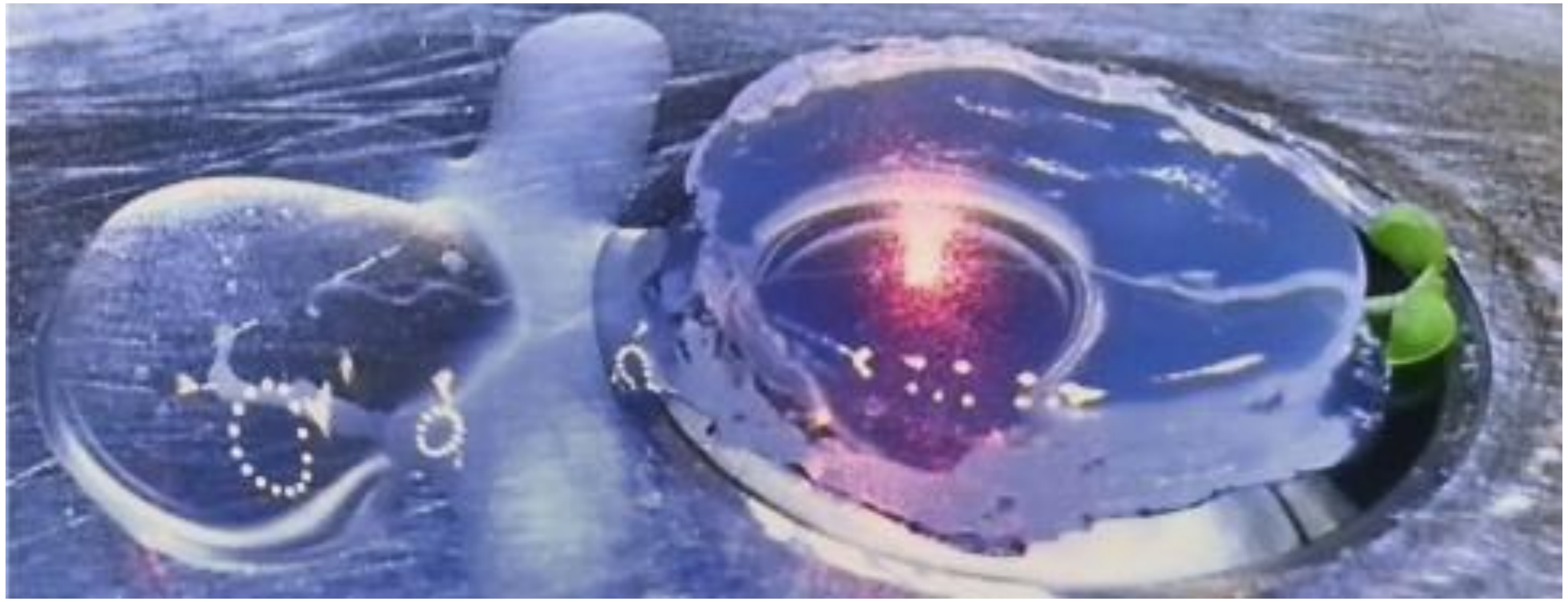
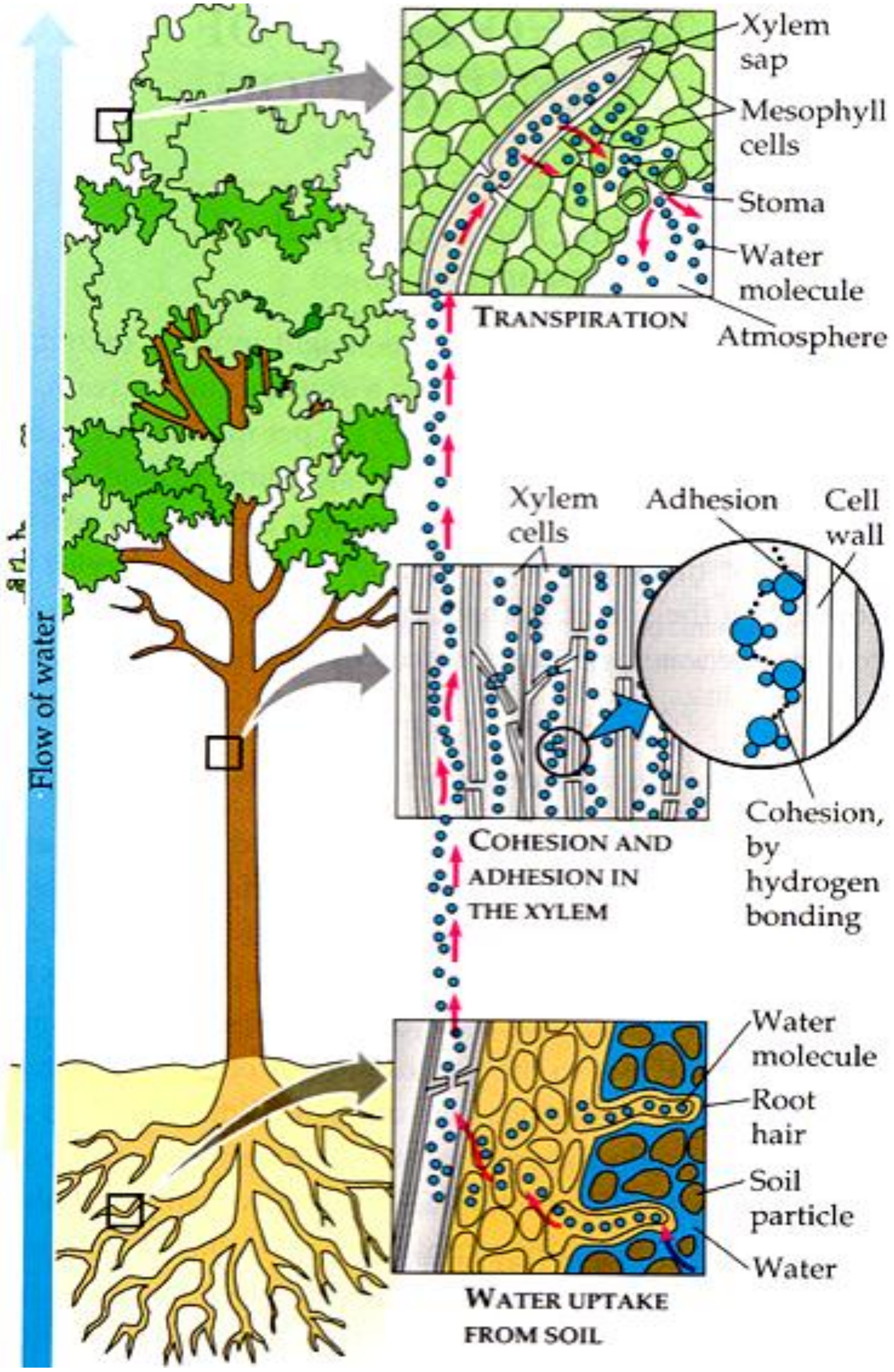
Non-invasive water flow imaging in plant roots at **cell resolution**



FC Pascut, V Couvreur, D Dietrich, N Leftley, G Reyt, Y Boursiac, M Calvo-Polanco, P Mehra, I Casimiro, C Maurel, DE Salt, X Draye, DM Wells, MJ Bennett & KF Webb

figshare UCLouvain University of Nottingham INRAE

What drives water movement ?

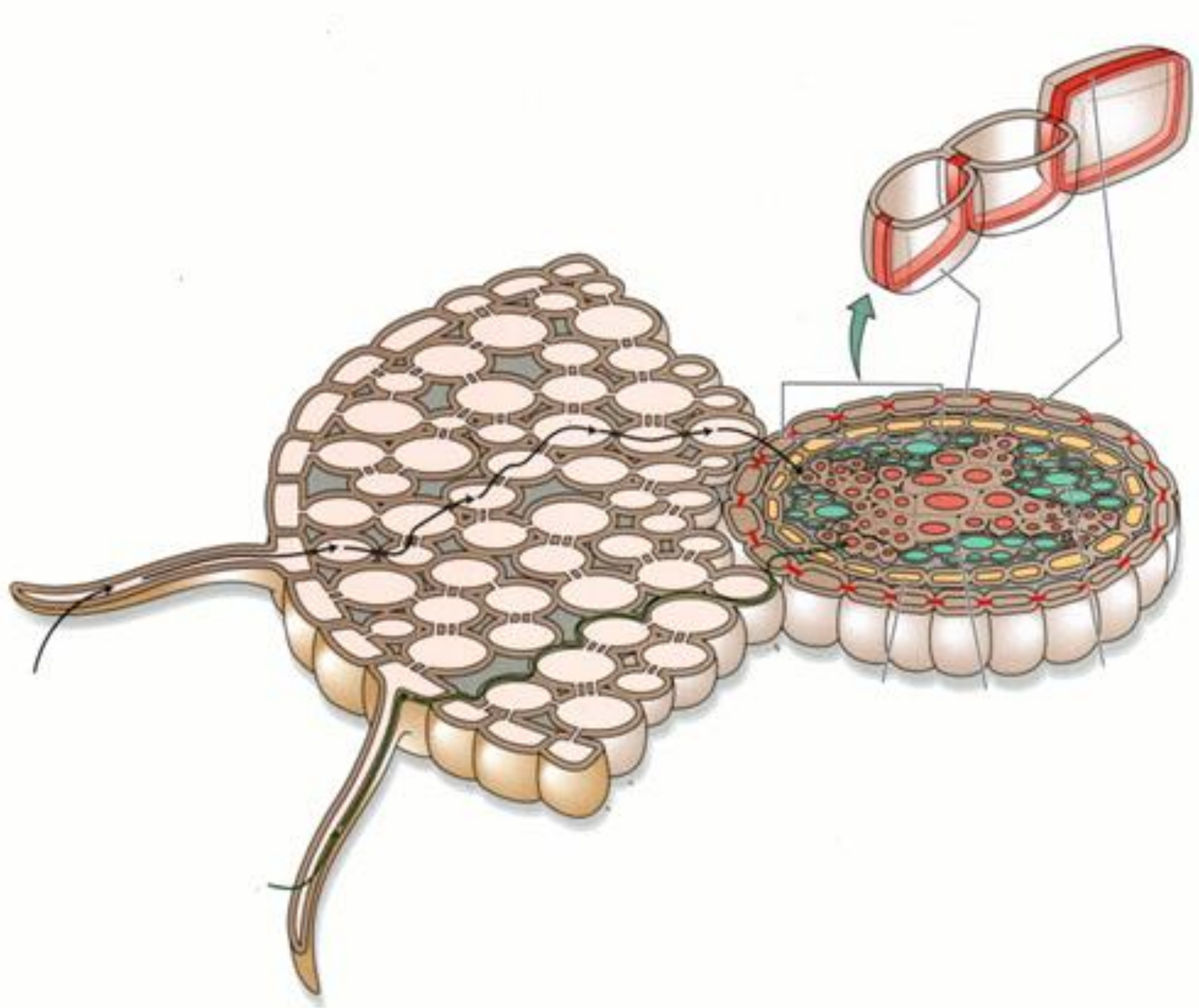


$$F = K \,.\, \Delta\Psi$$ (van den Honert, 1948)

components ?

