

# C8545 Developmental Biology

## Lesson 7 Plant Embryogenesis

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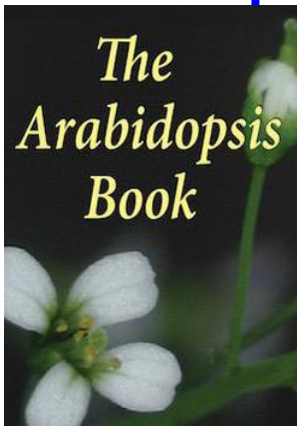
[hejatk@sci.muni.cz](mailto:hejatk@sci.muni.cz), [www.ceitec.eu](http://www.ceitec.eu)



EVROPSKÁ UNIE  
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ  
INVESTICE DO VAŠÍ BUDOUCNOSTI



# Literature



- **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/>.
- Dubová J., Hejátko J., Friml J. (2005) Reproduction of Plants, in Encyclopedia of Molecular Cell Biology and Molecular Medicine (ed, R. A. Meyers), pp. 249 – 295. Wiley-VCH, Weinheim, Germany
- Selected original papers in scientific journals

# Outline of Lesson 7

## Plant Embryogenesis

- Overview of the embryo formation in *Arabidopsis*
- Mechanism of the apical-basal axis formation
  - female gametophyte prespecification, invariant cell division or positional information?
  - differential gene expression
  - auxin gradients formation
  - the role of auxin signalling
- Root meristem formation
  - auxin and hypophysis identity
  - differential gene expression and root meristem patterning
  - auxin-cytokinin interaction and the root meristem organization centre formation

# Outline of Lesson 7

## Plant Embryogenesis

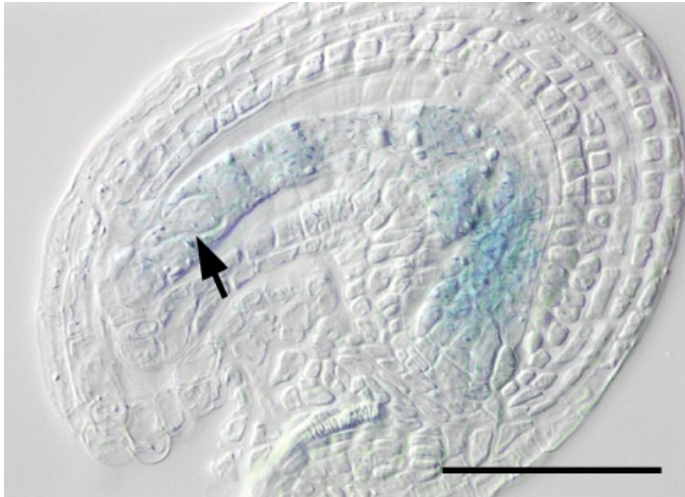
- Patterning of the apical embryo pole
  - generation of cotyledons and shoot apical meristem
  - proper spacing of lateral organs
  - adaxial-abaxial axis formation
- Radial embryo patterning
  - epidermal layer specification
  - separating vascular and ground tissue

# Outline of Lesson 7

## Plant Embryogenesis

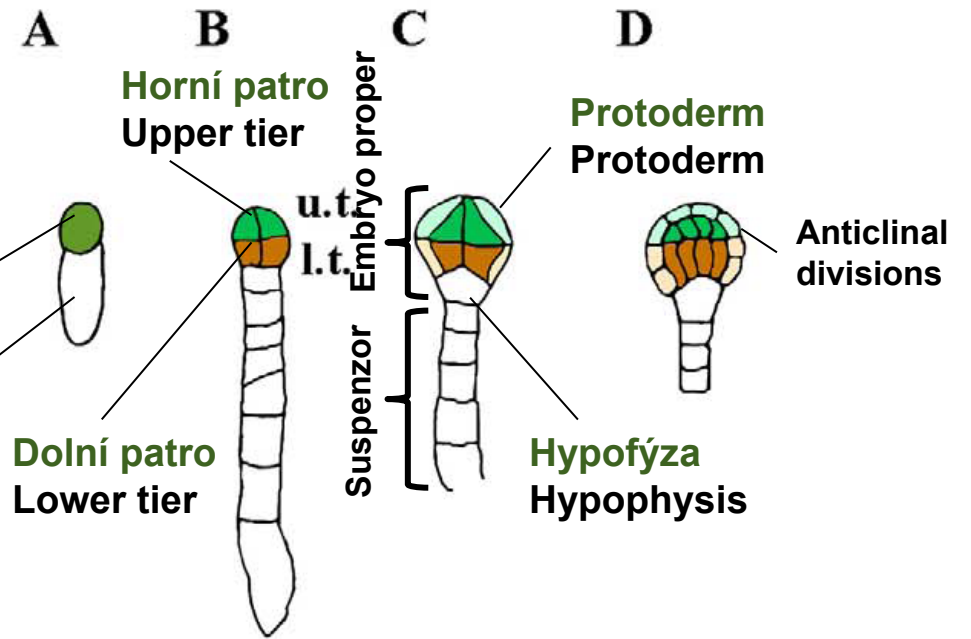
- Overview of the embryo formation in *Arabidopsis*

Hejátko et al., *Mol Genet Genomics* (2003)

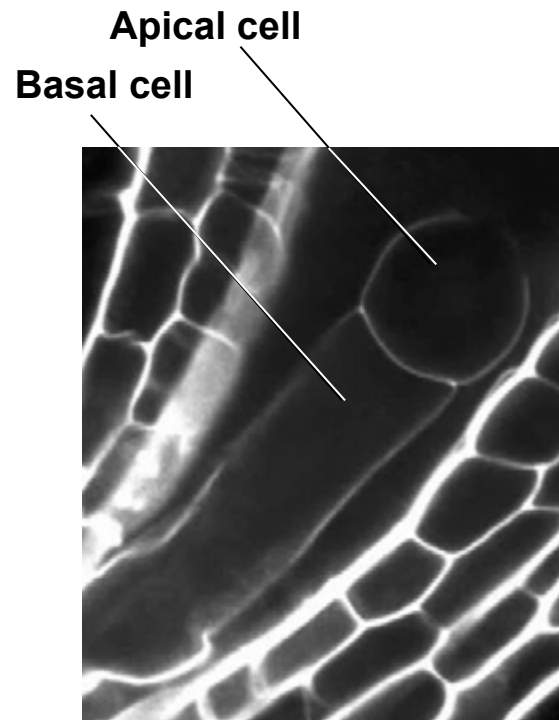


Apical cell-active protein biosynthesis

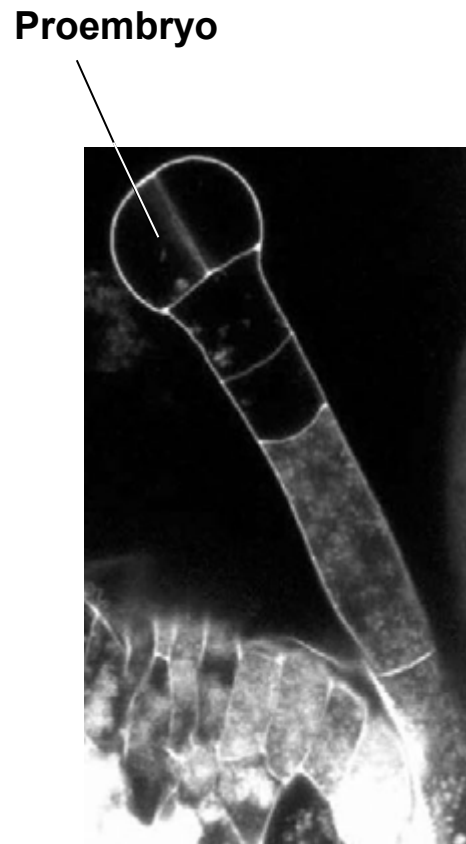
Basal cell-highly vacuolated



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

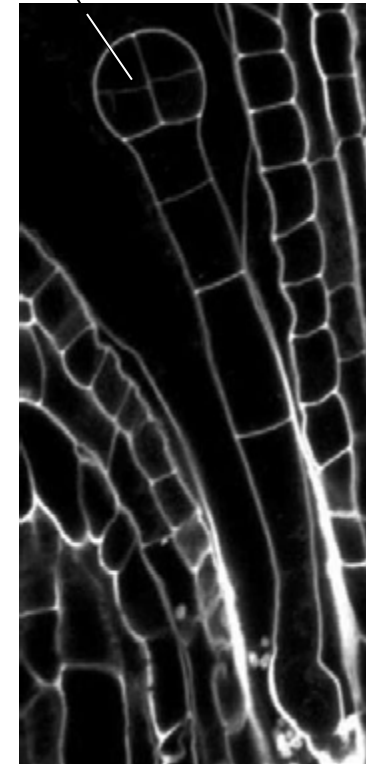


Capron et al., *Arabidopsis Book* (2009)



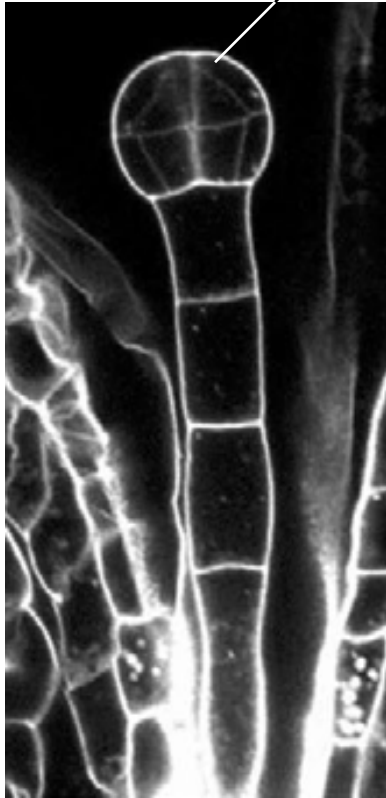
**Proembryo stage**

Four out of eight  
cells of the embryo  
proper



**Octant stage**

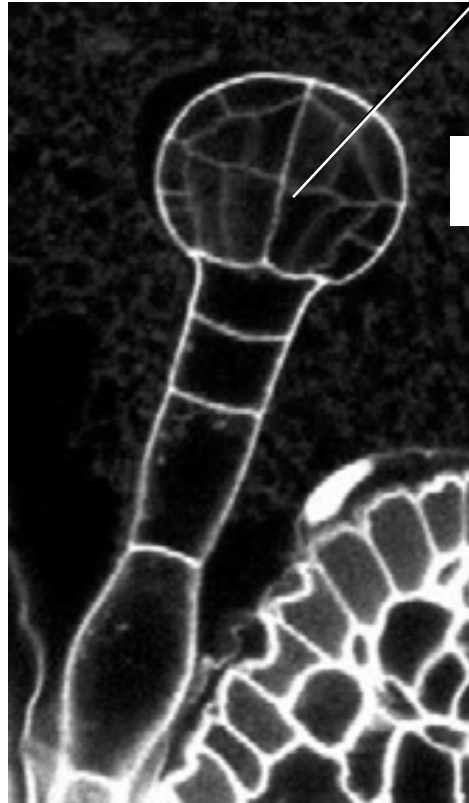
Protoderm



**Dermatogen stage**

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

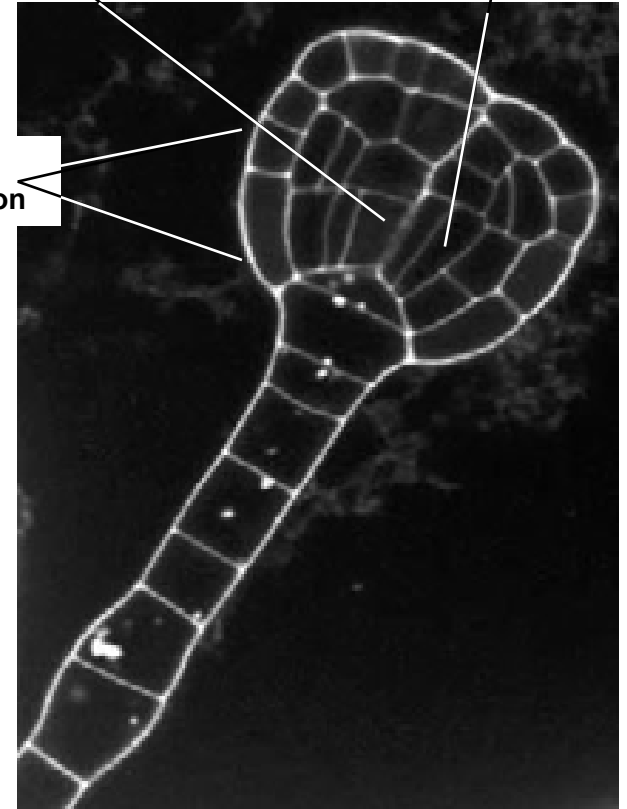
Prospective vascular tissue



**Early globular stage**

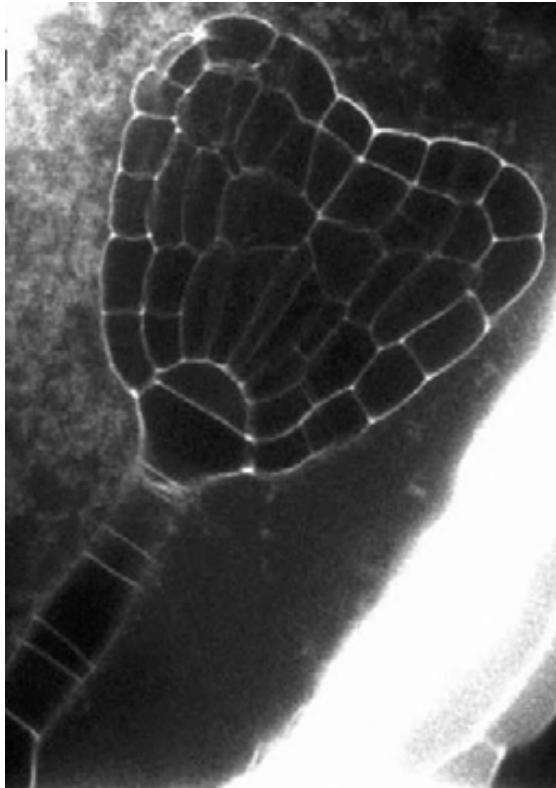
Prospective ground tissue/základní pletivo

U/L tier differentiation



**Triangular embryo stage**



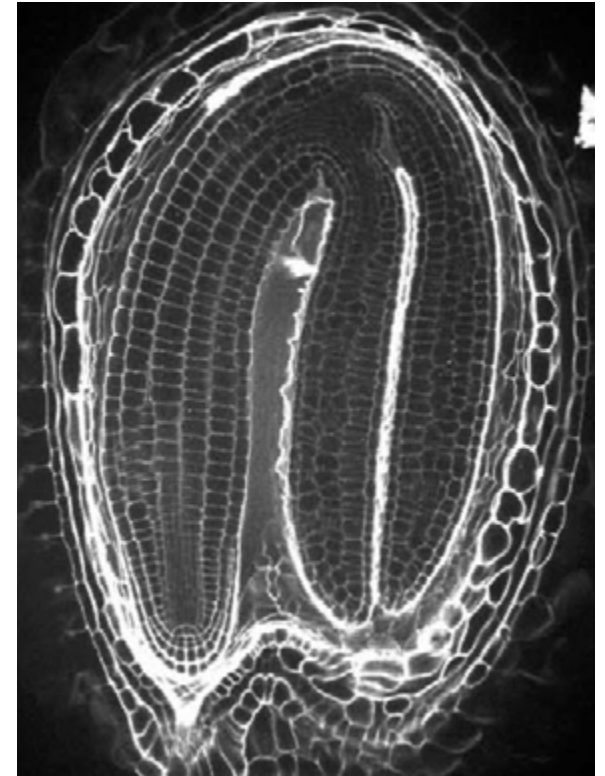


**Heart stage**

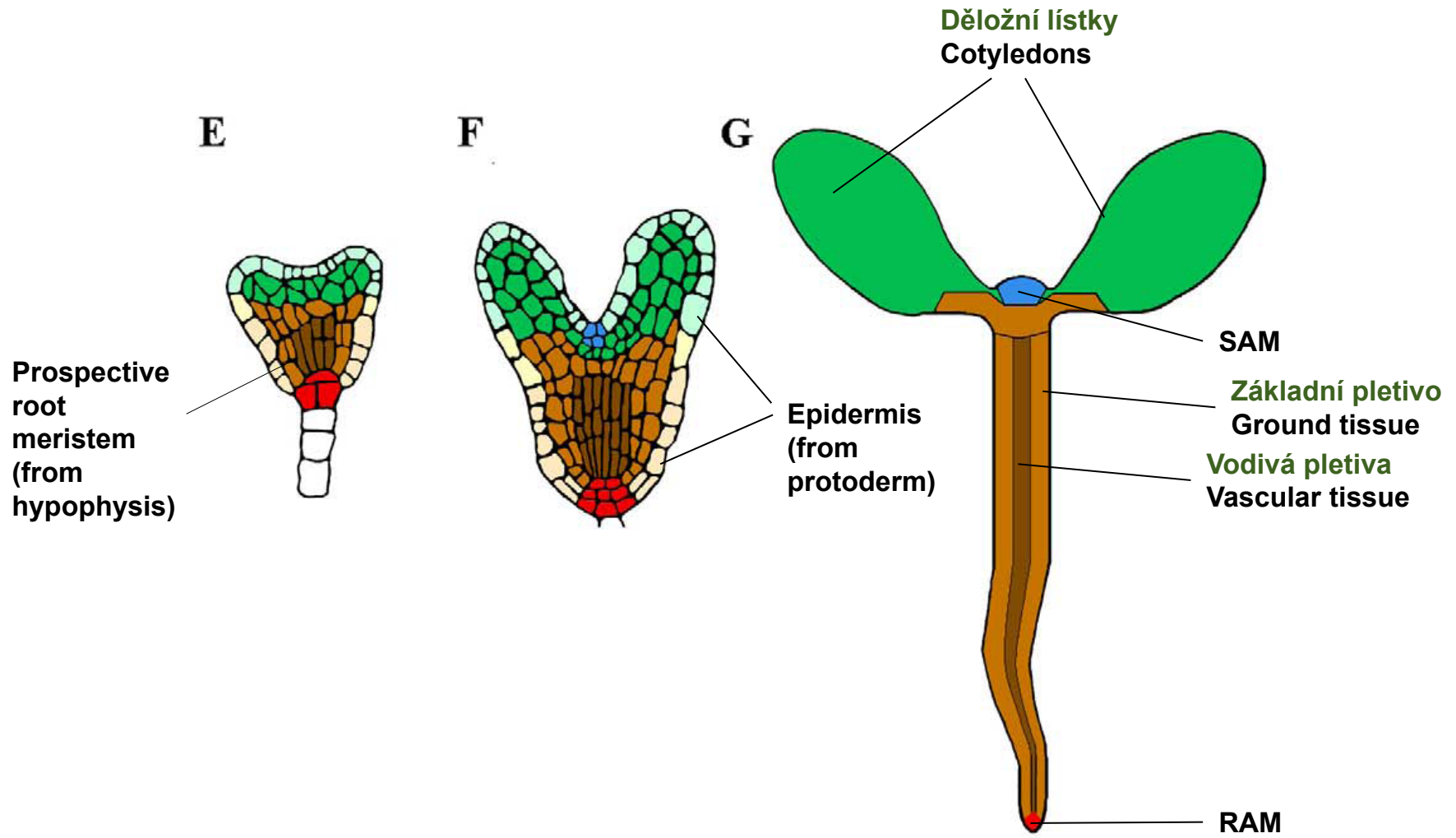
Capron et al., *Arabidopsis Book* (2009)



**Topedo stage**



**Bended cotyledon stage**



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

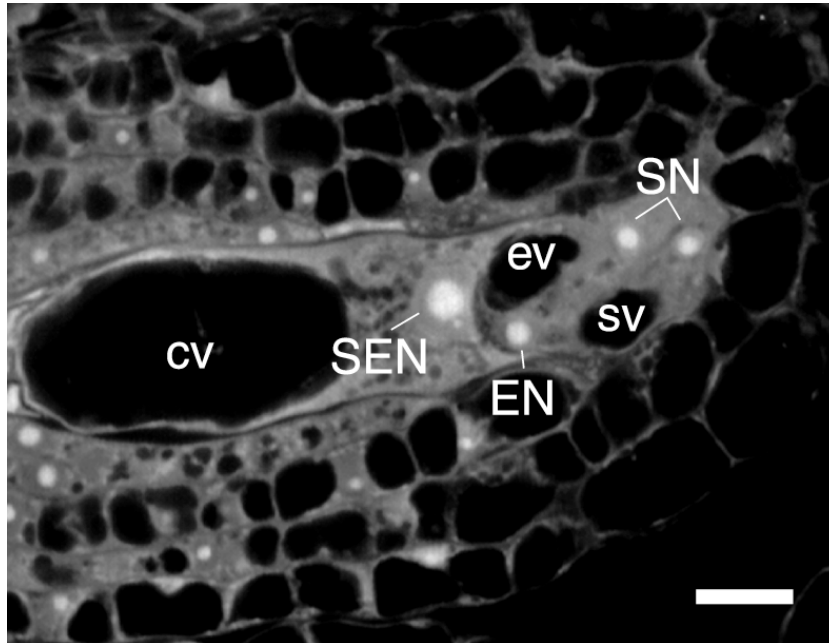
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## Plant Embryogenesis

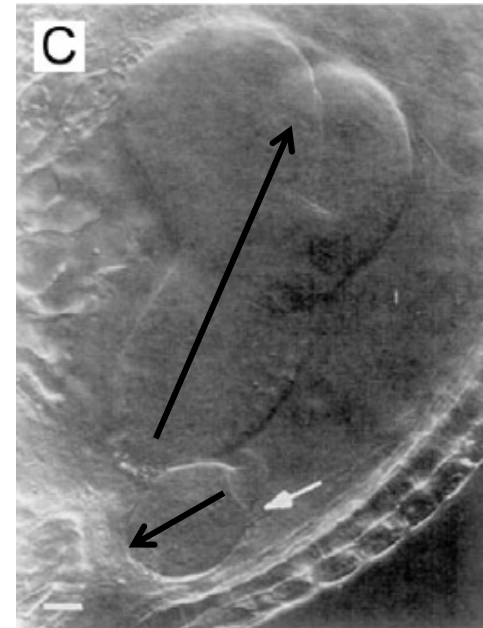
- Overview of the embryo formation in *Arabidopsis*
- Mechanism of the apical-basal axis formation
  - female gametophyte prespecification, invariant cell division or positional information?

