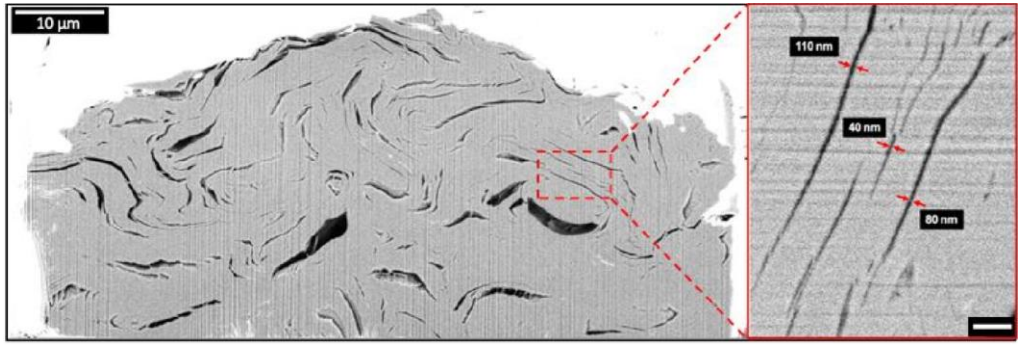
Loughborough

- Fatigue testing of fine grain graphite (e.g., SNG742; SINO steel)
- P-FIB-tomography (With NNL)
- Started on ex situ Au ion irradiation on fine grain graphite



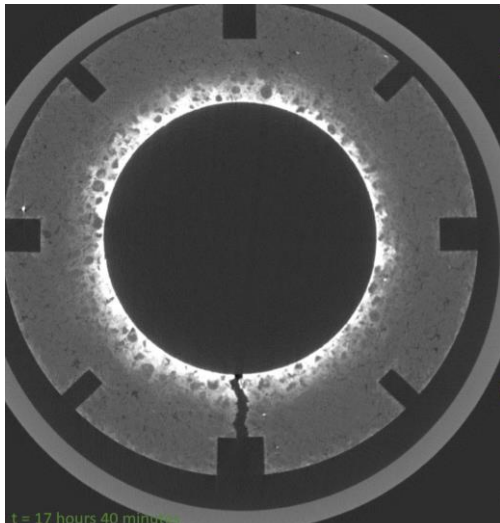
Manchester

- Keyway root cracking – notch radius effect (experimental and modelling)
- Intercalation (Bromine) to simulate internal stress
- Implant fission products (Cs, Kr, Ag) into graphite matrix via ion irradiation.

NNL

- Electron Tomography of Nano-Cracks in Nuclear Graphite (With ORNL)
- Keyway route cracking (with Manchester)

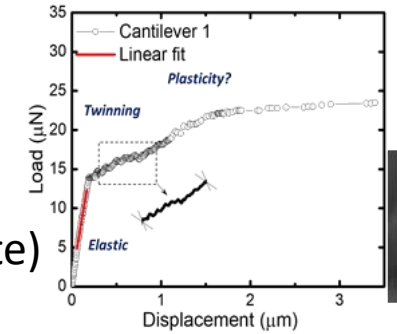


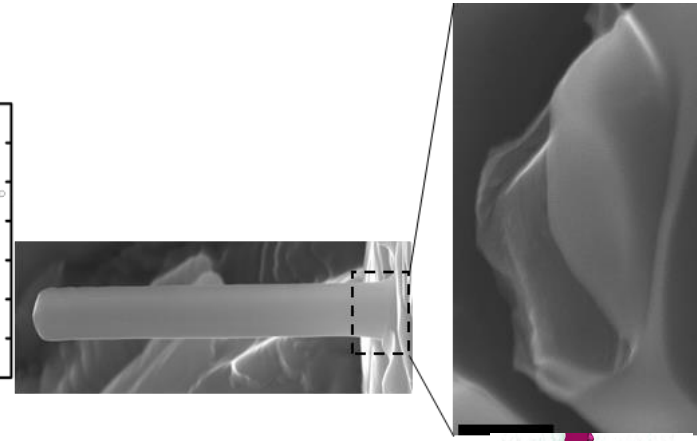


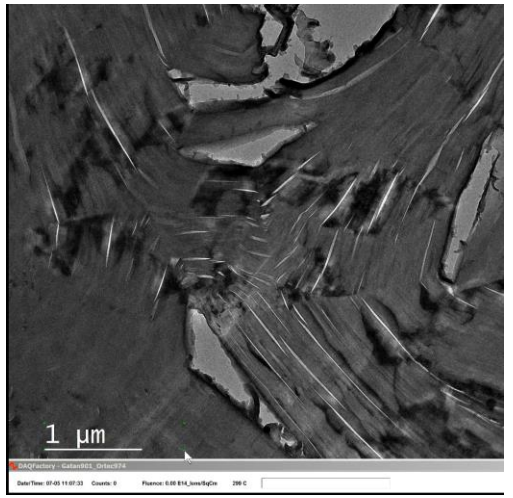
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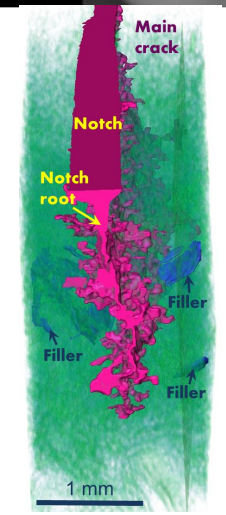
Bristol

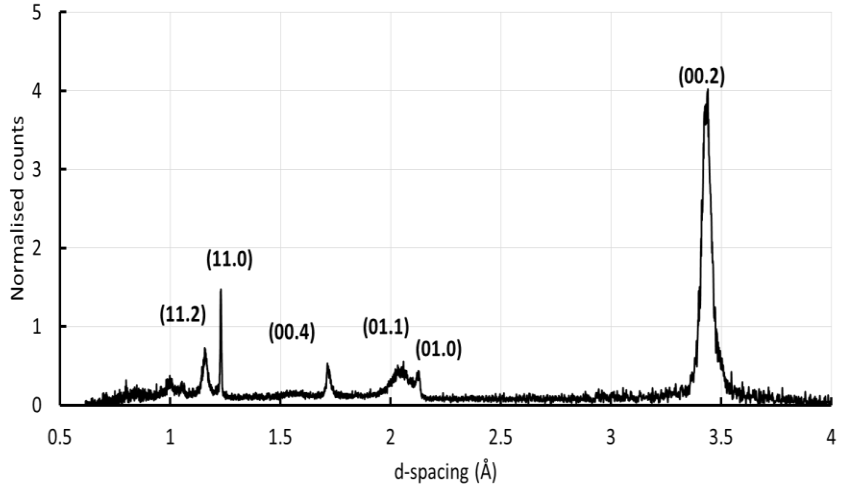
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6. **ACCENT sample analysis**





