C8545 Developmental Biology

Lesson 8

Postembryonic Plant Development

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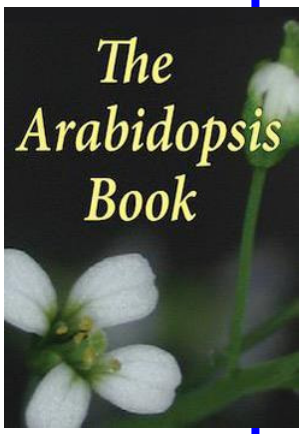
Literature



- **Fred H. Wilt and Sarah Hake, Principles of Developmental Biology** (W.W. Norton & Company, New York, London, 2004)
- **Capron A, Chatfield S, Provart N, Berleth T 2009**. Embryogenesis: Pattern Formation from a Single Cell. *The Arabidopsis Book*. Rockville, MD: American Society of Plant Biologists, doi: 10.1199/tab.0126, http://www.aspb.org/publications/arabidopsis/.
- Essau, K., 1965, Plant Anatomy, 2nd edition, Willey, 978-0471244554
- Selected original papers in scientific journals

Outline of Lesson 8

Postembryonic Plant Development

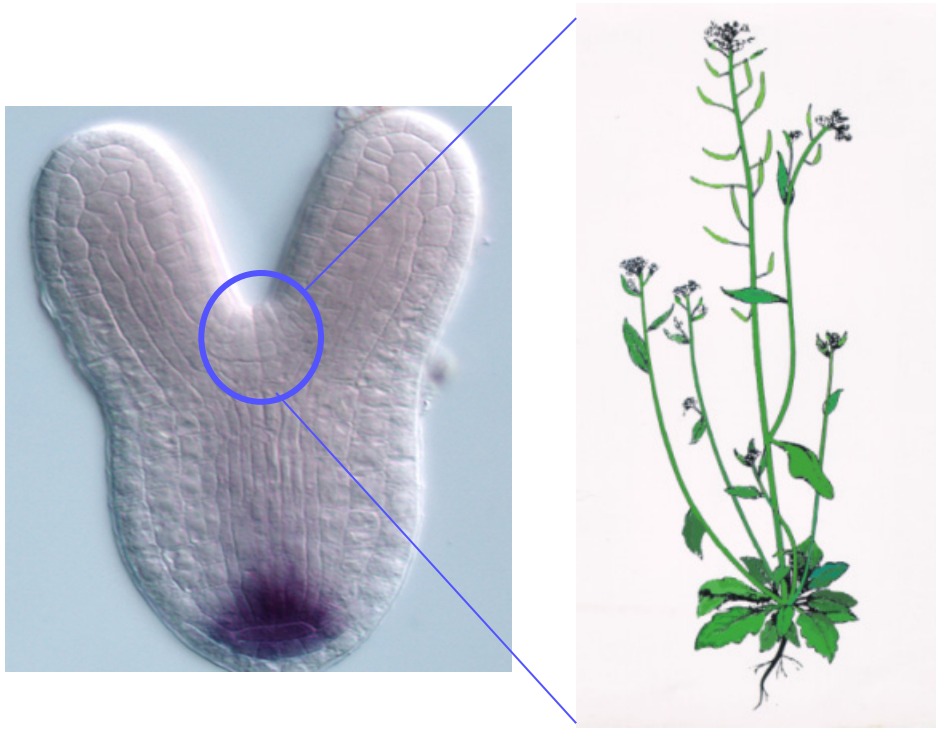
- The role of plant meristems in the plant postembryonic development
- Shoot apical meristem (SAM)
  - Structure of the SAM
  - SAM establishment and maintenance
- Phyllotaxy
  - Fibonacci series and golden mean in the nature
  - Molecular determinants of phyllotaxy
- Root apical meristem (RAM)
  - RAM structure
  - Positioning of RAM organization centre
  - Radial root patterning
  - RAM size determination
- Lateral root formation
- Vascular tissue formation in shoot and root

Outline of Lesson 8

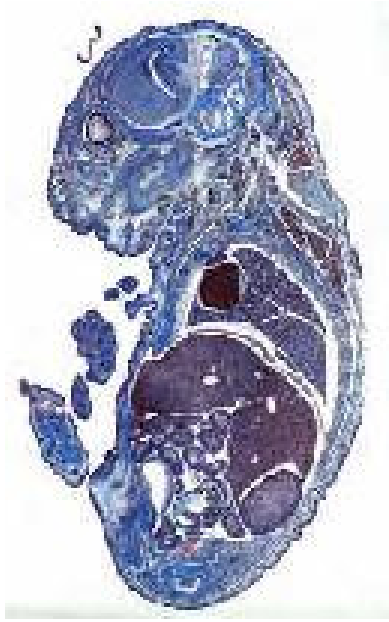
Postembryonic Plant Development

- The role of plant meristems in the plant postembryonic development

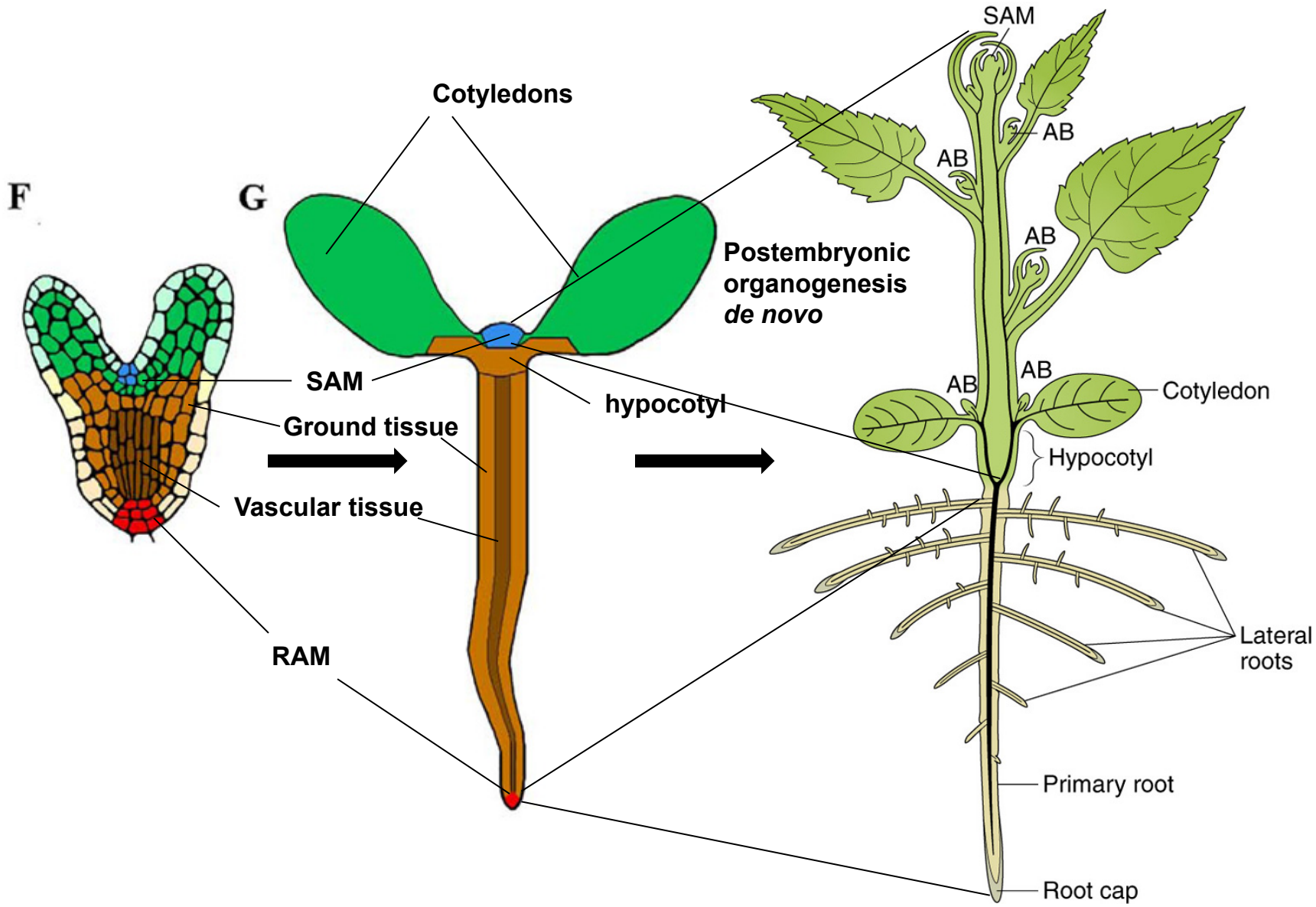
What is the principal difference between plants and animals?



Arabidopsis thaliana, embryo at the torpedo stage



Mus musculus, embryo, longitudinal section


F
G
Cotyledons
SAM
Ground tissue
Vascular tissue
RAM
hypocotyl
Postembryonic
organogenesis
de novo
SAM
AB
AB
AB
AB
AB
Cotyledon
Hypocotyl
Lateral
roots
Primary root
Root cap

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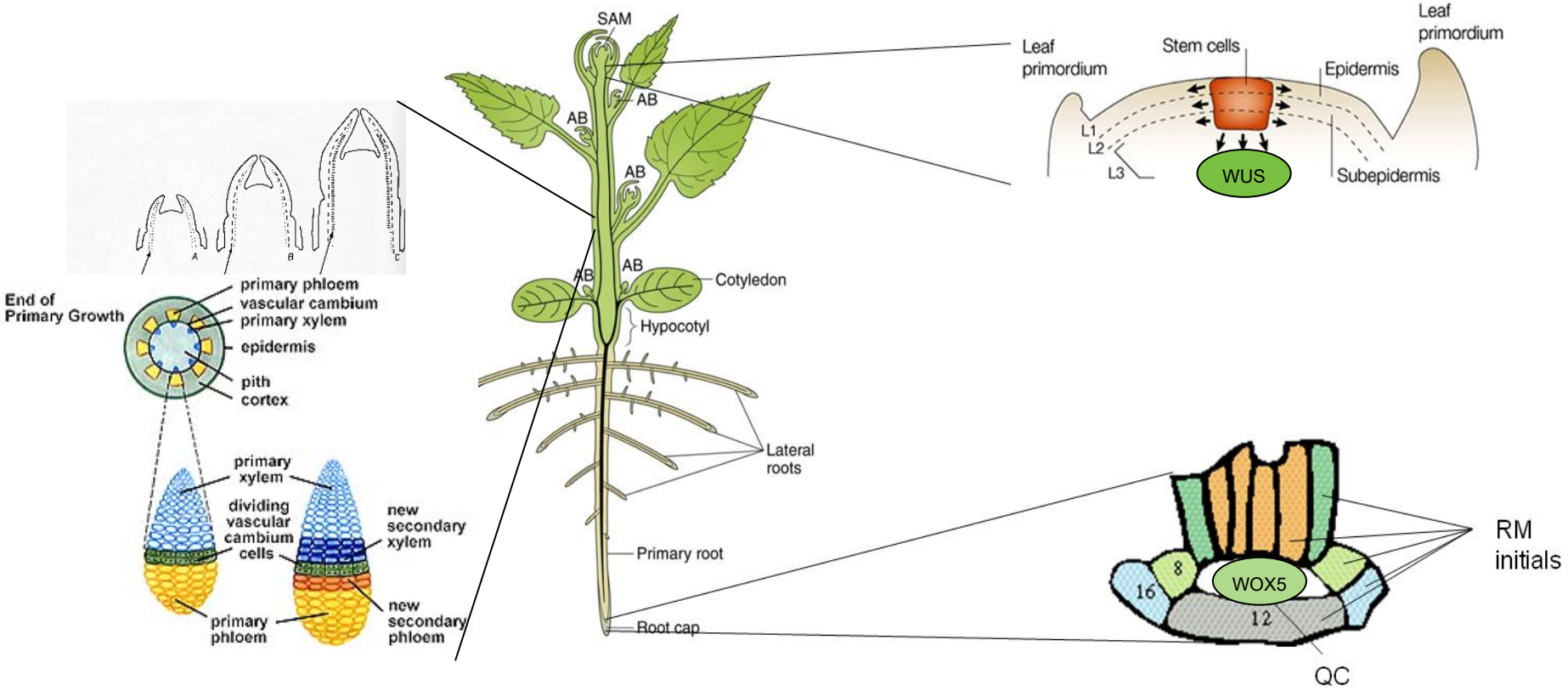

Division↔Differentiation

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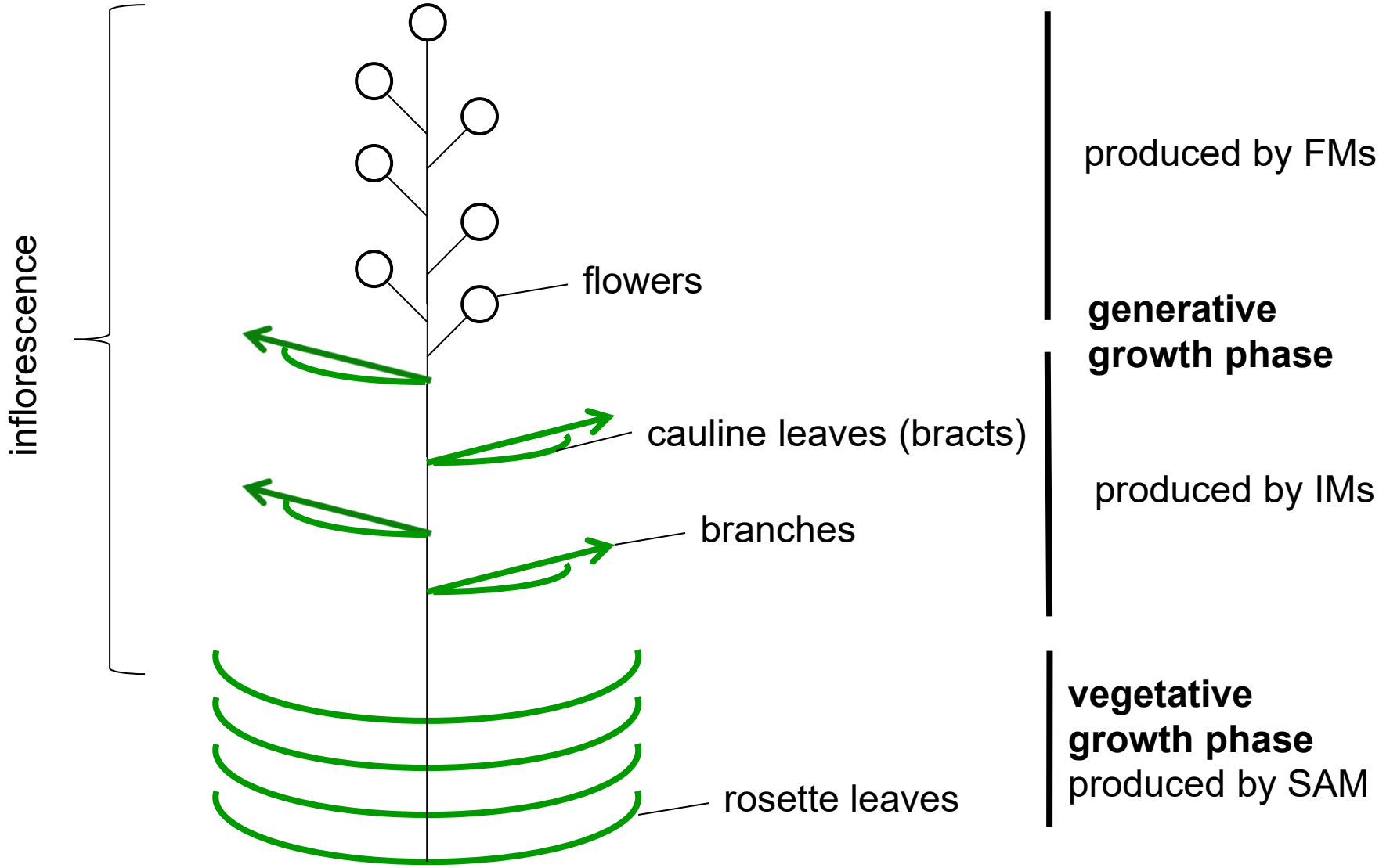
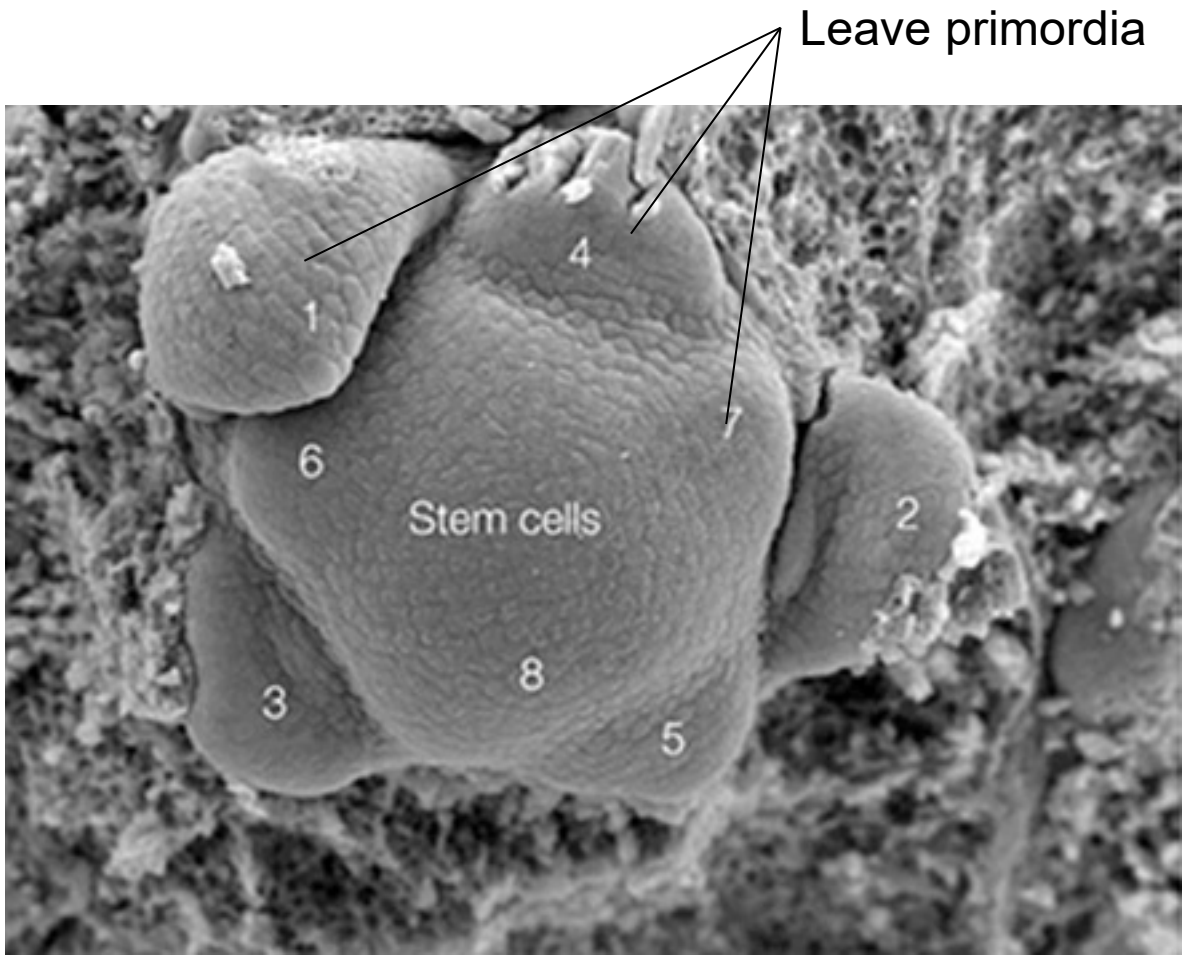
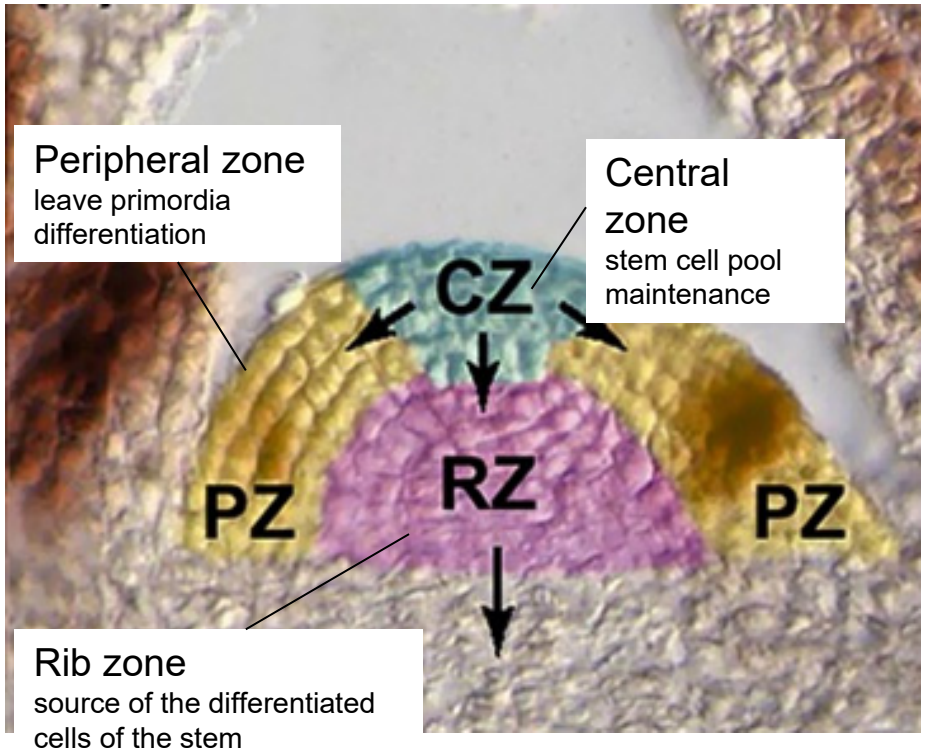
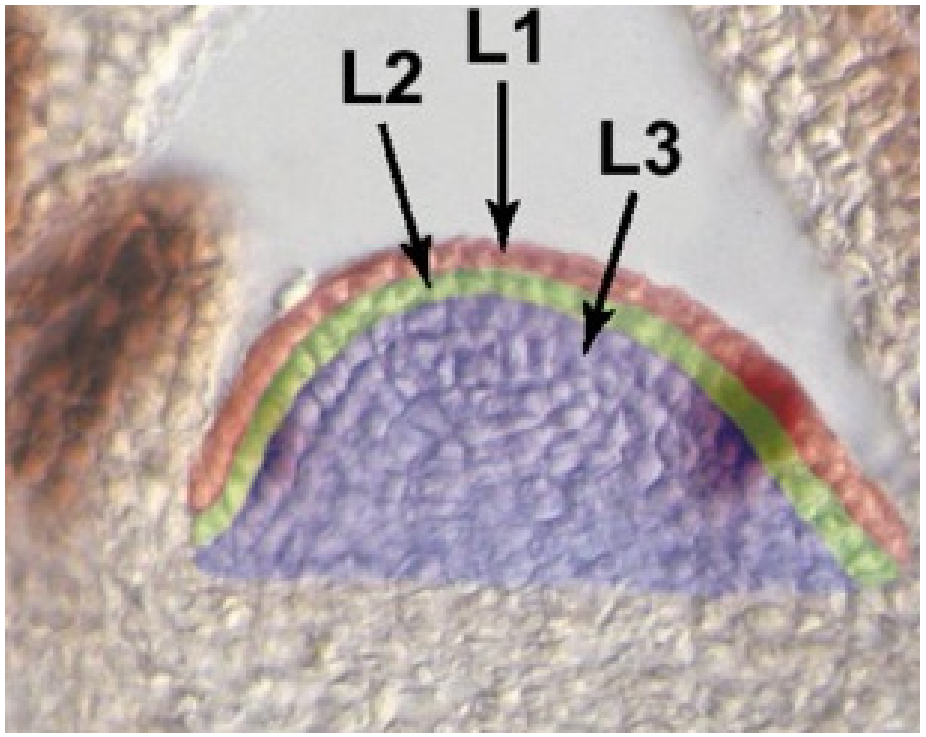
  - Structure of the SAM