**Proximal** ← **Distal**

**WT**



**twin**



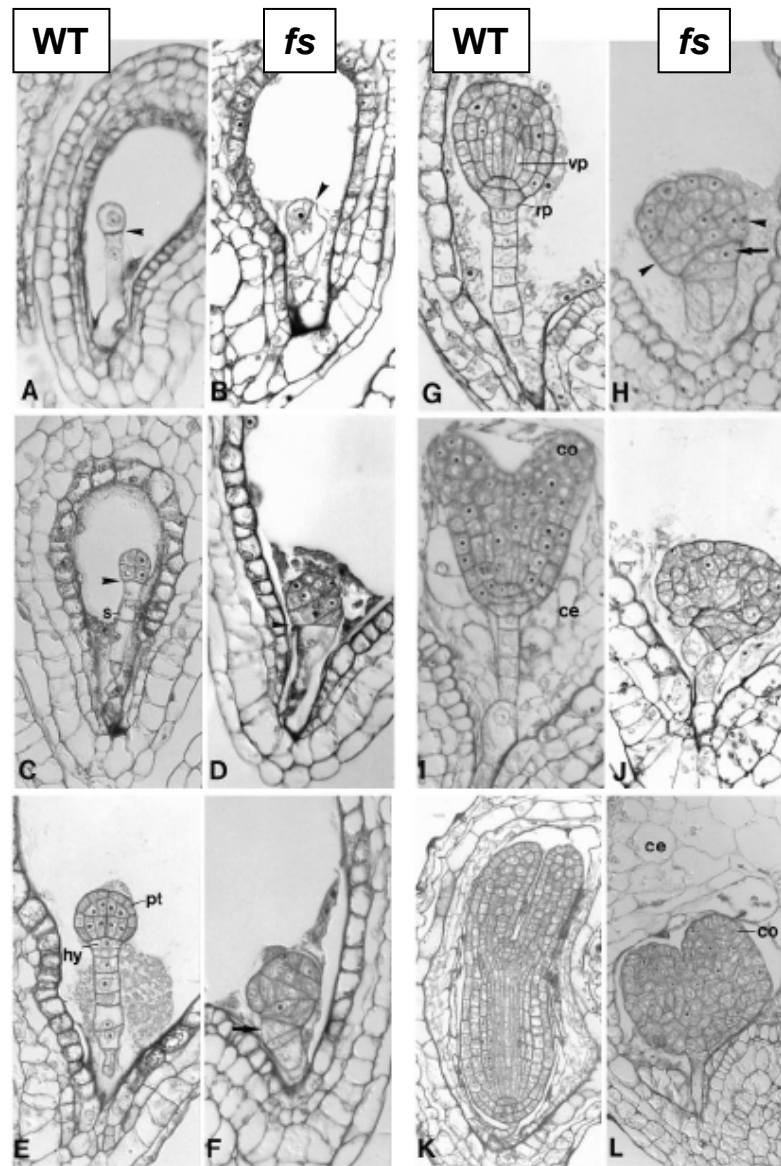
**Proximal**



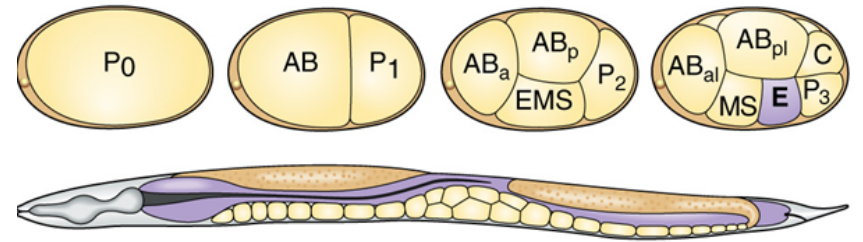
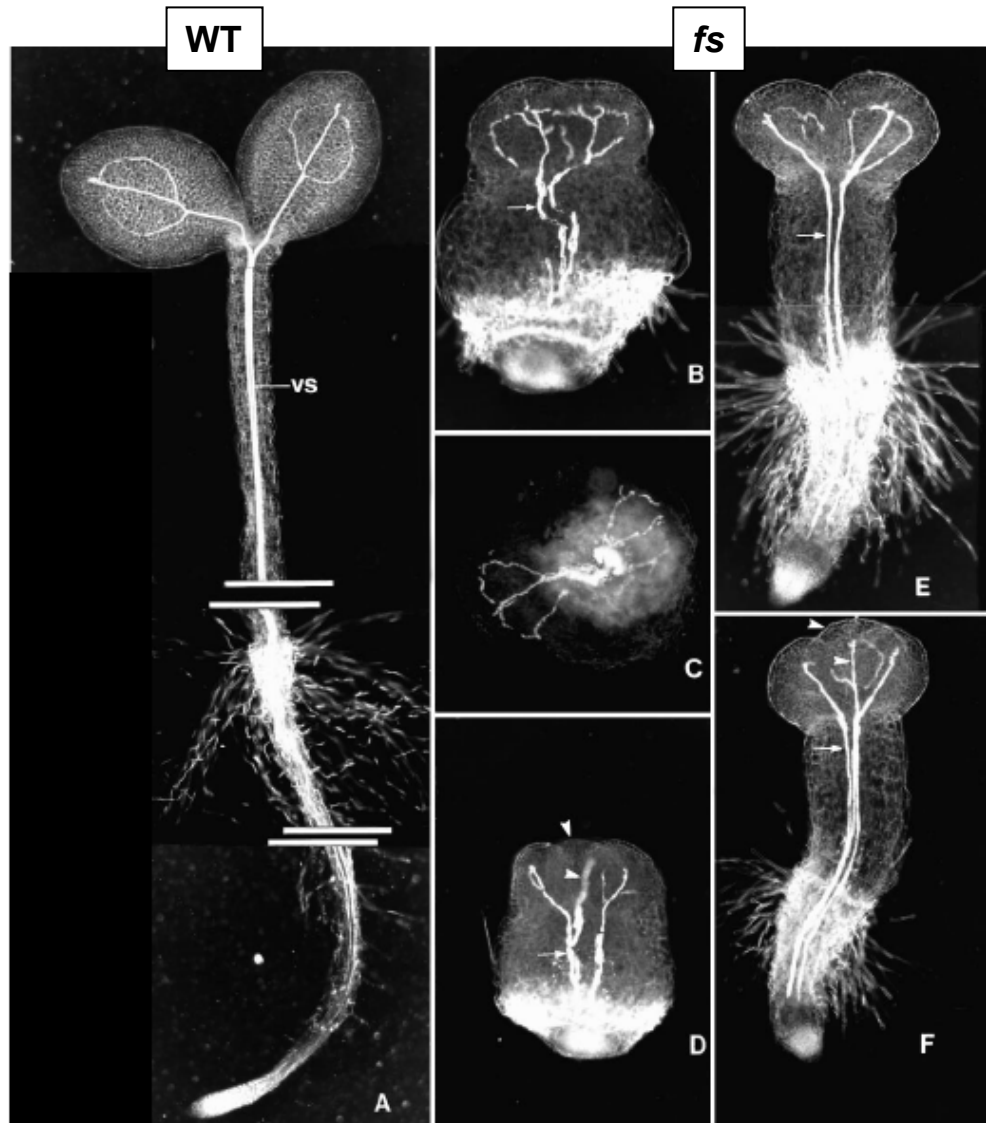
**Distal**

Hejátko et al., *Mol Genet Genomics* (2003)

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



Torres-Ruiz and Jurgens, *Development* (1994)



Torres-Ruiz and Jurgens, *Development* (1994)

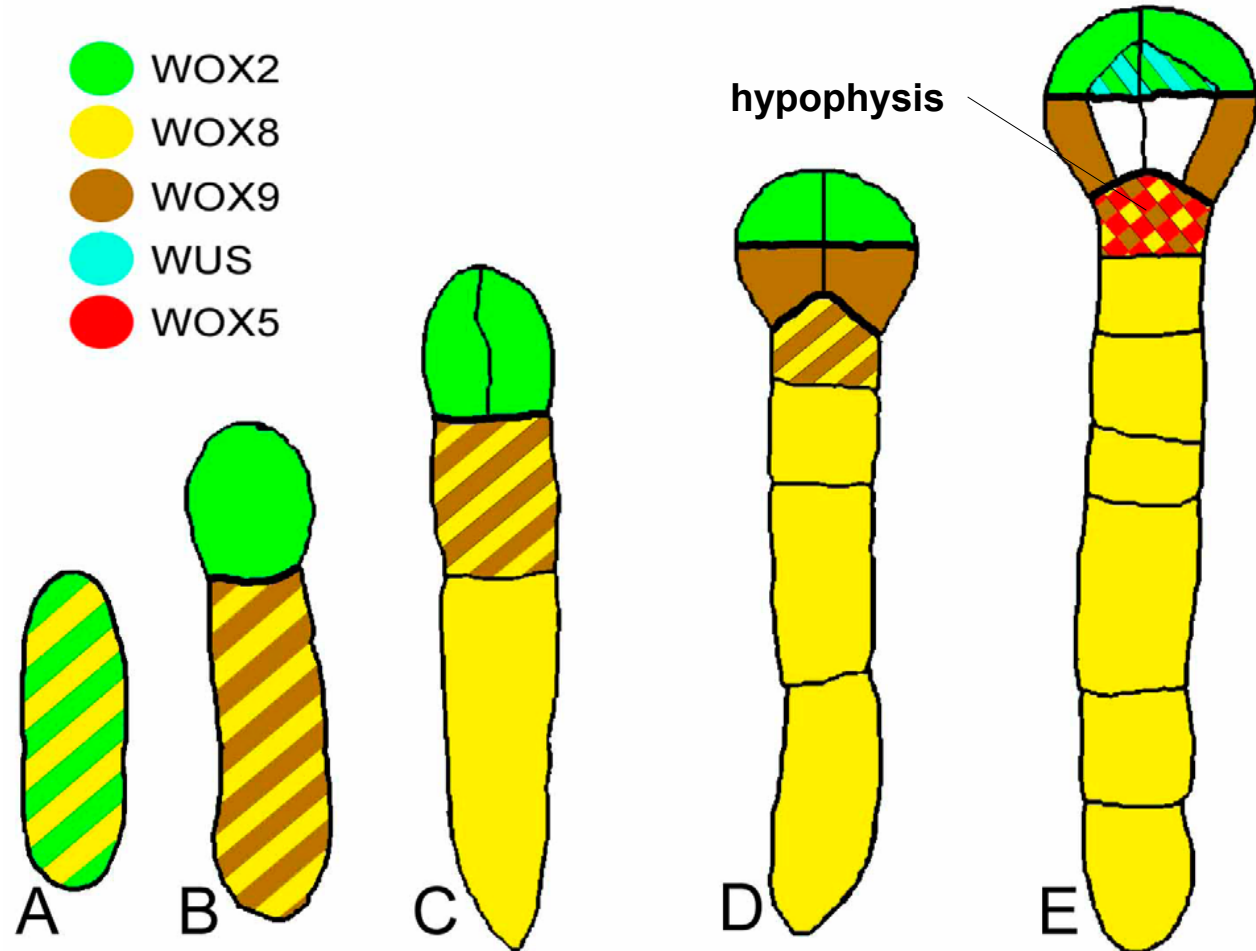


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## Plant Embryogenesis

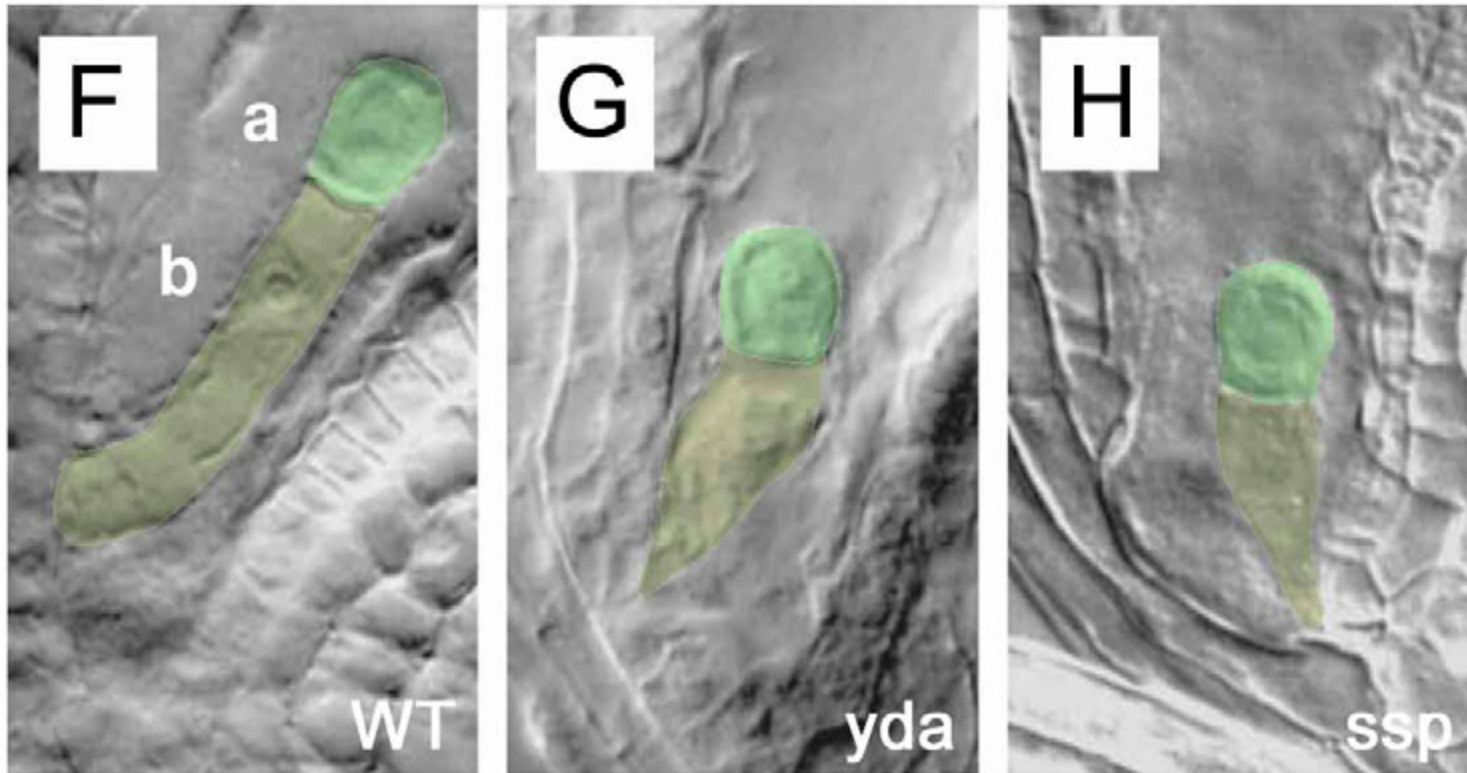
- Overview of the embryo formation in *Arabidopsis*
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  - differential gene expression

## Differential expression of **WUSCHEL-RELATED HOMEODOMAIN (WOX)** gene family



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





**YODA (YDA)**

mitogen-activated protein  
kinase kinase (MAPKK)

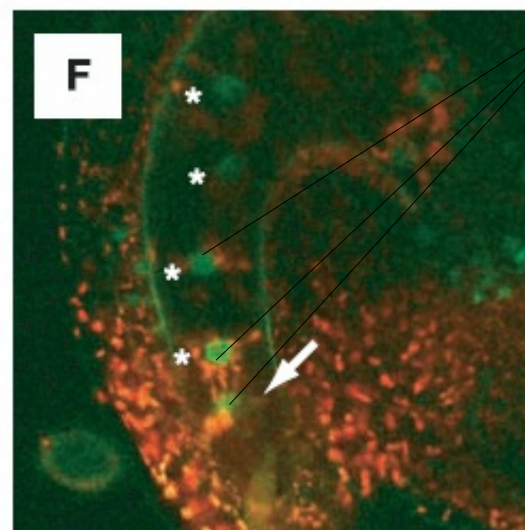
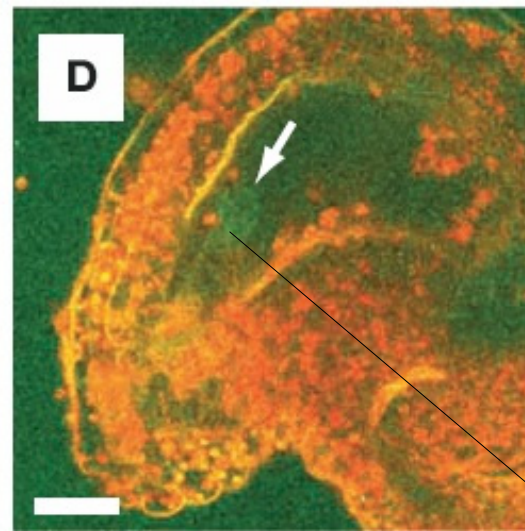
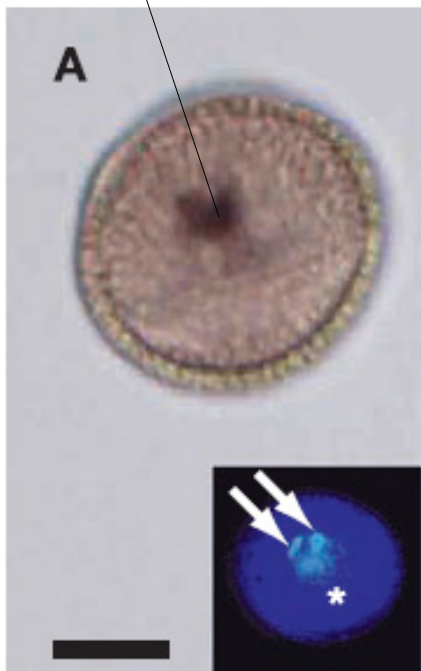


**SHORT SUSPENSOR (SSP)**

interleukin-1 receptor-associated kinase  
(IRAK)/Pelle-like kinase

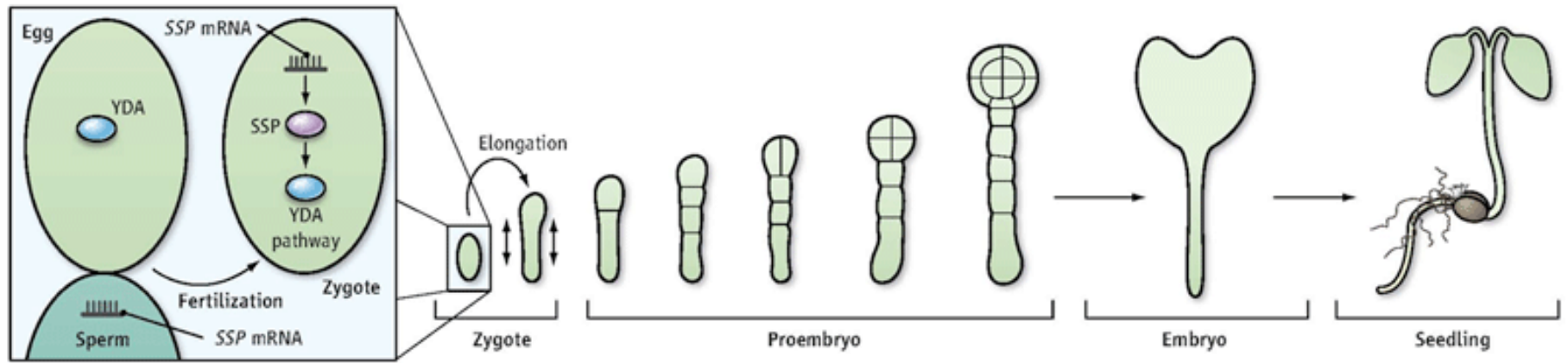
Capron et al., *Arabidopsis Book* (2009),

**SSP mRNA *in situ* localization**



**SSP-YFP**

Bayer et al., *Science* (2009)