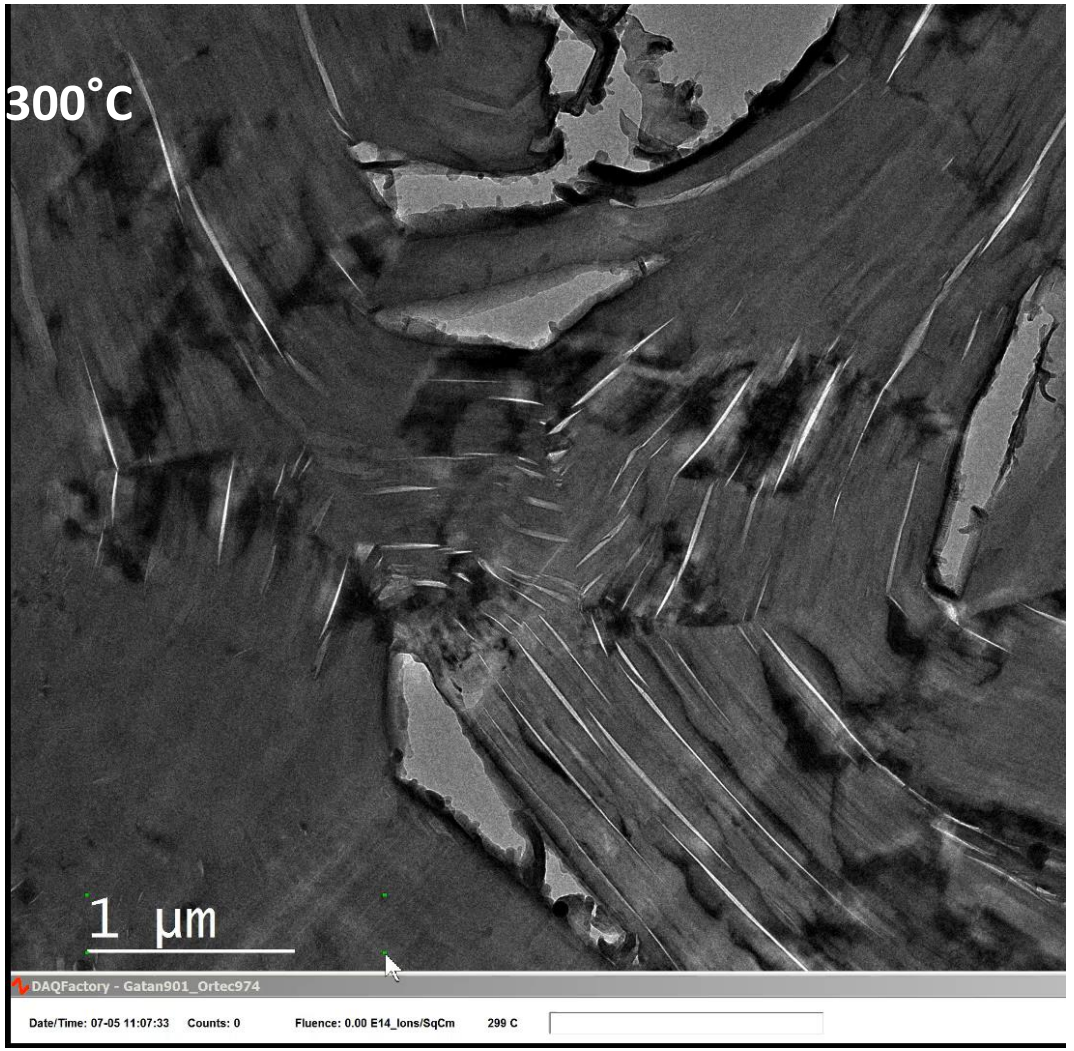






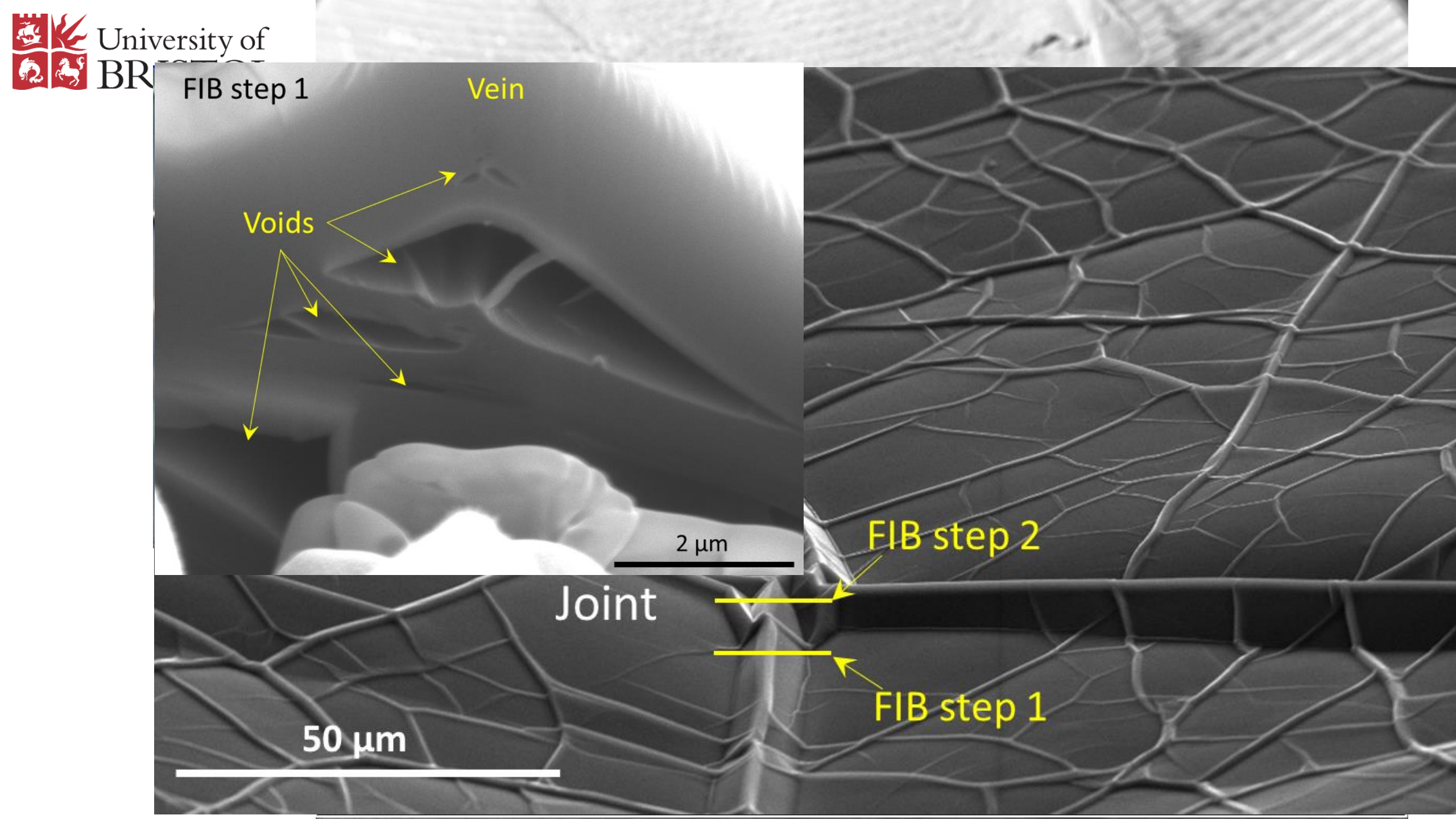
x situ ion irradiation





Josh Kane, Will Wines (INL); Steve Johns & Karthik Chinnathambi (Boise State)

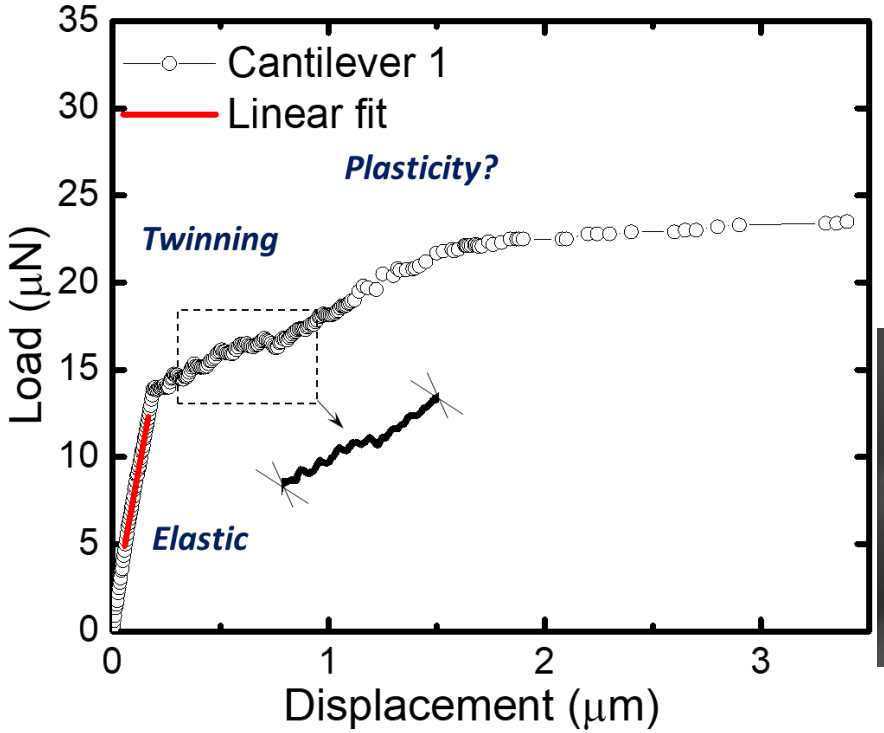
IVEM Facility, Argonne National Lab, USA

