OAK RIDGE National Laboratory

Imaging with Neutrons

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NEUTRON IMAGING OAK RIDGE NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

The Neutron Imaging Team for the General User

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HFIR MARS Scientist

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Intelligence, Machine
Learning, Hyperspectral
Imaging

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Associate (SA)

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Imaging SA

Harley Skorpenske,
SNS Group Leader

Hassina Bilheux,
SNS VENUS Scientist

Outline

- Imaging at the High Flux Isotope Reactor MARS beamline:
  - Principle of neutron radiography and computed tomography at a continuous source
  - The CG-1D imaging beamline
  - Examples

Yuxuan

- Imaging at the Spallation Neutron Source:
  - Principle of neutron radiography at a pulsed source
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~~– The~~ VENUS !!!~~construction project~~

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- Scientific programming

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Hassina

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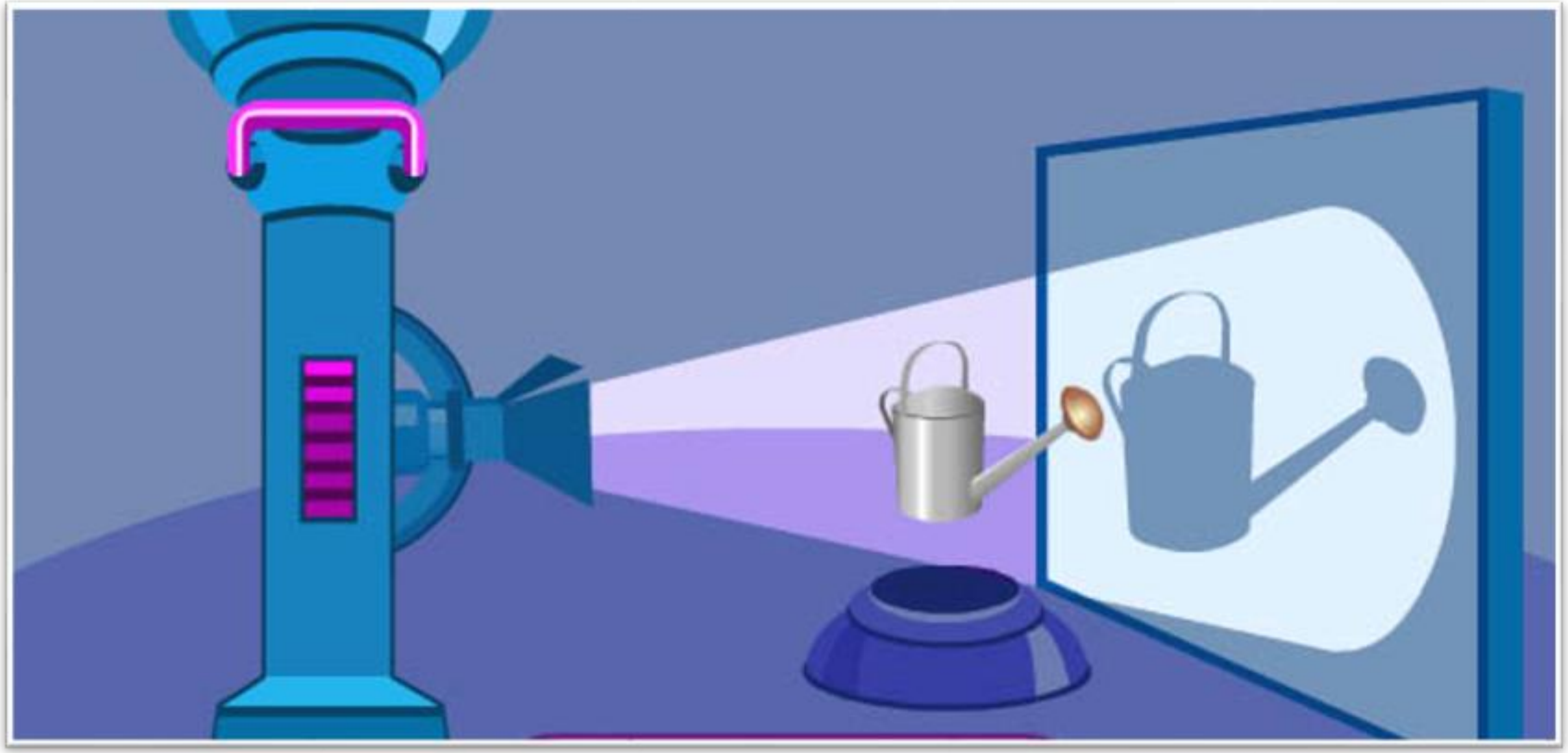
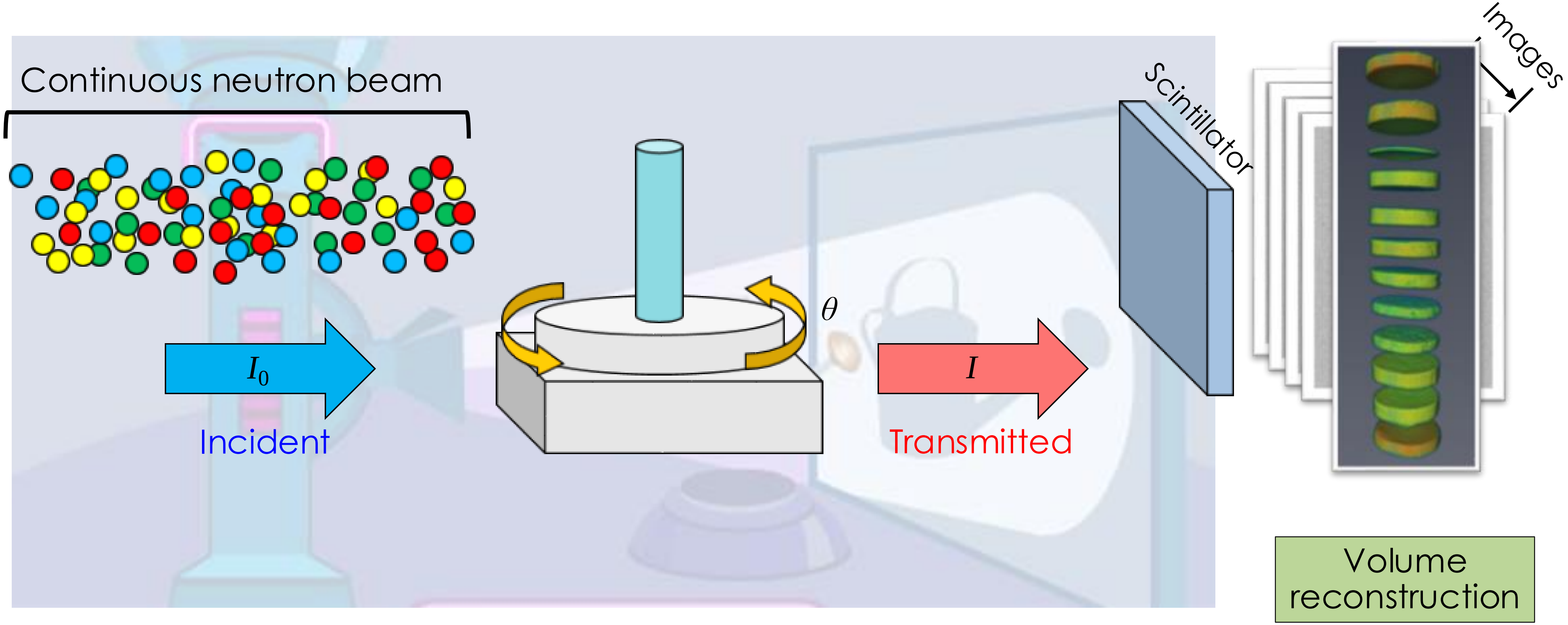
Neutron imaging measures the transmitted neutrons though an object



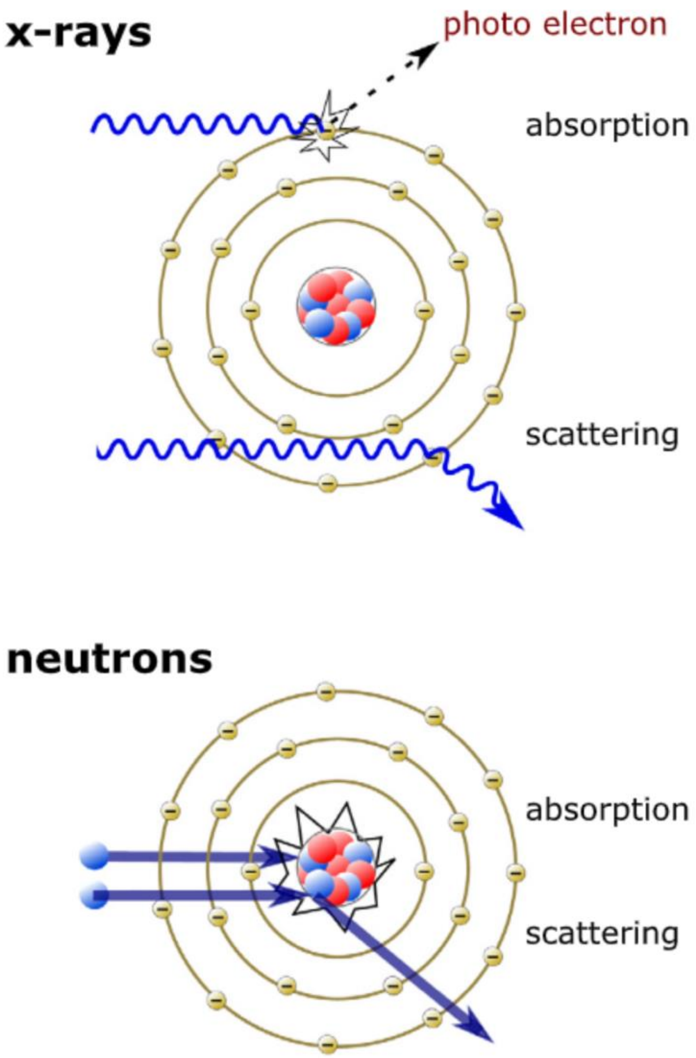
Source **Object** **Detector**

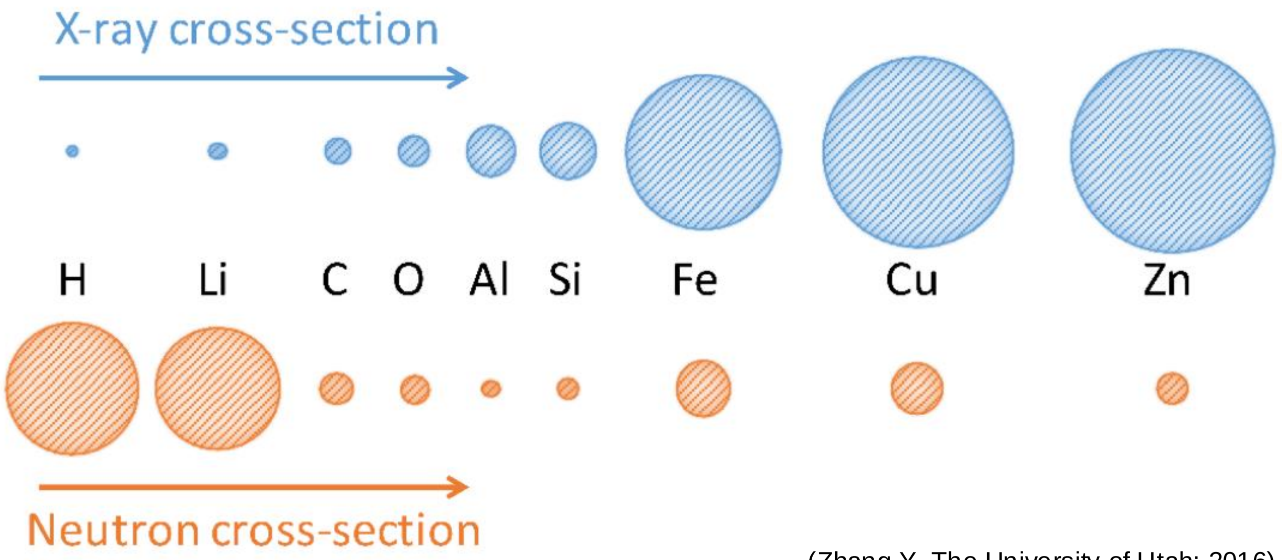
(Figure source: aven.amritalearning.com,. (2013). Shadows and Pin Hole Camera.)

Transmitted neutrons recorded as image/images



Neutrons interact uniquely with matter



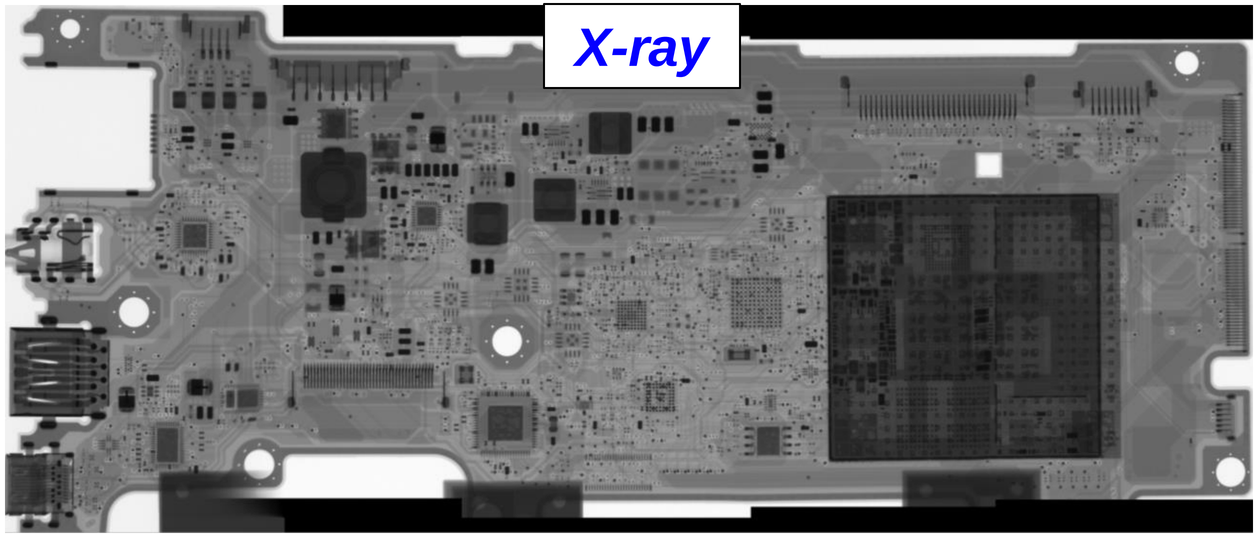


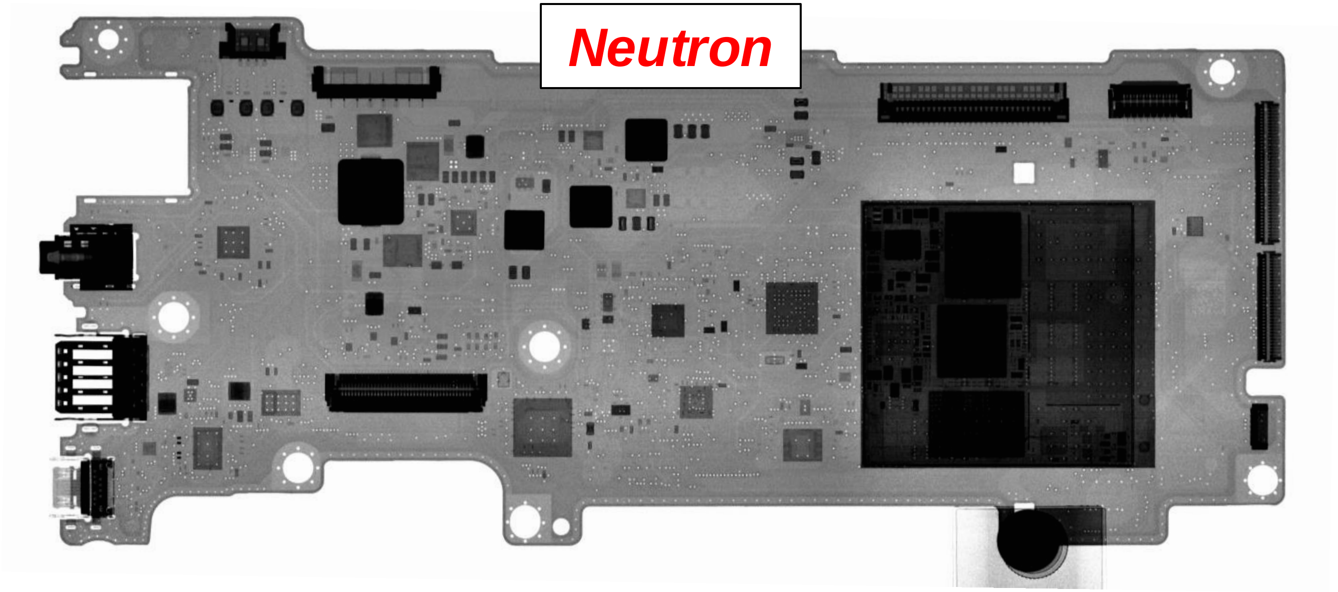
(Zhang Y. The University of Utah; 2016)

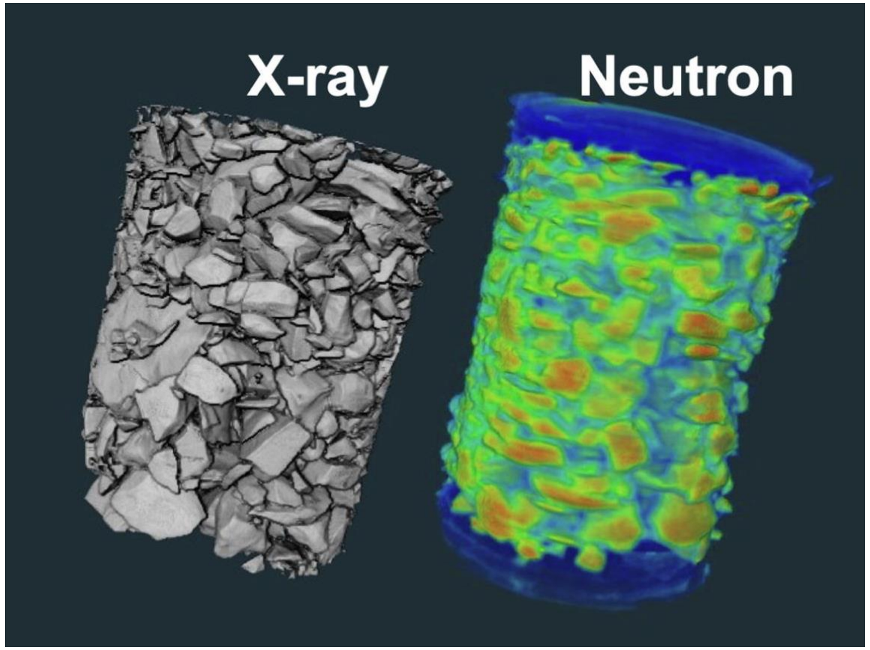
- **Non-destructive**
- **High penetration through metals**
- **Sensitive to light elements (H, Li, etc.)**
- **Isotopic contrast**

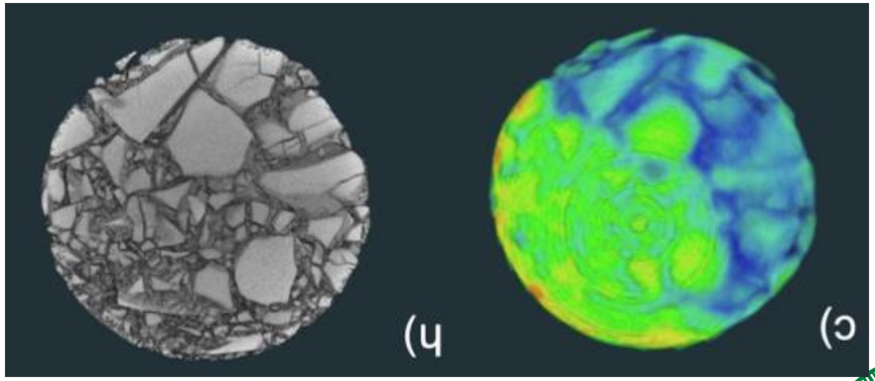
A. Tengattini, et al. Geomechanics for Energy and the Environment 27 (2021)

Neutrons interact uniquely with matter (cont'd)





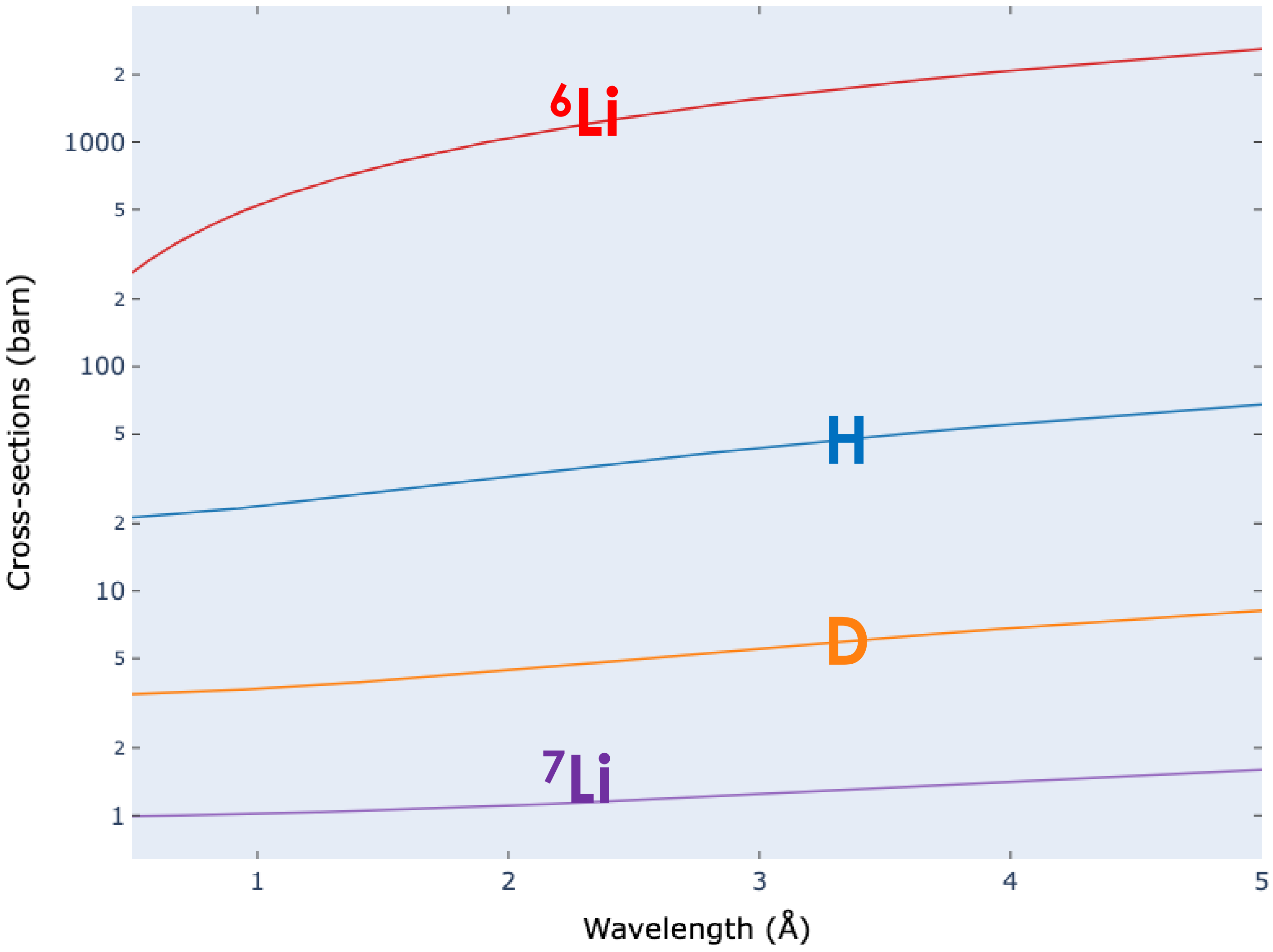




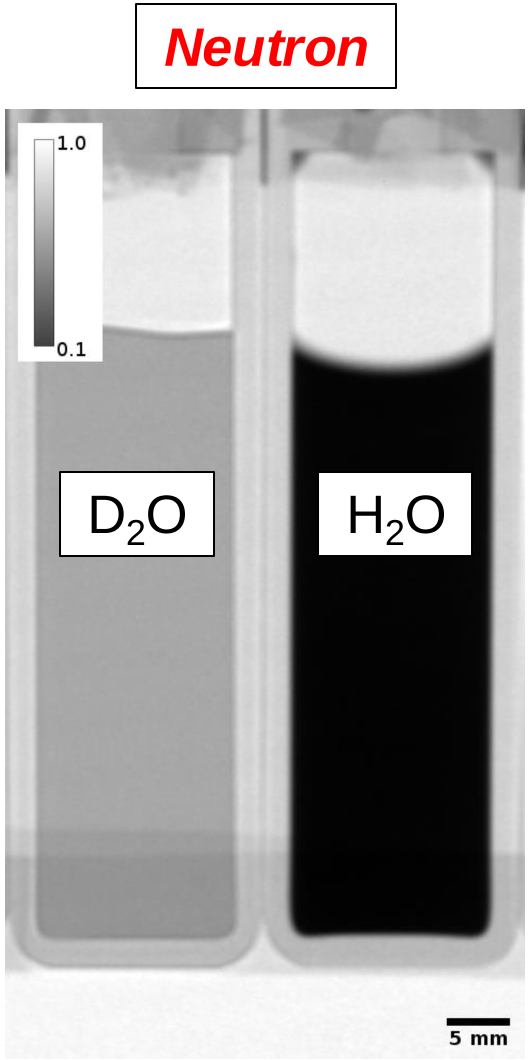
IPTS-33592, Y. Zhang, 2024

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

Neutrons interact uniquely with matter (cont'd)

