

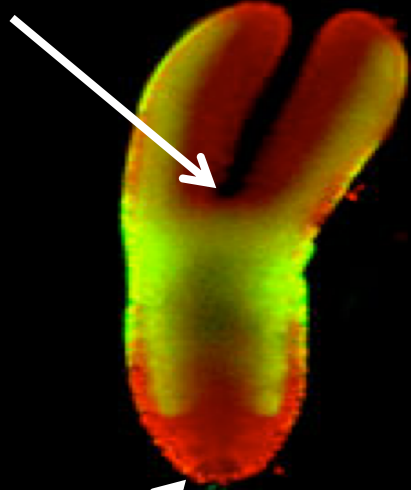
# Plant morphogenesis II



Photo:Nicolas Vereecken

# Meristems produce plant organs, while maintaining themselves

Shoot apical meristem



Root apical meristem

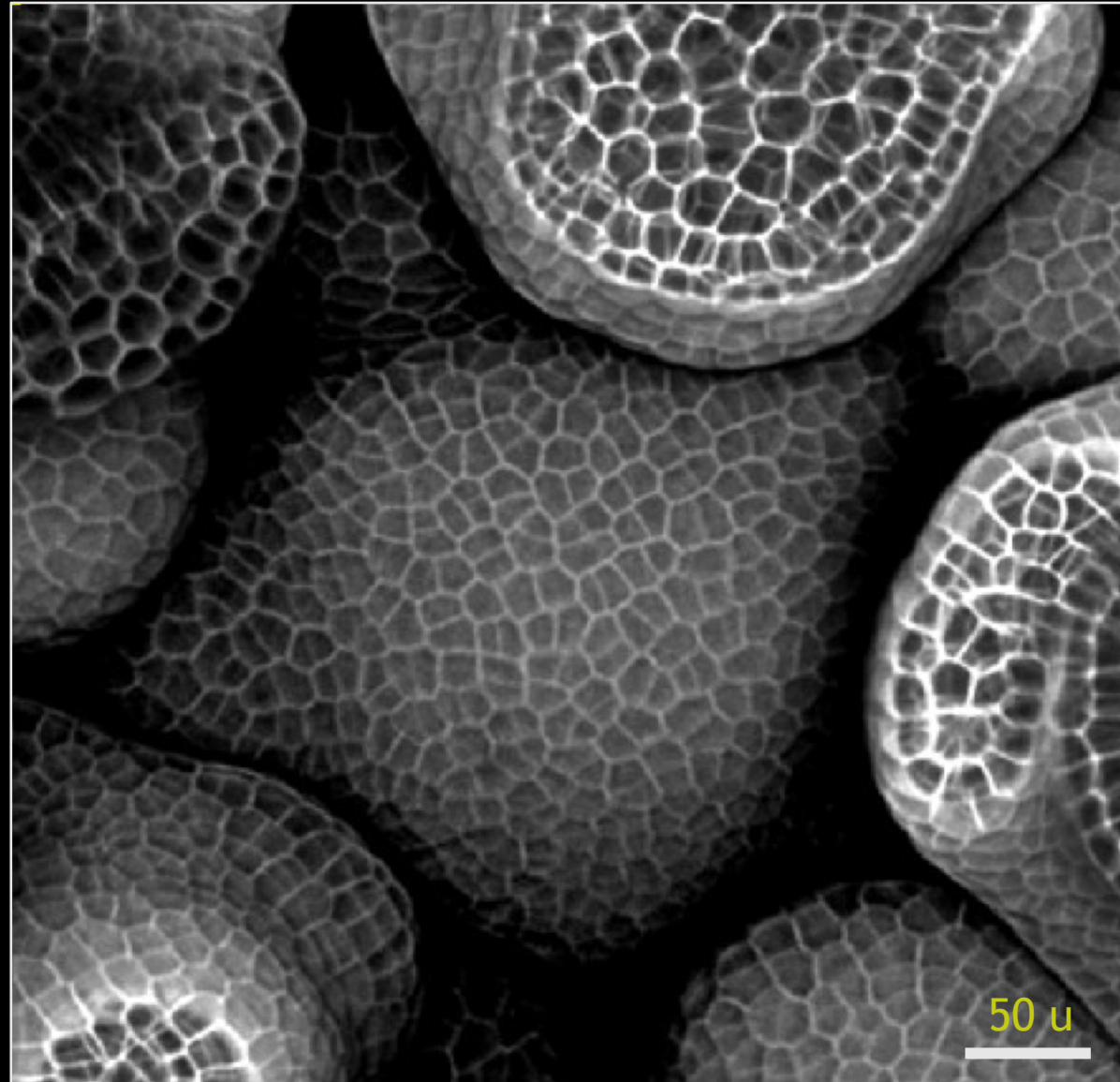
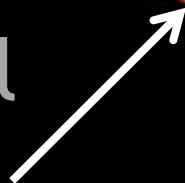


# Meristems produce plant organs, while maintaining themselves

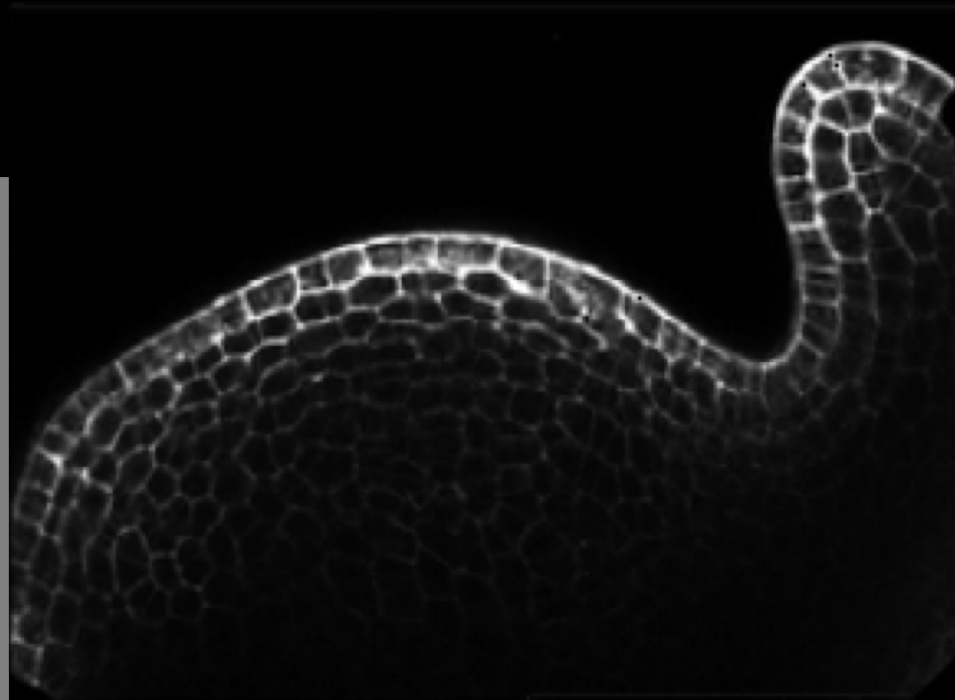
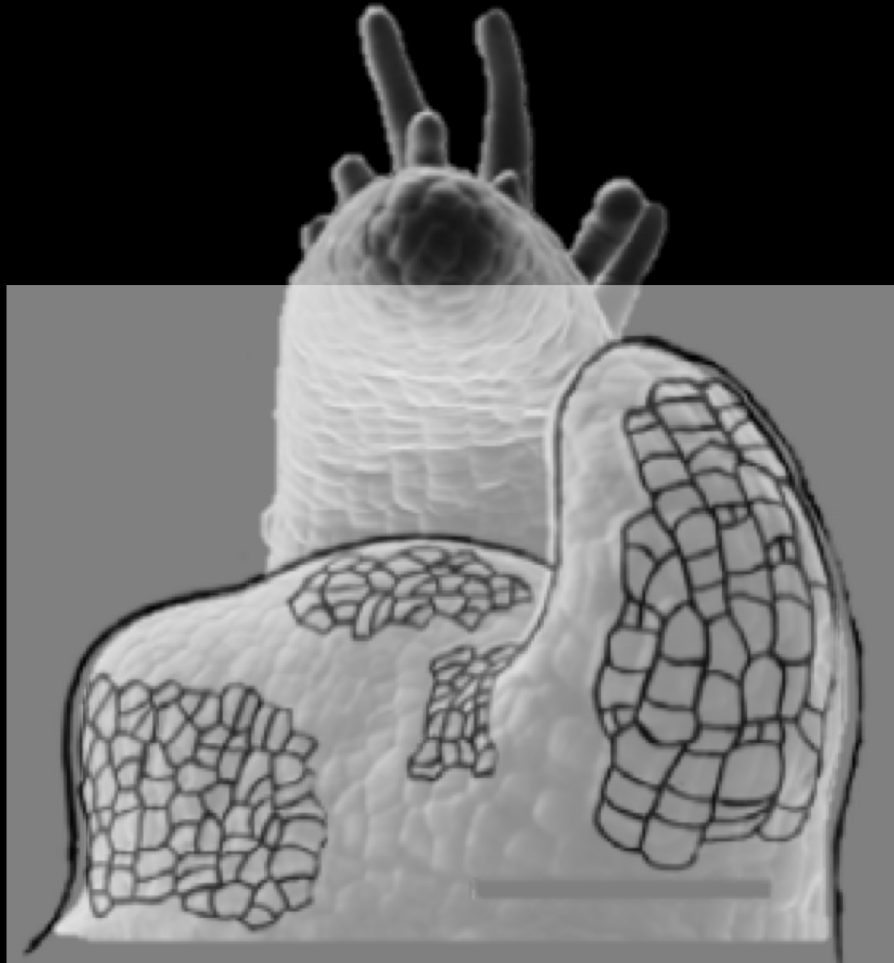
Shoot apical meristem



Root apical meristem



Meristems produce plant organs, while maintaining themselves



## Phyllotaxis (organ arrangement)

Leaf morphology (whole organ)

Leaf pattern (cellular features)



Phyllotaxis (organ arrangement)

Leaf morphology (whole organ)

Leaf pattern (cellular features)



Phyllotaxis (organ arrangement)

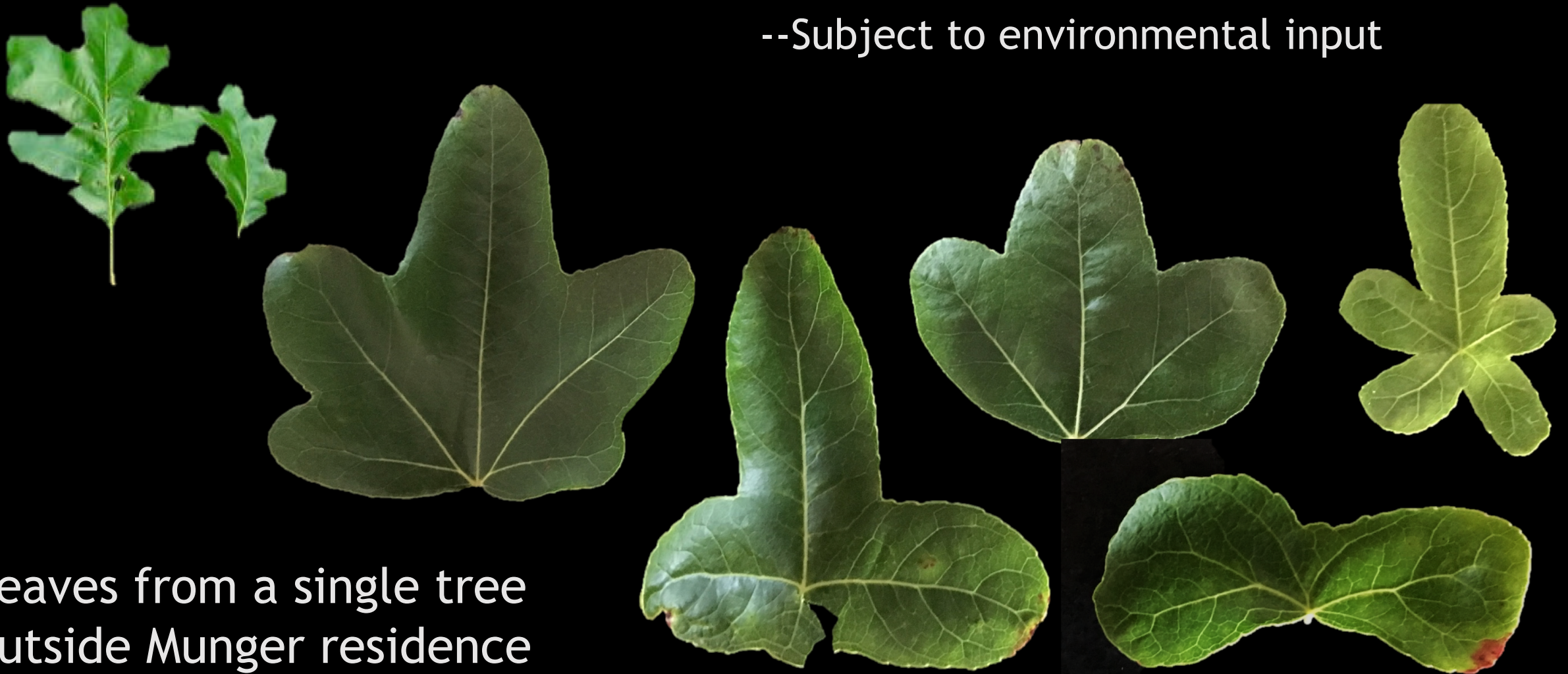
**Leaf morphology (whole organ)**

Leaf pattern (cellular features)

--Cell division #s and directions

--Differential expansion

--Subject to environmental input



Leaves from a single tree  
outside Munger residence

Phyllotaxis (organ arrangement)

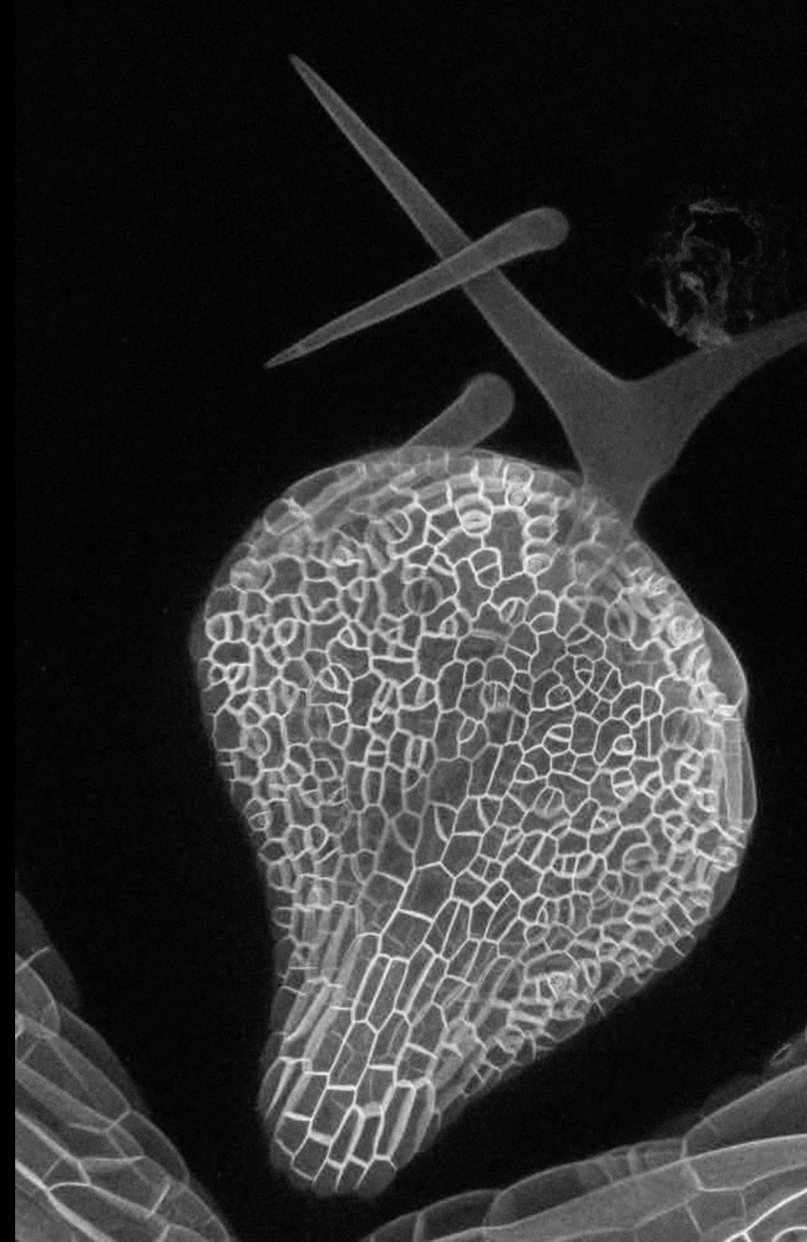
Leaf morphology (whole organ)