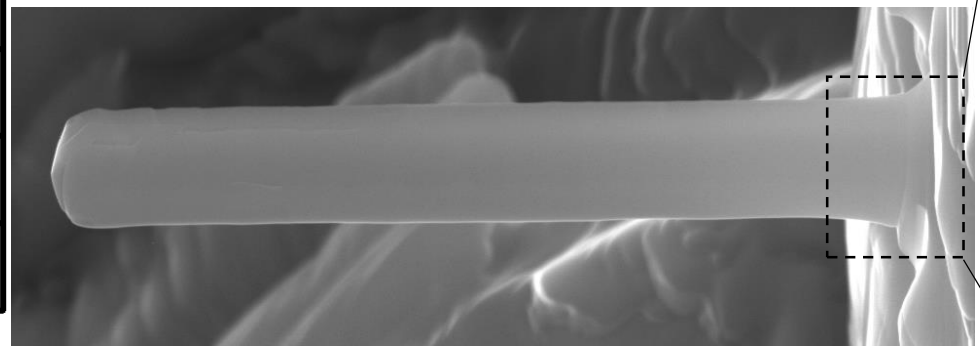

University of
FIB step 1
Vein
Voids
2 µm
FIB step 2
Joint
FIB step 1
50 µm

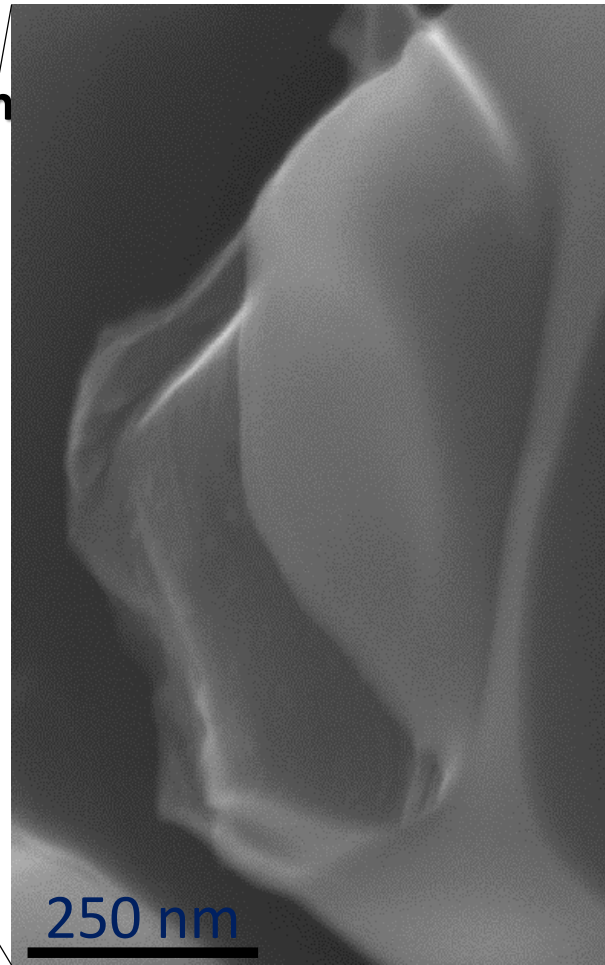
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Micro-mechanical testing (with INL)

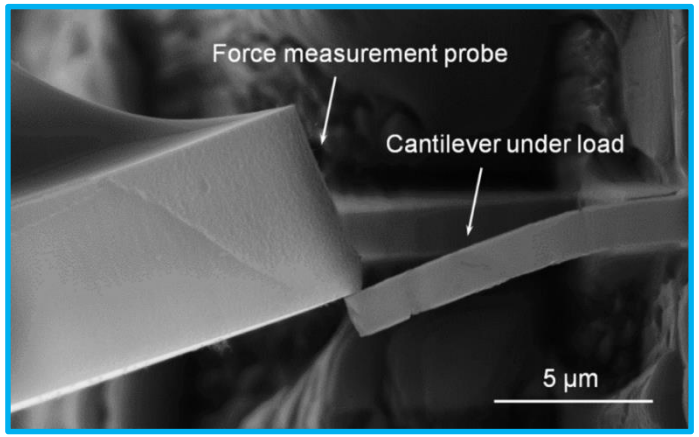
- **Property change with irradiation (INL)**
- **Ion/neutron implantation → nano-scale damage mechanism → dimensional chan**



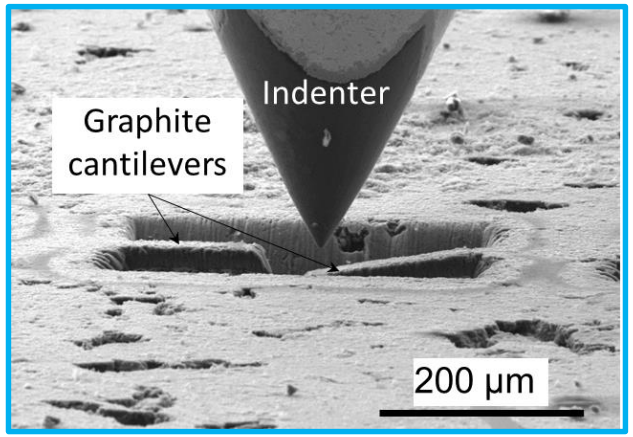




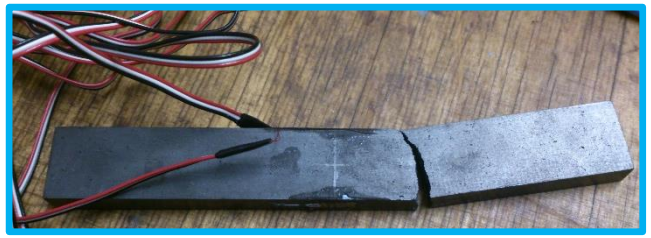
Microstructure: Multiple length-scales



10-20 µm in length (micro-scale)

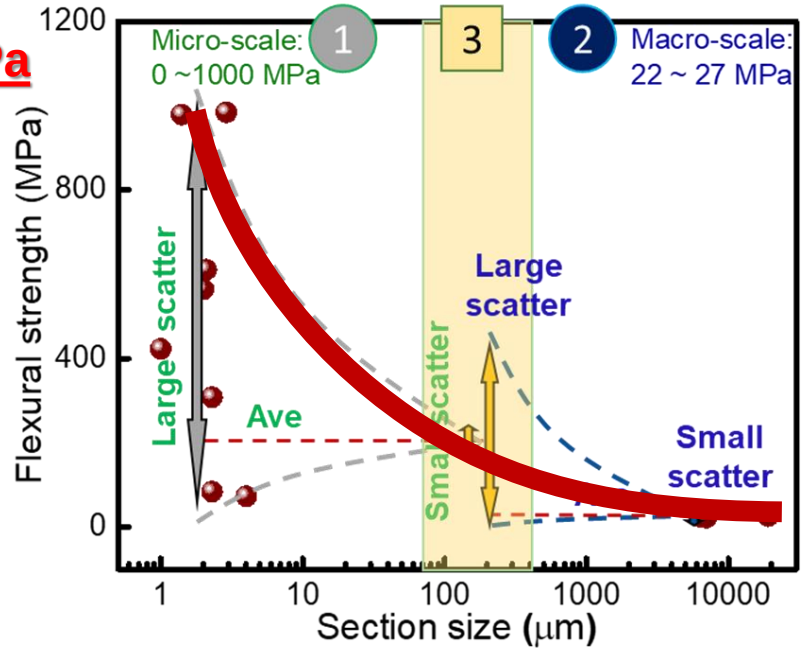


100-200 µm in length (meso-scale)

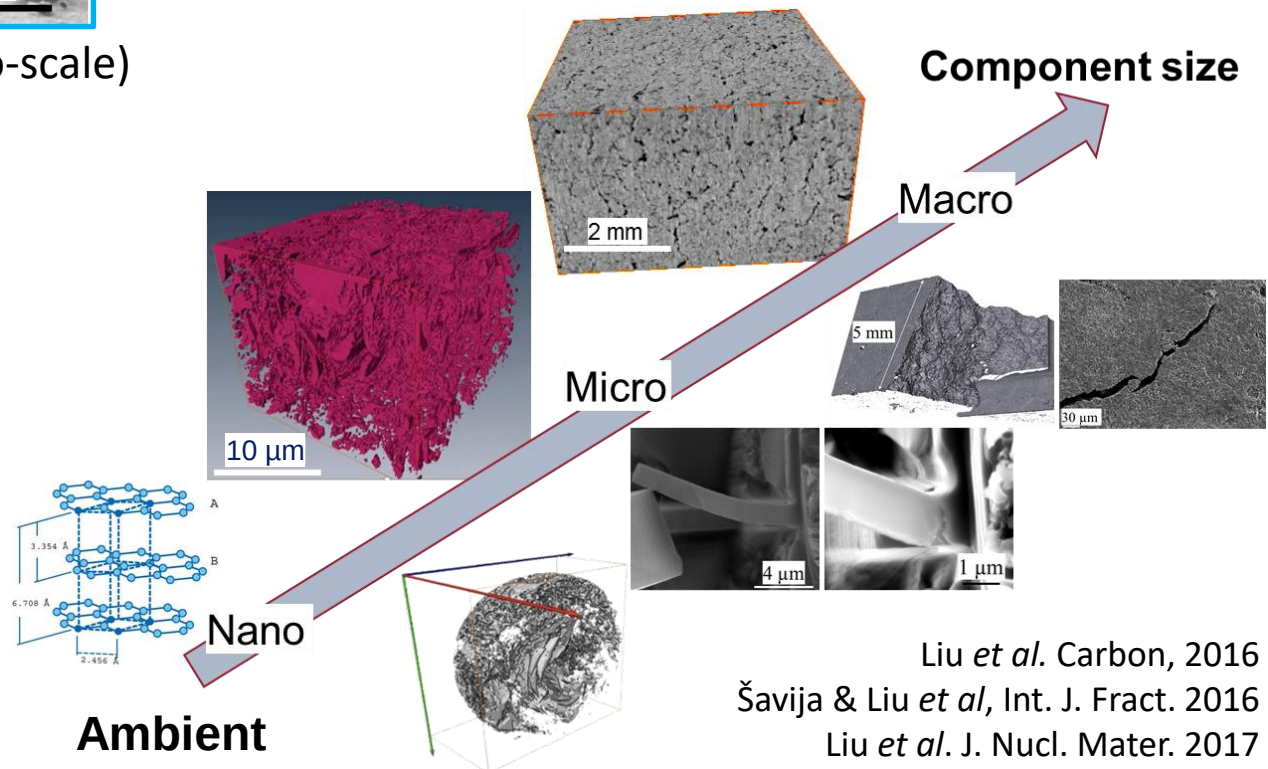


20 cm in length (macro-scale)

