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Imaging hydraulic failures in trees using x-ray microtomography

Eric Badel

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Eric Badel. Imaging hydraulic failures in trees using x-ray microtomography. Colloque Xylème, May 2014, Besse, France. pp.22. hal-01268527

HAL Id: hal-01268527

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Submitted on 5 Jun 2020

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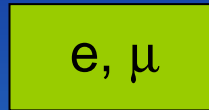
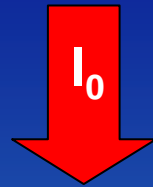
Imaging hydraulic failures in trees by x-ray microtomography

Eric BADEL
Hervé COCHARD

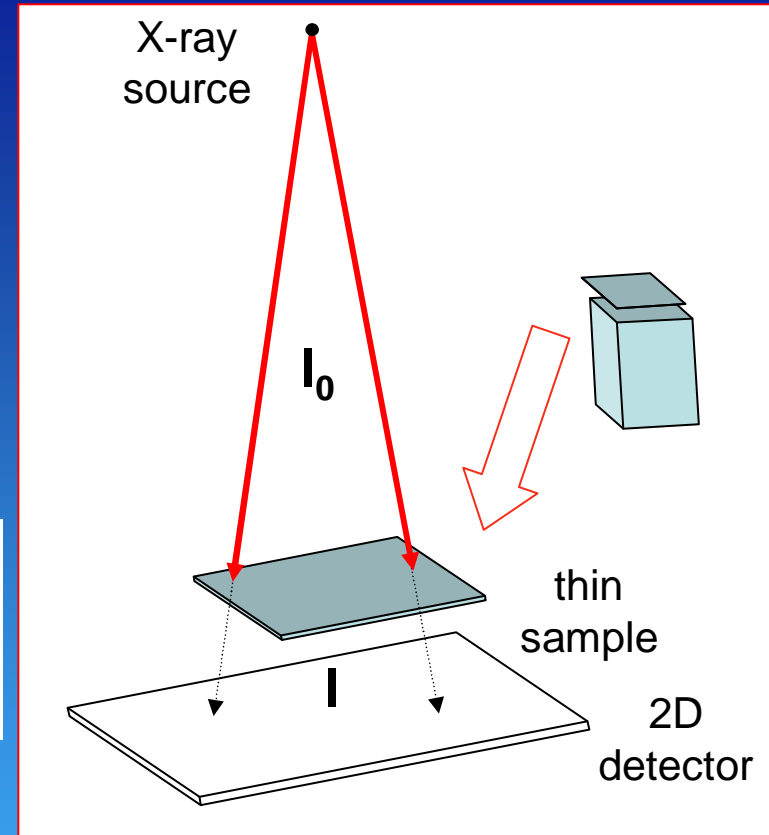
UMR PIAF, INRA-UBP 5 chemin de Beaulieu, Clermont Ferrand

2D X-ray radiography

Röntgen 1895



$$\ln\left(\frac{I}{I_0}\right) = -\mu e$$



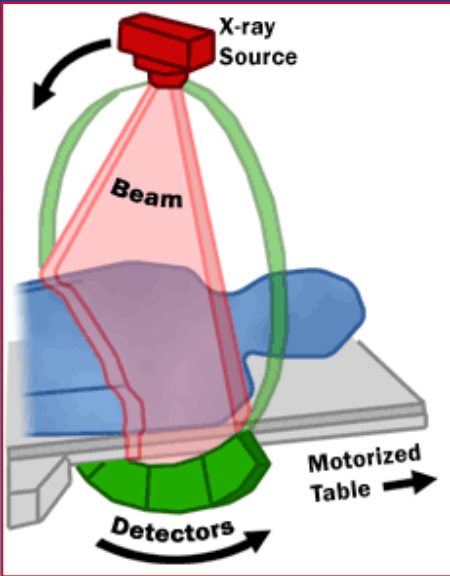
μ : X-ray absorption is a function of :

- atomic components
- matter density
- incident x-ray energy

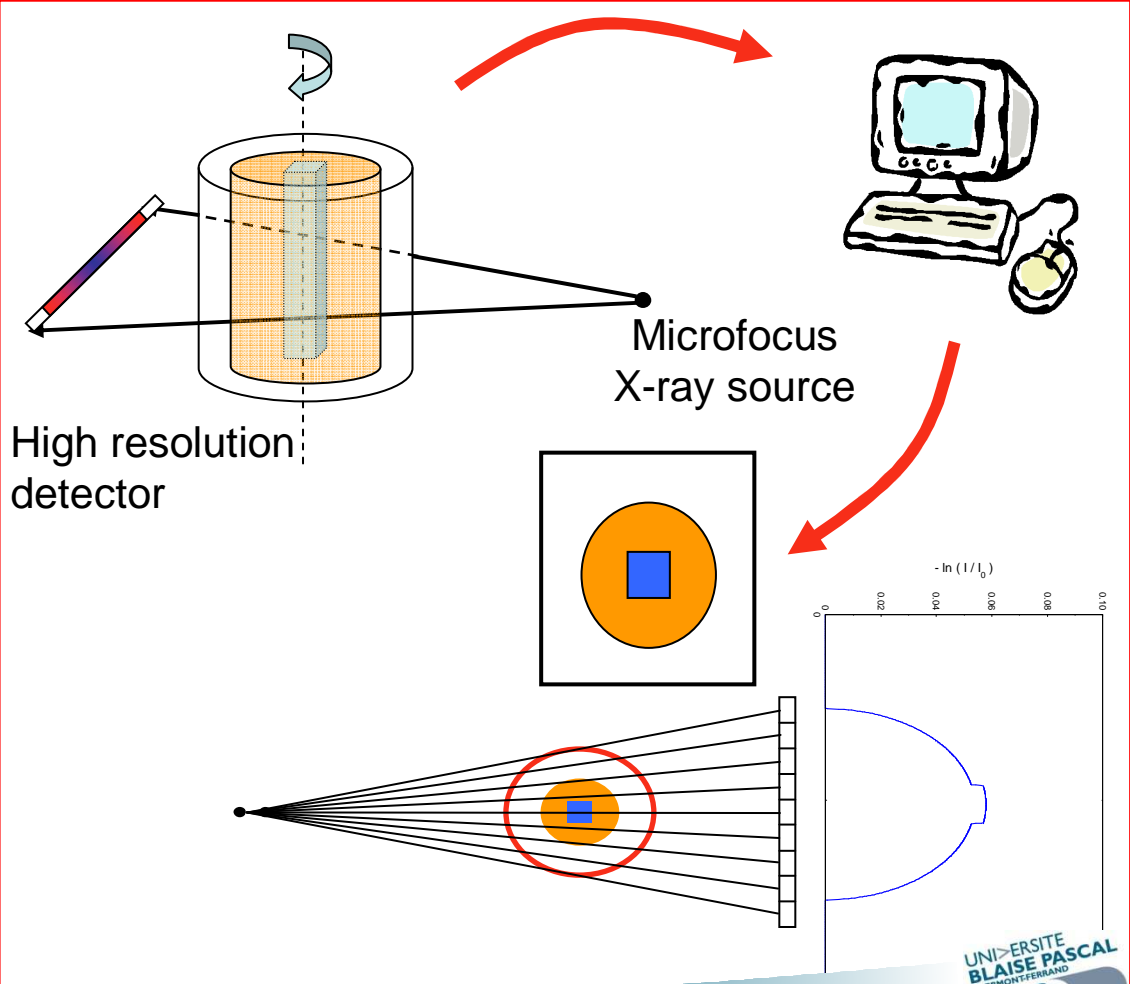
- integrative information through the thickness
- spatial resolution is a function of sample thickness and tomographic components (X-ray spot size, detector...)

