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09/13/2023

Novi-Sim Free trial

Virtual Tomography – Optimizing Data Acquisition Parameters Without a CT Scanner

presented by: Awen Autret

Can you briefly describe how you simulate CT data?

How is CT data simulated?

Simulation workflow:

1. Generate source spectrum

Lab X-ray source
Transmission
Reflection

Synchrotron X-ray source
Low divergence beam

2. Apply filters effect to the spectrum

Filters
- Chemical composition
- Density
-Thickness

3. Compute wavefront state after object

Object
- CAD models
- Chemical composition
- Density

4. Propagate wavefront and compute radiographs

Detector
- Scintillator
- PSF
- Sensor

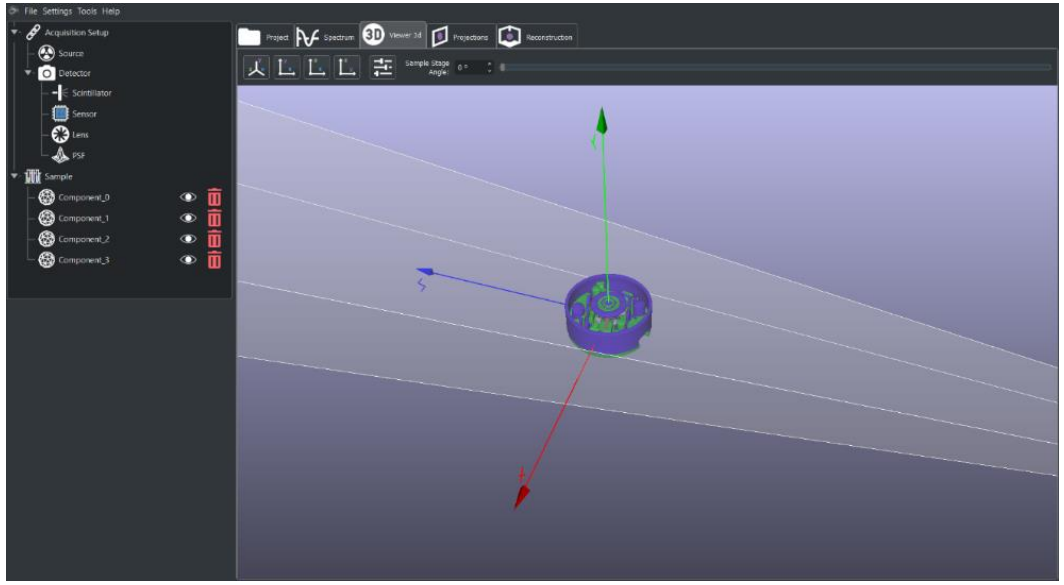
Physical models involved in a CT simulation:

- X-ray absorption, phase shift (ray tracing approach) **[Chantler2005]**
- Phase contrast (wave optics approach) **[Shen2008,Autret2017]**
- Noise propagation and coupling with PSF **[Martin2006]**
- X-ray scattering (hybrid approach) **[Kim2013,Jan2011, Agostinelli2003]**

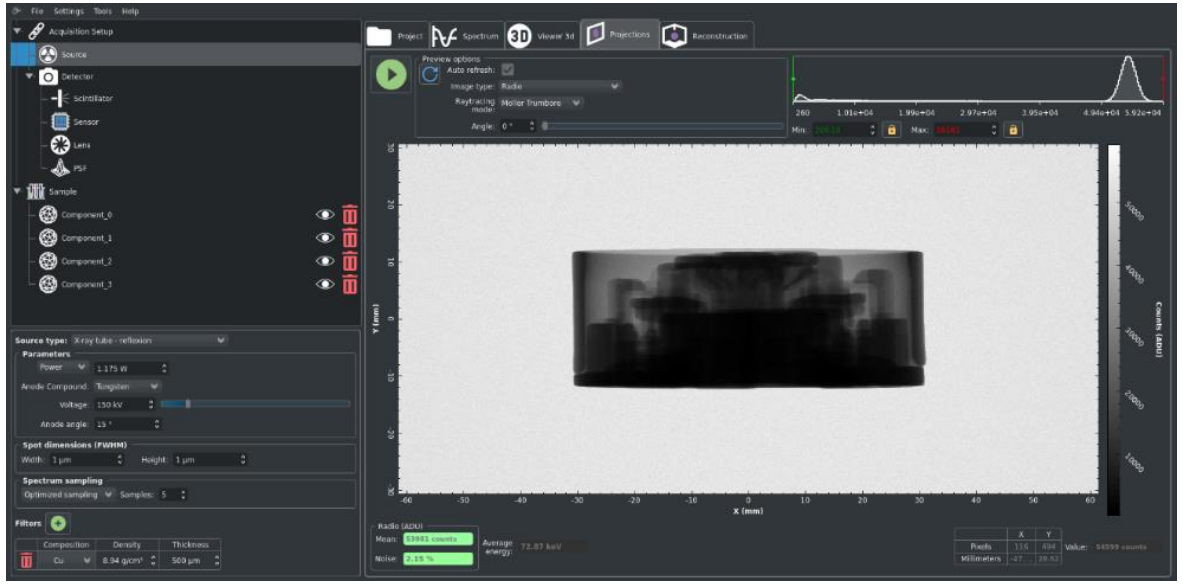
[Chantler2005] Chantler, C. T., et al. "X-ray form factor, attenuation and scattering tables (version 2.1) NIST." Gaithersburg, MD Available at http://physics. nist. gov/ffast (2005).
[Shen2008] Shen, A., et al. "Optimization and simulation of phase contrast imaging." Second International Symposium on Intelligent Information Technology Application (2008).
[Autret2017] Autret, A., et al. "Novi-Sim: A new fast simulation tool for X-ray tomography. " Int. Conf. on Tomography of Materials and Structures (2017)
[Martin2006] Martin, T., et al. "Recent developments in X-ray imaging with micrometer spatial resolution." Journal of synchrotron radiation (2006)
[Kim2013] Kim, K. S., et al. "Ultra-fast hybrid CPU–GPU multiple scatter simulation for 3-D PET." IEEE journal of biomedical and health informatics (2013)
[Jan2001] Jan, S., et al. "GATE V6: a major enhancement of the GATE simulation platform enabling modelling of CT and radiotherapy." Physics in Medicine & Biology (2011)
[Agostinelli2003] Agostinelli, S., et al. "GEANT4—a simulation toolkit." Nuclear instruments and methods in physics research section A (2003)

CT simulation in practice

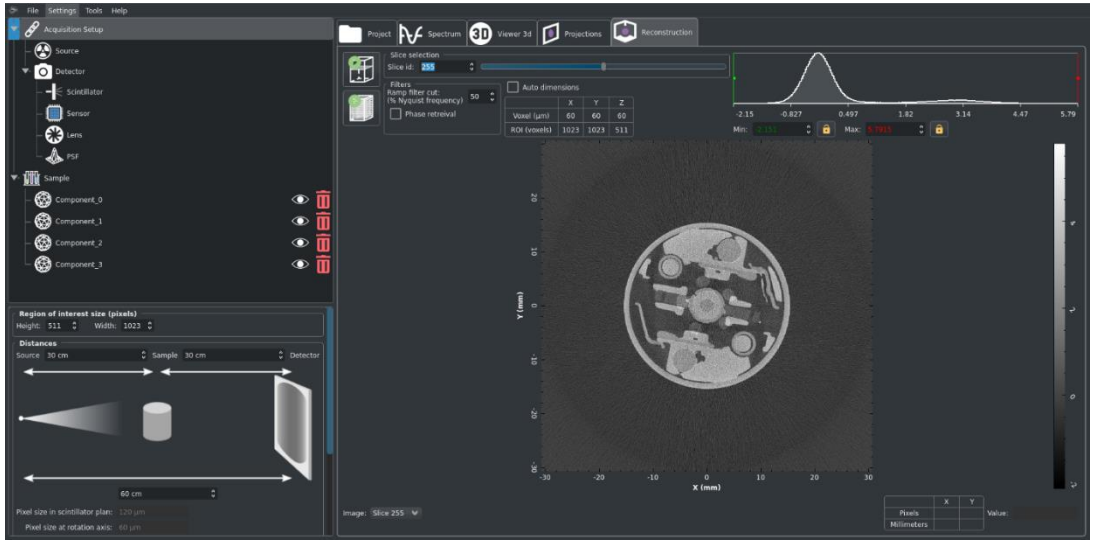
1. Setting up the objects



2. Configuring the system



3. Reconstruction of the generated radiographs



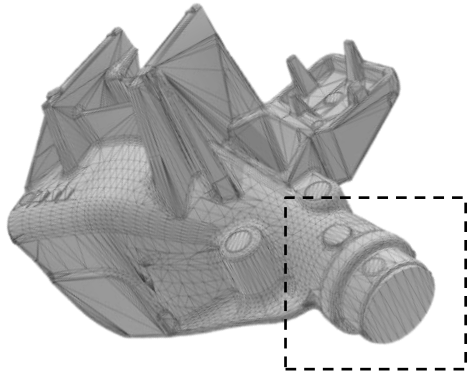
Polling Question #1

Who uses NOVITOM's tools and how are they benefitting from the simulation capability?

