Engineering strain mapping facilities

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Outline

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- What makes a “good” residual stress instrument?
- What is available out there
- What’s missing
- What’s new
- What’s next

Acknowledgements

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What makes a good instrument for engineering residual stress analysis?

- Large sample capacity for both weight and volume (linear dimensions)
- Translation facility for large distance with accuracy below 0.1 mm
- Access to load frames and sample environment facilities
- Small gauge volume capability
- Cover the range of measurements from near-surface to in-depth
- Easy access
  - Short time from application to beam
  - High hit rate
- Easy physical access
- Low-cost (no-cost) access
- Good instrument scientist support; reliable operation
- Good user programme; strong user community

There are more facilities out there than you might think…

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- **SYNCHROTRON FACILITIES**

- **Europe**
- ALBA Synchrotron Light Facility, Cerdanyola del Vallès, Spain
- ANKA Synchrotron Strahlungsquelle, Karlesruhe, Germany
- BESSY GmbH, Albert-Einstein-Str.15
- Diamond Light Source, United Kingdom
- Dortmund Electron Test Accelerator (DELTA), Dortmund, Germany
- Elettra Synchrotron Light Source, Trieste, Italy
- European Synchrotron Radiation Facility (ESRF), Grenoble, France
- Petra III, Hamburg, Germany
- Siberian Synchrotron Radiation Centre (SSRC) – VEPP 3/VEPP 4, Novosibirsk, Russia
- SOLEIL, France
- Swiss Light Source (SLS) at the Paul Scherrer Institut

- **South America**
- Laboratorio Nacional de Luz Síncrotron (LNLS) Sao Paolo, Brazil

- **Asia/Pacific**
- Australian Synchrotron, Melbourne, Australia
- Beijing Synchrotron Radiation Facility (BSRF), Beijing, China
- Raja Ramanna Center INDUS-1 & INDUS-2), Indore, India
- National Synchrotron Radiation Laboratory (NSRL), Hefei, China
- National Synchrotron Radiation Research Center (NSRRC), Hsinchu, Taiwan
- Pohang Accelerator Laboratory, Pohang, Korea
- SESAME, Jordan
- Shanghai Synchrotron Radiation Facility (SSRF), Shanghai, China
- Singapore Synchrotron Light Source (SSLS), Singapore
- Spring-8 Compact SASE Source (SCSS), Japan
- Super Photon Ring – 8 GeV (Spring8), Hyogo, Japan

- **North America**
- Advanced Light Source (ALS), Berkeley, California, USA
- Advanced Photon Source (APS), Argonne, Illinois, USA
- Canadian Light Source (CLS), Saskatoon, Canada
- Cornell High Energy Synchrotron Source (CHESS), Ithaca, New York, USA
- National Synchrotron Light Source (NSLS), Brookhaven, New York, USA
- Stanford Synchrotron Radiation Laboratory (SSRL), Menlo Park, California, USA

There are more facilities out there than you might think…

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- **NEUTRON FACILITIES**

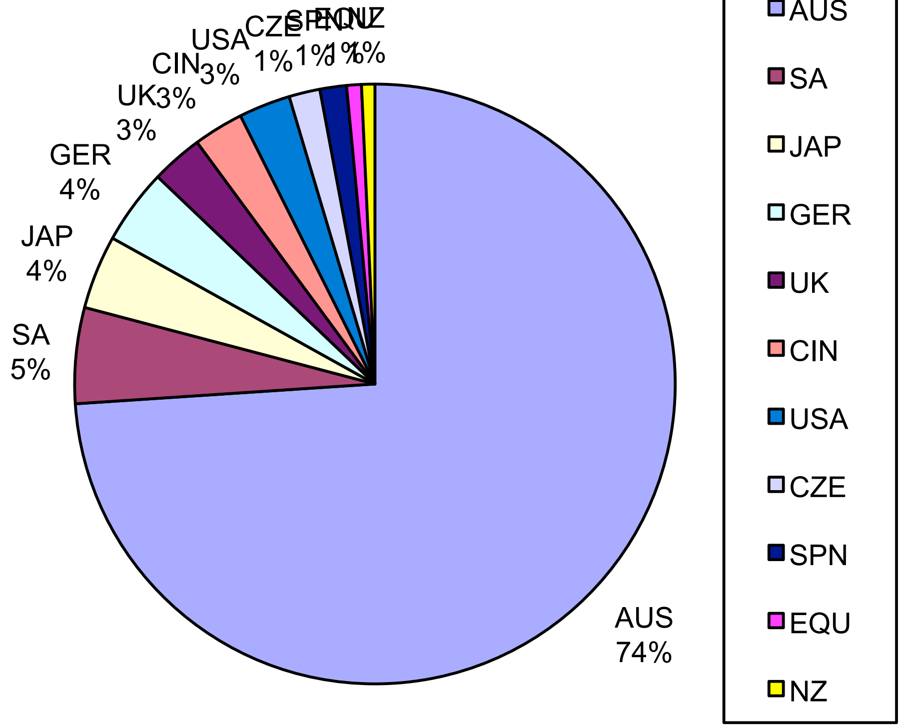
- **Asia/Pacific**
- Chinese Spallation Neutron Source (CSNS), Beijing, China
- DHRUVA Research Reactor, Trombay, India
- High-flux Advanced Neutron Application Reactor (HANARO), Taejon, South Korea
- ISSP Neutron Science Laboratory, Kashiwa, Japan
- JAERI-KEK Joint Facility, J-PARC, Japan
- OPAL, Lucas Heights, Australia

- **Europe**
- FRM-II, Munich, Germany
- Frank Laboratory of Neutron Physics (FLNP), Dubna, Russia
- Institut Laue-Langevin (ILL), Grenoble, France
- Interfacultair Reactor Institute (IRI), Delft, The Netherlands
- ISIS - Rutherford Appleton Laboratory, United Kingdom
- KFKI, Budapest, Hungary
- LLB, Saclay, France
- Swiss spallation neutron source (SINQ) at the Paul Scherrer Institute
- Petersburg Nuclear Physics Institute, Gatchina, Russia

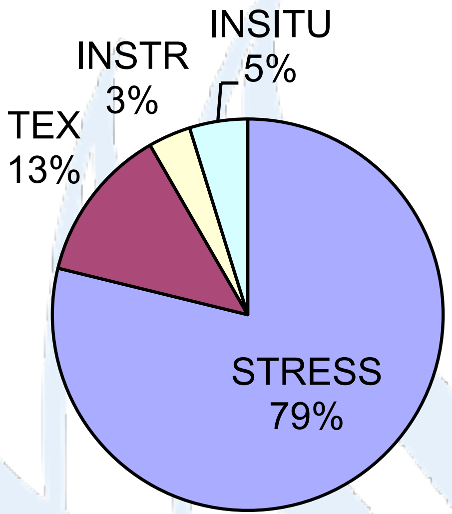
- **North America**
- Canadian Neutron Beam Centre (CNBC), Chalk River, Canada
- High Flux Isotope Reactor (HFIR), Oak Ridge, Tennessee
- Manuel Lujan Jr. Neutron Scattering Center at LANSCE, Los Alamos
- National Institute of Standards and Technology Reactor (NIST), Maryland
- Spallation Neutron Source (SNS), Oak Ridge

- NECSA, South Africa

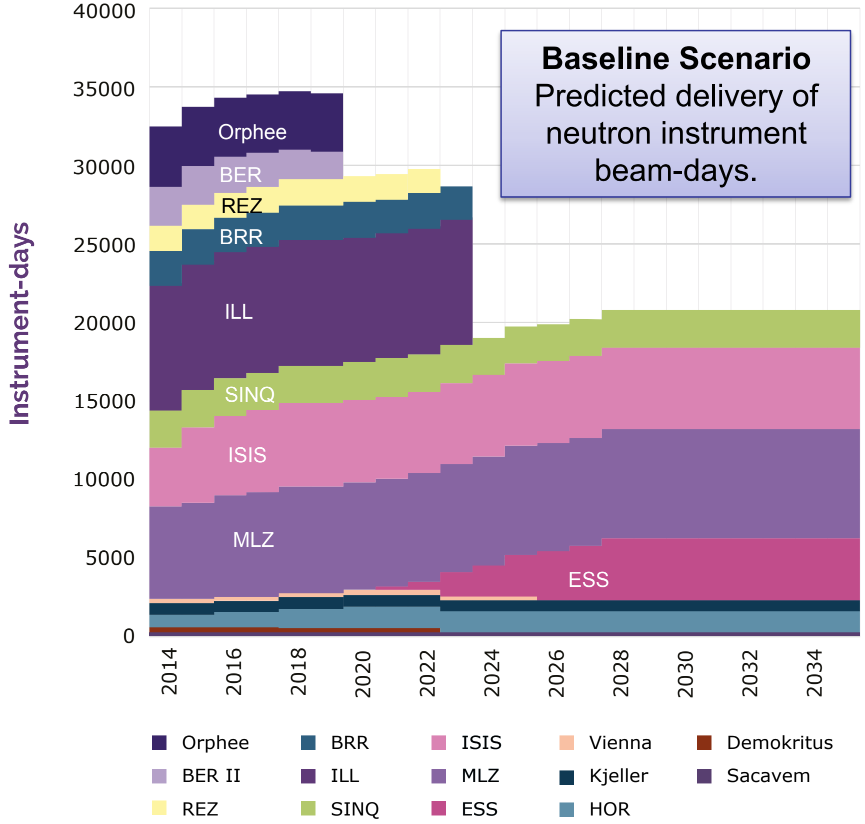
Having a local source makes a ***big*** difference



User base of KOWARI, OPAL, Australia



Many sources are coming to the end of their lives



What are the leading facilities?