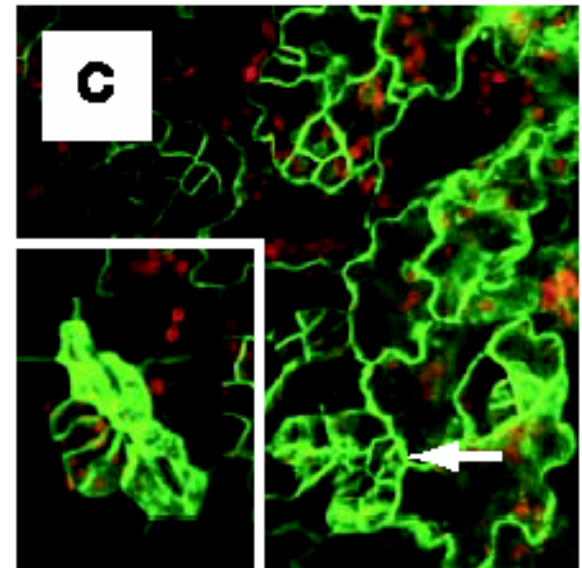
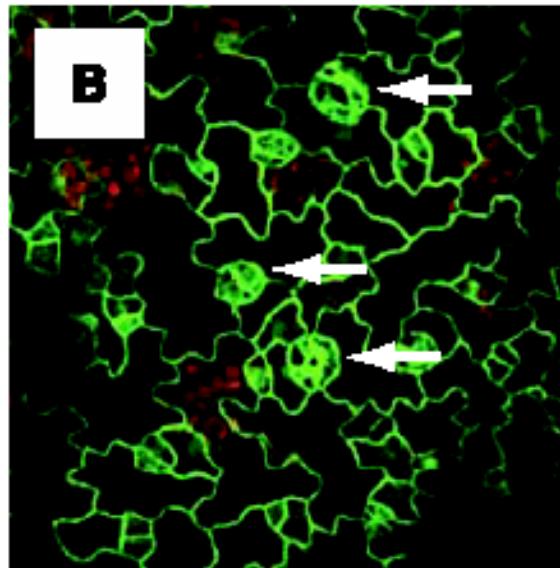
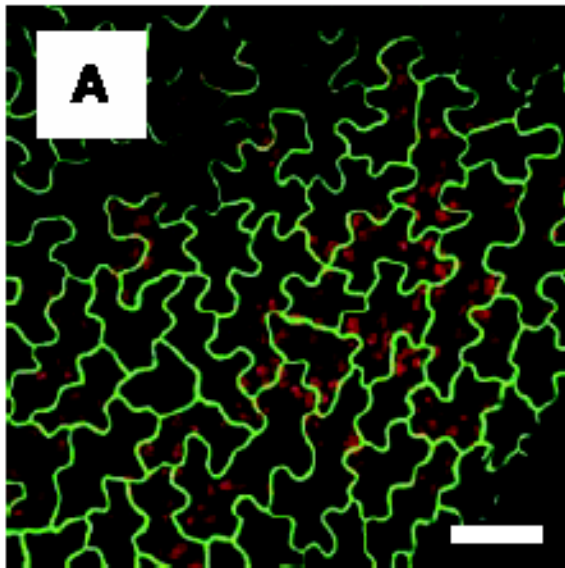
Grossniklaus, *Science* (2009)

myristoylation-deficient variant

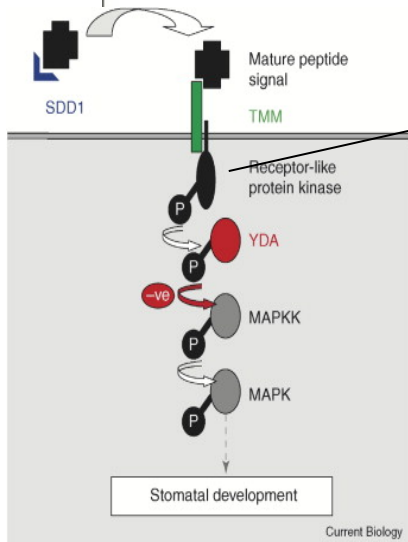
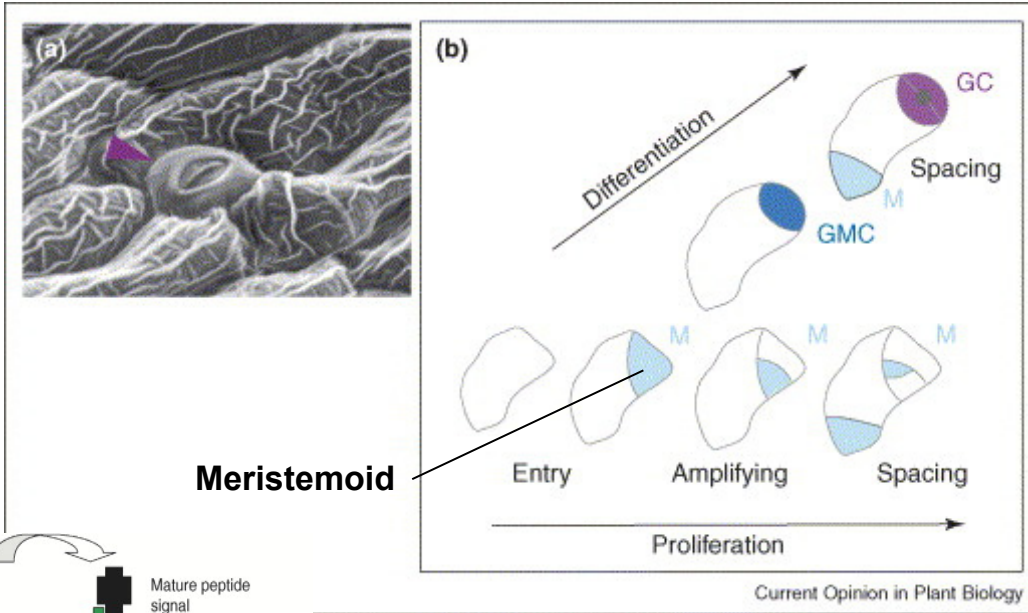
*Pro35S:SSP-YFP/WT*

*Pro35S:ssp-YFP/WT*

*Pro35S:SSP-YFP/yda*

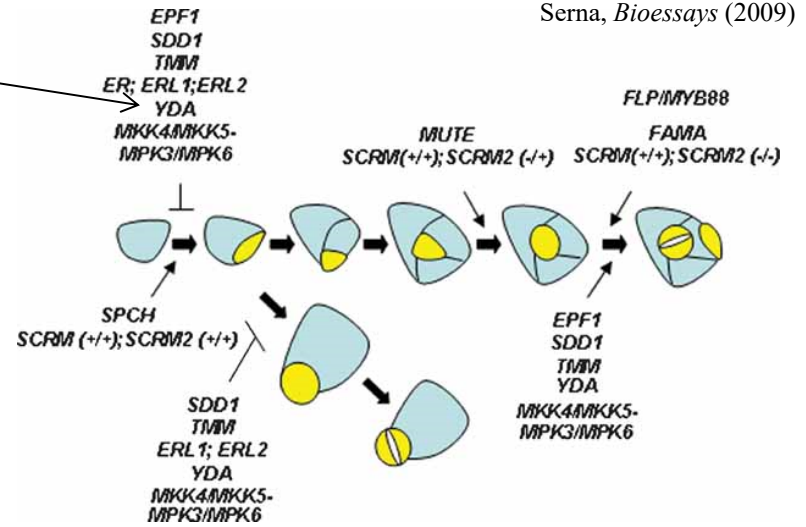


Bayer et al., *Science* (2009)



SSP

Bergmann, *Curr Opin Plant Biol* (2006)  
 Gray and Hetherington, *Curr Biol* (2004)

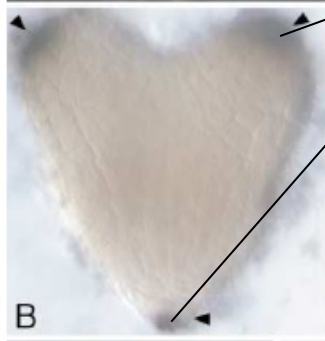
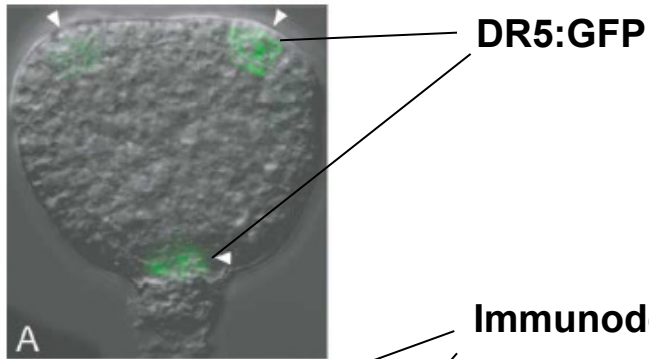


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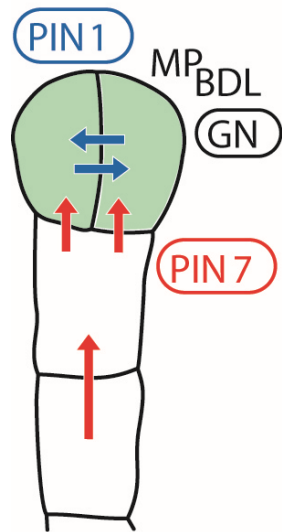
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  - auxin gradients formation

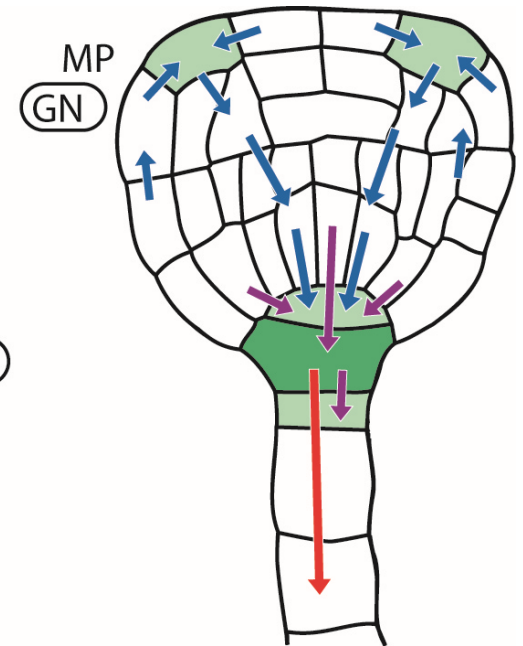
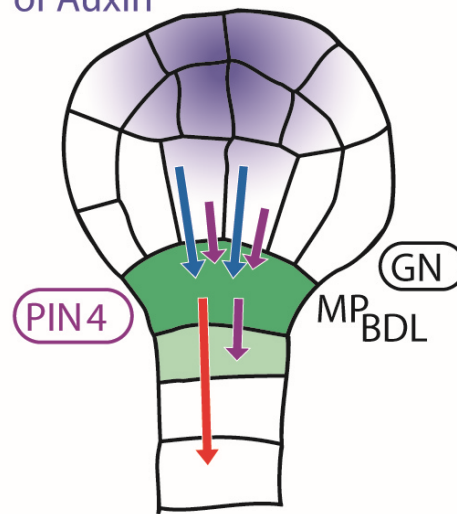




**Immunodetection of IAA**

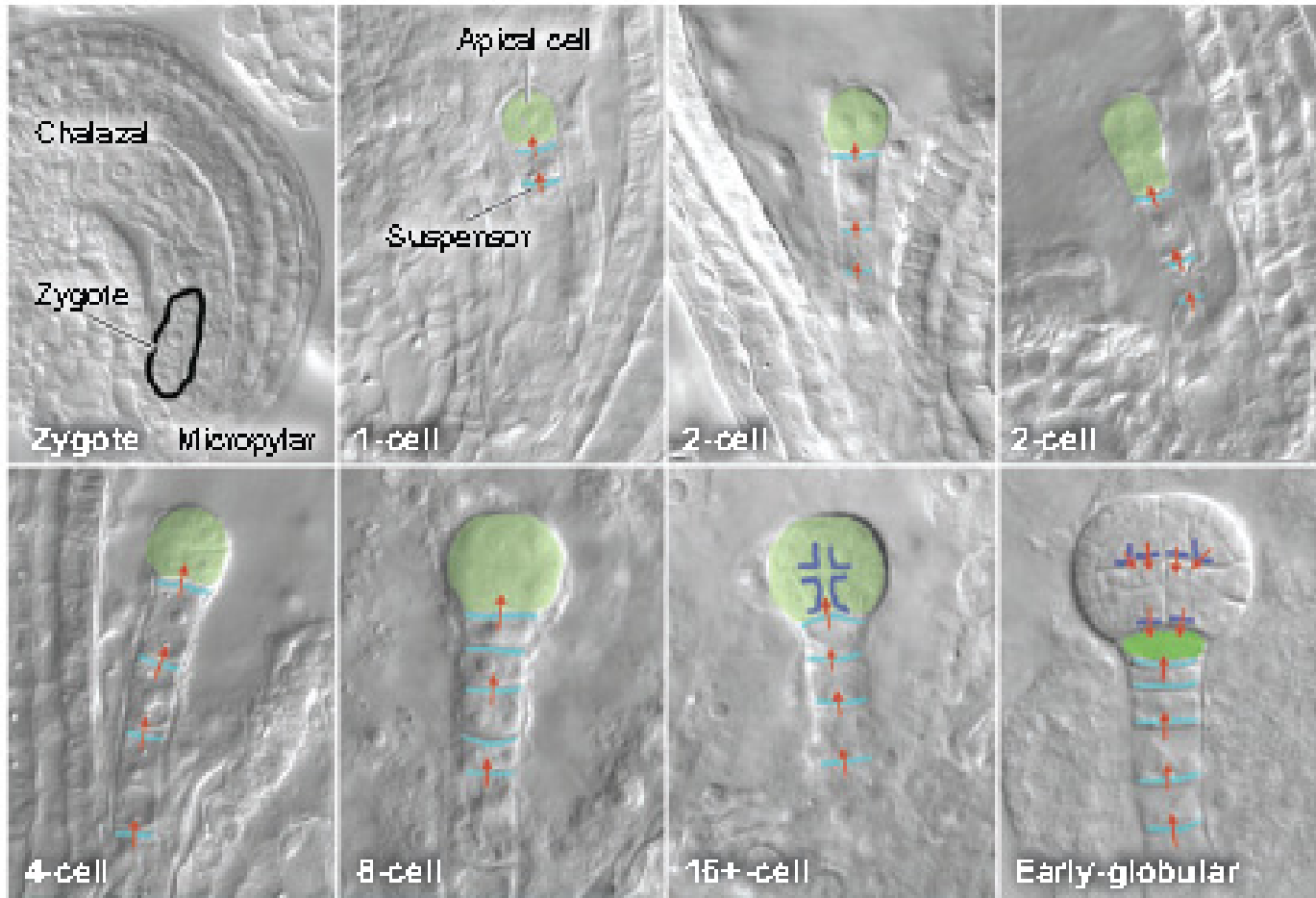


**Production of Auxin**



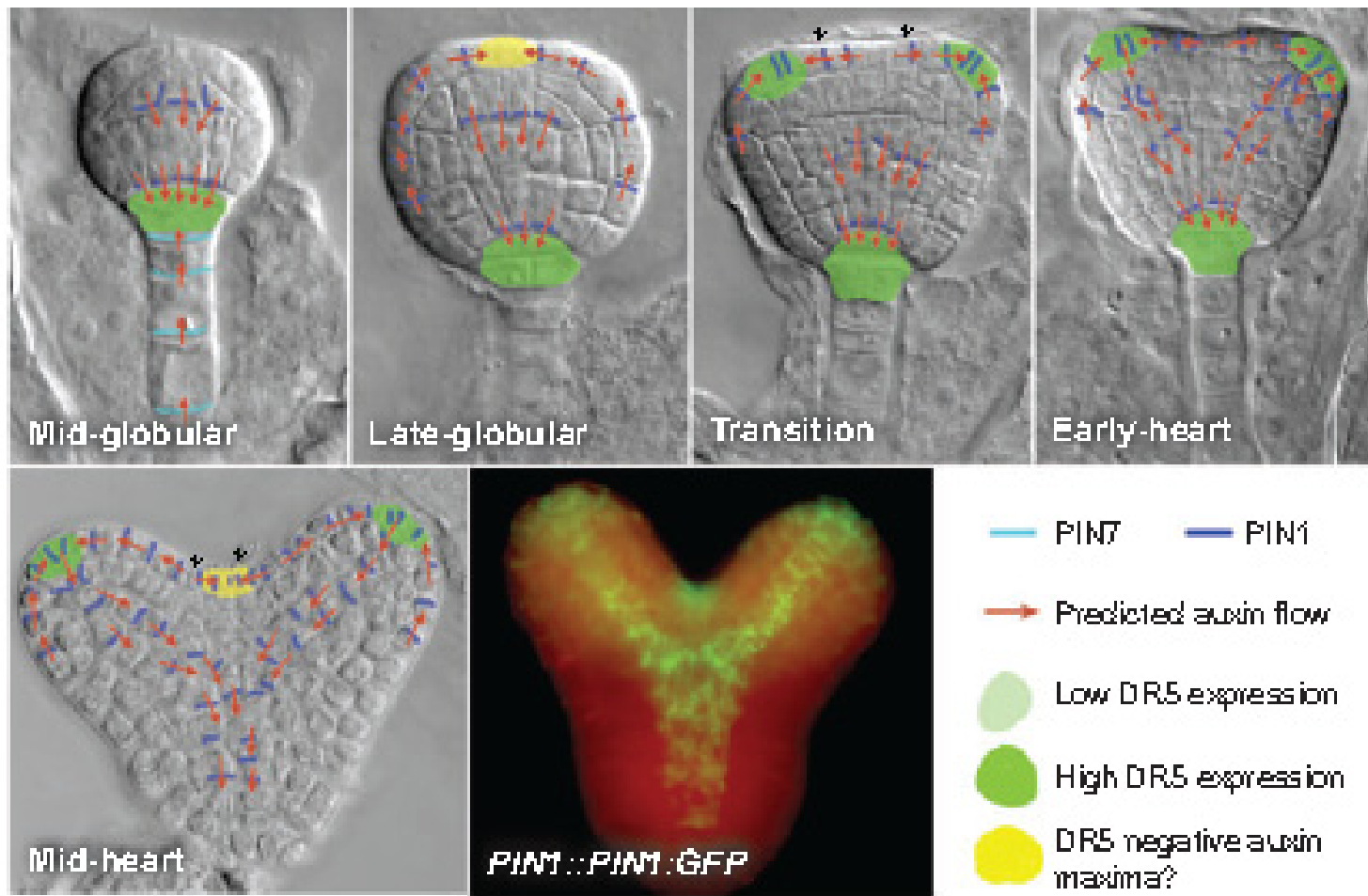
Benkova et al., *Cell* (2003)

Dubova, Hejatko, Friml (2005)

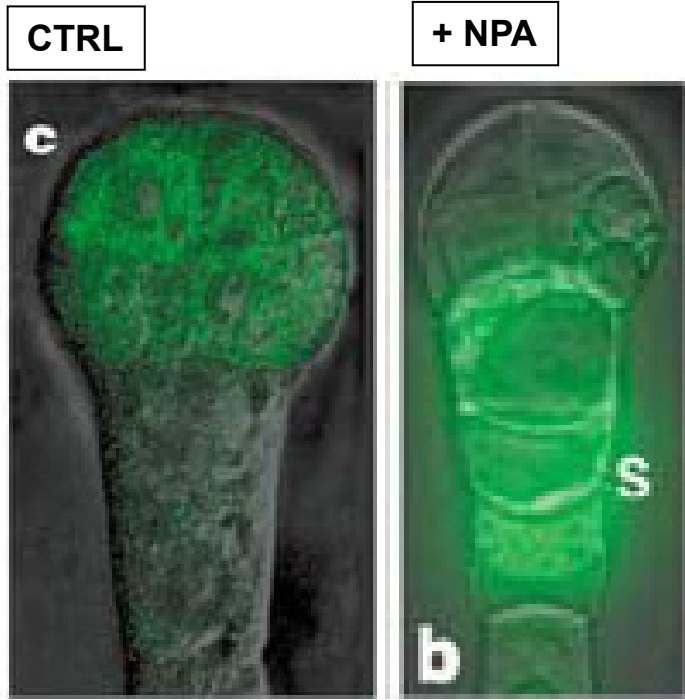


Bowman et al., *Annu. Rev. Plant. Biol.* (2008)

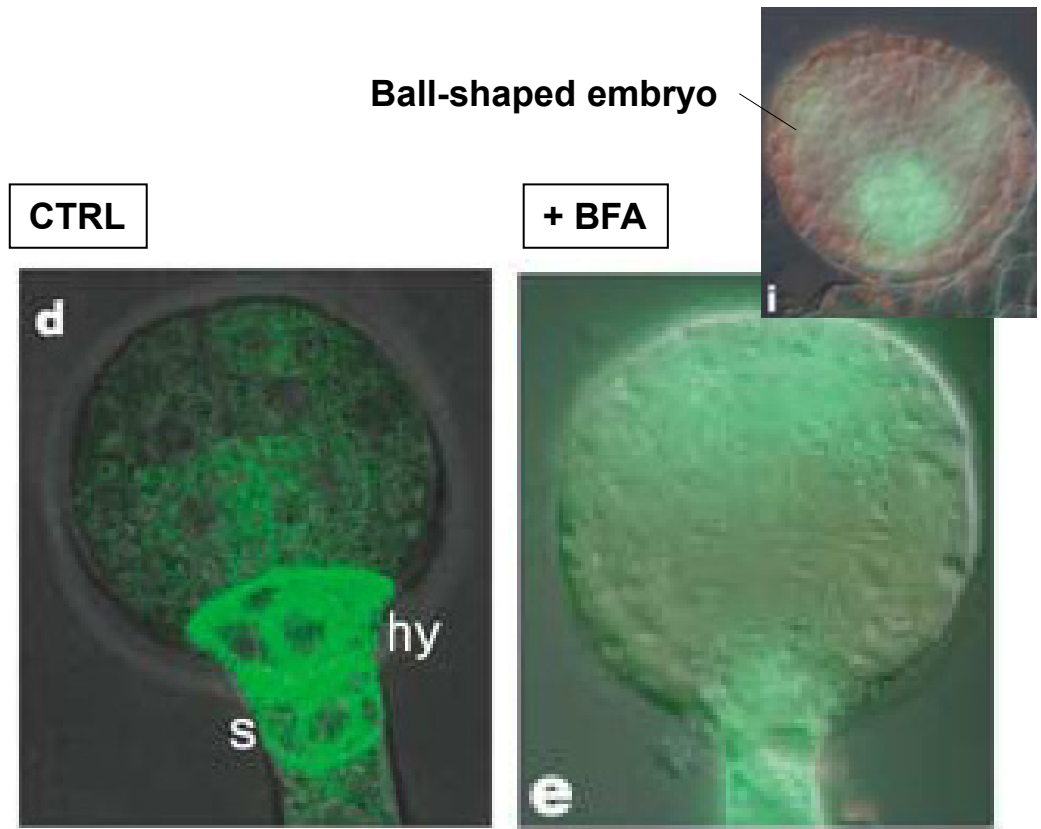




Bowman et al., *Annu. Rev. Plant. Biol.* (2008)