Feasibility analysis
Detection limit study

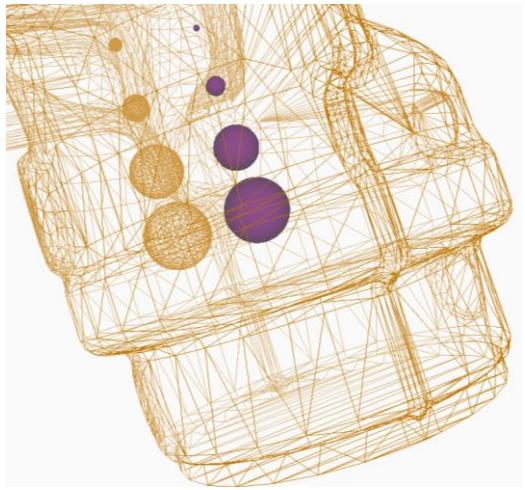
For:
- **Companies and institutions that use CT**

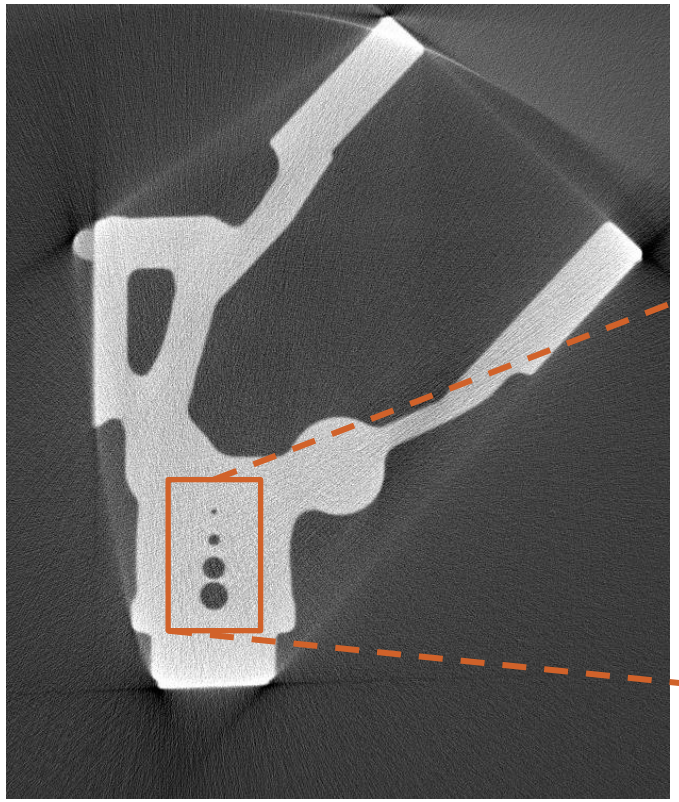
- For given experimental equipment, what are the geometrical detection limits of defects?



