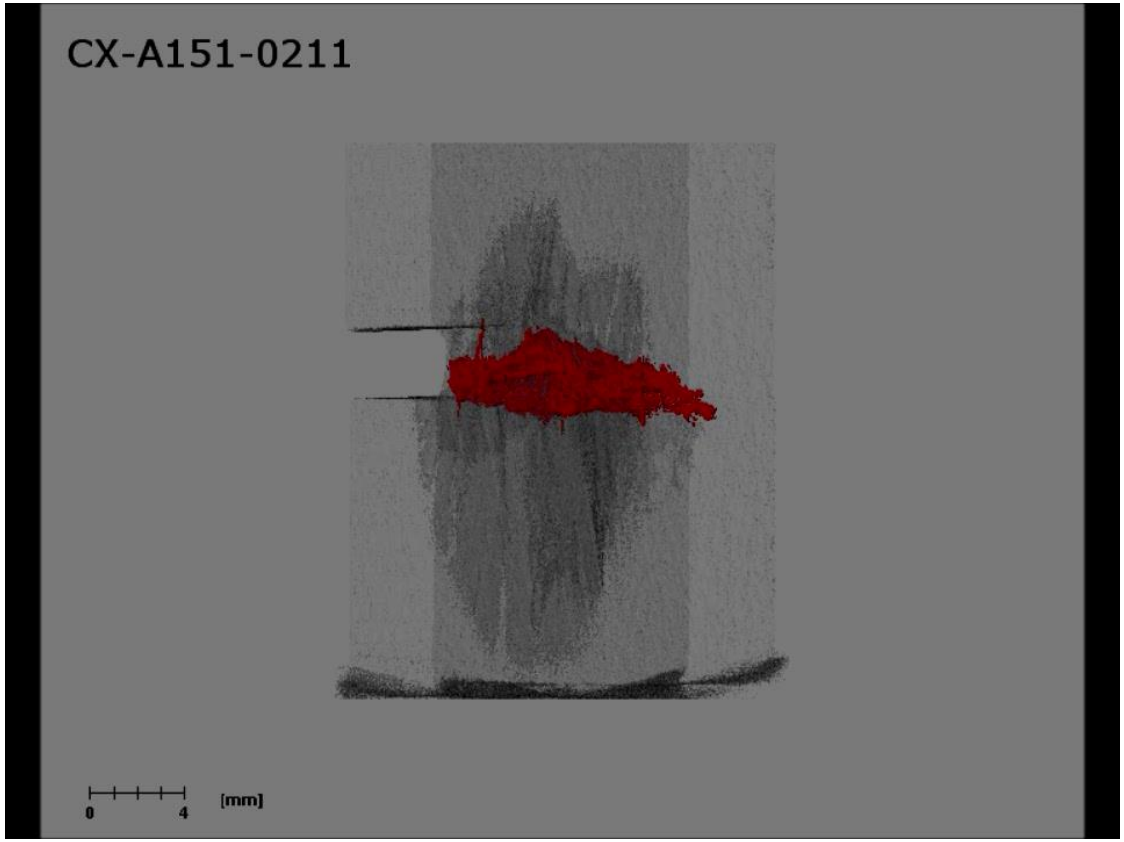
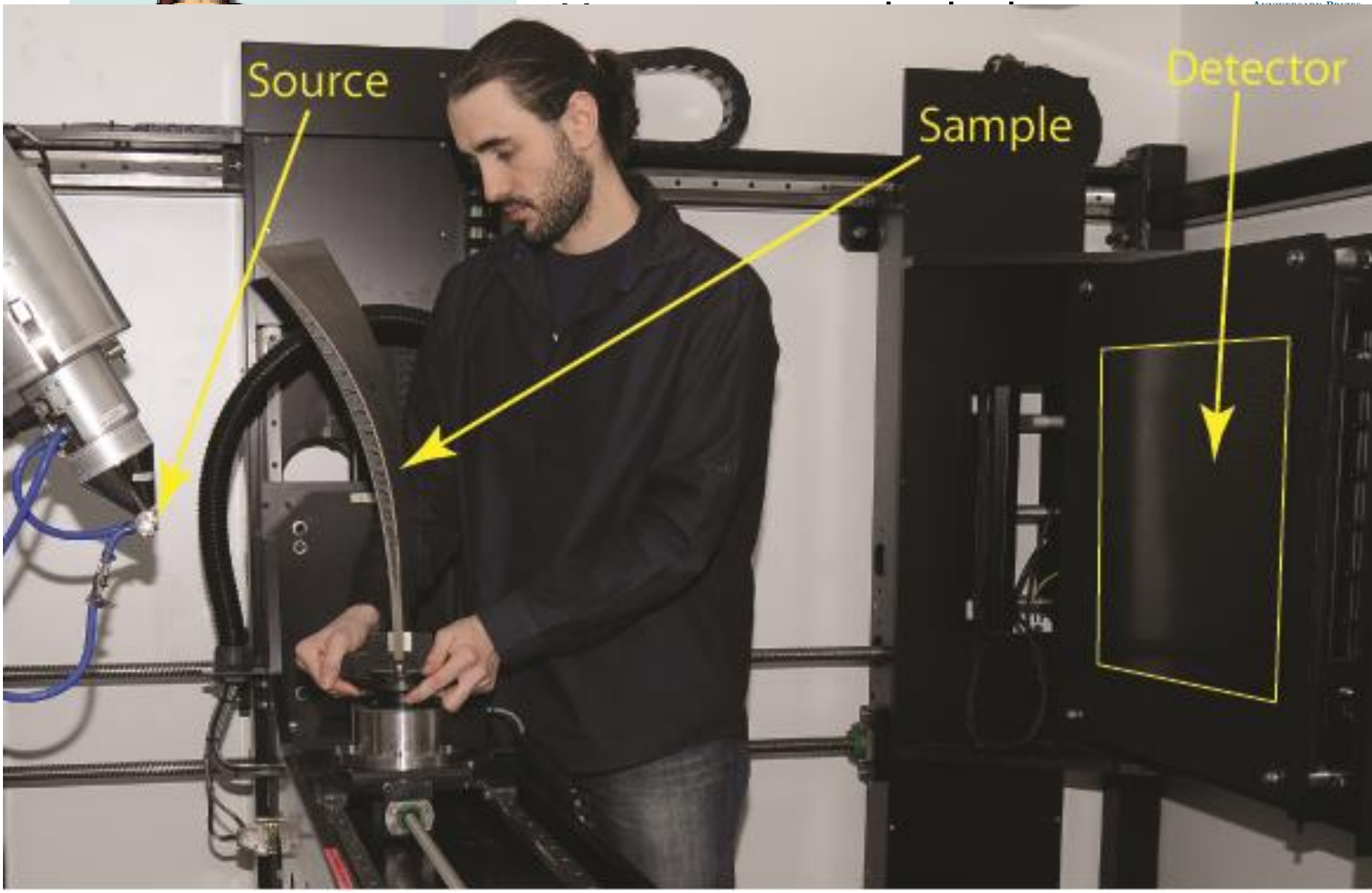


Damage and damage accumulation in fiber reinforced composites by X-ray CT

Phil Withers
Regius Professor of Materials Science

Henry Moseley X-ray Imaging Facility,
BP Int. Centre for Advanced Materials,
University of Manchester & Research Complex at Harwell

What is X-ray tomography?



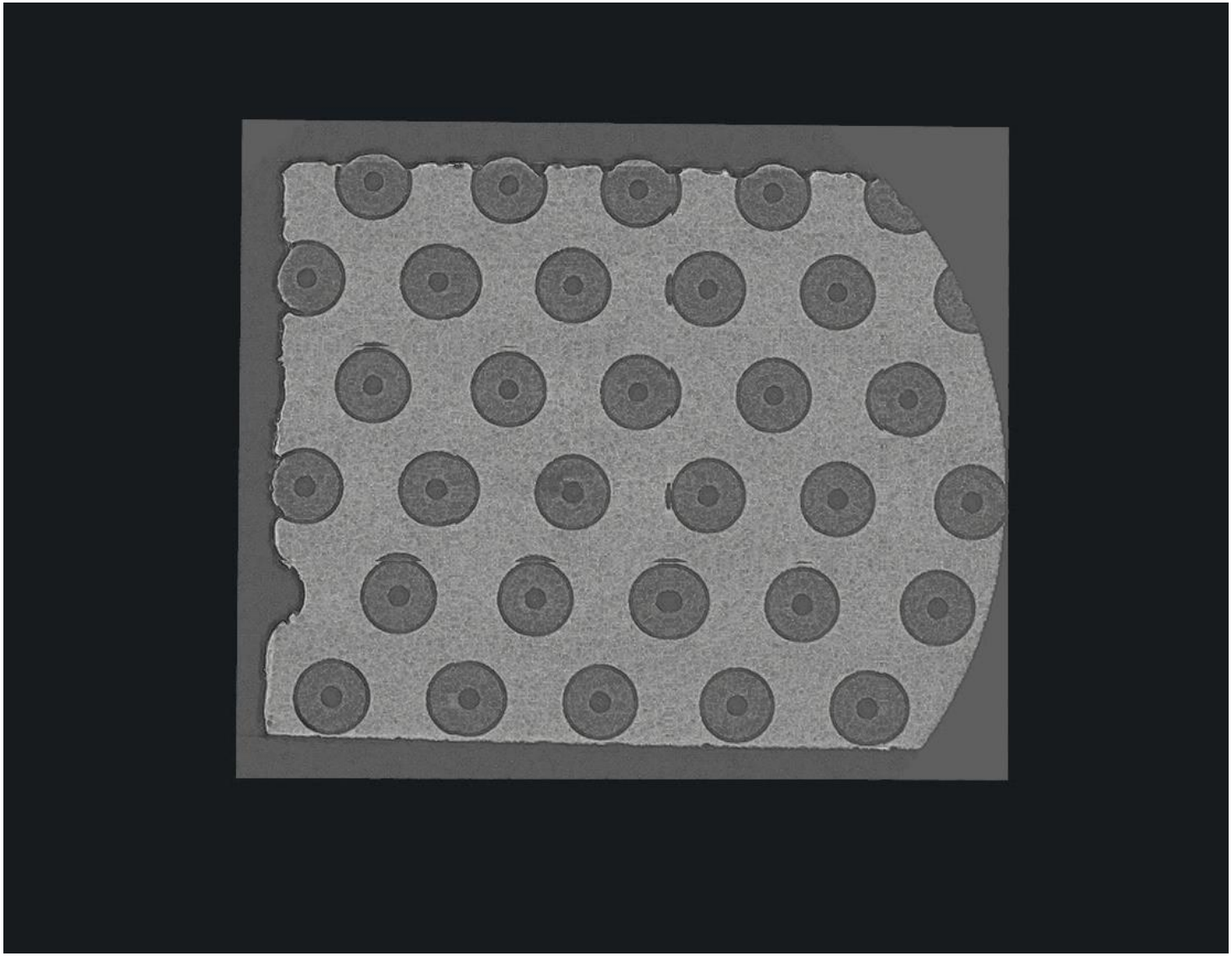
Time-lapse X-ray tomography

By repeatedly acquiring CT non destructively scans we can acquire 3D time lapse sequences

MANCHESTER 1824
The University of Manchester

Correlating over time:
Time Lapse CT

The Queen's Anniversary Prizes
For Higher and Further Education
2011 & 2013



What can it tell us?

