

Bi8940 Developmental Biology

Lesson 8

Postembryonic Plant Development

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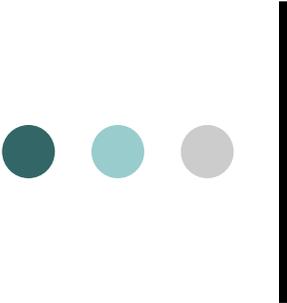
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

Tato prezentace je spolufinancována
Evropským sociálním fondem
a státním rozpočtem České republiky

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

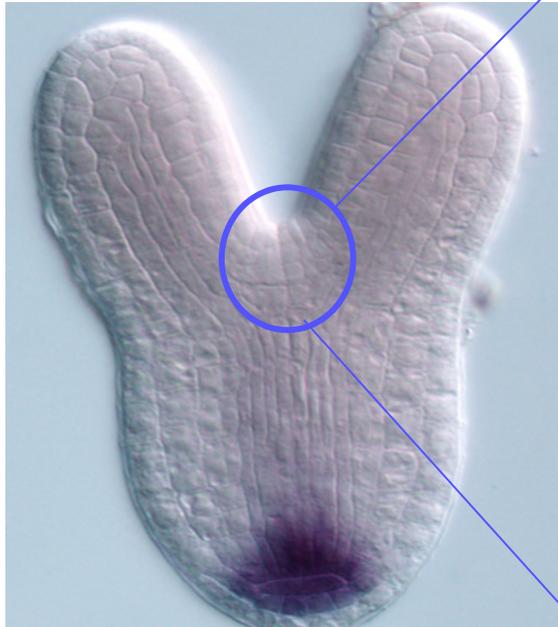
- The role of plant meristems in the plant postembryonic development



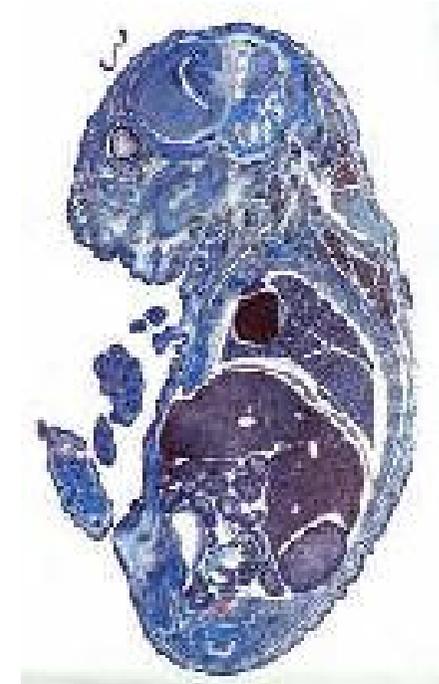
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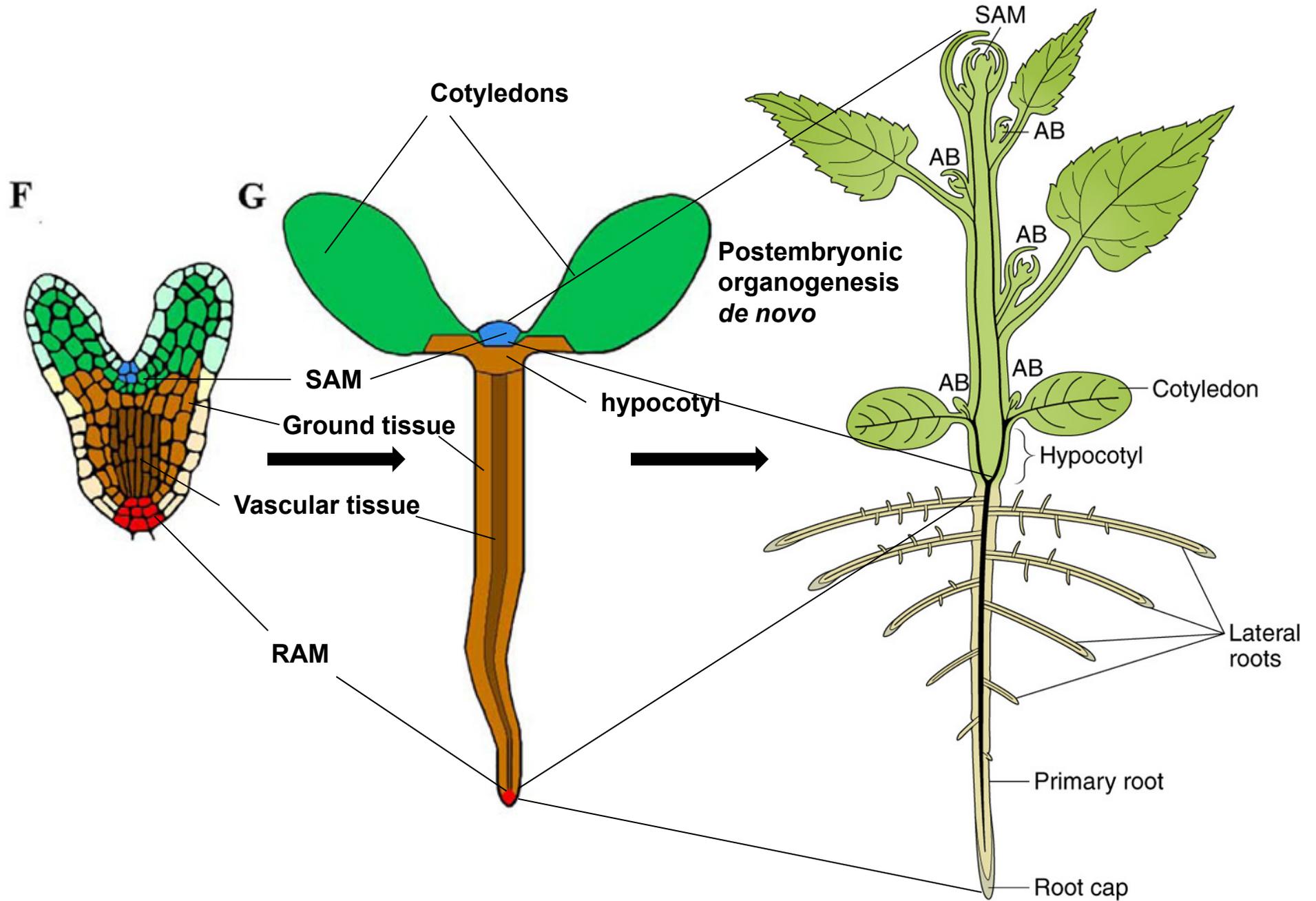
What is the principal difference between plants and animals?

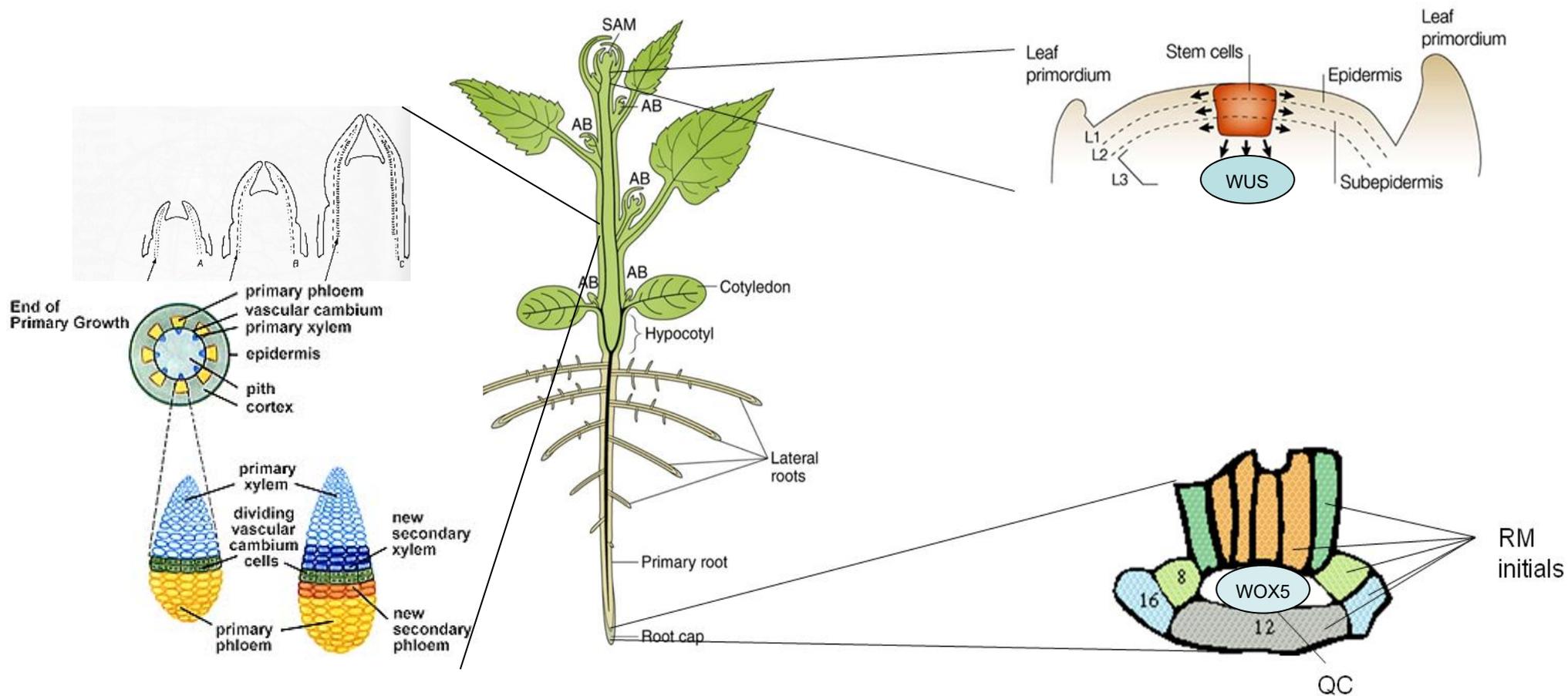


Arabidopsis thaliana, embryo at the torpedo stage

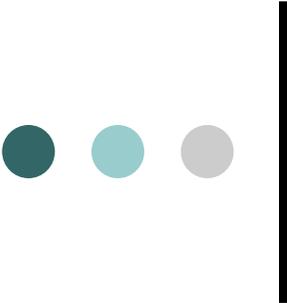


Mus musculus, embryo, longitudinal section





Division ↔ Differentiation

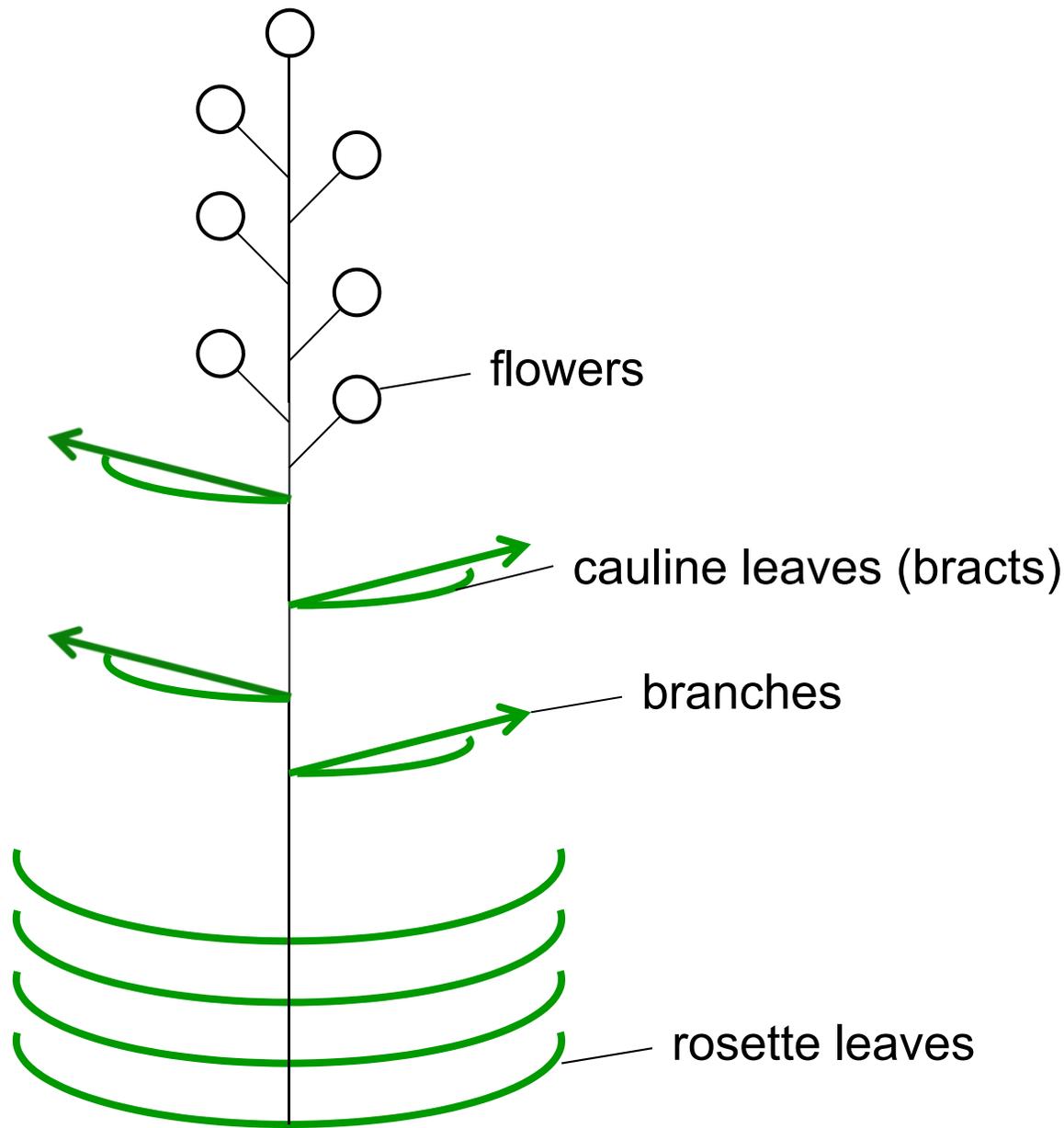


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- Shoot apical meristem (SAM)
 - Structure of the SAM

inflorescence



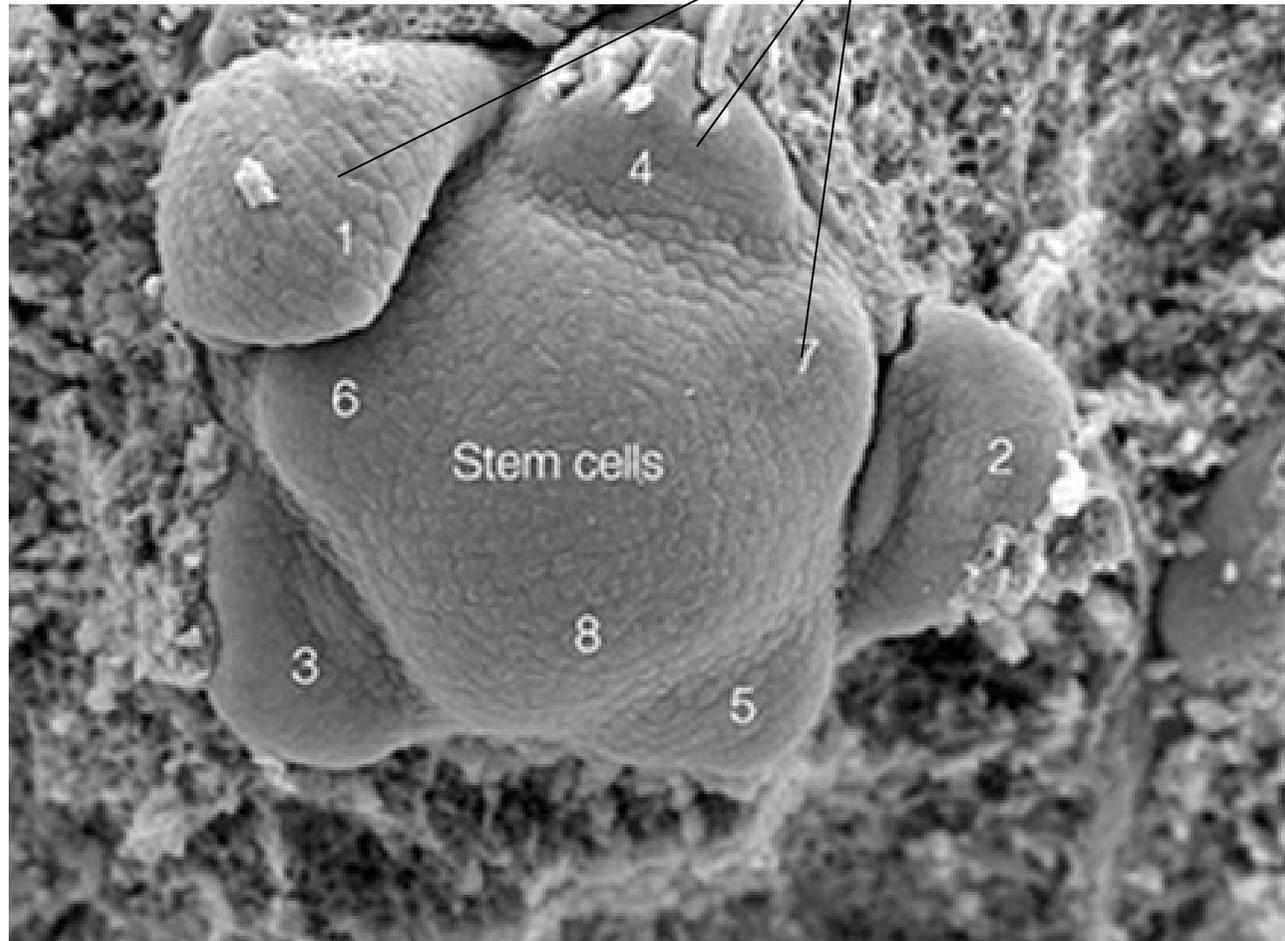
produced by FMs

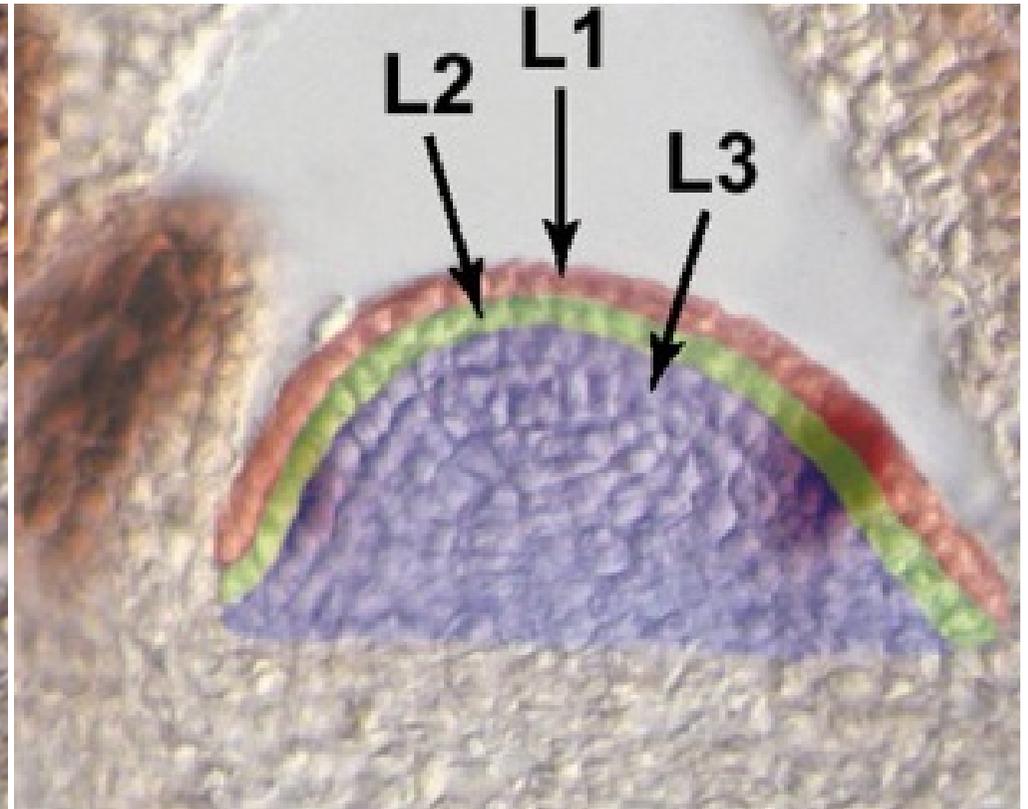
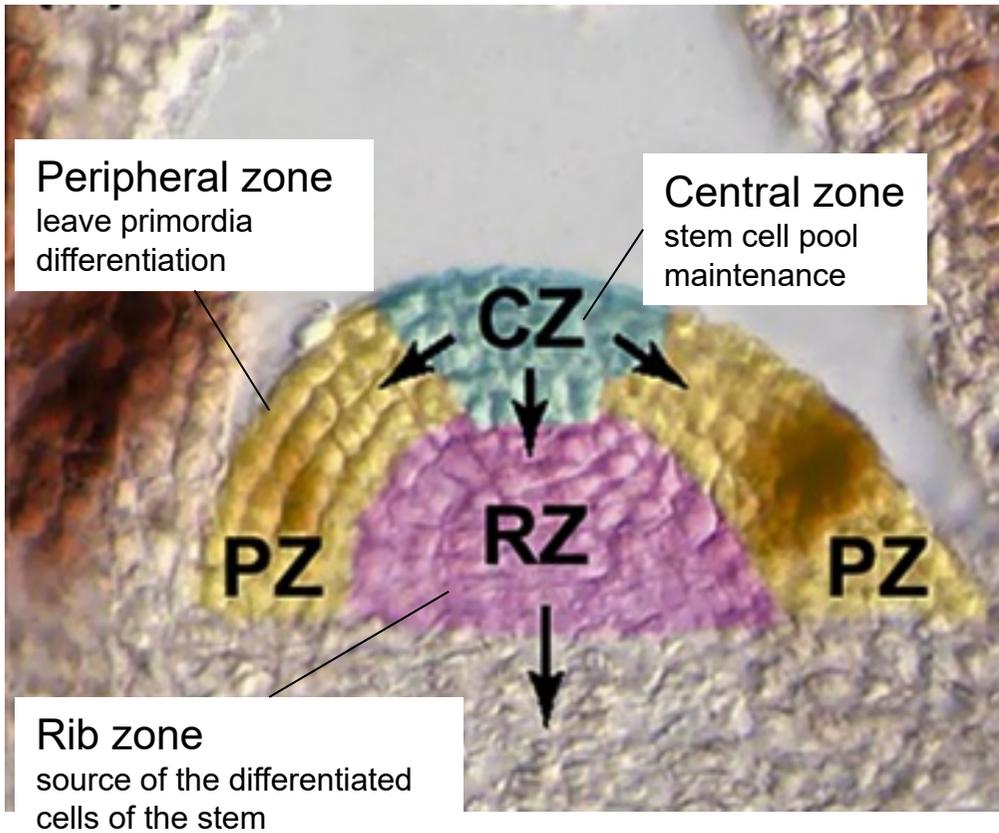
**generative
growth phase**