2-D X-ray tomography

Medical scanner
(low resolution)



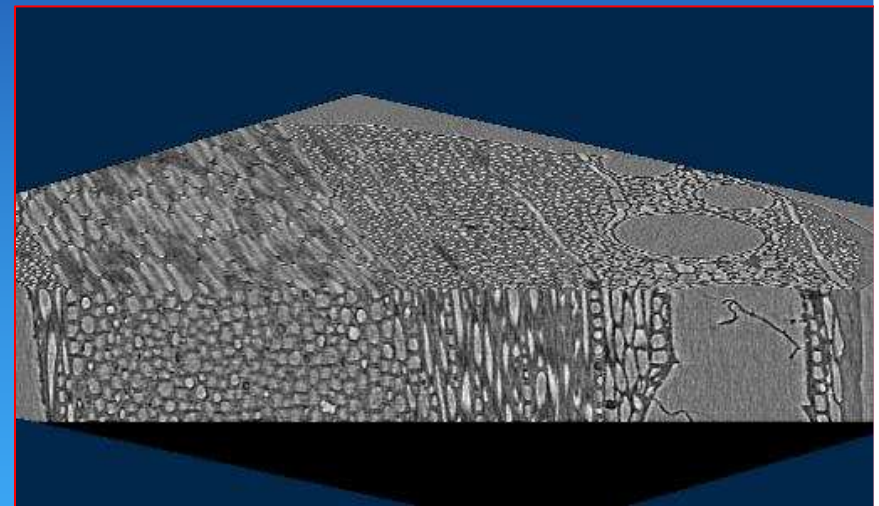
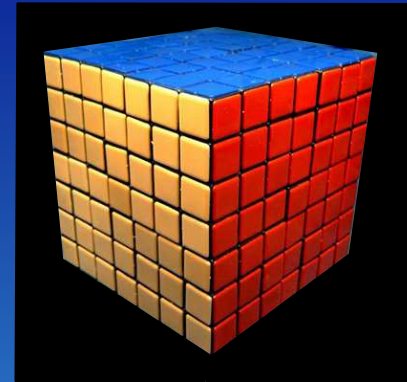
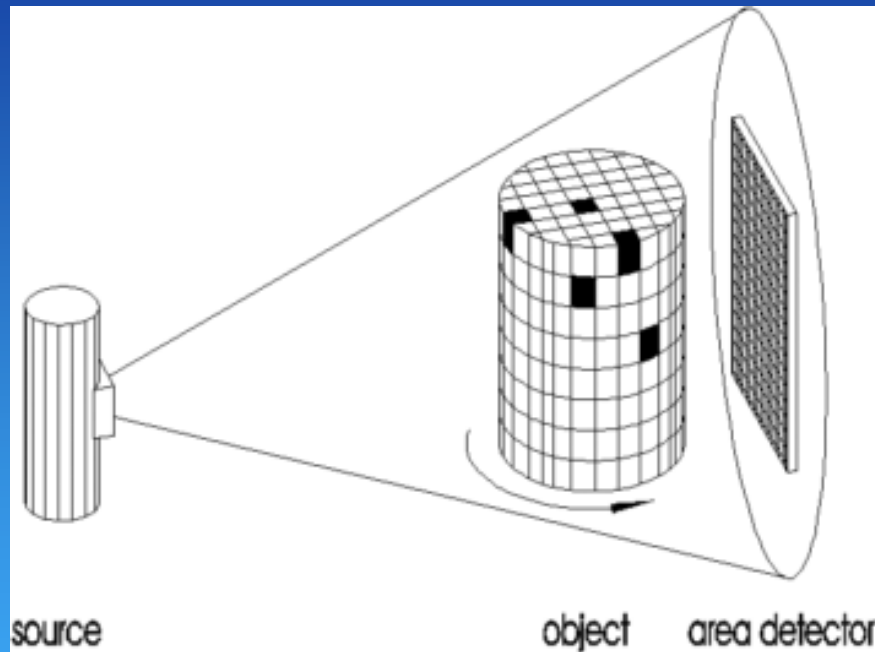
2D tomography
(high resolution)



Supreme Council of Antiquities



The 3D μ tomography



1000 to 2000 projections for 360° rotation

Few X-ray tools



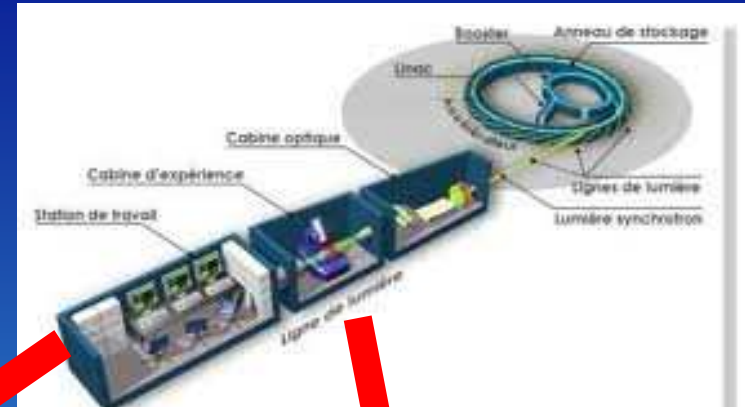
Small lab device

Lab device

Synchrotrons lights

X-ray	polychromatic	polychromatic	monochromatic
Beam	divergent	divergent	parallel
Spatial resolution	5-10 microns	1 micron	0.3 micron
Max sample size	4-5 cm	10 cm	1 mm
File size	16 Go	32 Go	64 Go or more
Scan time	10 min to 1 hour	10 min to 1 hour	1 s to few minutes

The synchrotron lights



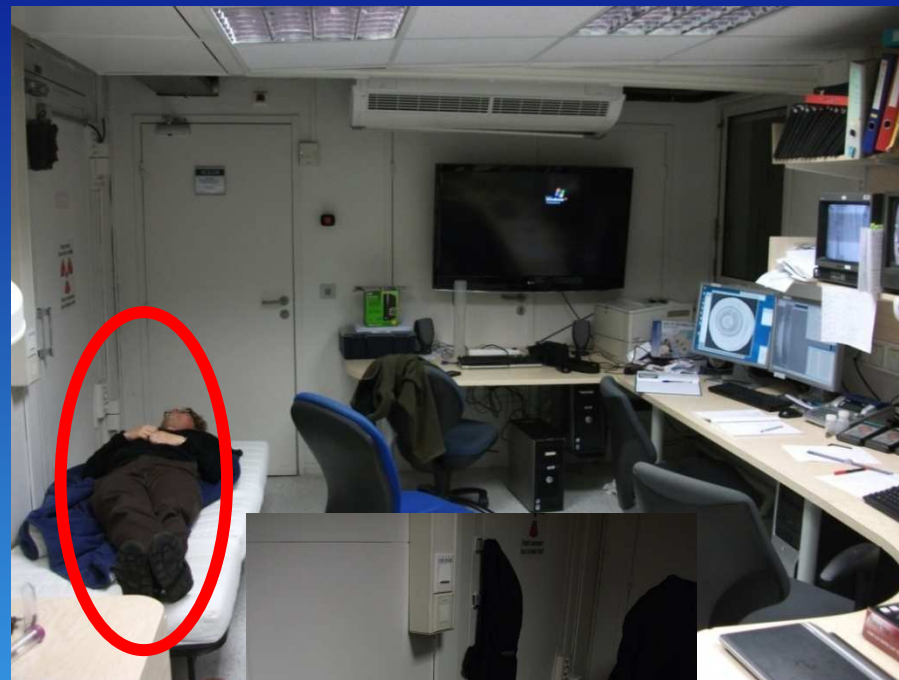
The synchrotron facilities vs lab devices