- Non destructive
- Can analyse delicate samples, e.g. impacted panels
- Can follow evolution over time, load, during degradation, etc in situ
- Object size limited by X-ray penetration (higher the higher the x-ray voltage)
- Can validate multiscale models

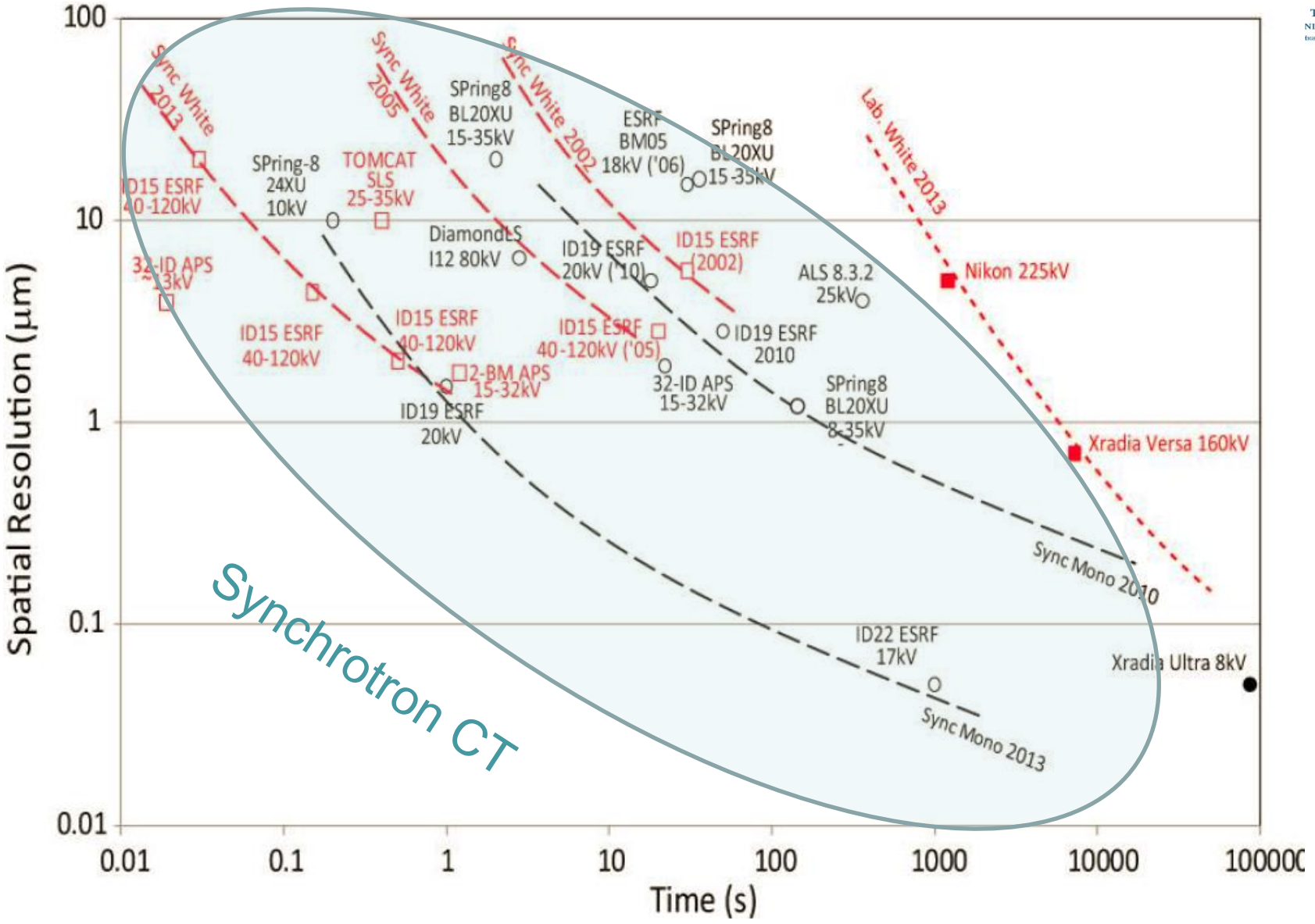
Limitations

- Normally can view the whole object at a resolution no better than 1/2000th the size of the object
  - So 500mm sample at 250μm
  - So 20mm sample at 10μm
  - So 2mm sample at 1μm
  - So 100μm sample at 50nm

  Field of view can be a problem for woven samples where the unit cell can be >20mm

  Region of interest scans or stitching together multiple scans can help
- Contrast between matrix and carbon fibres can be low
  - Phase contrast can help

Need to span short timescales



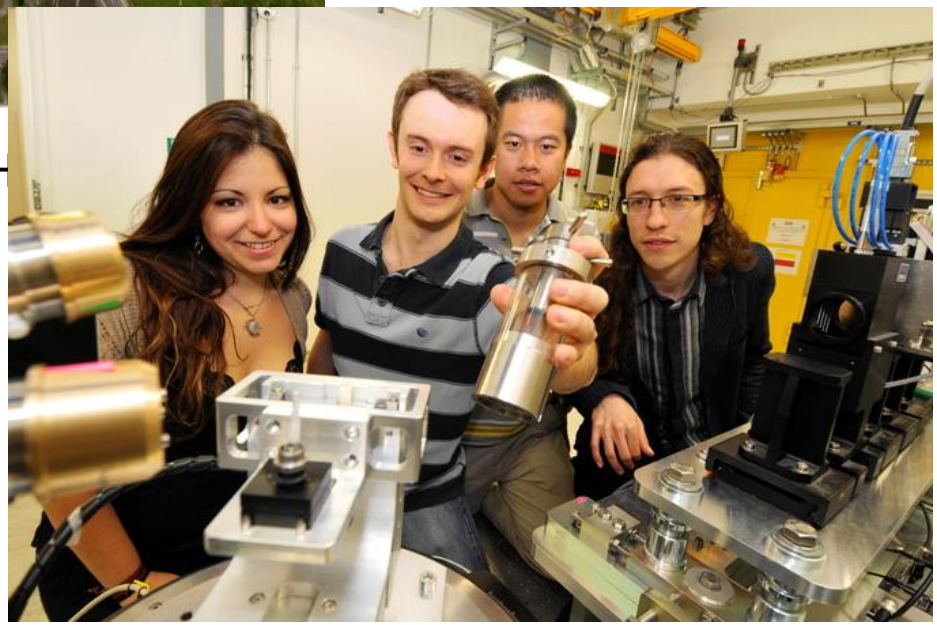
[See Maire & Withers. Int. Mater. Rev 2014]

