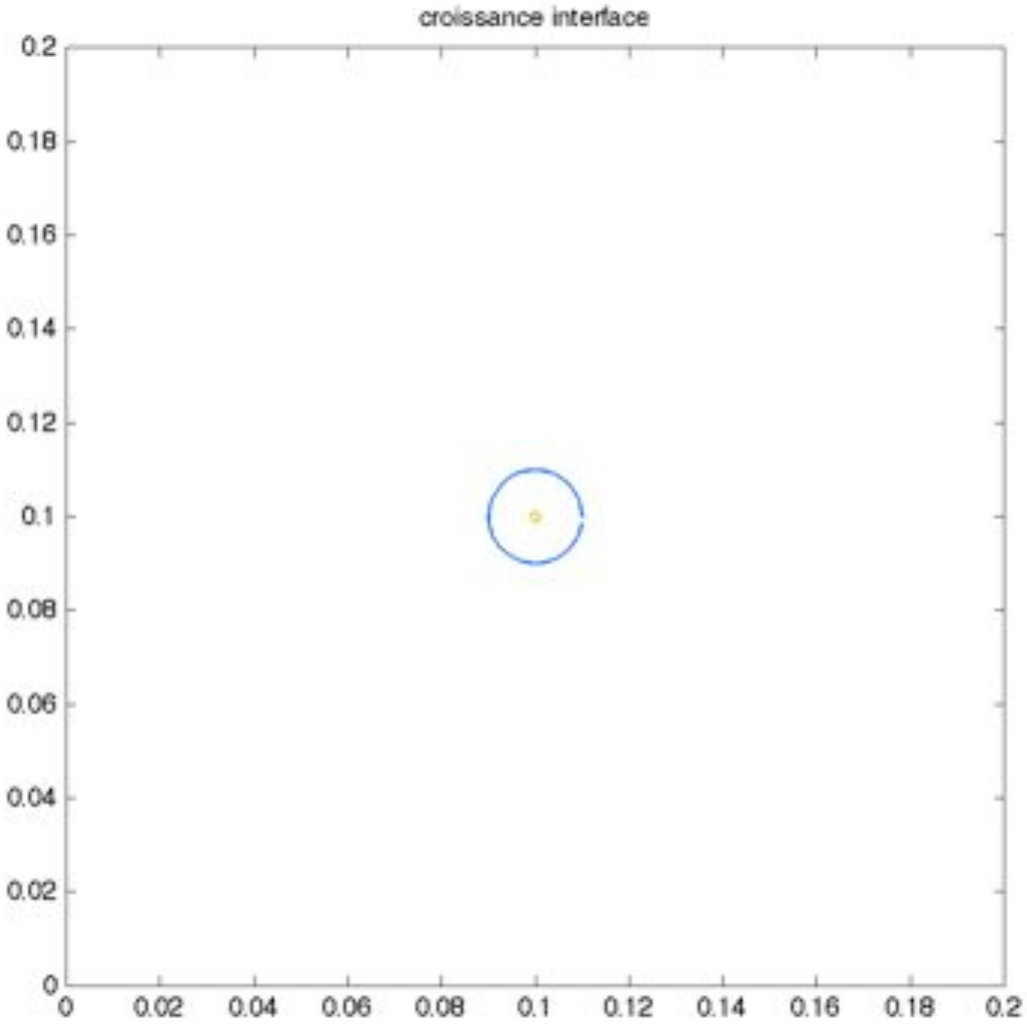


Surexpression de Sry2 et prolifération cellulaire

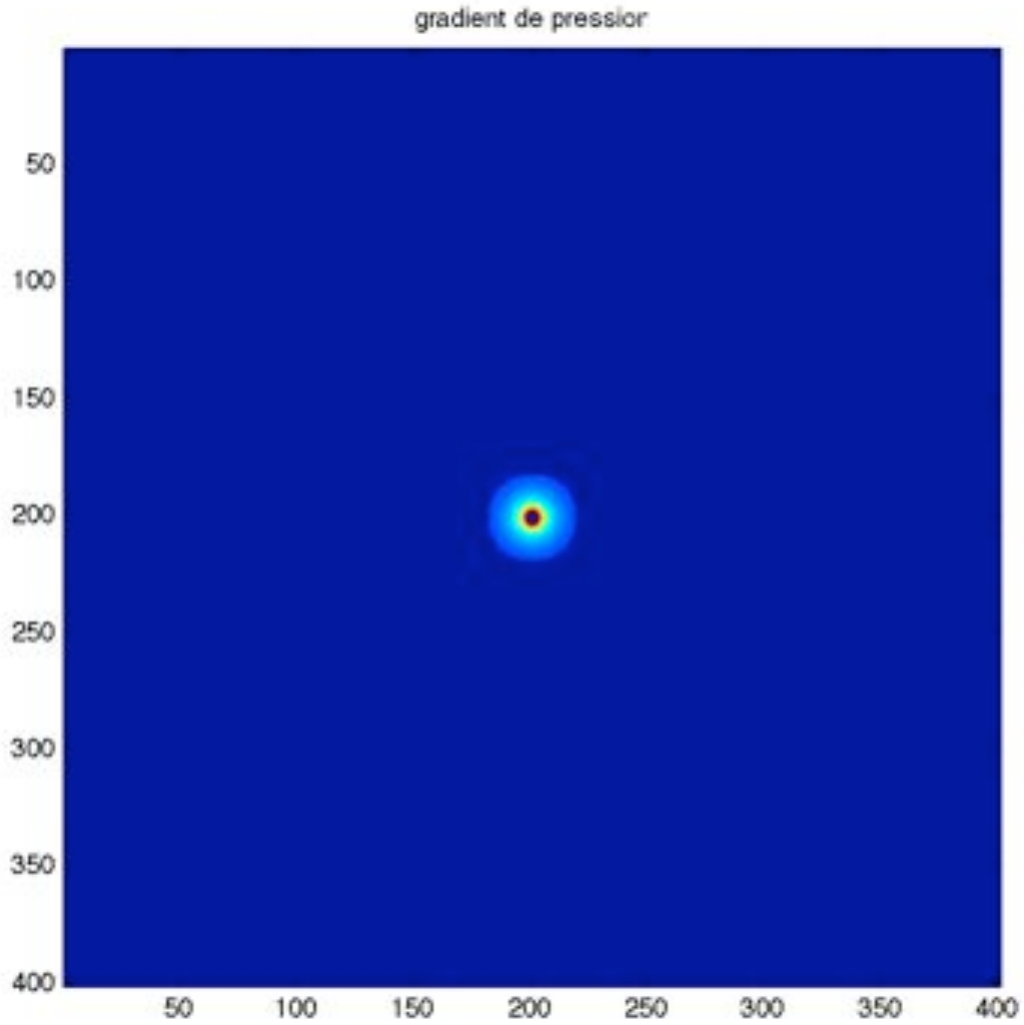
Mailleux *et al.*, Mech Dev. 2001


Max: 1.00
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Min: 3.331e-12