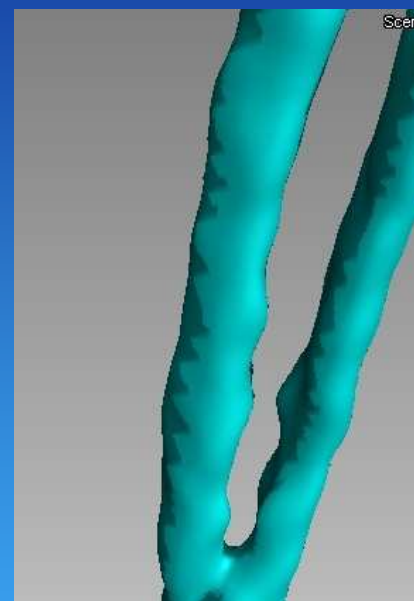
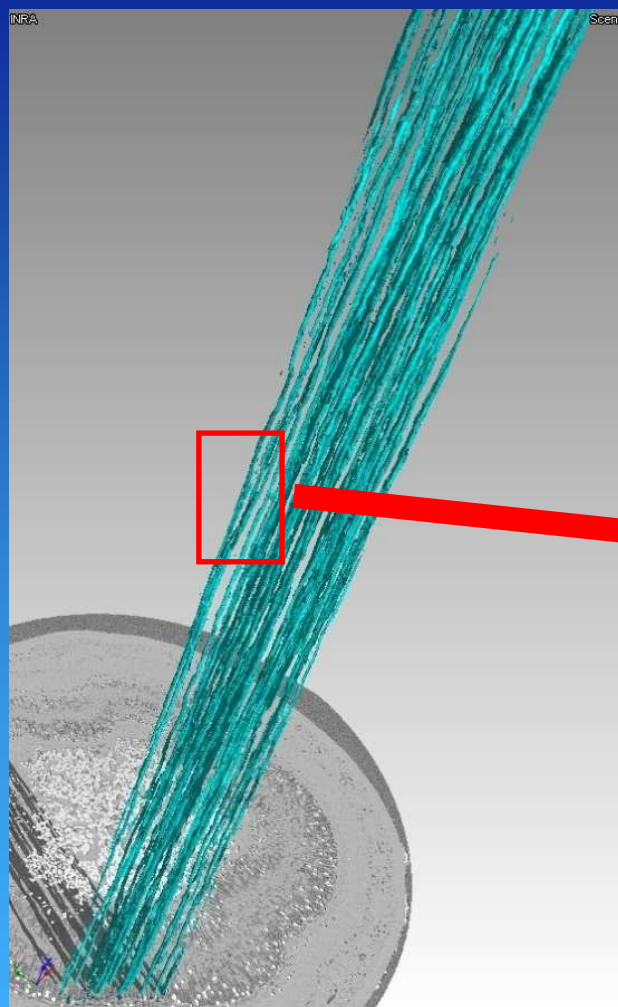
- very high x-ray intensity
- fast scan time
- the sample chamber is huge (but the scanned area is not larger than for the lab tools)



- access after a proposal
- short time experiments
- huge data to manage (1-4 To /j)
- very tiring

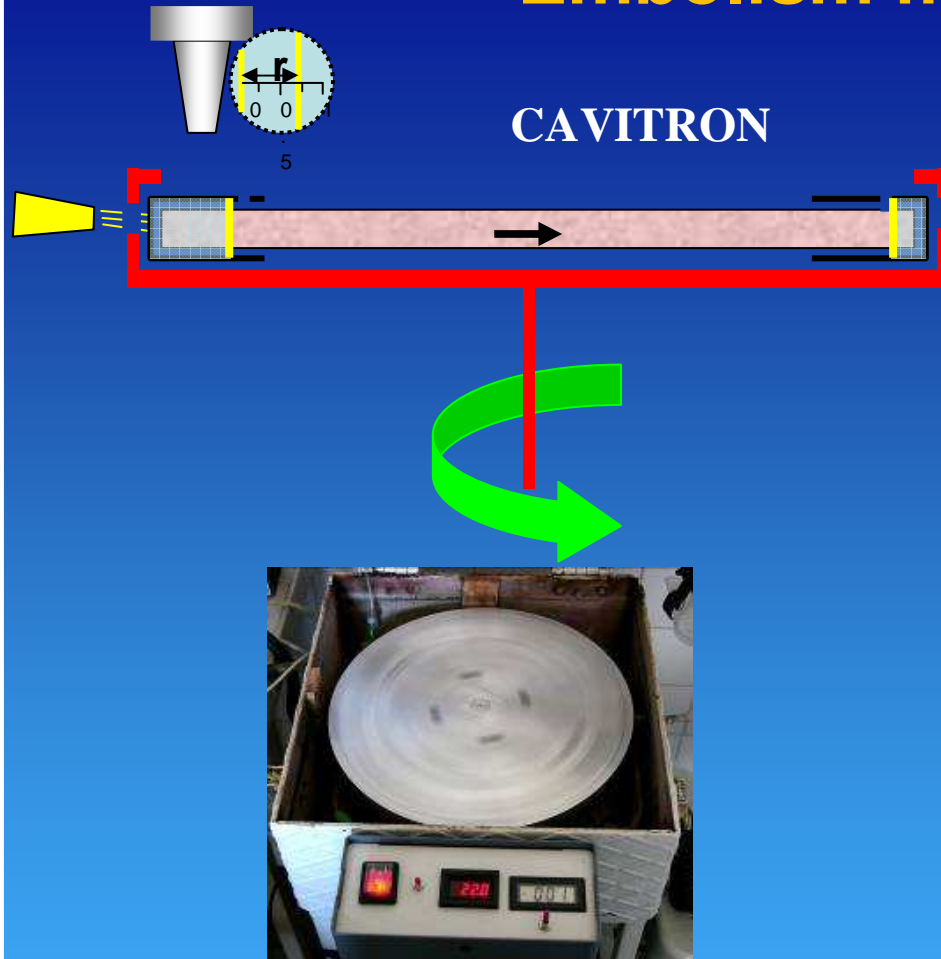


3D hydraulic network observation



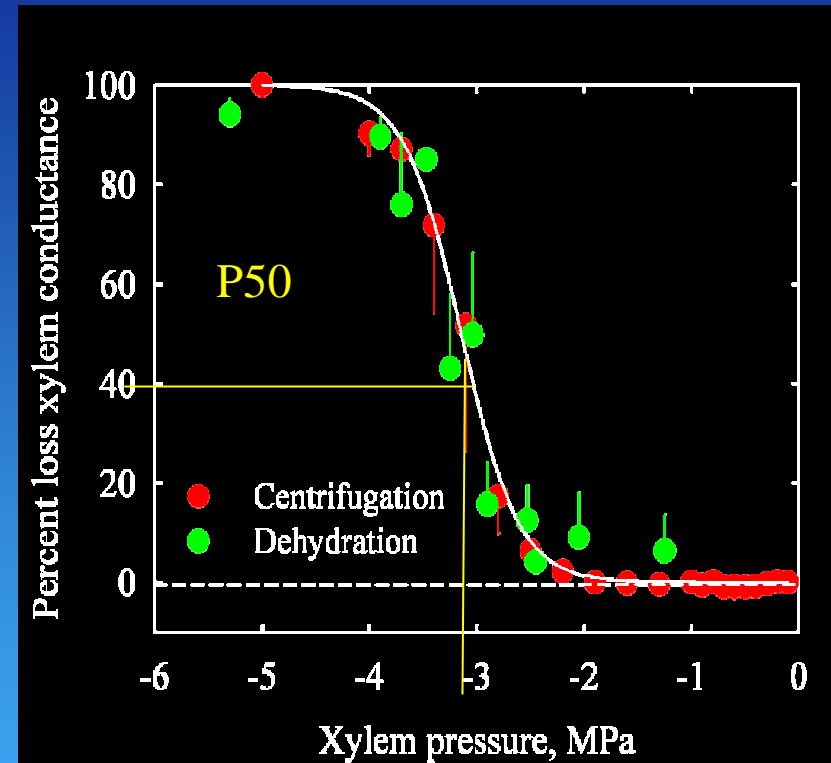
New information about the vessels network

