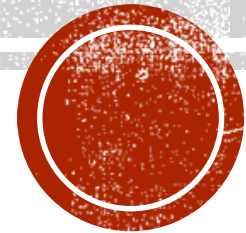




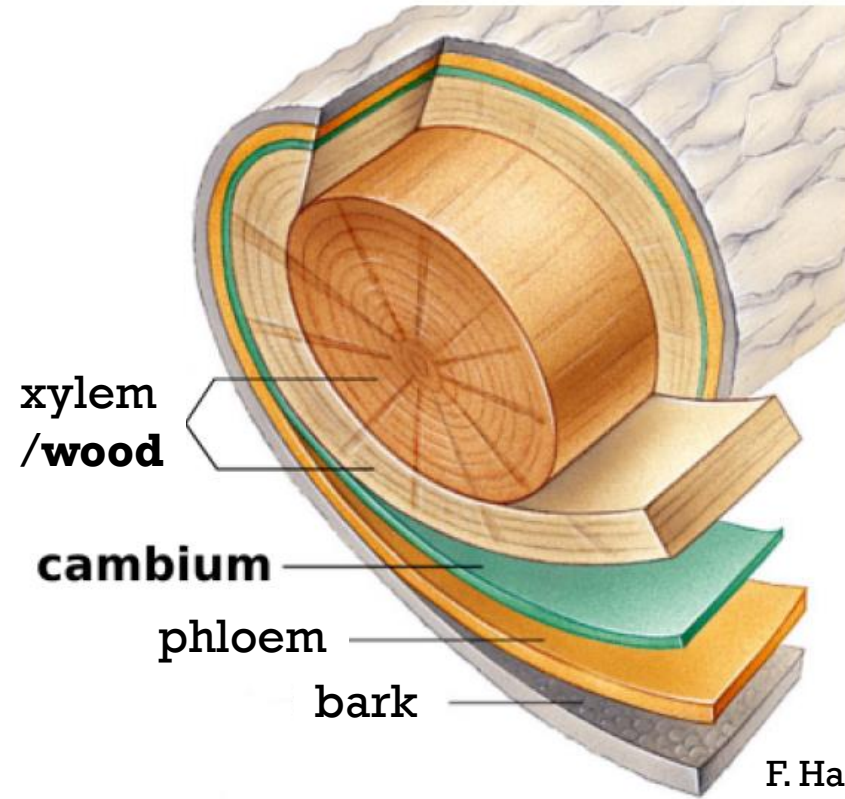
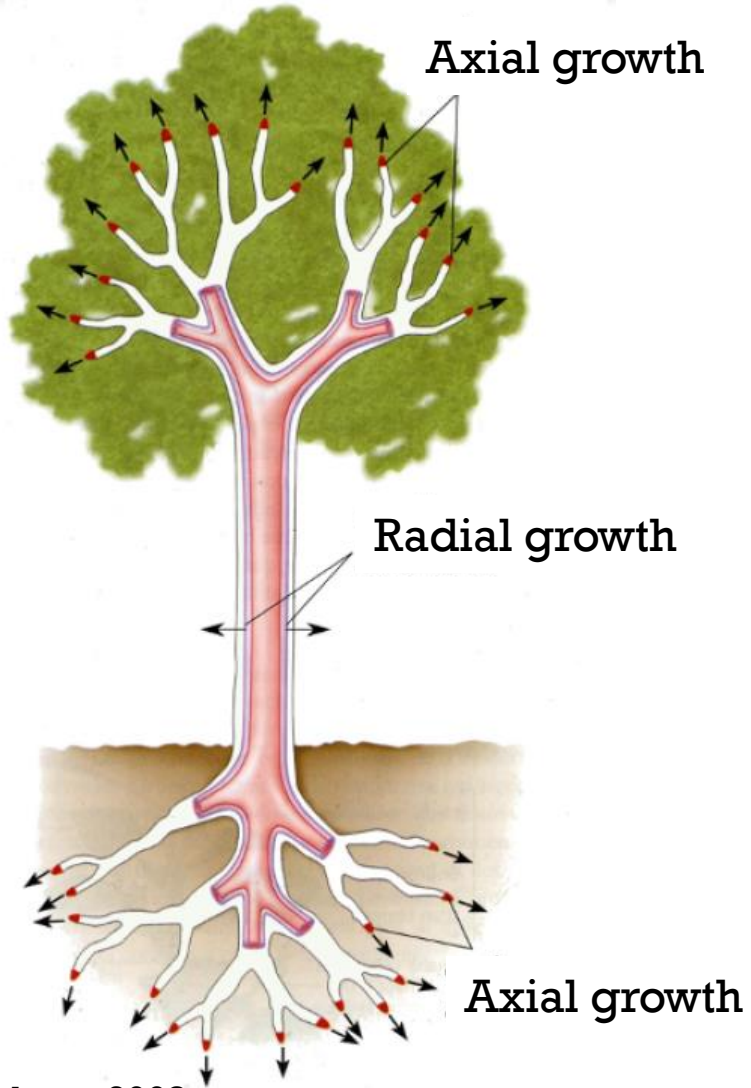
Modelling cell growth together with wall thickening

