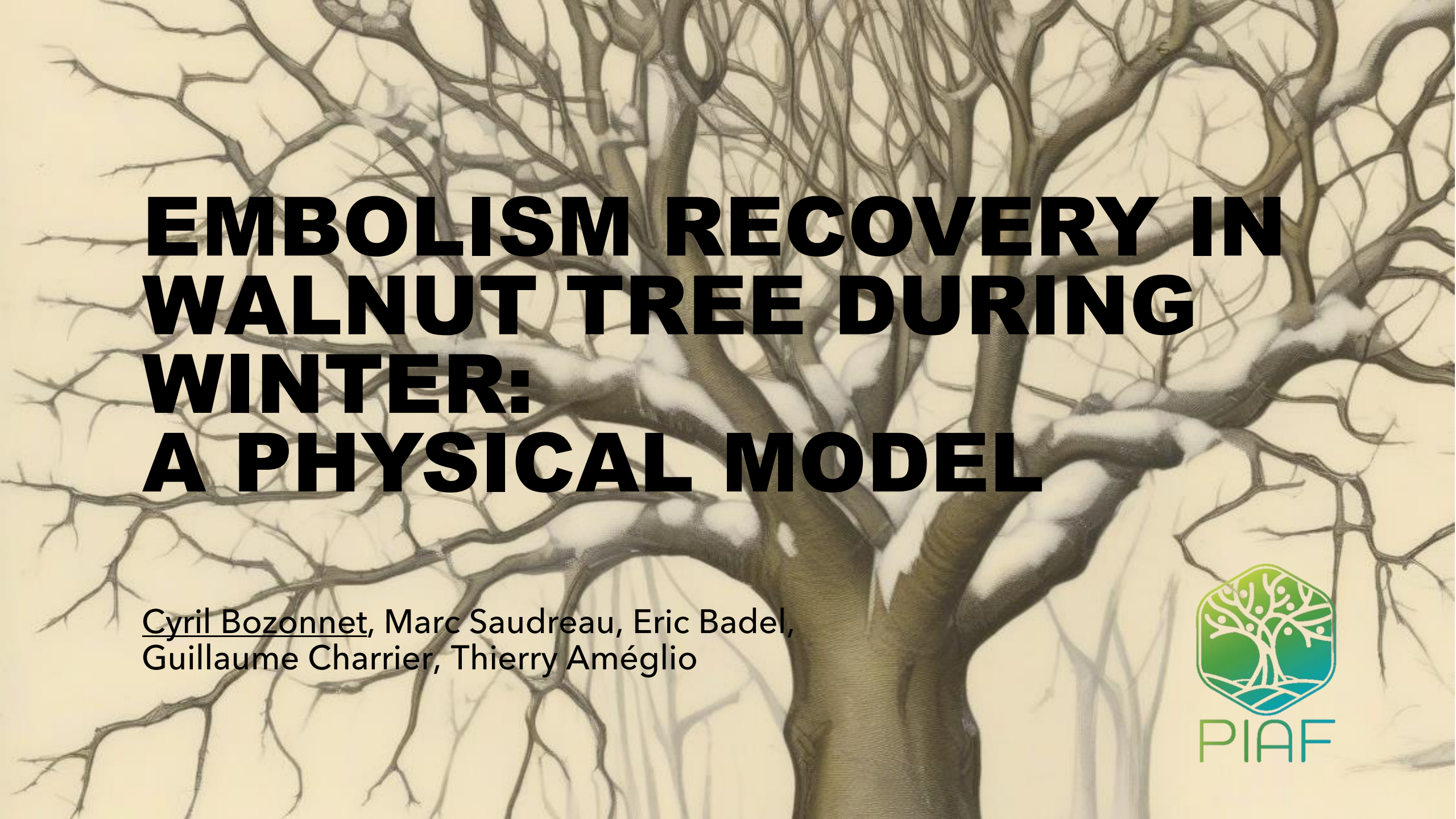
Walnut winter pressure build-up explained through physical modelling