Embolism measurements



Cochard et al 2005

Vulnerability curve

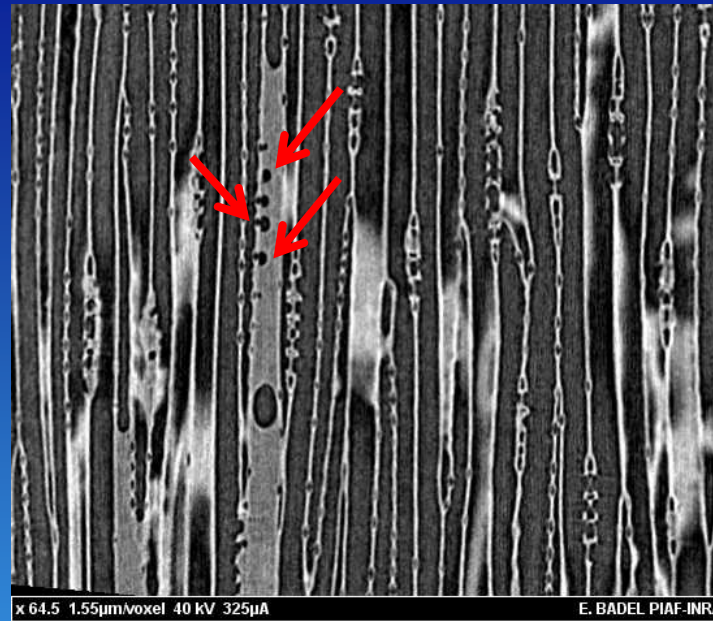
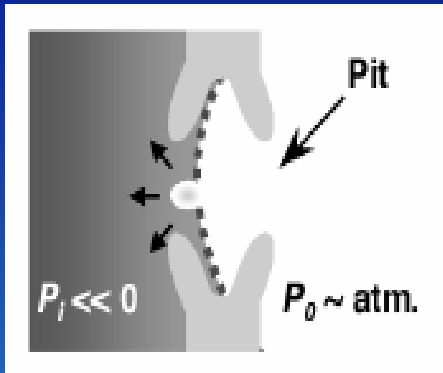


Increasing tension and measurement of the loss of conductivity
The big issue: not available for long vessels species

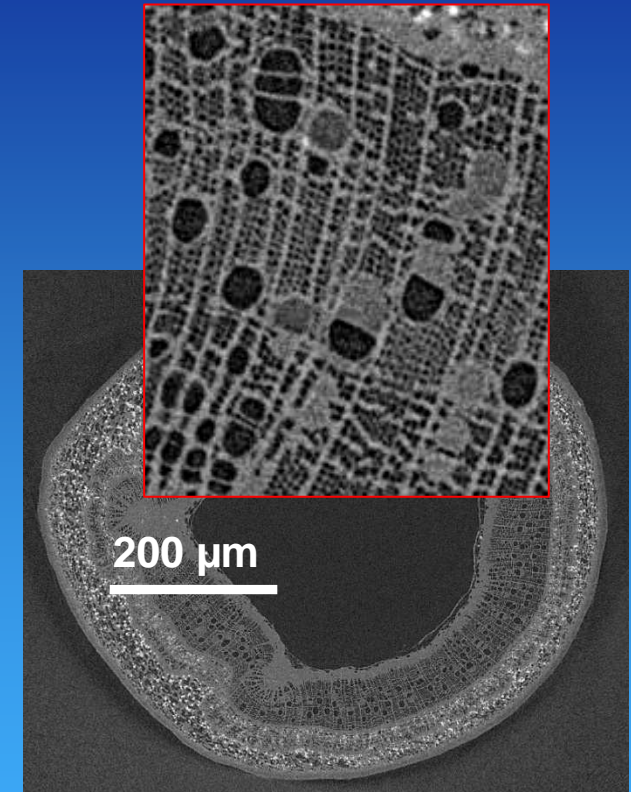
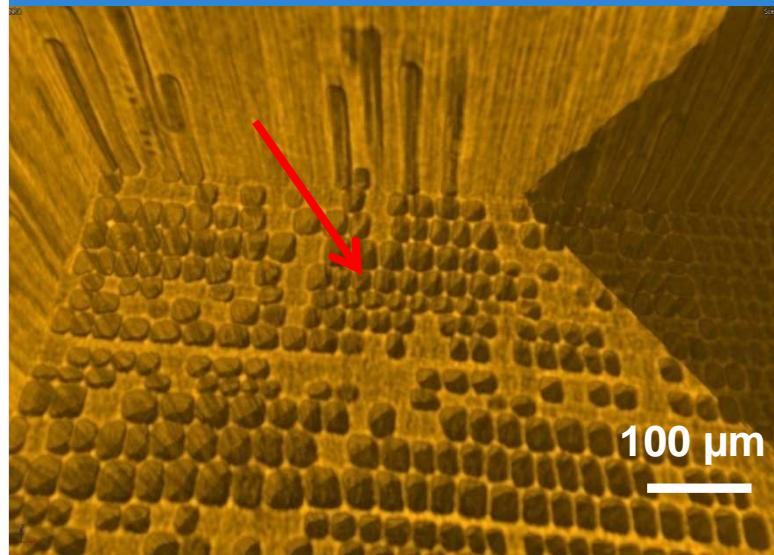
Embolism observation and measurements



Pinus sylvestris



Douglas



Walnut tree

What did we learn about embolism process thanks to X-ray tomography?