produced by IMs

**vegetative
growth phase**
produced by SAM

Leave primordia



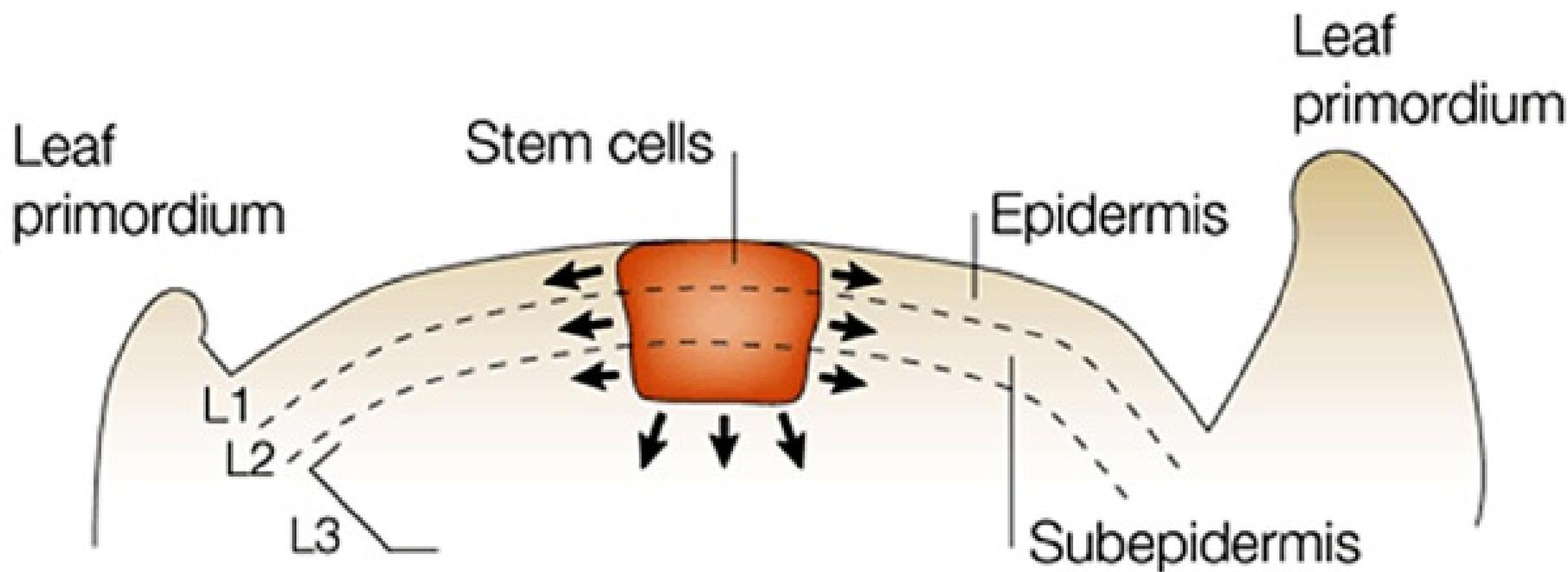


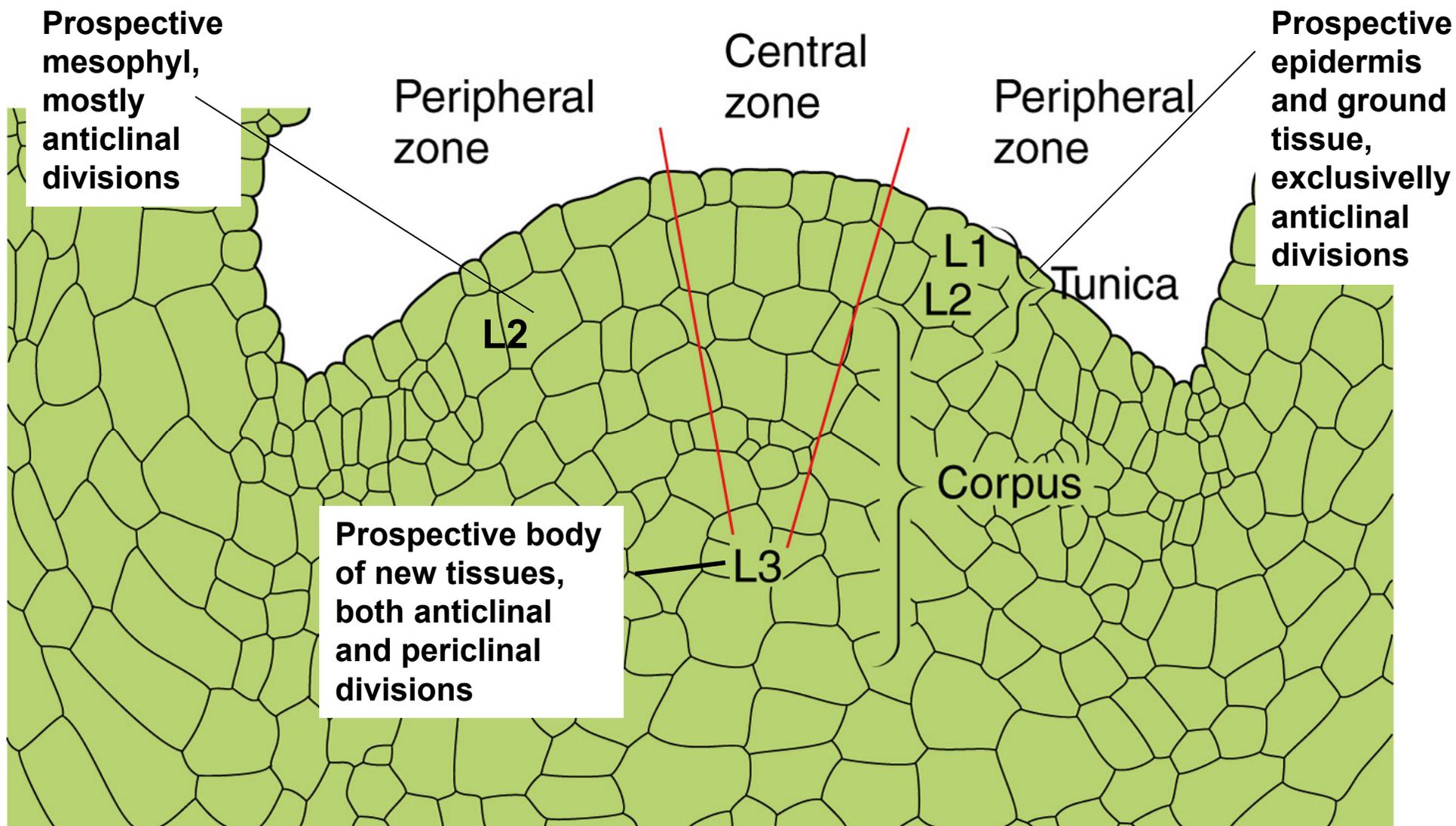
Bowman and Eshed, *Trends Plant Sci* (2000)



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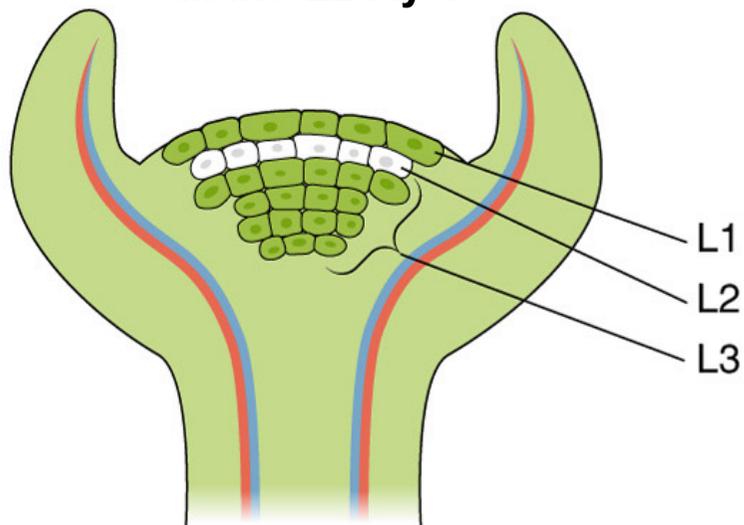
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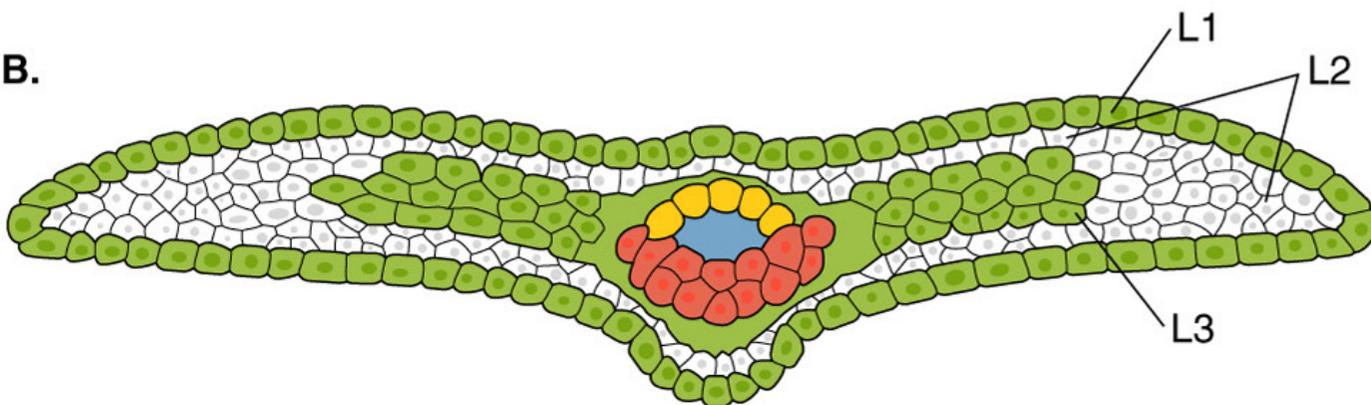


Chimera with albino L2 layer

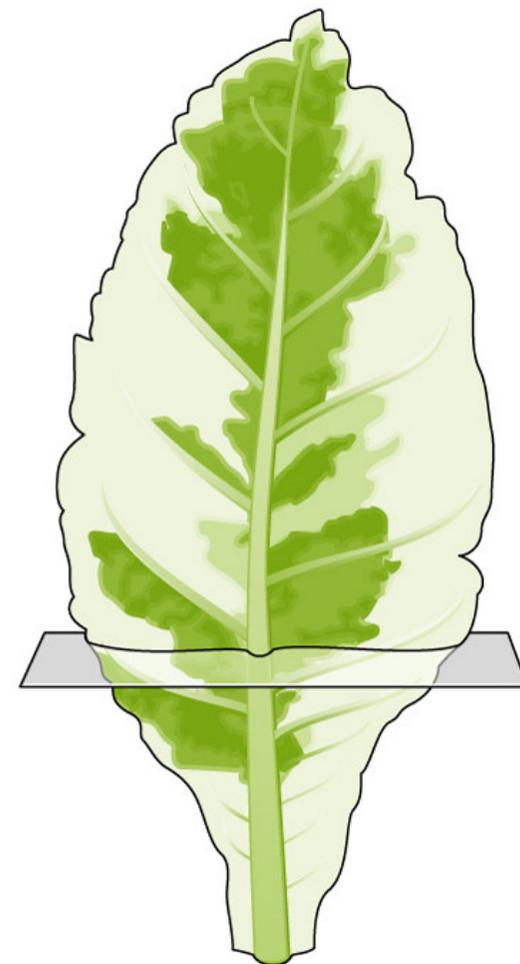
A.

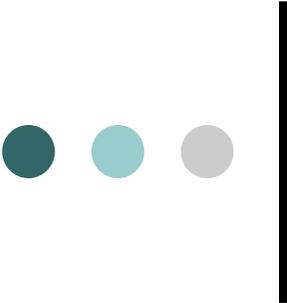


B.



C.



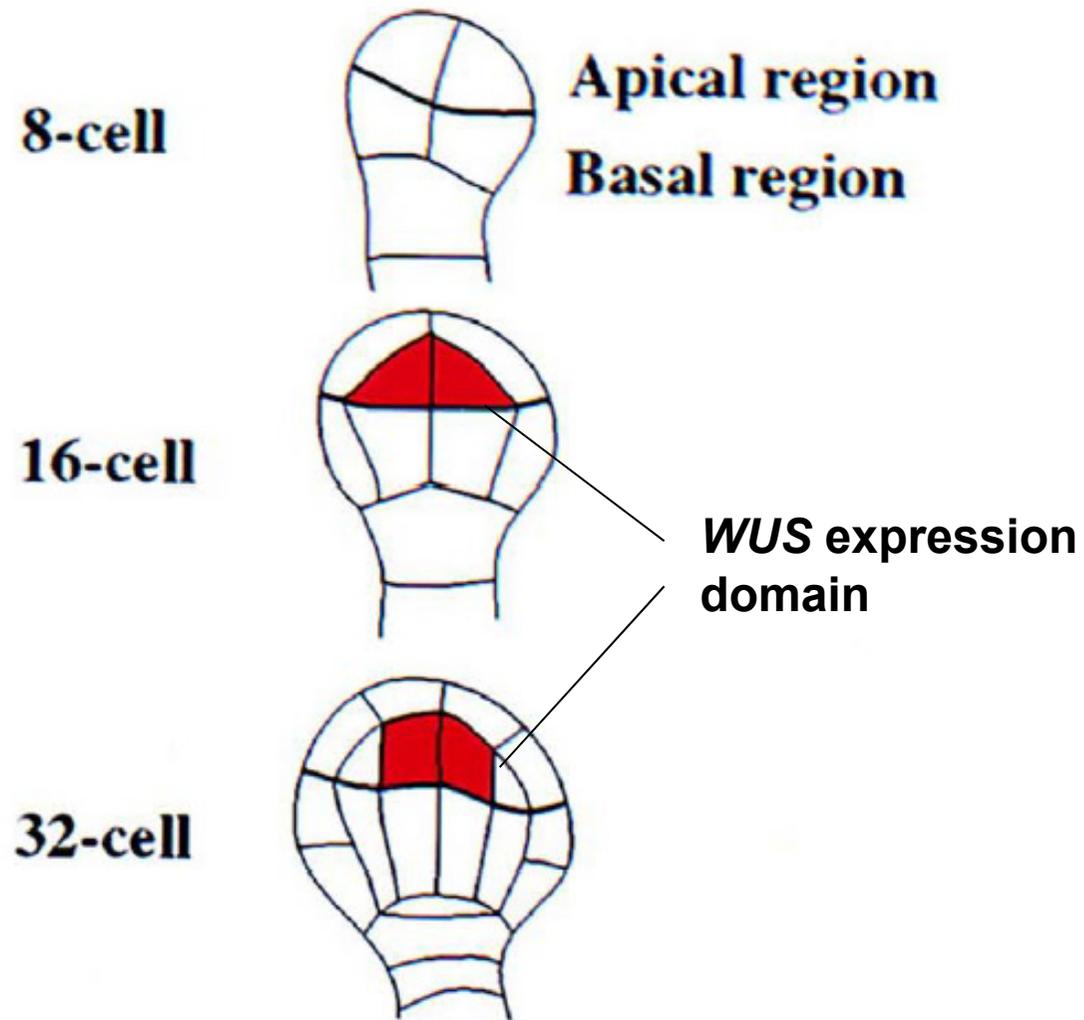


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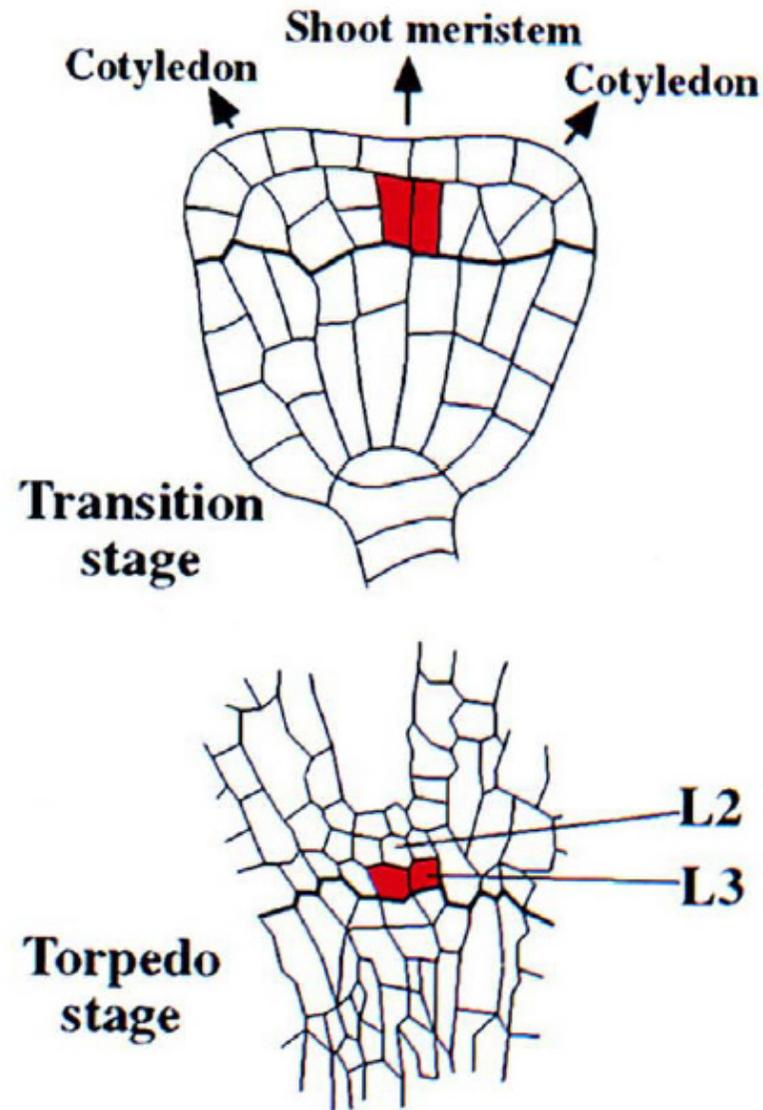
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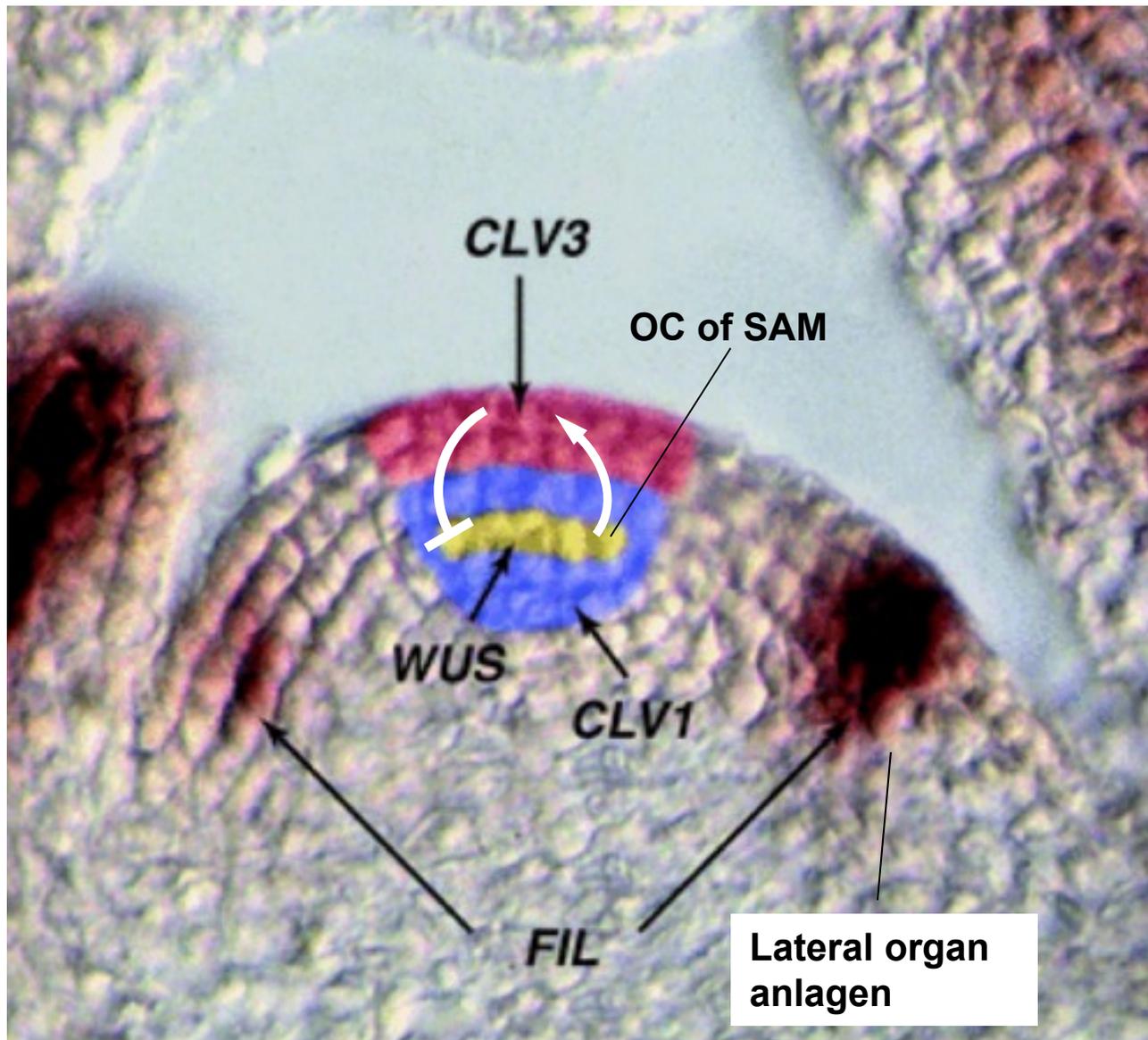
SAM specification



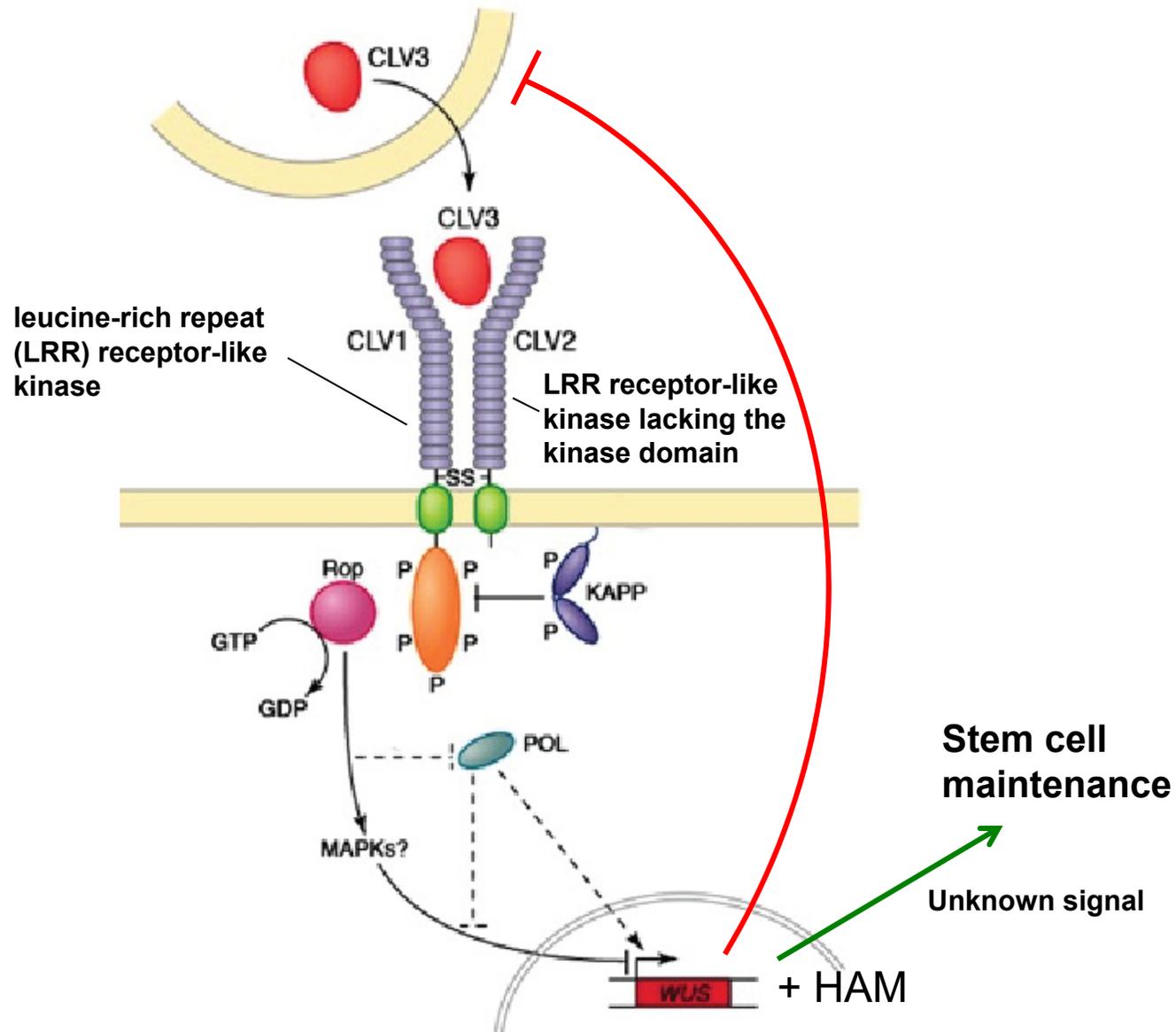
Capron et al., *Arabidopsis Book* (2009)