~1 GPa



~20 MPa



Liu *et al.* Carbon, 2016
Šavija & Liu *et al*, Int. J. Fract. 2016
Liu *et al*. J. Nucl. Mater. 2017

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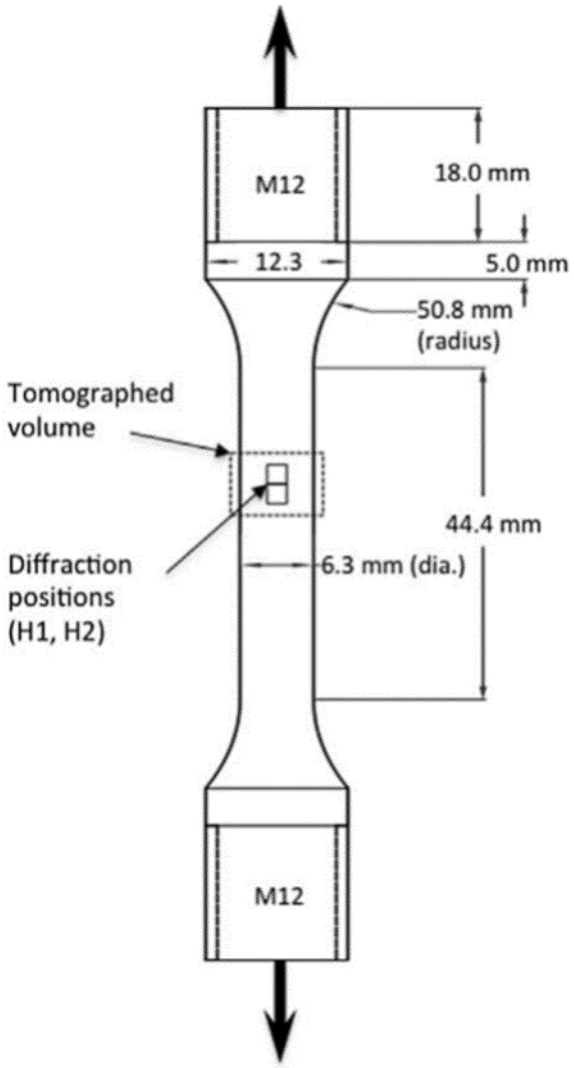
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    - Micro-mechanical testing

6. **ACCENT sample analysis**

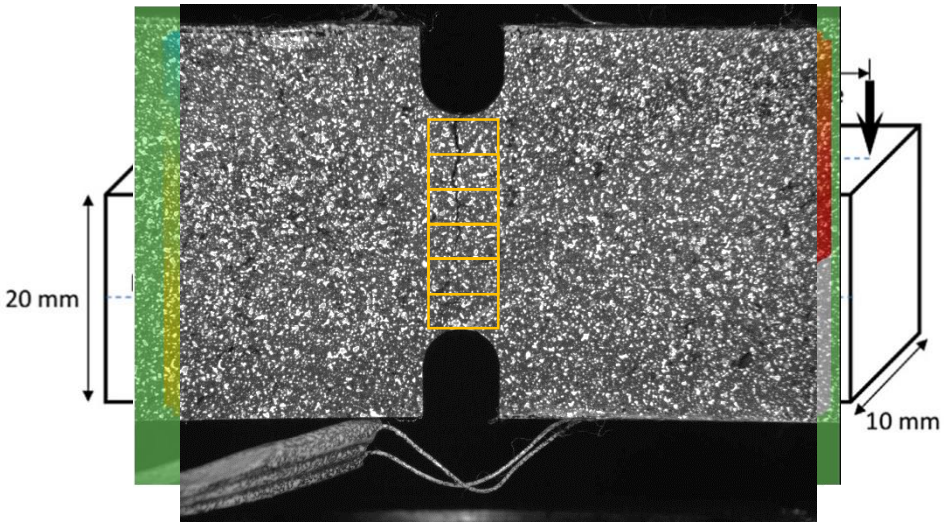
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Loading configurations for diffraction work

- Uniaxial tension; disc compression (X-ray diffraction): RT
- Four-point bending; disc compression (neutron diffraction): HT



Uniaxial tension



Four-point bending (with&without notches)

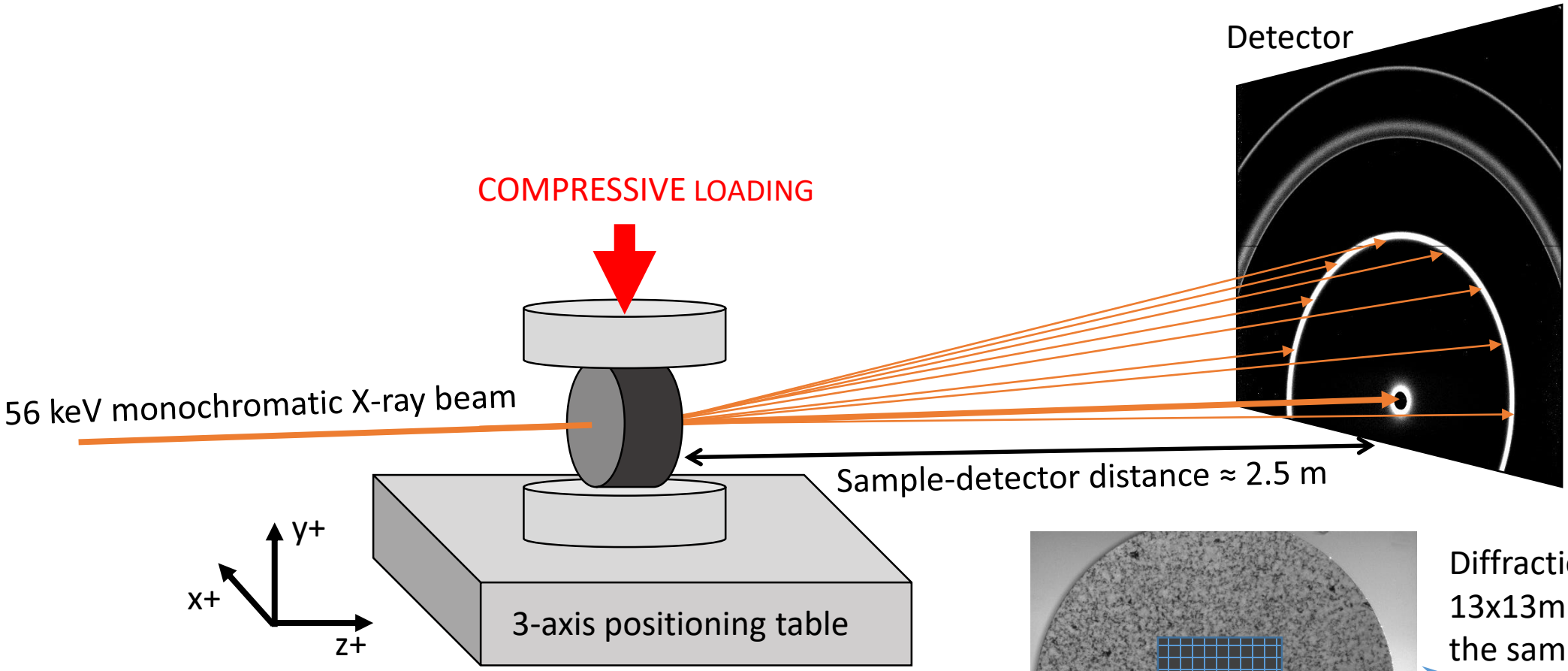


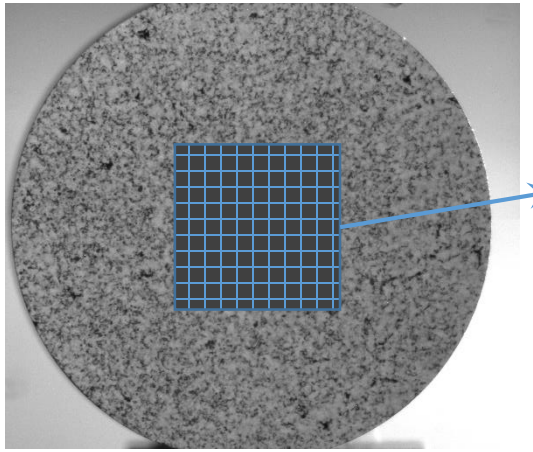
Disc compression (RT&HT)

- Elastic strain: diffraction
- Total strain: digital image correlation/digital volume correlation/engineering strain gauges

Marrow, T. J. Liu, D. et al.. Carbon, 96, 285–302 (2016).