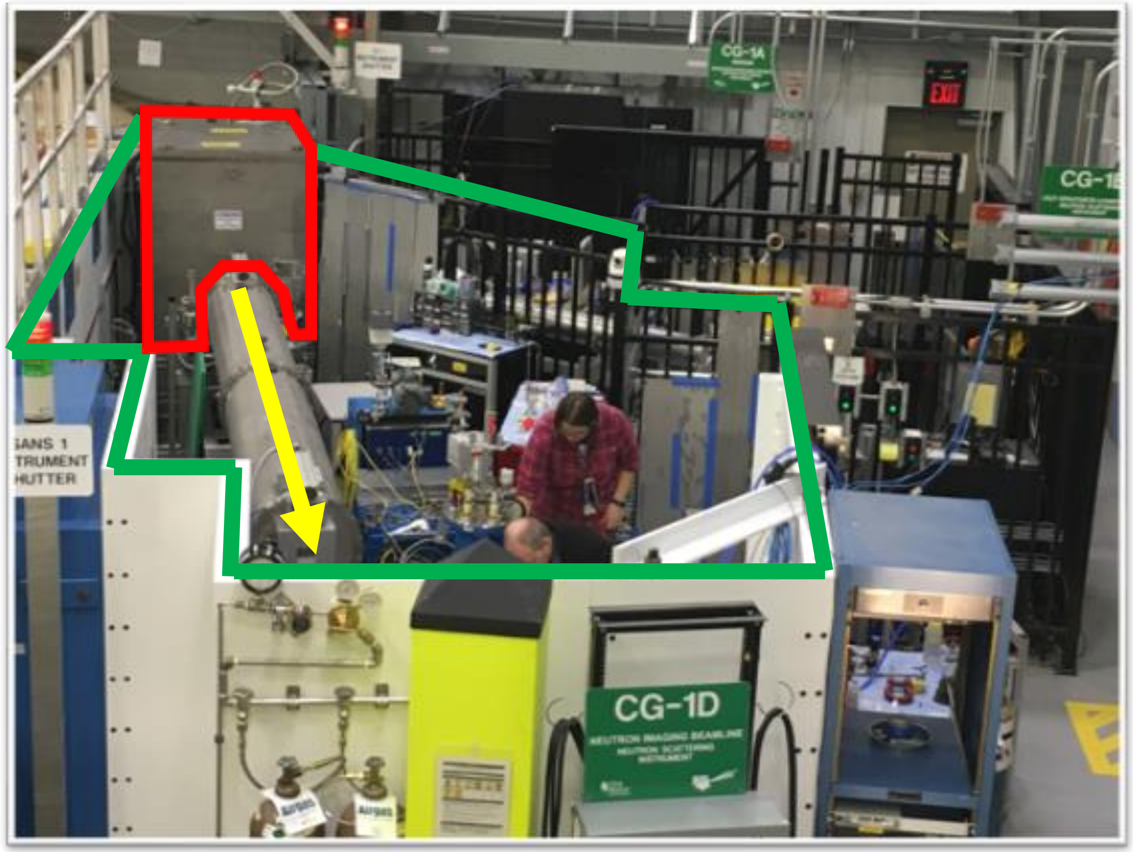


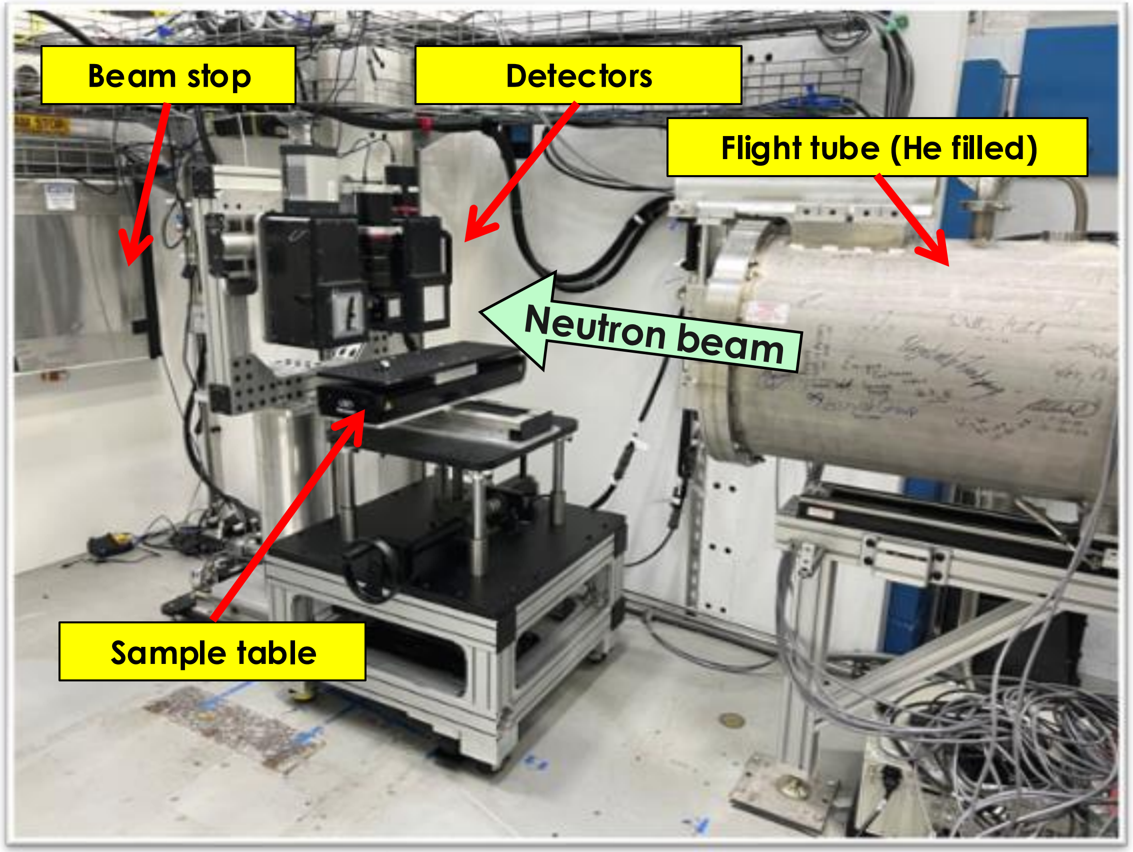
https://neuit.ornl.gov/



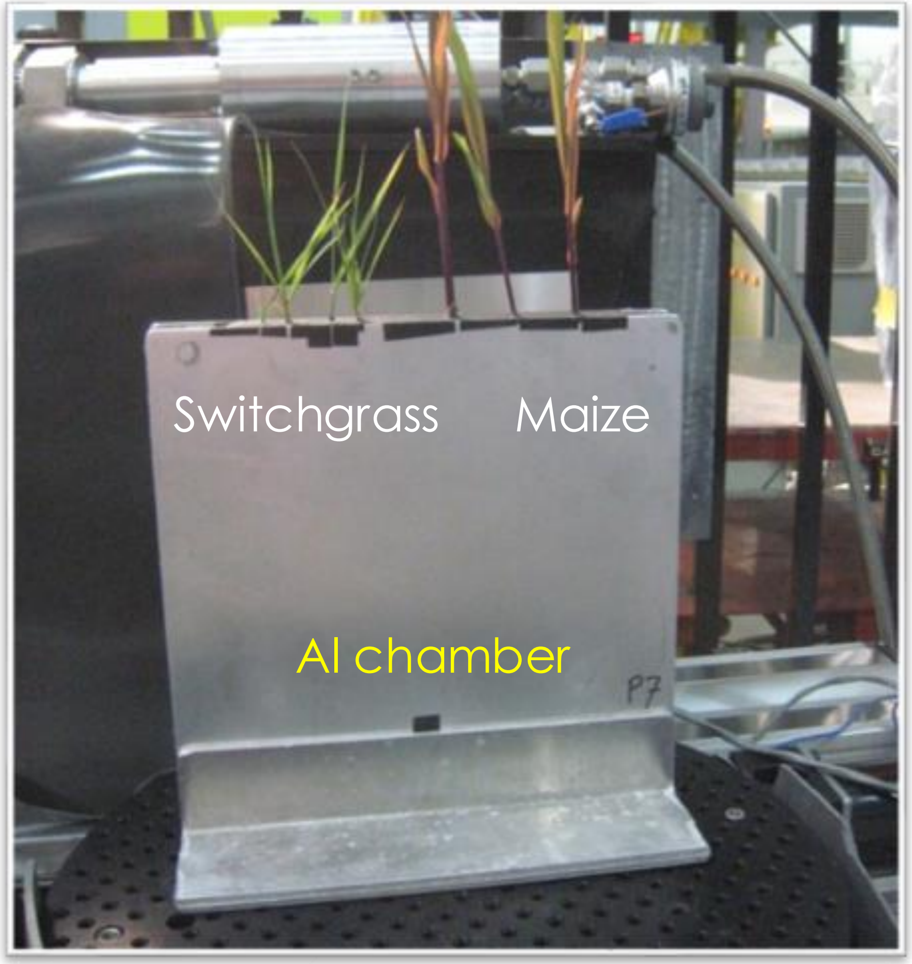
IPTS-26032, Y. Zhang, 2022

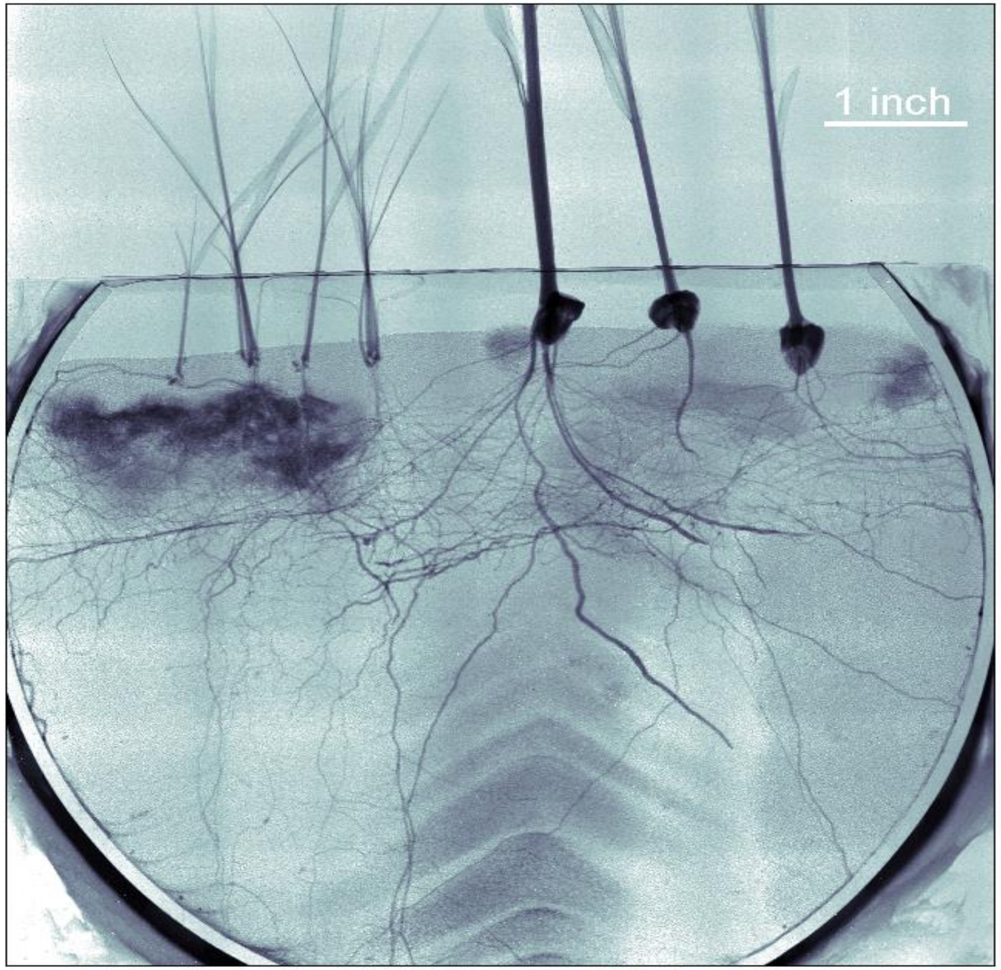
The MARS instrument at HFIR





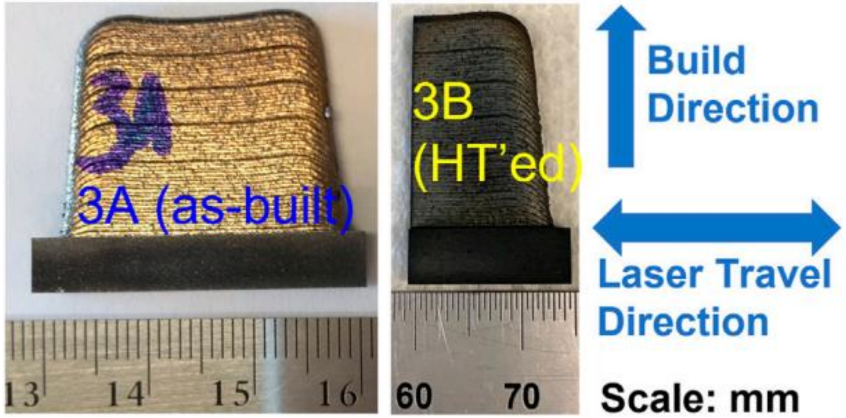
Example: visualize live root system

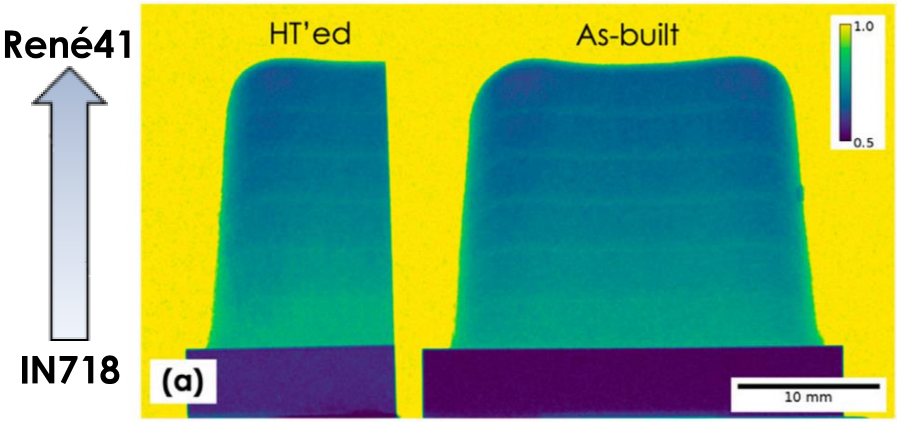




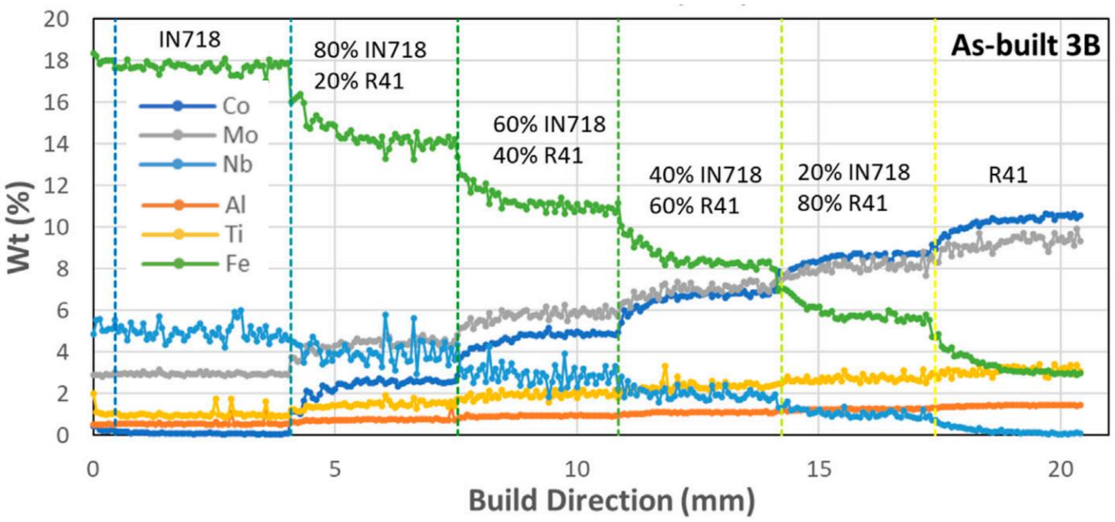
(J. Warren (PI), H, Bilheux, M. Kang, S. Voisin, C. Cheng, J. Horita, E. Perfect, Plant Soil, 2013)

Resolve the composition gradient in graded superalloy

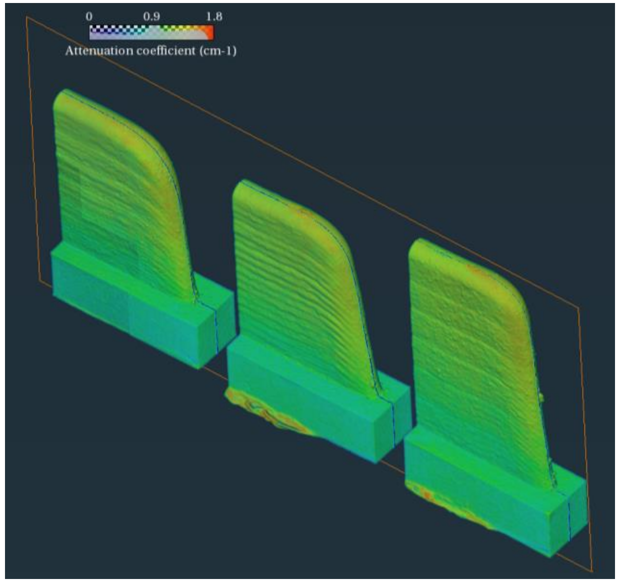




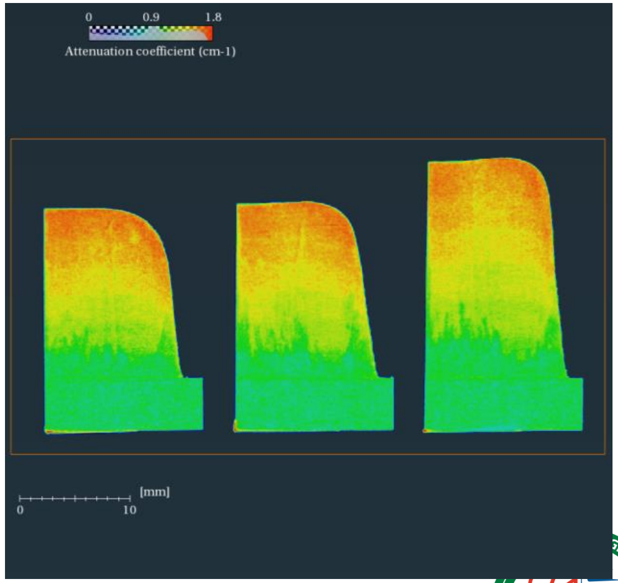
Transmission image



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

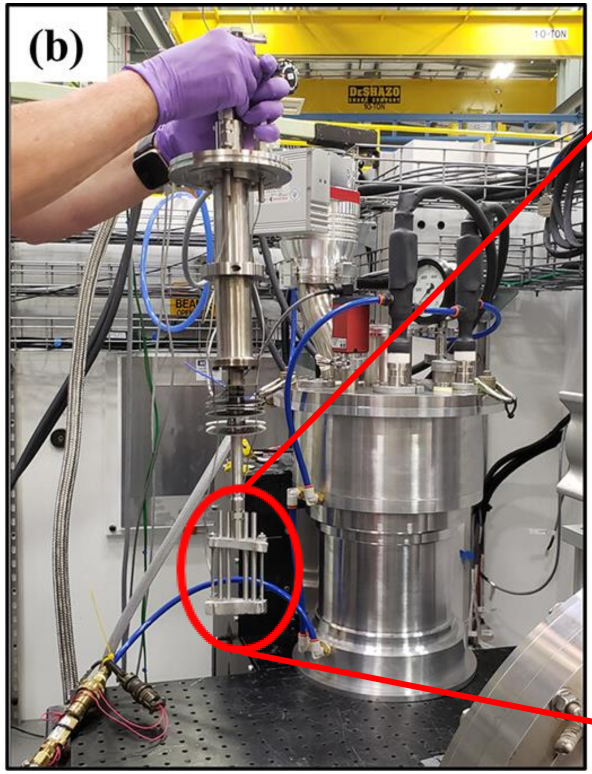


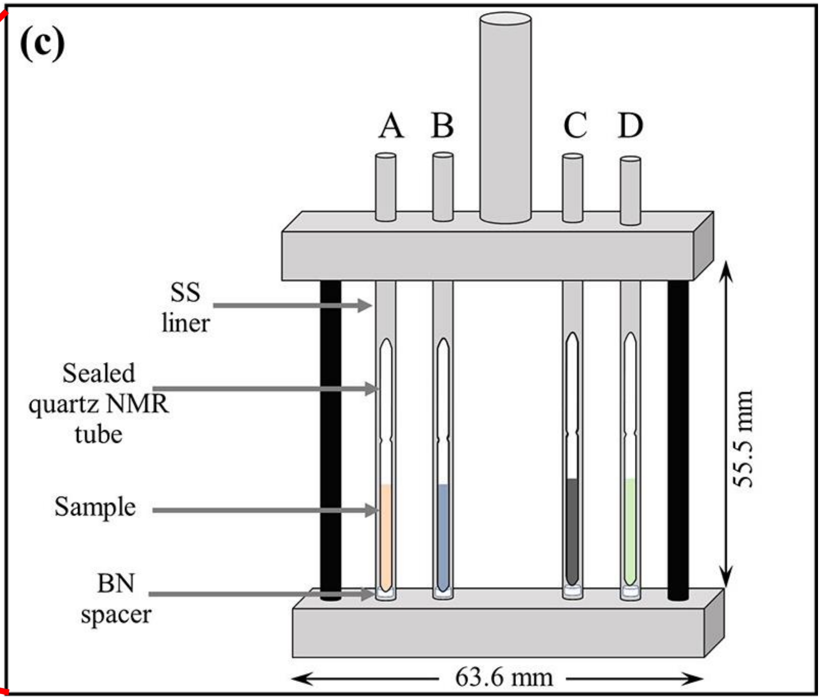
Reconstructed 3D volume (virtual slicing location in orange)

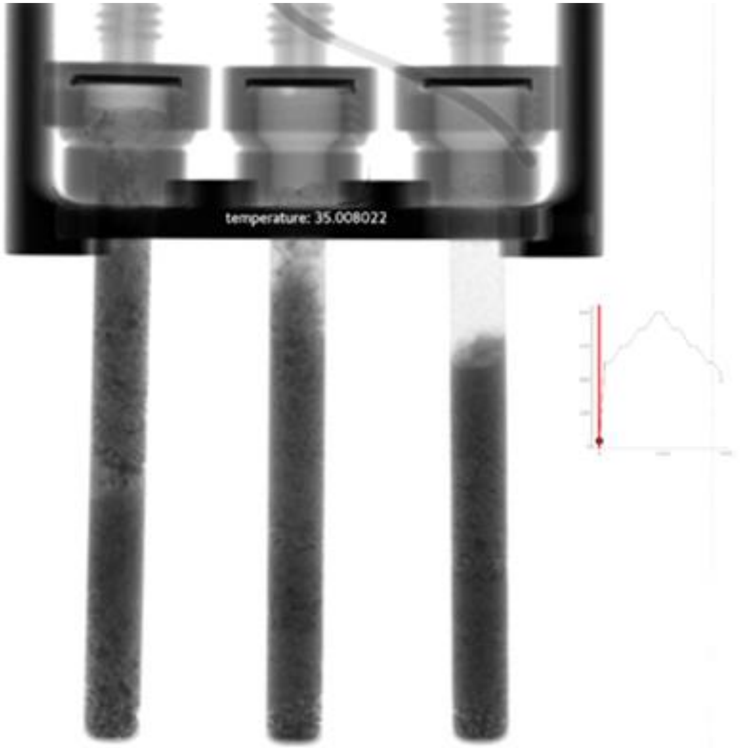


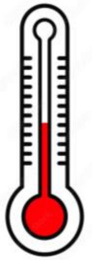
Cross-sectional view after virtually slicing

Measures molten salt densities at MSR operating temperatures





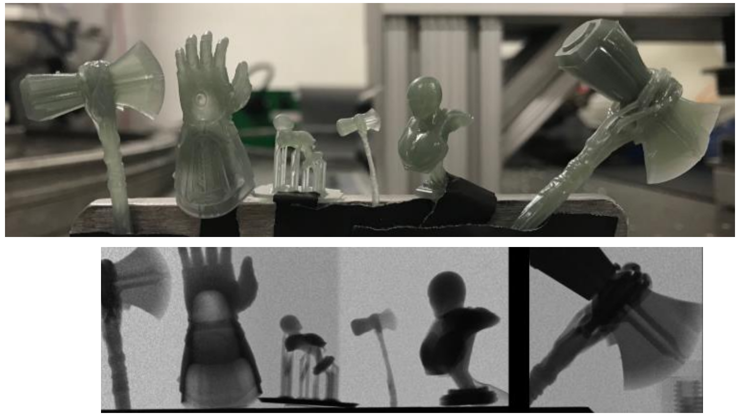




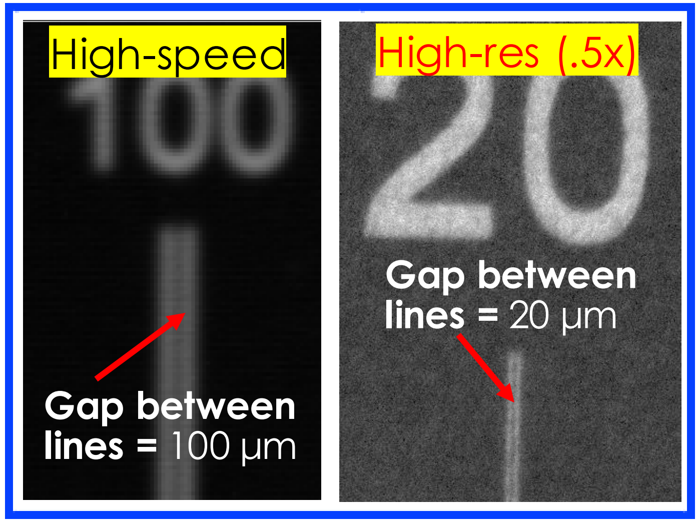
Moon J., Andrews H.B., Agca C., Bilheux J., Braatz A.D., McAlister A., McFarlane J., McMurray J.W., Robb K.R., Zhang Y., ***Industrial & Engineering Chemistry Research***, 61, 17665-17673 (**2022**)

Resolutions and FOVs

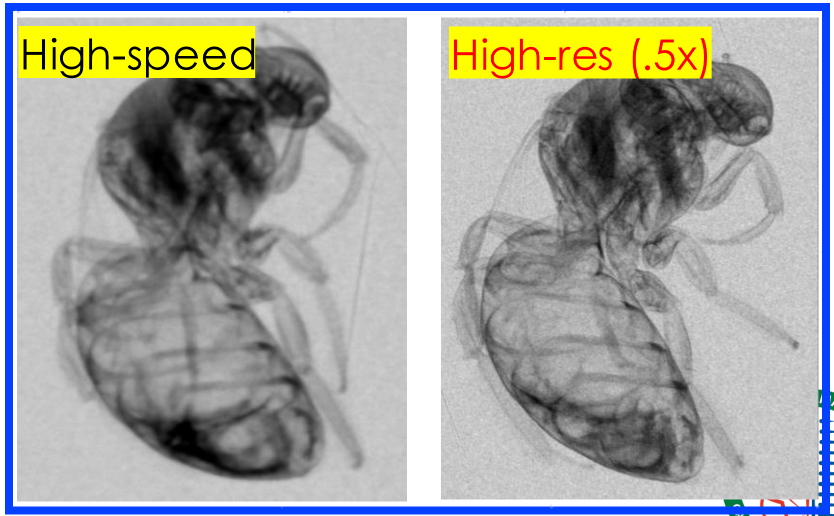
Type of detector	Field-of-view (FOV)	Pixel size (µm)	Highest spatial resolution (µm)	Typical acquisition time of 1 radiograph	Maximum speed @16 bit
High-res (1x)	36 x 24 mm^2	3.8	10-15	900 s	1 image/second
High-res (.5x)	50 x 48 mm^2	7.63	20-25	300 s	1 image/second
High-speed	88 x 88 mm^2	43	~100	—	74 image/second
Balanced	88 x 88 mm^2	16	~50	30-90 s	1 image/second



(Sample credit: George Williams)



IPTS-27734, Y. Zhang, 2022



IPTS-27734, Y. Zhang, 2022

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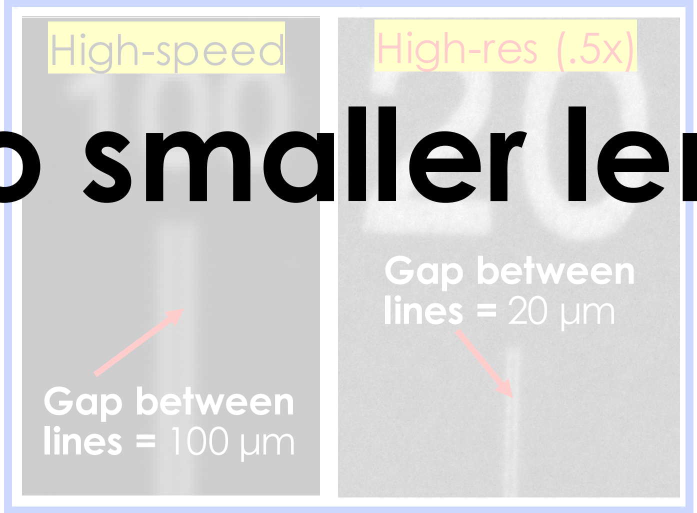
High-speed	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Balanced	88 x 88 mm^2	[illegible]	[illegible]	[illegible]	1 image/second

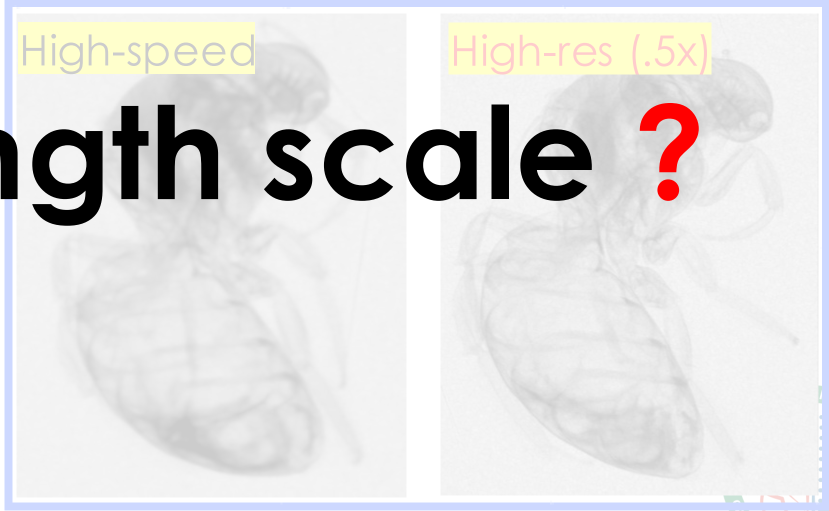
Transmission mode resolves micro features (10-100 μm) in cm sized samples ✓

Go down to smaller length scale ?

