In situ experiments using X-Ray tomography

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Outline

- Introduction
  - Motivation
  - X ray imaging Setups
- 1. In situ capabilities of X-Ray tomography
  - Deformation
    - Tension
    - Double torsion, Hydrostatic pressure, Fatigue
  - Temperature
    - Heating
    - Cooling
  - Mixed :
    - Hot tension
- 2. Case studies :
  - Ductile damage
- 3. FE and DVC
- 4. Prospects (high resolution, high speed)

Motivation for in situ experiments

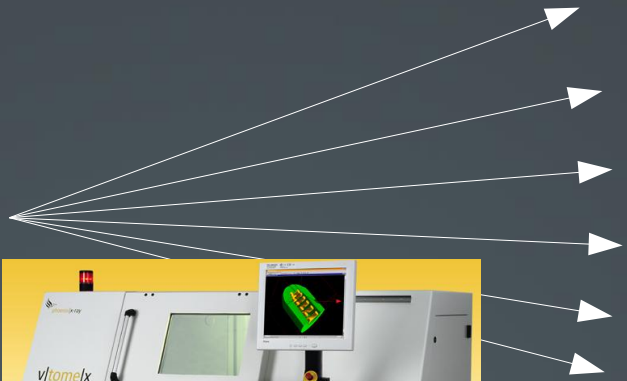
- Experimental mechanics : identification of the mechanisms at play *mostly by imaging*
  - What is hapening to the microstructure under load ?
  - Thermal, Mechanical...
- Allows to :
  - Understand
  - Optimize
  - Model
- Standard ways used so far to achieve this : OM, SEM, TEM, AFM
- Ideal imaging method : non destructive + bulk

All you need to know about XRCT (to understand this talk...)

- Radiography = bulk information but projected in 2D : $I=I_0.sum(exp(-\mu x))$
- Tomography (medical scanner) = 1000 radiographs of a same sample at different angles
- X-ray source + absorption detector + rotation stage
- Computed reconstructed step
- Final image = 3D map of μ

SETUPS : Parallel/divergent beam

- Two different systems :
  - Synchrotron (parallel, monochromatic, intense)
  - Laboratory tomographs (divergent, polyλ, weak)

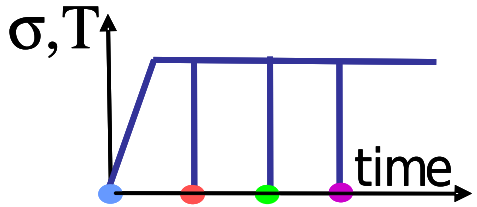


Different constraints on the in situ devices

Different ways of studying microstructural evolution

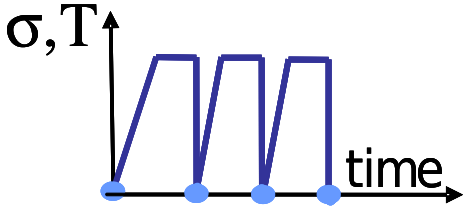
Whatever the observation method

Post mortem



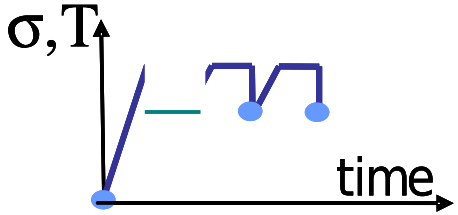
Several samples
Tomography at RT

Ex situ



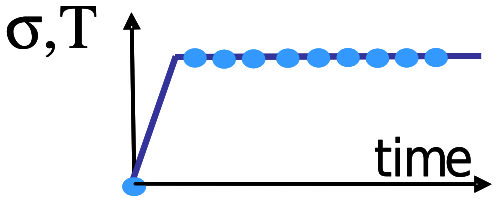
One sample
Treatment out of the tomograph
Tomography at RT

Interrupted in situ



One sample
Treatment carried out
on the tomograph

Continuous in situ



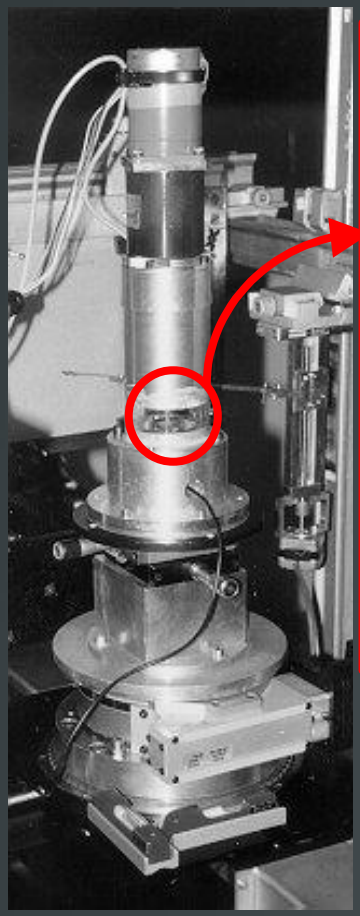
One sample
Treatment carried out
on the tomograph
No interruption

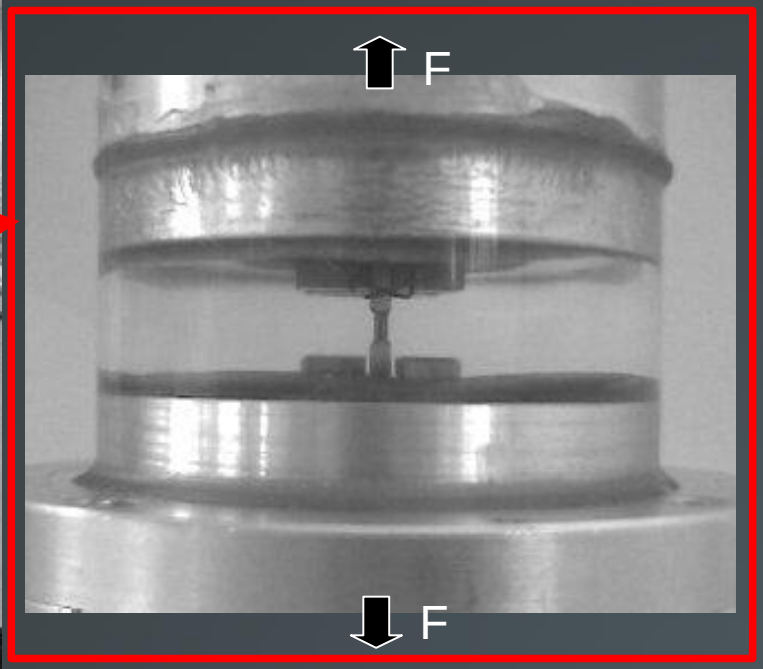
1. Deformation

A standard tensile frame (pillars) induces missing views ...reconstruction ?