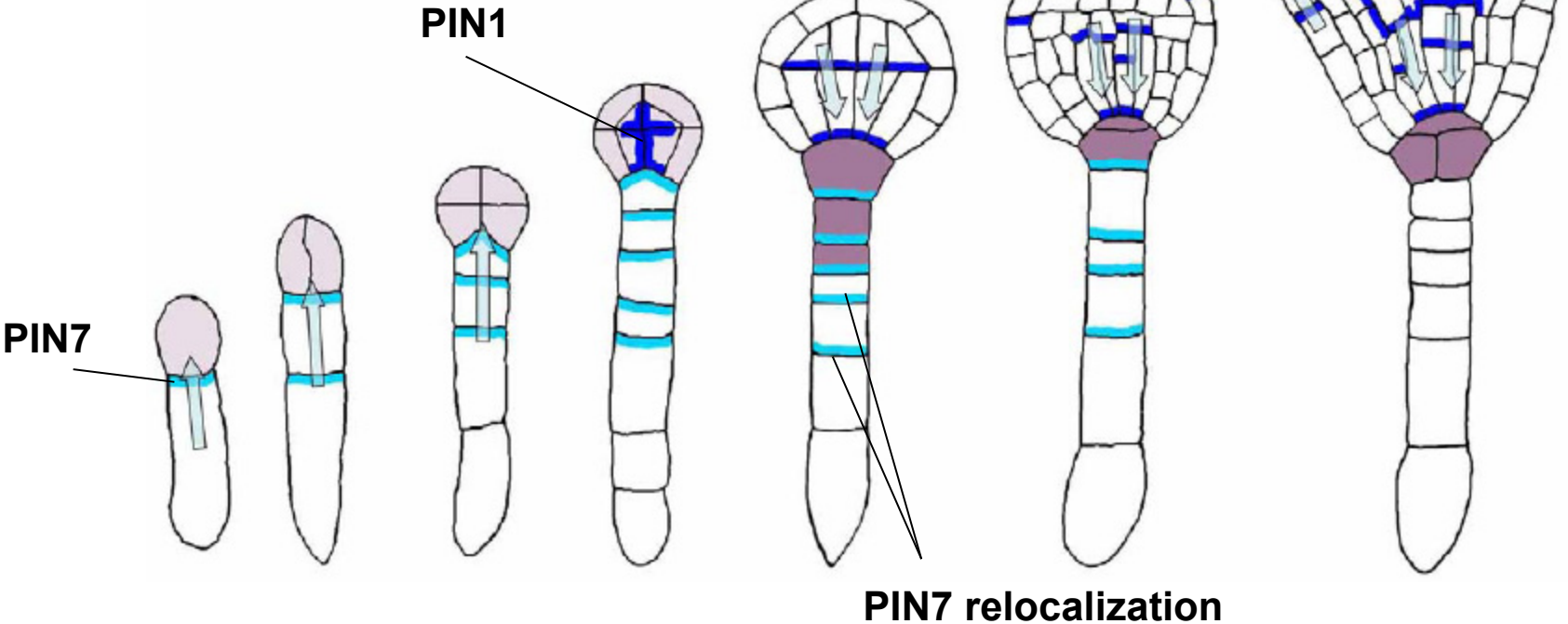
octant stage



globular stage

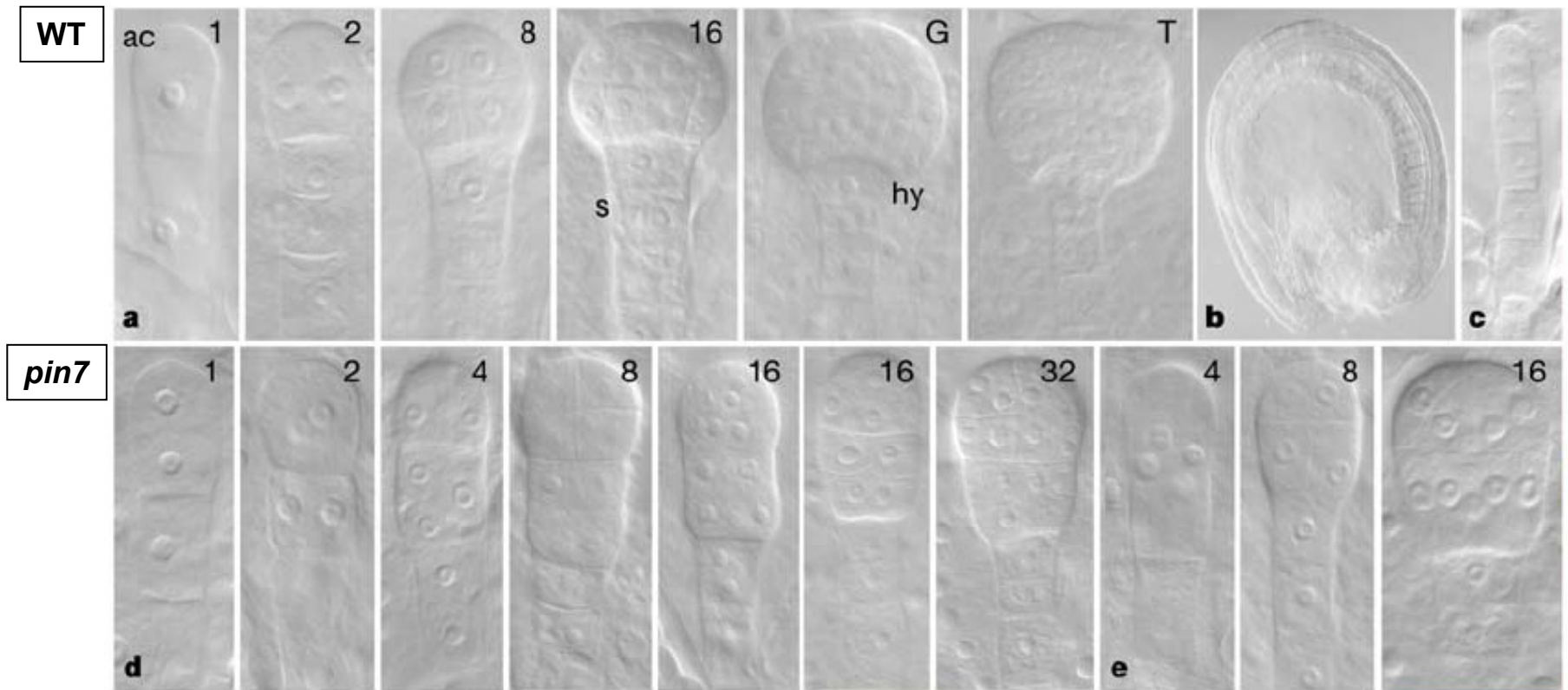
Friml, *Nature* (2003)

**Bilateral symmetry via PIN1 localization**

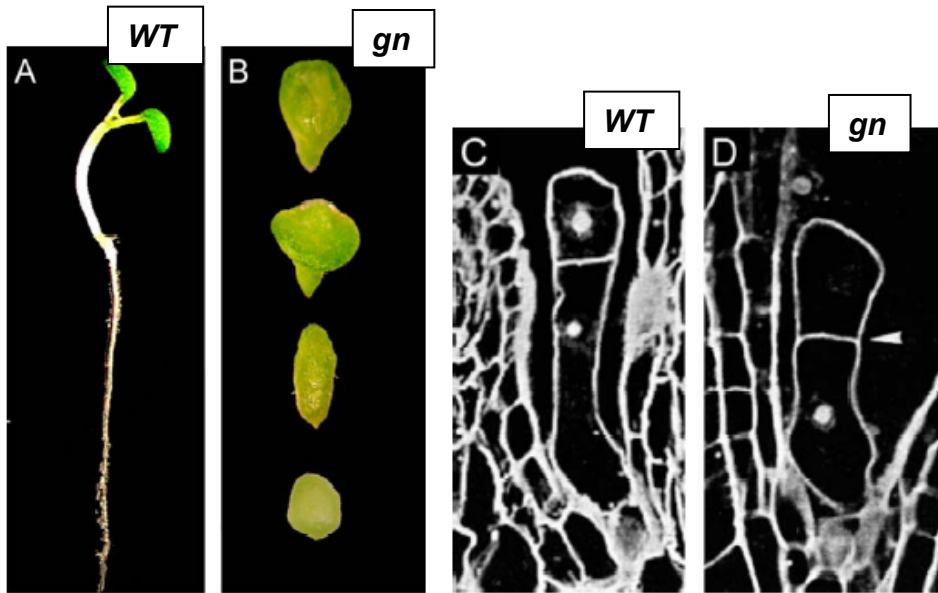


**Dermatogen stage**

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

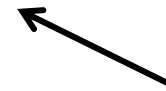


Friml et al., *Nature* (2003)

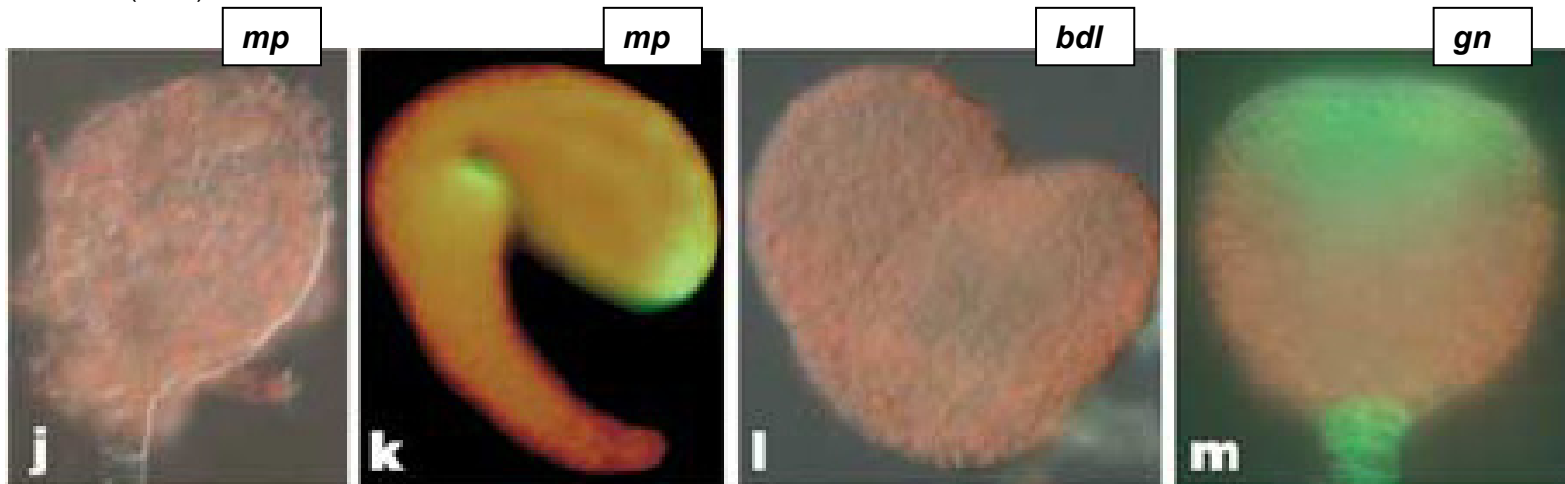


Mutations affecting embryo patterning are associated with changes in the auxin maxima formation

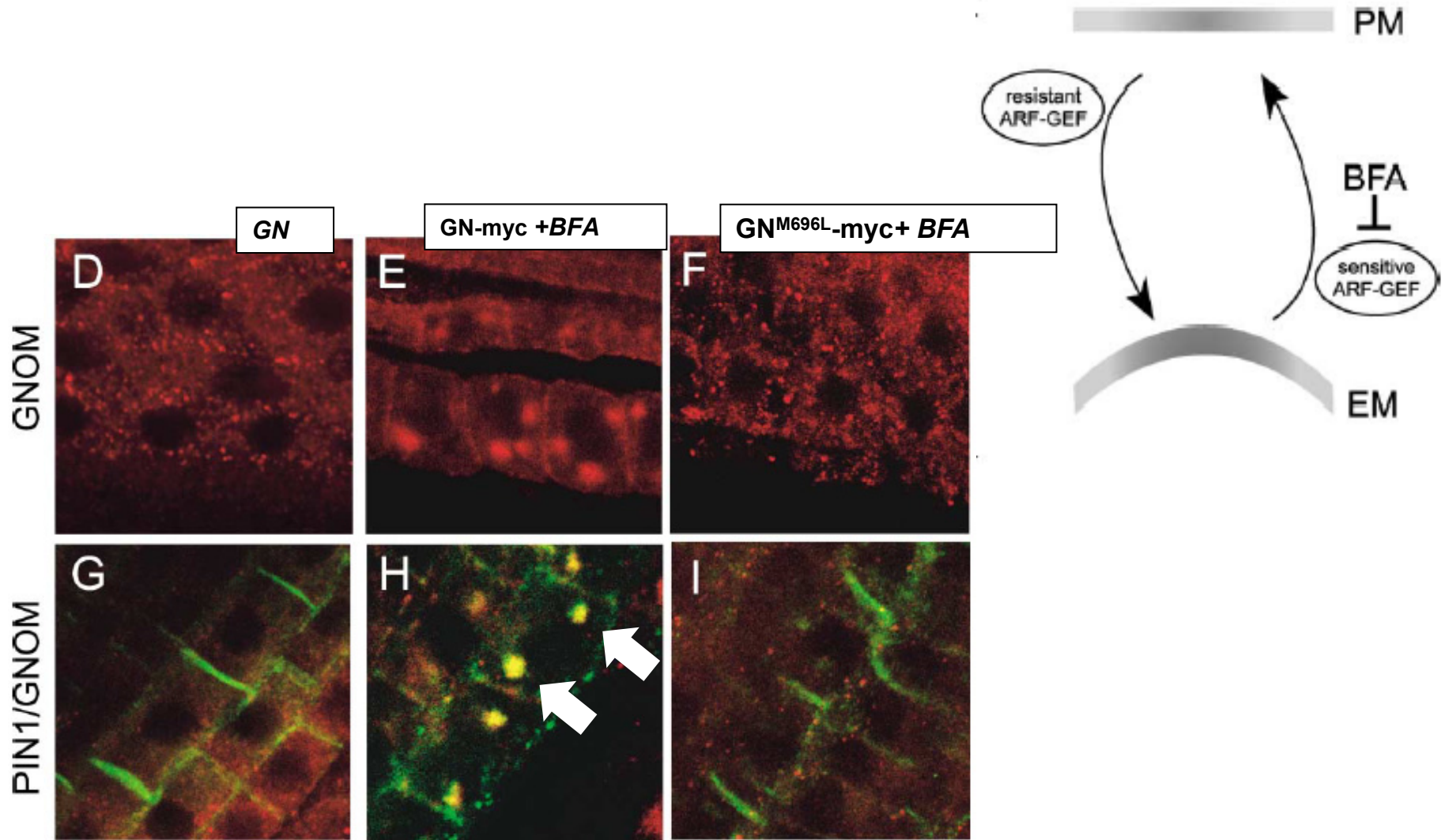
Adenosyl ribosylation factor  
Guanine nucleotide Exchange  
Factor (ARF GEF),



Richter et al., *E J Cell Biol* (2010)

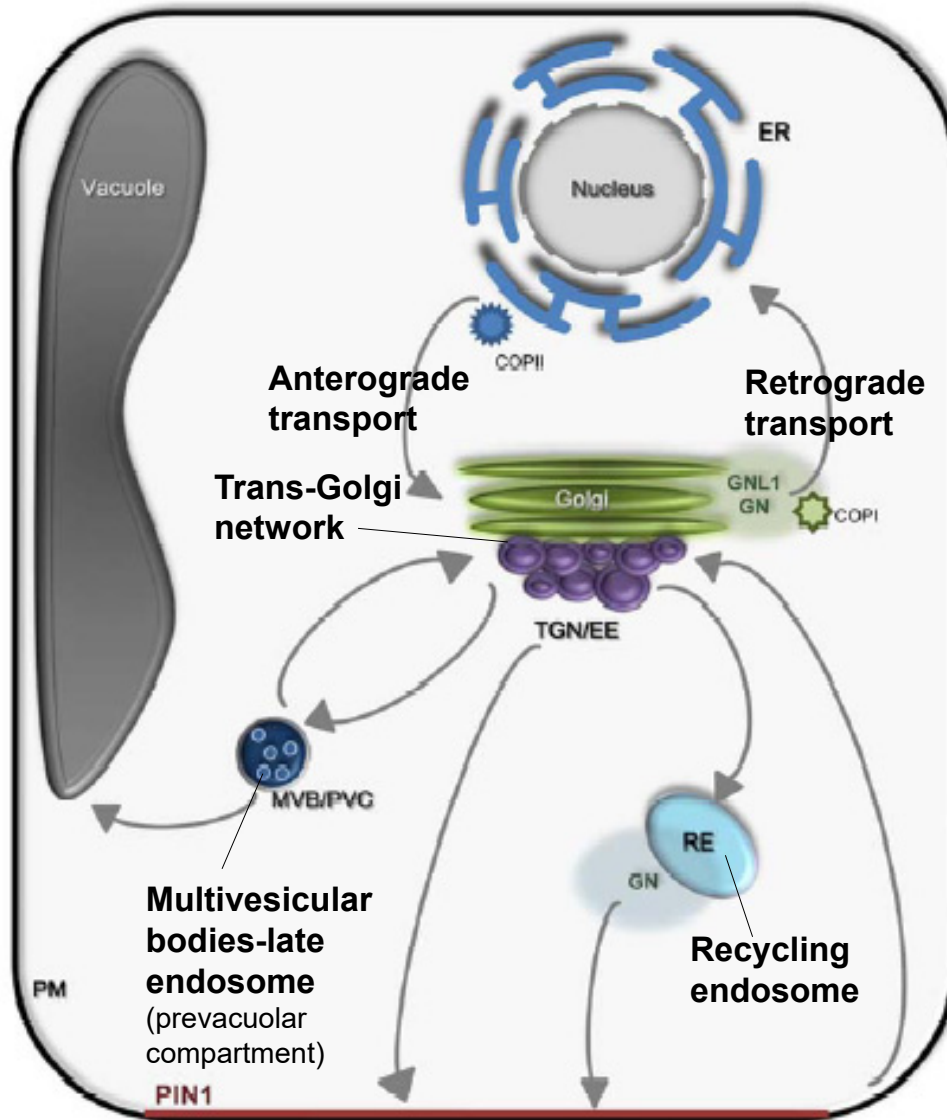


Friml et al., *Nature* (2003)



Geldner et al., *Cell* (2003)

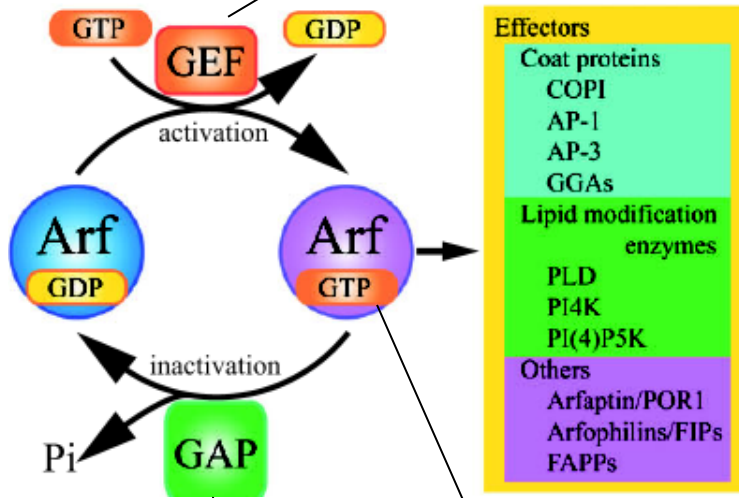




Richter et al., *E J Cell Biol* (2010)

A

Adenosyl ribosylation factor  
Guanine nucleotide Exchange  
Factor (ARF GEF),

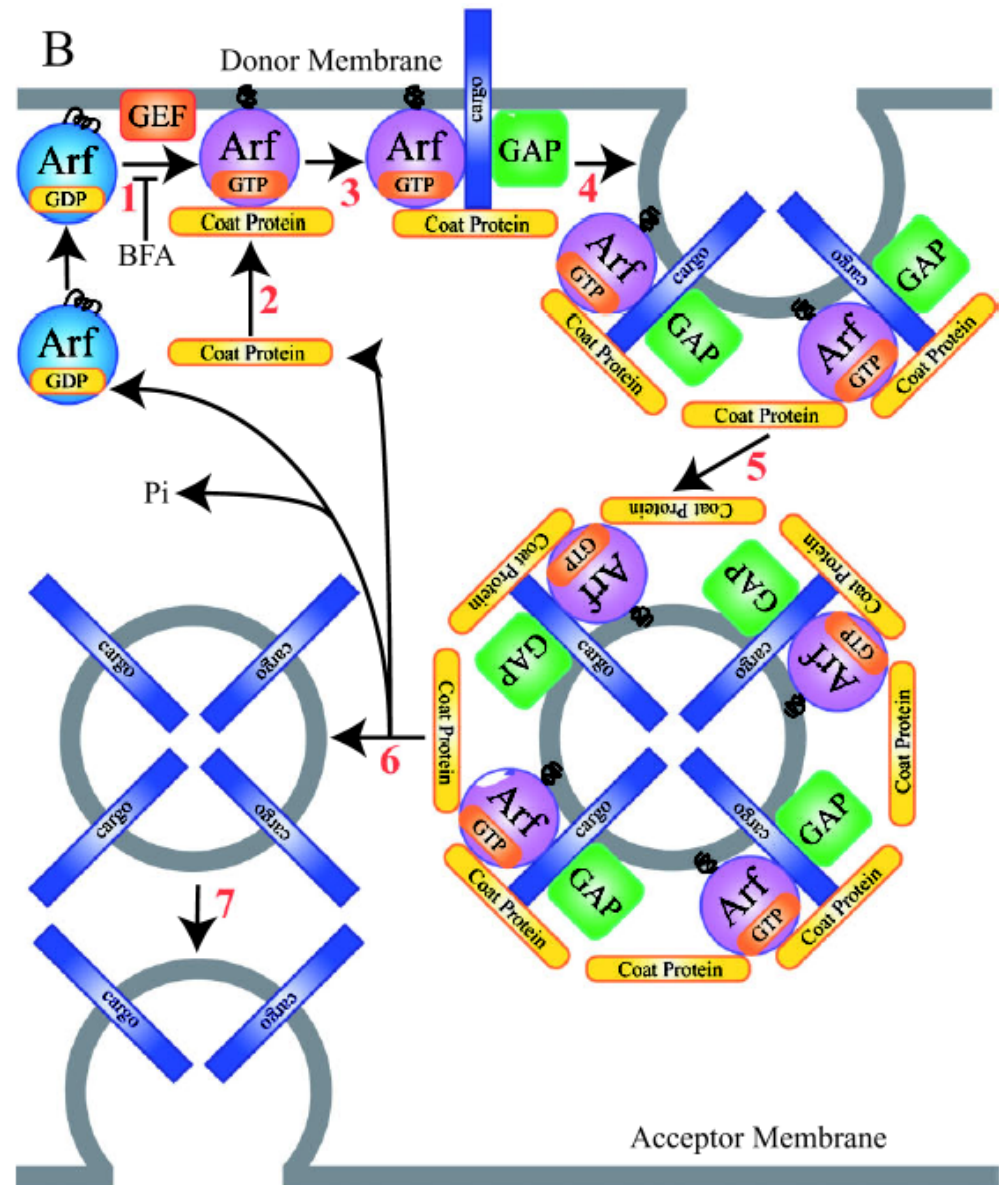


Adenosyl ribosylation factor

GTPase-activating  
protein

Shin et al., *J Biochem* (2004)