(Sample credit: George Williams)



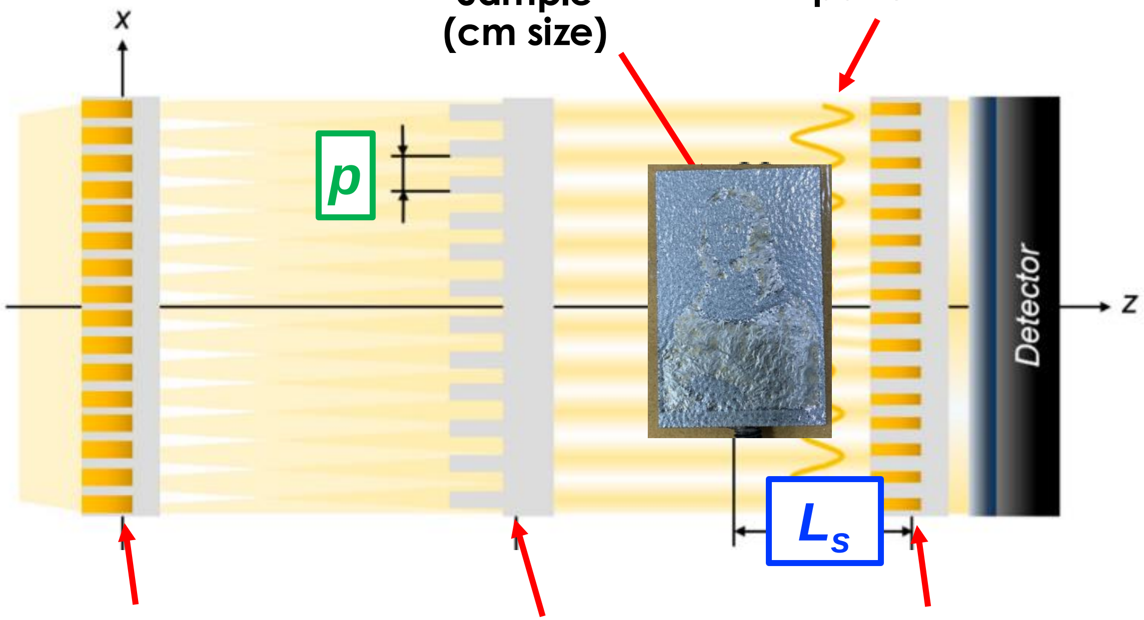
IPTS-27734, Y. Zhang, 2022



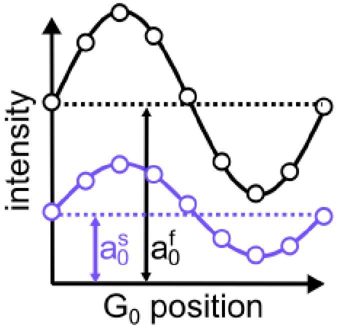
IPTS-27734, Y. Zhang, 2022

What is neutron grating interferometry (**nGI**)?

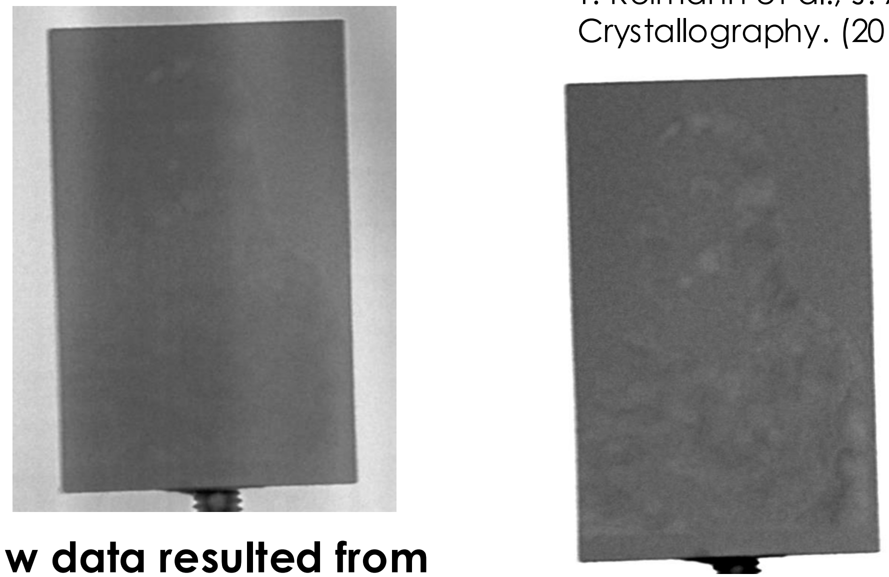
A neutron imaging instrumentation that enable the utilization the **wave properties of neutron**, to spatially resolve sub μm internal features



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



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



Raw data resulted from a step-wise scan

Transmission Image (TI)

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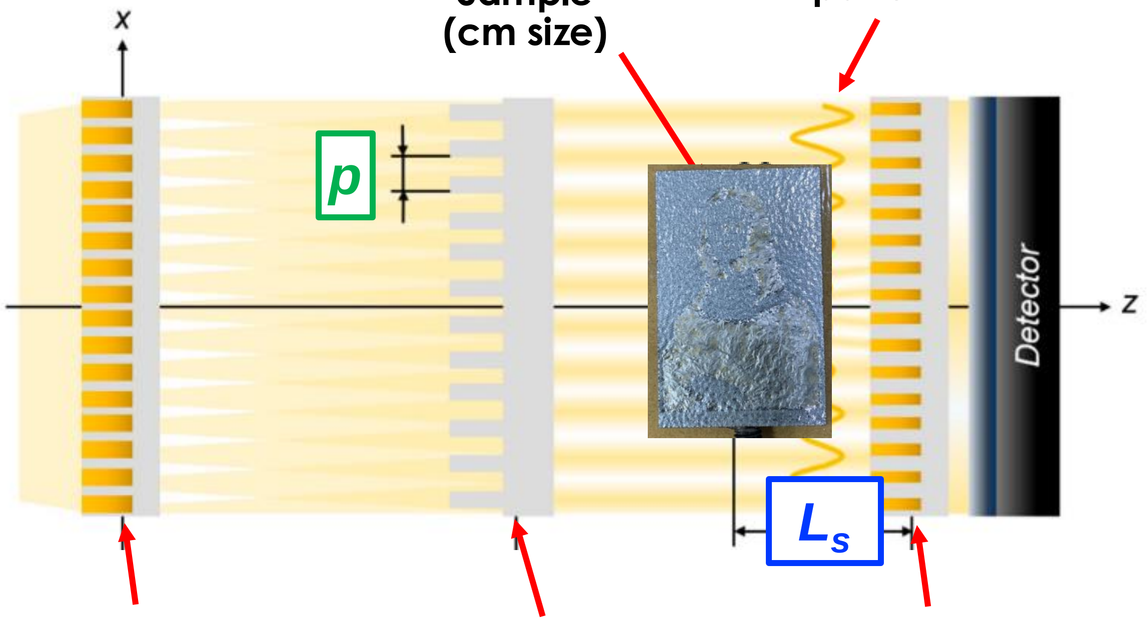

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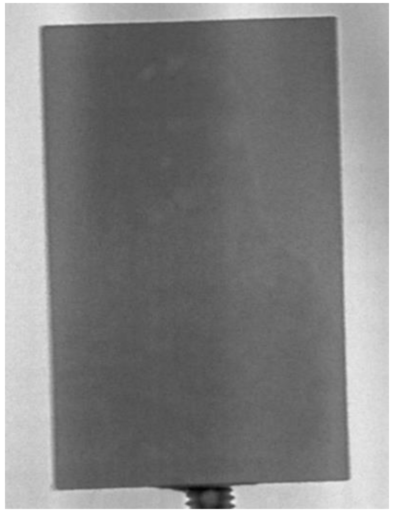
(Sample courtesy of Dr. Chris Fancher)



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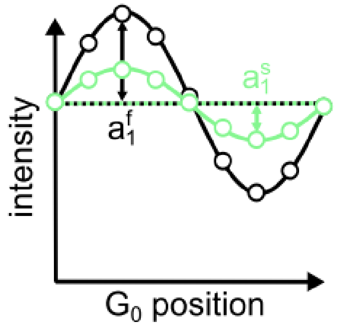
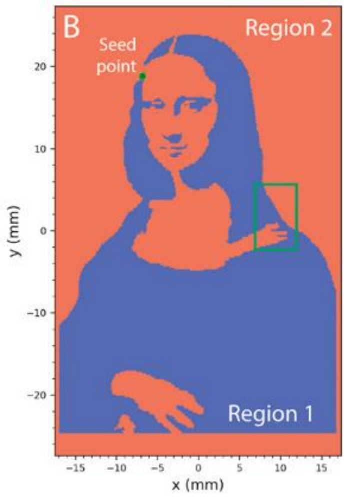


T. Reimann et al., J. Applied Crystallography. (2016)

Dark Field Image (DFI)

More about this sample along with the nGI results

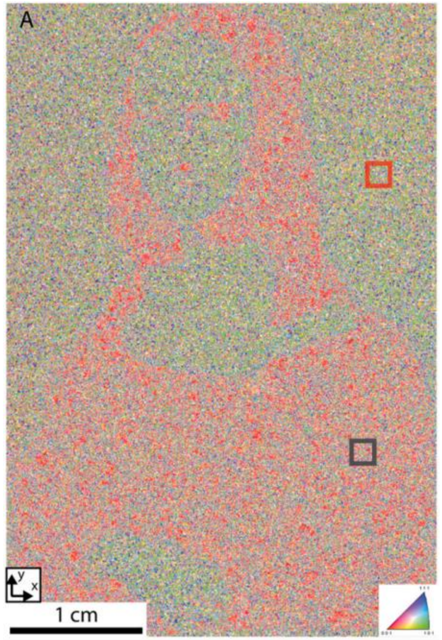
Inconel



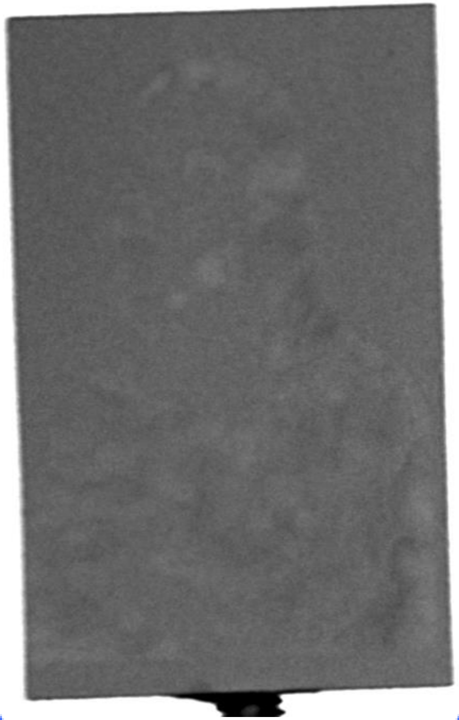
Two different cooling rate regions in an Inconel sample

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).

More about this sample along with the nGI results

Inconel

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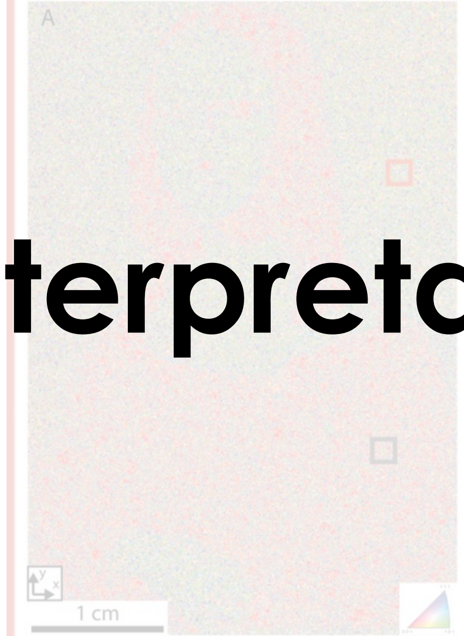


Transmission (TI)

Dark Field (DFI)

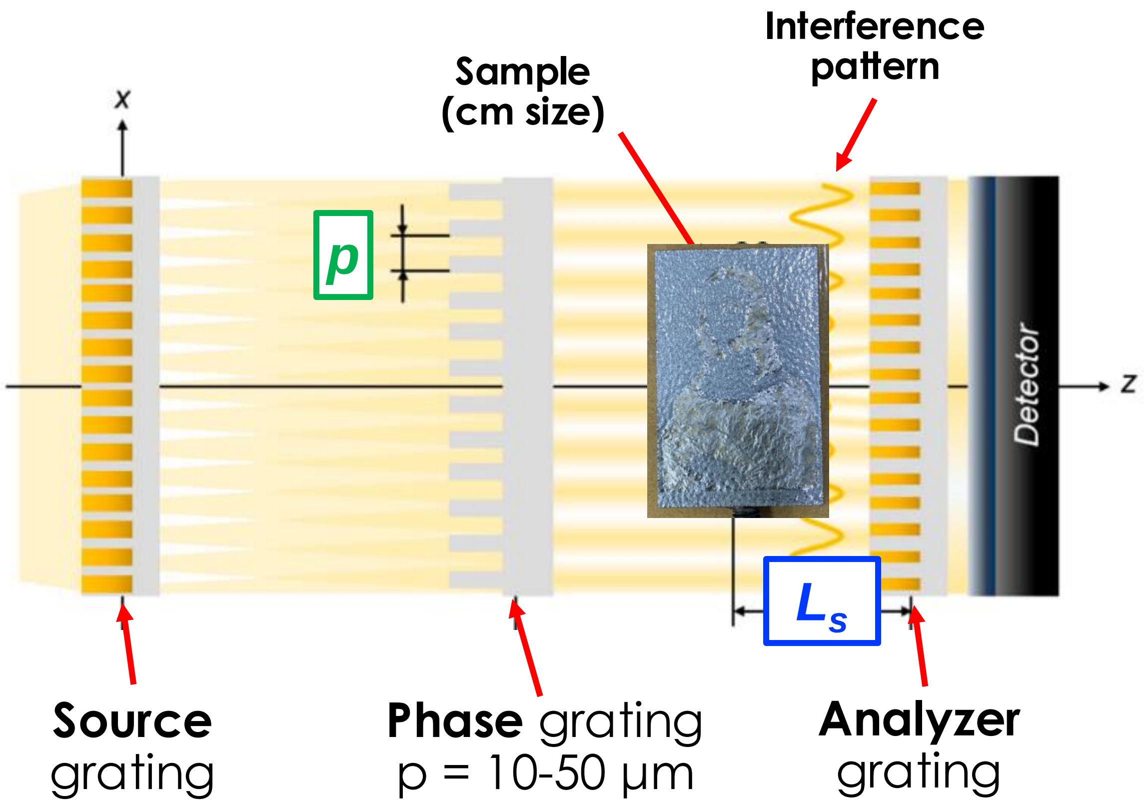
How to interpretate the DFI?

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).

Scan through various correlation lengths to understand the length scale



Y. Kim et al., *Applied Sciences* (2022).

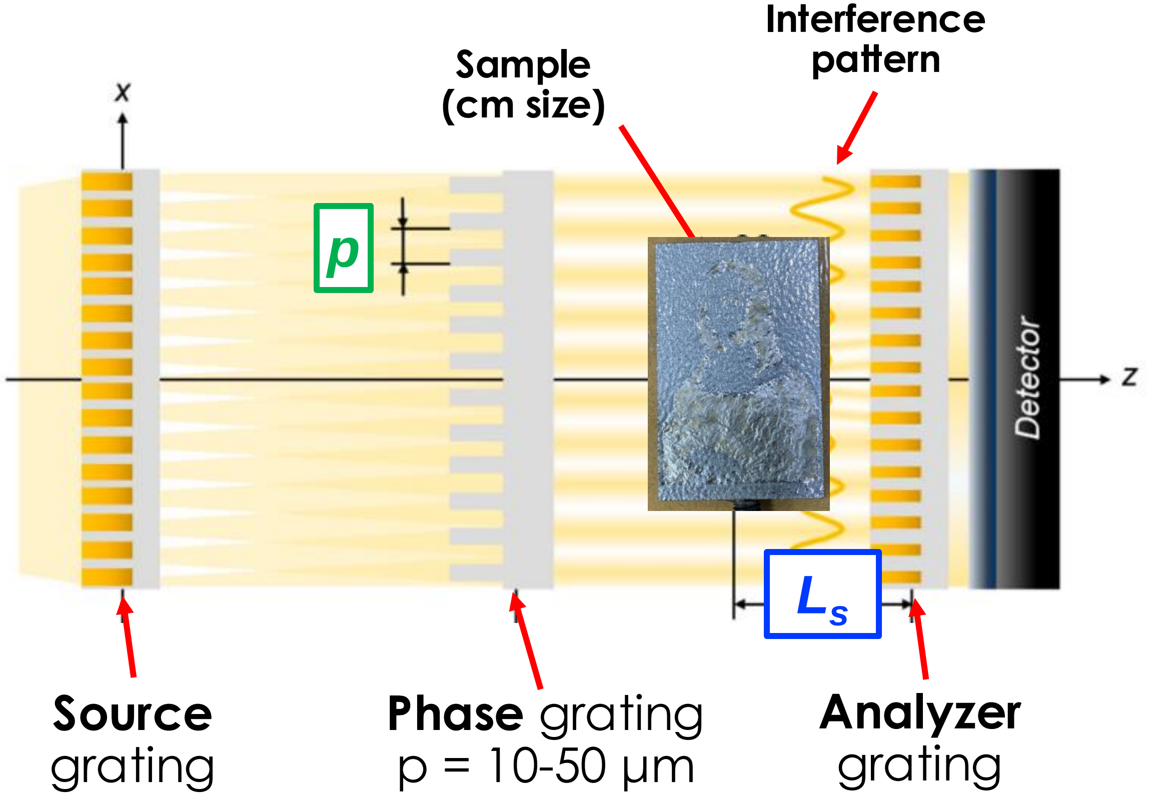
Autocorrelation length

Neutron Wavelength

$$\xi = \lambda L_s / p$$

(Sample courtesy of Dr. Chris Fancher)

Scan through various correlation lengths to understand the length scale



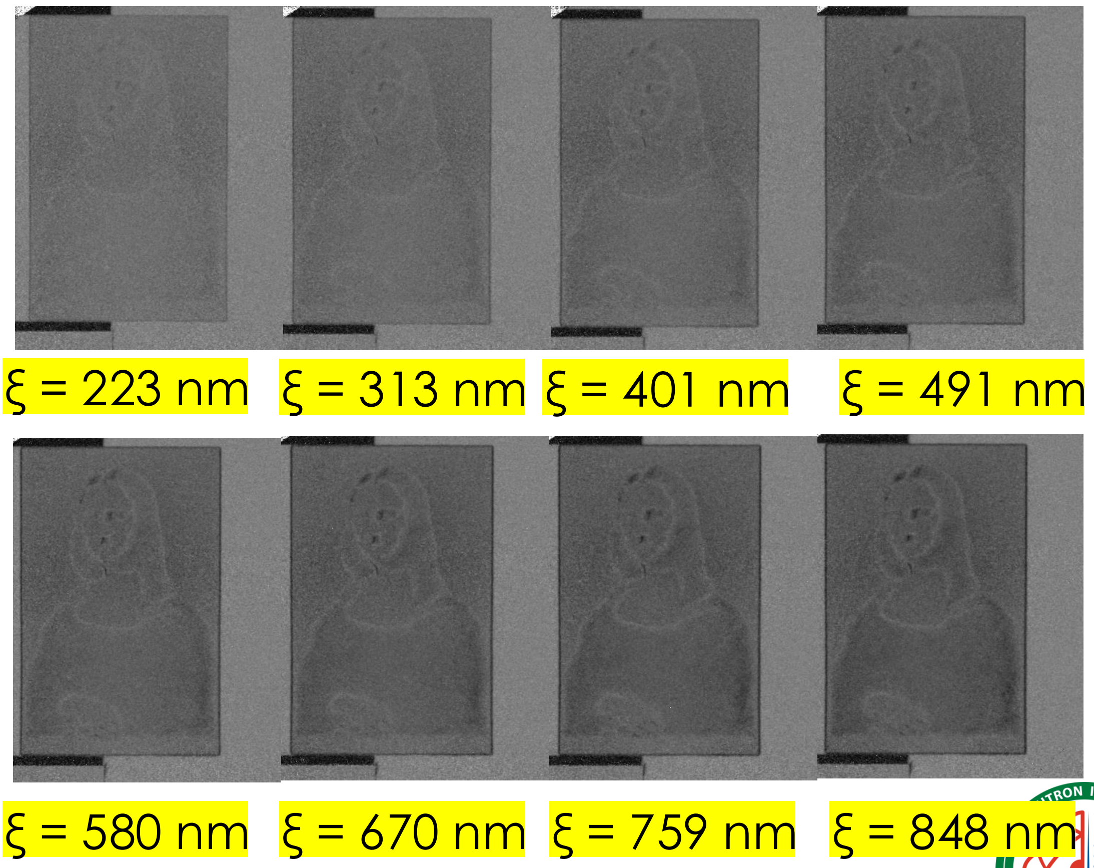
Y. Kim et al., *Applied Sciences* (2022).

(Sample courtesy of Dr. Chris Fancher)

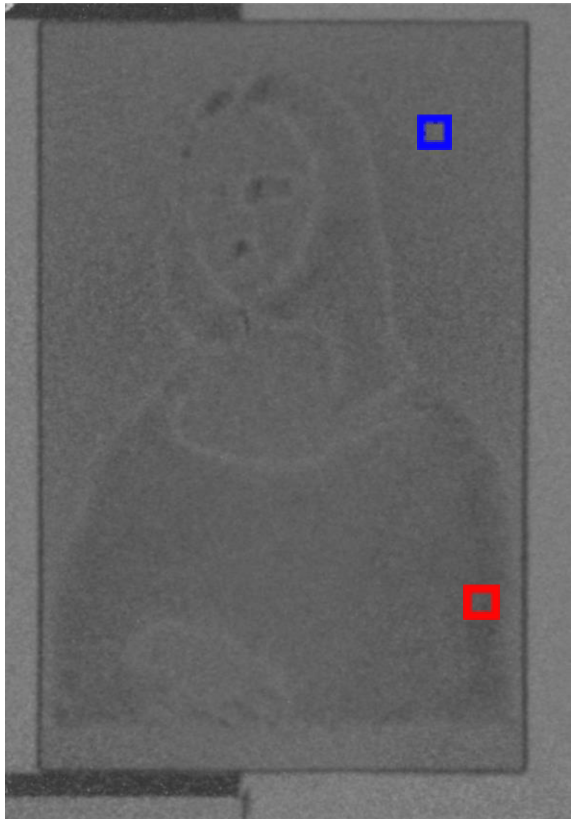
Correlation length

Neutron Wavelength

$$\xi = \lambda L_s / p$$

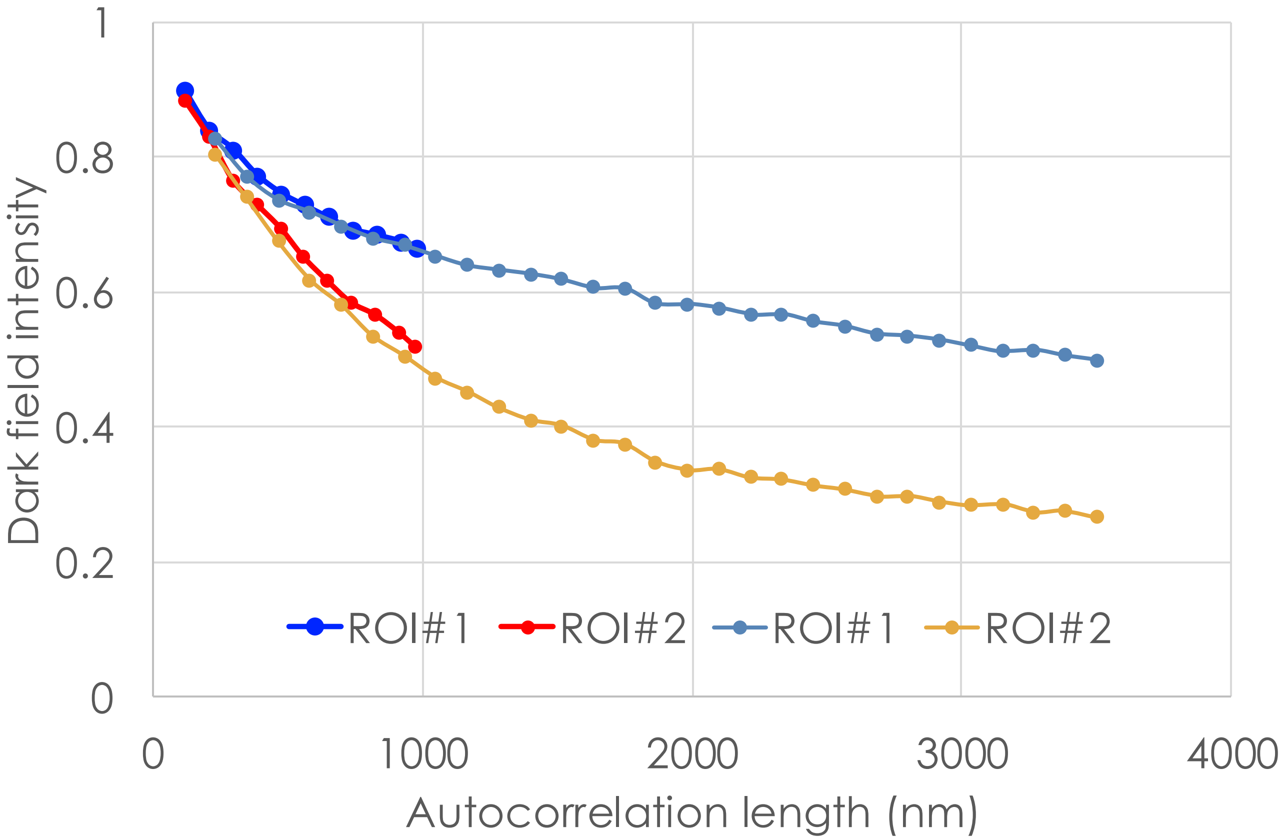


Plotting the dark field intensity vs. ξ in region-of-interest (ROI)