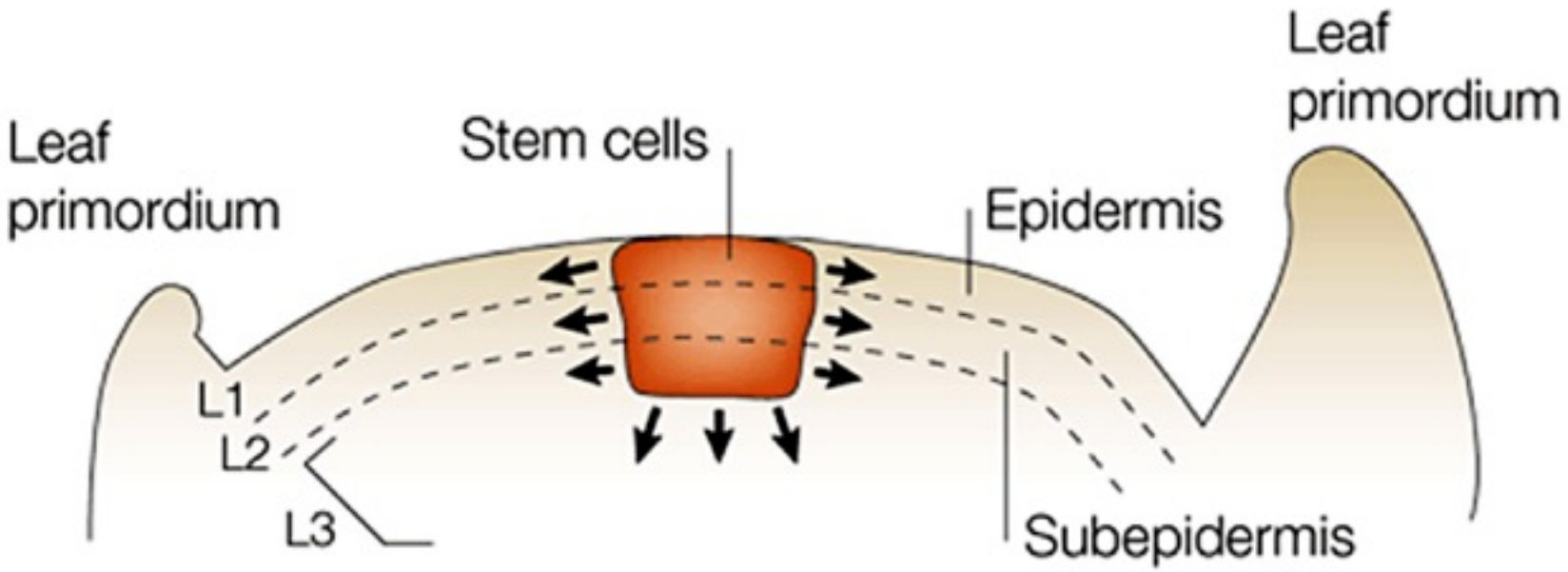

inflorescence
flowers
cauline leaves (bracts)
branches
rosette leaves
produced by FMs
generative growth phase
produced by IMs
vegetative growth phase
produced by SAM

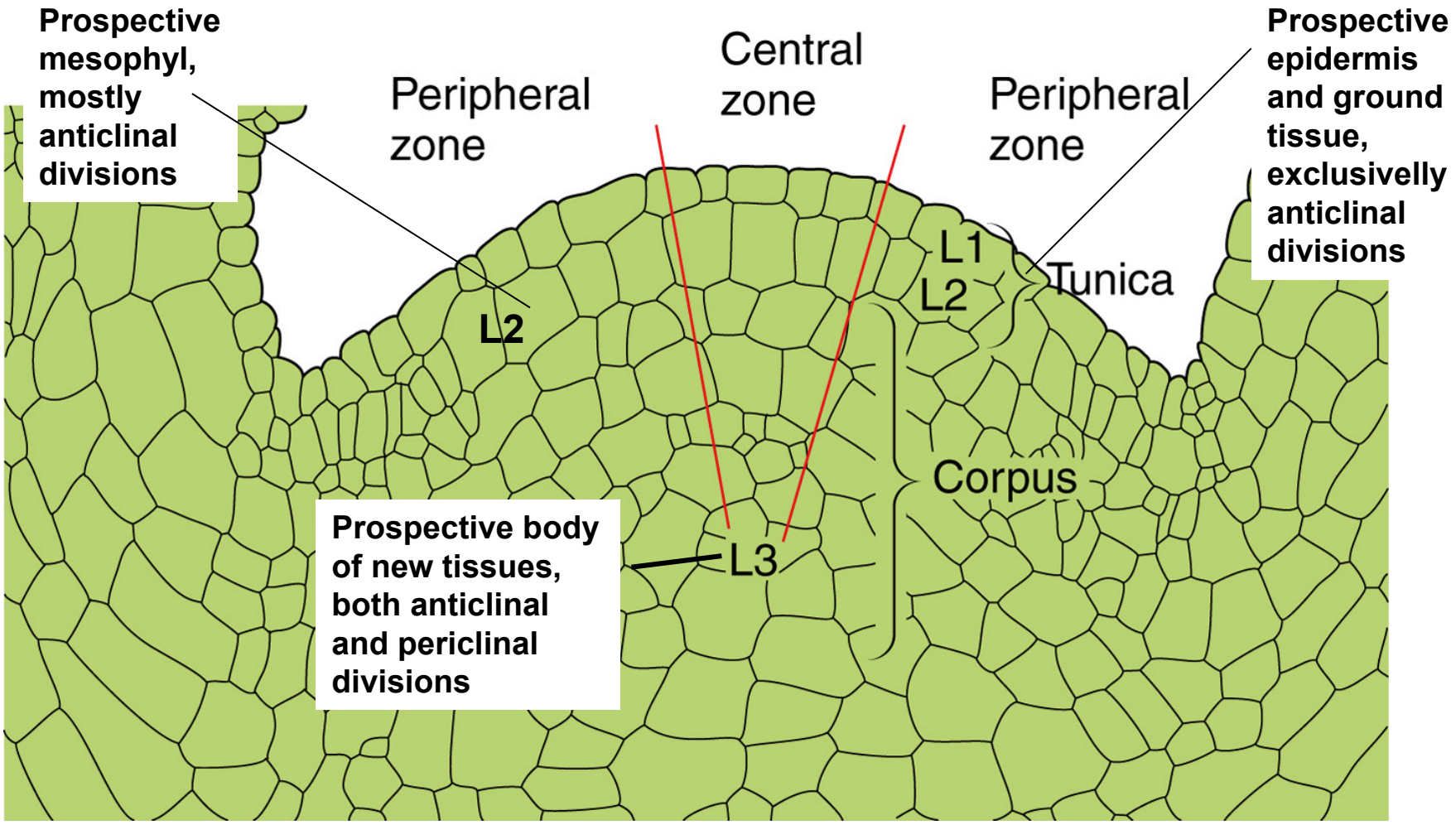

Leave primordia
1
4
7
6
Stem cells
2
8
3
5





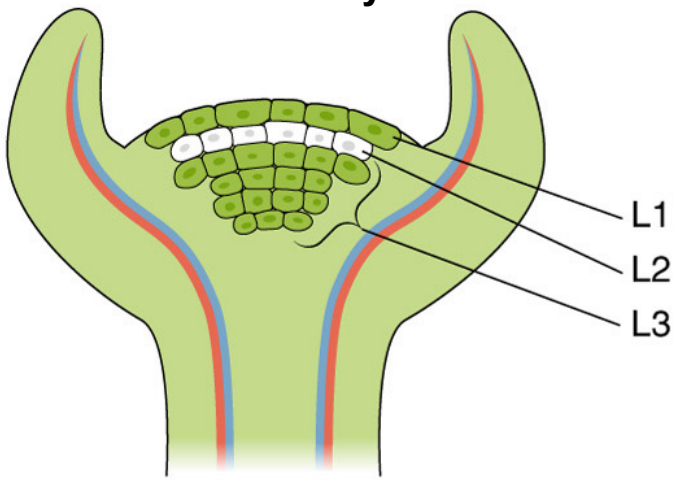
Bowman and Eshed, *Trends Plant Sci* (2000)


Leaf
primordium
Stem cells
Epidermis
Leaf
primordium
L1
L2
L3
Subepidermis

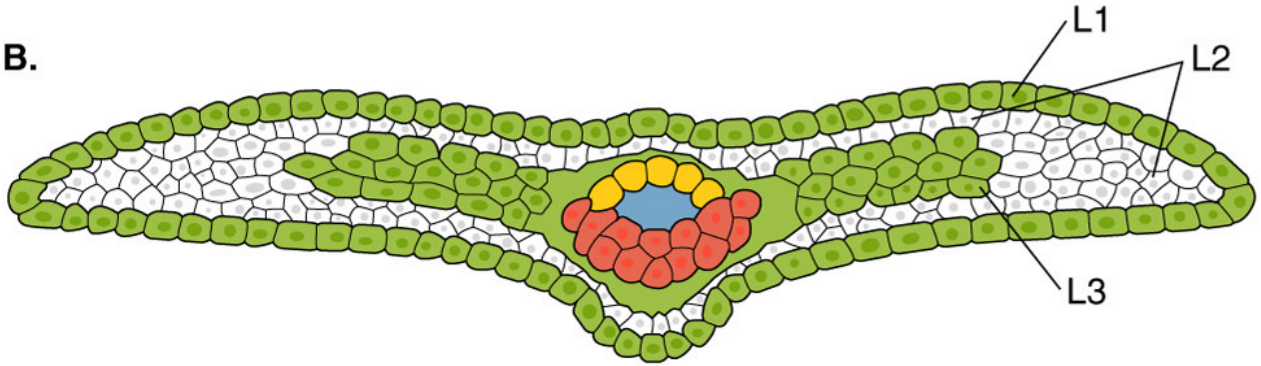

Prospective mesophyl, mostly anticlinal divisions
Peripheral zone
Central zone
Peripheral zone
Prospective epidermis and ground tissue, exclusivelly anticlinal divisions
L1
L2
Tunica
L2
Corpus
Prospective body of new tissues, both anticlinal and periclinal divisions
L3

Chimera with albino L2 layer

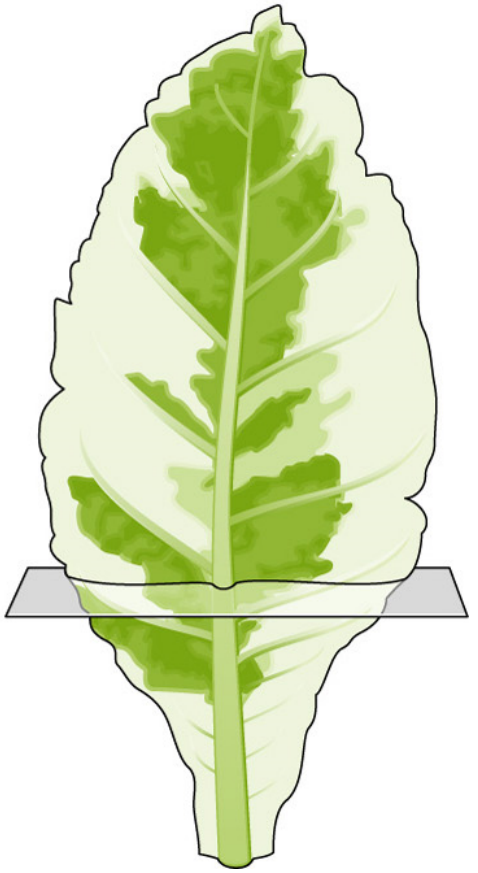
A.



B.



C.



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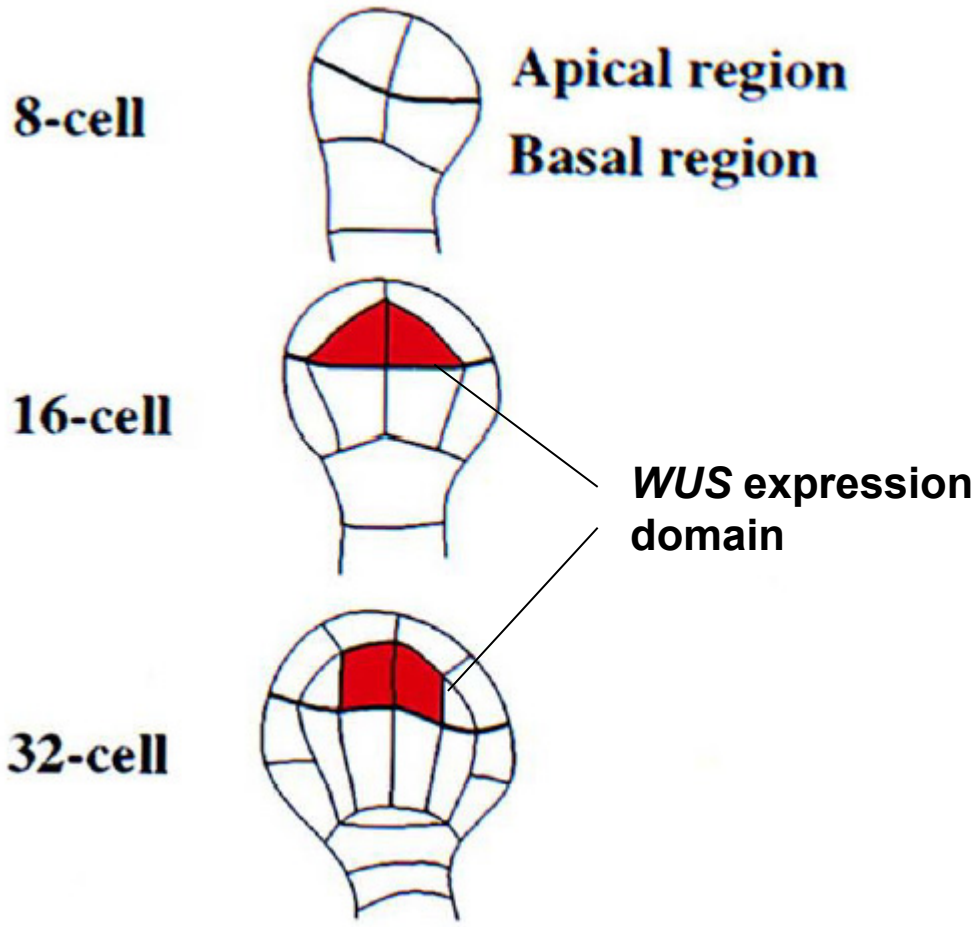
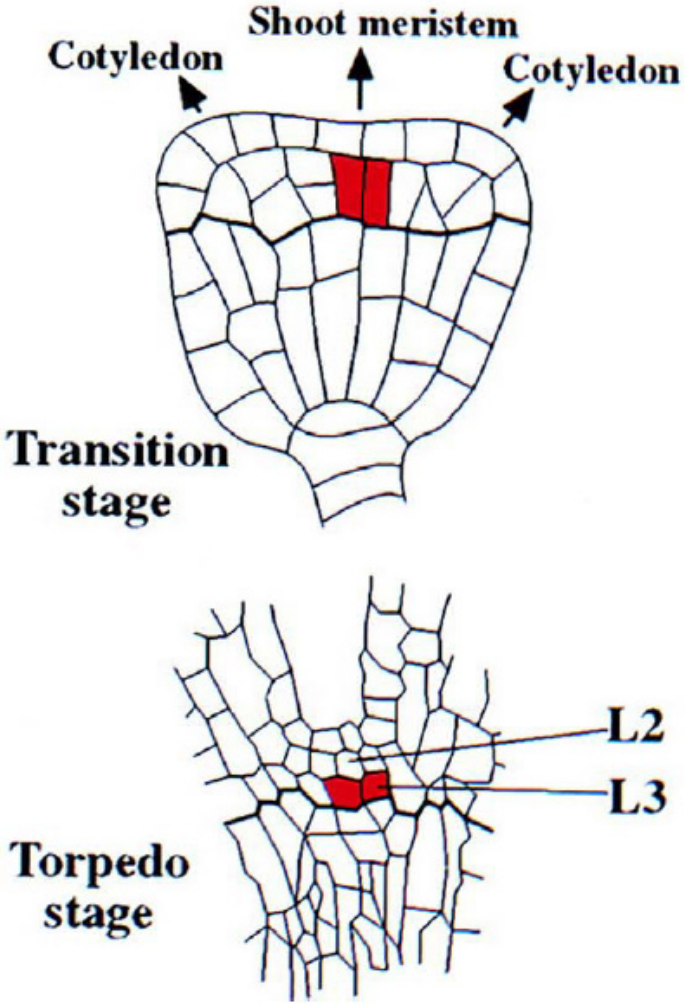
- The role of plant meristems in the plant postembryonic development
- Shoot apical meristem (SAM)
  - Structure of the SAM
  - SAM establishment and maintenance

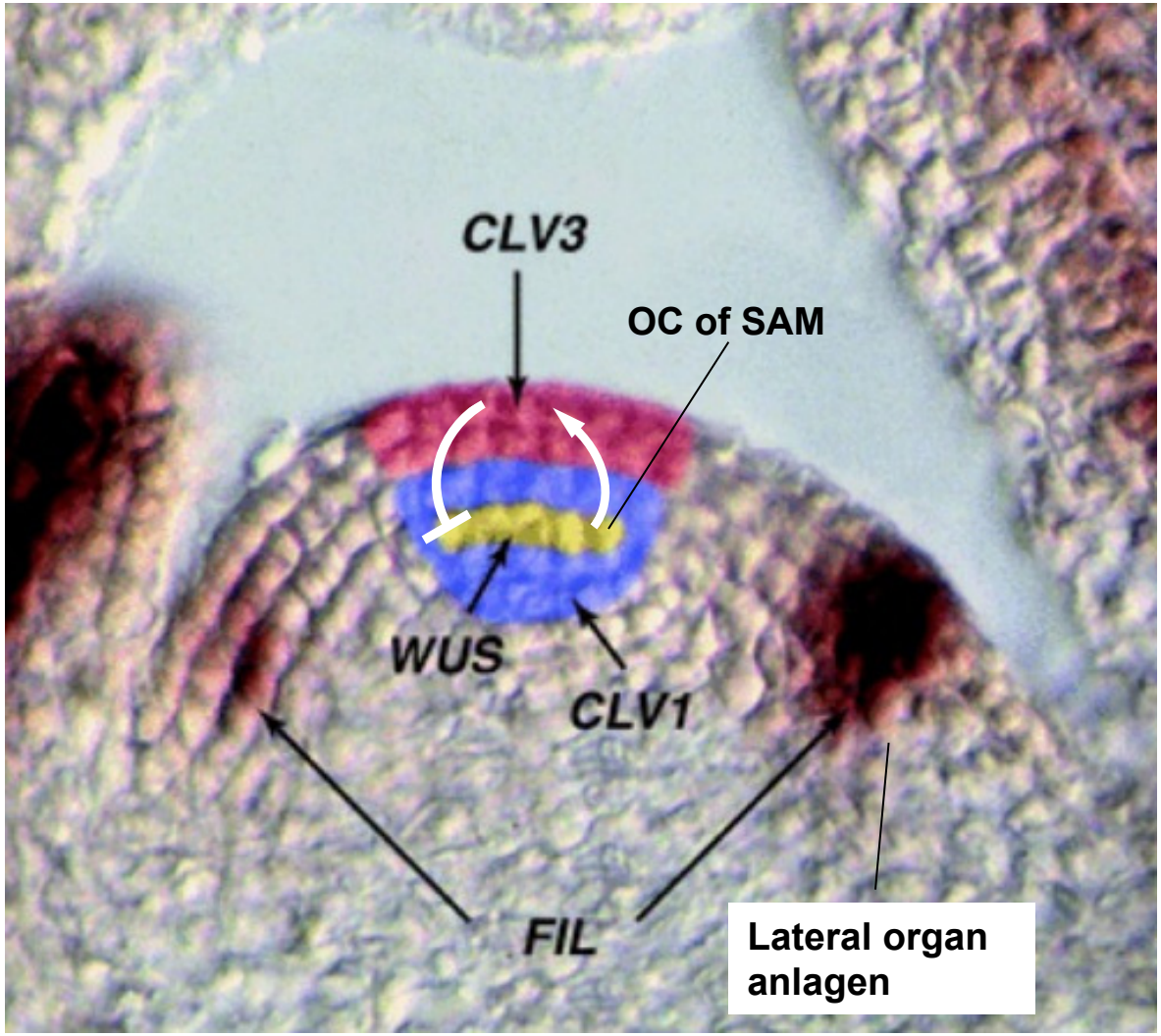
SAM specification



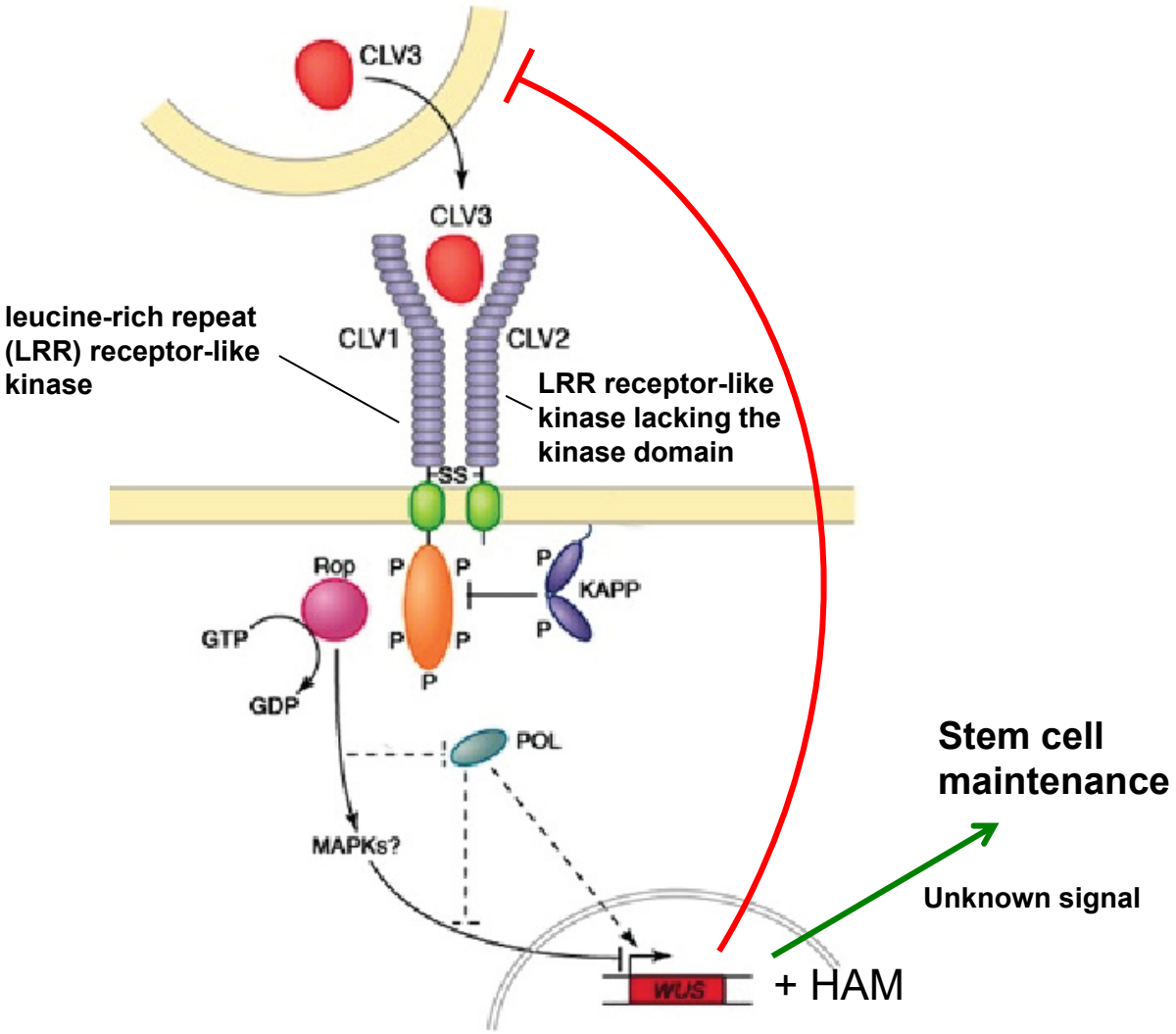
Capron et al., *Arabidopsis Book* (2009)