Leaf pattern (cellular features)

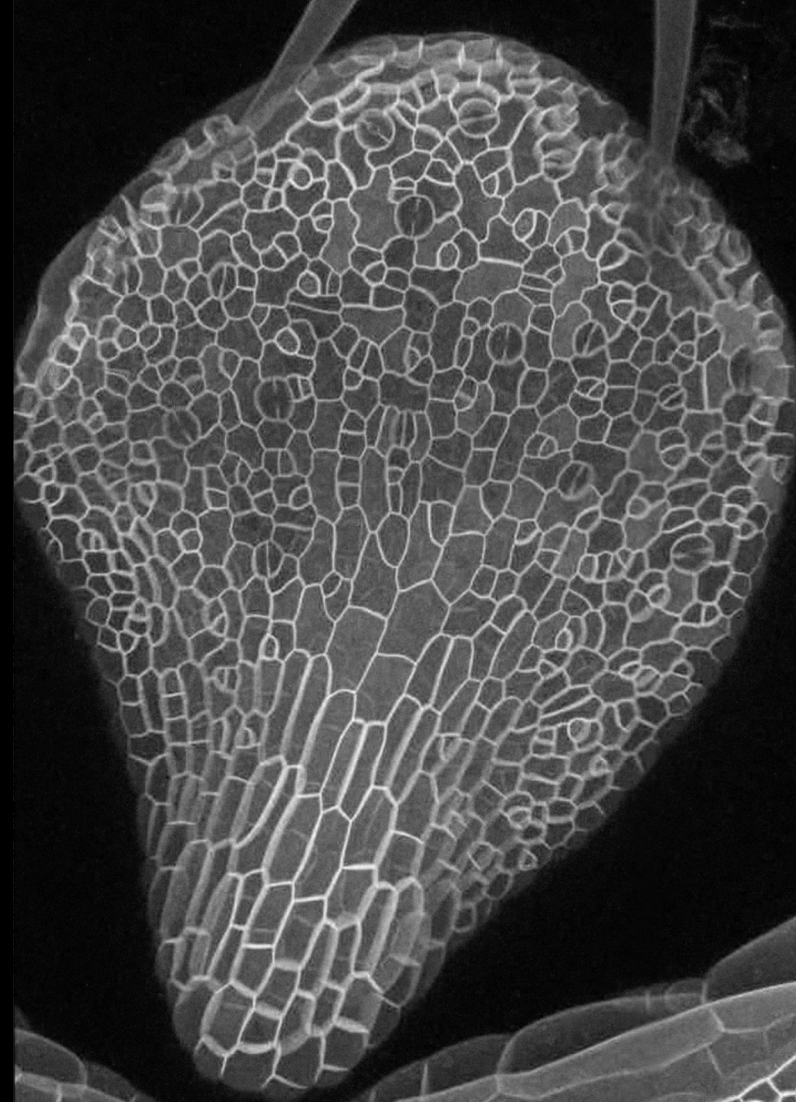




Leaves in two classes of flowering plants (monocots and dicots)  
grow in very different ways



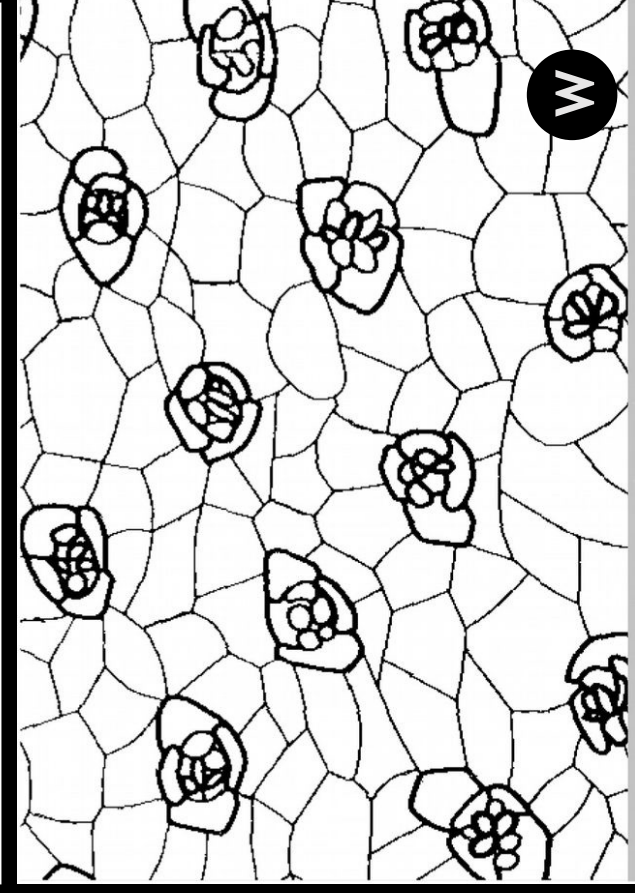
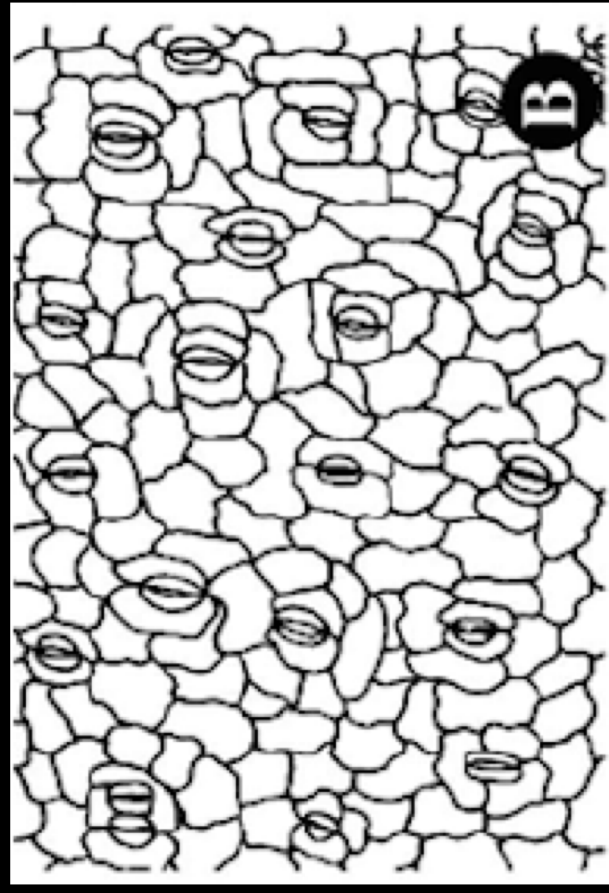
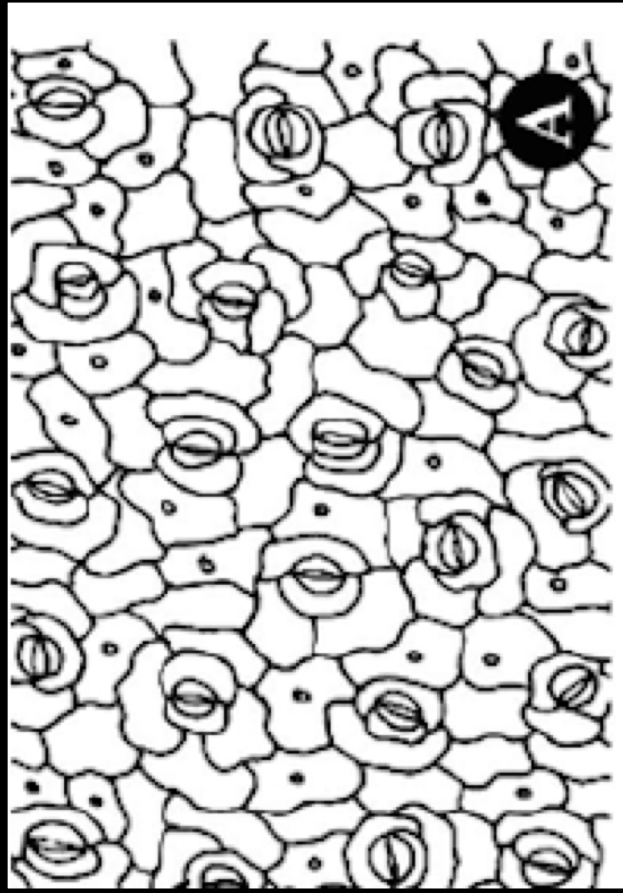
# Building and patterning the epidermis of the Arabidopsis leaf



# Building and patterning the epidermis of the Arabidopsis leaf



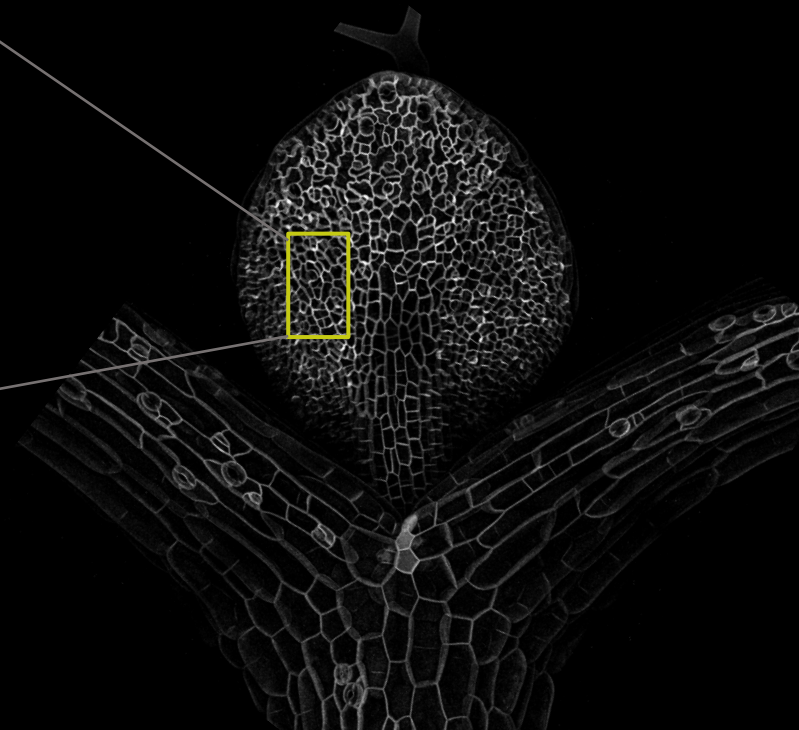
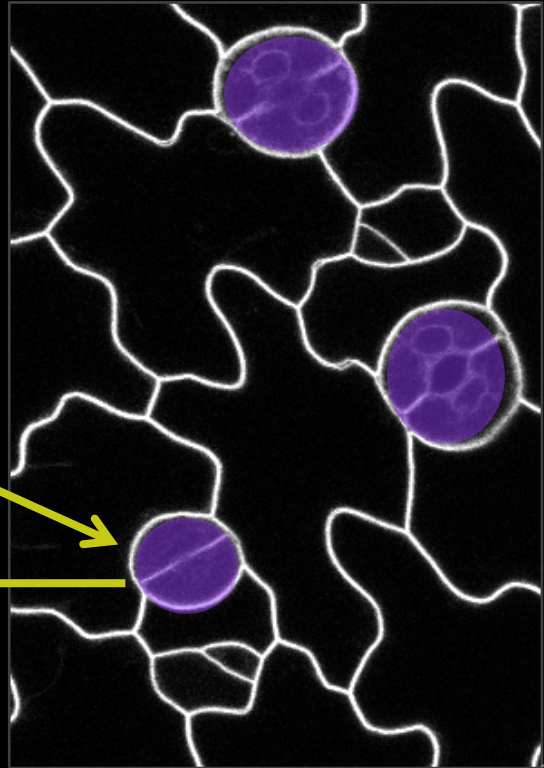
# Building and patterning the epidermis of the Arabidopsis leaf



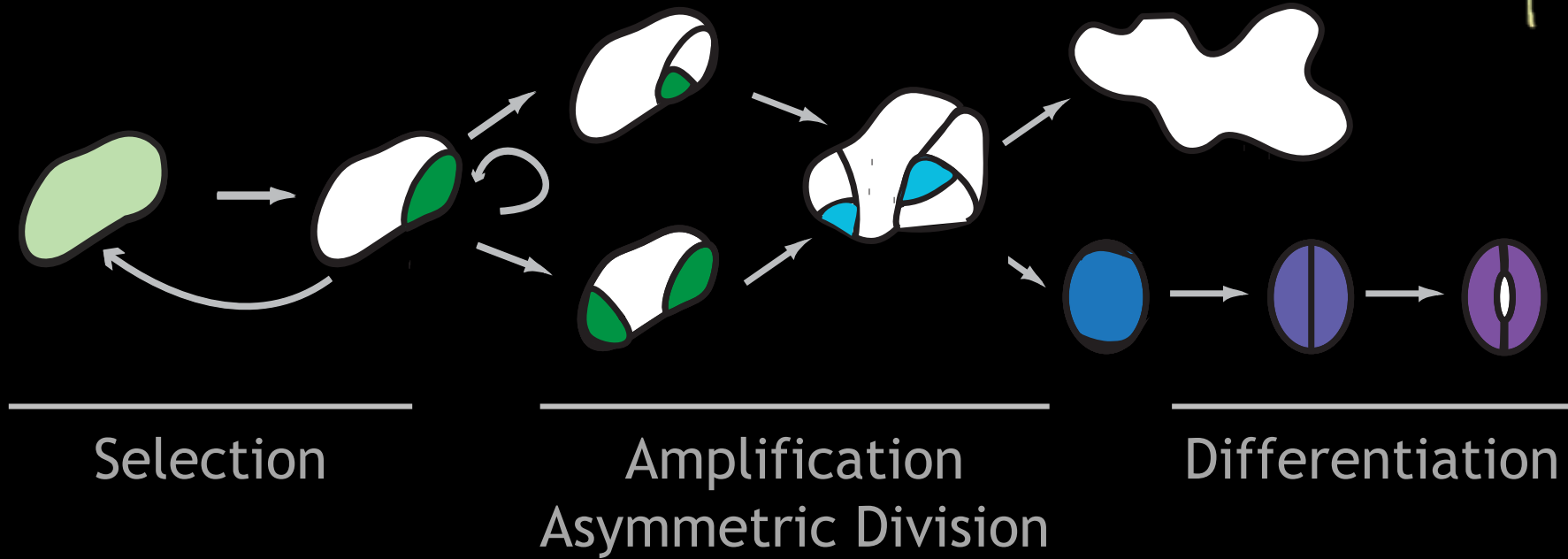
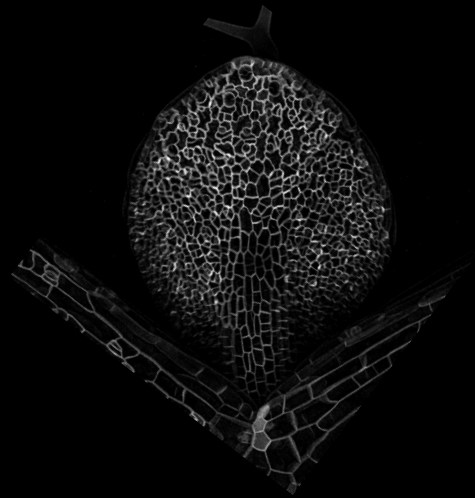
Stomatal lineage products  
Pavement cells + **stomata**