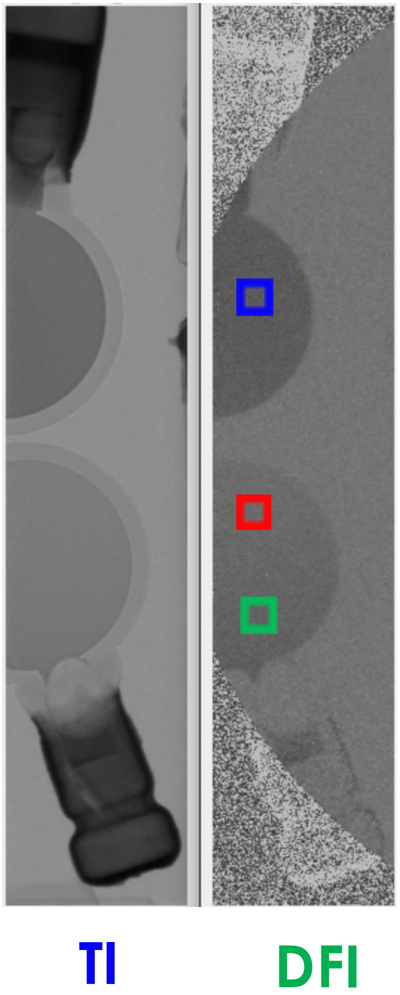
DFI

(Sample courtesy of Dr. Chris Fancher)

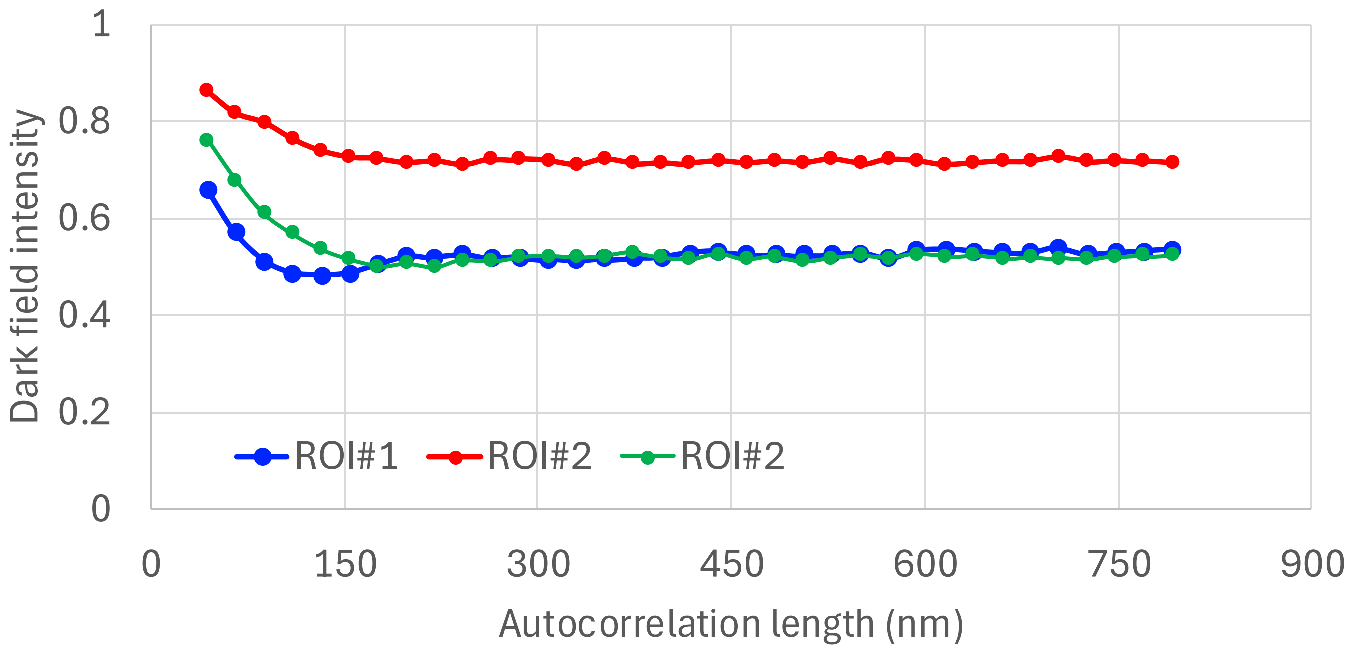


- Indicating different microstructures between selected ROIs

Measurement of suspended PMMA spheres in solution as a calibration standard



(Sample courtesy of Dr. Fankang Li)

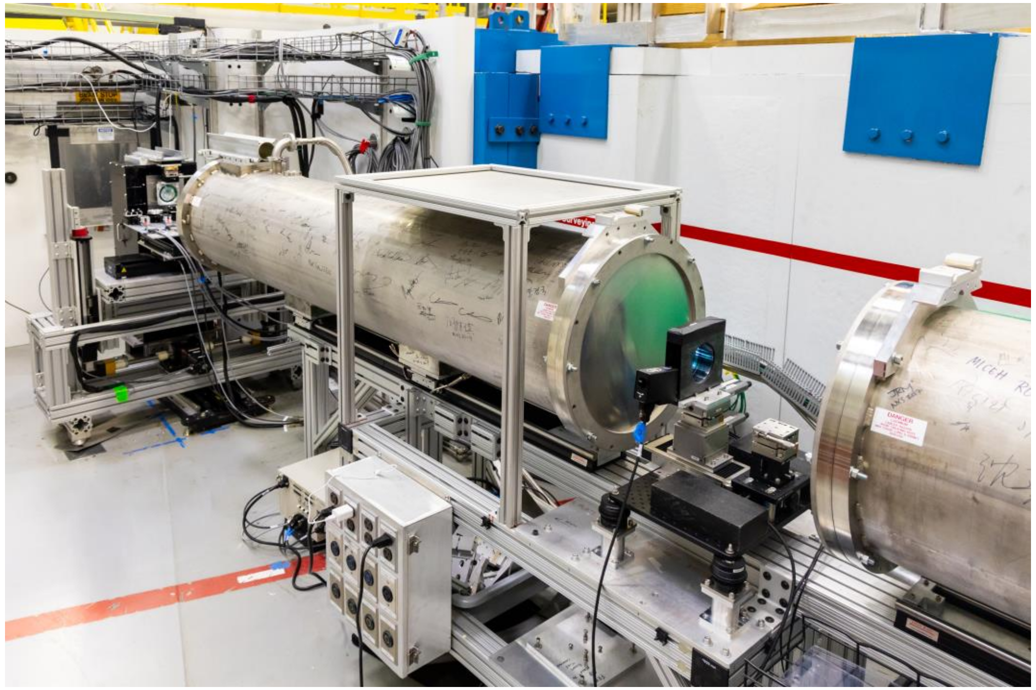


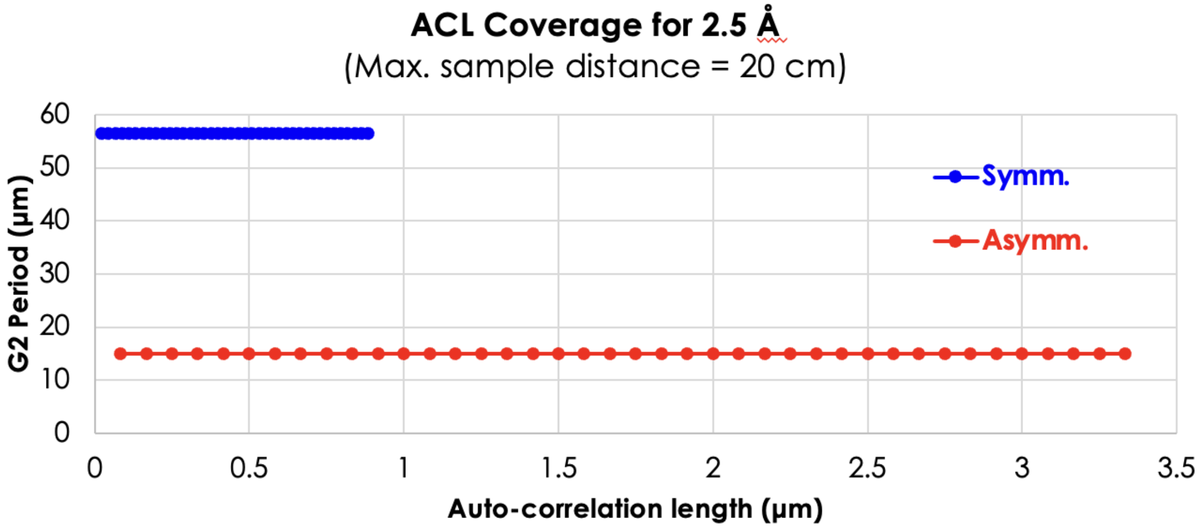
- The curves indicate the size of the PMMA spheres,which match well with the spec. (~100 nm in the top cell, ~150 nm in the bottom cell)
- Some settling observed in the bottom cell, resulted difference in number density of PMMA can be observed

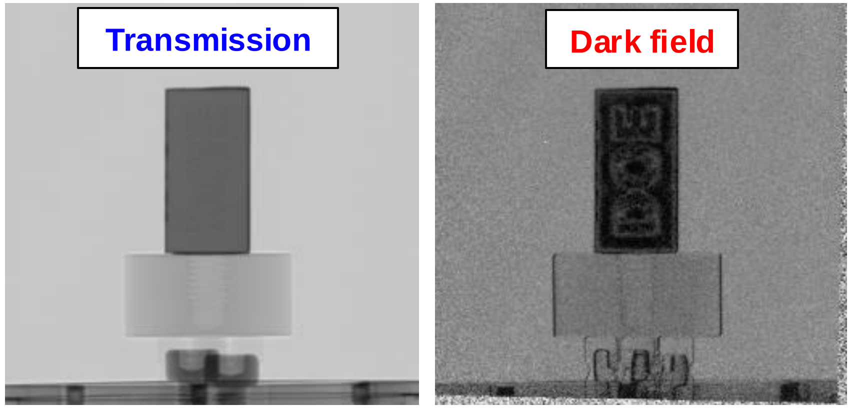
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

nGI capability at MARS

Two setups to cover ACL ranges from ~40 nm to ~3400 nm







(Sample courtesy of R. Dehoff)

Outline

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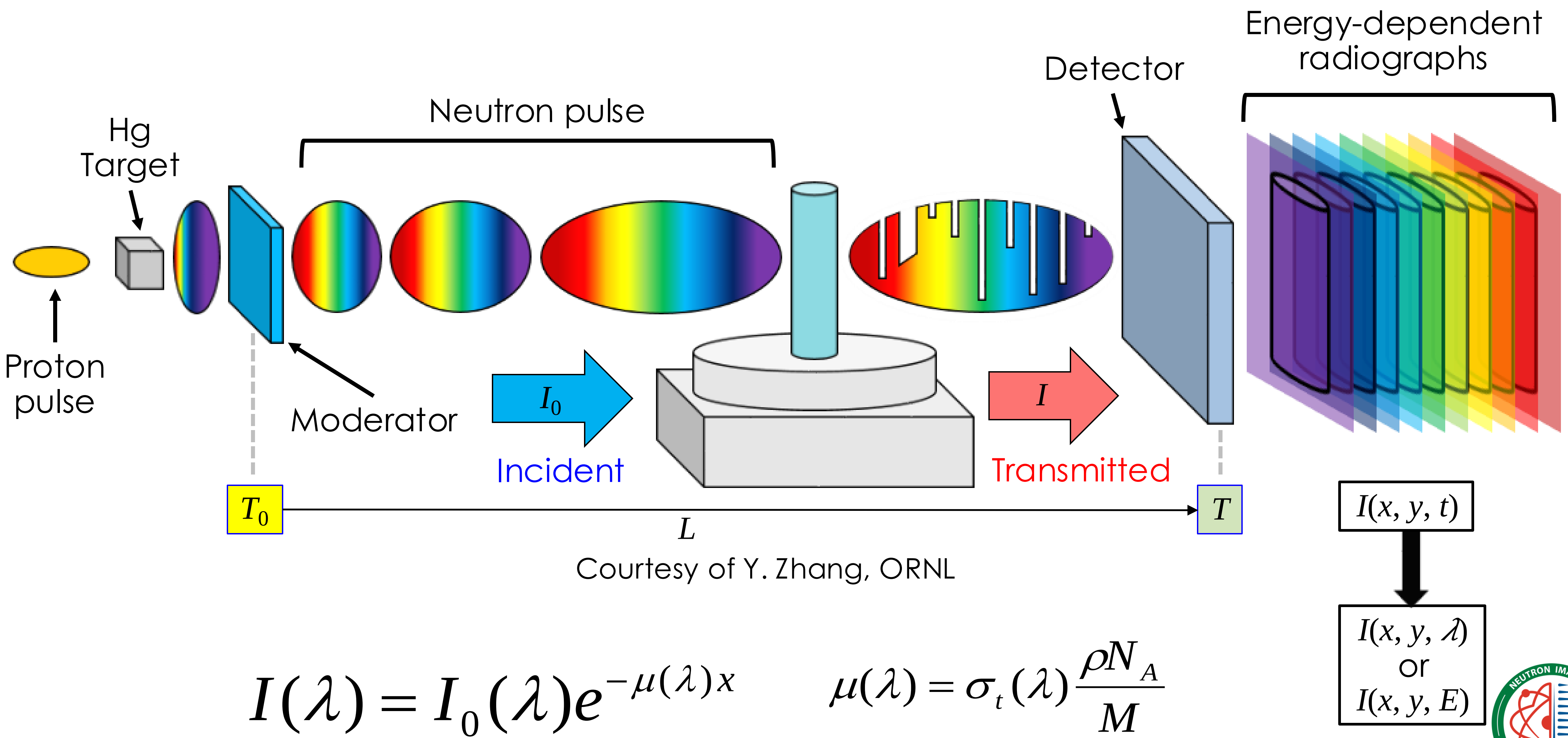
  - Principle of neutron radiography and computed tomography at a continuous source
  - The CG-1D imaging beamline
  - Examples
- **Imaging at the Spallation Neutron Source:**
  - **Principle of neutron radiography at a pulsed source**
  - **Examples**
  - **~~The~~ VENUS !!!~~construction project~~**
- Scientific programming

Yuxuan

Hassina

Jean

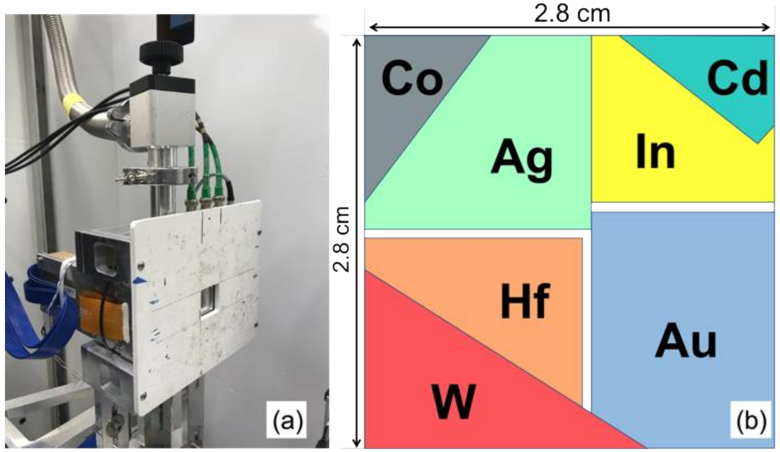
Imaging at a pulsed source (SNS)

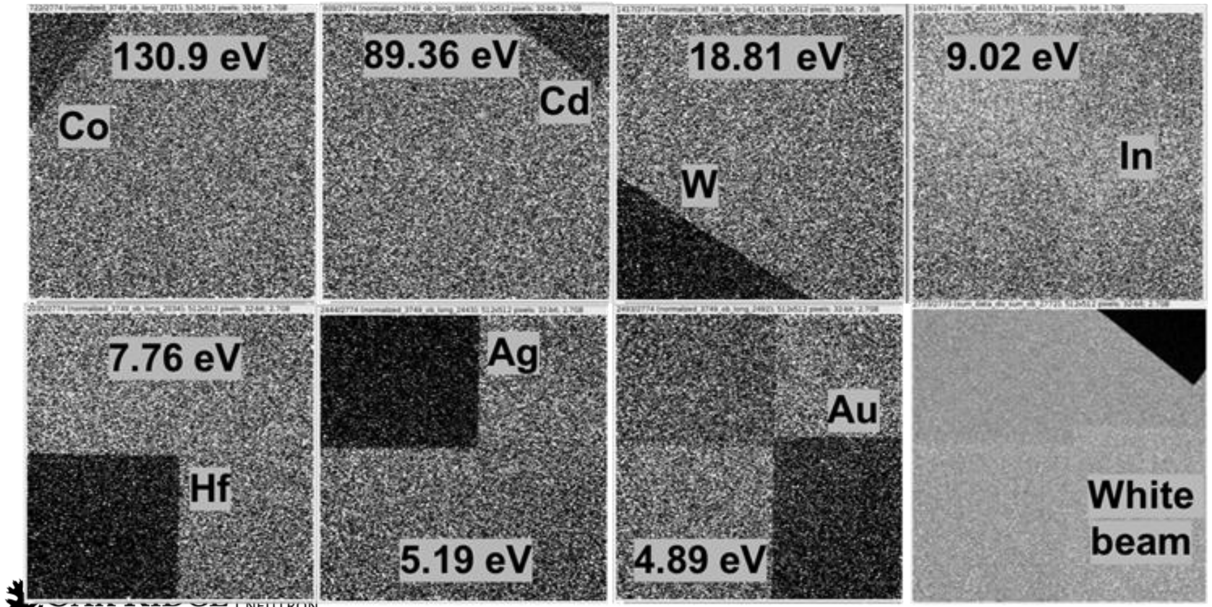


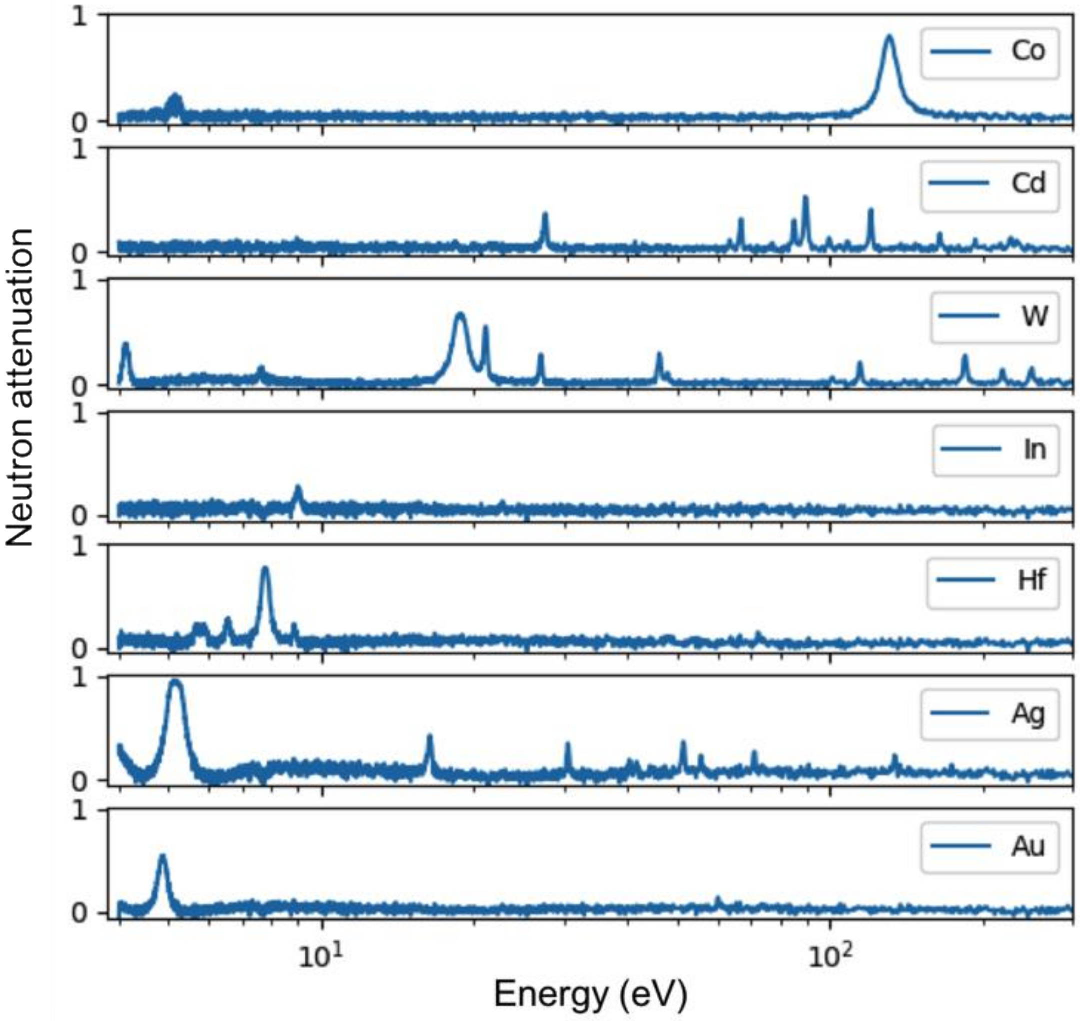
Courtesy of Y. Zhang, ORNL

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

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



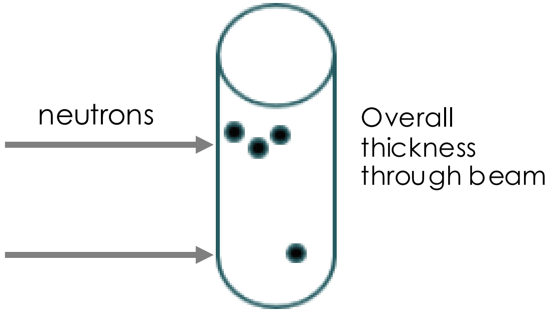




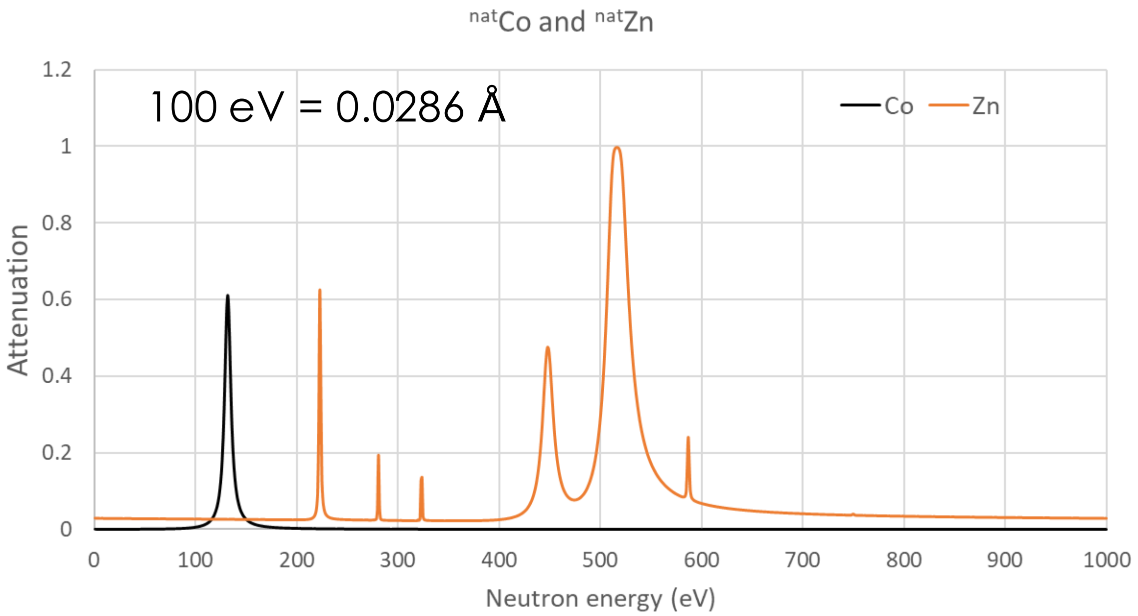
Zhang Y., Myhre K.G., Bilheux H.Z., Tremsin A.S., Johnson J.A., Bilheux J., Miskowiec A., Hunt R.D., Santodonato L., Molaison J.J., "Neutron Resonance Radiography and Application to Nuclear Fuel Materials", *Transactions of the American Nuclear Society,* (2018).

