OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Imaging with Neutrons

Hassina Bilheux, Senior Imaging Scientist
Yuxuan Zhang, Imaging Scientist
Jean Bilheux, Computational Imaging Scientist

September 7, 2025

U.S. DEPARTMENT OF ENERGY

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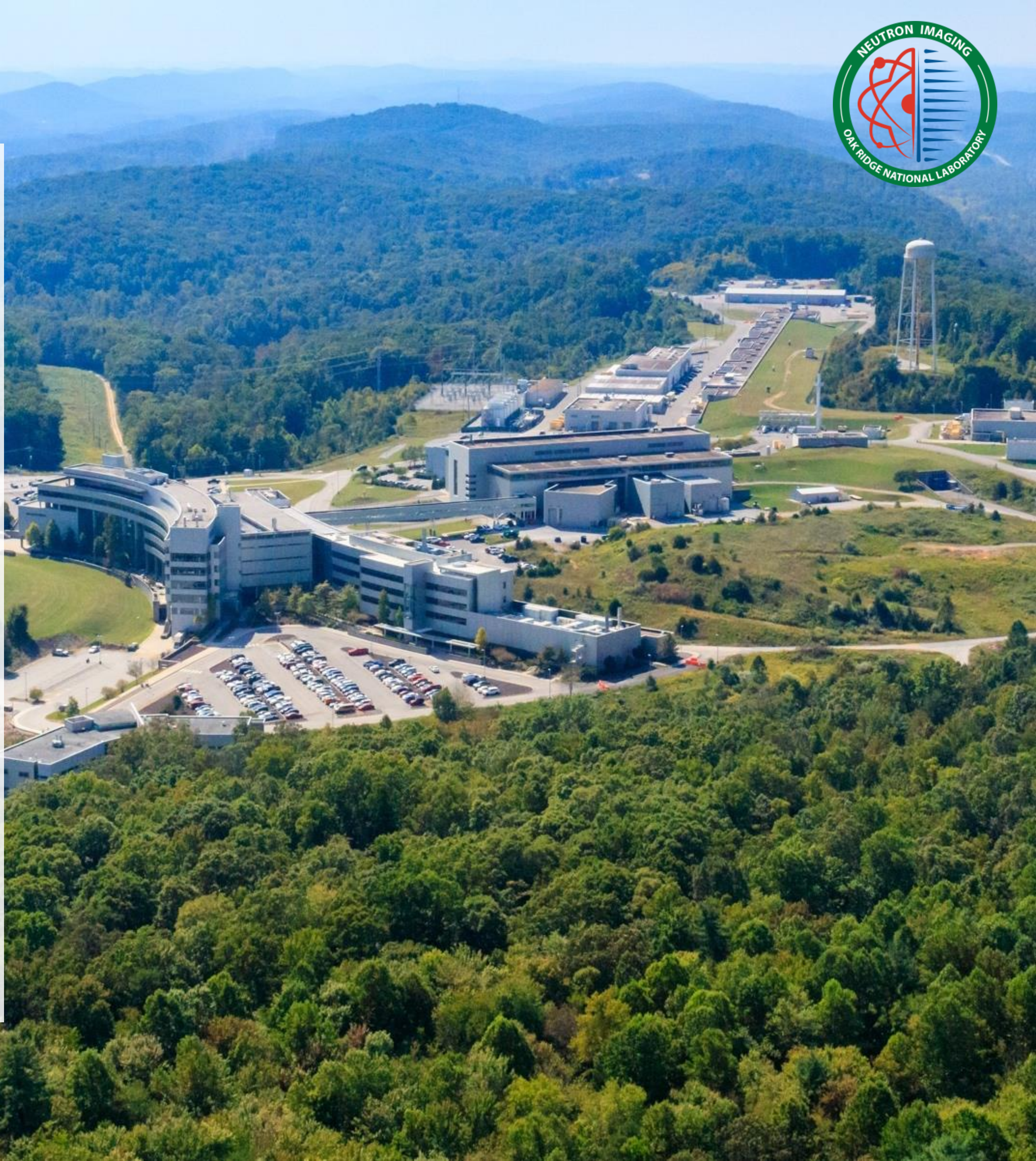


The Neutron Imaging Core Team

Hassina Bilheux,
VENUS IS

Shimin Tang,
VENUS IS, AI expert

Jean Bilheux
Computational Instrument Scientist

James Torres
MARS IS

Yuxuan Zhang
MARS IS

Kevin Yahne
VENUS SA

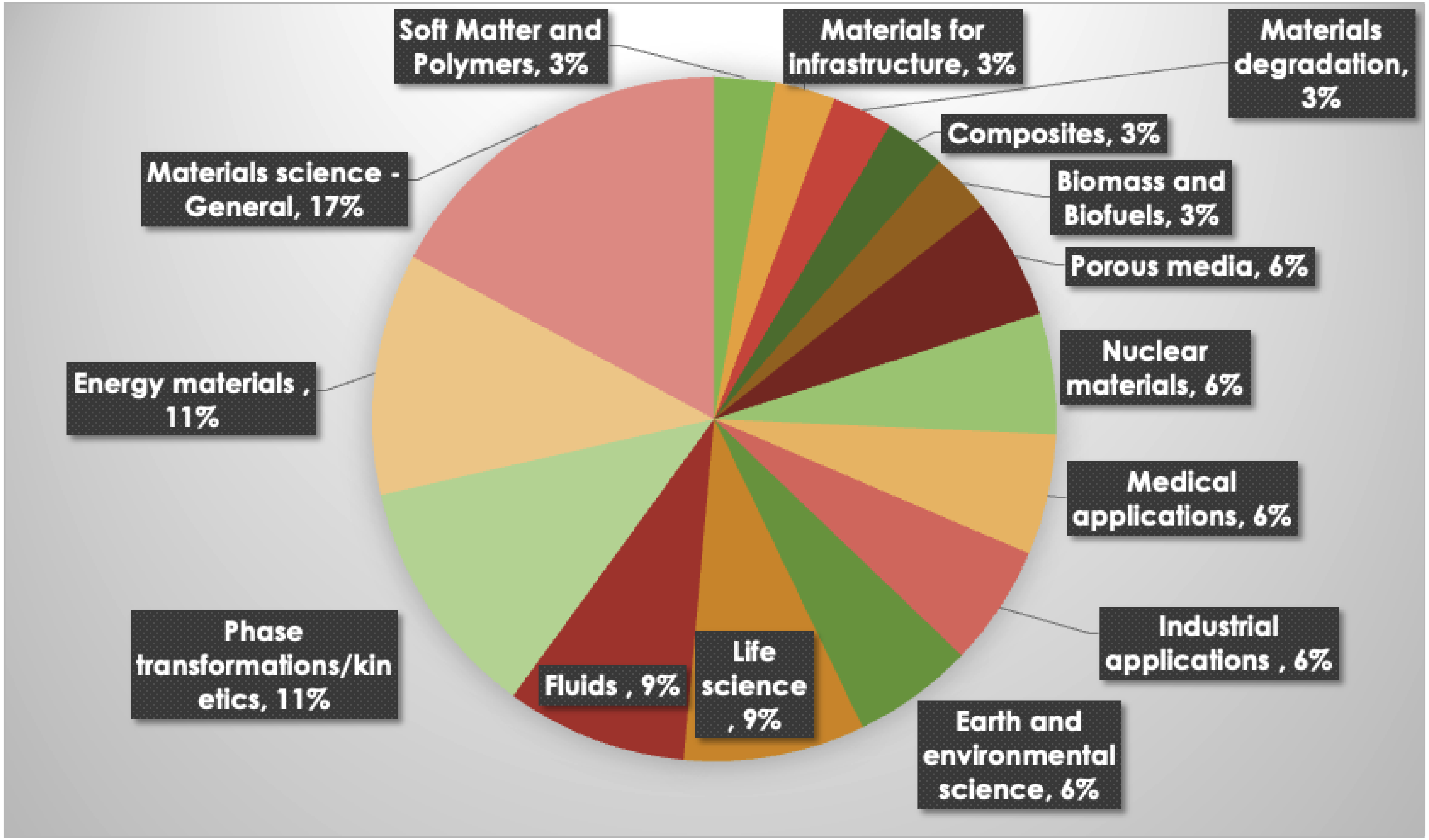
Harley Skorpenske,
SNS SA Group Leader

Chen Zhang
Computational Instrument Scientist

Roger Hobbs
MARS SA

Sam McKay
Phase contrast imaging postdoc

Imaging has a very broad scientific portfolio



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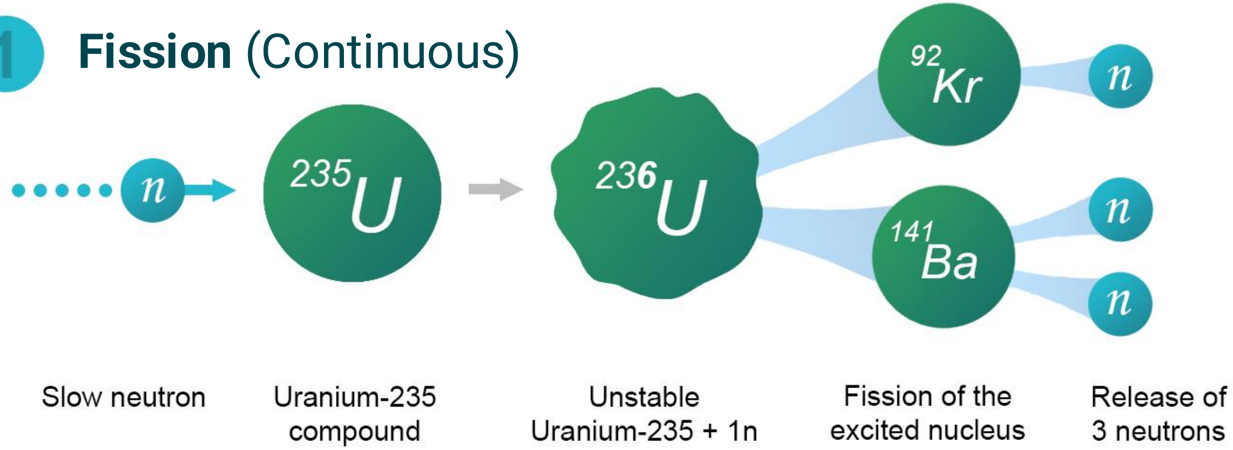
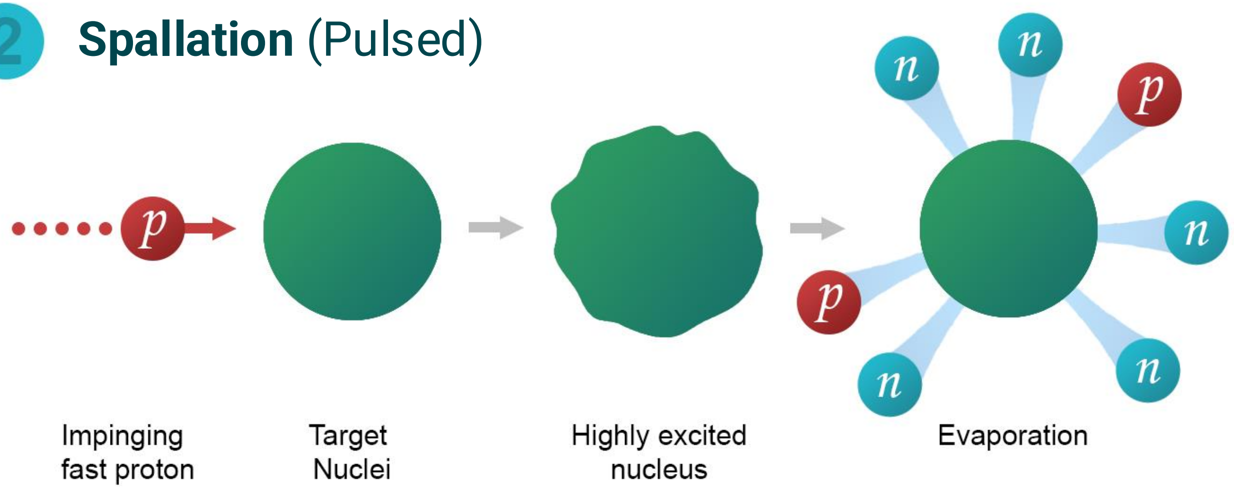
We have two neutron sources, HFIR and SNS, at ORNL

1 **Fission** (Continuous)



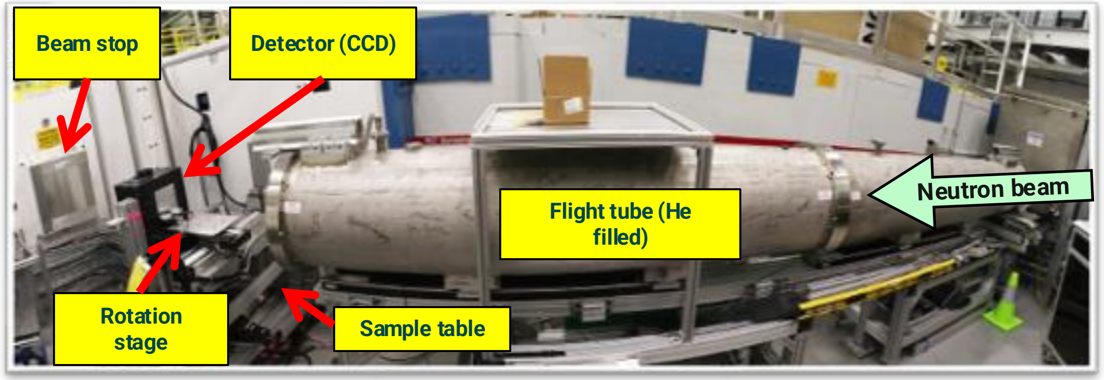
2 **Spallation** (Pulsed)



https://pan-learning.org/wiki/index.php/Introduction_to_neutron_scattering

At each source, there is a dedicated imaging instrument

MARS – **M**ultimodal **A**dvanced **R**adiography **S**tation (dedicated *cold neutron* imaging instrument)



https://neutrons.ornl.gov/mars

VENUS – Versatile Neutron Imaging Instrument at the SNS (*time-of-flight* neutron imaging instrument)

https://neutrons.ornl.gov/venus

Outline

- Imaging at HFIR (Yuxuan)
  - Principle of neutron radiography and computed tomography at a continuous source
  - The MARS beamline
  - Applications and examples

- Imaging at SNS (Hassina)
  - Principle of hyperspectral imaging at a pulsed source
  - The VENUS beamline
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- Software for imaging (Jean)

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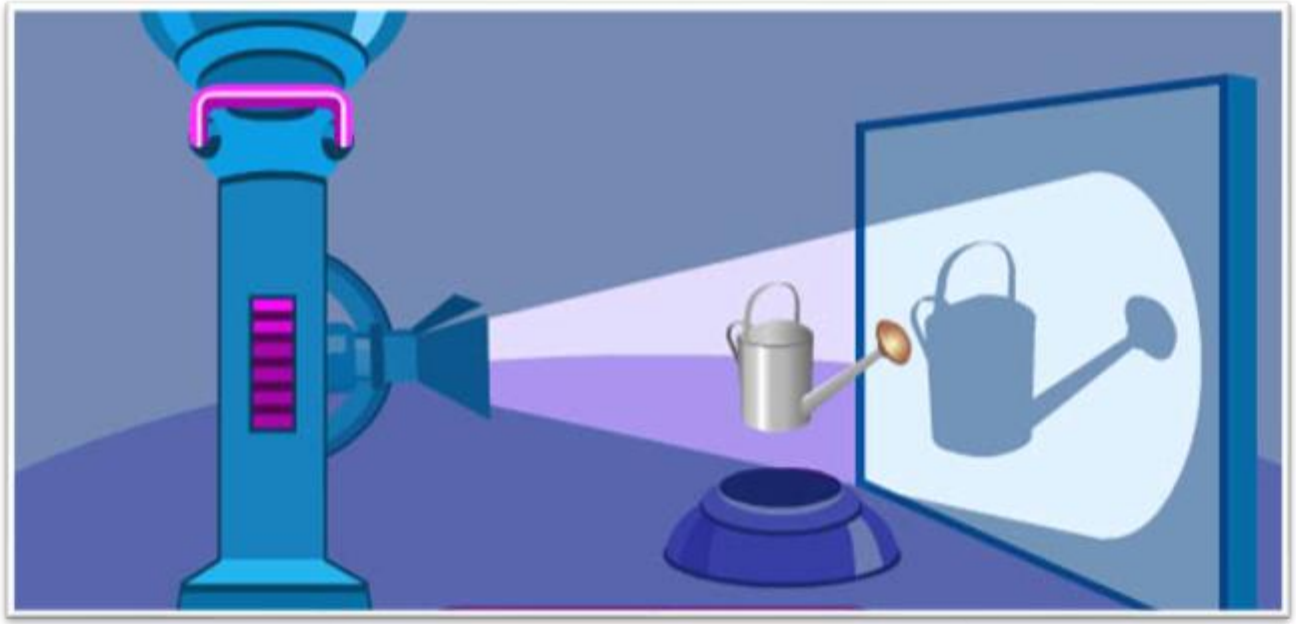
- Software for imaging (Jean)

What is Neutron Imaging?

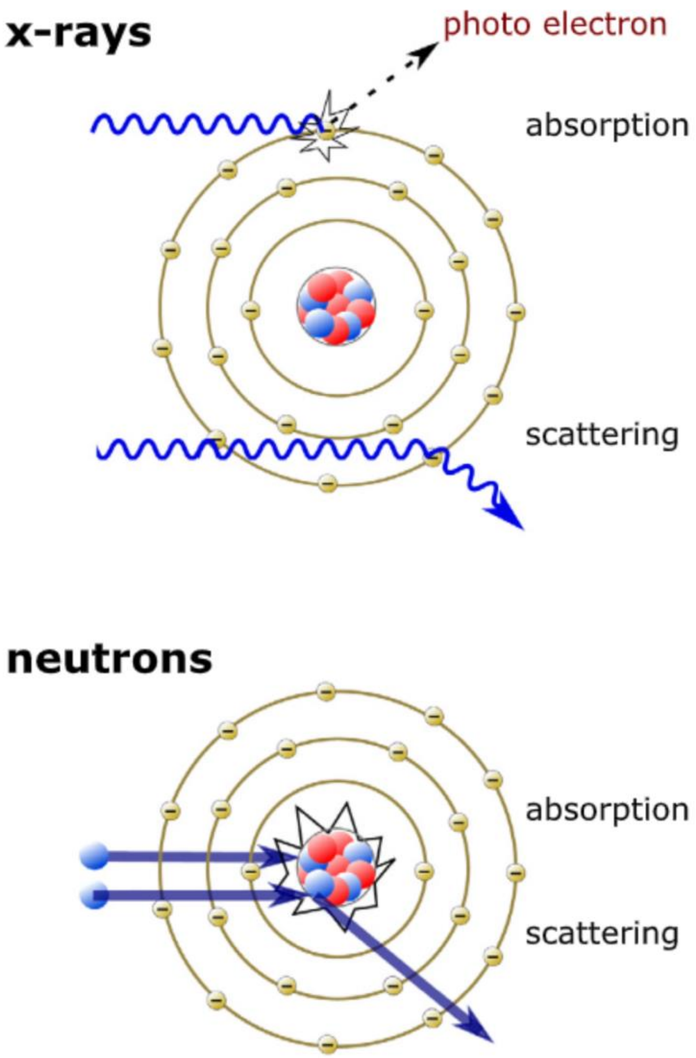
- Neutron Imaging is a **non-destructive** technique for **spatially resolving** the structure of a sample. The basic principle is similar to that of X-ray radiography

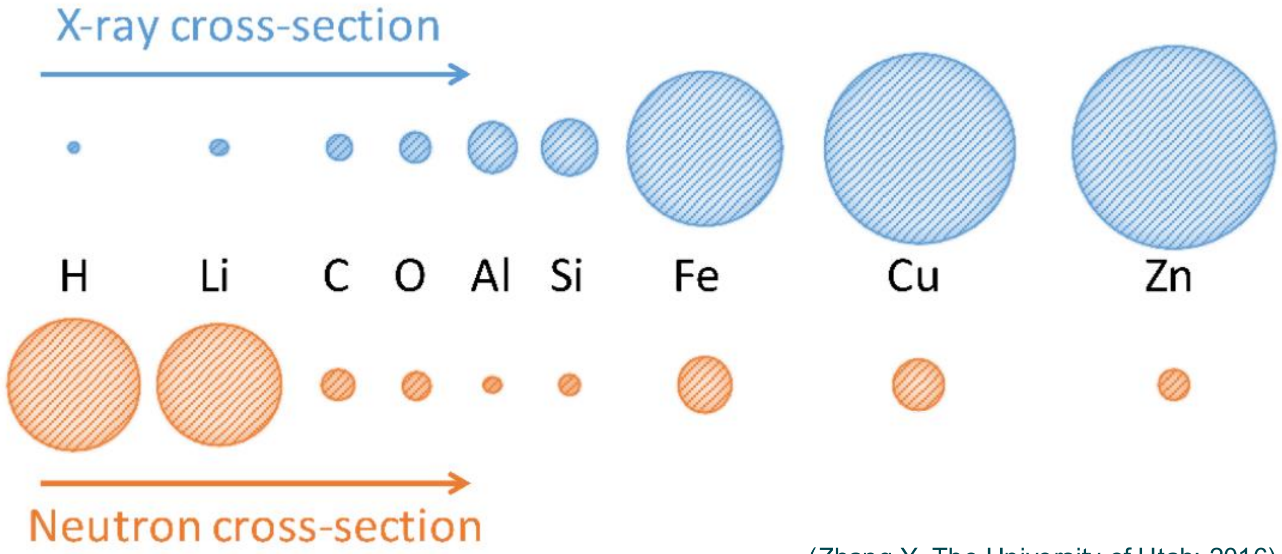


Source **Object** **Detector**

(Figure source: aven.amritalearning.com,. (2013). Shadows and Pin Hole Camera.)

Neutrons interact uniquely with atoms



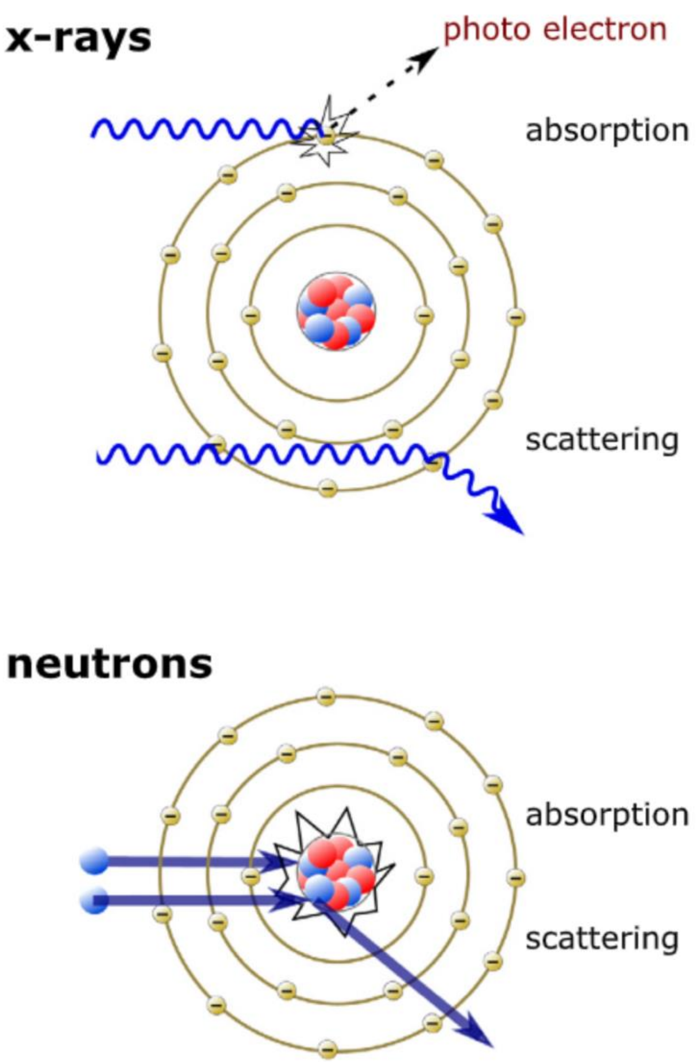


(Zhang Y. The University of Utah; 2016)

- High penetration through metals (Al, Fe, etc.)
  - ✓ Complex SE (temperature, pressure, etc.)
  - ✓ Sample size on the order of cm
- Sensitive to light elements (H, Li, etc.)
- Isotopic contrast

A. Tengattini, et al. Geomechanics for Energy and the Environment 27 (2021)

Neutrons interact uniquely with atoms (cont'd)