Cyril Bozonnet, M. Saudreau, Eric Badel, Guillaume Charrier, Thierry Ameglio



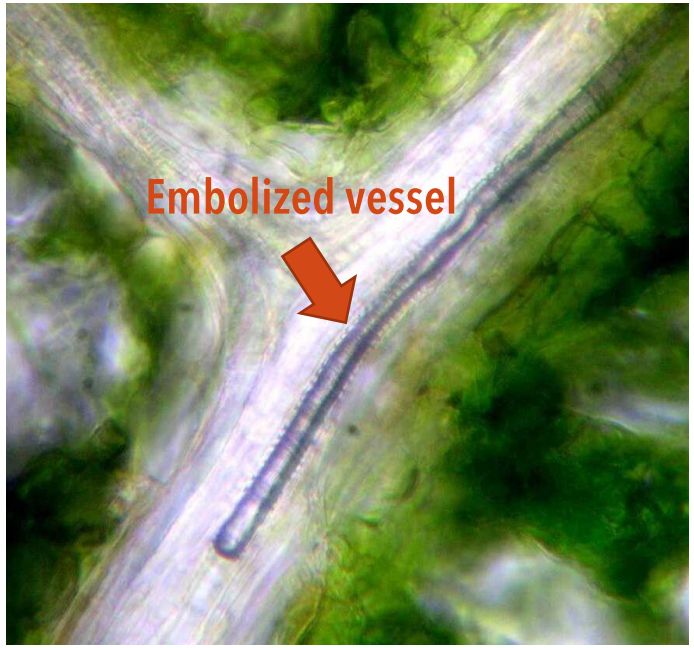
EMBOLISM RECOVERY IN WALNUT TREE DURING WINTER: A PHYSICAL MODEL

Cyril Bozonnet, Marc Saudreau, Eric Badel,
Guillaume Charrier, Thierry Améglio

PIAF

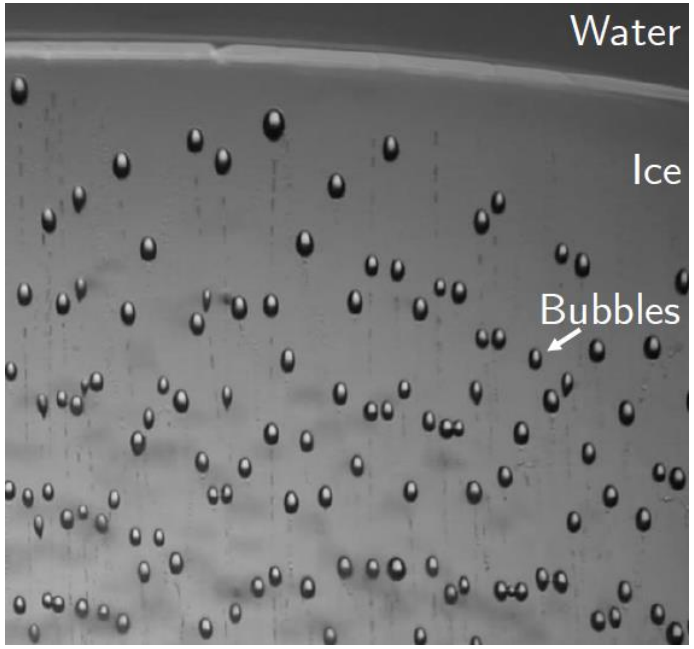
EMBOLISM: HOW IT HAPPENS

Summer:
excessive tension on the water column



© Hervé Cochard

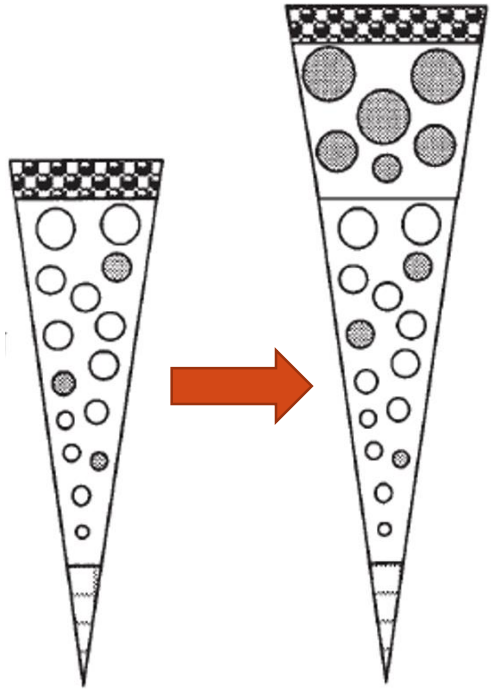