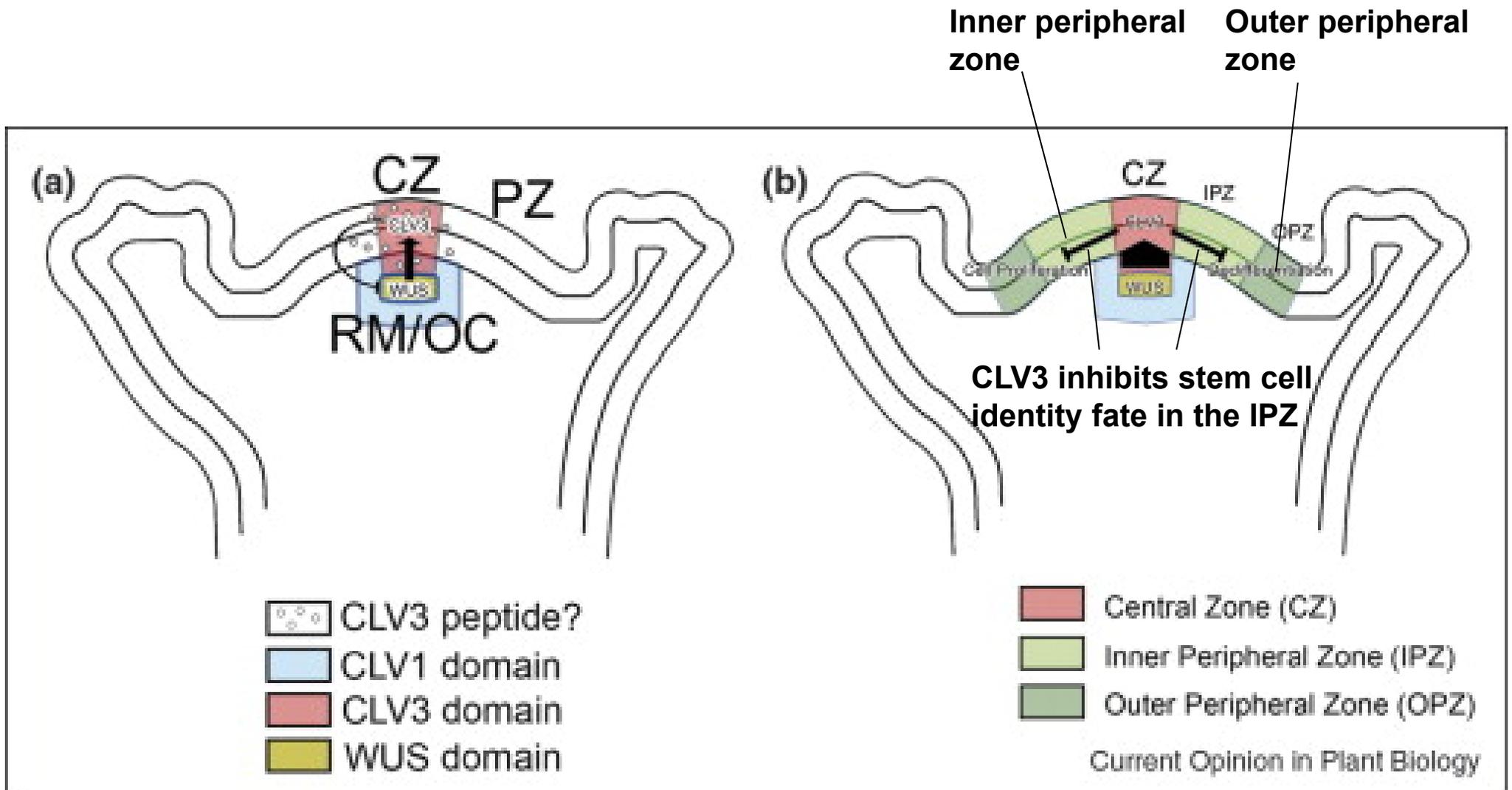
Capron et al., *Arabidopsis Book* (2009)



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

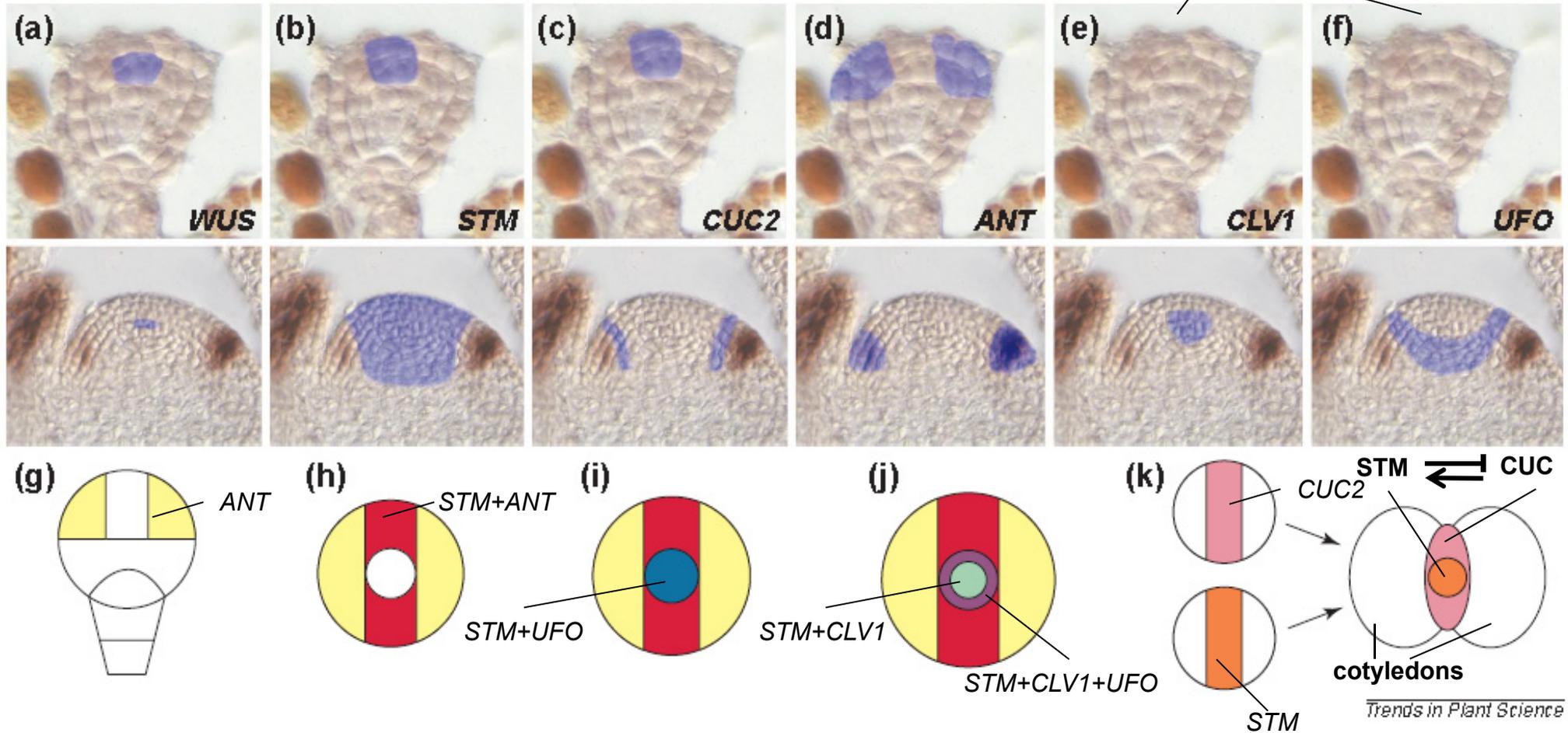


Carles et al., *Trends Plant Sci* (2003)

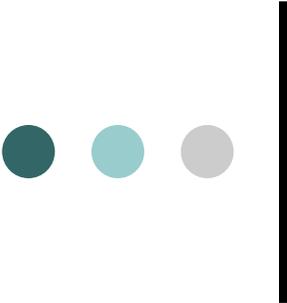


Reddy, *Current Opinion Plant Biol* (2000)

Expression in the later (heart) stage



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



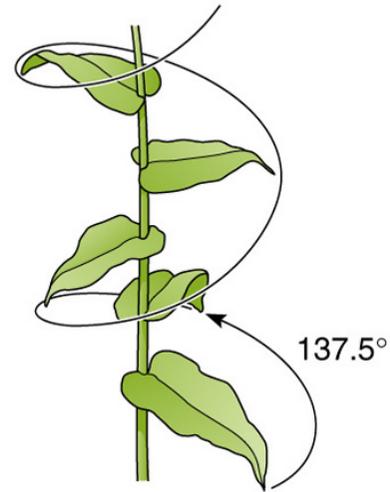
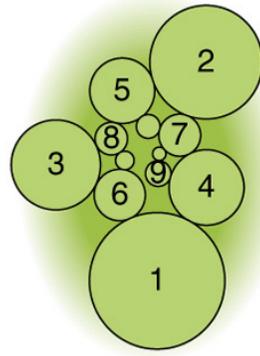
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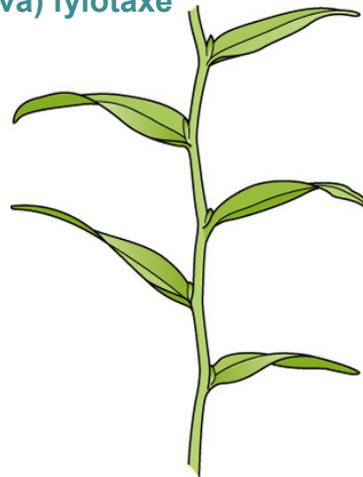
A. Spiral phyllotaxy

Spirální (vřetenovitá) fylotaxe



B. Whorled phyllotaxy

Přeslenitá (kruhová) fylotaxe



distichous
distichie 1 leaf



decussate
dvojčetný 2 leaves
přeslen



tricussate
trojčetný 3 leaves
přeslen

<code>i</code>	<code>ai</code>	abs err	<code>Pi</code>	<code>Qi</code>	<code>Pi/Qi</code>
0	1	6.2E-01	1 /	1 =	1.0000000000000000
1	1	-3.8E-01	2 /	1 =	2.0000000000000000
2	1	1.2E-01	3 /	2 =	1.5000000000000000
3	1	-4.9E-02	5 /	3 =	1.6666666666666667
4	1	1.8E-02	8 /	5 =	1.6000000000000000
5	1	-7.0E-03	13 /	8 =	1.6250000000000000
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 =	1.6180555555555556
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
20	1	3.7E-09	17711 /	10946 =	1.618033985017358
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 =	1.618033988738303
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...

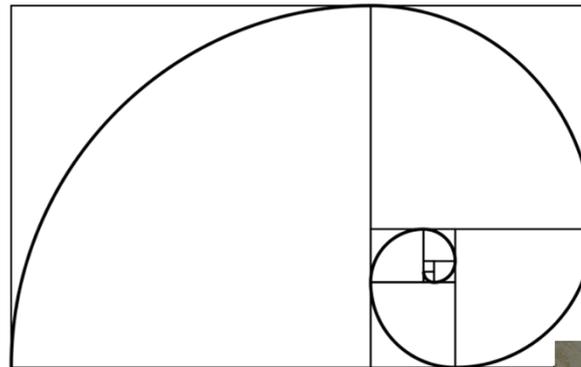
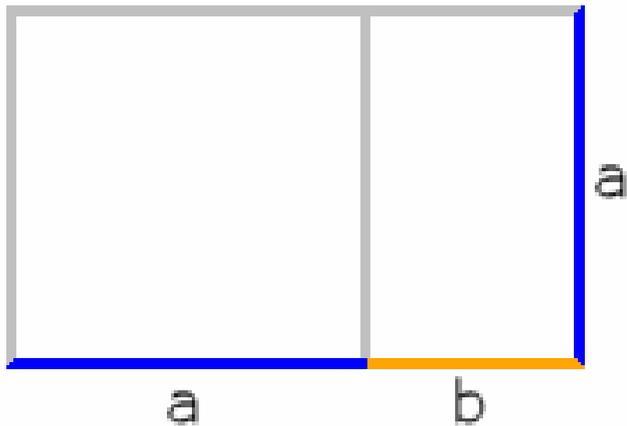
$$\varphi = \frac{1 + \sqrt{5}}{2} \approx 1,618\ 033\ 988\ 749\ 894\ 848 \dots$$

Wikipedia



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



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



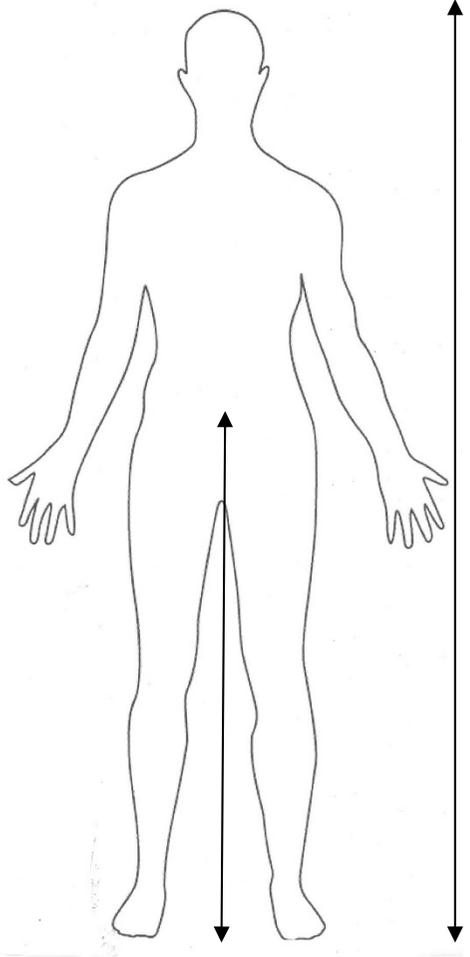
Fibonacci series – the beauty of math

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



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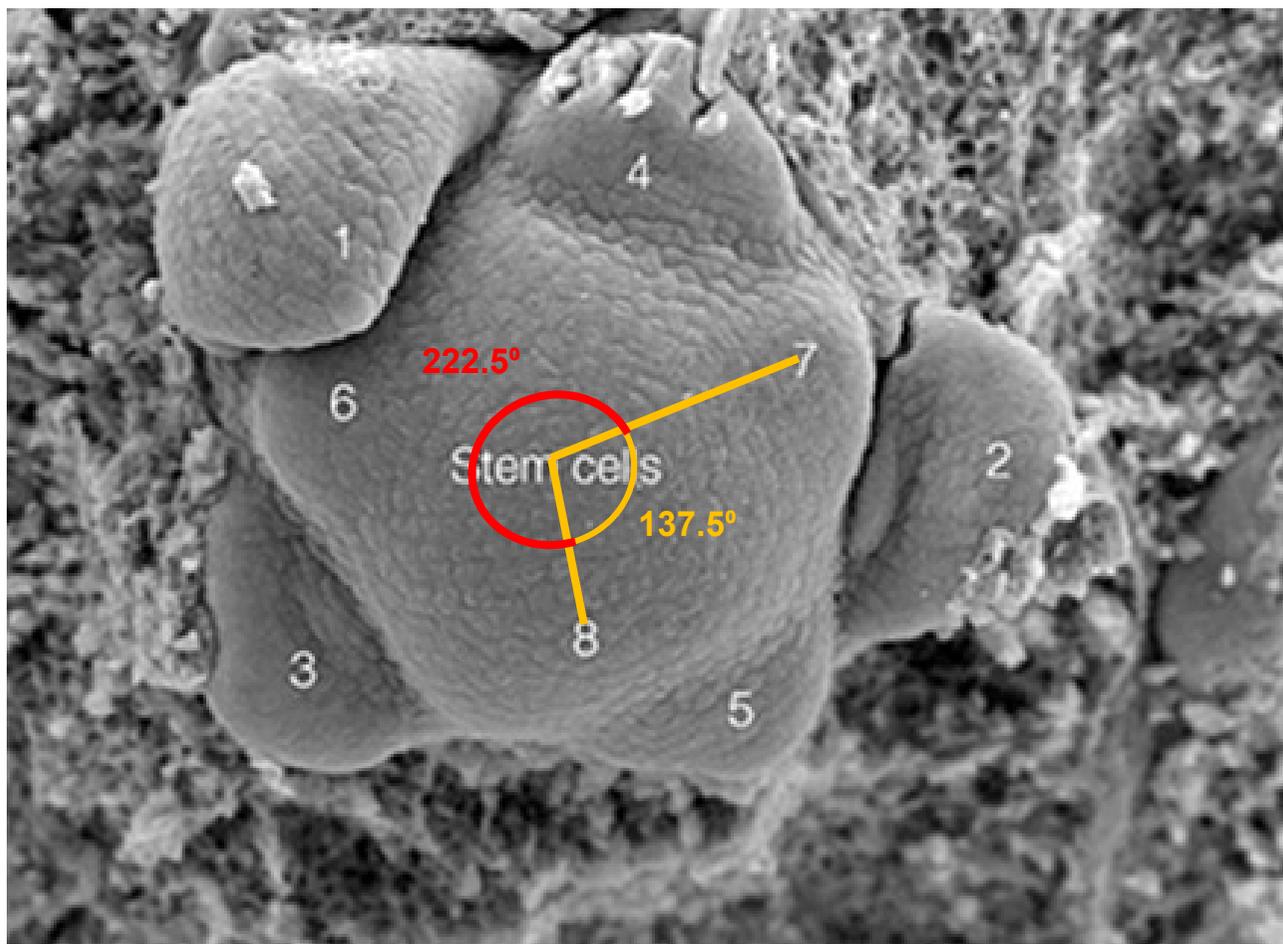
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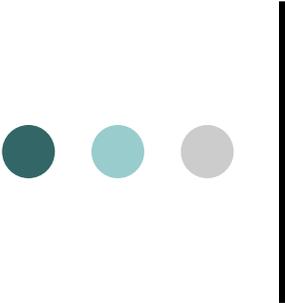
Golden mean in nature

<https://youtu.be/nt2OIMAJj6o>





$$222.5/137.5 = 1.618$$

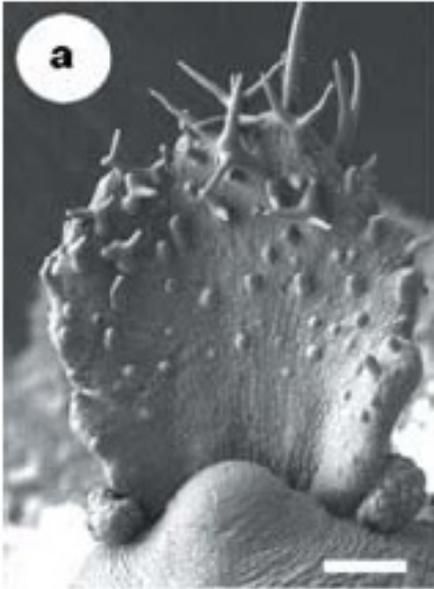


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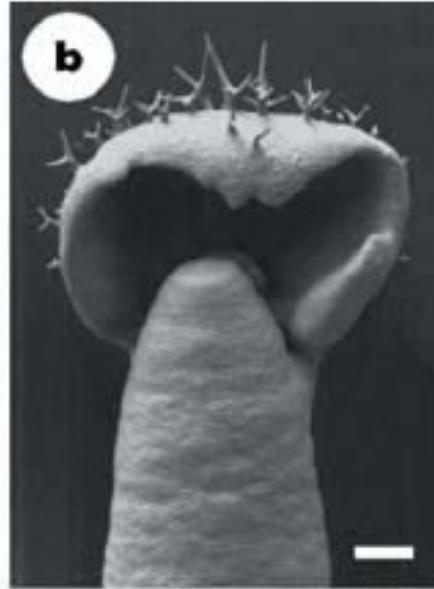
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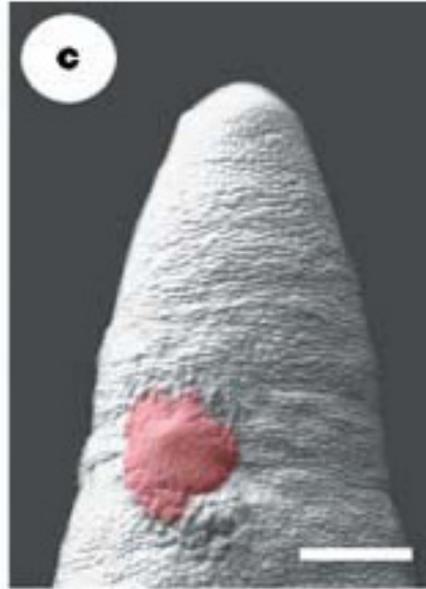
pin1 + IAA (SAM)



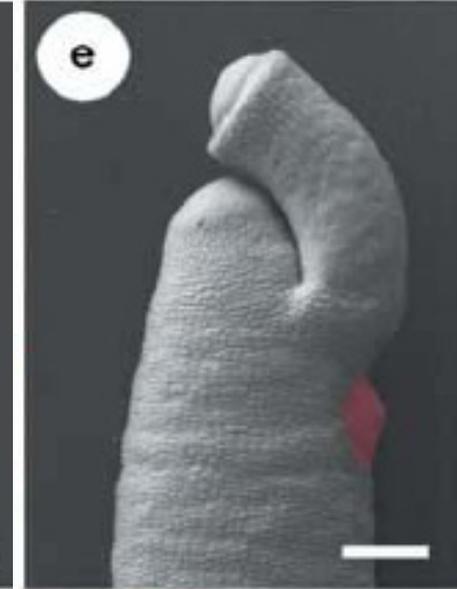
pin1, lfy + IAA (IM)