CO<sub>2</sub> in  
H<sub>2</sub>O and O<sub>2</sub> out



# Stomatal lineage: a model for cell fate, asymmetry and communication



# The stomatal lineage team...



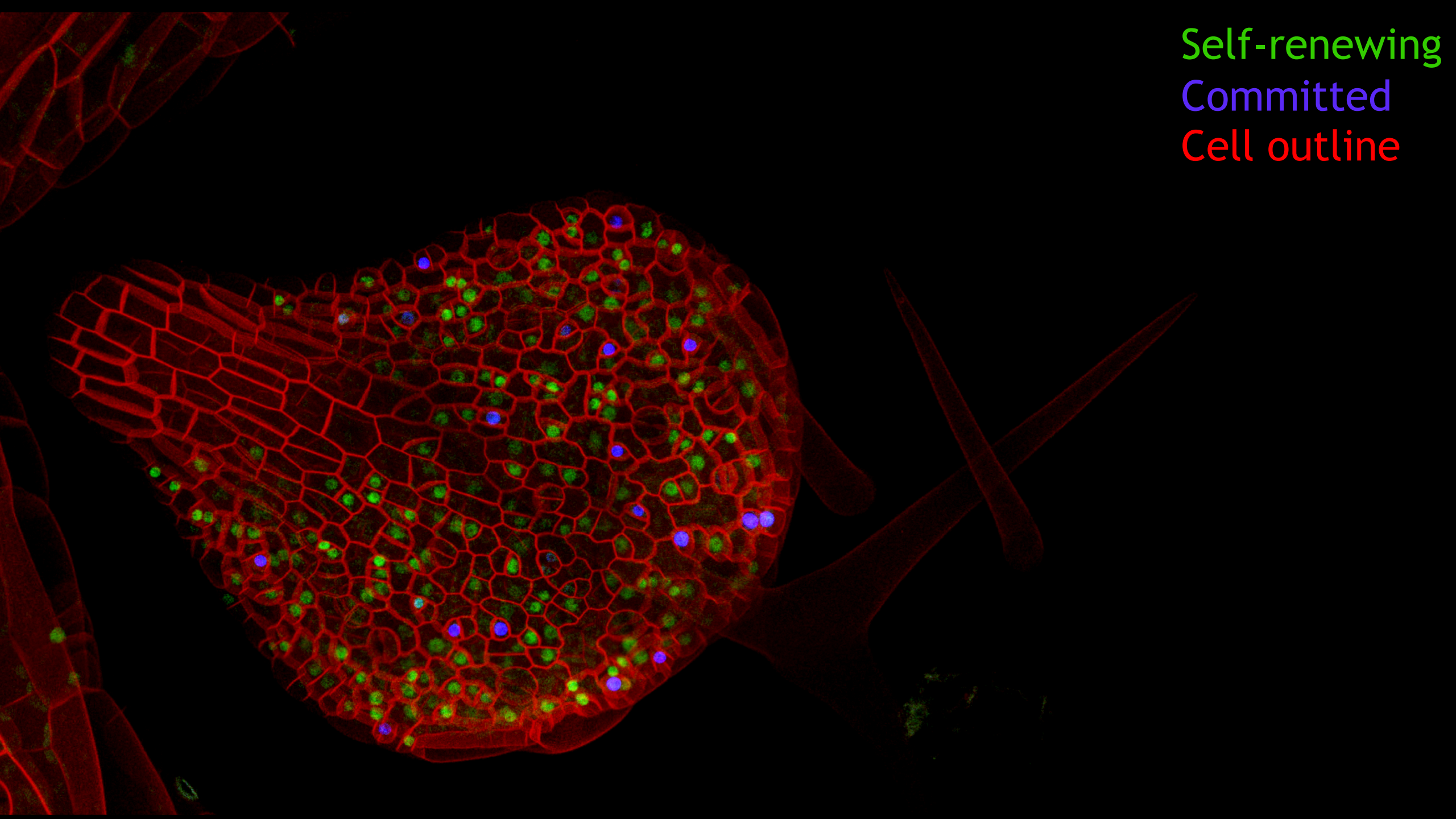
Anne Vaten  
On Sun Lau  
Martin Bringmann  
Kelli Davies  
Emily Abrash  
Cora MacAlister



Dirk Spencer  
Yan Gong  
Andrew Muroyama

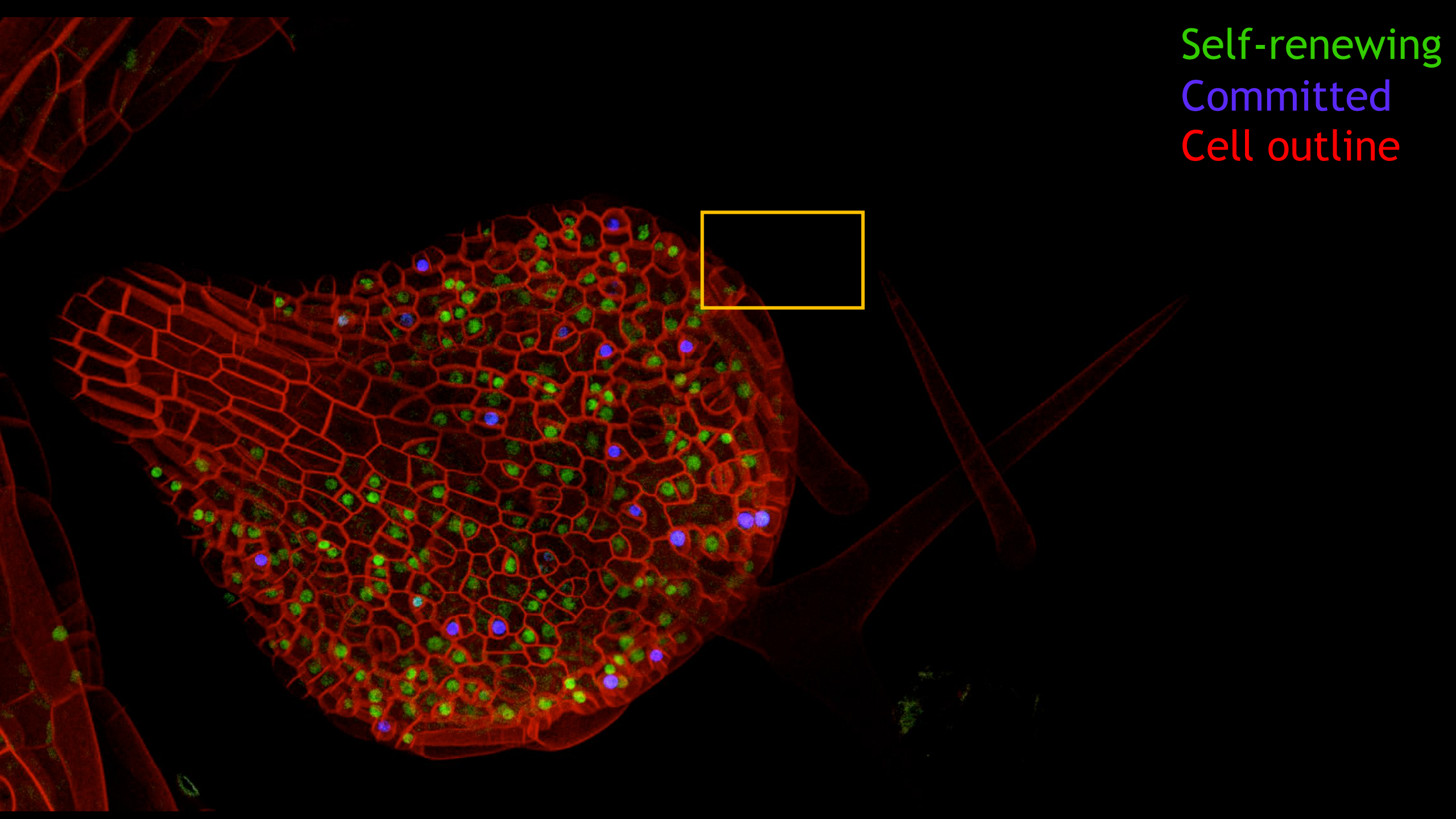


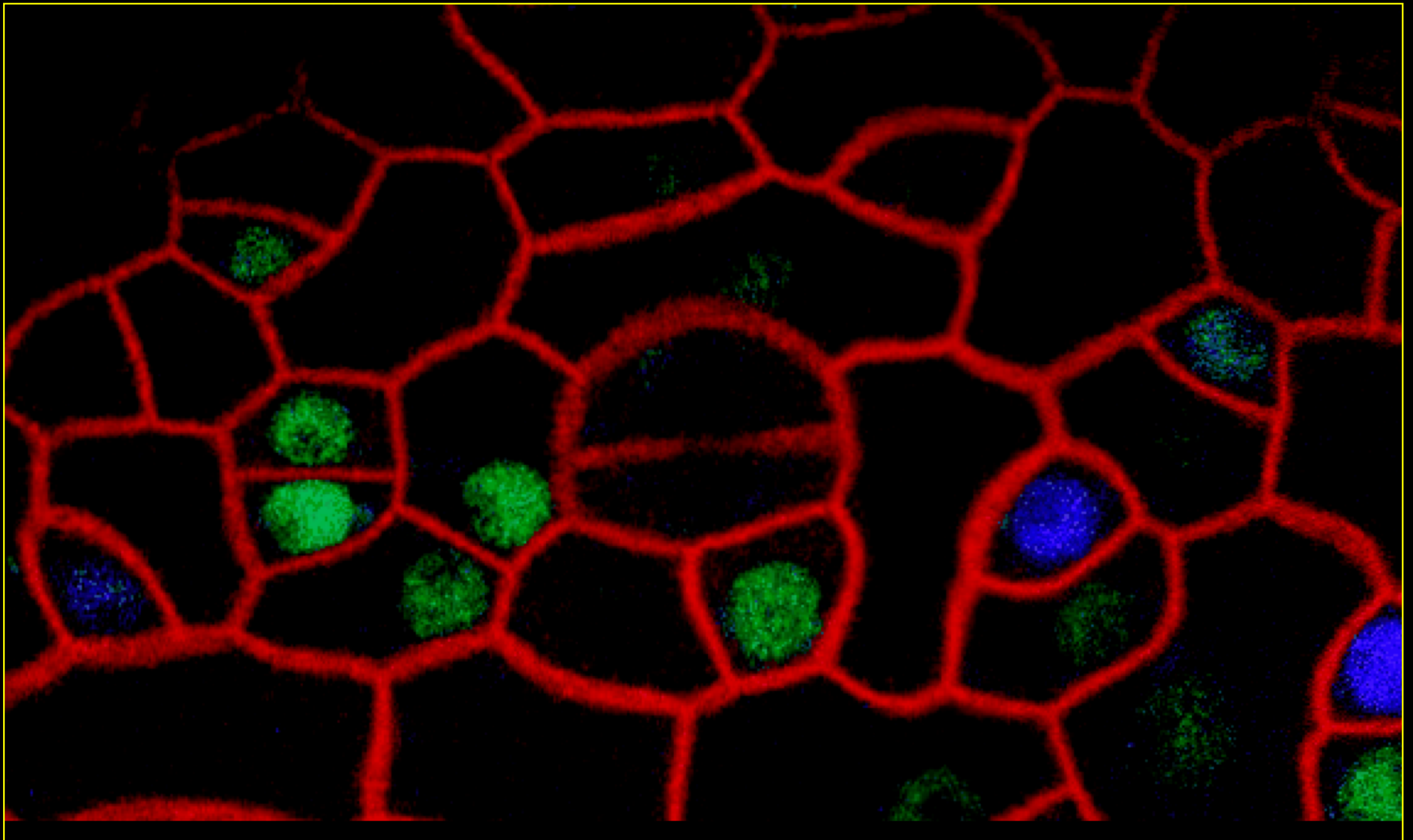
Self-renewing  
Committed  
Cell outline



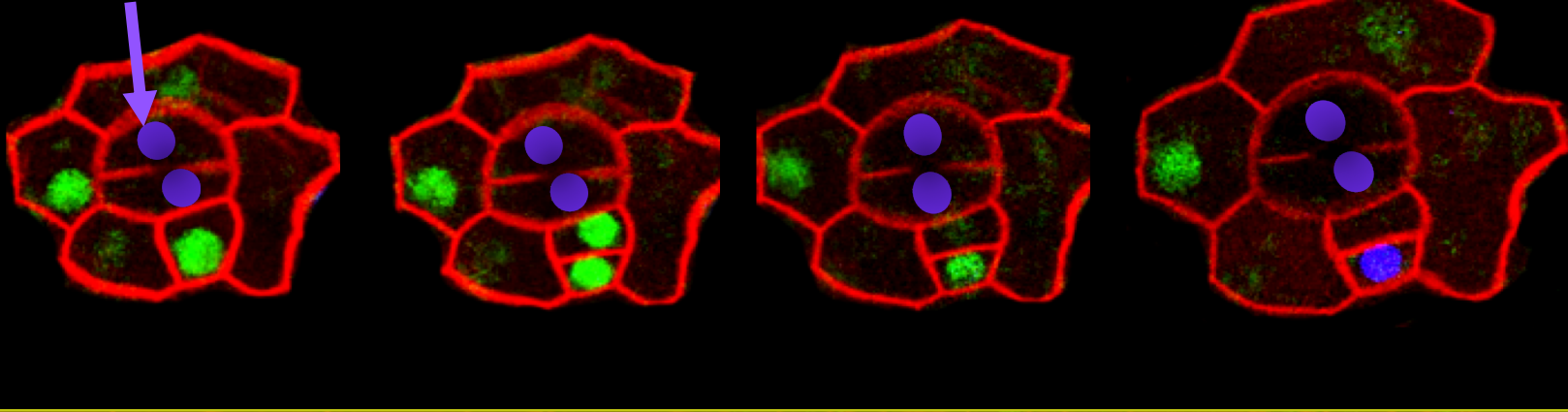


Self-renewing  
Committed  
Cell outline

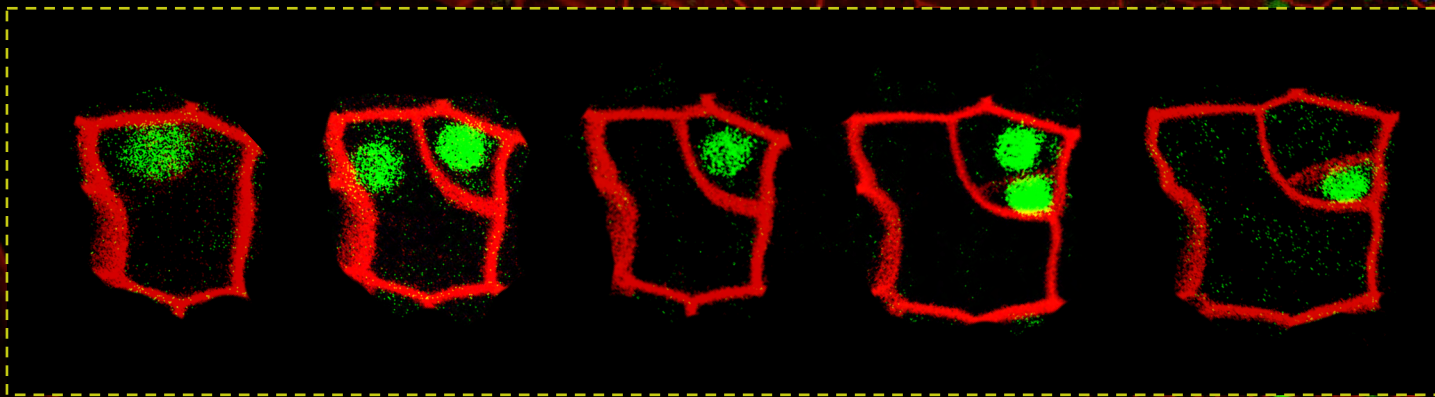




stoma (breathing pore)



Oriented  
Asymmetric  
Divisions &  
Differential  
Fate



Asymmetric  
Self-renewing  
divisions

## Questions to ask in/about the stomatal lineage

How are cells “chosen” to initiate the lineage?