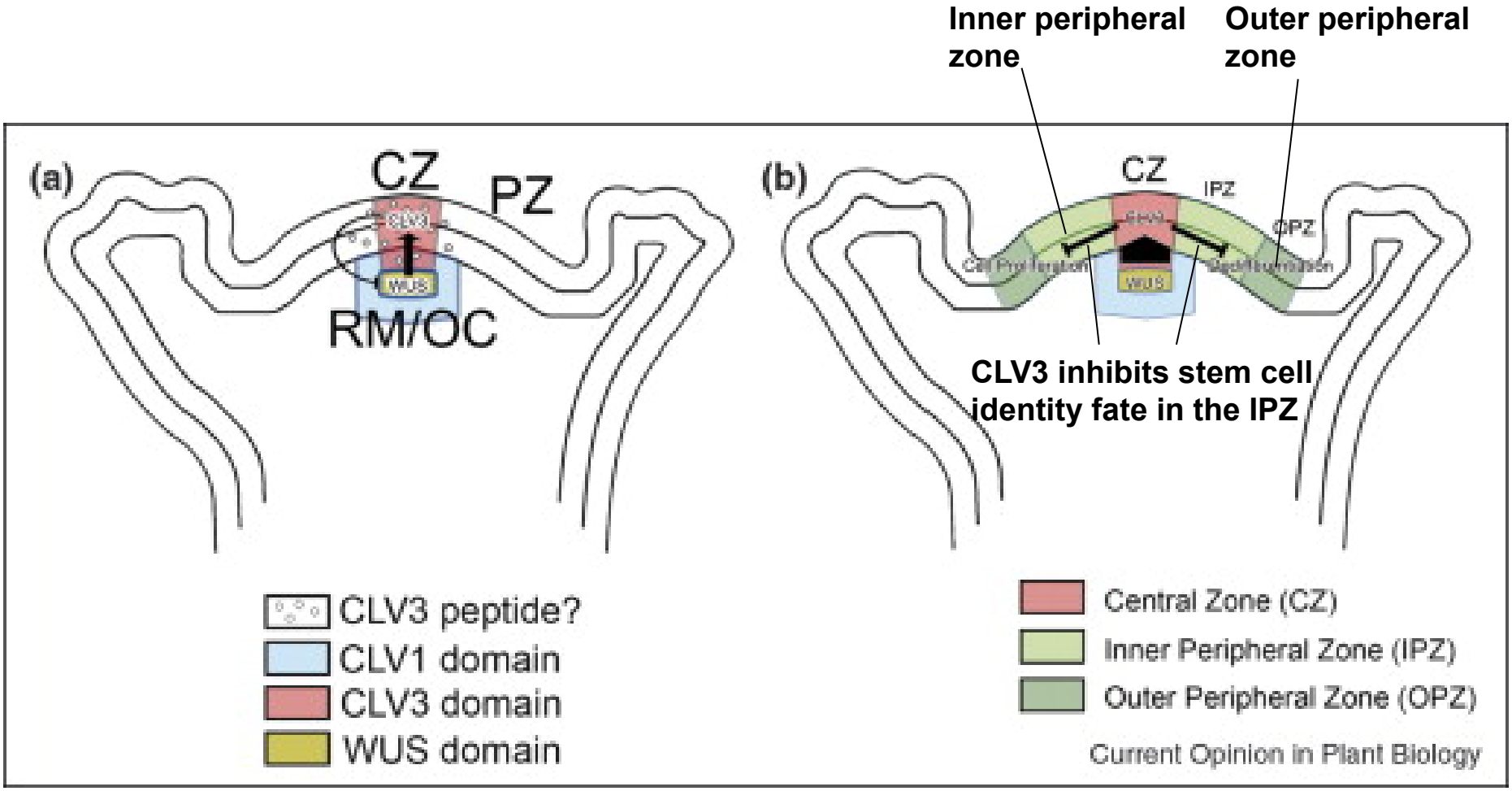
Capron et al., *Arabidopsis Book* (2009)



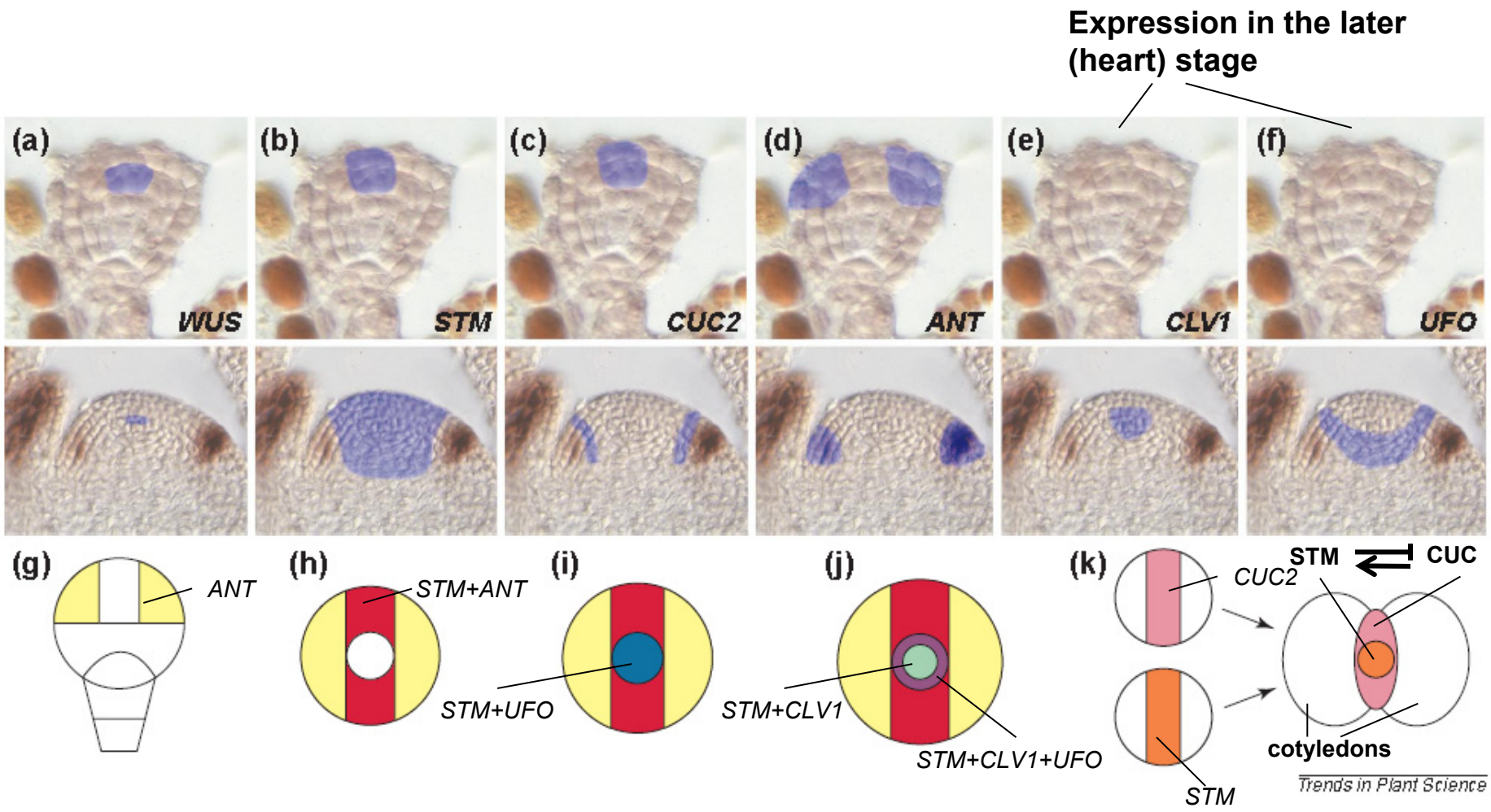
Bowman and Eshed, *Trends Plant Sci* (2000)



Carles et al., *Trends Plant Sci* (2003)



Reddy, *Current Opinion Plant Biol* (2000)



Bowman and Eshed, *Trends Plant Sci* (2000)

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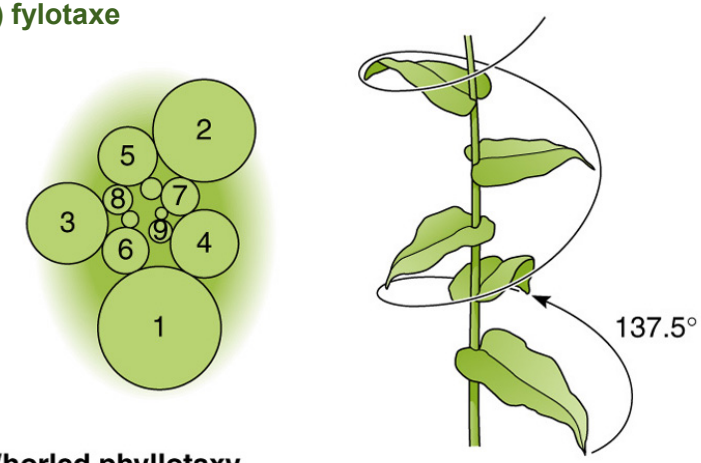
- Phyllotaxy
  - Fibonacci series and golden mean in the nature

A. Spiral phyllotaxy

Spirální (vřetenovitá) fylotaxe



B. Whorled phyllotaxy

Přeslenitá (kruhová) fylotaxe

distichous
distichie 1 leaf

decussate
dvojčetný přeslen 2 leaves

tricussate
trojčetný přeslen 3 leaves

<code>i	ai	abs err	Pi		Qi		Pi/Qi
0	1	6.2E-01	1	/	1	=	1.000000000000000
1	1	-3.8E-01	2	/	1	=	2.000000000000000
2	1	1.2E-01	3	/	2	=	1.500000000000000
3	1	-4.9E-02	5	/	3	=	1.666666666666667
4	1	1.8E-02	8	/	5	=	1.600000000000000
5	1	-7.0E-03	13	/	8	=	1.625000000000000
6	1	2.6E-03	21	/	13	=	1.615384615384615
7	1	-1.0E-03	34	/	21	=	1.619047619047619
8	1	3.9E-04	55	/	34	=	1.617647058823529
9	1	-1.5E-04	89	/	55	=	1.618181818181818
10	1	5.6E-05	144	/	89	=	1.617977528089888
11	1	-2.2E-05	233	/	144	=	1.618055555555556
12	1	8.2E-06	377	/	233	=	1.618025751072961
13	1	-3.1E-06	610	/	377	=	1.618037135278515
14	1	1.2E-06	987	/	610	=	1.618032786885246
15	1	-4.6E-07	1597	/	987	=	1.618034447821682
16	1	1.8E-07	2584	/	1597	=	1.618033813400125
17	1	-6.7E-08	4181	/	2584	=	1.618034055727554
18	1	2.6E-08	6765	/	4181	=	1.618033963166706
19	1	-9.8E-09	10946	/	6765	=	1.618033998521803
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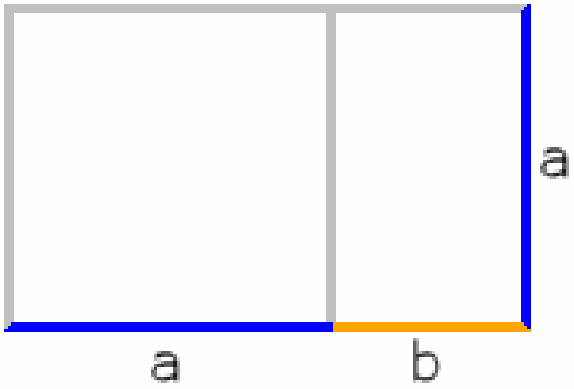
21	1	-1.4E-09	28657	/	17711	=	1.618033990175597
22	1	5.4E-10	46368	/	28657	=	1.618033988205325
23	1	-2.1E-10	75025	/	46368	=	1.618033988957902
24	1	7.9E-11	121393	/	75025	=	1.618033988670443
25	1	-3.0E-11	196418	/	121393	=	1.618033988780243
26	1	1.2E-11	317811	/	196418	=	1.18033988738303
27	1	-4.4E-12	514229	/	317811	=	1.618033988754322
28	1	1.7E-12	832040	/	514229	=	1.618033988748204
29	1	-6.5E-13	1346269	/	832040	=	1.618033988750541
30	1	2.5E-13	2178309	/	1346269	=	1.618033988749648

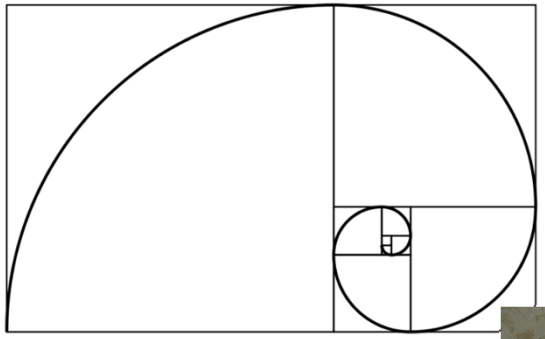
Leonardo Fibonacci (1180-1250)

Fibonacci series: 0, 1, 1, 2, 3, 5, 8, 13, 21…

$$\varphi = \frac{1+\sqrt{5}}{2} \approx 1{,}618\ 033\ 988\ 749\ 894\ 848\ \ldots$$

Wikipedia



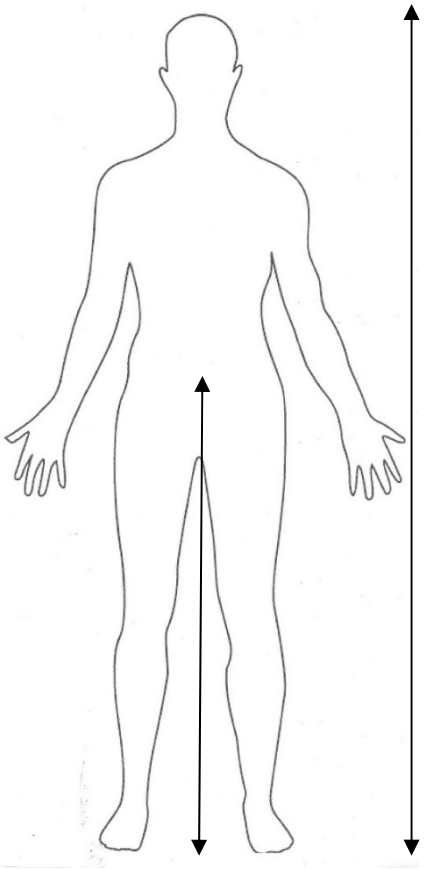


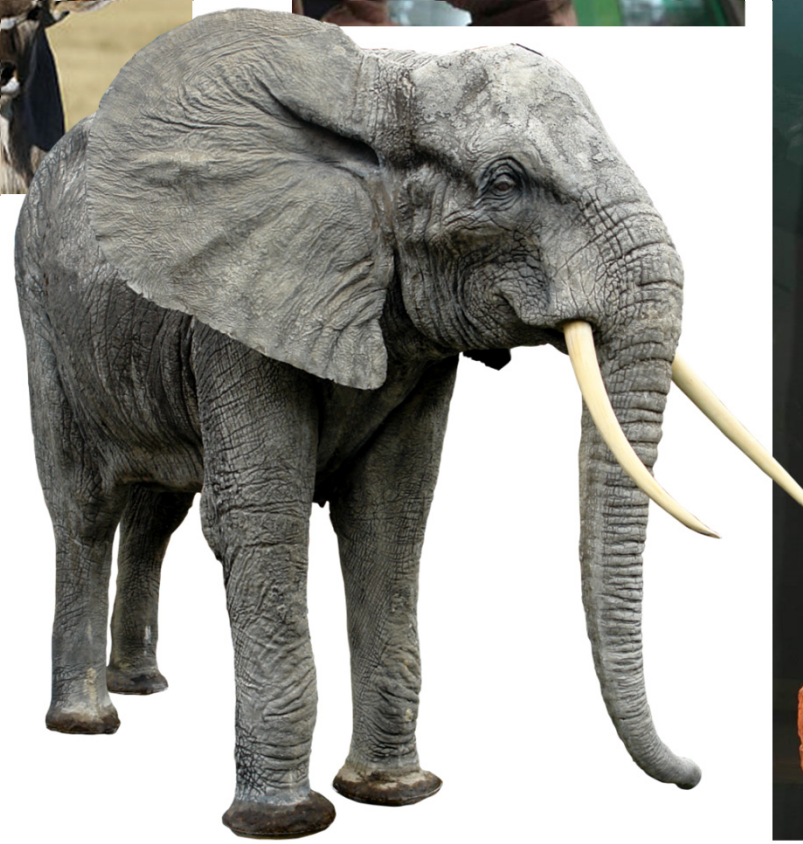
a + b / a = a/b = 1.618
“golden mean” or “divine ratio”
“zlatý řez“

1.618=Φ, according to “Fidios”, the creator of Pantheon

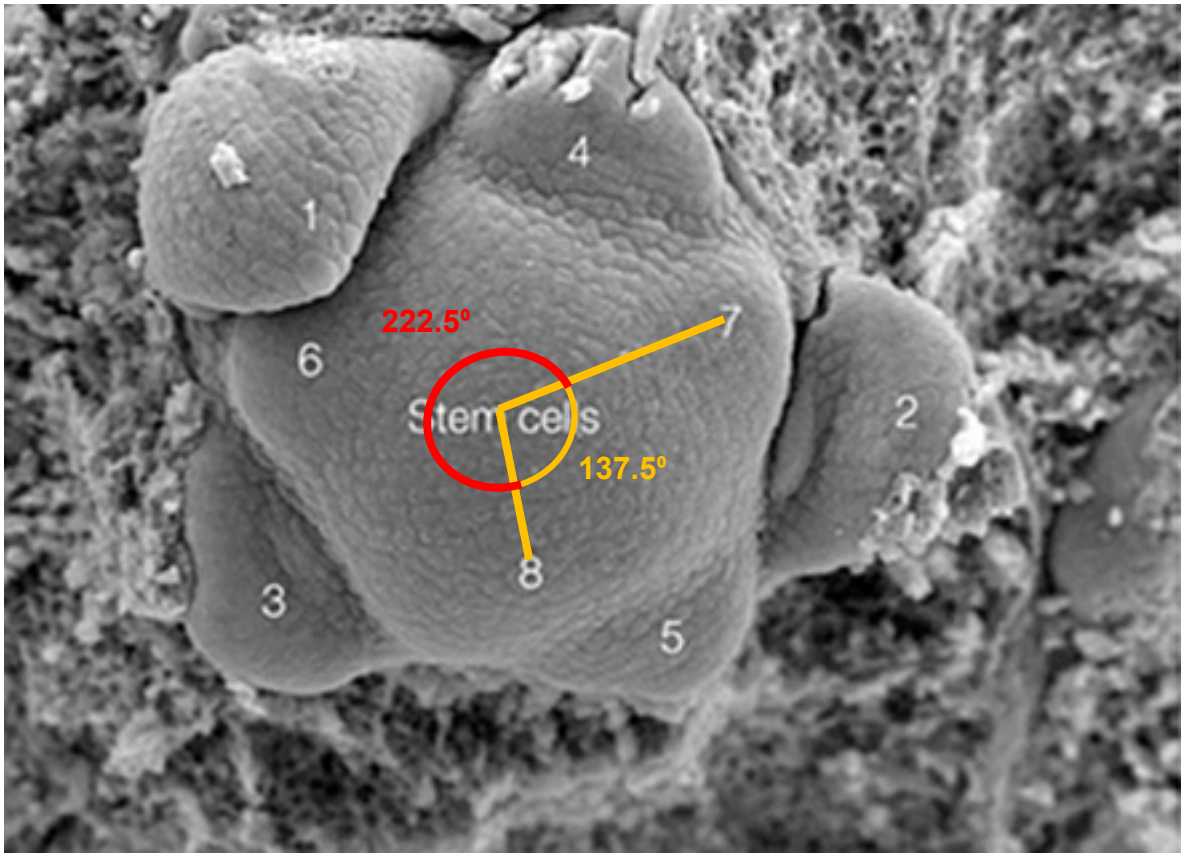
Fibonaci series – the beauty of math

TED lecture by Arthur Benjamin, https://youtu.be/SjSHVDfXHQ4)





Golden mean in nature
https://youtu.be/nt2OlMAJj6o



222.5/137.5 = 1.618

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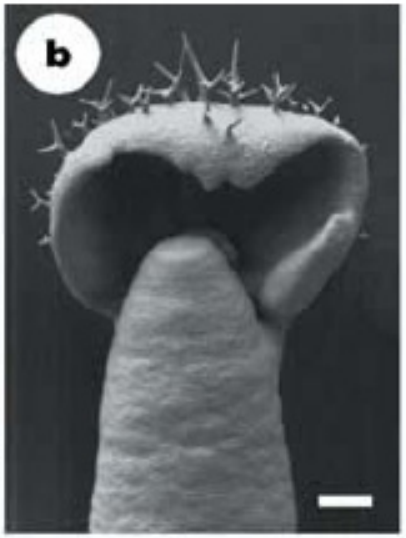
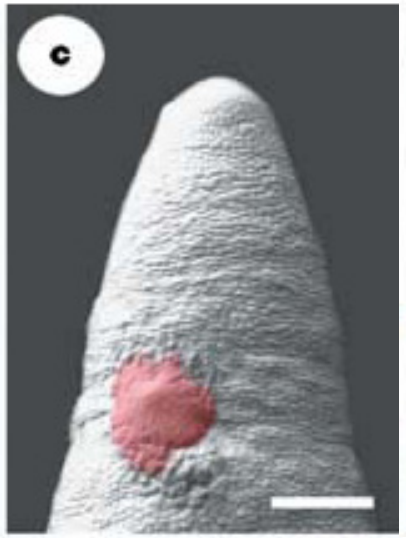
  - Fibonacci series and golden mean in the nature
  - Molecular determinants of phyllotaxy

pin1 + IAA (SAM)

pin1, lfy + IAA (IM)