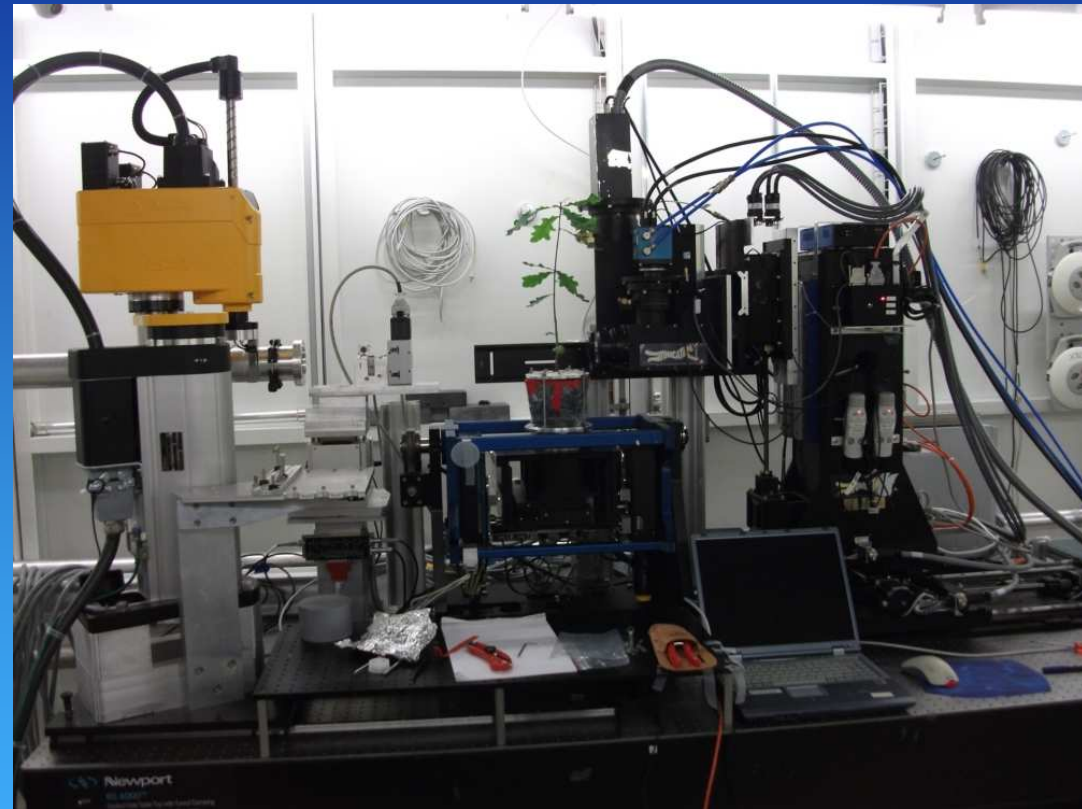
Few experiments using synchrotron radiations or
our Nanotom (Clermont-Ferrand)

Experiments using synchrotron light and living trees

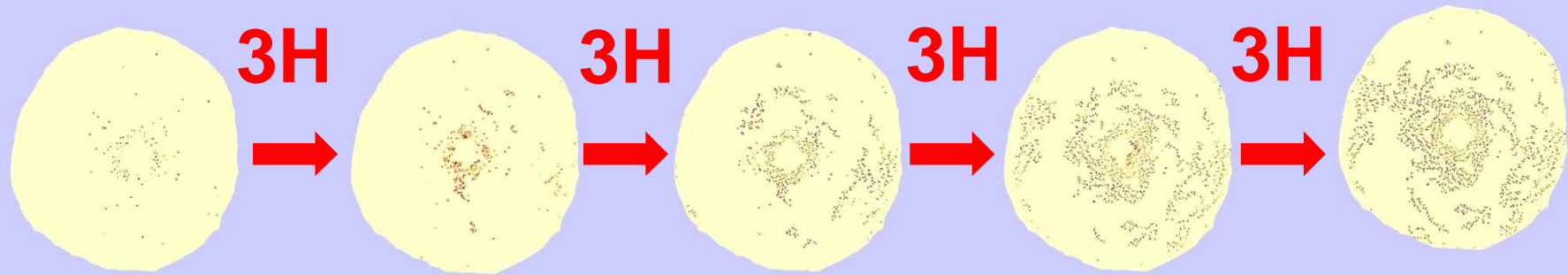


Experiments using synchrotron light and living trees

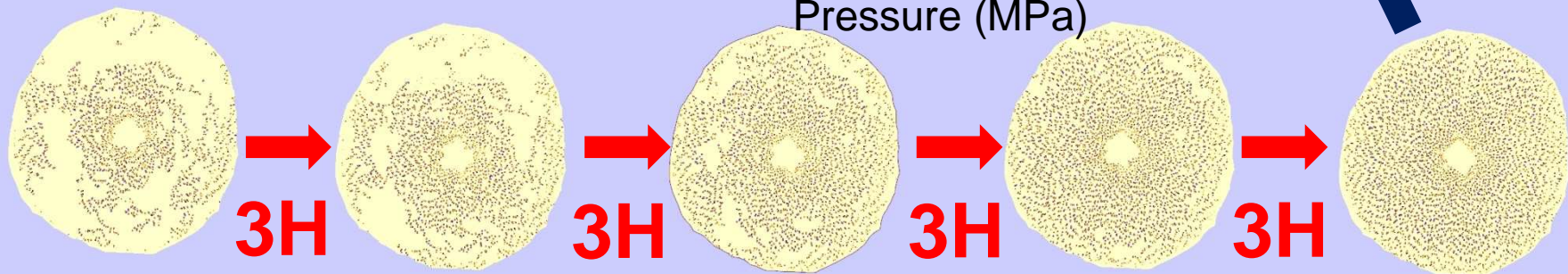
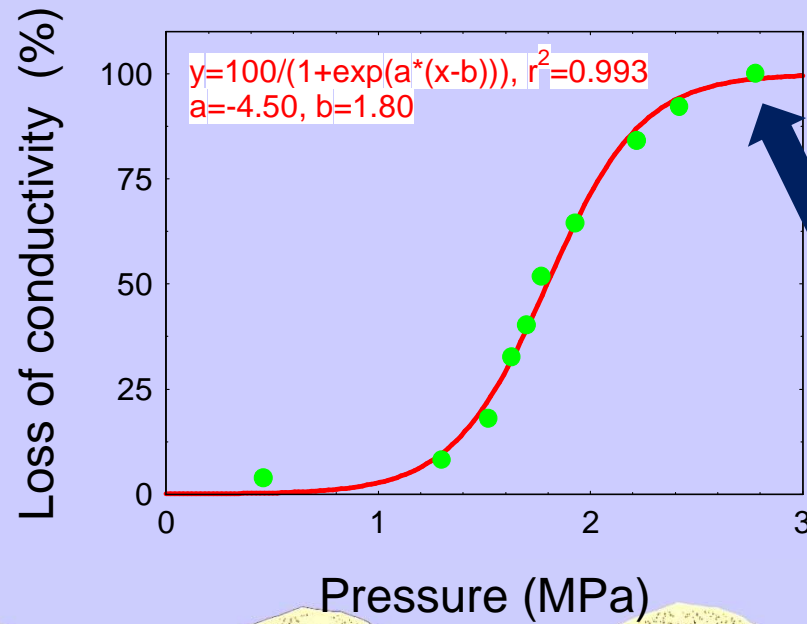
light stimulation, fan, root stress => tension in hydraulic conduits



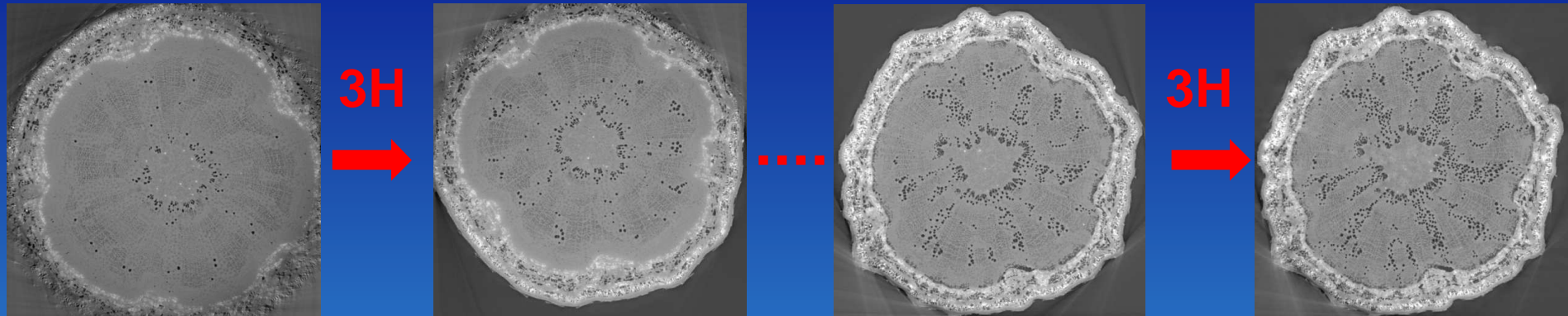
Live embolism spreading observation (poplar tree)