B



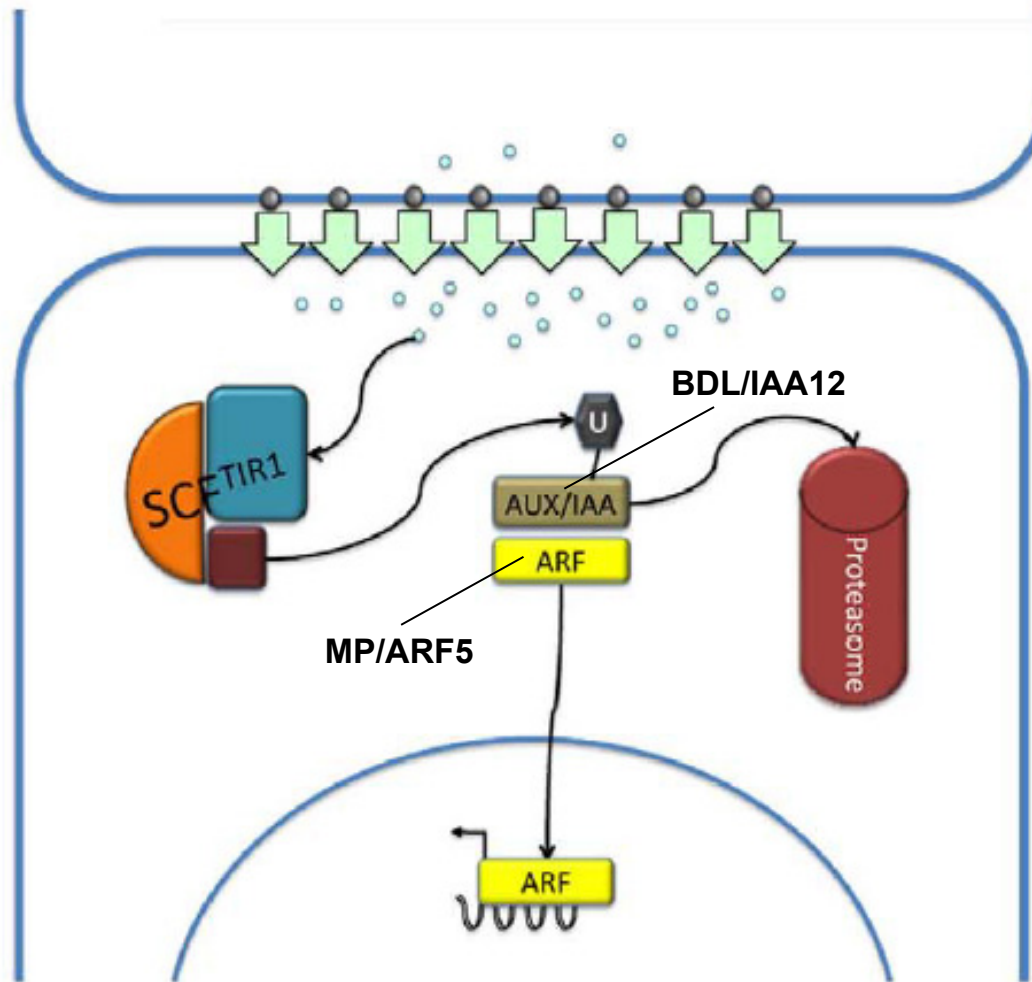


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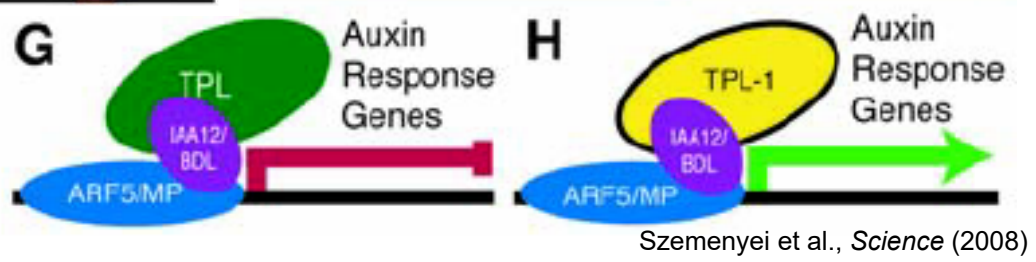
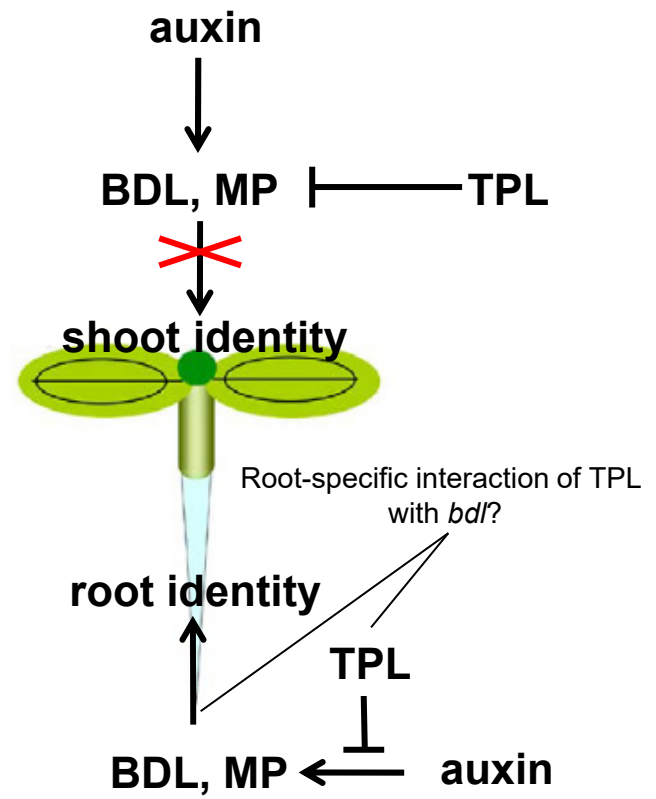
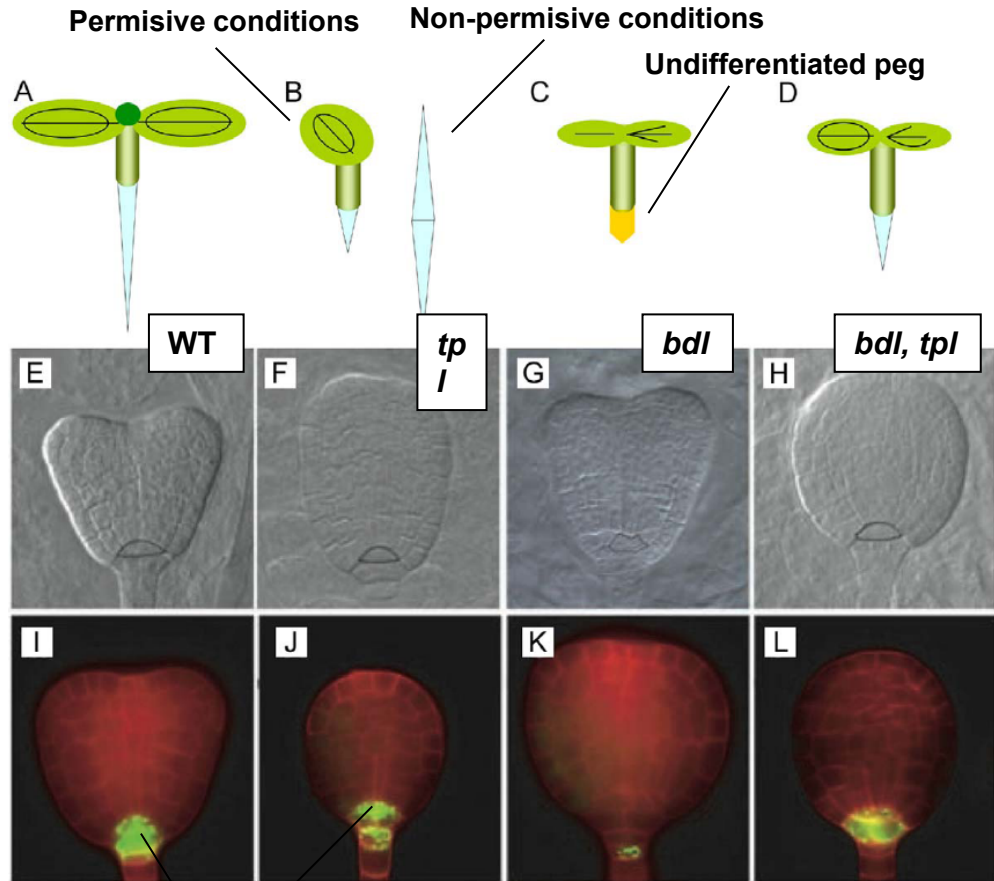
## Plant Embryogenesis

- Overview of the embryo formation in *Arabidopsis*
- Mechanism of the apical-basal axis formation
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  - differential gene expression
  - auxin gradients formation
  - the role of auxin signalling

## Auxin signalling and its role in the embryo patterning



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



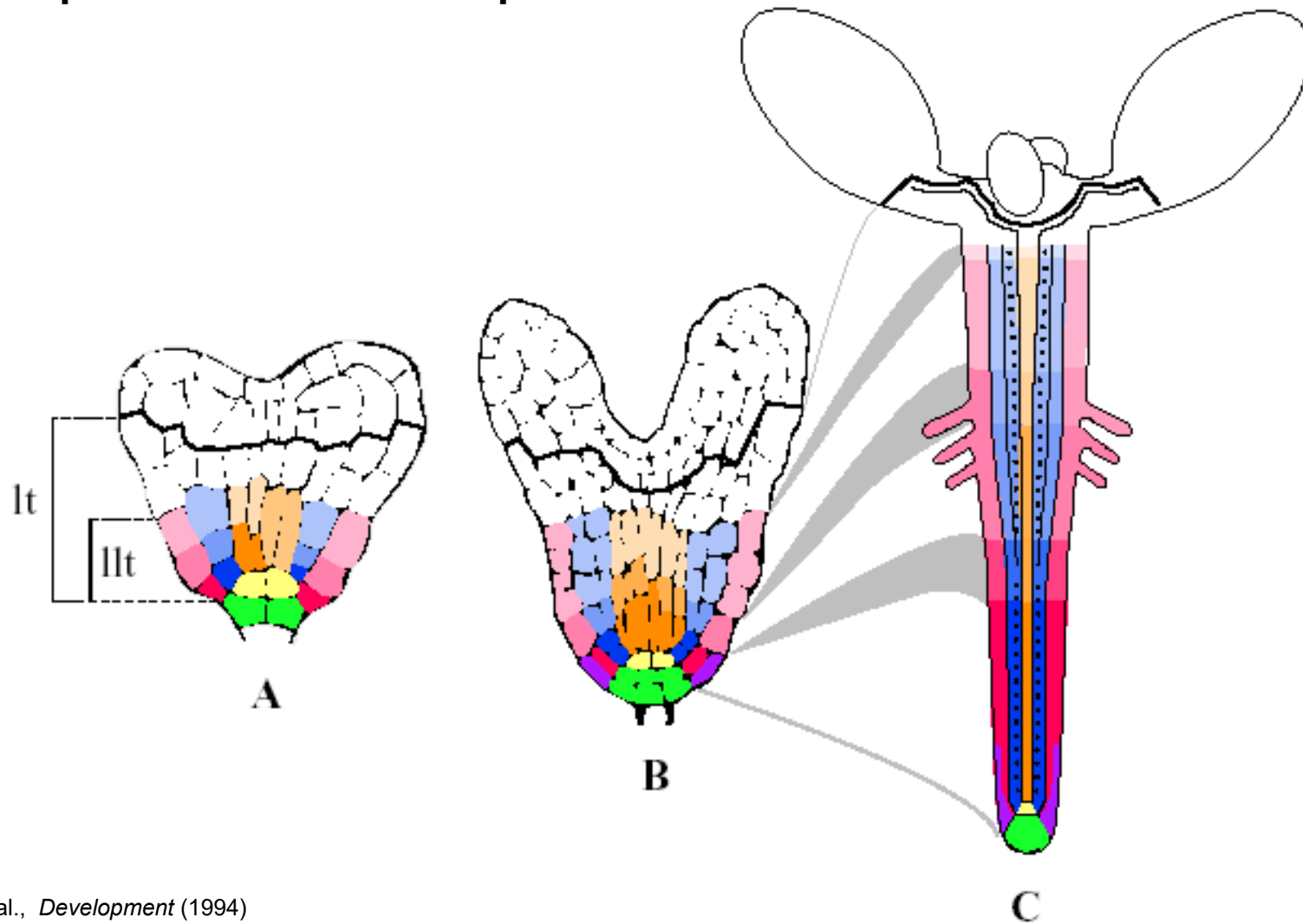
Capron et al., Arabidopsis Book (2009)

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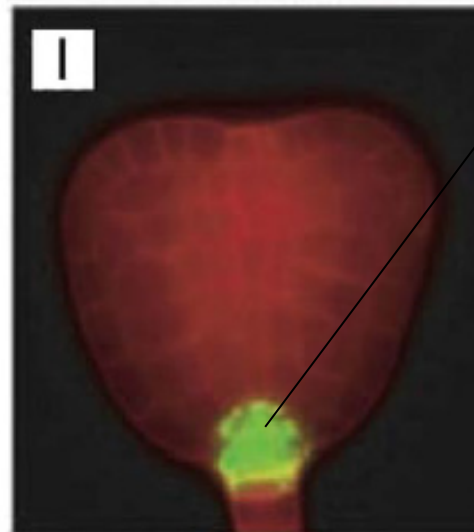
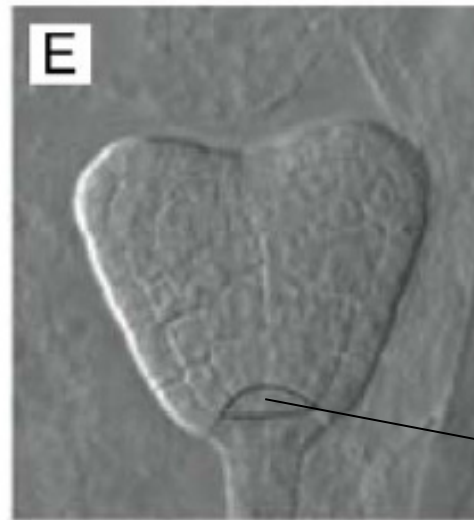
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- Root meristem formation
  - auxin and hypophysis identity

# Root apical meristem develops from the LT descendants



Sheres et al., *Development* (1994)



**Lens shaped cell**



**Klidové centrum**  
**Quiscent centre**



**Organizational**  
**centre for the**  
**RAM formation**

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

auxin  
 ↓  
 BDL, MP  
 ↓  
 TOM TF

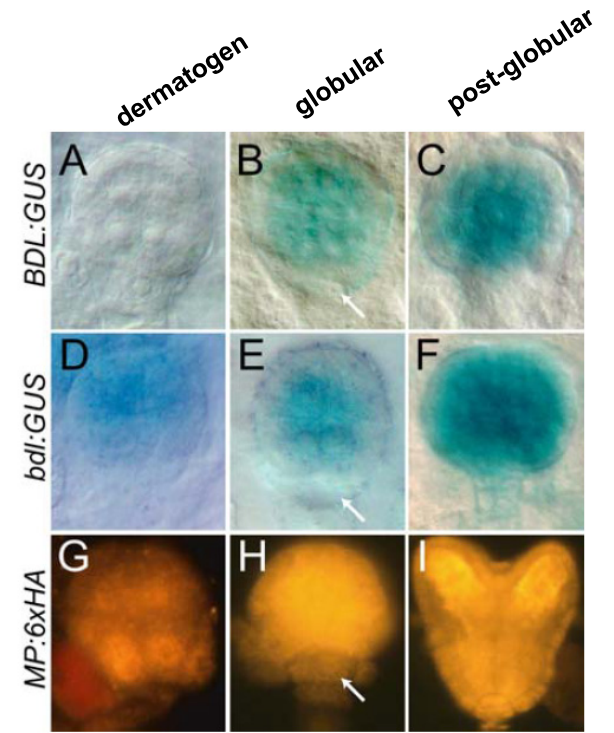
Auxin flow from the UT

Hypophysis

Lens shaped cell

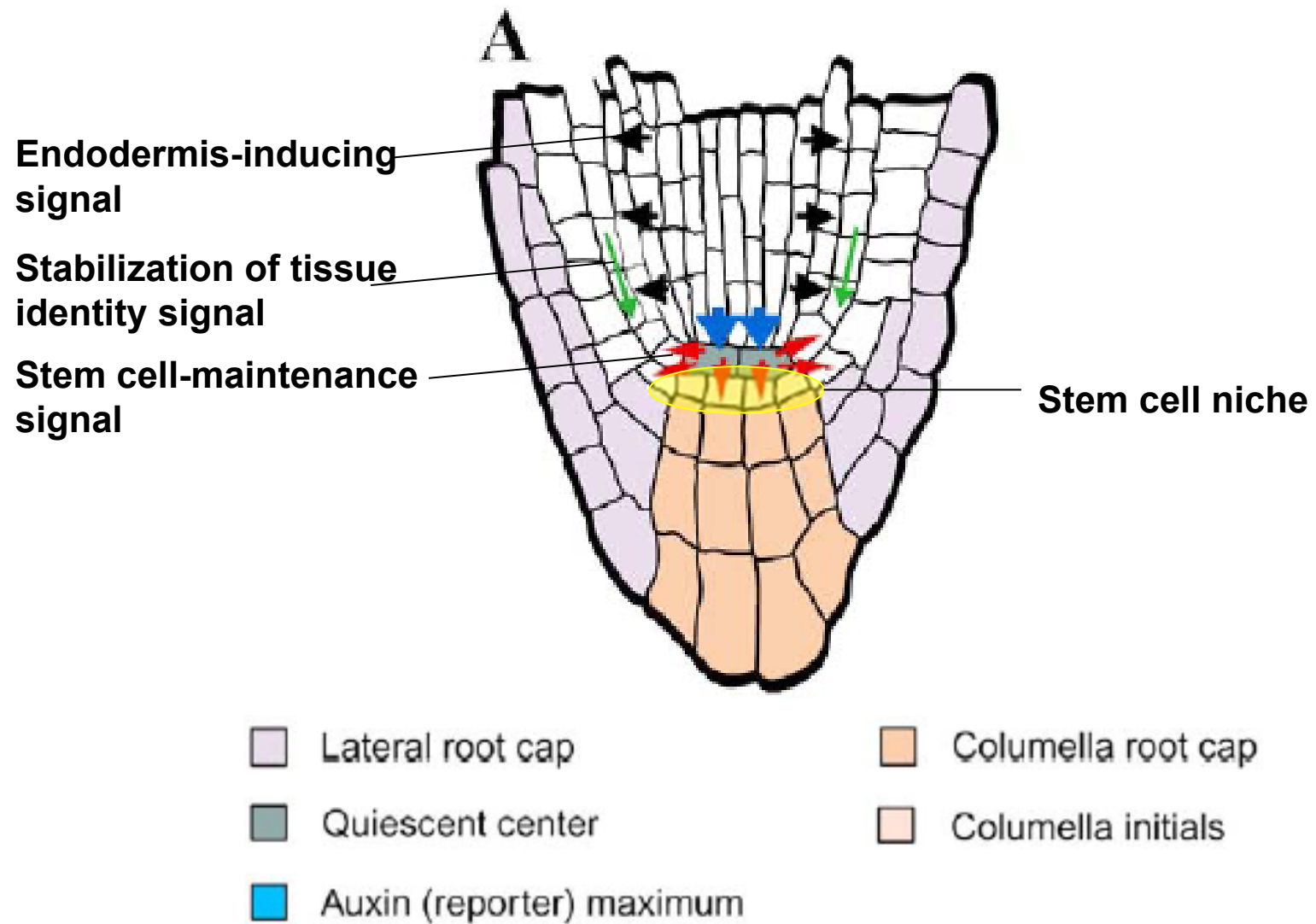
Globular stage

Late globular-early triangular embryo stage



Weijers et al., *Dev Cell* (2006)