CAD design in STL format

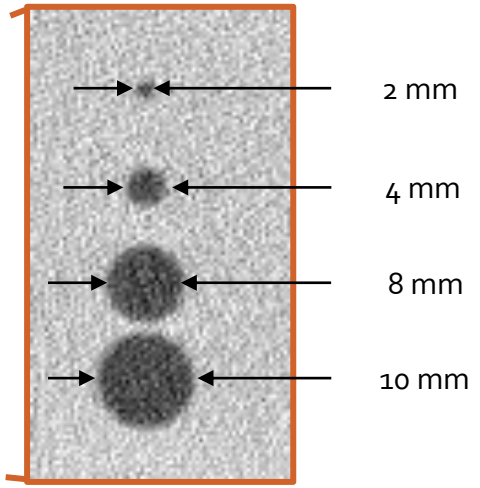
Add inclusions + pores





A slice of the CT scan of the part

Pores of different sizes introduced to the part in Novi-Sim

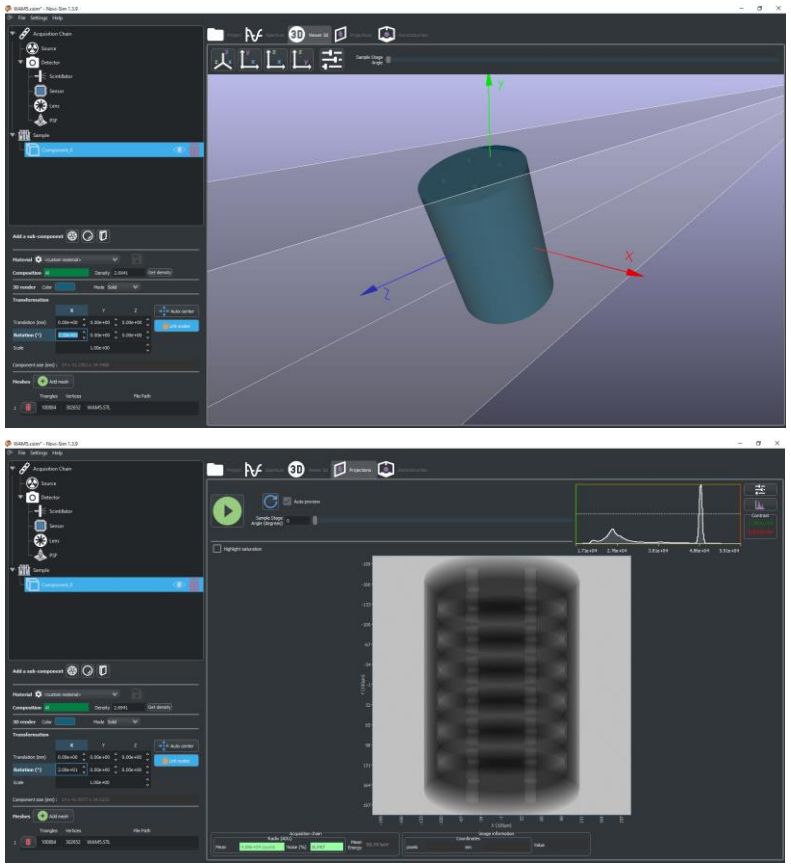


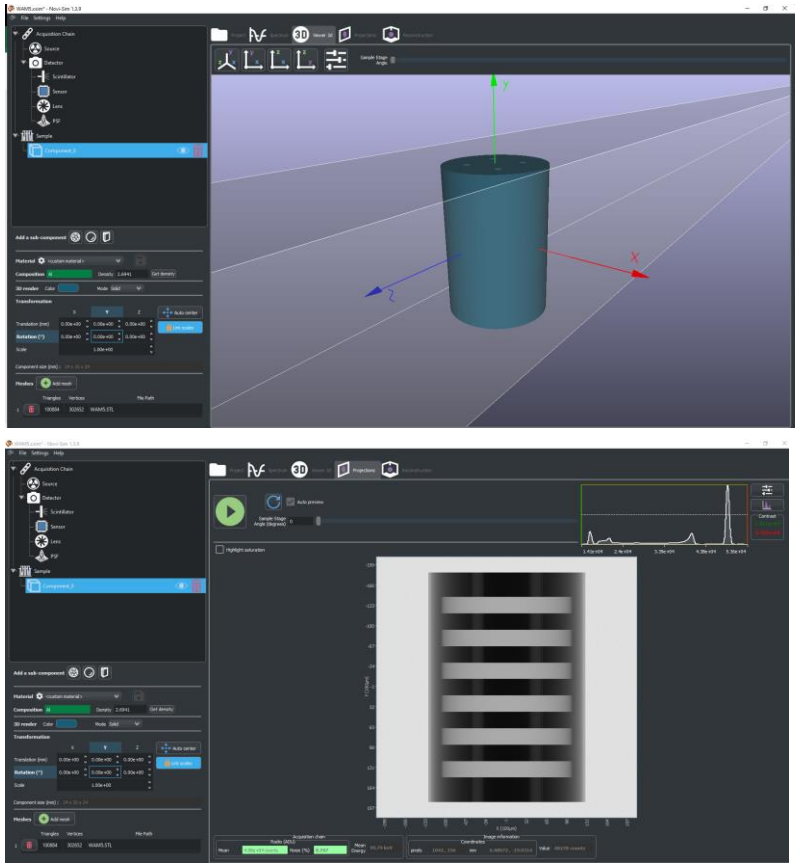
Setup optimization

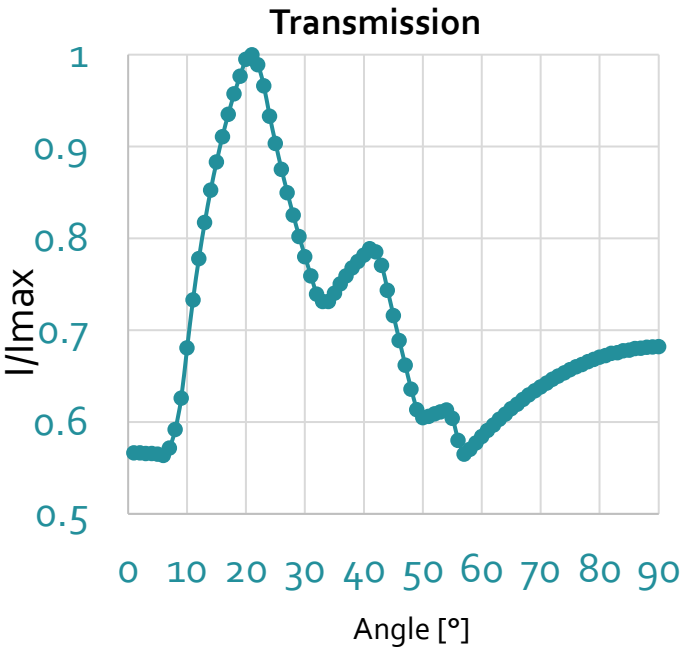
For:

➢ **Companies and institutions that use CT**

- What sample orientation gives the best image quality?
- What scan time give a sufficient image quality to detect the defects of interest?
- What source tension and filters allow the wanted analysis and a fast acquisition?





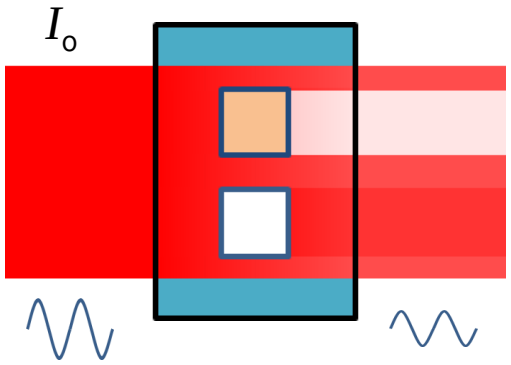


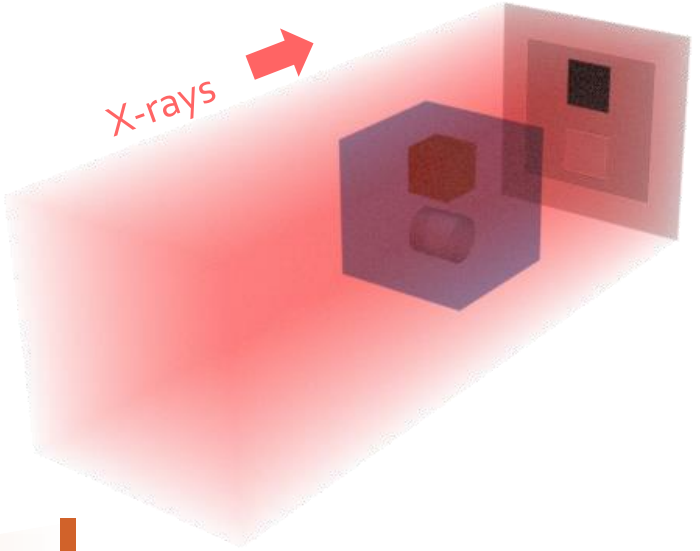
Optimization of acquisition parameters and part orientation

Training for radiography and CT

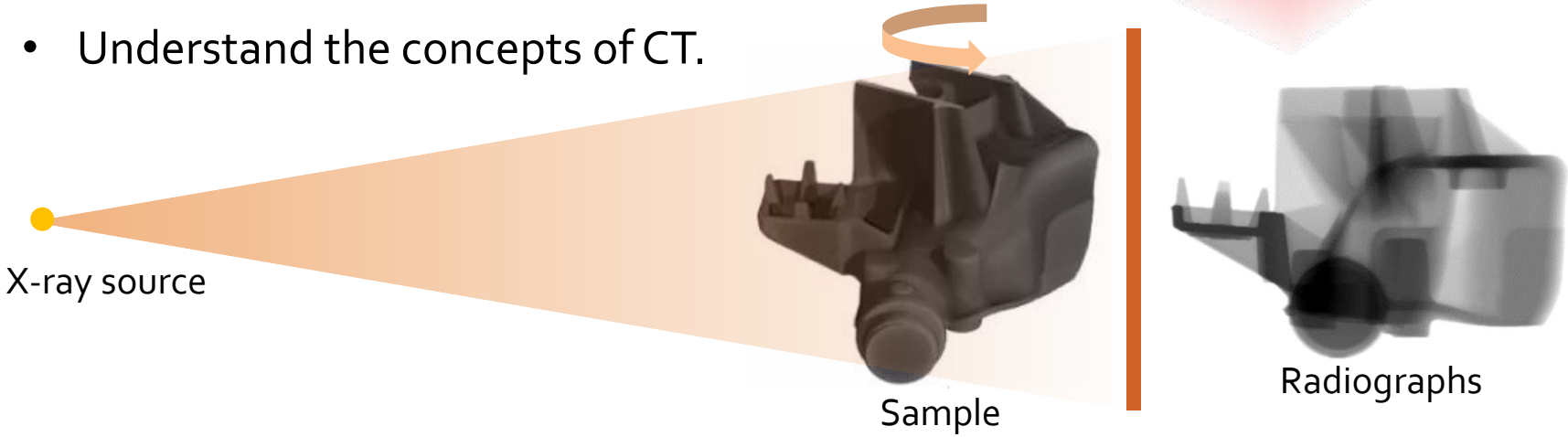
For:
- **Training institutions**

- Get a feeling and understand how X-rays interact with the matter to generate radiographs.

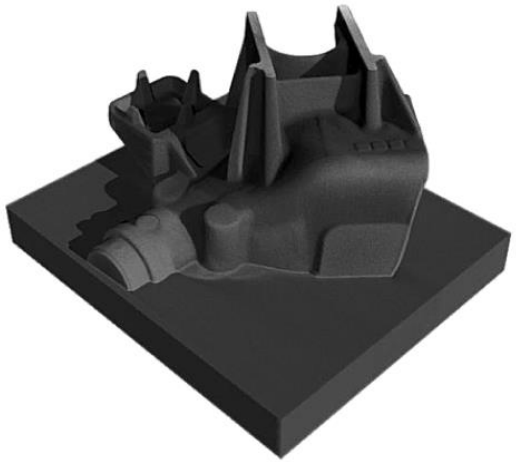




- Understand the concepts of CT.



Radiographs


CT
Reconstruction

- Understand how the acquisition parameters influence the CT images.

