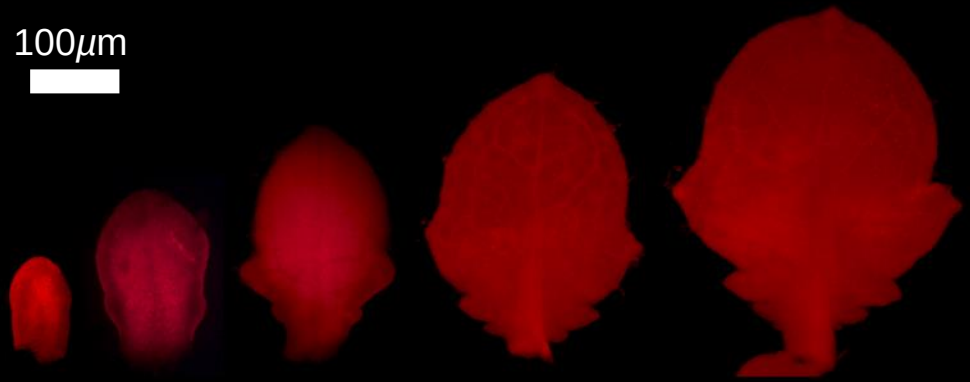
Model-based reconstruction of whole organ growth dynamics reveals invariant patterns in leaf morphogenesis

Jasmine Burguet
IJPB, INRAE, Versailles

Quantifying plant growth dynamics



Organ morphogenesis implies long-term **spatio-temporal** processes

- **Global goal**: determine how/where/when these processes operate during growth
- **Intermediate goal**: quantify organ shape evolution during growth

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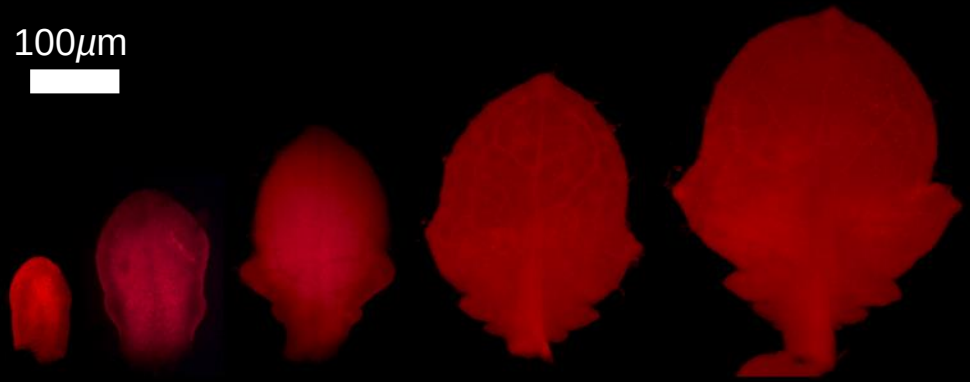

Organ morphogenesis implies long-term **spatio-temporal** processes

- **Global goal**: determine how/where/when these processes operate during growth
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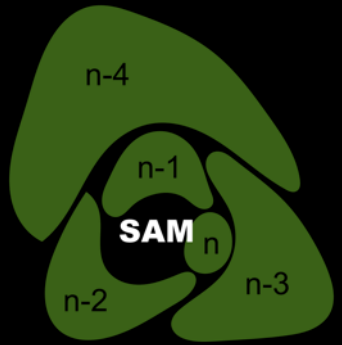
- Some challenges:
  - organs are not always accessible/observable from early to late stages
  - organ size changes a lot (from micro- to macro-scales)
  - long-term observation may significantly impact growth itself
  - multiple observations must be done/integrated to face variability

Quantifying plant growth dynamics: the leaf as a model

Arabidopsis thaliana



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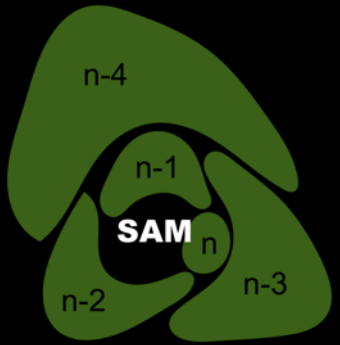
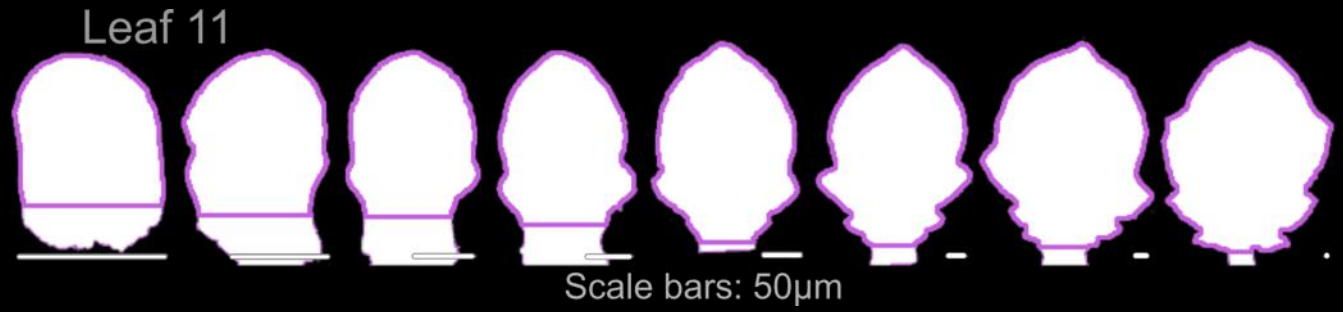
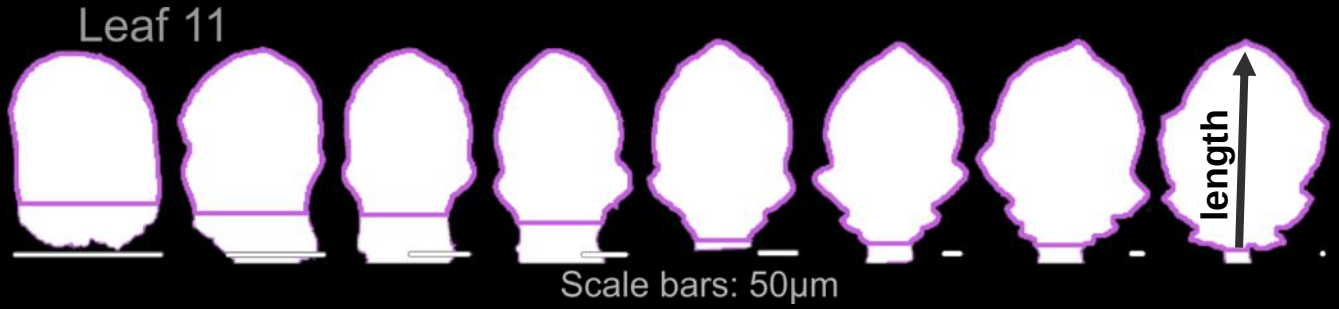