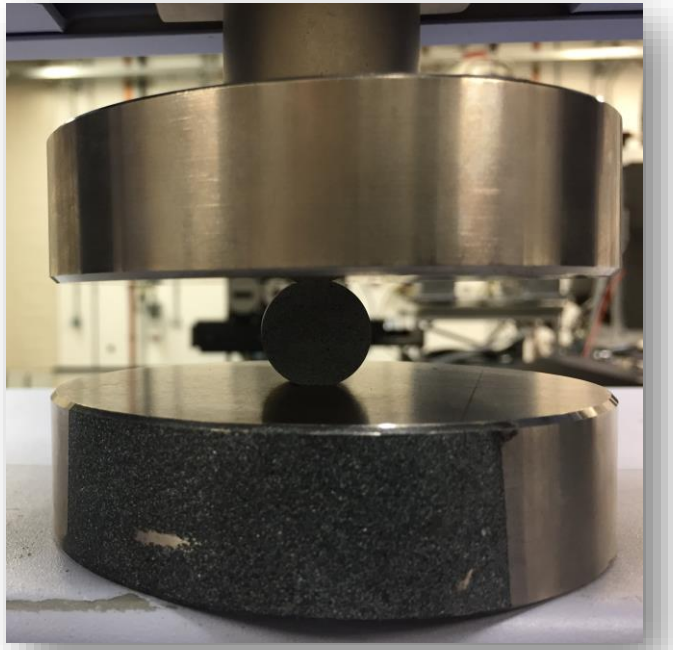
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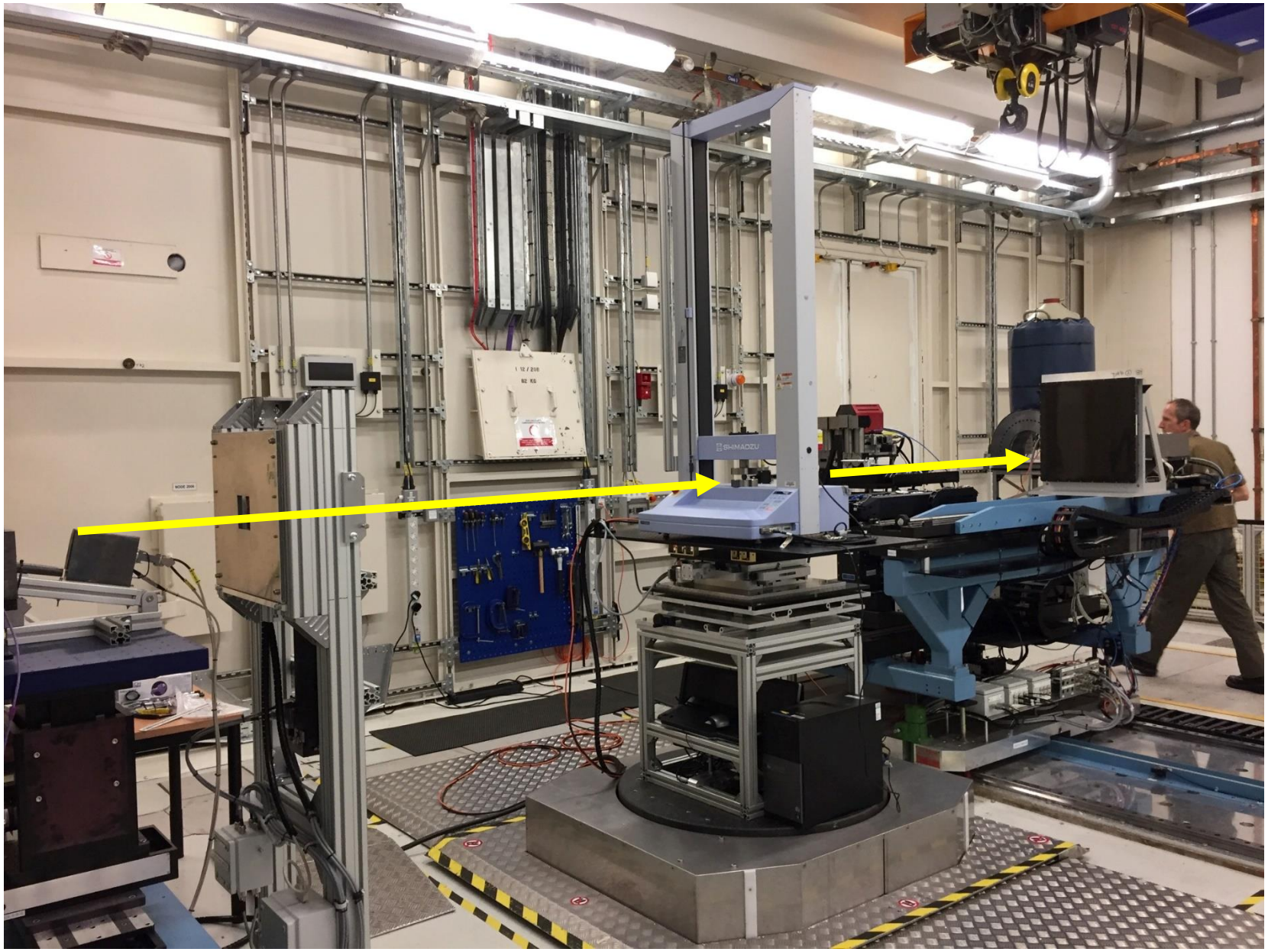




Diffraction map:
13x13mm at the centre of the sample
1 mm slit size, 50% overlap
868 measurements per map