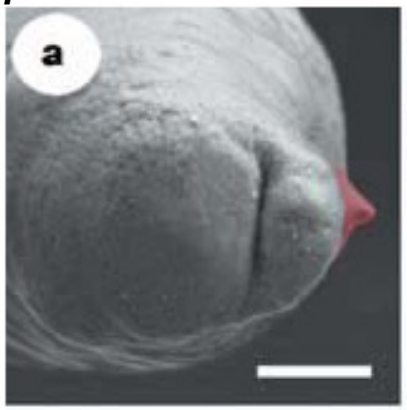


mp + IAA

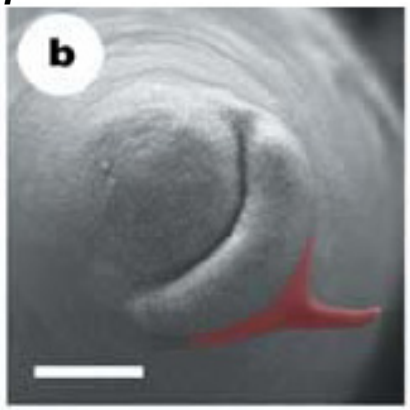


pid1 + IAA

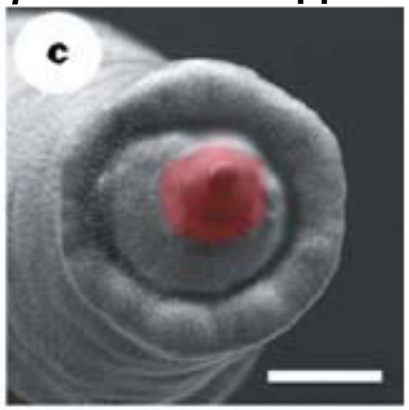
pin1 + IAA



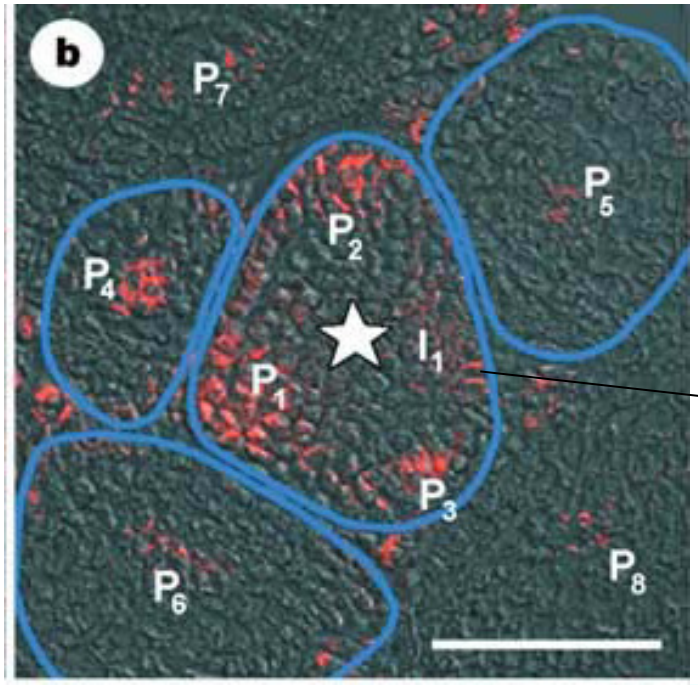
pin1 + more IAA



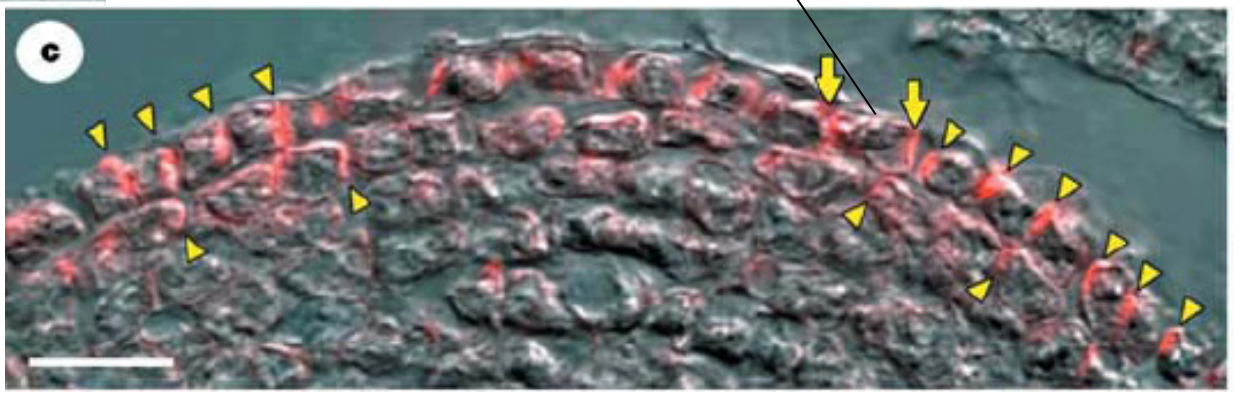
pin1 + central applied IAA



Reinhardt et al., *Nature* (2005)

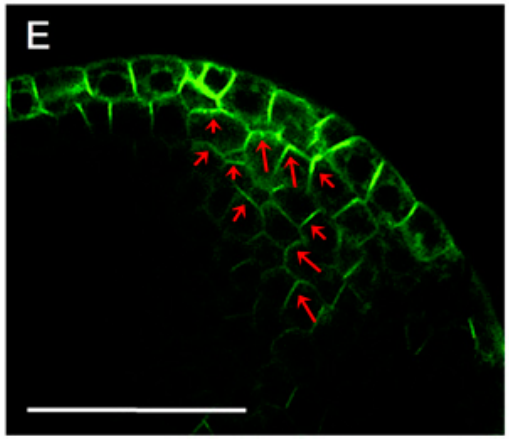


Position of incipient primordium



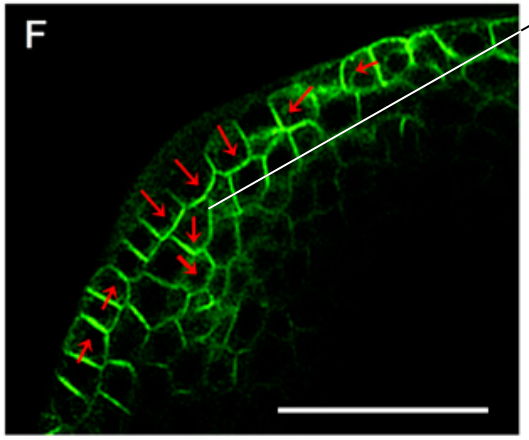
Reinhardt et al., *Nature* (2005)

10 h after IAA application



ProPIN1:PIN1-GFP

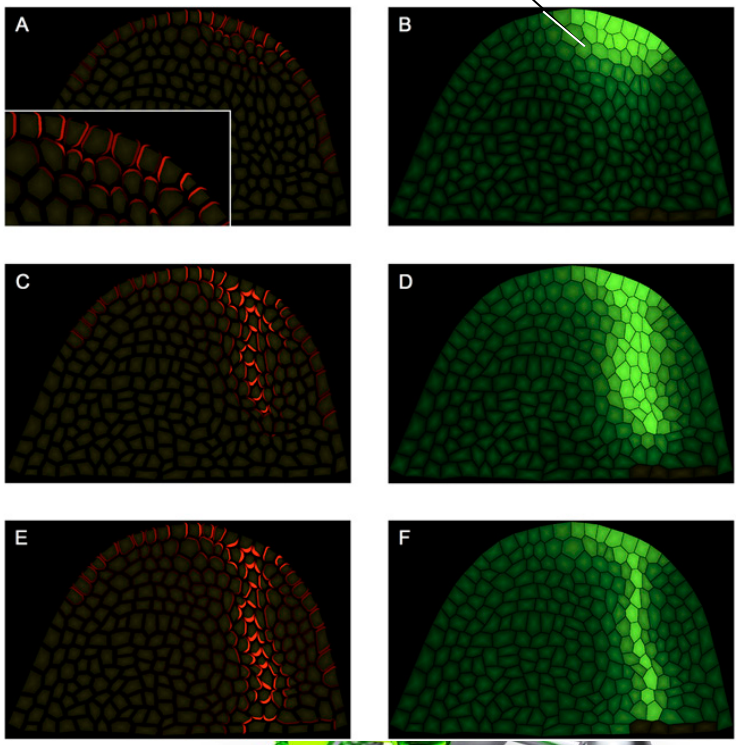
20 h after IAA application



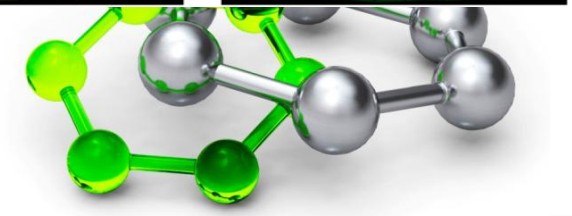
ProPIN1:PIN1-GFP

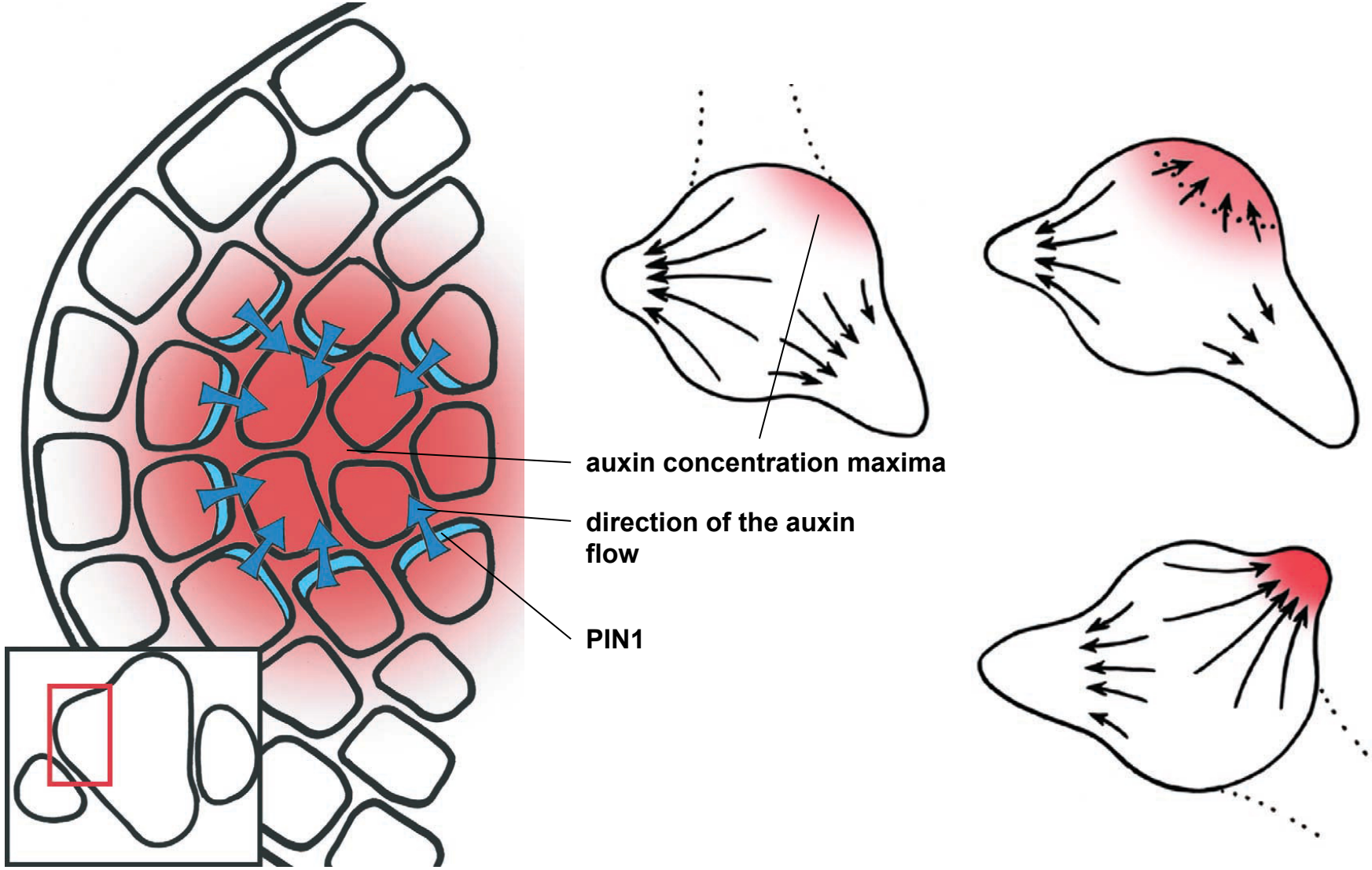
PIN1 relolalization

Auxin acummulation

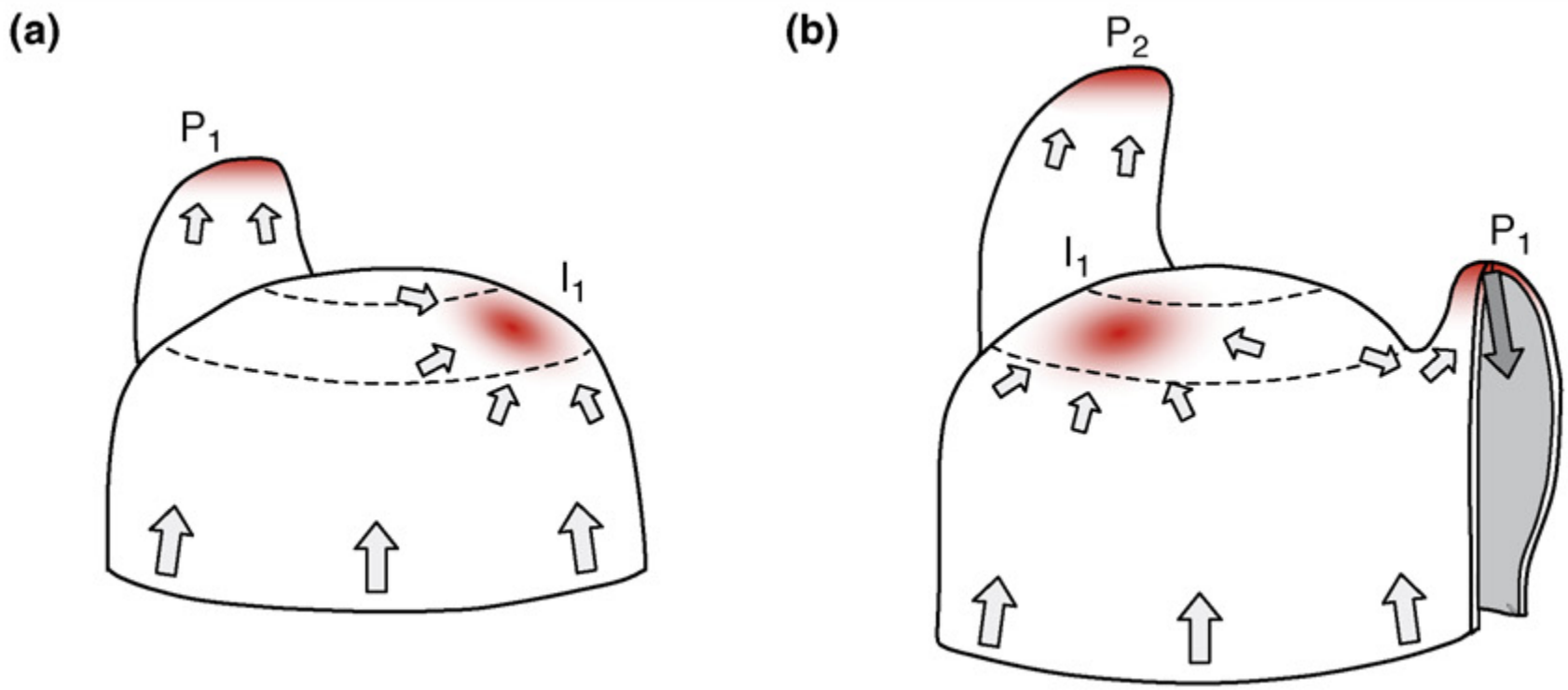


Bayer et al.,*Gene Dev* (2009)

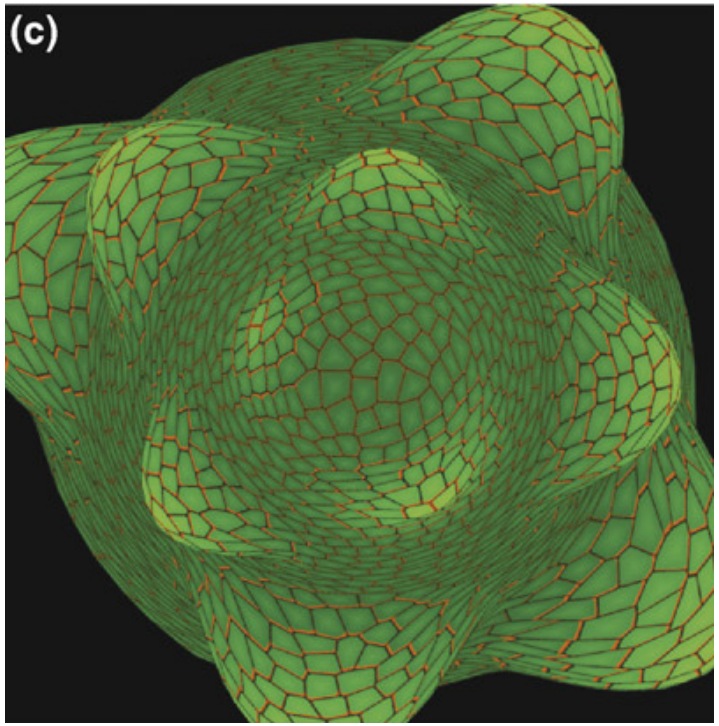


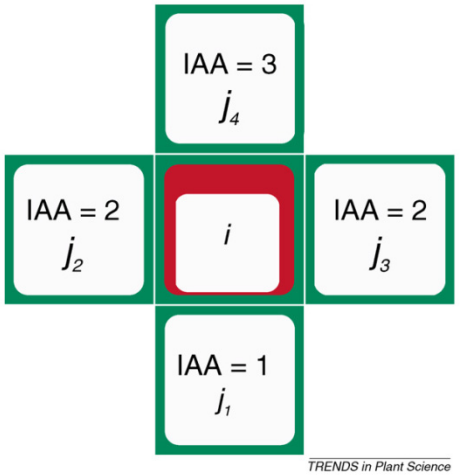


Reinhardt, *Current Opinion Plant Biol* (2005)

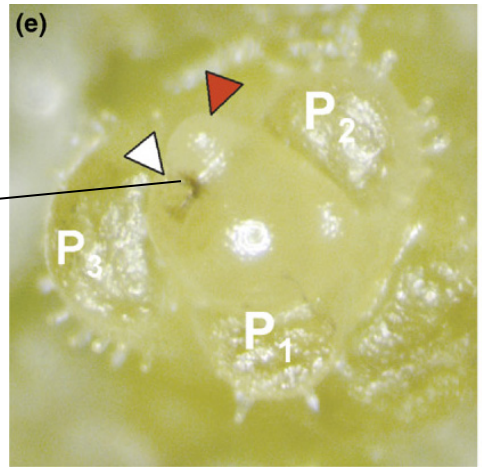


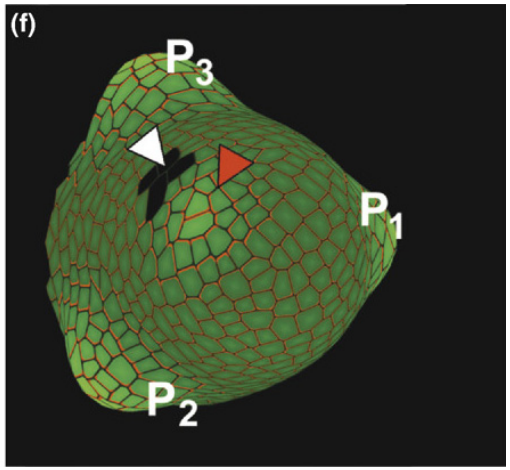
Kuhlermaier, *Trends Plant Sci* (2007)



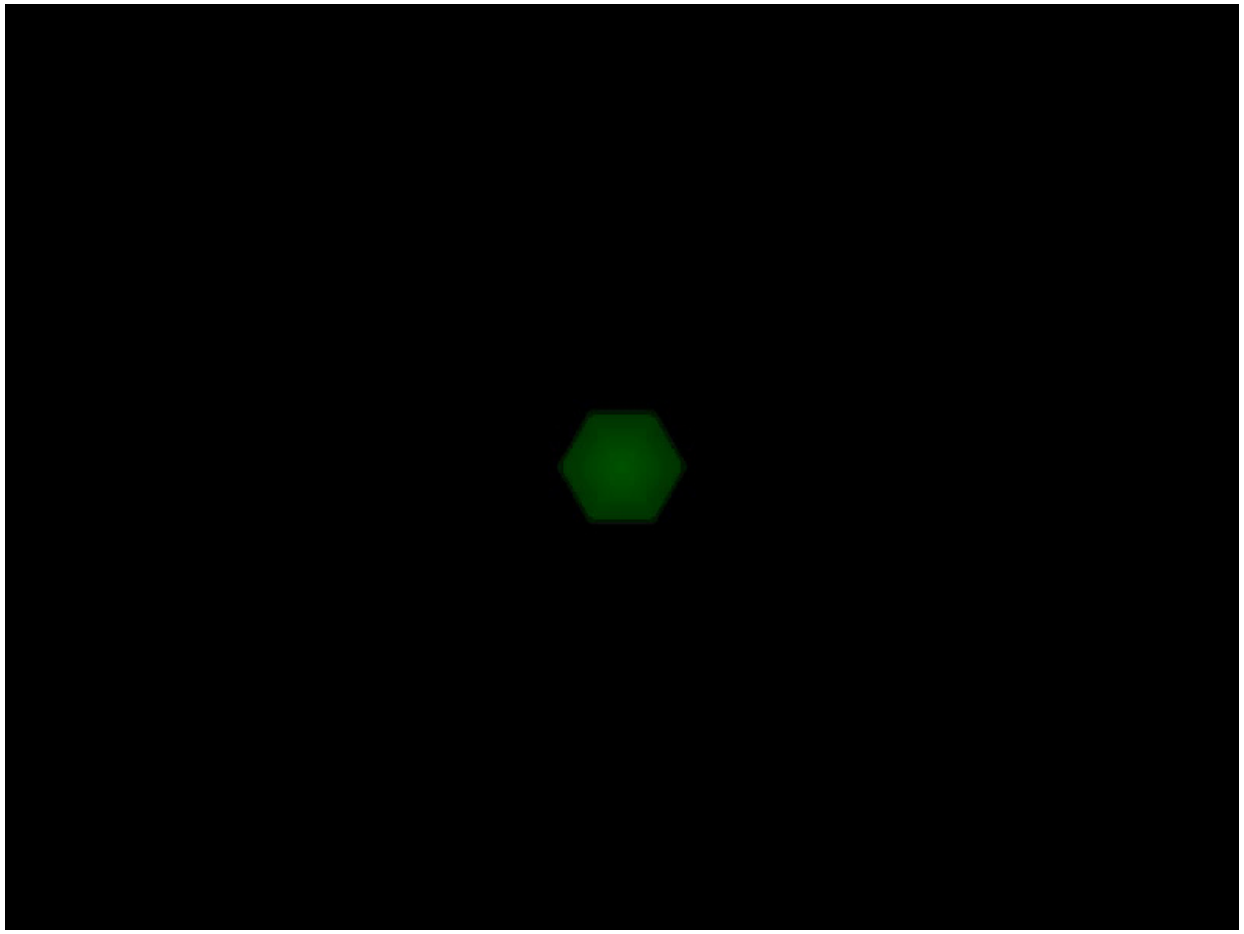


Laser ablation of incipient primordium

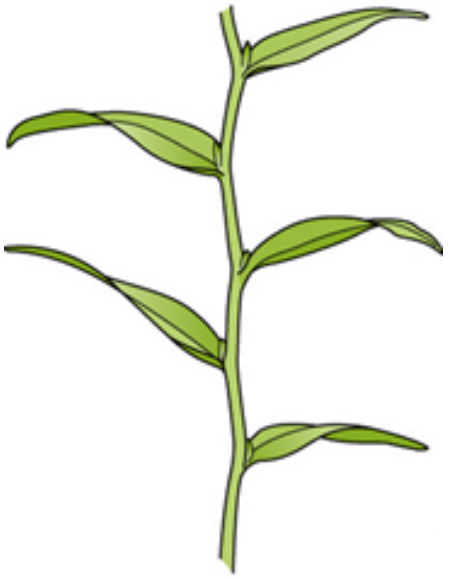




Kuhlermaier, *Trends Plant Sci* (2007)