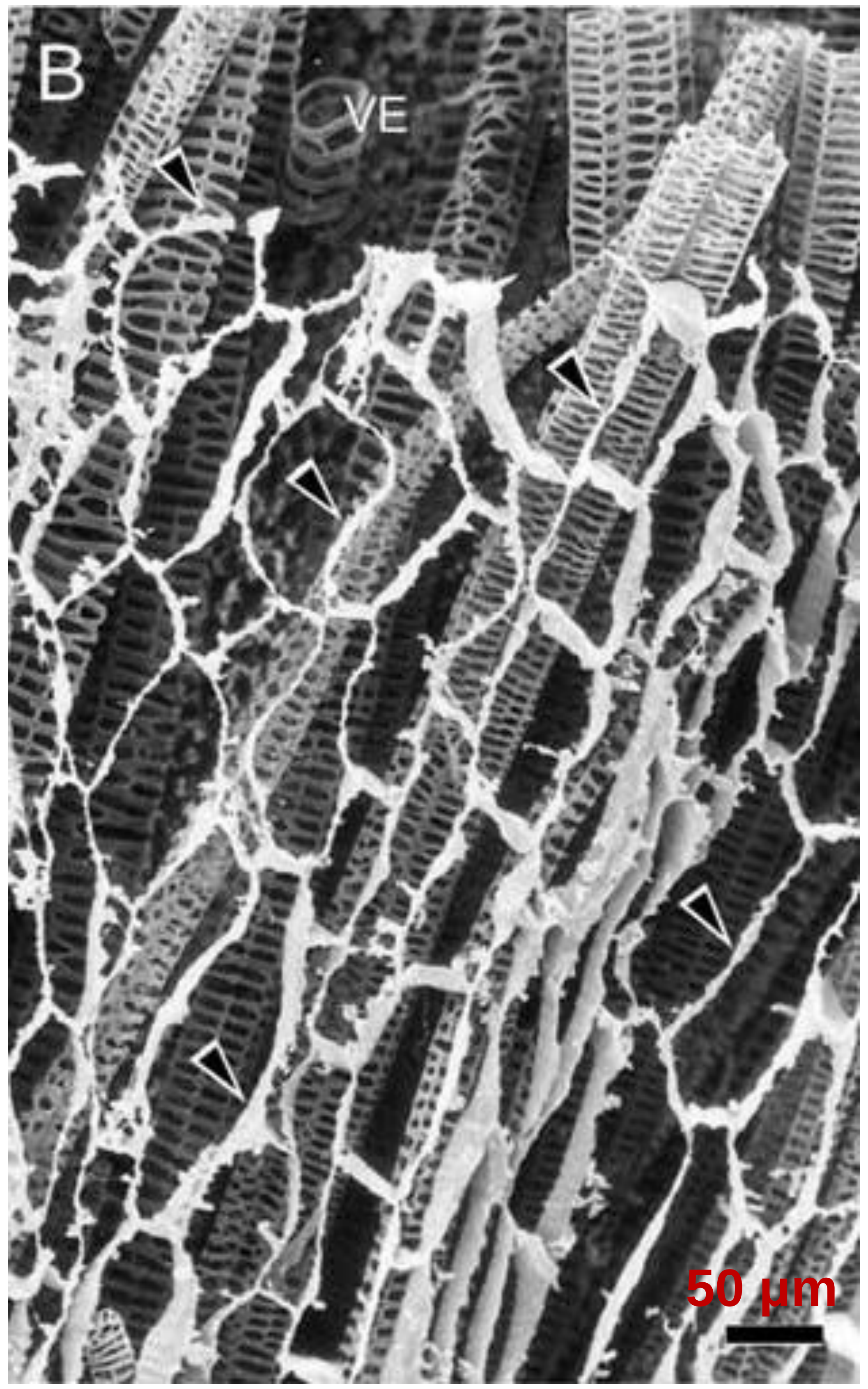
gravity matric

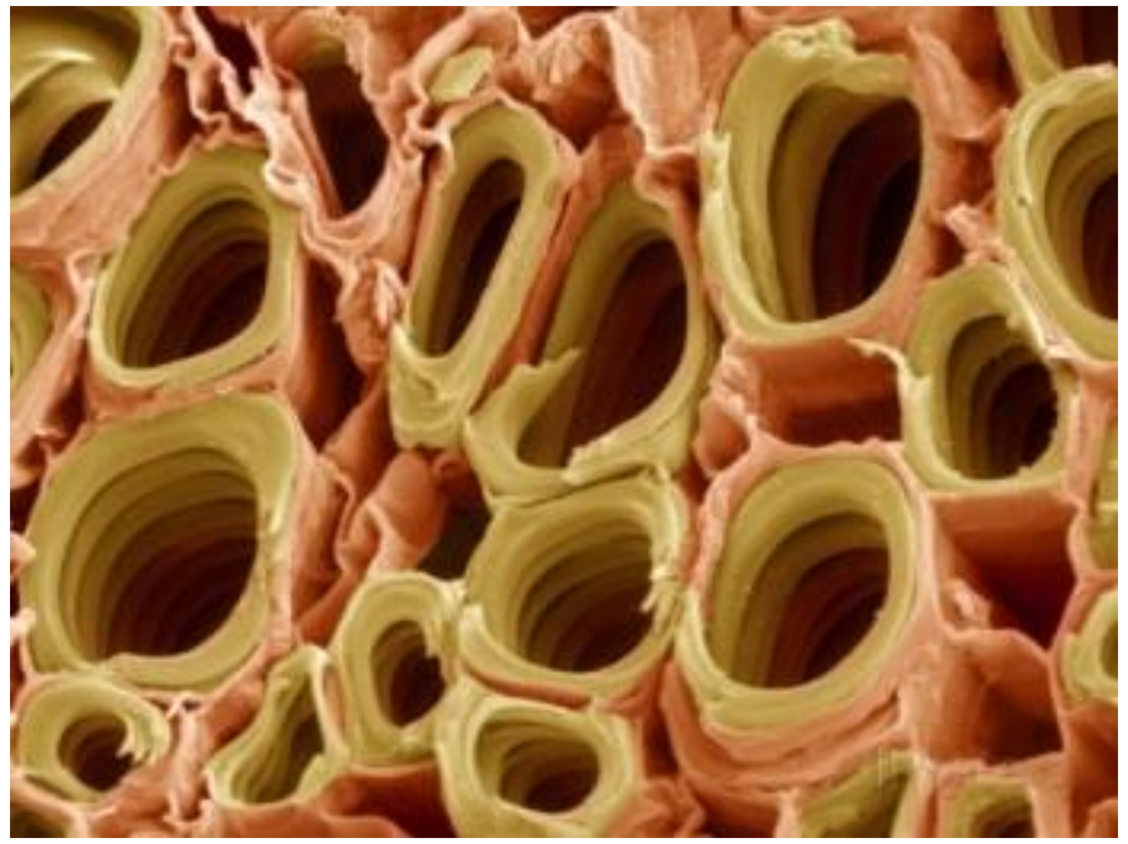
pressure osmotic

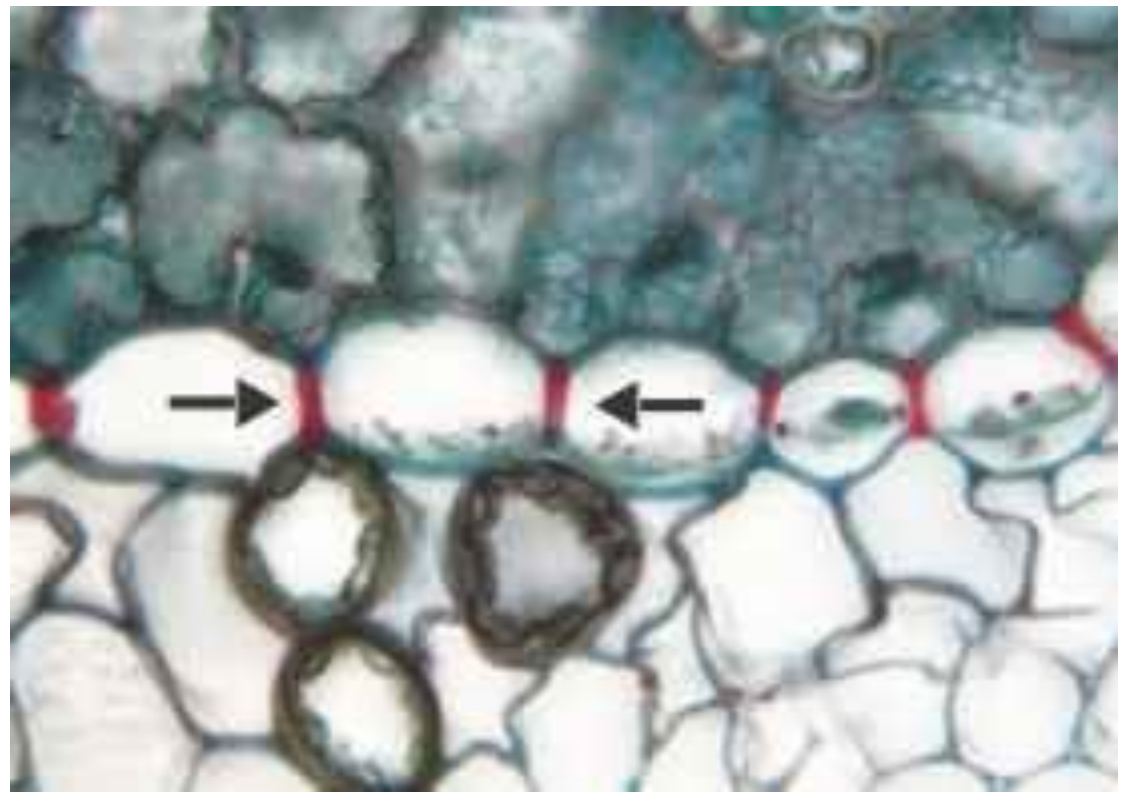


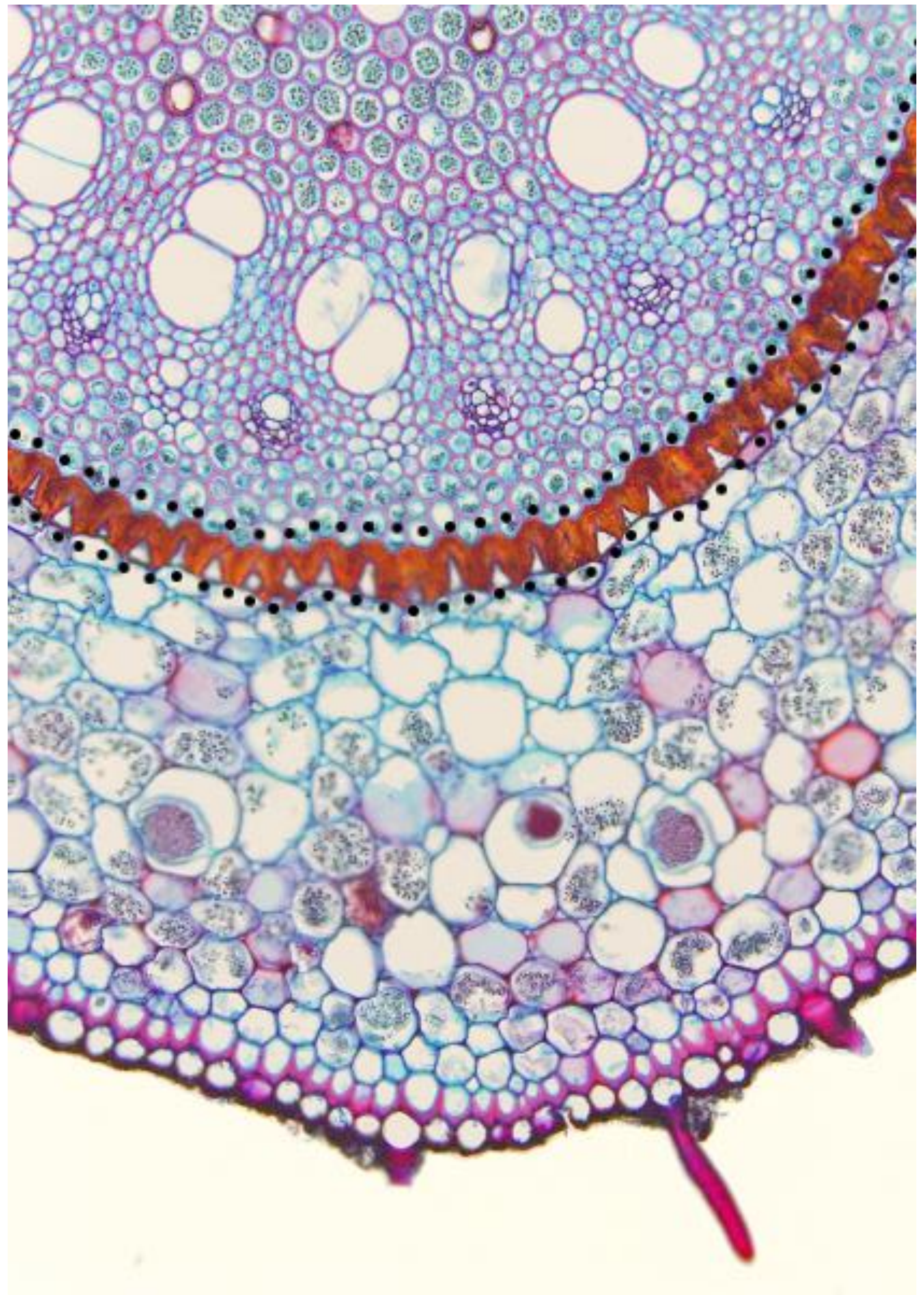
Apoplastic structures

- Scaffolds: Physical **separation** of compartments
- Thickening: Physical **support** against implosion / explosion
- Pipes: Long distance water **transport**





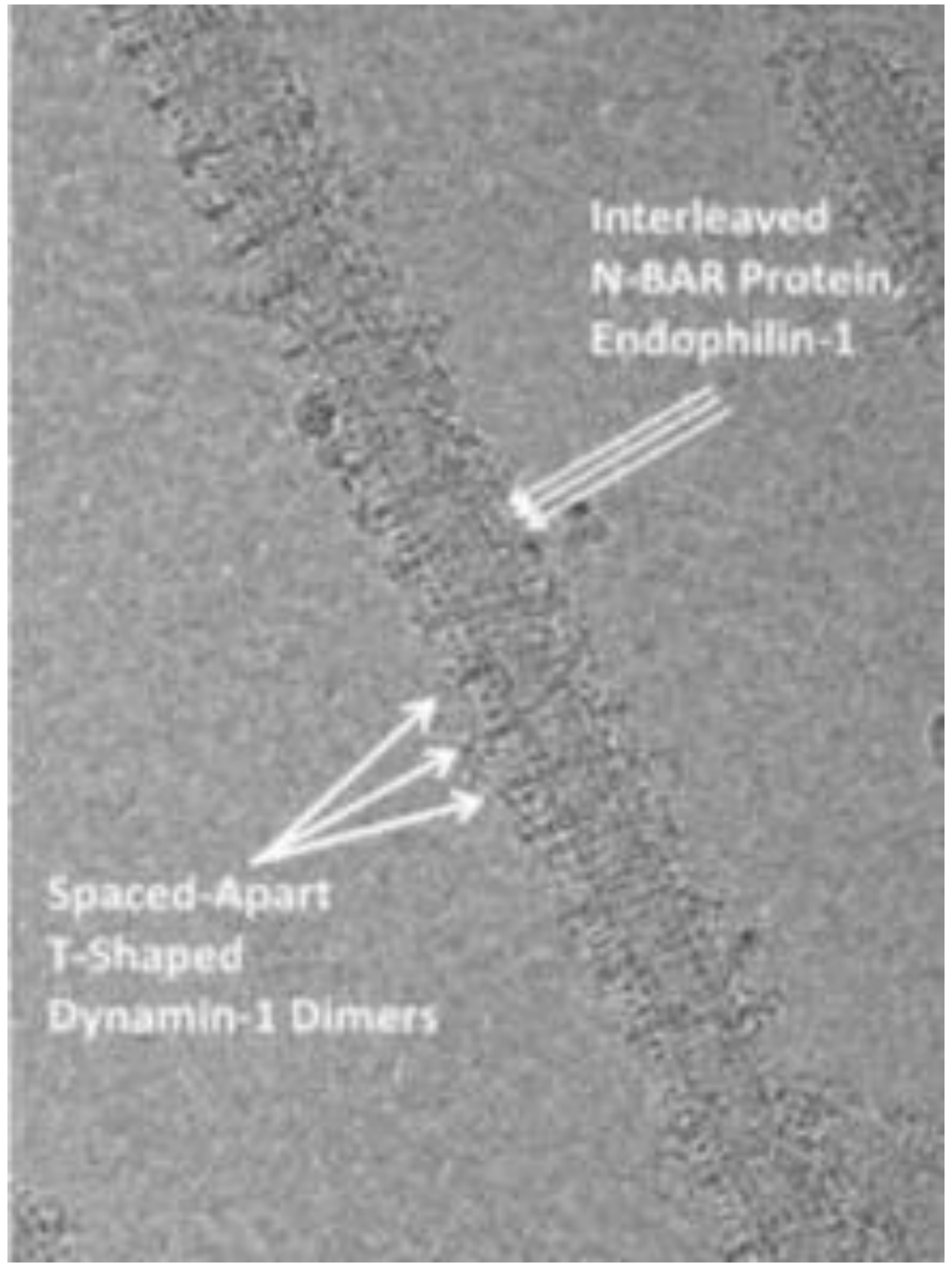


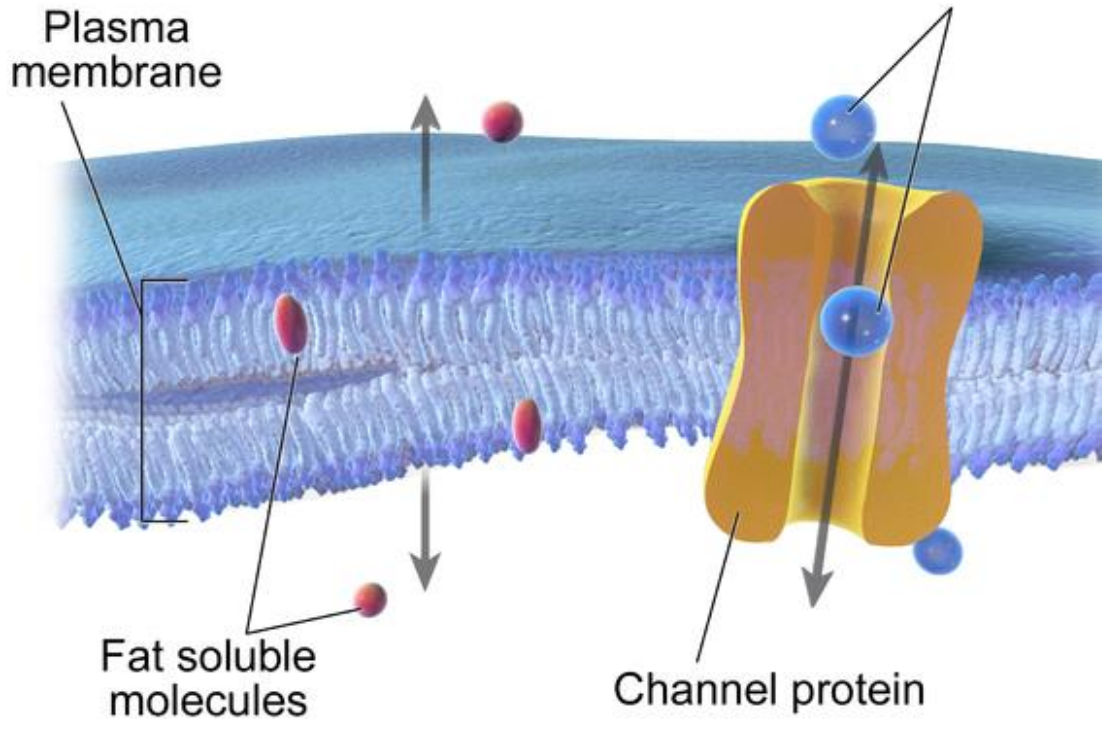


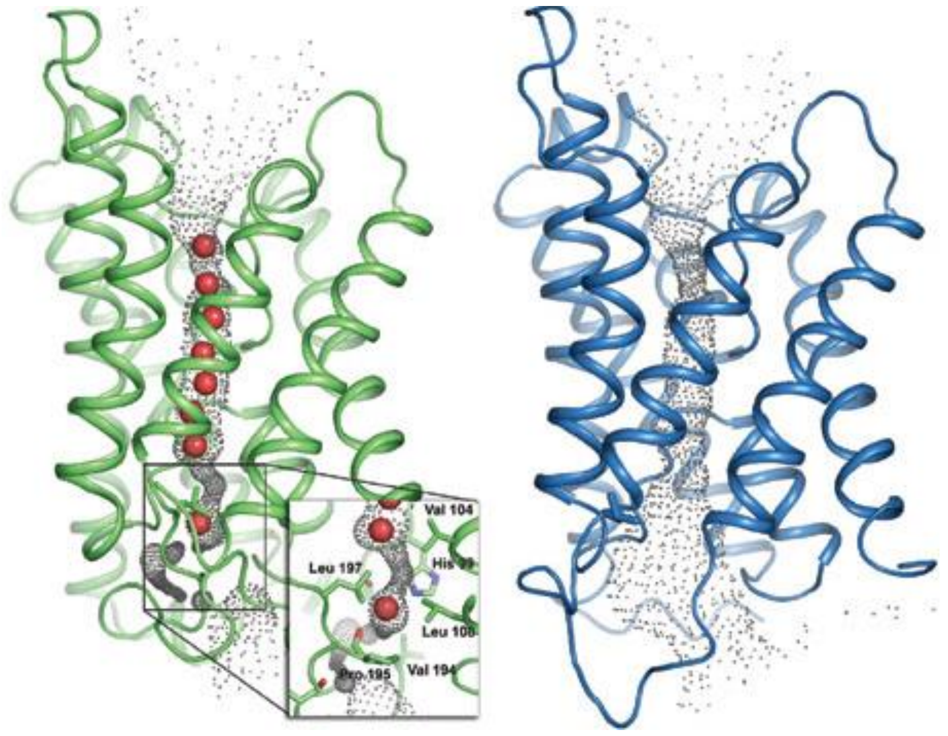
Credits: (left) Enstone et al., 2003 (centre top) Steve Gschmeissner (centre bottom) fossilhunters.xyz (right) mmegias.webs.uvigo.es

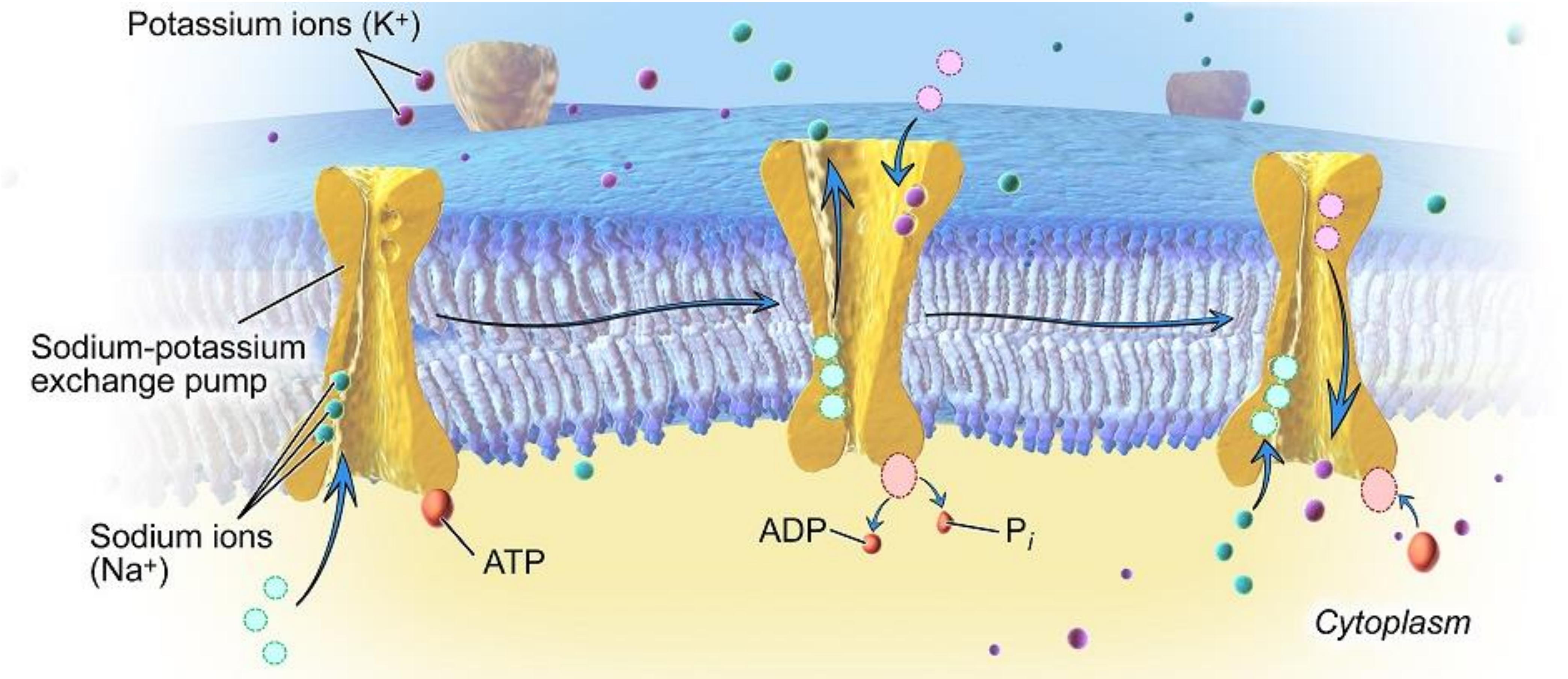
Transmembrane structures

- Pumps: Active **accumulation** of ions / molecules
- Channels: Passive **diffusion** of ions / molecules