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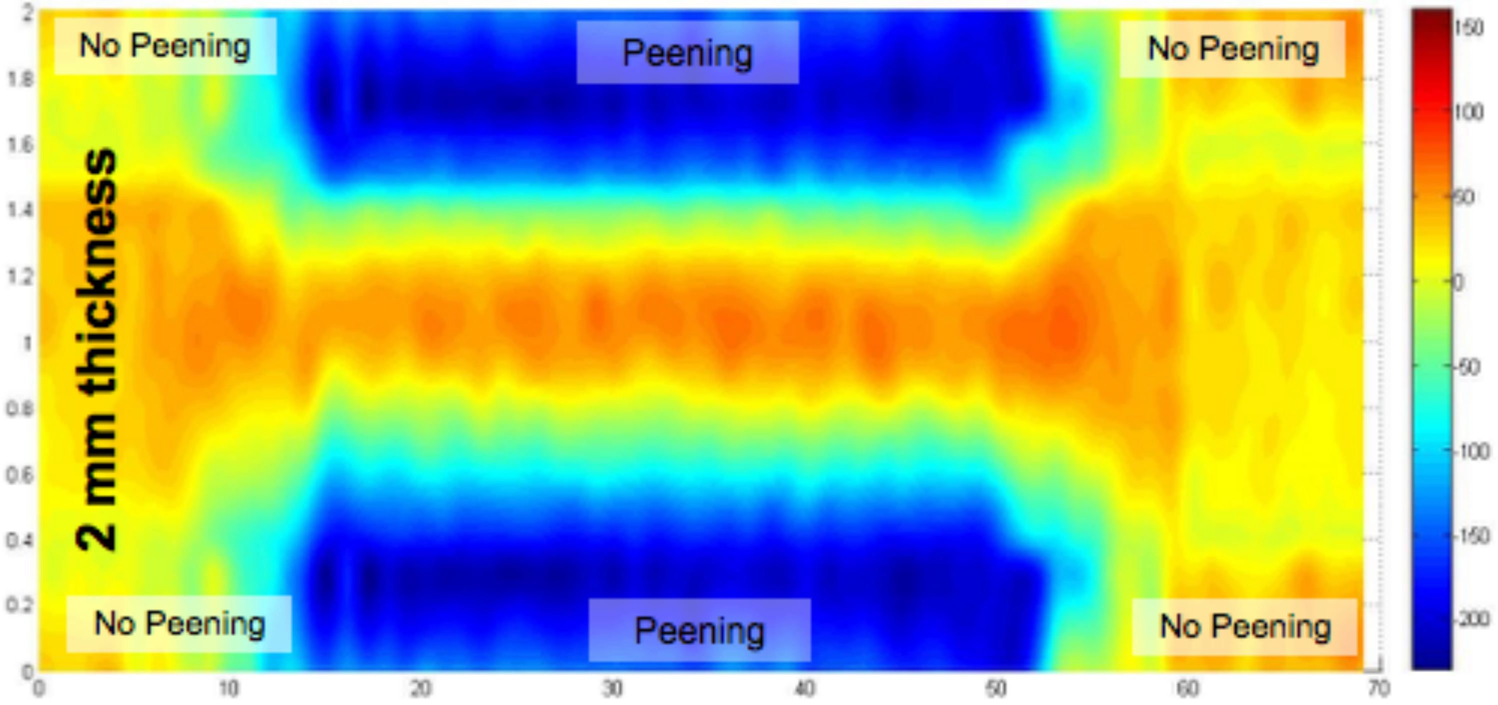
ISIS	ENGIN-X
SINQ	POLDI
ANSTO	Kowari
Diamond	I12 (JEEP)
APS	1-ID
ORNL, HFIR	NRSF2
ORNL, SNS	VULCAN
J-PARC	RADEN
ILL	SALSA
ISIS	IMAT
ESRF	ID31

What's missing?

- Filling the gap in the first millimetre from the surface



What's missing?

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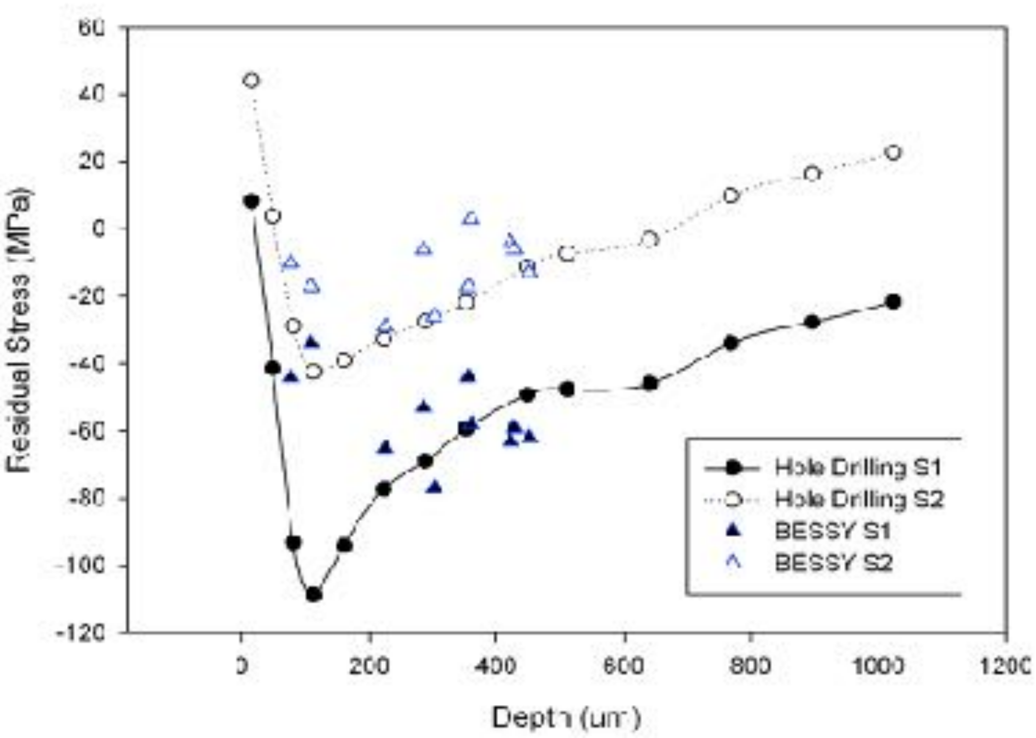
- Filling the gap in the first millimetre from the surface



What's new? IMAT at ISIS

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IMAT: Imaging and MATerials science