Building databases to train AIs

For:

- **Research labs**
- **Companies developing AI based CT image processing tools**

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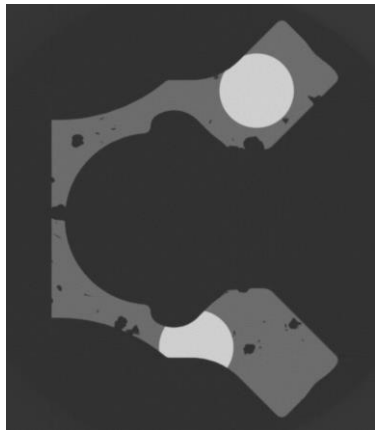
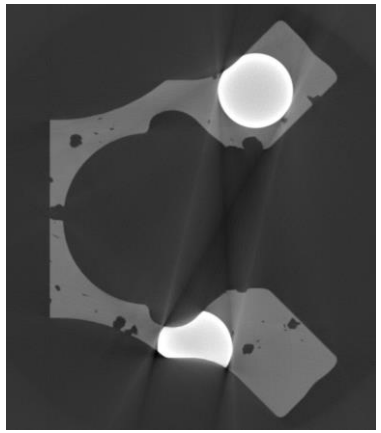
NOVI-SIM
X-RAY CT SIMULATOR



Artifact free image

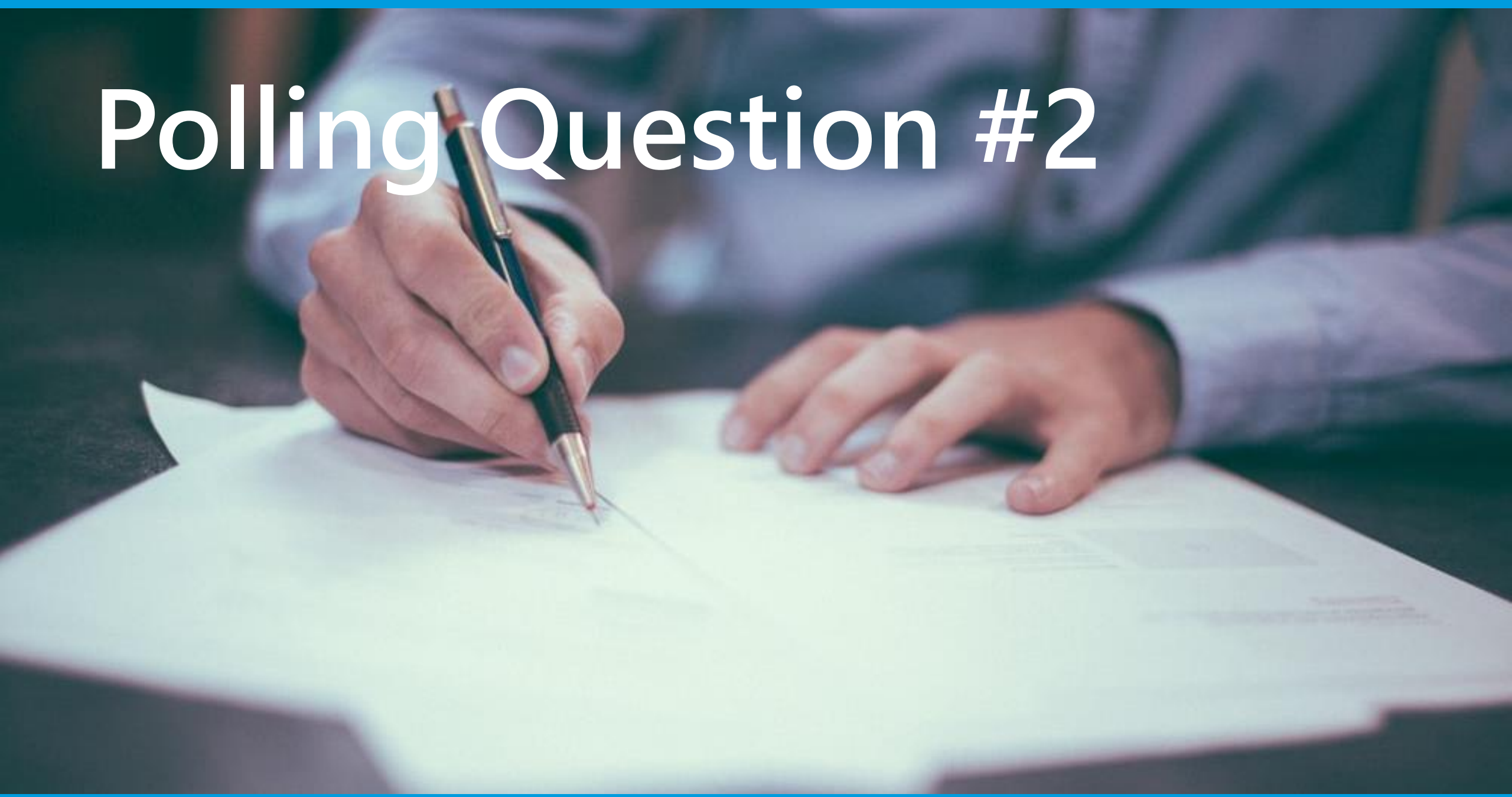


Artifact simulated image

Training database

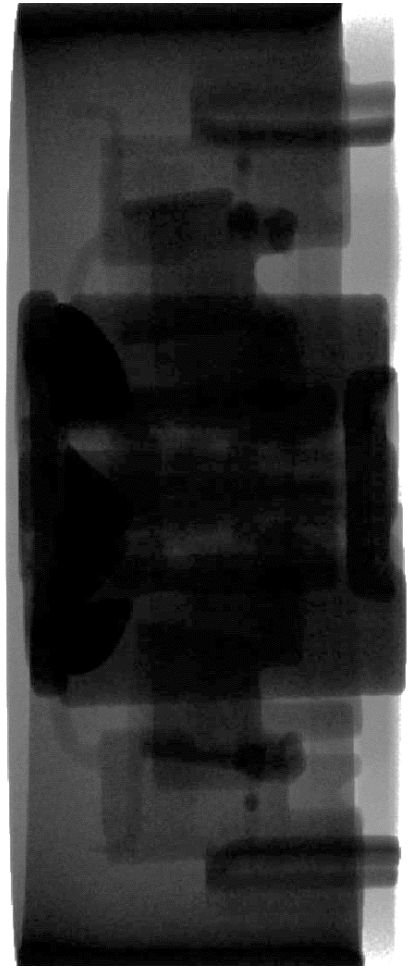
Neural network

Polling Question #2



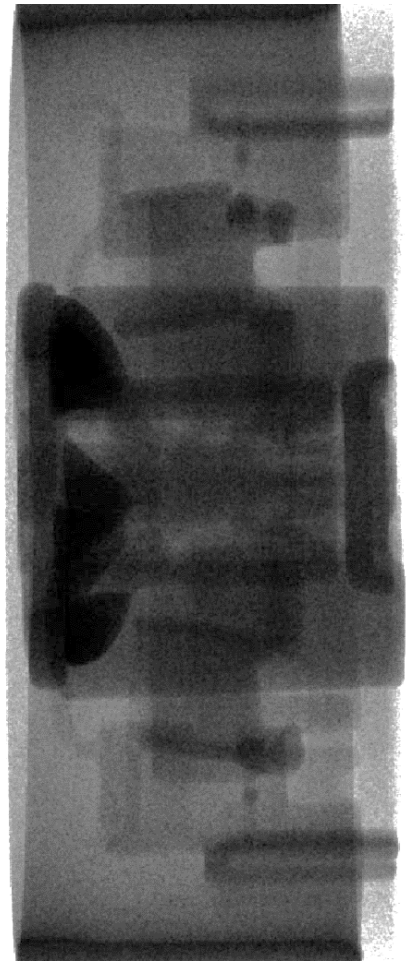
How can you use simulations to optimize measurement conditions?