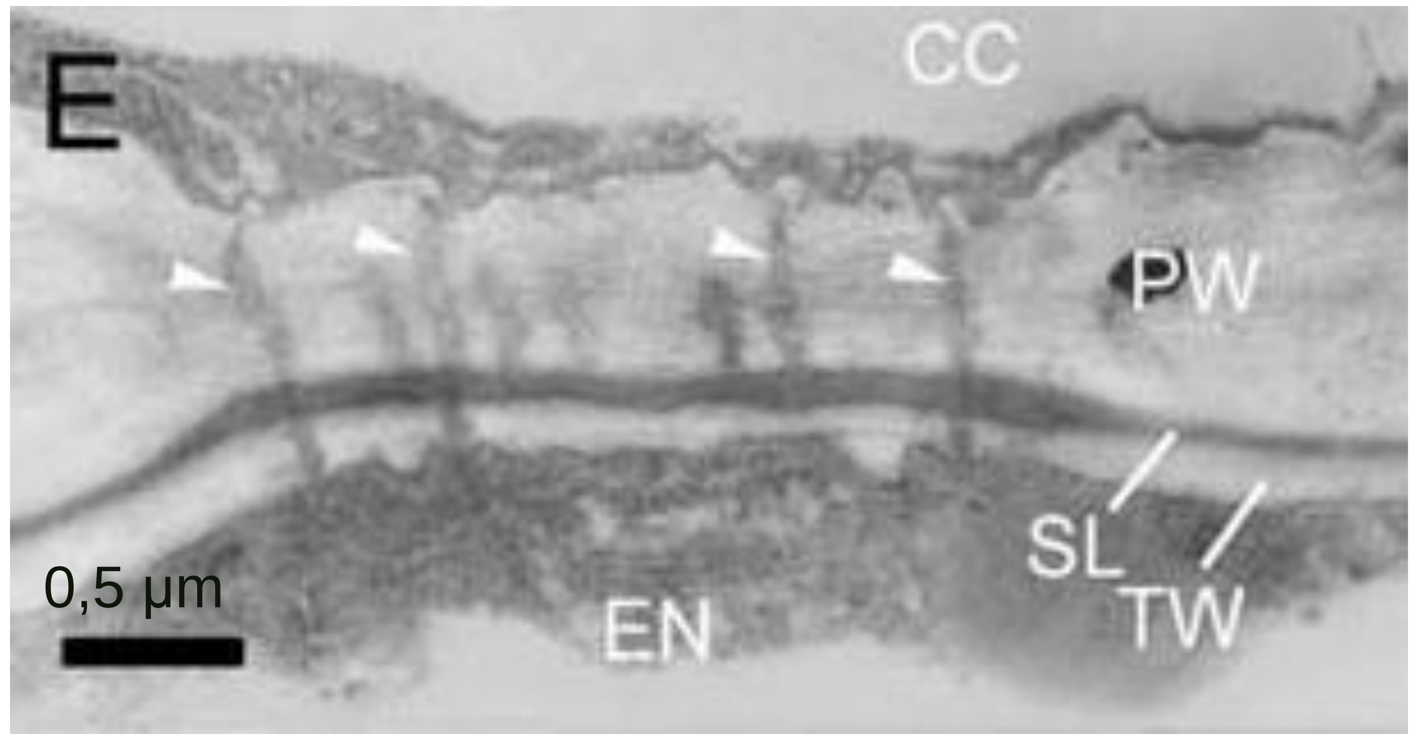


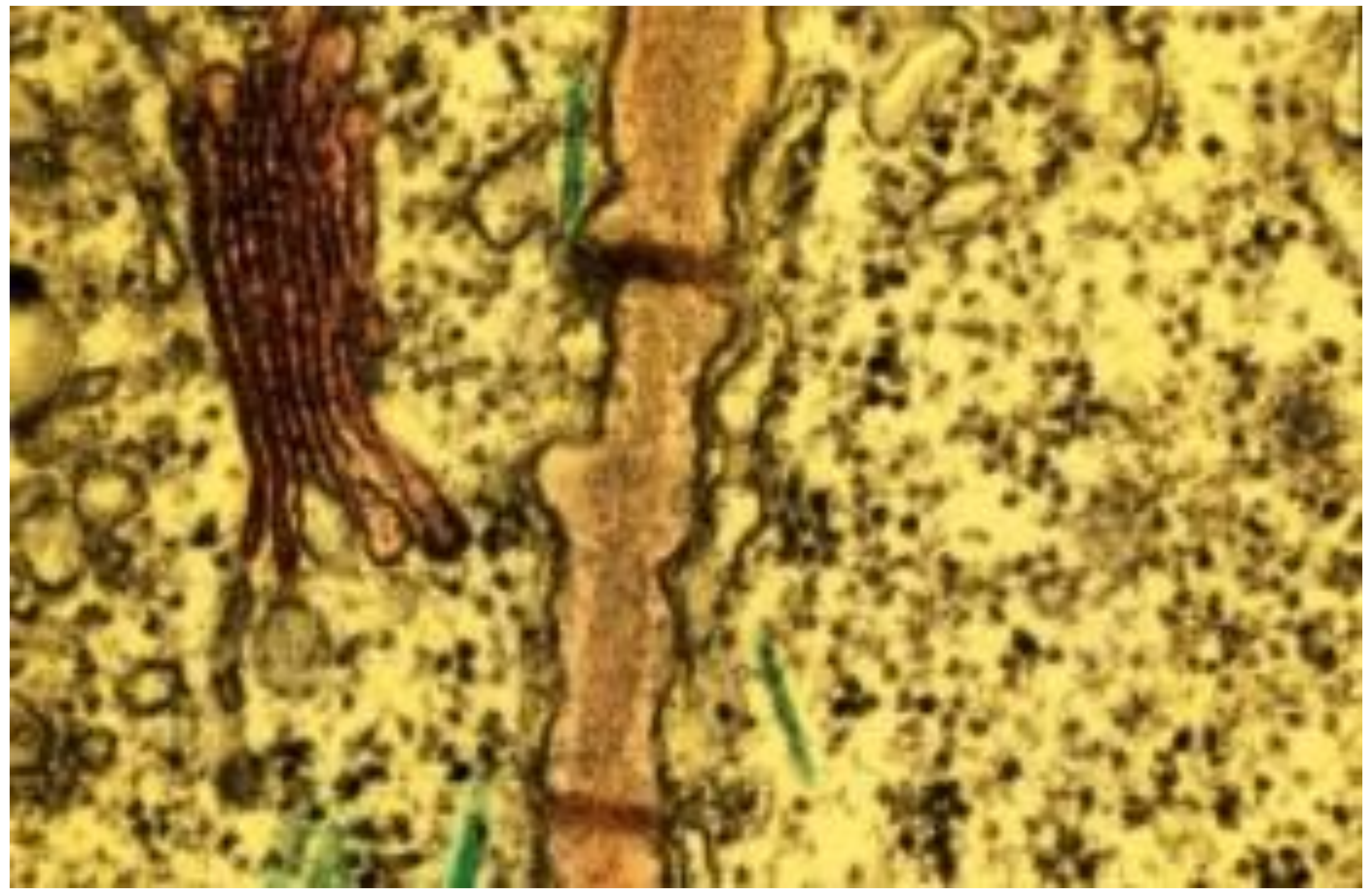


Credits: (left) cryolab.org (right top) Tornroth-Horsefield et al., 2007
(centre top and bottom) Bruce Blaus

Symplastic structures

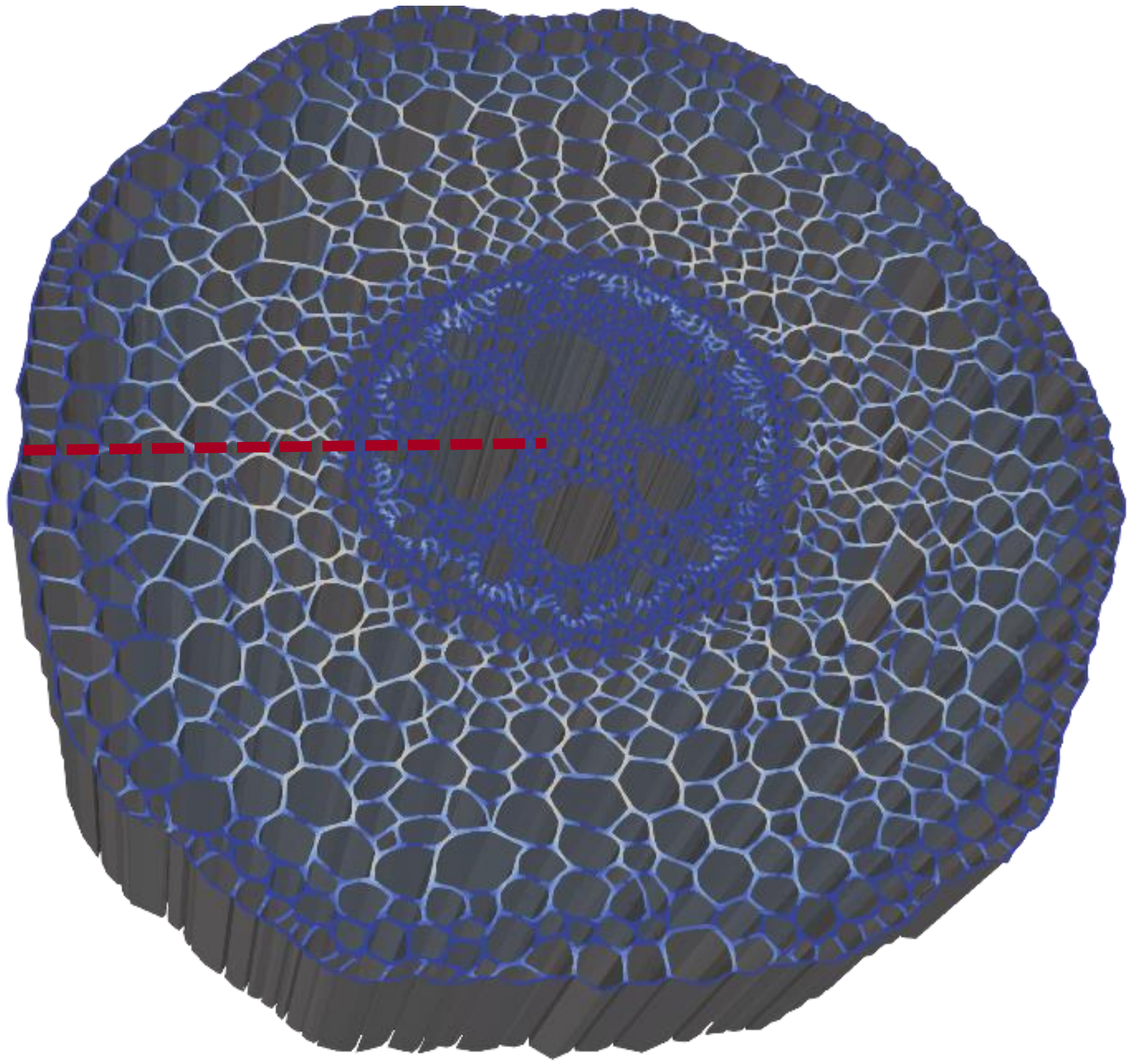
- Plasmodesmata: Passive **diffusion** of ions / molecules

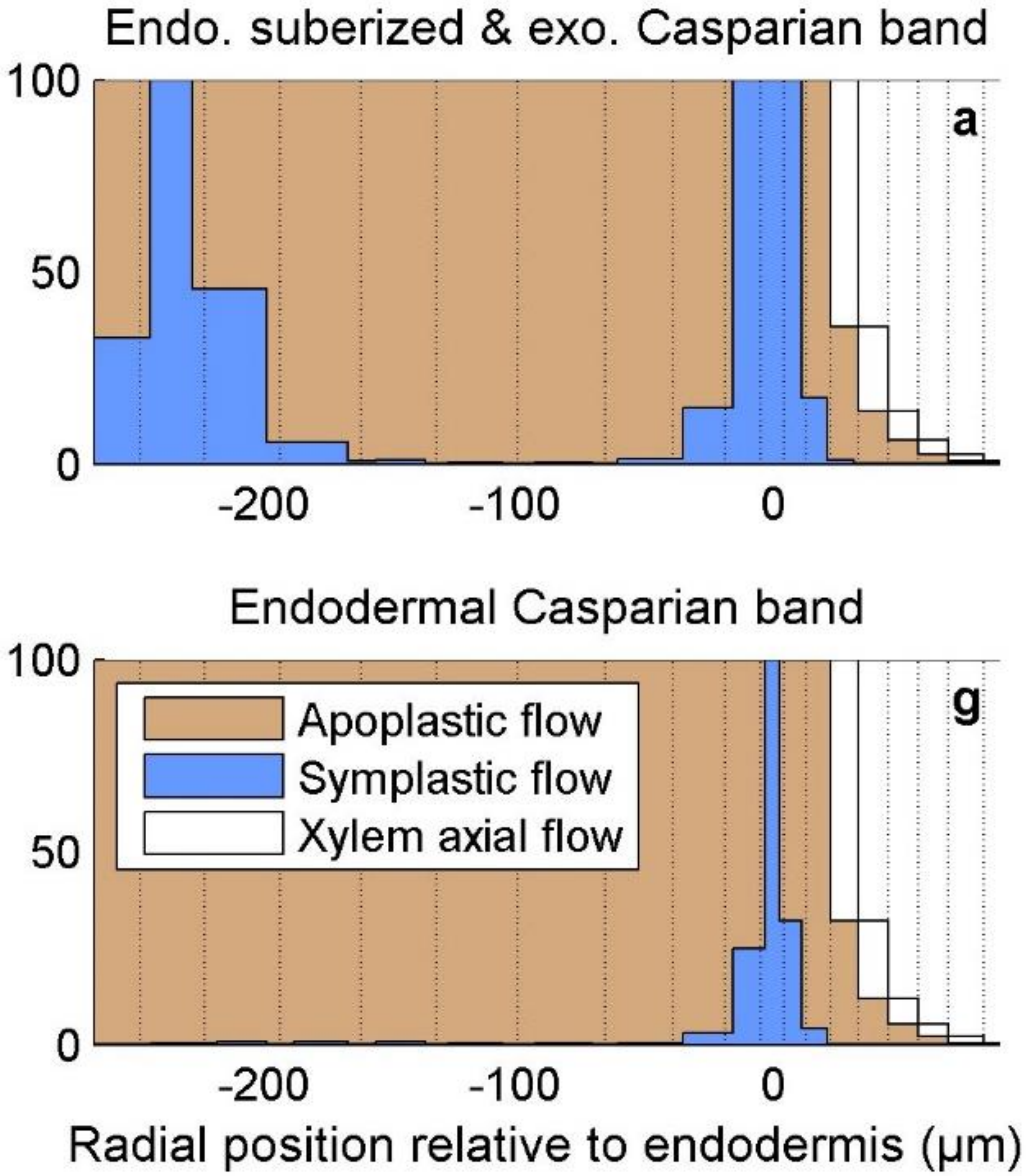


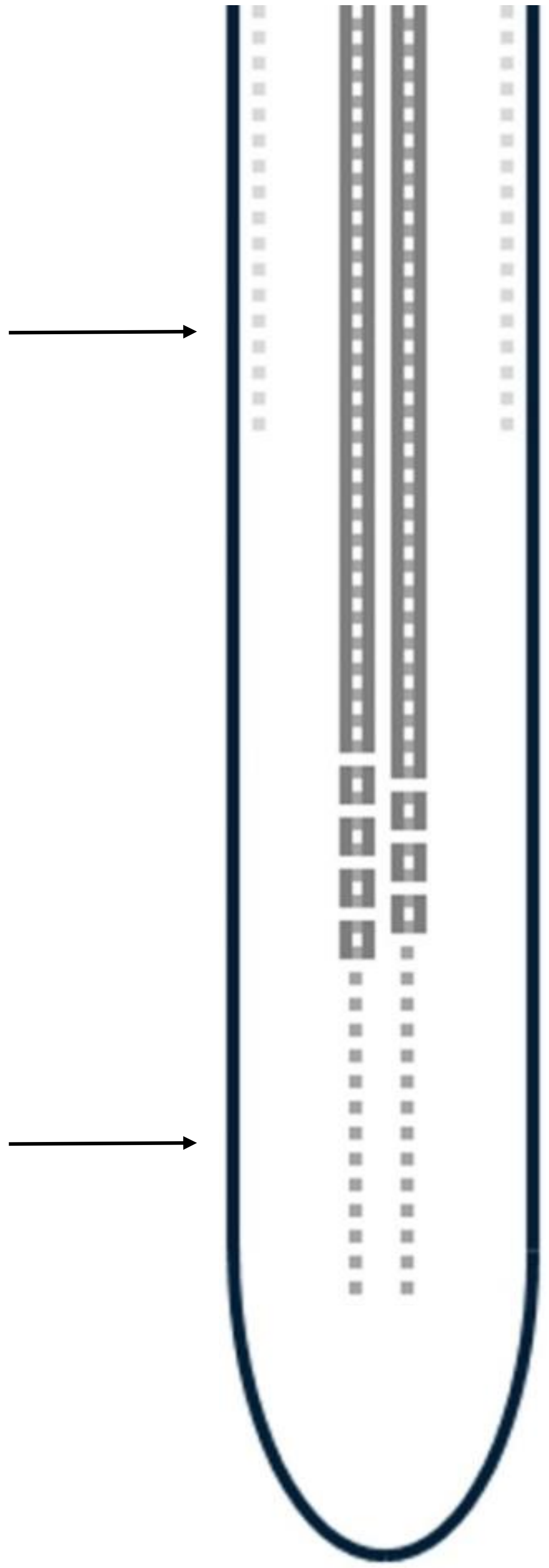


Credits: (left top) Enstone et al., 2003 (right) cache4.asset-cache.net
(left bottom) 4.bp.blogspot.com

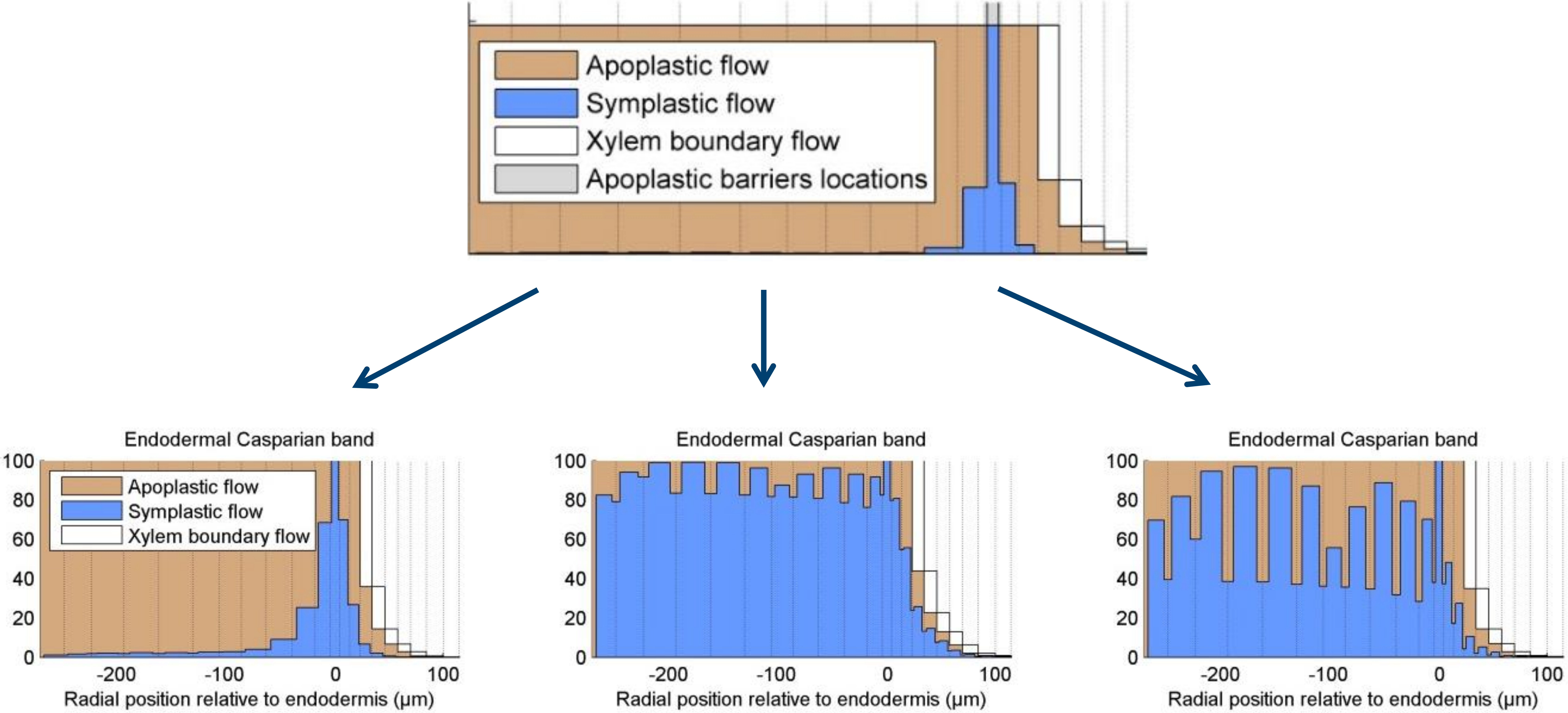
Condensed view of radial water flow pathways