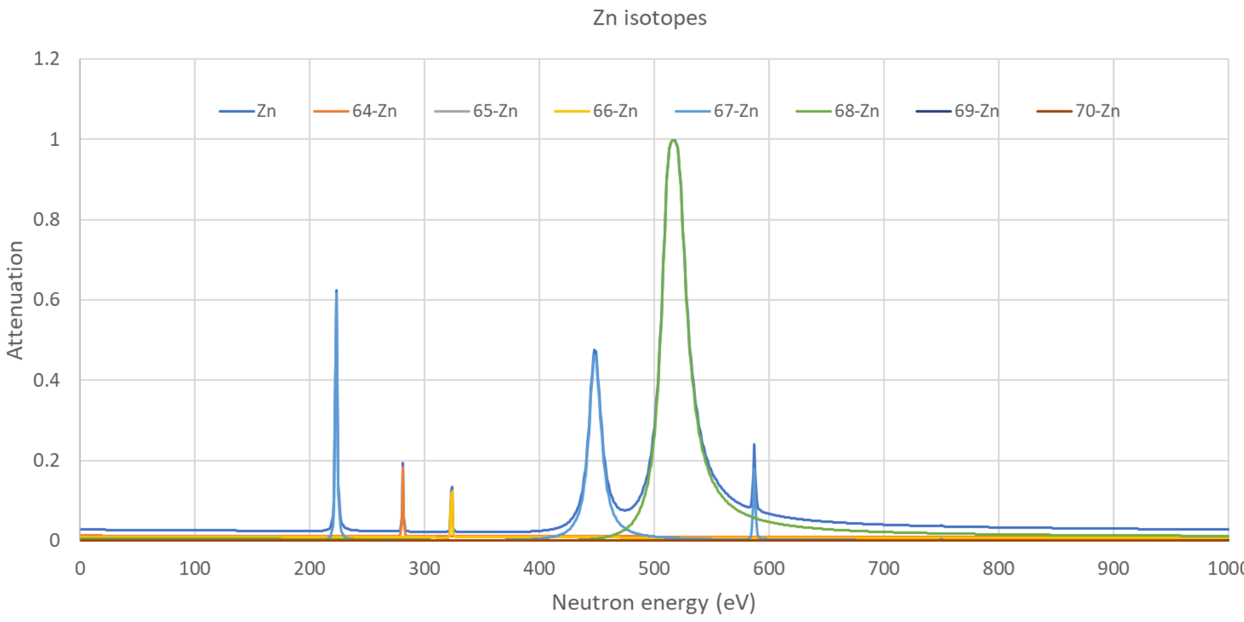
Resonance imaging (> 1eV or < 0.286 Å): preparing your experiment

- Soil surveys, contaminants in soil, etc.:
  - transmission through 0.01 mm thickness of ^{nat}Co (between 1 and 5 Å) = 99.5 %
  - transmission through 1 mm thickness of ^{nat}Zn (between 1 and 5 Å) = 96.4 %



Simulated resonance for elements of interest(*)

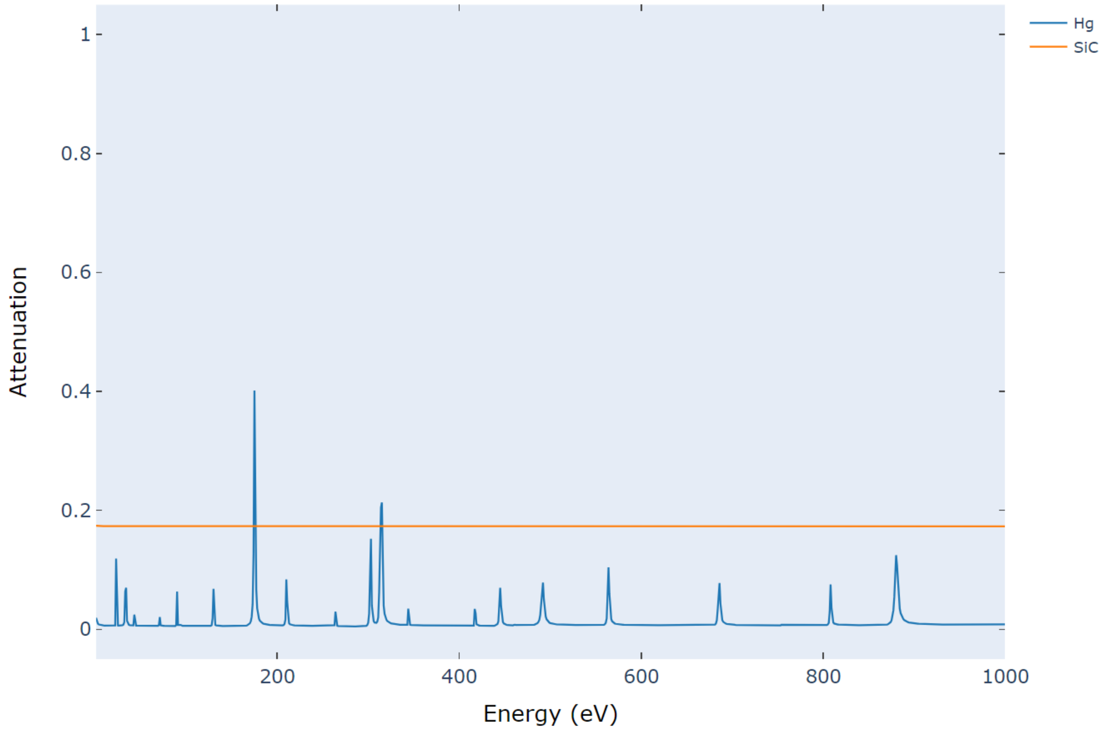




(*)Soil surveys in UK (1978-1983, 2000, 2011-2012)

Resonance imaging: preparing your experiment (cont'd)

- Hg contamination in soil
  - Assumptions: 0.1 mm Hg (13.6 g/cm³) + 12.5 mm SiC (with 1.5 g/cm³)
    - Transmission (1 and 5 Å) = 66.4 %



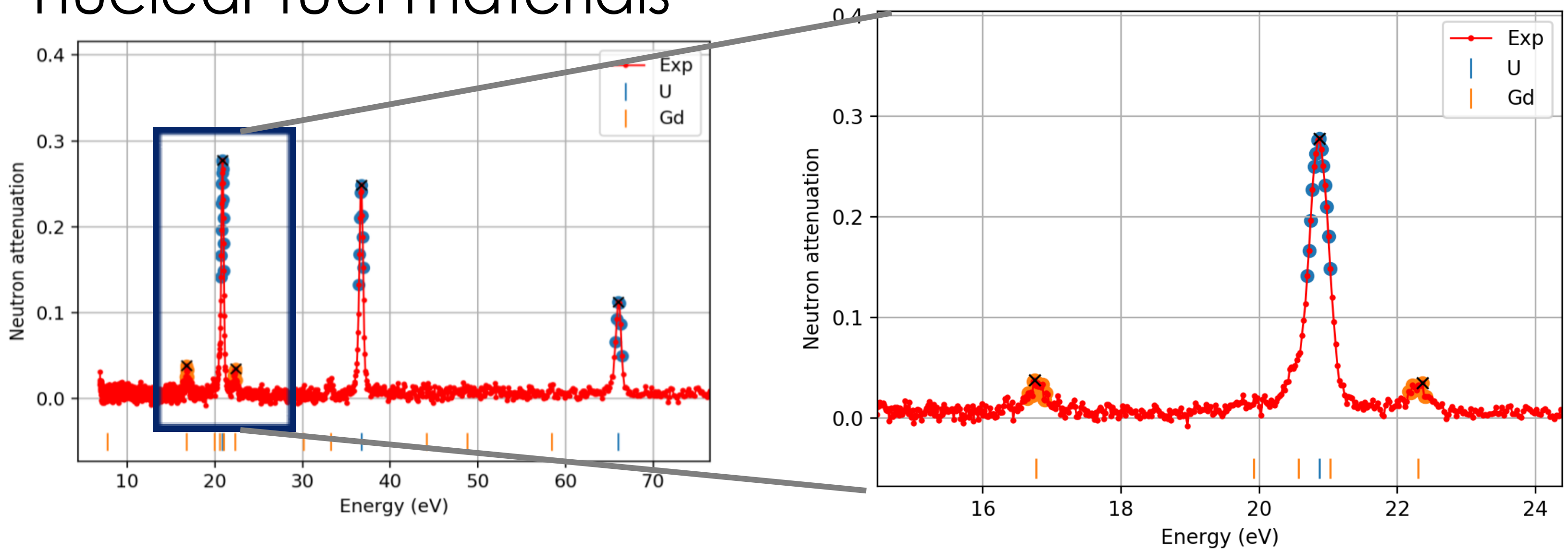
Resonance peaks plotted with:

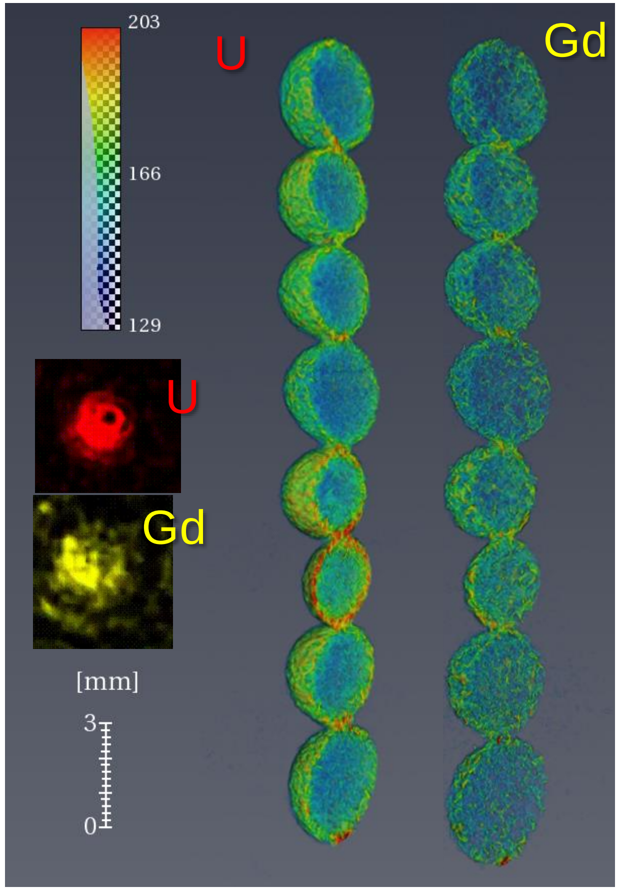
iNEUIT ("*I knew it*")

iNEUtron Imaging Toolbox

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





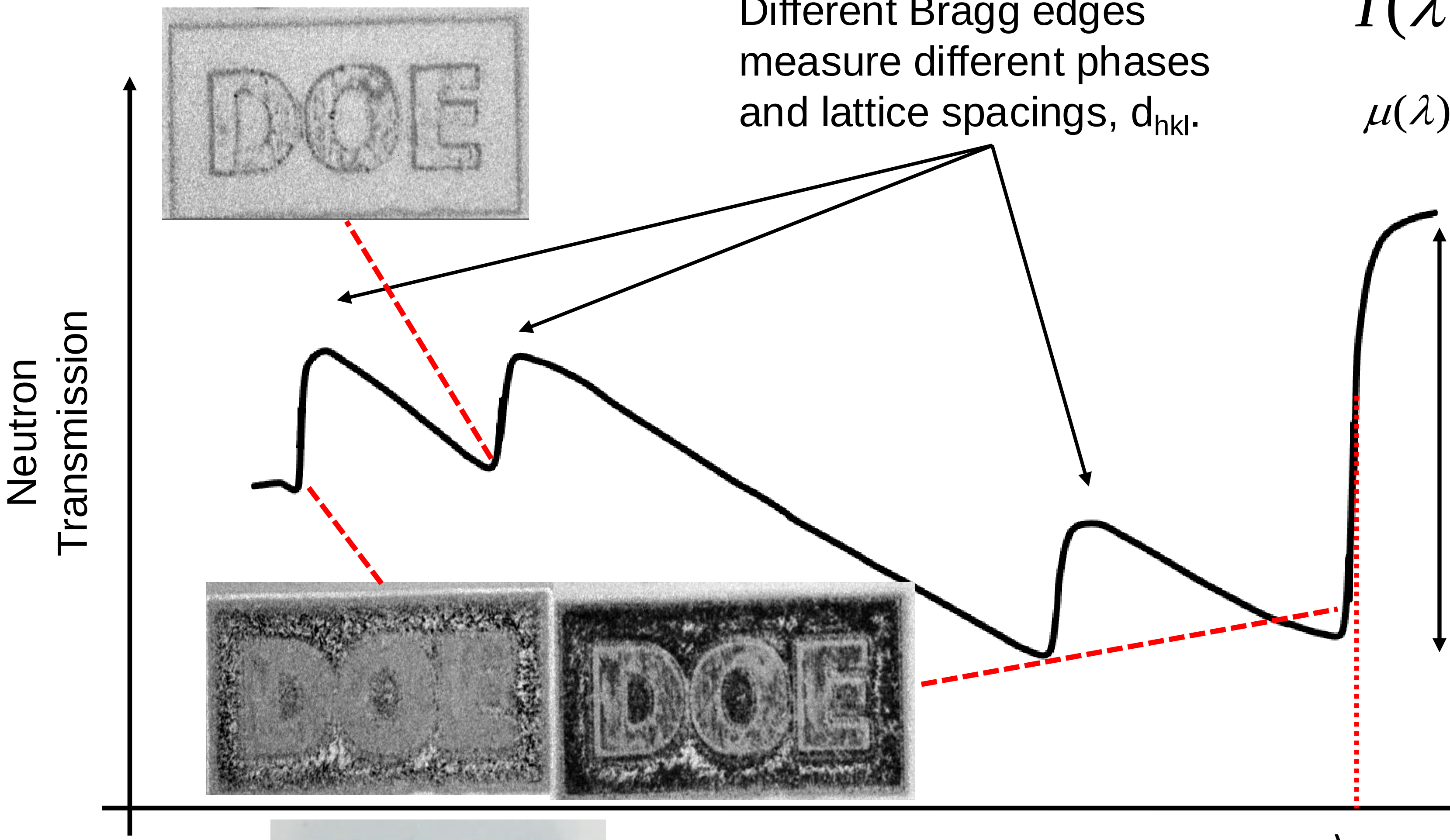
- **Quantitative analysis is being developed using in-house open-source Python package (ResoFit)**

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).

Bragg edge imaging: how does it work?

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

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



Neutron Wavelength

λ_{hkl}

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

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

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

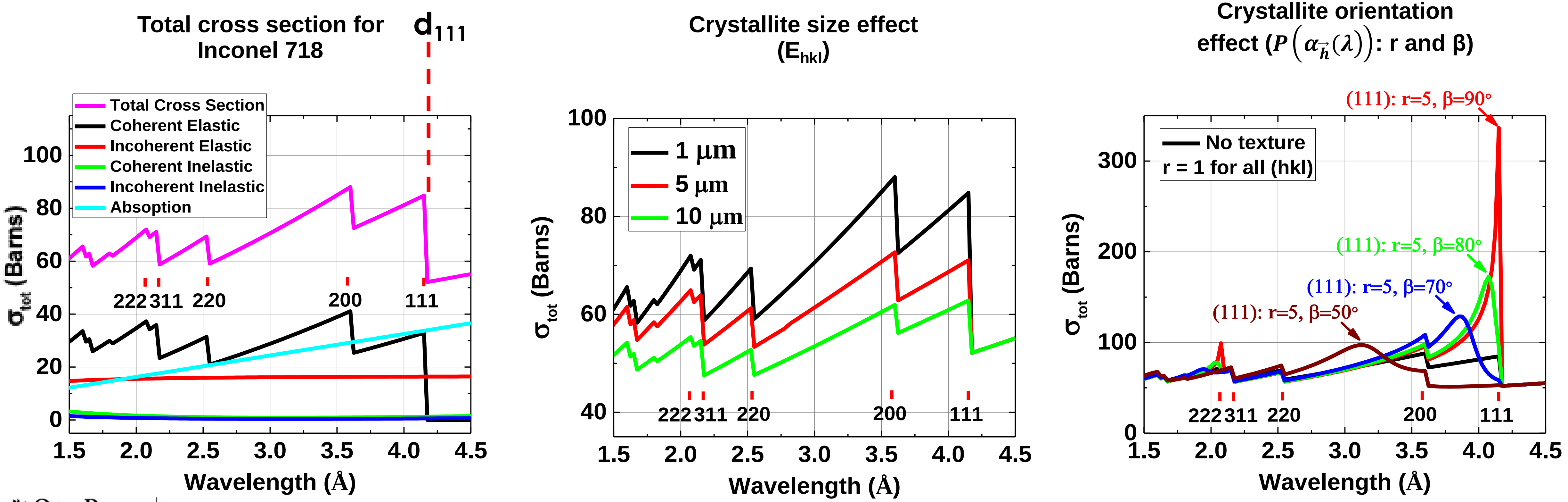
Principle of Bragg edge Transmission

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

March-Dollase model | Sabine's primary extinction model

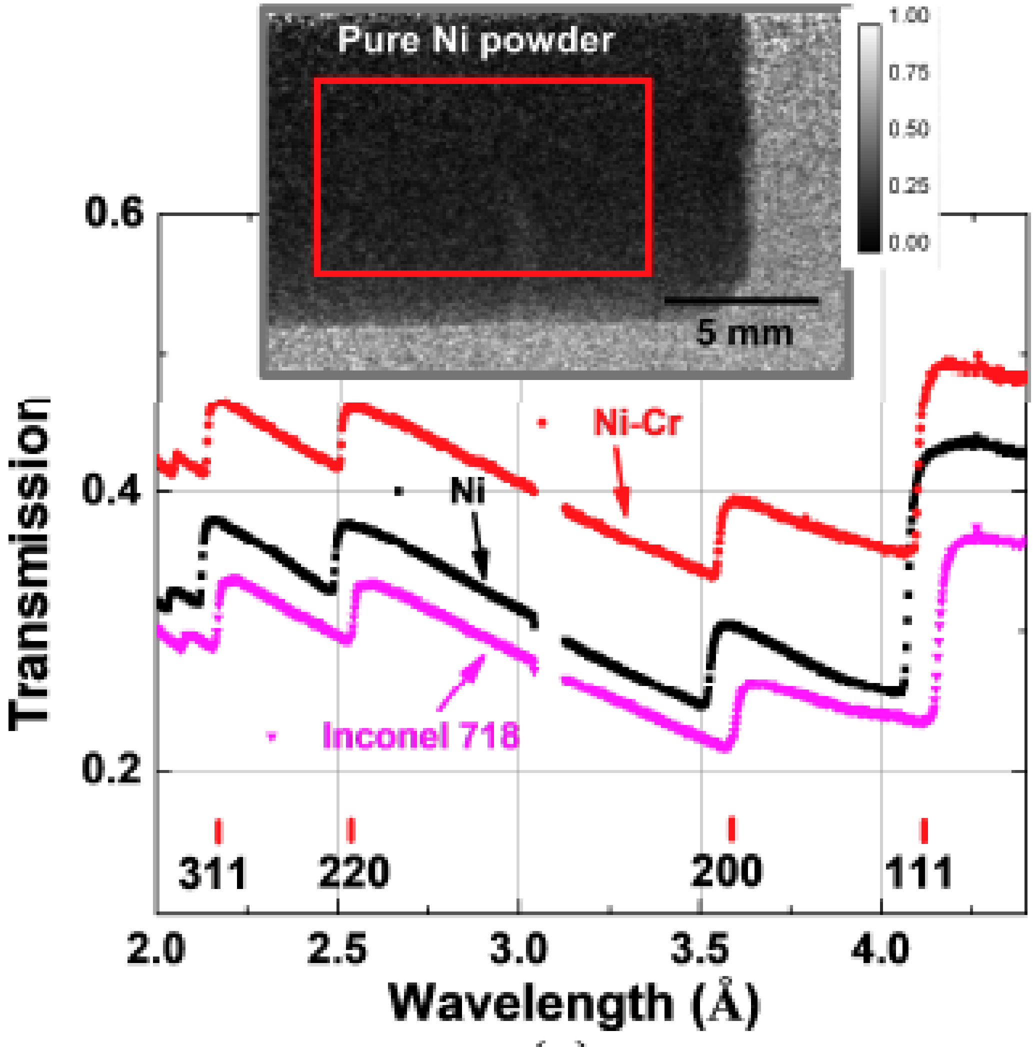
$$\sigma_{Bragg}(\lambda) = \frac{\lambda^2}{2V_0} \sum_{hkl}^{2d_{hkl}>\lambda} |F_{hkl}|^2 d_{hkl} \, P\left(\alpha_{\vec{h}}(\lambda)\right) E_{hkl}(\lambda, F_{hkl})$$

V_0: volume of unit cell
F_{hkl}: Structure factor including Debye-Waller factor

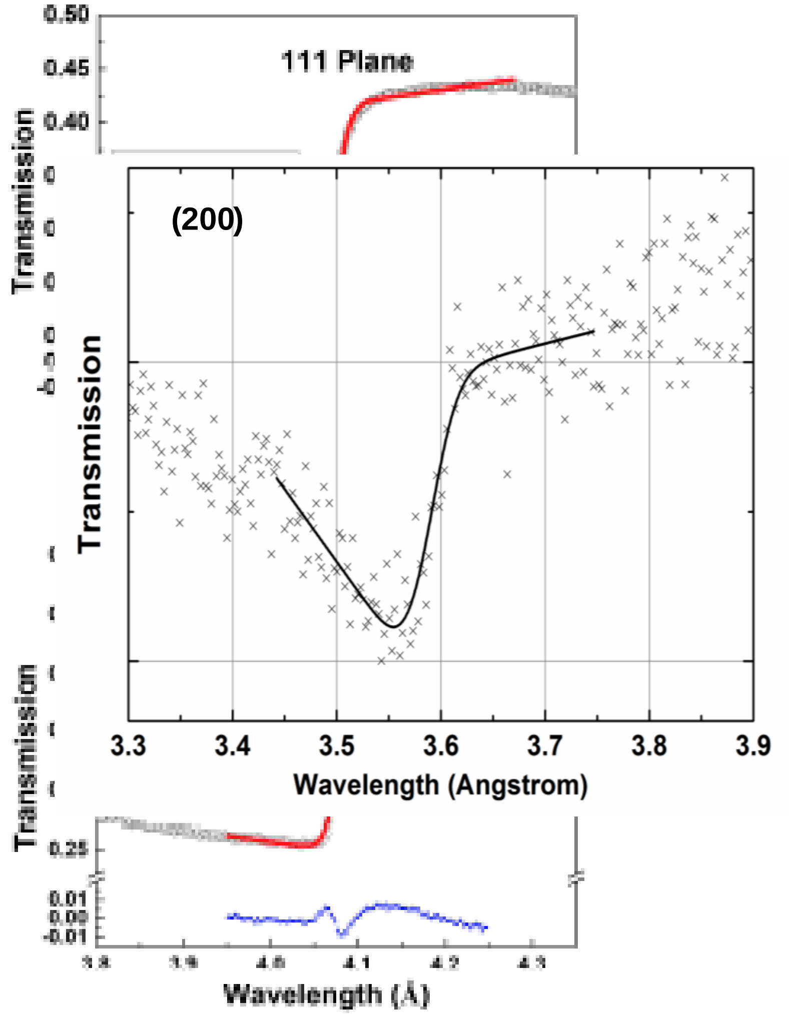


G. Song et al., Journal of Imaging, 3, 65 (2017).

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).

Materials Behavior: Monitoring residual strain relaxation and preferred grain orientation of additively manufactured Inconel 625 by in-situ neutron imaging

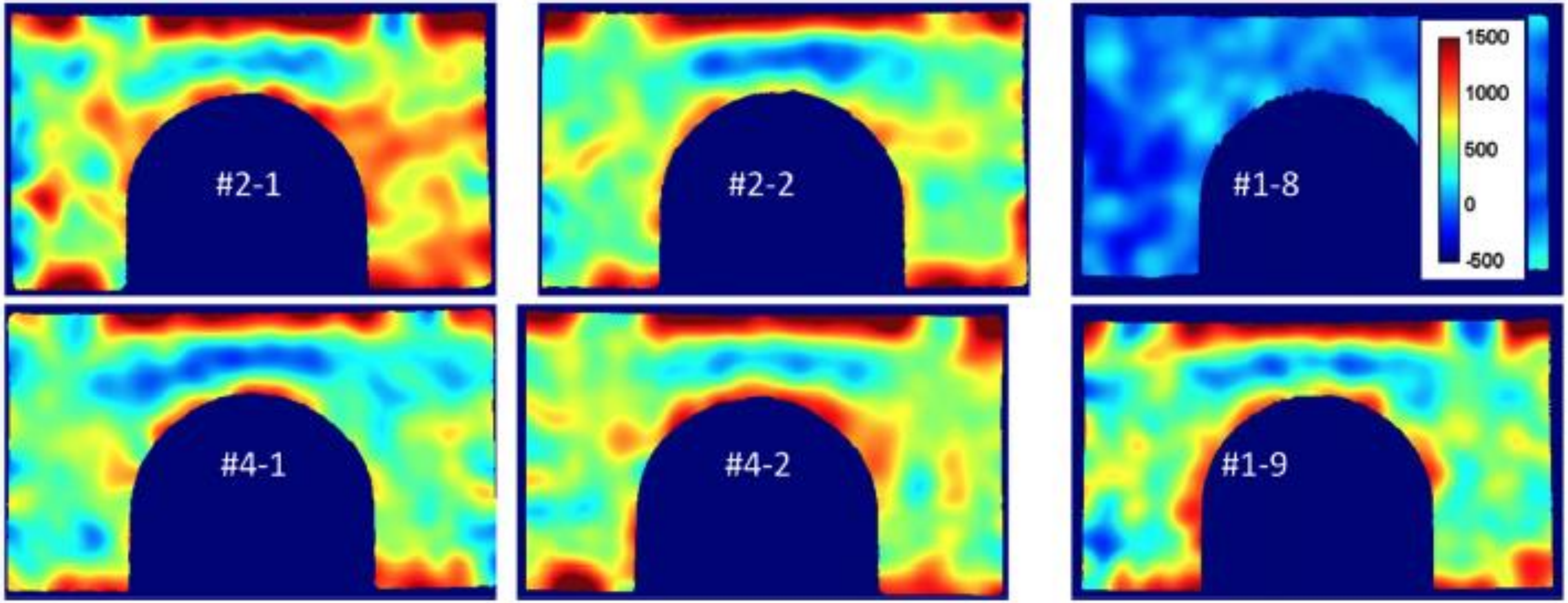


Fig. 8. Strain distribution (in microstrain) at the (111) Bragg edge measured at room temperature along the sample thickness direction X. SNAP beamline. The image integration time was about 2 h at SNAP. λ_0 value is taken from the annealed sample #1–8 (average across the entire sample). The legend indicates the strain values in microstrain.

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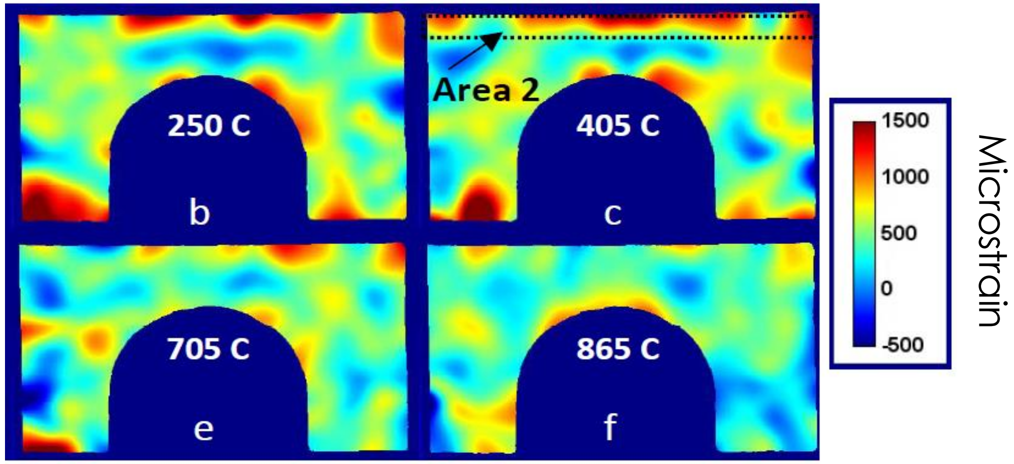
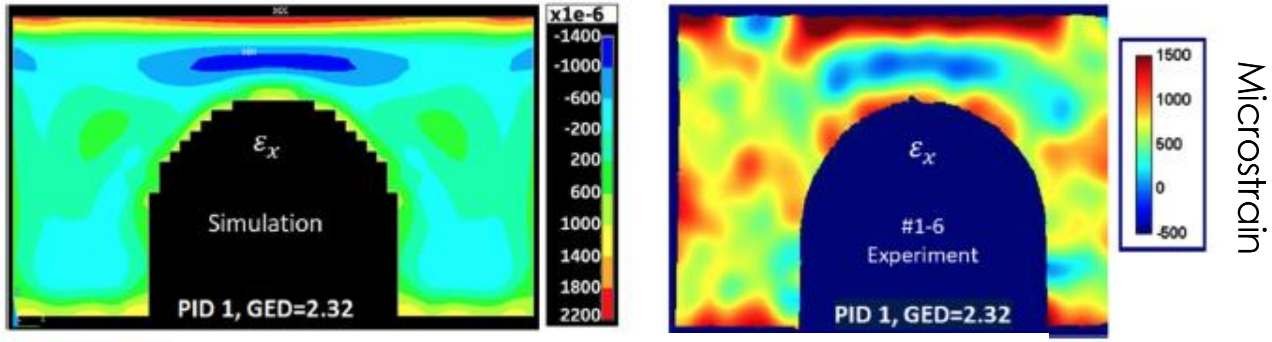
J-PARC

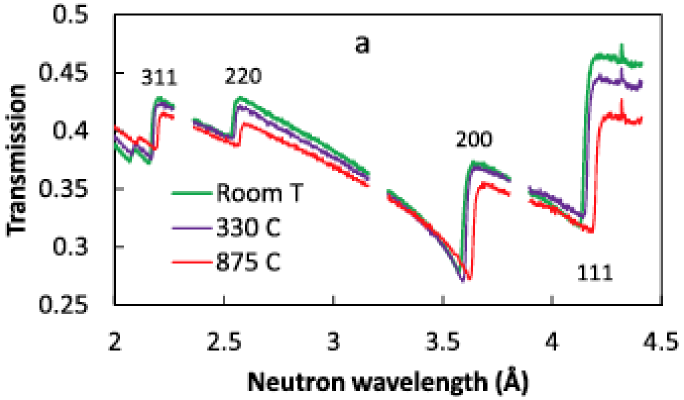
Engineered Materials: Monitoring residual strain relaxation and preferred grain orientation of additively manufactured Inconel 625 by in-situ neutron imaging (10 min measurements)





Modeled and experimental results.