y
z

Double interface modified Saffman-Taylor



Raphaël Clement


gradient de pressior
50
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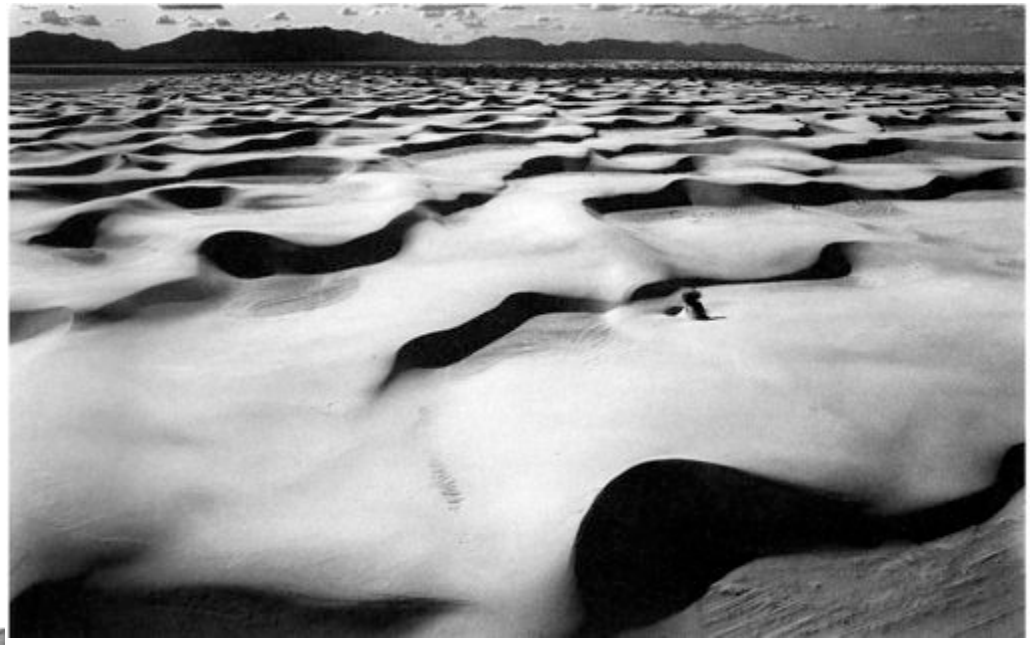
Dunes