- High penetration through metals (Al, Fe, etc.)
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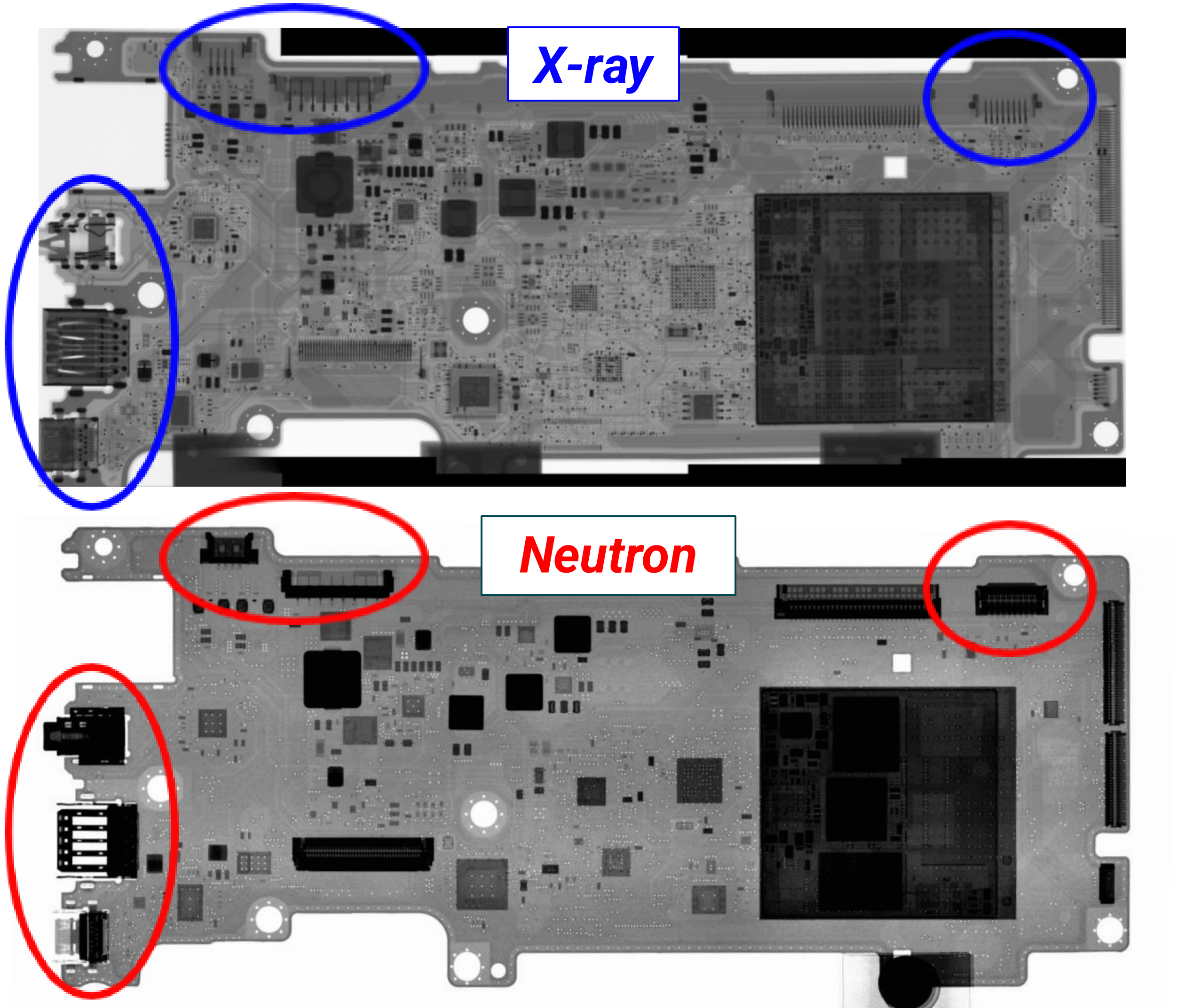
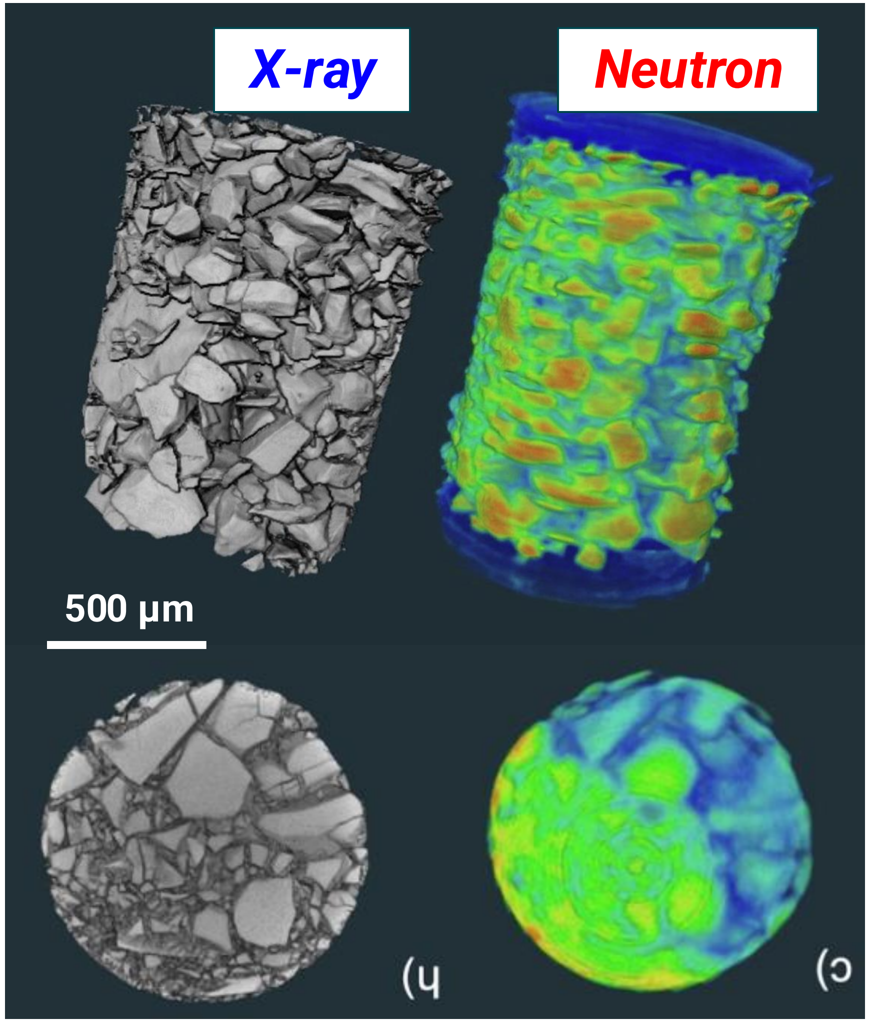
Lilies in a lead cask
(Dr. Daniel Hussey, NIST)

A. Tengattini, et al. Geomechanics for Energy and the Environment 27 (2021)

Neutrons offer unique contrast that complements X-ray contrast



Transmission radiographs of a microelectronics
(IPTS-33592, Y. Zhang, 2024)

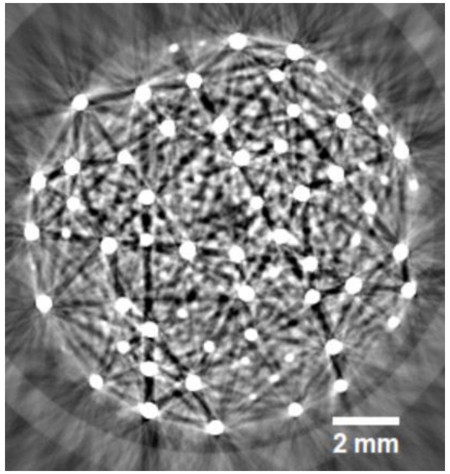


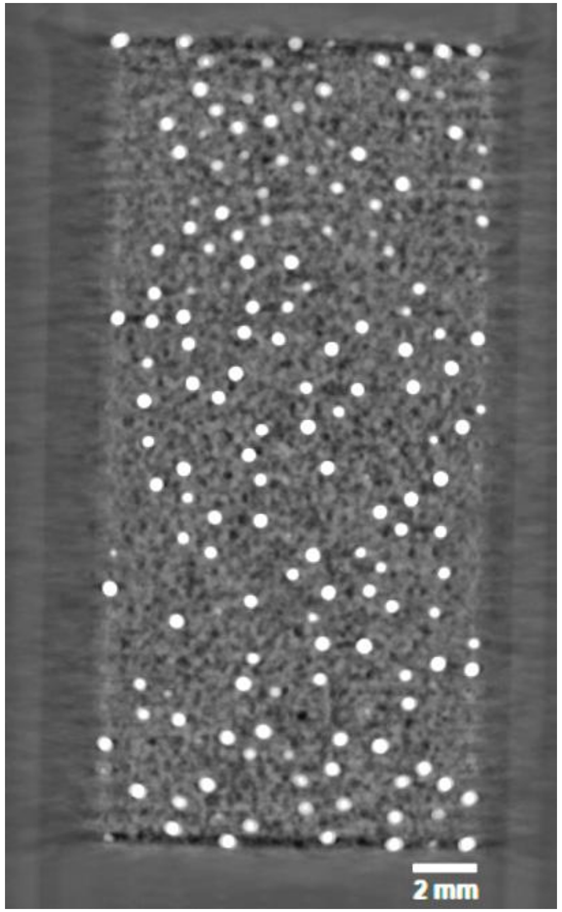
Gupta, D., Zhang, Y., Nie, Z., & Koenig, G. M. (2024).
Journal of Industrial and Engineering Chemistry

Neutrons offer unique contrast that complements X-ray contrast

CT slices of a TRISO fuel compact
(uranium spheres in graphite matrix)

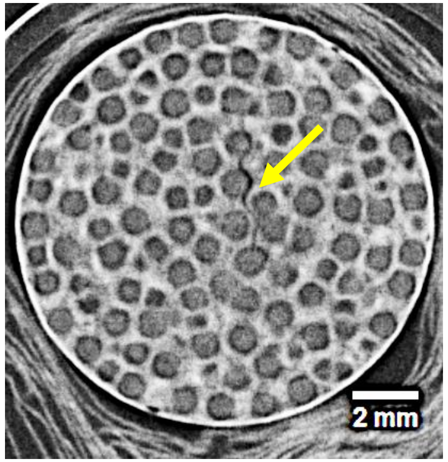
X-ray

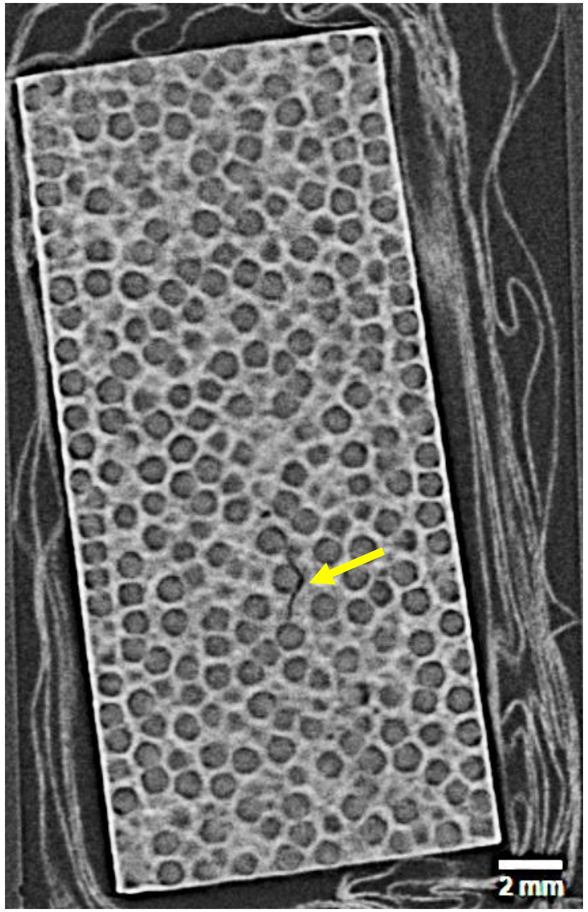




Able to resolve each uranium sphere, but radial slices have strong artifacts

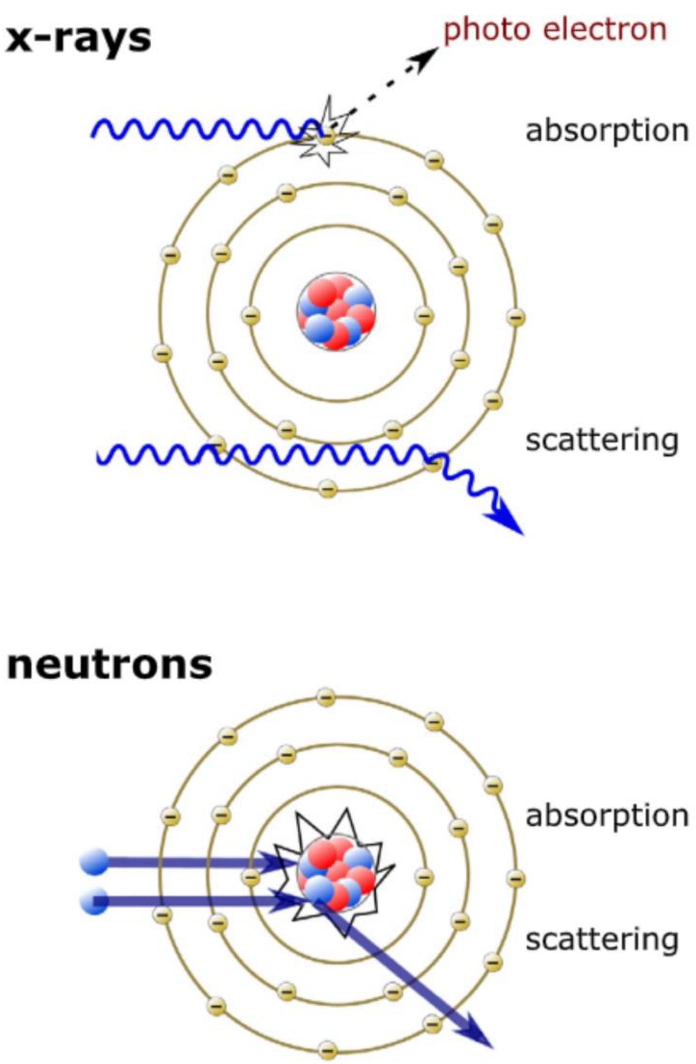
Neutron





Able to reveal defects/cracks (yellow arrow) in the graphite matrix

Neutrons interact uniquely with atoms (cont'd)



A. Tengattini, et al. Geomechanics for Energy and the Environment 27 (2021)

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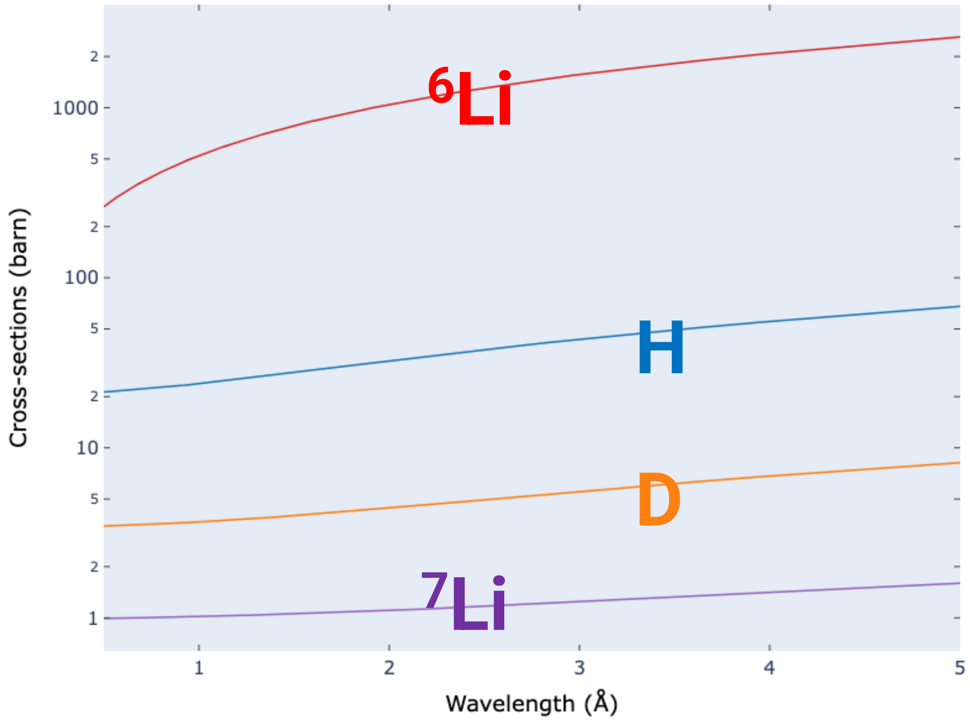
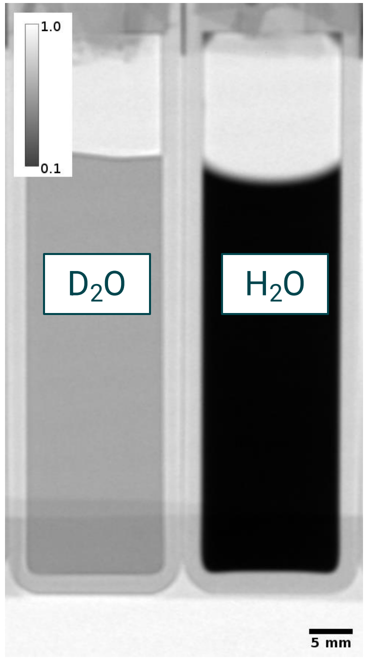
- **Isotopic contrast**

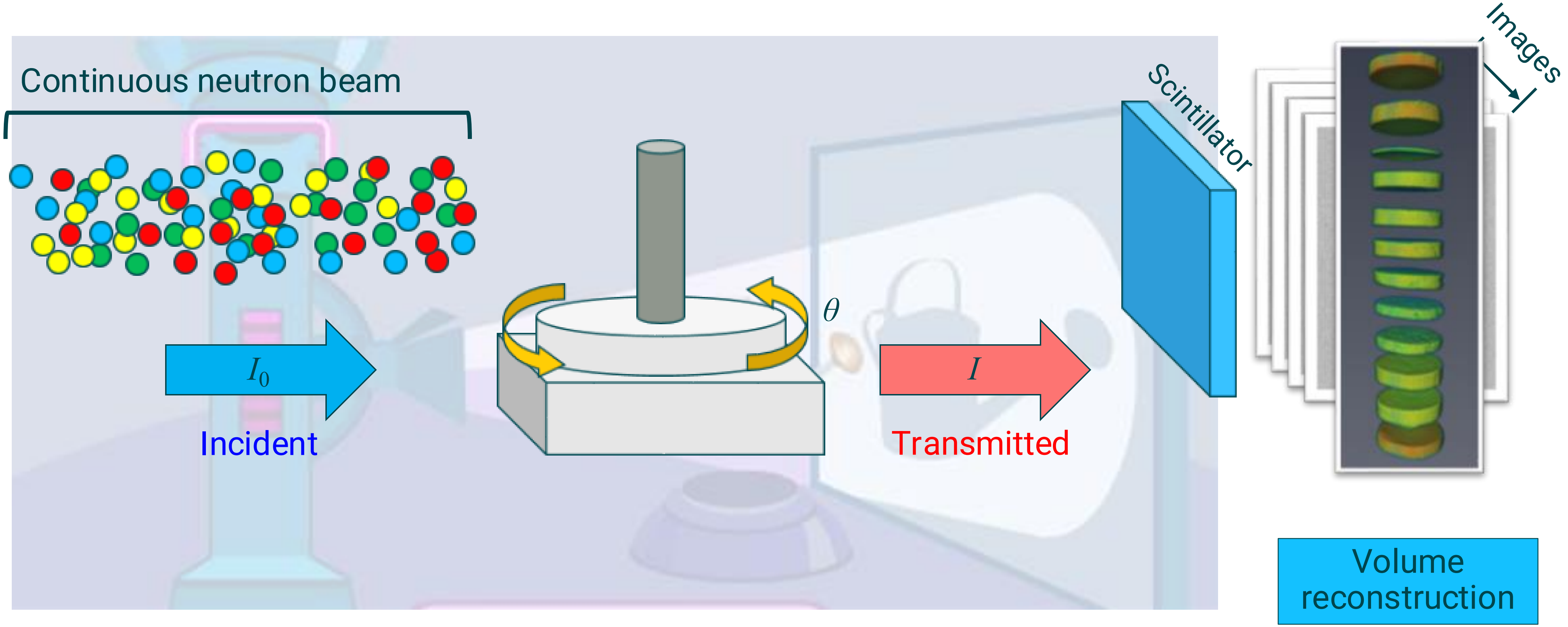


https://neuit.ornl.gov/

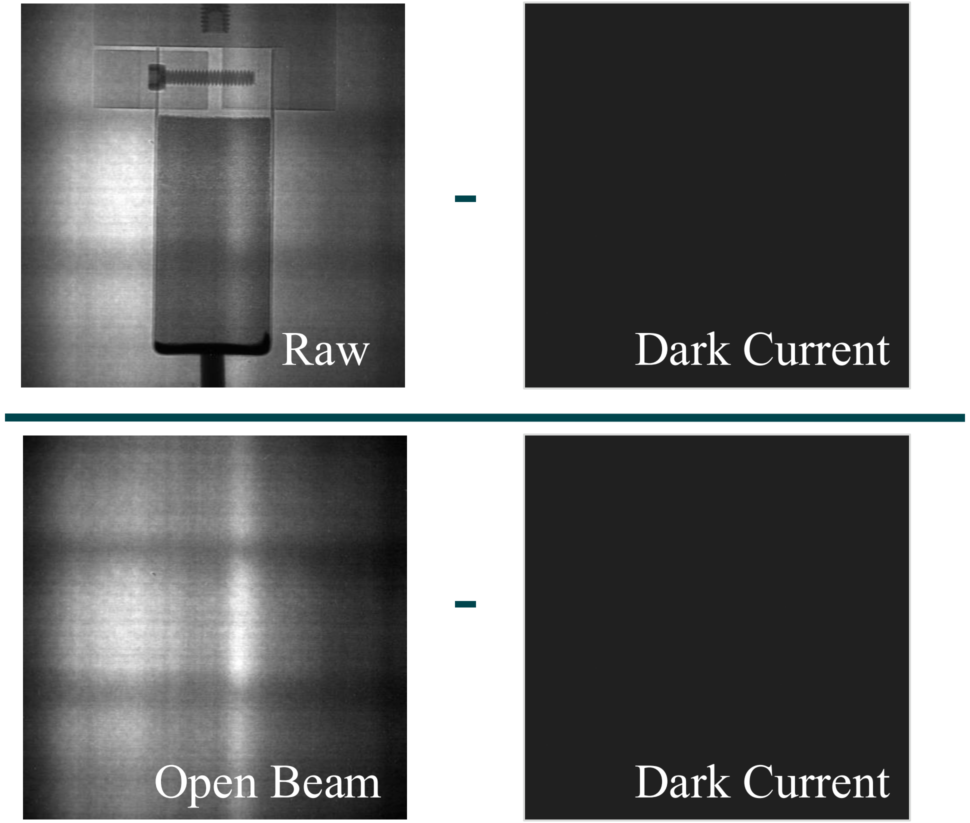


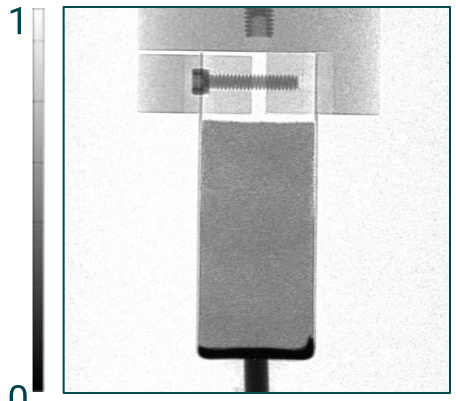
IPTS-26032, Y. Zhang, 2022

Transmitted neutrons recorded as image



From raw image to normalized image





$$\frac{\boldsymbol{Raw}(x,y) - \boldsymbol{DC}(x,y)}{\boldsymbol{OB}(x,y) - \boldsymbol{DC}(x,y)} = \textbf{Normalized Image}$$

Lambert-Beer Law

Transmission

Sample thickness

$$T = \frac{I}{I_0} = e^{-\mu x}$$

Attenuation co.