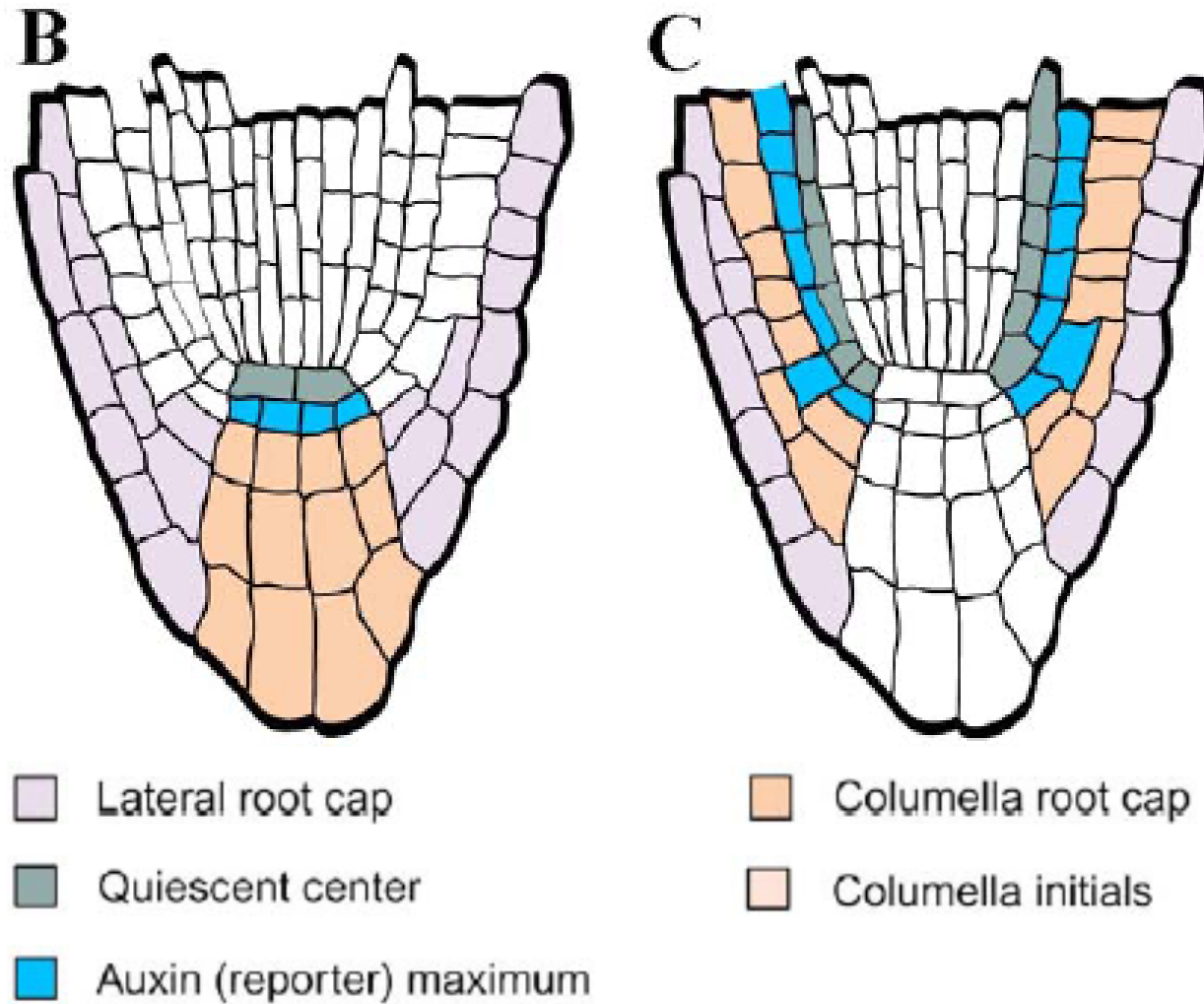
Capron et al., *Arabidopsis Book* (2009)



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



auxin response maximum displaced



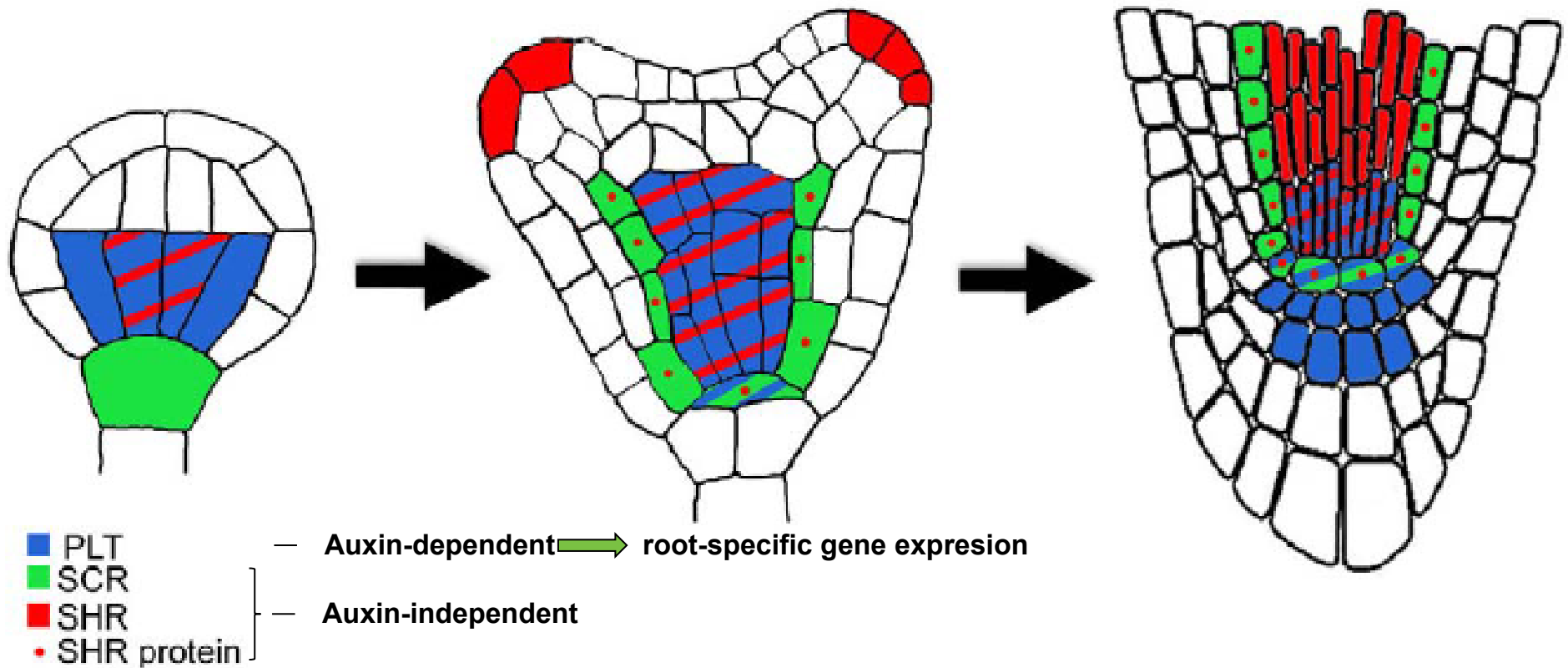
Capron et al., *Arabidopsis Book* (2009)

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- Root meristem formation
  - auxin and hypophysis identity
  - differential gene expression and root meristem patterning

## Auxin-dependent and auxin-independent differential gene expression patterns root meristem



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

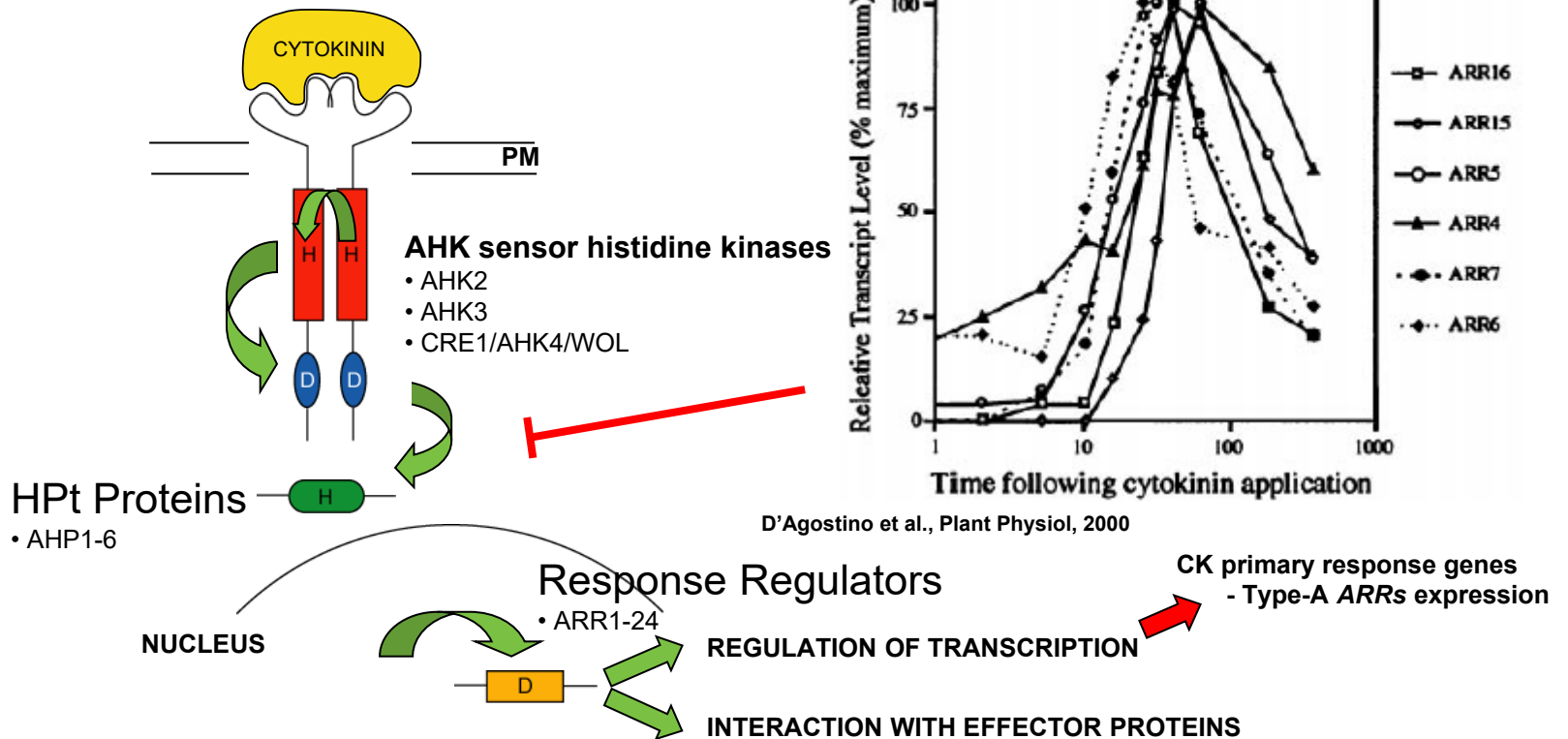
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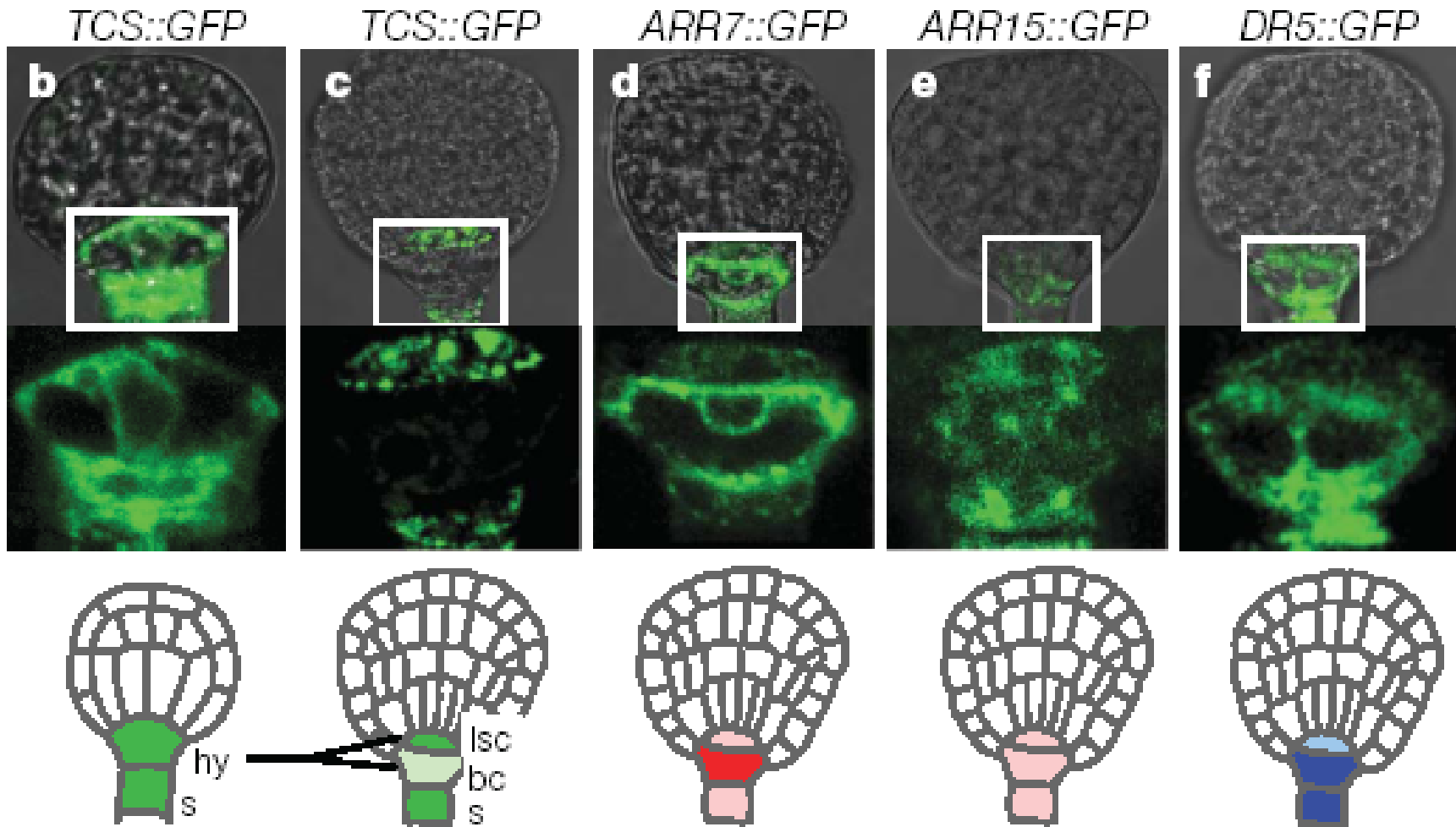
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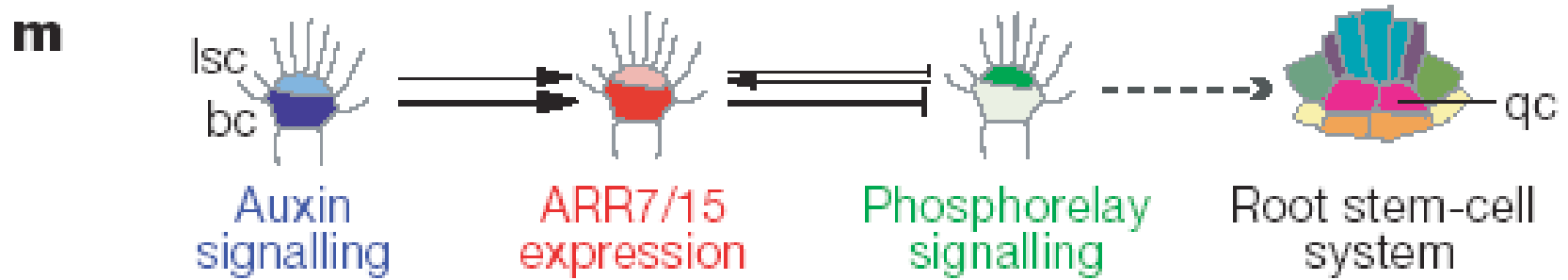
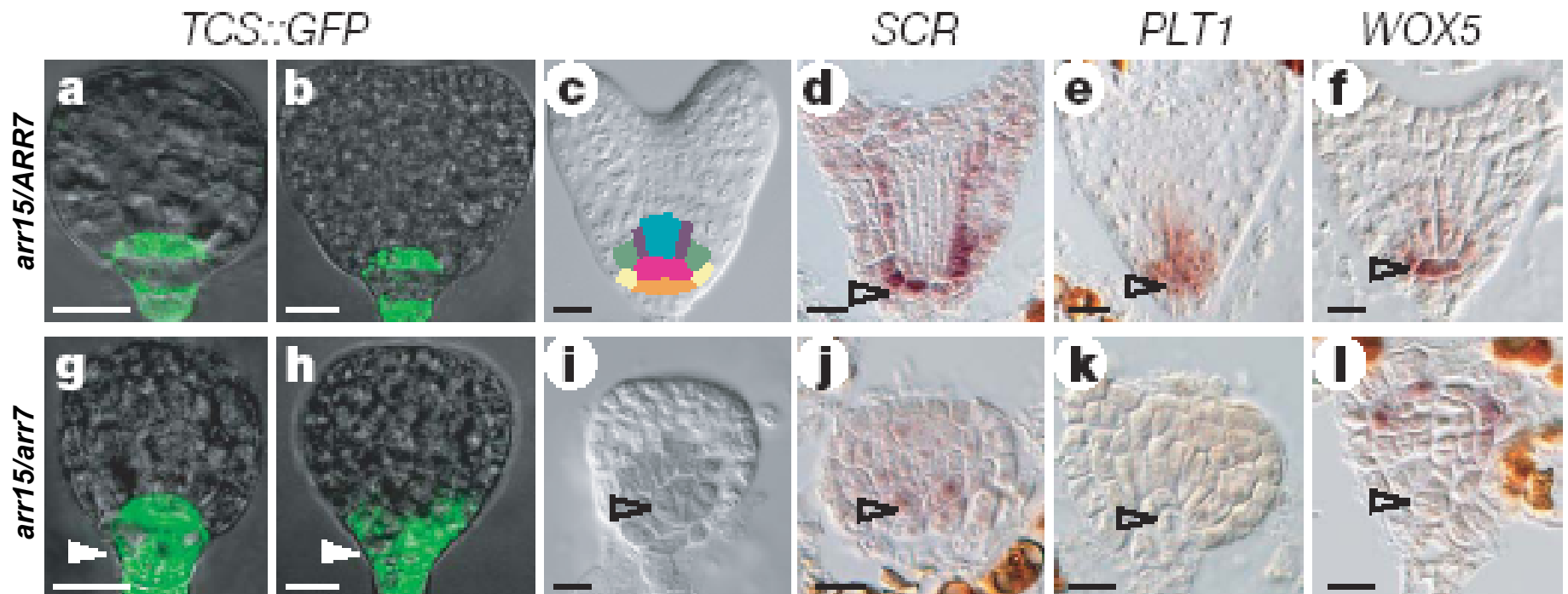
# Signal Transduction via TCS

## Recent Model of the CK Signaling via TCS Pathway





Muller and Sheen., *Nature* (2008)



Muller and Sheen., *Nature* (2008)

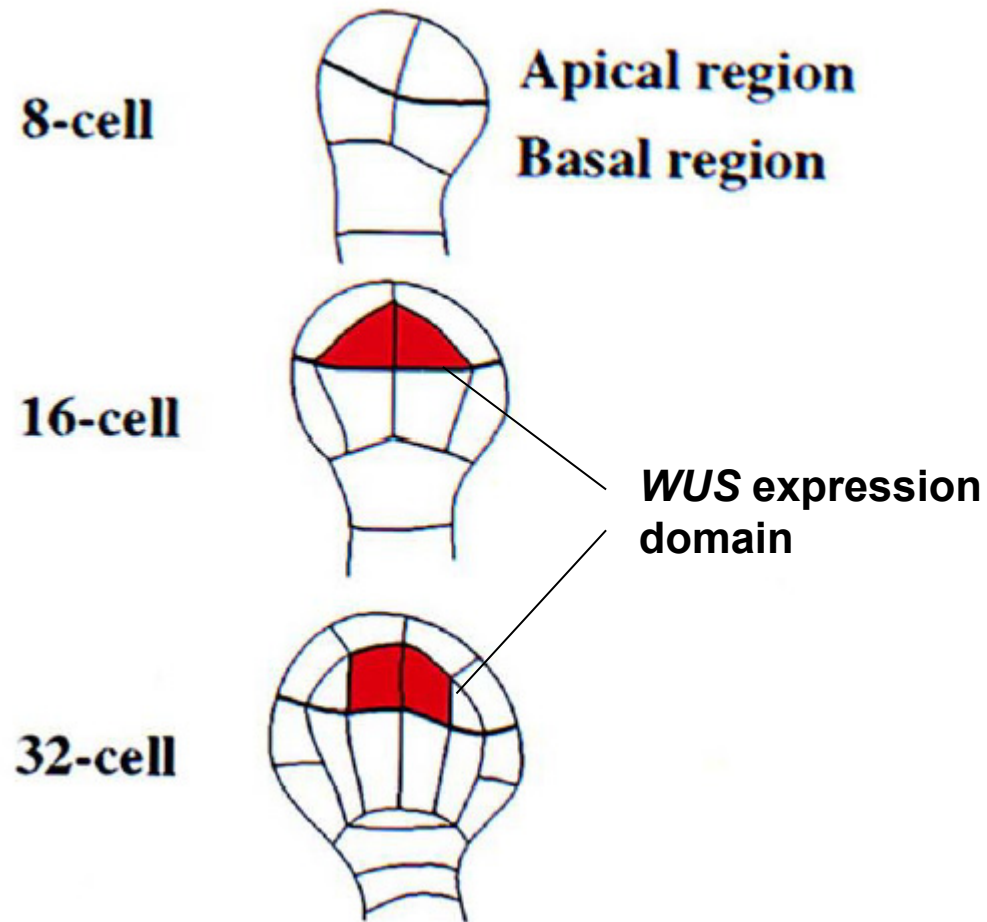


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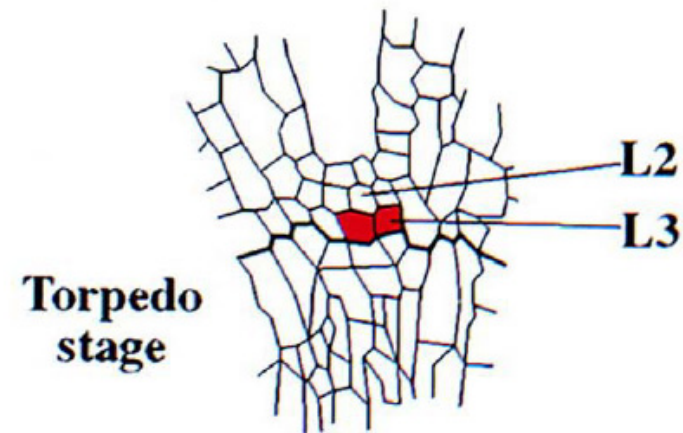
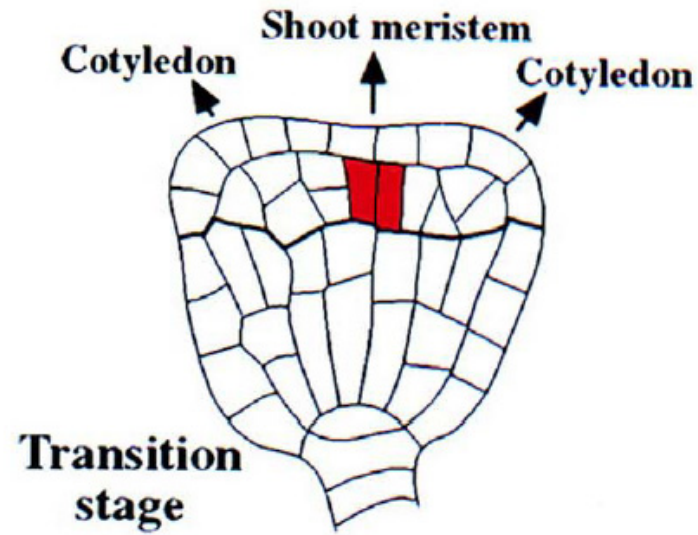
## Plant Embryogenesis