Cyril Bozonnet, Felix Hartmann, Tancreède Alméras, Ibrahim Cheddadi,
Joseph Gril, Bruno Moulia, Eric Badel



ANR CEMACam (Computational and Experimental Mechanics of Cambium)

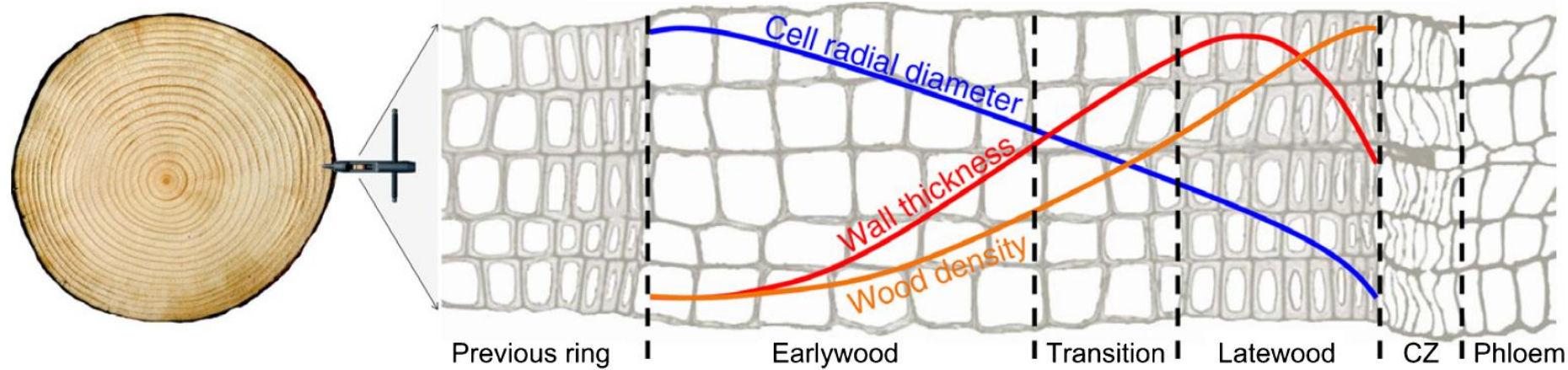
WOOD & CAMBIUM



Nabors, 2008

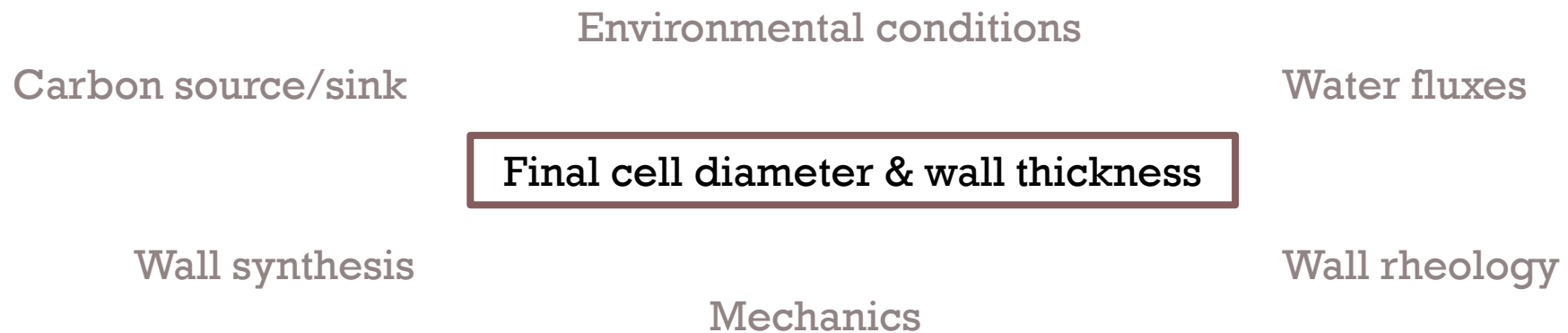
F. Hartmann, 2015

WOOD IN EXTRATROPICAL AREAS: TREE RINGS

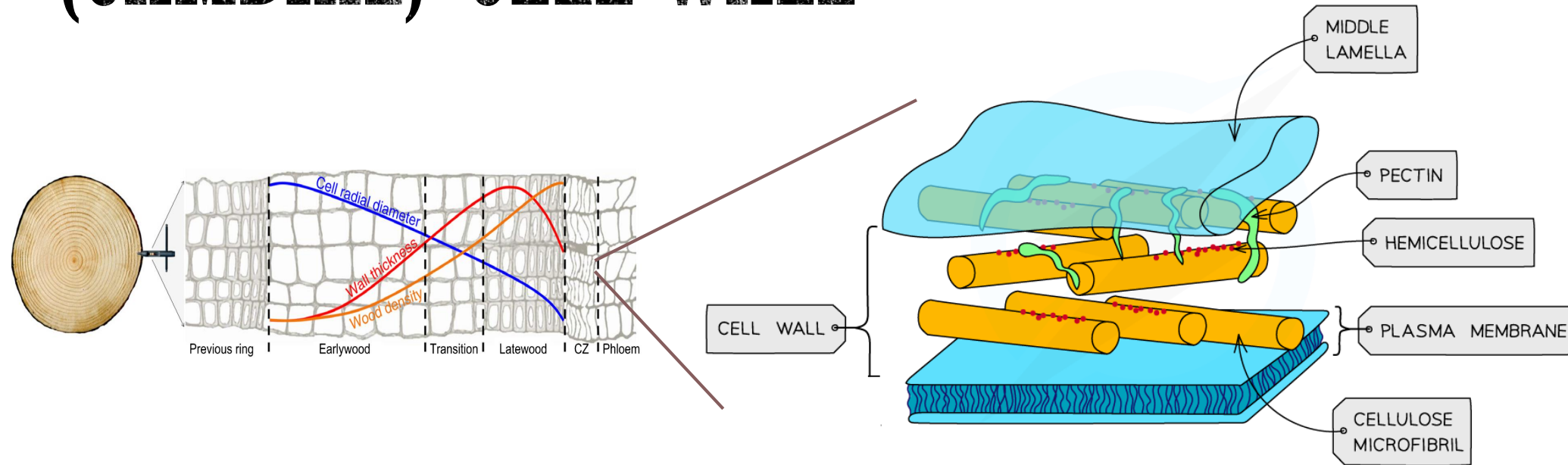


Following
Cuny et al., 2014

CZ: cambial zone



(CAMBIAL) CELL WALL



- Cell wall building requires a flux of different polymers (derived from sugars)
- **Coupled enlarging & thickening dynamics are key to wood formation**

THE LOCKHART MODEL (1965)

➤ The classical equations for plant cell growth



Length : $L(t)$
 Radius : R
 Thickness : W

Kinematics

$$\frac{1}{V} \frac{dV}{dt} = \frac{1}{L} \frac{dL}{dt}$$

Water fluxes

Elongation rate

$$\Phi_h (\Psi_{ext} - P + \Pi)$$

$$\Phi_w (P - P_y)^+$$

Conductivity

Difference in potentials

Extensibility

Yield pressure



With $\frac{dW}{dt} = 0$

What happens when $\frac{dW}{dt} \neq 0$?