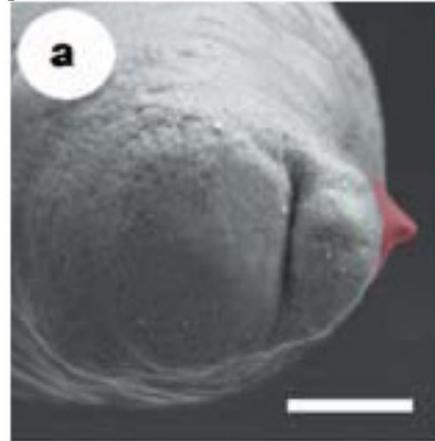
mp + IAA



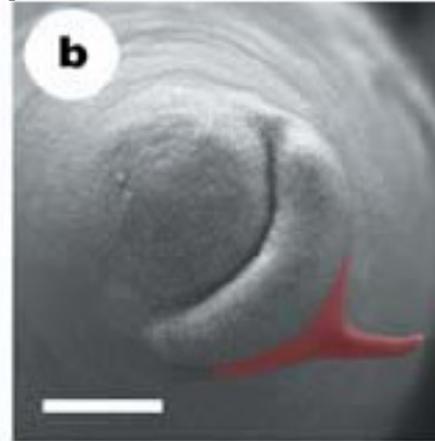
pid1 + IAA



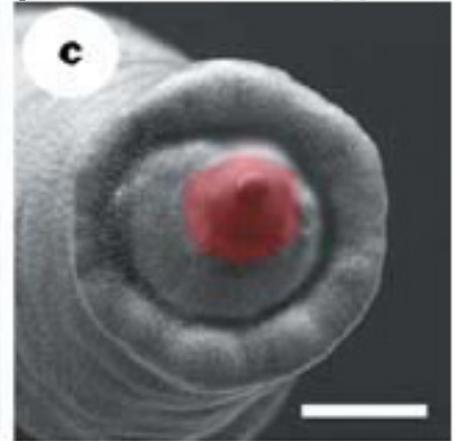
pin1 + IAA



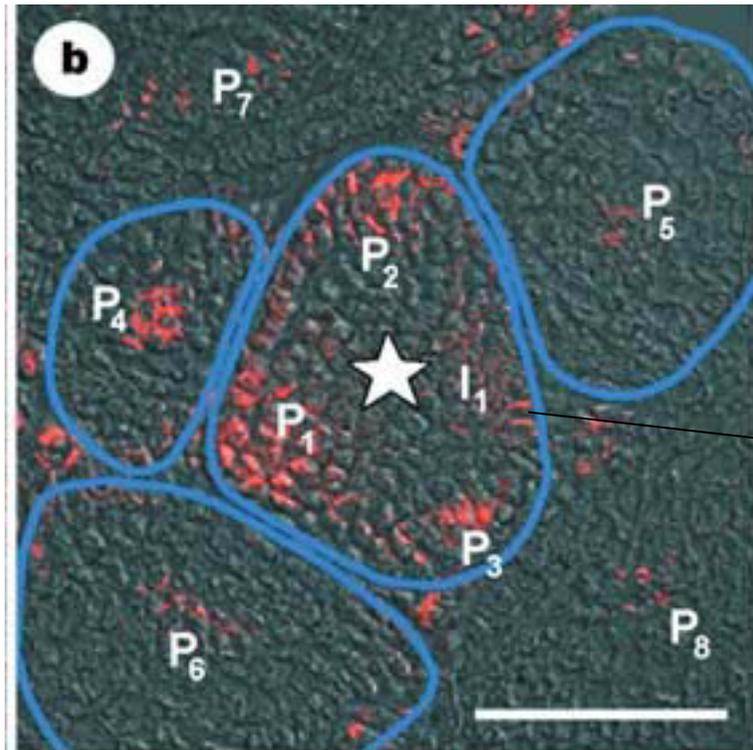
pin1 + more IAA



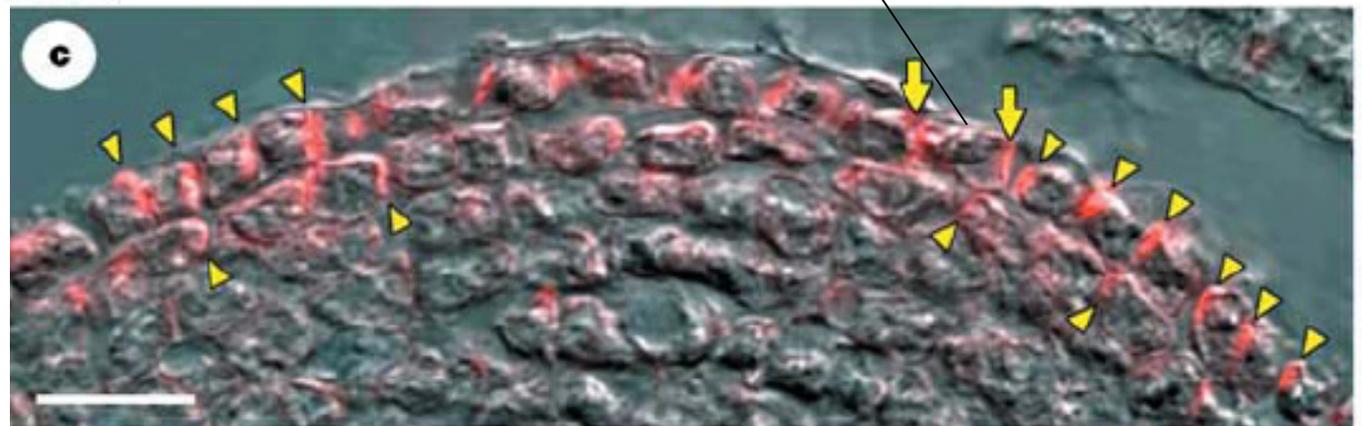
pin1 + central applied IAA



Reinhardt et al., *Nature* (2005)

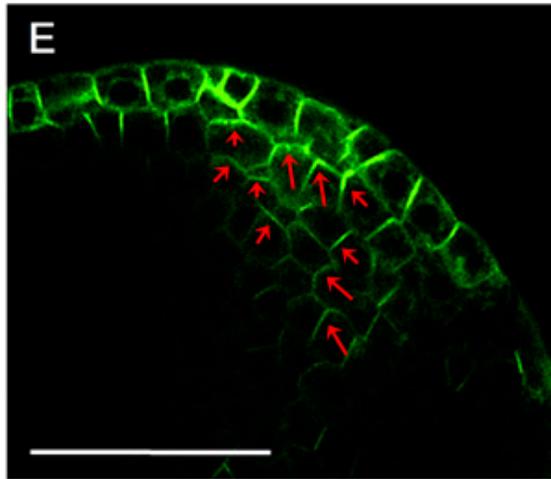


Position of incipient primordium



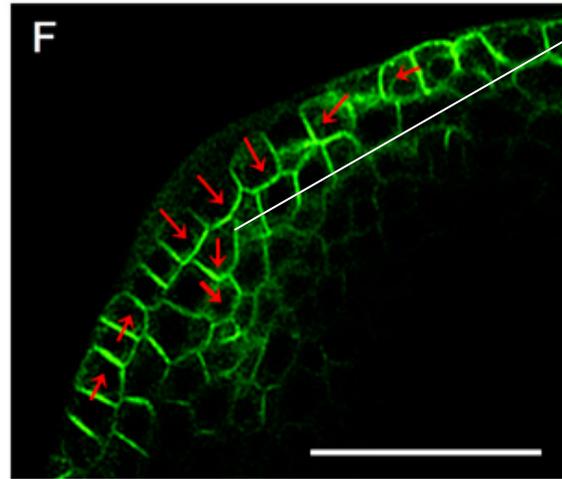
Reinhardt et al., *Nature* (2005)

10 h after IAA application



ProPIN1:PIN1-GFP

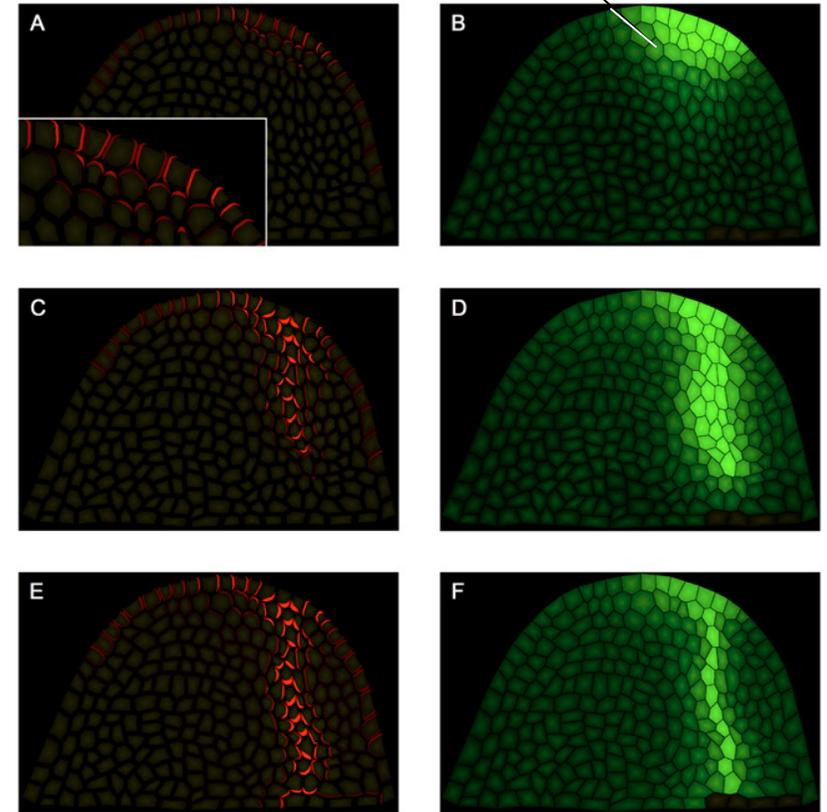
20 h after IAA application



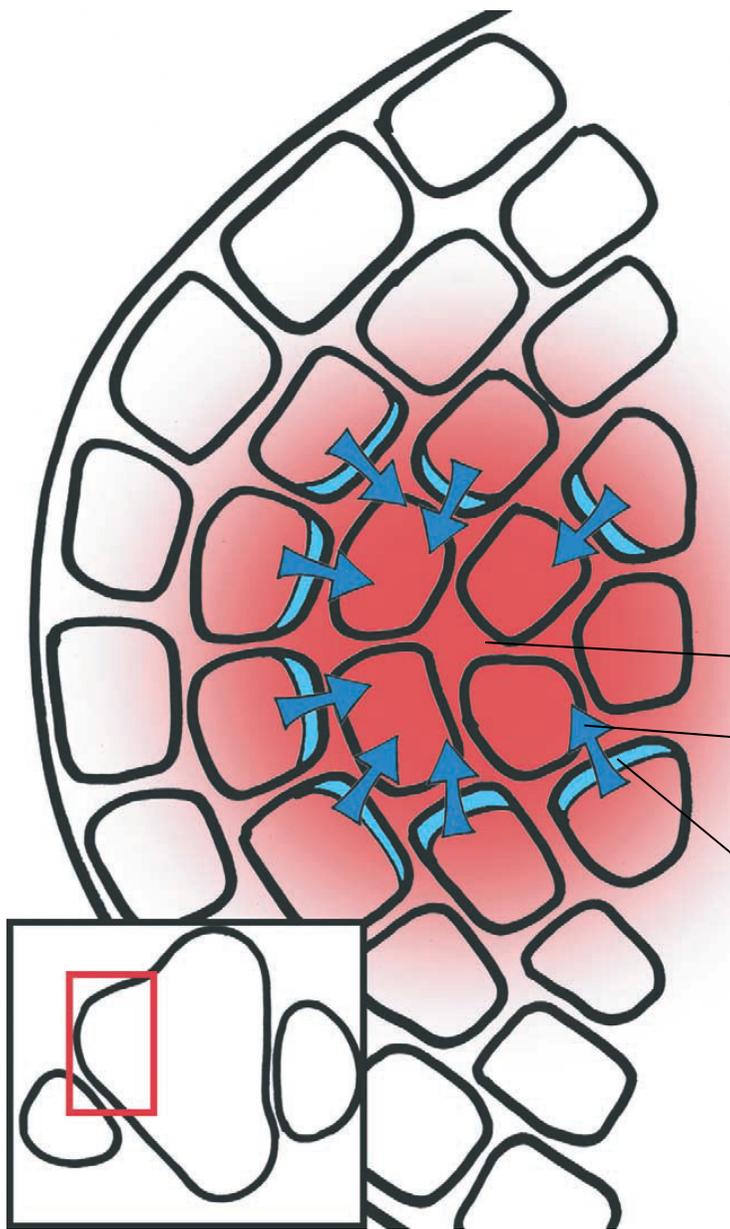
ProPIN1:PIN1-GFP

PIN1 relocalization

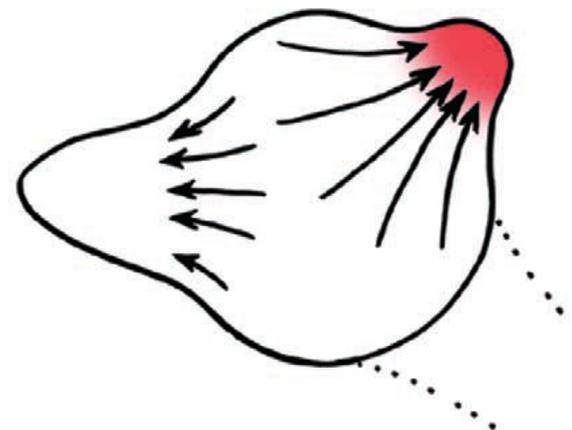
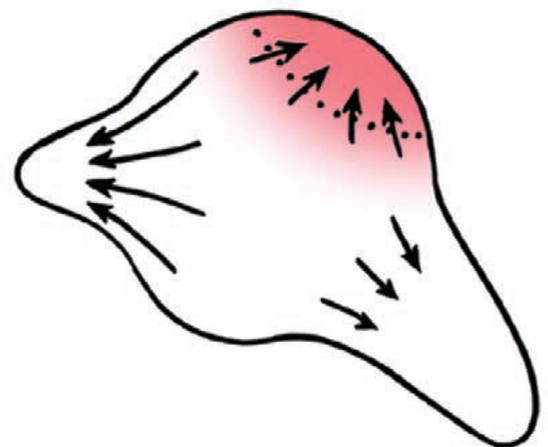
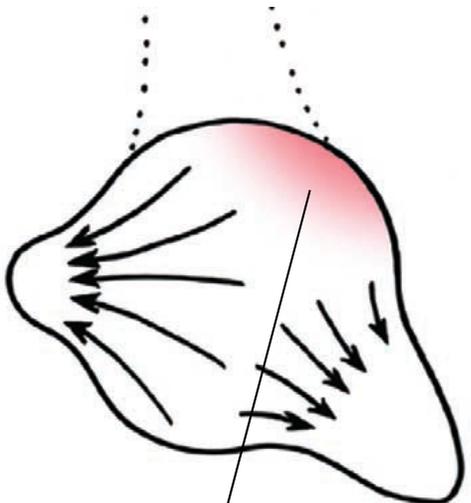
Auxin accumulation



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



auxin concentration maxima
 direction of the auxin flow
 PIN1



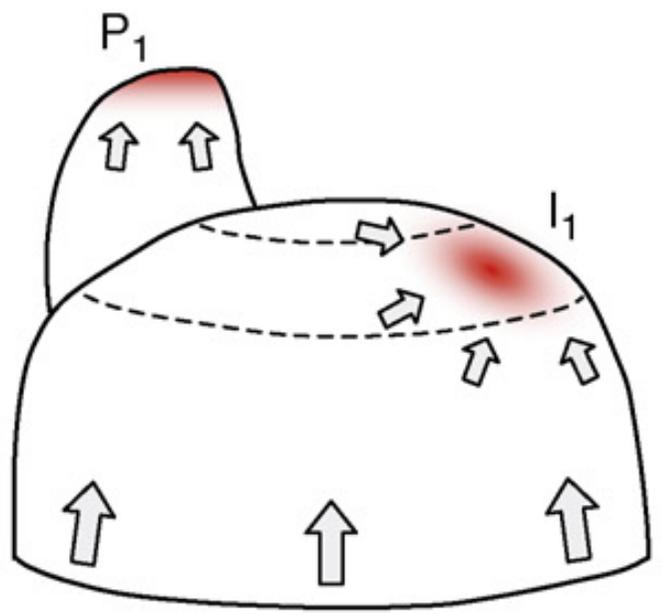
Reinhardt, *Current Opinion Plant Biol* (2005)



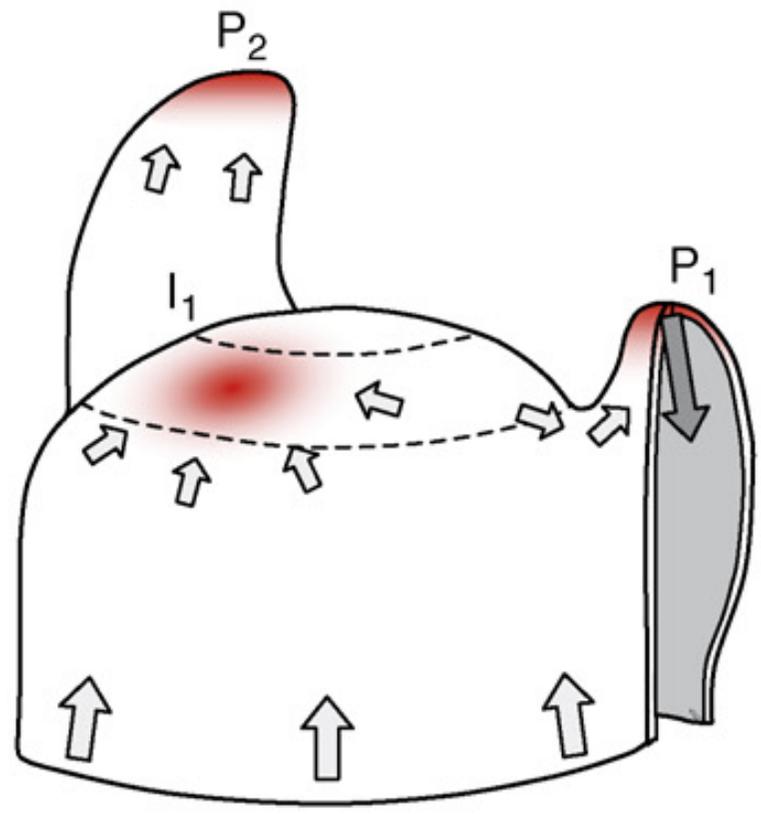
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(a)



(b)

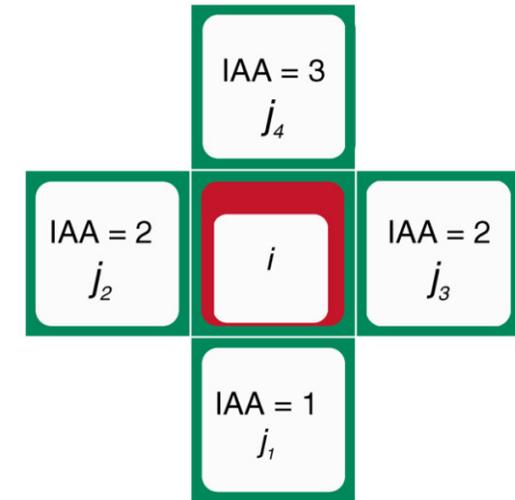
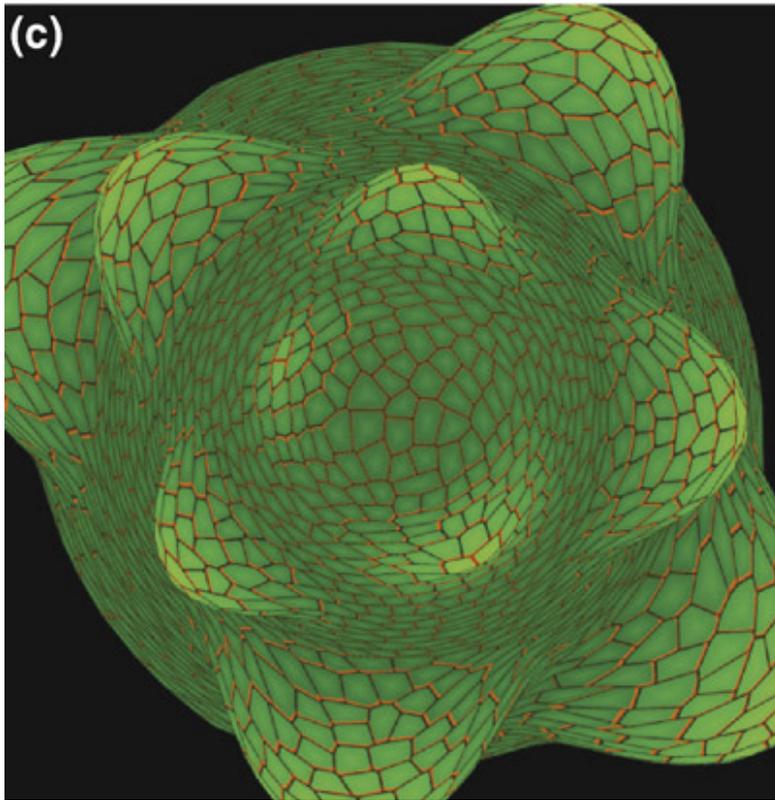


Kuhlermaier, *Trends Plant Sci* (2007)



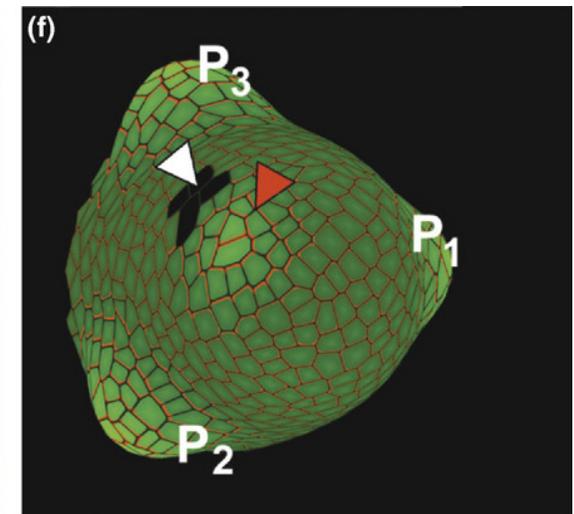
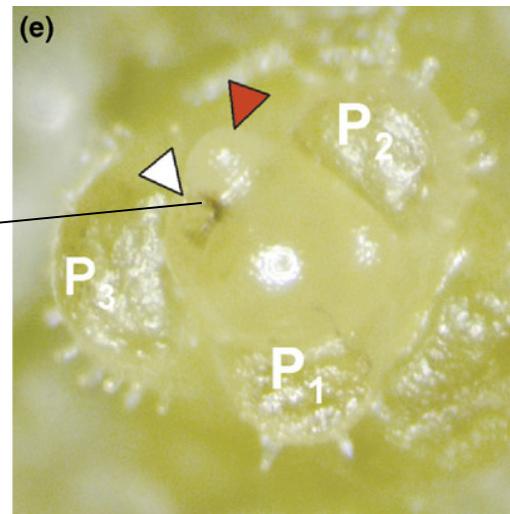
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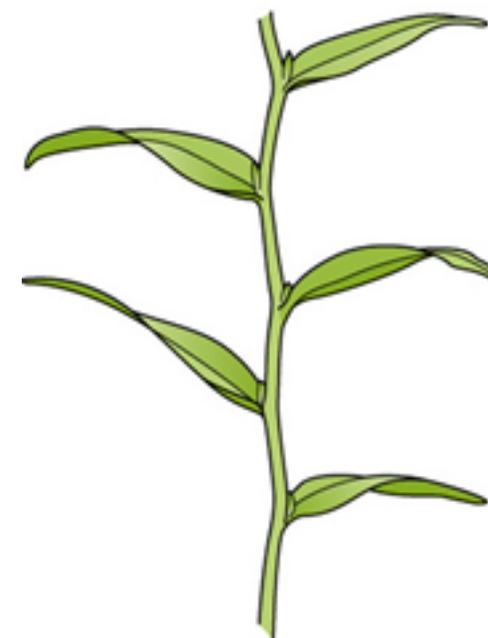
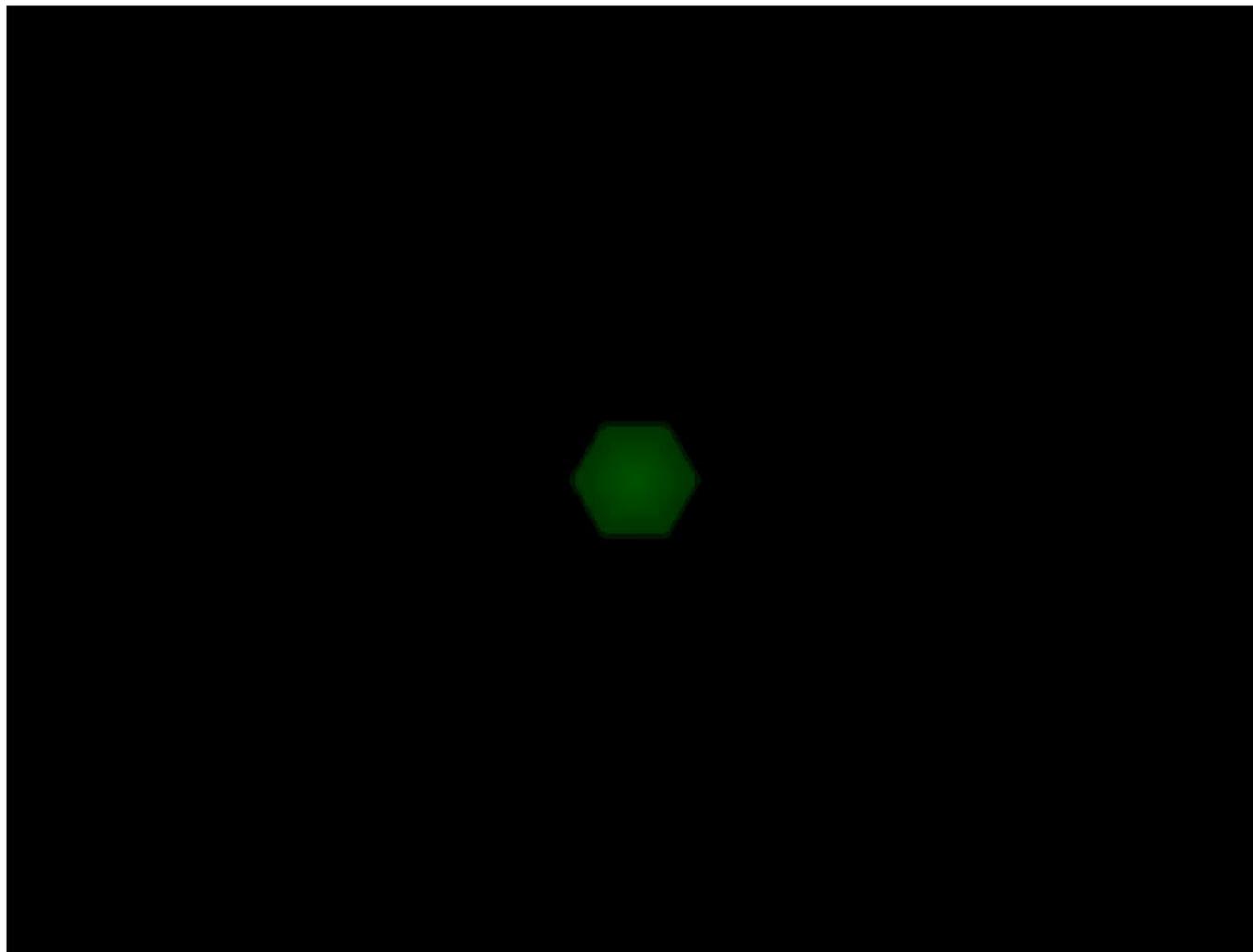
TRENDS in Plant Science