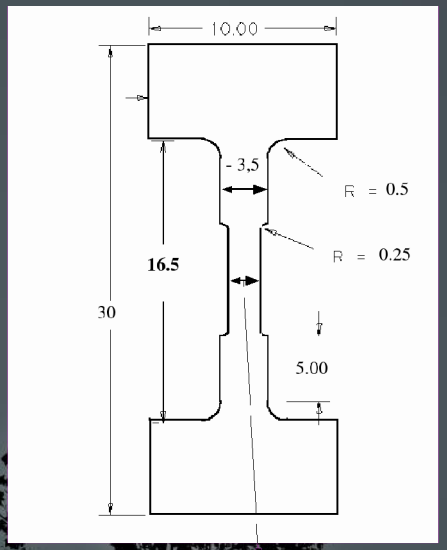
In situ testing

- Tension, compression





- Stepping motor
- Reductor
- F and disp recorded
- 10^{-5} – 1 mm/s
- Several Force sensors : 50 – 5000 N
- Grips adapted for different geometries

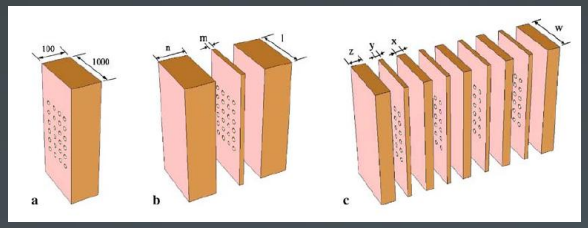


Buffière et al. Acta Mater 1998
Buffiere et al Exp Mech 2009

A lot achieved so far in the interrupted mode (15 years at the ESRF)

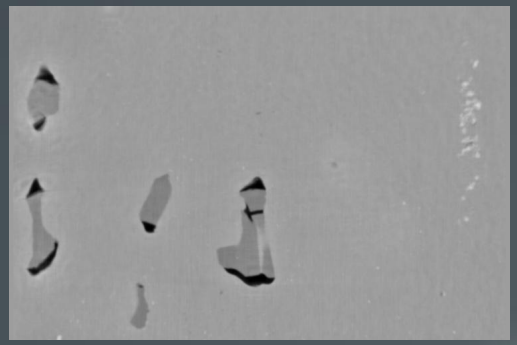
- Al/SiC
- TiSiC
- Al alloys
- Polymers, Composites
- Steels
  - DP,Trip, TWIP
- Co, Cu, Ti