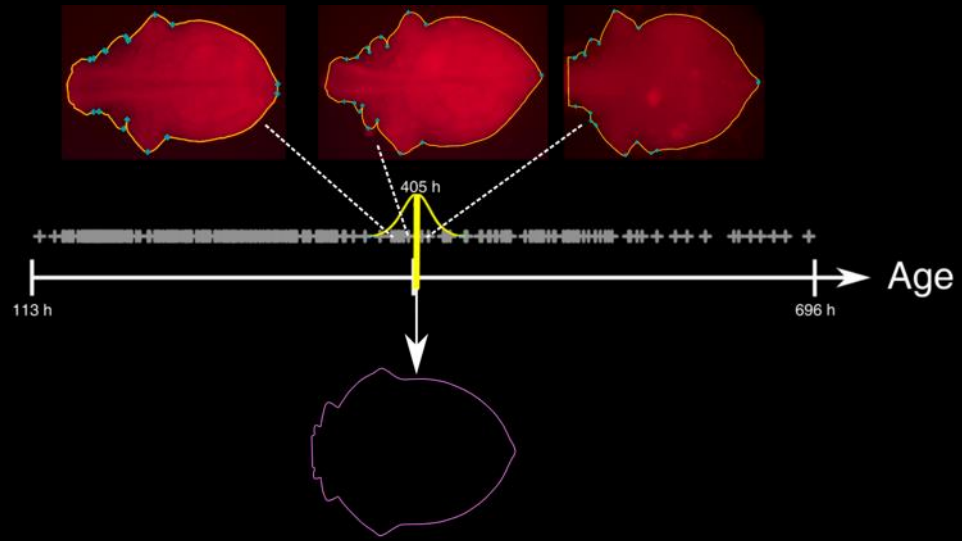


Quantifying plant growth dynamics: ***MorphoLeaf***

Biot et al. 2016



Leaf size as
a proxy of time



Local contour averaging
based on homologous
landmarks positions

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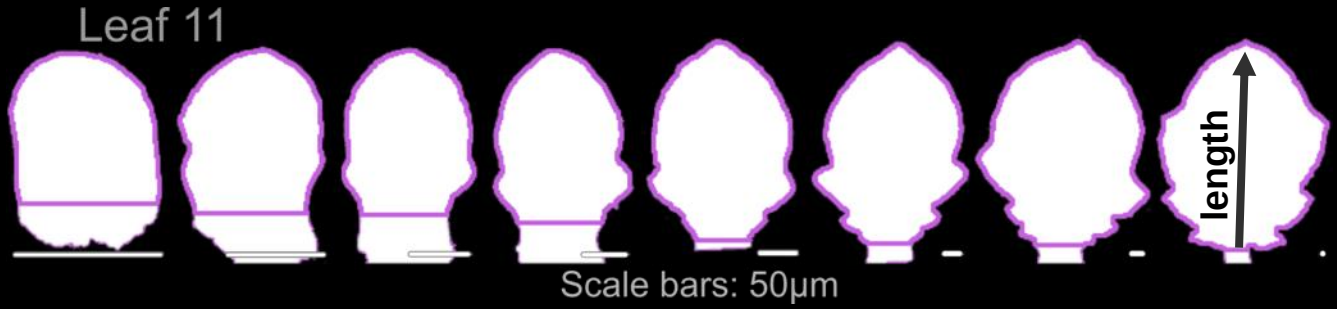

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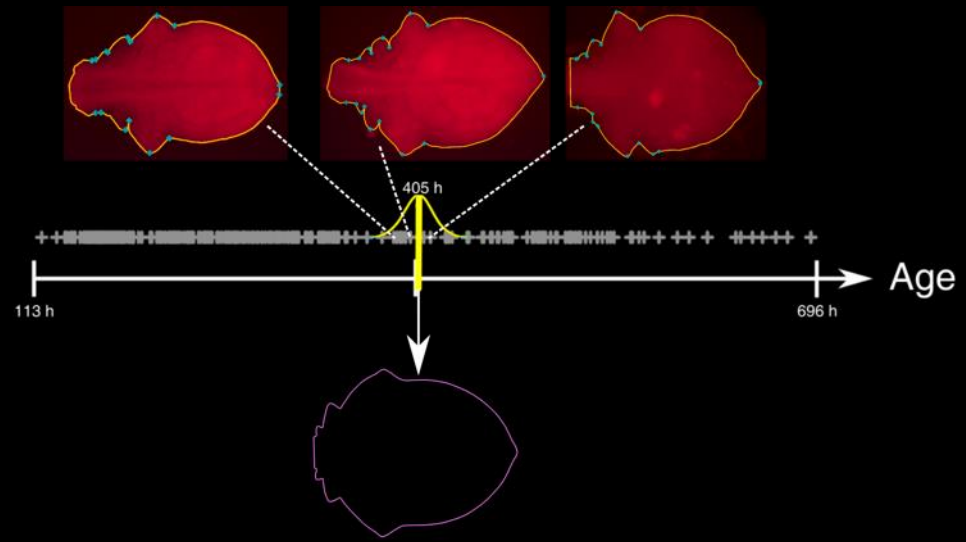