Avogadro constant

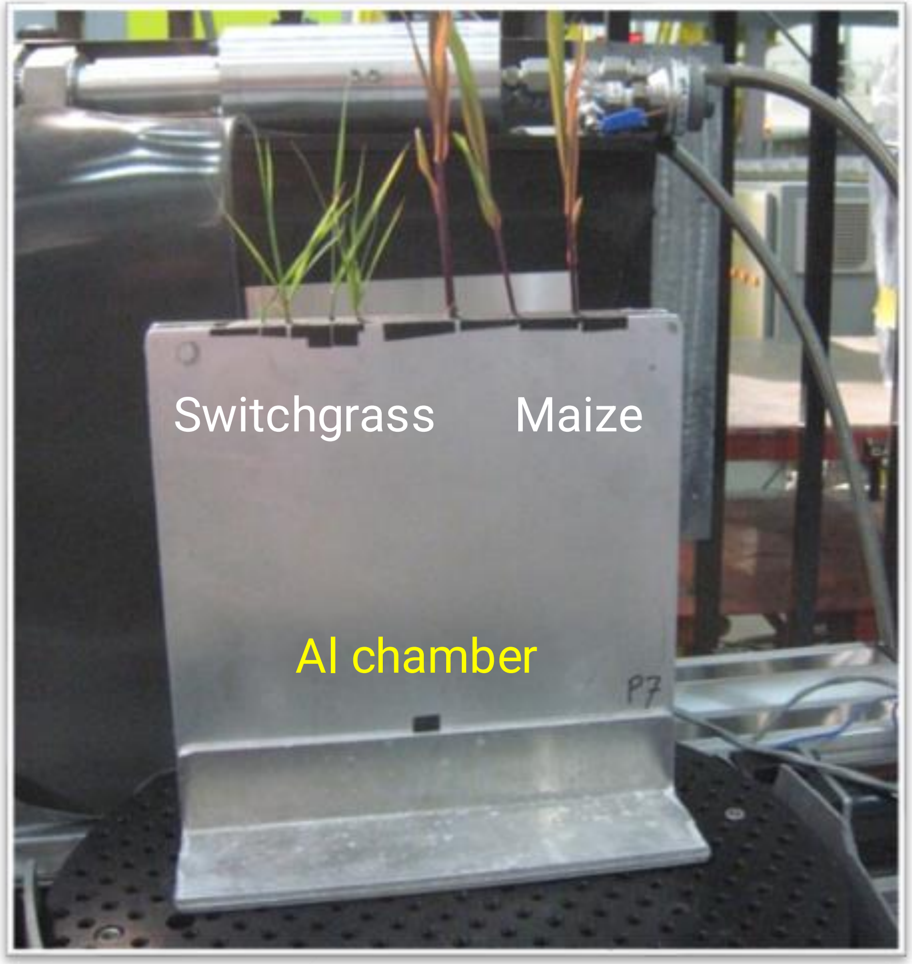
Density

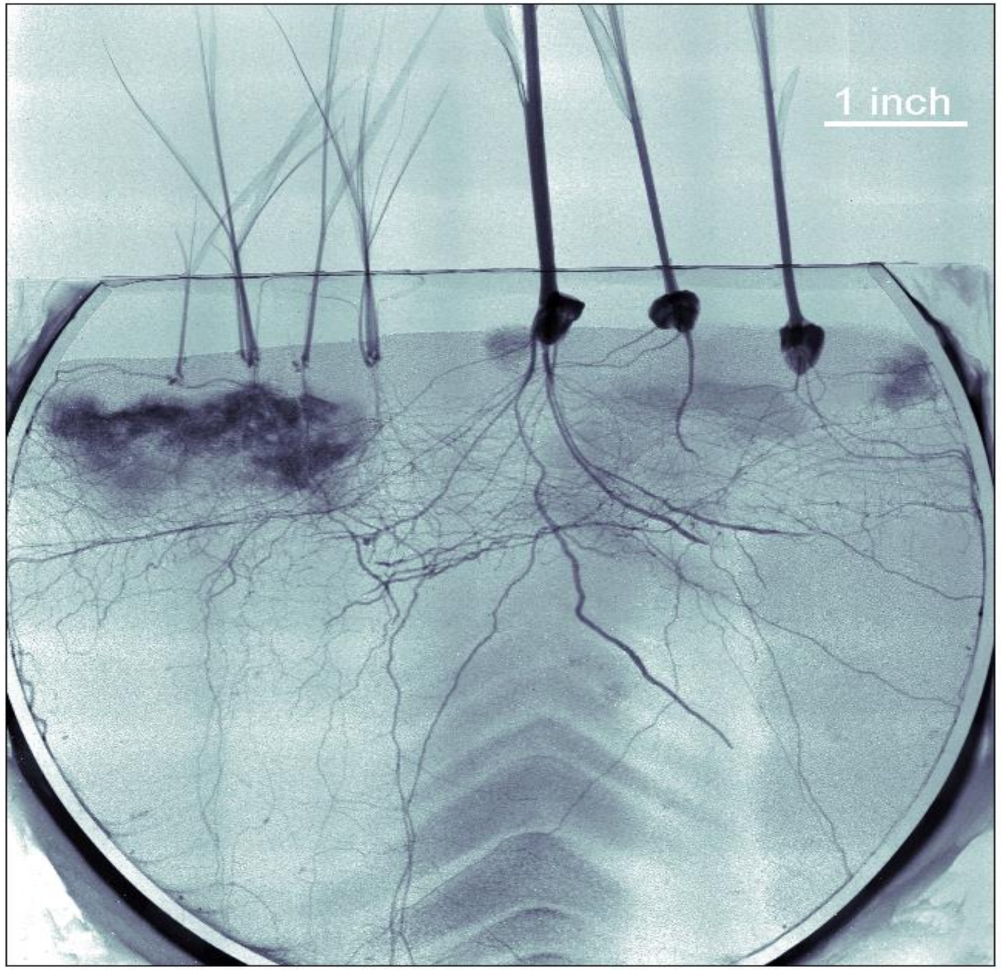
$$\mu = \sigma_{tot} \frac{\rho N_A}{M}$$

Total cross-section

Molar mass

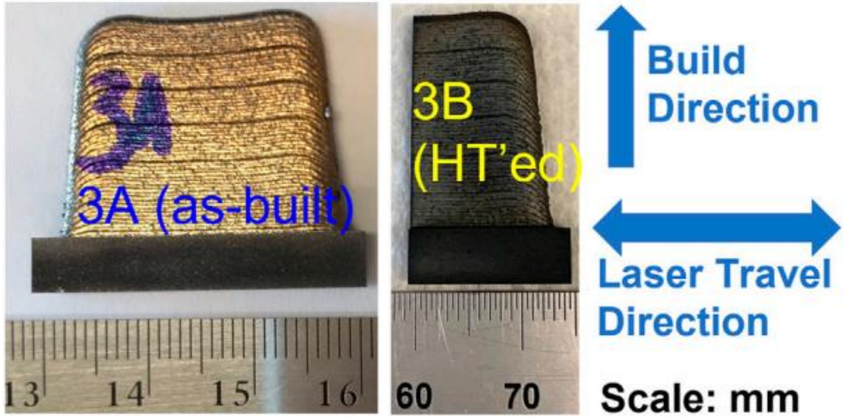
Visualizing live root system

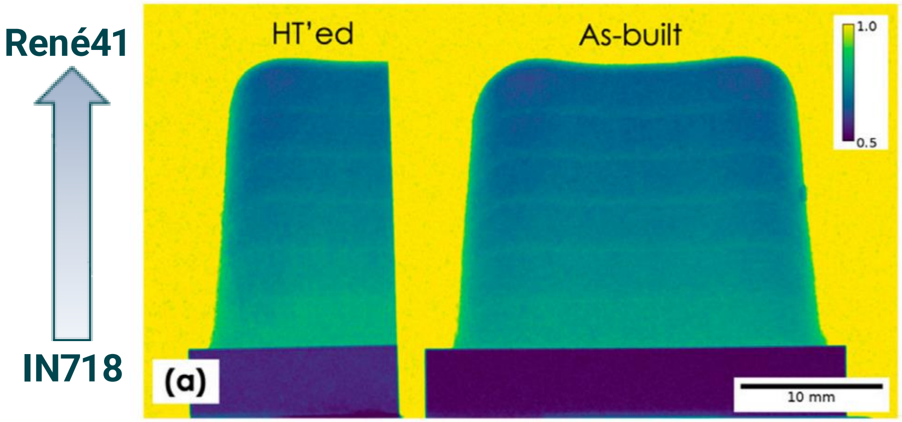




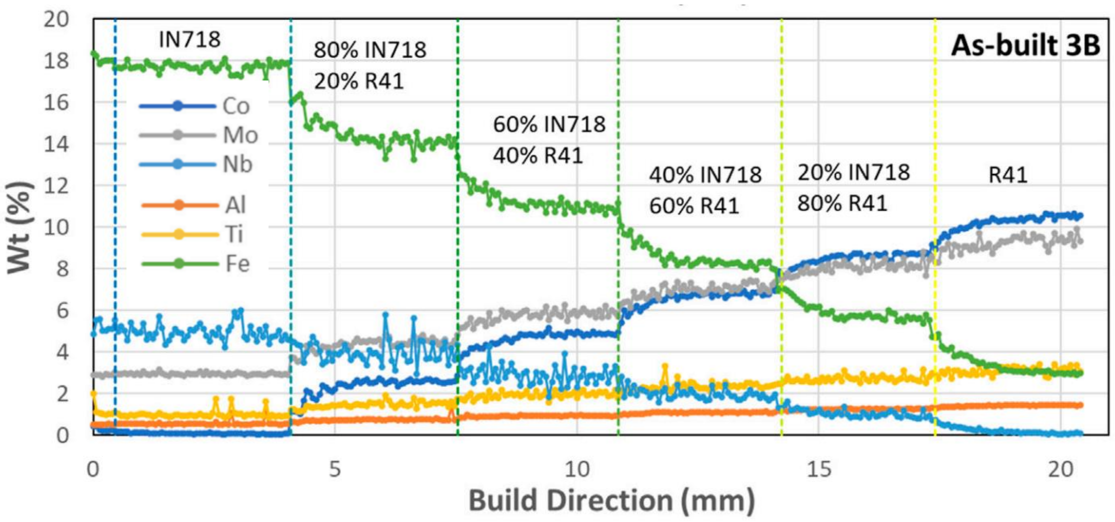
(J. Warren (PI), H, Bilheux, M. Kang, S. Voisin, C. Cheng, J. Horita, E. Perfect, Plant Soil, 2013)

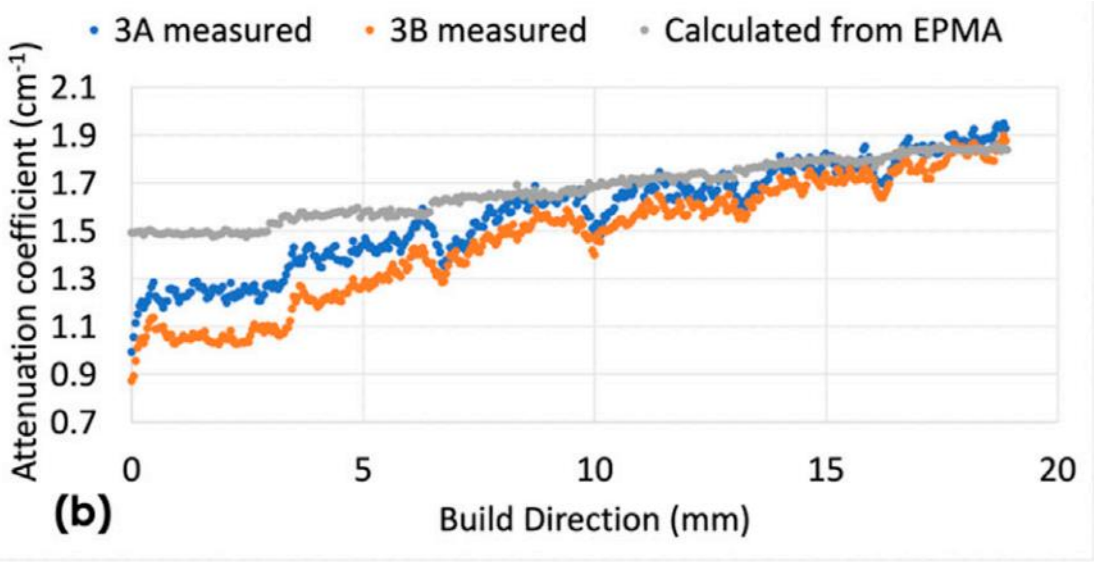
Resolve composition gradient in graded superalloy





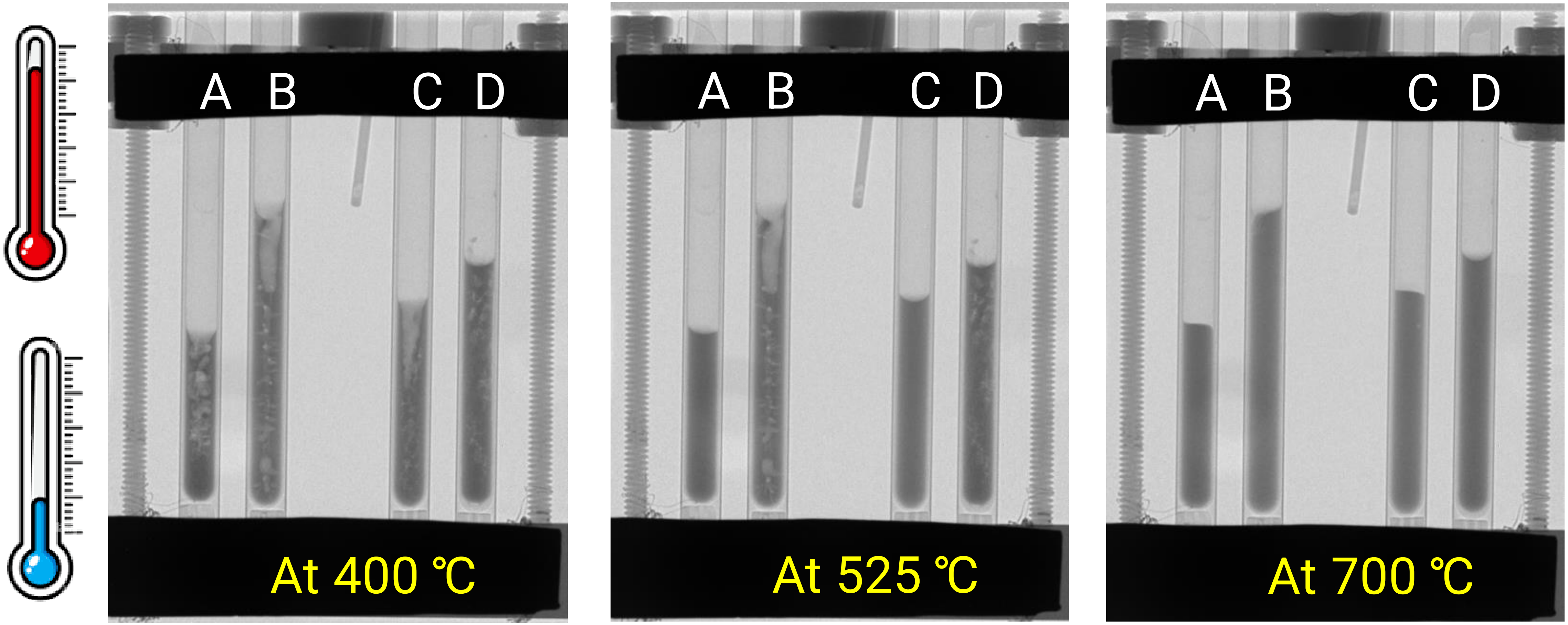
Transmission image





Huang S., Shen C., An K., Zhang Y., Spinelli I., Brennan M., Yu D., ***Frontiers in Metals and Alloys***, 1, 1070562 (**2022**)

Study dynamic processes – molten salt density vs. temp.



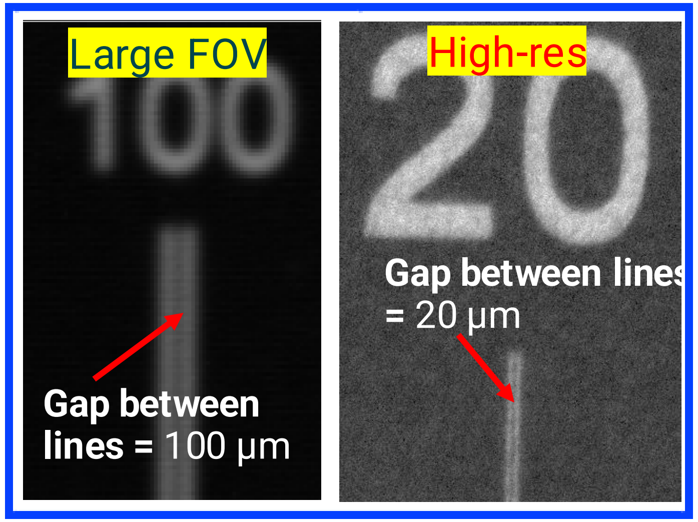
Selected neutron images upon heating (inside a vacuum furnace goes up to 1500 ℃)

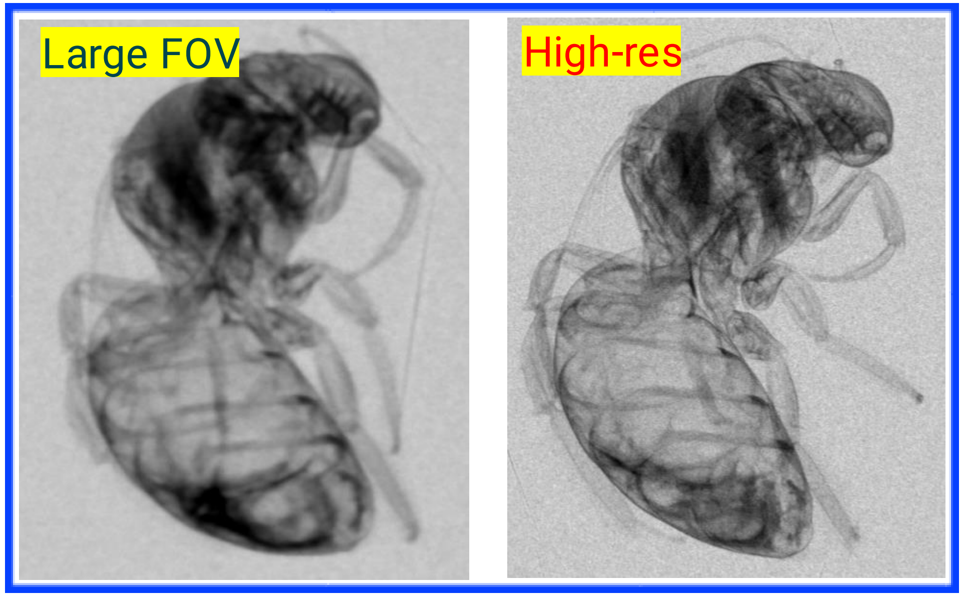
A: $KCl(42)–MgCl_2(58)$, B: $NaCl(50)–KCl(50)$, C: $KCl(63)–MgCl_2(37)$, and D: $ZrCl_4(28)–KCl(72)$.

Moon J., Andrews H.B., Agca C., Bilheux J., Braatz A.D., McAlister A., McFarlane J., McMurray J.W., Robb K.R., Zhang Y., ***Industrial & Engineering Chemistry Research***, 61, 17665-17673 (**2022**)

MARS detector specs

Type of detector	Field-of-view (FOV)	Pixel size (µm)	Highest spatial resolution (µm)	Typical acquisition time of 1 radiograph	Max. speed @16 bit
High-res (1x)	36 x 24 mm^2	3.8	10-15	900 s	1 image/second
High-res (.5x)	50 x 48 mm^2	7.63	20-25	300 s	1 image/second
High-speed (I)	90 x 90 mm^2	43	~100	< 30 s	24 image/second
High-speed (II)	56 x 56 mm^2	27	~100	< 30 s	74 image/second
Balanced	90 x 90 mm^2	16	~50	30-90 s	1 image/second





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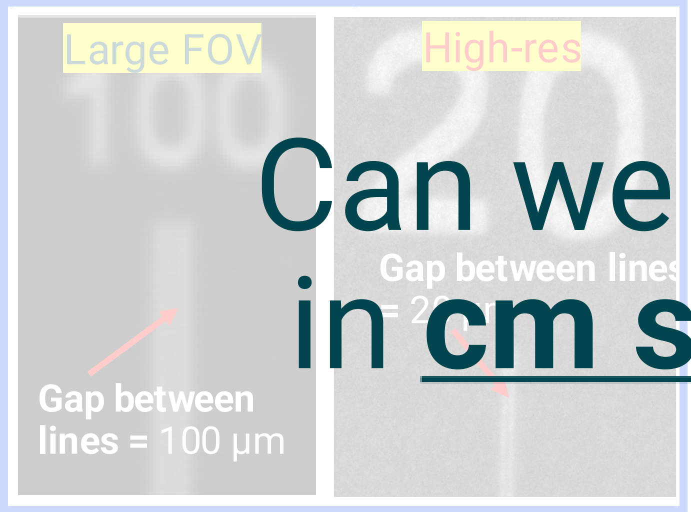
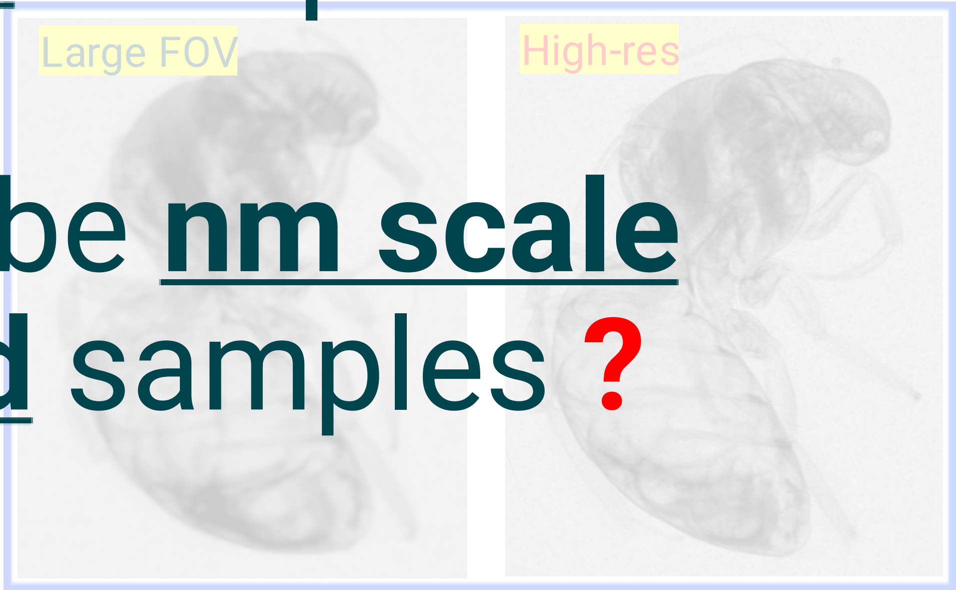
Balanced	90 x 90 [illegible]	[illegible]	[illegible]	30-[illegible] s	1 image/second

Transmission-based NI

Directly resolves **μm scale**
in **cm sized** samples ✓

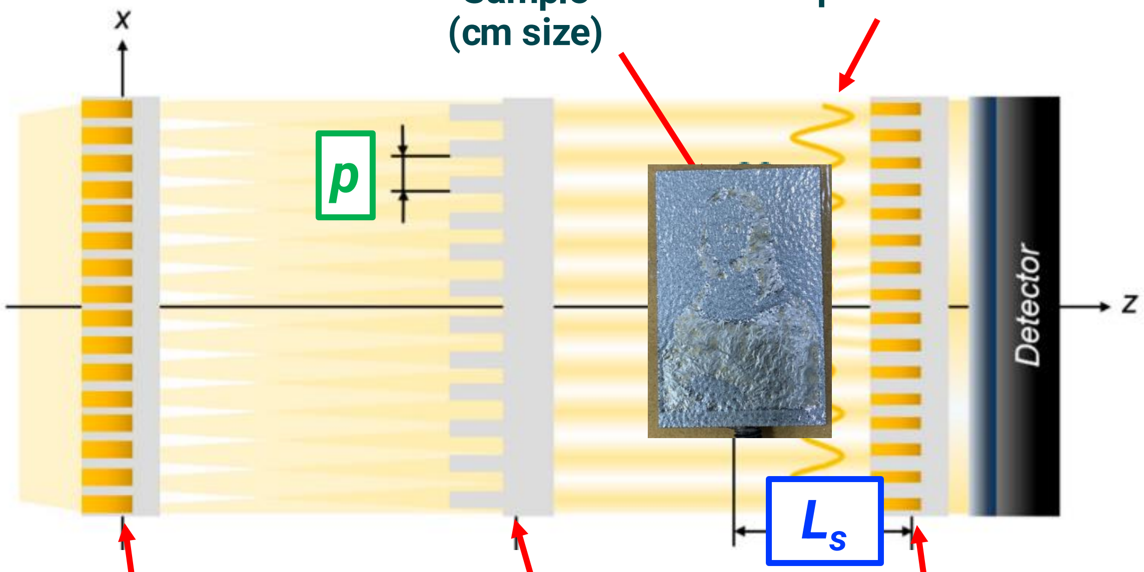




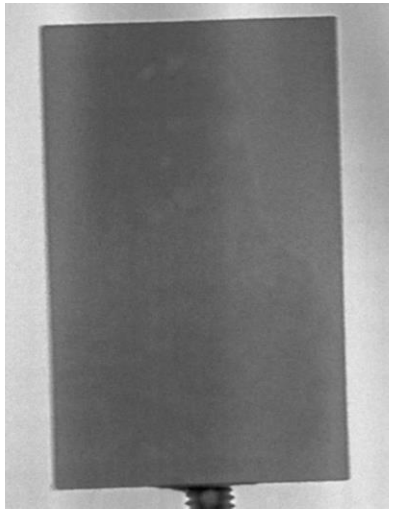
Can we probe **nm scale**
in **cm sized** samples **?**

What is neutron grating interferometry (nGI)?