- Model materials



Cu sheets
Mc Master University

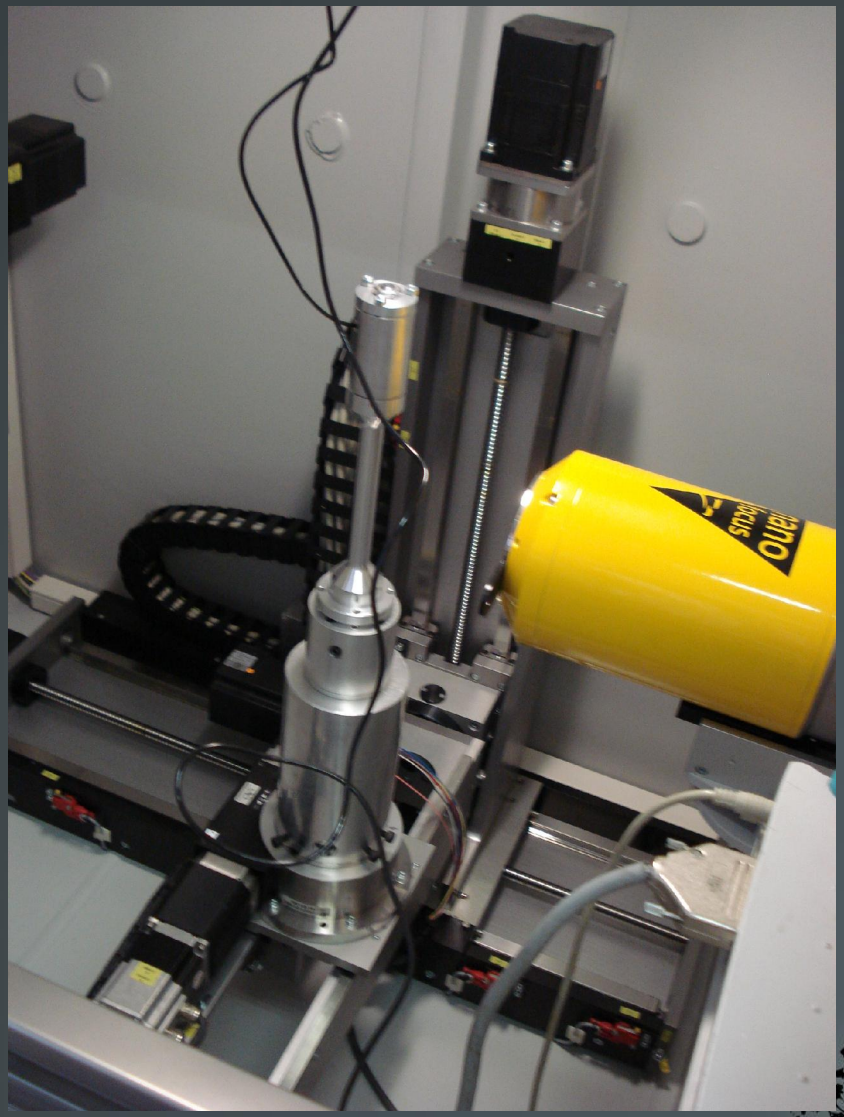
- Industrial

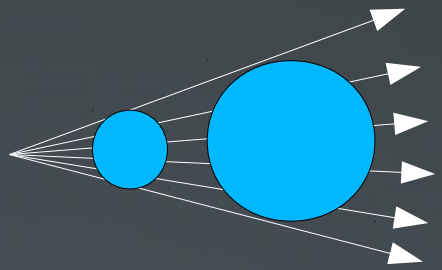


Al alloy 5xxx

From this initial machine : derivations

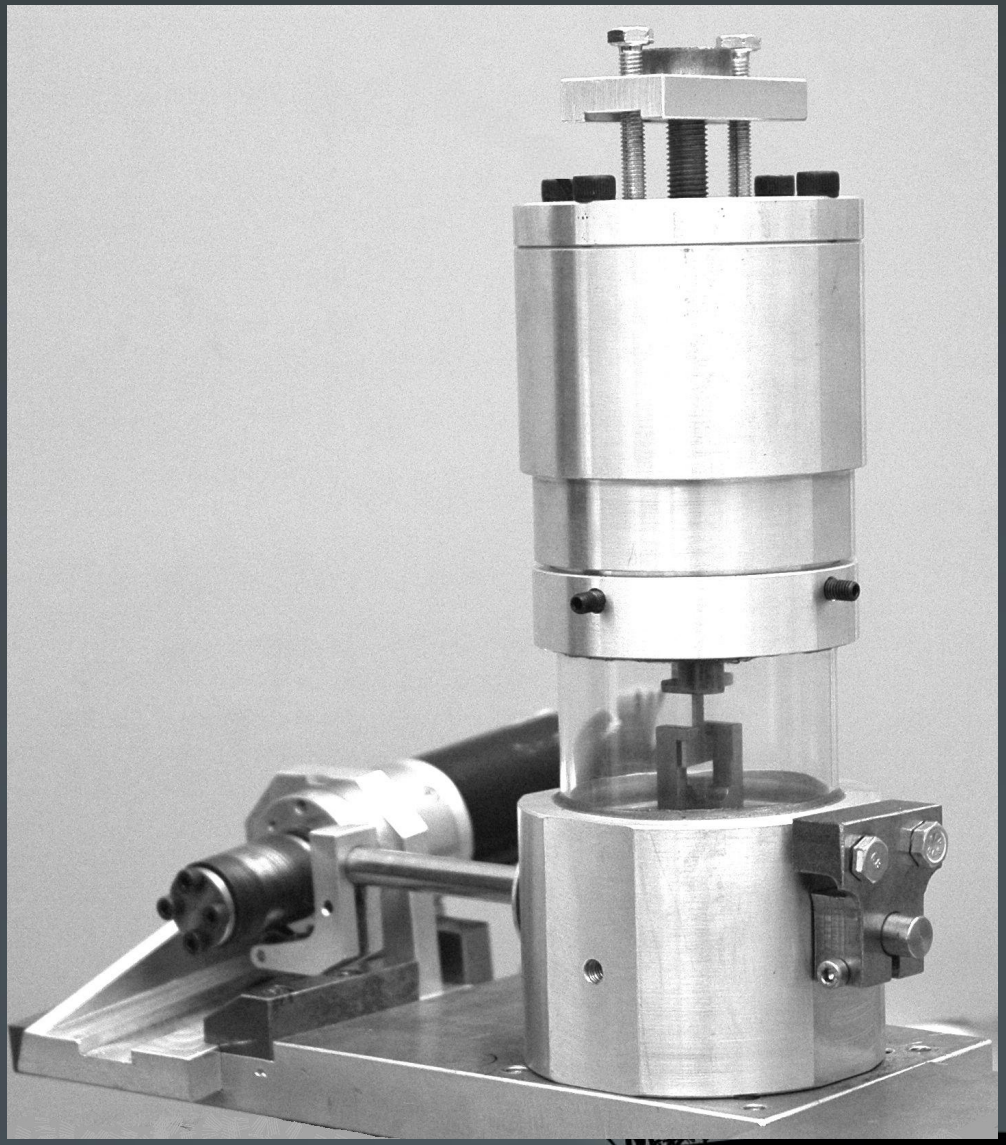
For a lab tomograph :