Winter:
Freeze/thaw cycles



Thievenaz *et al*, 2024

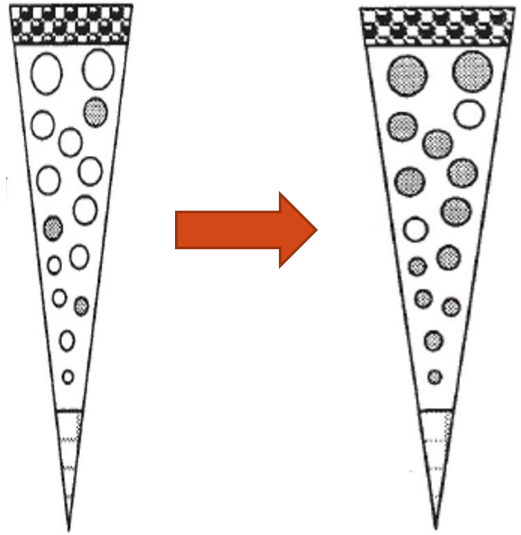
EMBOLISM RECOVERY: HOW IT HAPPENS

Creation of new vessels



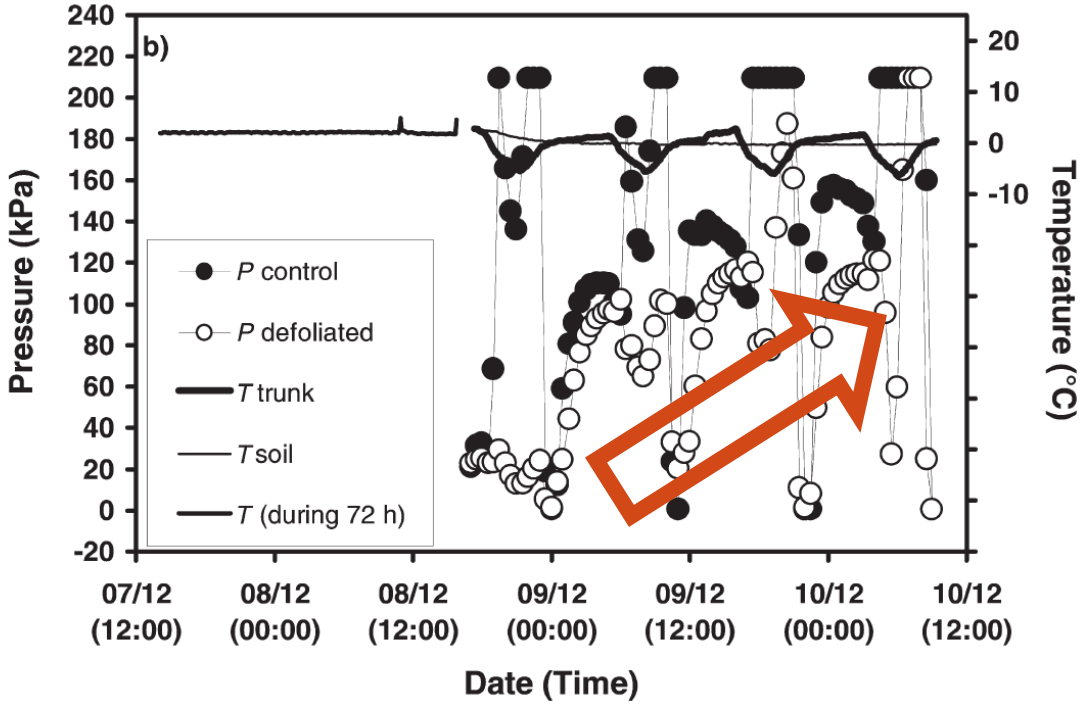
Refilling by positive pressure

From the roots or from the stems

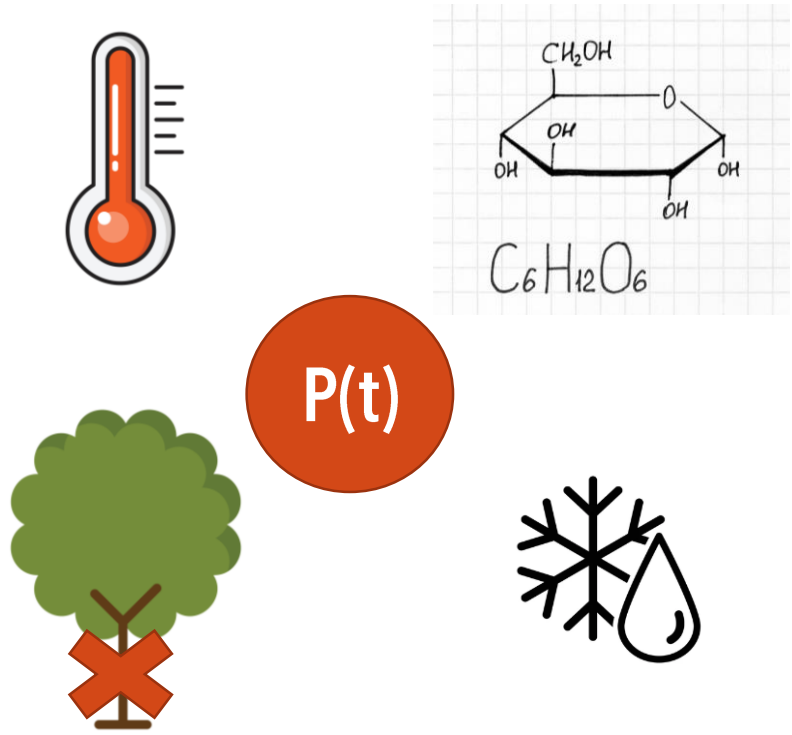


Pictures from Cochard *et al*, Tree Phys., 2001

STEM PRESSURE IN WALNUT TREE: WHAT DO WE KNOW?