Based on 1000 projections per scan

Synchrototron X-ray Imaging Facility

Research Complex at Harwell

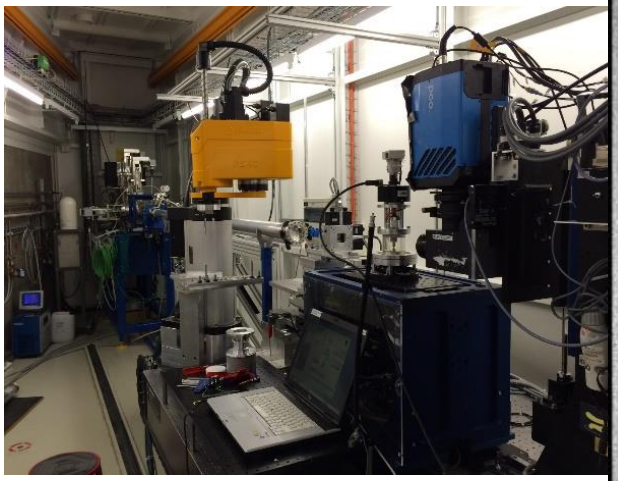
Manchester X-ray Imaging Facility @ H

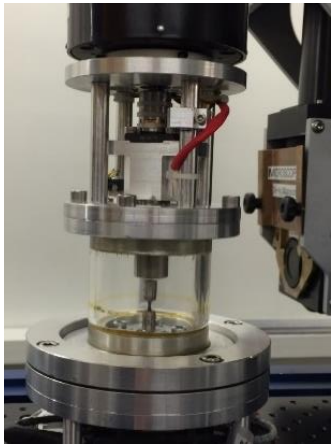


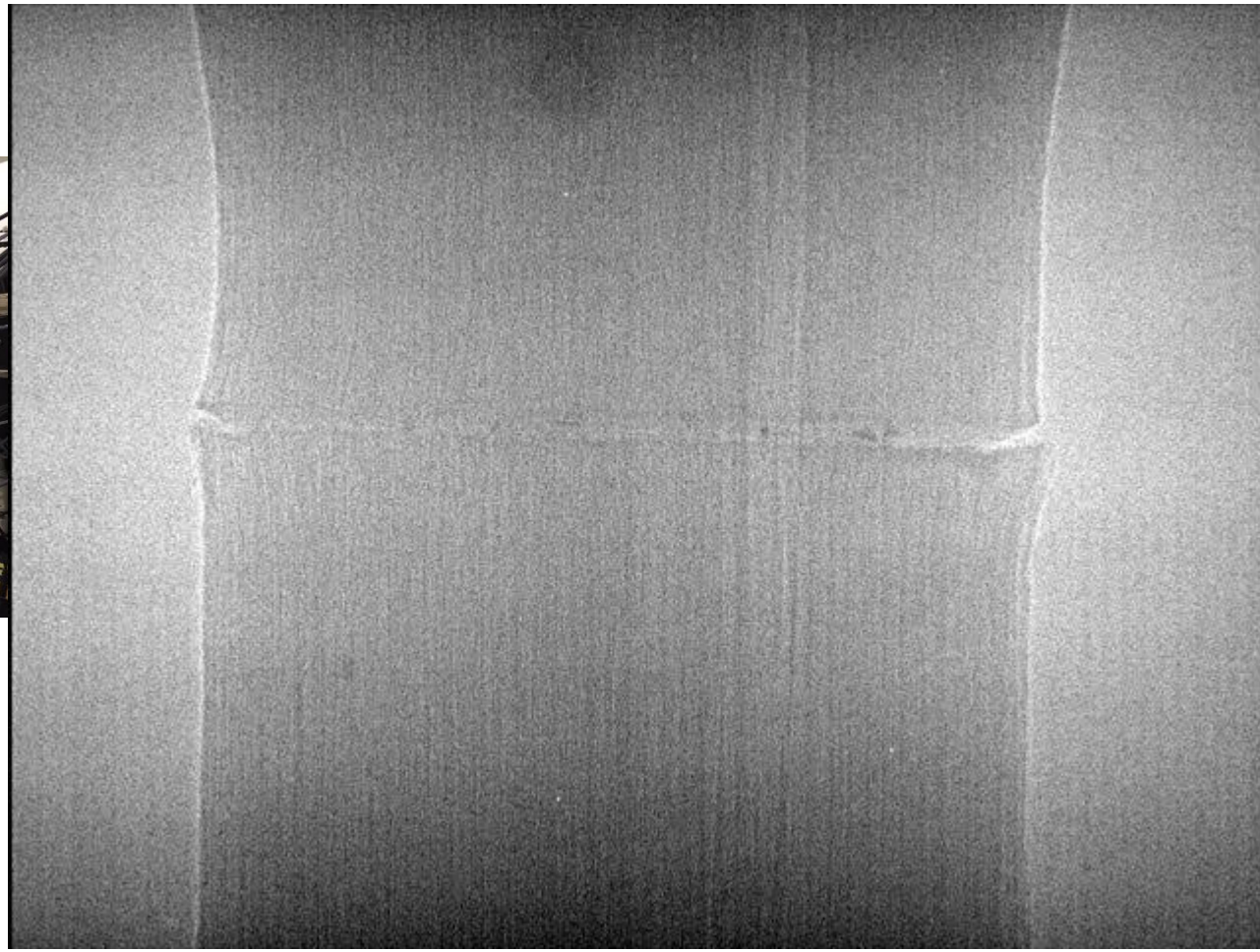
Ultra-high speed synchrotron imaging

Radiographs:

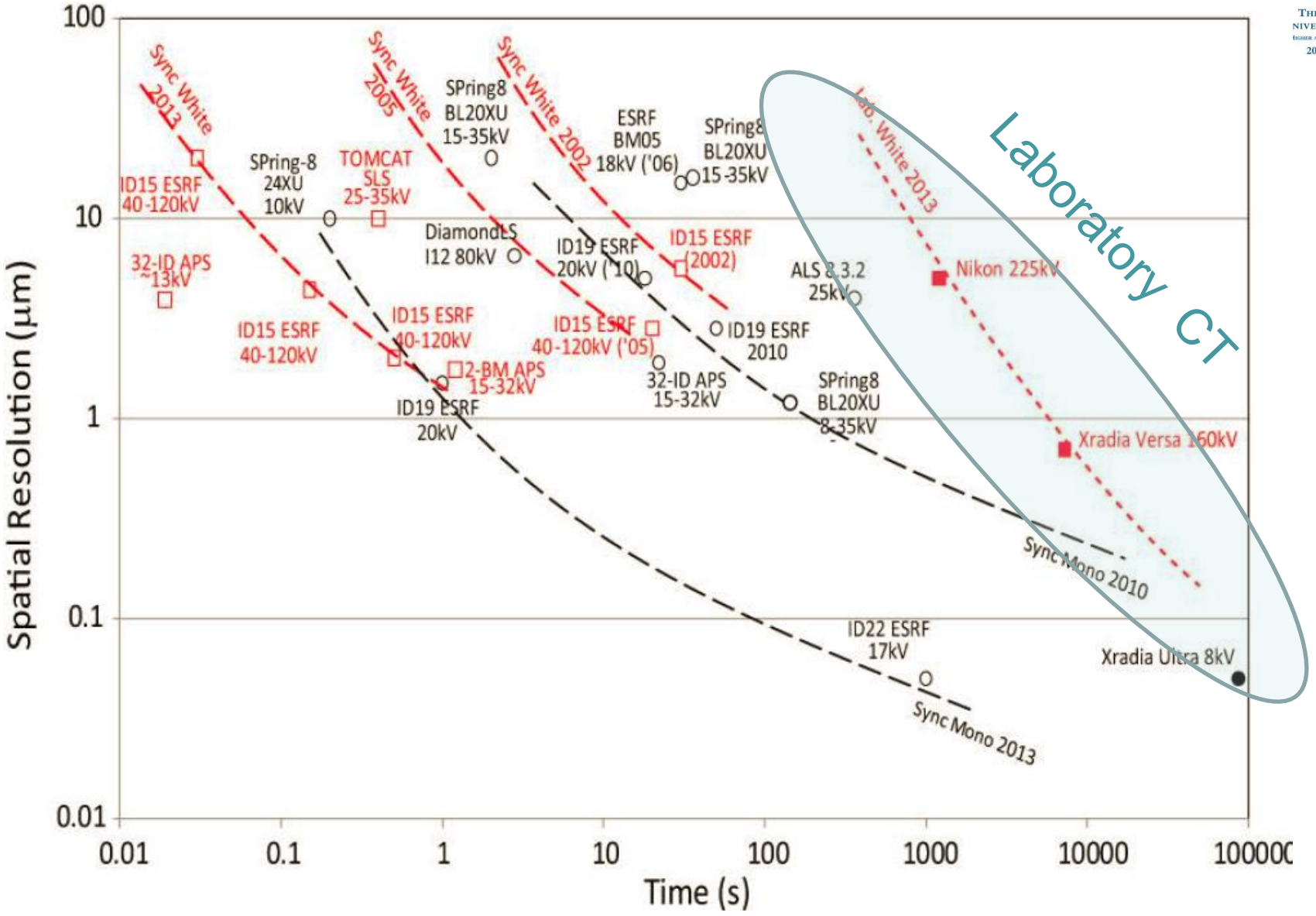
- 0.1 ms/projection (1000fps)
- 0.78º interval







Need to span long timescales



[See Maire & Withers. Int. Mater. Rev 2014]

Based on 1000 projections per scan

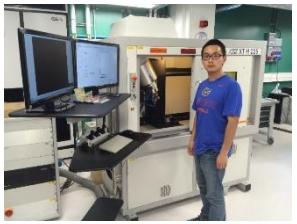
MANCHESTER 1824
The University of Manchester