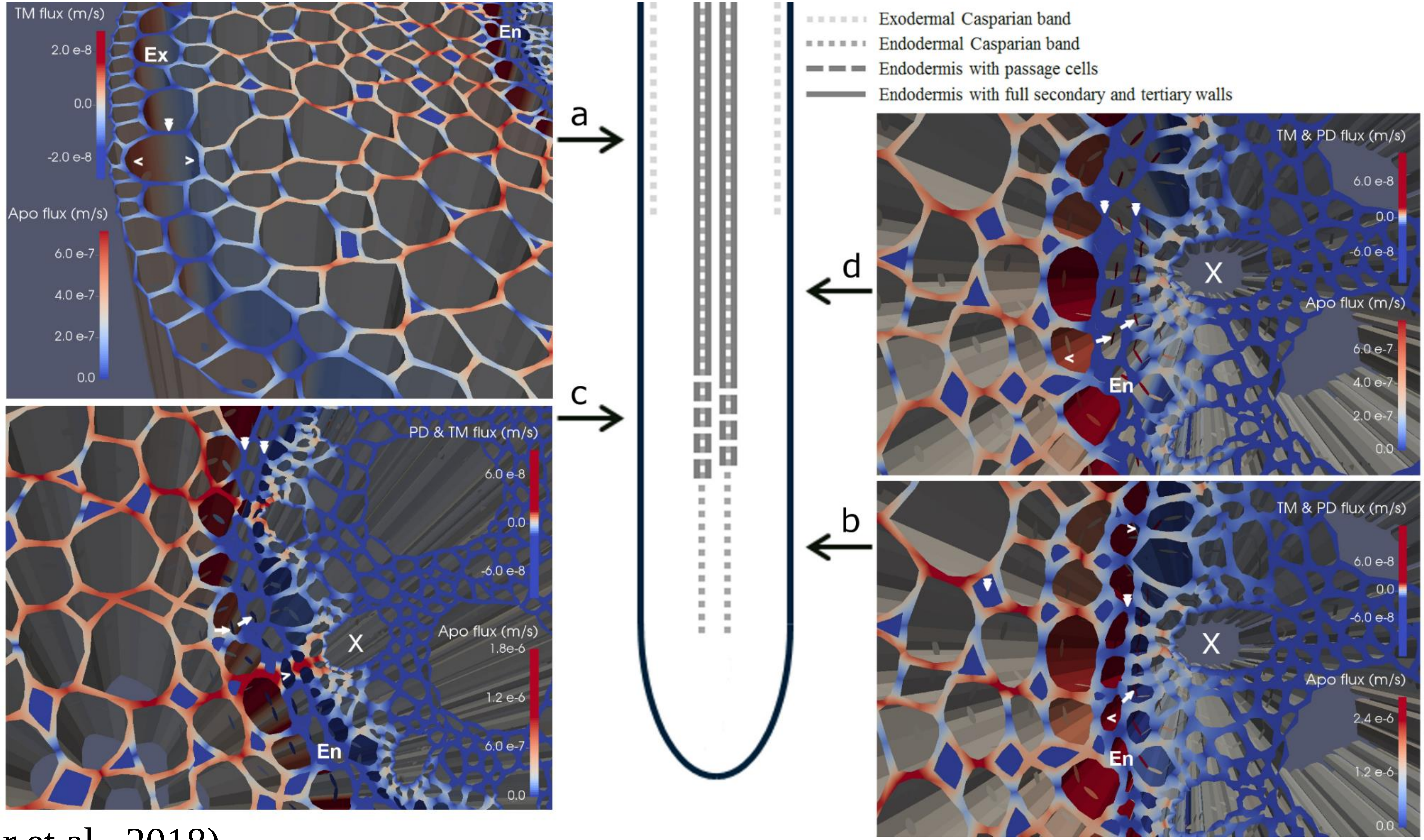




Quiz : Plasticity of radial water flow pathways

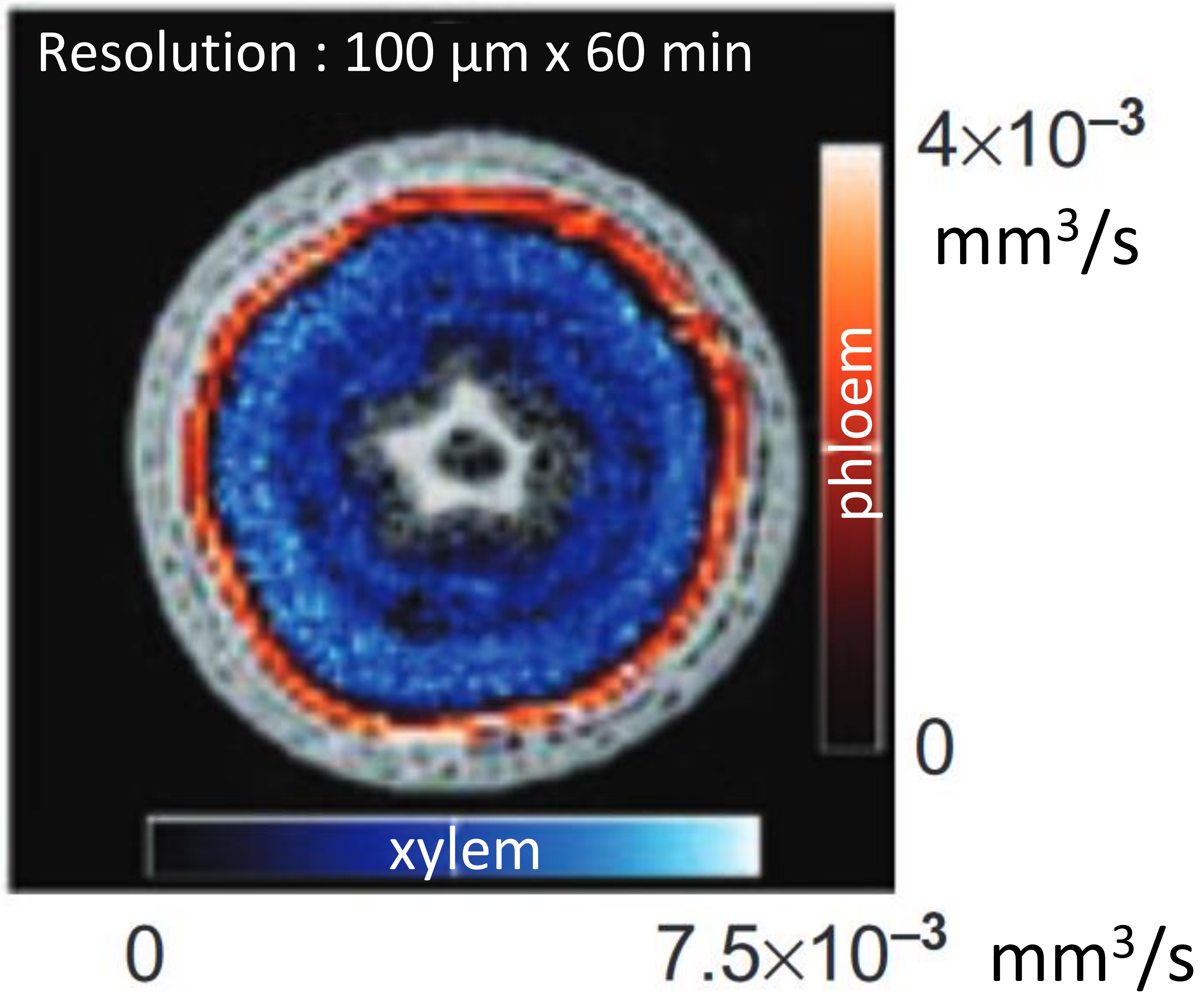


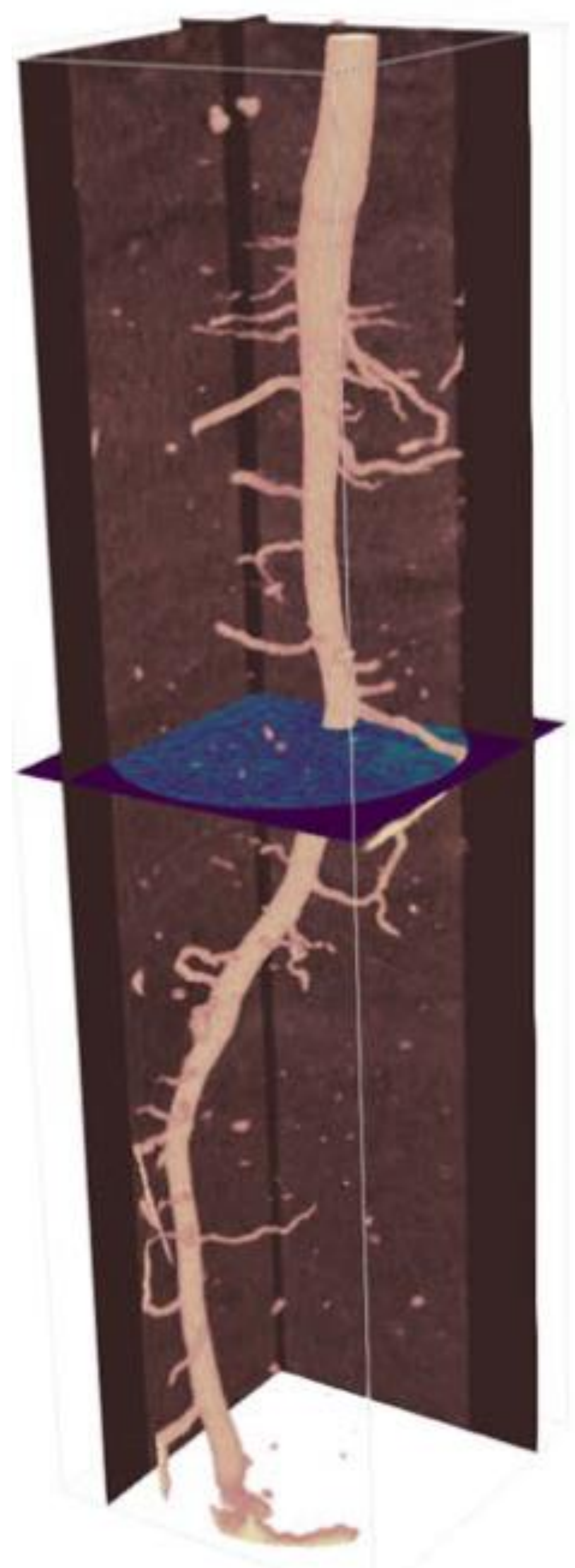
Exploration of water flow in hydraulic anatomies with MECHA

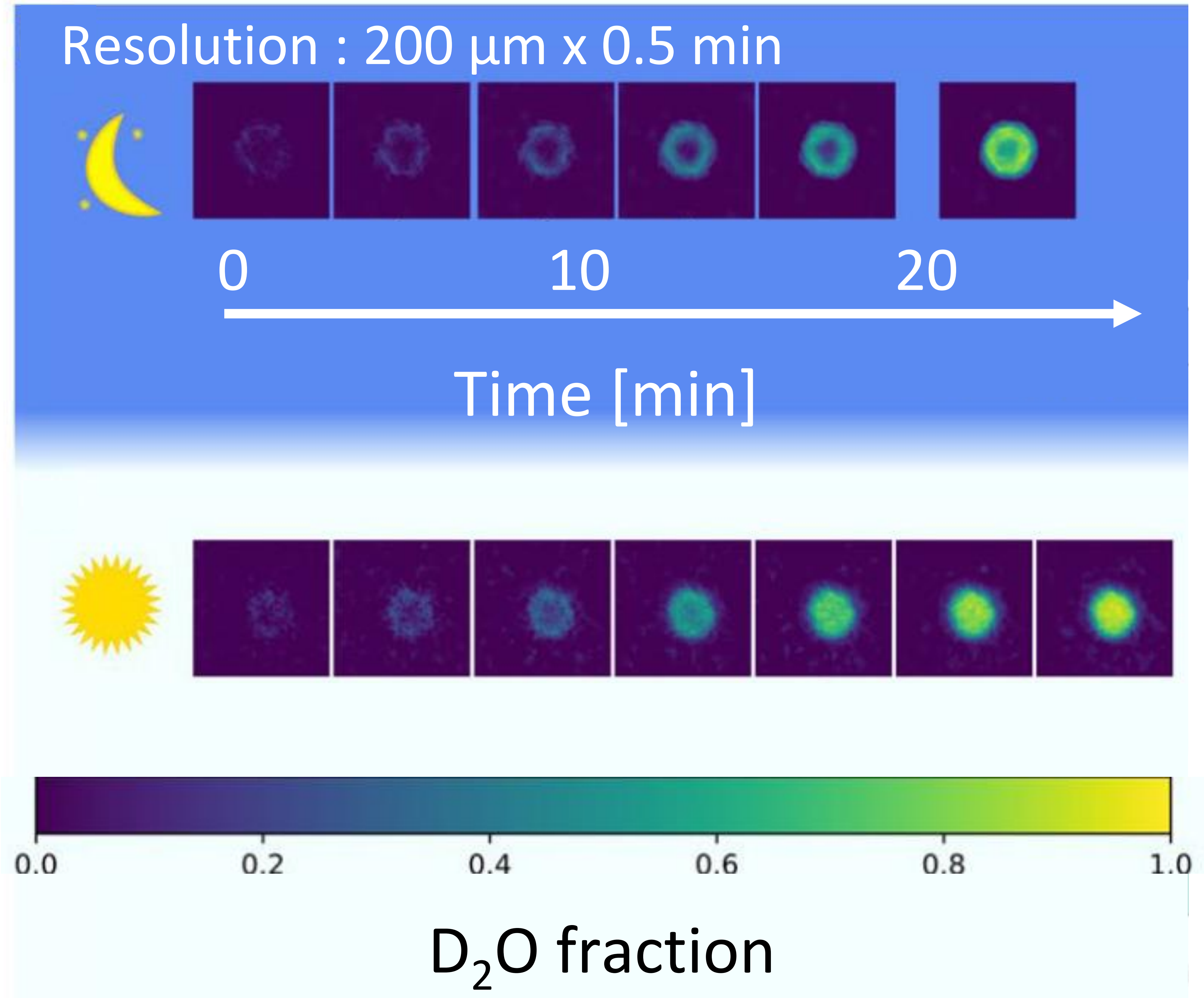


(Couvreur et al., 2018)