- Patterning of the apical pole of the plant embryo
  - generation of cotyledons and shoot apical meristem

## SAM specification

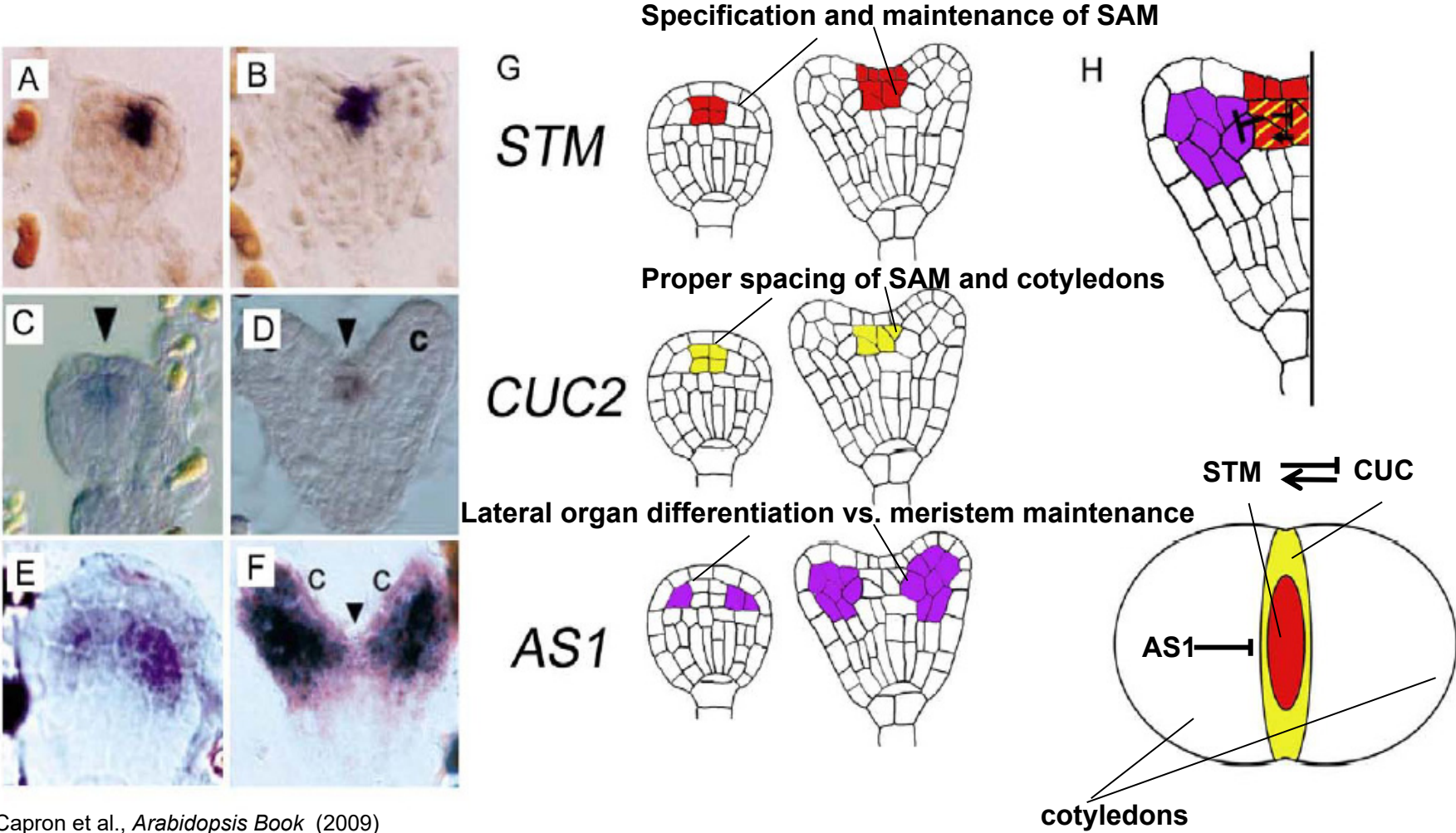


Capron et al., *Arabidopsis Book* (2009)



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

# Gene interactions during apical embryo pole patterning



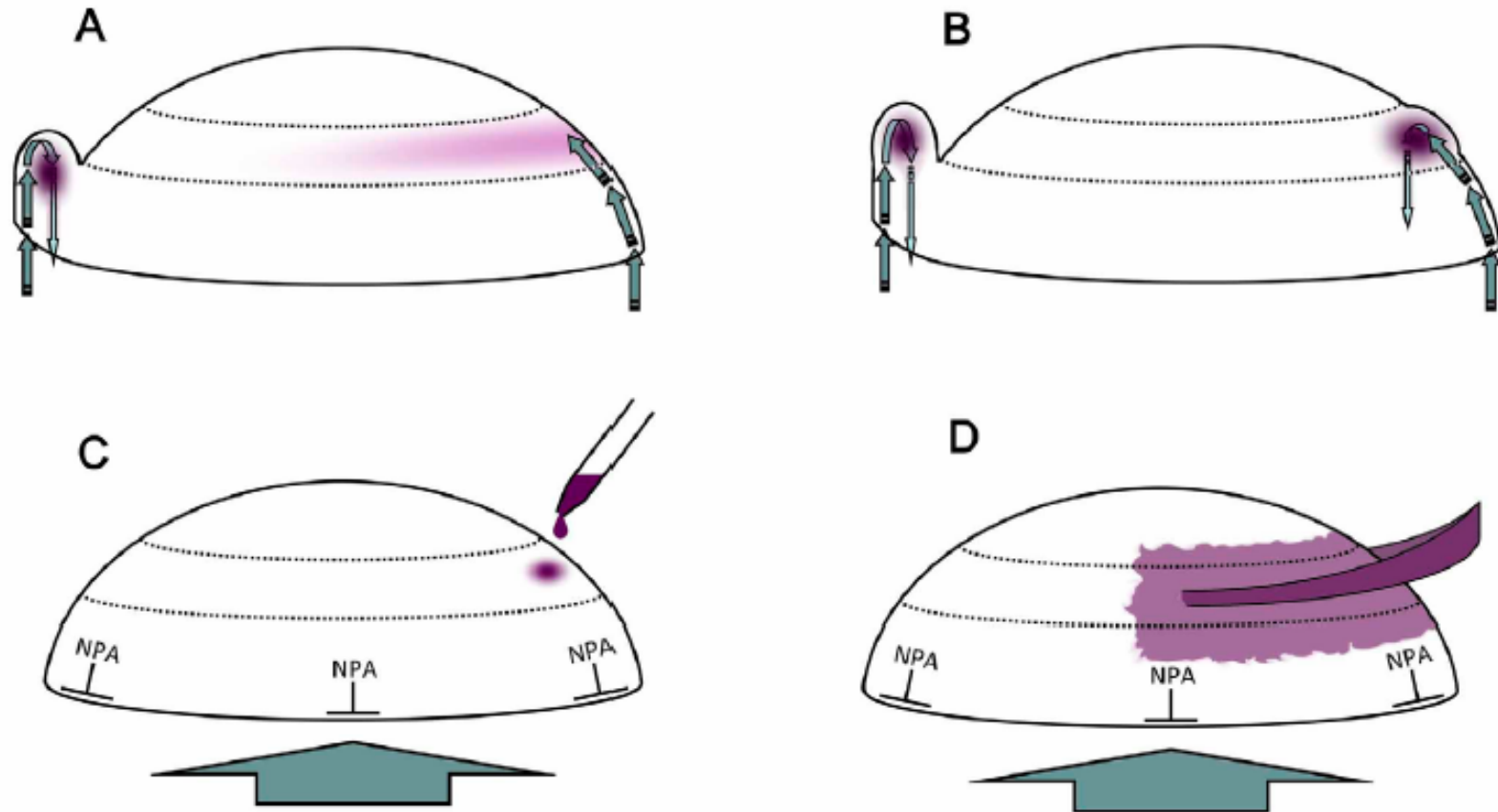
Capron et al., *Arabidopsis Book* (2009)

# Outline of Lesson 7

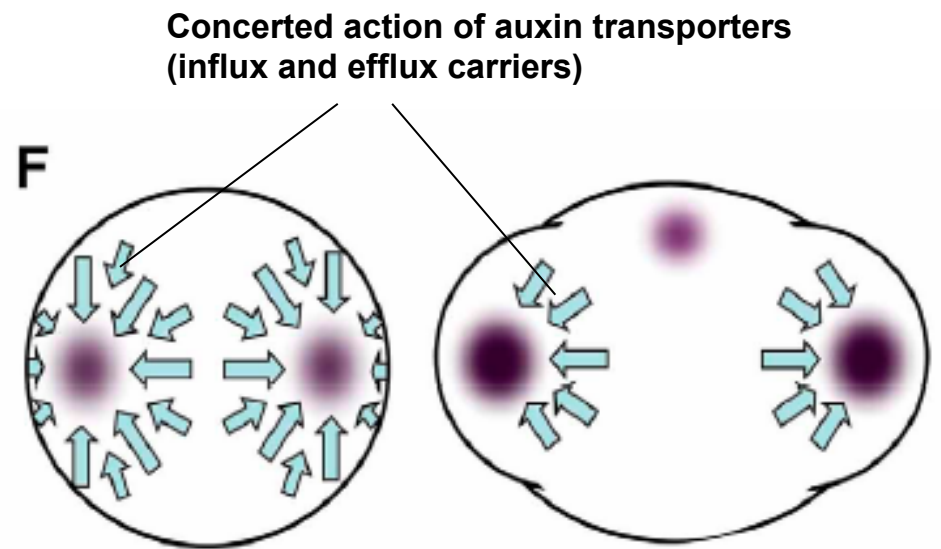
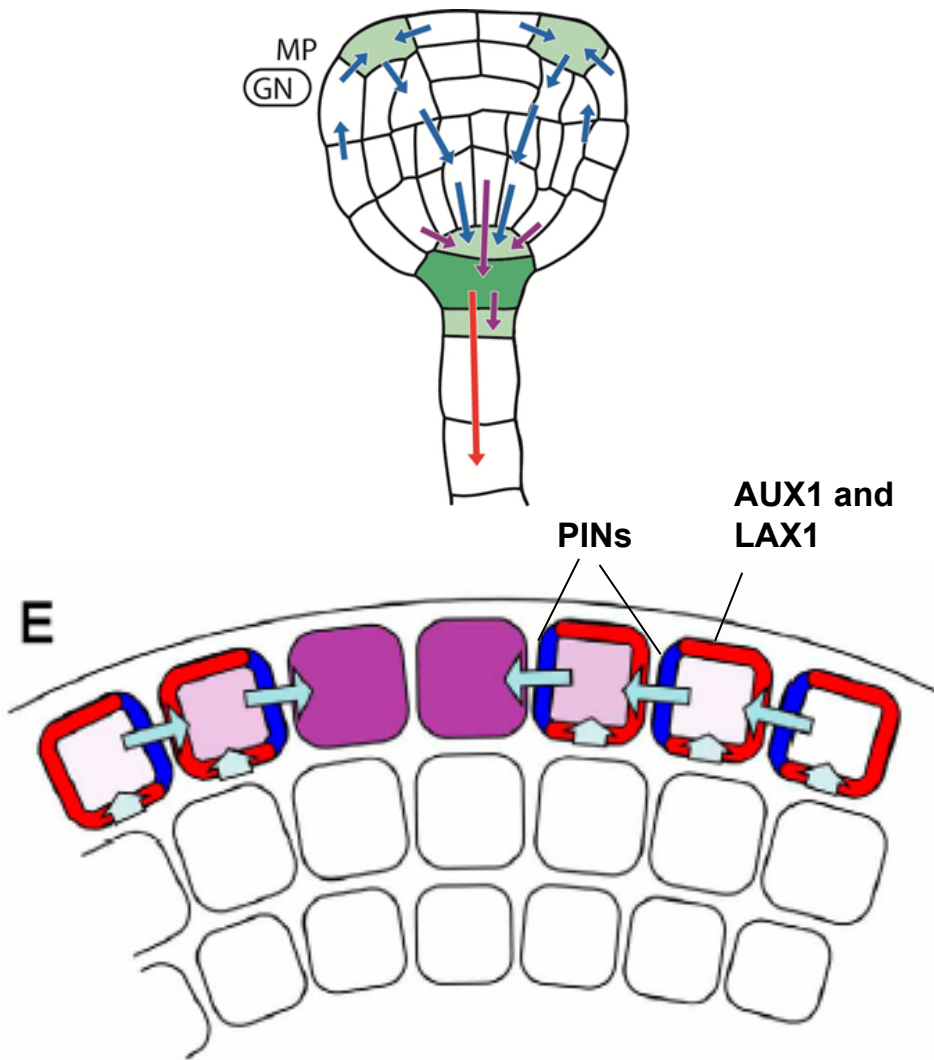
## Plant Embryogenesis

- Patterning of the apical pole of the plant embryo
  - generation of cotyledons and shoot apical meristem
  - proper spacing of lateral organs

## Auxin maxima are involved in lateral organ formation and acquiring of bilateral symmetry



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



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

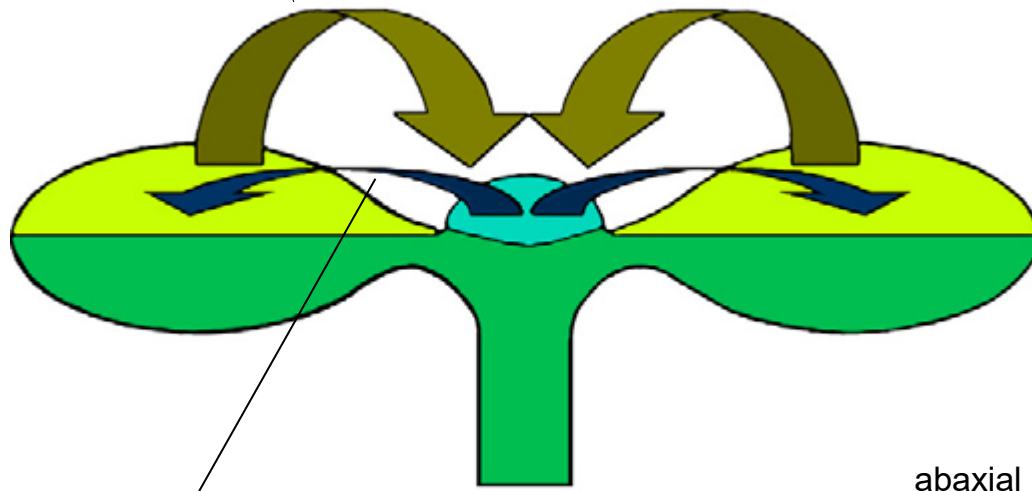


# Outline of Lesson 7

## Plant Embryogenesis

- Patterning of the apical pole of the plant embryo
  - generation of cotyledons and shoot apical meristem
  - proper spacing of lateral organs
  - **adaxial-abaxial axis formation**

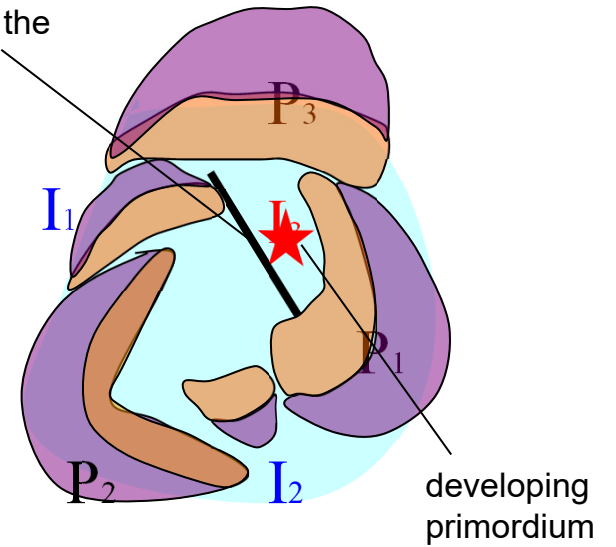
**SAM-inducing positive feedback from the adaxial pole**



**SAM-derived signals induce adaxial-abaxial diversification**

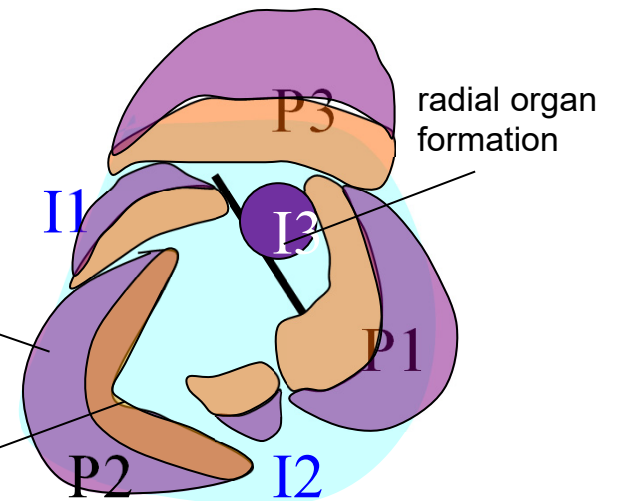
Capron et al., *Arabidopsis Book* (2009)

Incision in the meristem

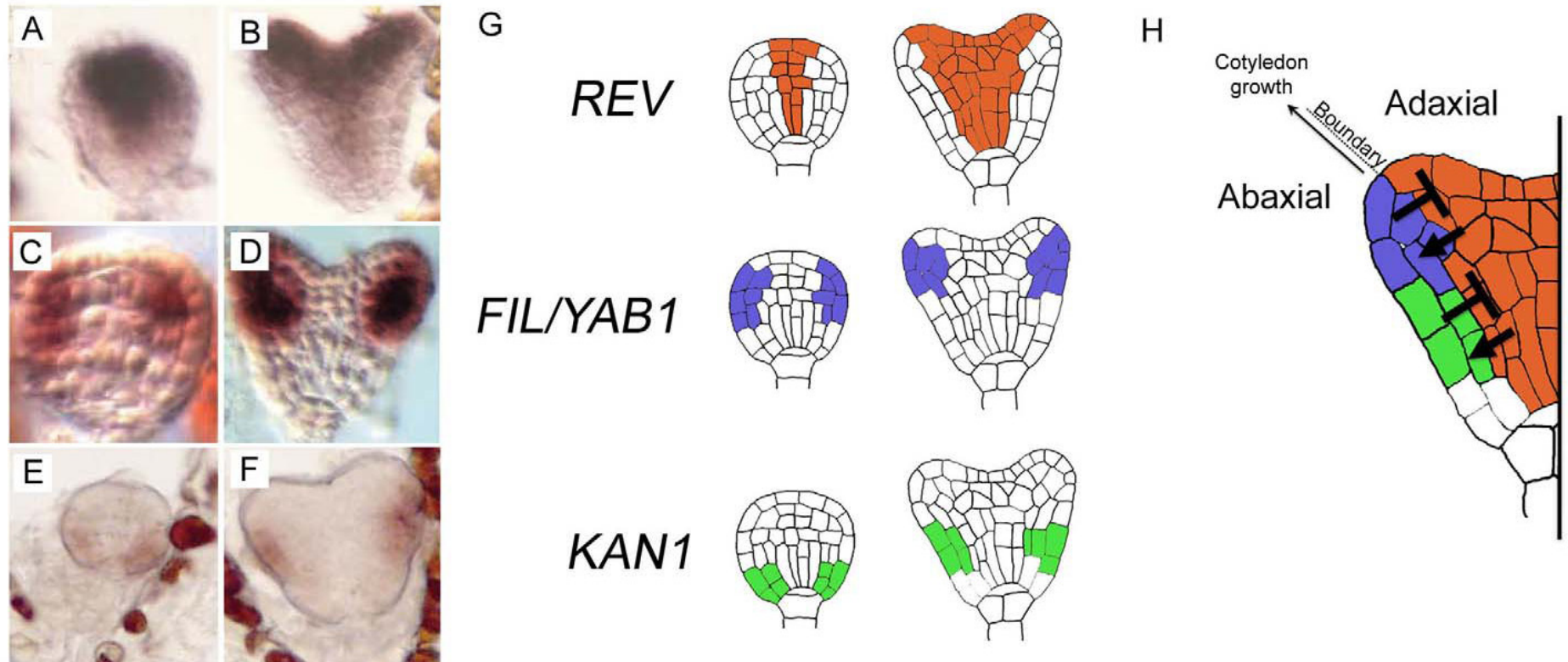


abaxial leaf side

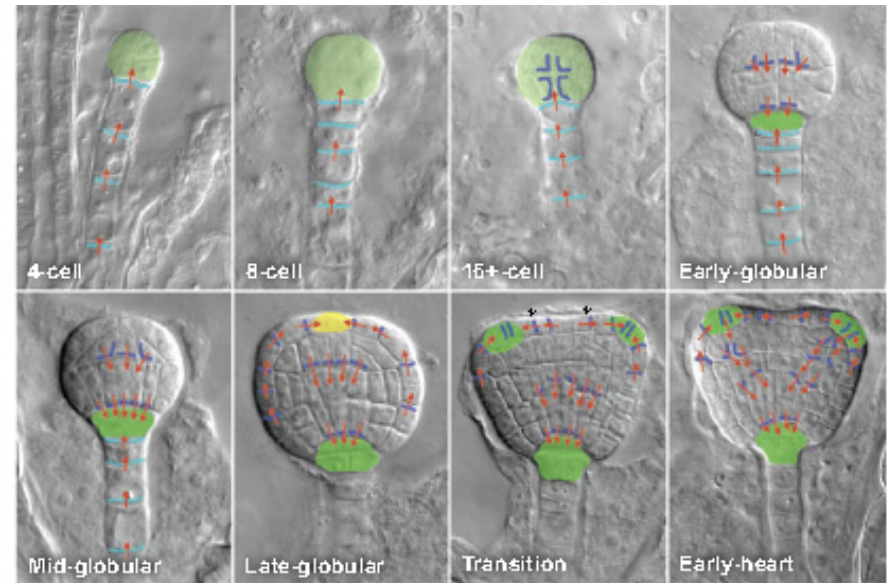
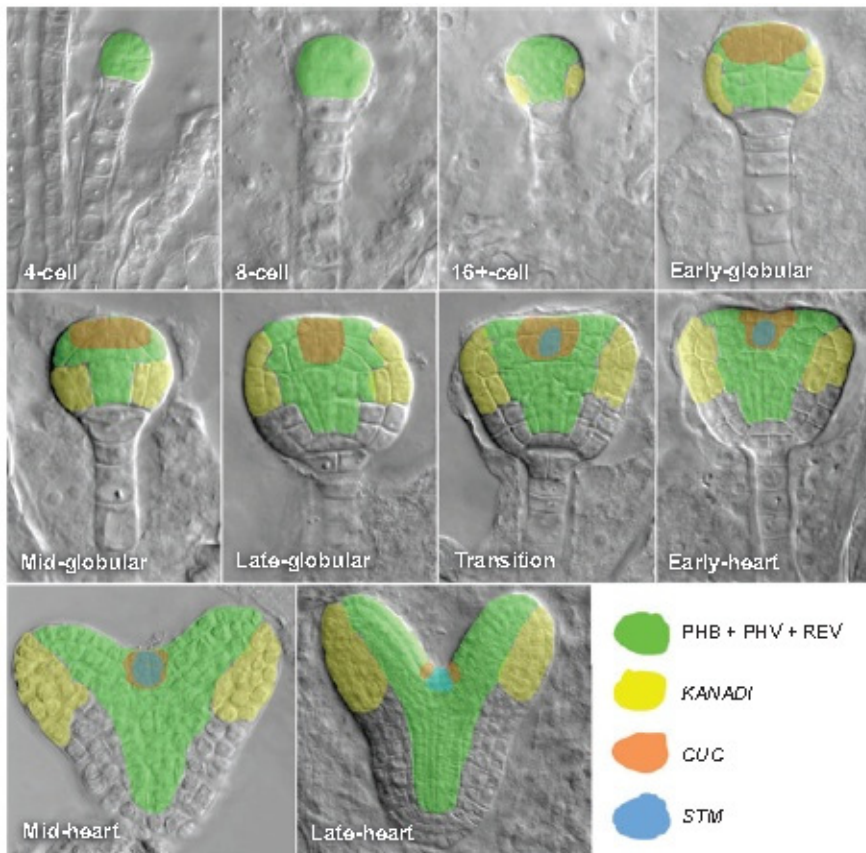
adaxial leaf side