AM Inconel 625 strain evolution as a function of temperature



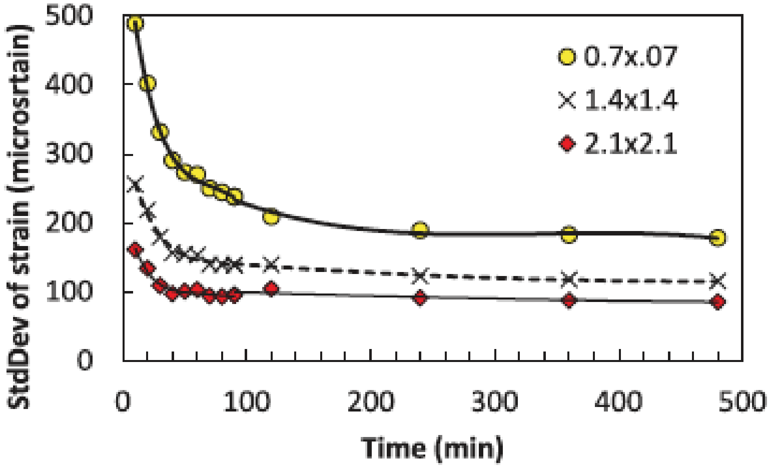


Fig. 16. Variation of the standard deviation of the reconstructed strain as a function of image integration time. Three different sizes of the area used for pixel grouping are used for strain reconstruction, as indicated by the legend (in mm^2).

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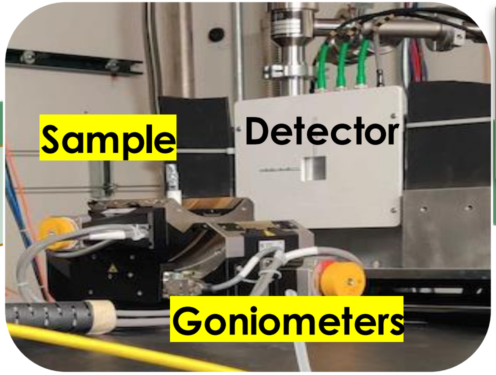
J-PARC

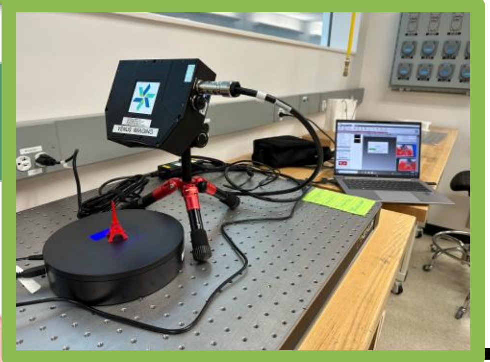
Tremsin et al, Additive Manufacturing, 2021.

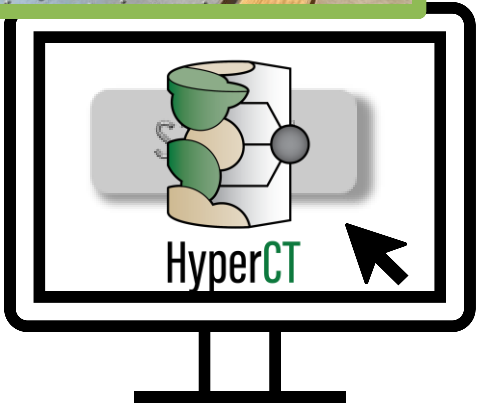
Tremsin et al, Nuc. Instr. Methods in Phys. Res. A, 2021.

Autonomous Hyperspectral Neutron CT Experiment at ORNL



Light scan and preselection of projection angles





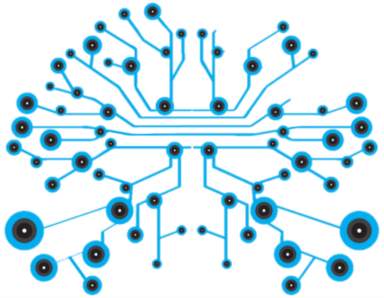
Continue

Stop

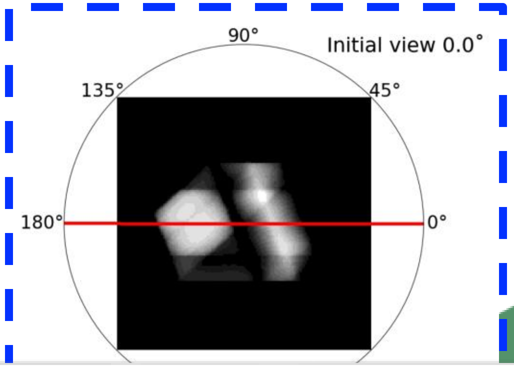
Autonomous Decision

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

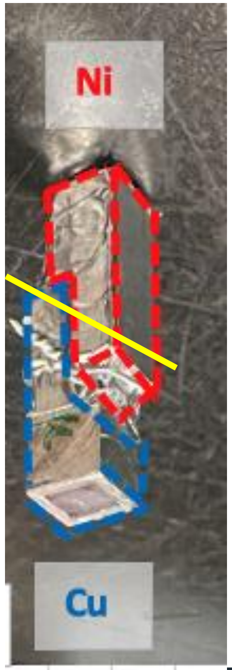


AI Quality Evaluation

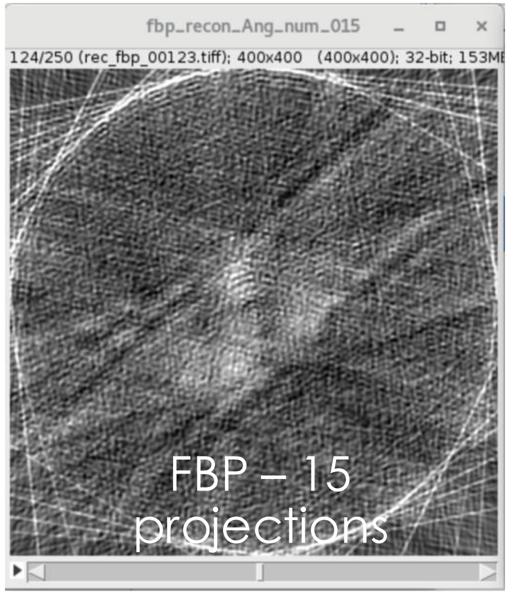


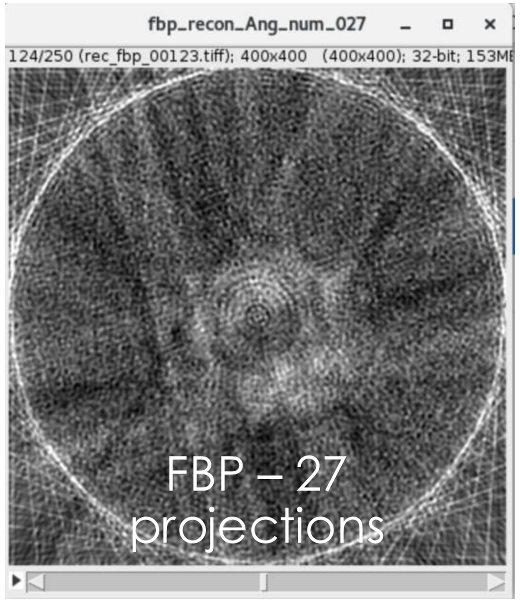
Sample Adaptive Scanning Angles (active learning)

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

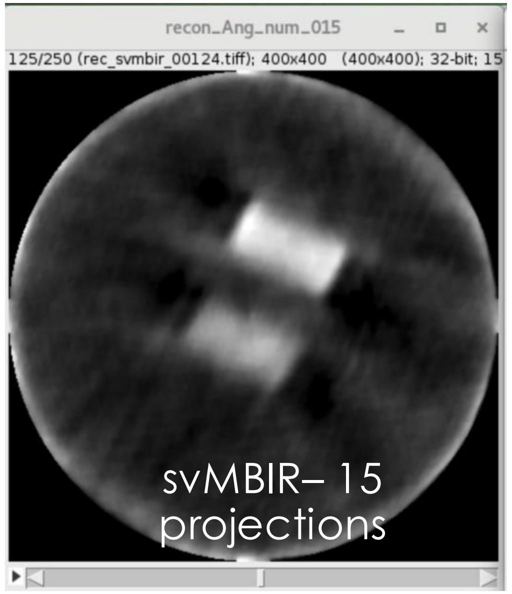


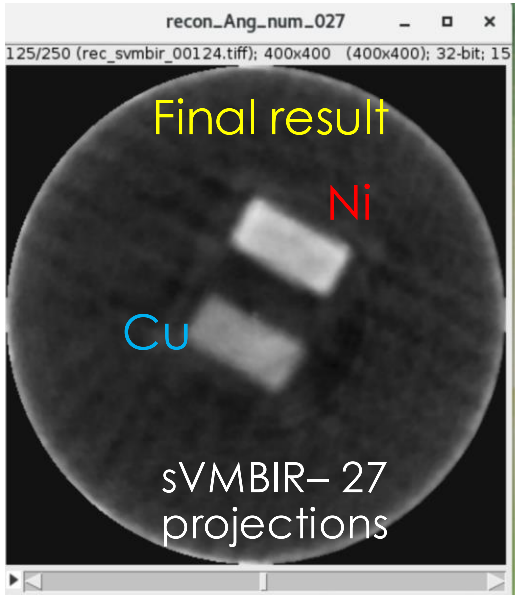
Conventional reconstruction methods

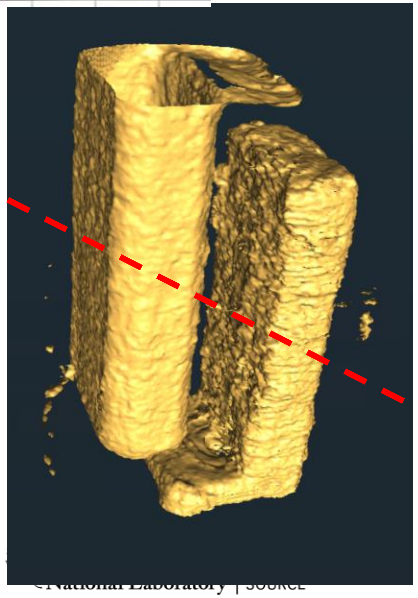




Our advanced algorithms/methods



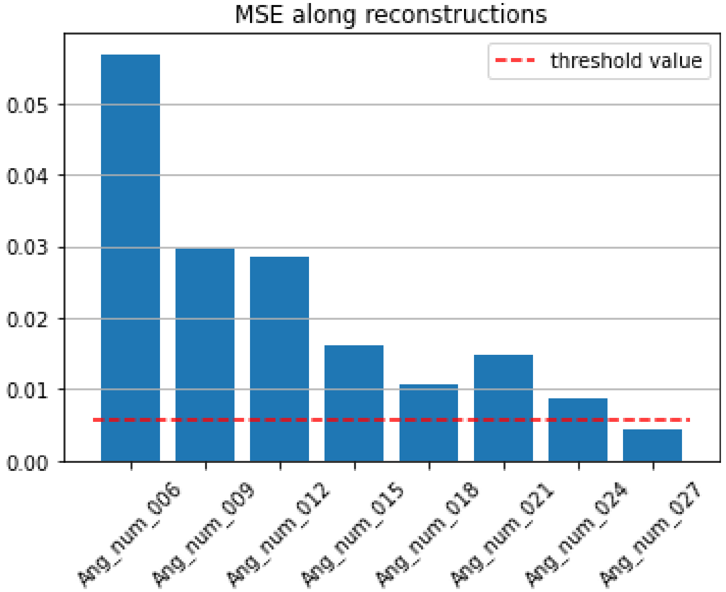


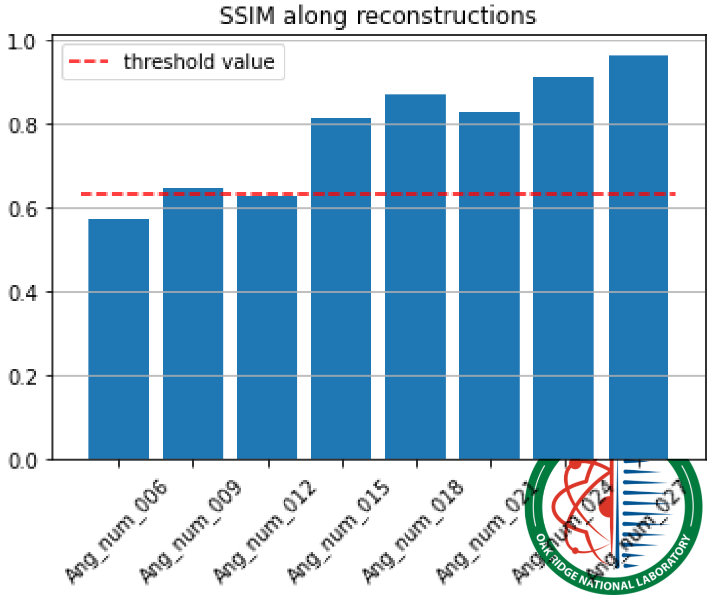


	Thresholds
MSE[1]	5.689×10^{-3}
SSIM[2]	0.634

[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.

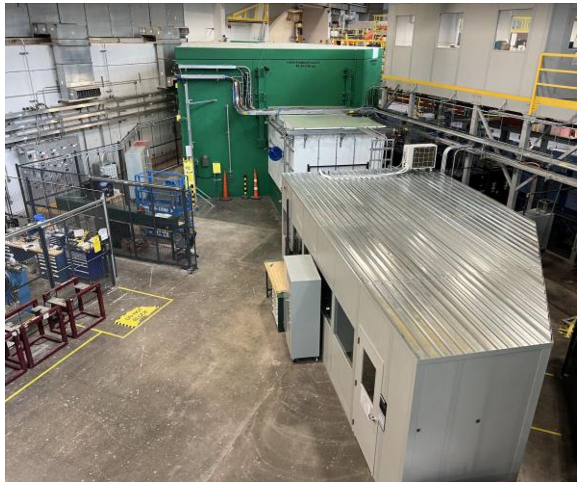
[1] Z. Wang, A. C. Bovik, H. R. Sheikh and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," IEEE Transactions on Image Processing, vol. 13, no. 4, pp. 600-612, Apr. 2004.





Neutron Imaging Capabilities at VENUS

- Bragg edge imaging
- Resonance imaging
- Epithermal imaging
- Largest field-of-view thermal/cold imaging
- Neutron grating interferometry (to be implemented)
- Polarized imaging (to be implemented)



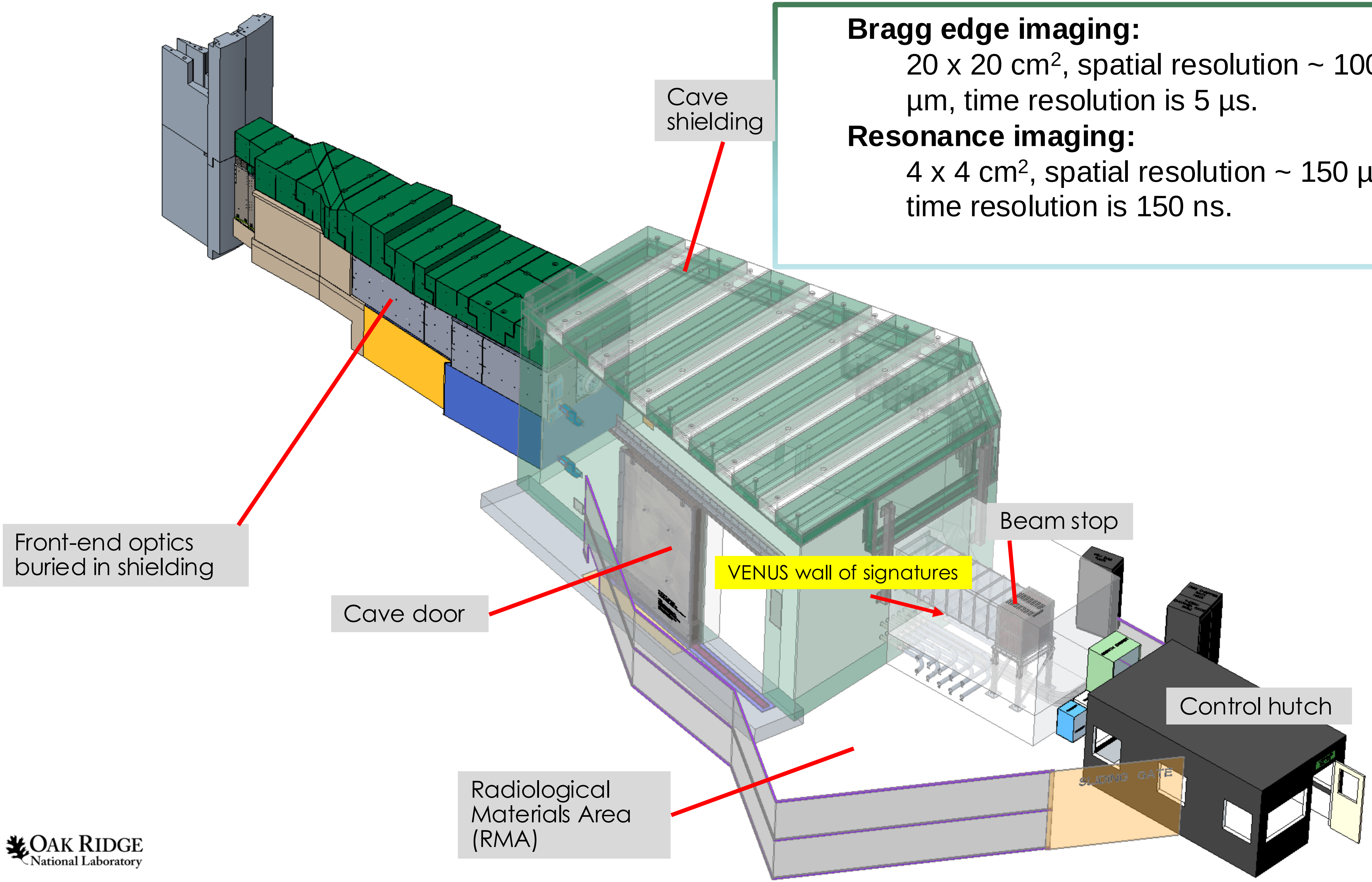
https://neutrons.ornl.gov/venus

Bragg edge imaging:

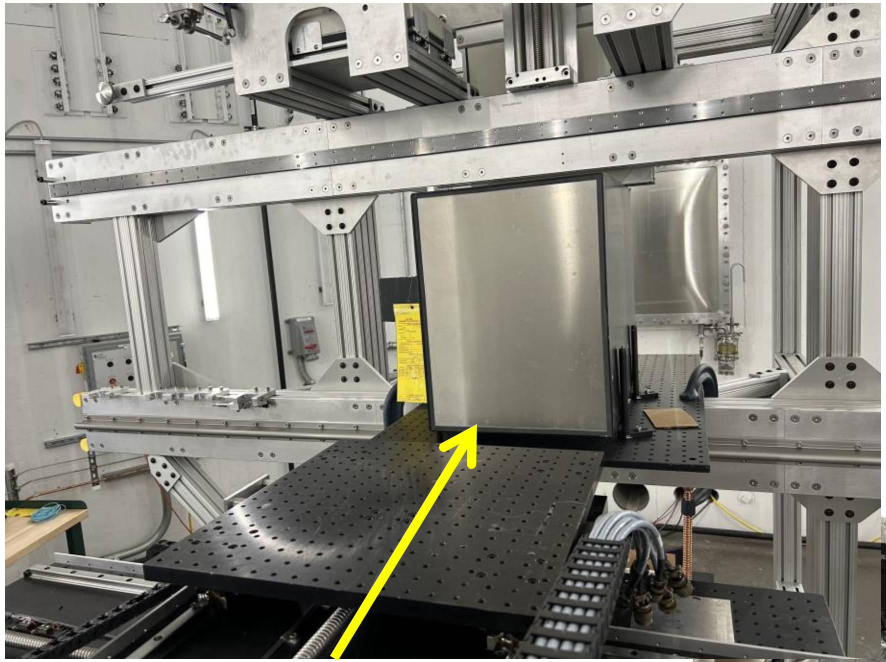
20 x 20 cm^2, spatial resolution ~ 100 µm, time resolution is 5 µs.

Resonance imaging:

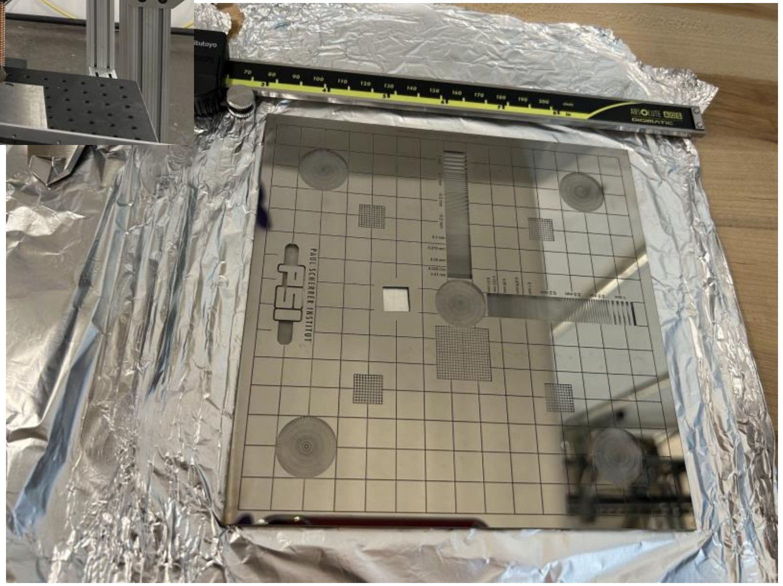
4 x 4 cm^2, spatial resolution ~ 150 µm, time resolution is 150 ns.