COUPLING WITH WALL THICKENING



Length : $L(t)$
Radius : R
Thickness : $W(t)$

Water volume

$$V = \pi(R - W)^2 L$$

Wall mass

$$M_w = \rho_w 2\pi R W L$$

Kinematics

$$\frac{1}{V} \frac{dV}{dt} = \frac{1}{L} \frac{dL}{dt} \left(1 + \frac{2W}{R} \right) - \frac{1}{V \rho_w} \frac{dM_w}{dt}$$

Lockhart

Not Lockhart

COUPLING WITH WALL THICKENING

$$\frac{1}{V} \frac{dV}{dt} = \frac{1}{L} \frac{dL}{dt} \left(1 + \frac{2W}{R} \right) - \frac{1}{V\rho_w} \frac{dM_w}{dt}$$

Water fluxes

Elongation rate

Wall polymer synthesis (from sugar)

$$\Phi_h(\Psi_{ext} - P + \Pi)$$

$$\frac{1}{L} \frac{dL}{dt} = \dot{\varepsilon}_L(\sigma)$$

$$\frac{dM_w}{dt} = v_w \frac{C_s}{C_s + K}$$

Cell sugar concentration

Synthesis speed

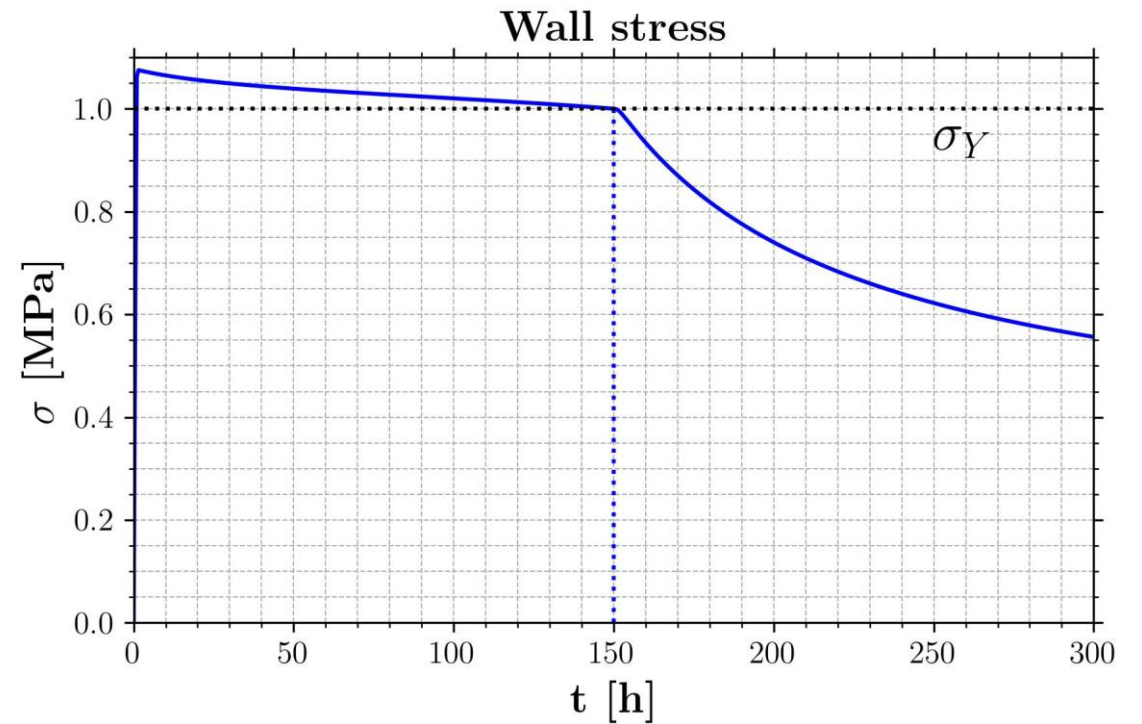
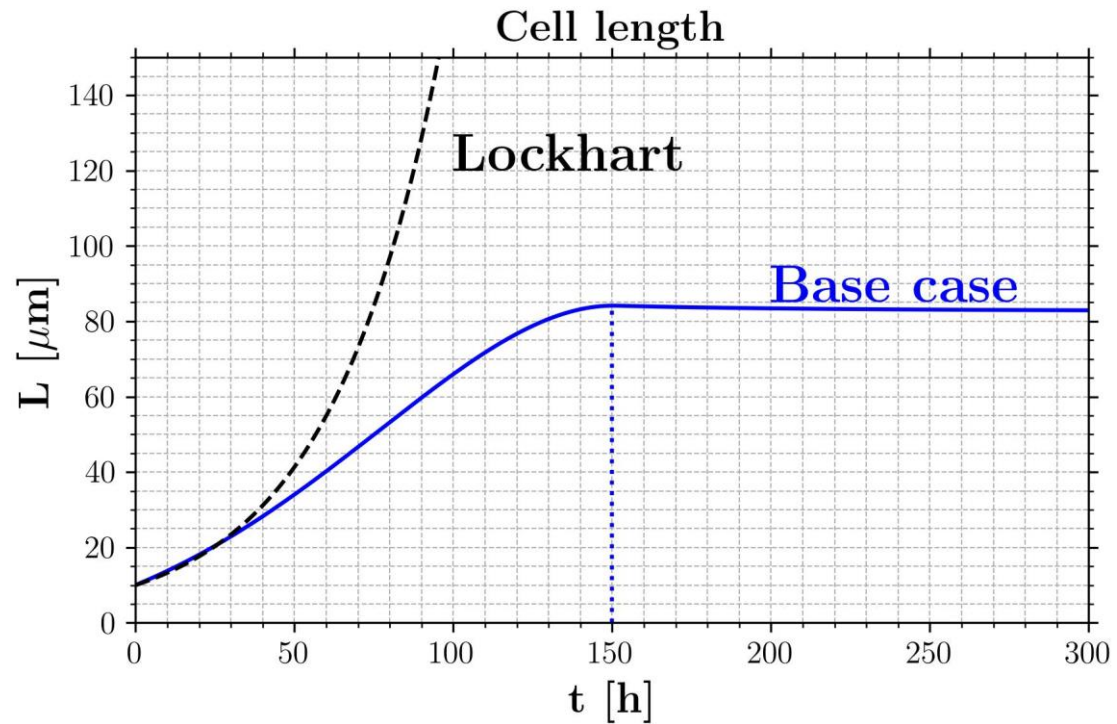
Naive approach to close the system

Wall as a single layer of varying thickness that behaves as a Bingham fluid

$$\dot{\varepsilon}_L = \Phi_w(\sigma - \sigma_Y)^+ + \frac{1}{E} \frac{d\sigma}{dt}$$