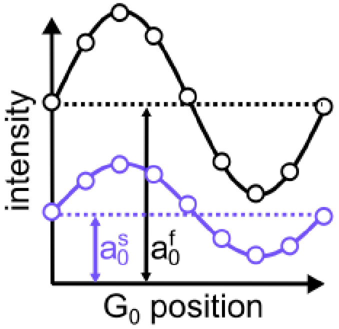
A neutron imaging instrumentation that enable the utilization the **wave properties of neutron**, to spatially resolve sub μm internal features



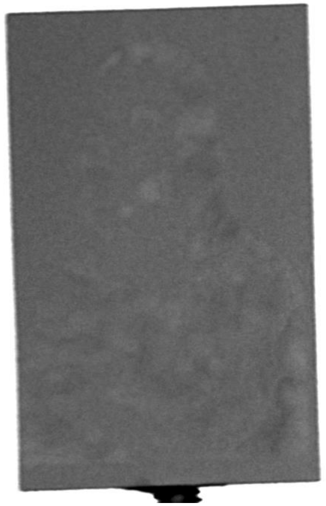
Y. Kim et al., *Applied Sciences* (2022).
(Sample courtesy of Dr. Chris Fancher)



Raw data resulted from a step-wise scan



T. Reimann et al., J. Applied Crystallography. (2016)



Transmission Image (TI)

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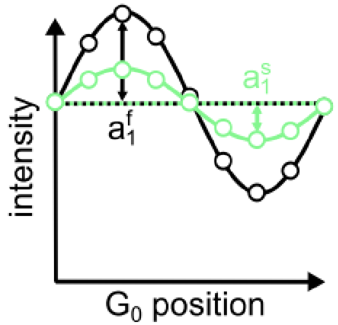

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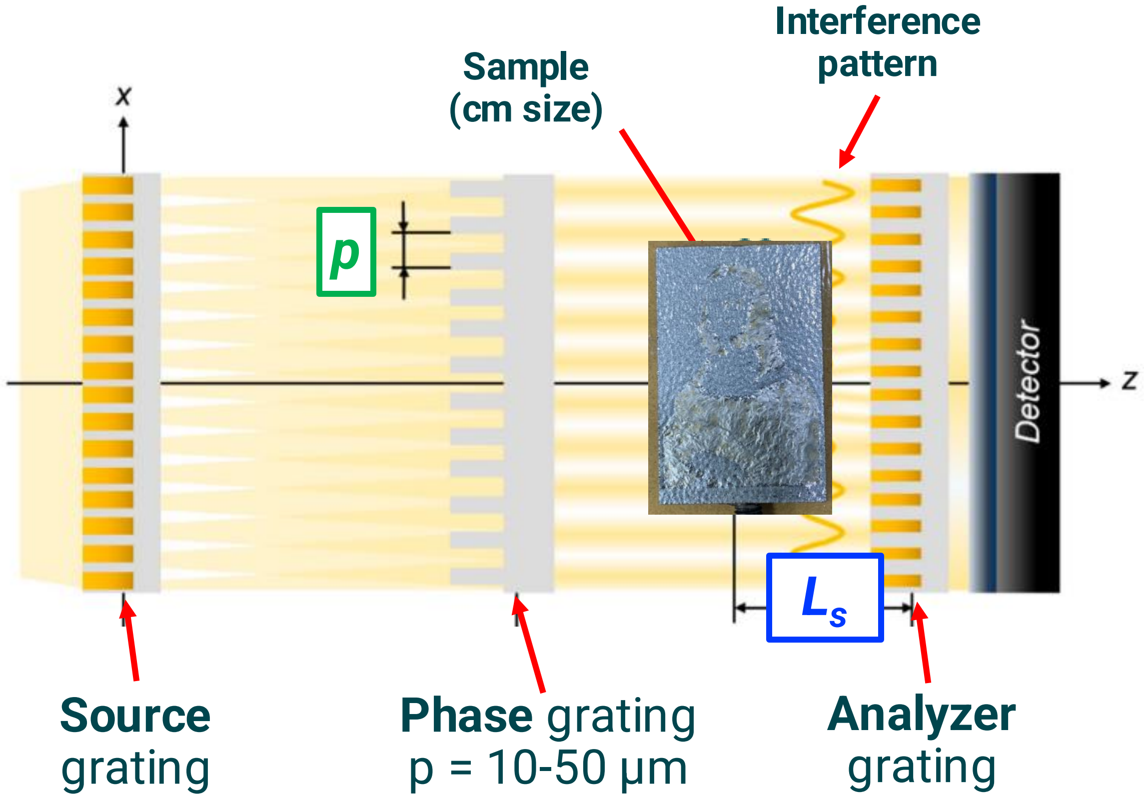

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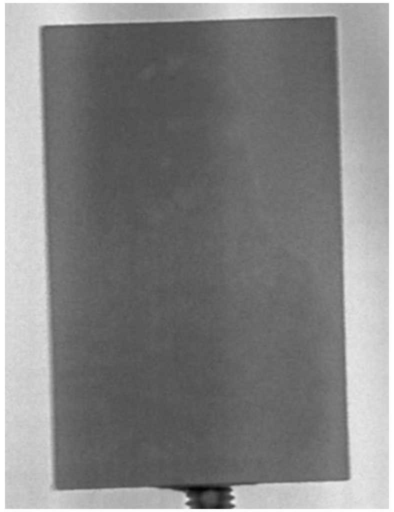
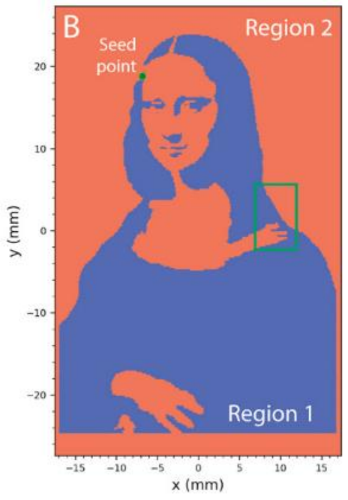


Raw data resulted from a step-wise scan

Dark Field Image (DFI)

More about this sample along with the nGI results

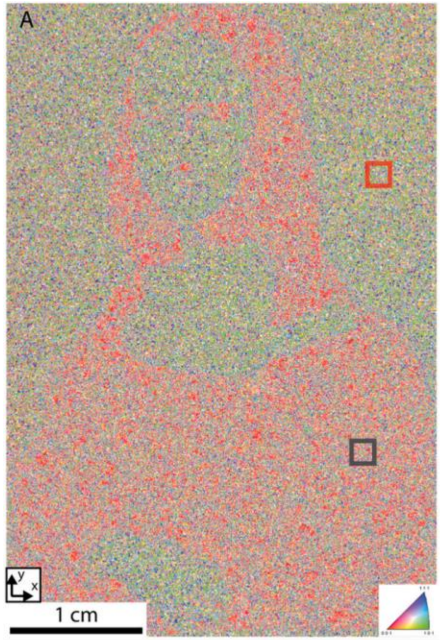
Inconel



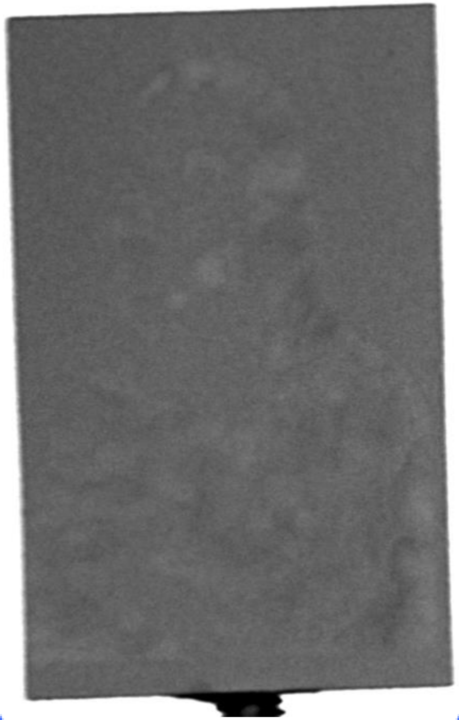
Two different cooling rate regions in an Inconel sample

Photo

EBSD



Transmission (TI)



Dark Field (DFI)

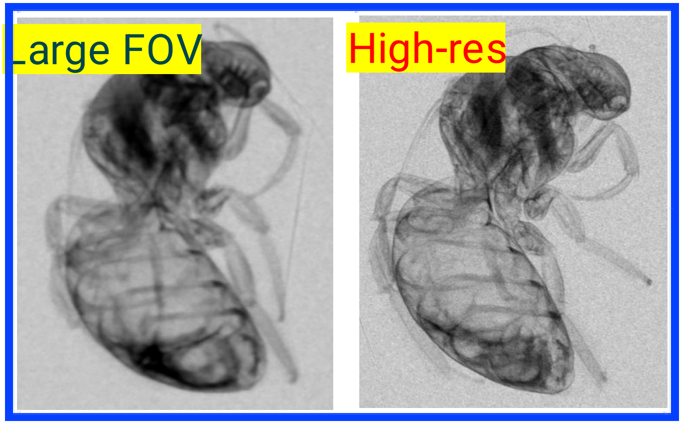
Color relates to the SANS from features in certain sizes

(Sample courtesy of Dr. Chris Fancher)

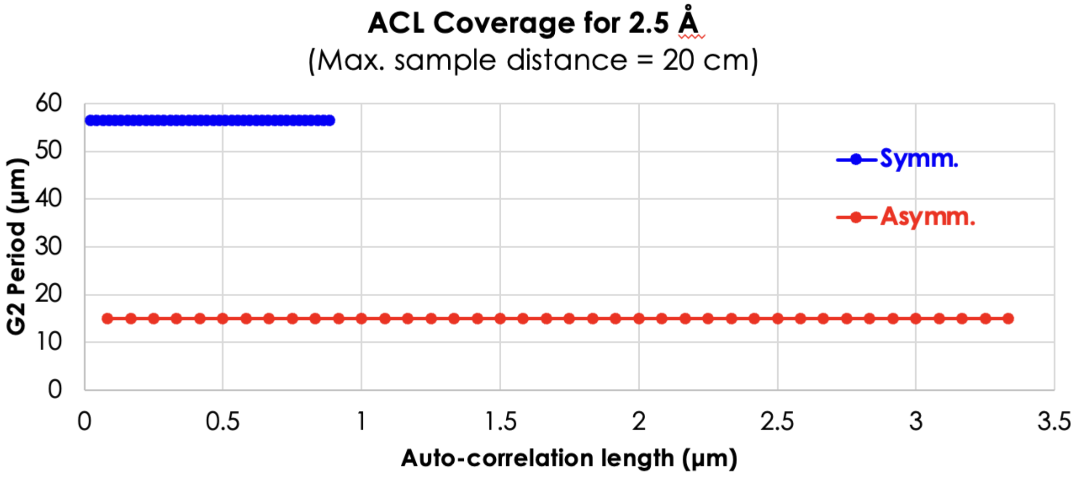
EBSD image is from Plotkowski et al., *Additive Manufacturing*. 46, 102092, (2021).

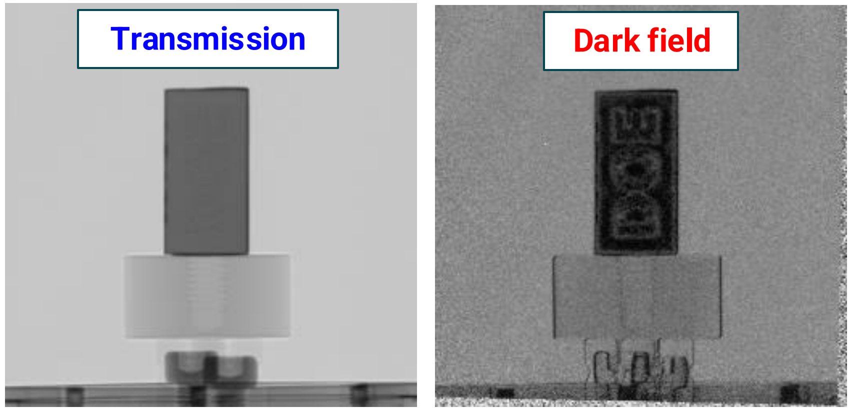
Neutron Imaging Capabilities at MARS

- Radiography & Tomography (high res.)



- nGI





(Sample courtesy of R. Dehoff)

- Polarized Neutron Imaging
- Monochromatic Imaging

Outline

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  - Applications and examples
- Imaging at SNS (Hassina)
  - Principle of hyperspectral imaging at a pulsed source
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- Software for imaging (Jean)

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September 7, 2025

Hyperspectral Neutron Imaging

Hassina Bilheux

Neutron Scattering Division

U.S. DEPARTMENT of ENERGY

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Neutron Radiography and Computed Tomography at the Oak Ridge National Laboratory

High Flux Isotope Reactor (HFIR)
Intense steady-state neutron flux
and a high-brightness cold neutron source

MARS – Yuxuan Zhang (previous talk)

Spallation Neutron Source (SNS)
World's most powerful accelerator-based neutron source

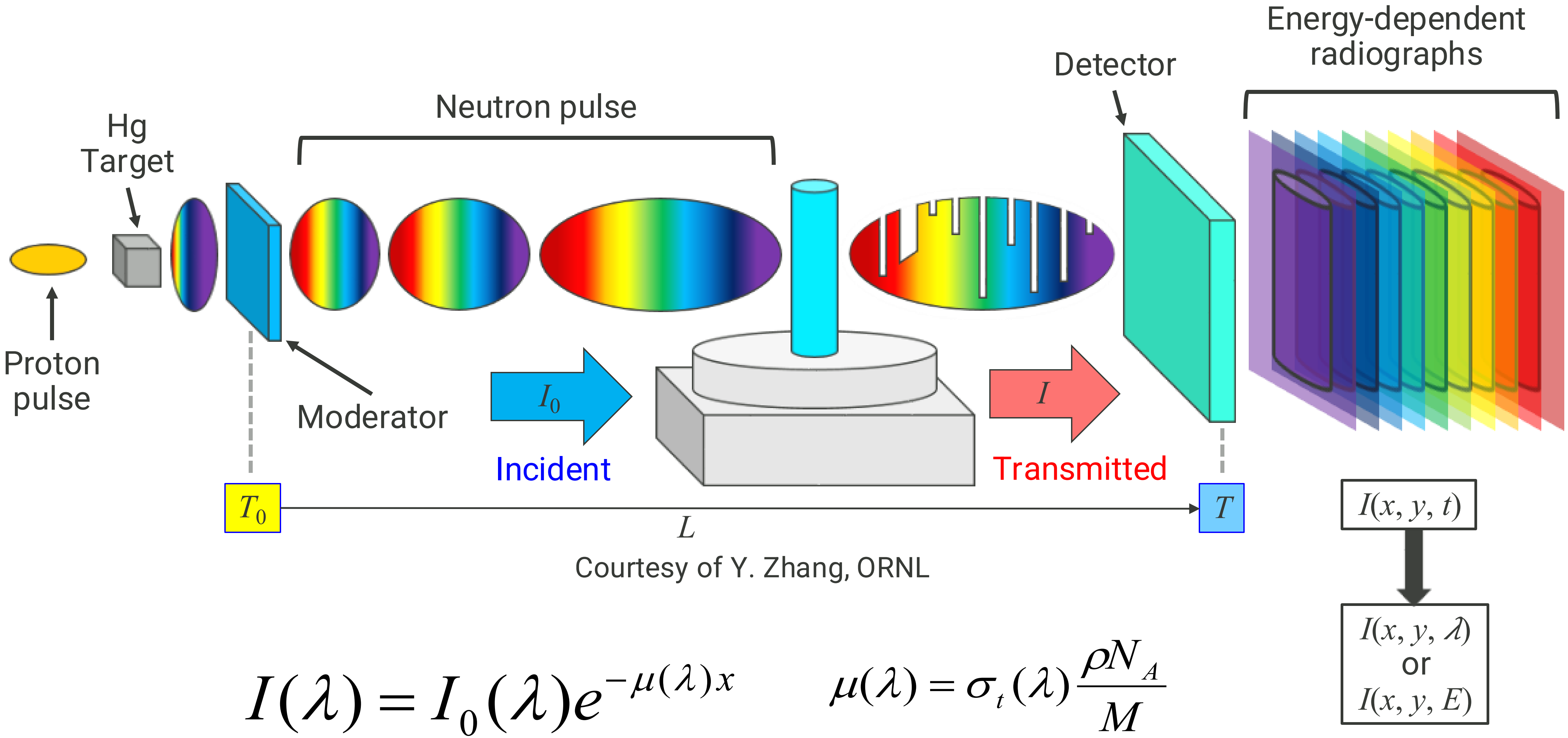
VENUS – this presentation

Software programming – Jean Bilheux (next talk)

What is hyperspectral neutron imaging?

- Collection of radiographs at different neutron wavelengths/energies
  - Data is ‘histogrammed’ into wavelength/energy- resolved radiographs
  - New detector technology can collect event data (histogram can be done after data collection)
- Neutron cross-sections vary as a function of wavelength/energy
- Imaging contrast can be changed using neutron cross-section properties

Imaging at a pulsed source (Spallation Neutron Source or SNS)



Courtesy of Y. Zhang, ORNL

$$I(\lambda) = I_0(\lambda)e^{-\mu(\lambda)x} \qquad \mu(\lambda) = \sigma_t(\lambda)\frac{\rho N_A}{M}$$

Neutron wavelength/energy can be determined by time-of-flight at a pulsed source such as the SNS

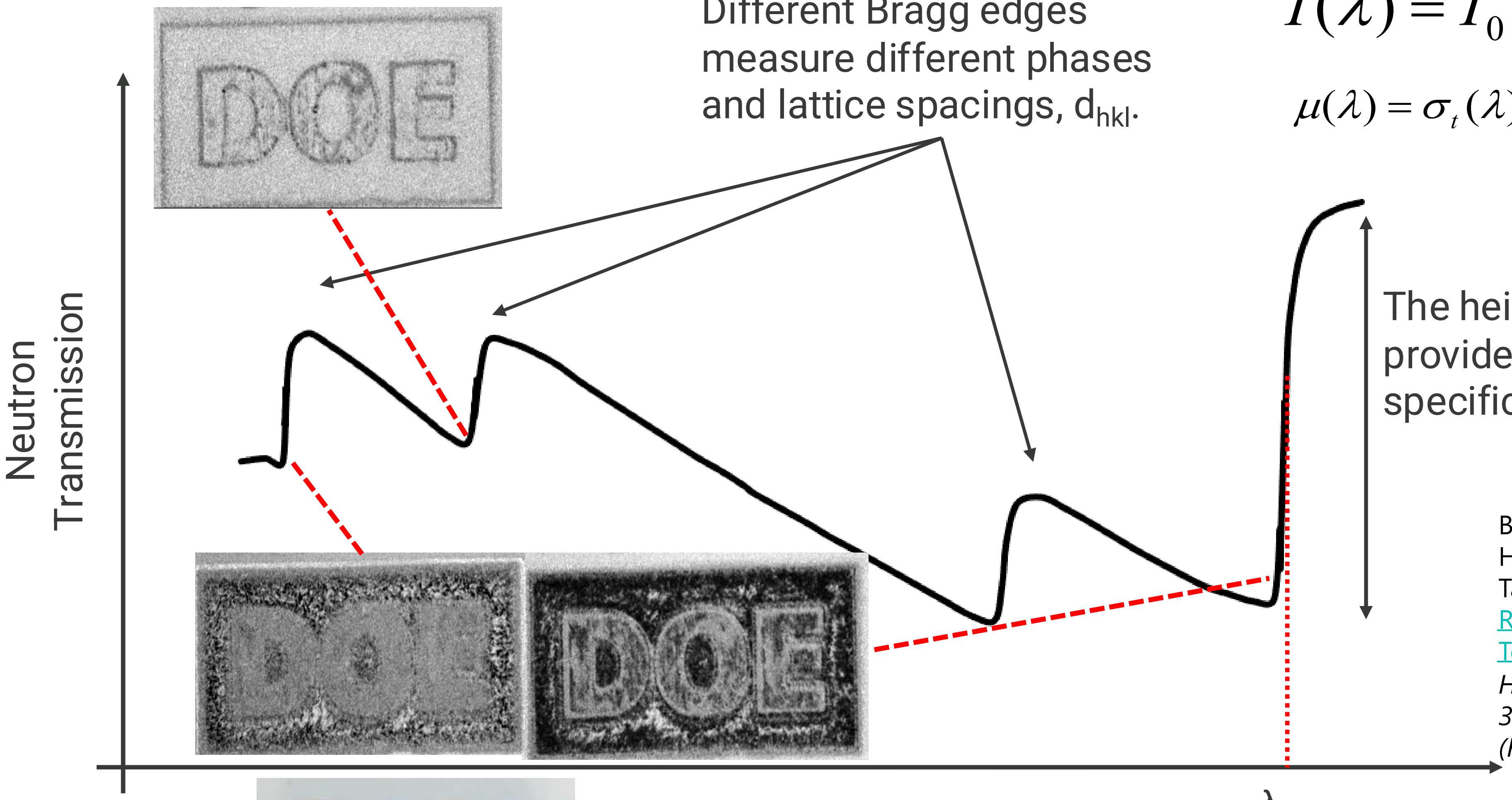
$$\lambda = \frac{h}{m_n v} = \frac{h}{m_n}\frac{(t - t_e)}{L}$$

$$E = \frac{h^2}{2m_n\lambda^2}$$

Neutron classification	Energy (meV)	Velocity ($m.s^{-1}$)	Wavelength (Å)
cold	1	437	9.04
thermal	25	2187	1.81
epithermal	1000	13,833	0.29

Bragg edge radiography

Bragg edge imaging: how does it work?



Different Bragg edges measure different phases and lattice spacings, d_{hkl}.

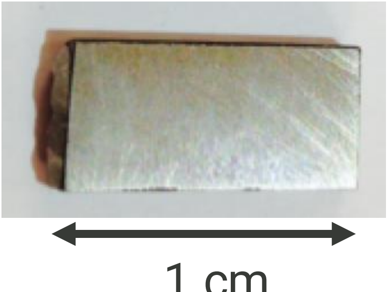
$$I(\lambda) = I_0(\lambda) e^{-\mu(\lambda) x}$$

$$\mu(\lambda) = \sigma_t(\lambda) \frac{\rho N_A}{M}$$

The height of Bragg edge provides the *amount* of a specific phase.

Barton J.P., Bilheux H.Z., Bossi R., Herwig K.W., Santodonato L., Taylor M., "Chapter 12: Neutron Radiography for Nondestructive Testing", *Nondestructive Testing Handbook, Fourth Edition: Volume 3, Radiographic Testing (RT)* (2019).

3D printed Inconel 718



The position of the Bragg edge, $\lambda_{hkl} = 2\, d_{hkl}$, is a measure of the *strain* in the sample

Principle of Bragg edge Transmission

$\lambda = 2d_{hkl}$

$\varepsilon = \frac{d - d_0}{d_0}$

- ✓ Utilizes thermal and cold neutrons (approximately between 1 and 10 Å)
- ✓ Obeys Bragg's Law $\lambda_{hkl} = 2d_{hkl} \sin \theta_{hkl}$ simplifies: $\mathbf{\lambda_{hkl} = 2d_{hkl}}$

March-Dollase model

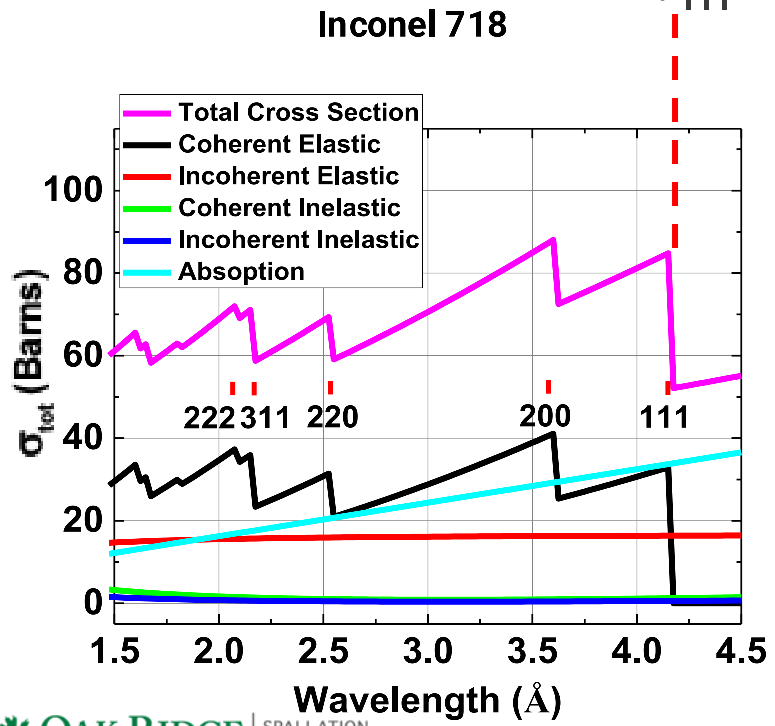
Sabine's primary extinction model

$$\sigma_{Bragg}(\lambda) = \frac{\lambda^2}{2V_0} \sum_{hkl}^{2d_{hkl}>\lambda} |F_{hkl}|^2 d_{hkl} \, P\left(\alpha_{\vec{h}}(\lambda)\right) E_{hkl}(\lambda, F_{hkl})$$

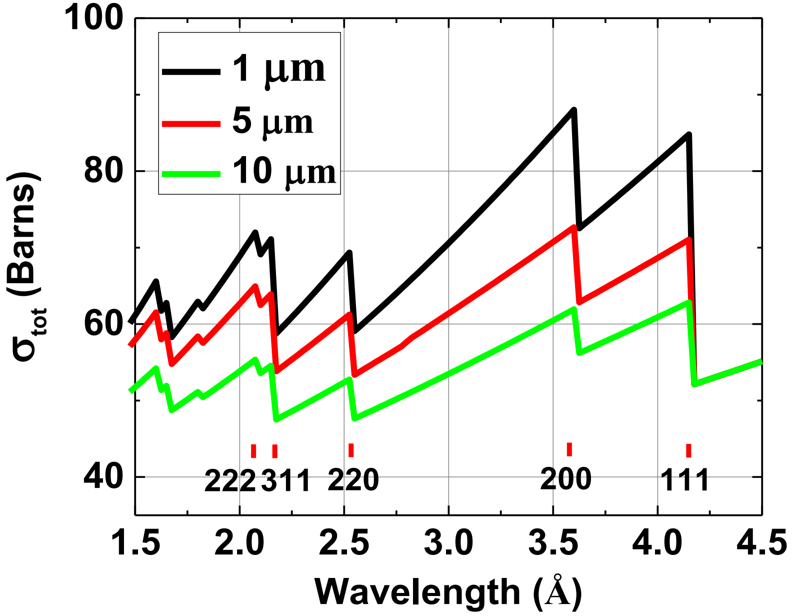
V_0: volume of unit cell

F_{hkl}: Structure factor including Debye-Waller factor

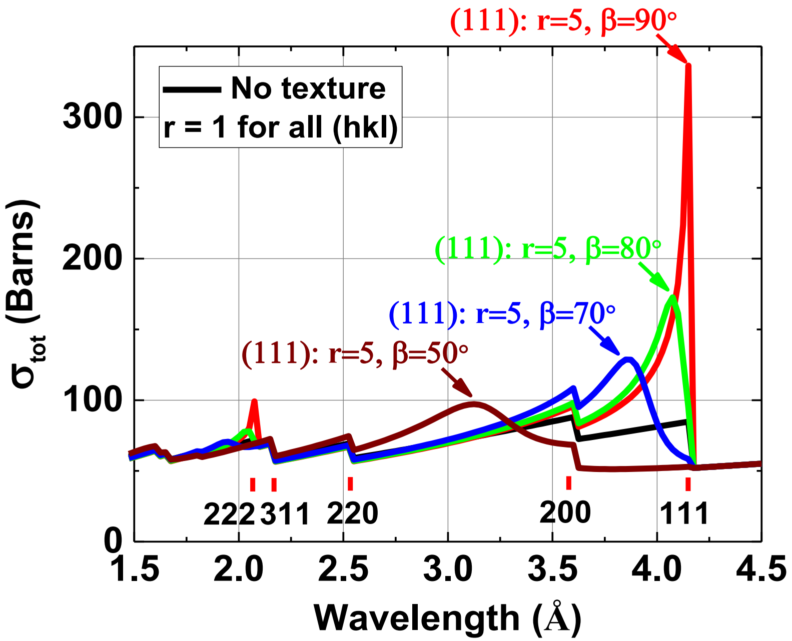
Total cross section for Inconel 718



Crystallite size effect (E_{hkl})