Laser ablation of incipient primordium



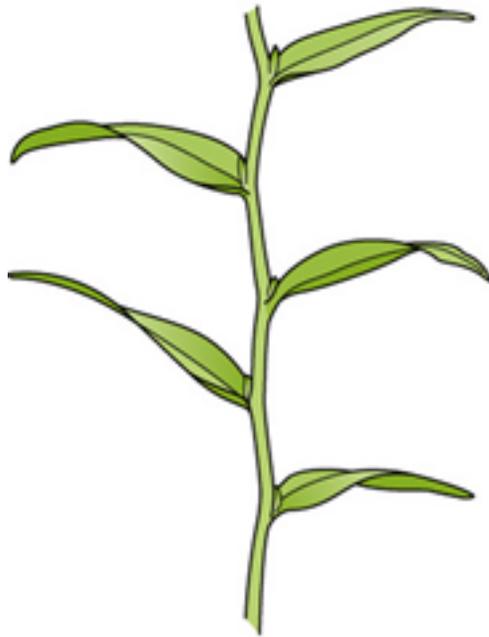
Kuhlermaier, *Trends Plant Sci* (2007)

Distichous Distichie



1 leaf

Distichous Distichie

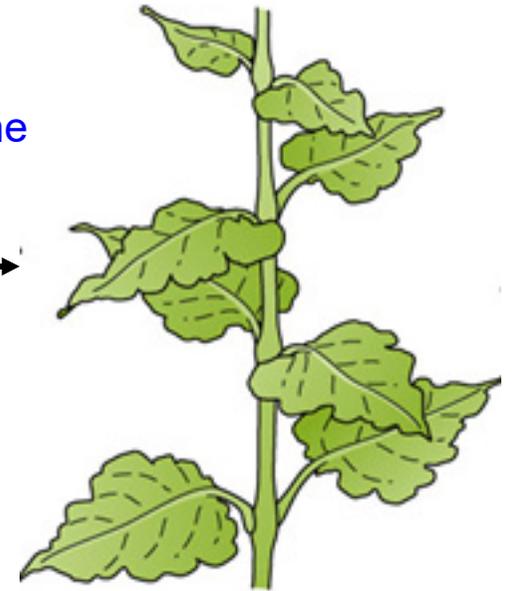


1 leaf

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

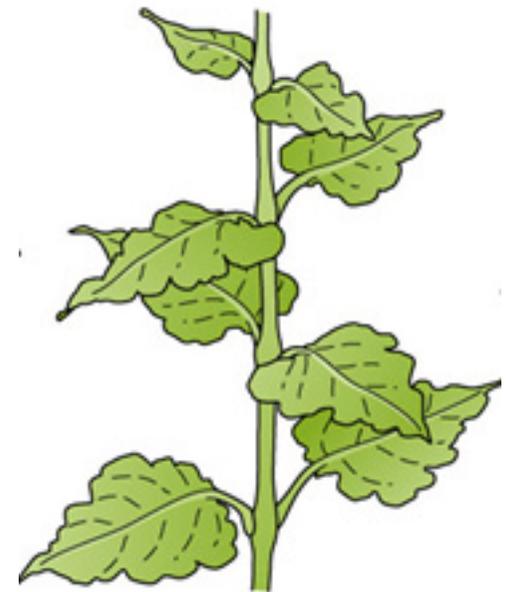


Decussate Dvojčetný přeslen



2 leaves

Decussate Dvojčetný přeslen



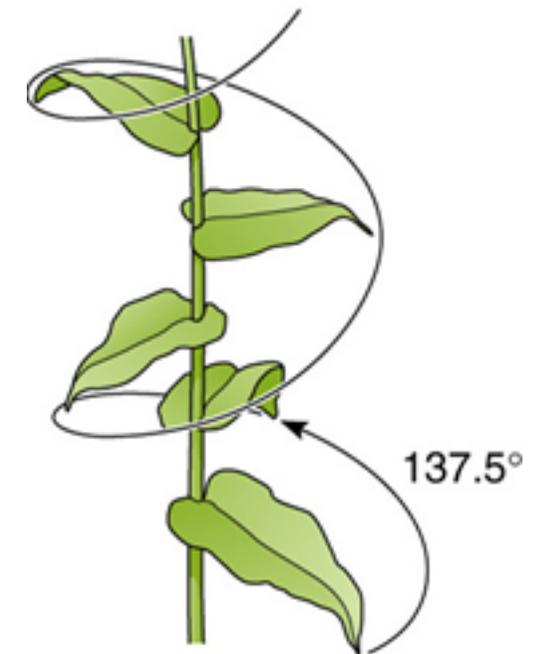
2 leaves

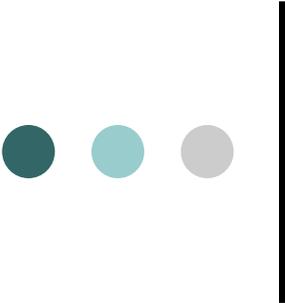
Tricussate Trojčetný přeslen



3 leaves

Spiral Spirálovitá fylotaxe

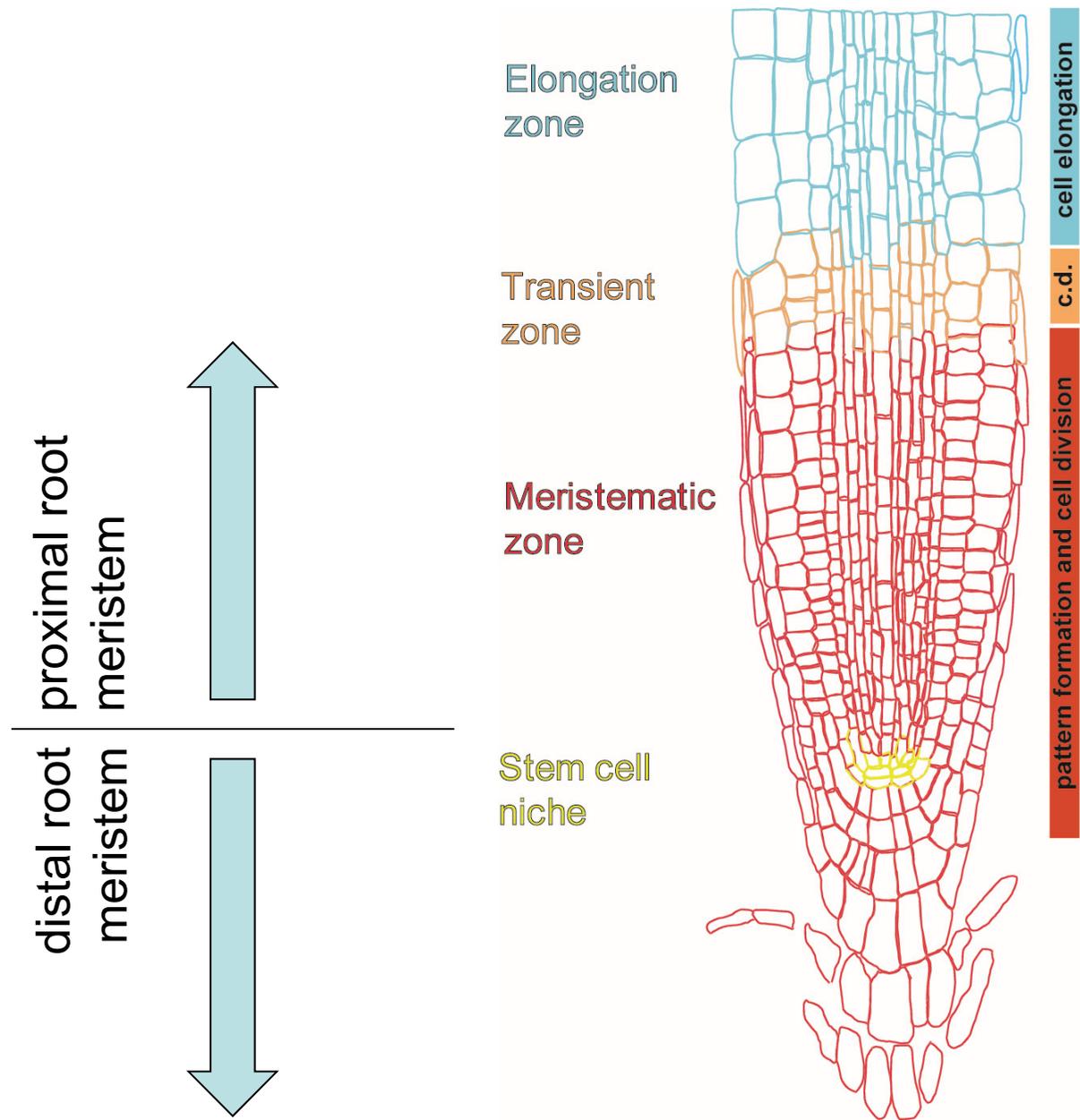




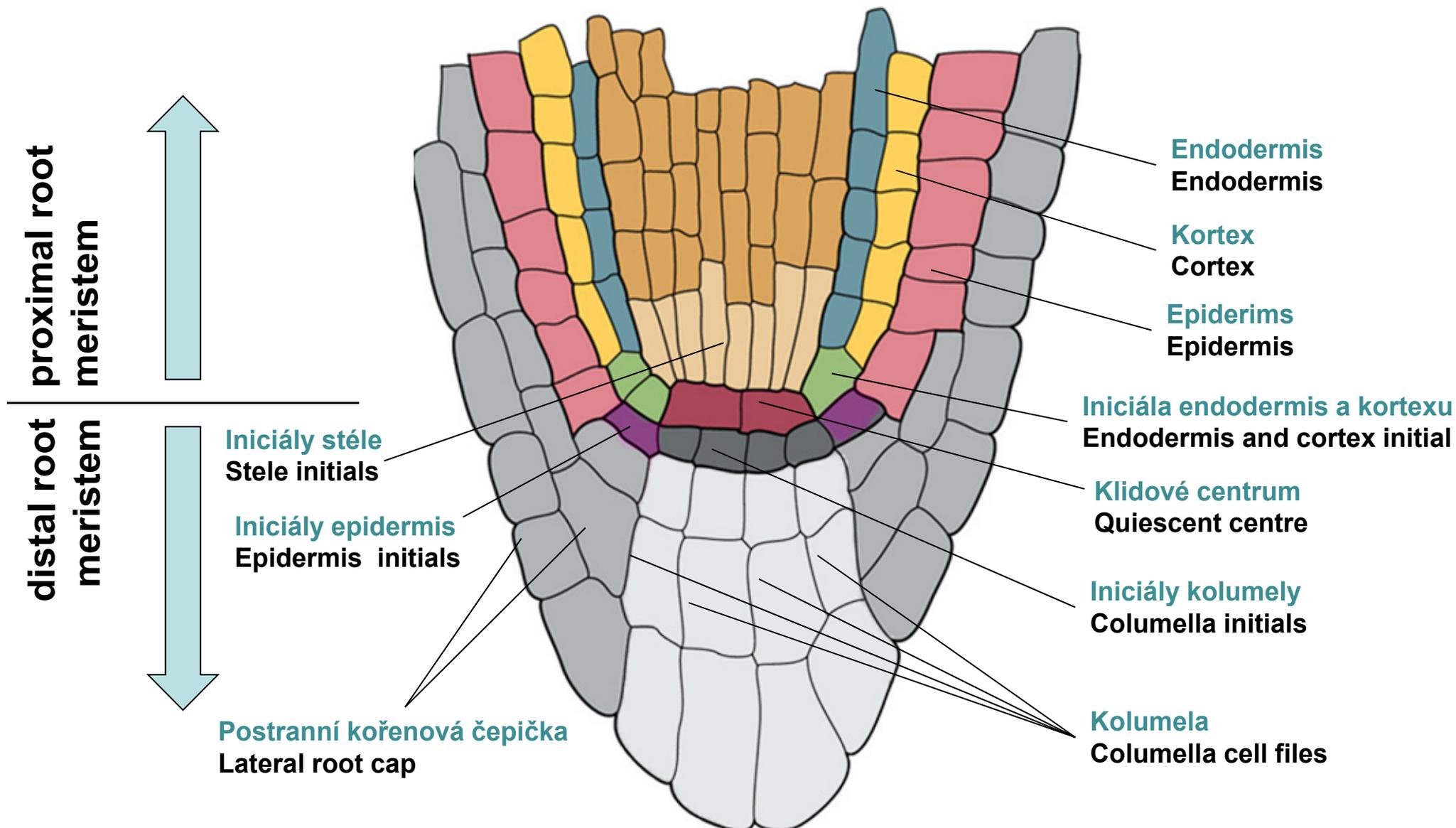
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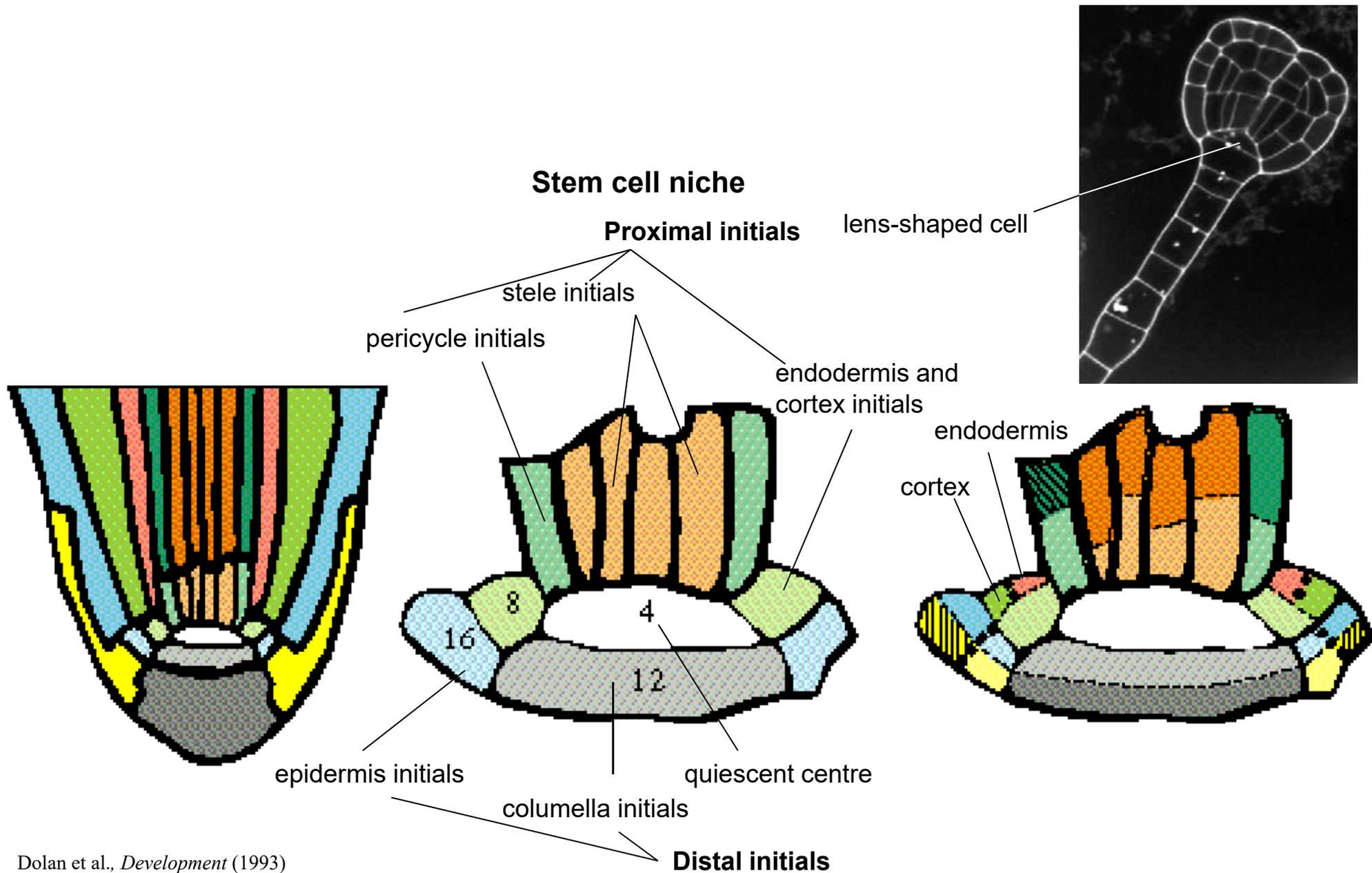
Postembryonic Plant Development

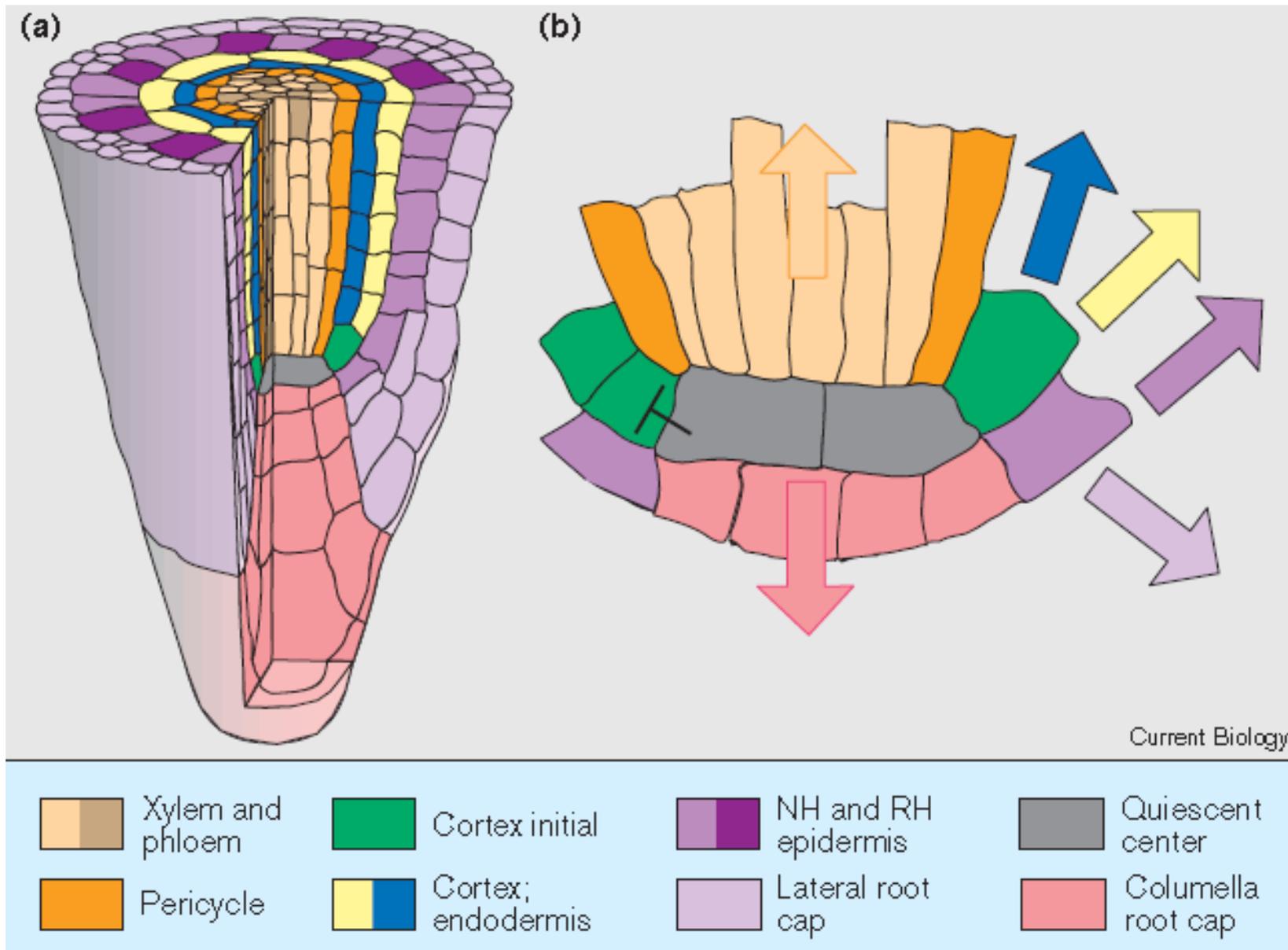
- The role of plant meristems in the plant postembryonic development
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 - Molecular determinants of phyllotaxy
- Root apical meristem (RAM)
 - RAM structure



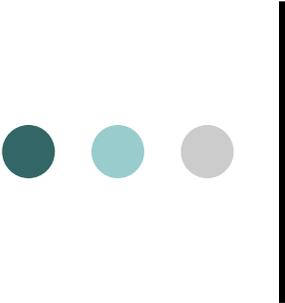
Benkova and Hejatko, *Plant Mol Biol* (2008)







Benfey and Scheres, *Current Biol* (2000)