$$\sigma = \frac{PR}{2W}$$

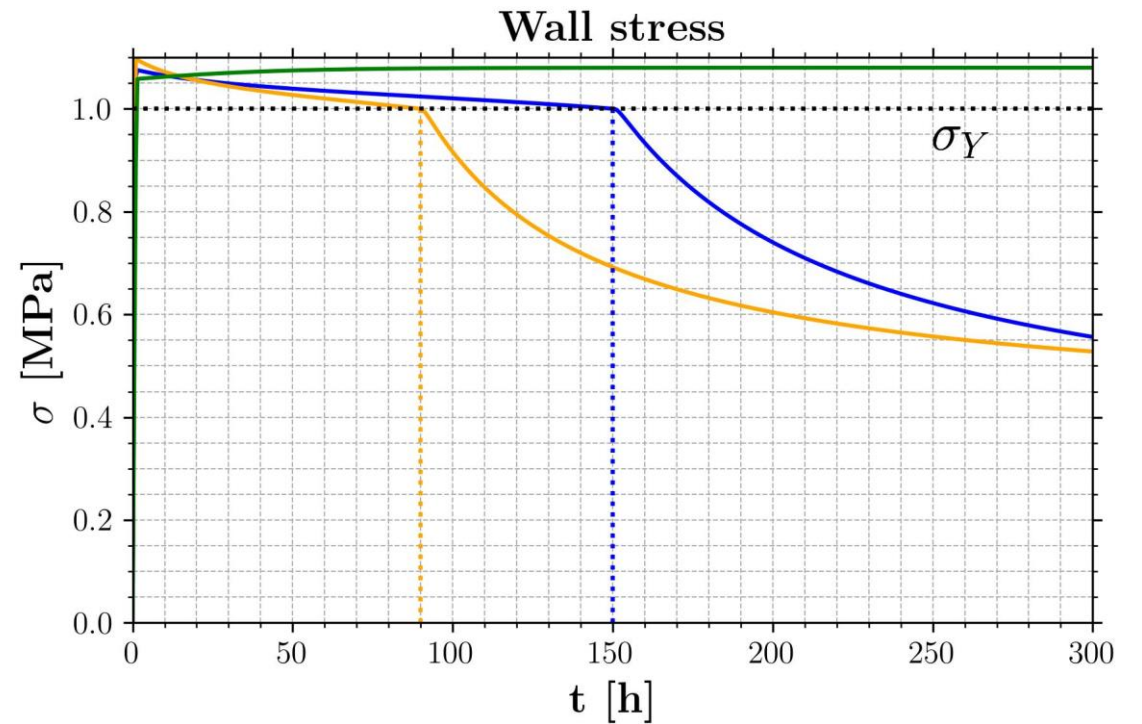
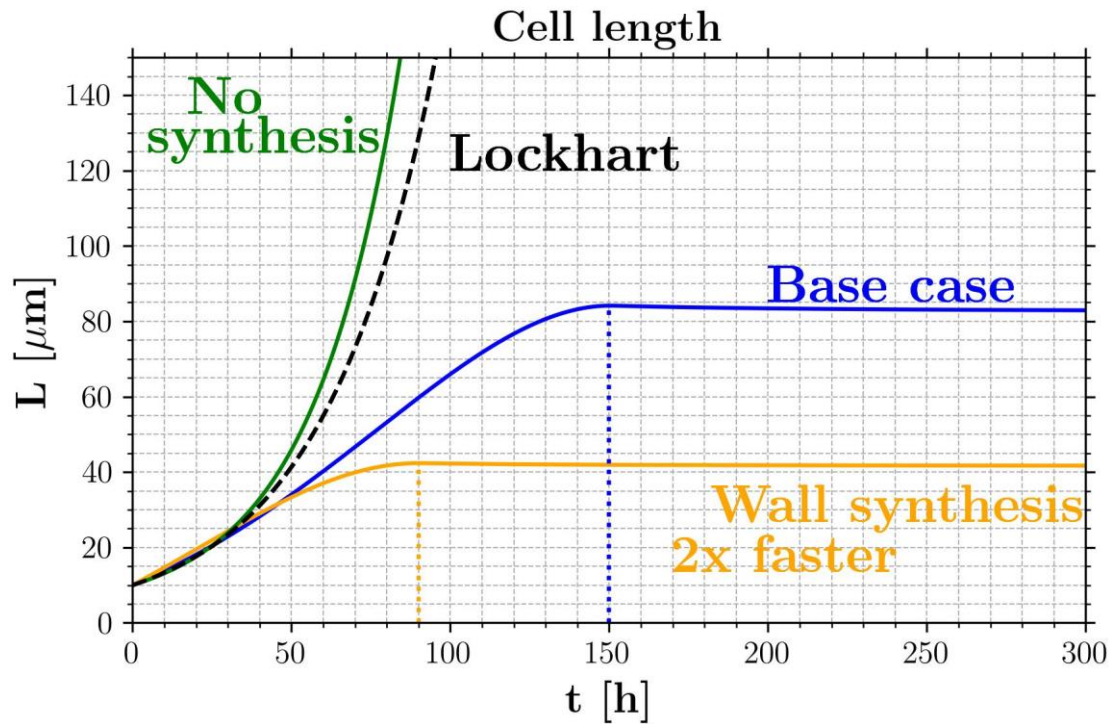
RESULTS