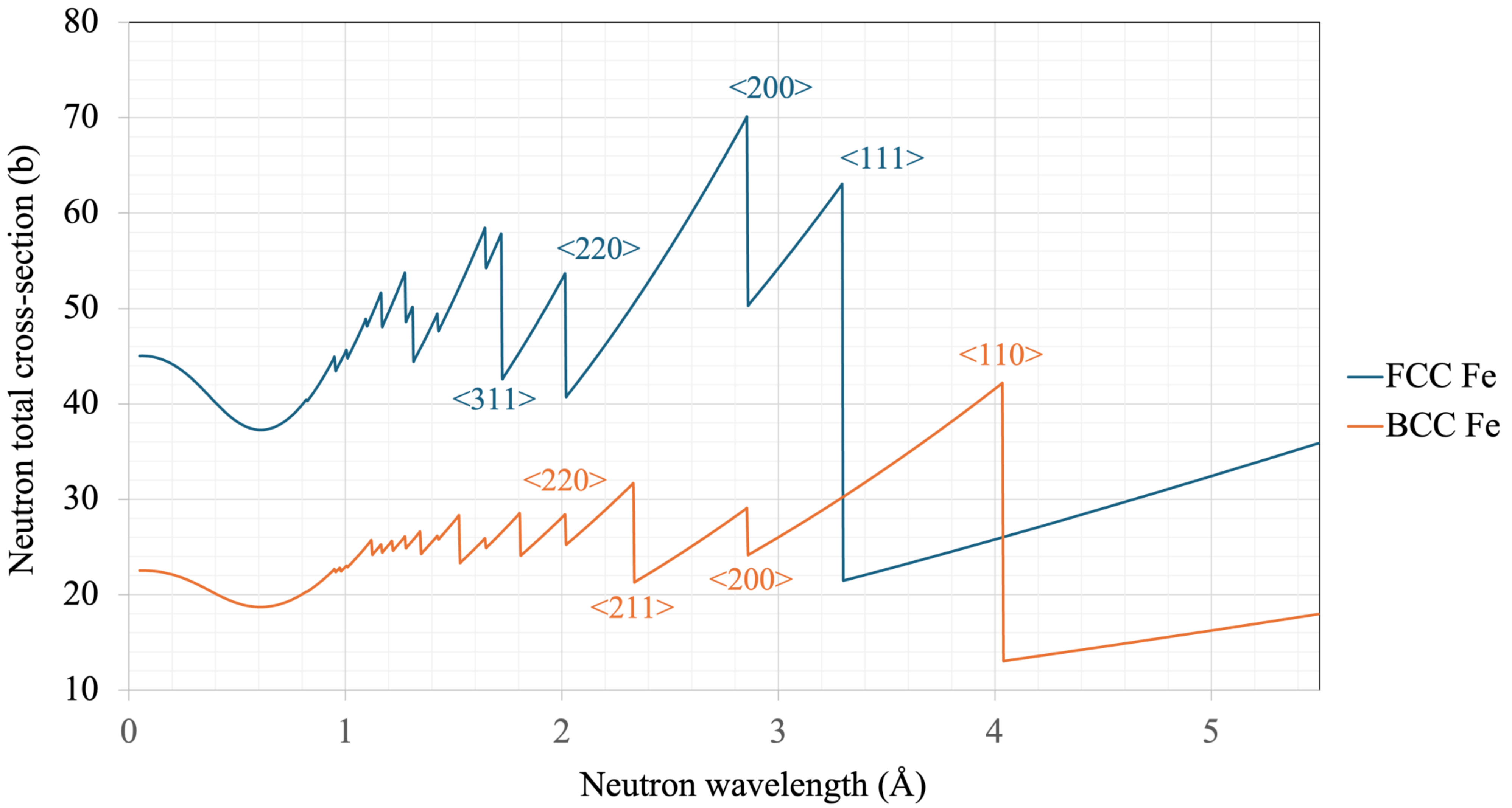


Crystallite orientation effect ($P\left(\alpha_{\vec{h}}(\lambda)\right)$: r and β)



G. Song et al., Journal of Imaging, 3, 65 (2017).

Calculated Bragg edges for Iron FCC and BCC phases

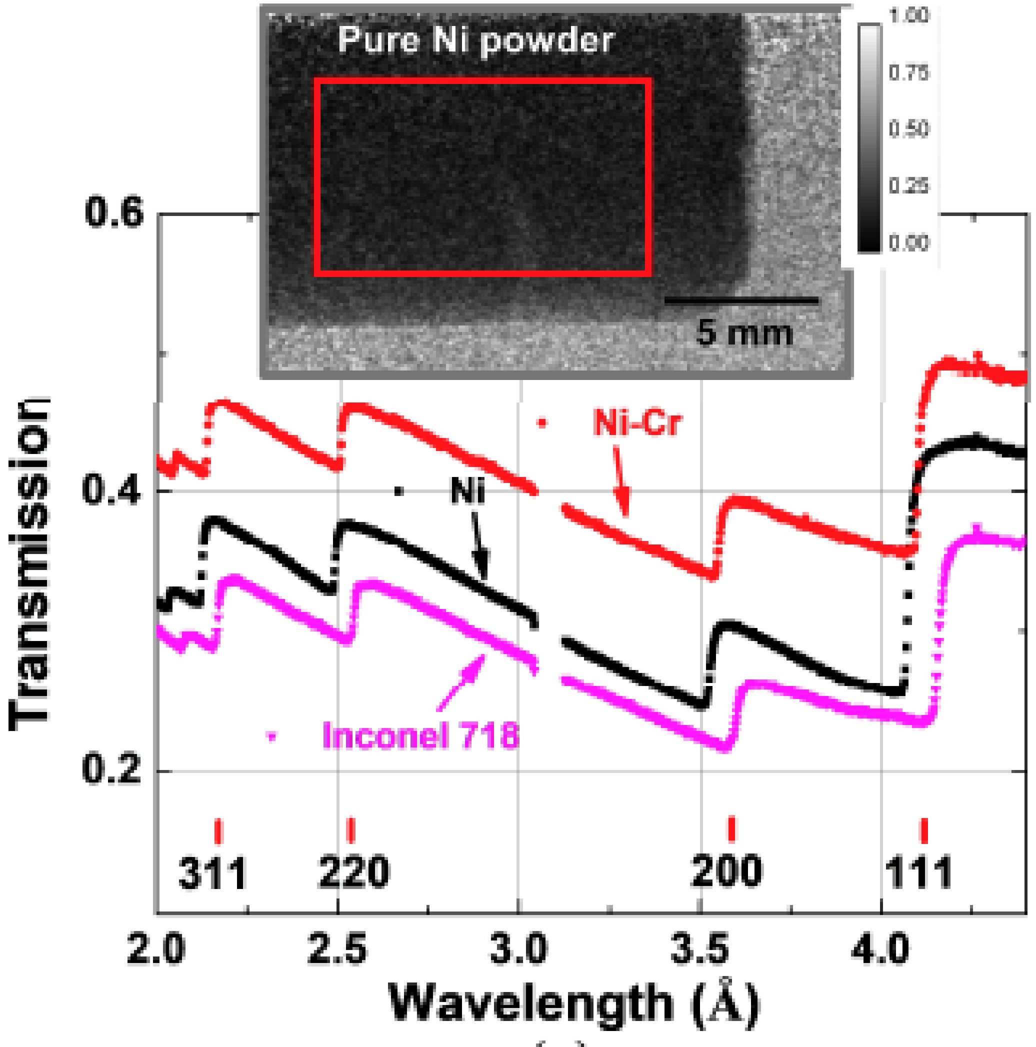


Bragg edges plotted with:

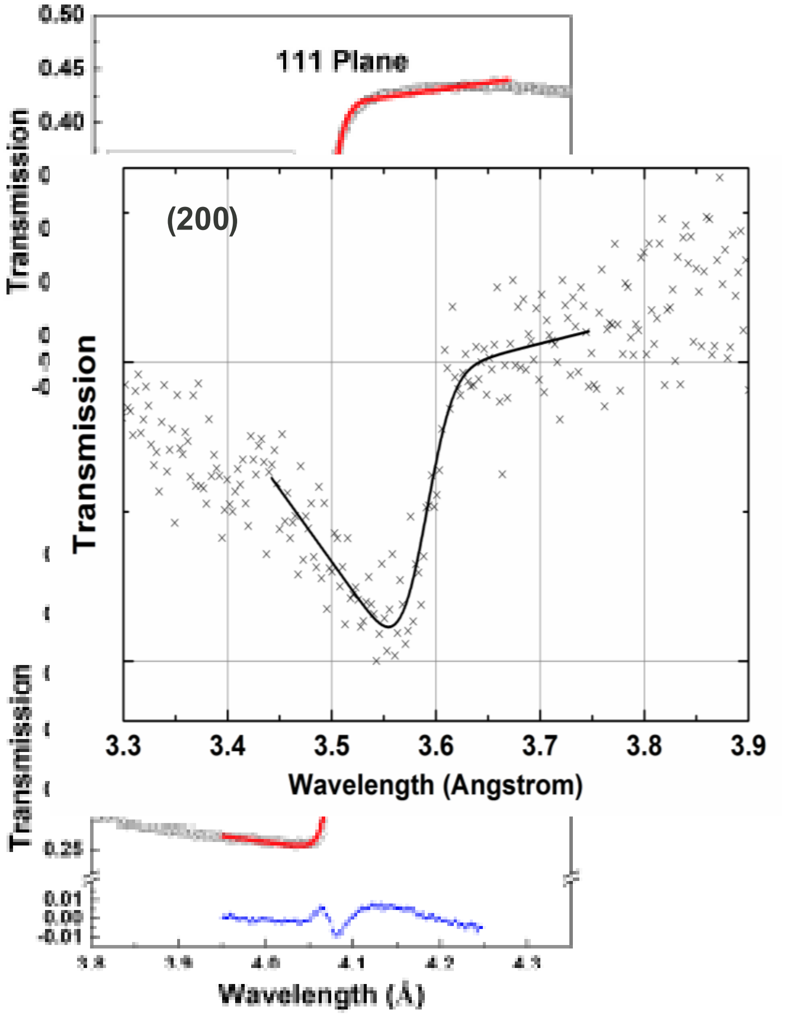
iNEUIT (“*I knew it*”)

iNEUtron Imaging Toolbox

The perfect case study: powders



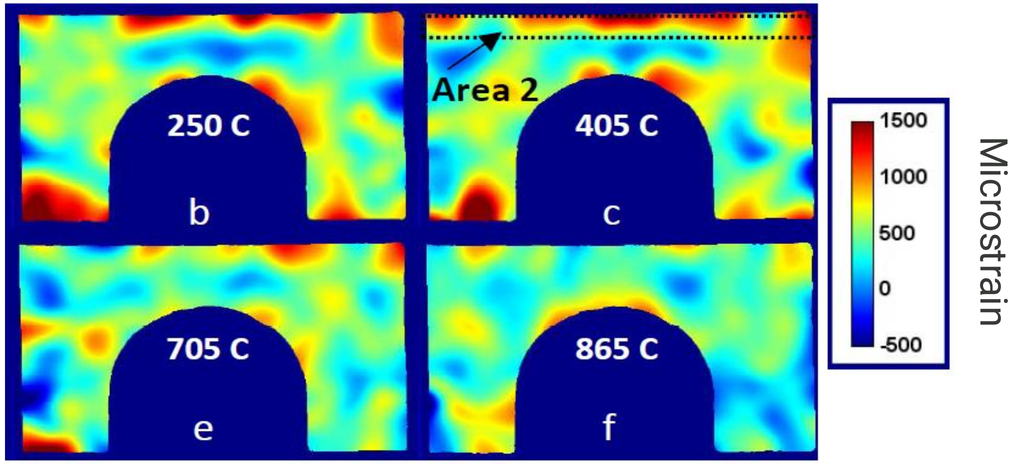
(a)



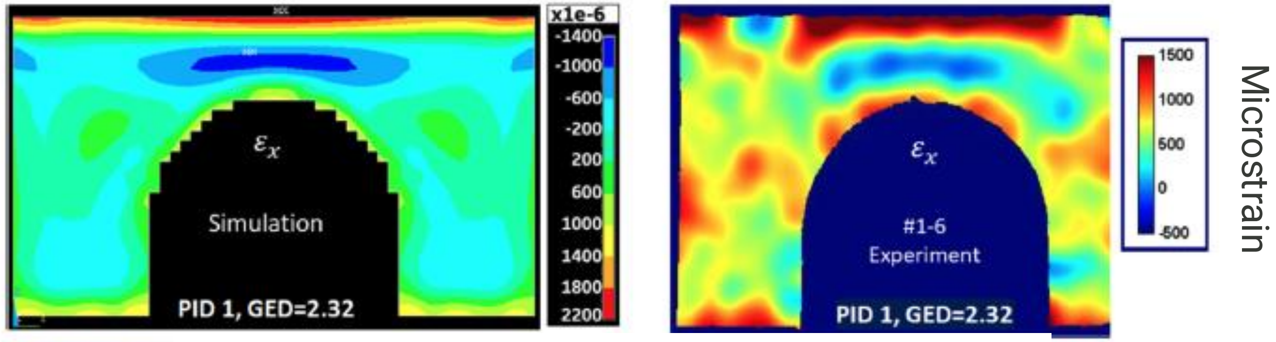
(c)

Song G., Lin J.Y., Bilheux J., Xie Q., Santodonato L., Molaison J.J., Skorpenske H.D., dos Santos A.M., Tulk C.A., An K., Stoica A.D., Kirka M.M., Dehoff R.R., Tremsin A.S., Bunn J.R., Sochalski-Kolbus L.M., Bilheux H.Z., "Characterization of Crystallographic Structures Using Bragg-Edge Neutron Imaging at the Spallation Neutron Source", *Journal of Imaging*, **3,** 4, 65 (2017).

Engineered Materials: Monitoring residual strain relaxation and preferred grain orientation of additively manufactured Inconel 625 by in-situ neutron imaging (10 min measurements)



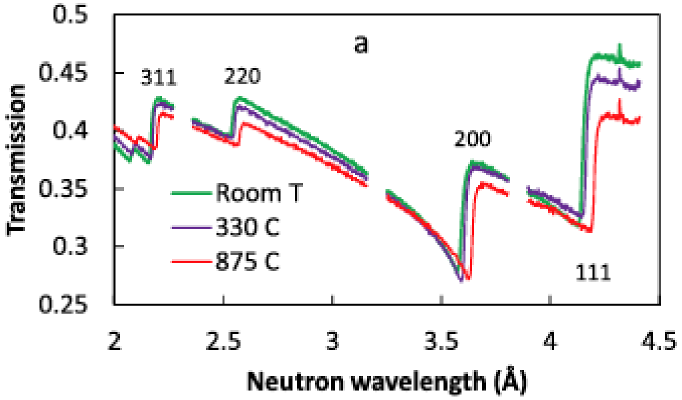
AM Inconel 625 strain evolution as a function of temperature



Modeled and experimental results.

$$\lambda = 2d_{hkl}$$

$$\varepsilon = \frac{d - d_0}{d_0}$$



Tremsin et al, Additive Manufacturing, 2021.

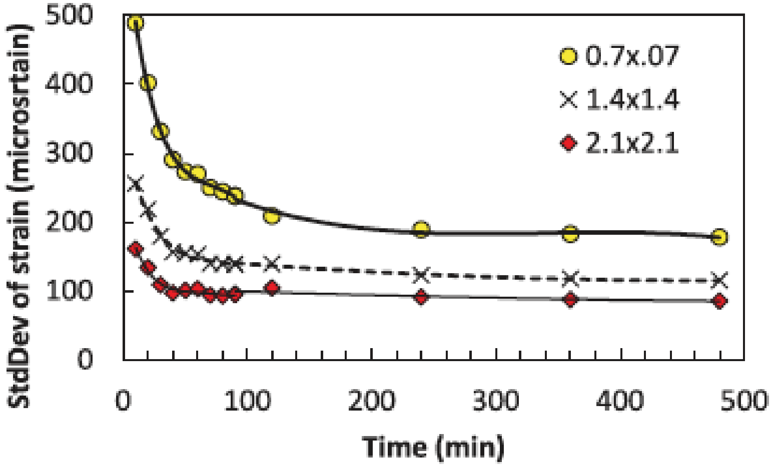


Fig. 16. Variation of the standard deviation of the reconstructed strain as a function of image integration time. Three different sizes of the area used for pixel grouping are used for strain reconstruction, as indicated by the legend (in mm^2).

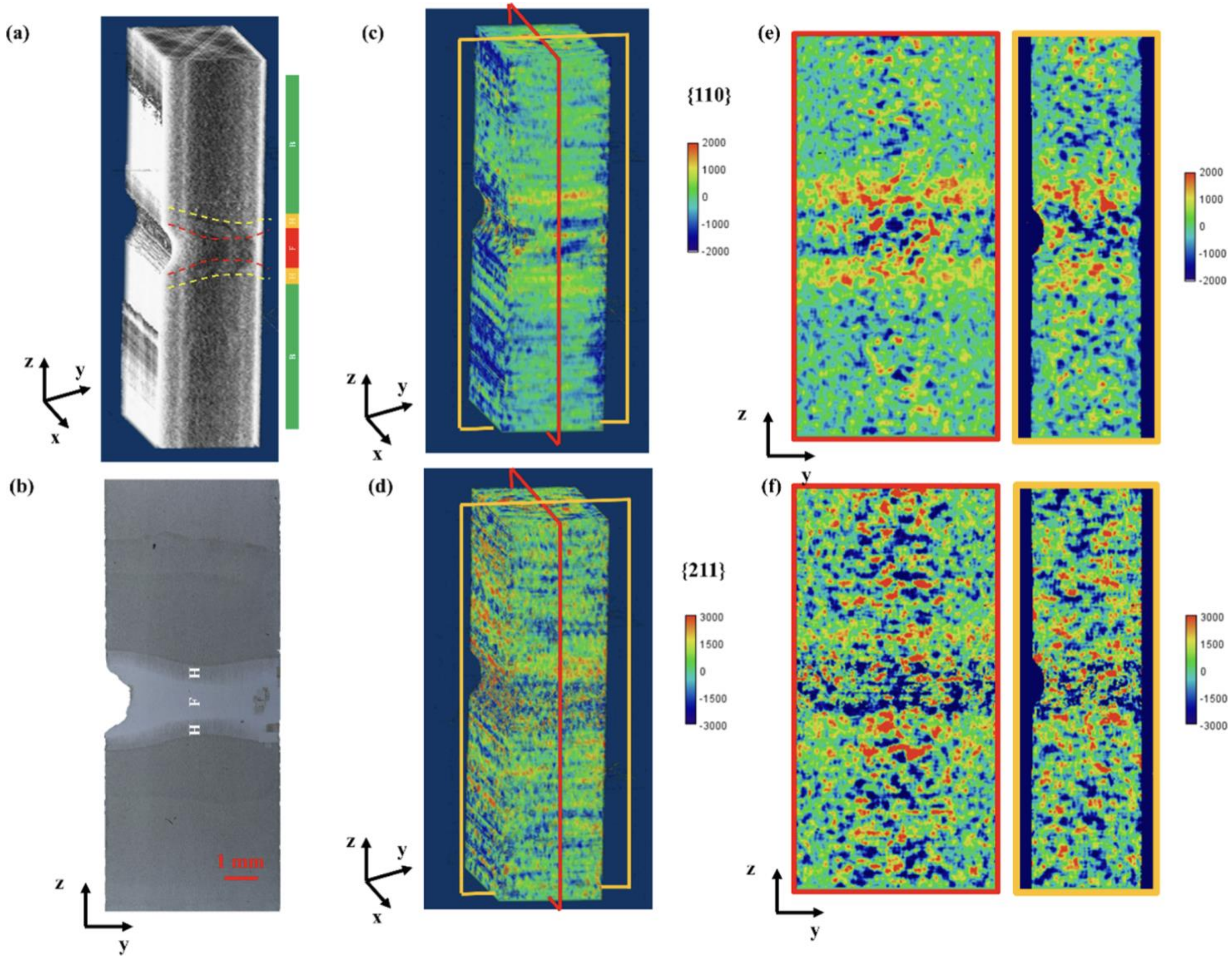
Tremsin et al, Nuc. Instr. Methods in Phys. Res. A, 2021.

Mapping residual stresses in welds: the example of Eurofer97

Material: Eurofer97- European Reduced Activation Ferritic-Martensitic (RAFM) steel, structural material candidate for fusion energy systems

Goal: predict longevity of engineering component by investigating the distribution of residual stress

Butt weld of two 6-mm thick Eurofer97 plates with dimensions of 150x75x6 mm^3



Zhu et al., Nuclear Materials and Energy 36 (2023) 101462.

Neutron wavelength/energy can be determined by time-of-flight at a pulsed source such as the SNS

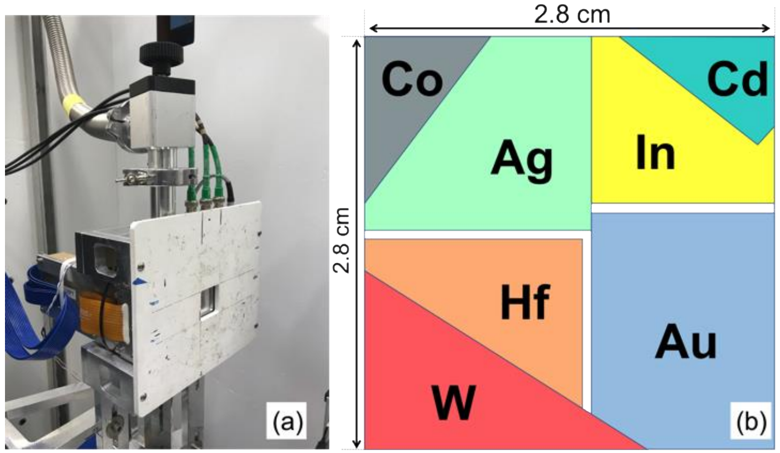
$$\lambda = \frac{h}{m_n v} = \frac{h}{m_n}\frac{(t - t_e)}{L}$$

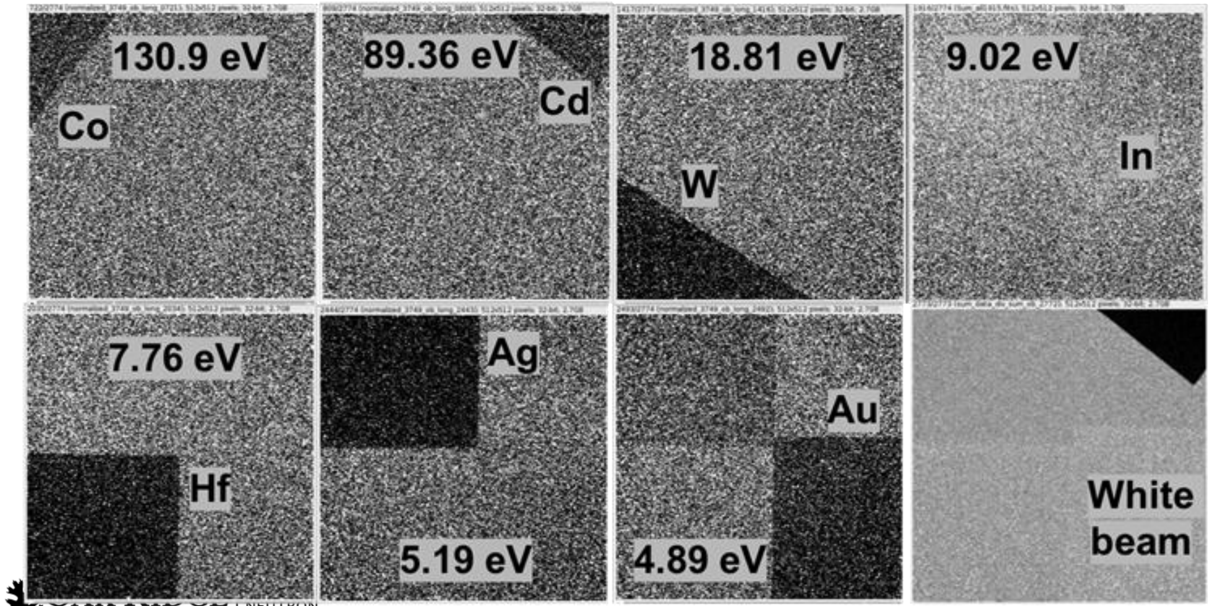
$$E = \frac{h^2}{2 m_n \lambda^2}$$

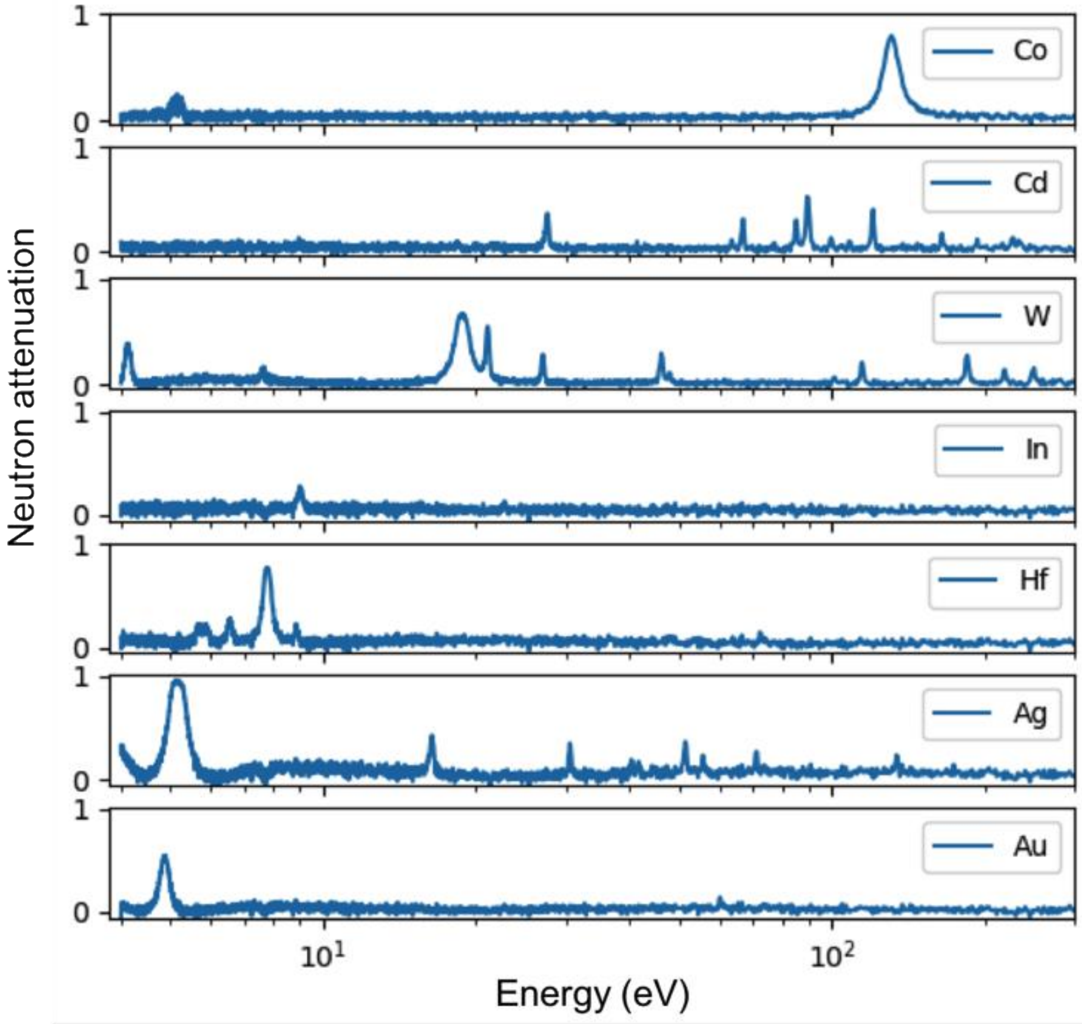
Neutron classification	**Energy (meV)**	**Velocity (m.s^{-1})**	**Wavelength (Å)**
cold	1	437	9.04
thermal	25	2187	1.81
epithermal	1000	13,833	0.29