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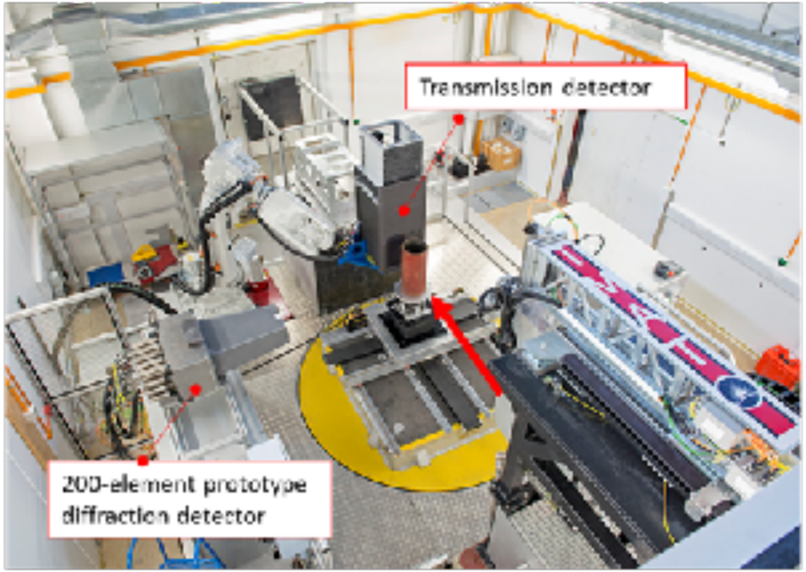
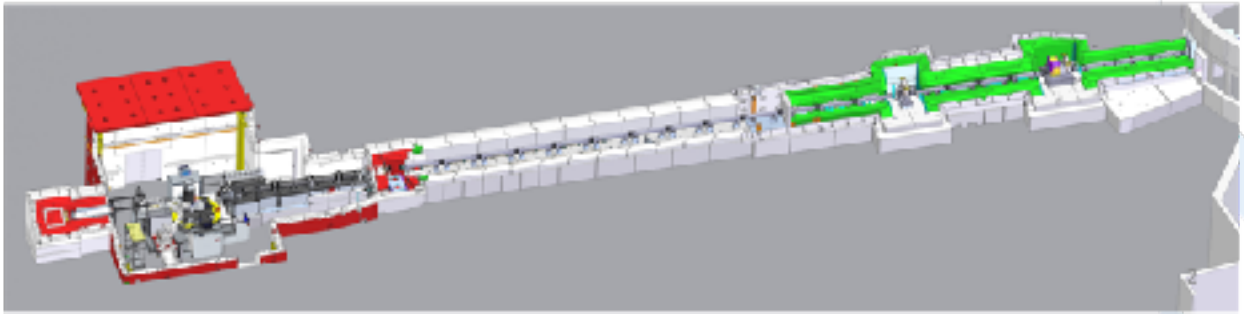




Neutron Radiography, Energy Selective Imaging

Neutron Tomography

Texture and Phase Analysis

Neutron Diffraction strain scanning

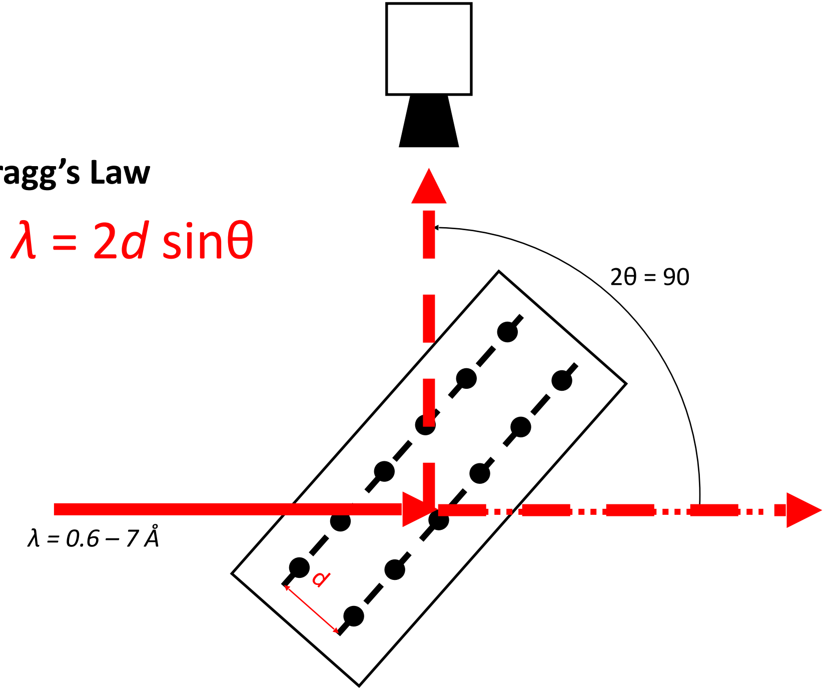
Neutron Transmission strain measurement and 2D strain mapping