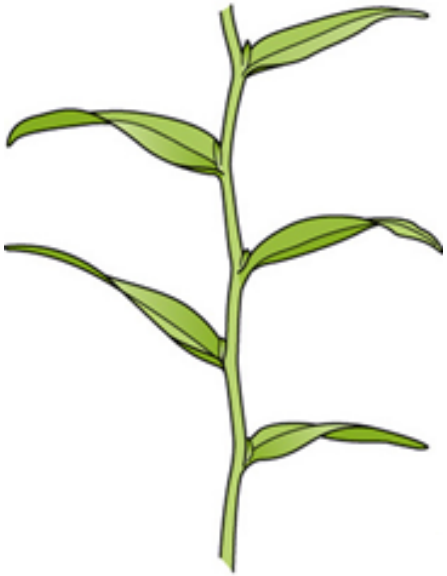
Distichous
Distichie



1 leaf

Distichous
Distichie

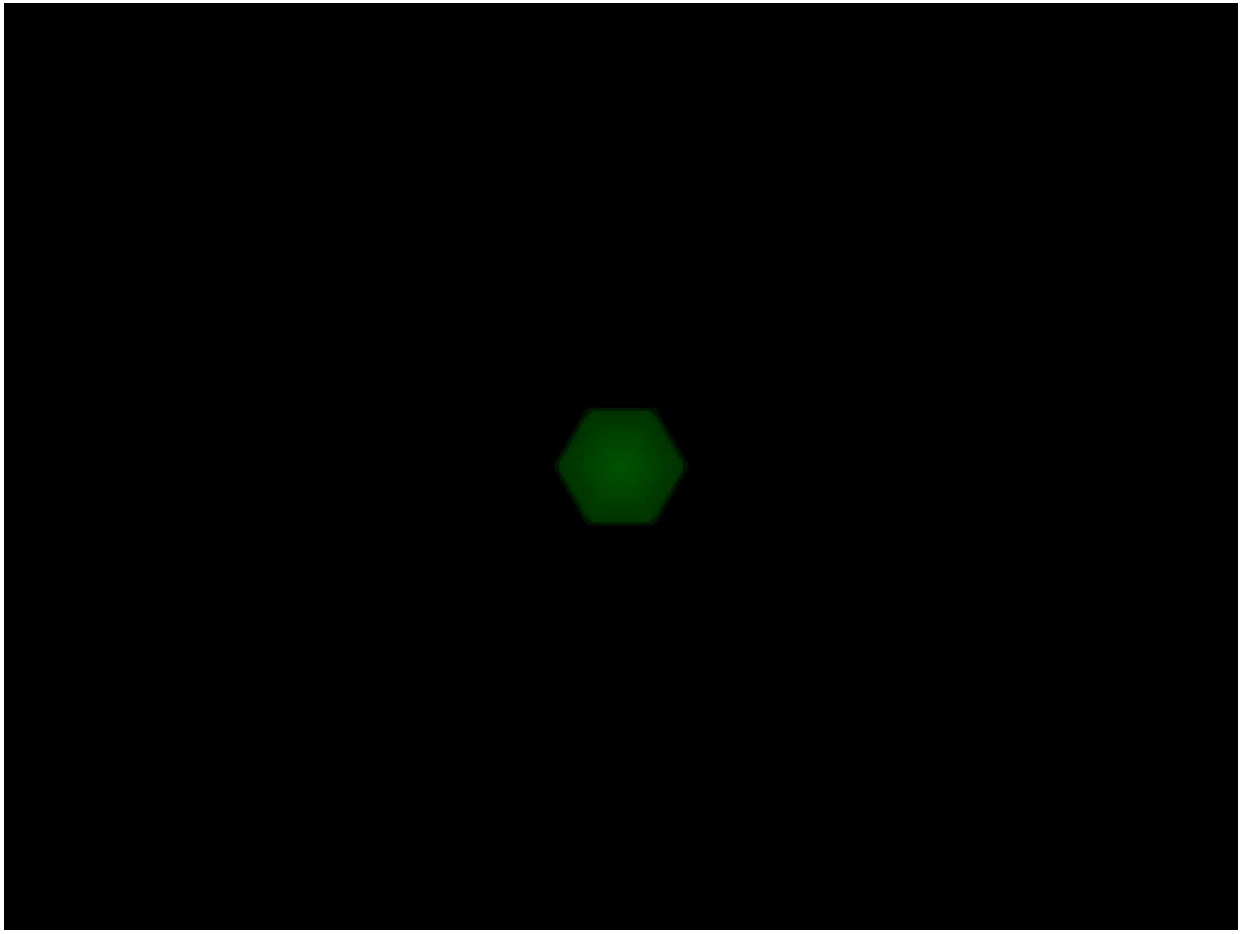
Decussate
Dvojčetný přeslen



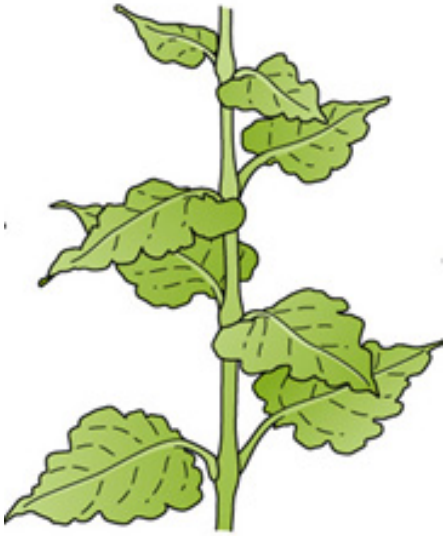
1 leaf

- increasing IAA production
- decreasing the width of the peripheral zone
- increasing the size of the central zone

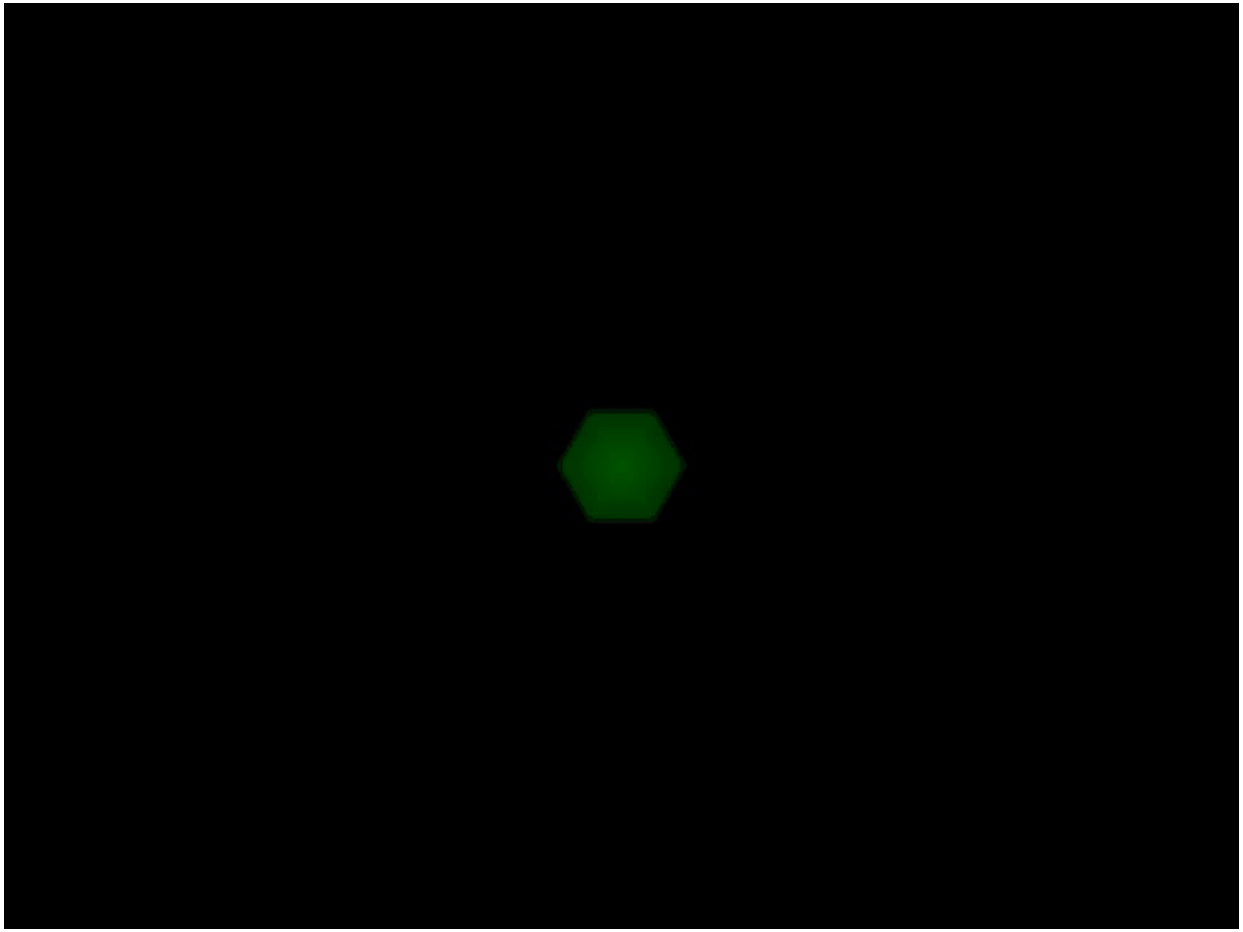
2 leaves



Decussate
Dvojčetný přeslen

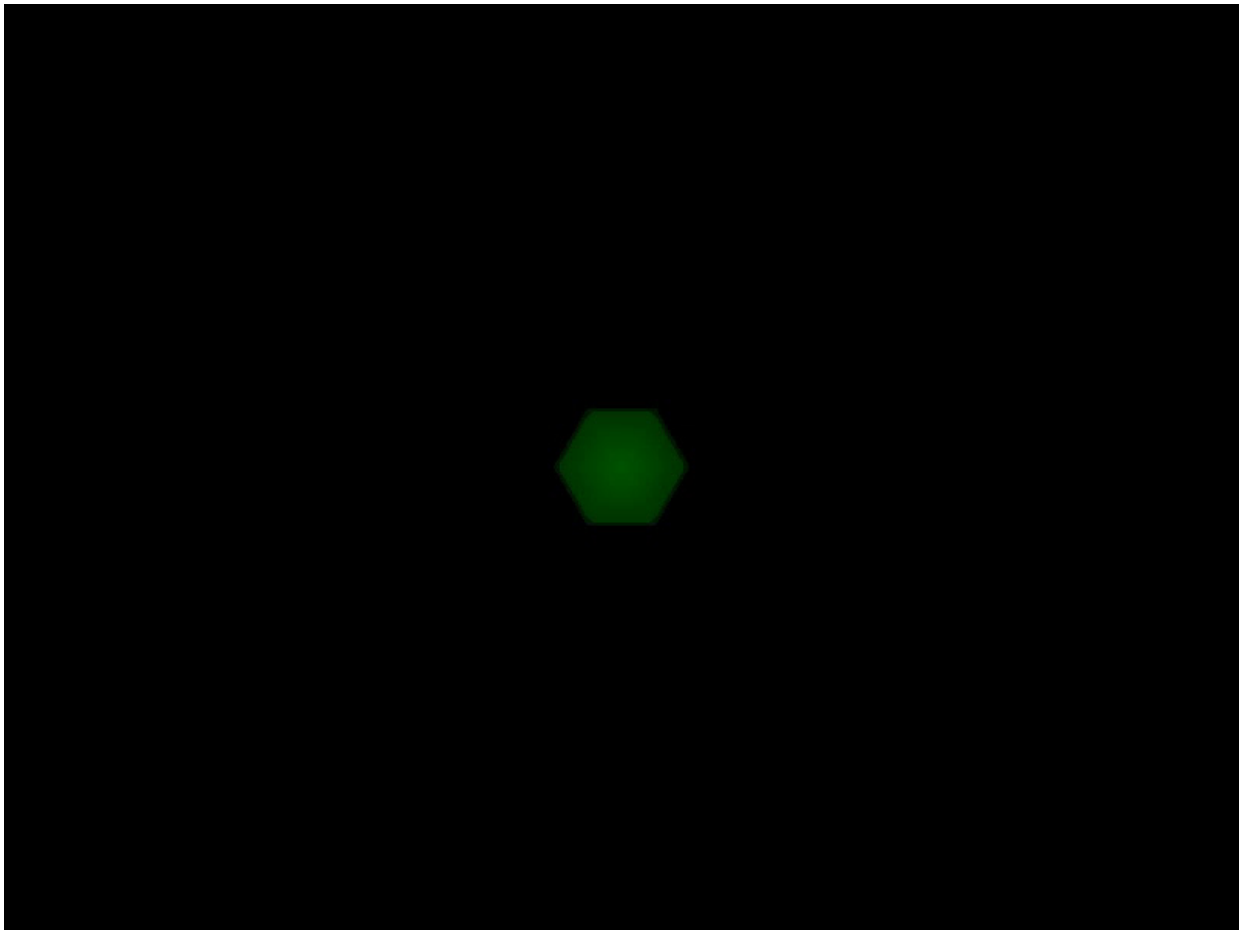


2 leaves

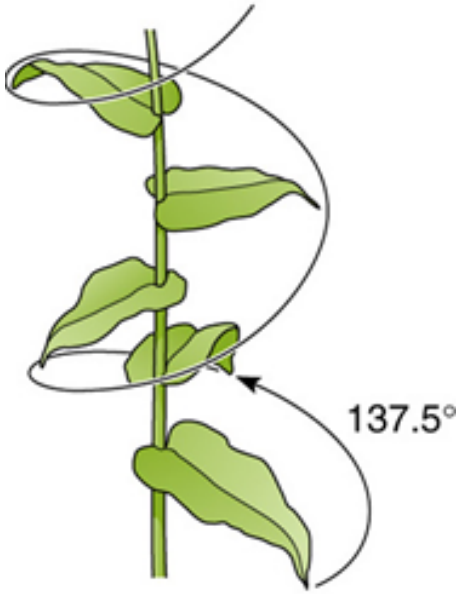


Tricussate
Trojčetný přeslen

3 leaves



Spiral
Spirálovitá fylotaxe



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Postembryonic Plant Development

- The role of plant meristems in the plant postembryonic development
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  - Molecular determinants of phyllotaxy
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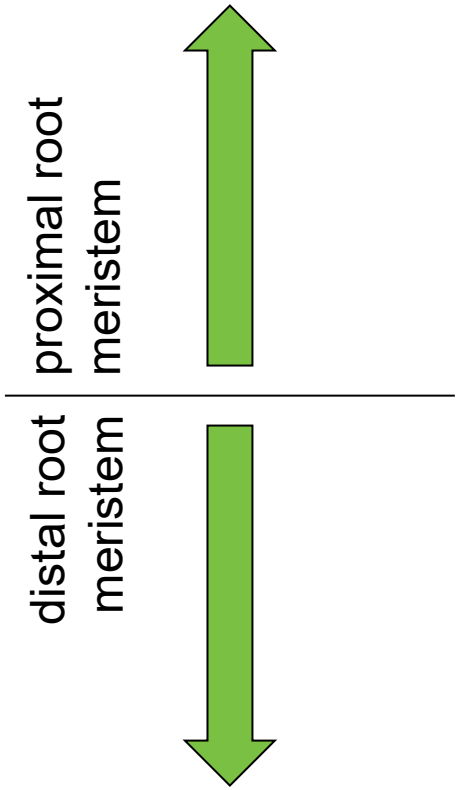
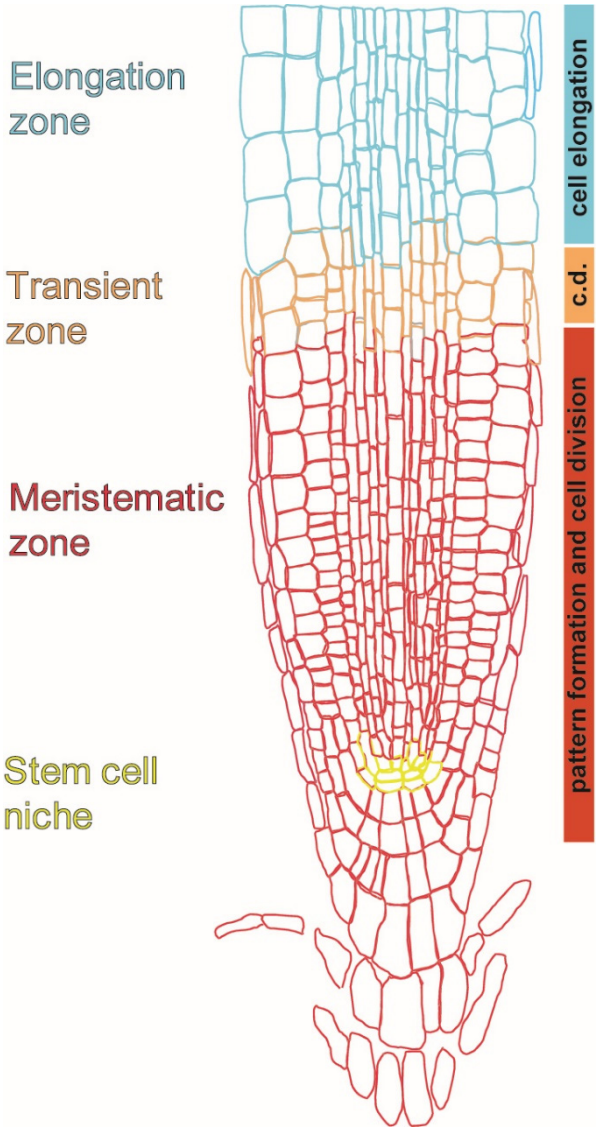
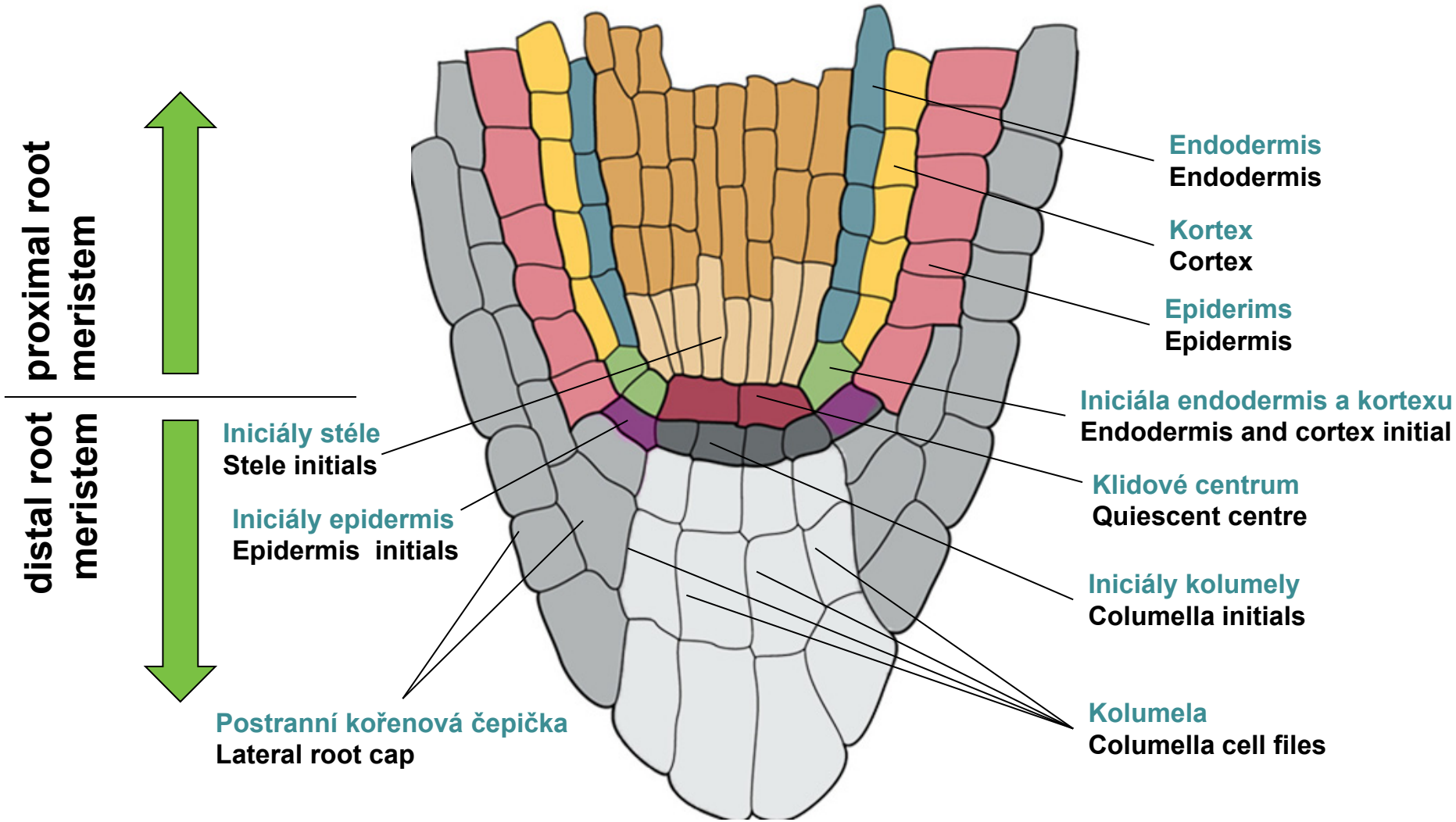
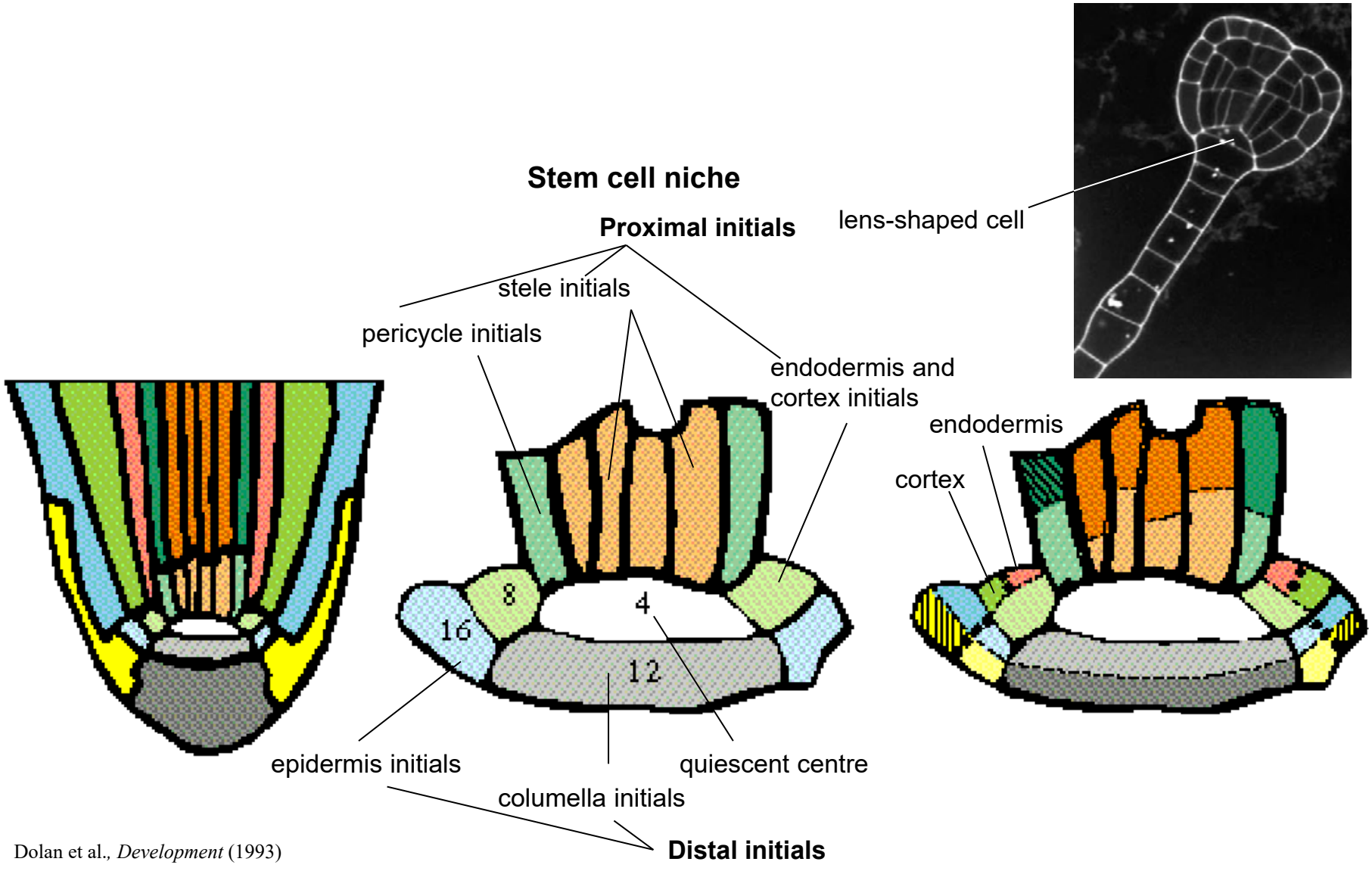
  - RAM structure