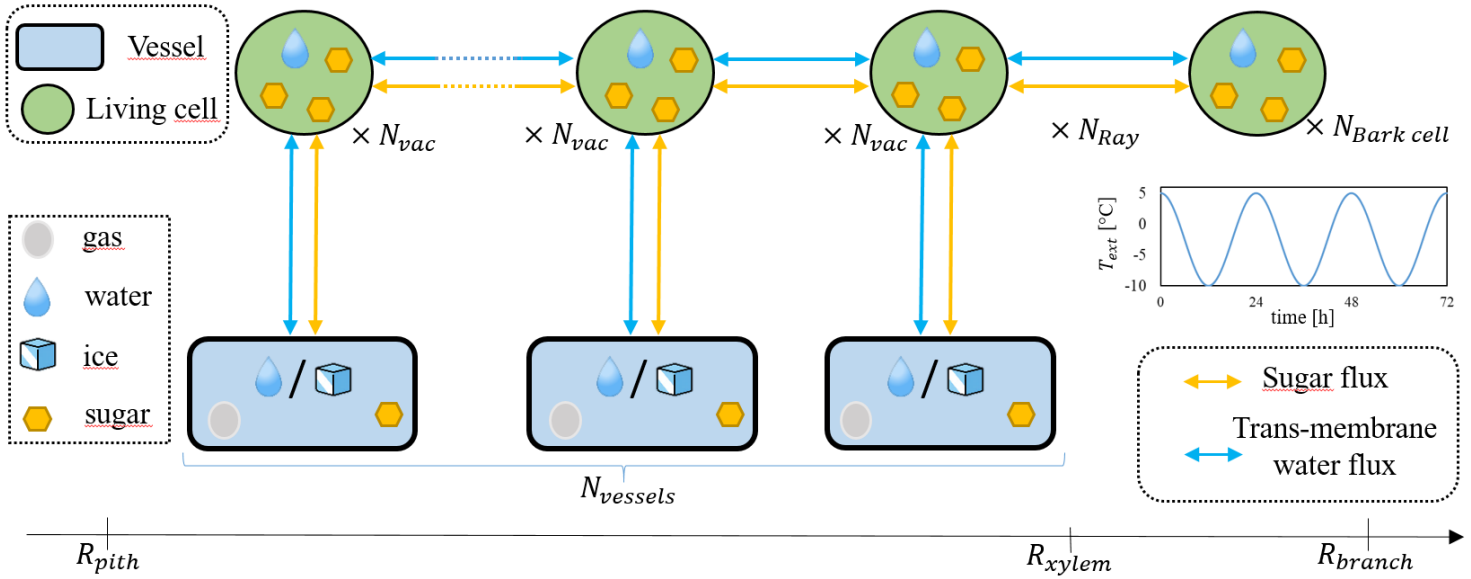
Améglio *et al*, Tree Phys., 2001



PHYSICAL MODELLING:
TO REPRODUCE & UNDERSTAND

MATLAB

Walnut branch anatomy



Heat transfer and phase change

$$\frac{dH}{dt} = \frac{1}{\rho}\nabla.(k\nabla T)$$

$$p_{ice} = \rho_w L \ln\left(\frac{T}{T_0}\right)$$

Water fluxes and P-V relationships

$$Q = k(\Delta P - \Delta\Pi)$$

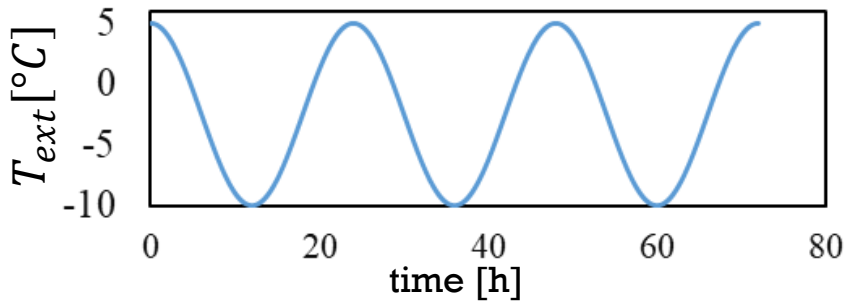
$$\frac{dP^{liv}}{dt} = \frac{E}{V^{liv}}\frac{dV^{liv}}{dt} \qquad P^v \approx \frac{nR_gT}{V_g^v}$$