Principles

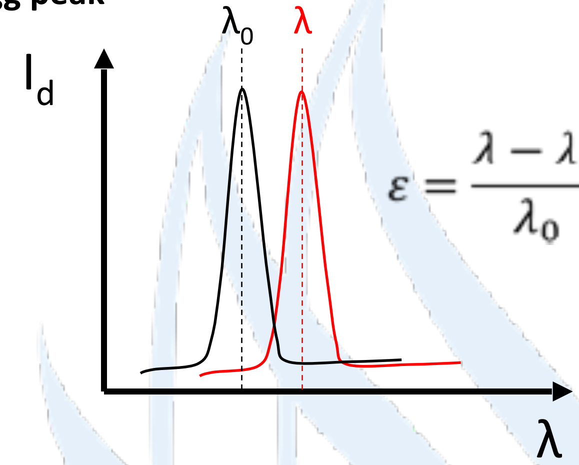
Neutron Diffraction

Bragg's Law

$$\lambda = 2d \sin\theta$$



Bragg peak



$$\varepsilon = \frac{\lambda - \lambda_0}{\lambda_0}$$

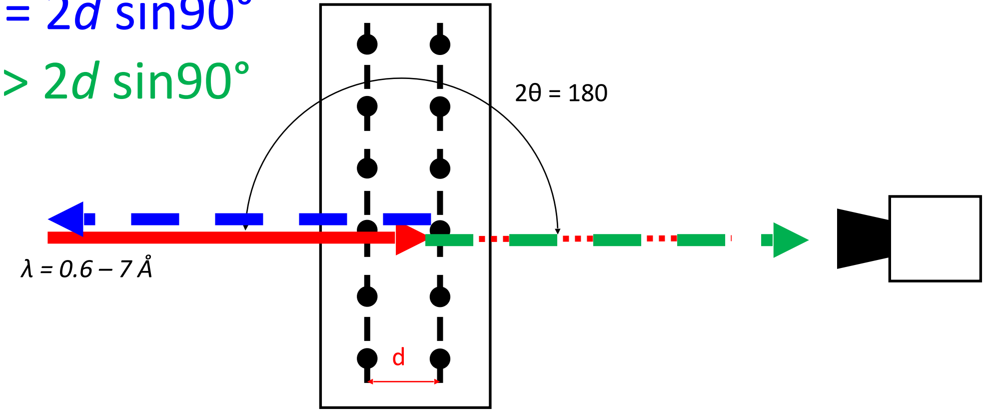
Principles

Neutron Transmission

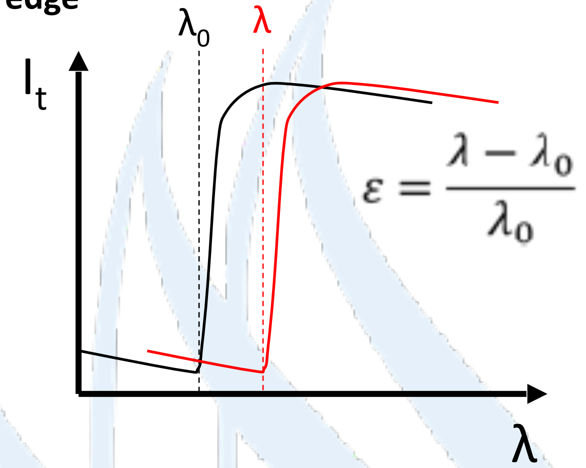
Bragg's Law

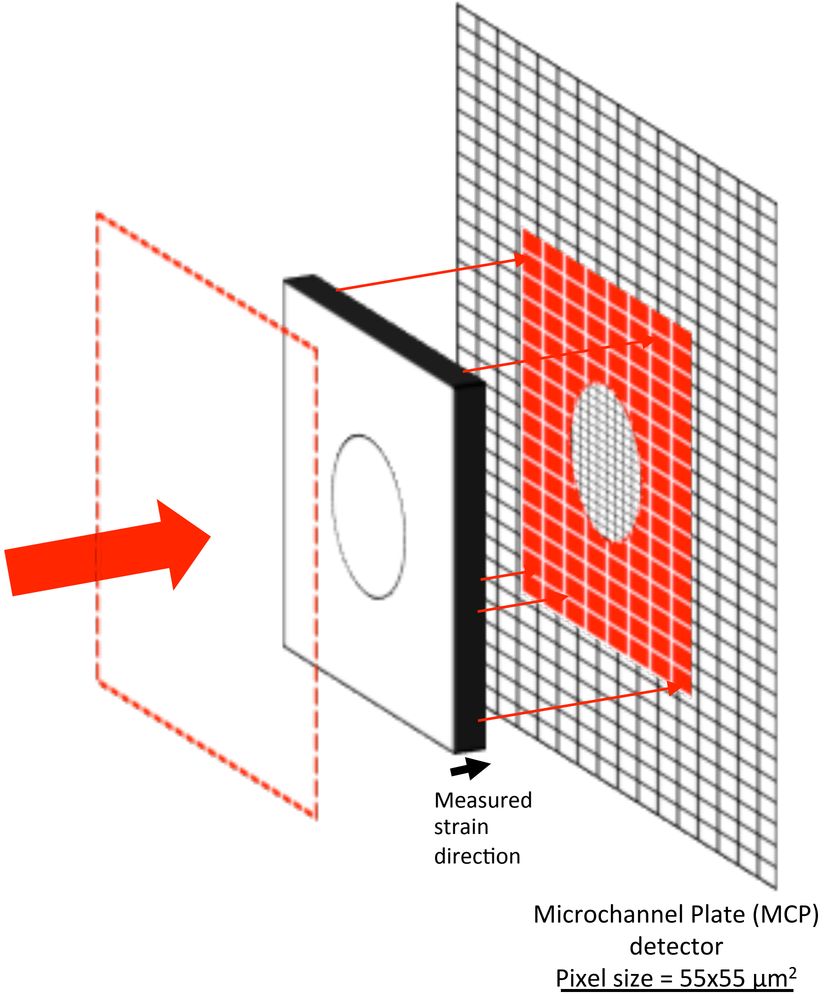
$\lambda = 2d \sin 90°$

$\lambda > 2d \sin 90°$



Bragg edge

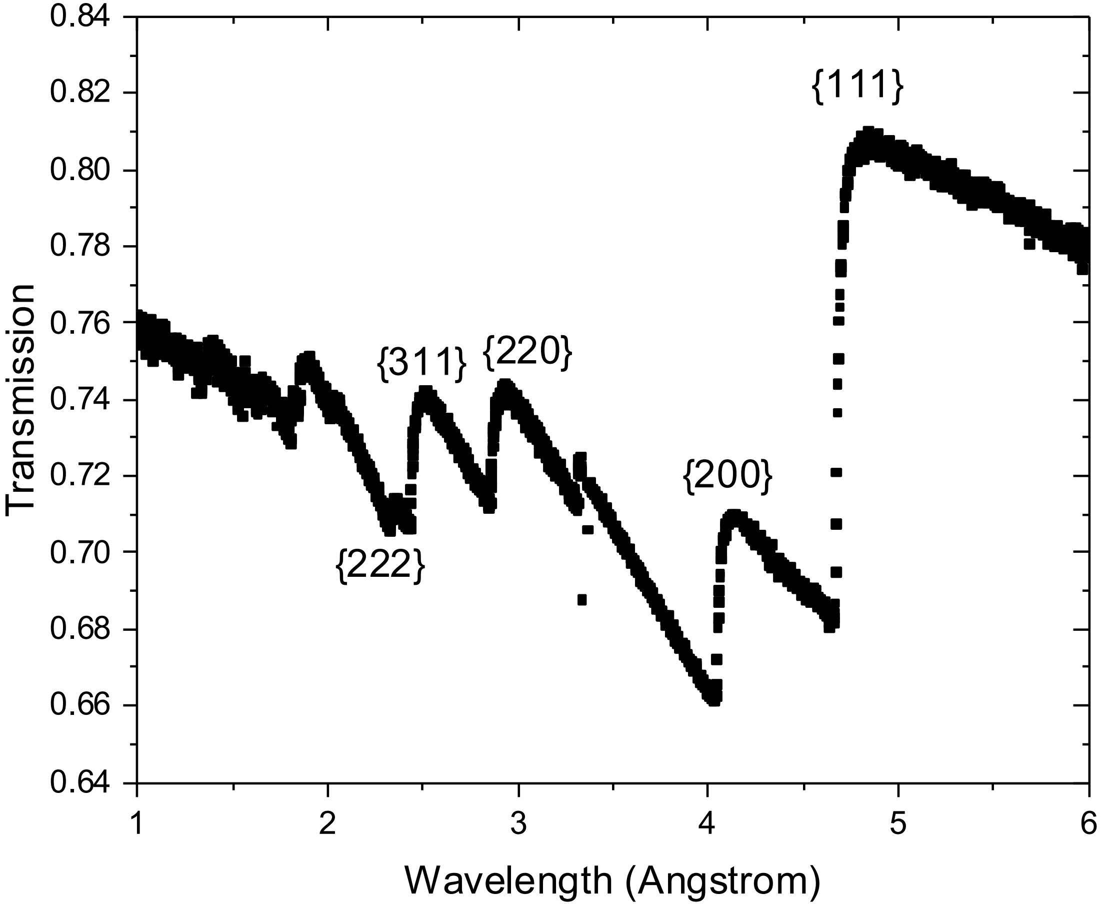




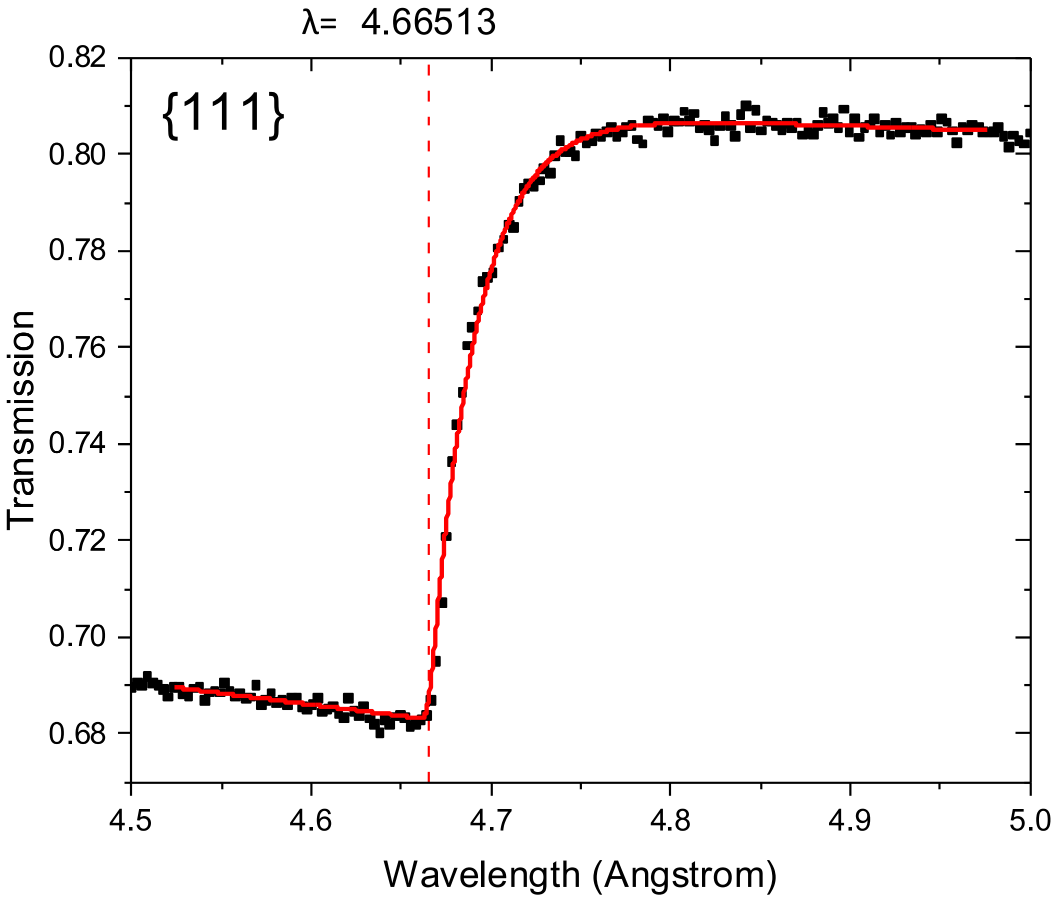
Through-thickness average 2D strain map

Strain direction: in the direction of incoming beam

Example: Aluminium Bragg Edges

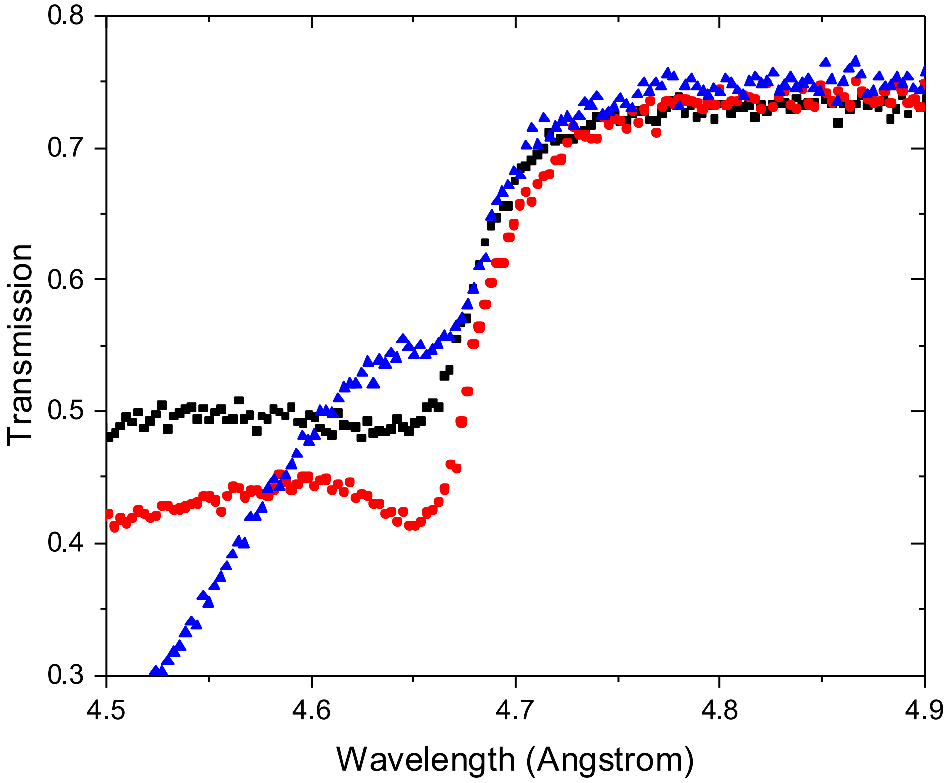


Edges are hard to fit



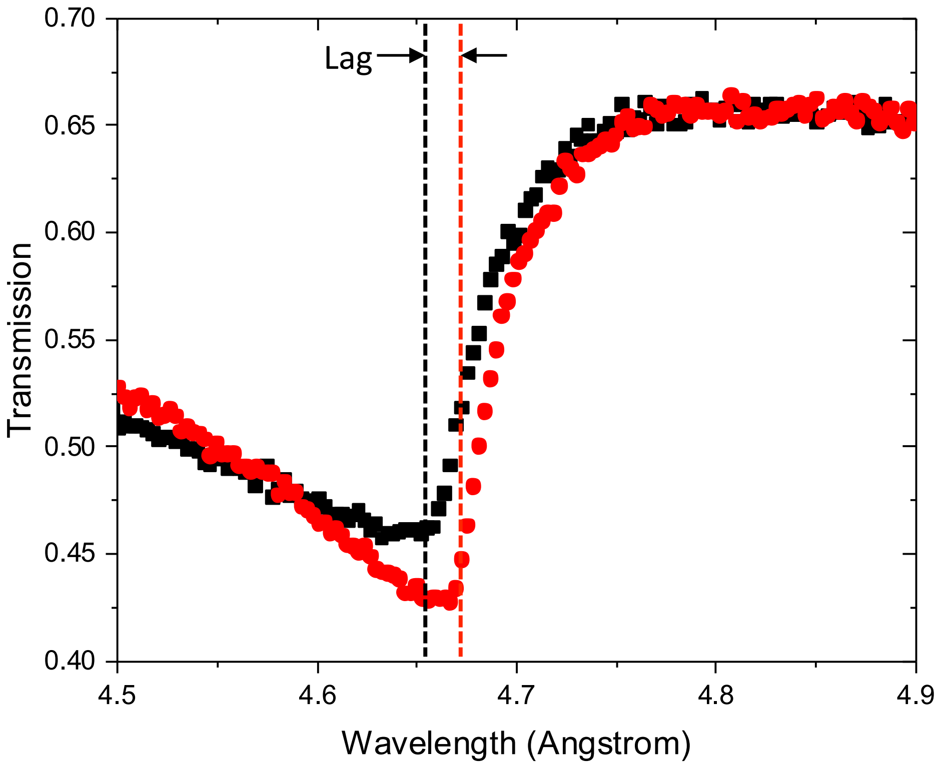
- Non-linear fitting function