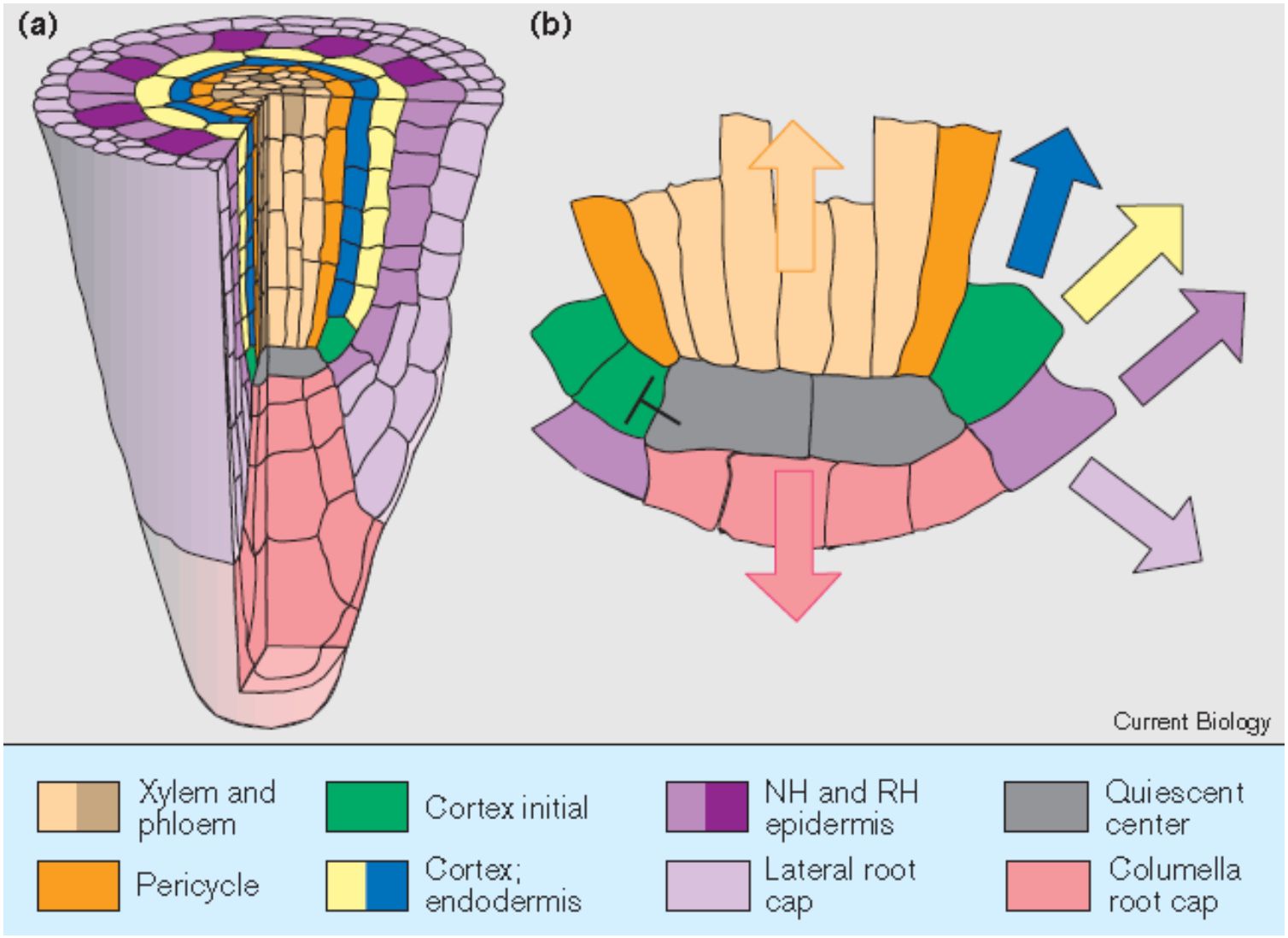


Benkova and Hejatko, *Plant Mol Biol* (2008)


proximal root meristem
distal root meristem
Iniciály stéle
Stele initials
Iniciály epidermis
Epidermis initials
Postranní kořenová čepička
Lateral root cap
Endodermis
Endodermis
Kortex
Cortex
Epiderims
Epidermis
Iniciála endodermis a kortexu
Endodermis and cortex initial
Klidové centrum
Quiescent centre
Iniciály kolumely
Columella initials
Kolumela
Columella cell files



Dolan et al., *Development* (1993)



Benfey and Scheres, *Current Biol* (2000)

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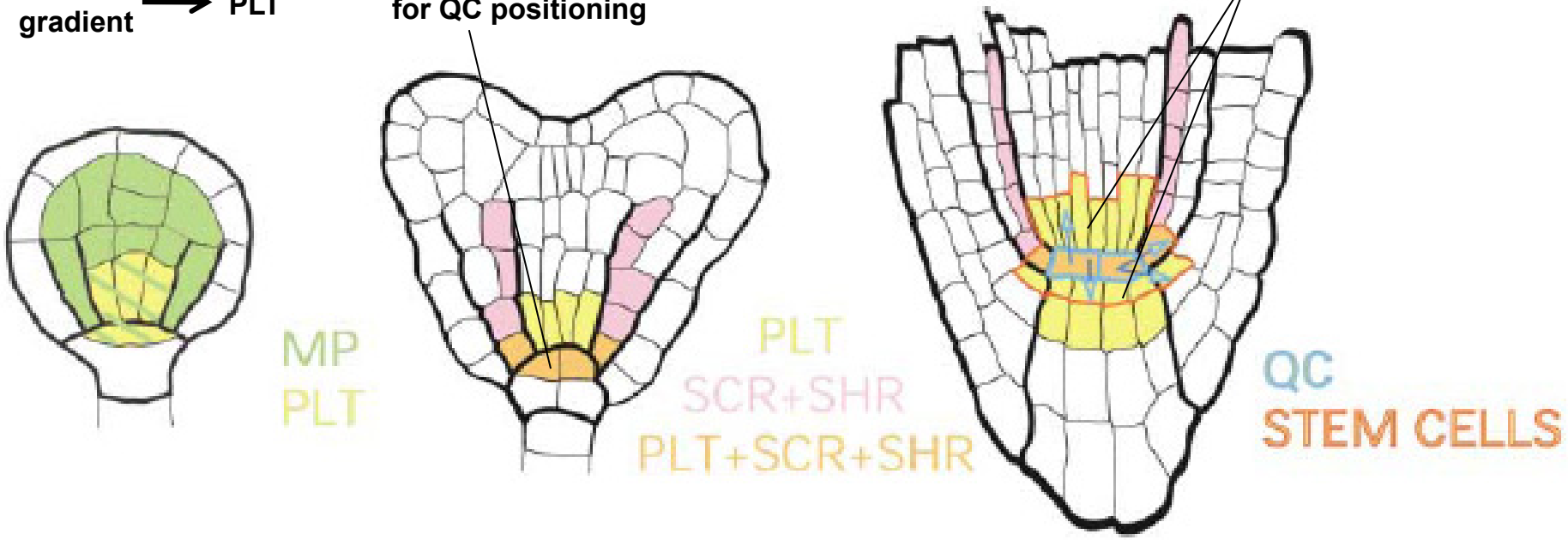
  - Positioning of RAM organizing centre

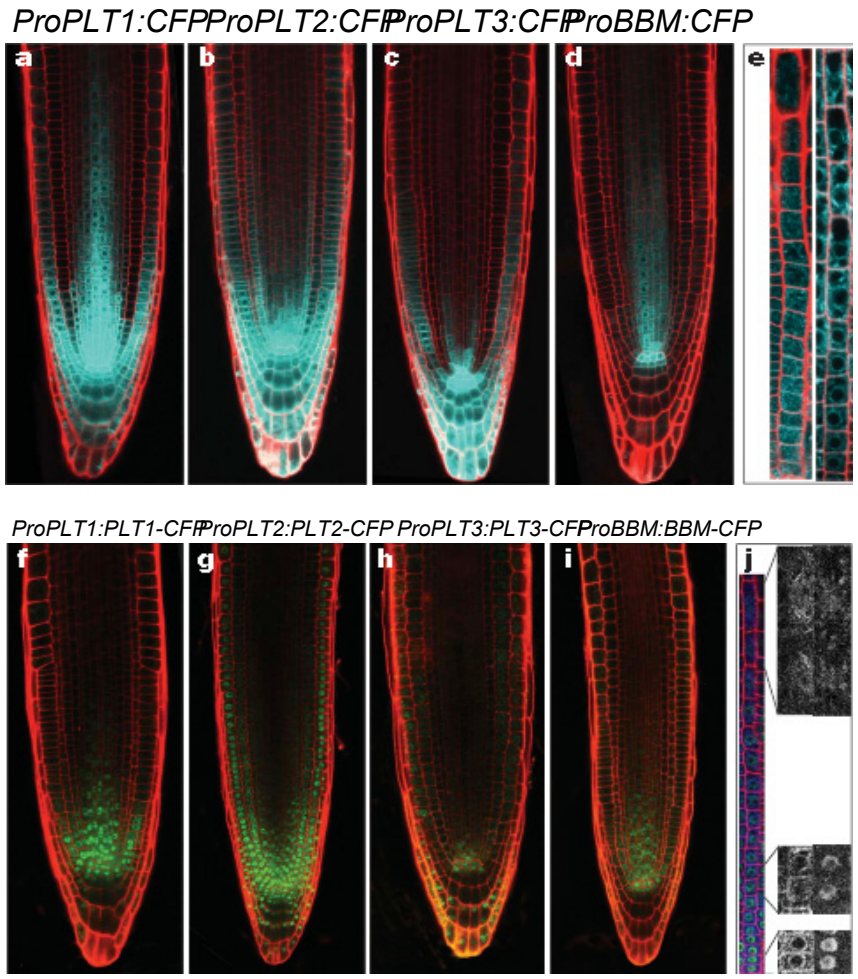
Auxin gradient → PLT

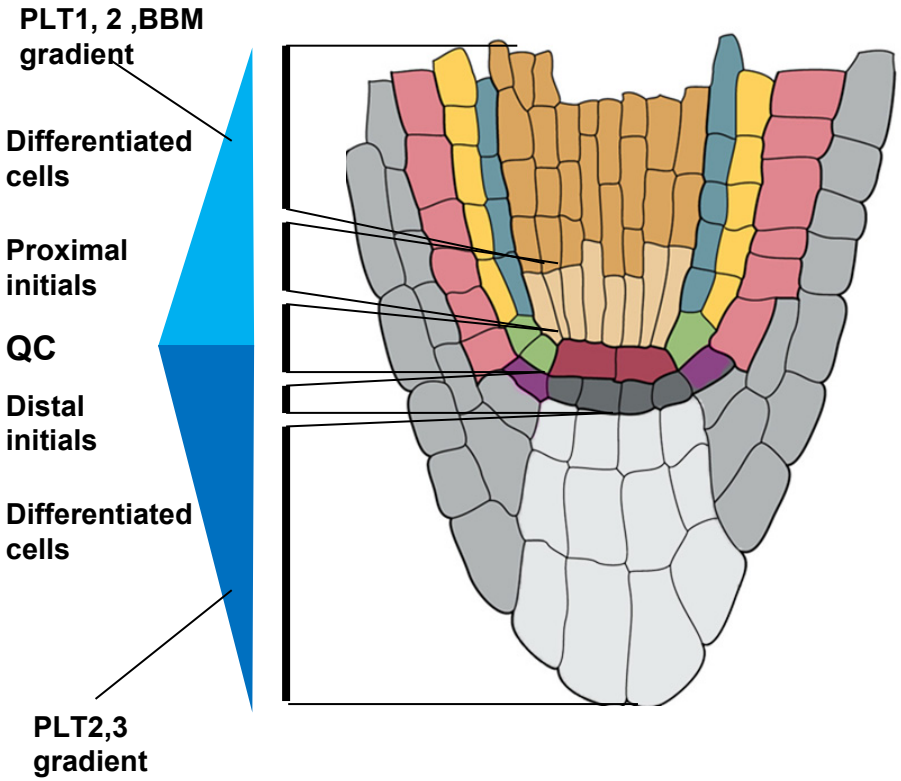
Overlap of expression of *PLT* and *SHR/SCR* provides the positional information for QC positioning

QC-mediated stem cell identity specification



Aida et al., *Cell* (2004)

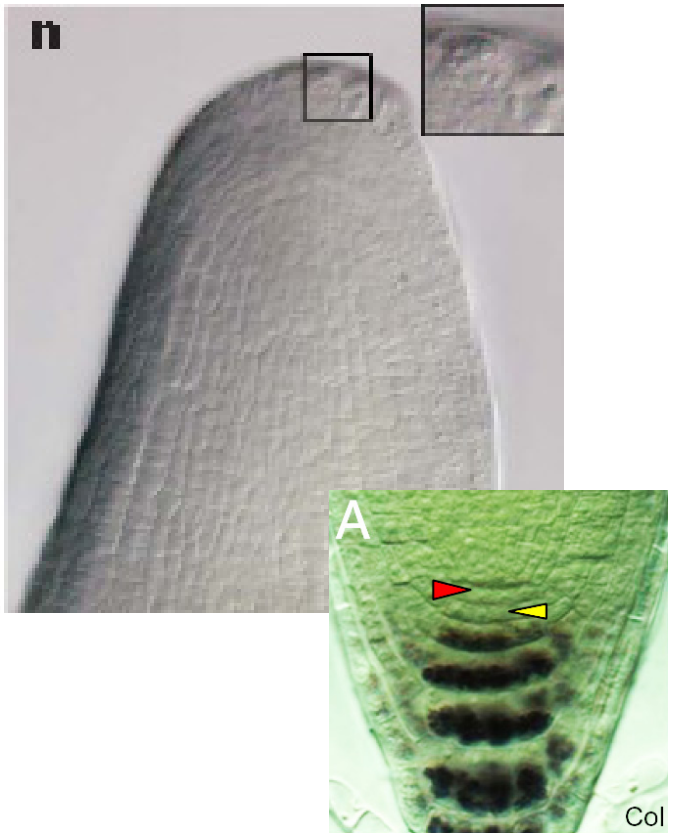




Galinha etal., *Nature* (2007)

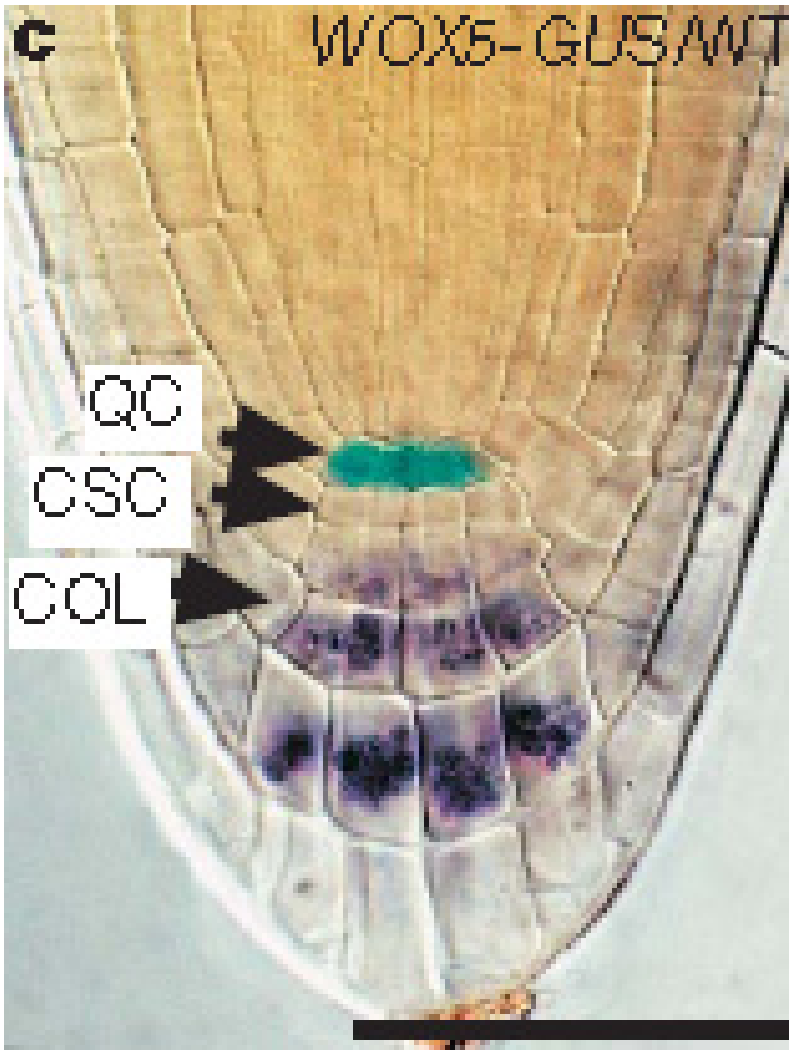
PLTs are master regulatory genes

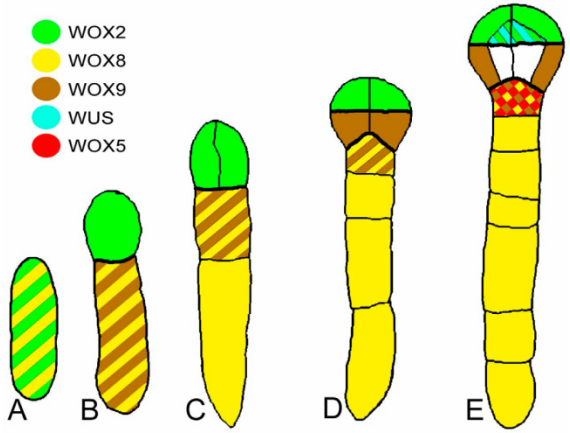
Pro35S-PLT2–GR



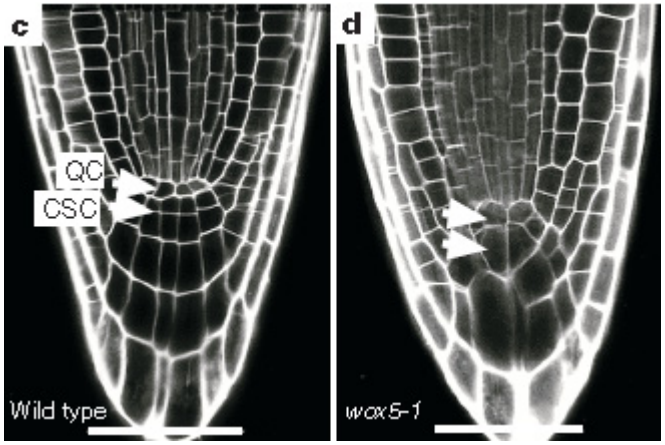
Galinha et al., *Nature* (2007)

Ding et al., *PNAS* (2010)





cellular pattern and cell identity of the stem cell niche affected



Sarkar etal., *Nature* (2007)

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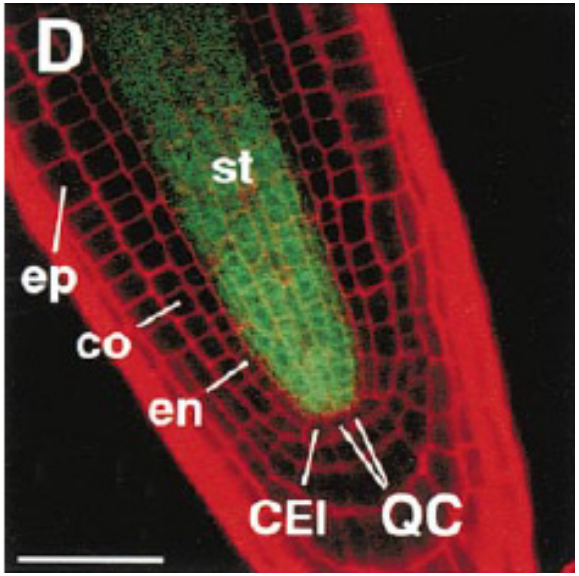
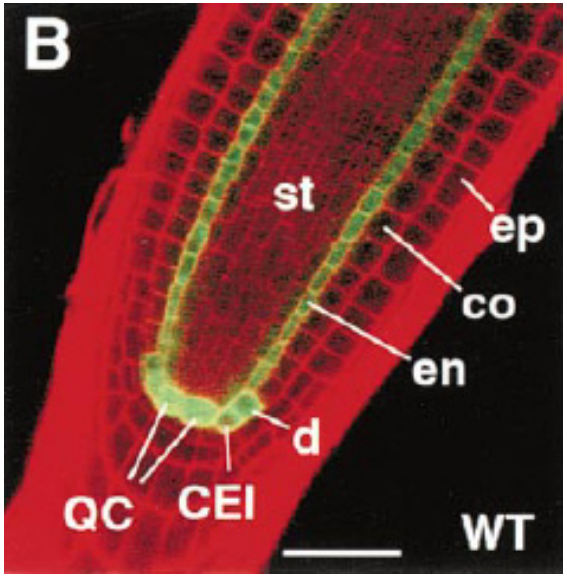
SHR and SCR, TFs from the GRAS family

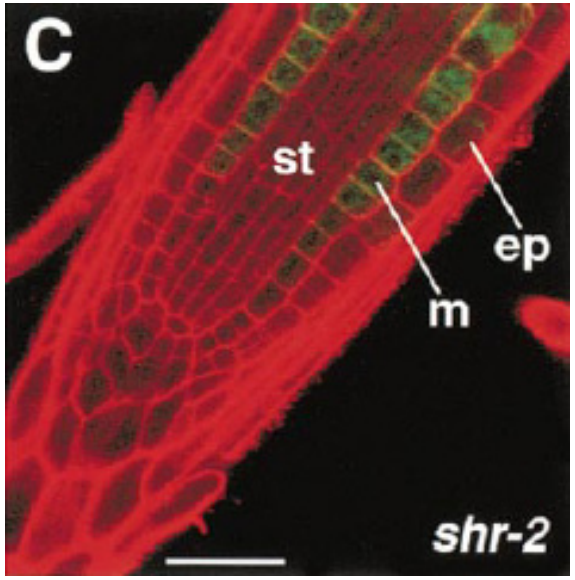
ProSHR:GFP/WT



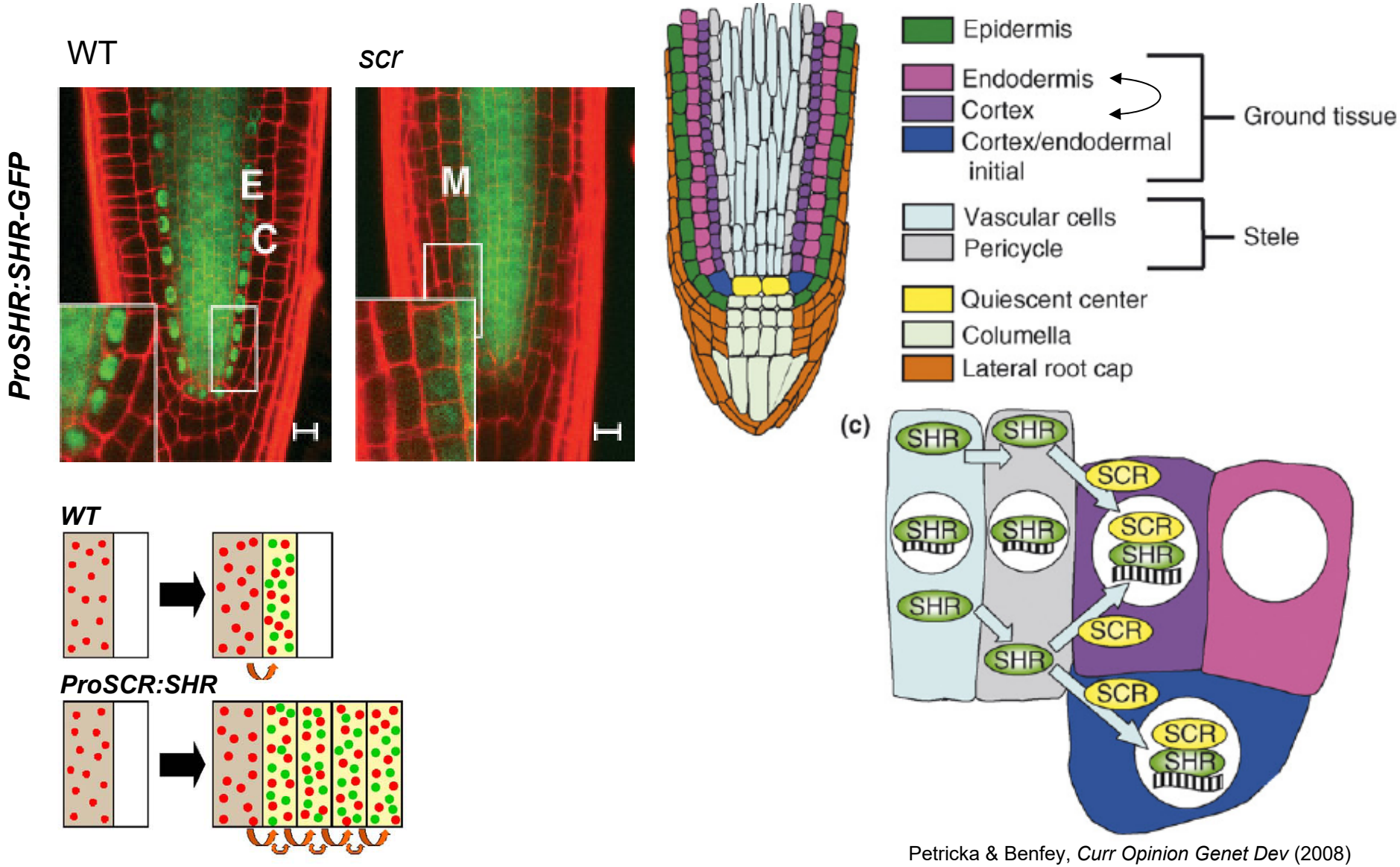
ProSCR:GFP/WT



ProSCR:GFP/shr-2



Helariutta et al., *Cell* (2000)