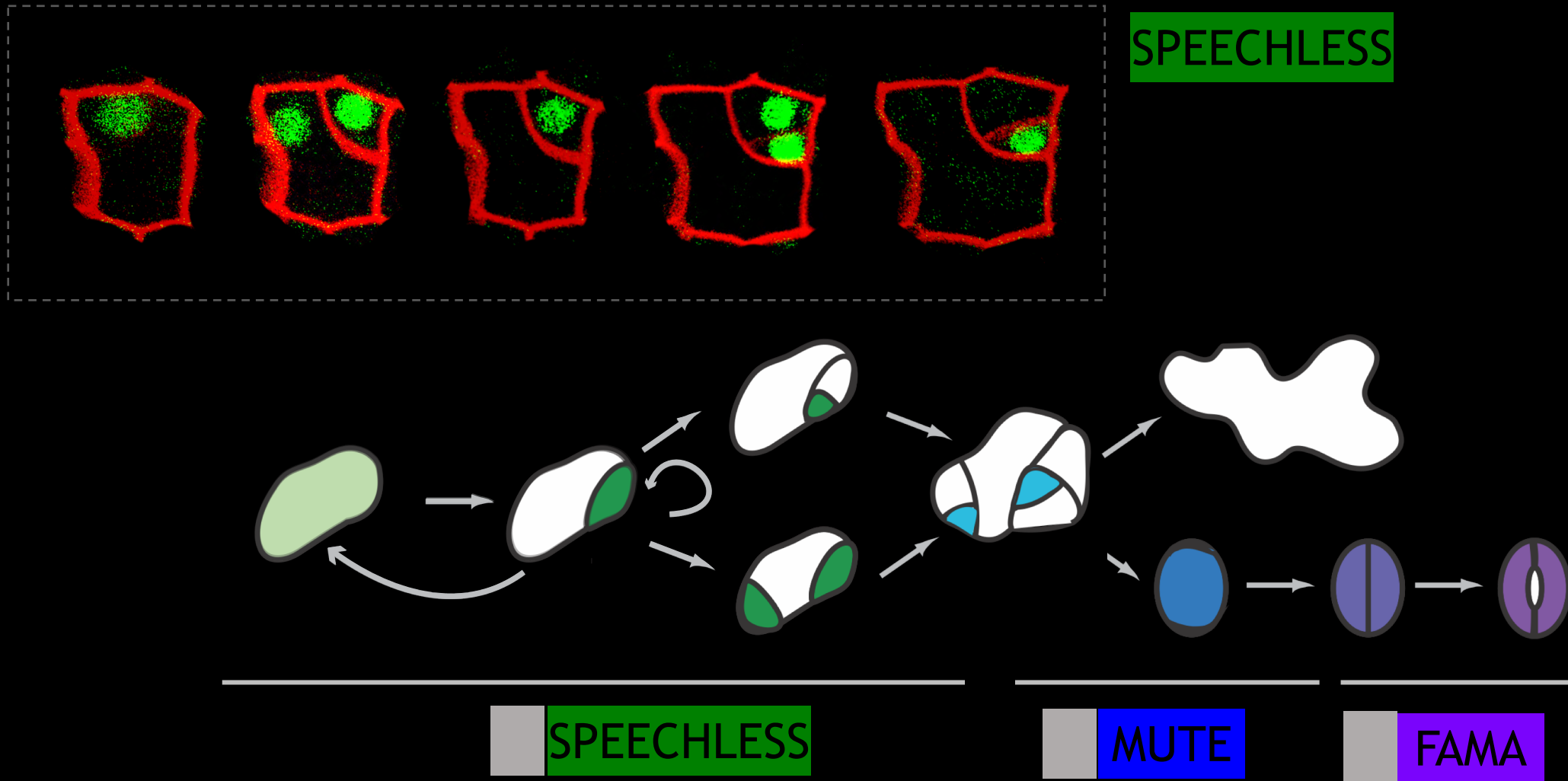
How does pattern emerge between siblings, neighborhoods, globally?

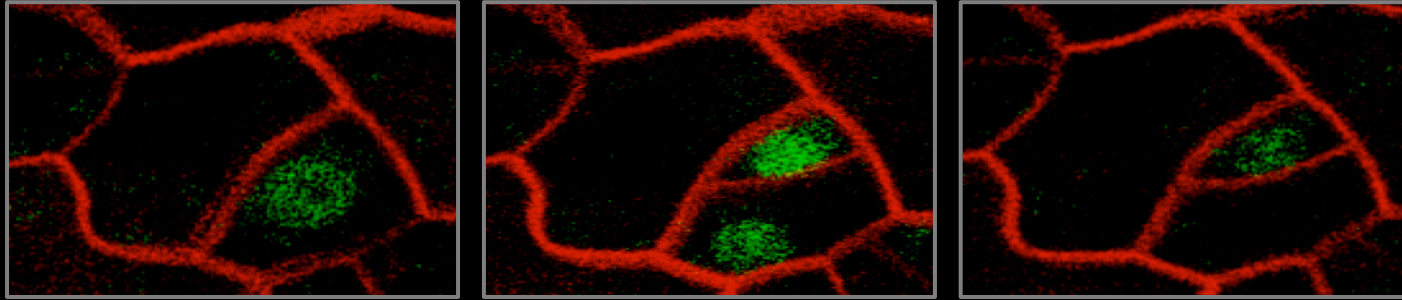
What types of information are cells integrating to make decisions?

Divisions are physically asymmetric and can be oriented:

What’s the relationship between that asymmetry and cell behavior and identity?

# bHLH transcription factors are at the core of cell identities



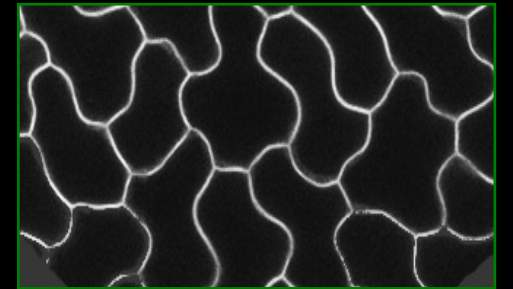


SCRM1/2

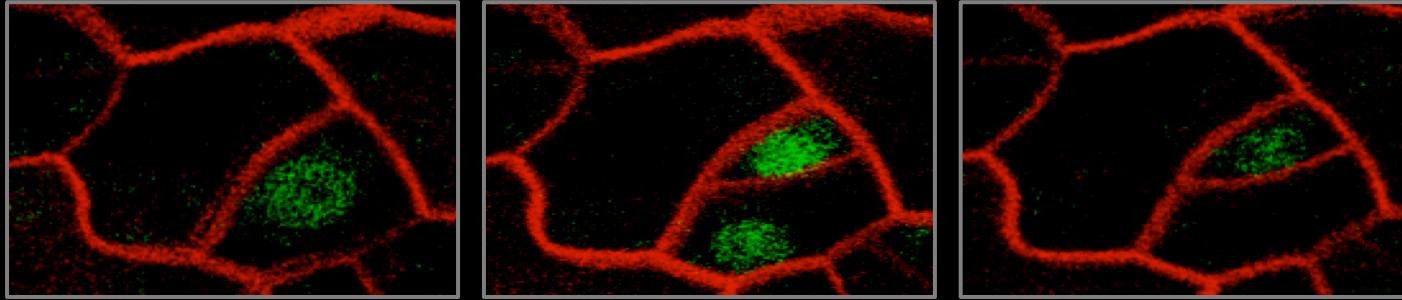


How are asymmetric divisions initiated and maintained?

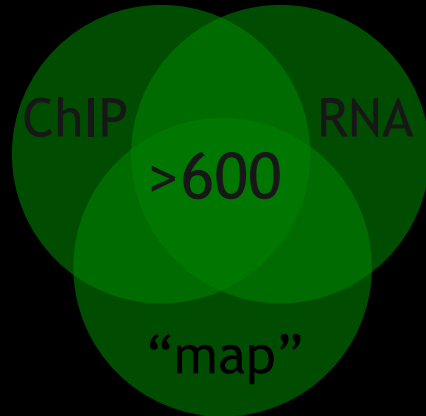
*spch*



Stochastic?



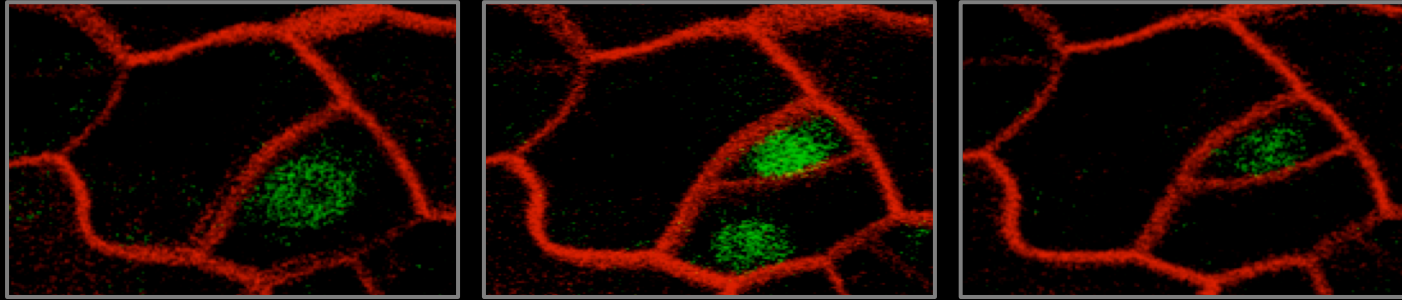
SPEECHLESS



ChIP-seq  
RNA-seq

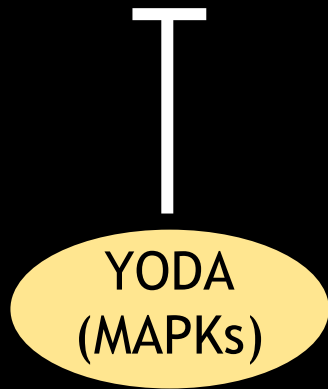
SPCH targets

Many targets of SPCH  
are related to promoting  
division and fate



How is the “repeated on/off” pattern of SPCH established?

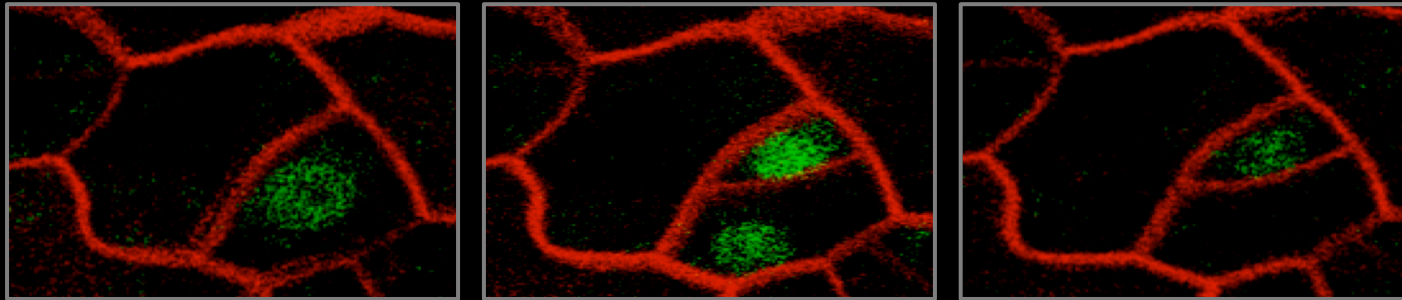
**SPEECHLESS**



*Work from: Bergmann, Gray, Kakimoto, Hara-Nishimura, Sack, Torii labs*





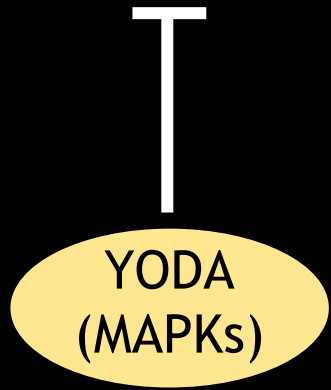


Formal model: *Horst et al., 2016*

+ feedback

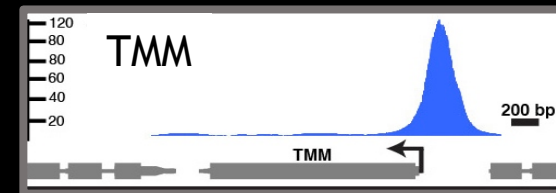
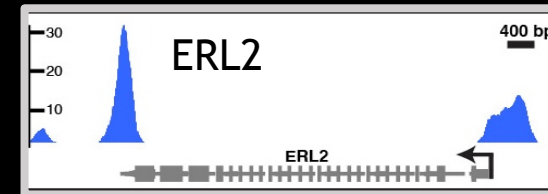
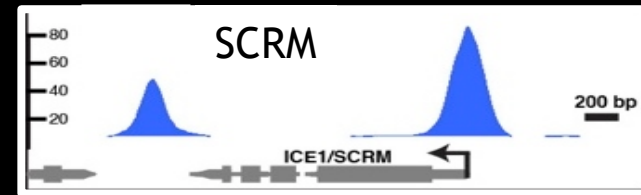


**SPEECHLESS**

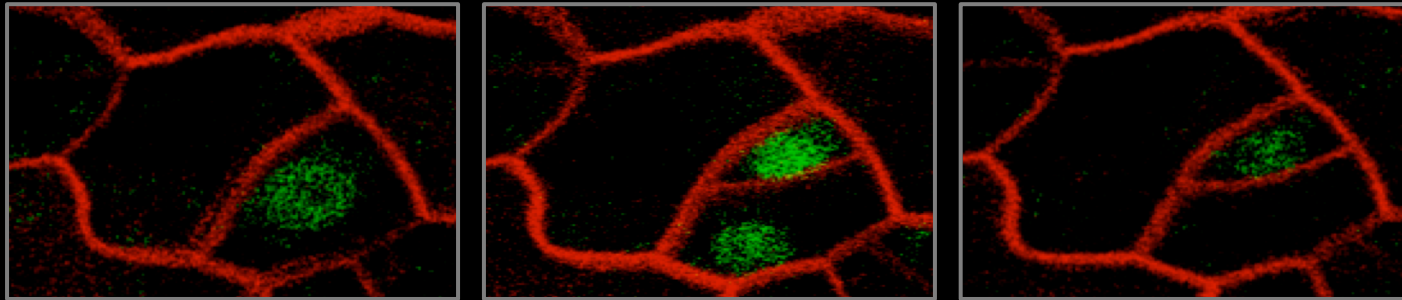


Delayed  
- feedback

EPFL ligands  
ERECTA/TMM receptors



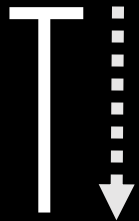
*Lau et al., 2014*



How is SPCH on/off coordinated spatially?