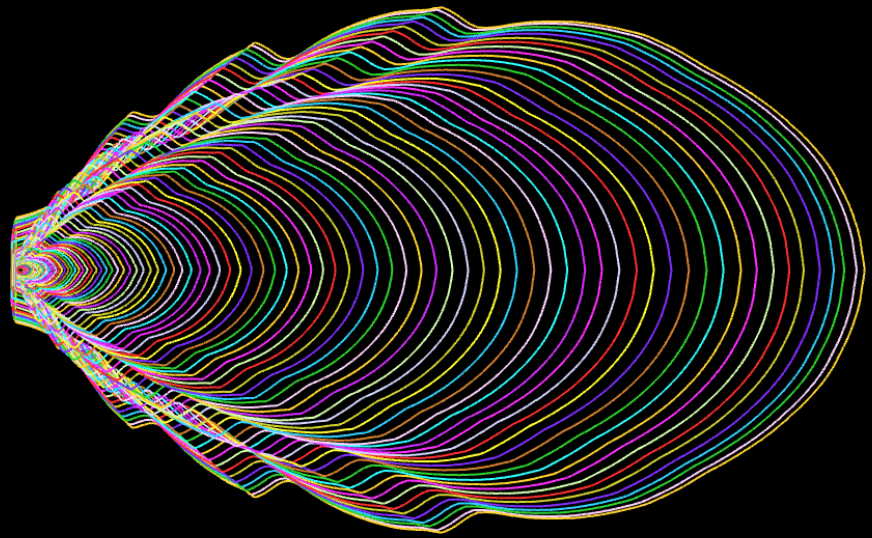

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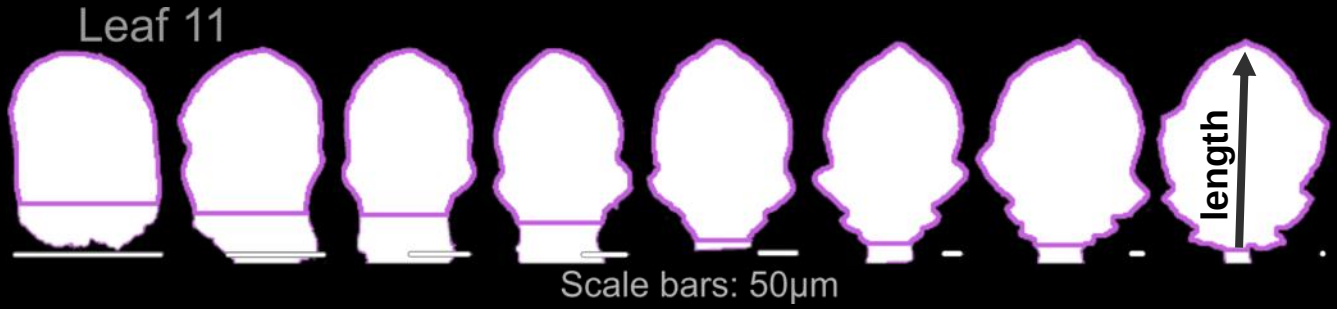
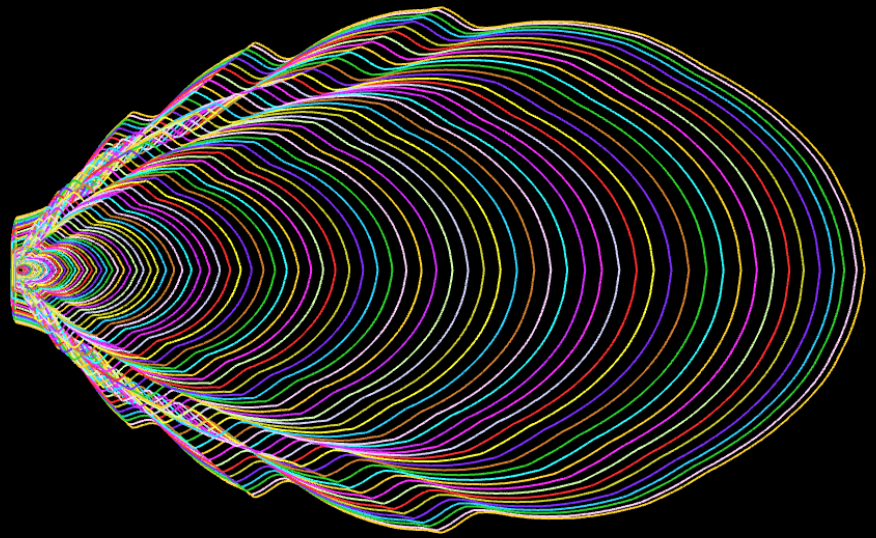
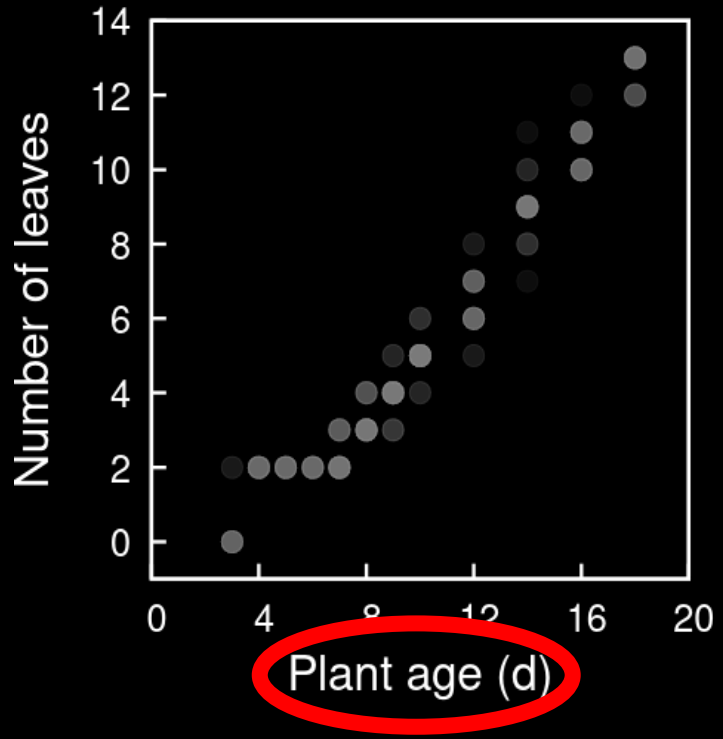