Outline of Lesson 8

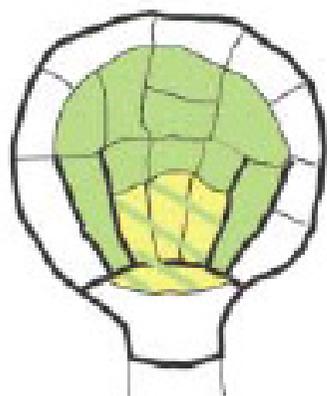
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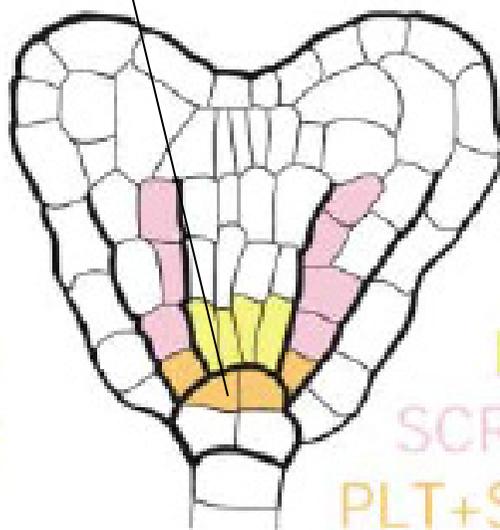
Auxin gradient → PLT

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

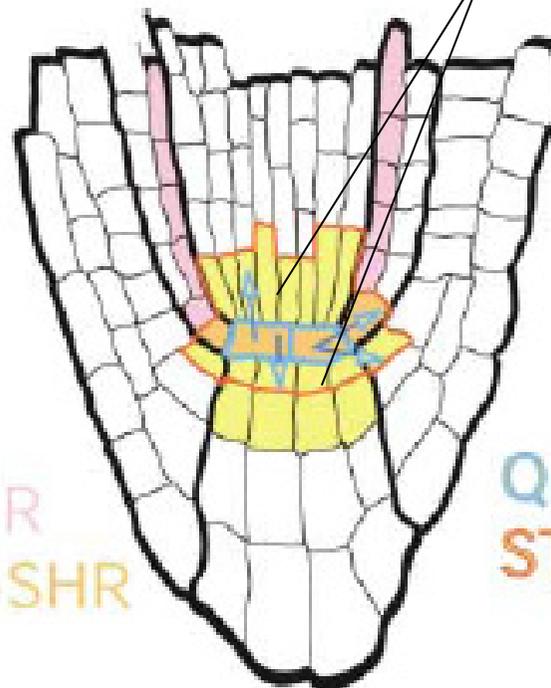
QC-mediated stem cell identity specification



MP
PLT



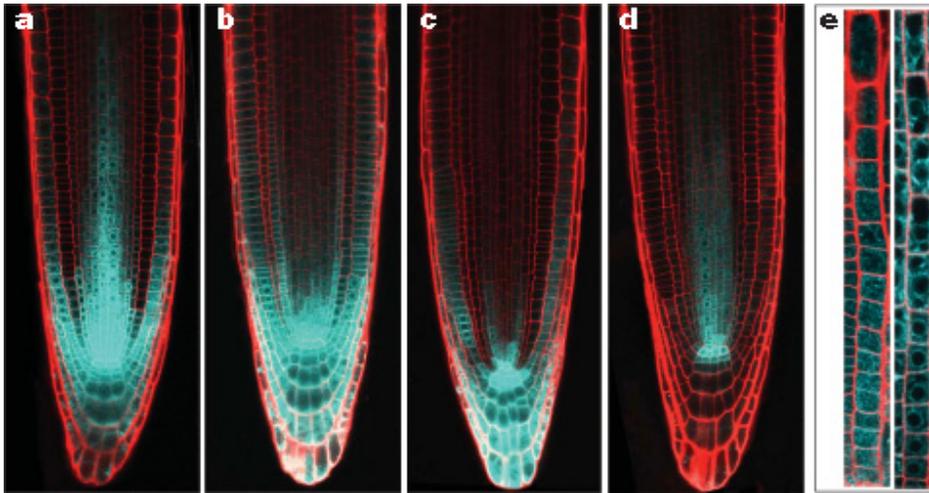
PLT
SCR+SHR
PLT+SCR+SHR



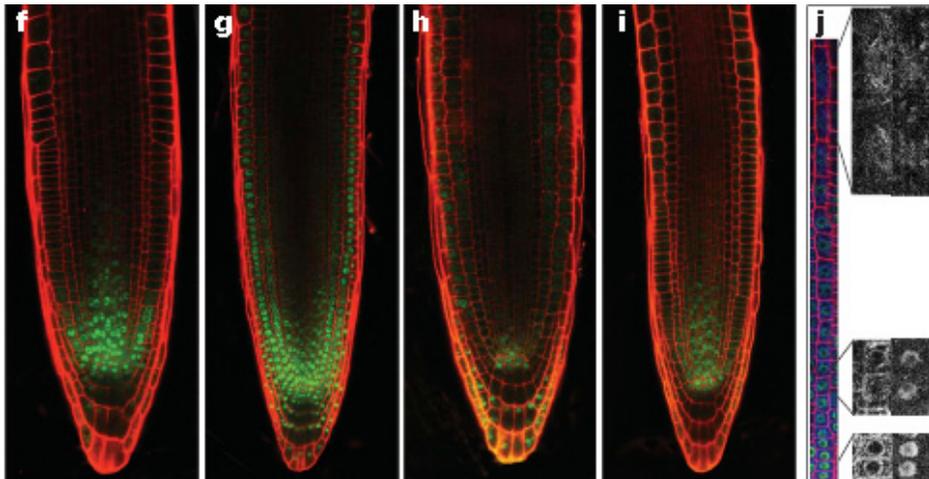
QC
STEM CELLS

Aida et al., *Cell* (2004)

ProPLT1:CFP ProPLT2:CFP ProPLT3:CFP ProBBM:CFP



ProPLT1:PLT1-CFP ProPLT2:PLT2-CFP ProPLT3:PLT3-CFP ProBBM:BBM-CFP



PLT1, 2, BBM
gradient

Differentiated
cells

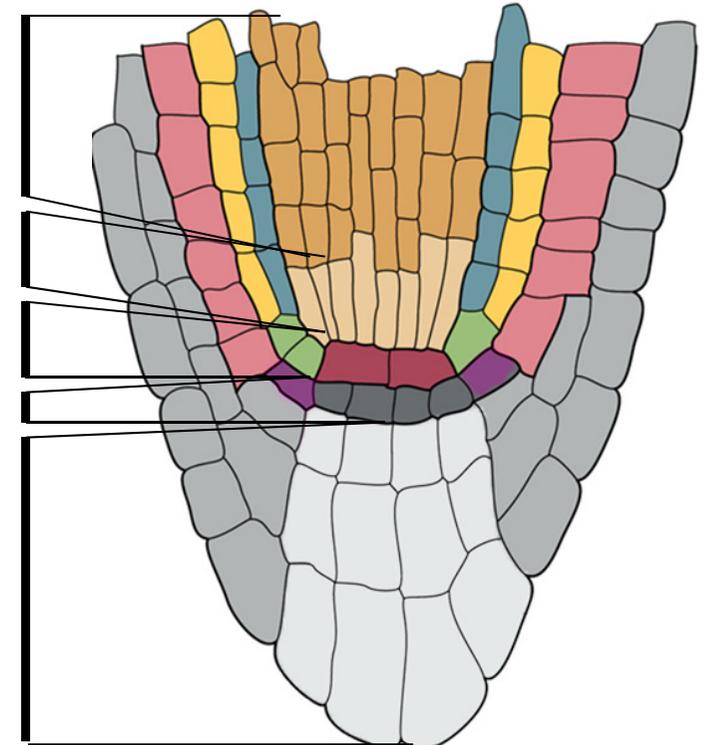
Proximal
initials

QC

Distal
initials

Differentiated
cells

PLT2,3
gradient



Galinha et al., *Nature* (2007)

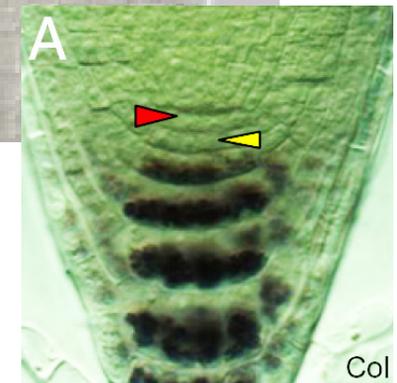
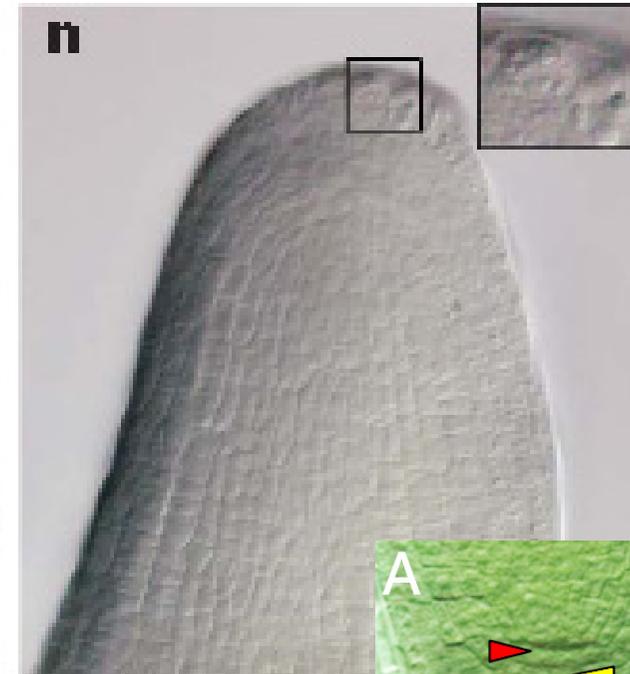


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PLTs are master regulatory genes

Pro35S-PLT2-GR



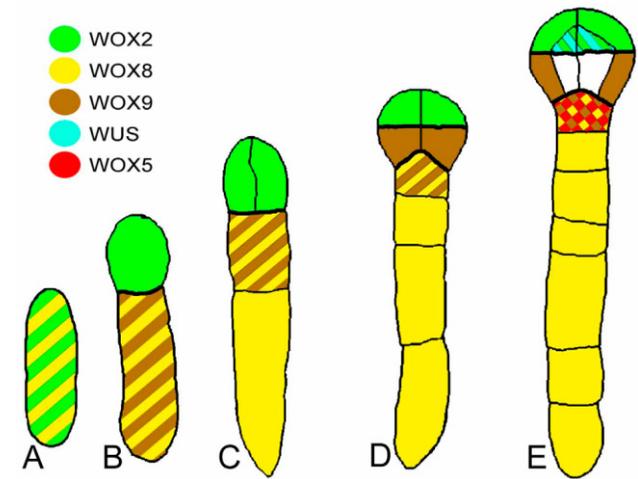
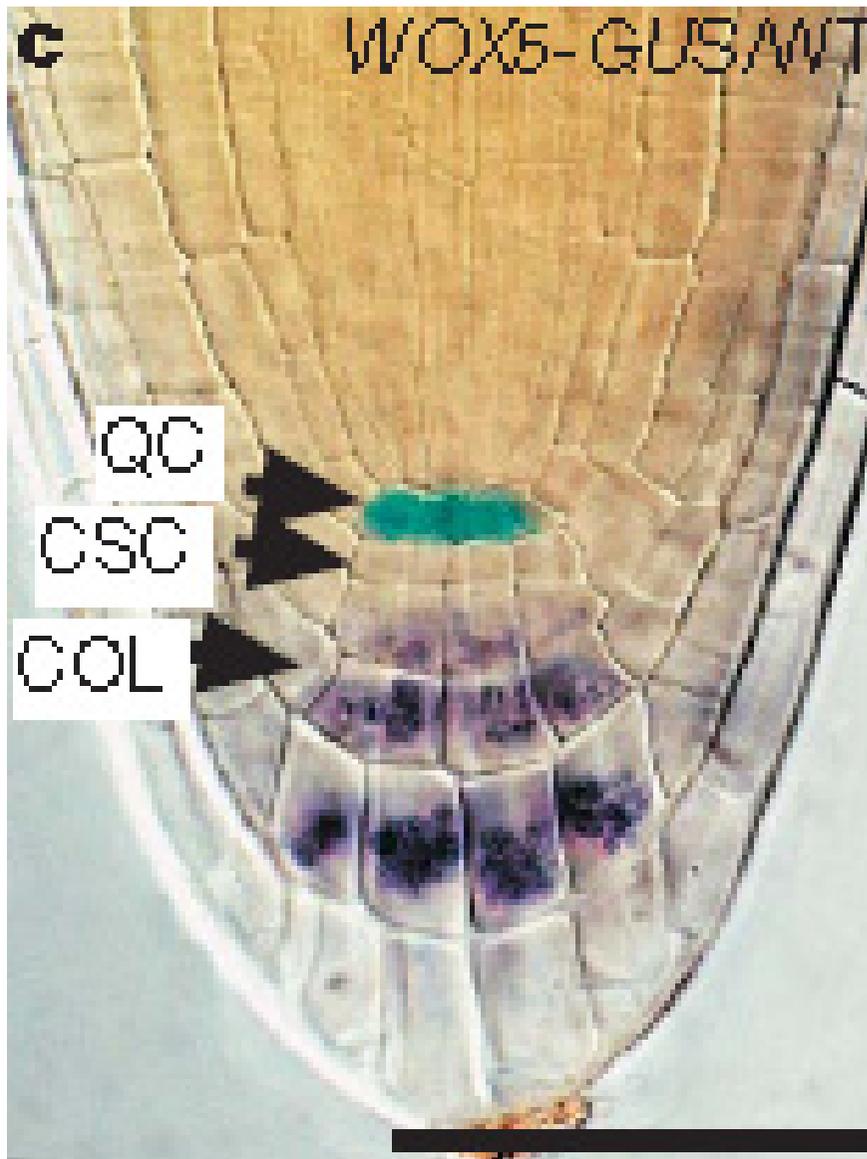
Galinha et al., *Nature* (2007)

Ding et al., *PNAS* (2010)

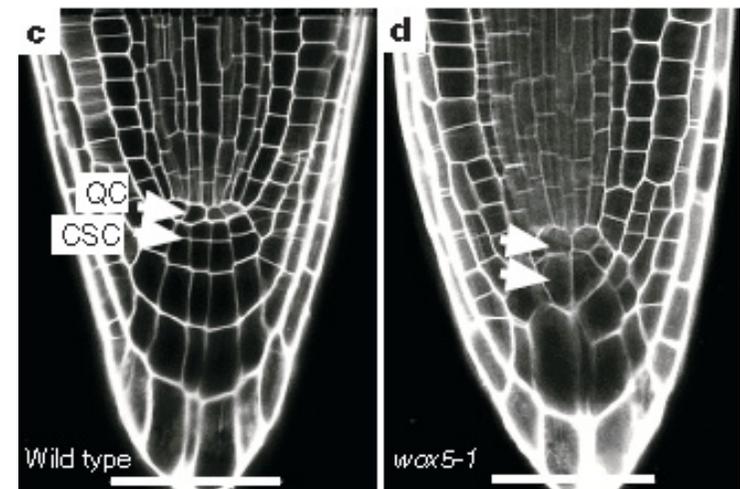


INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

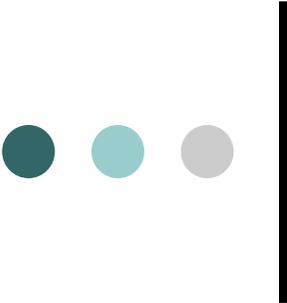
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cellular pattern and cell identity of the stem cell niche affected



Sarkar et al., *Nature* (2007)



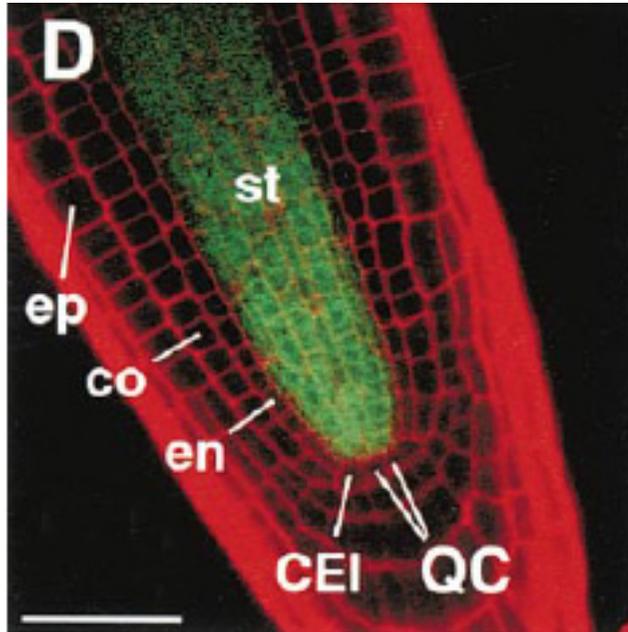
Outline of Lesson 8

Postembryonic Plant Development

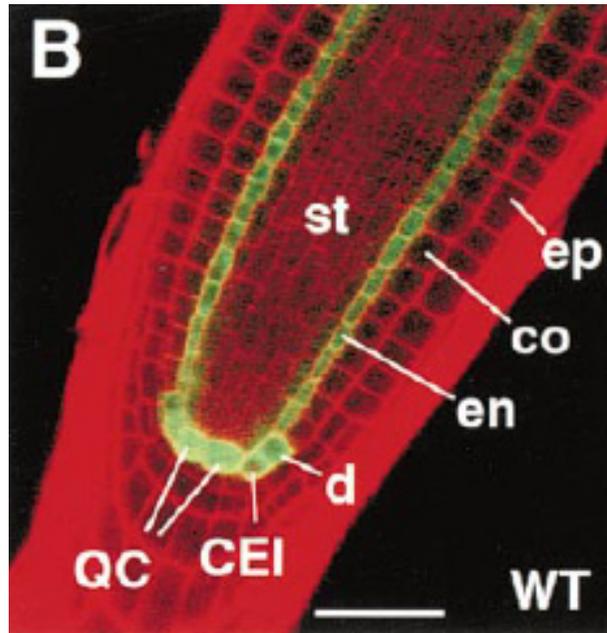
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SHR and SCR, TFs from the GRAS family

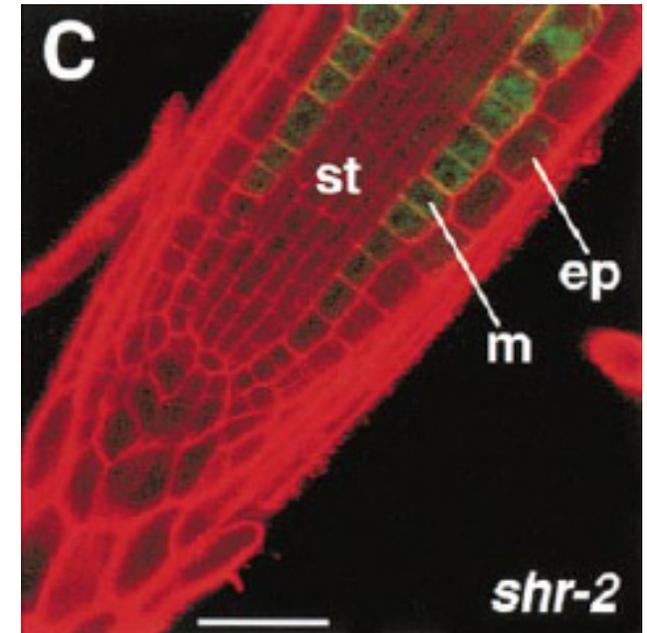
ProSHR:GFP/WT



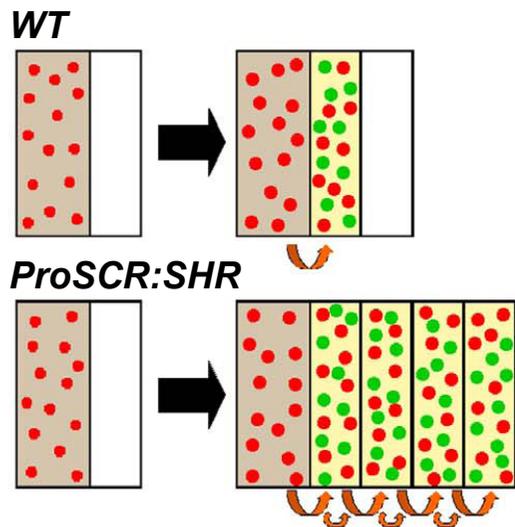
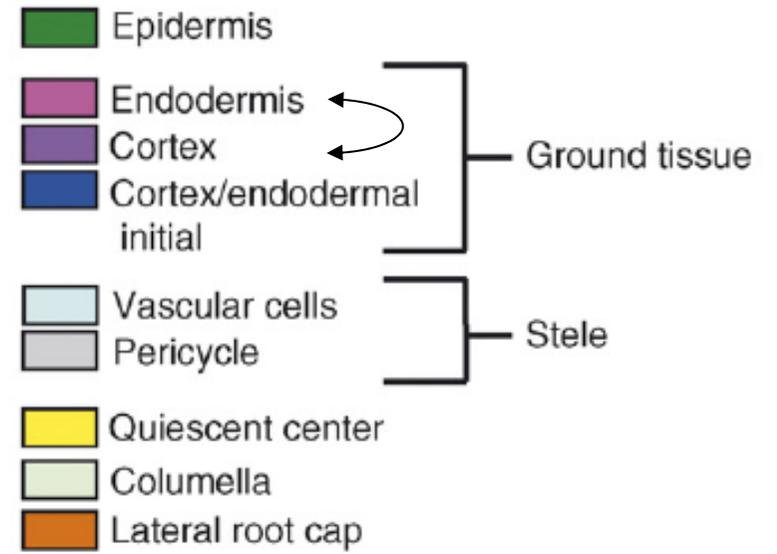
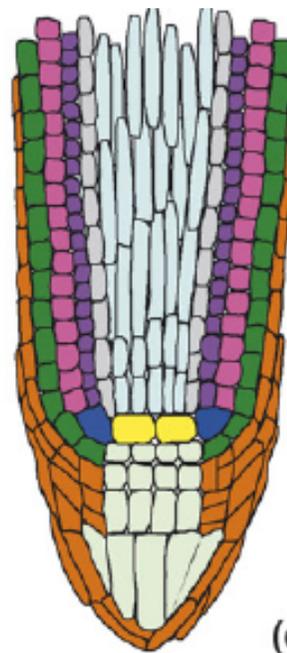
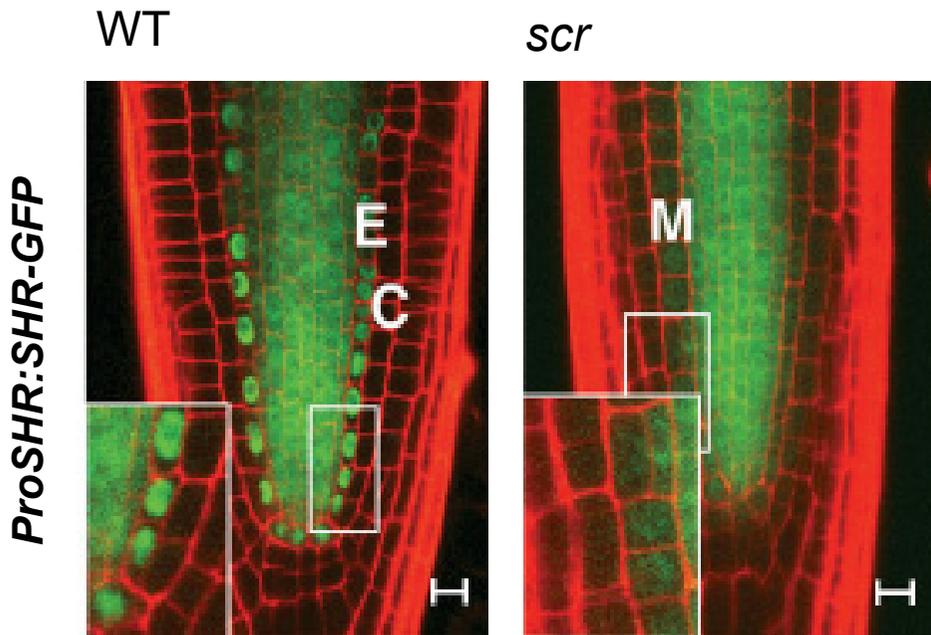
ProSCR:GFP/WT