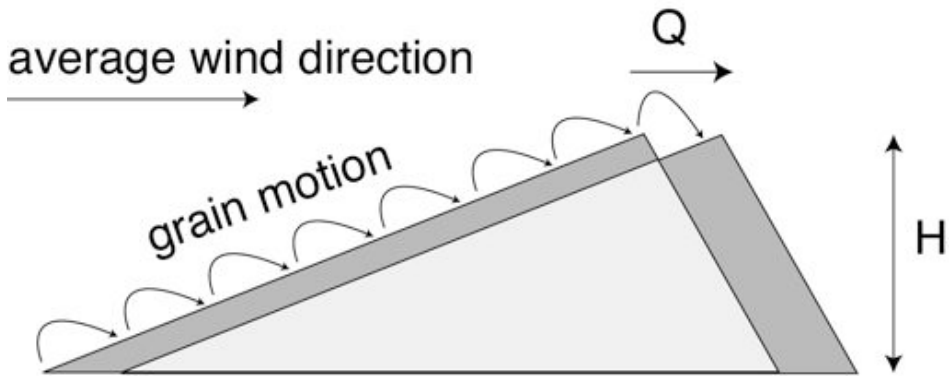
« Zoologie »



Dunes Transverses

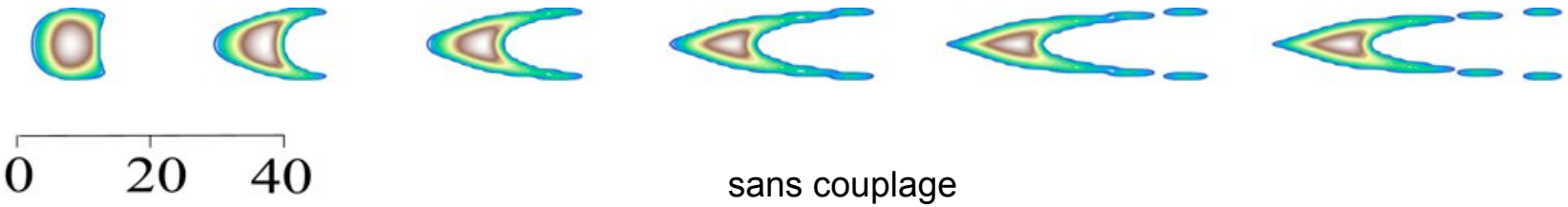
Barchane

Forme siamoise



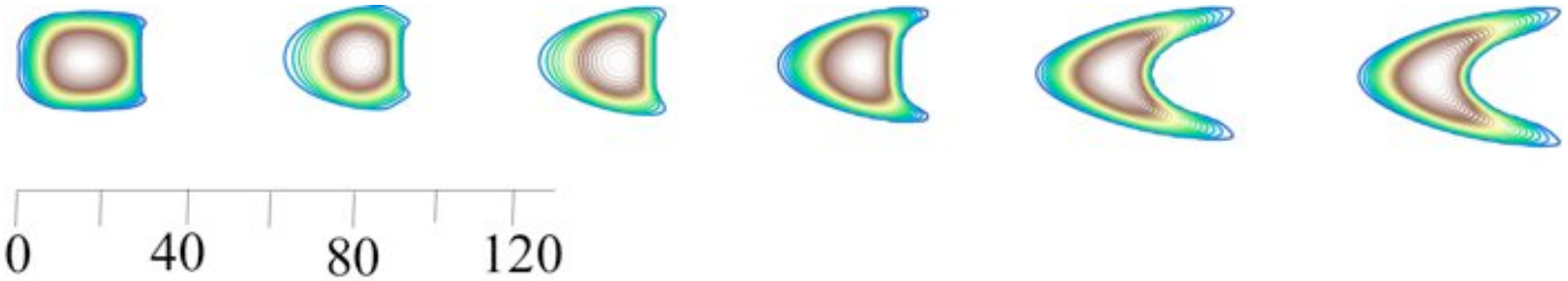
$$LH=QT$$

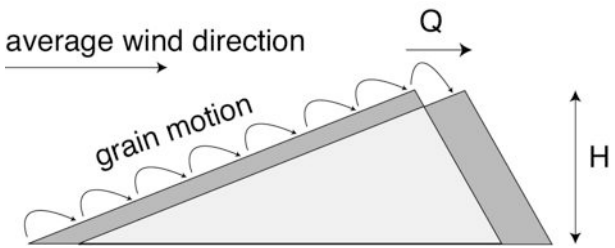