Scan parameters optimization using radiographs



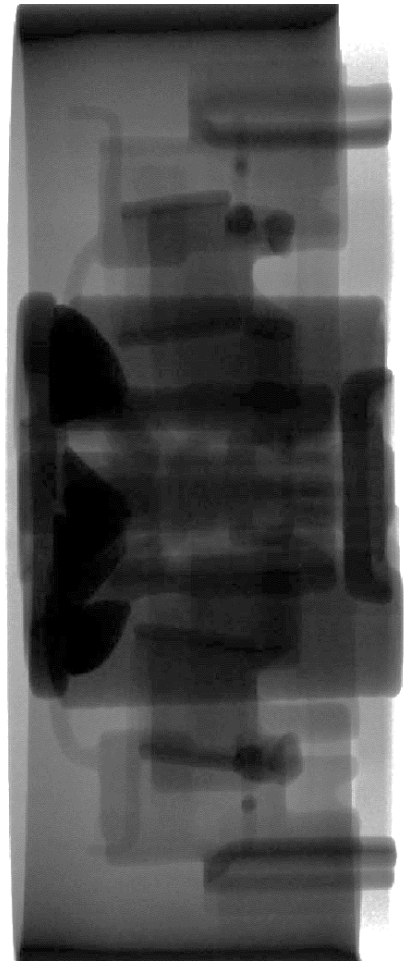
Low transmission

Add filters

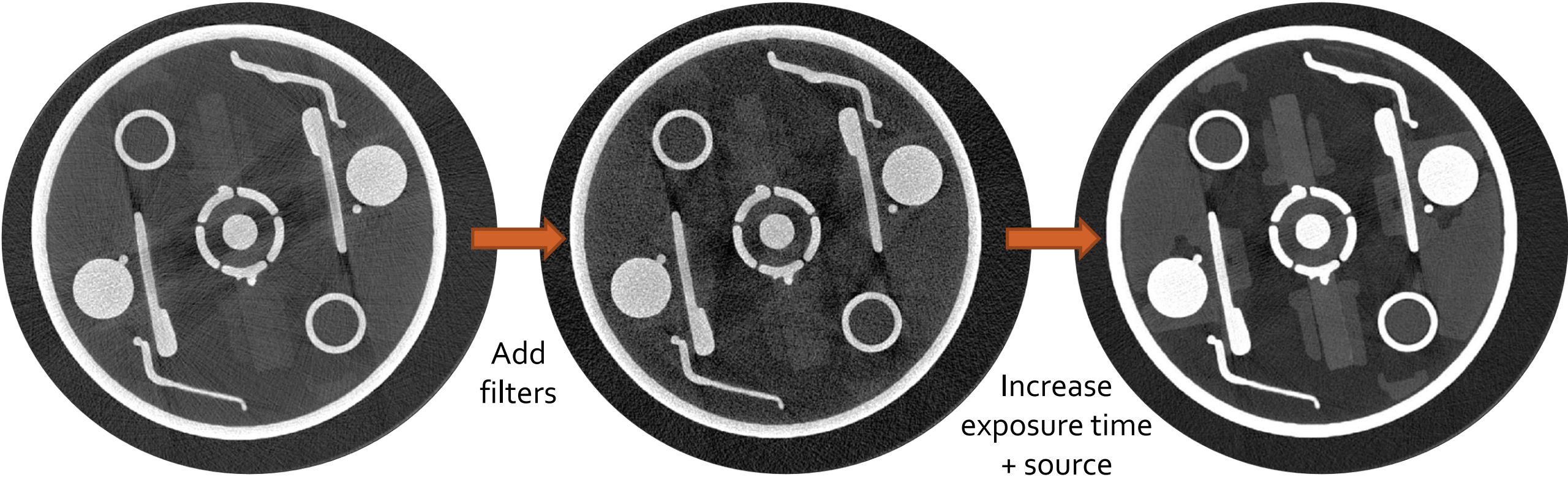


Low signal to noise ratio

Increase exposure time



Scan parameters optimization using tomography



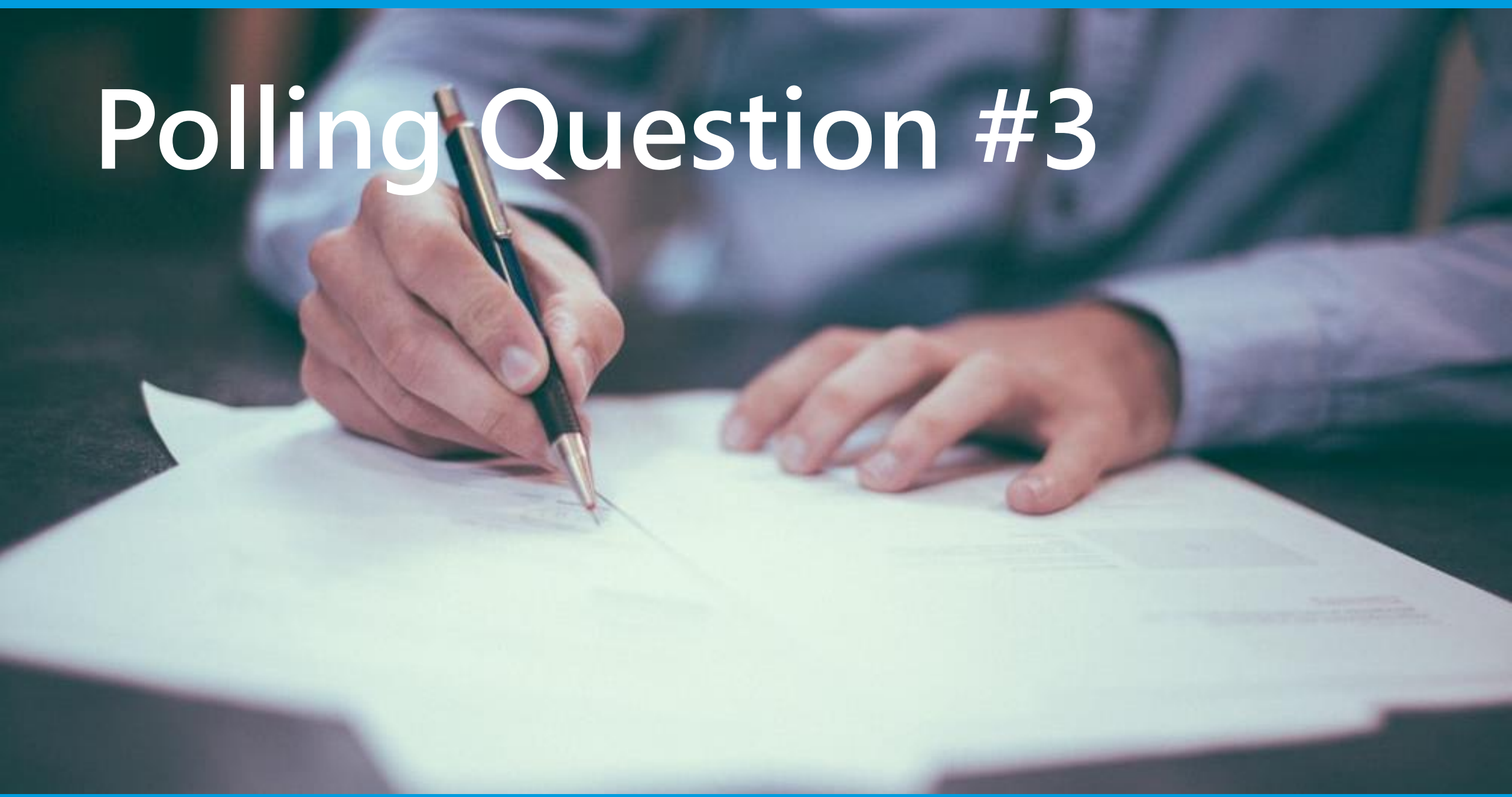
Beam hardening + streaks

Add filters

Beam hardening + noise

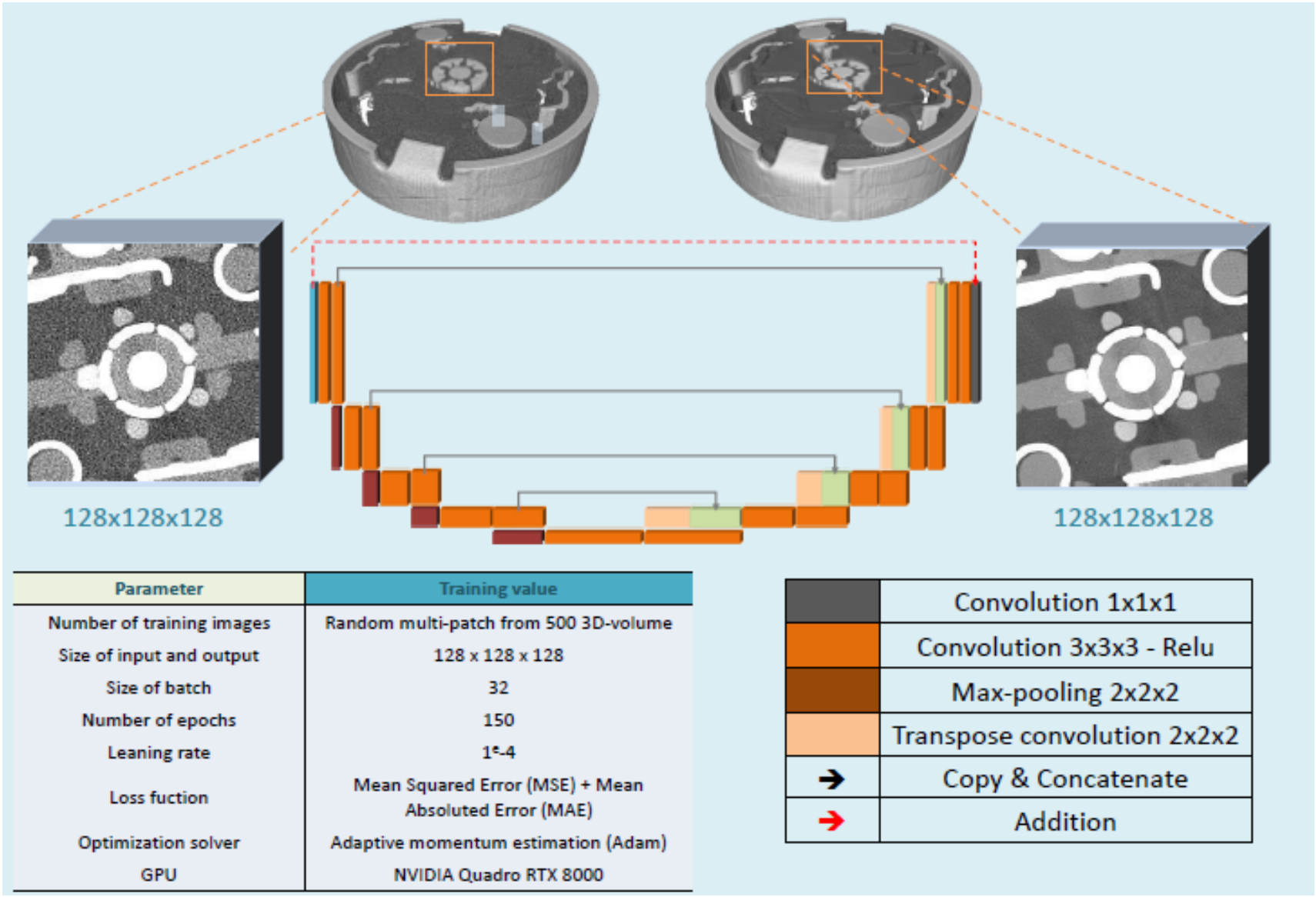
Increase exposure time + source tension

Polling Question #3



Can you use simulations to create training data for machine learning?

Noise reduction



Parameter	Training value
Number of training images	Random multi-patch from 500 3D-volume