Henry Moseley Facility 2015

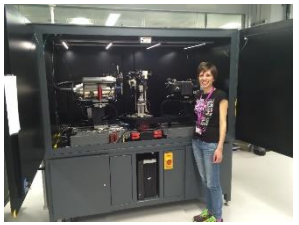
THE QUEEN'S ANNIVERSARY PRIZES FOR HIGHER AND FURTHER EDUCATION 2011 & 2013

Cabinet based systems

RTT 110



Nikon XTH 225



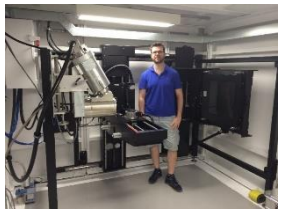
2x Versa 520

FEI HeliScan

Zeiss ultra

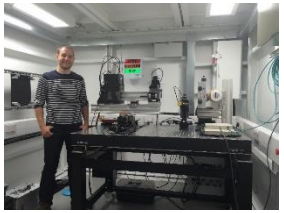
Gatan XuM

Walk-in enclosure systems



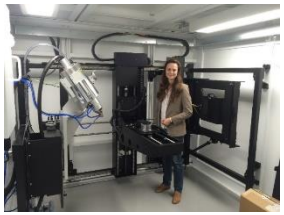
320/225kV

Zeiss 410



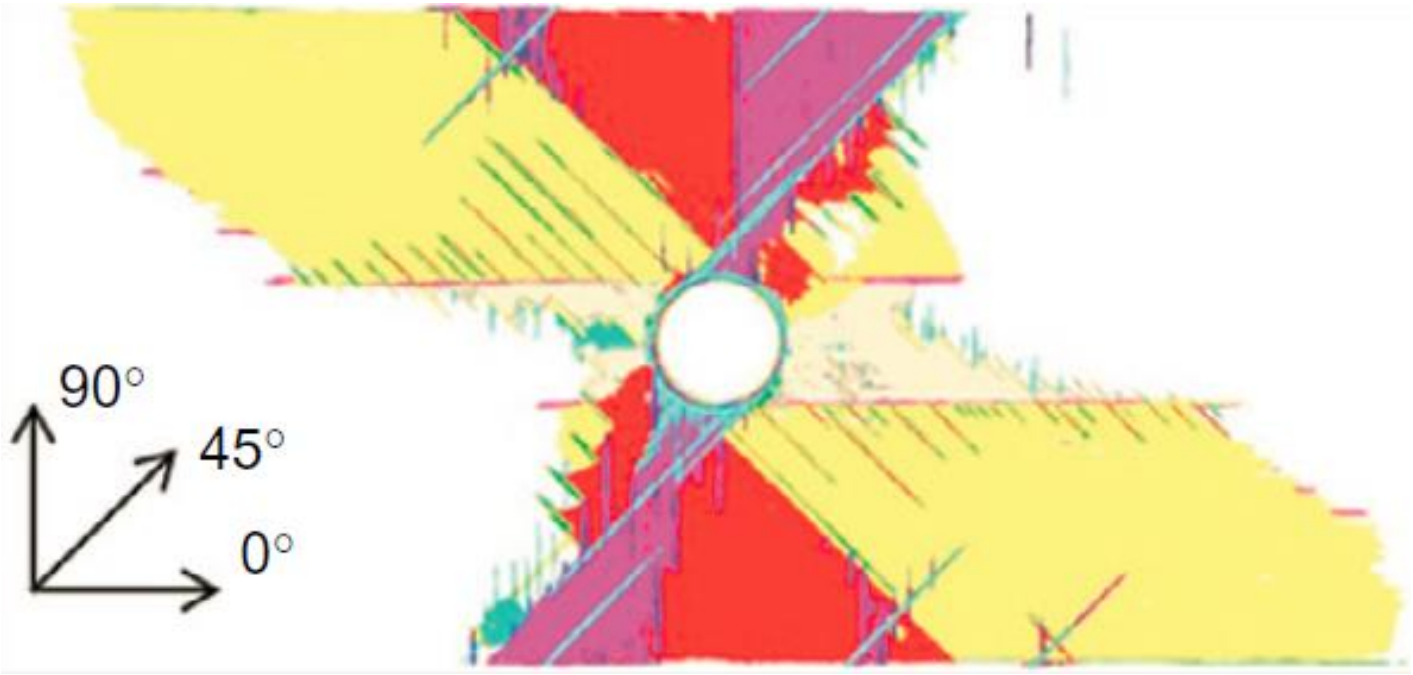
Spectroscopic imaging bay

Plus lots of rigs for in situ imaging



High flux bay

The detectability of Damage



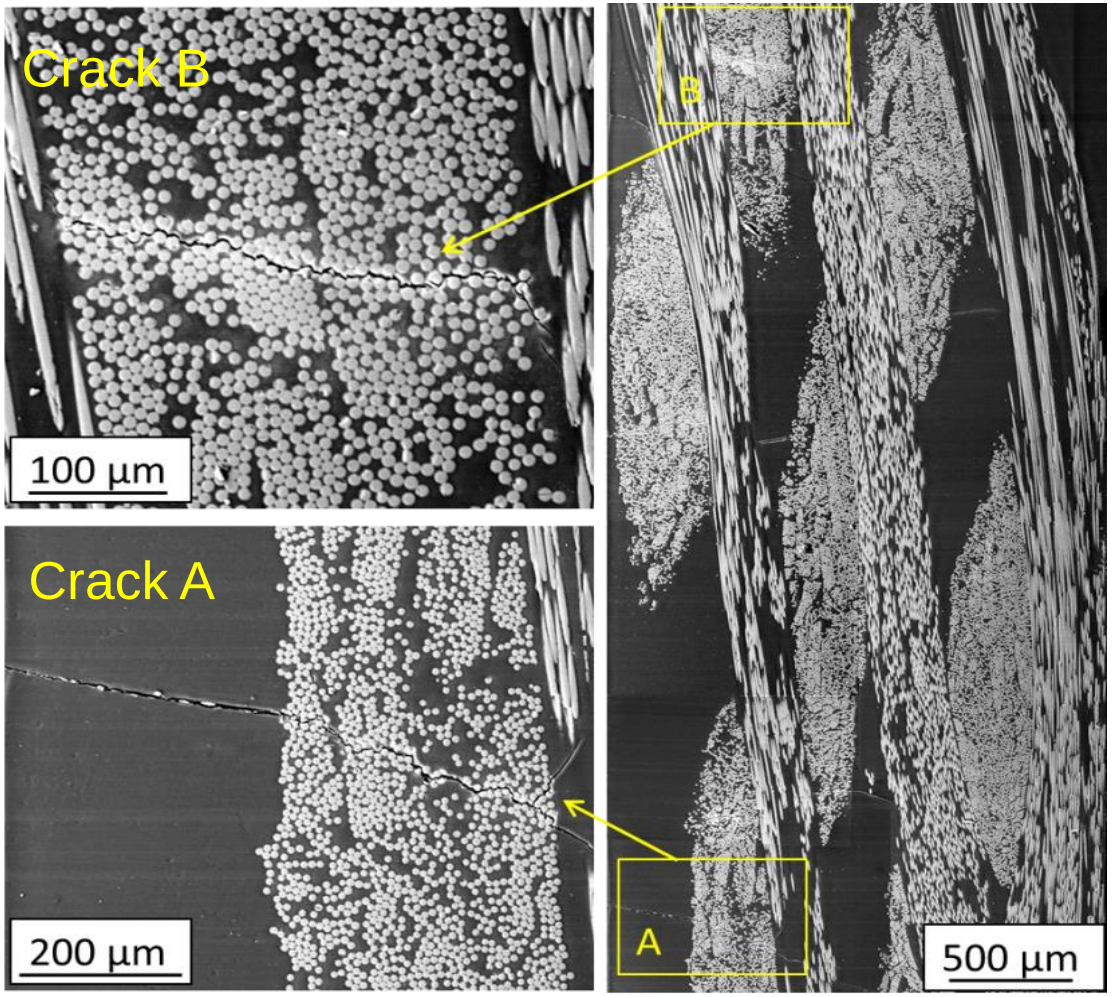
[Nixon-Pearson , Hallett, P.J. Withers, Rouse Composite structures]

Improving defect detectability

- Pores and resin rich areas normally easy to detect but cracks can be difficult to detect because the crack opening can be <1μm
- A number of strategies can help (Yu and Withers):
  - Increasing the resolution
  - Applying a load to open cracks
  - Applying a contrast agent

Woven composite test case

- Fatigued woven composite sample subjected to two thirds of fatigue life:



(a) Post mortem SEM

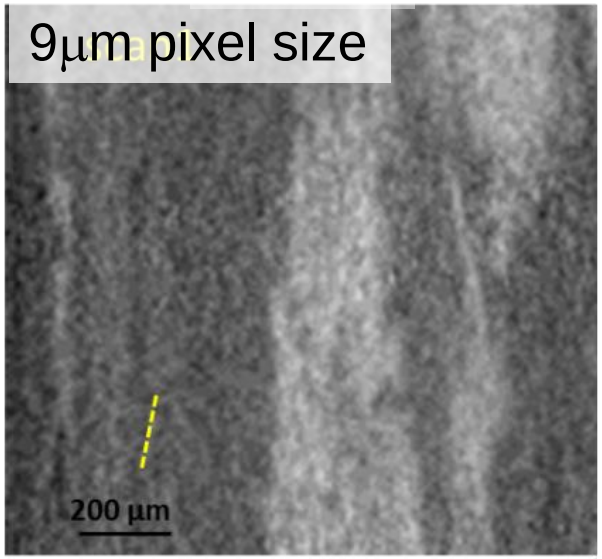
(b) 9µm pixel size CT slice

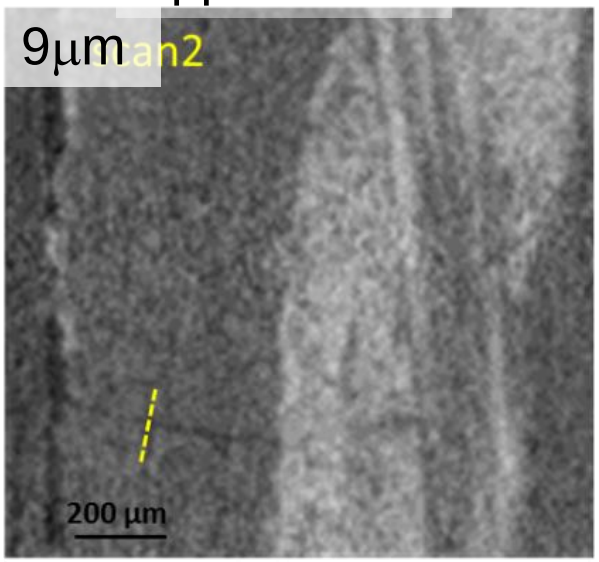
Increasing resolution/opening cracks

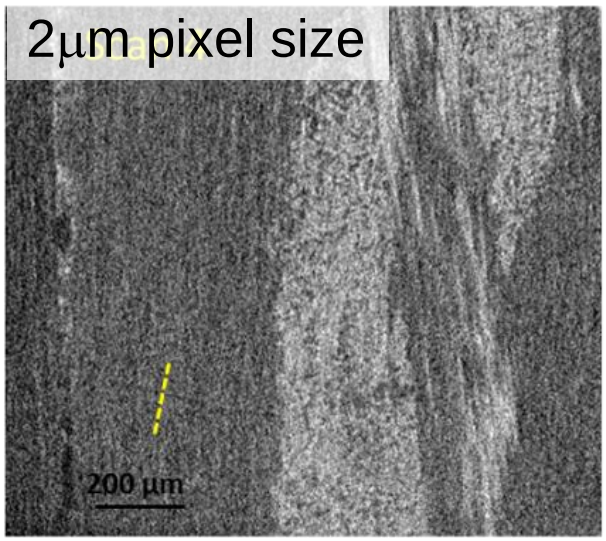
No load

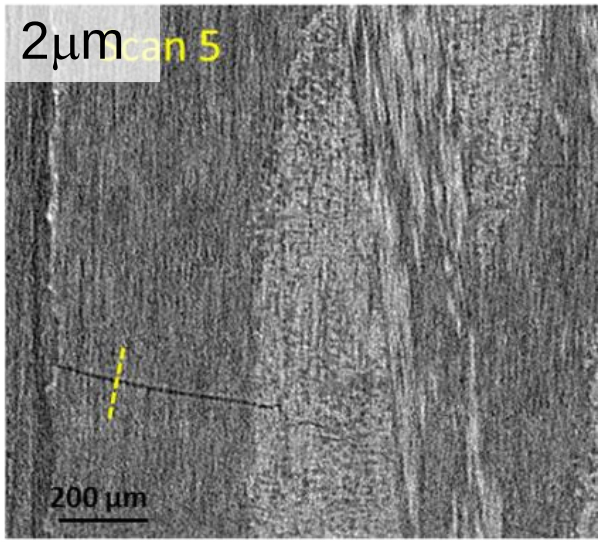
Applied load

Increasing resolution







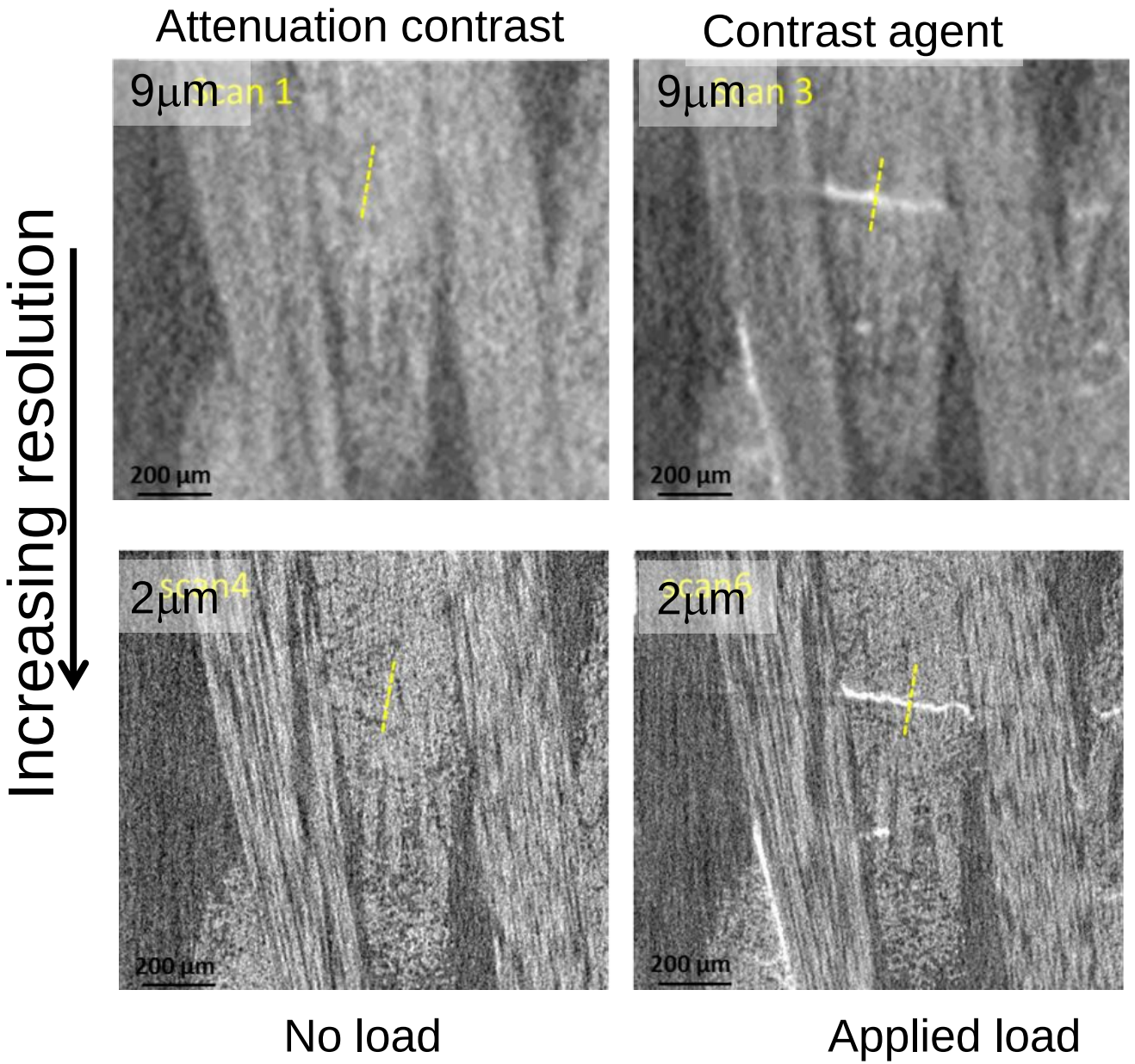


Crack A

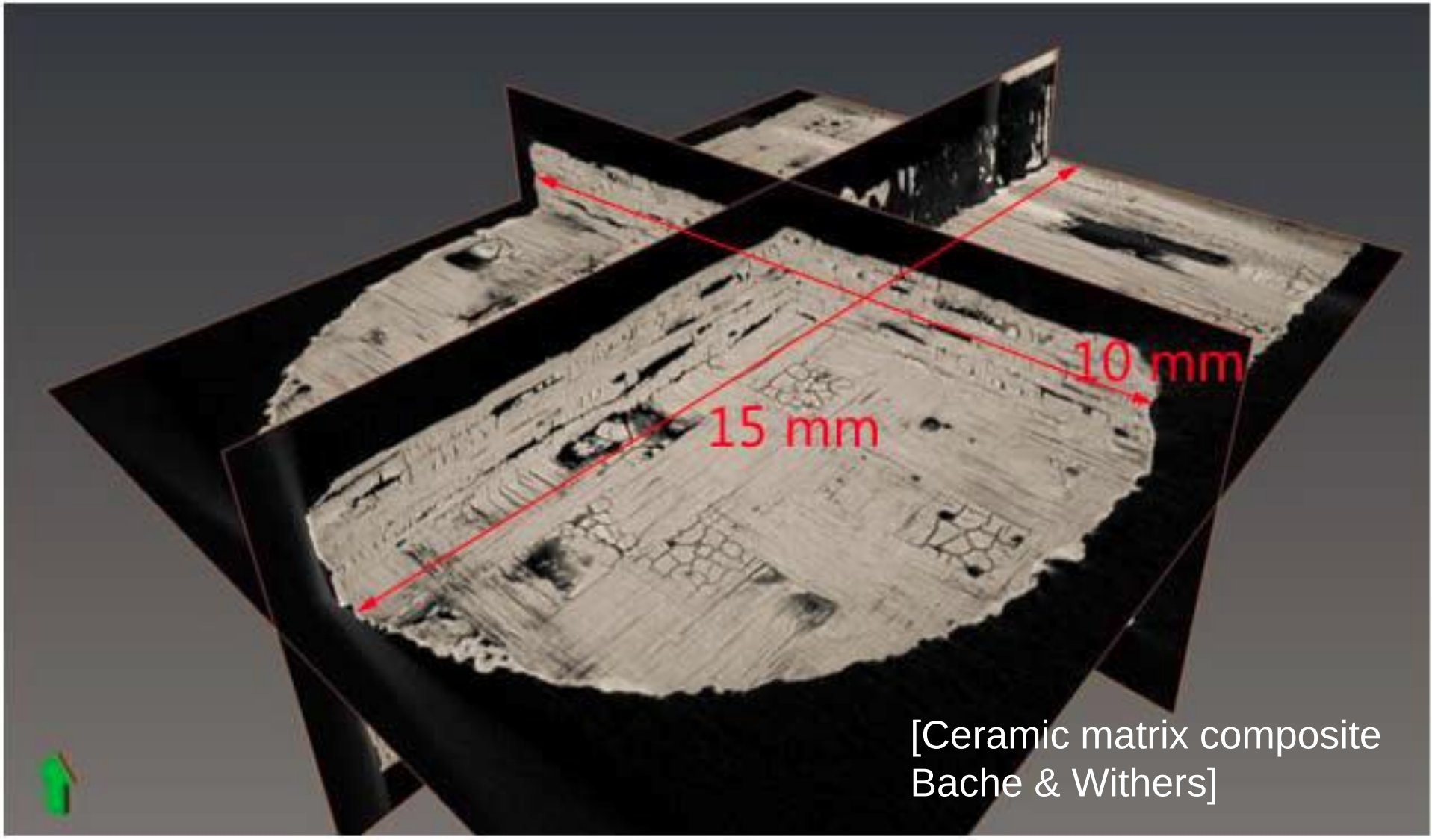
No load

Applied load

Using contrast agent (staining)



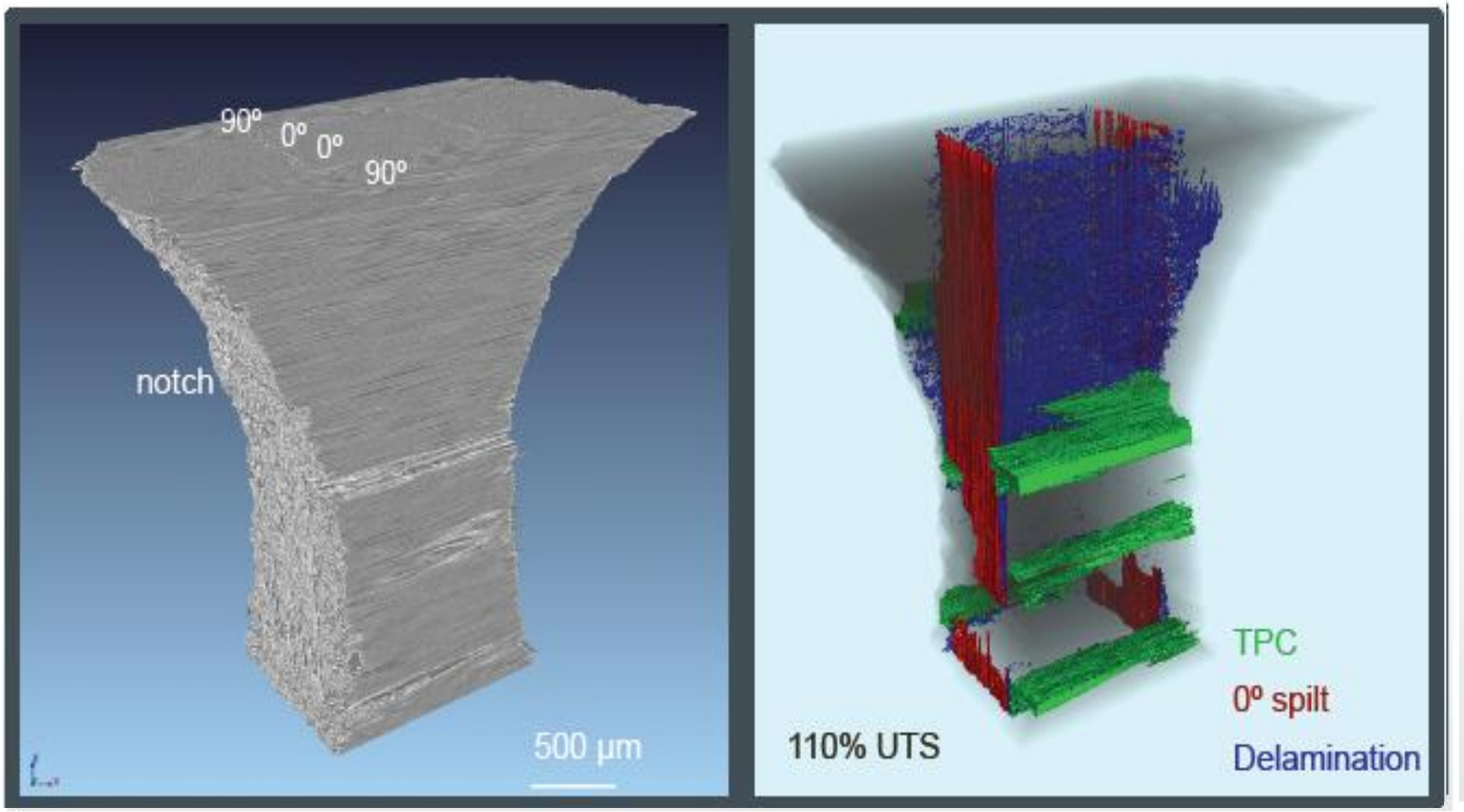
Applications: Monitoring Composite fabrication



[Ceramic matrix composite
Bache & Withers]

Applications: Tensile Failure

$[90/0]_s$ 110% UTS (nominal)