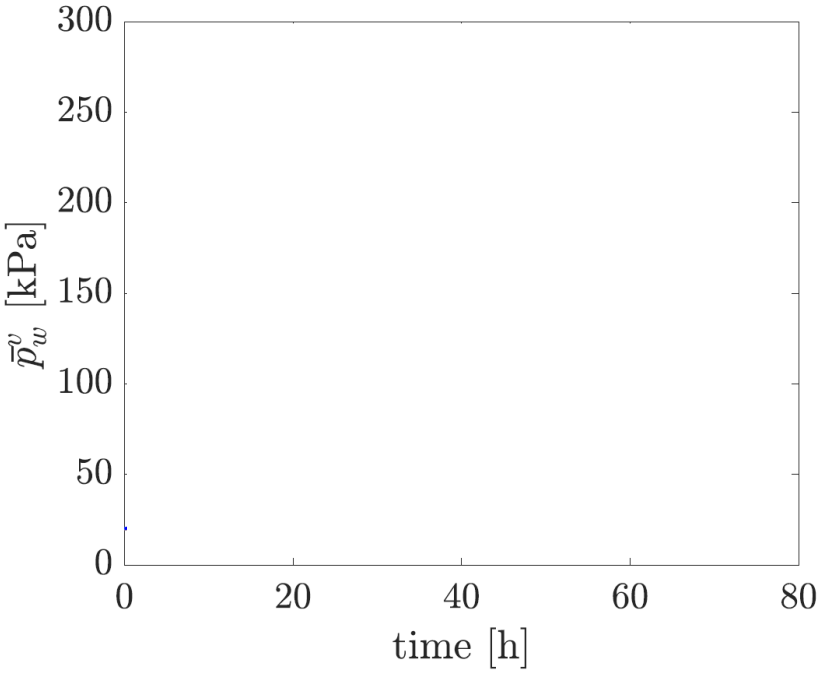
Diffusive sugar fluxes

$$C_s = \frac{n_s}{V}$$

$$\frac{dn_s}{dt} = D_s \Delta C_s$$

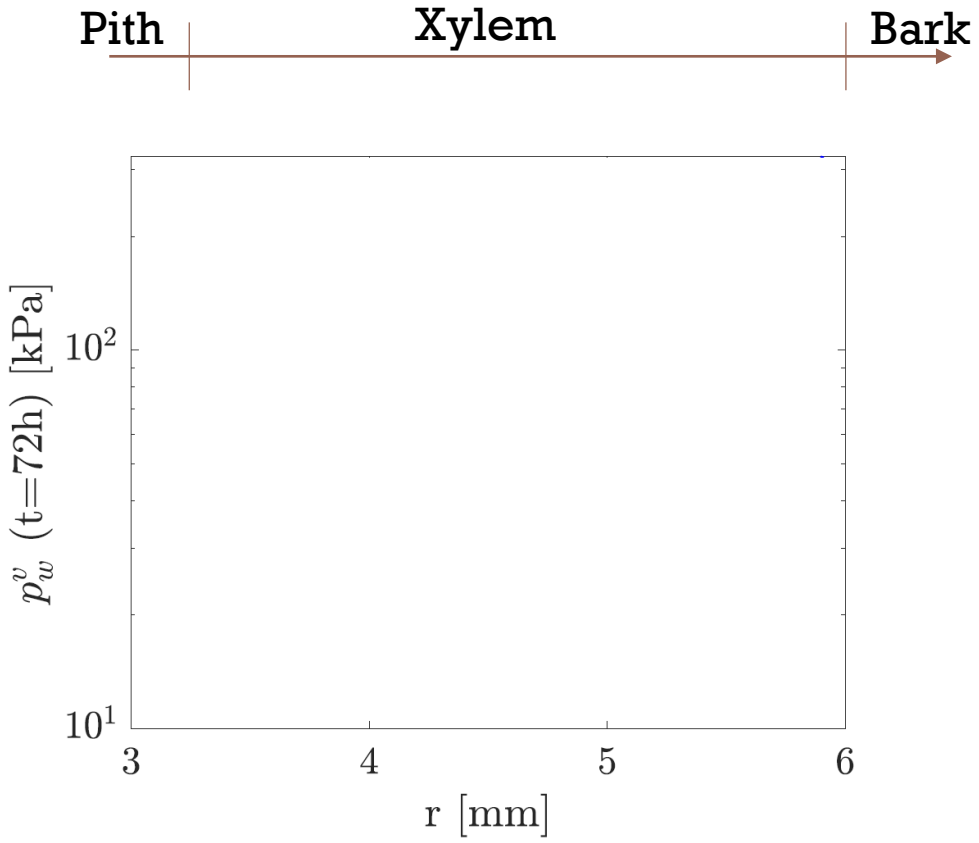
RESULTS:
EFFECT OF SUGAR FLUXES





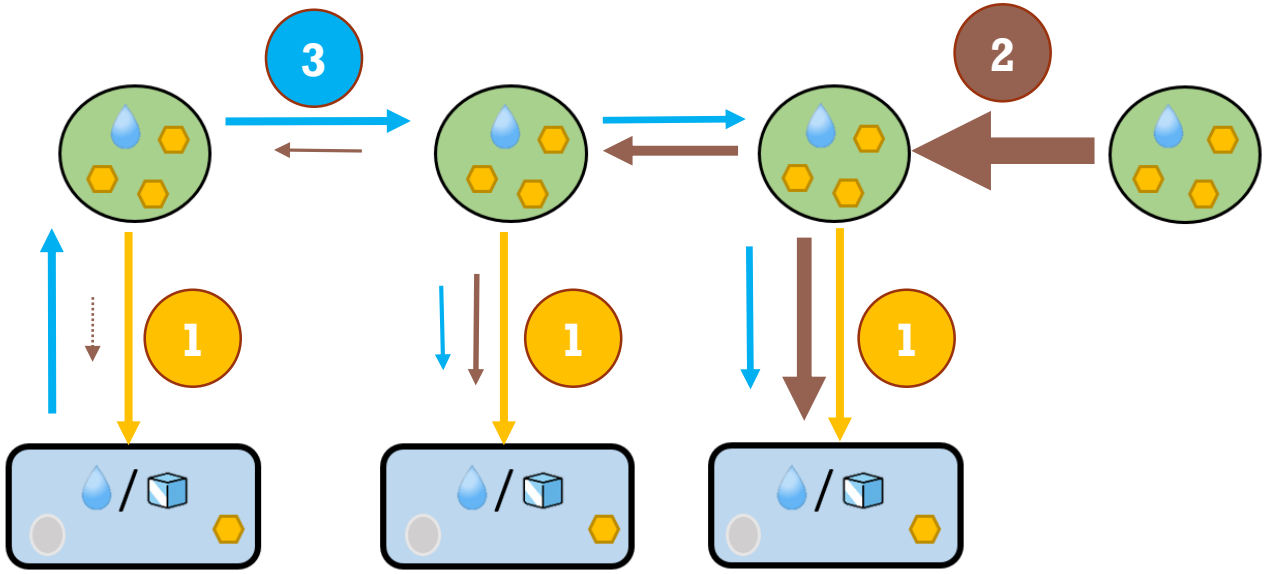
- No sugar fluxes
  - No pressure build-up
- With vessel-VAC fluxes
  - Very little pressure build-up (+0.7kPa)
- With vessel-VAC and ray fluxes
  - Significant pressure build-up (+43kPa)

RESULTS:
EFFECT OF SUGAR FLUXES



- No sugar fluxes
  - Nearly homogeneous pressure profile
- With vessel-VAC fluxes
  - Homogeneous pressure profile
- With vessel-VAC and ray fluxes
  - Very high radial gradient