Edges are hard to fit



- Textured 7150

Use cross correlation



- Determine the "lag" between the two signals

Example: $AlSiC_p$ MMC

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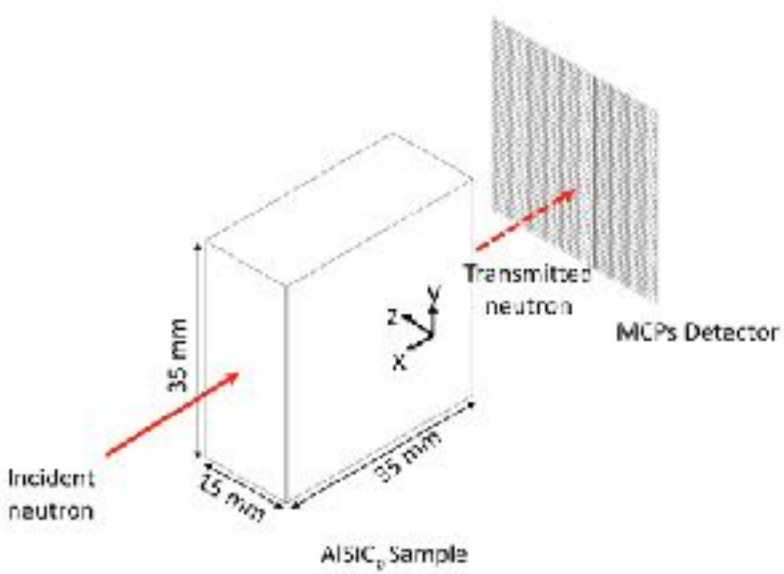
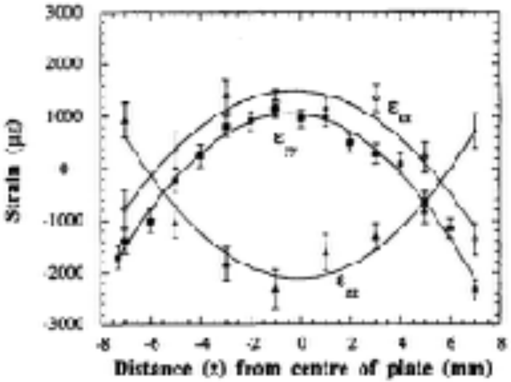
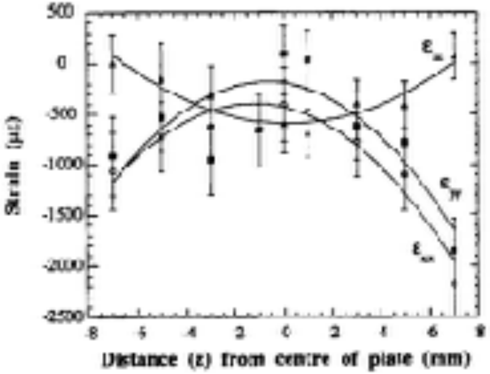


Neutron Diffraction Results

Aluminium



SiC



Source:

[1] M. E. Fitzpatrick, M. T. Hutchings, and P. J. Withers, "Separation of macroscopic, elastic mismatch and thermal expansion misfit stresses in metal matrix composite quenched plates from neutron diffraction measurements," *Acta Mater.*, vol. 45, no. 12, pp. 4867–4876, 1997.

Result: Aluminium

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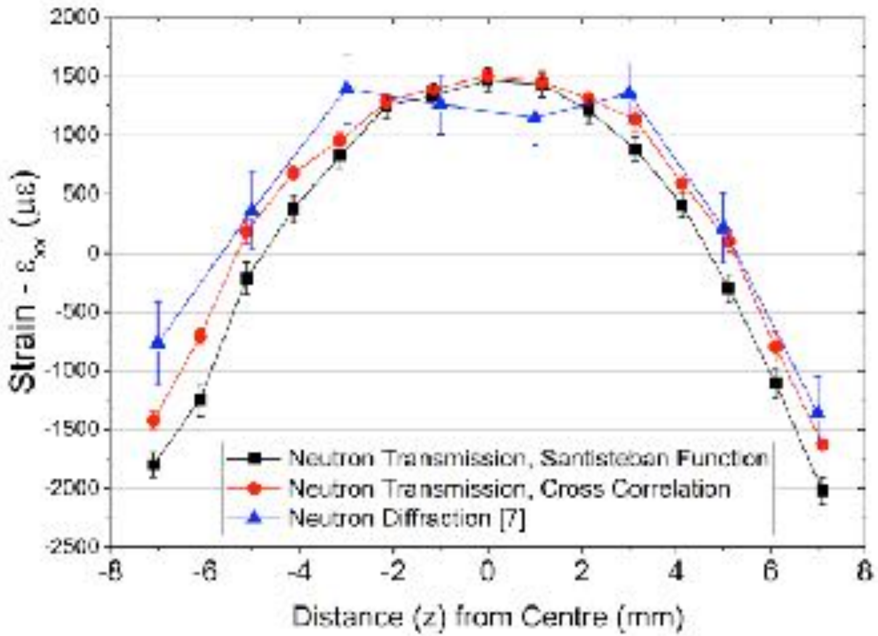