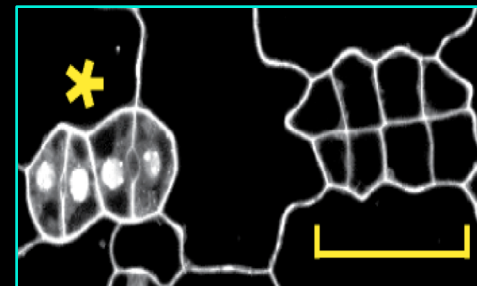


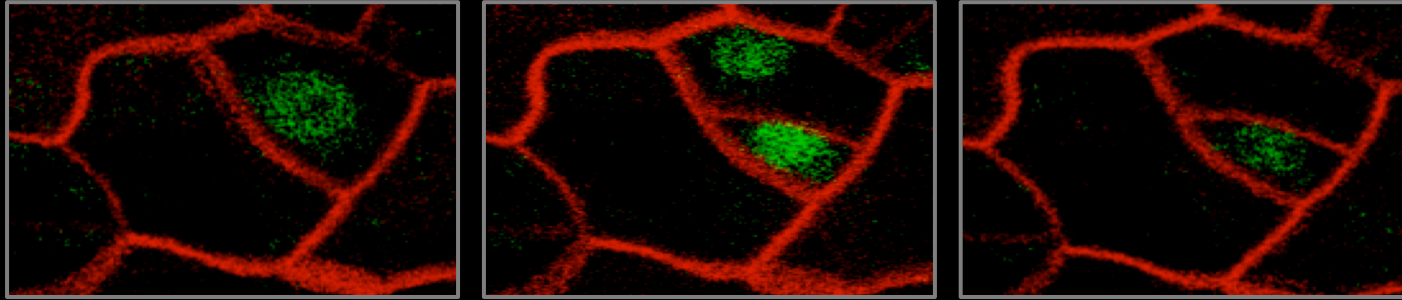
SPEECHLESS



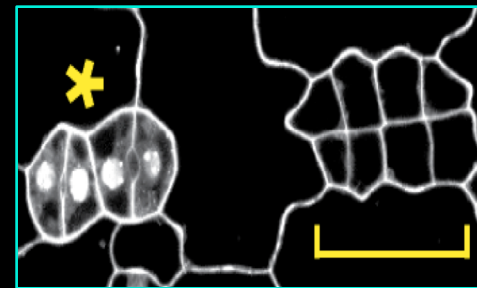
YODA  
(MAPKs)

Polarity  
information

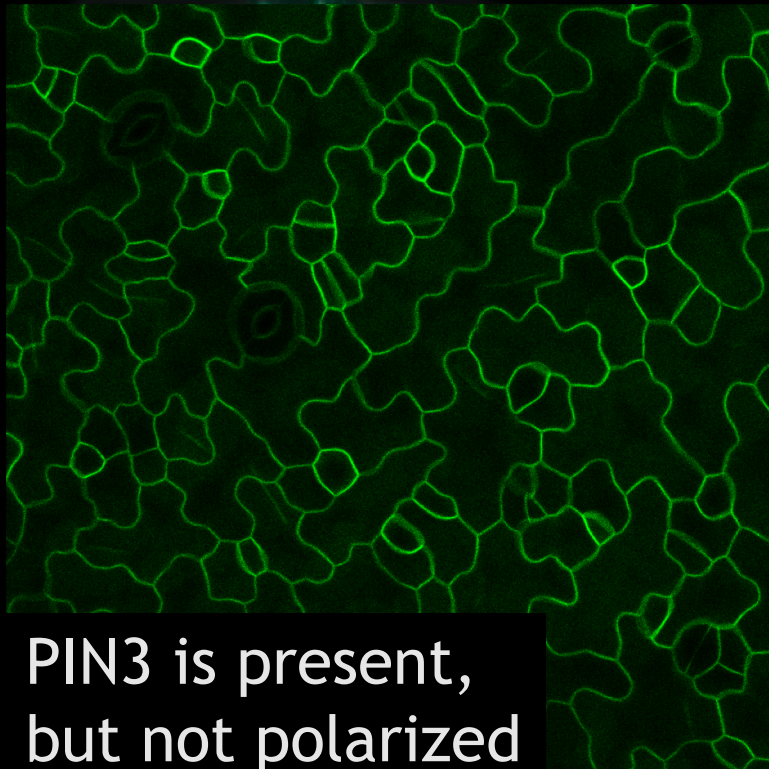
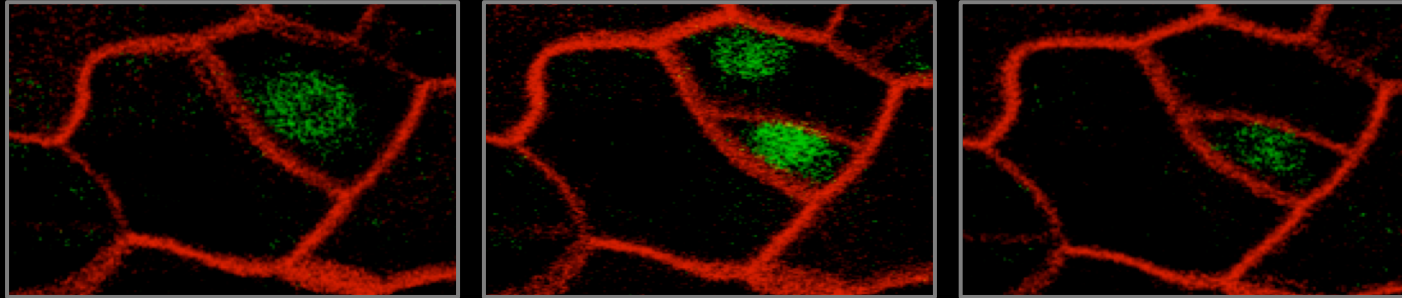




Polarity  
information

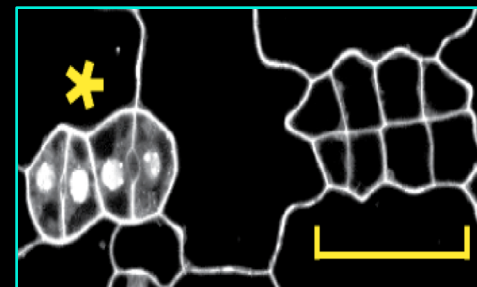


“everything you know is wrong”

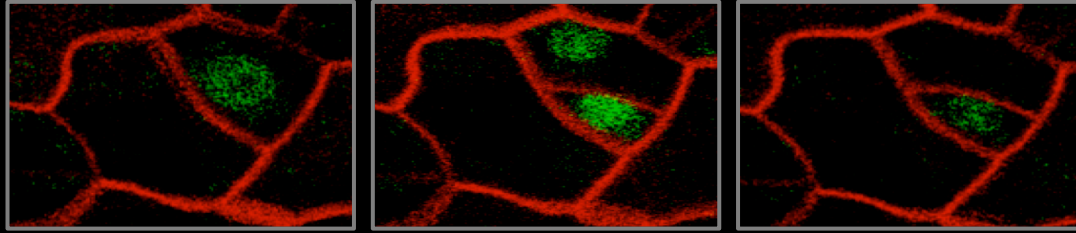


PIN3 is present,  
but not polarized

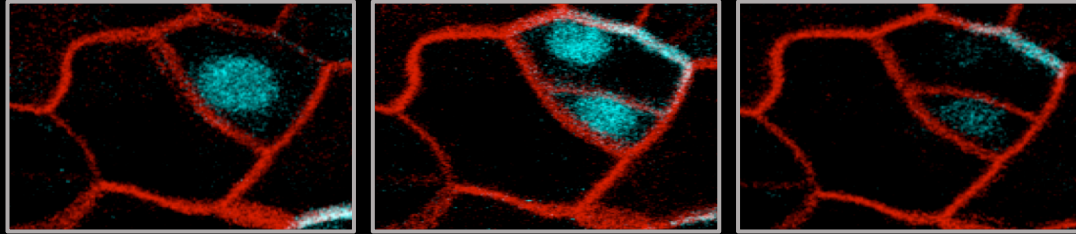
Polarity  
information



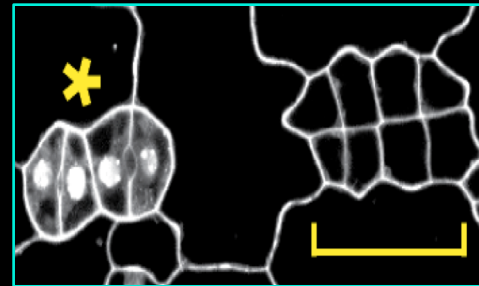
SPCH



BASL

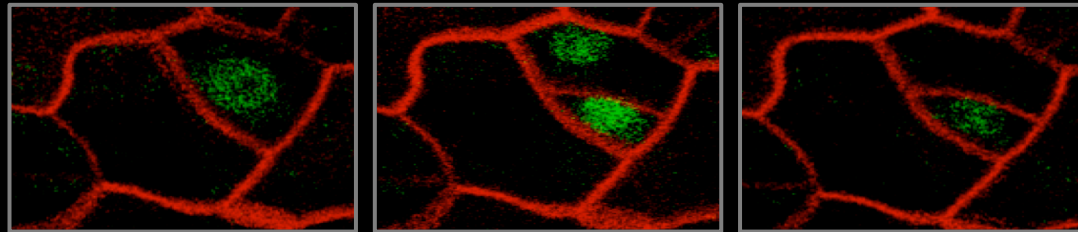


Polarity information

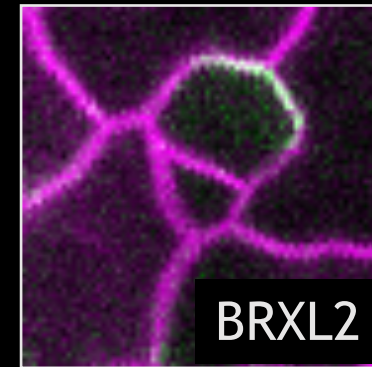
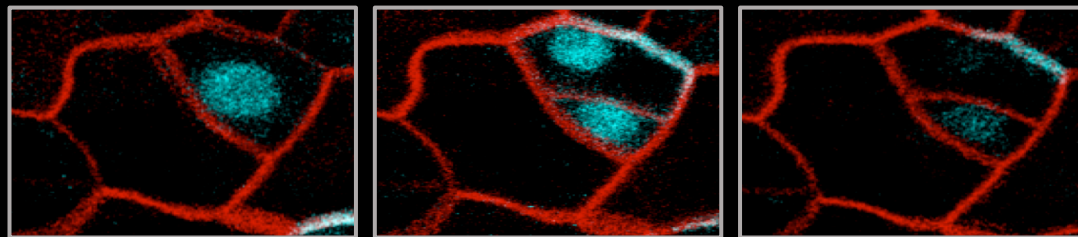