Leaf size as
a proxy of time

This is not the real
temporal dynamics!
Time should be
reintroduced
⇒ “dating” leaves



First : determining the starting time using modeling



Available time: plant age

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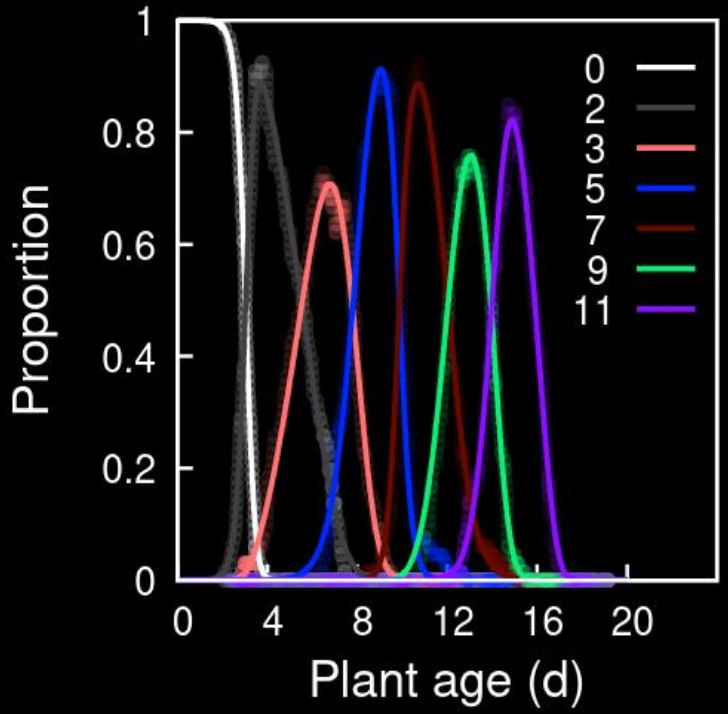

$$\frac{dN_k(t)}{dt} = \alpha_{k-1}(t)N_{k-1}(t) - \alpha_k(t)N_k(t)$$

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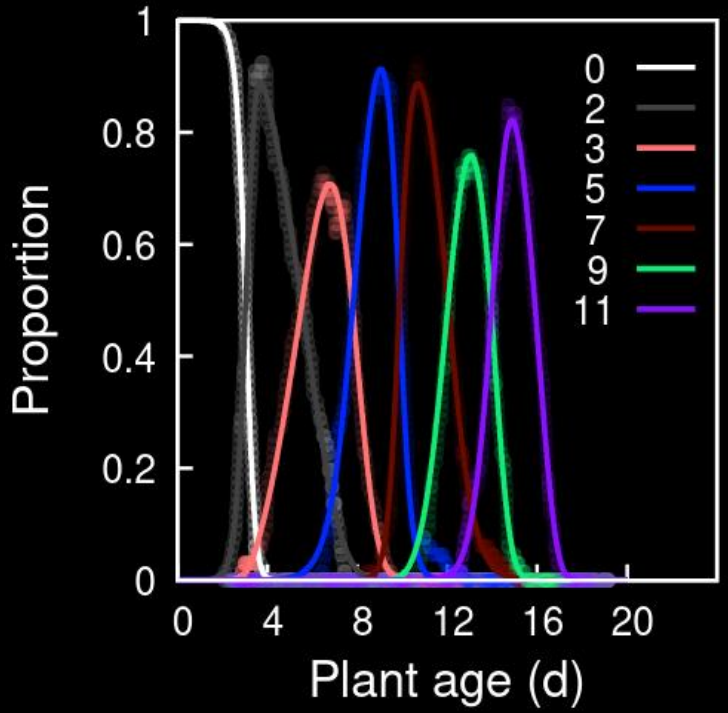
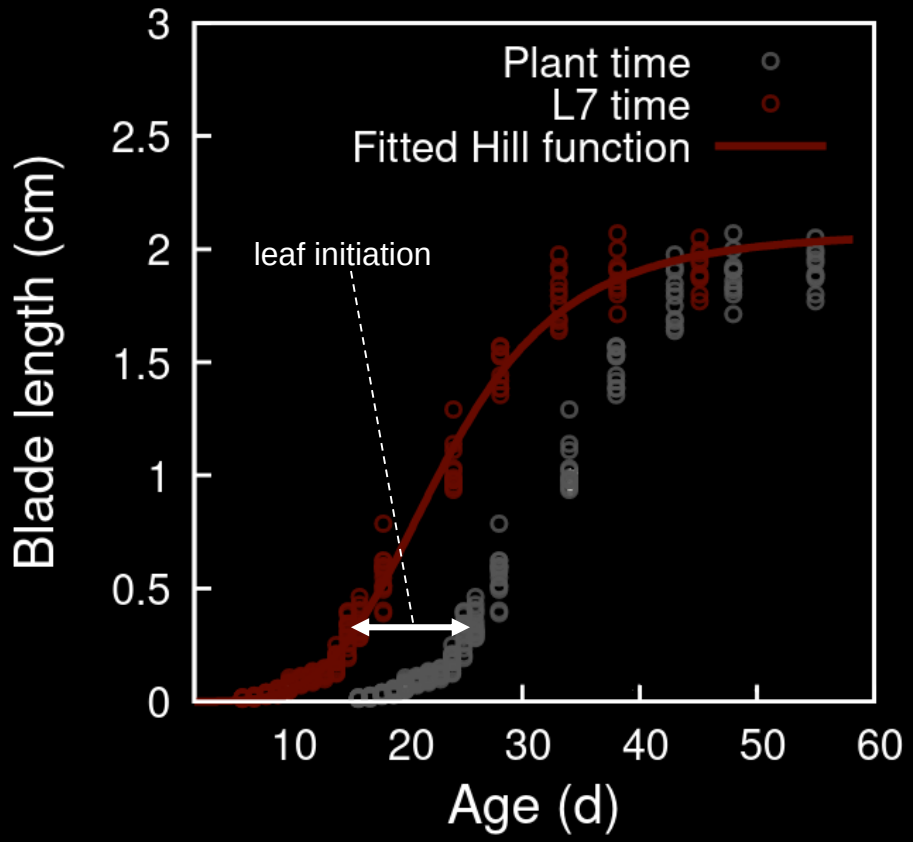