Resonance radiography

Higher energy neutrons can also be used for imaging (neutrons of energies higher than 1 eV): Resonance Imaging



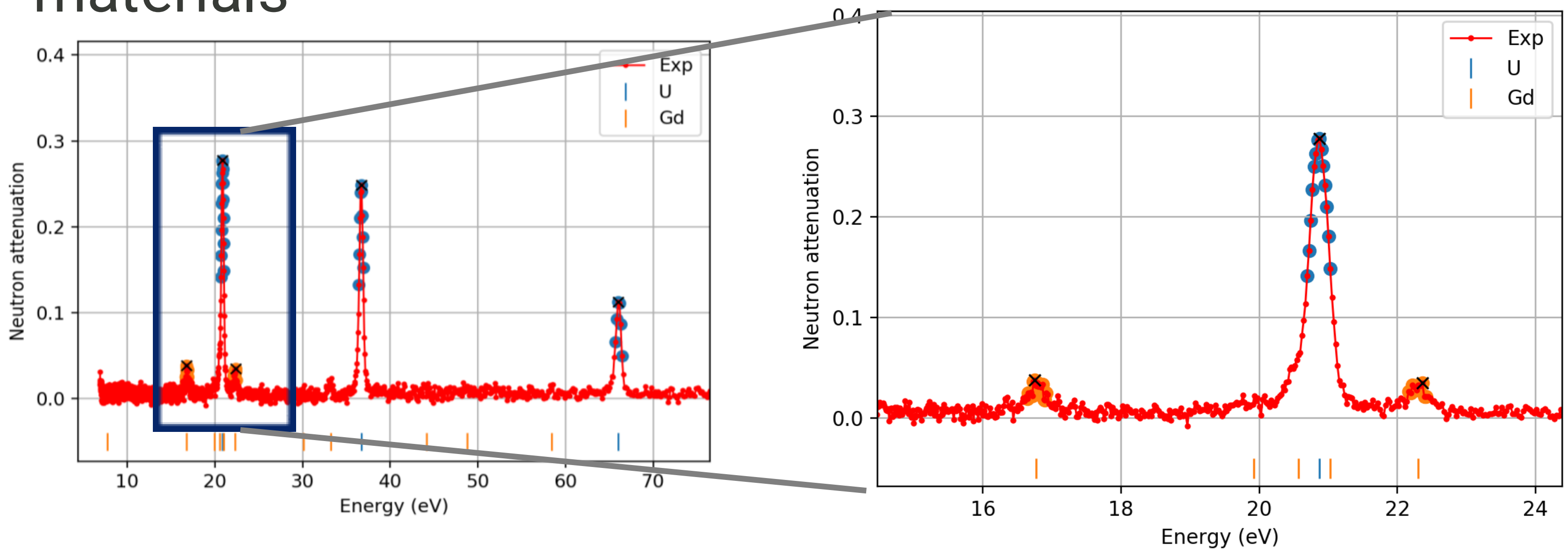


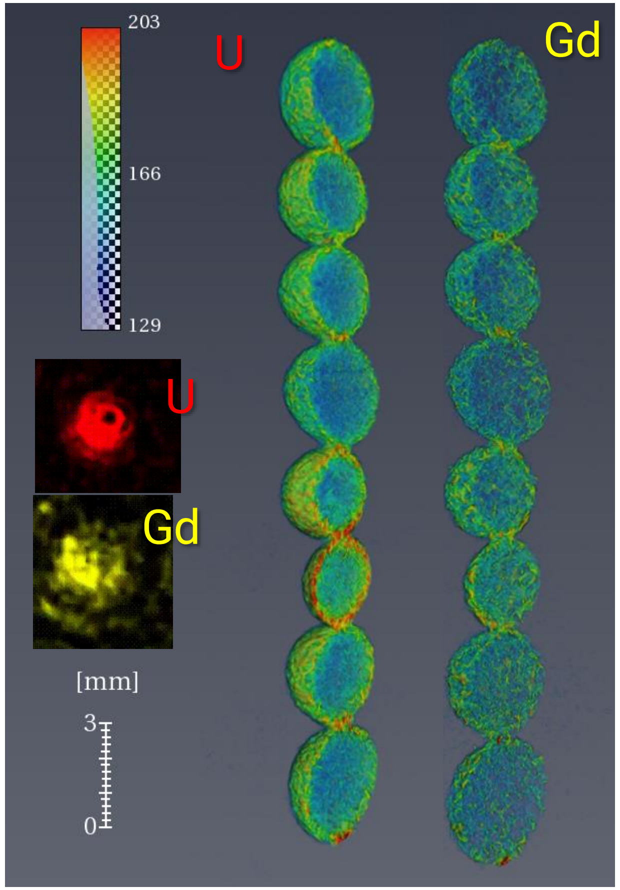


Zhang Y., Myhre K.G., Bilheux H.Z., Tremsin A.S., Johnson J.A., Bilheux J., Miskowiec A., Hunt R.D., Santodonato L., Molaison J.J., "Neutron Resonance Radiography and Application to Nuclear Fuel Materials", *Transactions of the American Nuclear Society,* (2018).

Using epithermal neutrons (energy > 1 eV), resonance imaging can map the isotopic content in advanced nuclear fuel materials in 3D

- Distribution of elements drive the performance of the novel advanced nuclear fuel materials



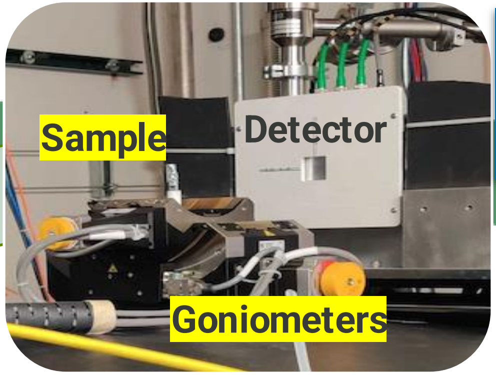


- **Quantitative analysis is being developed using in-house open-source Python package (ResoFit)**

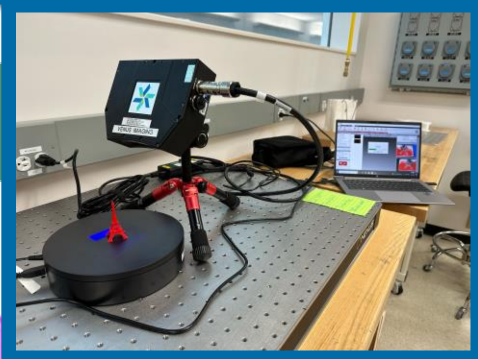
Myhre K.G., Zhang Y., Bilheux H.Z., Johnson J.A., Bilheux J., Miskowiec A., Hunt R.D., "Nondestructive Tomographic Mapping of Uranium and Gadolinium Using Energy-Resolved Neutron Imaging", *Transactions of the American Nuclear Society,* (2018).

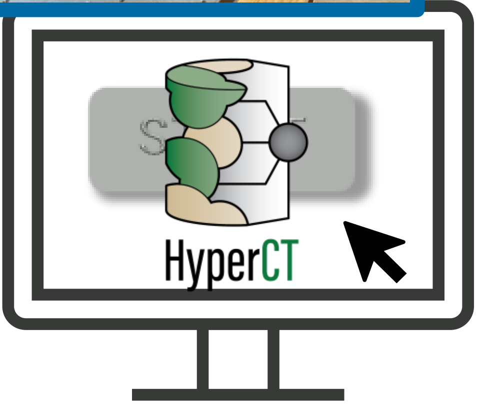
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Autonomous Hyperspectral Neutron CT Experiment at ORNL



Light scan and preselection of projection angles





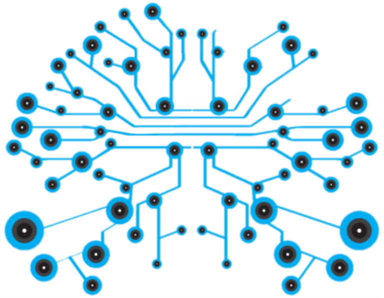
Continue

Stop

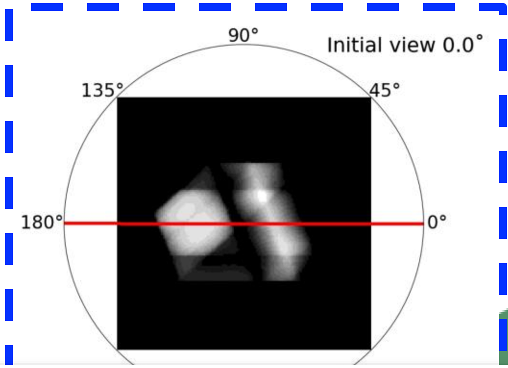
Autonomous Decision

Up to factor 5 improvement in time

- Optimization of the scan based on the unique sample geometry
- Ability to provide real-time reconstructed data using advanced iterative reconstruction methods

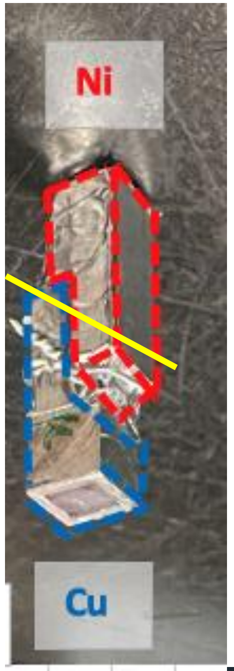


AI Quality Evaluation

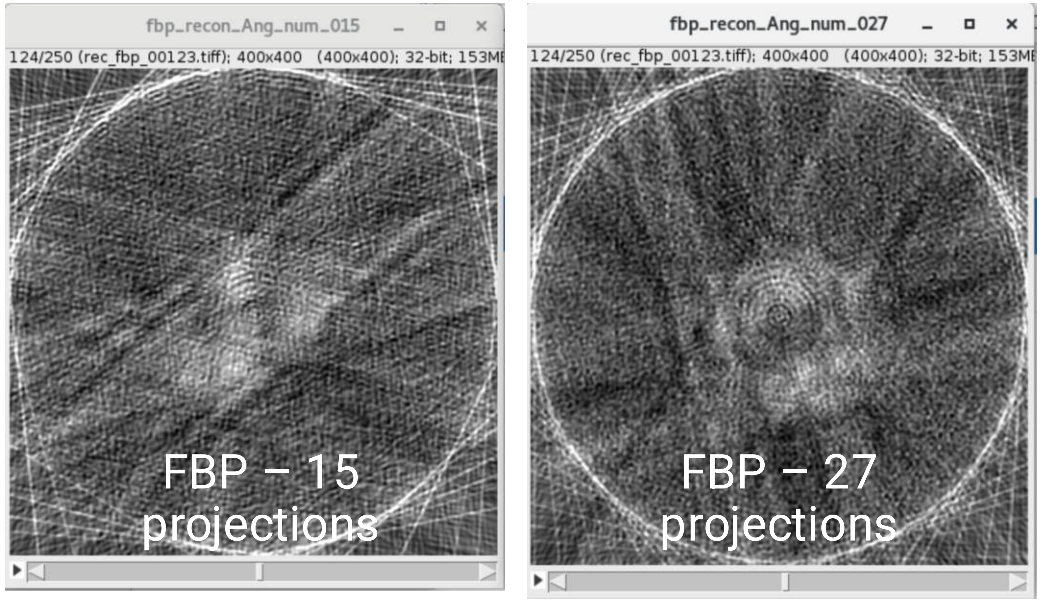


Sample Adaptive Scanning Angles (active learning)

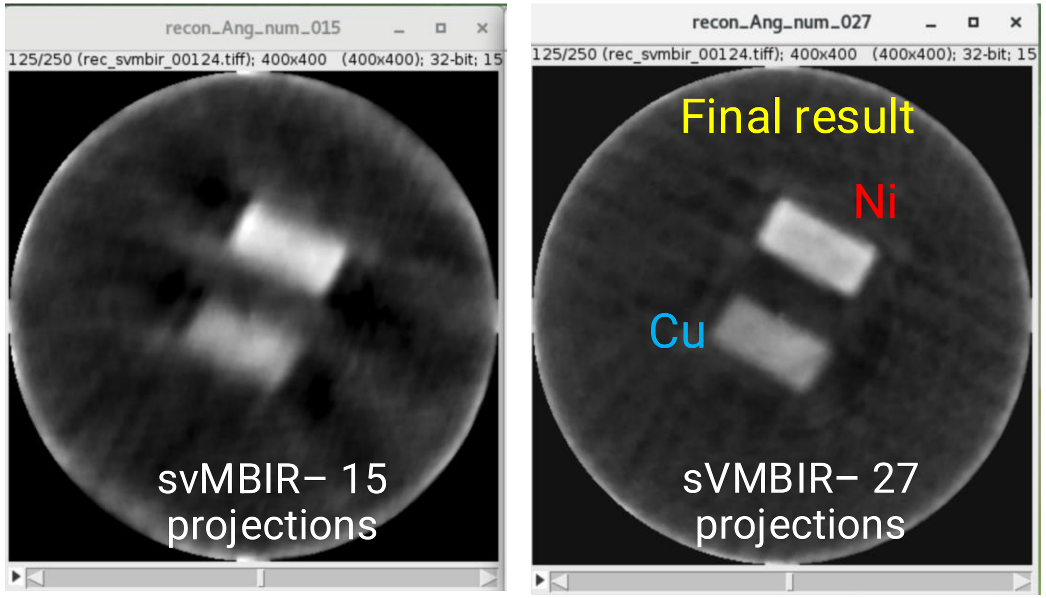
<311> Bragg edge reconstruction at ~ 2.17 Å ± 0.2 Å

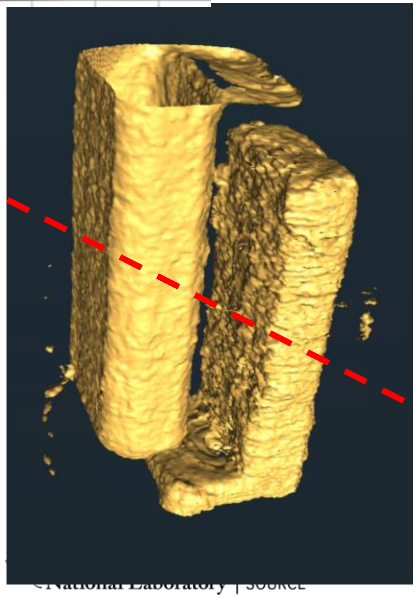


Conventional reconstruction methods

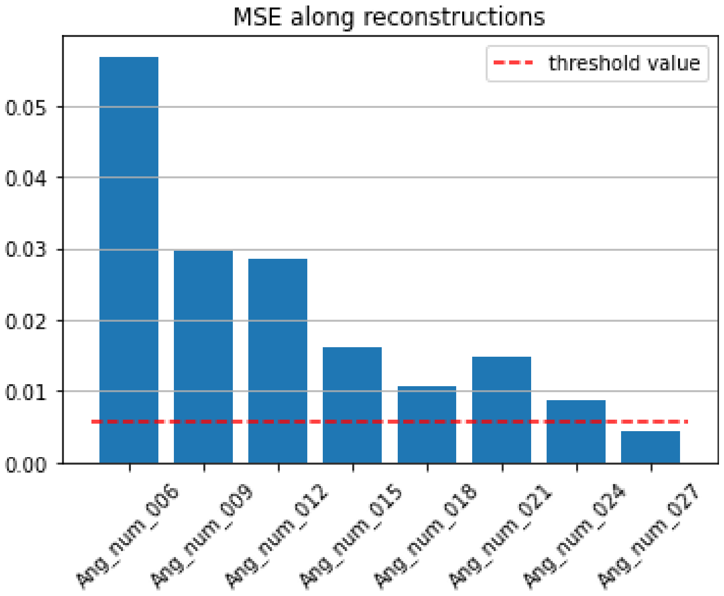


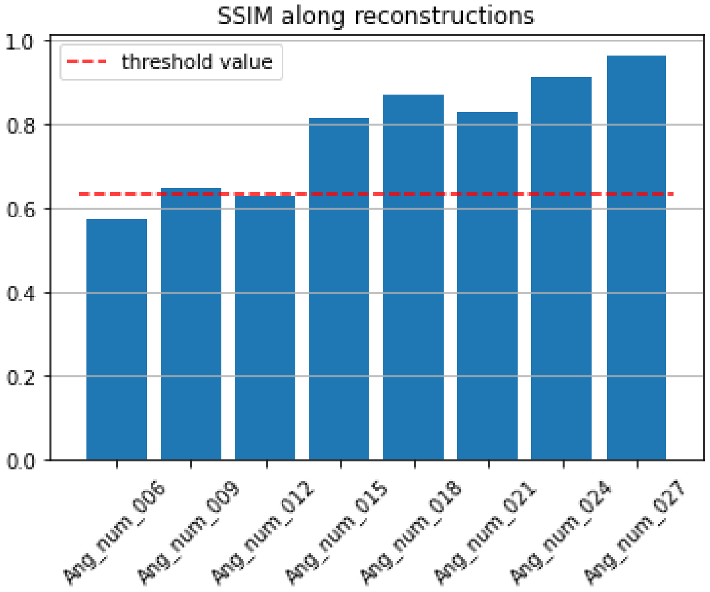
Our advanced algorithms/methods





	Thresholds
MSE[1]	5.689×10^{-3}
SSIM[2]	0.634





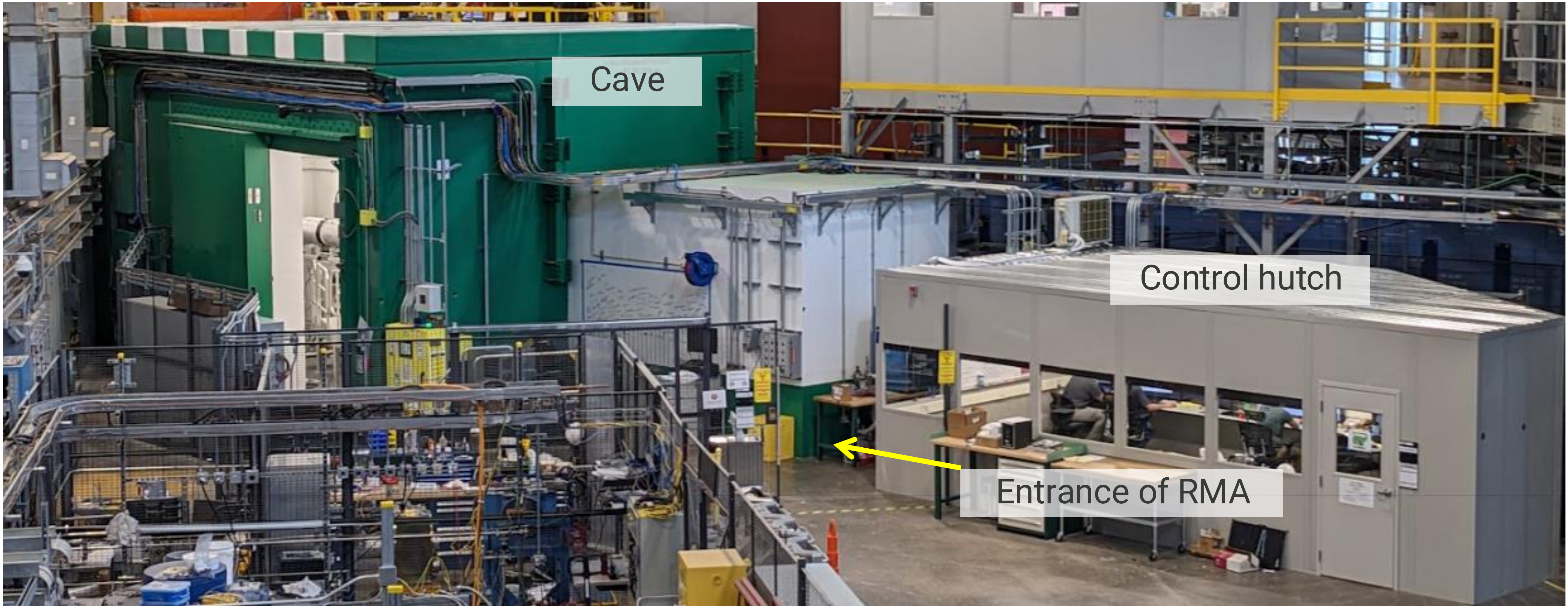
[1] Zhou Wang; Bovik, A.C.; ,"Mean squared error: Love it or leave it? A new look at Signal Fidelity Measures," Signal Processing Magazine, IEEE, vol. 26, no. 1, pp. 98-117, Jan. 2009.

[1] Z. Wang, A. C. Bovik, H. R. Sheikh and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," IEEE Transactions on Image Processing, vol. 13, no. 4, pp. 600-612, Apr. 2004.

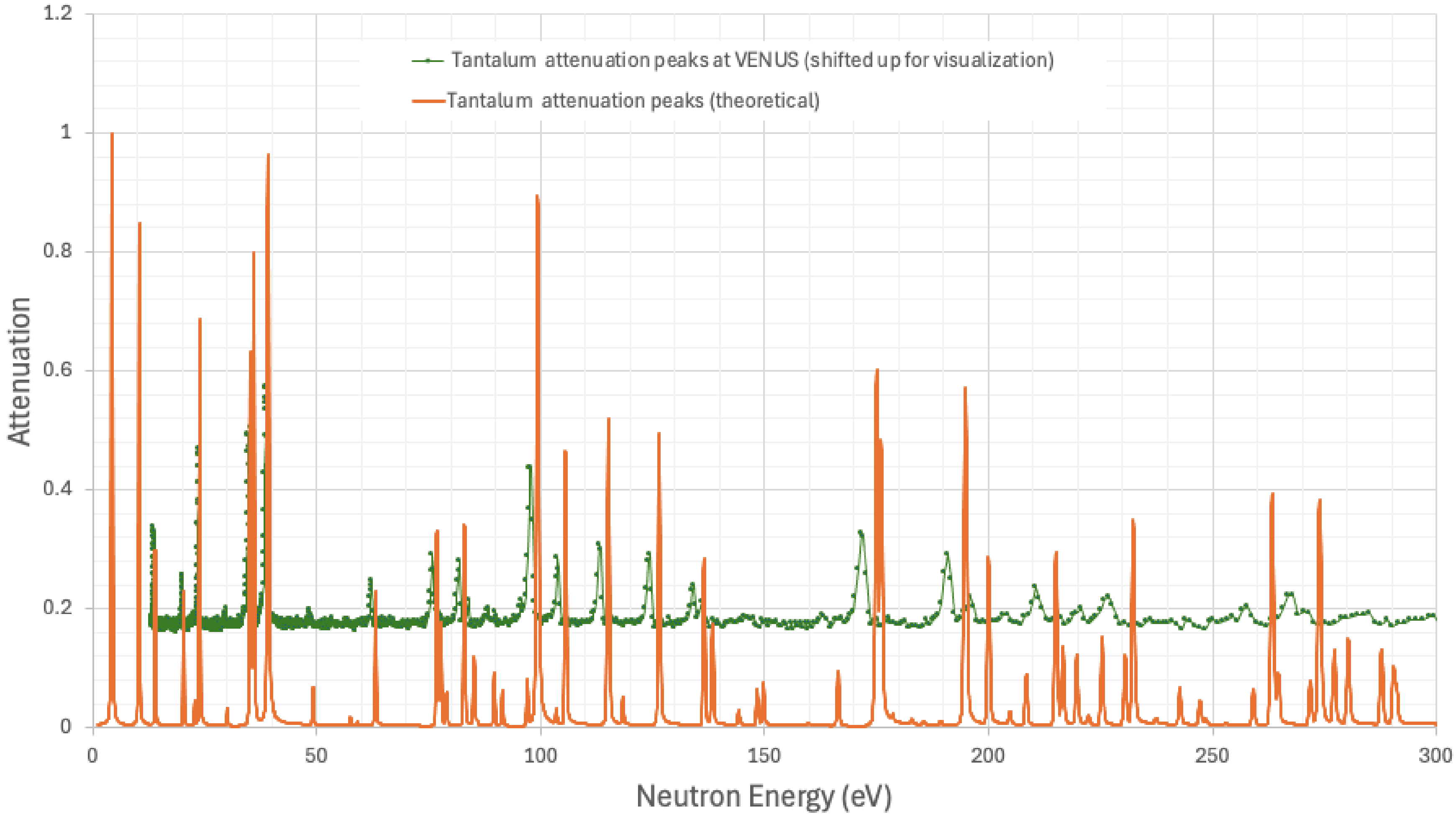
The VENUS facility

- VENUS is a *time-of-flight* imaging beamline capable of separating neutron wavelengths to measure unique sample features/contrast such as:
  - Microstructure, phases, preferred grain orientation, strain with **Bragg edge radiography** of advanced *crystalline* materials (energy, superalloys, etc.)
  - Elemental/isotopic content with **resonance radiography/CT but also temperature gradients**