## Specificity in gene expression is involved in the adaxial-abaxial patterning



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



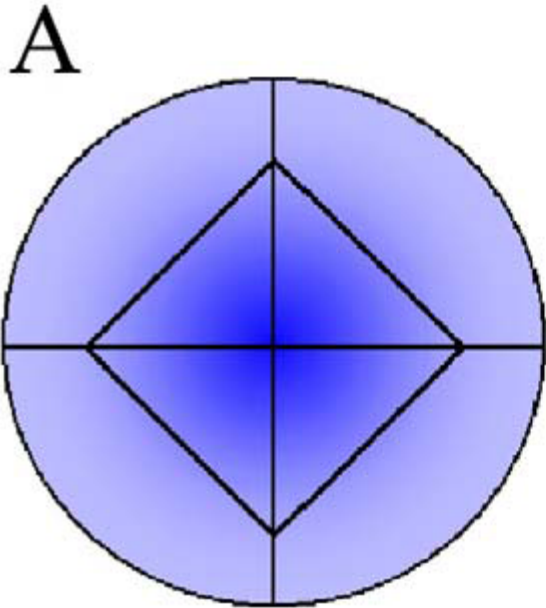
Bowman et al., *Annu. Rev. Plant. Biol.* (2008)

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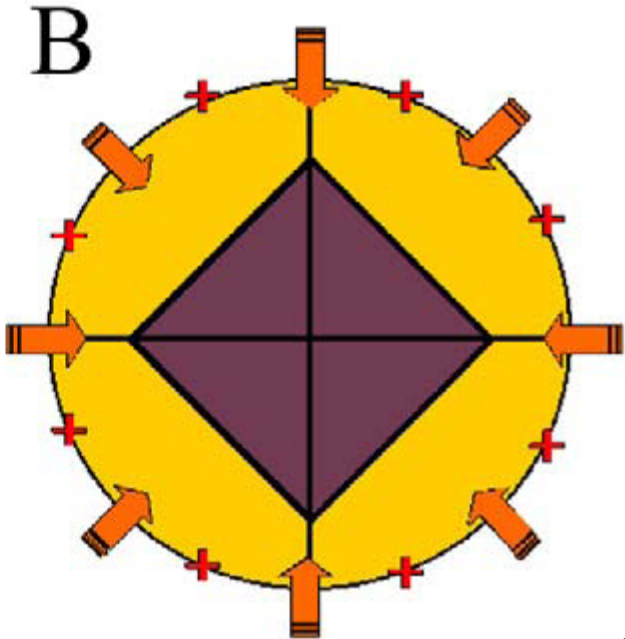
## Plant Embryogenesis

- Patterning of the apical pole of the plant embryo
  - generation of cotyledons and shoot apical meristem
  - proper spacing of lateral organs
  - adaxial-abaxial axis formation
- Radial embryo patterning
  - epidermal layer specification

# Epidermal layer specification



Single morphogen model



"Outside-in" model

ectopic expression of epidermal markers

*knolle* and *keulle* cytokinesis mutants (incomplete CW)

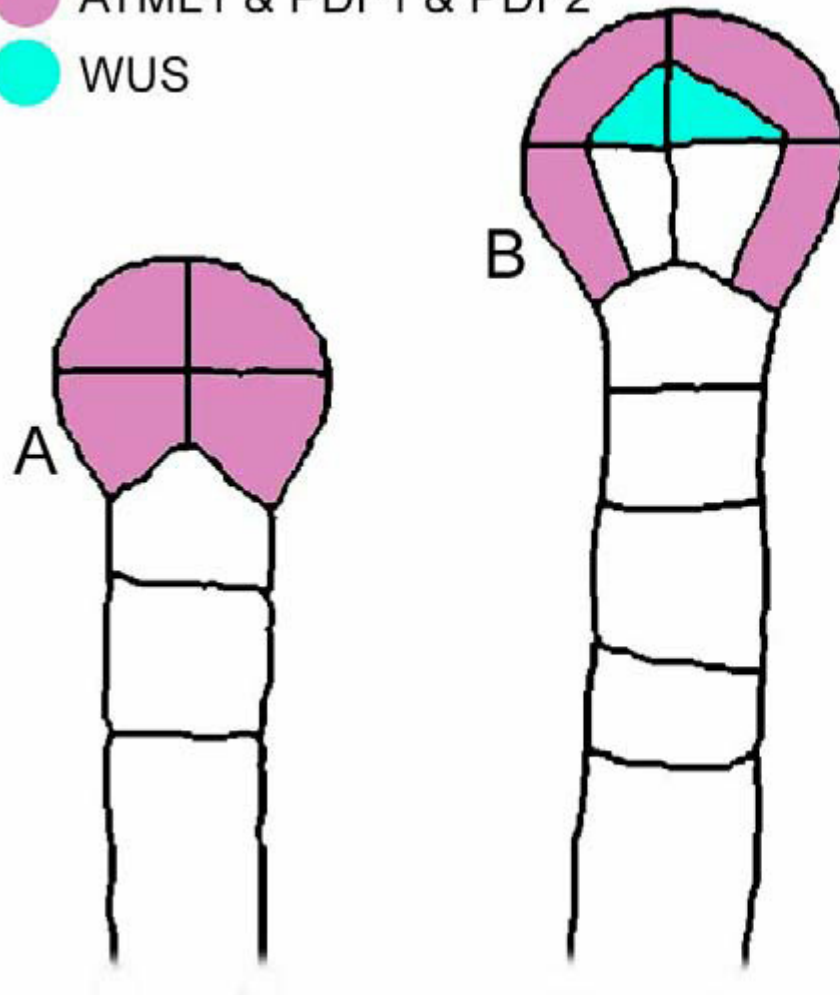


Capron et al., *Arabidopsis Book* (2009)

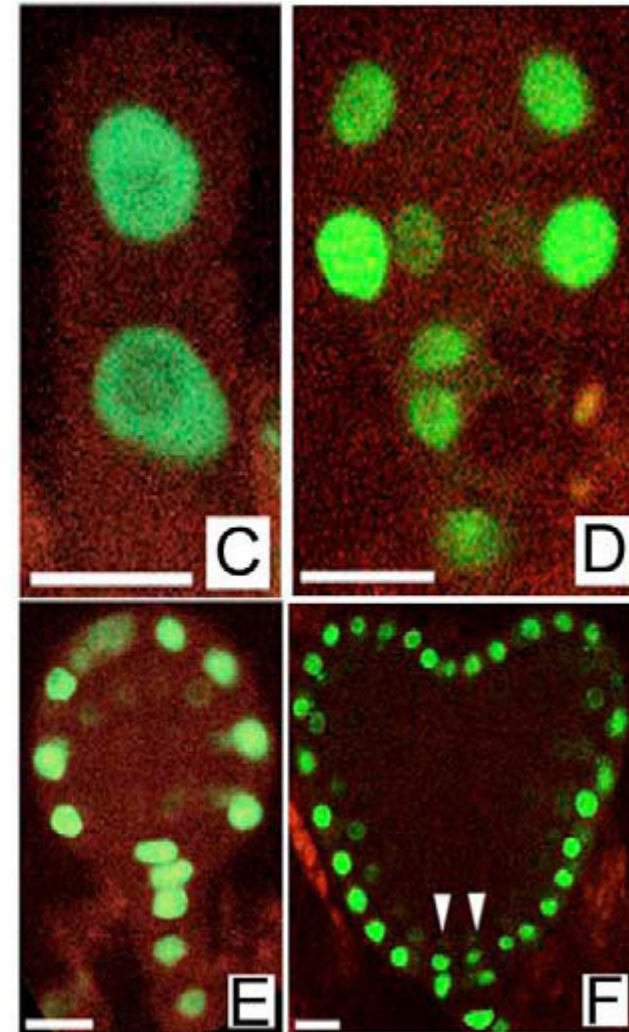


**MERISTEM LAYER1 (AtML1) and  
PROTODERMAL FACTOR 1 and 2**

- ATML1 & PDF1 & PDF2
- WUS



**ProATML1:NLS-3xeGFP**



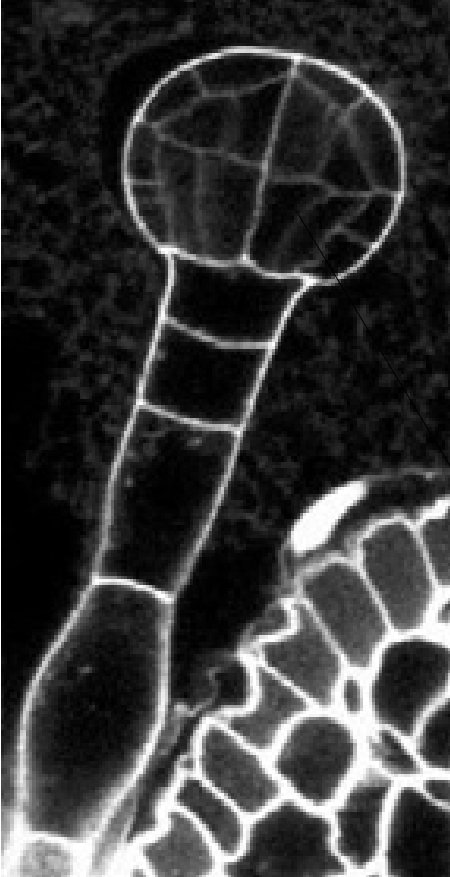


# Outline of Lesson 7

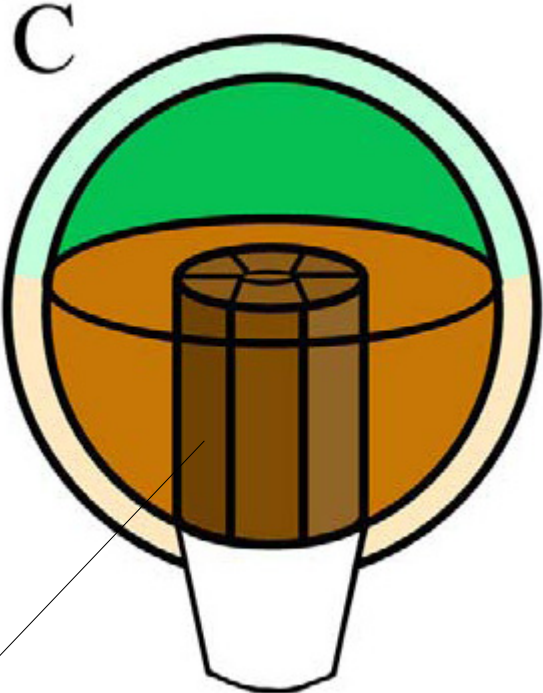
## Plant Embryogenesis

- Patterning of the apical pole of the plant embryo
  - generation of cotyledons and shoot apical meristem
  - proper spacing of lateral organs
  - adaxial-abaxial axis formation
- Radial embryo patterning
  - epidermal layer specification
  - separating vascular and ground tissue

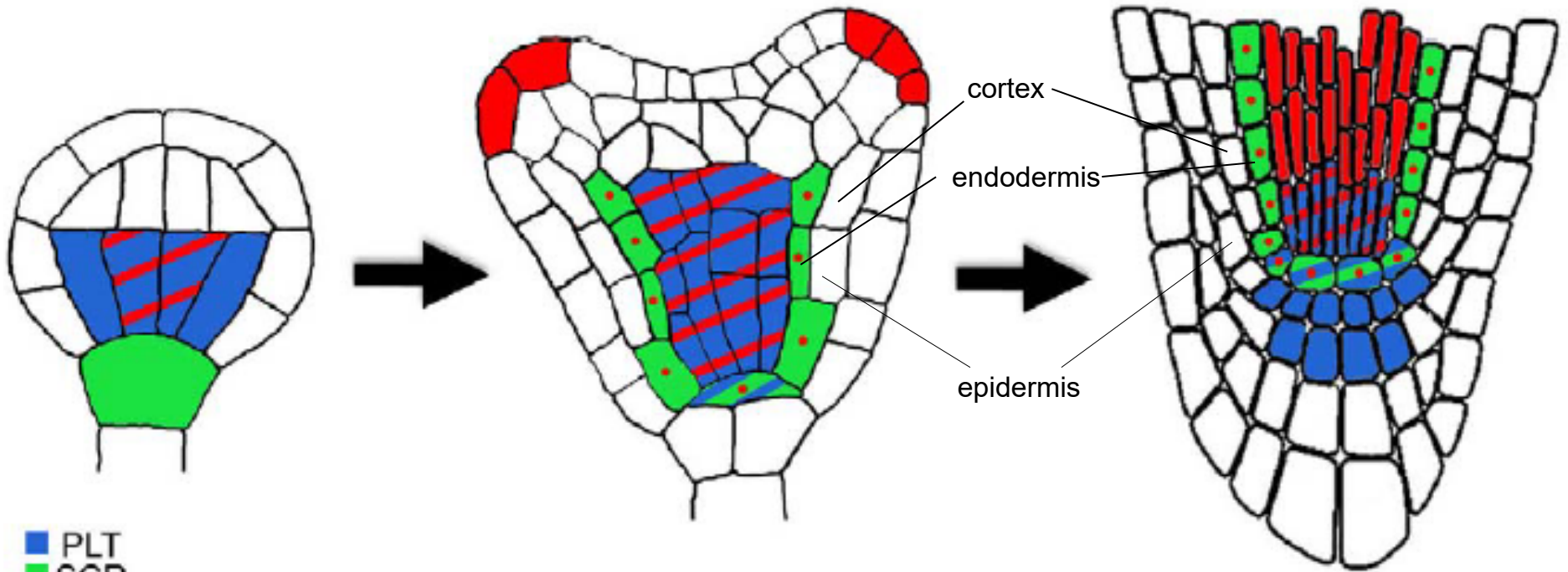
# Separation of vascular and ground tissue



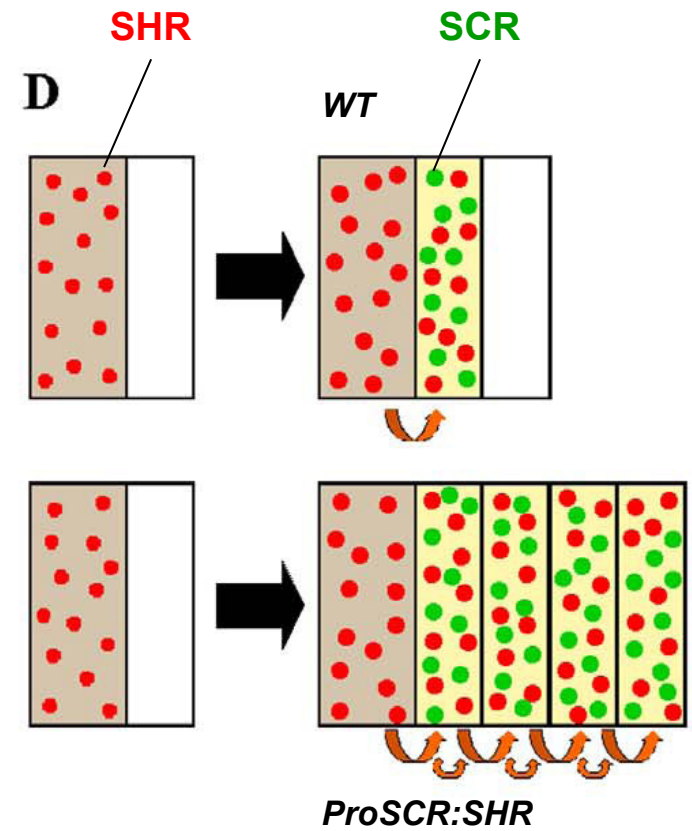
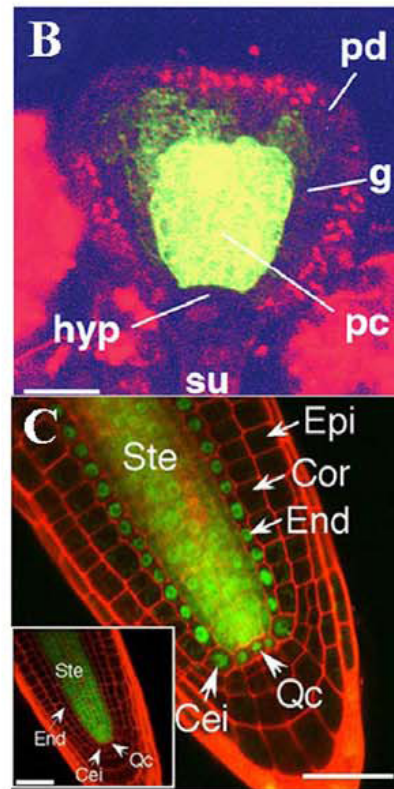
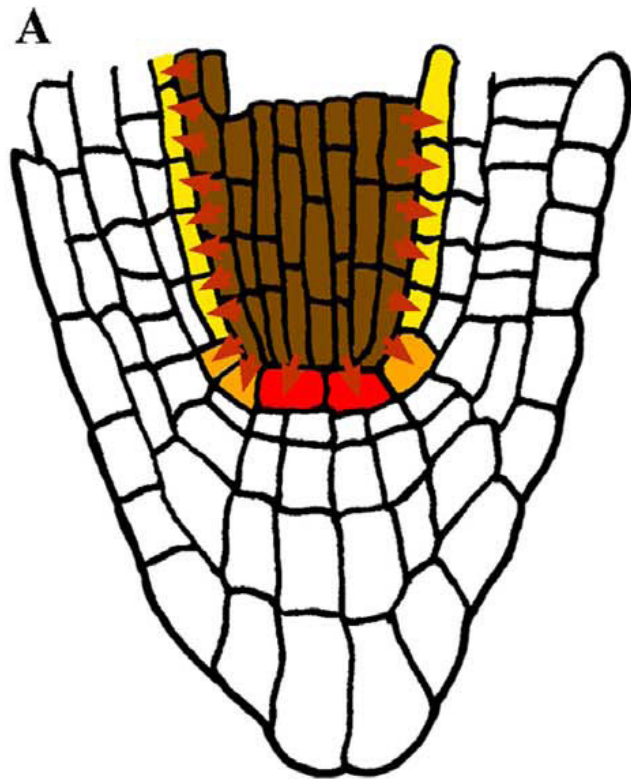
Early globular stage



Cell divisions predominantly along the apical-basal axis



- PLT
- SCR
- SHR
- SHR protein



# Key Concepts

## Plant Embryogenesis

- Similarly to animals, both **embryonic and extraembryonic tissue** forms during plant embryogenesis
- In plant embryogenesis, **positional information** rather than invariant cell division is decisive for the proper embryo patterning
- **Auxin gradient formation provides positional information** that together with **differential gene expression** directs downstream developmental events during plant embryogenesis
- **Auxin transport machinery** and **auxin signalling** are critical for the proper embryo development
- **Interaction of auxin with other growth regulators**, e.g. **cytokinins** emerges as a crucial regulatory factor for many developmental processes during plant embryo formation
- **Gene** and **protein interactions** allow formation of **distinct cell and tissue spatial patterns** and allow proper organogenesis

# Discussion