Petricka & Benfey, *Curr Opinion Genet Dev* (2008)

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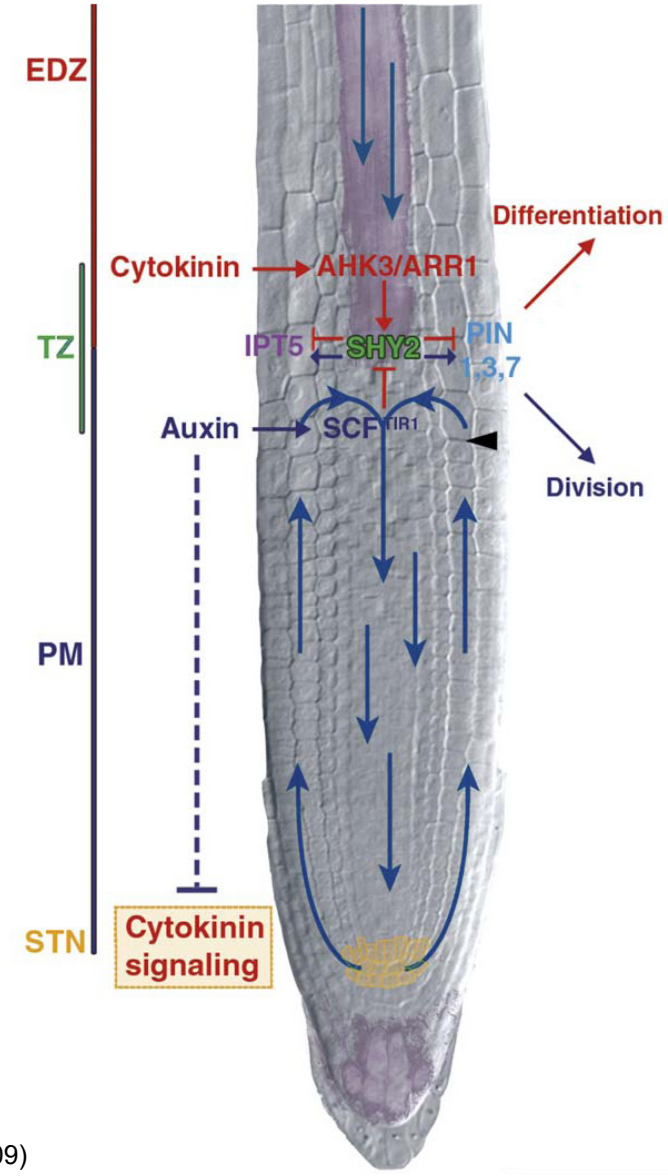

Moubayidin et al., *Trends in Plant Sci* (2009)

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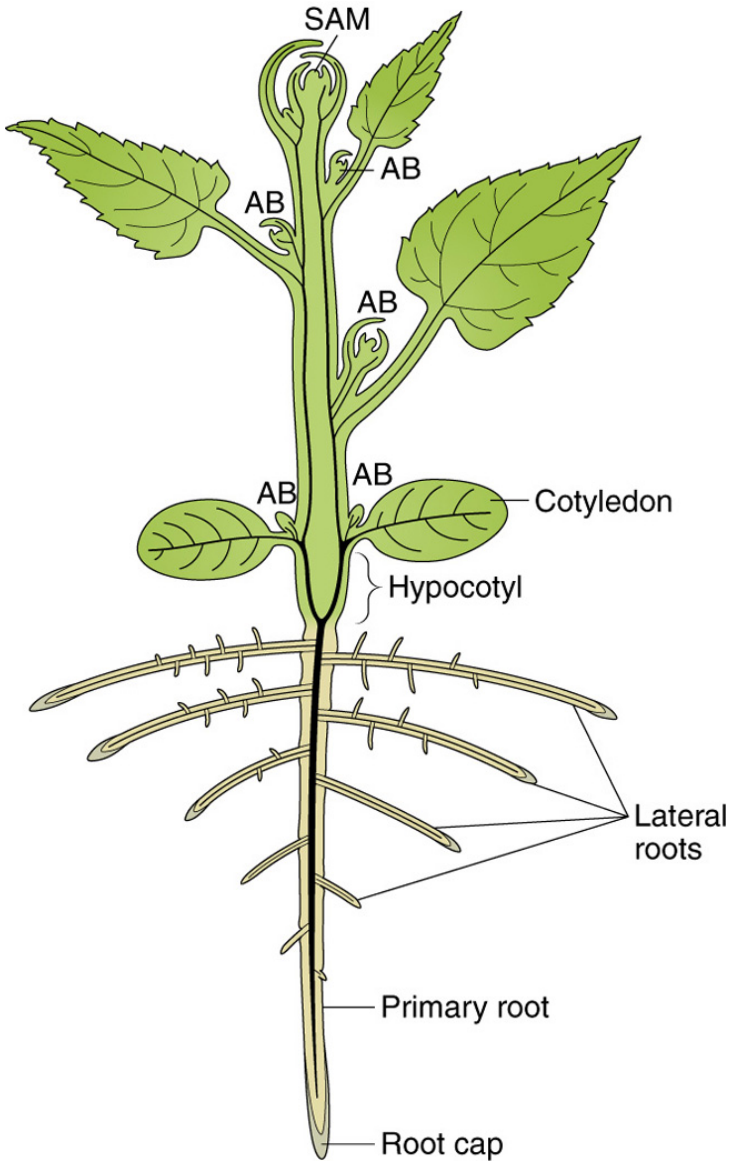
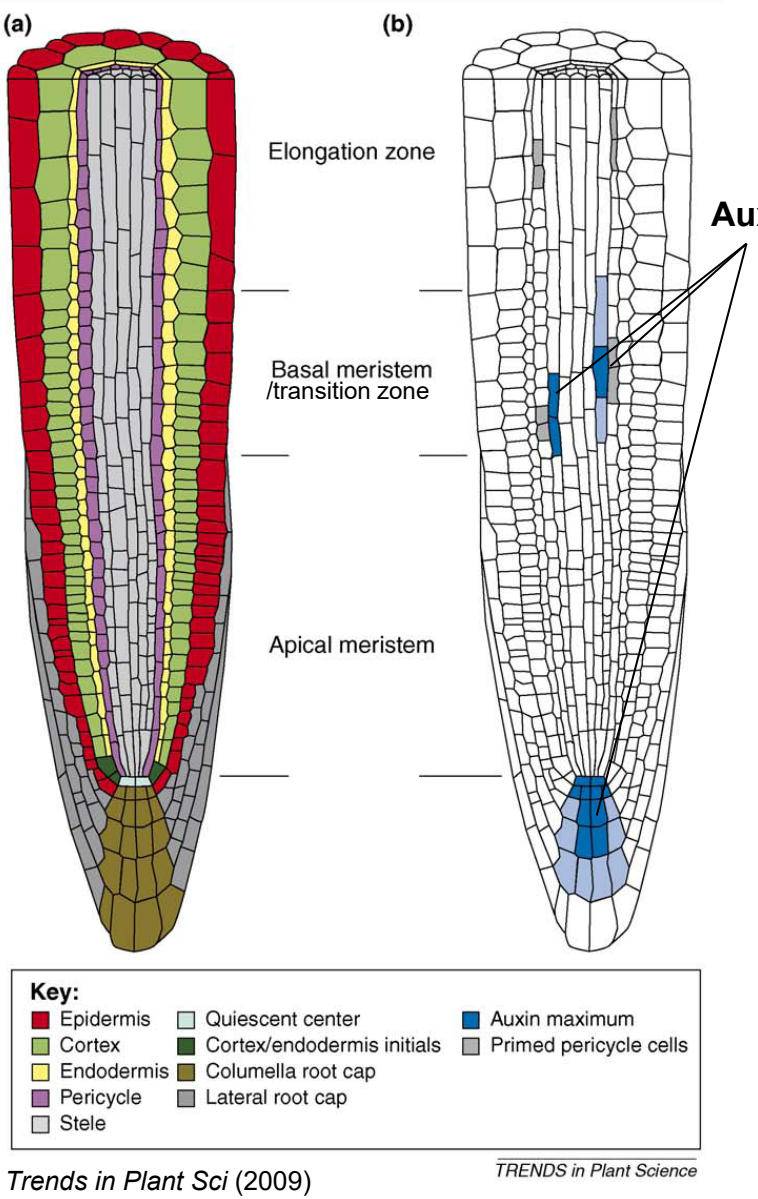
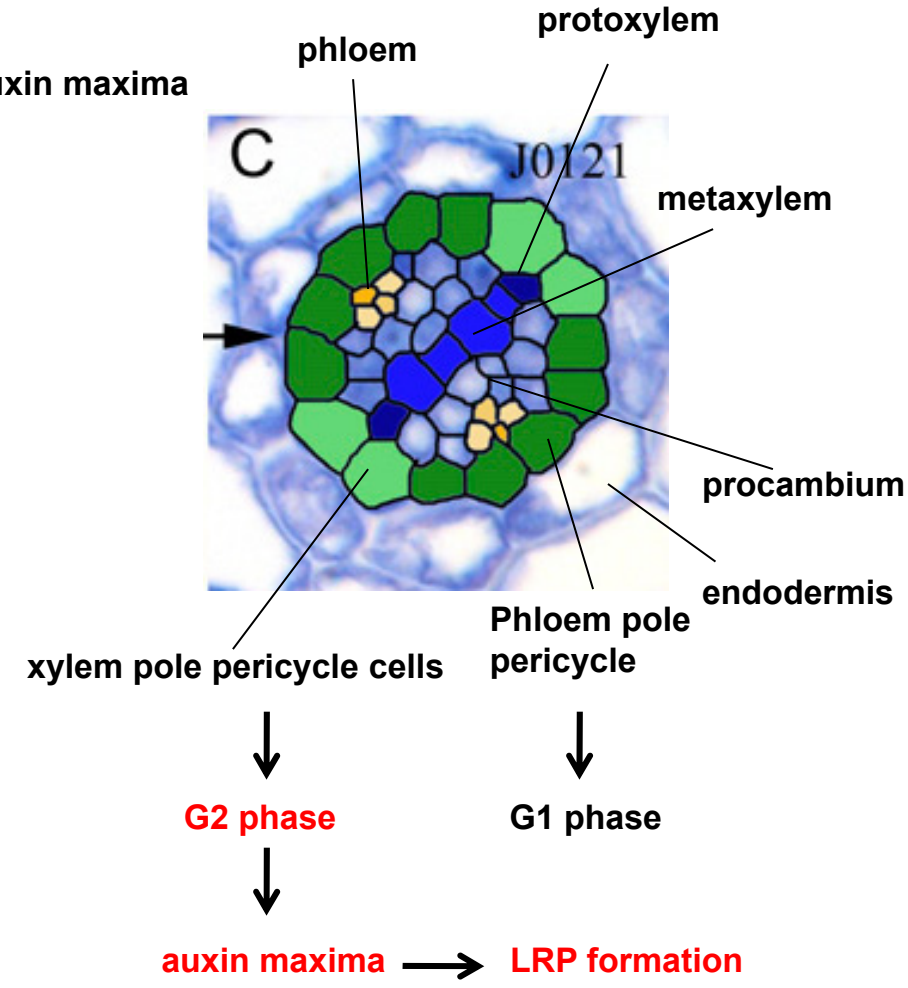
  - Root radial patterning
  - RAM size determination
- Lateral root formation

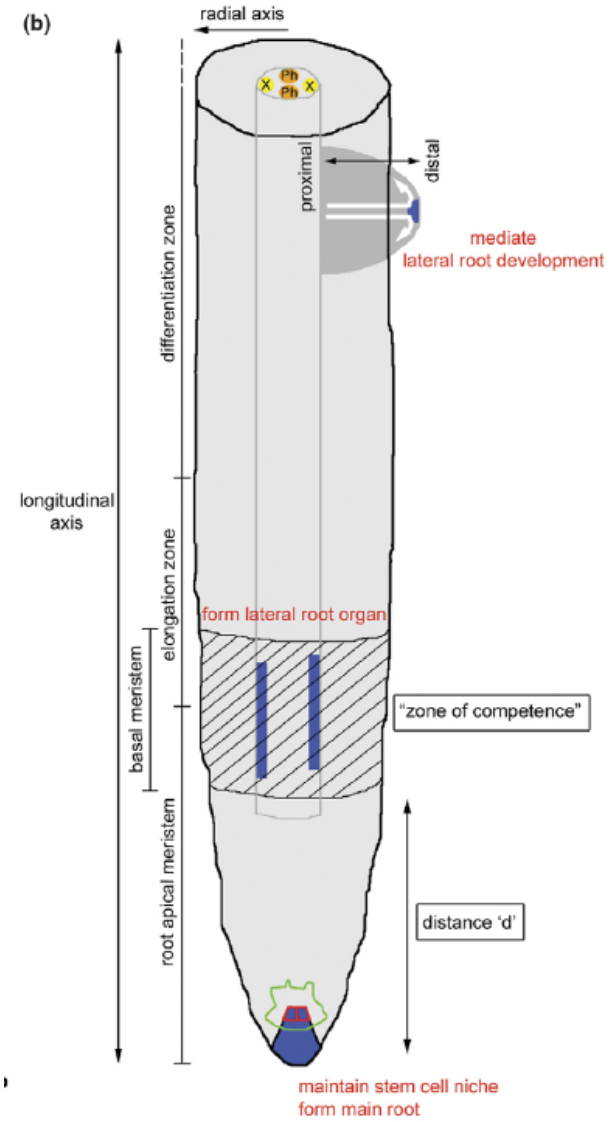

SAM
AB
AB
AB
AB
AB
Cotyledon
Hypocotyl
Lateral roots
Primary root
Root cap

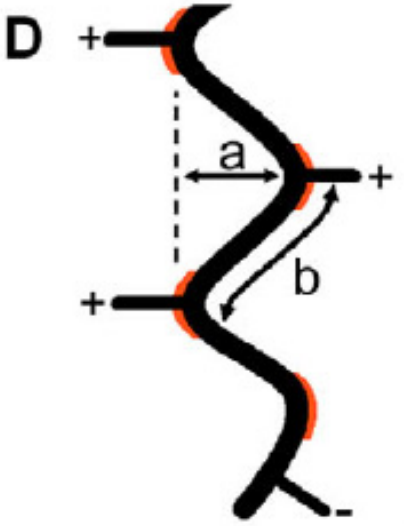


Peret etal., *Trends in Plant Sci* (2009)



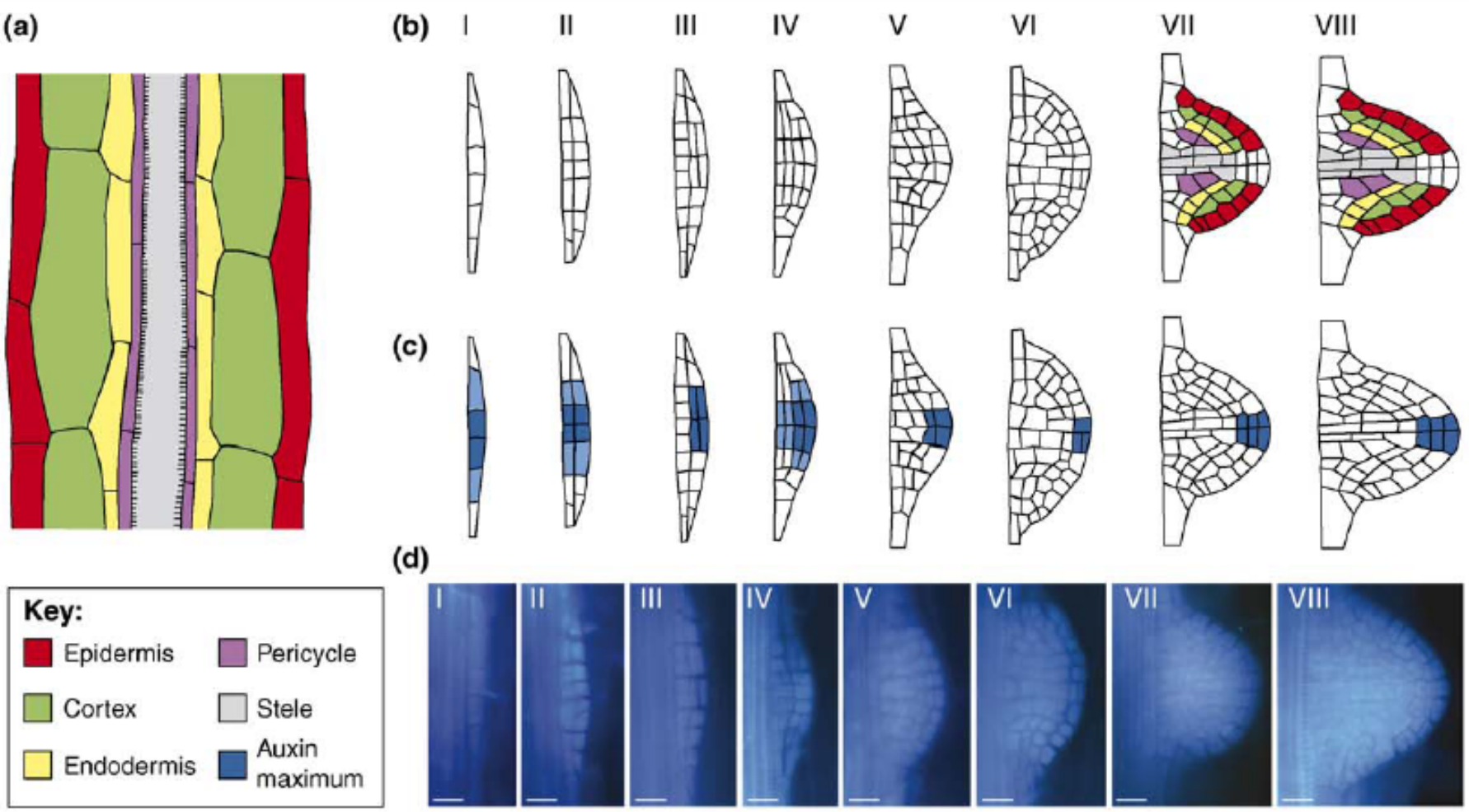
Parizot etal., *Plant Physiol* (2008)





De Smet and Jurgens., Current Opinion in Genetics & Development (2007)

De S,met etal., *PNAS* (2007)