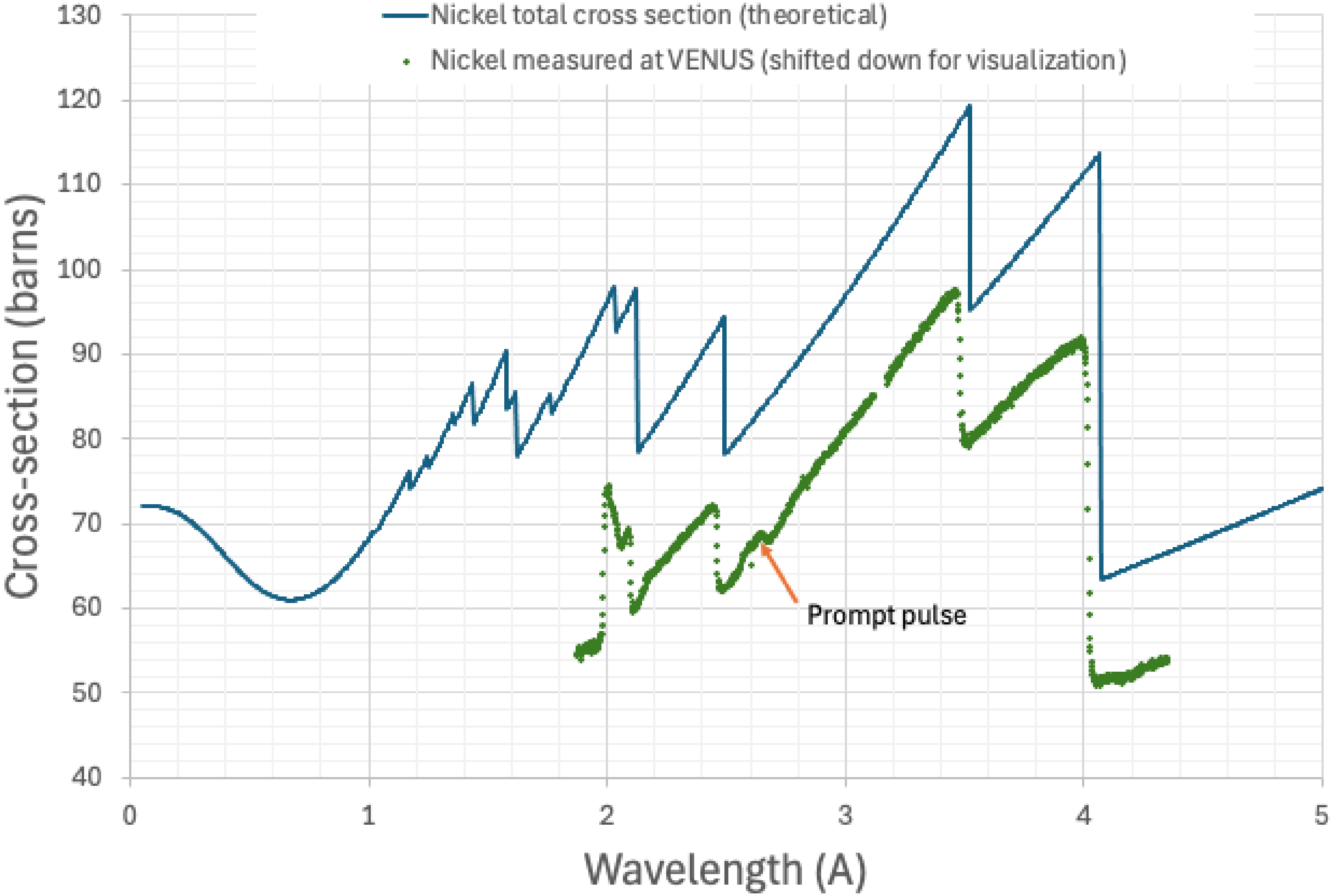
Photograph of VENUS showing the VENUS cave, control hutch and Radiological Materials Area (RMA)



Resonance radiography demonstrated with Tantalum foil and the microchannel plate (MCP) Timepix (TPX) detector



Bragg edge radiography demonstrated with Nickel powder and the microchannel plate (MCP) Timepix (TPX) detector



Acknowledgments

- Our sponsor: This research used resources at the Spallation Neutron Source, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory.
- The ORNL Neutron Imaging Team:
  - Yuxuan Zhang, Shimin Tang, Jean Bilheux, Kevin Yahne, Chen Zhang, Harley Skorpenske, James Torres, Roger Hobbs
- The VENUS construction team
- Our university, industry, and national laboratory collaborators

Scientific programming

5 things you must know

Jean Bilheux

Neutron Imaging Computer Instrument Scientist

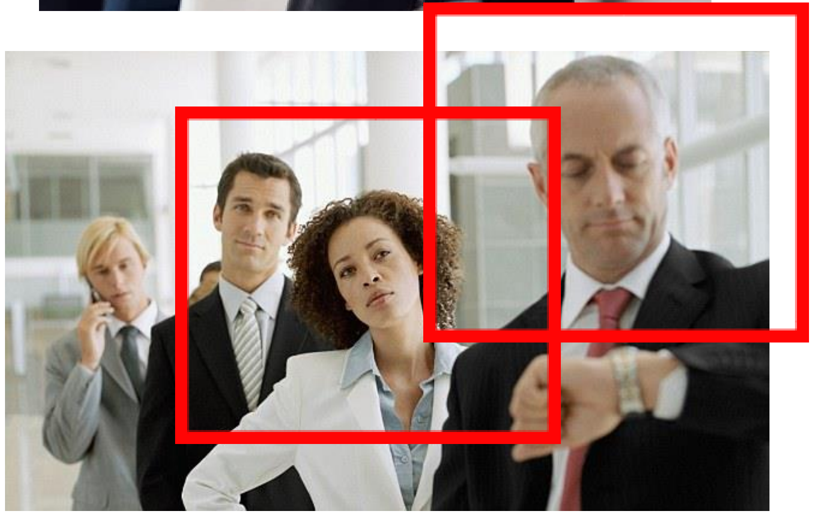
If you can't program …

Depend on others to implement the feature requested for you…and wait in line !

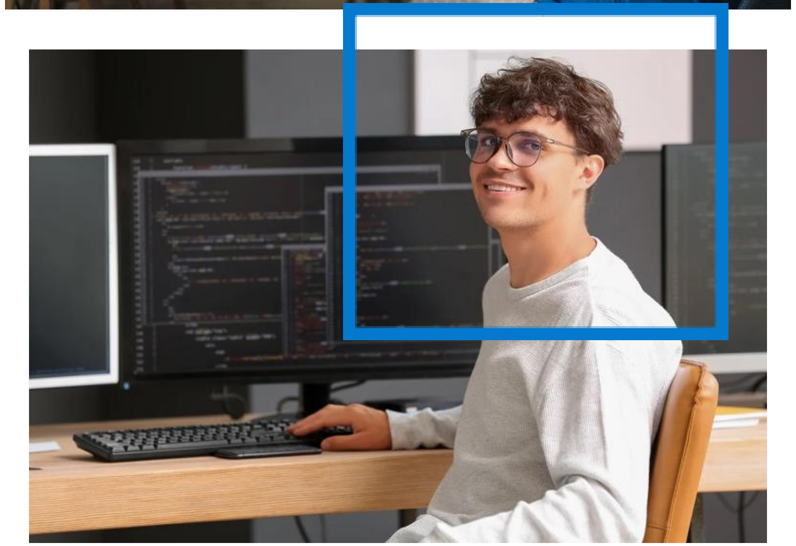
… but if you can program

- More Independent
- Faster output
- More flexibility of things you can try and do
- Stronger argument to prove your point
- Share with community
- Good skills to have

Proof by pictures



No programming skills



With programming skills

The 5 things that will save your life

1 **Pick the right language**

Which language to pick ?

Objective - C

SQL

VBA

HTML JS CSS

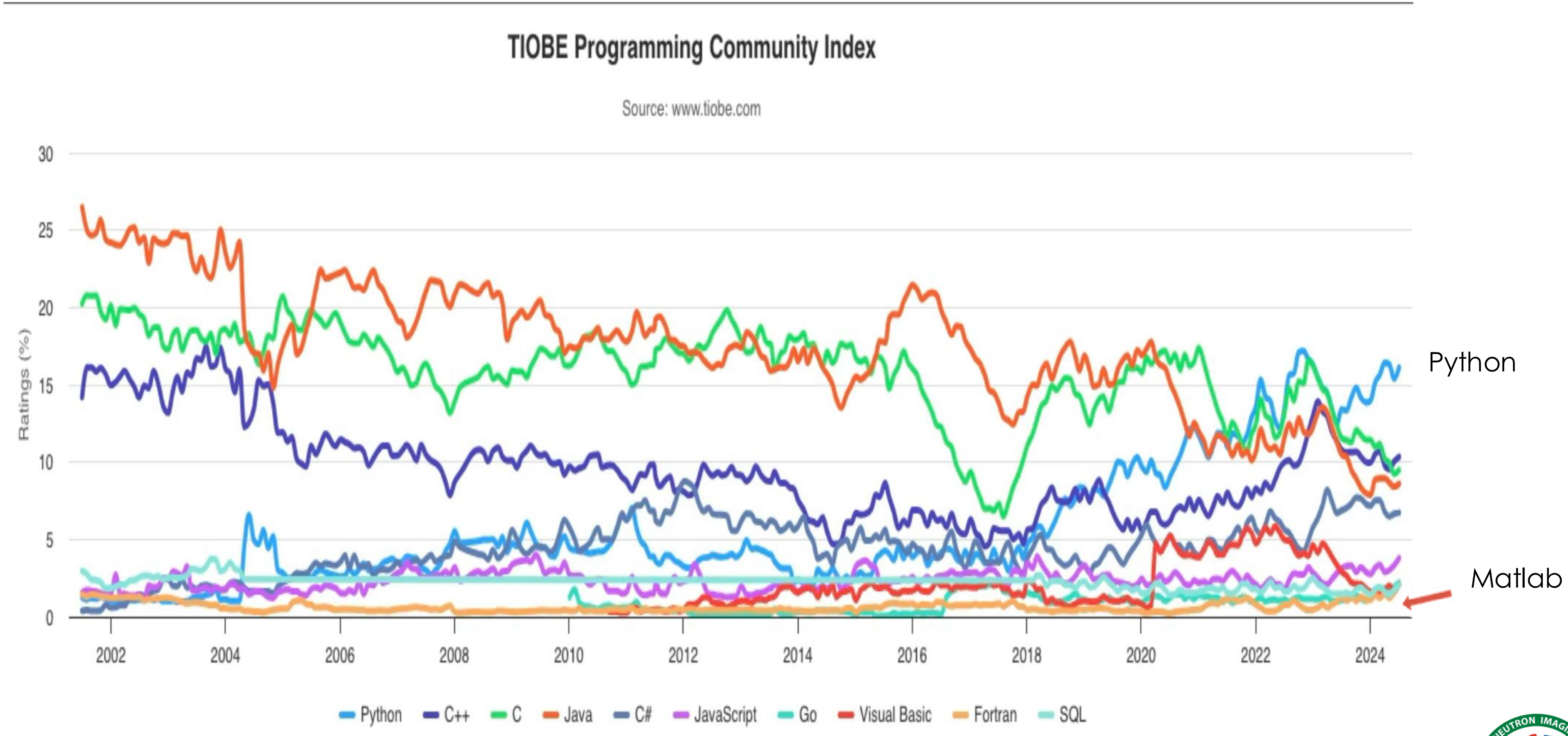
BASIC

MATLAB

GO

Which language ?

Language popularity over the past 20+ years



https://www.tiobe.com/tiobe-index/

Which language ?

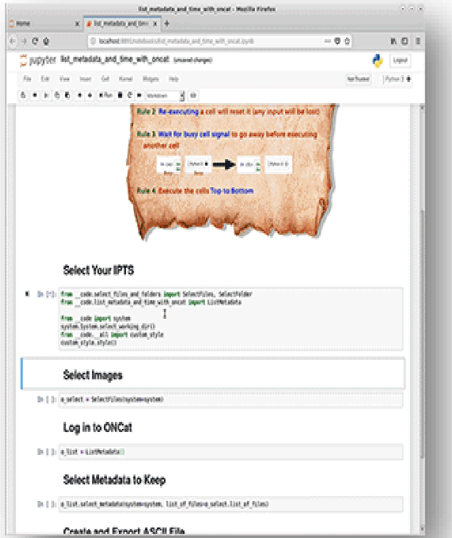
Jul 2024	Jul 2023	Change	Programming Language	Ratings	Change
1	1		Python	16.12%	+2.70%
2	3	^	C++	10.34%	-0.46%
3	2	v	C	9.48%	-2.08%
4	4		Java	8.59%	-1.91%
5	5		C#	6.72%	-0.15%
6	6		JavaScript	3.79%	+0.68%
7	13	^^	Go	2.19%	+1.12%
8	7	v	Visual Basic	2.08%	-0.82%
9	11	^	Fortran	2.05%	+0.80%
10	8	v	SQL	2.04%	+0.57%
11	15	^^	Delphi/Object Pascal	1.89%	+0.91%
12	10	v	MATLAB	1.34%	+0.08%
13	17	^^	Rust	1.18%	+0.29%
14	16	^	Ruby	1.16%	+0.25%
15	12	v	Scratch	1.15%	+0.08%
16	9	vv	PHP	1.15%	-0.27%
17	18	^	Swift	1.13%	+0.25%

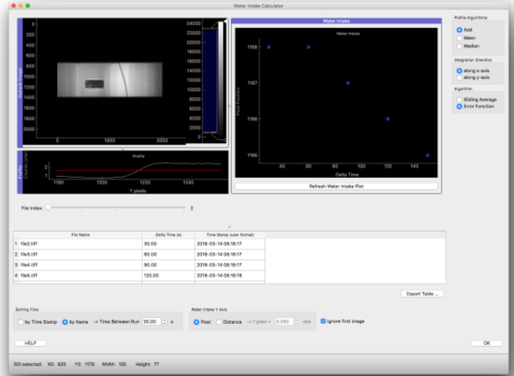
https://www.tiobe.com/tiobe-index/

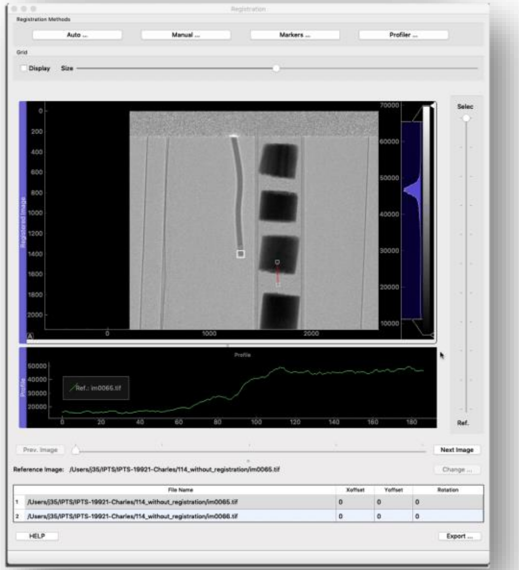
Python

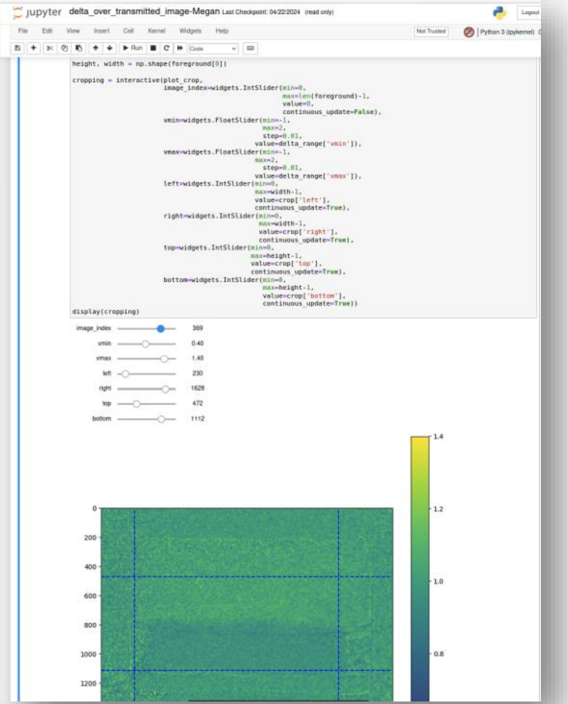
- Huge community (help, libraries, …)
- Easy to learn (no compiler needed)
- Easy to build GUI (standalone application, Web interface)
- Run on any platform (iOS …)
- Notebooks

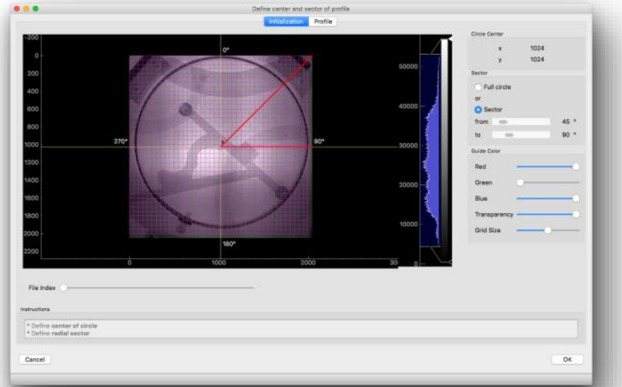
Notebooks

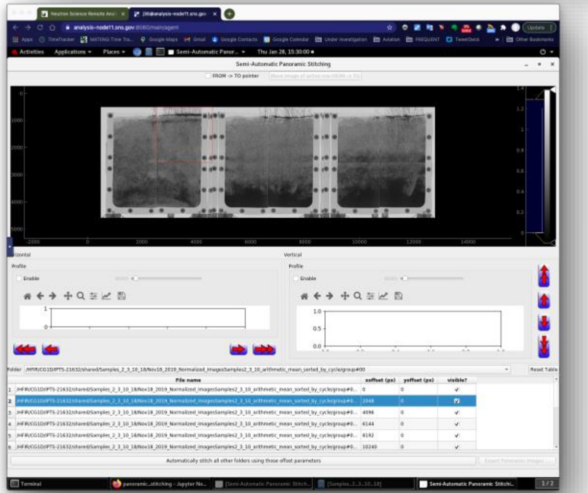

Select Your IPTS
Select Images
Log in to ONCat
Select Metadata to Keep

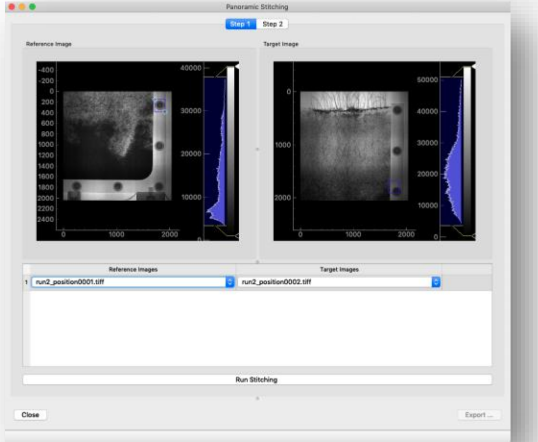


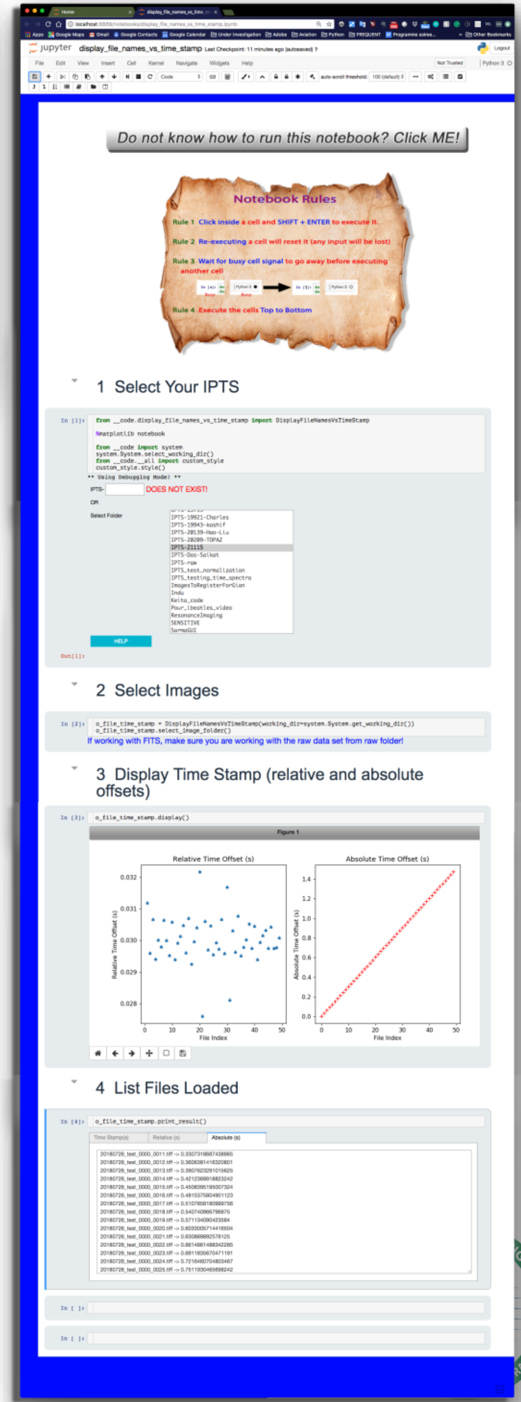



jupyter delta_over_transmitted_image-Megan






Panoramic Stitching
Run Stitching


Do not know how to run this notebook? Click ME!
Notebook Rules
1 Select Your IPTS
2 Select Images
3 Display Time Stamp (relative and absolute offsets)
4 List Files Loaded