- **Synchrotron x-ray diffraction strain mapping + 3D tomography**





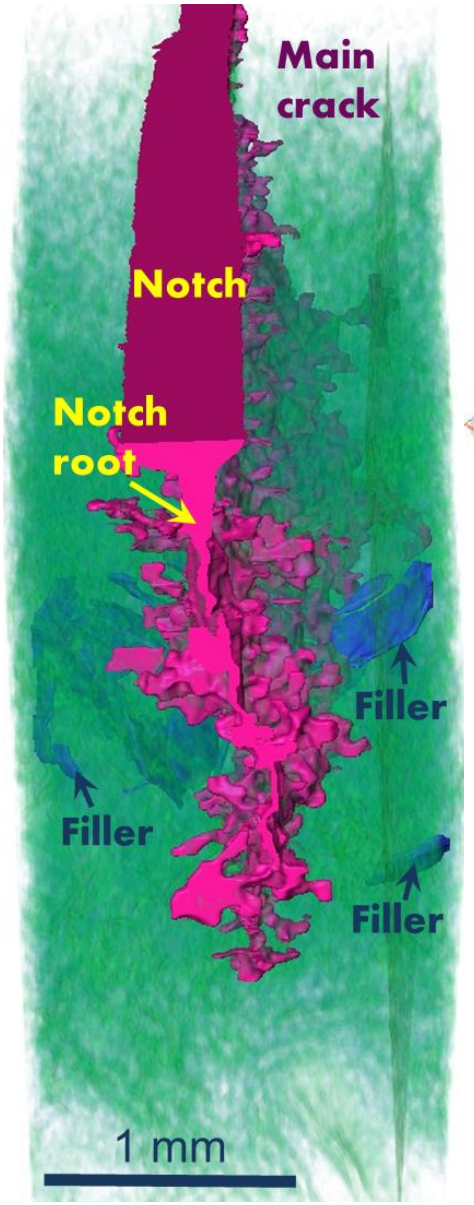
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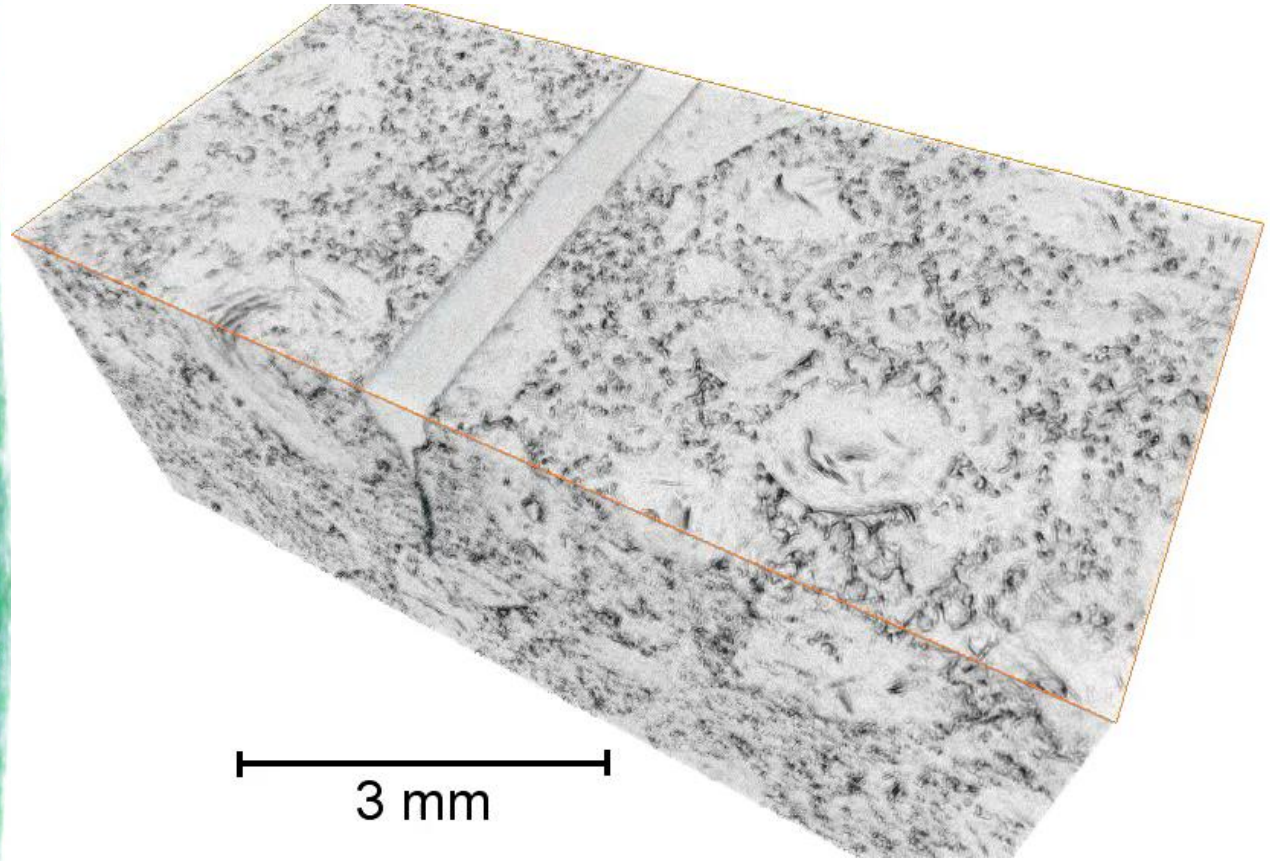
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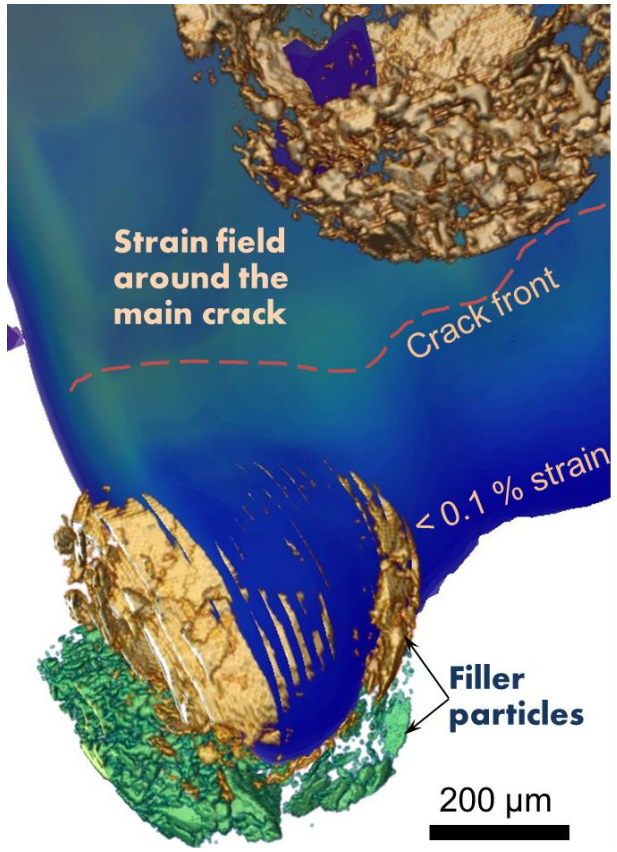
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In situ high temperature XCT



- 3D maximum principal strain overlay (DVC)





- Interaction between filler particles and strain field

- 3D segmentation of a crack at 1000°C

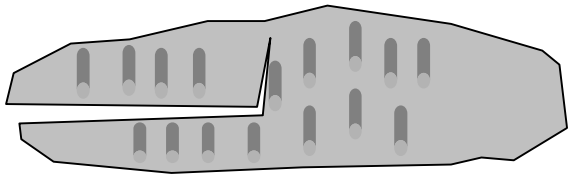
D. Liu & R. O. Ritchie et al. Nature Communications, 2017

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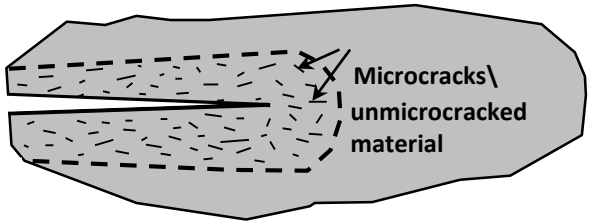
In situ high temperature XCT