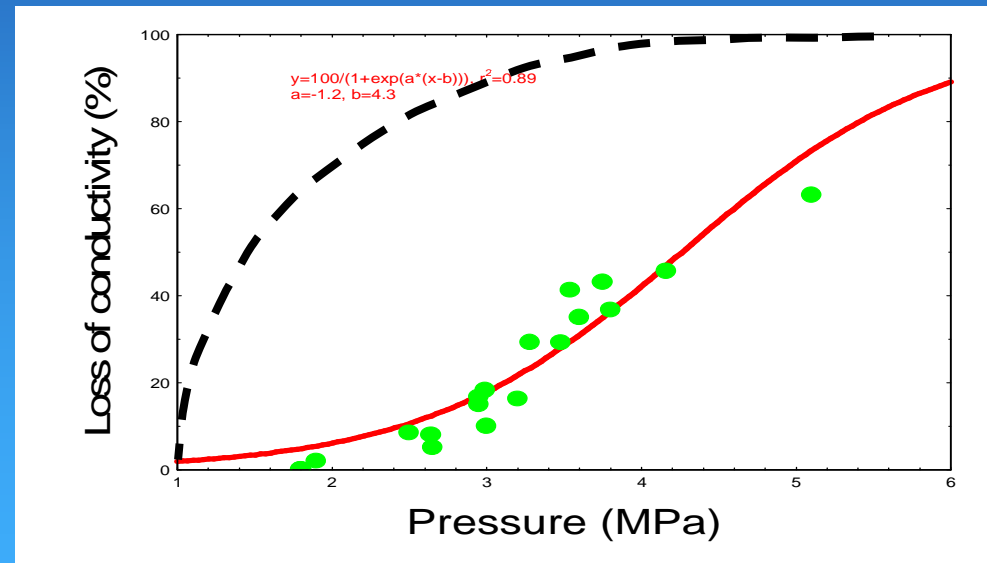
10 min / scan using
synchrotron radiation
(Swiss Light Source)



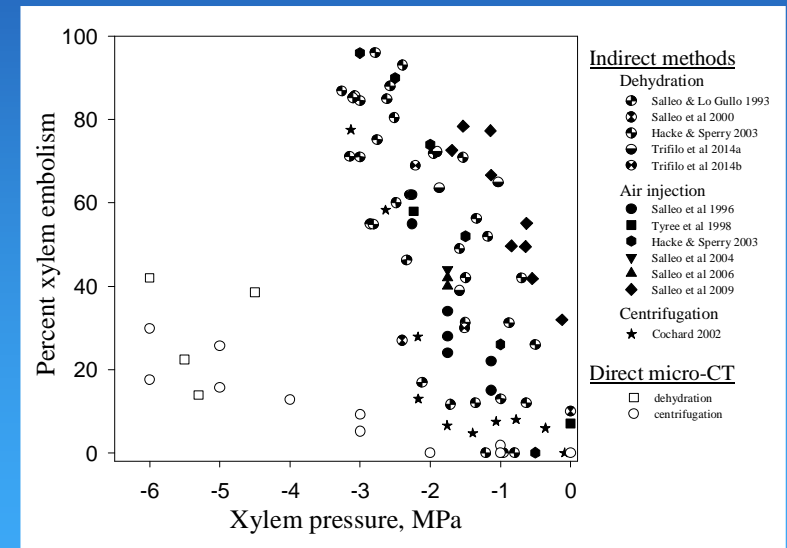
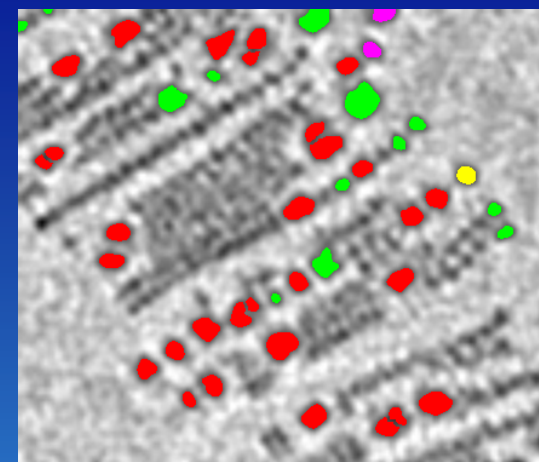
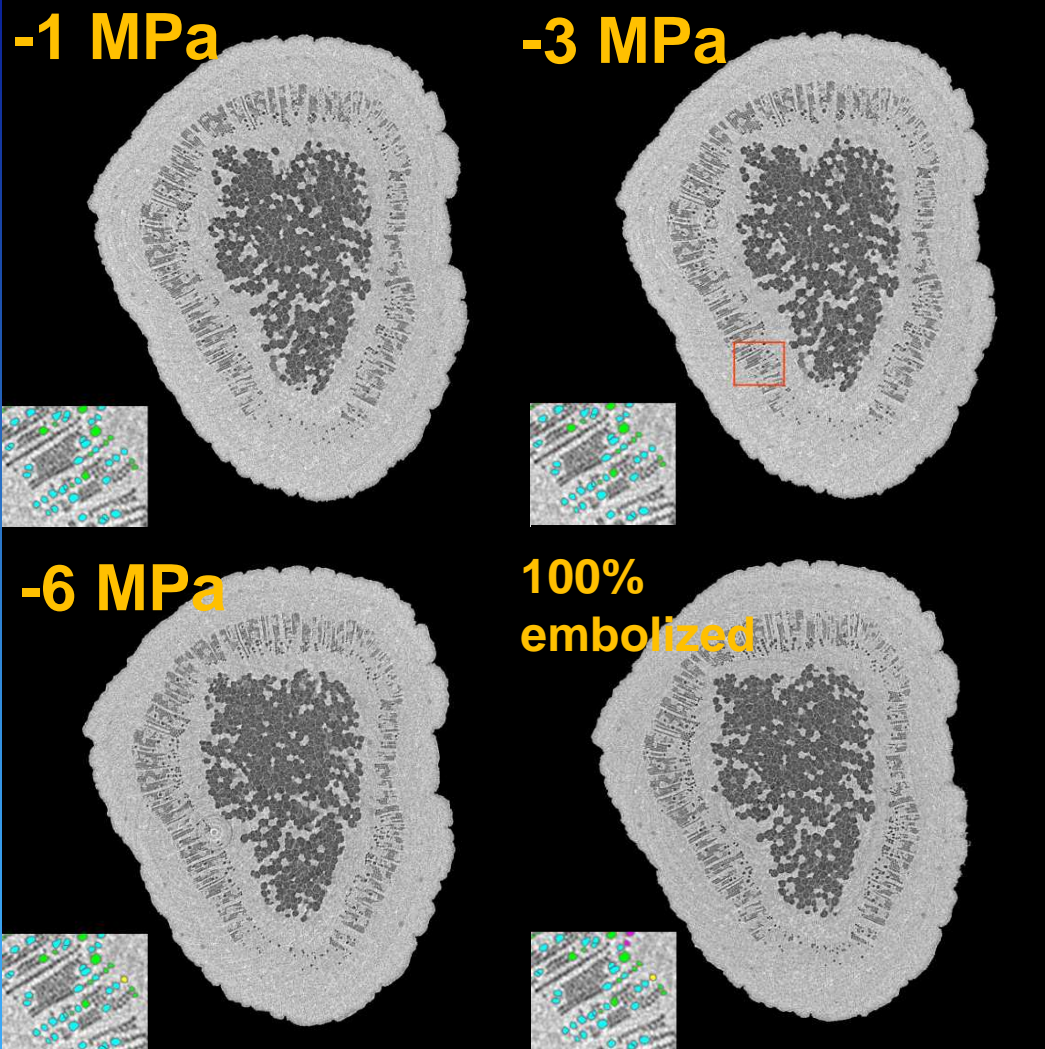
Live embolism spreading observation (oak tree)