Largest field of view: 20 x 20 cm^2

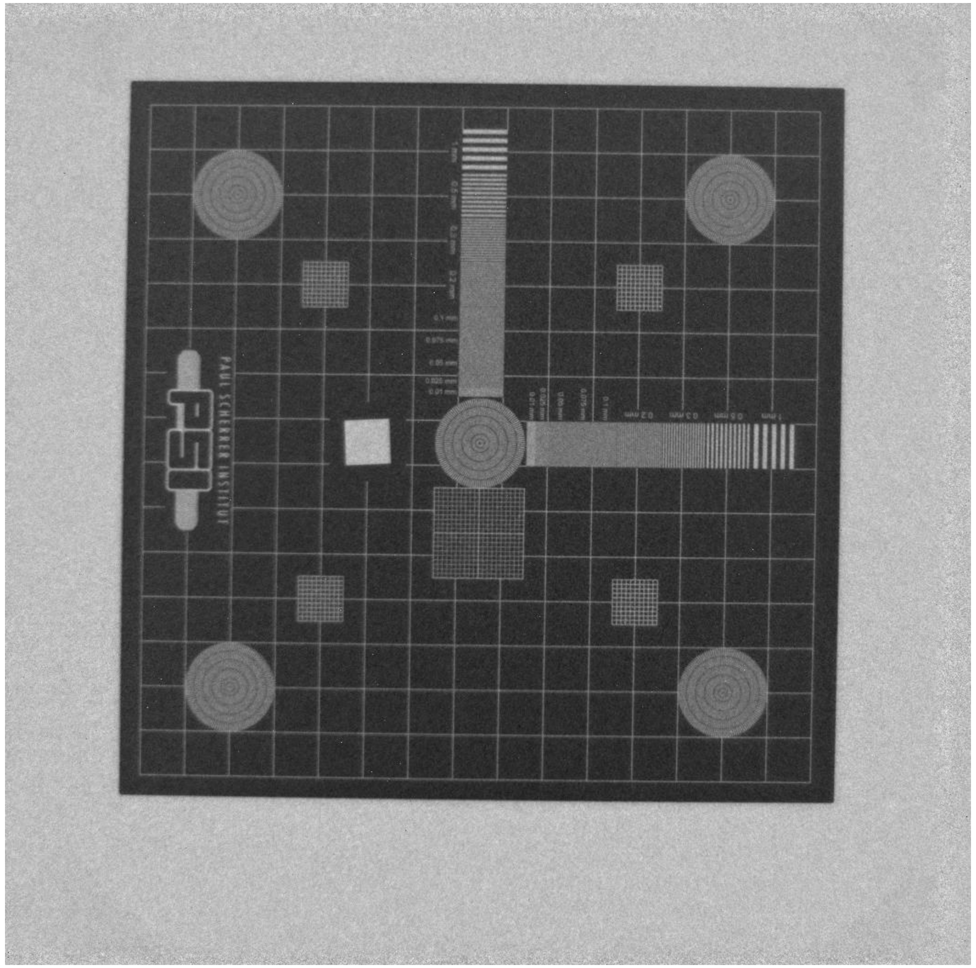


Imaging detector at VENUS



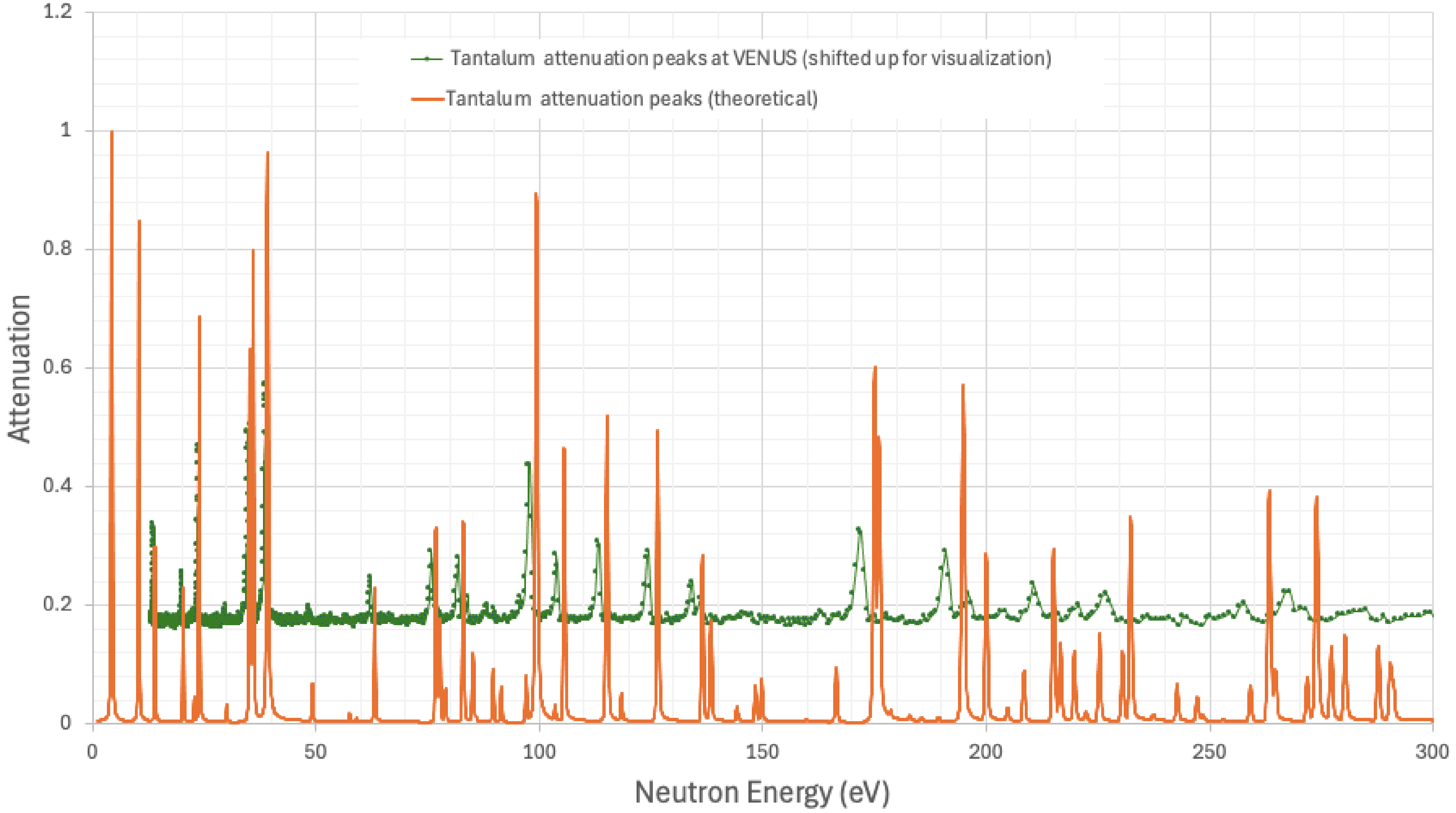
Spatial resolution mask

20 cm

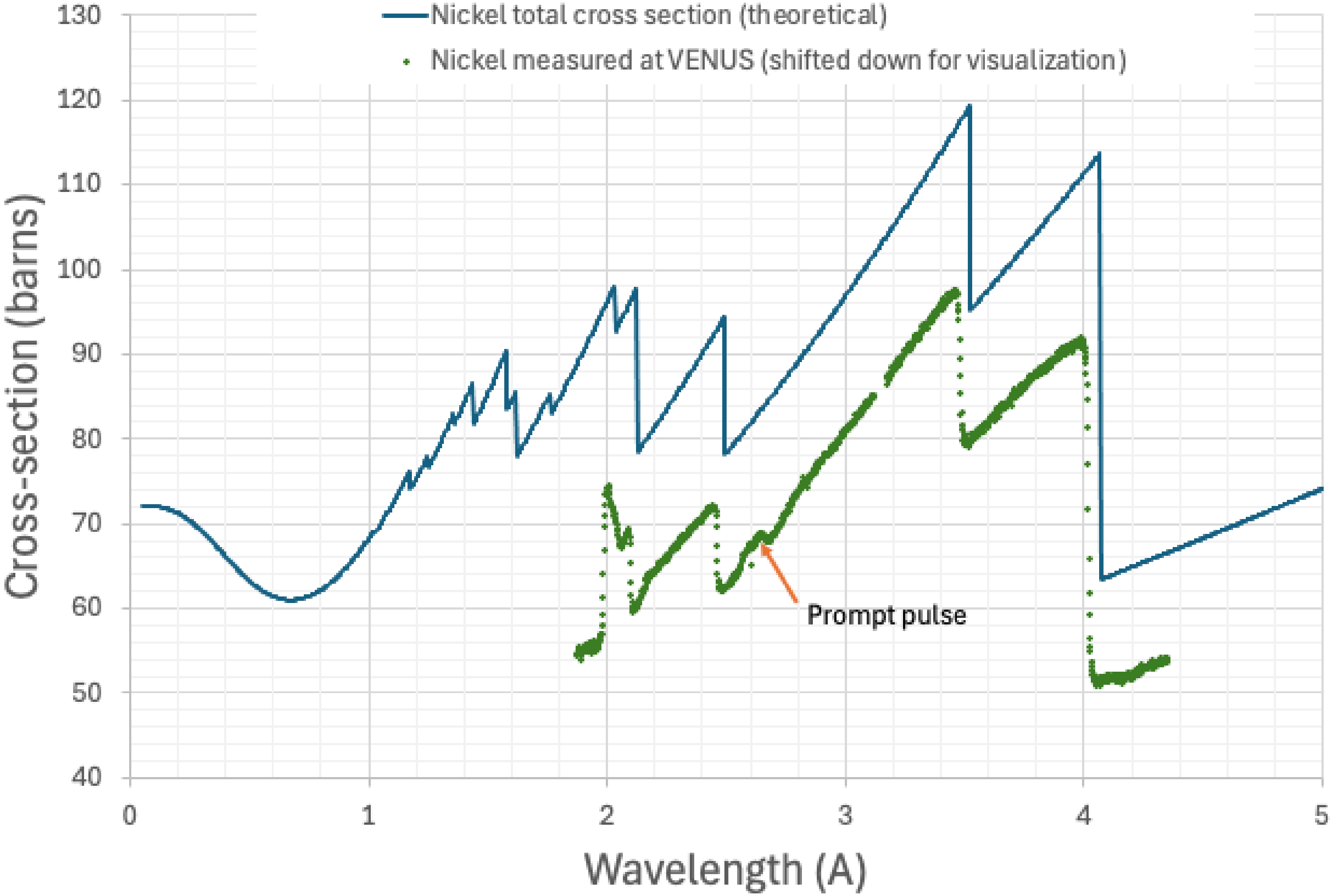


First 20x20 cm^2 large field-of-view radiograph measured at VENUS (July 24, 2024)!!!

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



We hope to see you at VENUS!

The VENUS control hutch

VENUS

Outline

- Imaging at the High Flux Isotope Reactor MARS beamline:
  - Principle of neutron radiography and computed tomography at a continuous source
  - The CG-1D imaging beamline
  - Examples

Yuxuan

- Imaging at the Spallation Neutron Source:
  - Principle of neutron radiography at a pulsed source
  - Examples
  - ~~The~~ VENUS !!!~~construction project~~

Hassina

- **Scientific programming**

Jean

Scientific programming

5 things you must know

Jean Bilheux

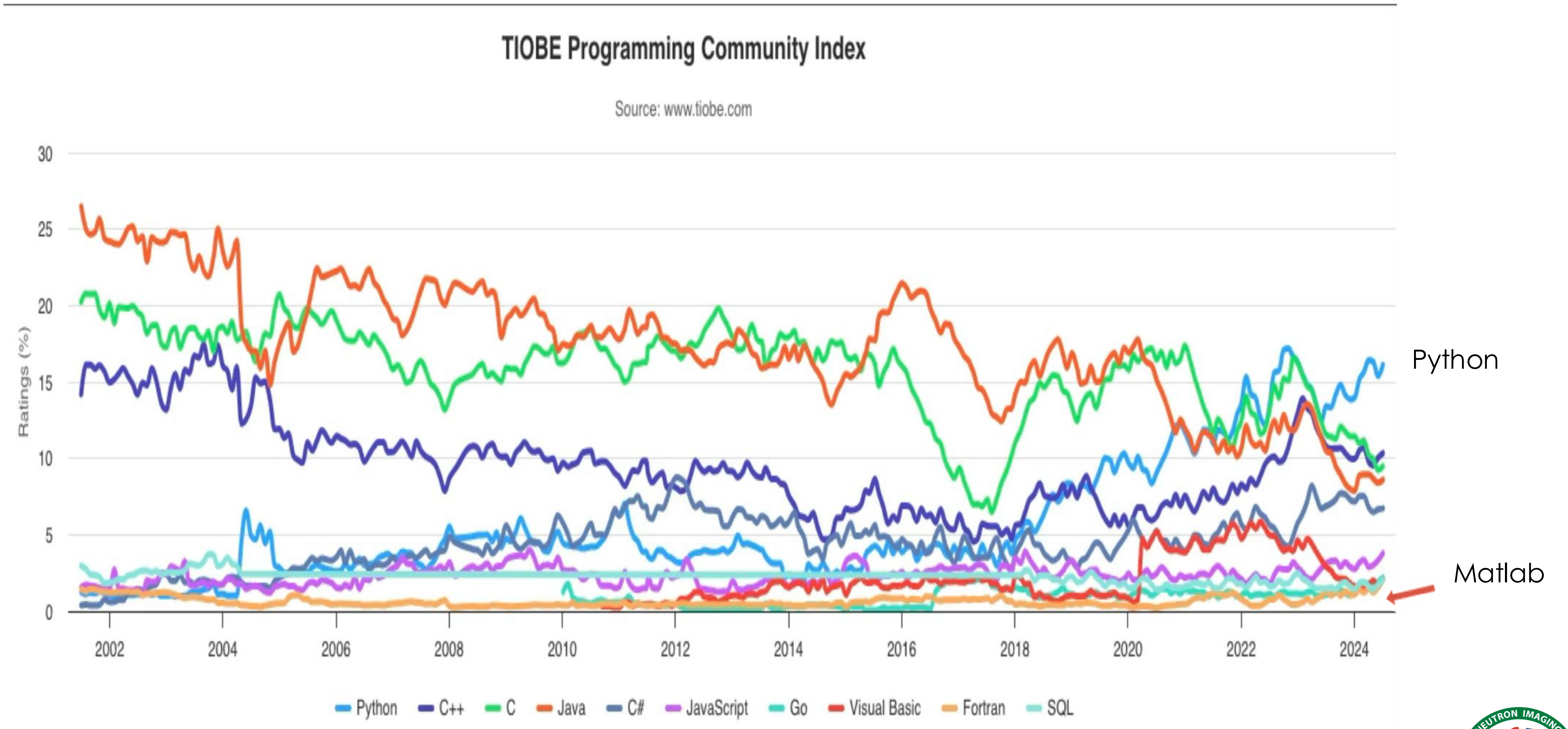
Neutron Imaging Computer Instrument Scientist

The 5 things that will save your life

The 5 things that will save your life

1 Pick the right language

Which language ?



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

Which language ?

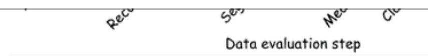
Jul 2024	Jul 2023	Change	Programming Language	Ratings	Change
1	1		Python	16.12%	+2.70%
2	3	^	C++	10.34%	-0.46%
3	2	v	C	9.48%	-2.08%
4	4		Java	8.59%	-1.91%
5	5		C#	6.72%	-0.15%
6	6		JavaScript	3.79%	+0.68%
7	13	^^	Go	2.19%	+1.12%
8	7	v	Visual Basic	2.08%	-0.82%
9	11	^	Fortran	2.05%	+0.80%
10	8	v	SQL	2.04%	+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%

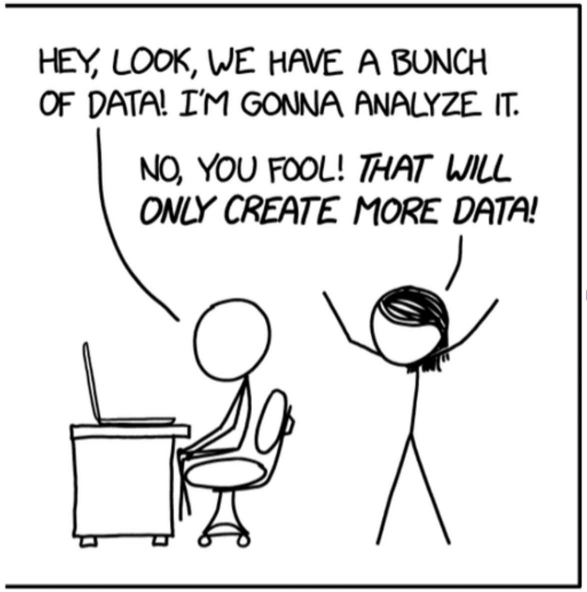
https://www.tiobe.com/tiobe-index/

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





From xkcd

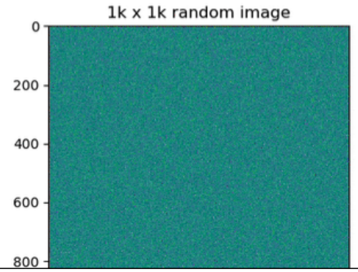
So... how much is a TB, really?

We have been talking about different data amounts of MB, GB, and TB. But, what does that really mean in reality? Let us explore what is a TB.

If **you** looked at one image with 1024 x 1024 pixels (1 Mpixels)

Here we create one image with 1000x1000 pixels with random values form a uniform distribution [0,1] and show it.

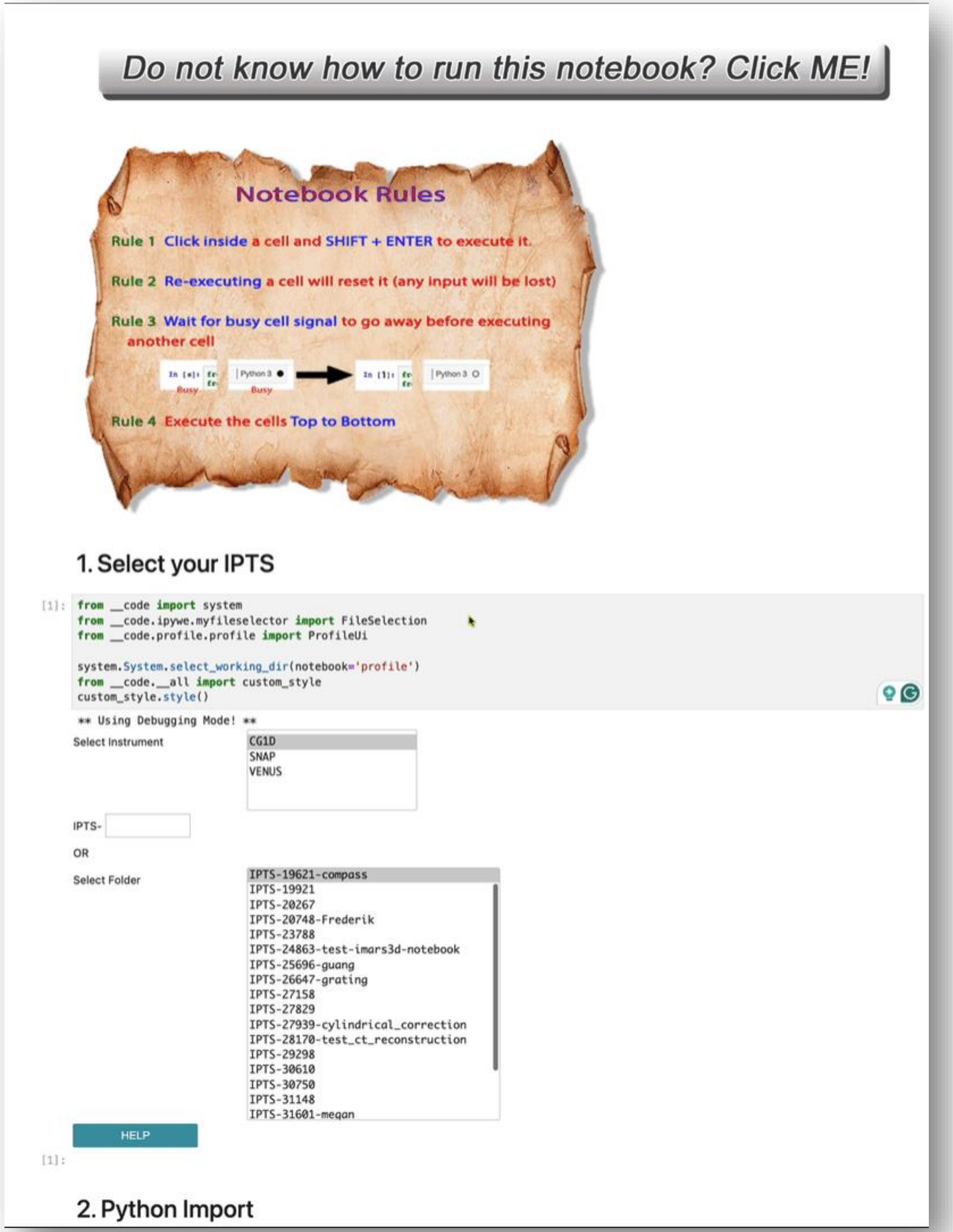
In [2]:
```
%matplotlib inline
import matplotlib.pyplot as plt
import numpy as np

plt.figure(figsize=(4,4))
plt.imshow(np.random.uniform(size = (1024, 1024)),
           cmap = 'viridis');
plt.title('1k x 1k random image');
```



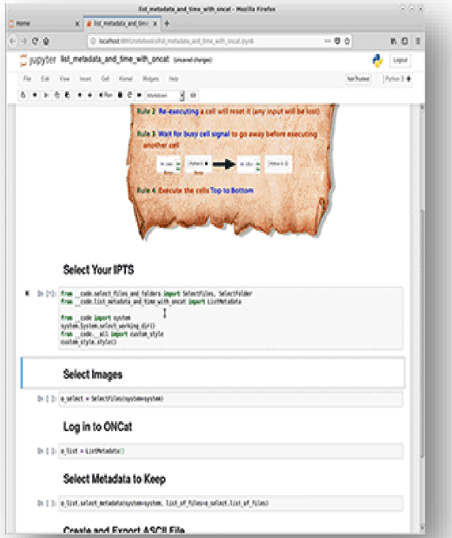
OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

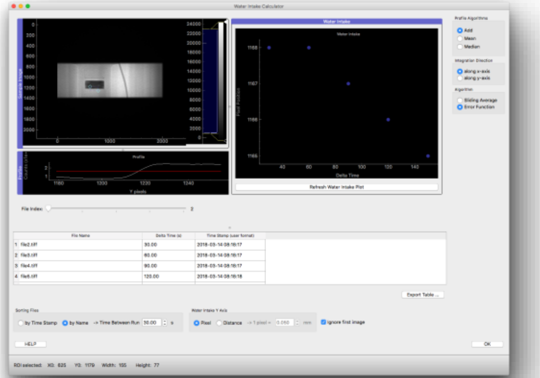
https://imaginglectures.github.io/Quantitative-Big-Imaging-2024/

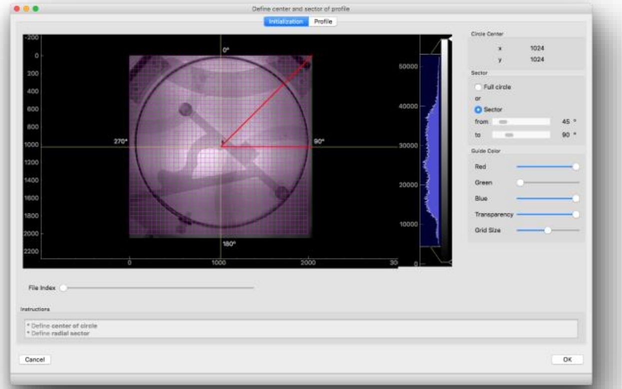
Notebooks

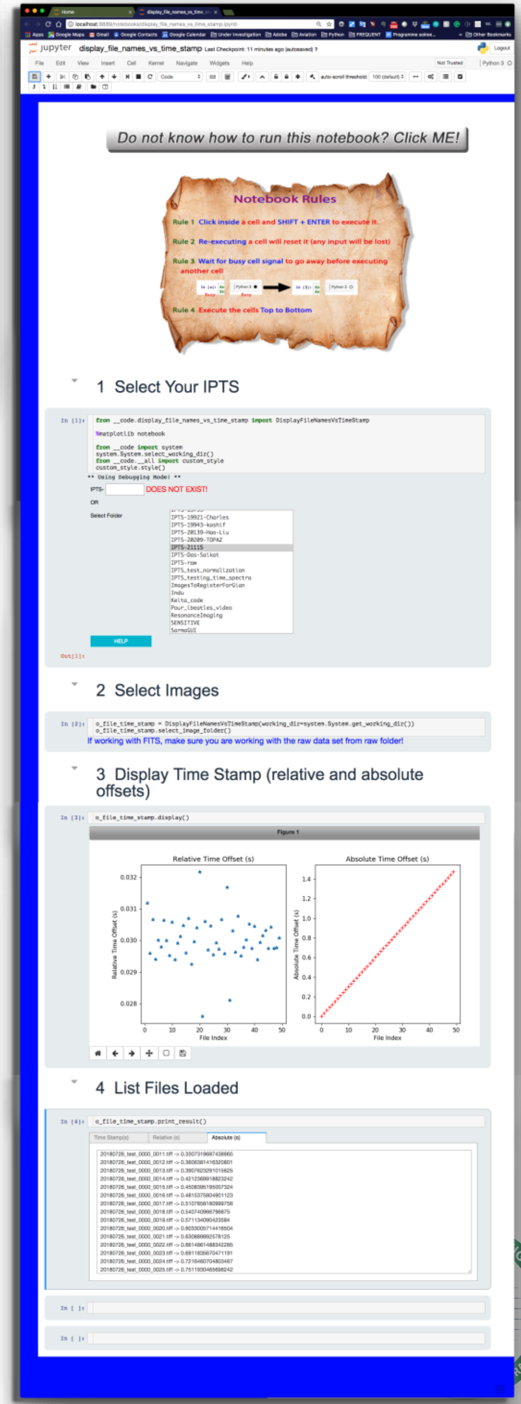

Do not know how to run this notebook? Click ME!
Notebook Rules
Rule 1 Click inside a cell and SHIFT + ENTER to execute it.
Rule 2 Re-executing a cell will reset it (any input will be lost)
Rule 3 Wait for busy cell signal to go away before executing another cell
Busy
Busy
Rule 4 Execute the cells Top to Bottom
1. Select your IPTS
[1]:
from __code import system
from __code.ipywe.myfileselector import FileSelection
from __code.profile.profile import ProfileUi
system.System.select_working_dir(notebook='profile')
from __code.__all import custom_style
custom_style.style()
** Using Debugging Mode! **
Select Instrument
CG1D
SNAP
VENUS
IPTS-
OR
Select Folder
IPTS-19621-compass
IPTS-19921
IPTS-20267
IPTS-20748-Frederik
IPTS-23788
IPTS-24863-test-imars3d-notebook
IPTS-25696-guang
IPTS-26647-grating
IPTS-27158
IPTS-27829
IPTS-27939-cylindrical_correction
IPTS-28170-test_ct_reconstruction
IPTS-29298
IPTS-30610
IPTS-30750
IPTS-31148
IPTS-31601-megan
HELP
[1]:
2. Python Import

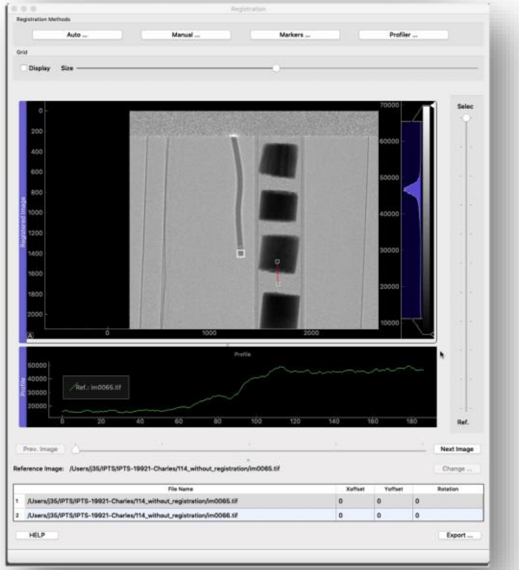
Notebooks

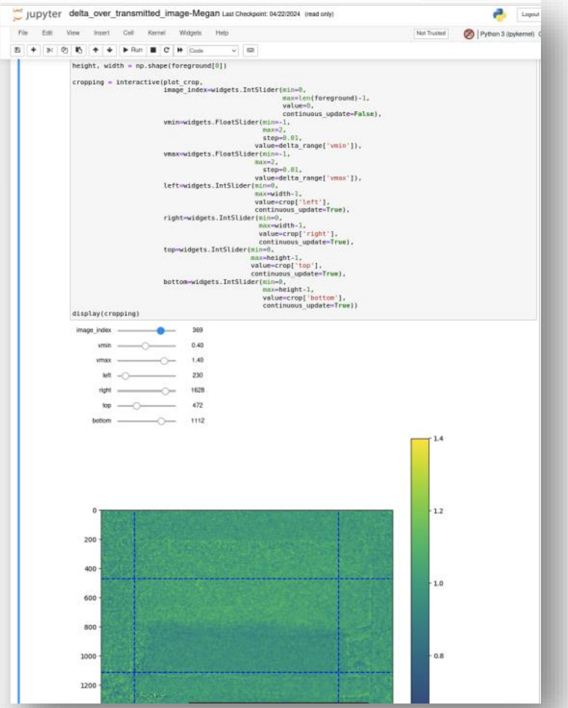

Select Your IPTS
Select Images
Log in to ONCat
Select Metadata to Keep

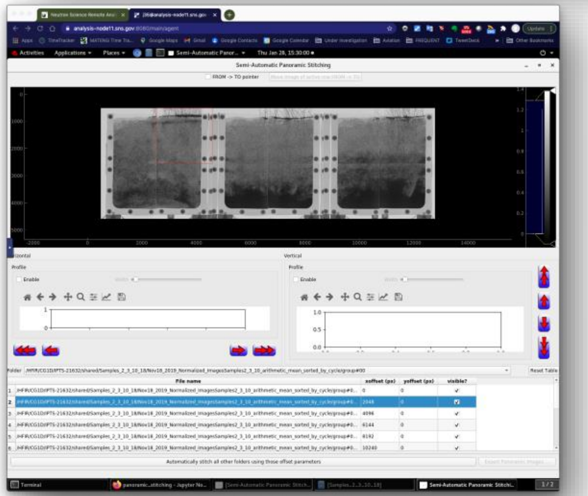


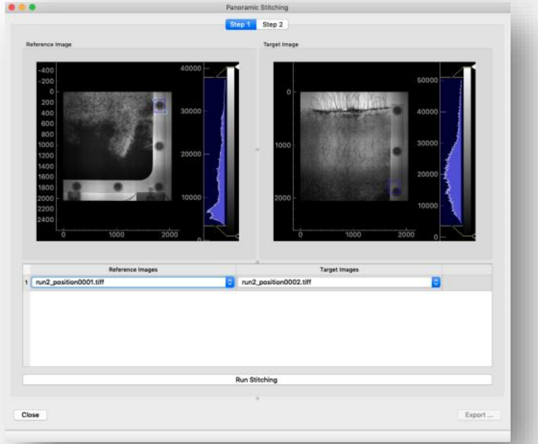



Do not know how to run this notebook? Click ME!
Notebook Rules
1 Select Your IPTS
2 Select Images
3 Display Time Stamp (relative and absolute offsets)
Relative Time Offset (s)
Absolute Time Offset (s)
4 List Files Loaded