*basl-*

SPCH



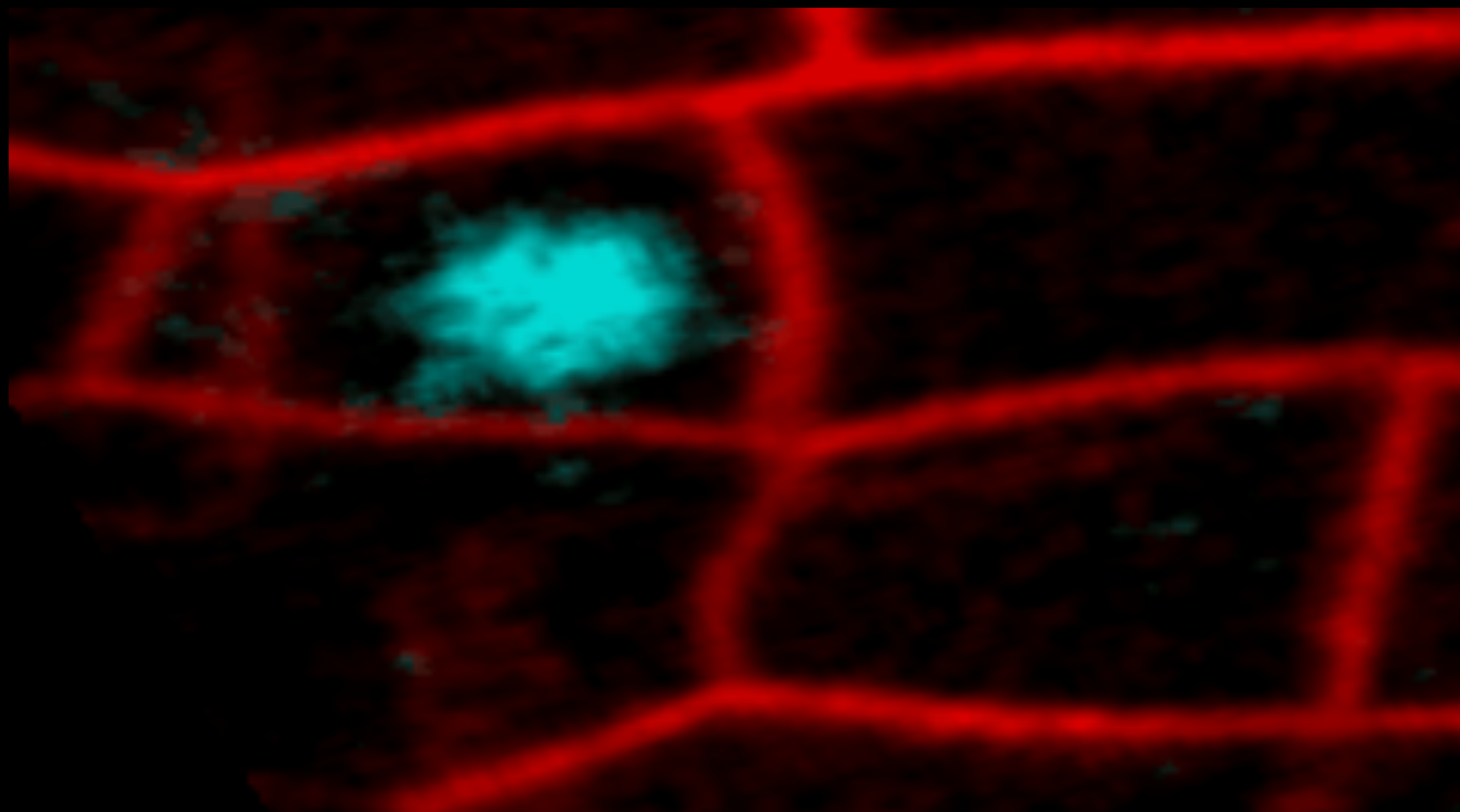
BASL



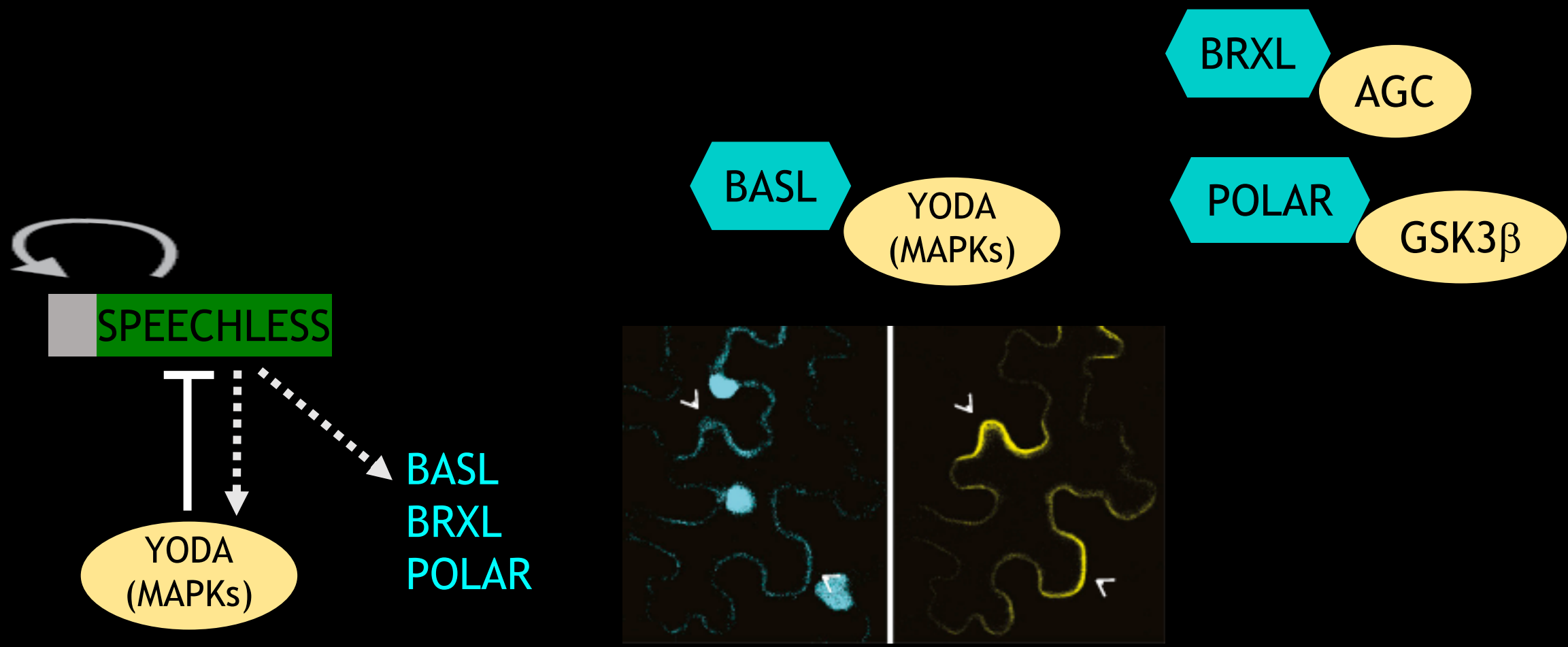
BRXL2



POLAR

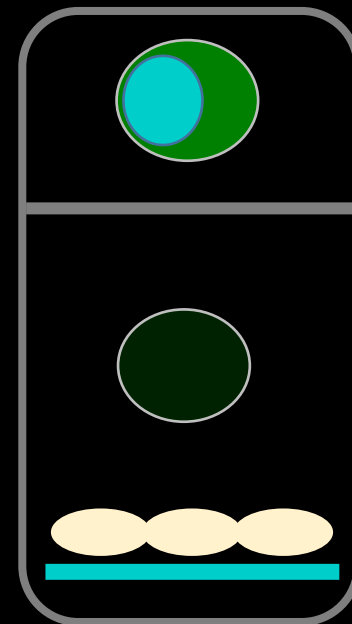
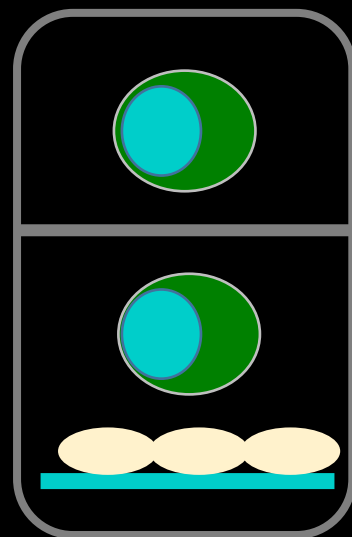
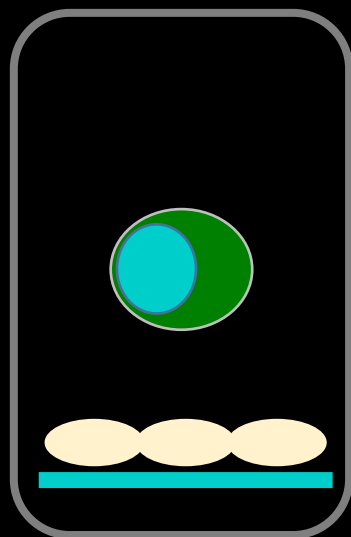
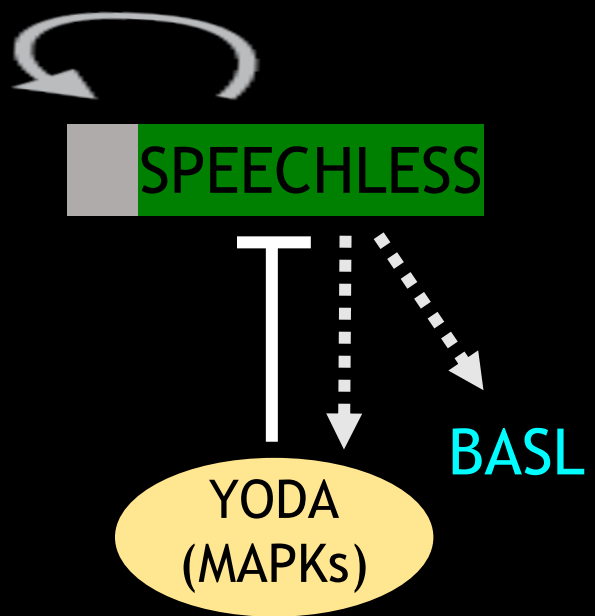


# These novel, *plant specific, polarized* proteins link SPCH and signaling



Zhang et al., 2015

Juan Dong's Lab, Waksman



+ Post-division growth



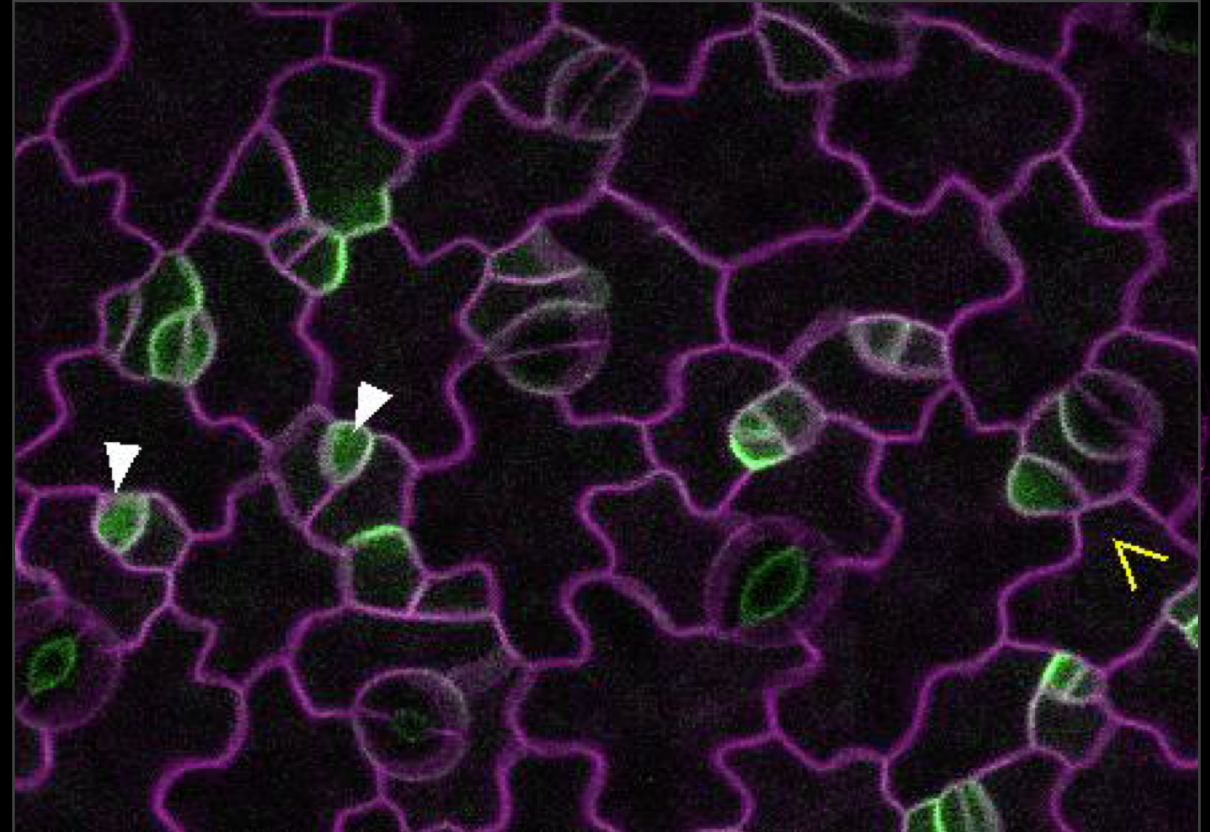
## The narrow view

How do plants set up  
and use information  
for fates and local pattern?



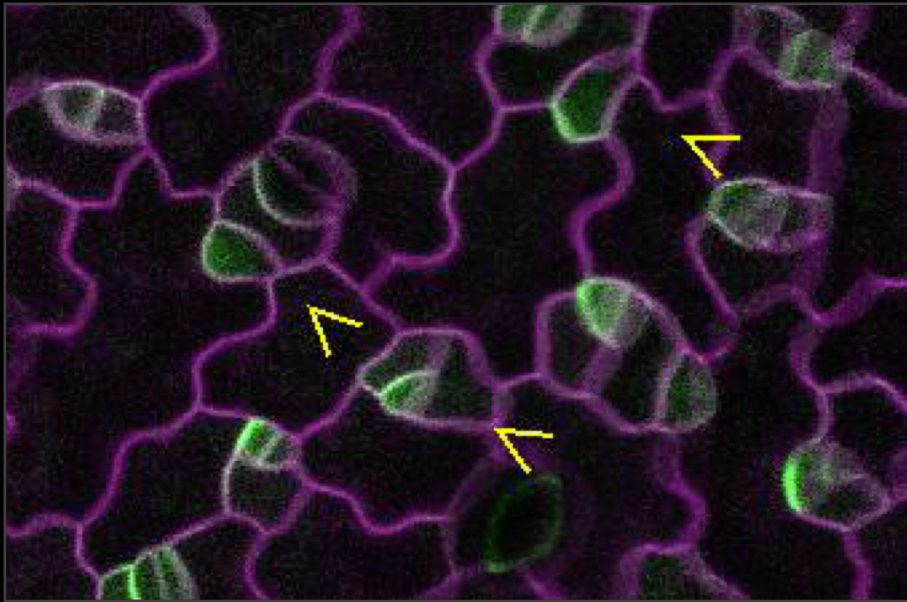
## A broader view

What happens when products of these  
dispersed populations interact?

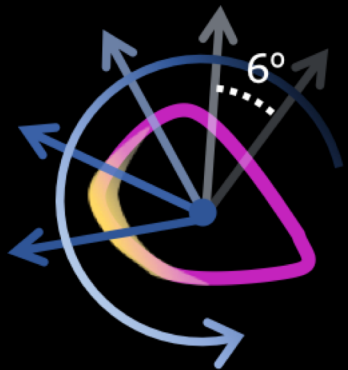
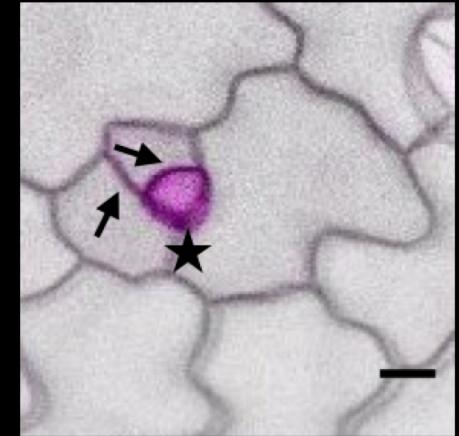
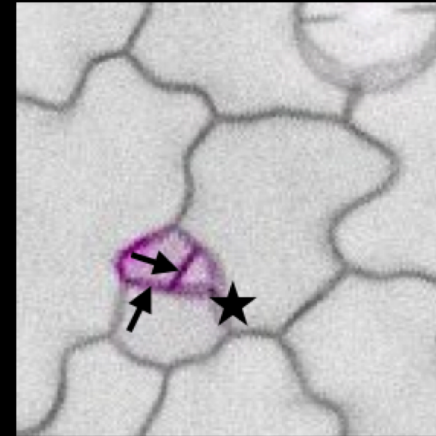
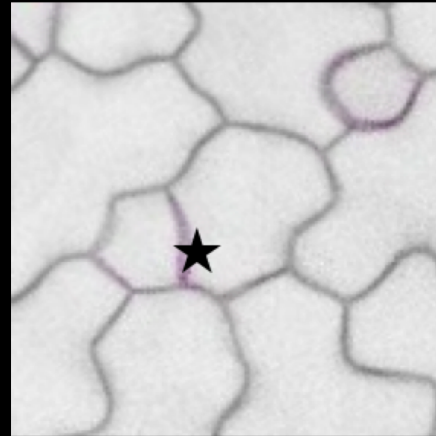


# New imaging pipeline to capture polarity dynamics and final fate

Capture cell dynamics from birth to division (24 hr @20min)

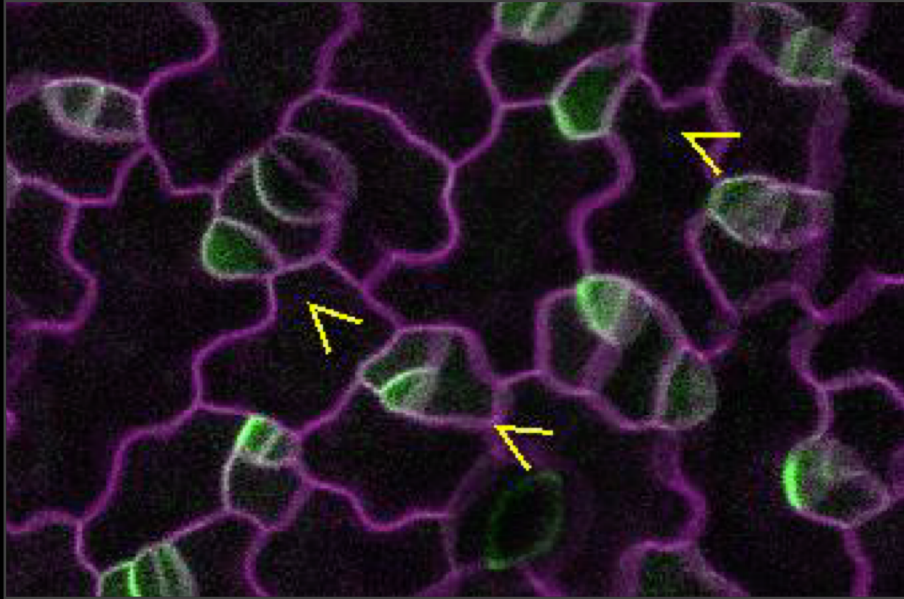


Capture divisions and ultimate fate (+72 hr @24hr intervals)

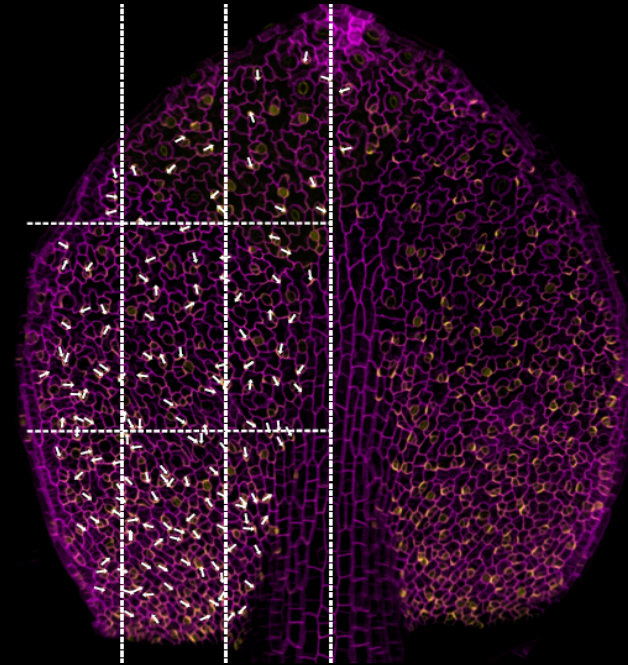


**POME**  
Quantitative  
polarity  
Measurement

## A broader view



## An even broader view



Is there planar polarity?