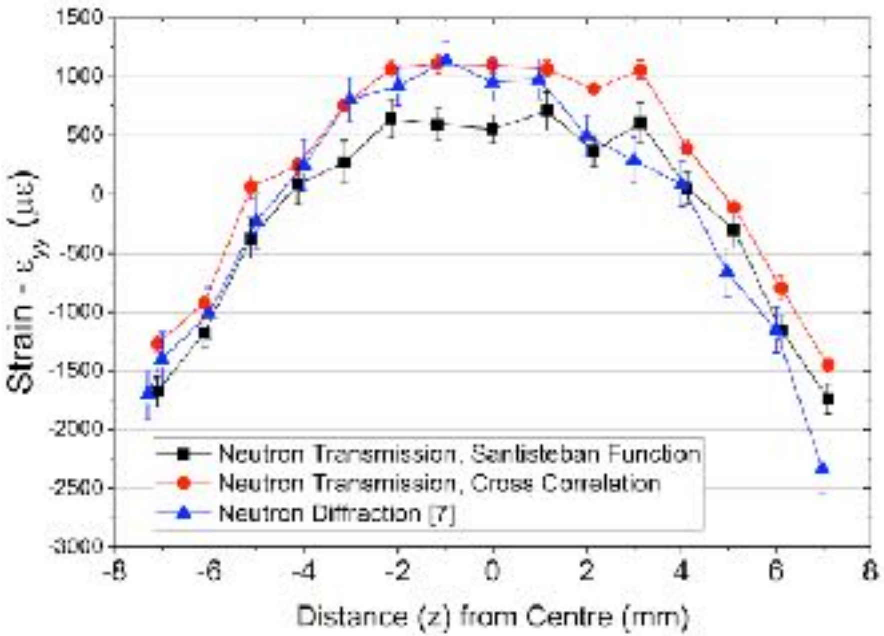

Example: Thermal Expansion

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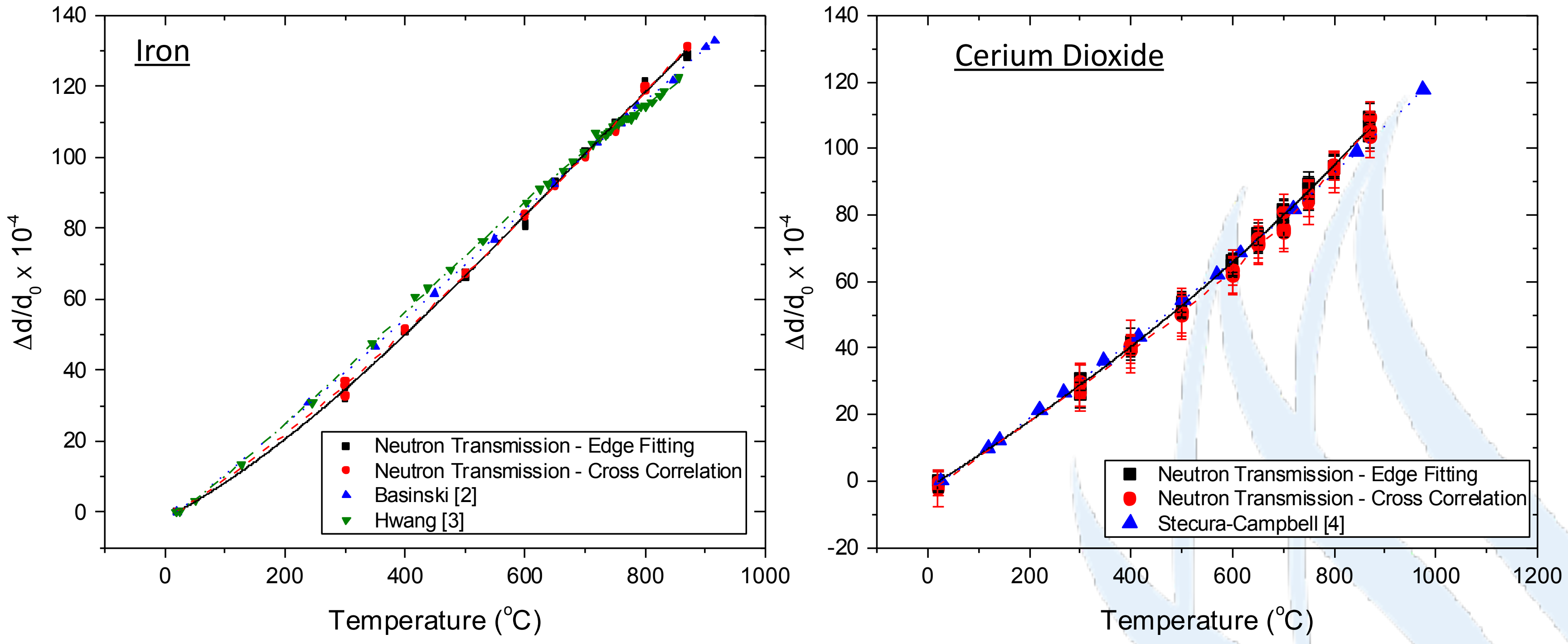

[2] Z. S. Basinski, W. Hume-rothery, and A. L. Sutton, "The lattice expansion of iron," Proc. R. Soc. Lond. A. Math. Phys. Sci., vol. 229, no. 1179, pp. 459–467, 1955.
[3] J.-W. Hwang, "Scholars' Mine Thermal expansion of nickel and iron, and the influence of nitrogen on the lattice parameter of iron at the Curie temperature," 1972.
[4] S. Stecura and W. J. Campbell, "Thermal expansion and phase inversion of rare-earth oxides," Washington, 1961.