The 5 things that will save your life

1 Pick the right language

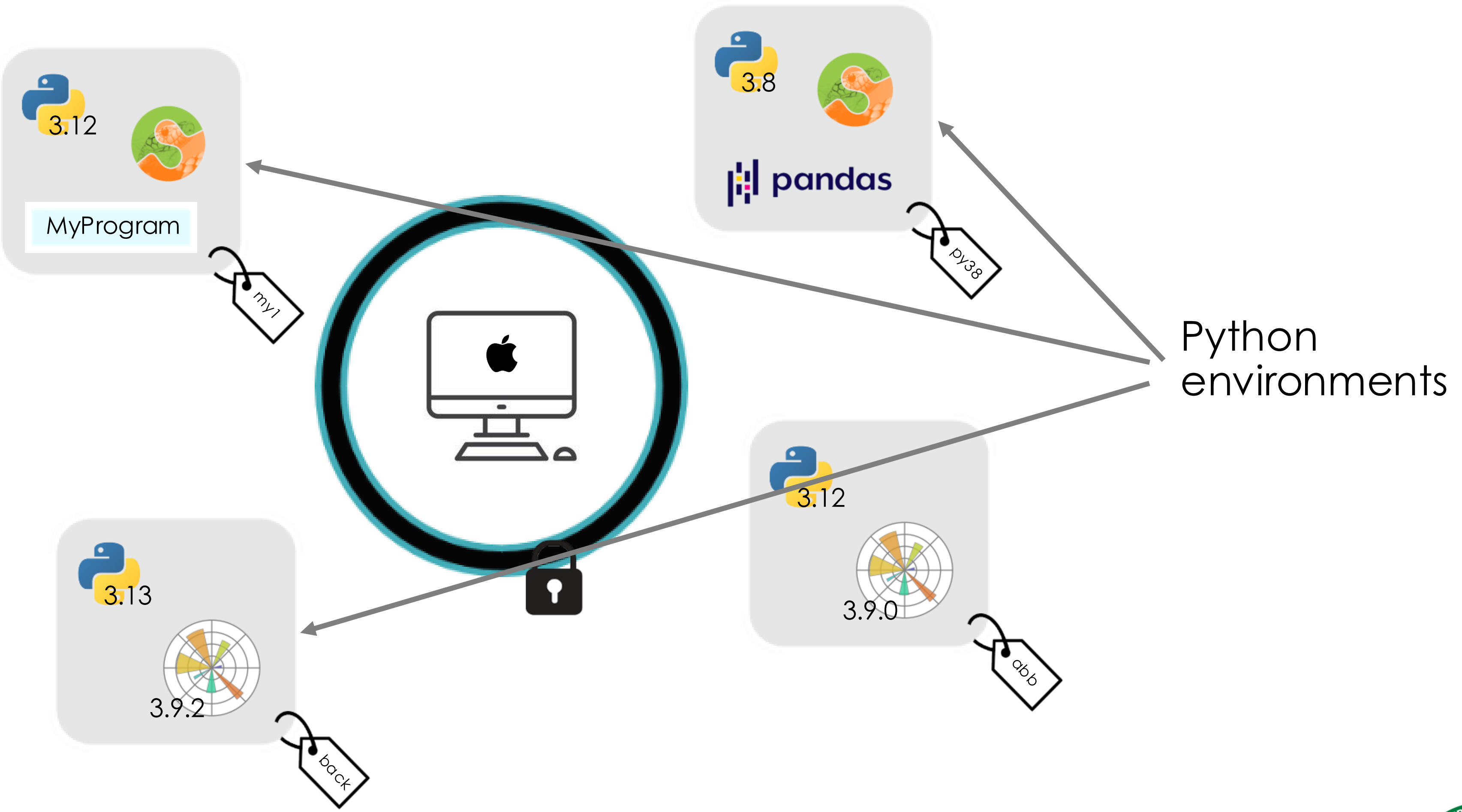
2 **Stay green**

Stay green

We need to preserve our **environment!**

~~Anaconda.com~~

Micromamba
pixi



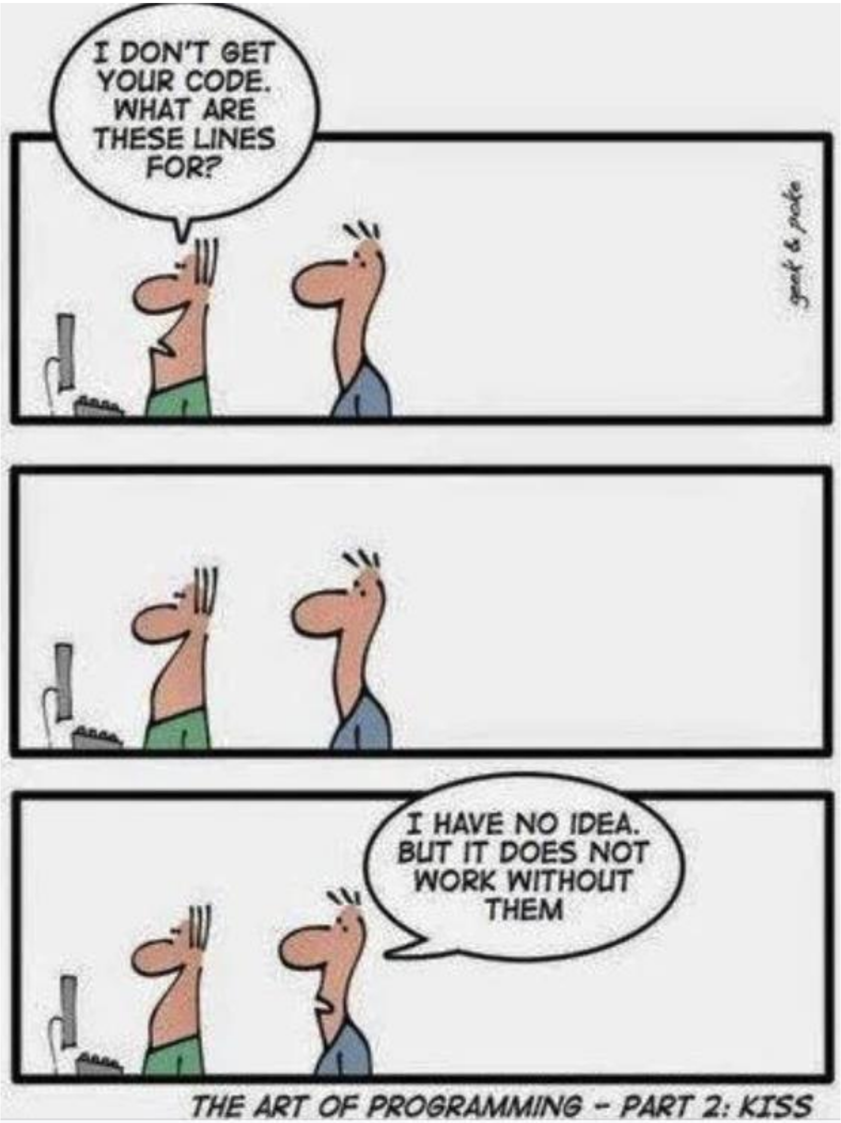
The 5 things that will save your life

1 Pick the right language

2 Stay green

3 **Write good code**

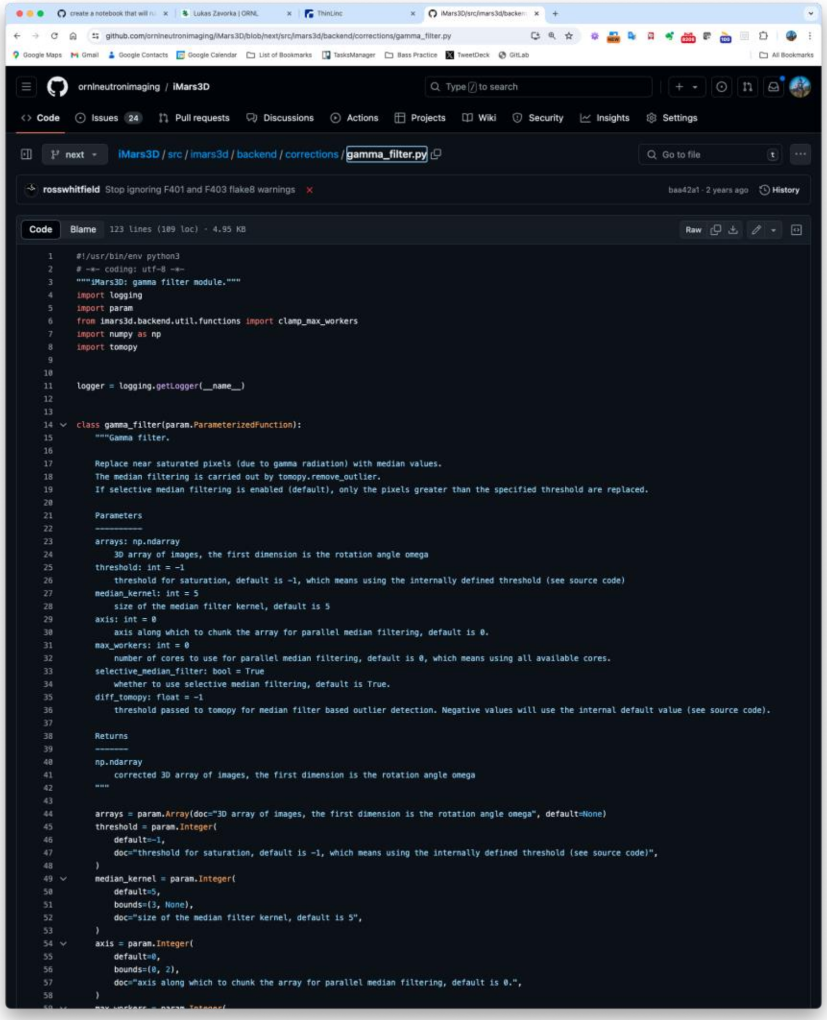
Write good code

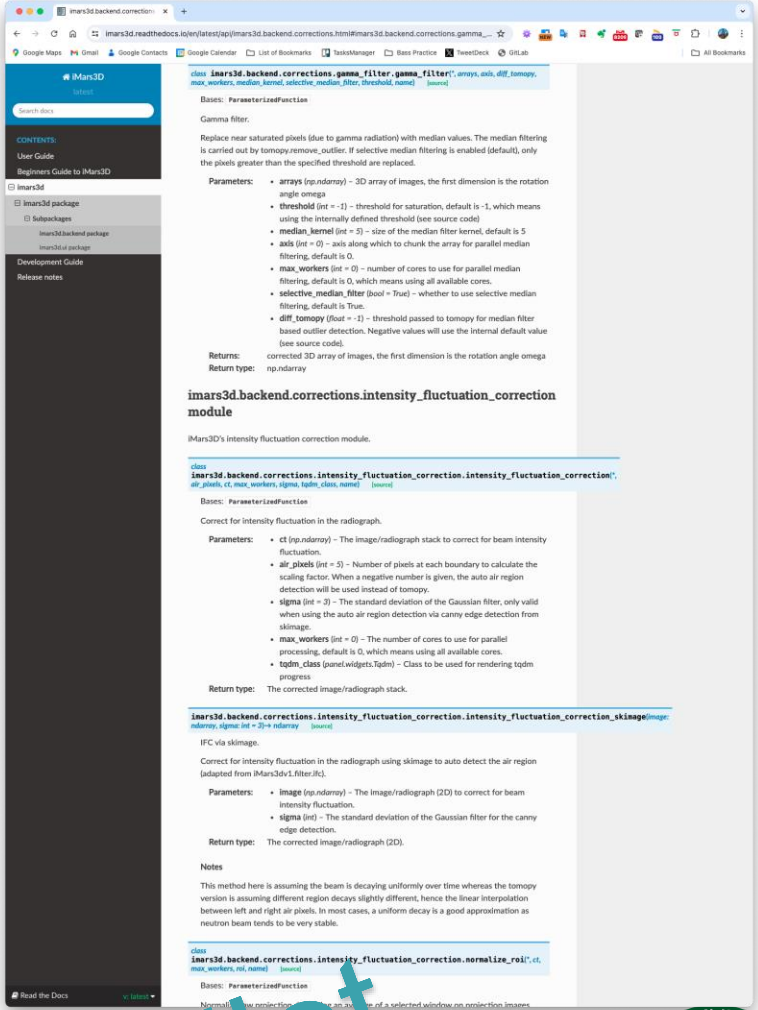


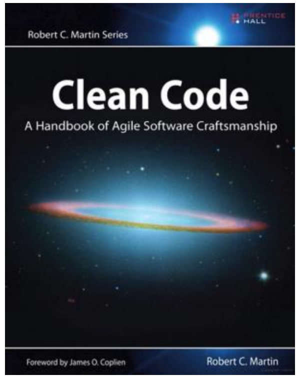
There is a good chance that later, you will be the one trying to understand your own code.

Write good code

- Name of variable is what they represent
- Name of method indicates what they do
- Explain strange choices
- Add examples at top of methods/classes







copilot

https://www.youtube.com/results?search_query=clean+code+uncle+bob

Write good code

Unit Test

Workflow

- decide the code to write
- Write the test
- It should fail
- Write the code to pass the test
- It should pass
- Move on to the nex

If a code doest not have unit tests,

it's broken !

Advantages

- The unit tests are often used as documentation to learn how the software works
- You write better code (simpler)
- People will trust your code
- You can check the unit test coverage
- ke changes, you will quickly till works
- If someone report a bug, first write a unit test to reproduce the bug, then fix it!

copilot

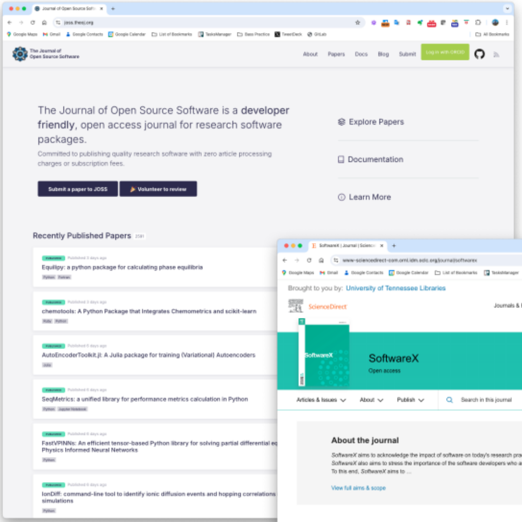
Disadvantages

- It seems slower to code (but overall, it's not)

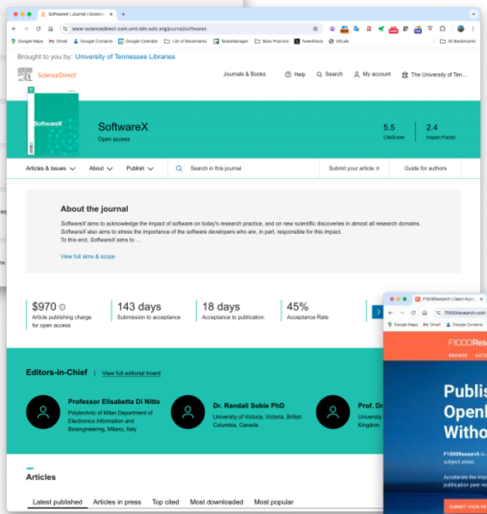
Write good code

- [x] Code
- [x] Unit tests
- [x] Documentation
- [ ] License file
- [ ] Future work file

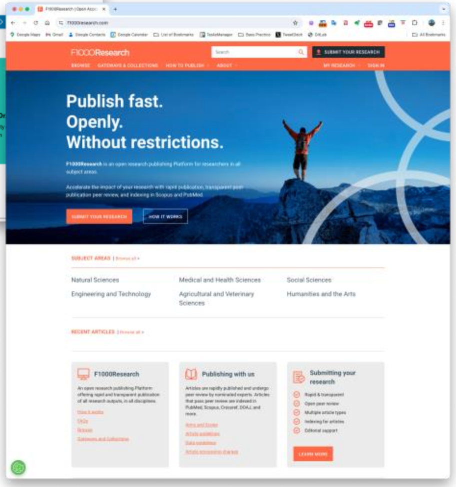
…



JOSS



Software X



F1000Research

DOI

Getting a publication out of your software !

The 5 things that will save your life

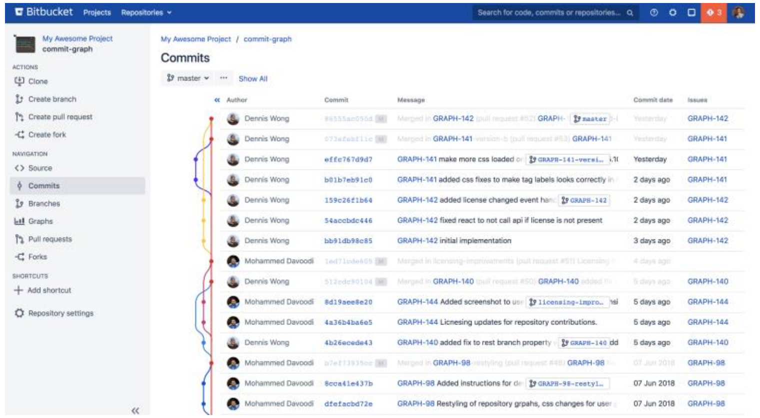
1 Pick the right language

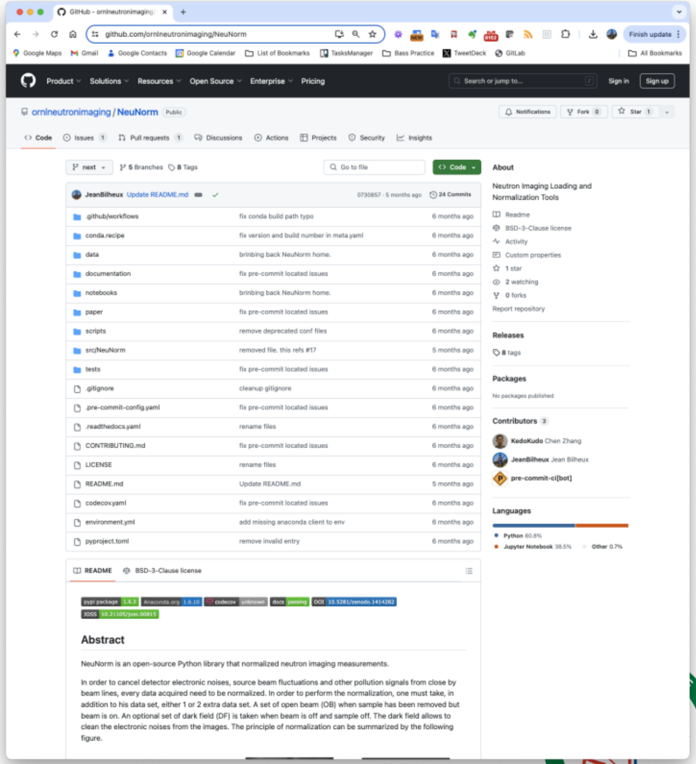
2 Stay green

3 Write good code

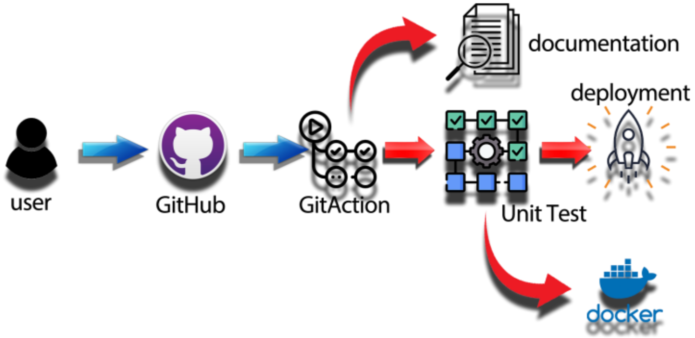
4 **How to keep your job!**

Repositories





- Backup of your project
- Provide a full history (easy to reverse changes, …)
- Ideal for collaboration (parallel work, …)
- Documentation
- Necessary tool for publication of the code
- Easy to share code (web interface, …)
- GitAction (automatic test, deployment, build documentation ….)



The 5 things that will save your life

1 Pick the right language

2 Stay green

3 Write good code

4 How to keep your job!

5 **Use the best debugging tool**

Best debugging tool

Each of you will leave today with that tool!

- Any OS
- Any computing language
- It takes no time to learn how to use it
- It automatically works with any software version you are trying to debug.
- It has a very small carbon footprint
- 99% accurate

Best debugging tool

- Tell your new friend what your program does, and you will find what is wrong with it !

The Yellow Duck

The 5 things that will save your life

1 Python

2 use environments

3 Good naming & unit tests

4 Repository

5 Talk to your yellow duck

Acknowledgements

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Resources at the **High Flux Isotope Reactor (HFIR)** and **Spallation Neutron source (SNS)**, U.S. DOE Office of Science User Facilities operated by ORNL, were used in the research.

References

- python
- Jupyter notebooks
- Micromamba
- Pixi

- Wants to know more about the Neutron Imaging Notebooks: neutronimaging.ornl.gov https://forms.office.com/g/gtdnJGM87r

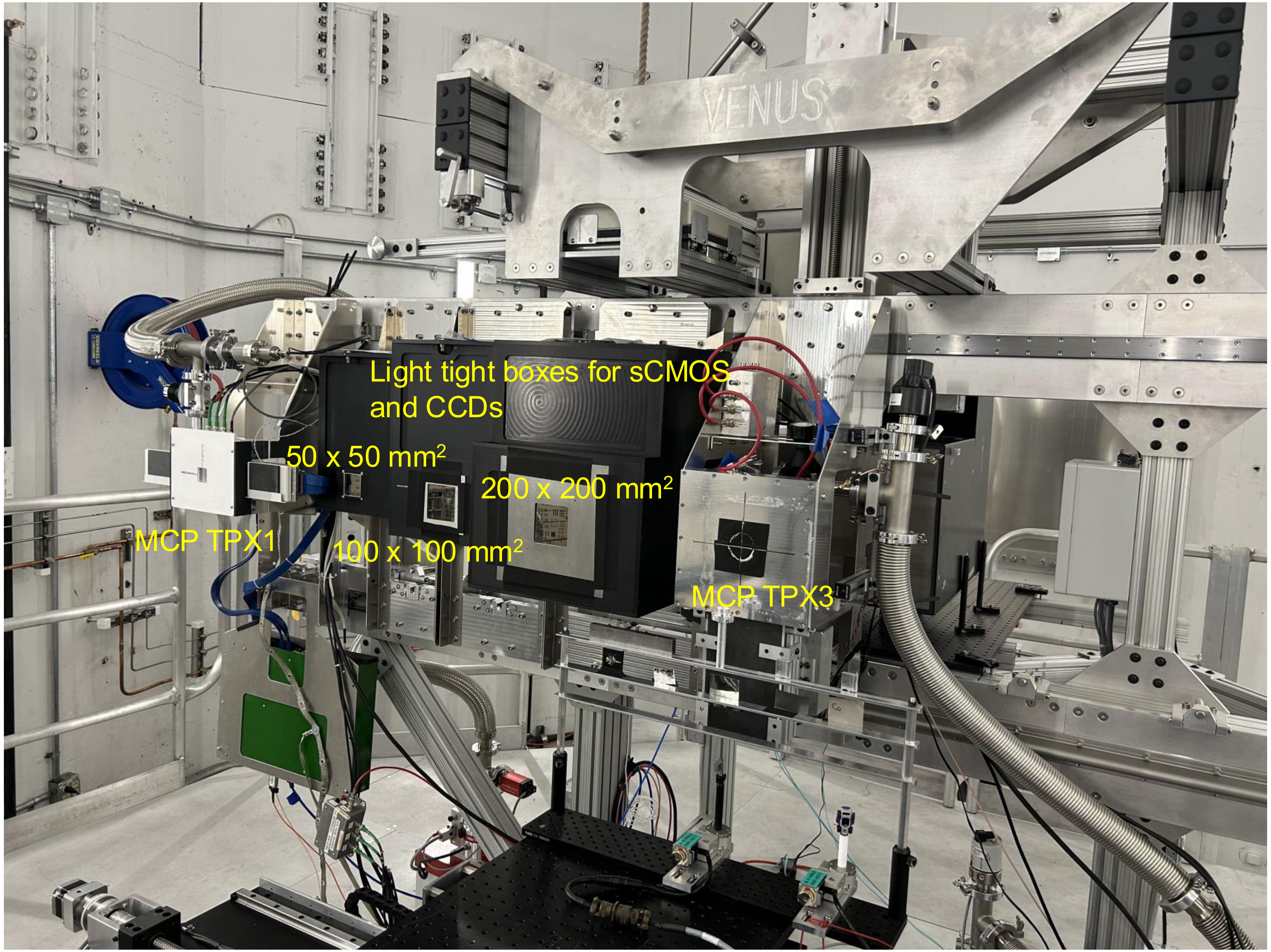
Thank you

Questions

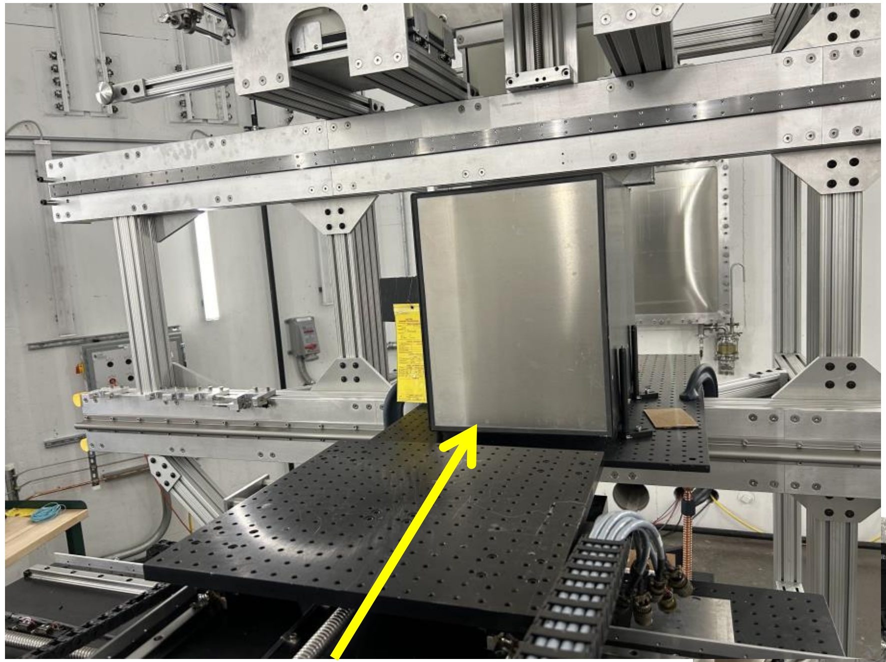
ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Large sample and sample environment area inside the VENUS cav

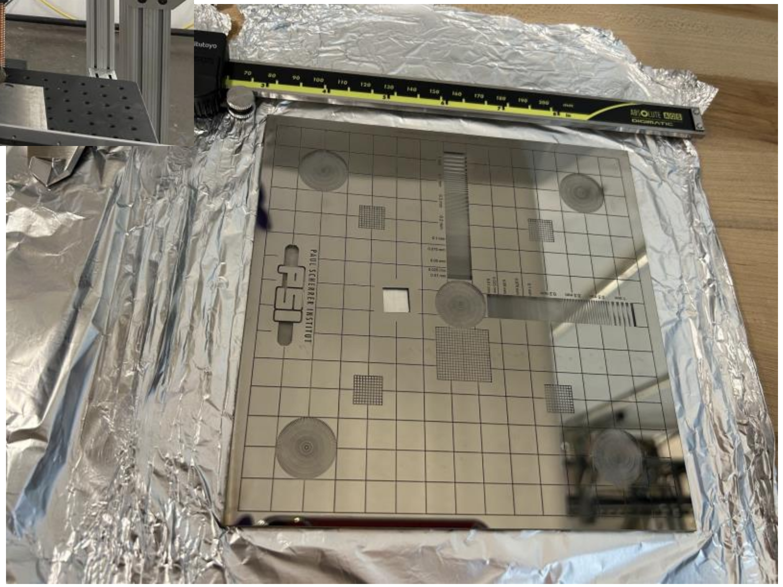
View of all VENUS detectors



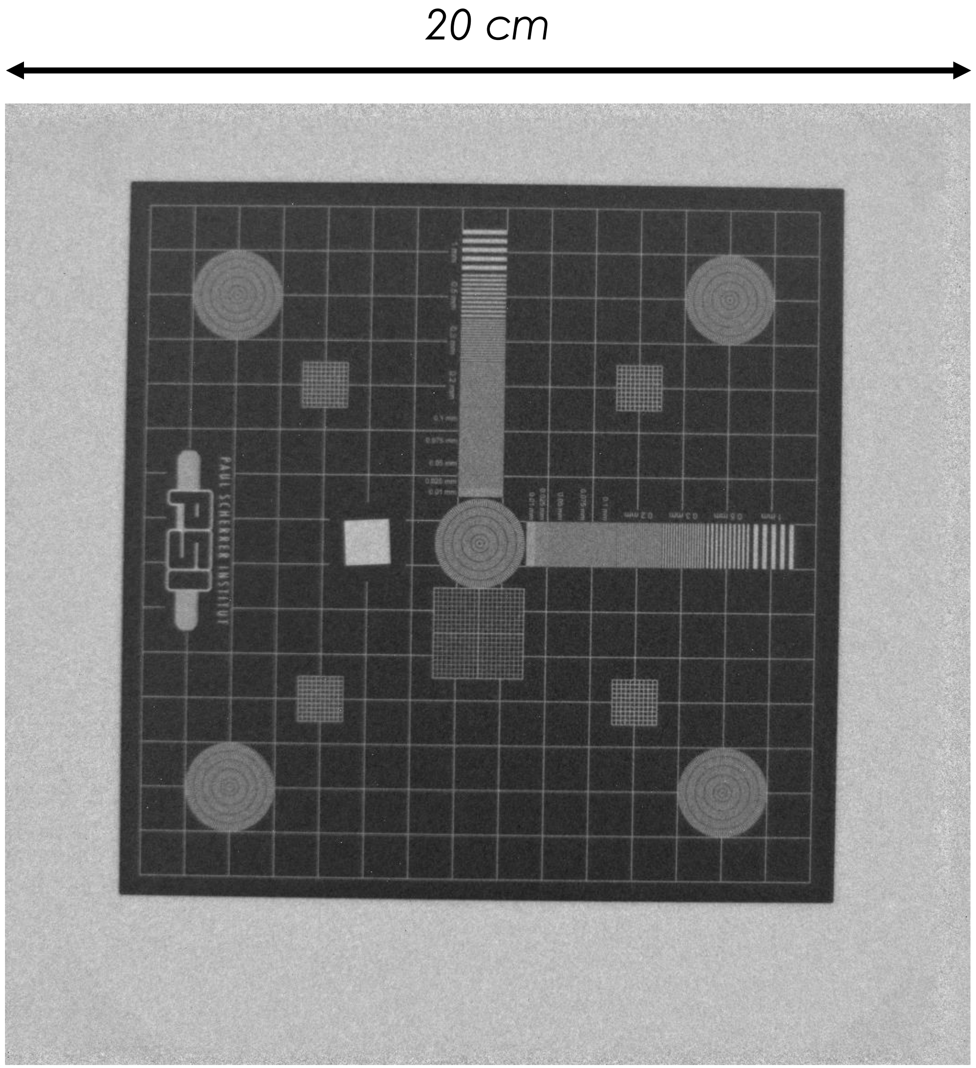
Largest field of view: 20 x 20 cm^2



Imaging detector at VENUS



Spatial resolution mask



First 20x20 cm^2 large field-of-view radiograph measured at VENUS (July 24, 2024)!!!