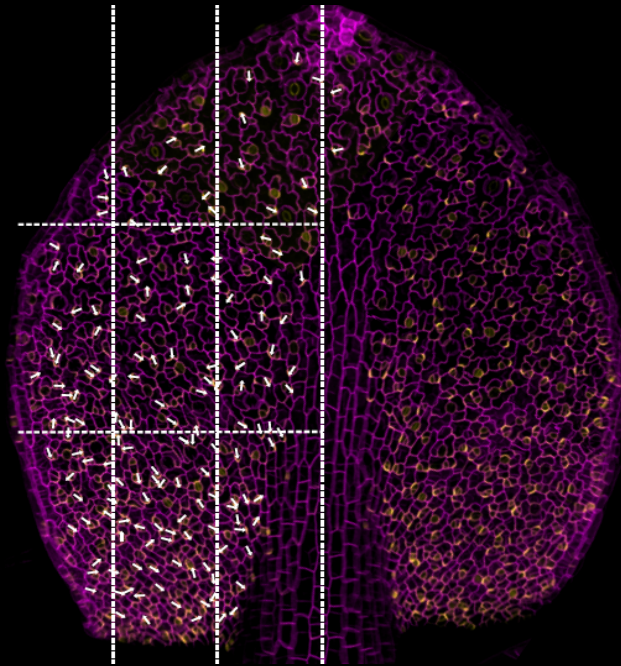
What happens when products of these dispersed populations interact?

Are local behaviors coordinated across the organ?  
If so, how?

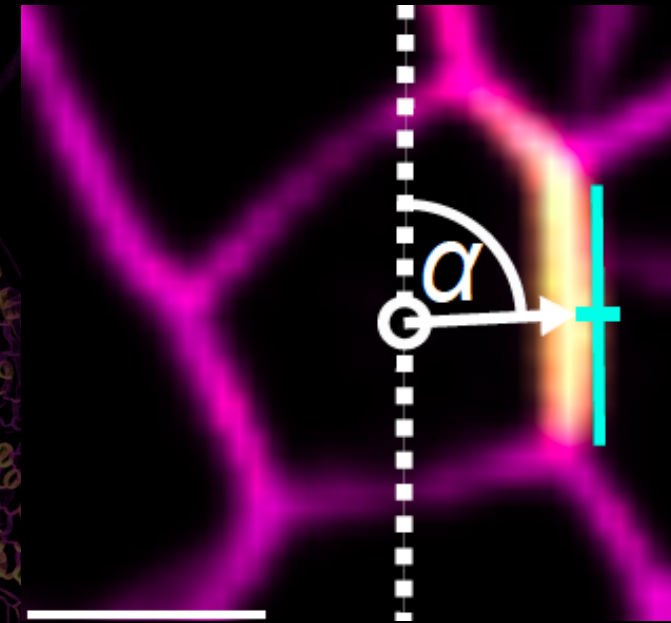
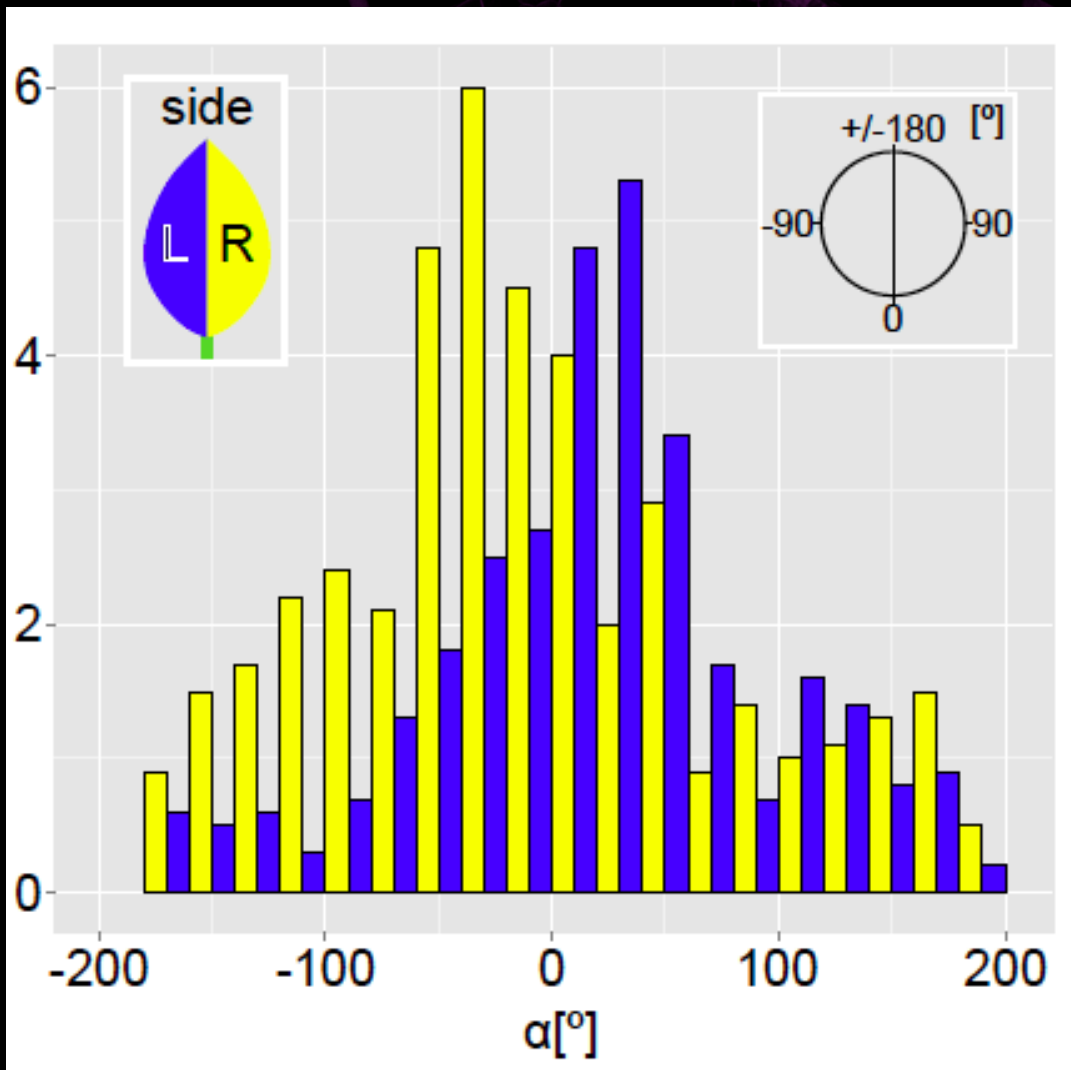
## An even broader view

Are local behaviors  
coordinated across the organ?  
If so, how?

Is there planar polarity?



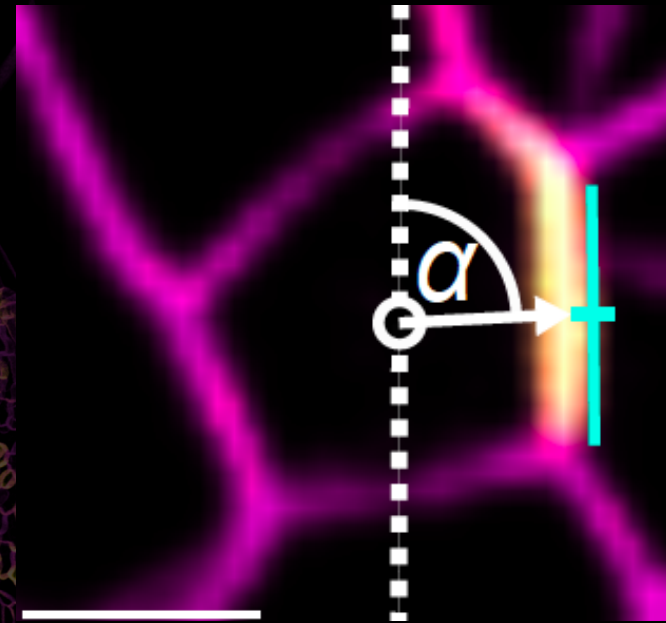
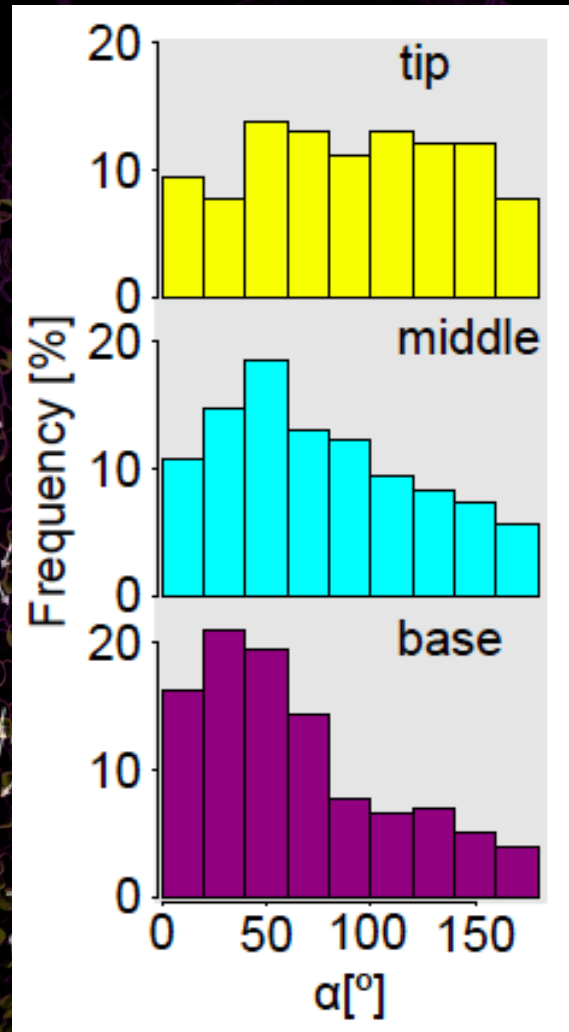
# Do cellular polarities follow the leaf axis?



Polarity angle  $\alpha$

Equally oriented  
at all points?

# Do cellular polarities follow the leaf axis?



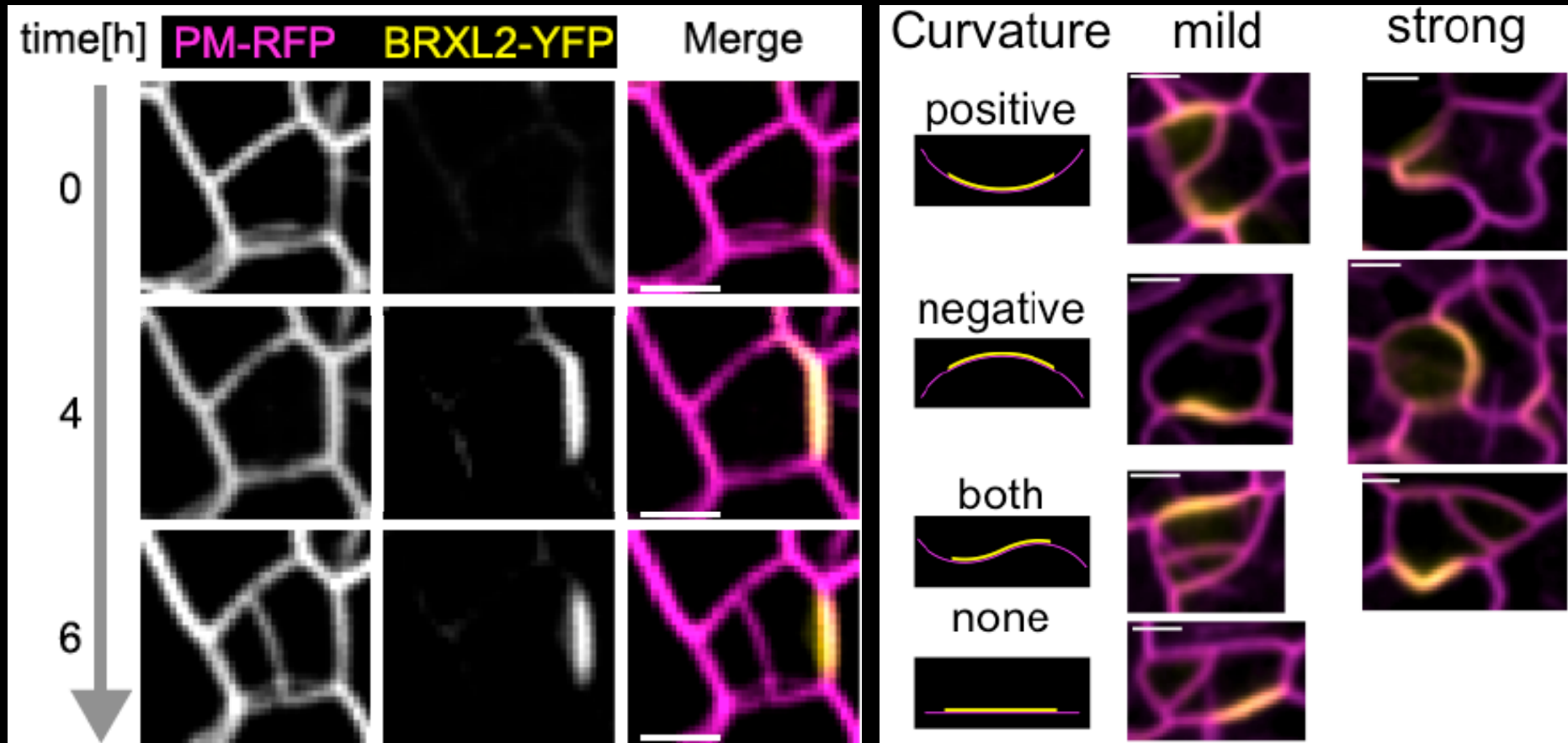
Polarity angle  $\alpha$

Equally oriented  
at all points?

# What's the relationship between BRXL2 and local growth?

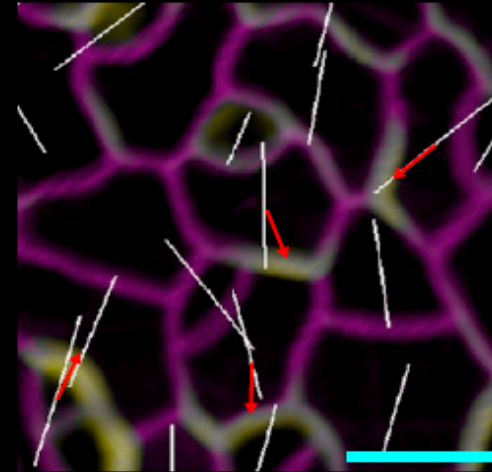
Monitor BRXL2 polarity over time

Does BRXL2 just go to the curviest or fastest growing region?