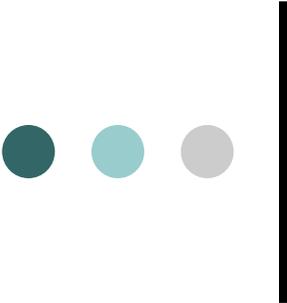
ProSCR:GFP/shr-2



Helariutta et al., *Cell* (2000)



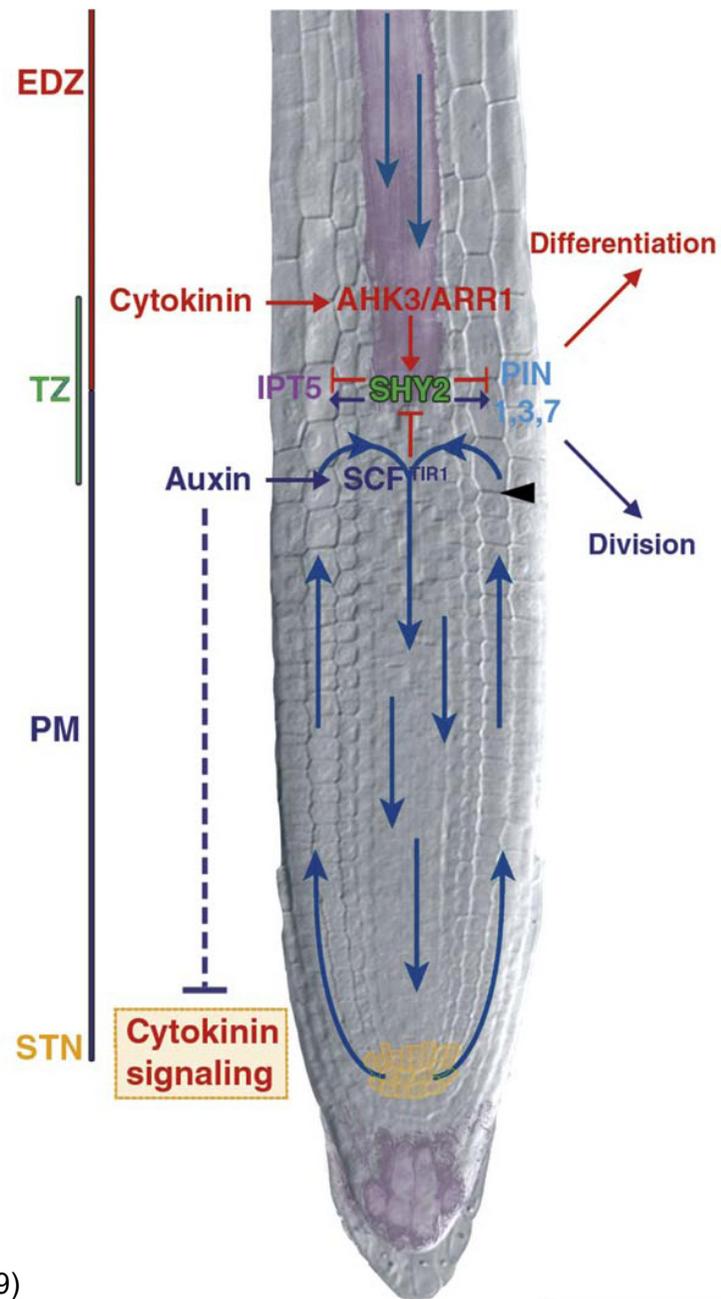
Petricka & Benfey, *Curr Opin Genet Dev* (2008)



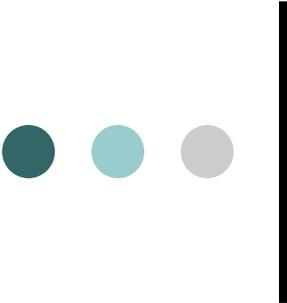
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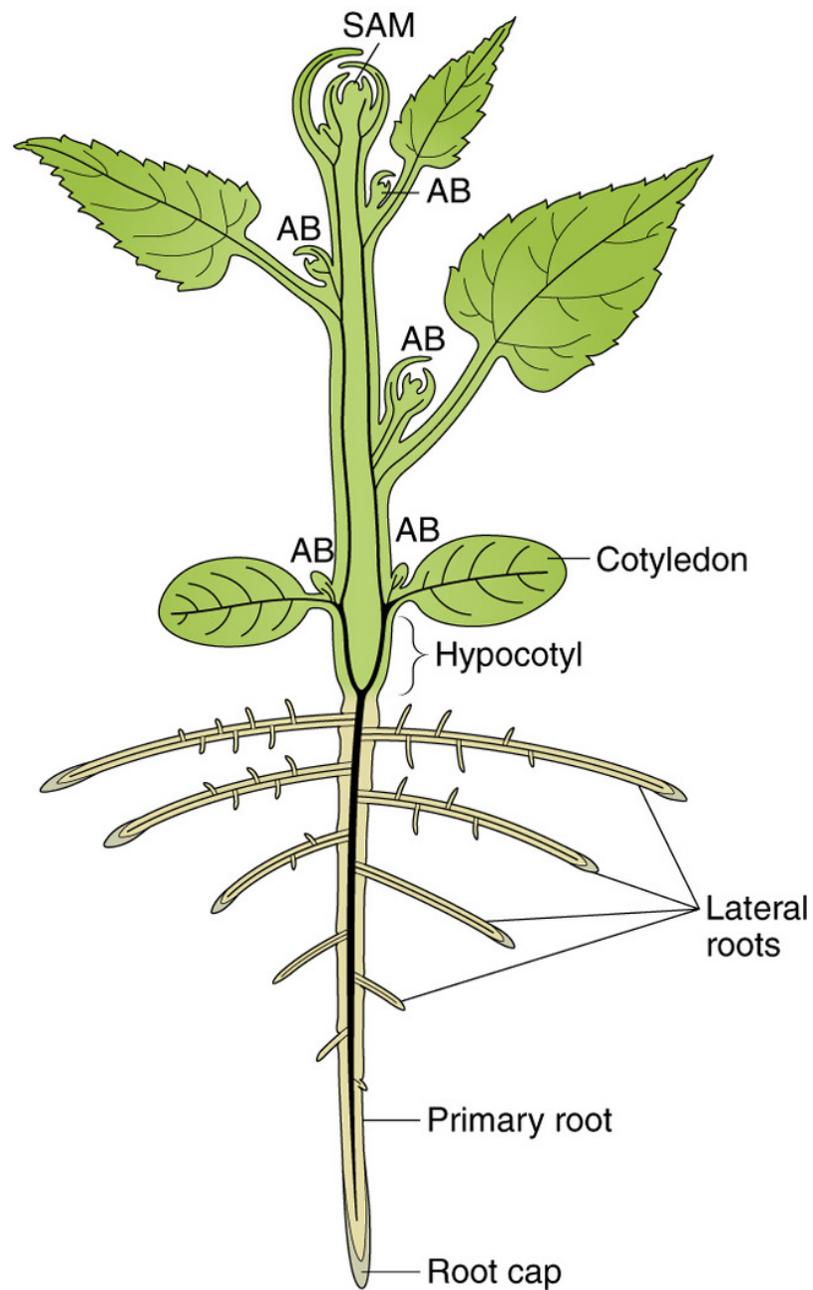
Moubayidin et al., *Trends in Plant Sci* (2009)

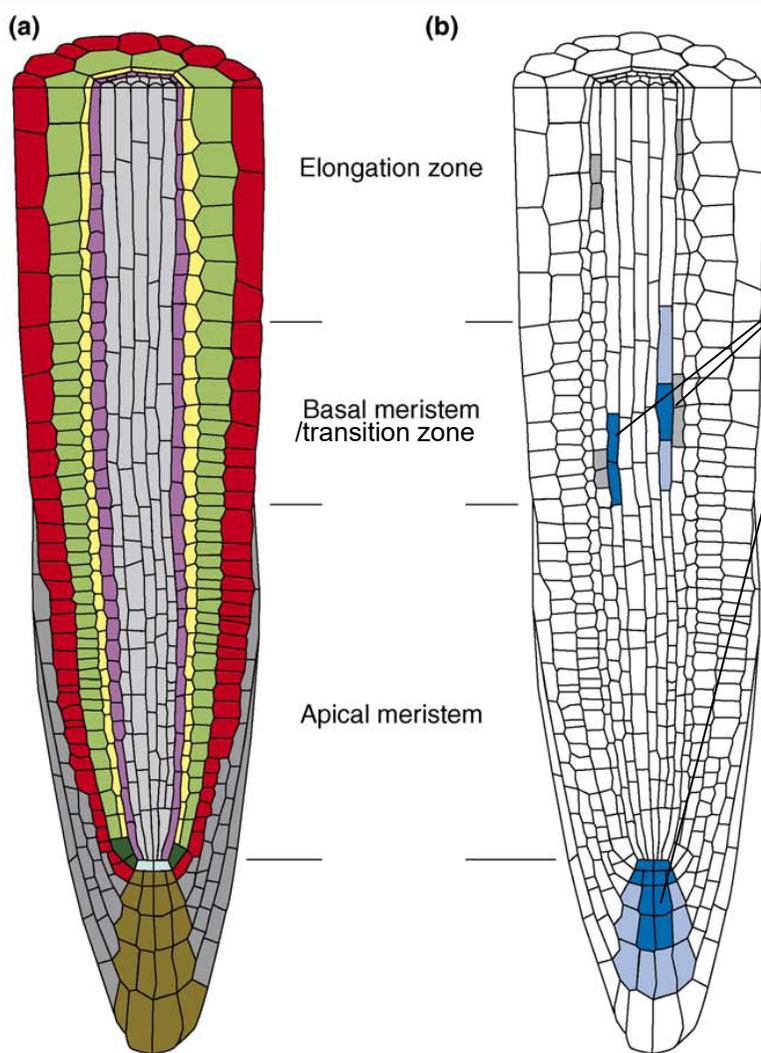


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 - Root radial patterning
 - RAM size determination
- Lateral root formation

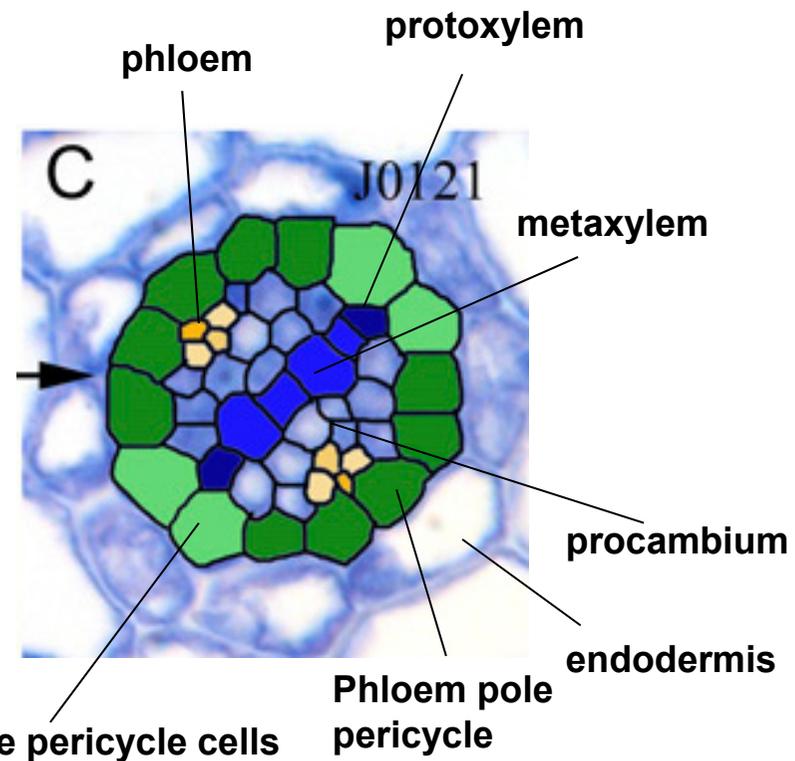




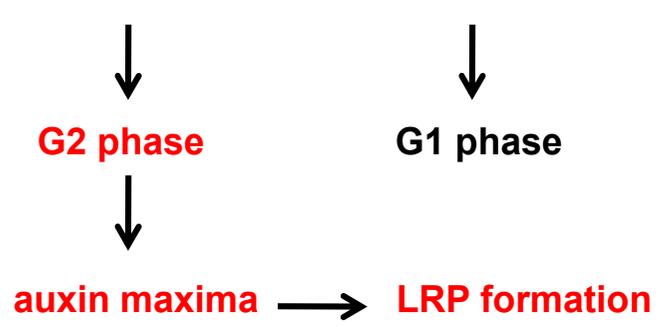
Peret et al., *Trends in Plant Sci* (2009)

TRENDS in Plant Science

Auxin maxima

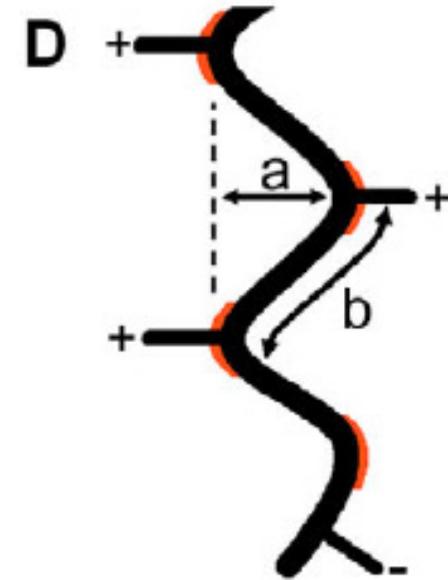
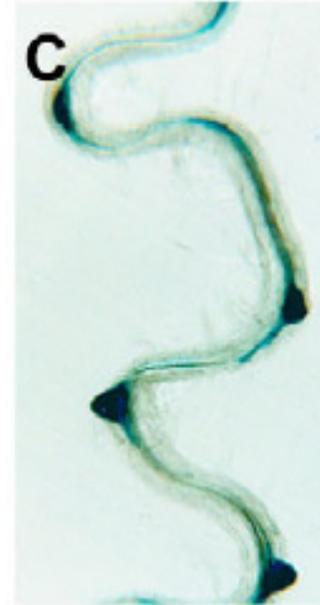
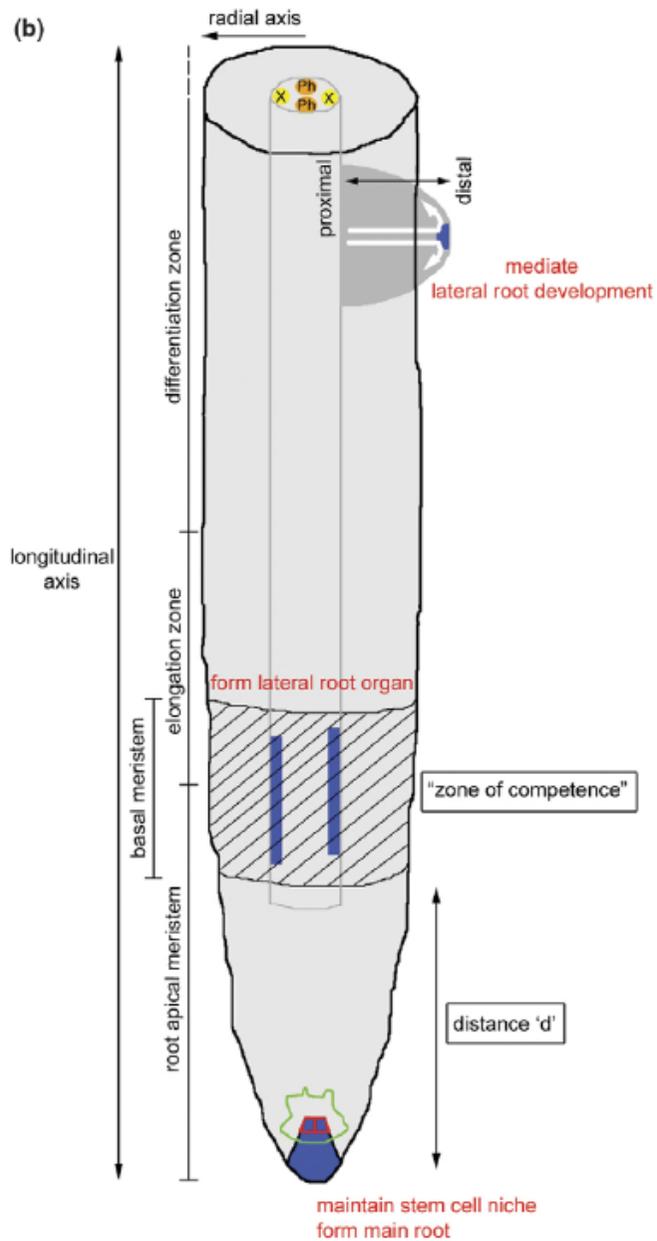


Parizot et al., *Plant Physiol* (2008)



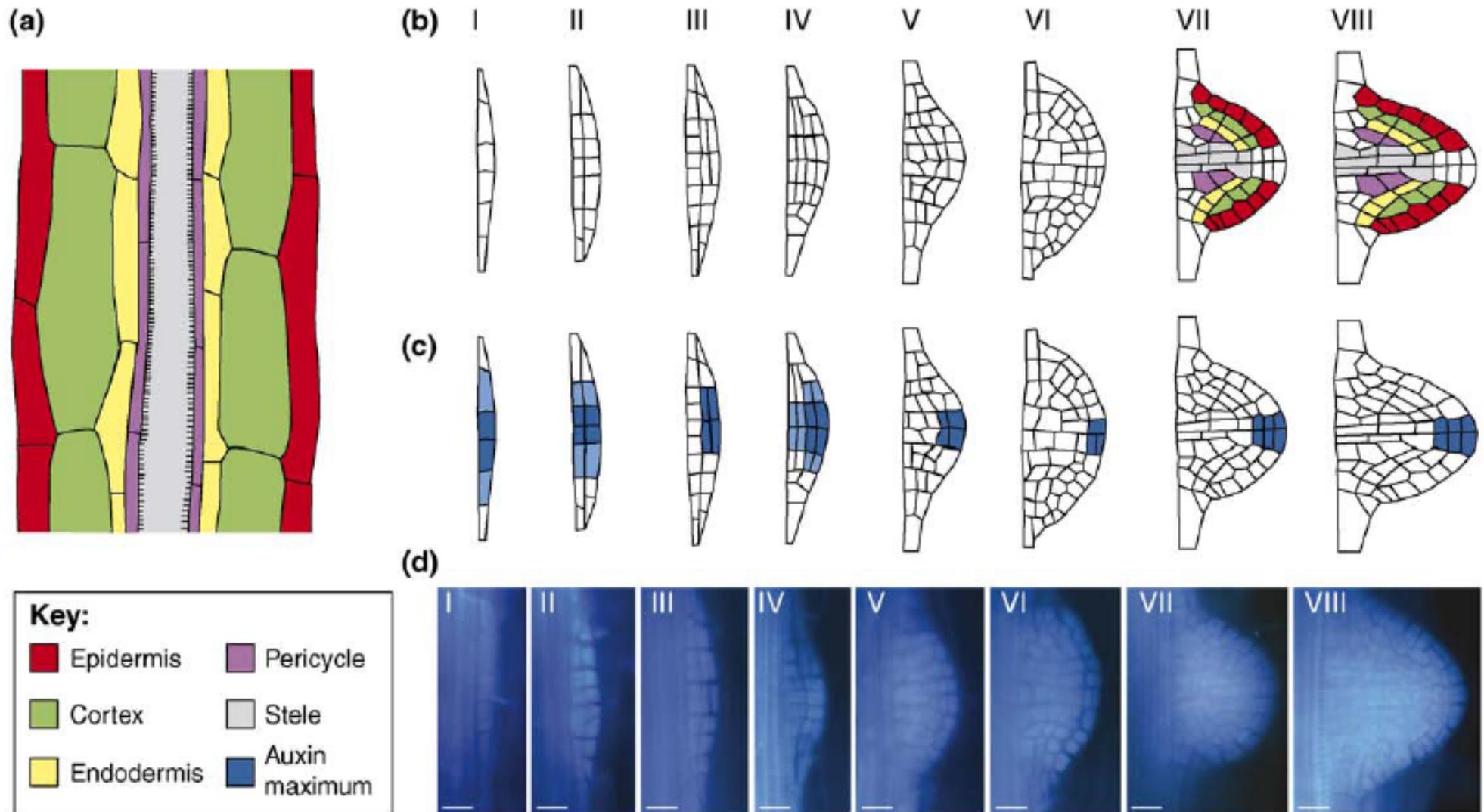
INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

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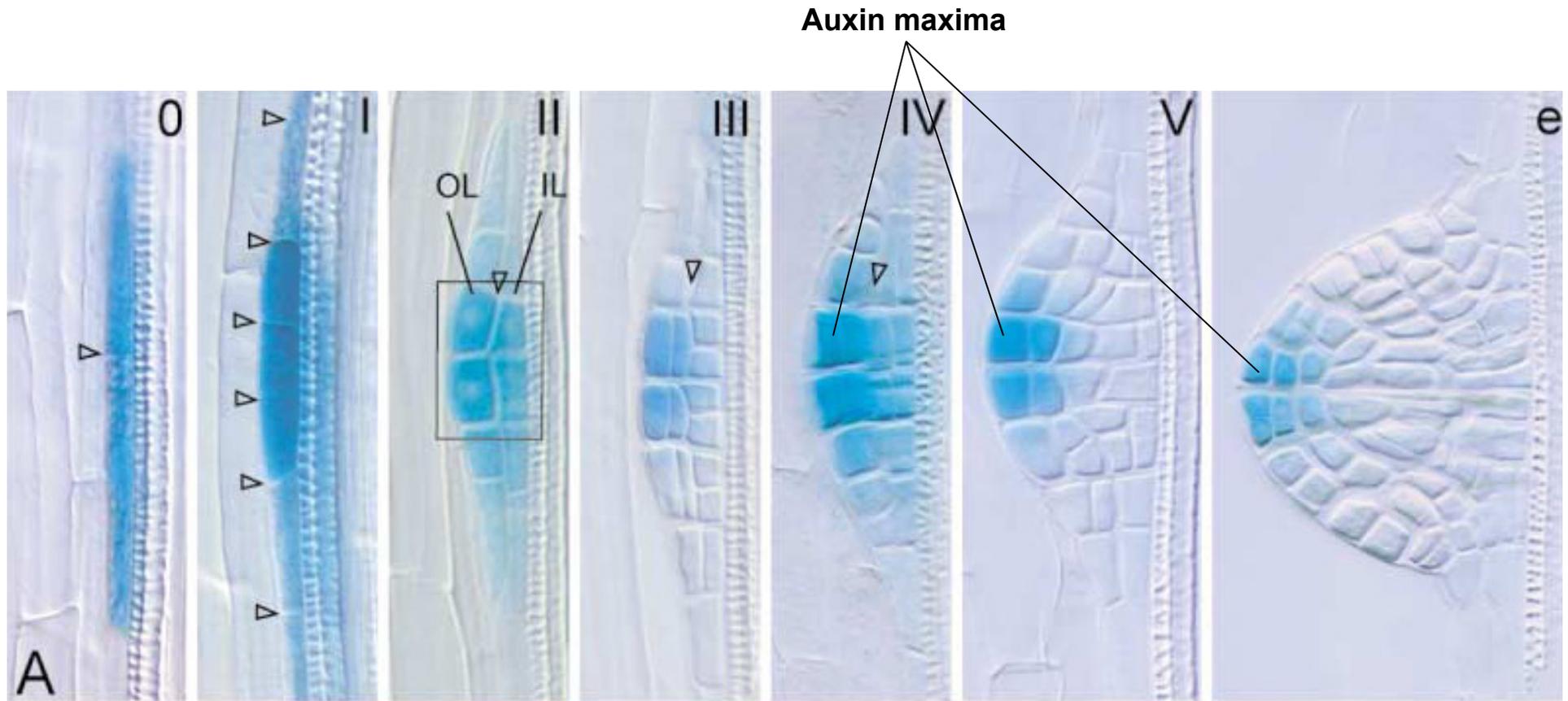