WHAT HAPPENS?
FOR T>0°C



1 Water and sugar fluxes VAC <-> vessels

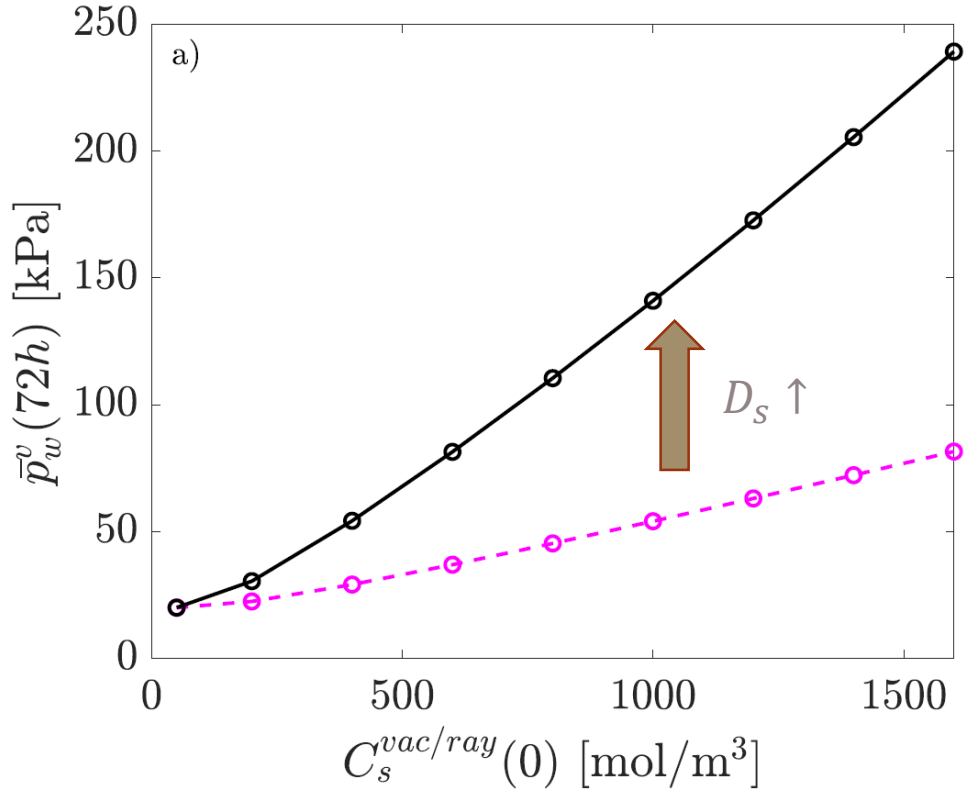
2 Sugar and water transport from the bark

- Strong radial osmotic gradient

3 Water fluxes between vessels

- Mean pressure increase ($P \sim \frac{nRT}{V}$)
- **The pressure build-up is not homogeneous across the stem!**