Neutron Transmission 2D Strain Map

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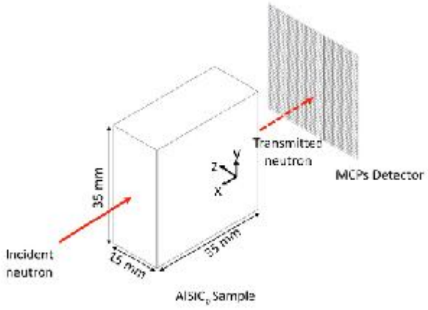
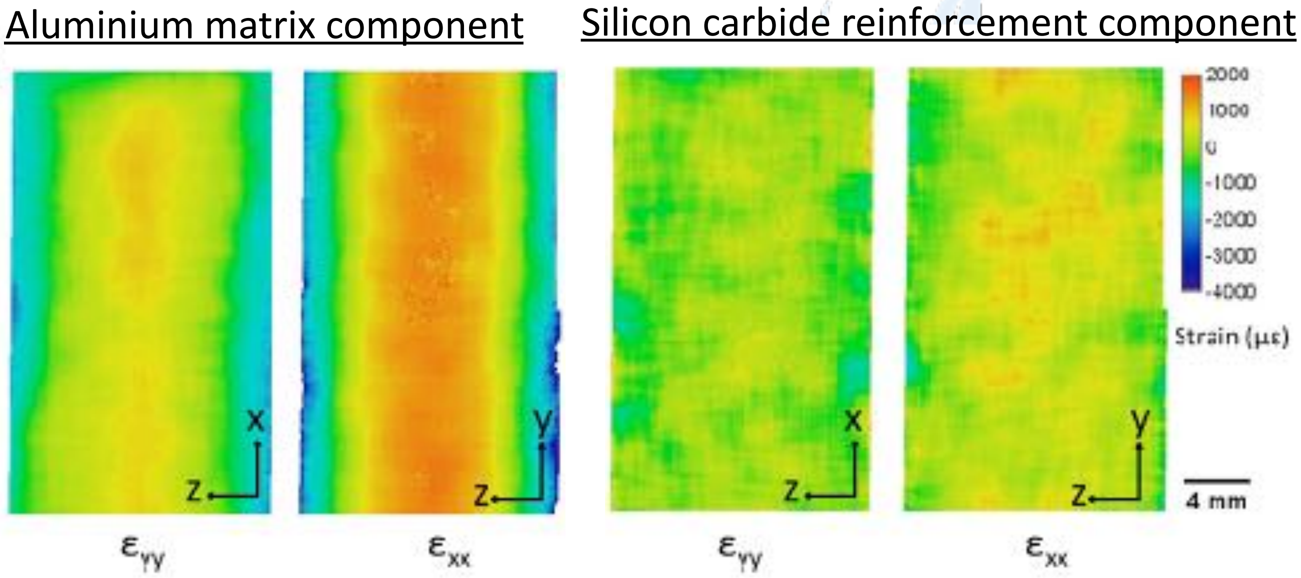
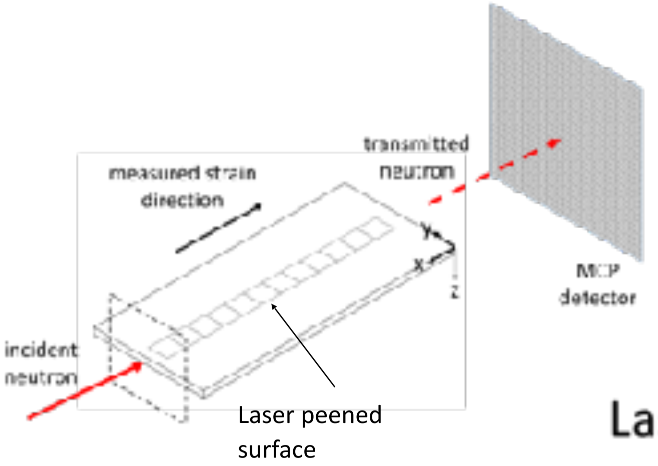
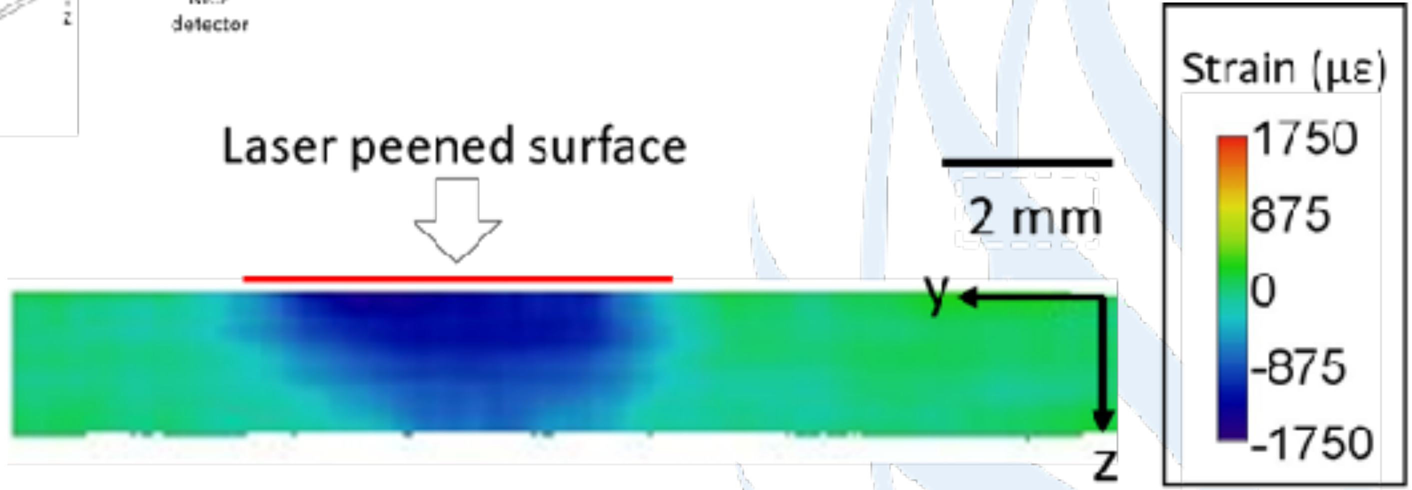




Example: Strain Mapping on Laser-shock Peened Sample





Example: Strain Mapping on Laser-shock Peened Sample

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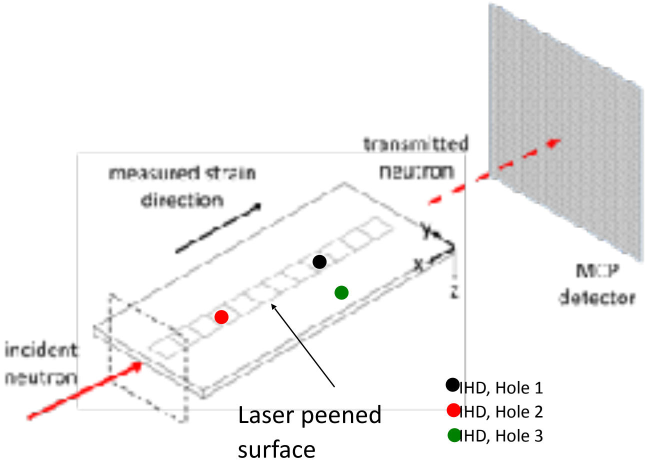
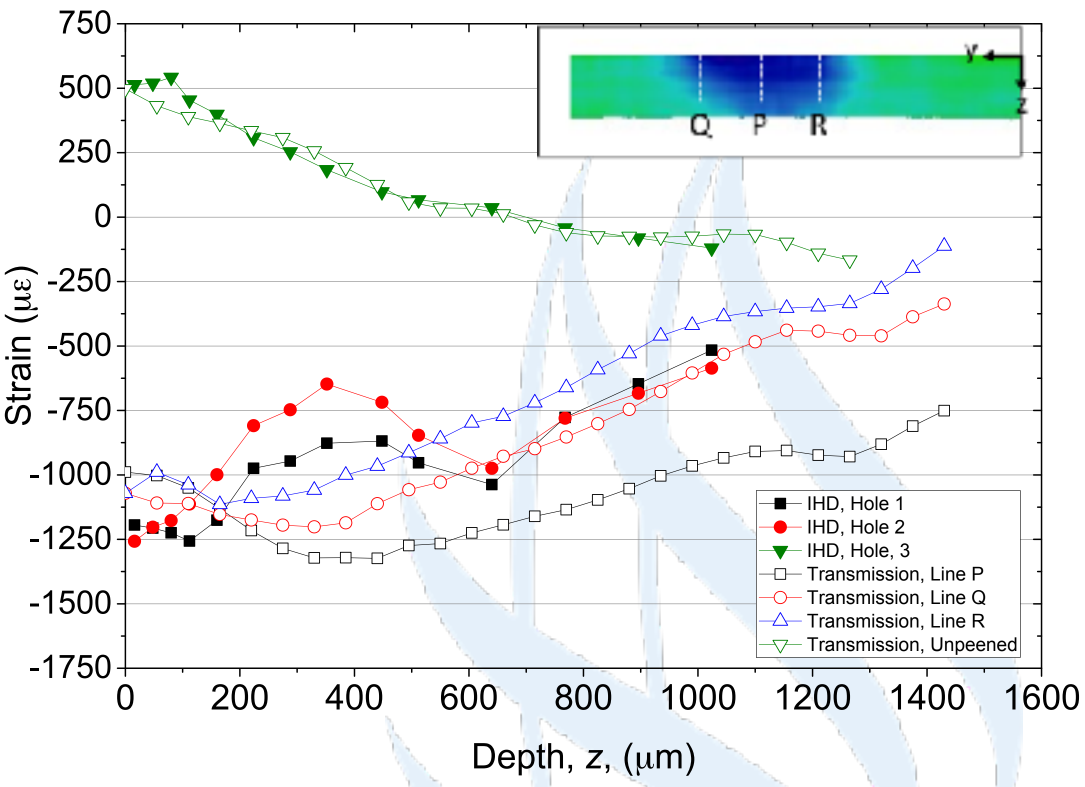
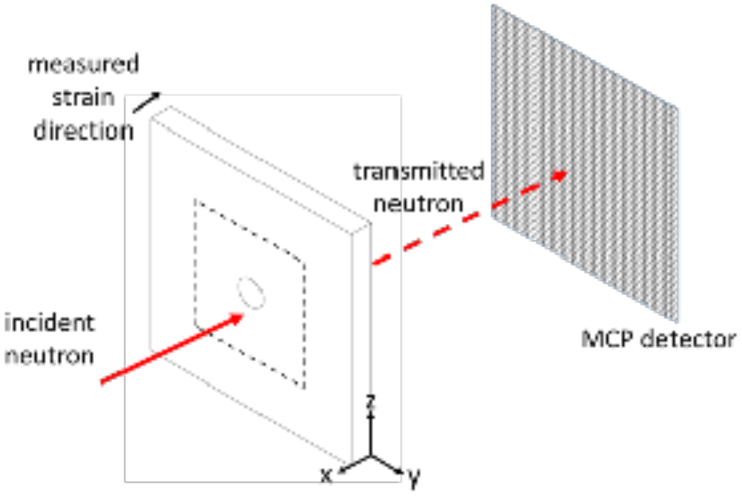
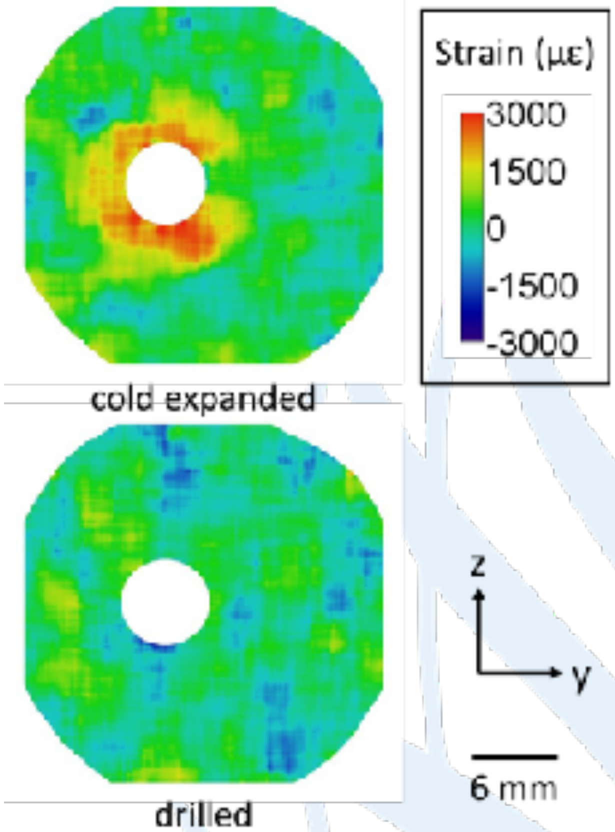