Modeling strategy useable to estimate initiation time of any structures appearing sequentially

Second: relying organ size and age



- Leaf size is recorded as a function of plant age
- Time translation is applied to get measures as a function of leaf age
- A sigmoid (Hill function) is fitted to the data

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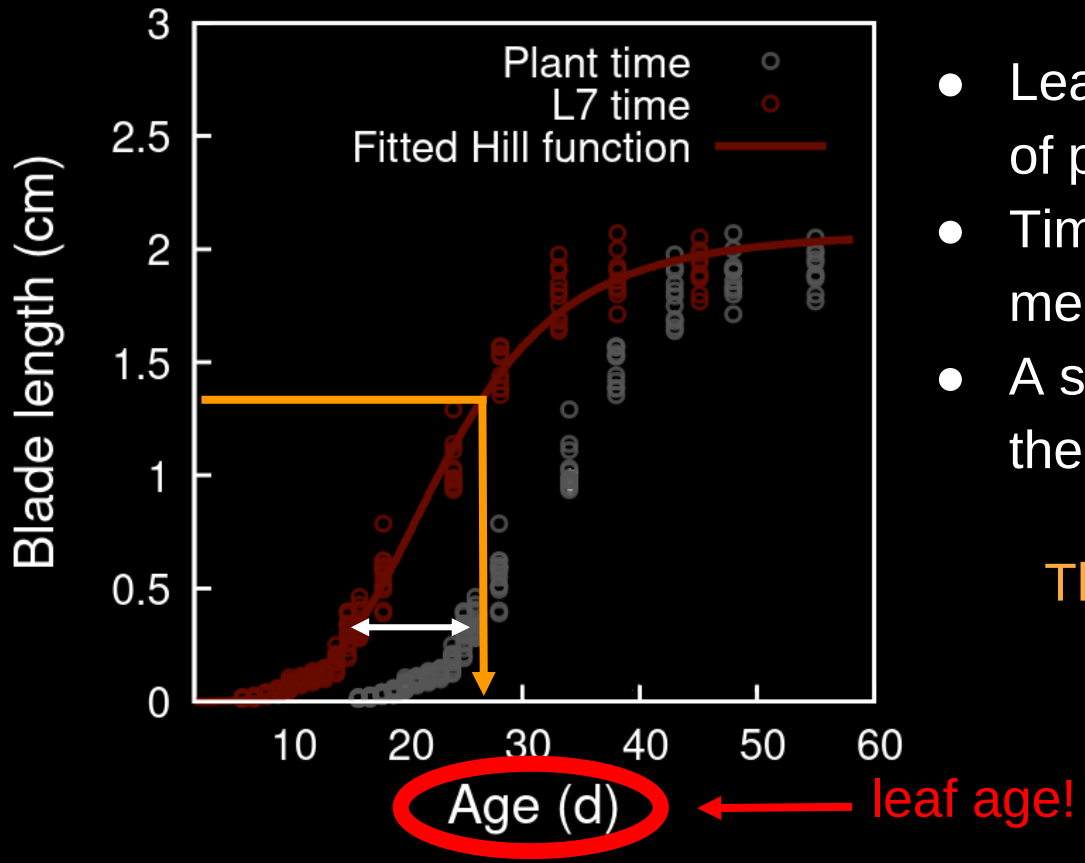

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The organ age can be retrieved from its size

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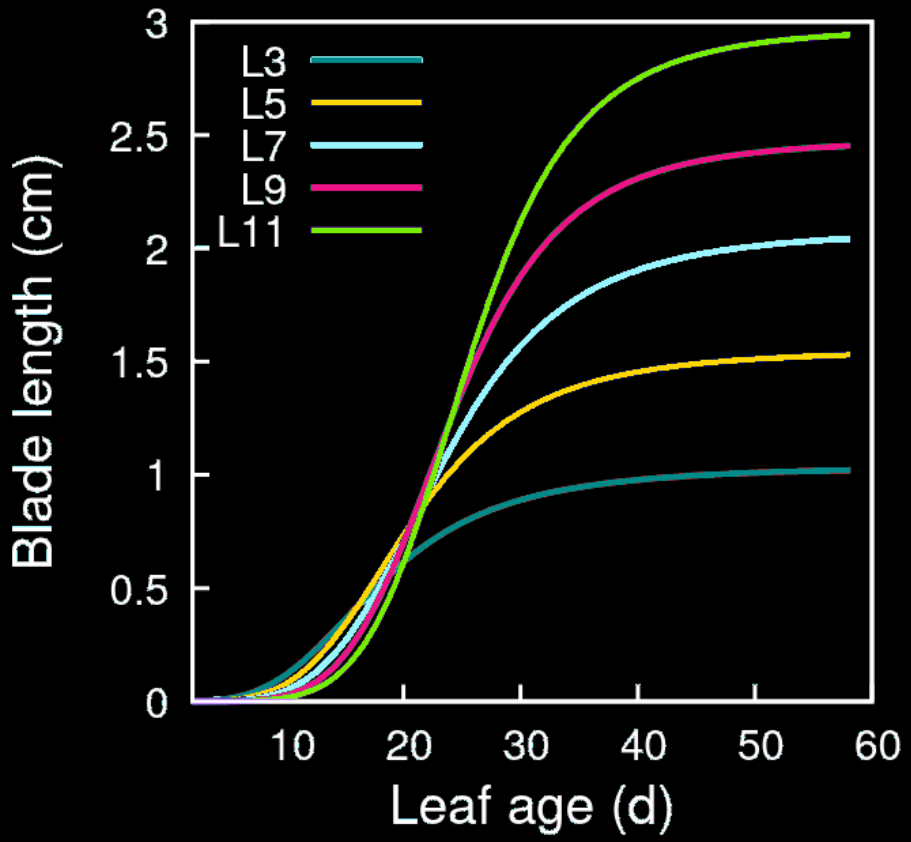