- **Toughening mechanisms**

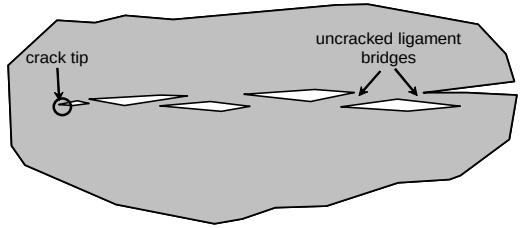
Crack deflection



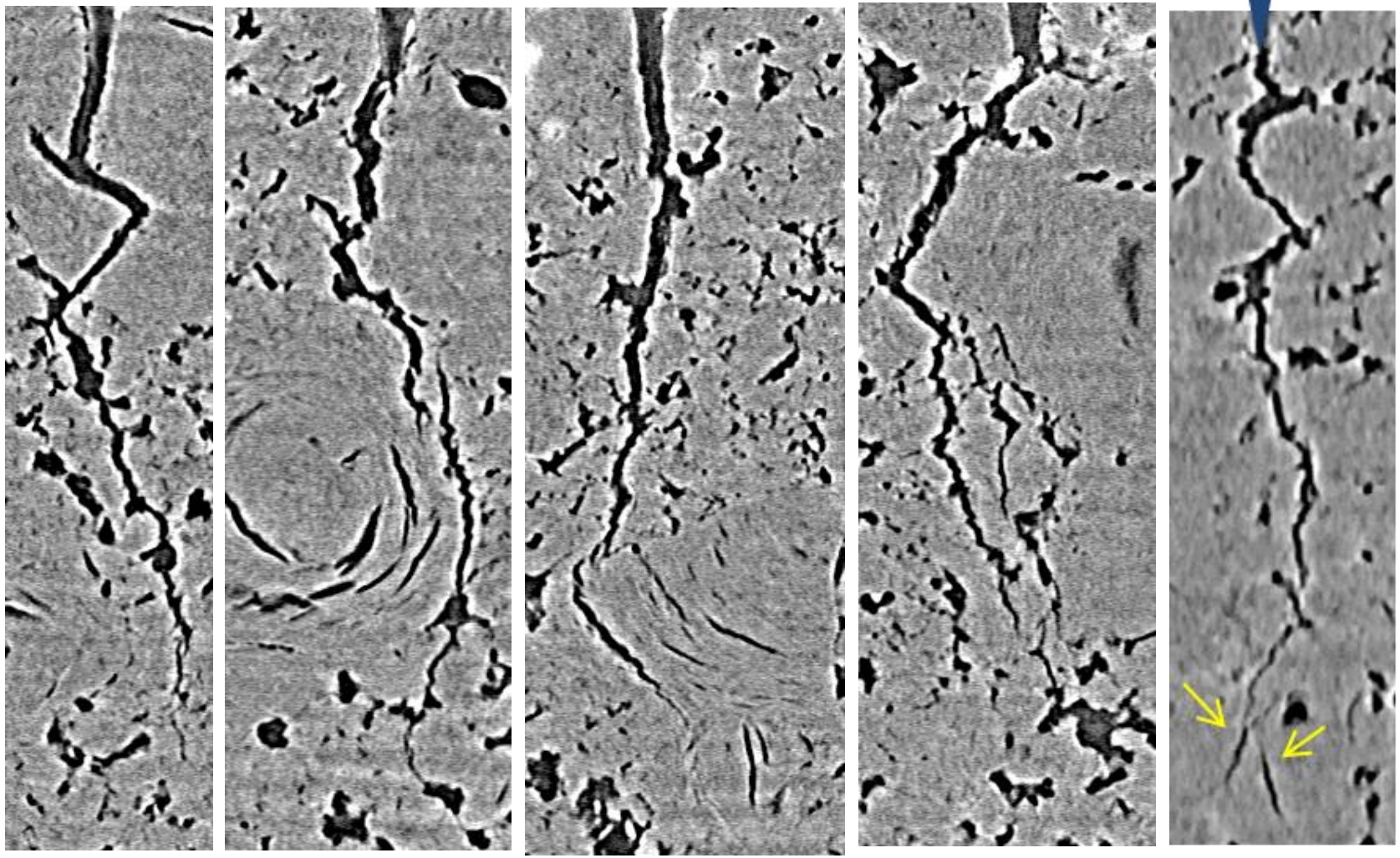
Constraint micro-cracking



Uncracked-Ligament Bridging



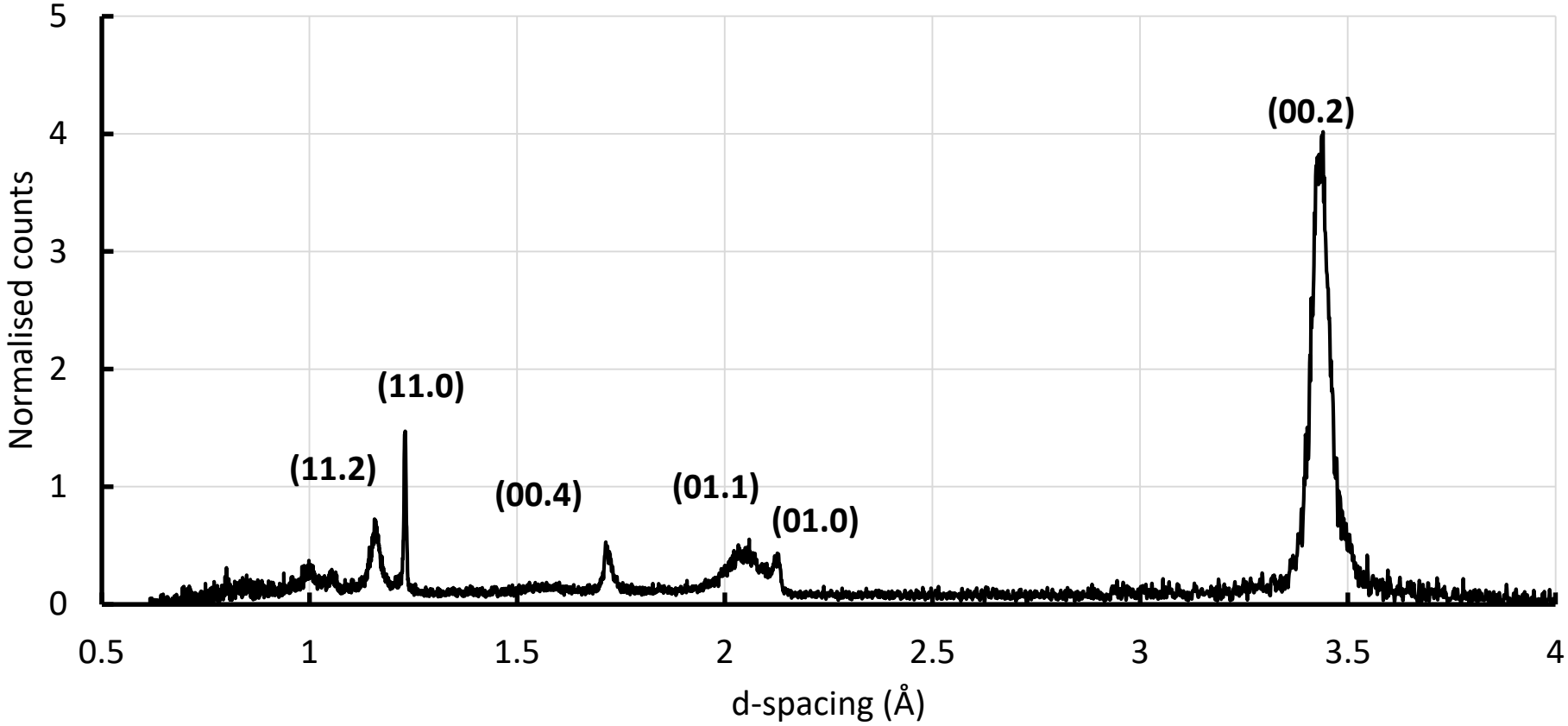
- Less micro-cracking at HT
- More bifurcation at HT



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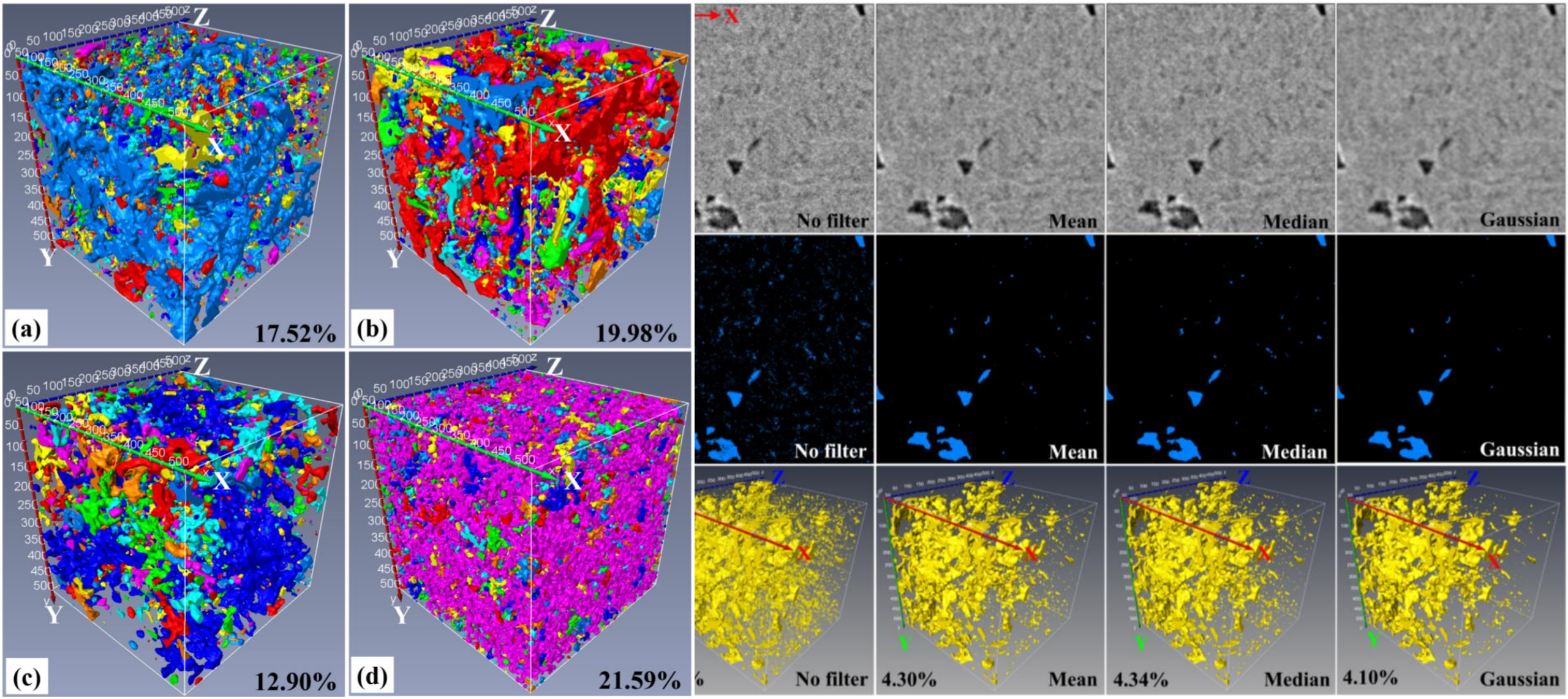
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Normalised counts
d-spacing (Å)
(00.2)
(11.0)
(11.2)
(00.4)
(01.1)
(01.0)
0
1
2
3
4
5
0.5
1
1.5
2
2.5
3
3.5
4