Panoramic Stitching
Reference Image
Target Image
Run Stitching

The 5 things that will save your life

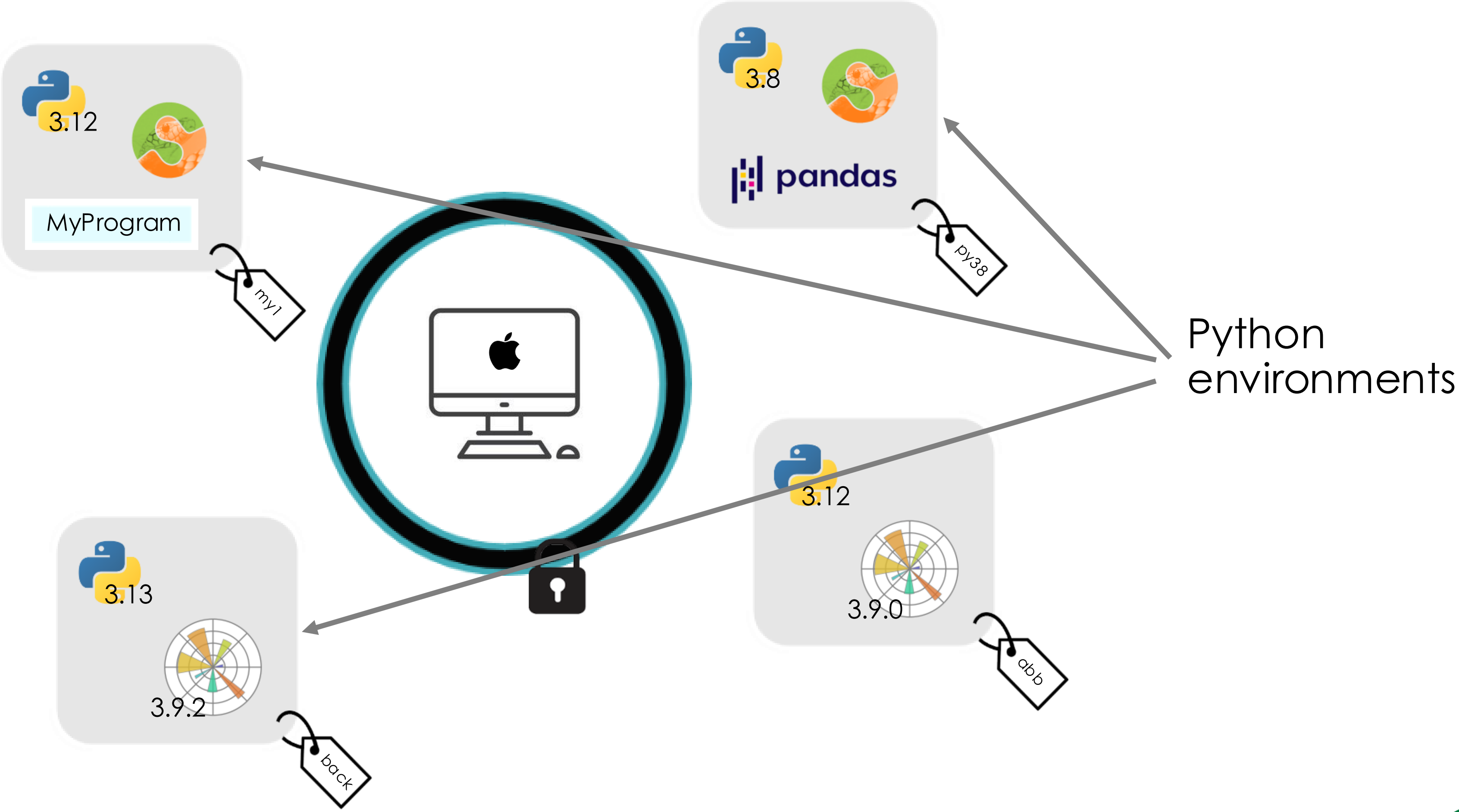
1 Pick the right language

2 **Stay green**

Stay green

We need to preserve our **environment!**

Anaconda.com



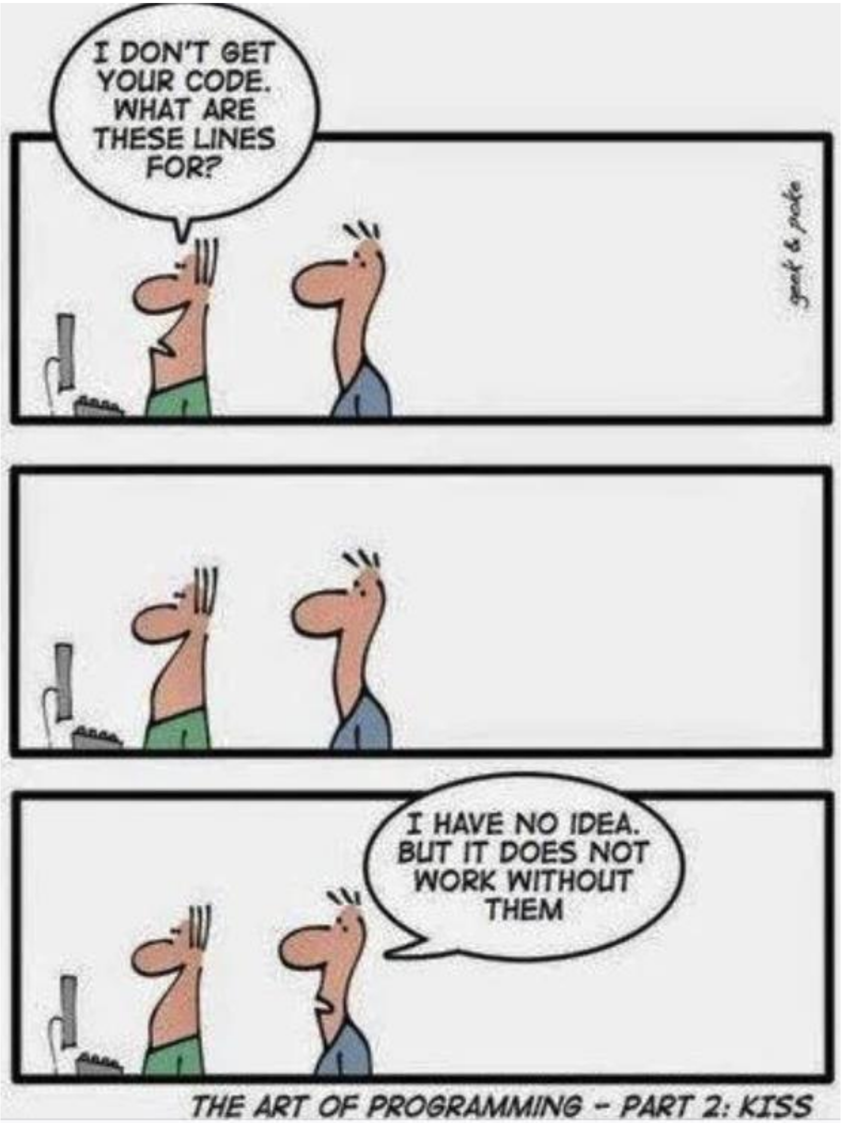
The 5 things that will save your life

1 Pick the right language

2 Stay green

3 **Write good code**

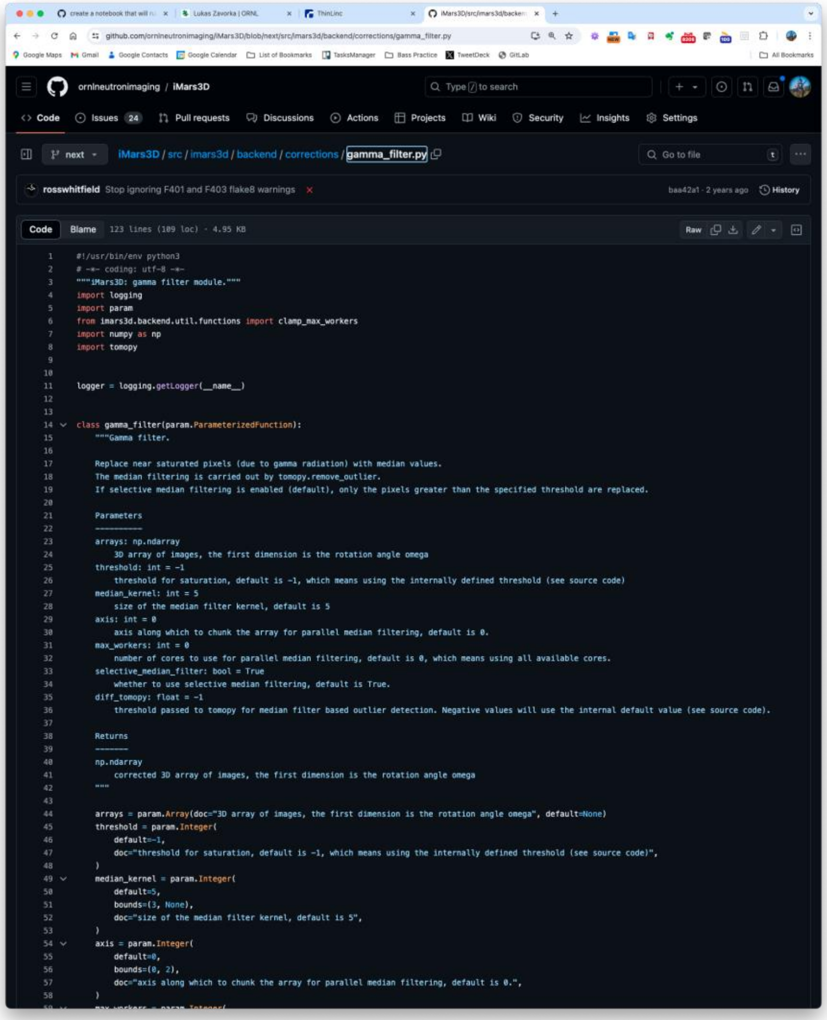
Write good code

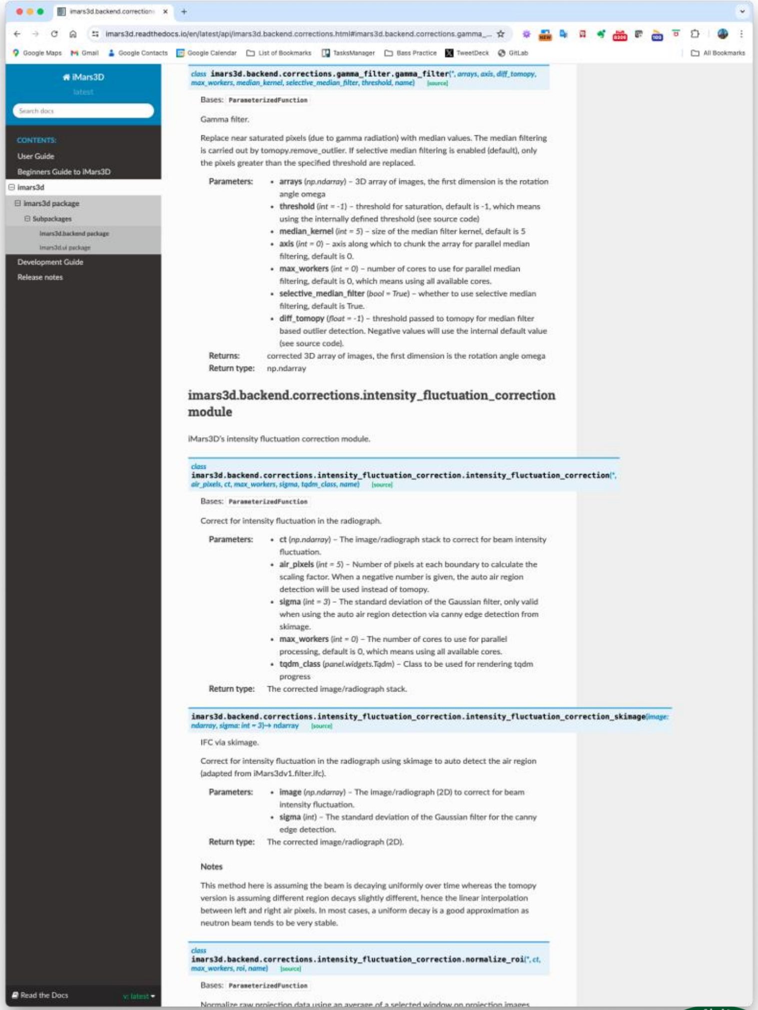


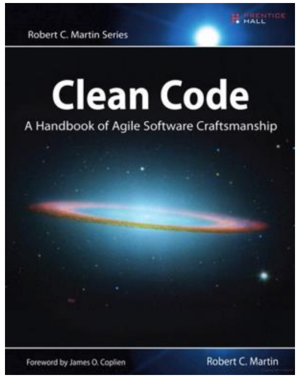
There is a good chance that later, you will be the one trying to understand your own code.

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







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

OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

Unit Test

Write good code

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 next one

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
- Later on, when you make changes, you will quickly find out if the software still works
- If someone report a bug, first write a unit test to reproduce the bug, then fix it!

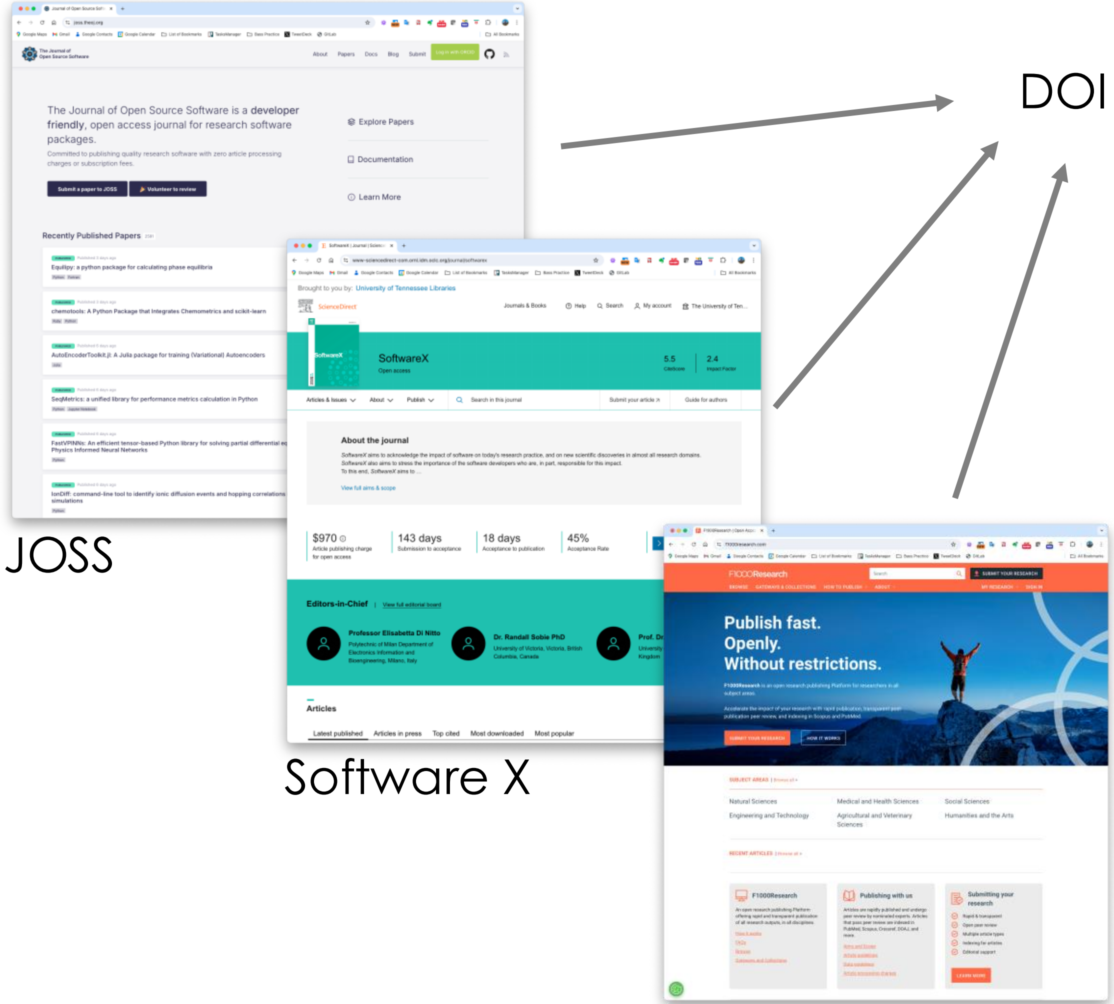
Disadvantages

- 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

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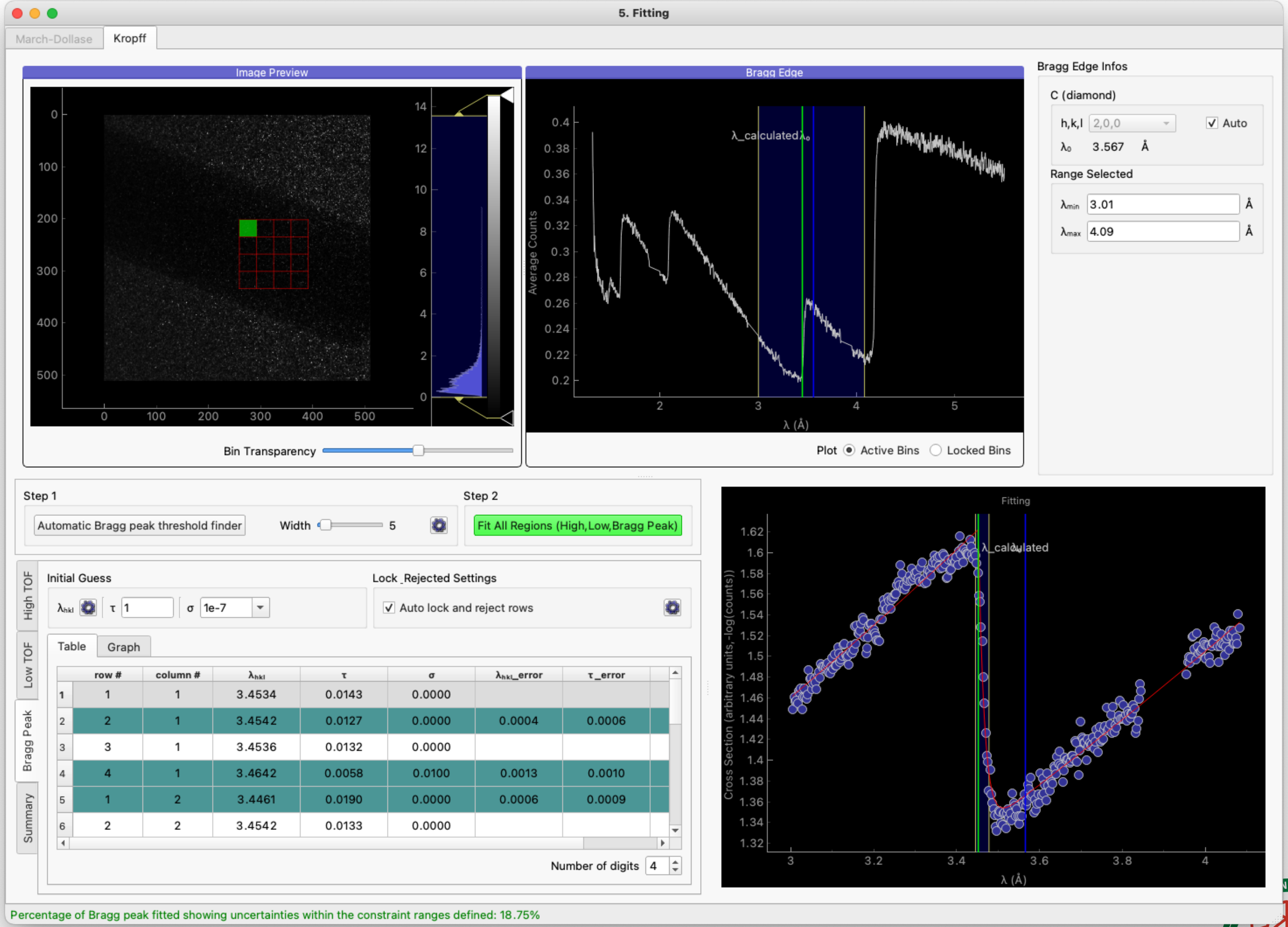
4 **How to keep your job!**

iBeatles

- Program that perform automatic **strain mapping calculation**

- 1 million lines of code
- 5 years development

- Kept top secret until today (**only copy** is on this machine!)

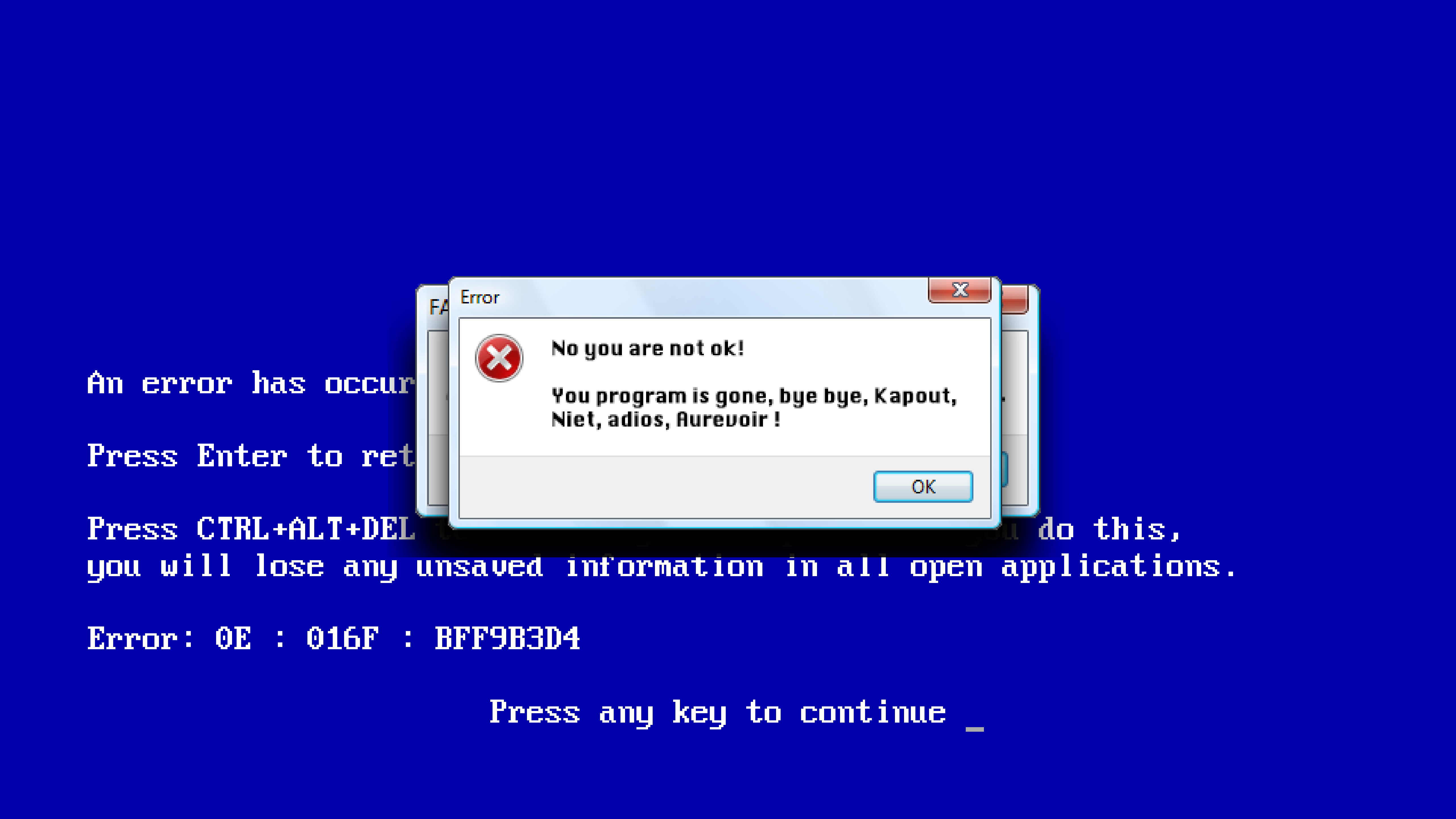


iBeatles

Demo time !

iBeatles

Demo time !

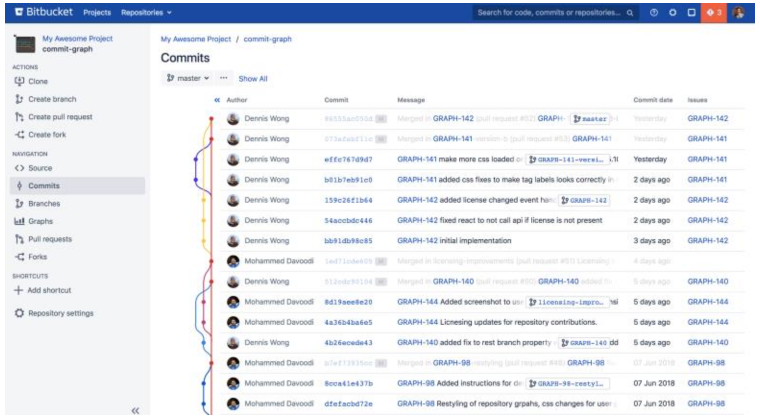


Error
No you are not ok!
You program is gone, bye bye, Kapout, Niet, adios, Aurevoir !
OK
An error has occur
Press Enter to ret
Press CTRL+ALT+DEL
do this,
you will lose any unsaved information in all open applications.
Error: 0E : 016F : BFF9B3D4
Press any key to continue _

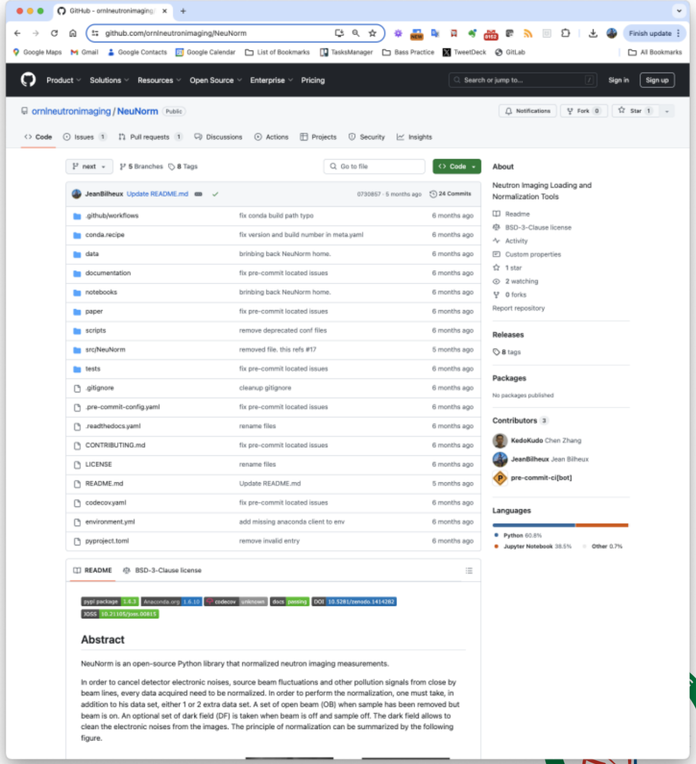

BACKUP

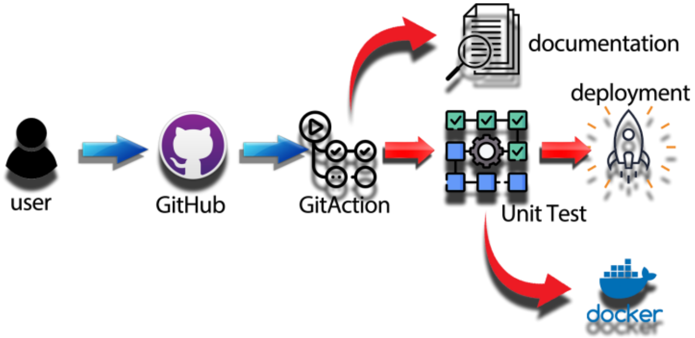
Repositories

- 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 never needs any software update
- It has a very small carbon footprint

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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https://forms.office.com/g/gtdnJGM87r

Thank you

Questions

NXS Lecture - Yuxuan Zhang, Hassina Bilheux & Jean Bilheux: "Neutron Imaging"

neutronimaging.ornl.gov