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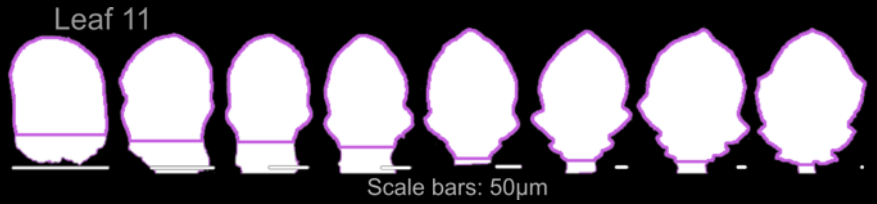
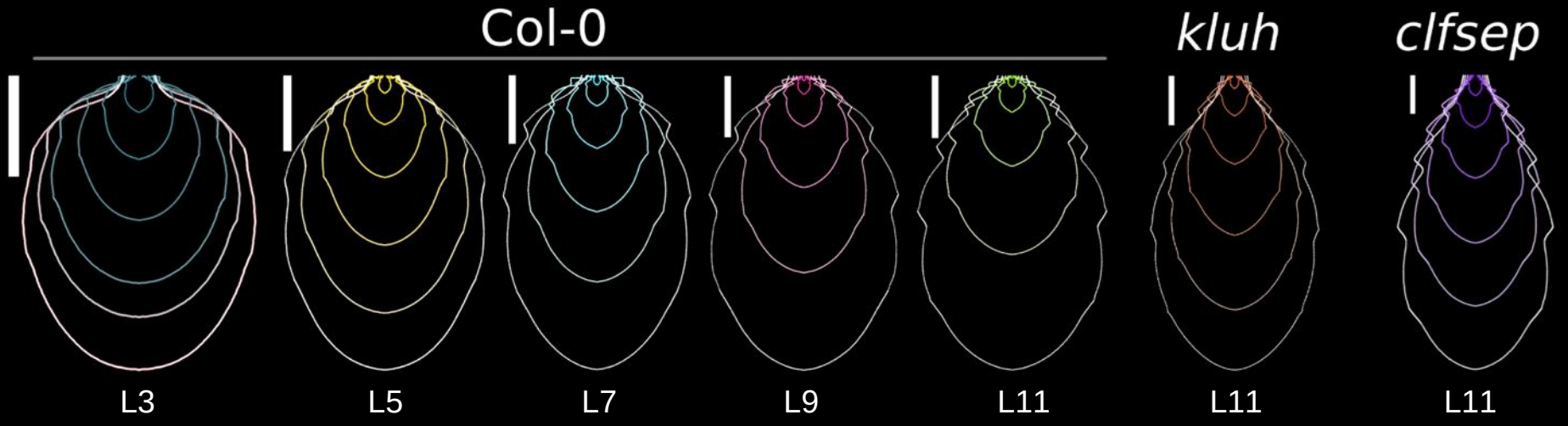
Reconstructing temporal growth trajectories



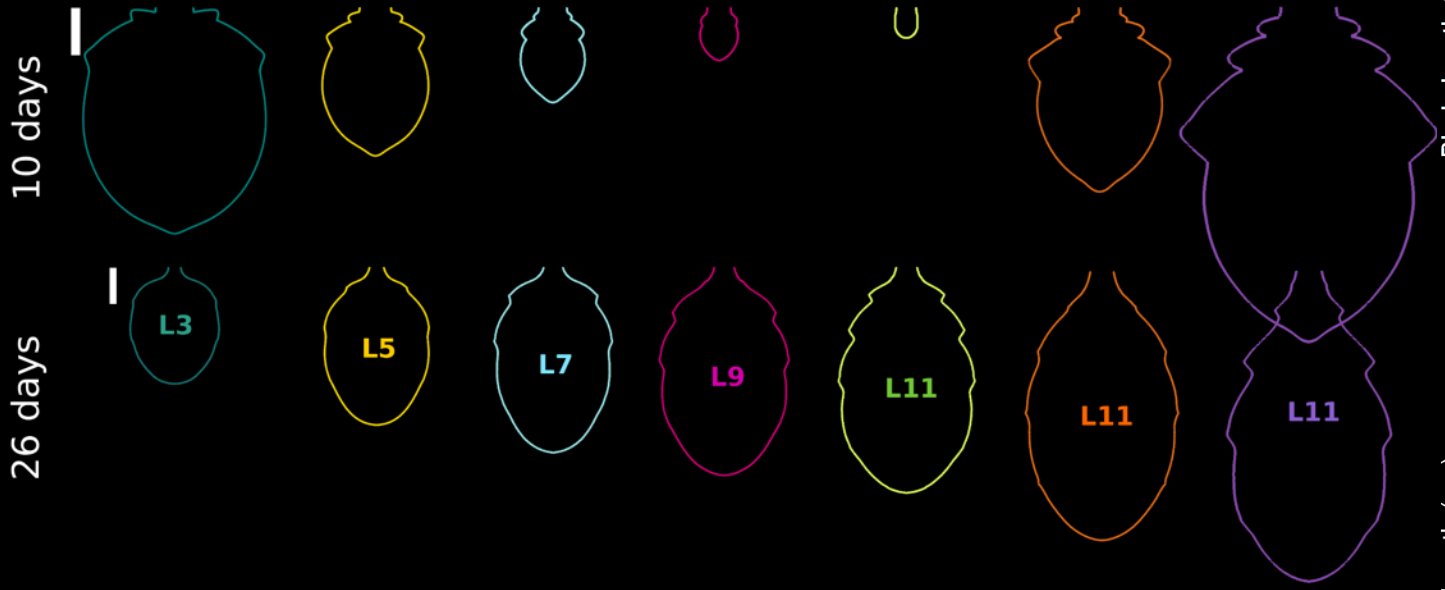
The continuous organ shape evolution is retrieved from fixed images only