Imaging water flow in plants – multiple methods

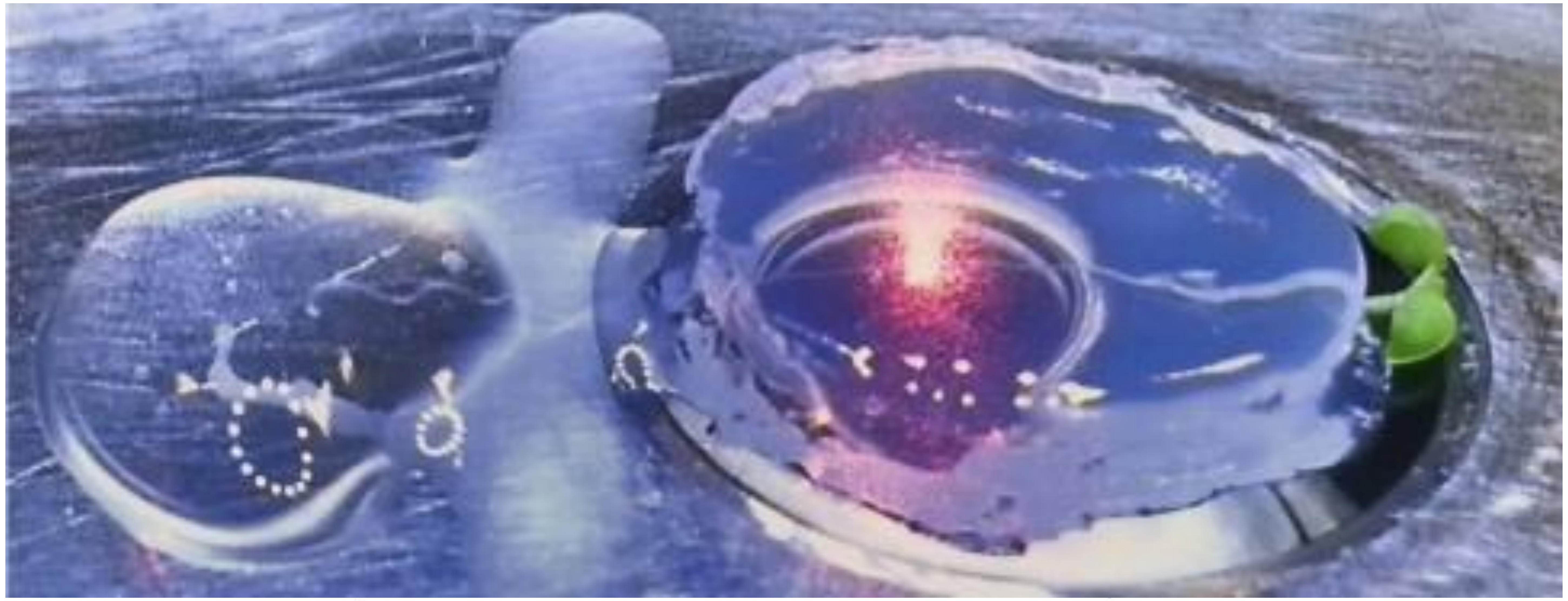




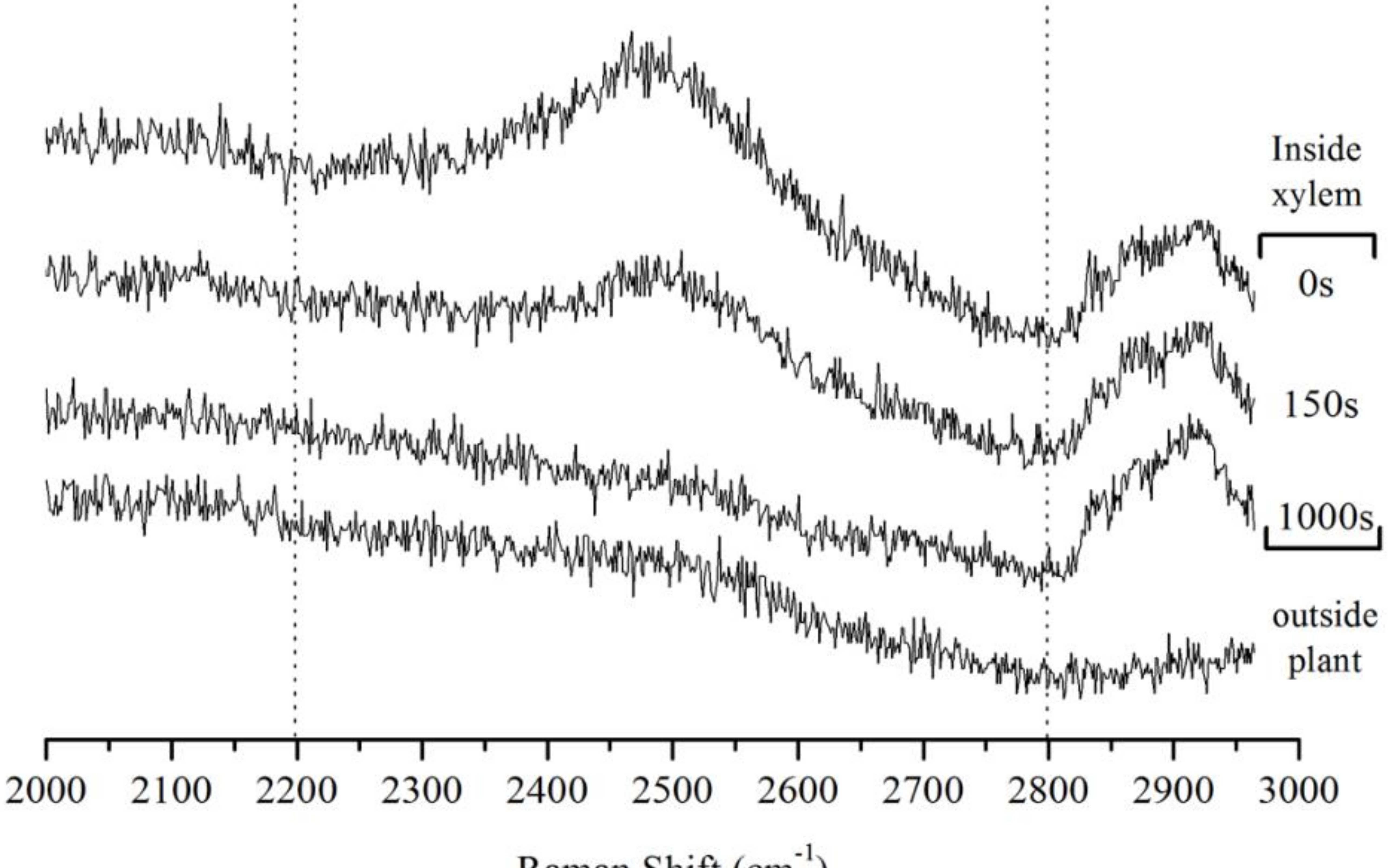


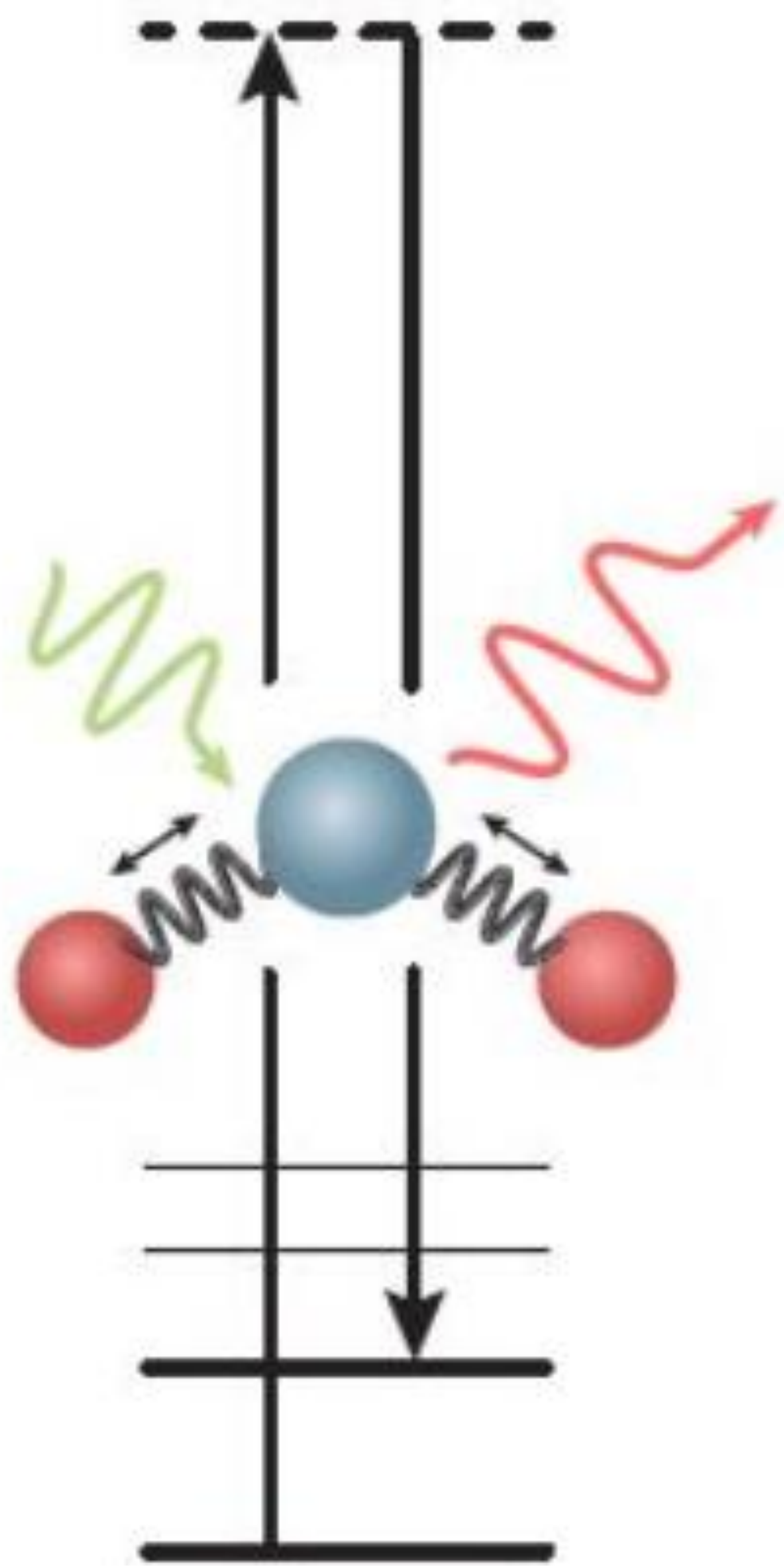
Magnetic Resonance Imaging
(Windt et al., 2006)

Rapid Neutron Tomography
(Zarebanadkouki et al., 2019)

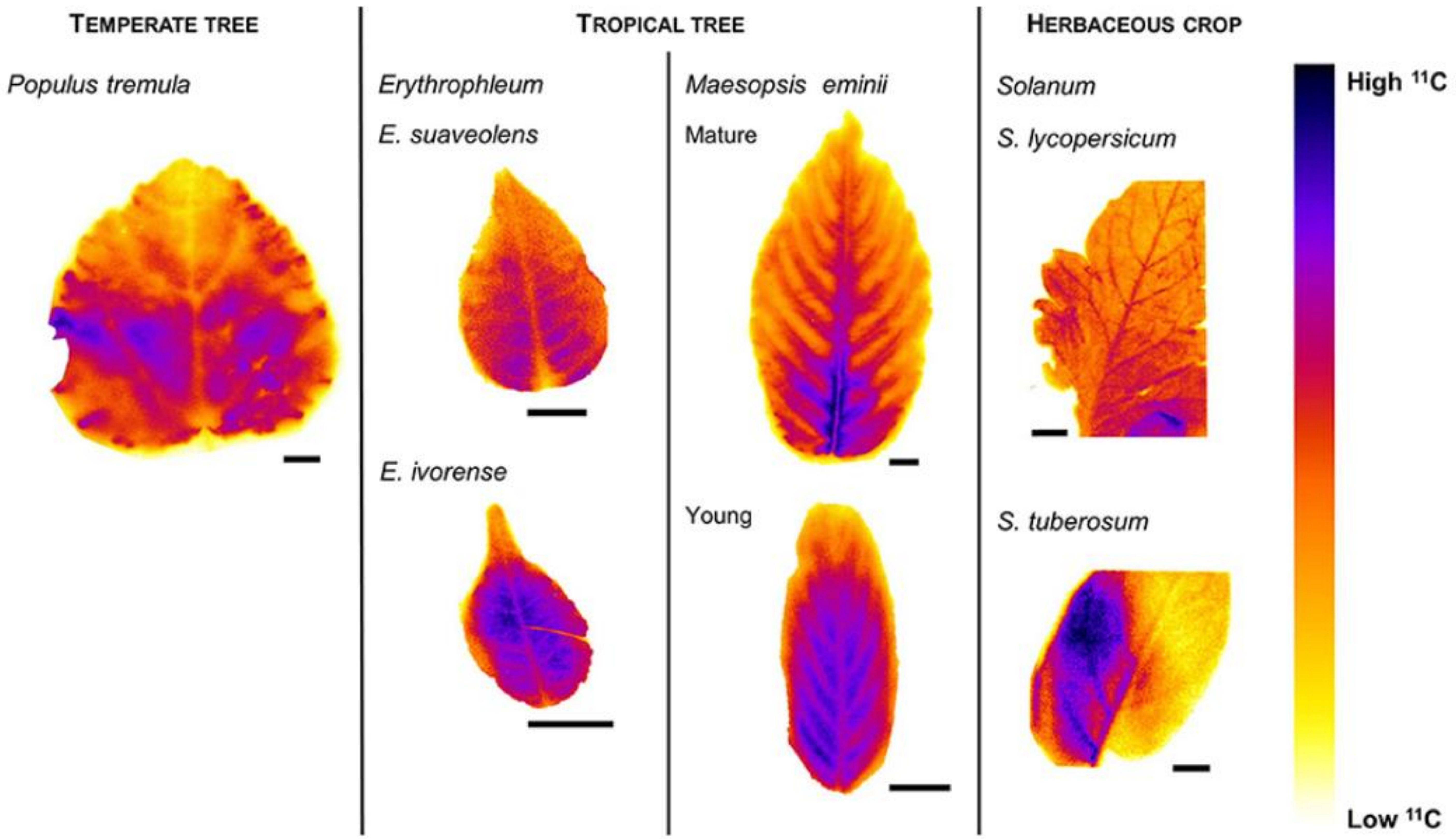


Raman MicroSpectroscopy
« RMS » (Pascut et al., 2021)

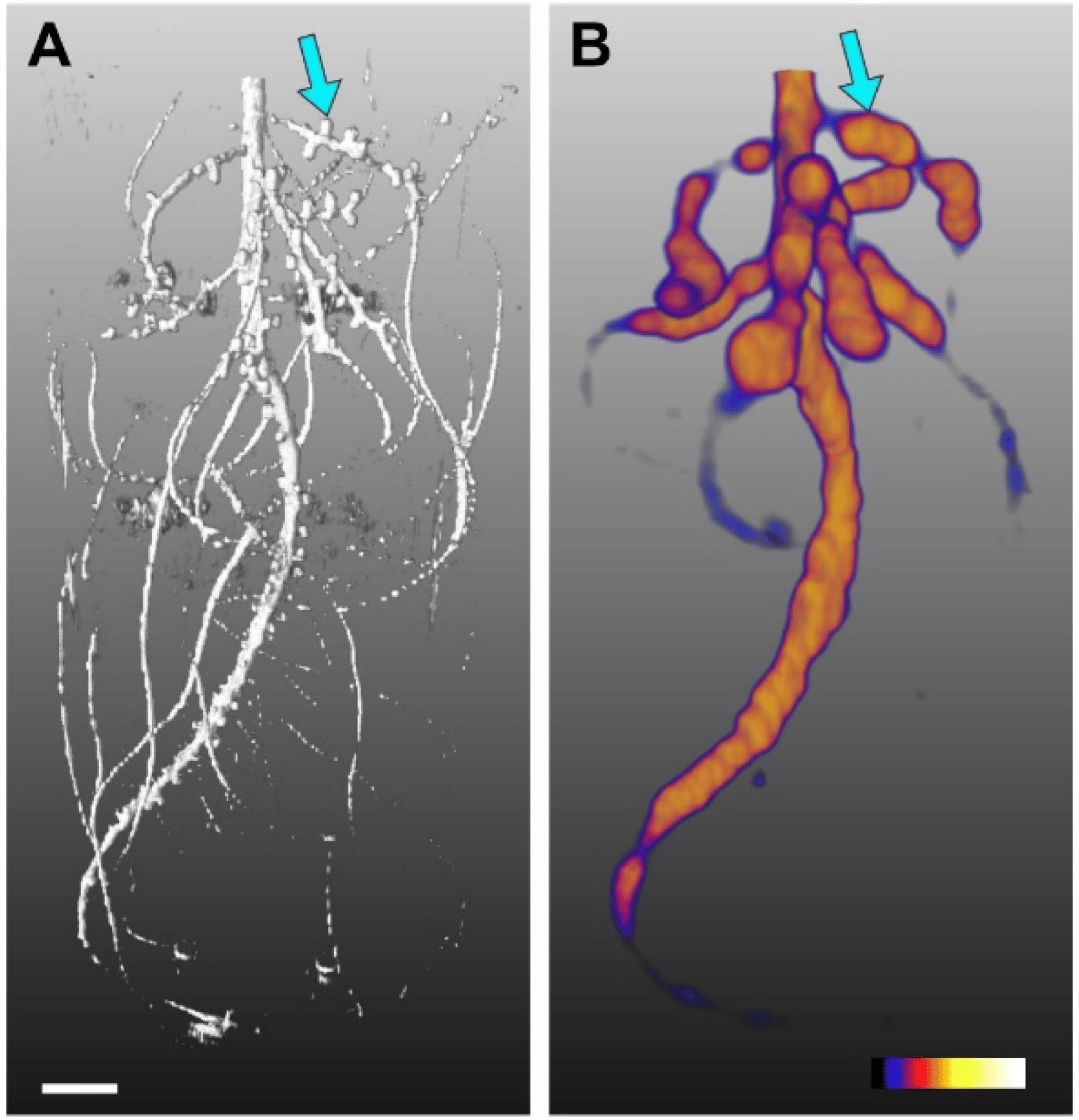




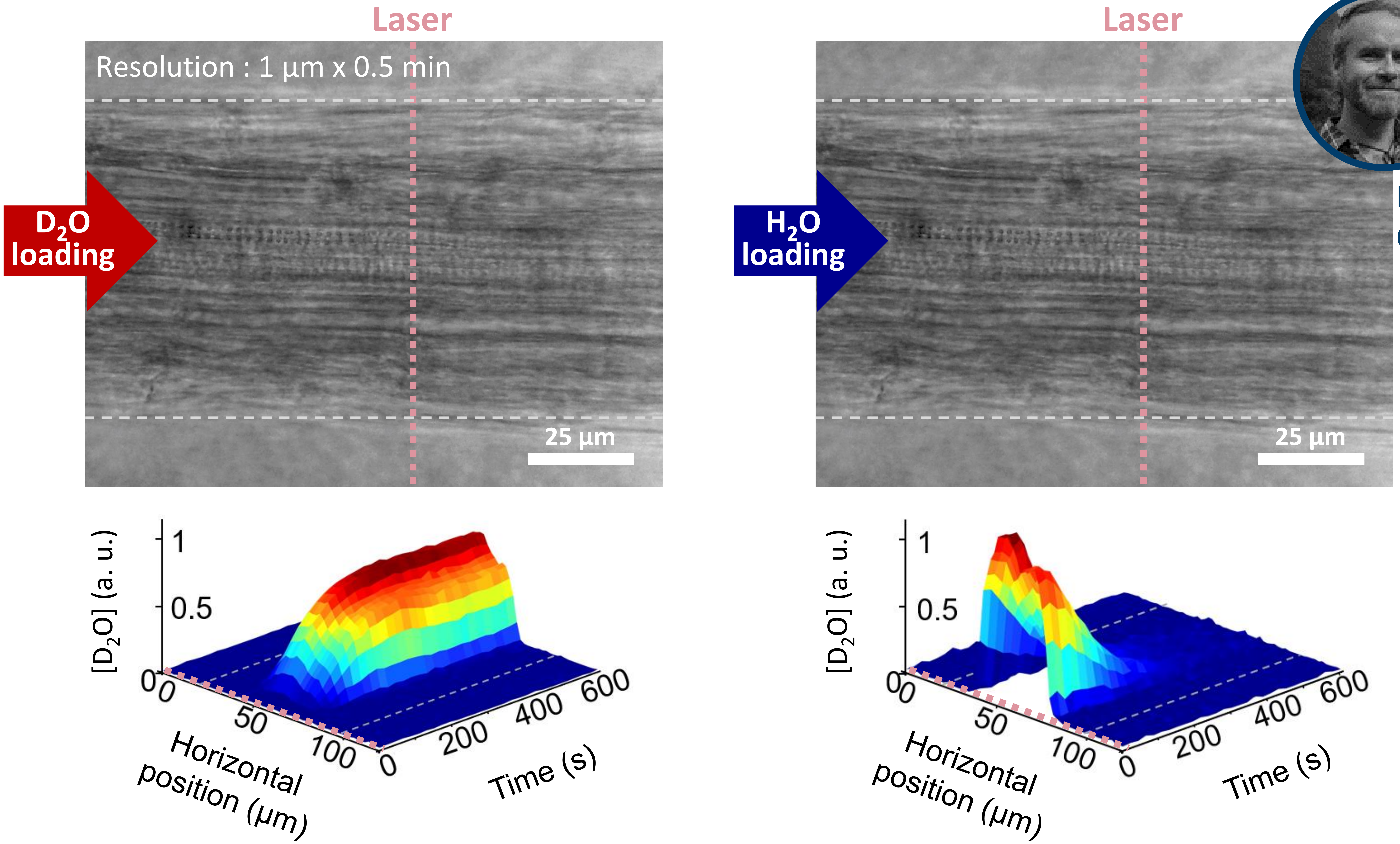
Imaging carbon transport in plants



^{11}C PET-scan autoradiographs
(Hubeau et al., 2019)



MRI & PET-scans of ^{11}C in roots
(Metzner et al., 2022)

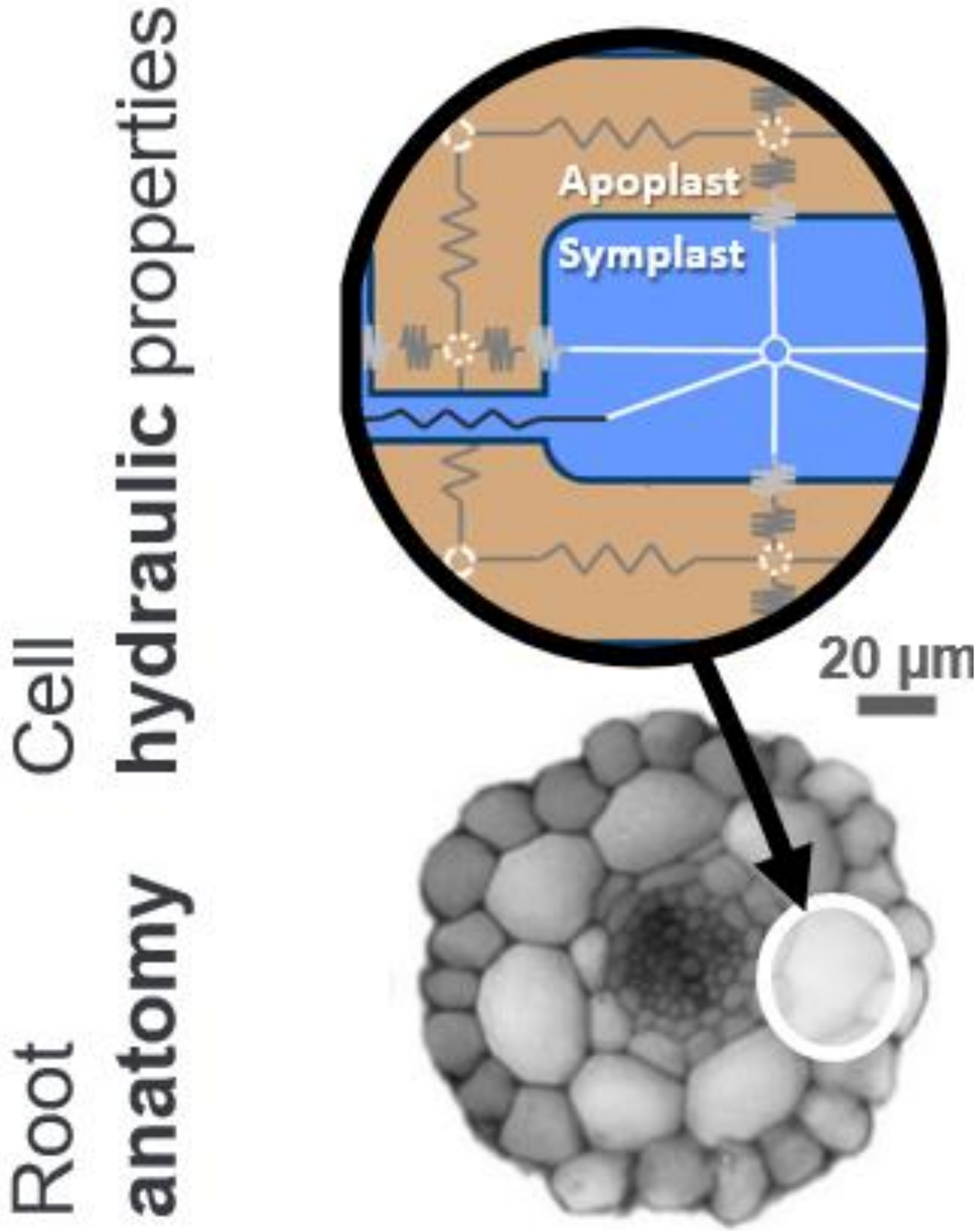


Kevin Webb
Cristian Pascut

Pascut et al. (2021) "Non-invasive hydrodynamic imaging in plant roots at cellular resolution." Nat. Commun.