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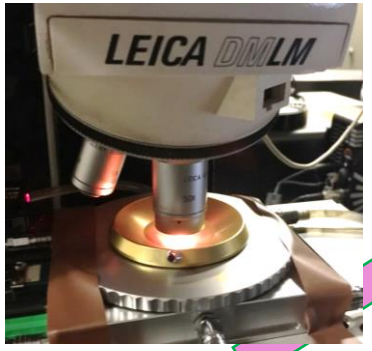
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(a)
17.52%
(b)
19.98%
(c)
12.90%
(d)
21.59%
X
Y
Z
No filter
Mean
Median
Gaussian
No filter
Mean
Median
Gaussian
No filter
4.30%
Mean
4.34%
Median
4.10%
Gaussian

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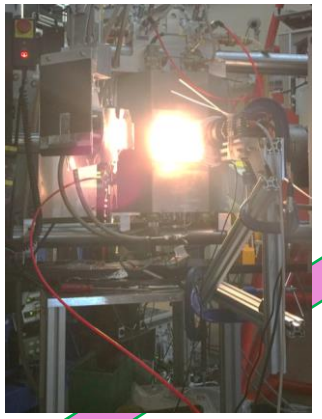
Microstructure: Multiple length-scales

Crystal bonding



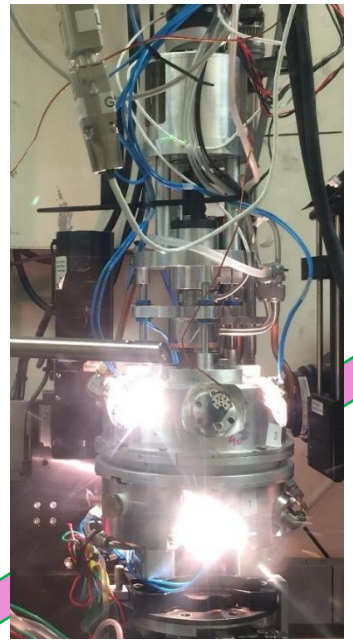
Raman spectroscopy

Lattice strain



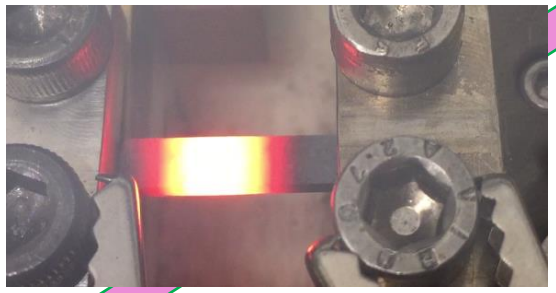
Neutron and X-ray diffraction

3D microstructure



X-ray computed micro-tomography (XCT)

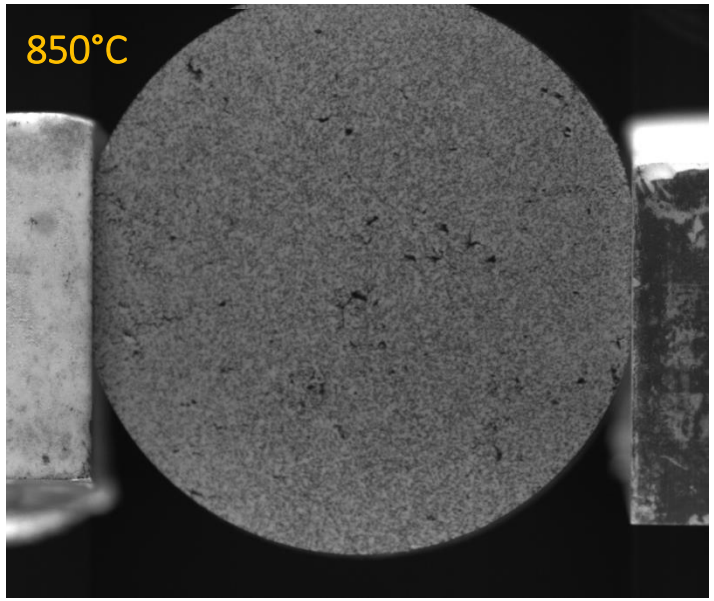
Macro-scale deformation

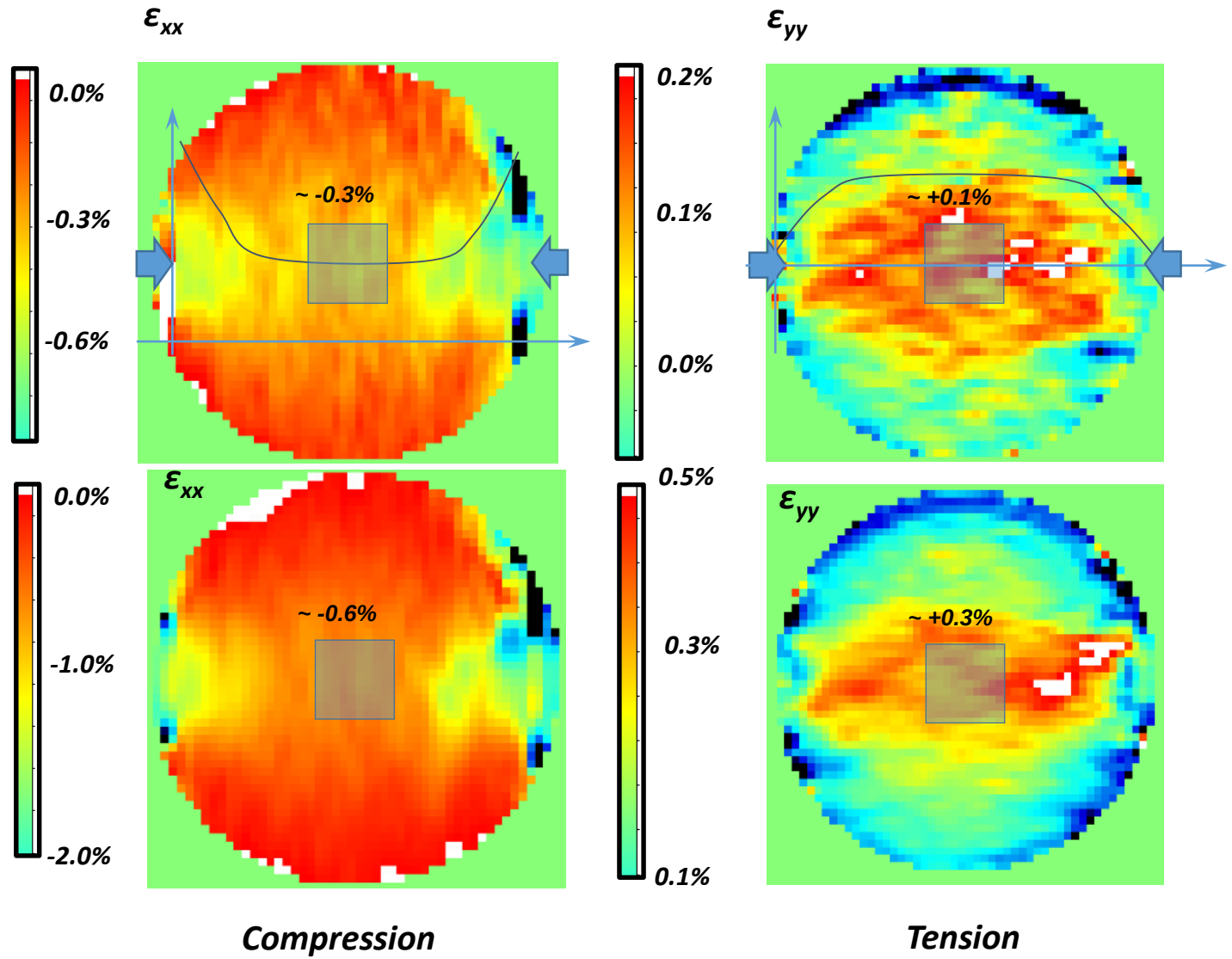


Electrothermal Mechanical Testing System (ETMT)

Elevated temperature

• Digital image correlation: Strain distribution (total strain)





- 4x4 mm gauge area at the sample centre
  - Coincides with the neutron gauge volume
  - Averaged to give the total surface strain
    ε_{xx}: compressive strain
    ε_{yy}: tensile strain