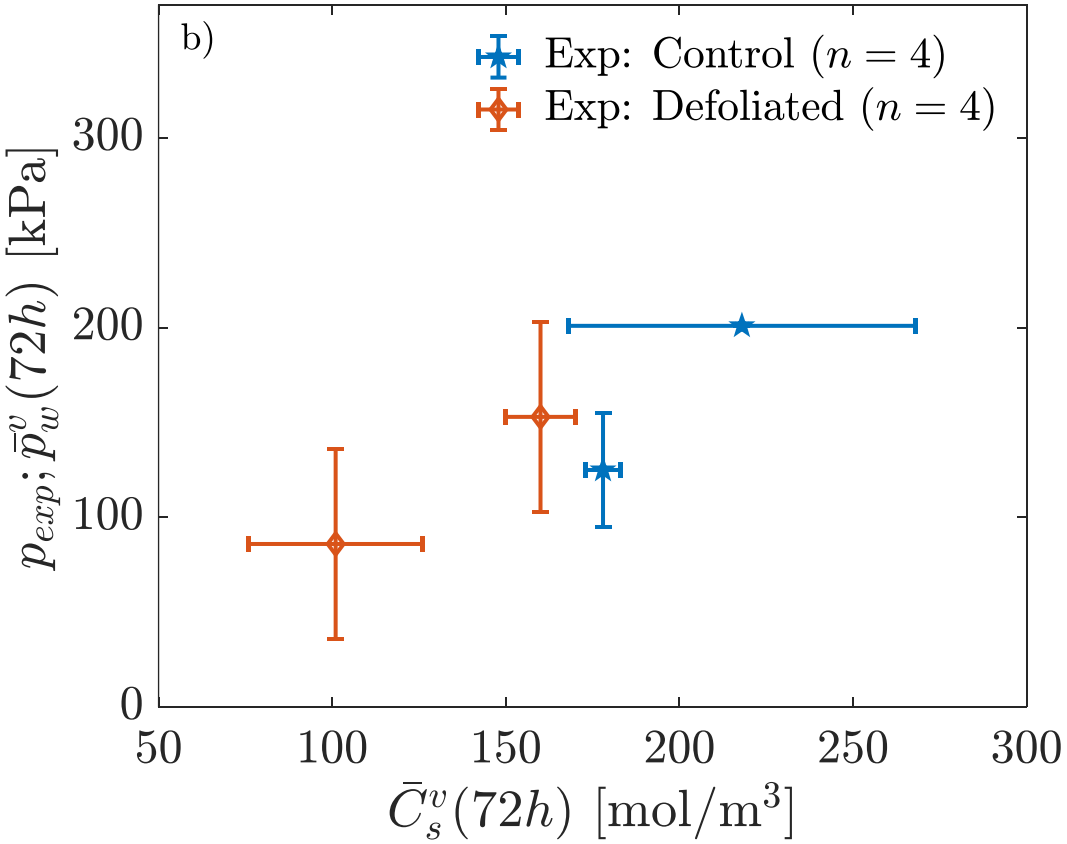
RESULTS:
VESSEL PRESSURE *VS* LIVING CELL INITIAL SUGAR CONTENT



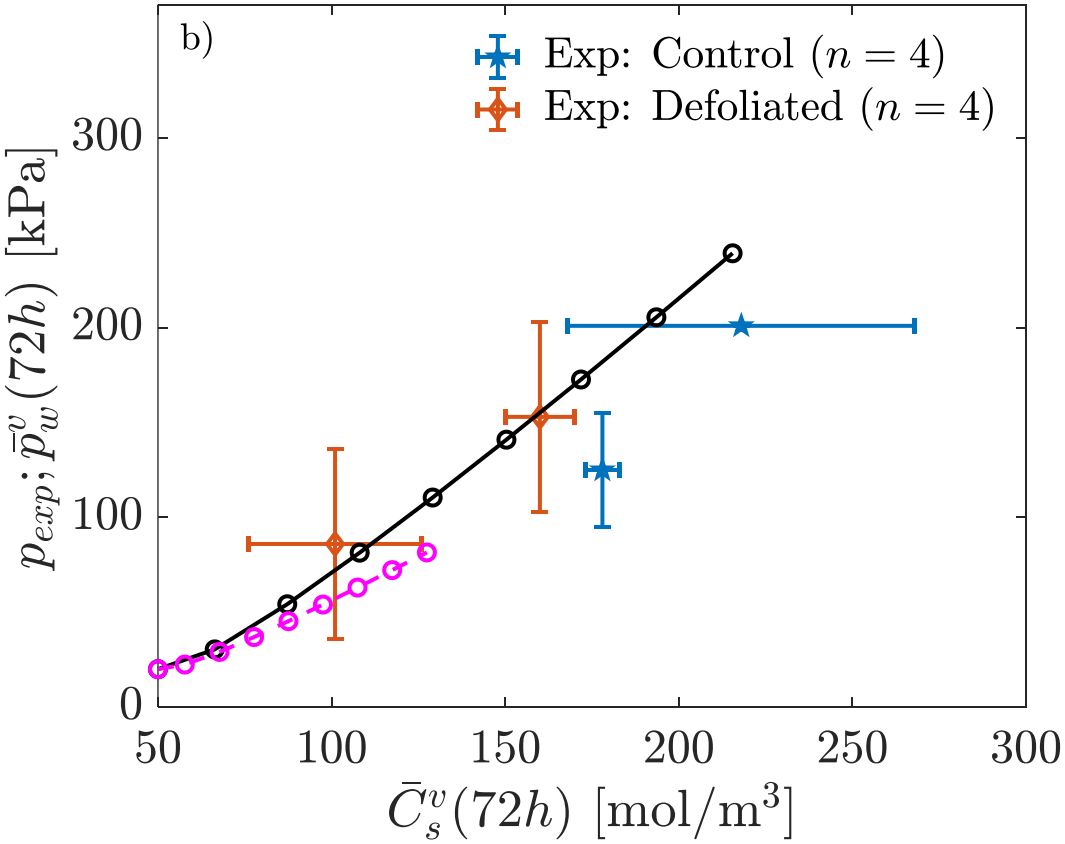
Stem pressure build-up occurs if:

- Living cells contain soluble sugar
- Transport is possible (makes things faster!)

VALIDATION:
VESSEL PRESSURE *VS* VESSEL SUGAR CONTENT



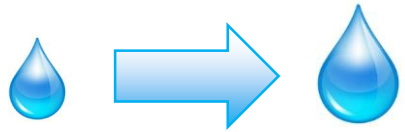
VALIDATION:
VESSEL PRESSURE *VS* VESSEL SUGAR CONTENT



- ✓ Strong correlation between vessel pressure and vessel sugar content (both are measurements/results !)
- ✓ Similar magnitudes.

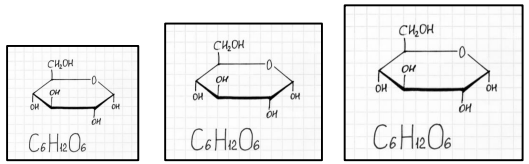
TO SUM-UP:

Stem pressure build-up in walnut tree seems to be due to…



…a transfer of water between vessels across the ray,

triggered by



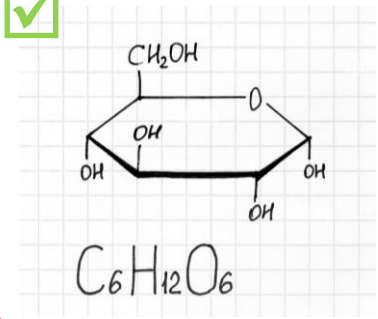
a radial imbalance in sugar concentration.

The ability to dispose of soluble sugar and transport them radially are keys to pressure build-up.

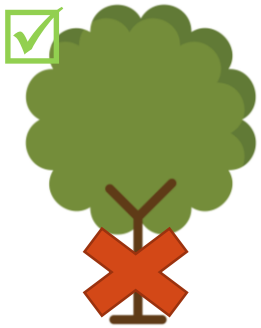
→ Unique abilities in species that develop stem pressure?