The idea of modelling water flow in root hydraulic anatomies

Xavier Draye



Water flow equations :

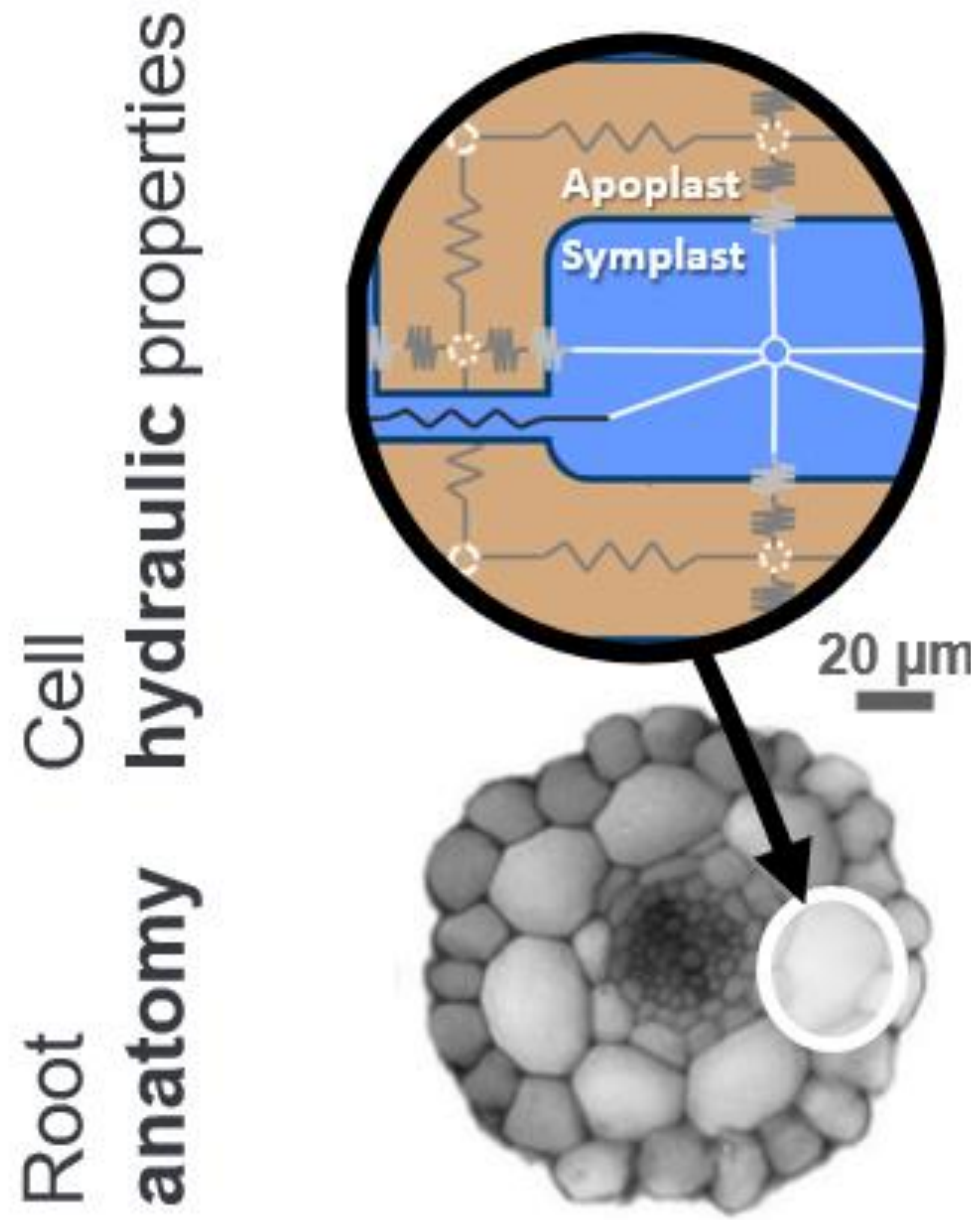
- Flow = Conductance x ψ_w gradient
- Mass conservation
- No water capacitance

Unknown water pressures

$$M_{p,u} \cdot \Psi_{p,u} = M_{p,BC} \cdot \Psi_{p,BC} + M_o \cdot \Psi_o$$

Invert 150k x 150k conductance matrix

Parametrizing cell hydraulic parameters



Water flow equations :

- Flow = **Conductance** x ψ_w gradient
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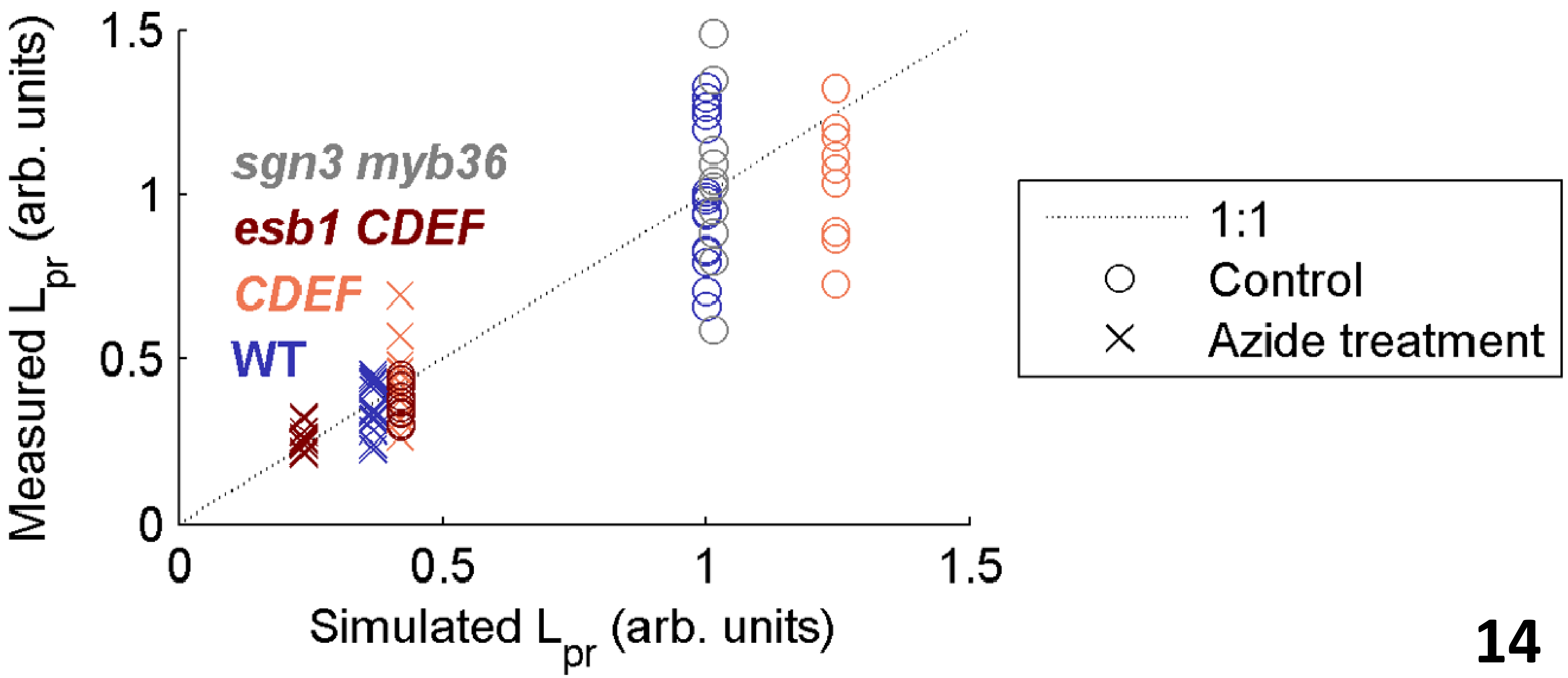
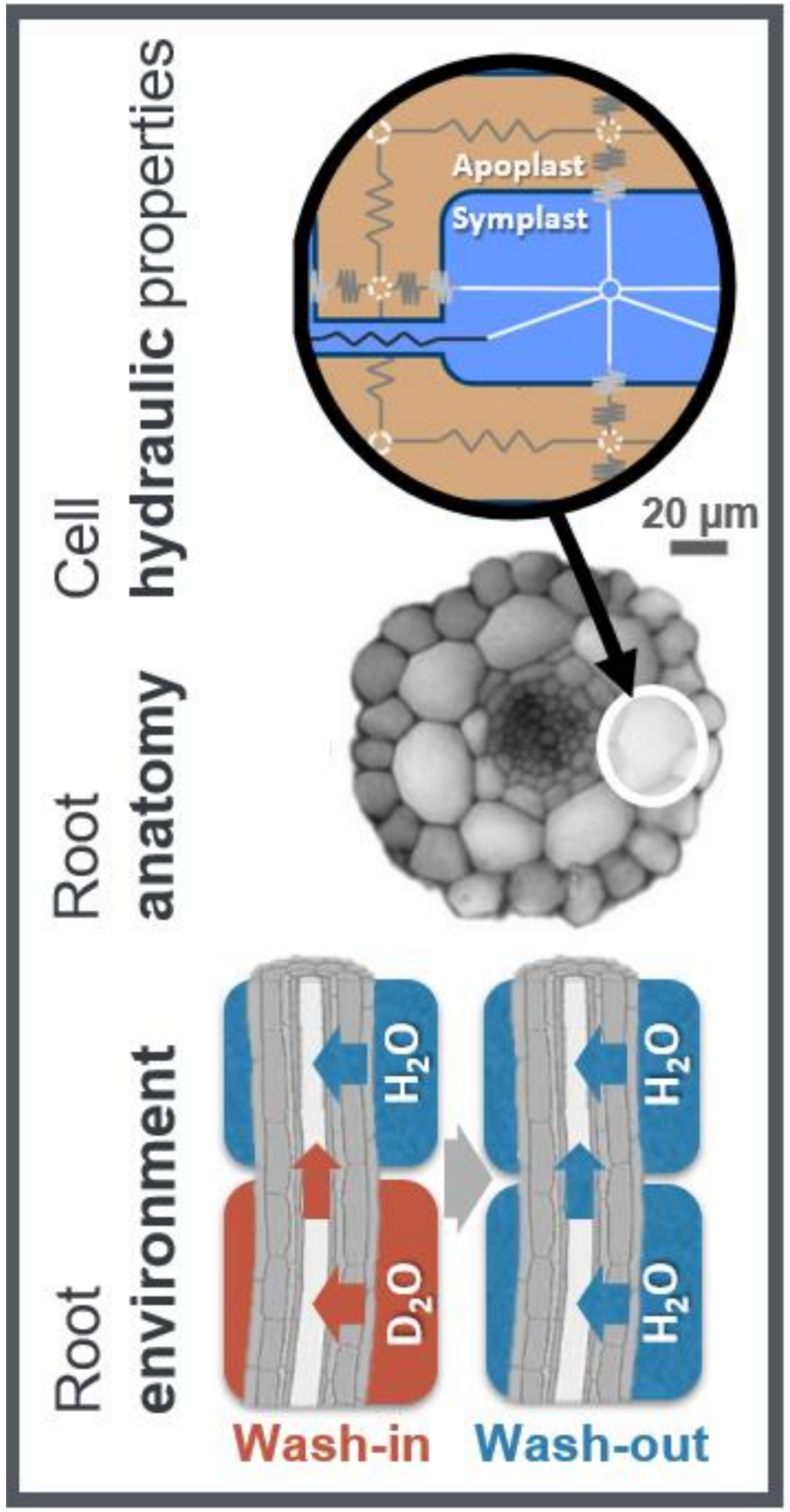


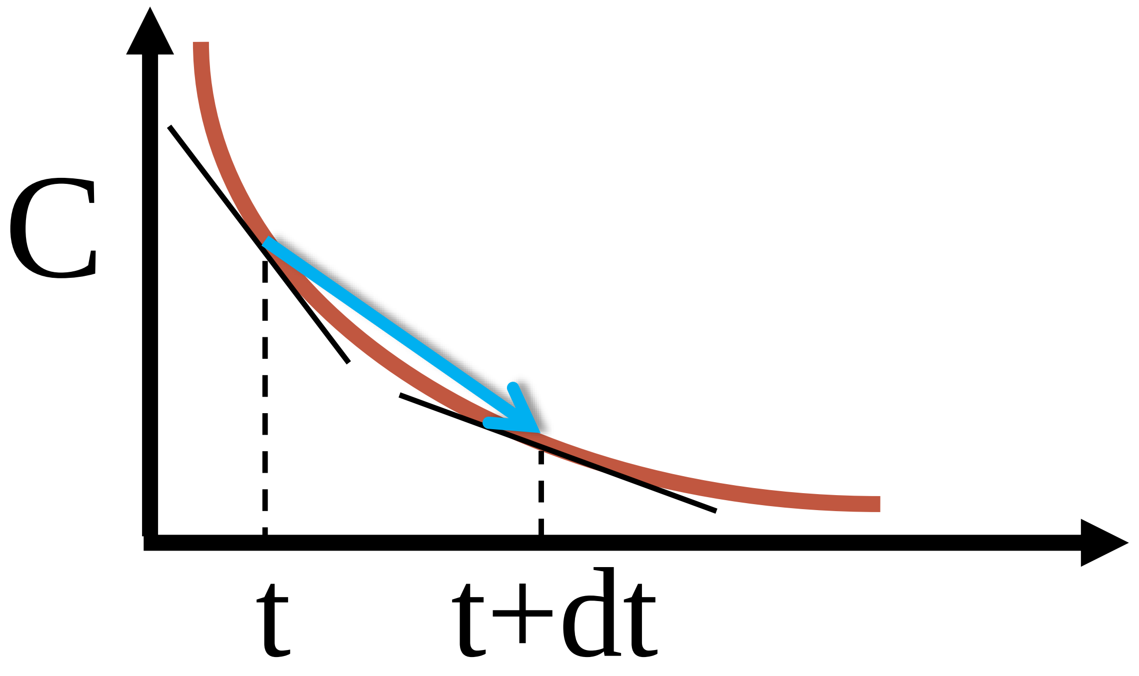
Modelling solute advection – diffusion in hydraulic anatomies



Solute concentration changes with :

- Solute advection
- Solute diffusion
- No metabolism / selective transport for D_2O

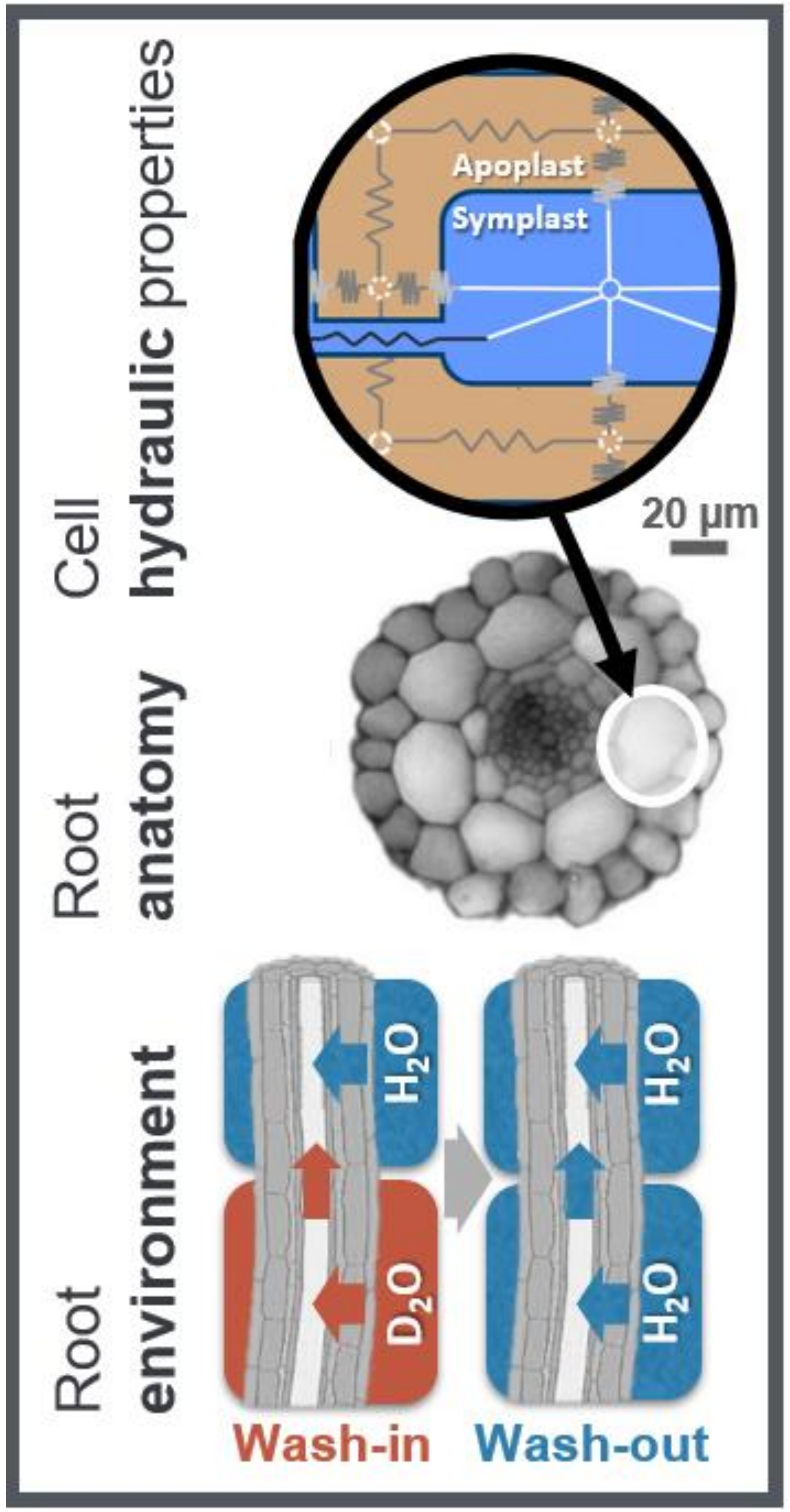
Crank-Nicholson method for implicit solution :