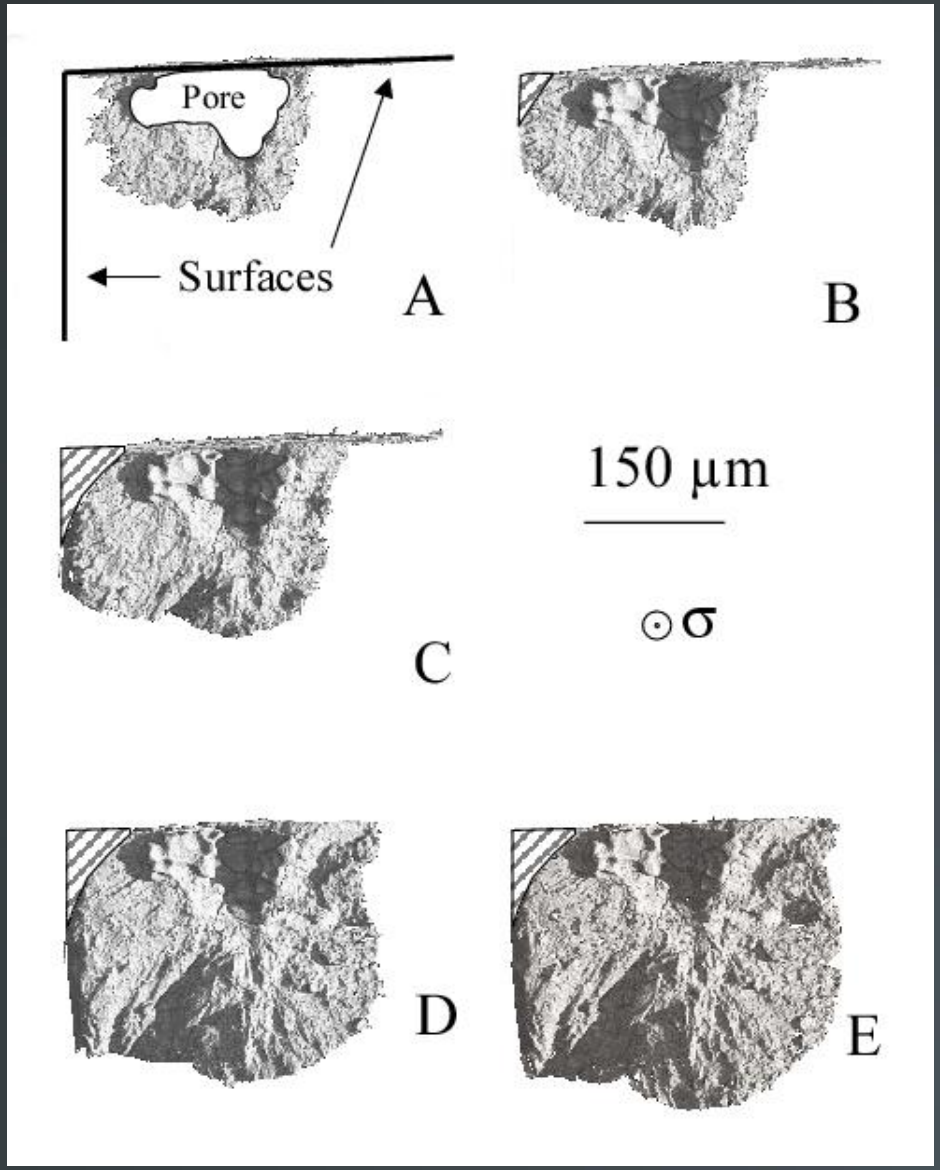




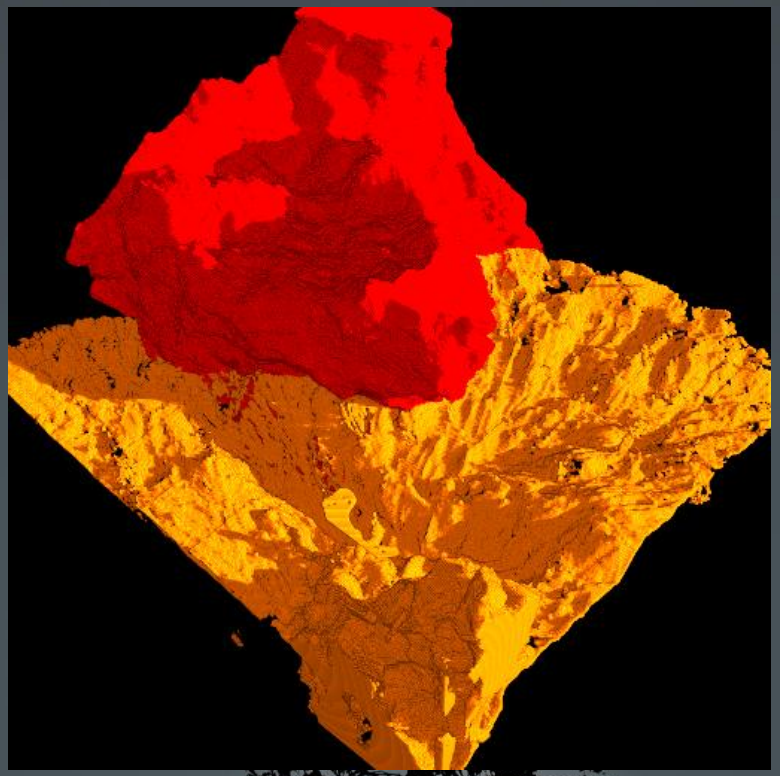
Faster (fatigue device)

- 50 Hz
- Tension mostly , Buffiere et al.
- Ex situ compression of metal hollow spheres, Caty et al.