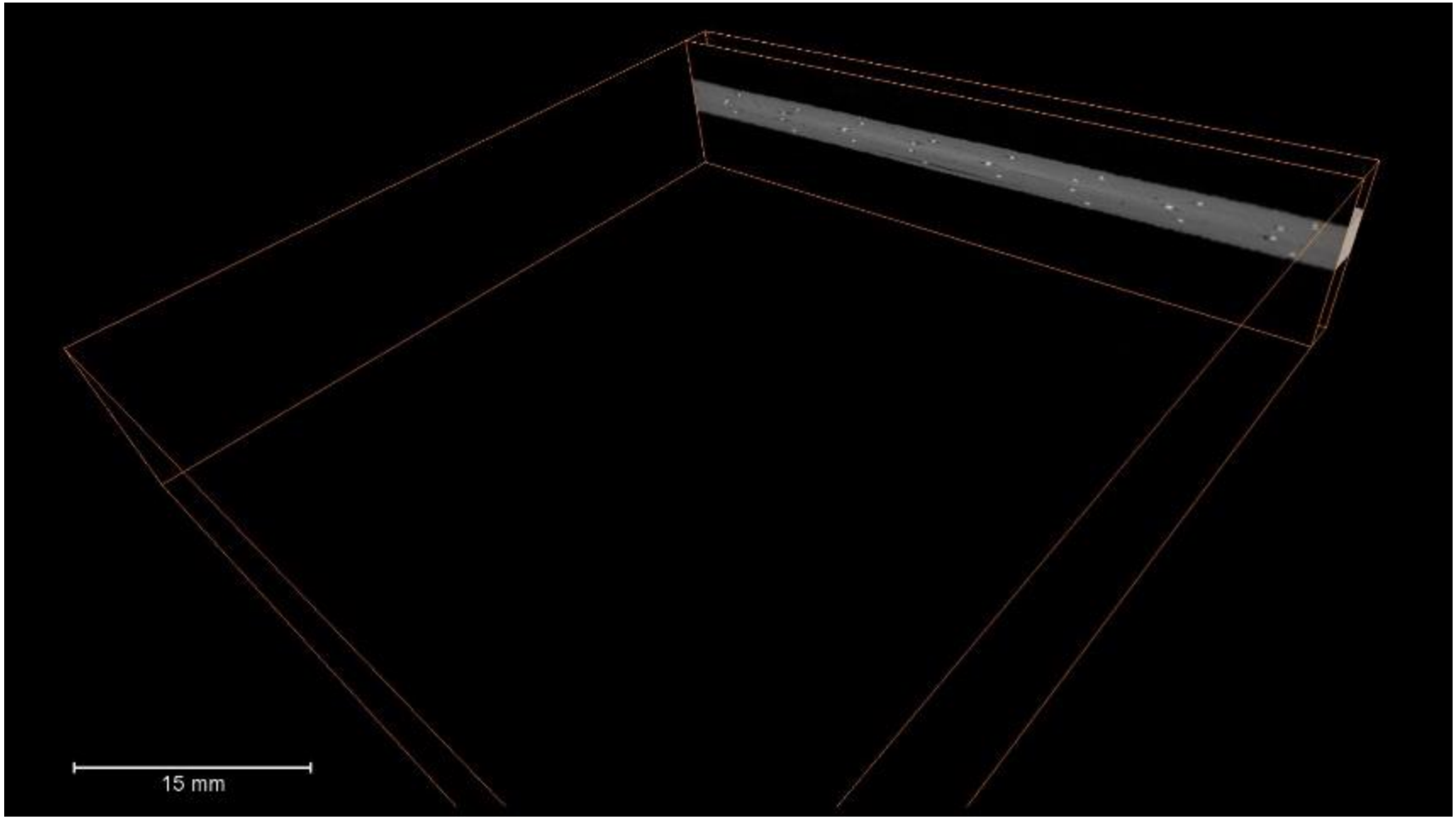


Courtesy Ian Sinclair

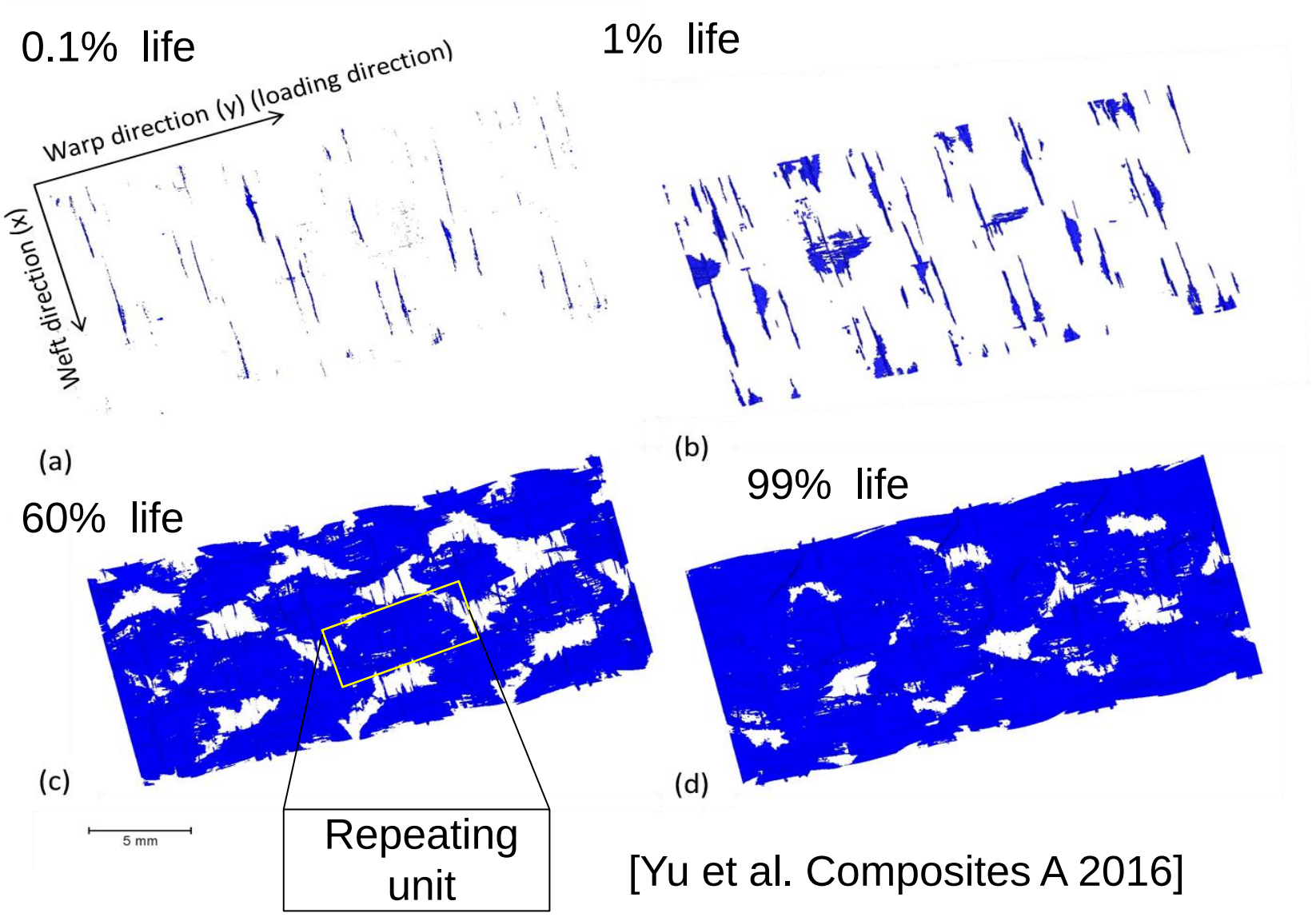
MANCHESTER 1824
The University of Manchester