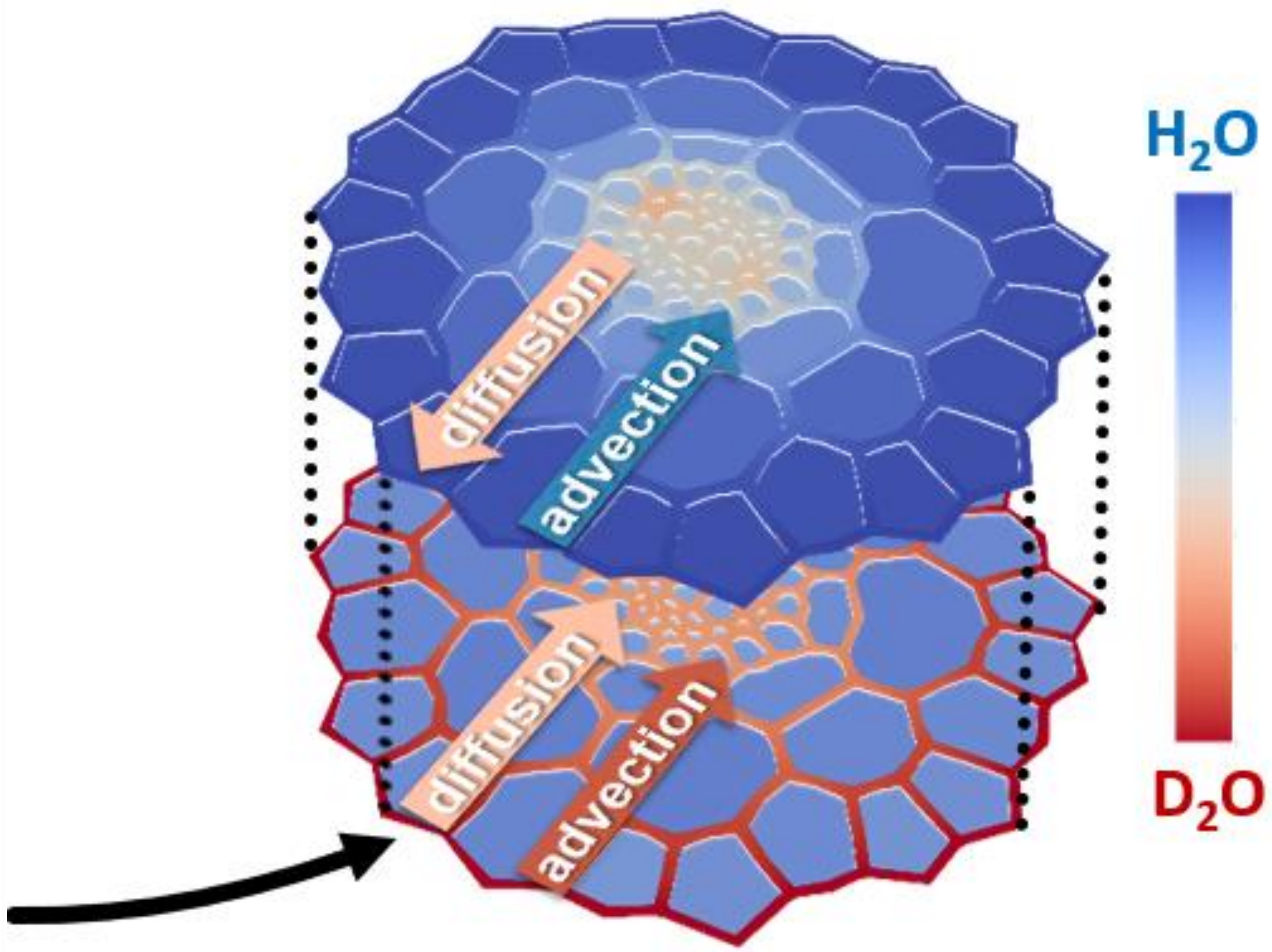


$$\left(diag(\mathrm{V}) - \frac{dt}{2} \cdot \mathbf{M}\right) \cdot \mathrm{C}_{t+dt} = \left(diag(\mathrm{V}) + \frac{dt}{2} \cdot \mathbf{M}\right) \cdot \mathrm{C}_t - dt \cdot \mathrm{F}_{\mathrm{BC}}$$

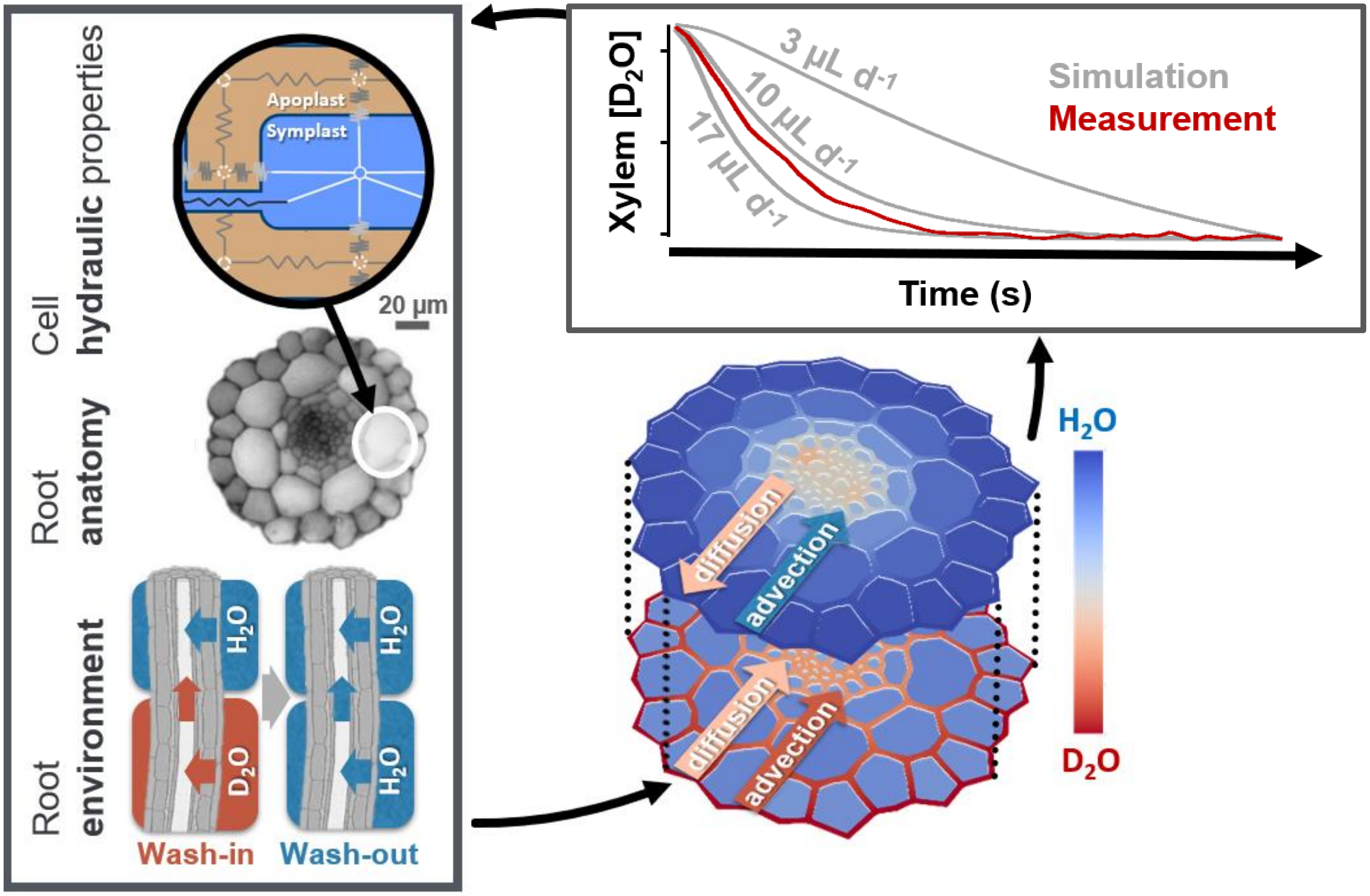
Invert 150k x 150k conductance matrix

Modelling solute advection – diffusion in hydraulic anatomies

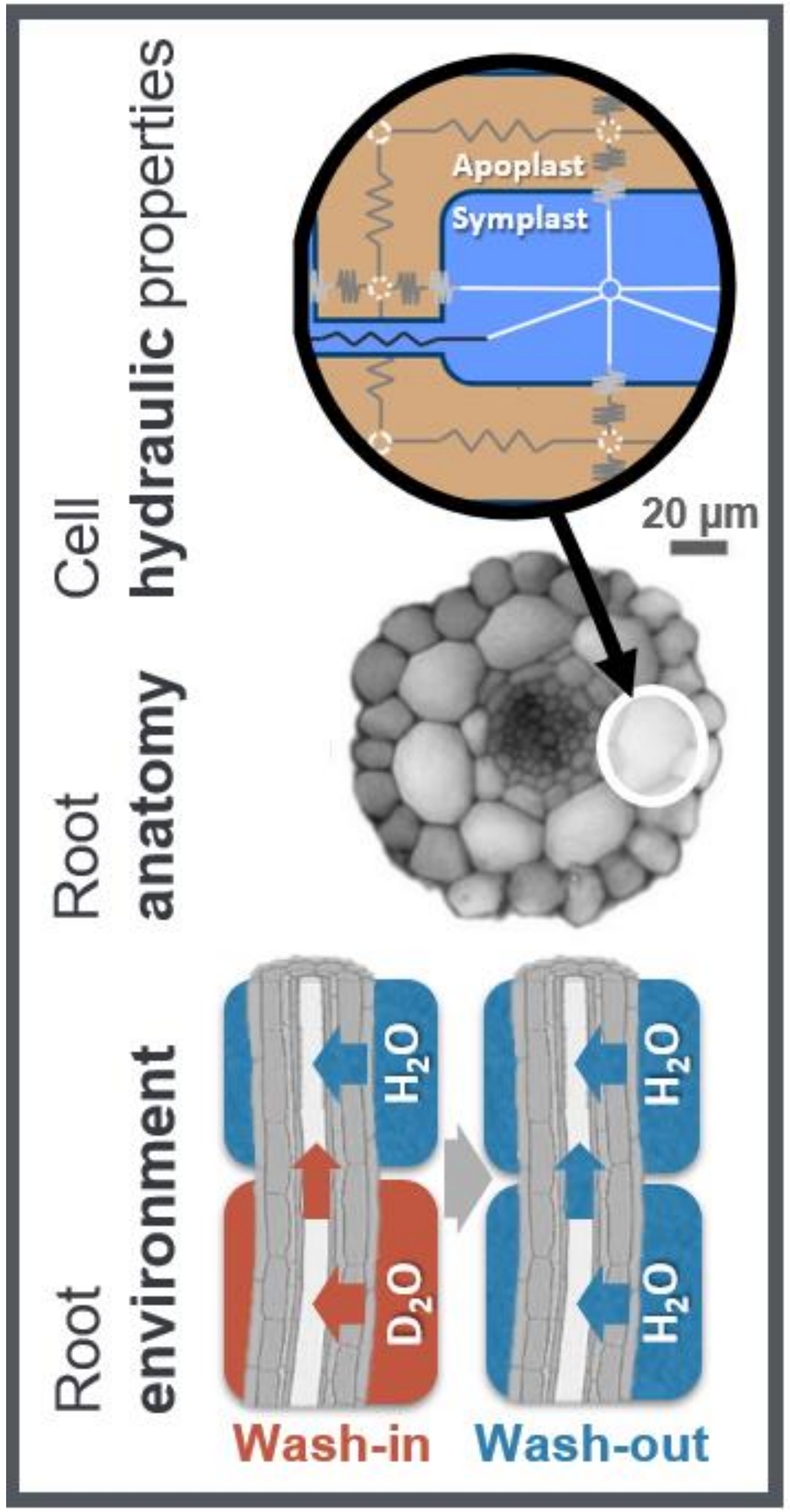


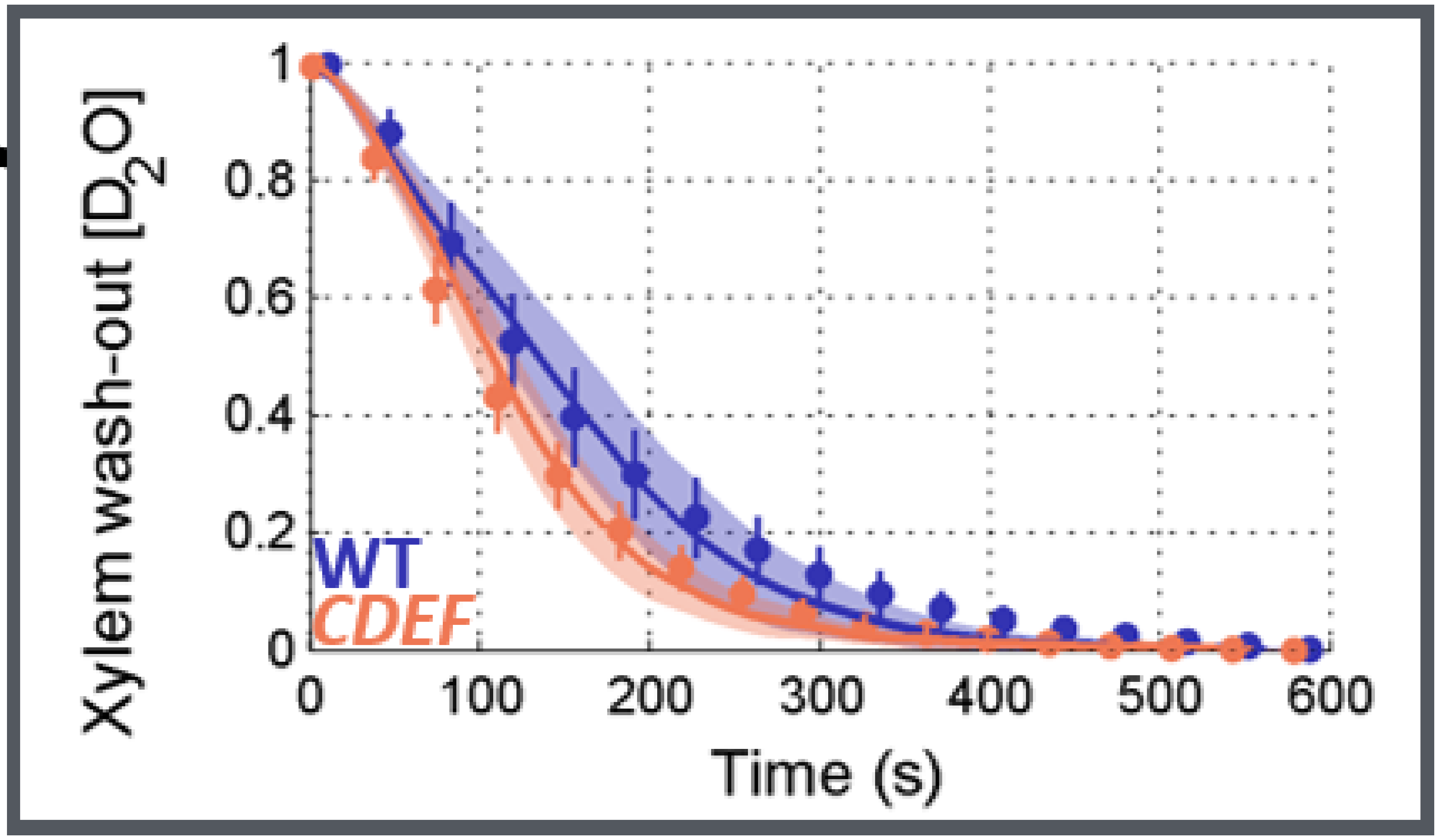


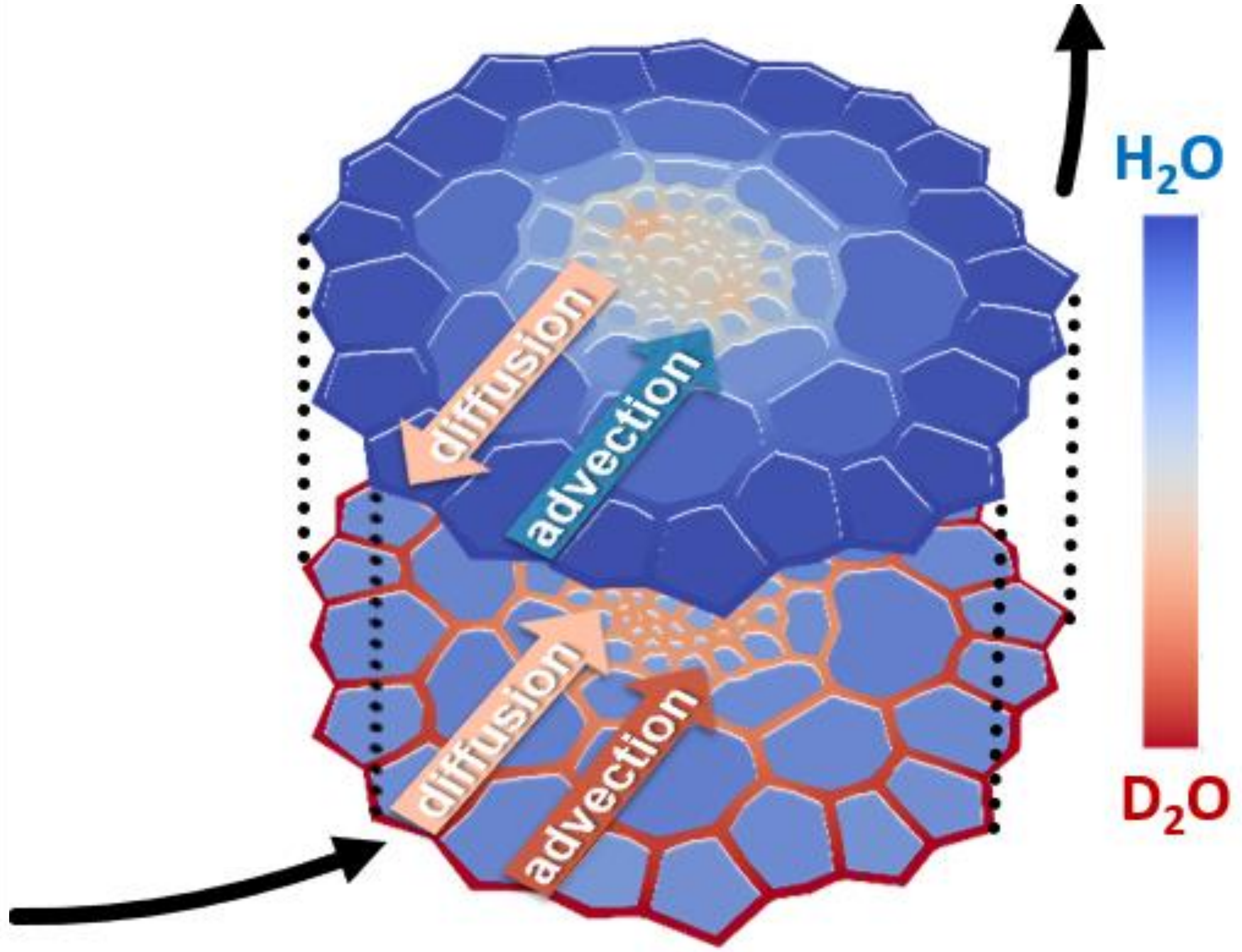
Inverse parametrization scheme for diffusion and uptake rate