Cavitron
X-ray images



Laurus: long vessels species



(Cochard, Delzon and Badel , submitted)

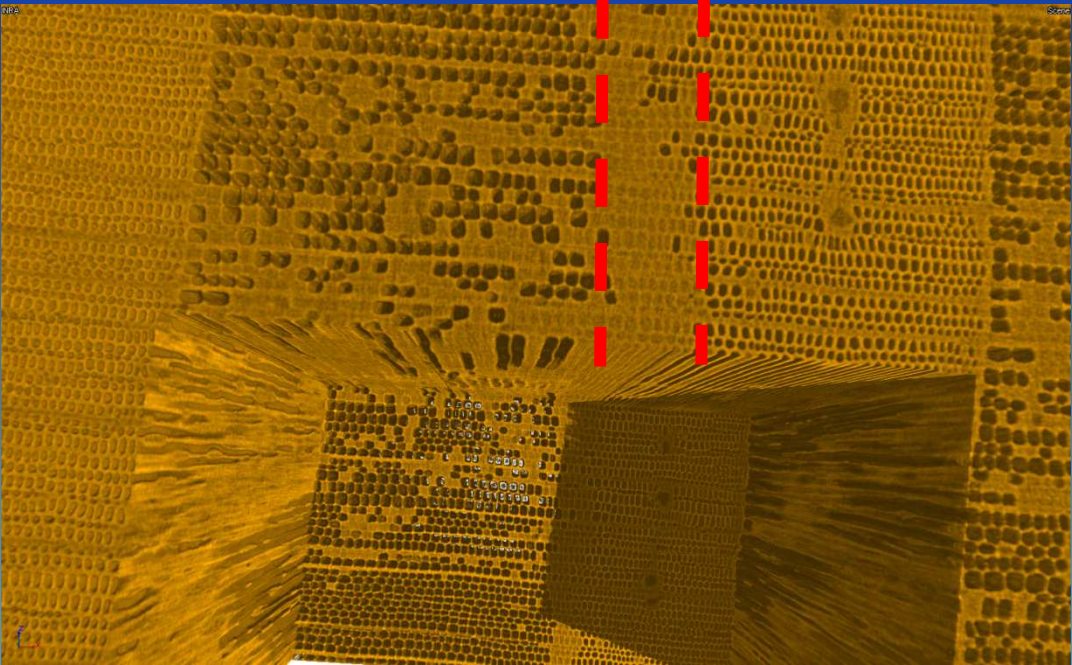
Long vessel species , with big vessels do not show 'R' shaped vulnerability curve and can be very resistant!



Embolism start

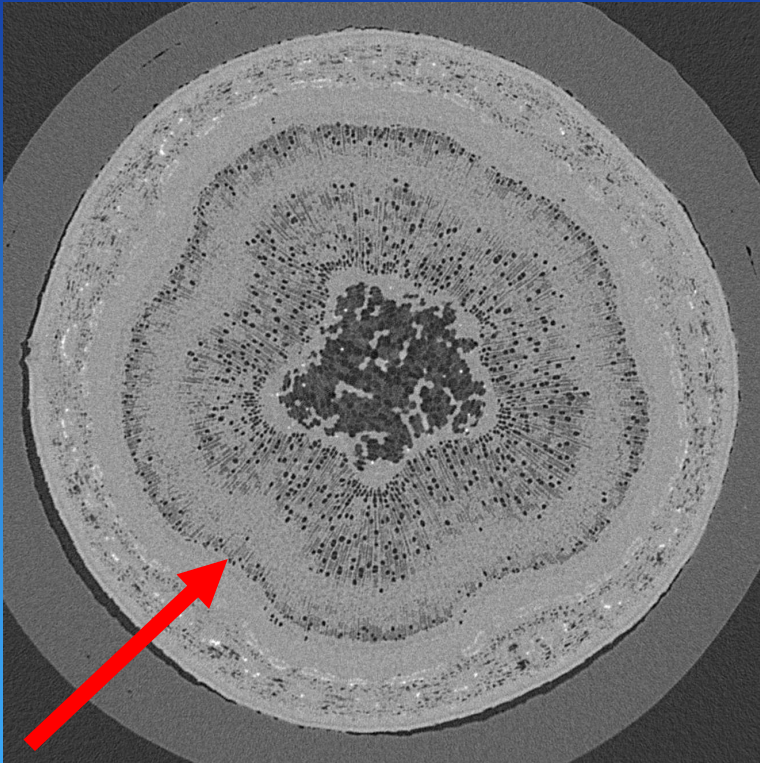


Douglas



(Dalla Salda et al, unpublished)

Poplar

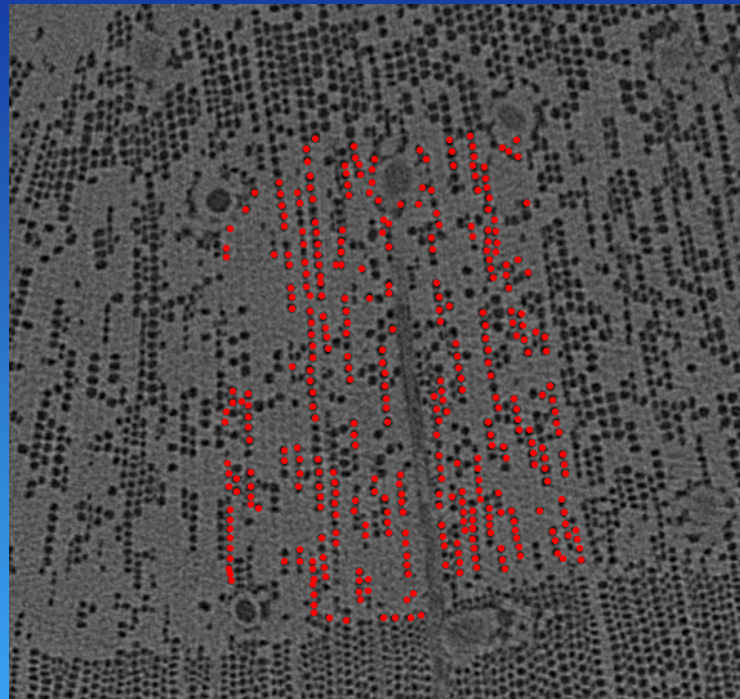
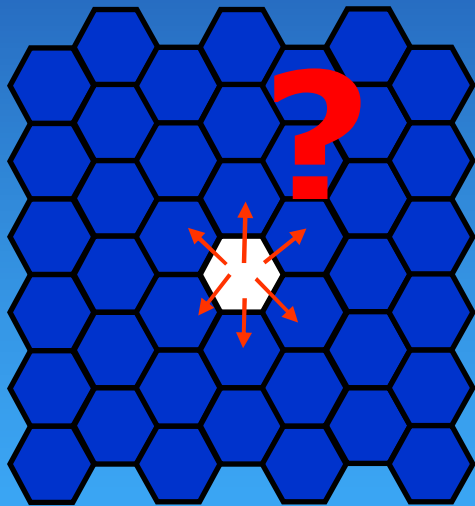


At the annual ring level, embolism is not a random process!