Comparison with Incremental Hole Drilling Measurement

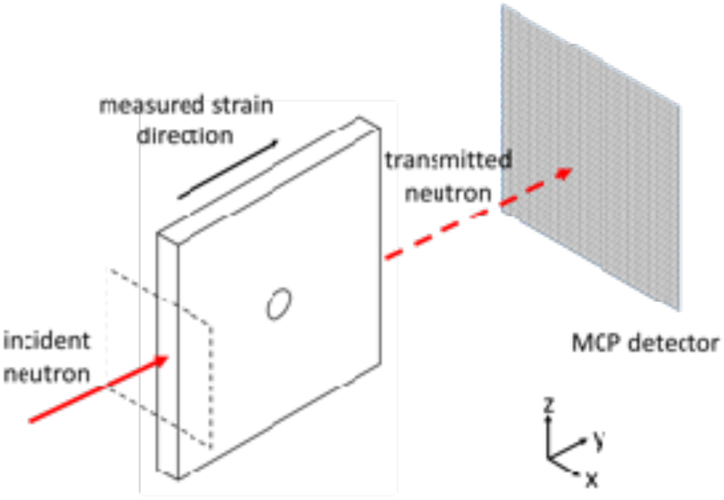


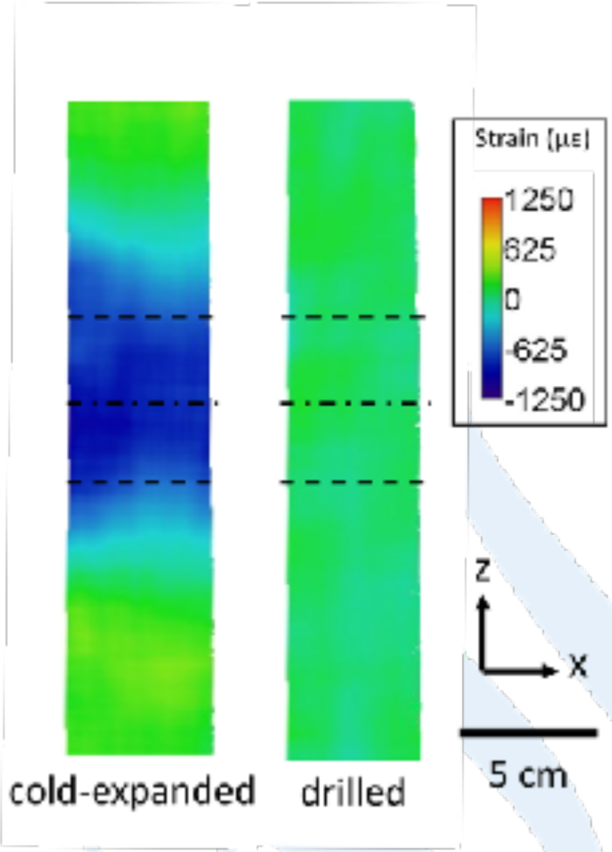
Example: Strain Mapping on Cold Expanded Hole





Example: Strain Mapping on Cold Expanded Hole





What's next?

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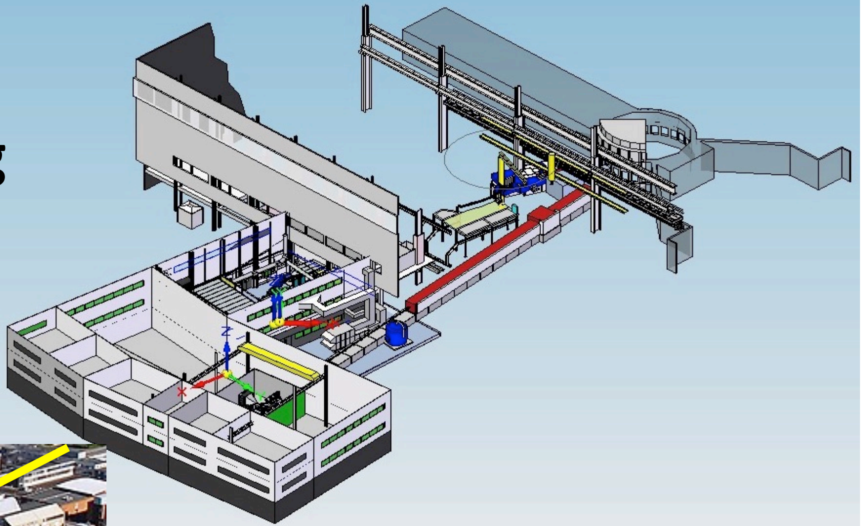
Science & Technology Facilities Council
ISIS

The Open University

International Stress Engineering Centre (I-SEC)

@Harwell (UK)



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Third Generation Strain Instrument: e-MAP

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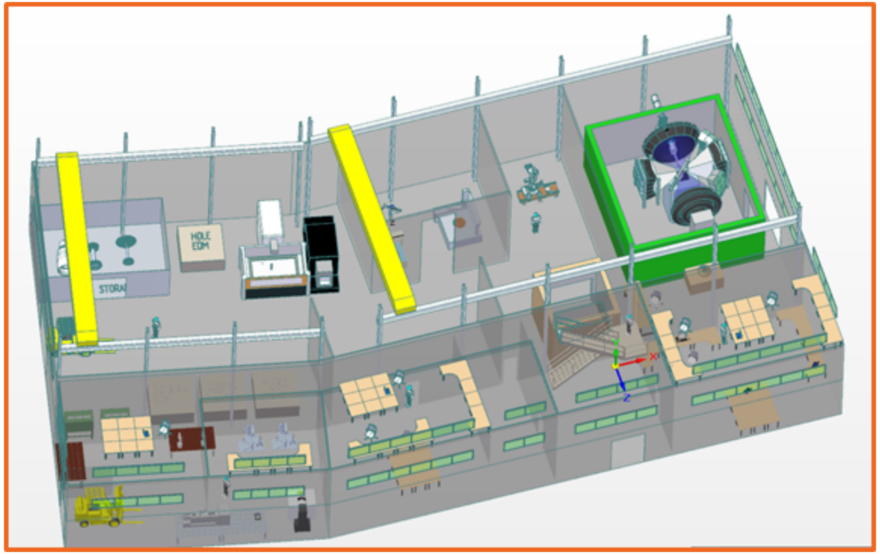
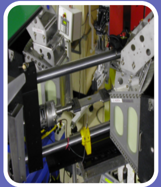


- 15x current flux on ENGIN-X

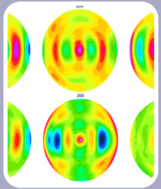
Strain scanning

- Big objects
- Interfaces
- Additive manufacturing



In-situ processes

- Time dependent processes
- Long term experiments
- Big sample environment (ALM machine)



Other measurements

- Texture
- High throughput sample changing
- Imaging?

Questions?