TO SUM-UP:
& PERSPECTIVES

Addition of temperature dependant H+/sugar co-transport?

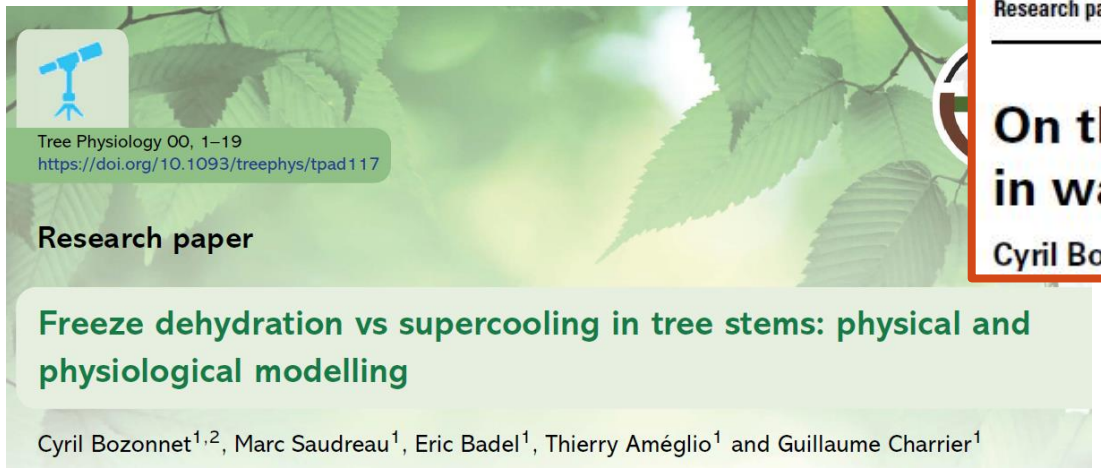


P(t)



Adding dissolved gas expulsion from freezing water?

Heterogeneous pressure build-up → Heterogeneous recovery?



Code available at: https://github.com/cyrilbz

Thank you !

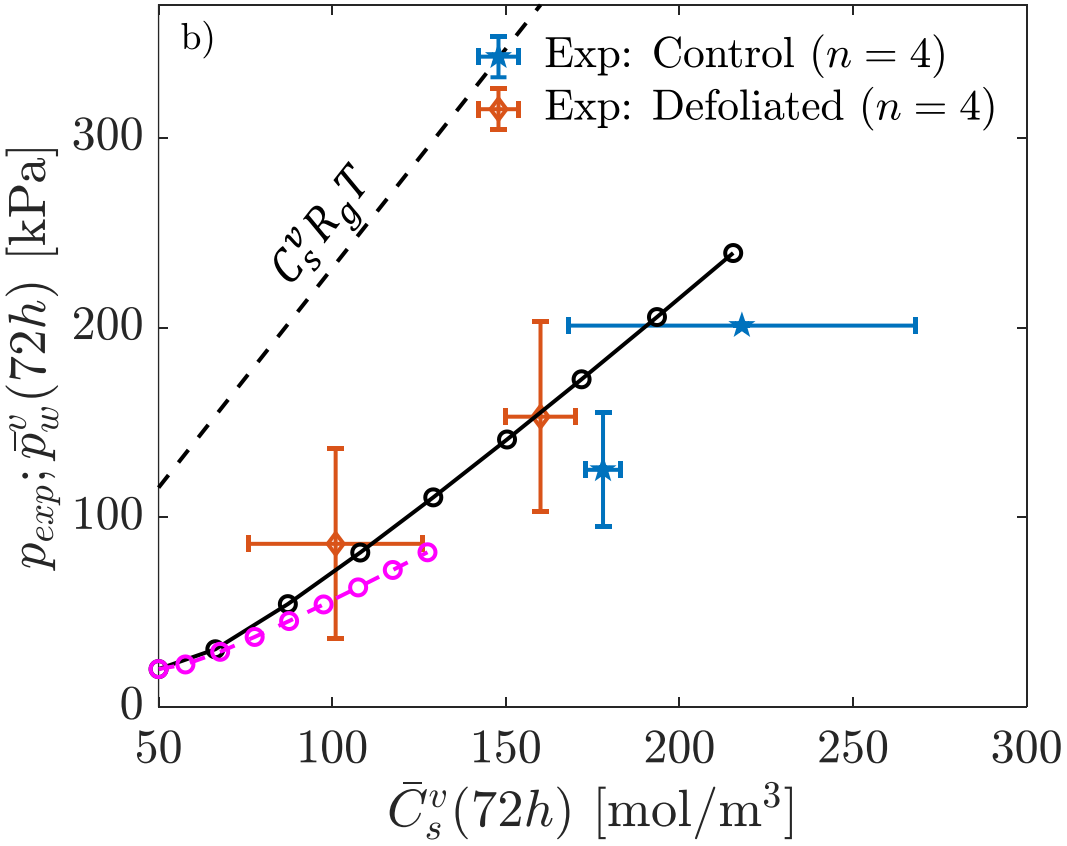
PIAF

anr

FWF

Back-up slides

VALIDATION:
VESSEL PRESSURE *VS* VESSEL SUGAR CONTENT



- ✓ Strong correlation between vessel pressure and vessel sugar content (both are measurements/results !)
- ✓ Similar magnitudes.