Size of input and output	128 x 128 x 128
Size of batch	32
Number of epochs	150
Leaning rate	1e-4
Loss fuction	Mean Squared Error (MSE) + Mean Absoluted Error (MAE)
Optimization solver	Adaptive momentum estimation (Adam)
GPU	NVIDIA Quadro RTX 8000

	Convolution 1x1x1
	Convolution 3x3x3 - Relu
	Max-pooling 2x2x2
	Transpose convolution 2x2x2
→	Copy & Concatenate
→	Addition

[Nguyen2022] Nguyen, Duy, et al. "Ring Artifacts Removal & Noise Reduction in X-Ray Computed Tomography Using Deep-Learning." (2022).

Noise reduction – Examples

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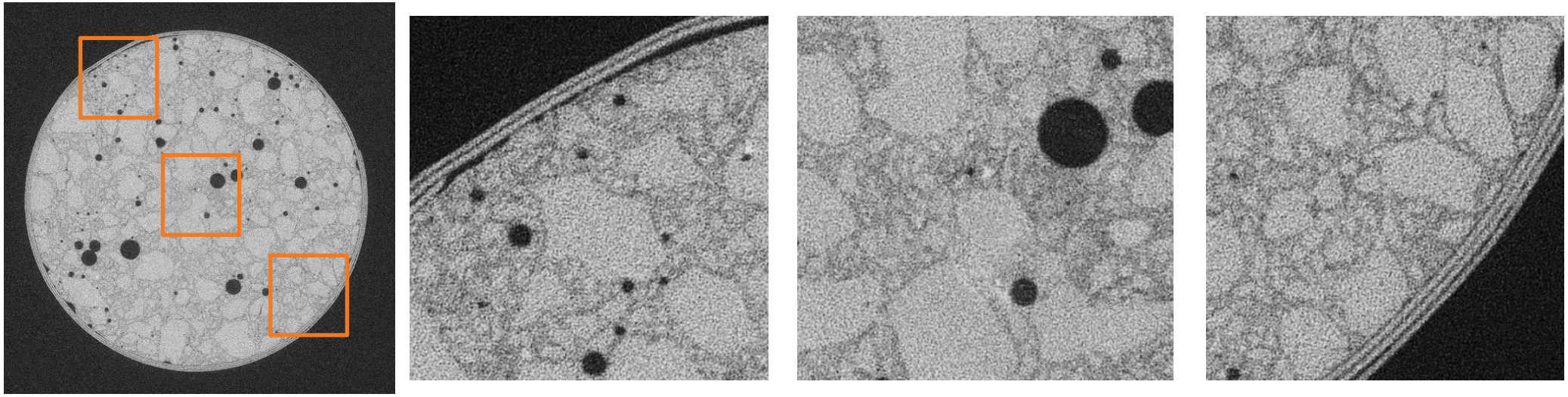
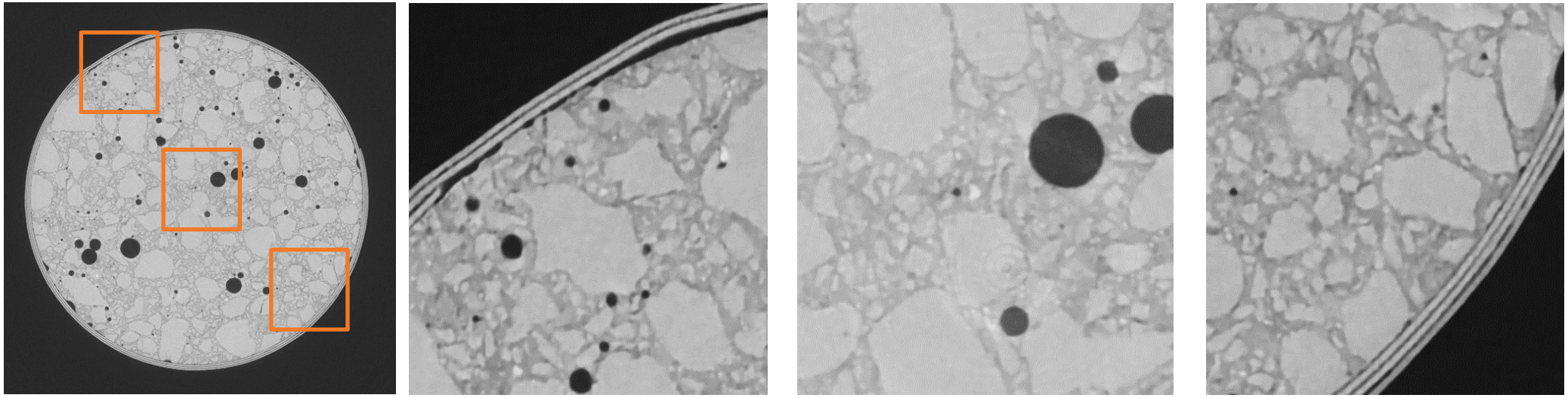
Original