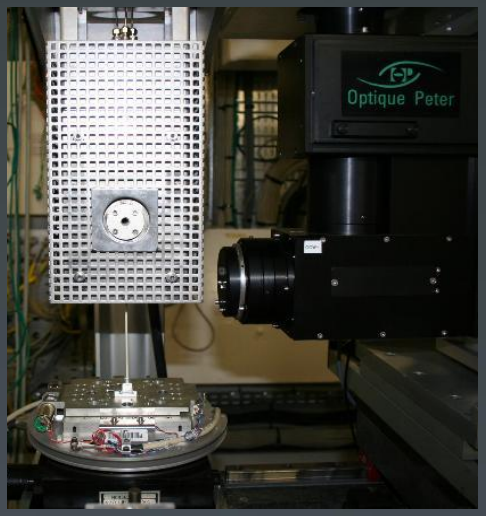


- JY Buffière, W Ludwig
- Cracks initiate at the pore/surface intersection

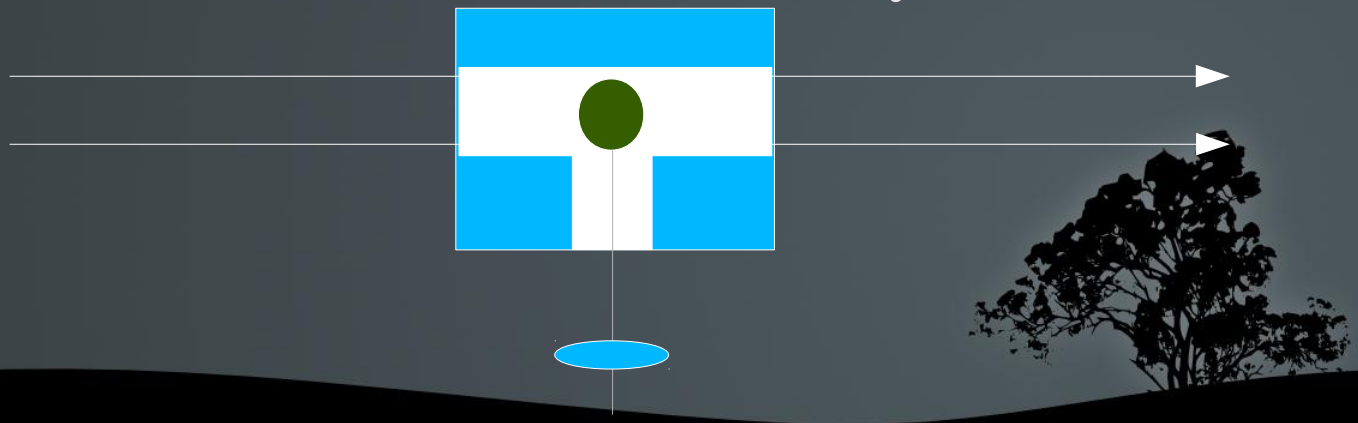


2. Temperature

Furnances



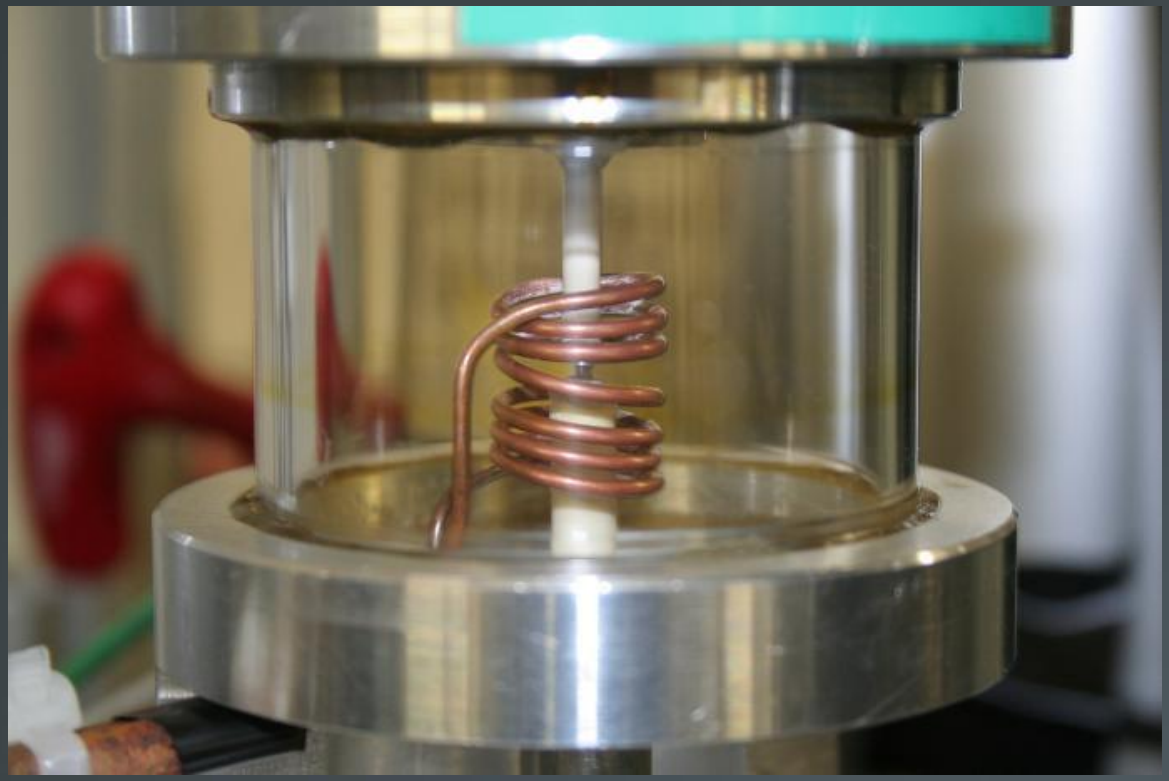
- The problem of missing views vanishes
- Different technologies for heating
  - Lamps
  - Induction
  - Standard resistors
- The sample rotates in the furnance which is fix and equipped with windows for the X rays