De Smet and Jurgens., Current Opinion in Genetics & Development (2007)

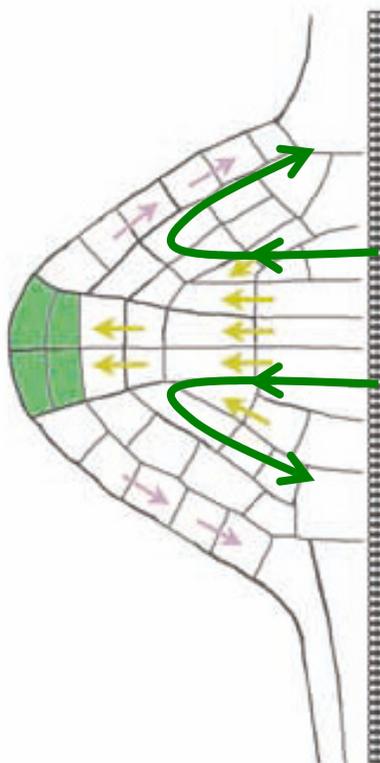
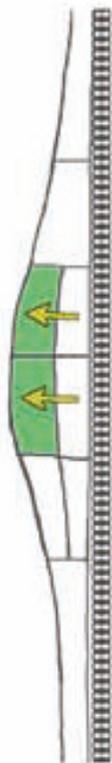
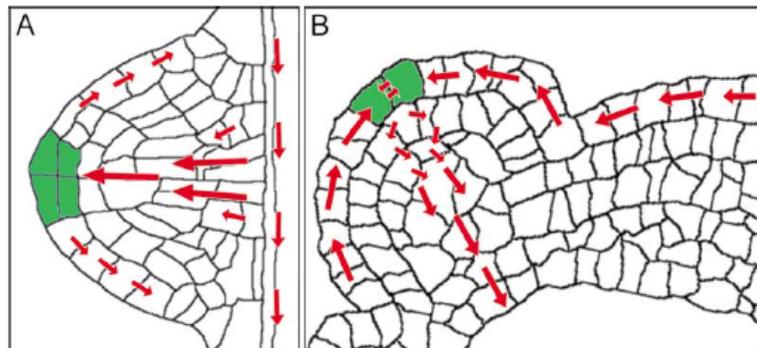
De Smet et al., PNAS (2007)



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



Benkova et al., *Cell* (2003)



fountain-like
auxin flow

- PIN1
- PIN2
- Auxin

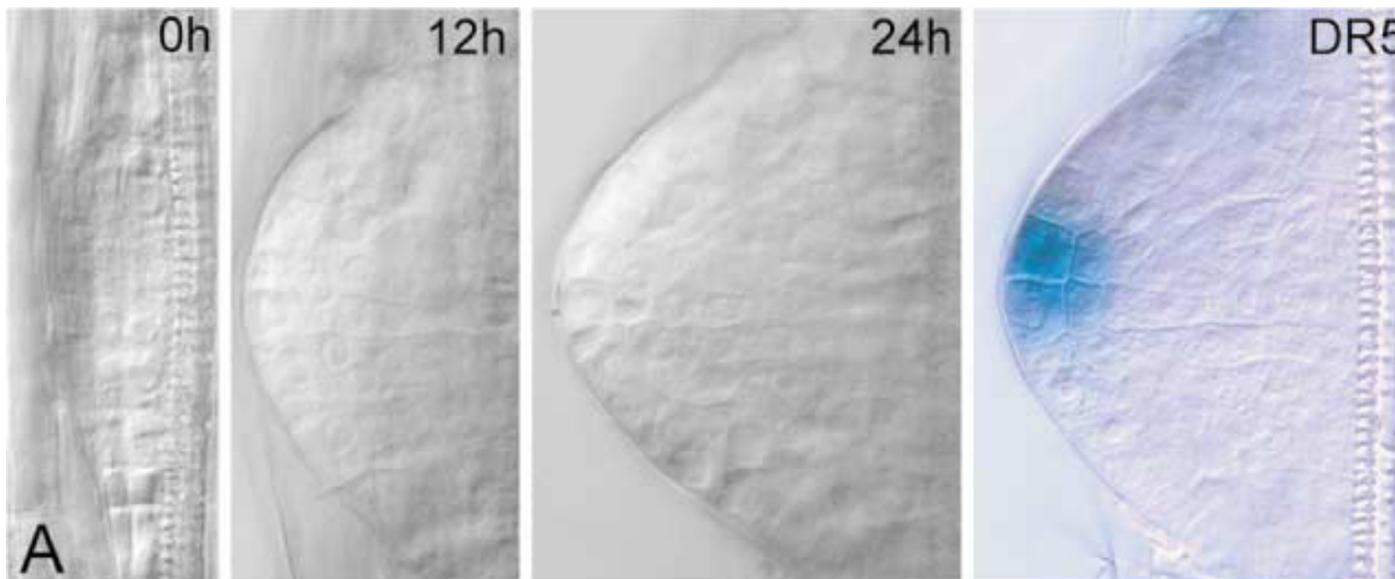
Tanaka et al., *Cell Mol Life Sci* (2003)



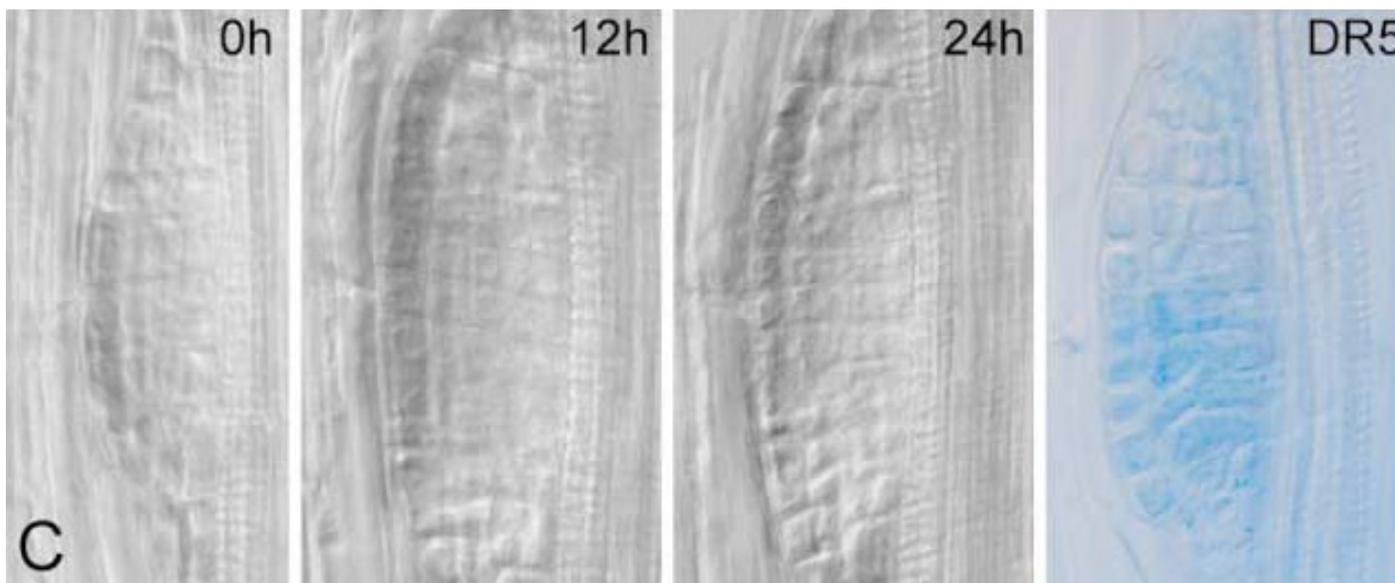
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WT



pin1



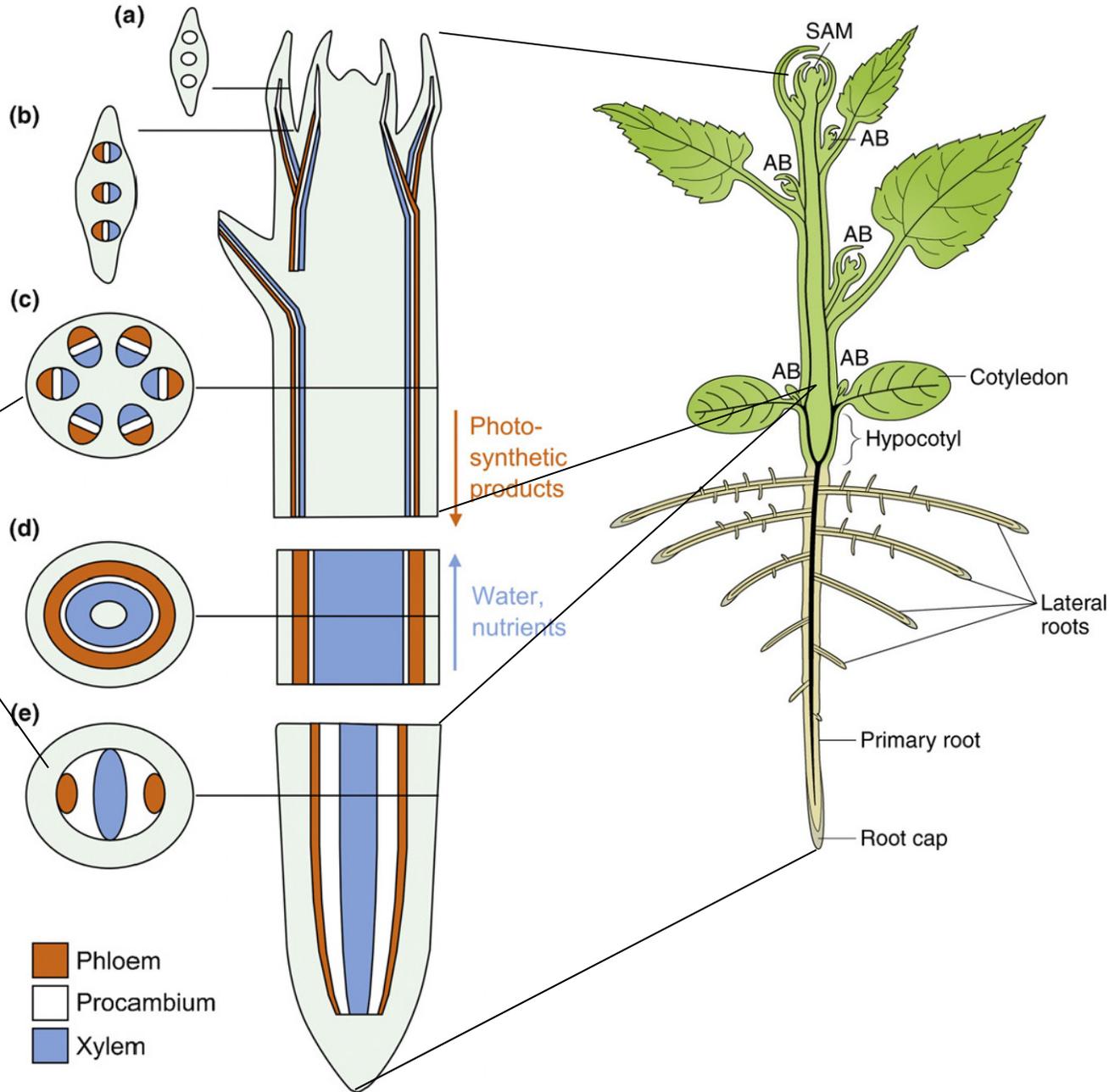
Benkova et al., *Cell* (2003)

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- Lateral root formation
- Vascular tissue formation in shoot and root

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

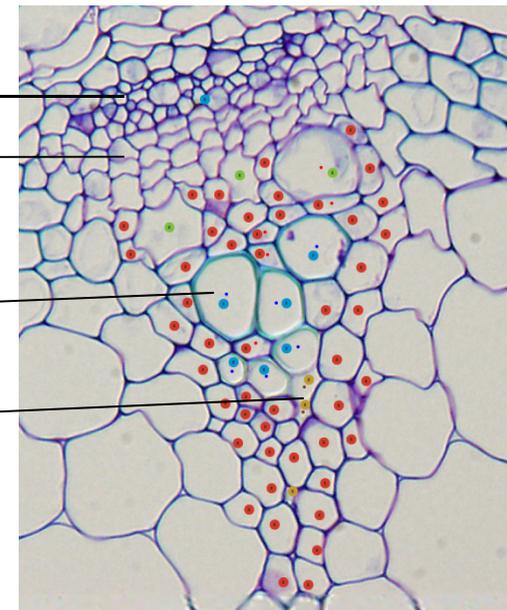
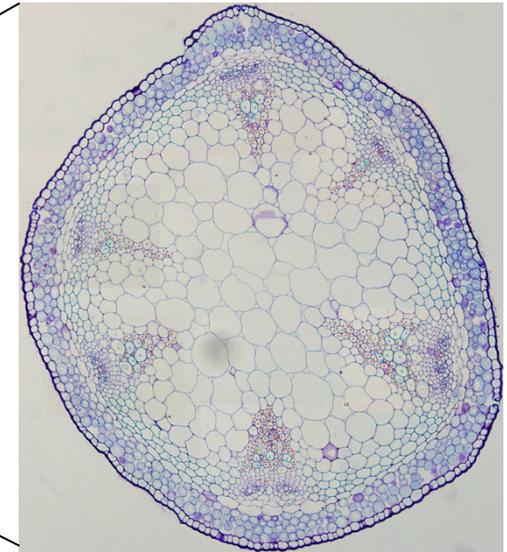
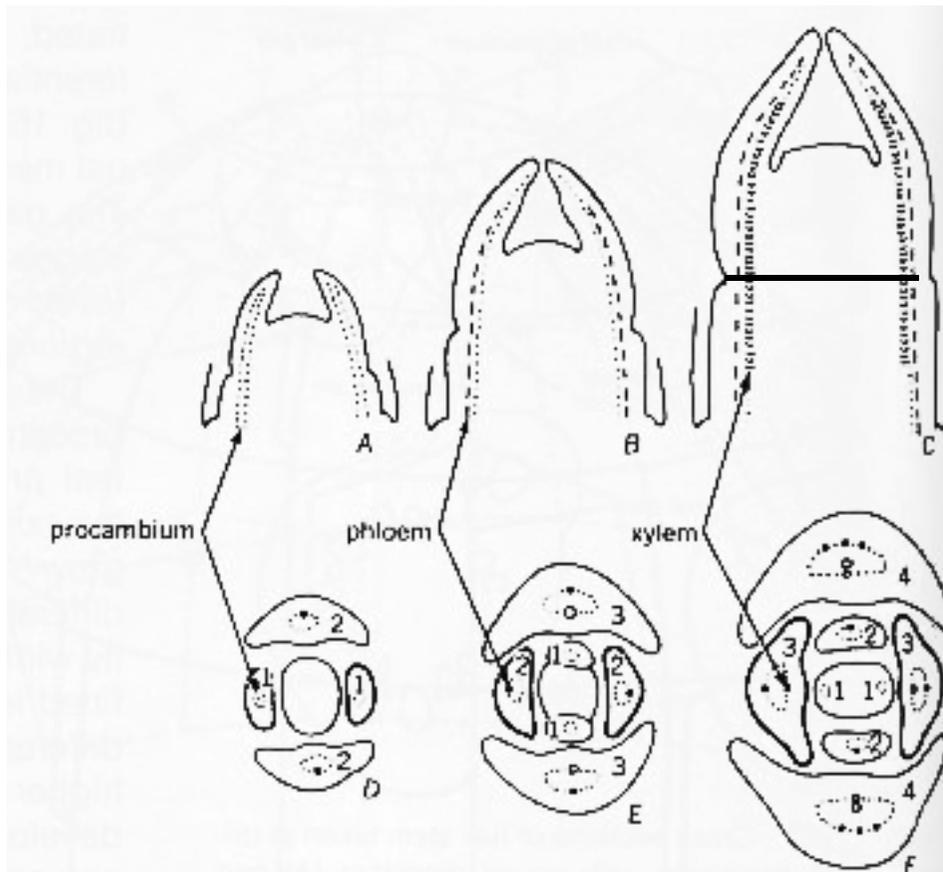


Lehesranta et al., *Trends in Plant Sci* (2010)



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Phloem

Procambium

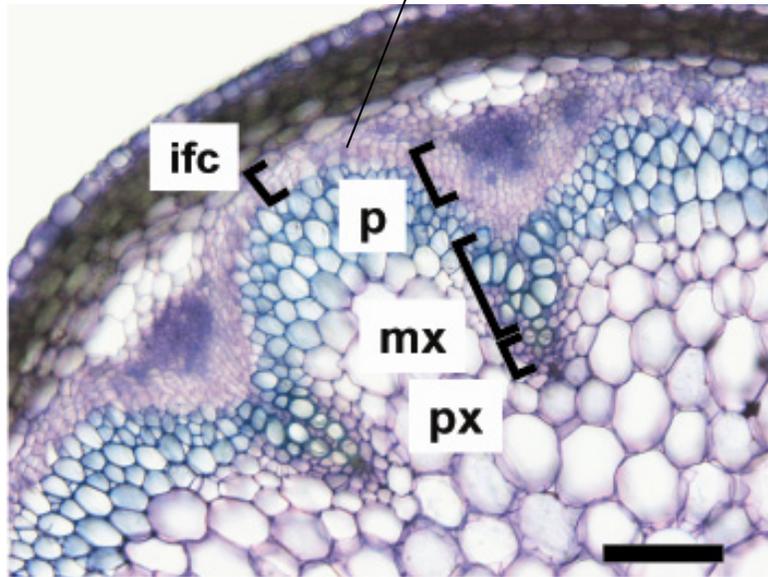
Metaxylem

Protoxylem

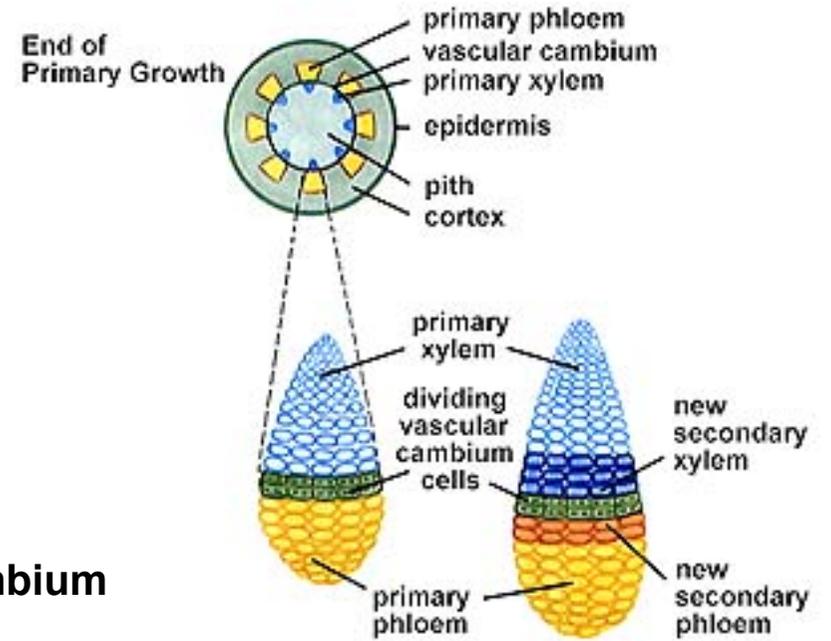
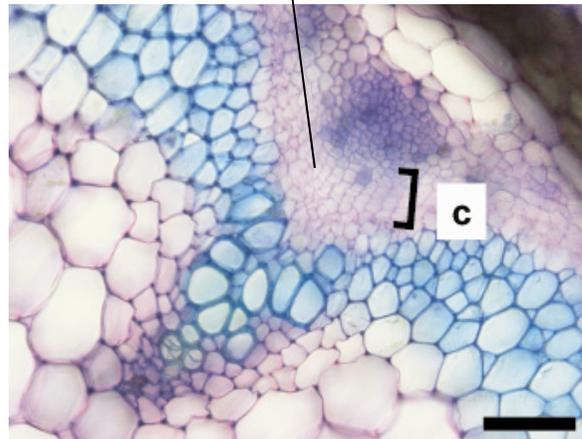
Esau, 1977

Hejatkó et al., *Plant Cell* (2009)

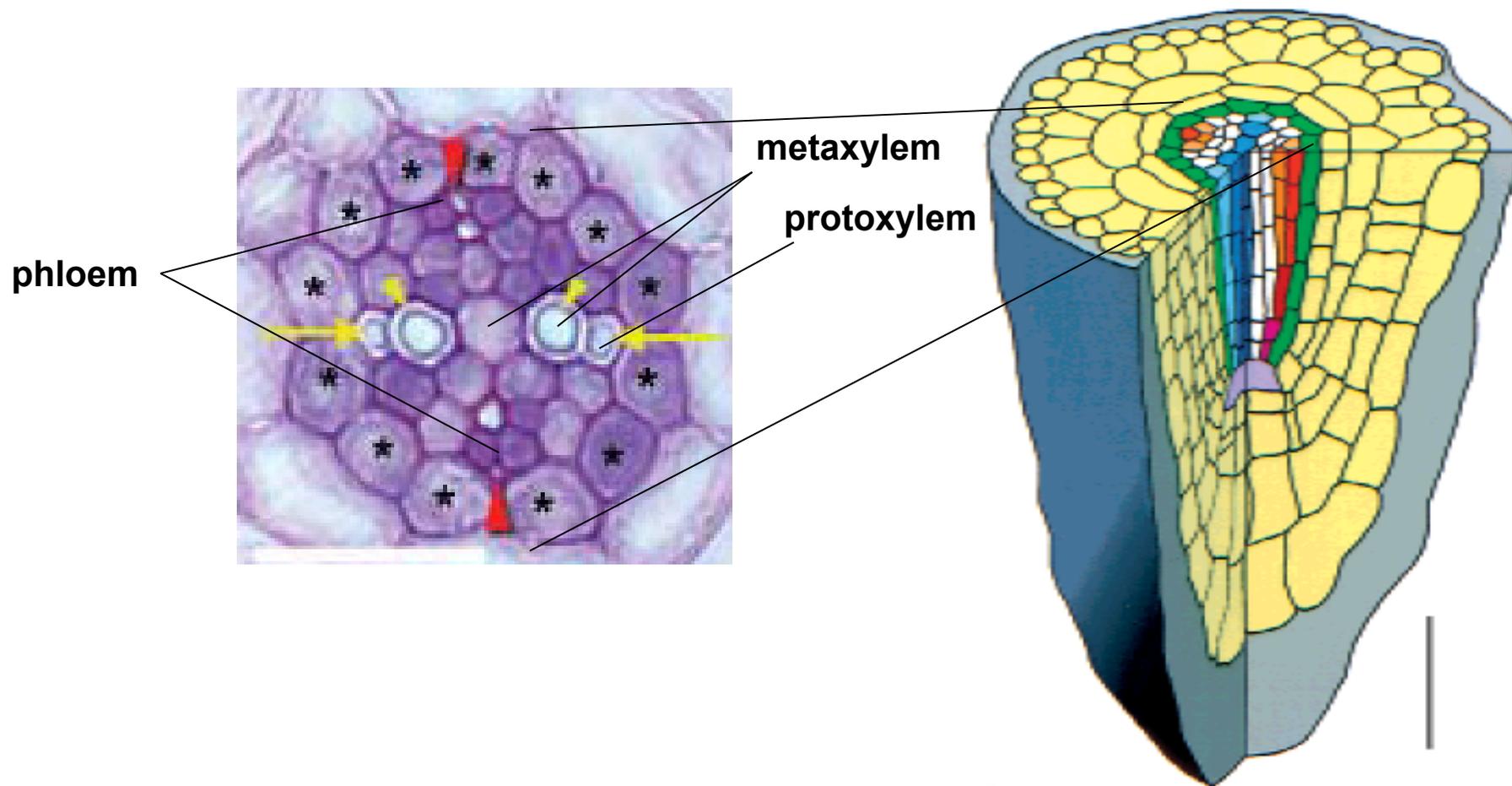
Interfascicular cambium



Vascular cambium



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



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.