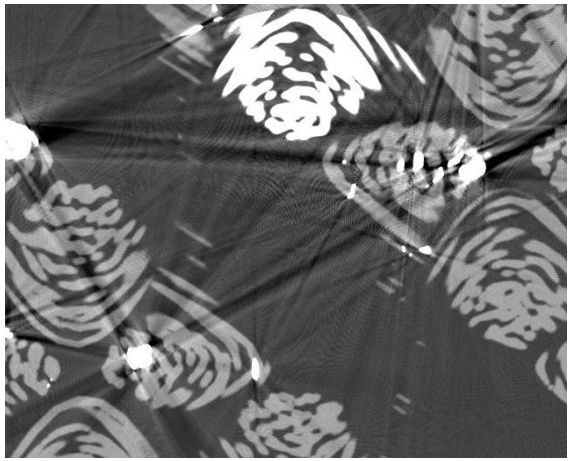


AI corrected

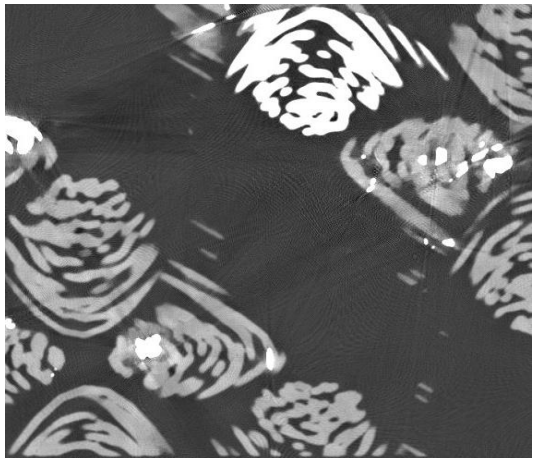


Beam hardening correction- Simulated example

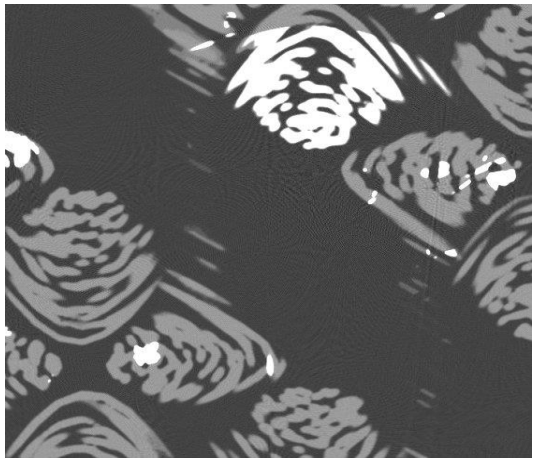
- Network architecture
  - U-Net 2D **[Ronneberger2015]**
  - 4 levels
  - 32 filters
  - Activation function : ReLu
  - Max pooling, transposed convolution
- Training set
  - $5x10^4$ pairs of 1024^2 images
- Speed
  - ~30 minutes per 2048^3 volume using a Titan RTX



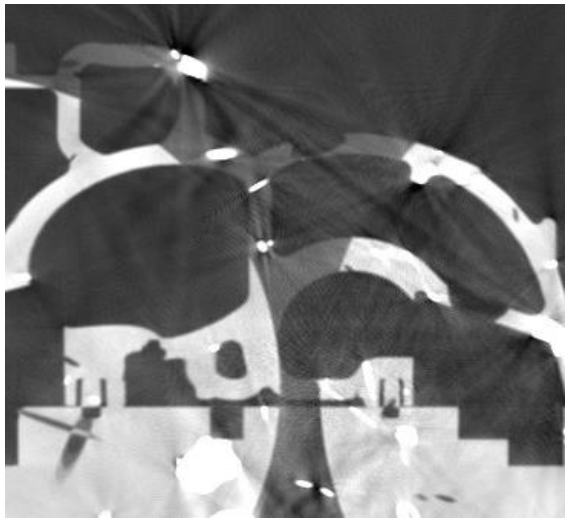
Original

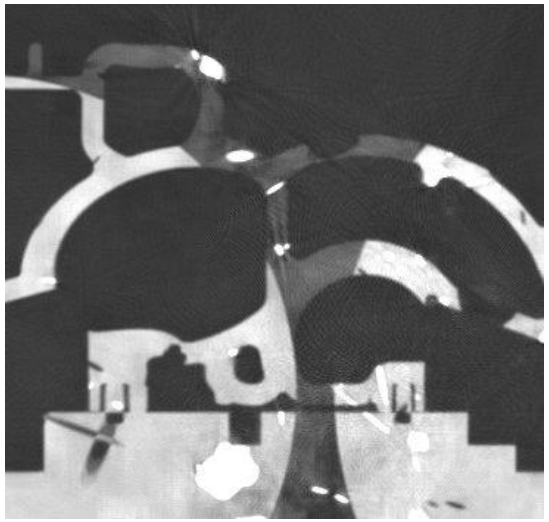


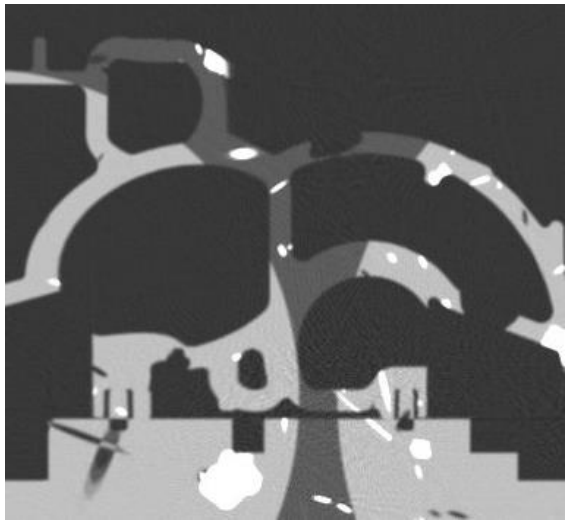
AI corrected



Ground truth

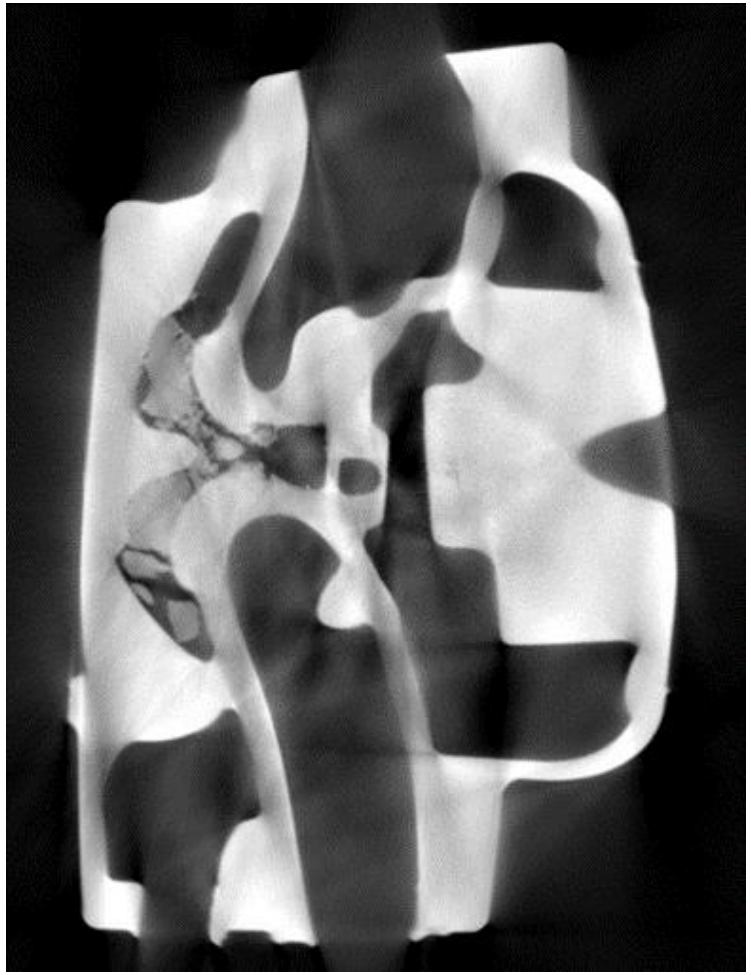






[Ronneberger2015] Ronneberger, O., et al. "U-net: Convolutional networks for biomedical image segmentation." *MICCAI 2015*