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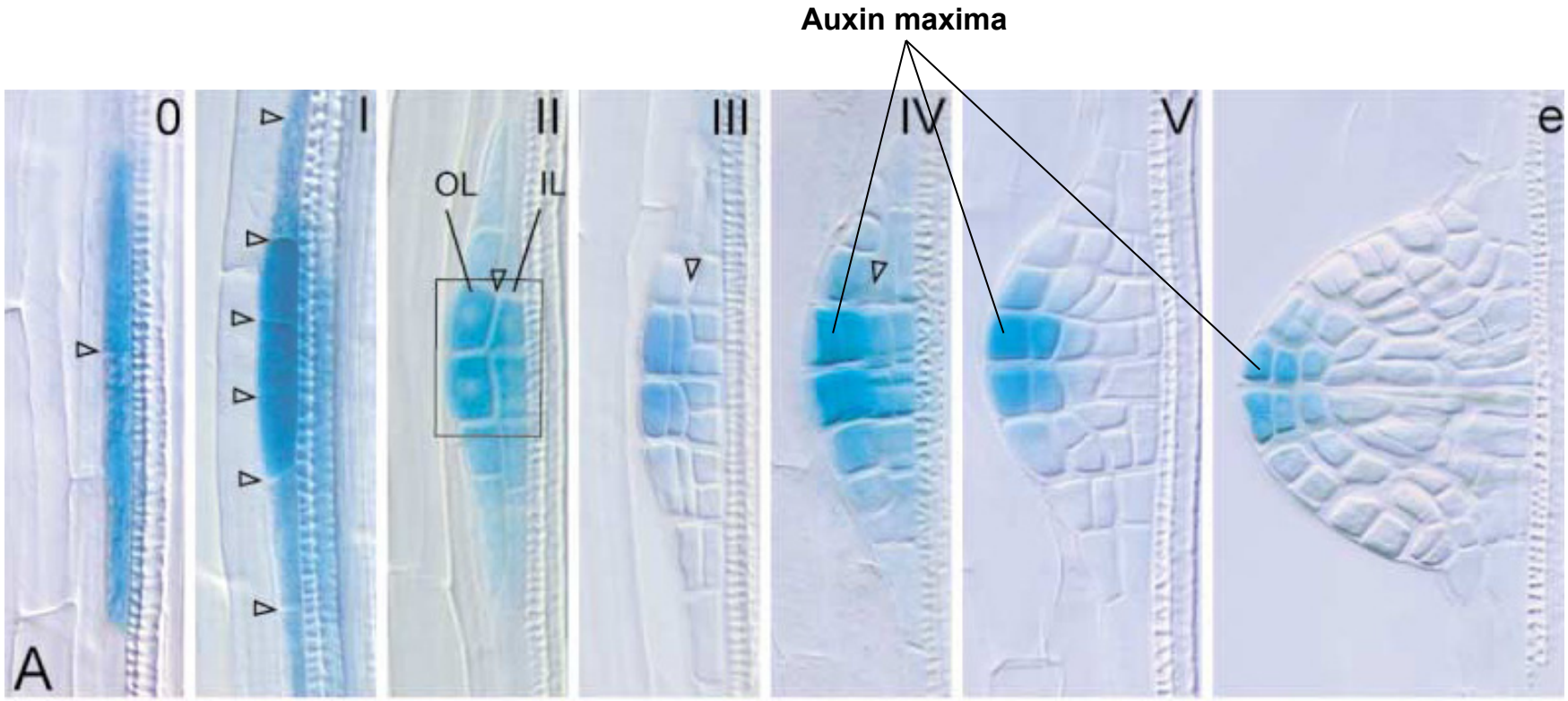
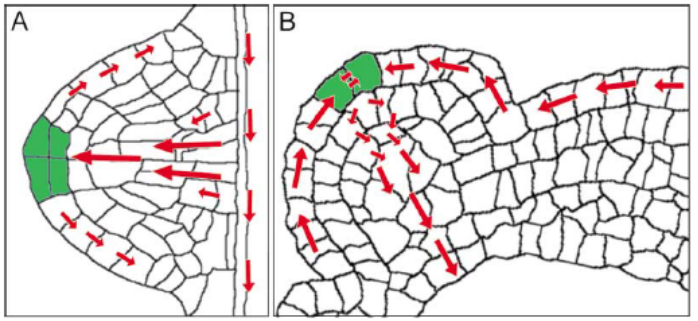
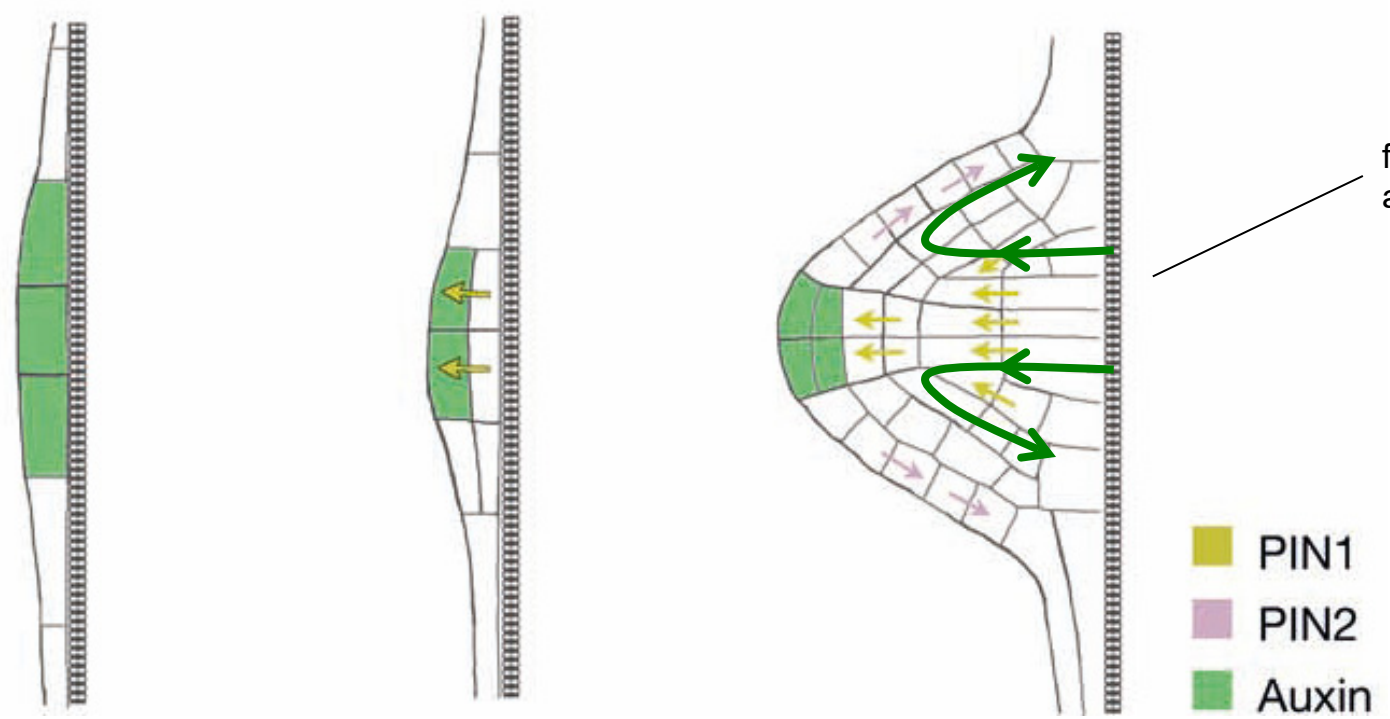


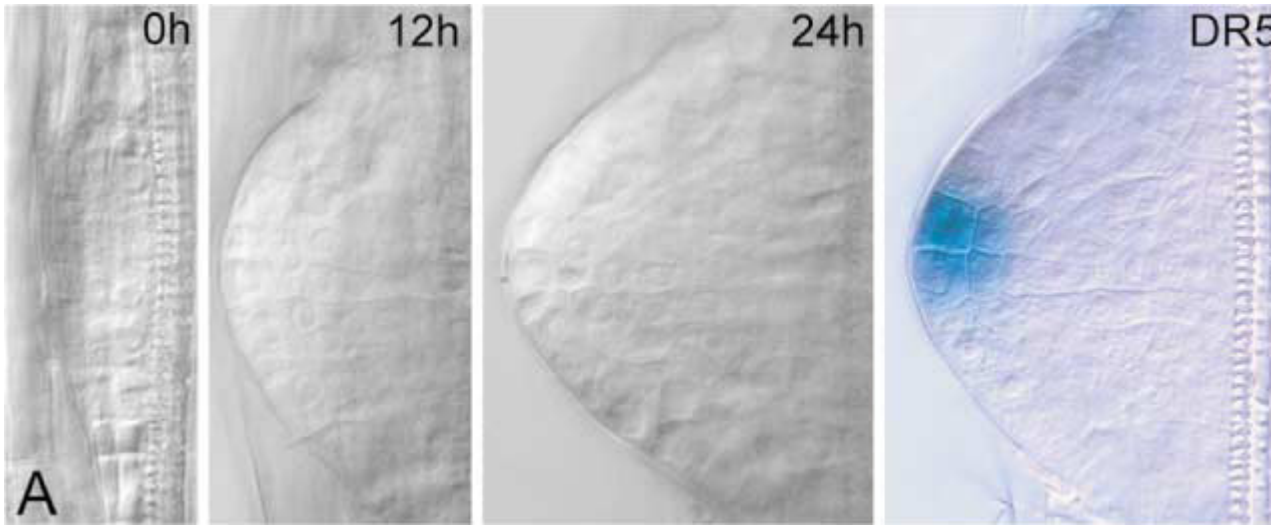
Benkova etal., *Cell* (2003)



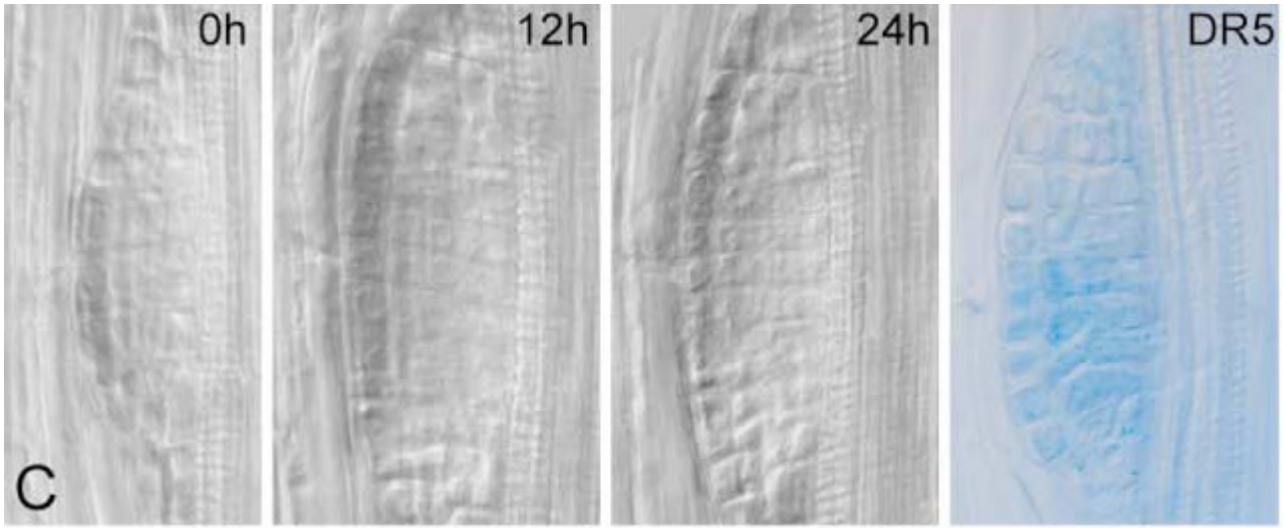


Tanaka etal., *Cell Mol Life Sci* (2003)

WT



pin1



Benkova et al., *Cell* (2003)

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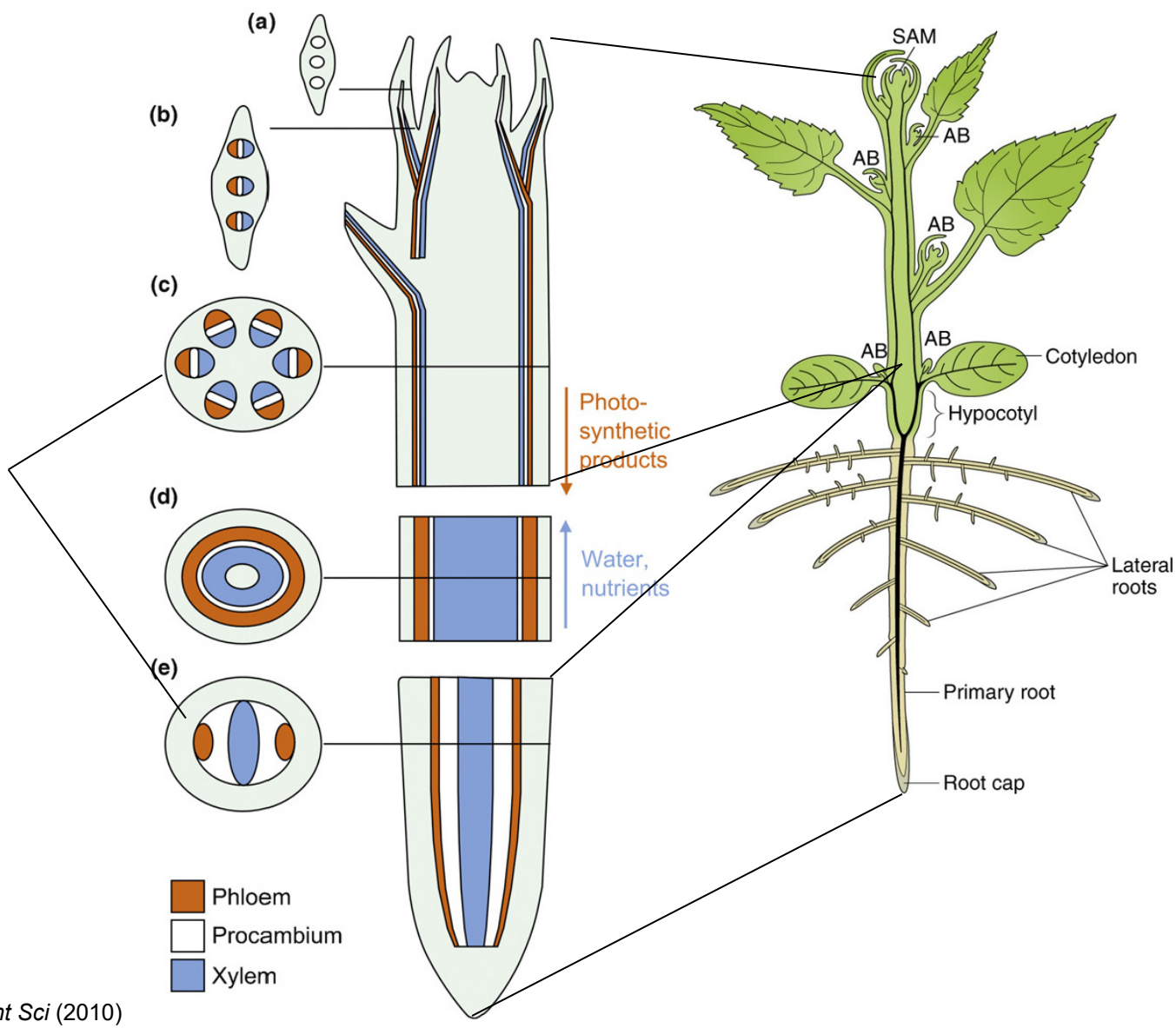
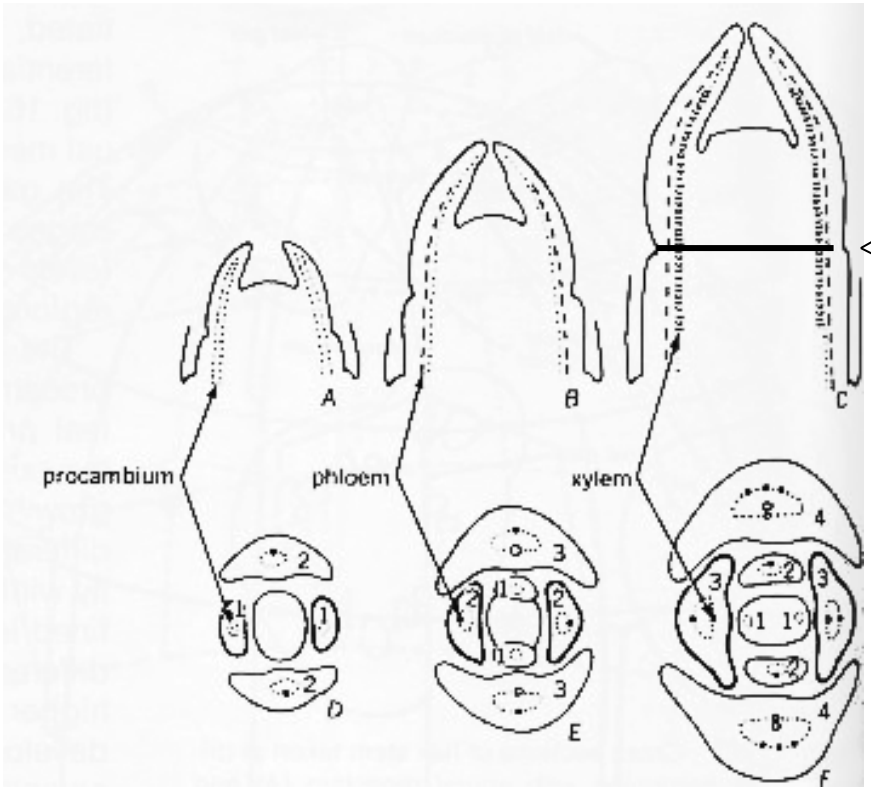
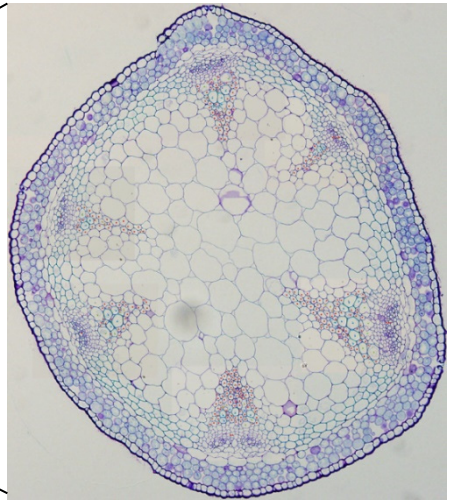
  - RAM size determination
- Lateral root formation
- Vascular tissue formation in shoot and root

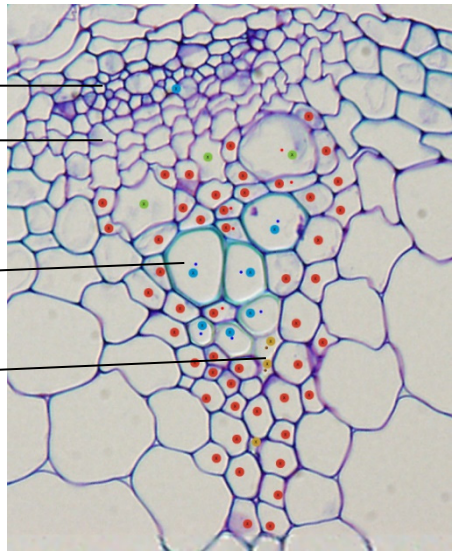
Radial expansion of both shoot and root thanks to (pro)cambium



Lehesranta et al., *Trends in Plant Sci* (2010)



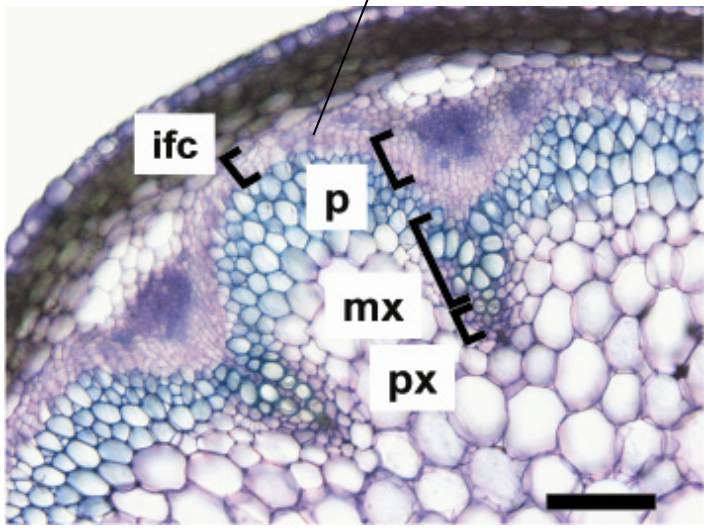


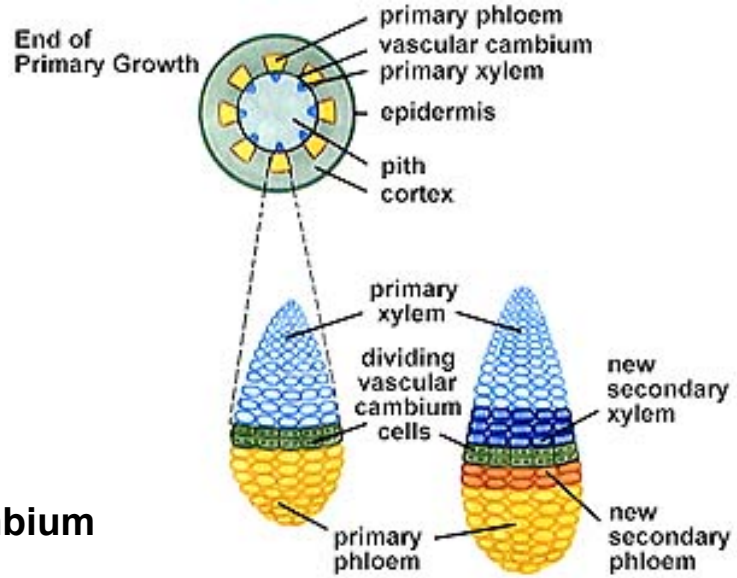


Esau, 1977

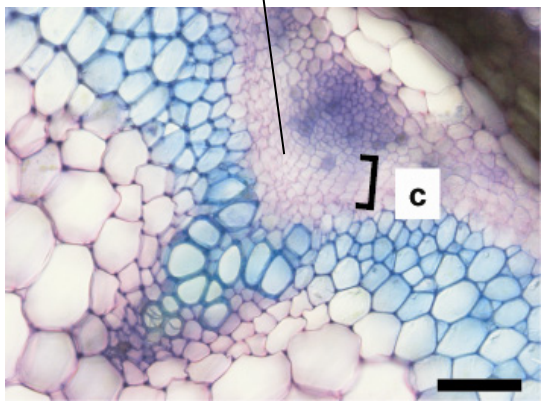
Hejatko et al., *Plant Cell* (2009)

Interfascicular cambium

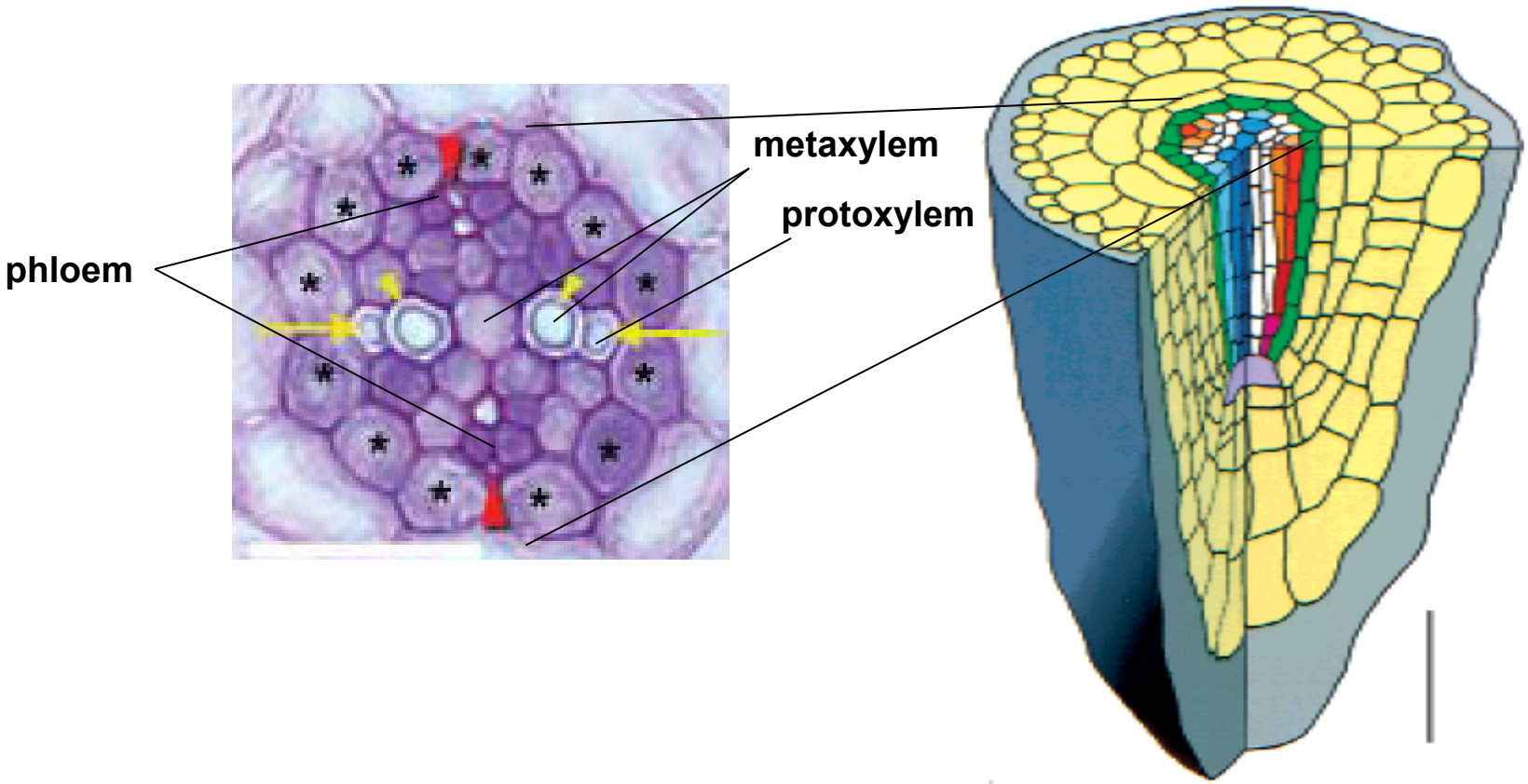




Vascular cambium



Hejatko et al., *Plant Cell* (2009)


phloem
metaxylem
protoxylem

Key Concepts

Postembryonic Plant Development

- Plants, in contrast to animals, form most of their tissues and organs during **postembryonic development** via **postembryonic *de novo* organogenesis**.
- Both shoot and root growth occurs via **directed cell proliferation** and **differentiation** in plant **meristems**.
- **Organizing centres** are formed in both shoot and root apical meristems.
- **Auxin gradients** determine **novel organ initiation** and **spacing** in the shoot apical meristem.
- **Auxin-driven morphogen gradient** acts in the **specification of the stem cell niche** and **cell differentiation** in the root.
- **Auxin maxima** specify positions of novel organ formation e.g. **lateral root primordia**.
- **(Pro)cambium** contains **stem cell pool** and allows **vascular tissue formation** and **radial growth** of plants.

Discussion