Embolism spreading



-1.5 MPa



At the cell level, lonely seeds of embolism start more or less randomly; then spreading occurs in radial direction.
Question: how?

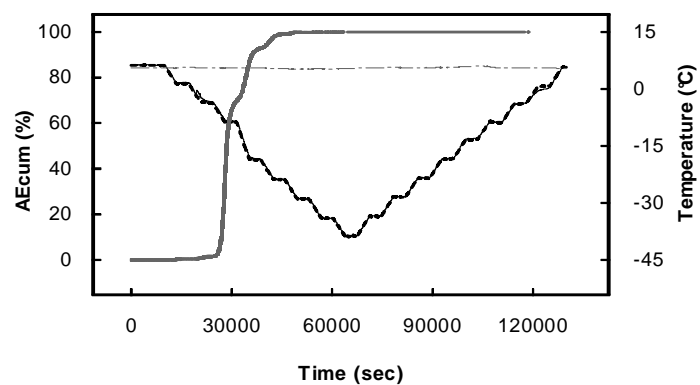
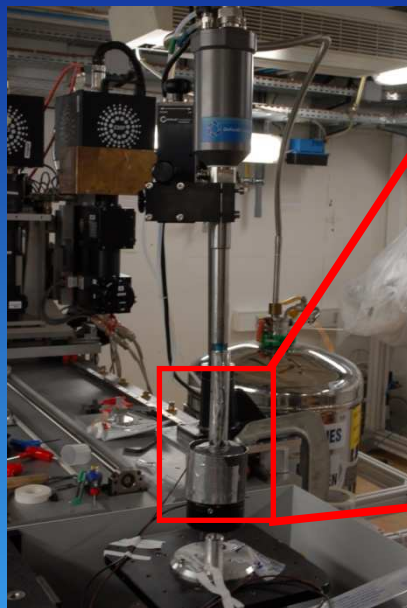
Freeze/thaw induced embolism



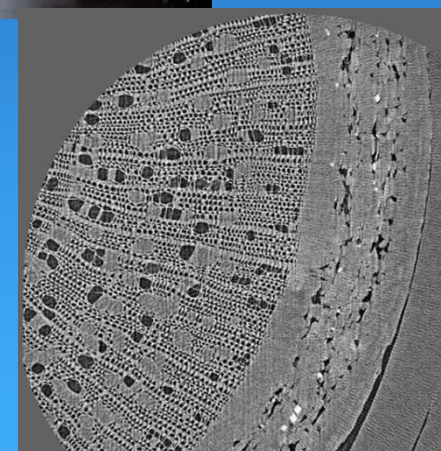
Freezing box



Cryo-stat



Acoustic recording during X-ray scan



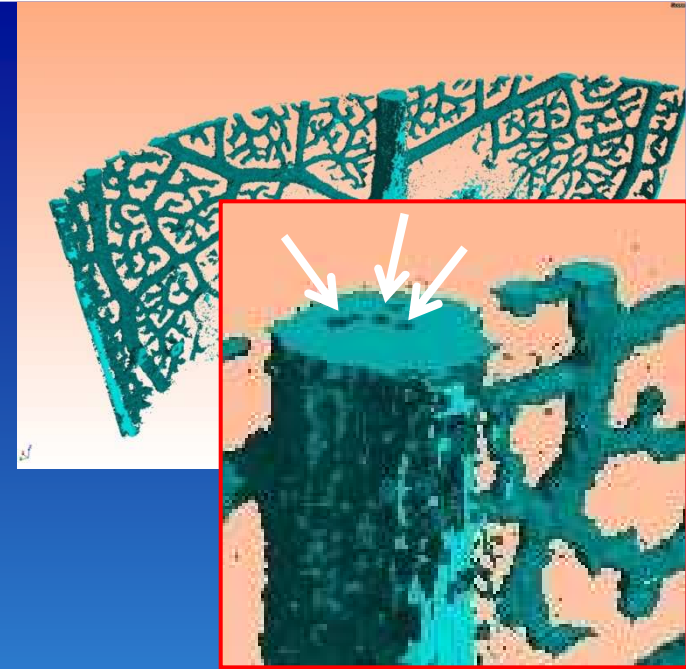
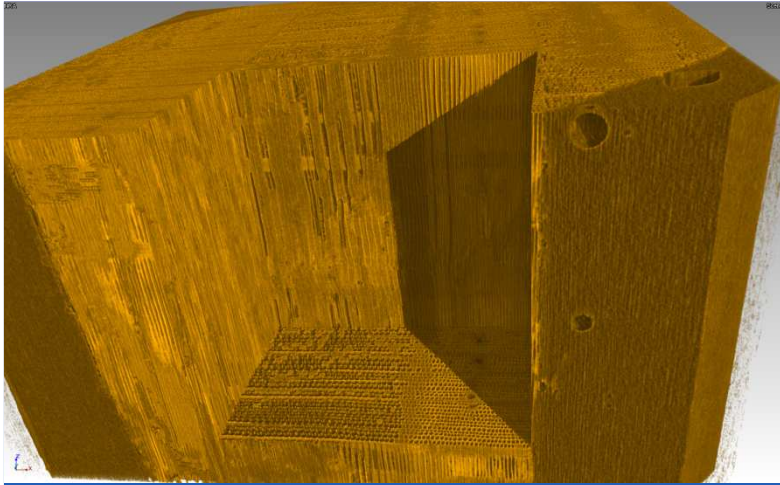
Charra Vaskou, Badel, Charrier, Mayr, Ameglio, in prep.



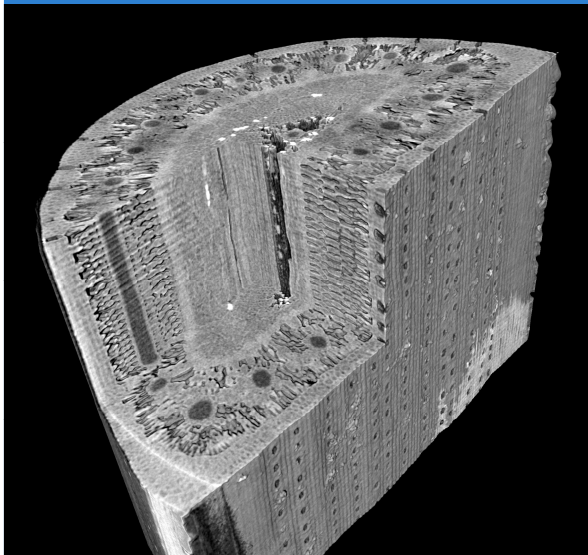
Conclusion - Prospect

- **X-ray observation may over-estimate the embolism but never under-estimate it!**
- Great opportunity to look inside living trees under stress
- Visualization will help to understand the mechanism.
- X-ray tomography is becoming a reference method for embolism evaluation!
- Need to ensure the tree health is not impacted by the x-ray radiations
- Need to improve the sample environments for stresses control (cold, heat, RH%, light)
- We always want more : higher resolution with larger field of view and faster scans.





Thank you



...and if you do not have a synchrotron,
you're welcome in Clermont-Ferrand

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