- Wall synthesis parameters: Friend *et al.*, Nature communications, 2022
- $\sigma_Y = 1\text{MPa}$
- All other parameters: Dumais, New Phytologist, 2021

All parameters
are constant !

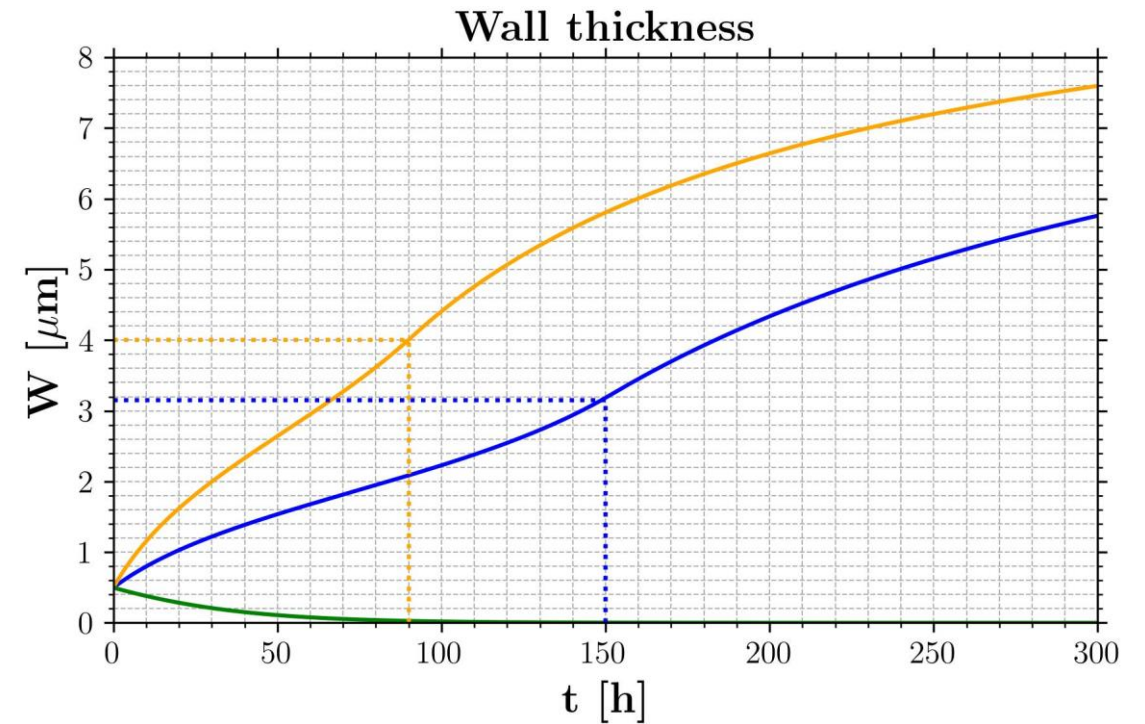
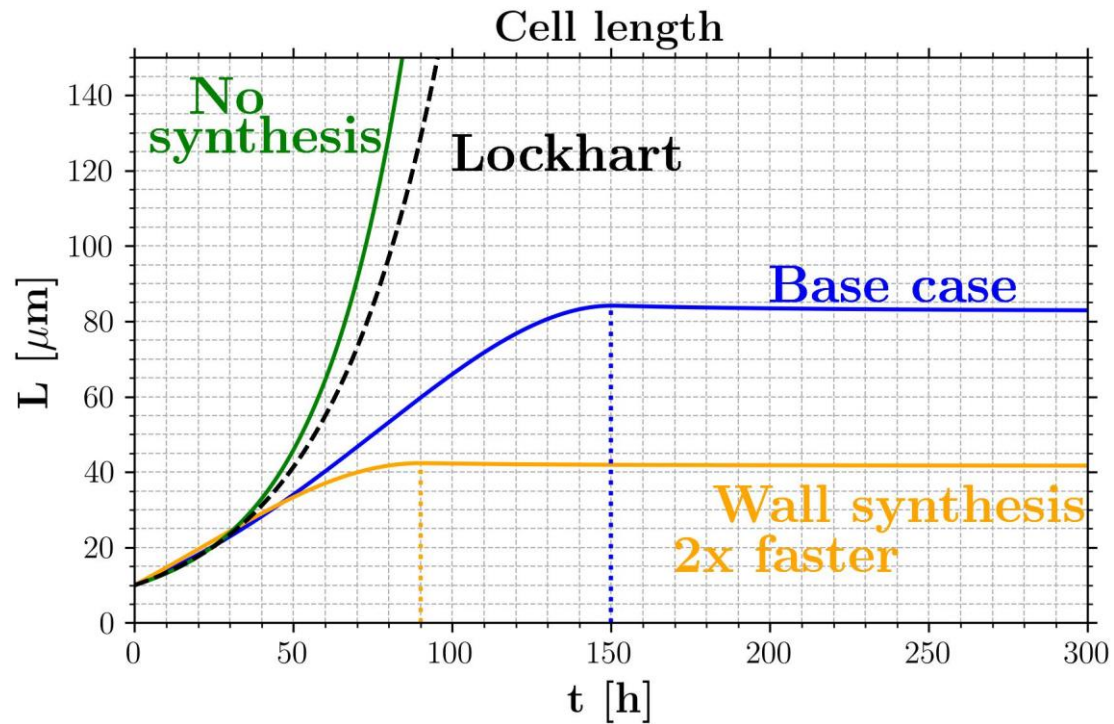
RESULTS