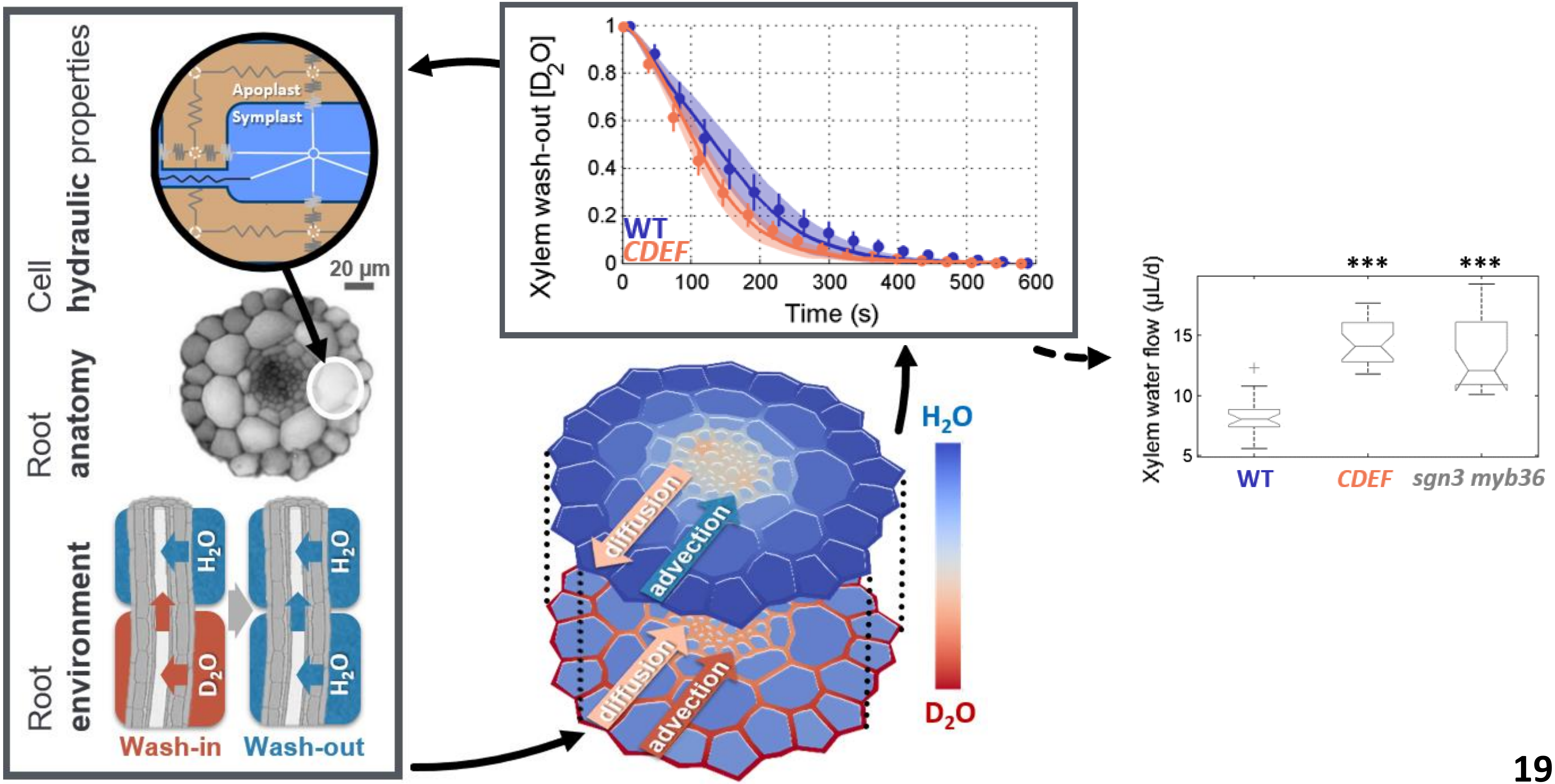
Inverse parametrization scheme for diffusion and uptake rate







Hydrophobic barrier mutants have higher xylem water flow rates

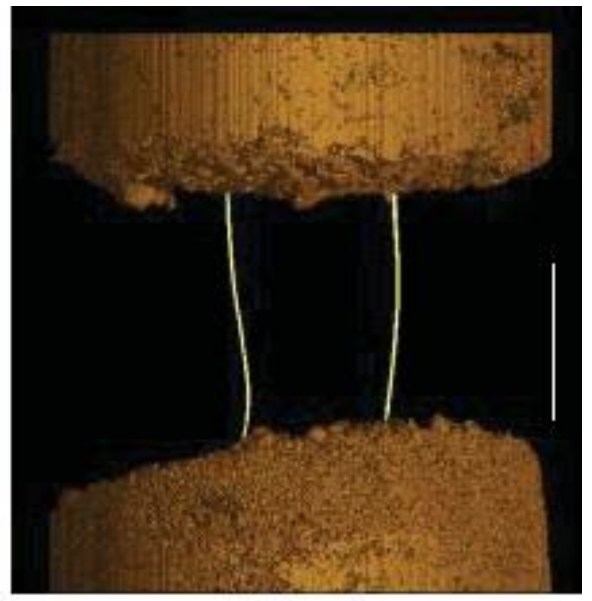


Mechanisms behind the « xerobranching » response

Poonam Mehra

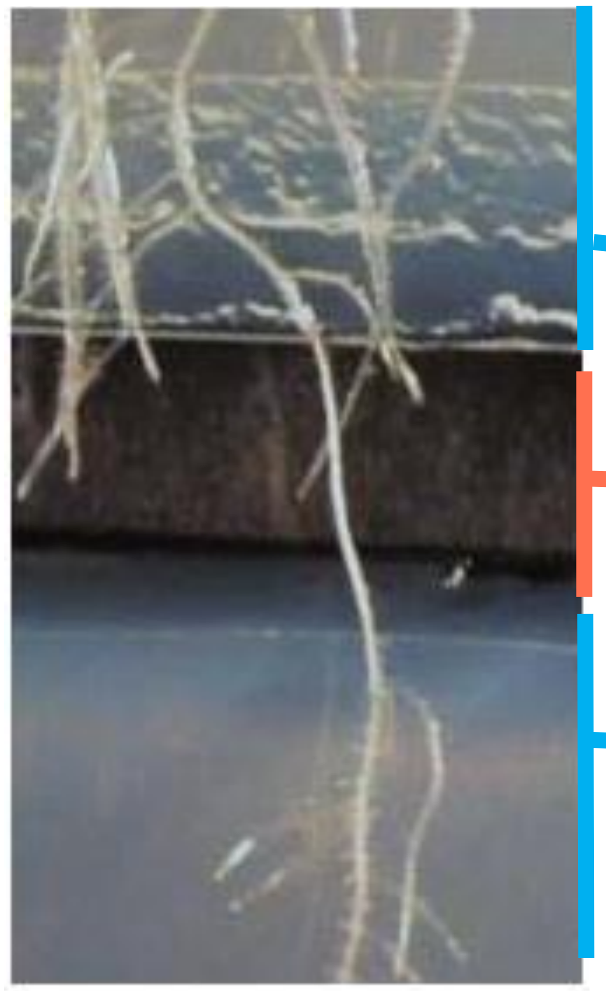
~~lateral roots~~
in **air gaps**

Tomato



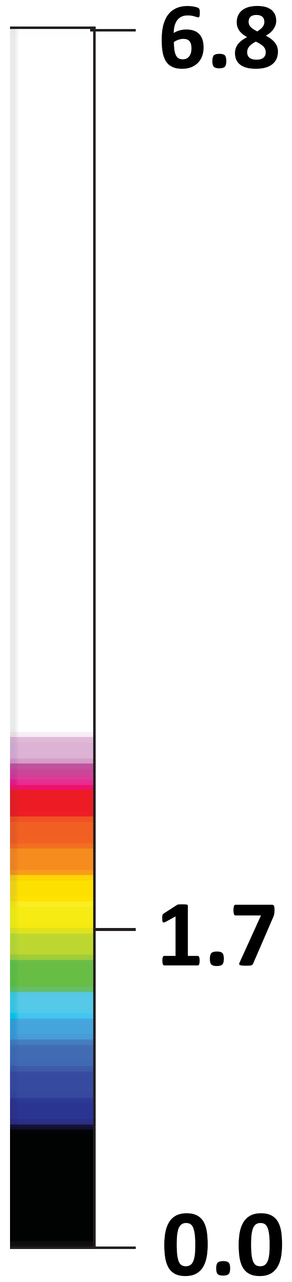
WT

Arabidopsis



Col-0

Control

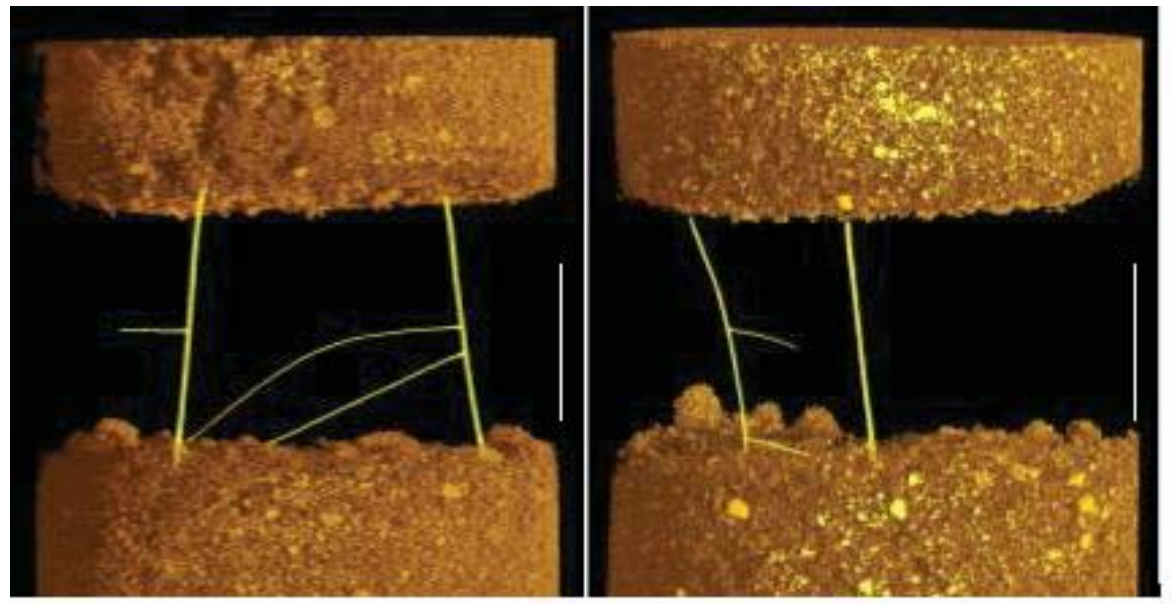


nlsABACUS2-400n
Emission ratio

4-5 mm
into air

1-2 mm
into gel

Control by phloem –
biosynthesised **ABA**



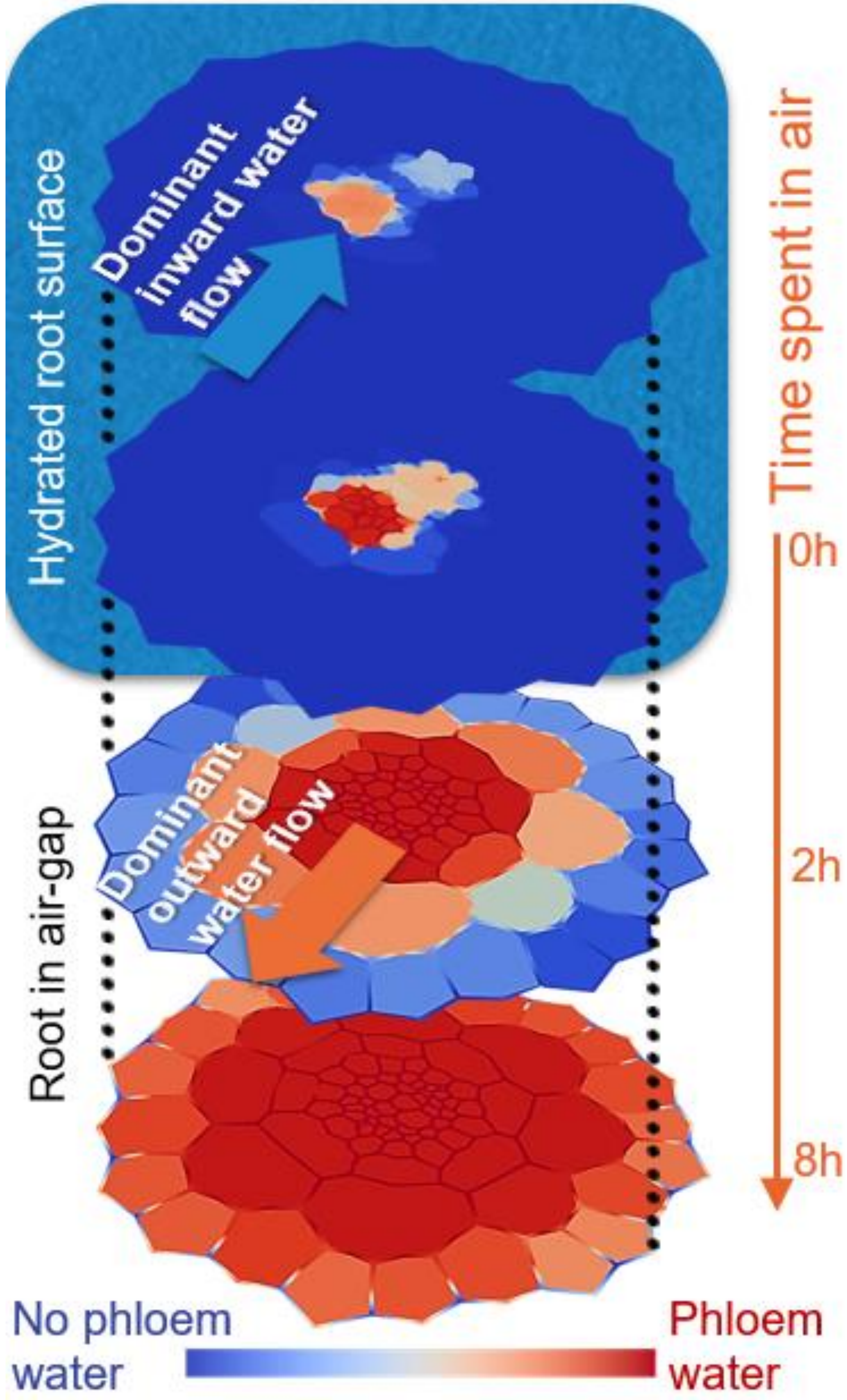
notabilis *flacca*

aba2-1

Mehra et al. (2022) "Hydraulic flux–responsive hormone redistribution determines root branching." *Science*

Could ABA be dragged with water flow in the EZ during a Xerobranching response ?

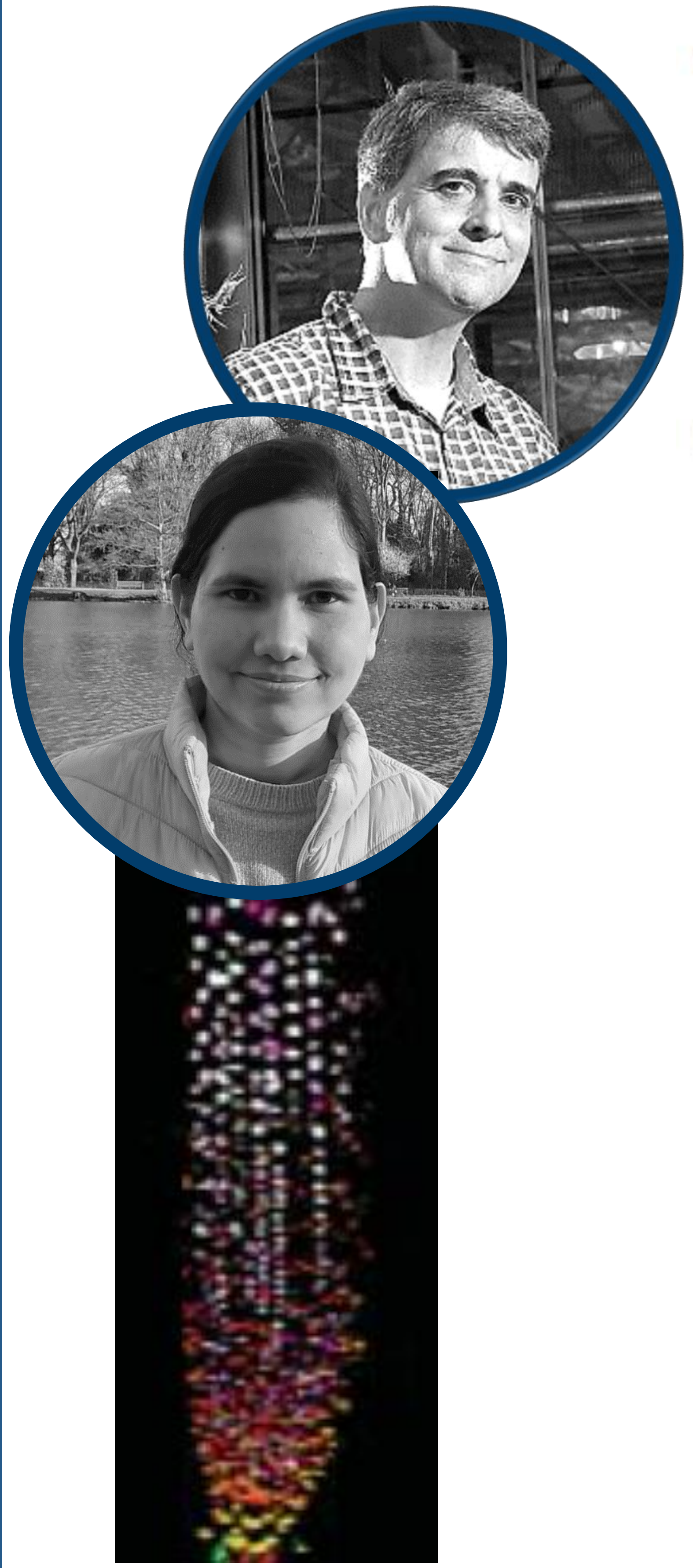
… as a « hydro-signal »



Mehra et al. (2022) "Hydraulic flux–responsive hormone redistribution determines root branching." *Science*

THANK YOU FOR YOUR ATTENTION! ☺

Funding



Watching plants drink