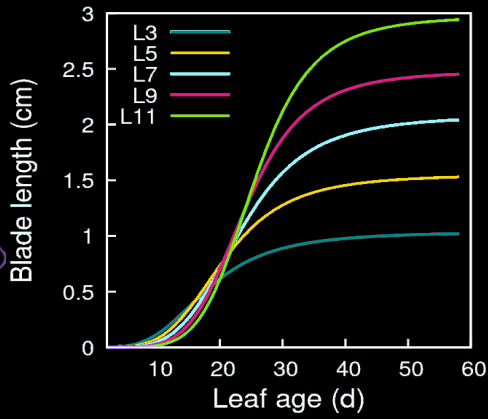
Reconstructing temporal growth trajectories

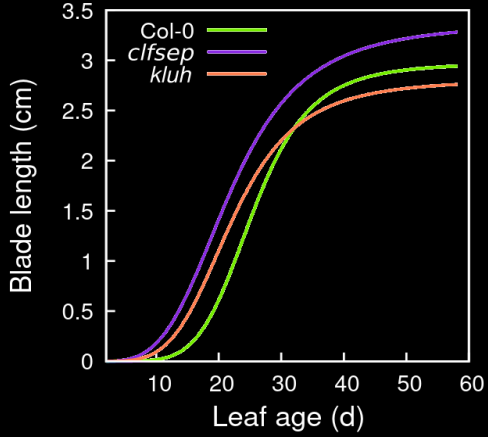


Contours of leaves at 220h, 290h, 360h, 430h, 500h and 570h after initiation

Reconstructing temporal growth trajectories



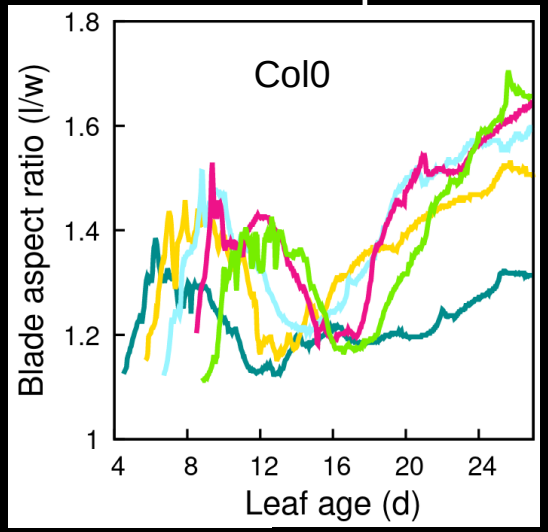




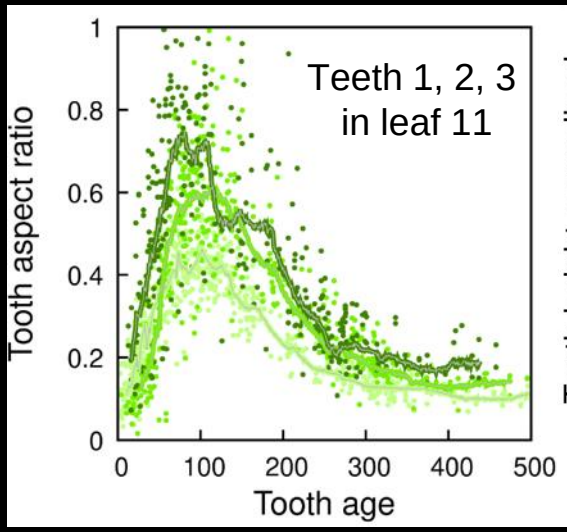
Whole growth has to be considered to fully understand developmental kinetics