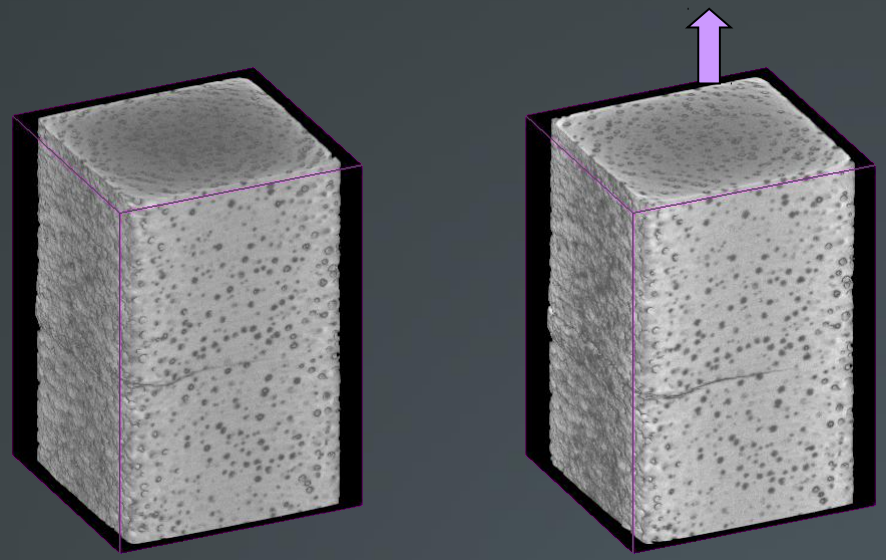
Cooling

3. Both Temperature+Deformation

Tension test in the semi solid state

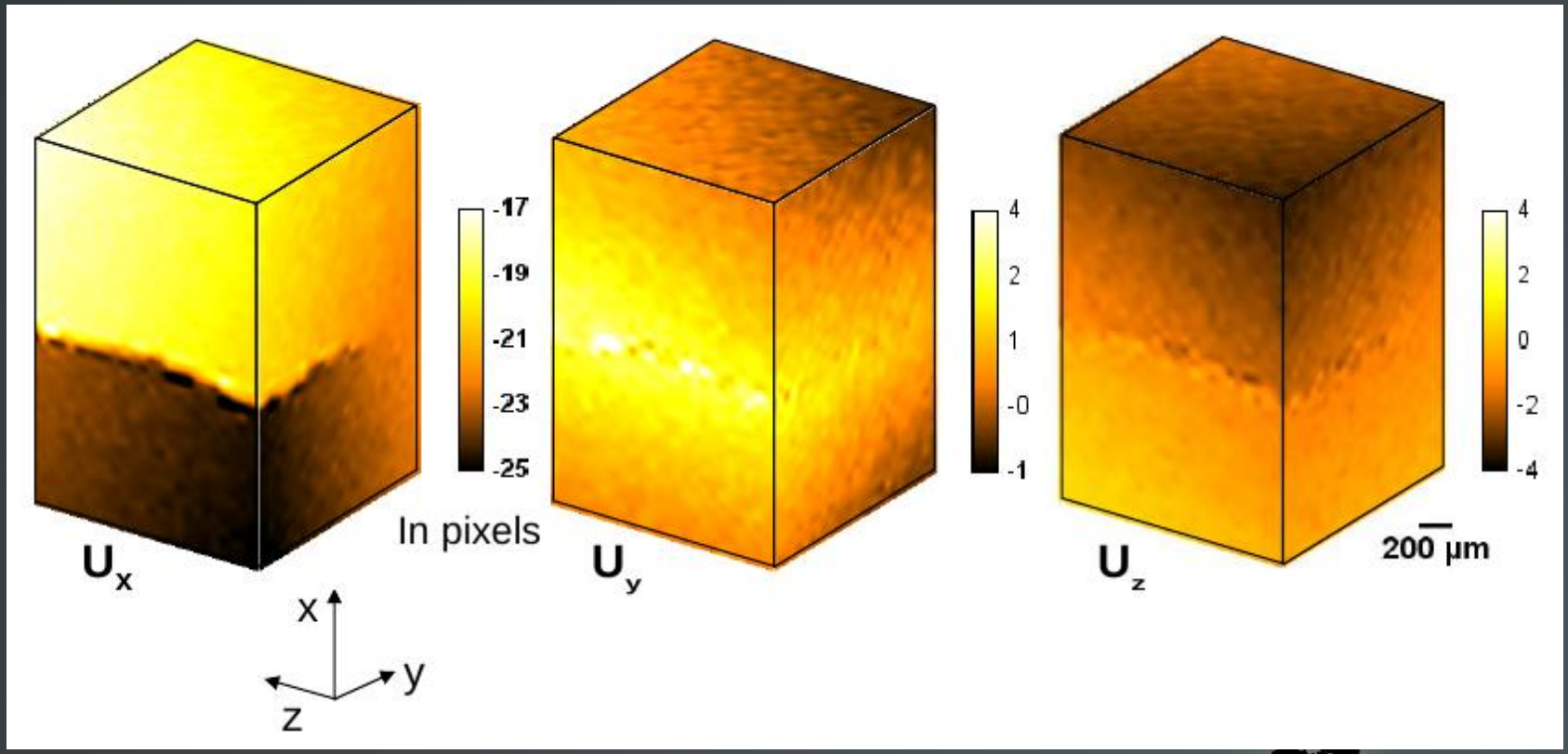


DVC
the propavenfis project



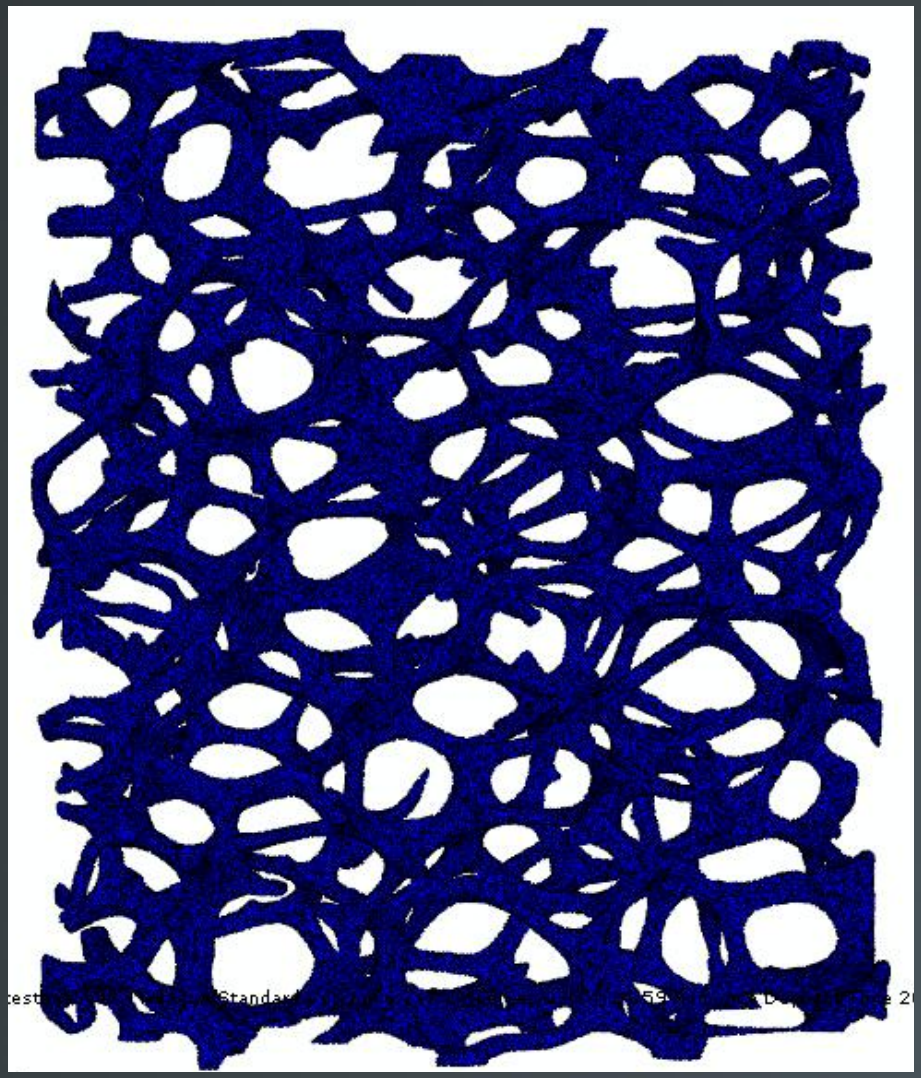
- Two images of the specimen in reference state and in deformed state obey the following relation:
  - $f(\mathbf{x})=g(\mathbf{x}-\mathbf{u})$ *optical flow conservation*
- From the knowledge of f and g, the problem consists in estimating **u** as accurately as possible