Applications: Impact damage

The Queen's Anniversary Prizes
For Higher and Further Education
2011 & 2013



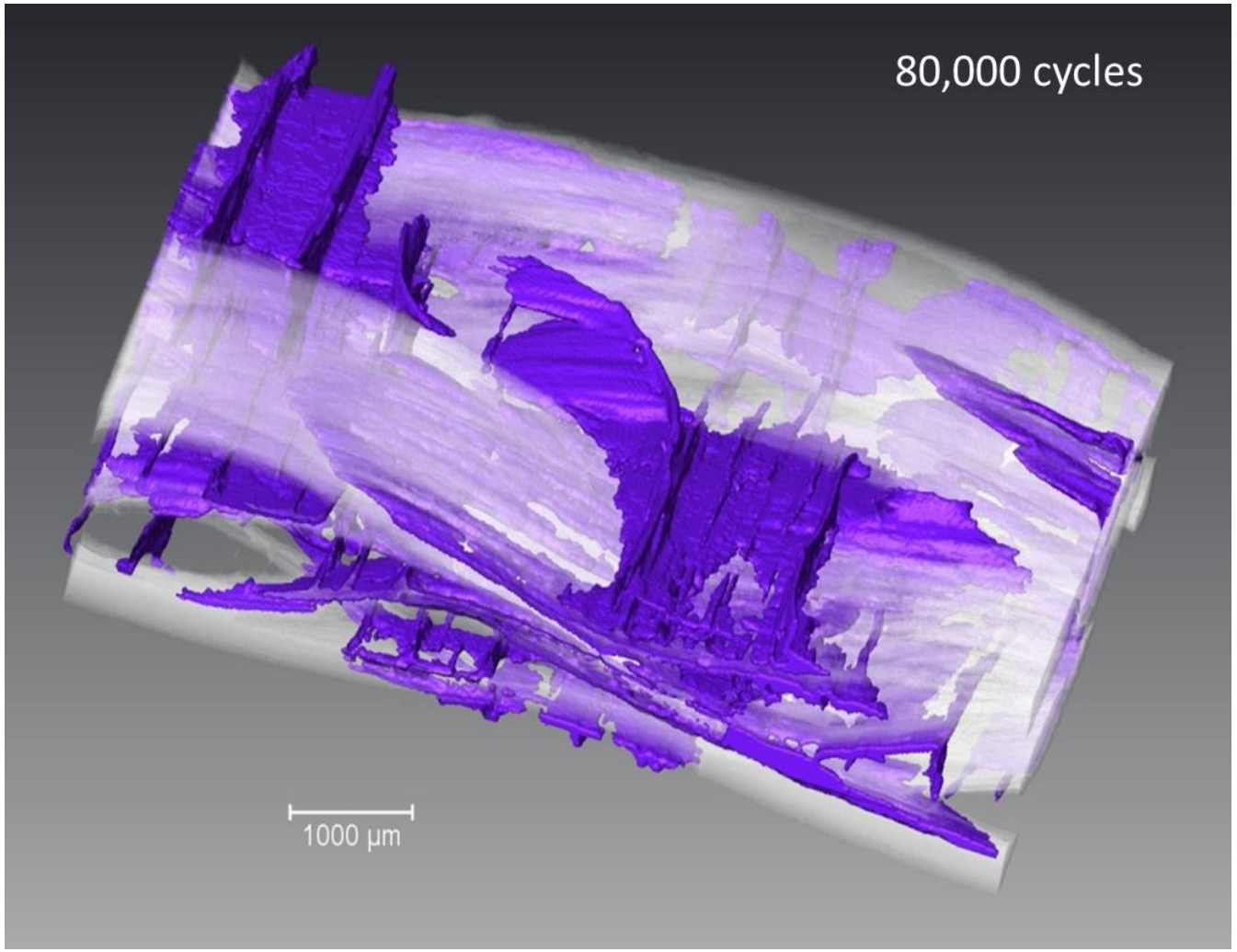
Applications: following fatigue damage



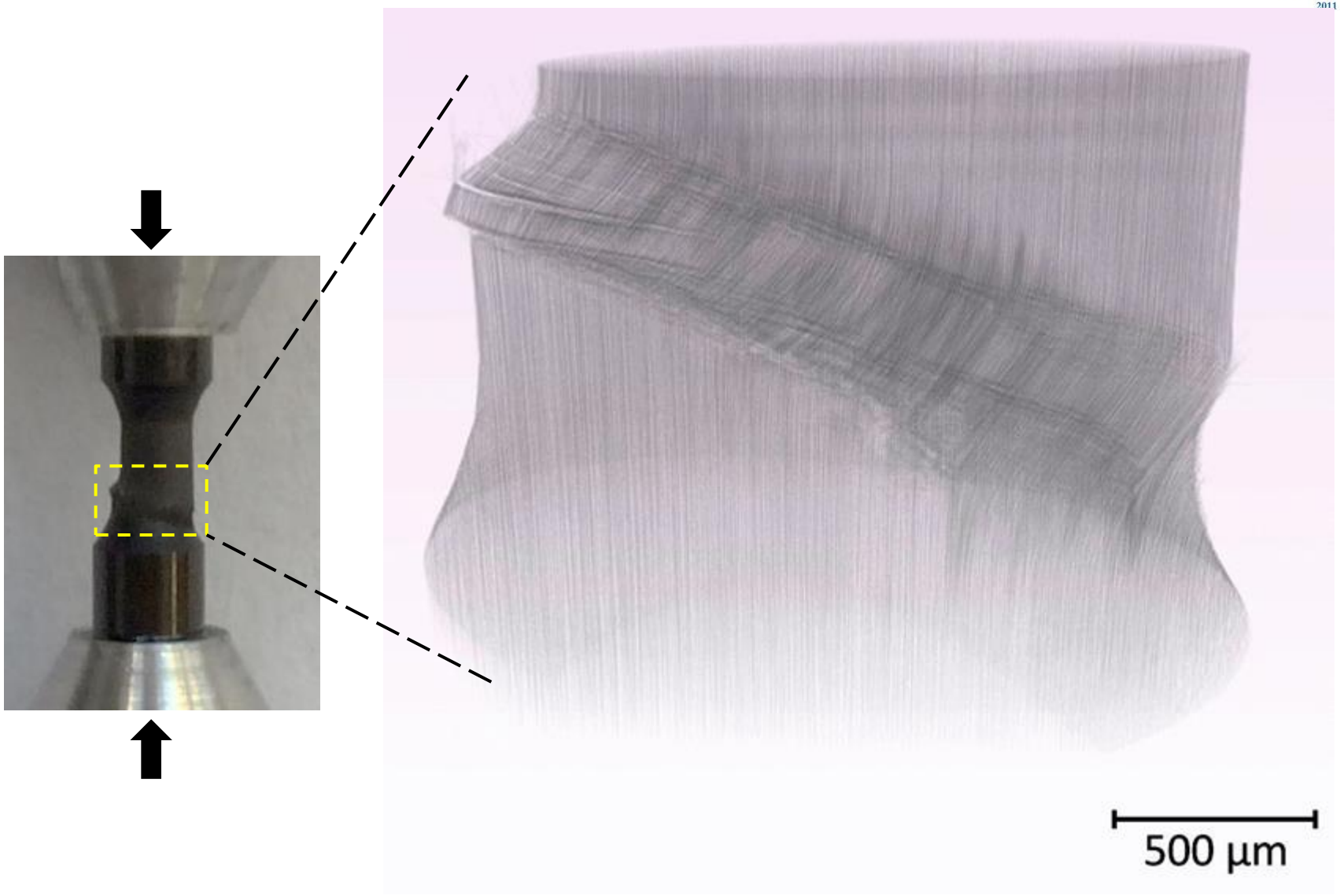
[Yu et al. Composites A 2016]

MANCHESTER 1824
The University of Manchester

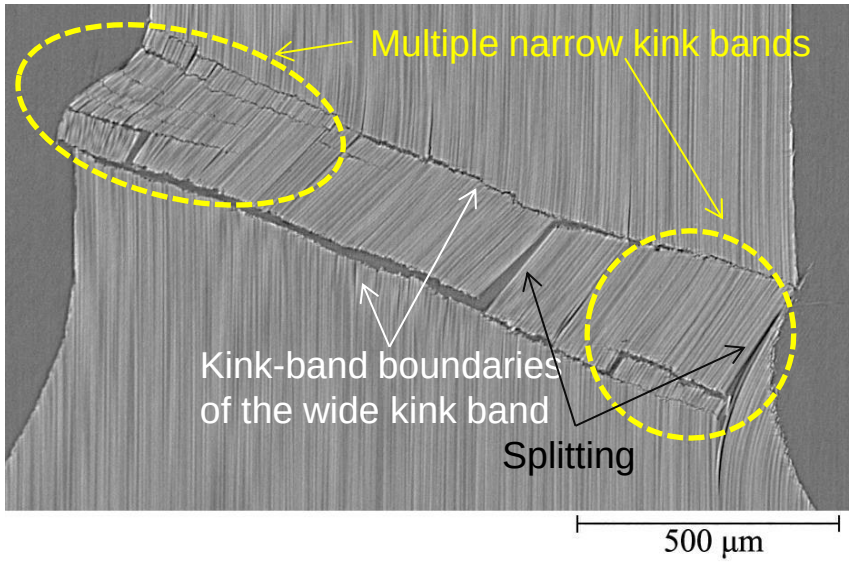
The Queen's Anniversary Prizes
For Higher and Further Education
2011 & 2013

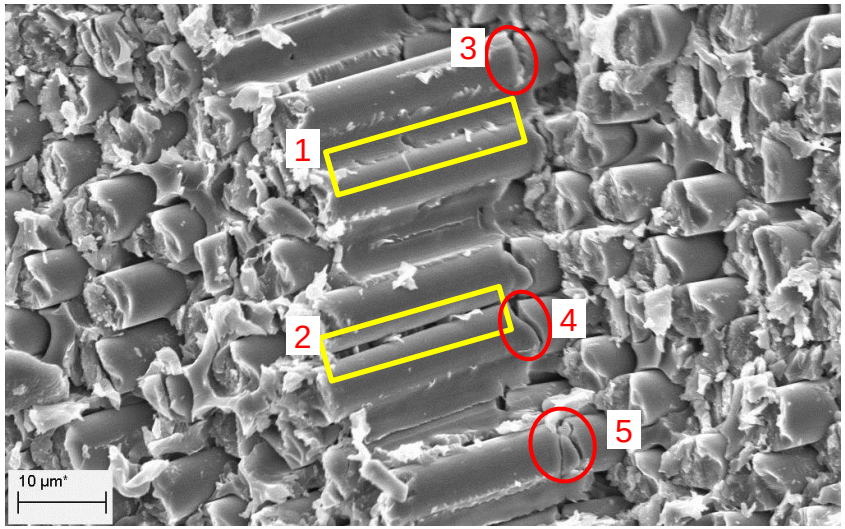


Applications: Kink band formation

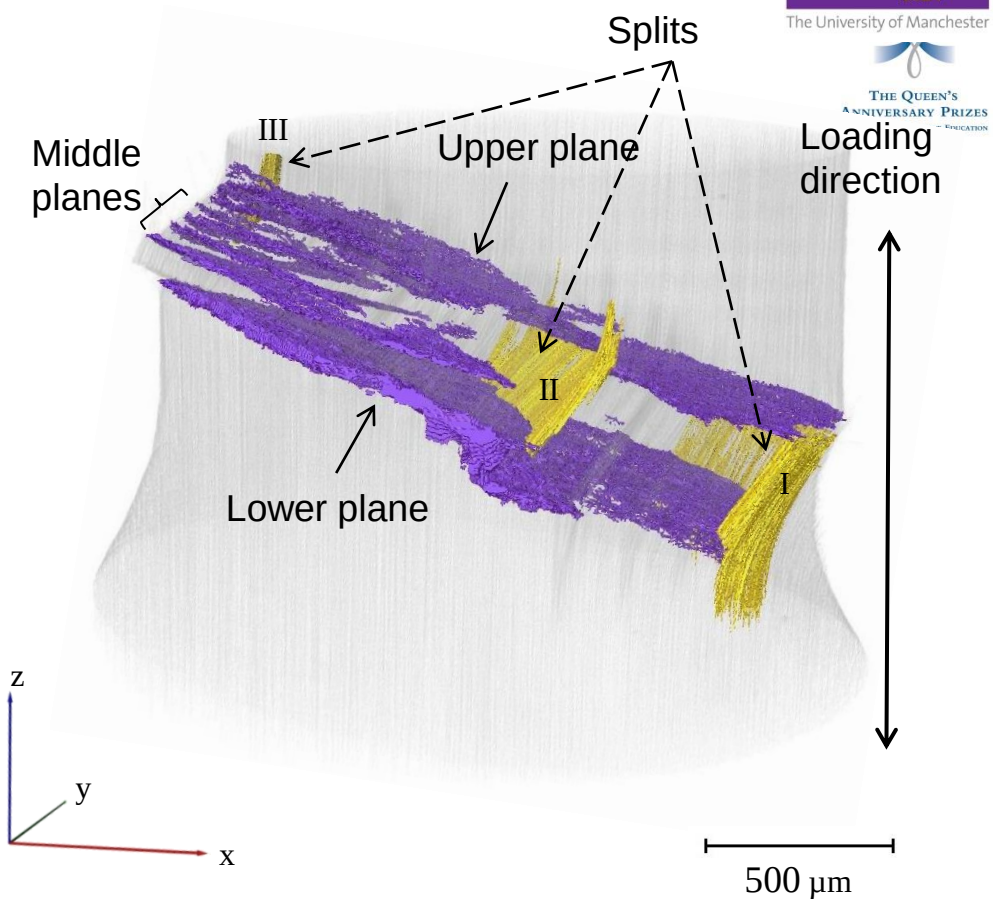


Post mortem





1 Matrix micro-cracking
2 Splitting
3 Fibre fracture perpendicular to the fibre direction
4 Angled fibre fracture
5 Fibre fracture with a wedge