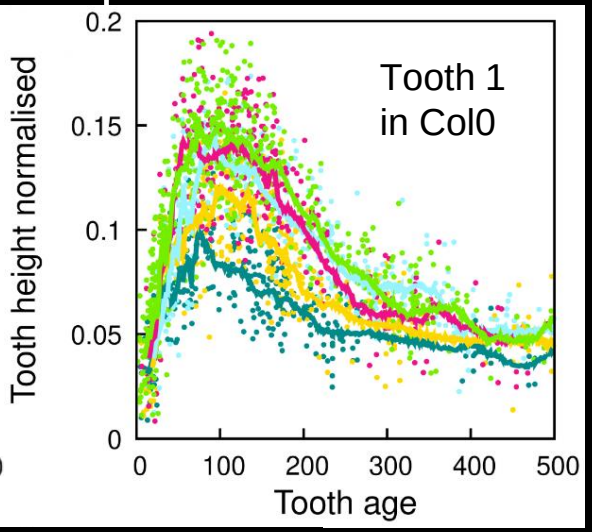
Quantifying shapes during growth

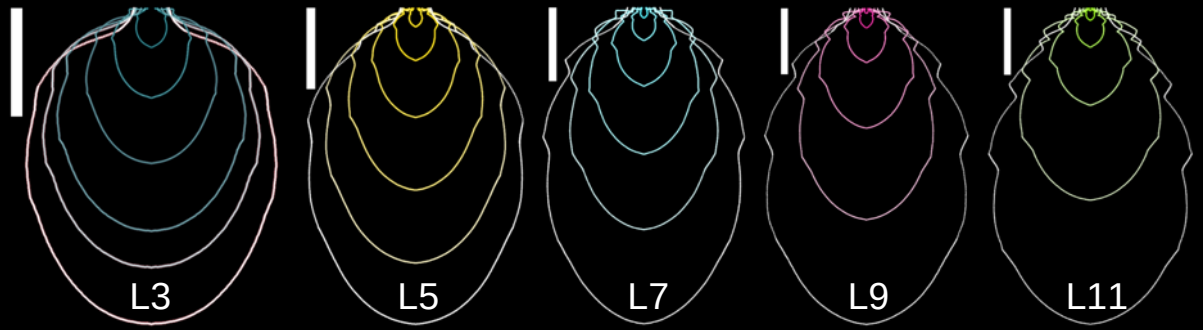
Global shape



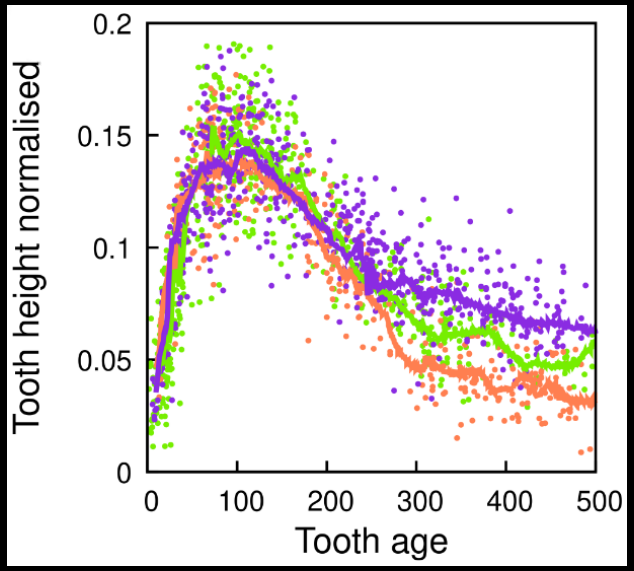
Local shape

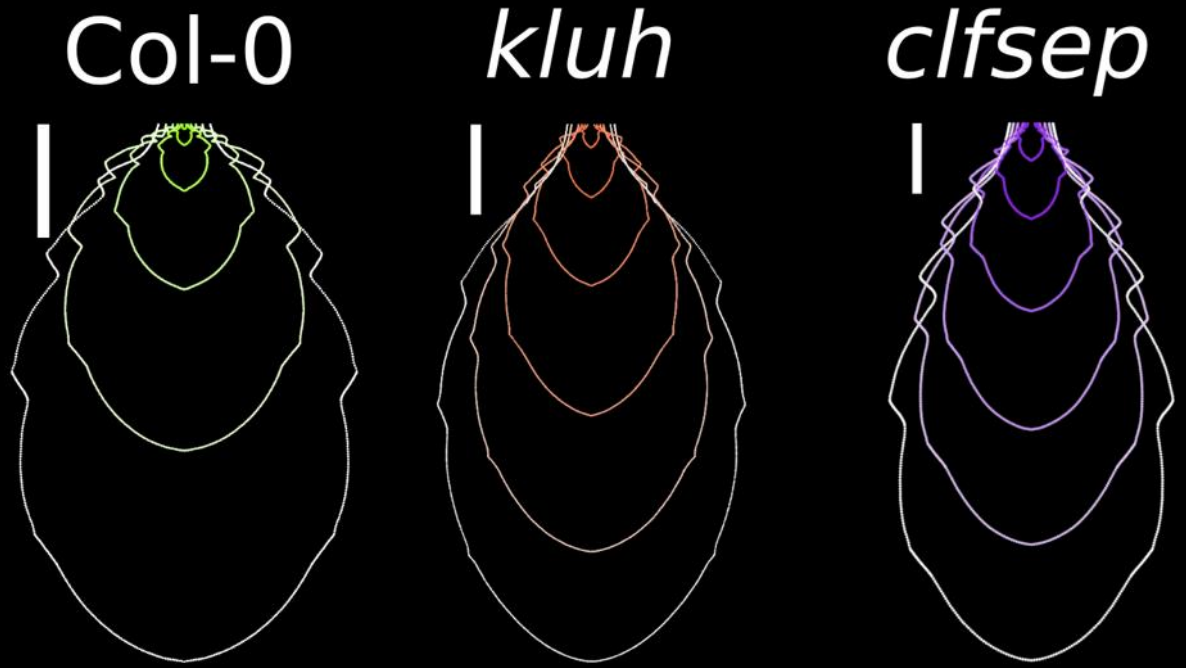






Revealing key events during the development





Static data used to reconstruct morphodynamics

- a model to determine apparition times (simple counting protocols)
- a fitted growth function relating size and age
- explicit long-term morphodynamics can be retrieved/quantified
- the effects of alterations (mutation, environment, …) can be localized/quantified during all growth

In *Aradidopsis thaliana*:

- leaf heteroblasty was characterized during growth (global/local scales)
- dynamics of successive leaves in *Arabidopsis thaliana* follow a same program, with graded parameters
- key developmental events can be revealed in space and time (using, e.g., mutants)

A collaborative work at IJPB, INRAE Versailles

Team Modeling and Digital Imaging

- Philippe ANDREY
- Eric BIOT
- Mohamed OUGHOU

Team Transcription Factors and Architecture

- Nicolas ARNAUD
- Patrick LAUFS
- Aude MAUGARNY-CALES