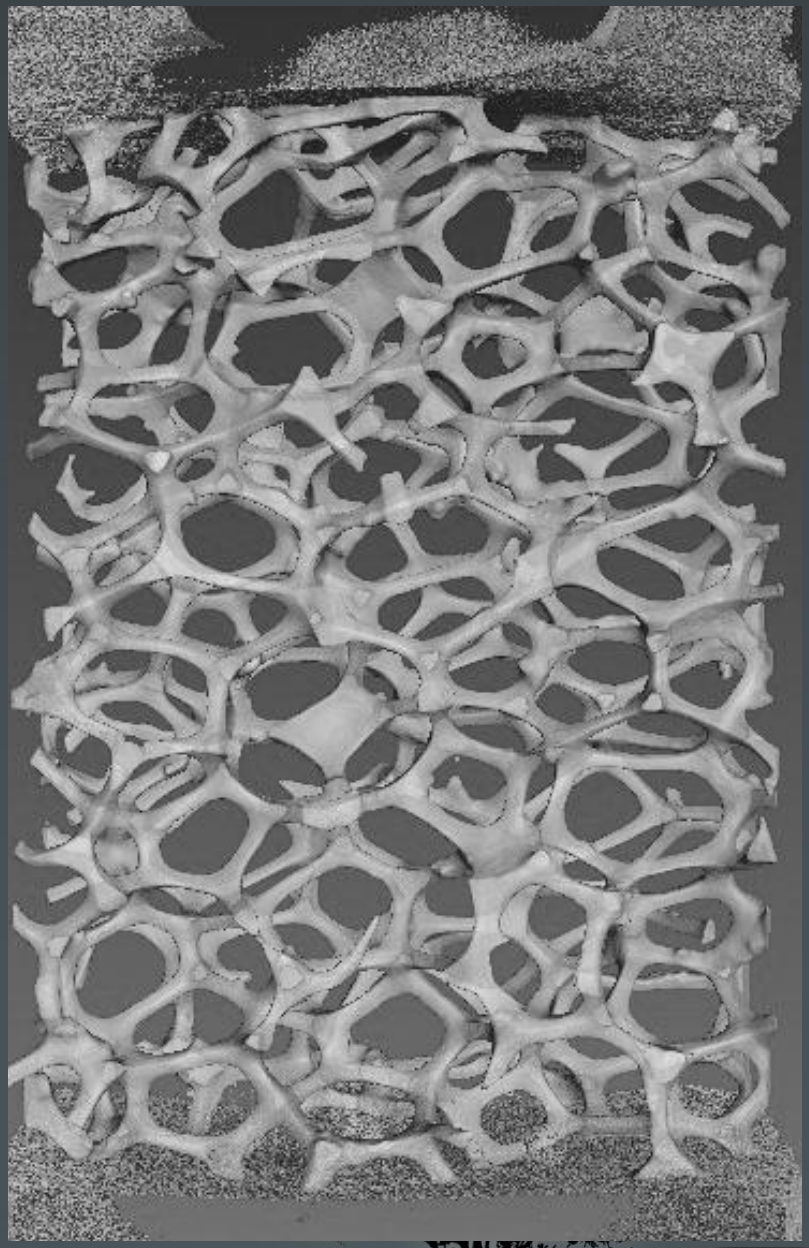
3D displacement fields



- Mainly mode I opening (Ux)