$$C = Q/H$$



sans couplage

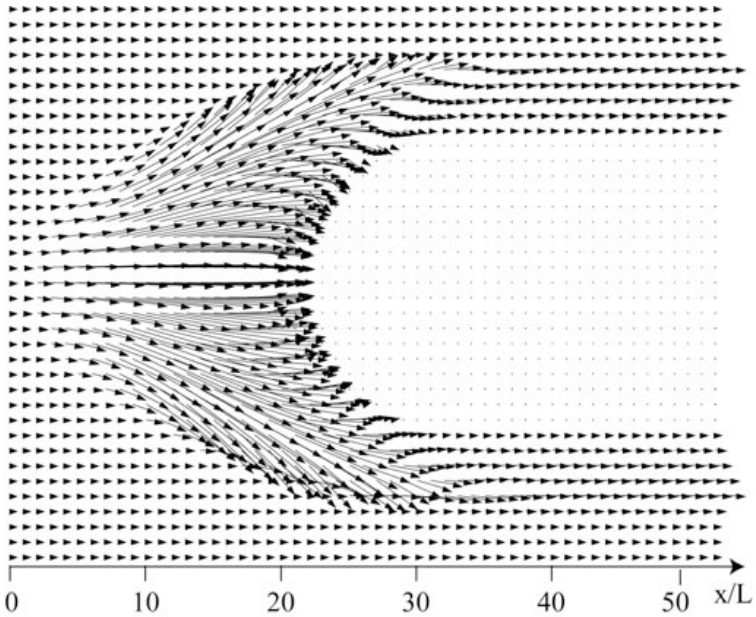
avec diffusion latérale

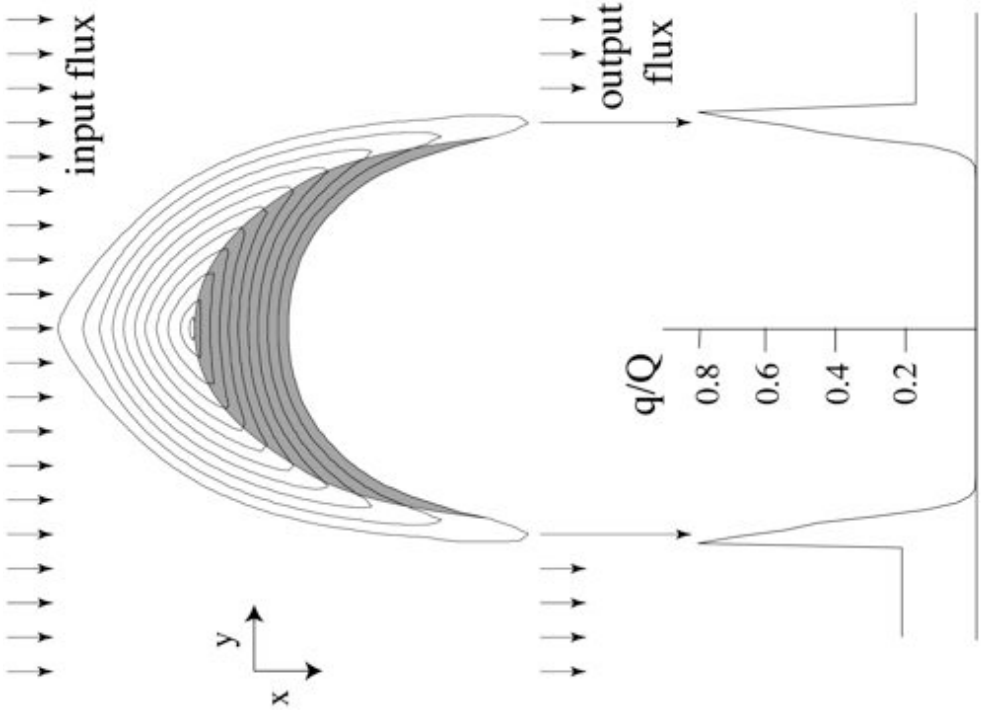




LH=QT

$C = Q/H$

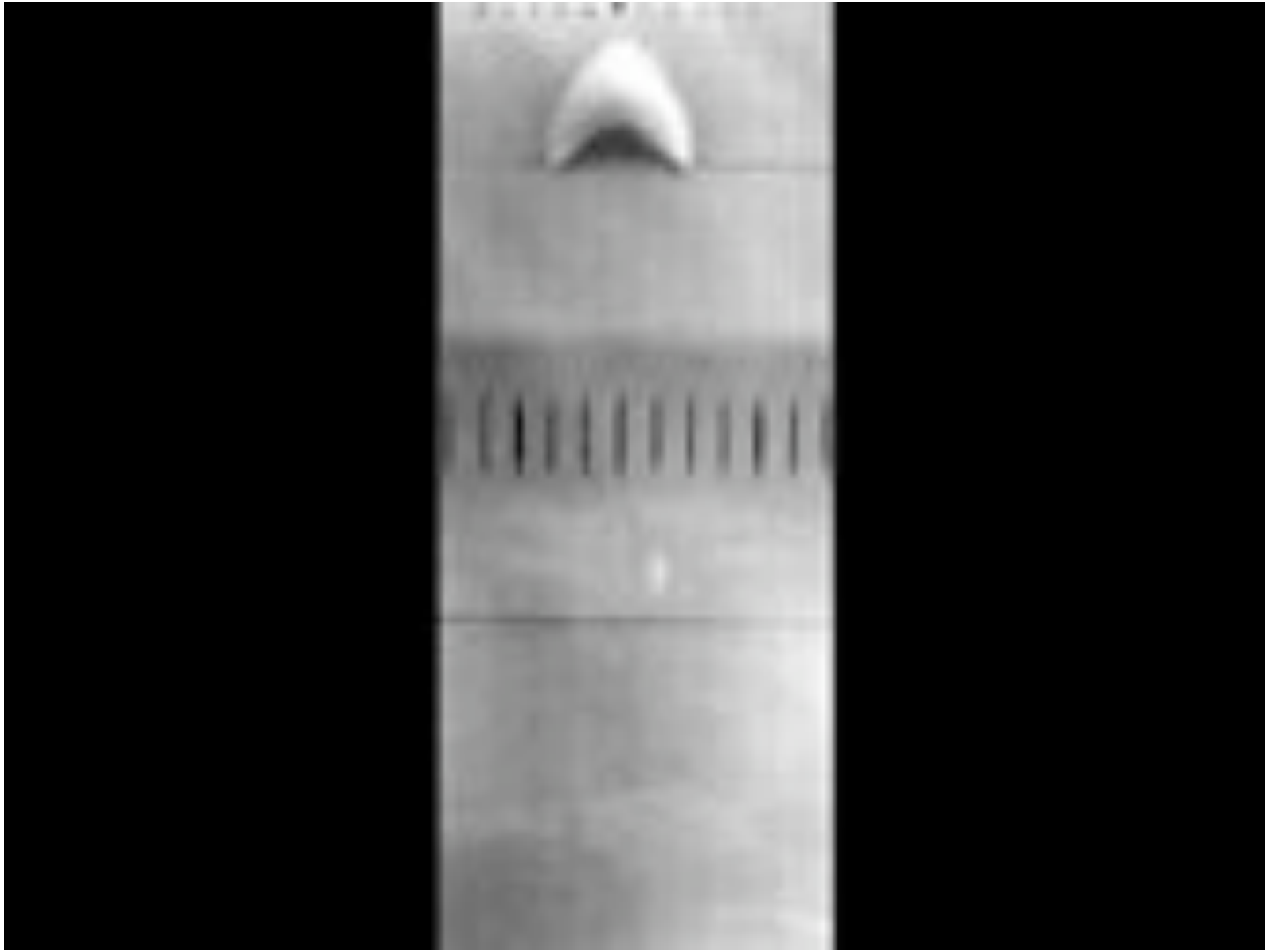




Flux de sable

Intéraction = Mécanisme de stabilisation

(raisonement virtuel, avec « force de rappel »)



The mechanisms of interaction within the shape
induce and constrain the shape itself

Self-regulation of the shape
Also essential for shape maintenance

Where the regulation comes from ?