- Wall synthesis parameters: Friend *et al.*, Nature communications, 2022
- $\sigma_Y = 1\text{MPa}$
- All other parameters: Dumais, New Phytologist, 2021

All parameters
are constant !

RESULTS



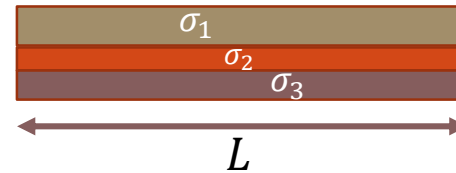
➤ Wall synthesis speed impacts final cell length & wall thickness

- Wall synthesis parameters: Friend *et al.*, Nature communications, 2022
- $\sigma_Y = 1\text{MPa}$
- All other parameters: Dumais, New Phytologist, 2021

All parameters
are constant !

CURRENT WORK: COUPLING WITH (BETTER) WALL THICKENING?

Wall is composed of multiple layers spreaded onto each other



- Heterogeneous stresses / strains across the wall?

$$\dot{\varepsilon}_L = \frac{(\sigma_i - \sigma_{Y_i})^+}{\mu_i} + \frac{1}{E_i} \frac{d\sigma_i}{dt}$$

- Inclusion of micro-fibrils angles, wall layer aging,... and feedbacks on mechanical properties?

CONCLUSIONS

- Coupling wall thickening and growth is useful for exploring different scenarios related to wood formation
- It can be modelled starting from Lockhart's equations
- Faster wall synthesis induces smaller cells with thicker walls
- We are working towards a better description of the wall mechanics (with a more realistic geometry)

➤ Insertion in multicellular models