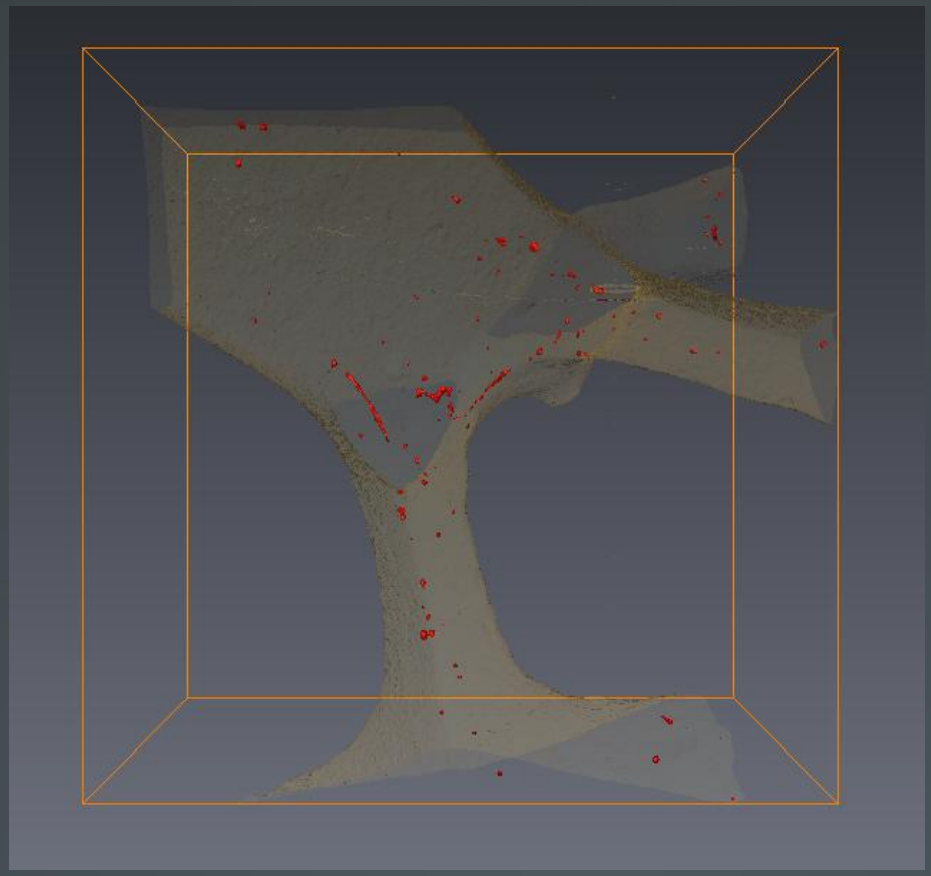
FE

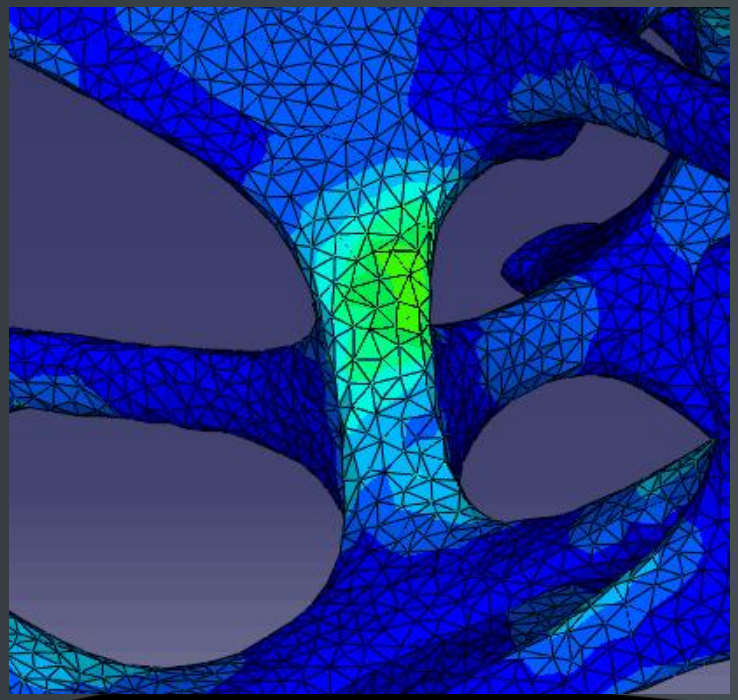




PHD T Zhang co supervized with Luc Salvo

Not broken

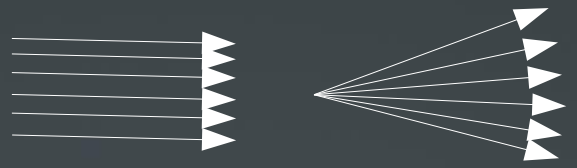




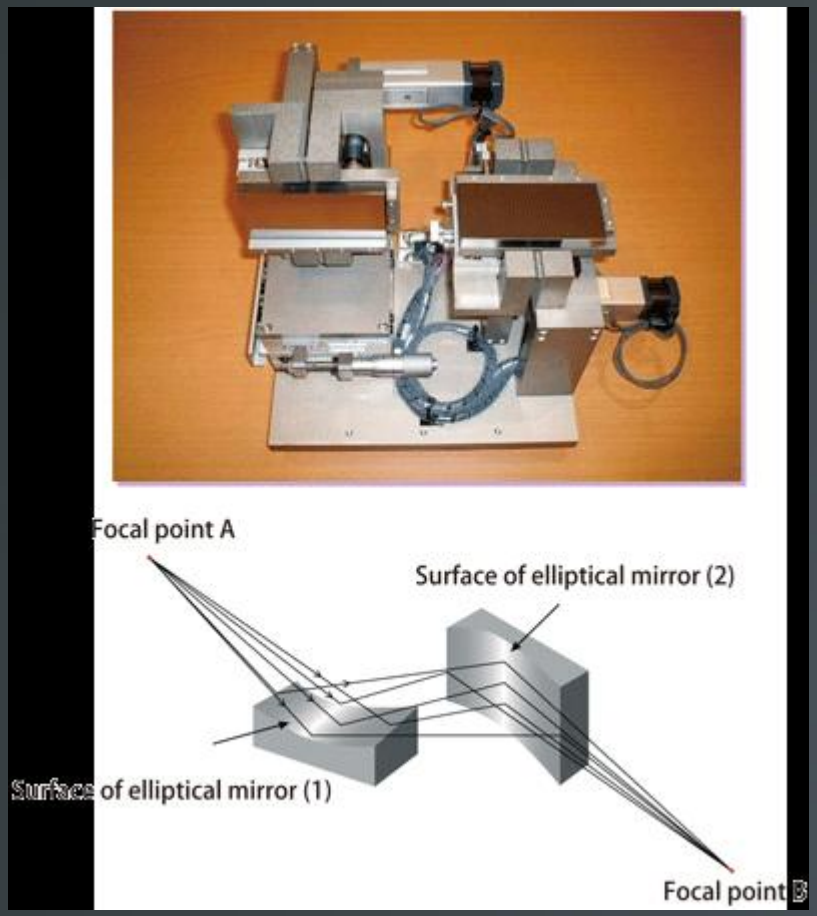
Highly stressed, no intermets

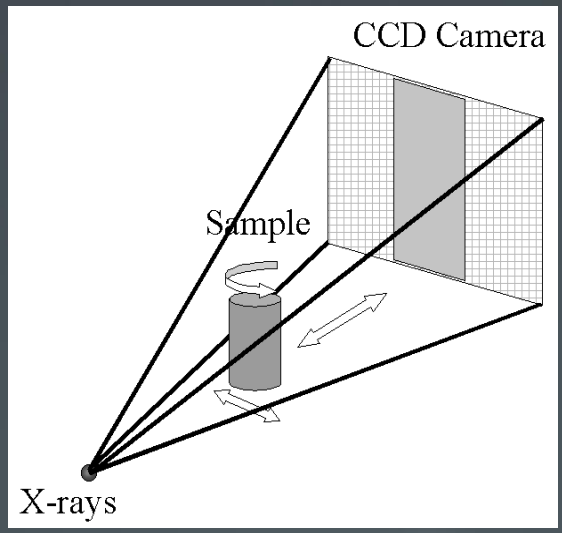
Prospects

Improve spatial resolution using KB mirrors



Use a conical beam on synchrotron to magnify





Spot size down to 20 nm

Temporal resolution

Using ID15 beamline (pink beam = high flux)

Resolution 1.5 µm

See previous movies

Conclusion

- In situ + X-Ray imaging brings a lot of new information in the field of materials science
- Radiography : no requirements
- Tomography : adapted devices
- + Digital volume correlation

+ FE simulation

= a complete set of new tools for experimental mechanics