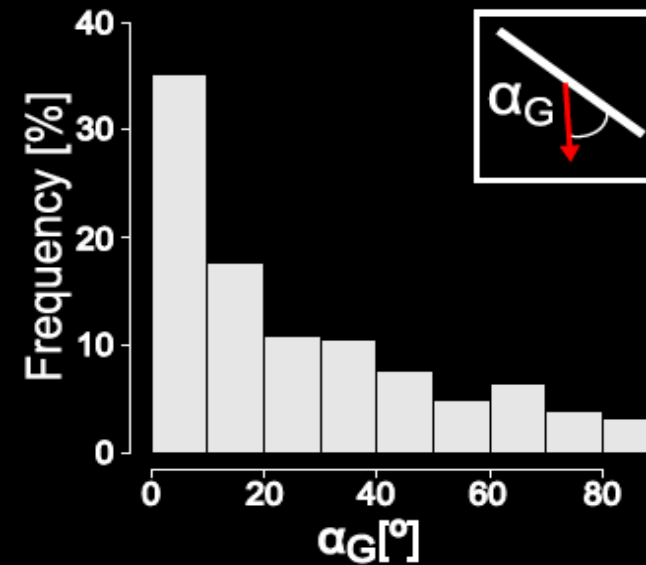


# What's the relationship between BRXL2 and local growth?

BRXL2-YFP PM-RFP



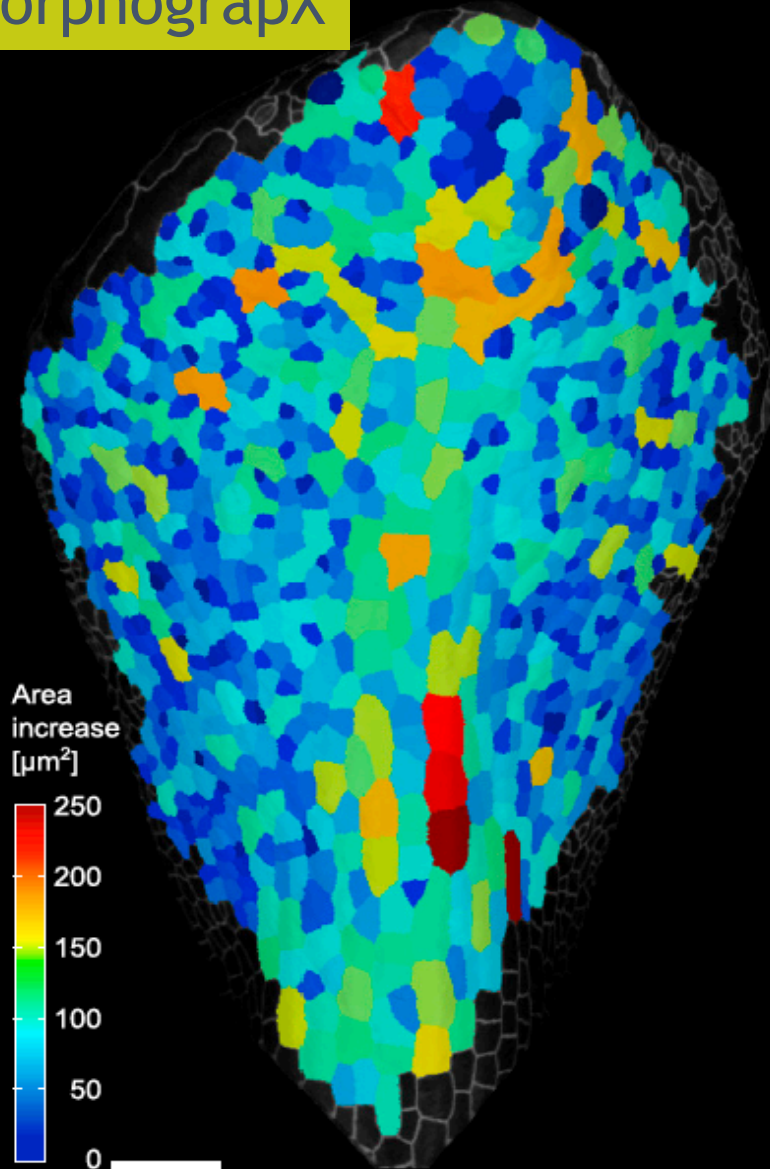
— PDGmax  
→ BRXL2-orientation



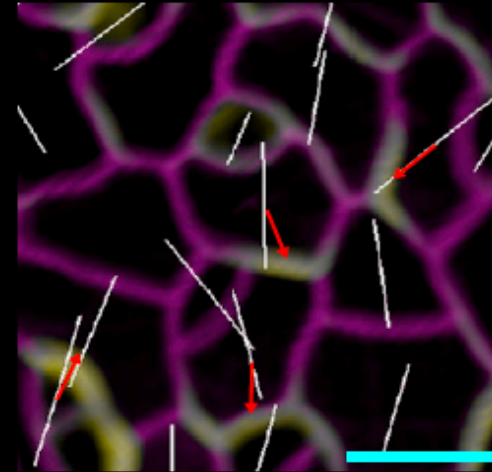


# What's the relationship between local and global growth?

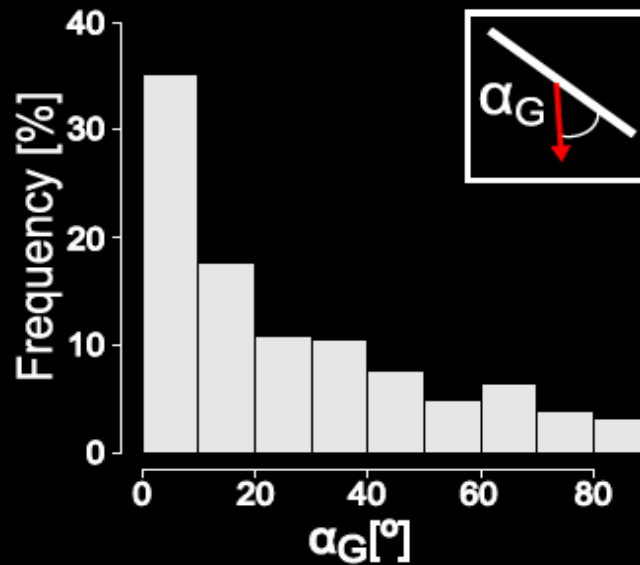
MorphograpX



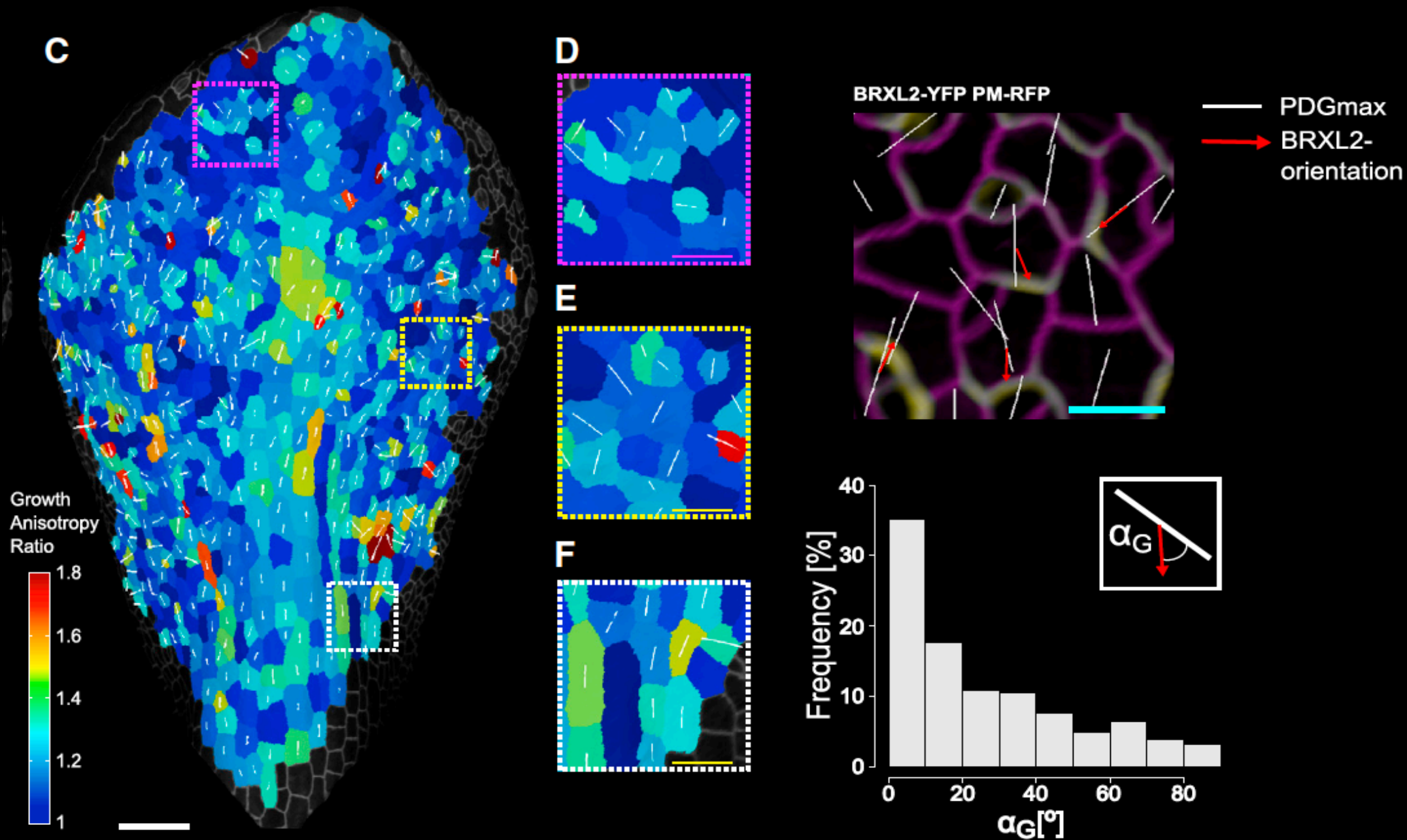
BRXL2-YFP PM-RFP



— PDGmax  
→ BRXL2-orientation



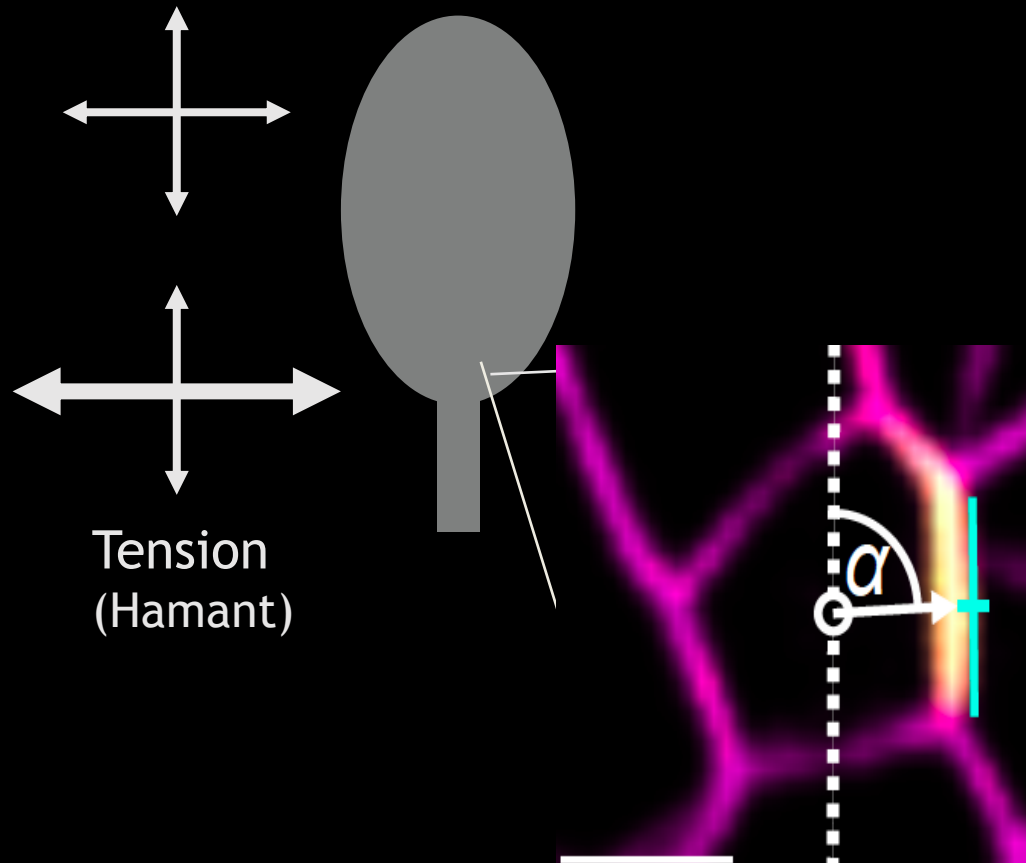
# What's the relationship between local and global growth?



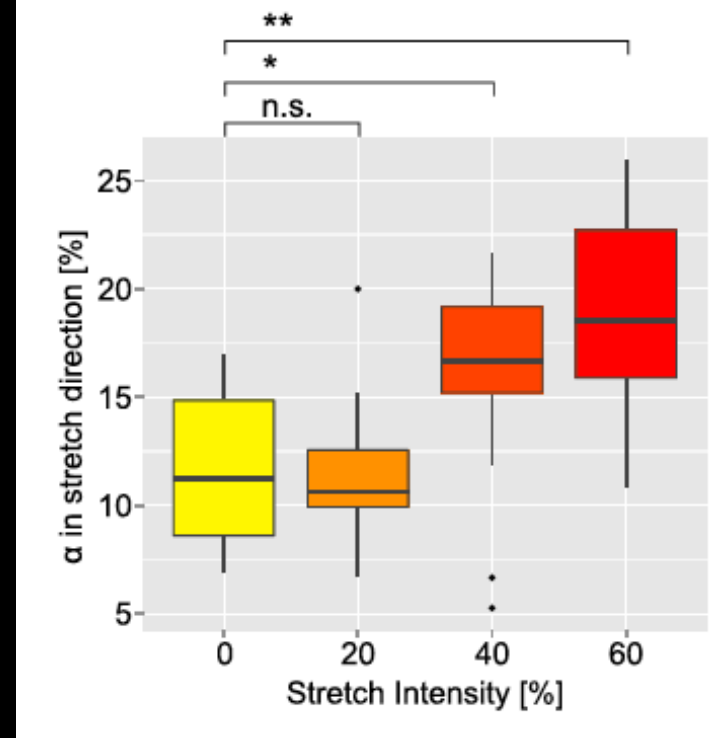
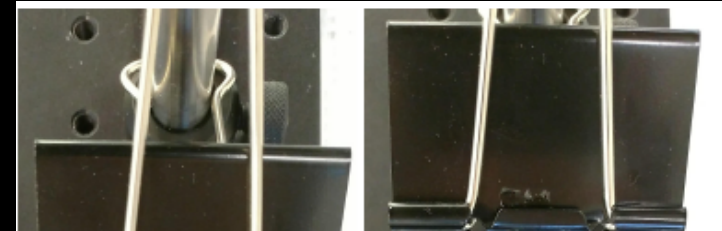
# Might BRXL2 orient relative to mechanical information?

Local ablation

PDMS-stretching



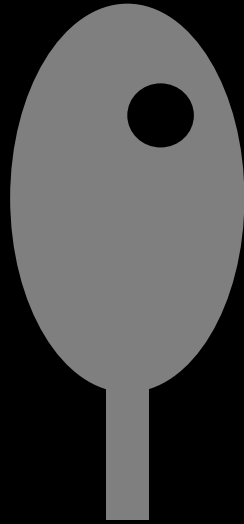
Realigned toward wound center



High-tech stretch device

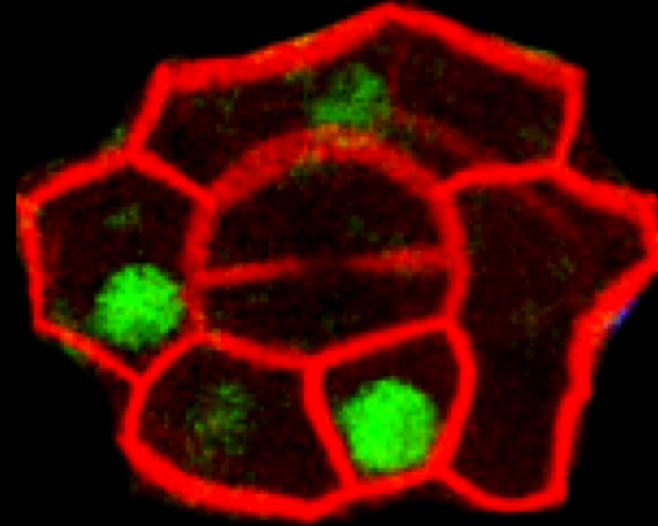
# Which information takes precedence?

Local ablation



Vs.

Neighboring stomata



14/15 cells orient  
polarity crescent  
relative to stomatal  
information

## Some questions to answer...

How does patterning work at multiple scales?

Is there feedback from growth (mechanical info) on divisions and pattern?

Patterning of stomatal is very flexible (and a bit sloppy).

What types of regulatory networks permit/favor this?

What is going to be predictive of cell behavior?

If plants have a natural planar polarity system and no cell movement, might cells in certain lineages need to escape to solve local problems?