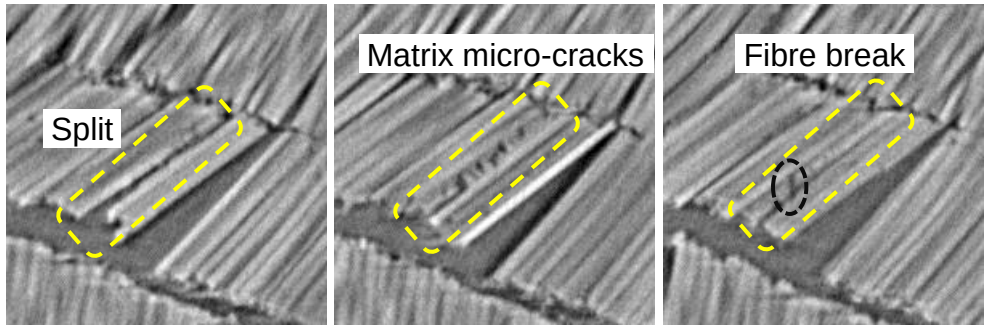
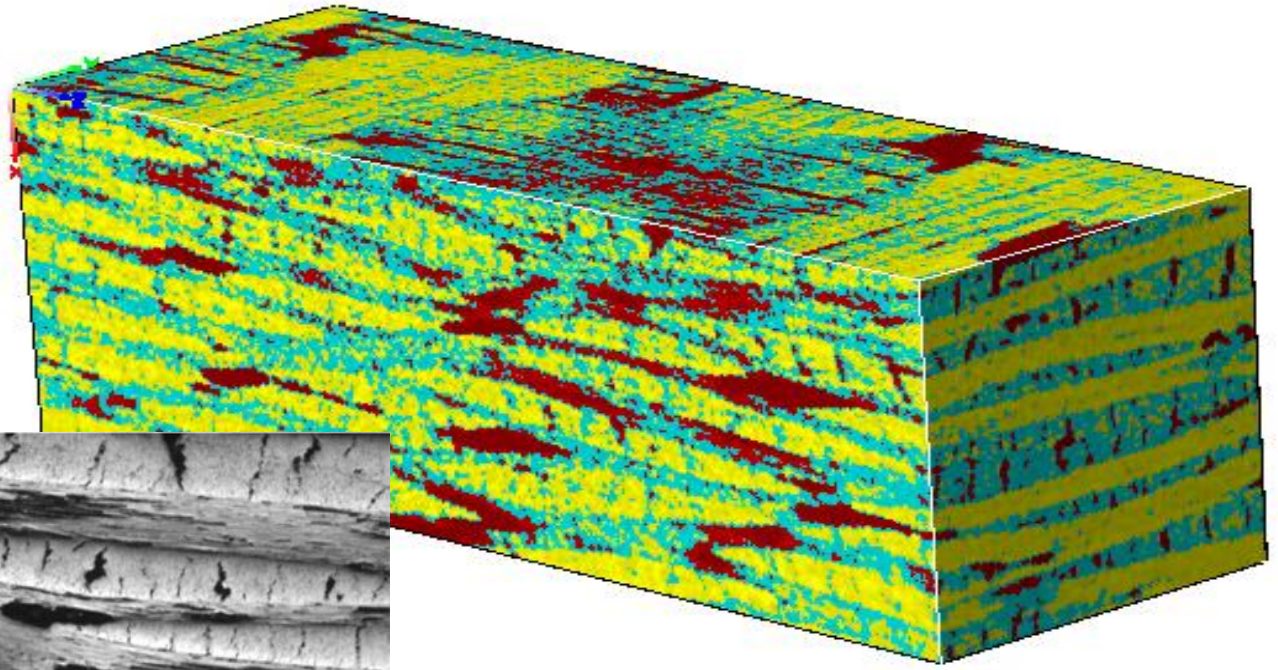
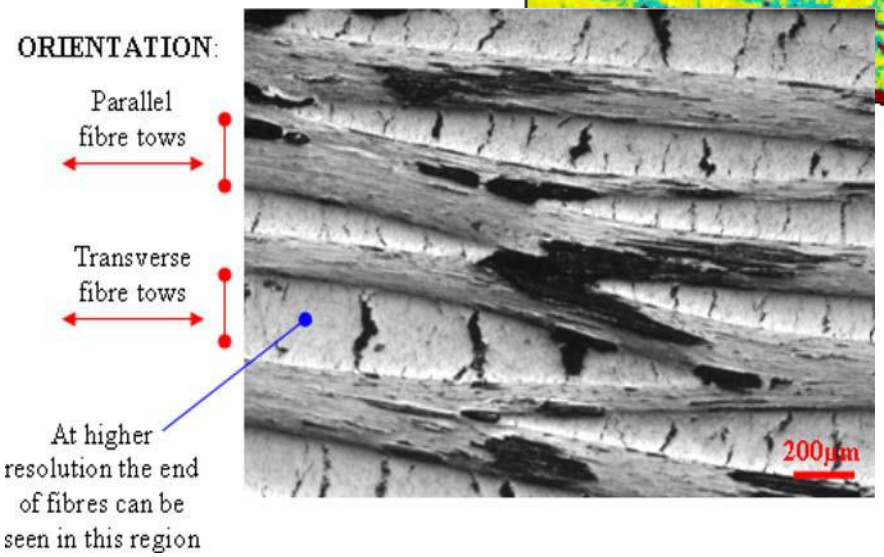


Image-based modelling

- Red = Porosity, Blue = fibres + matrix in direction 1, Yellow = fibres + matrix in direction 2

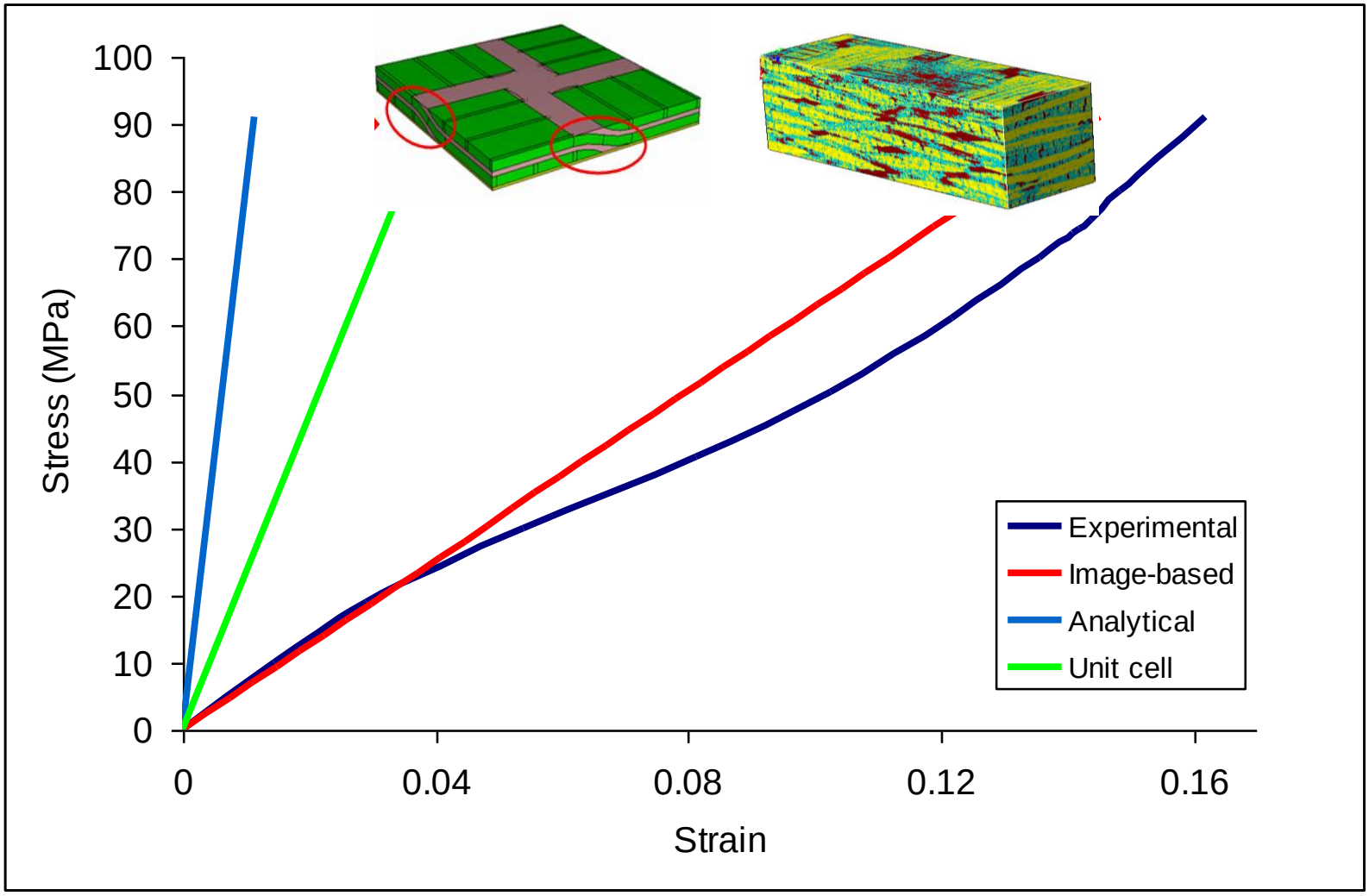




1mm

Stress/strain results

- Graphitised composite – perpendicular direction



Conclusions

- X-ray CT can provide insights into the effects of defects and their accumulation of damage through time-lapse 3D imaging, but:
  - Detectability of cracks can be low
  - Locating cracks requires high resolution or staining
- Multiscale approaches can be advantageous
- Region of interest or stitching together multiple images can to some extent overcome the competing demands of large volumes and high resolution
- Ideal for setting up realistic 3D FE models
- Can validate models through time dependent data
- High speed imaging (up to 300,000 radiographs per second) becoming possible to study fast events
- Lab. systems ideal for large objects or long timescale studies