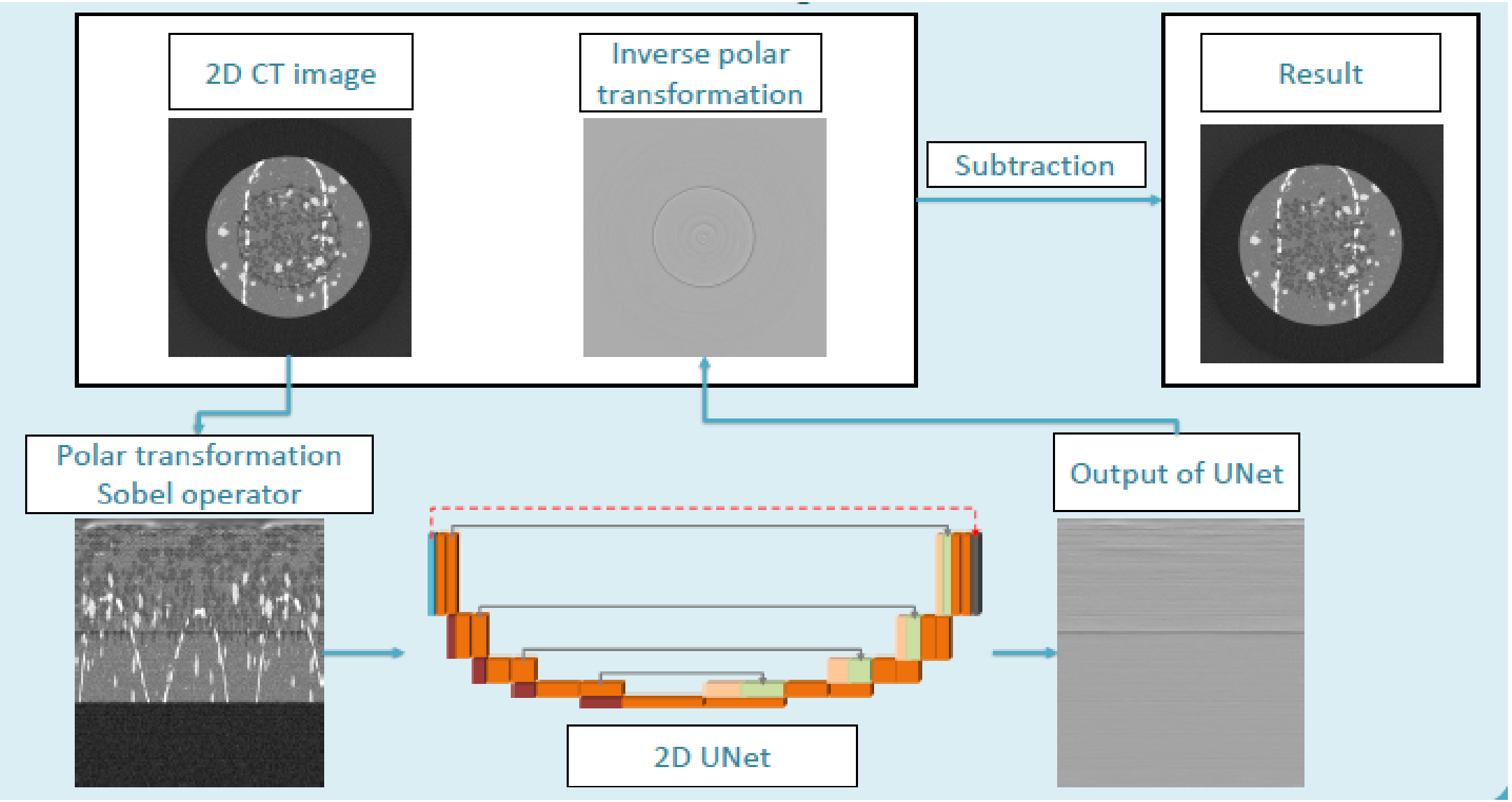
Beam hardening correction - Application



Original Image with artefacts

AI corrected image

Ring artifacts correction



Ring artifacts correction - Example

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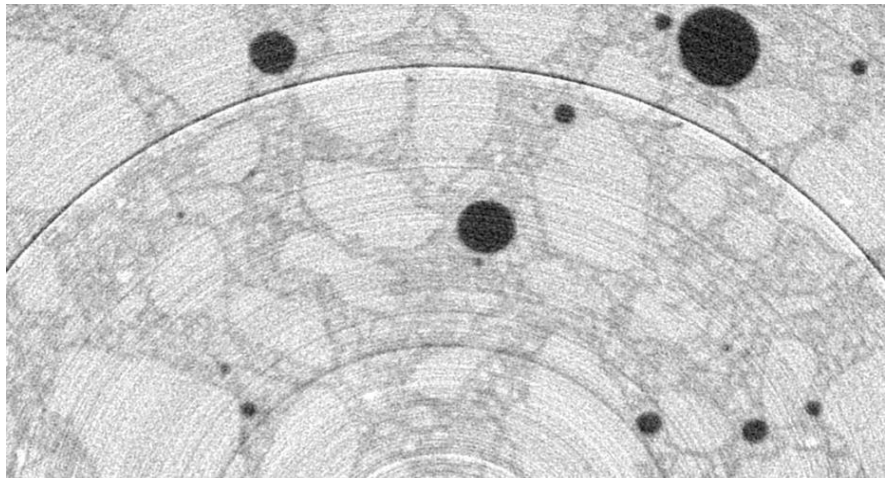
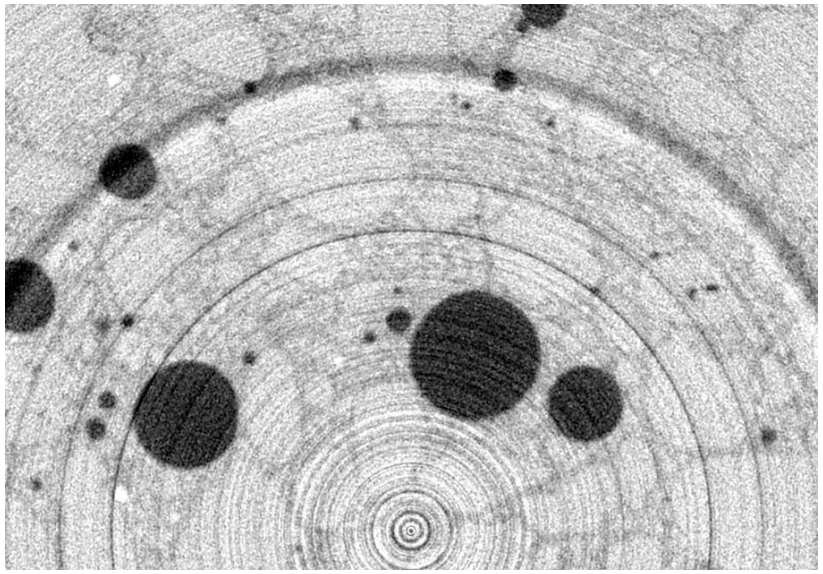
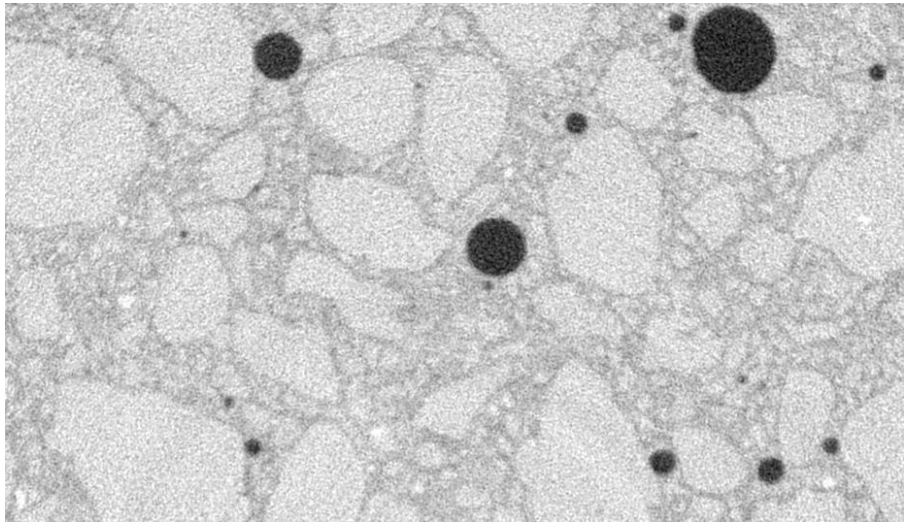
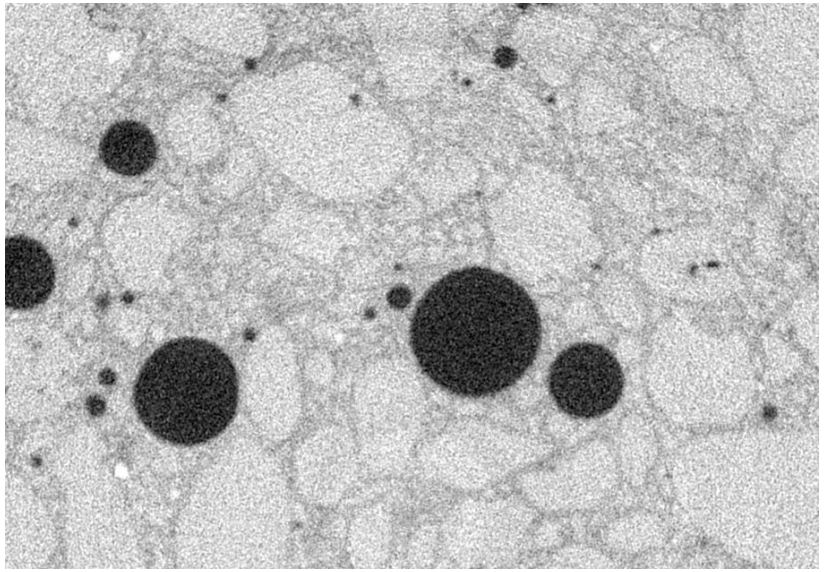
Original





AI corrected





Beam hardening correction to improve segmentation

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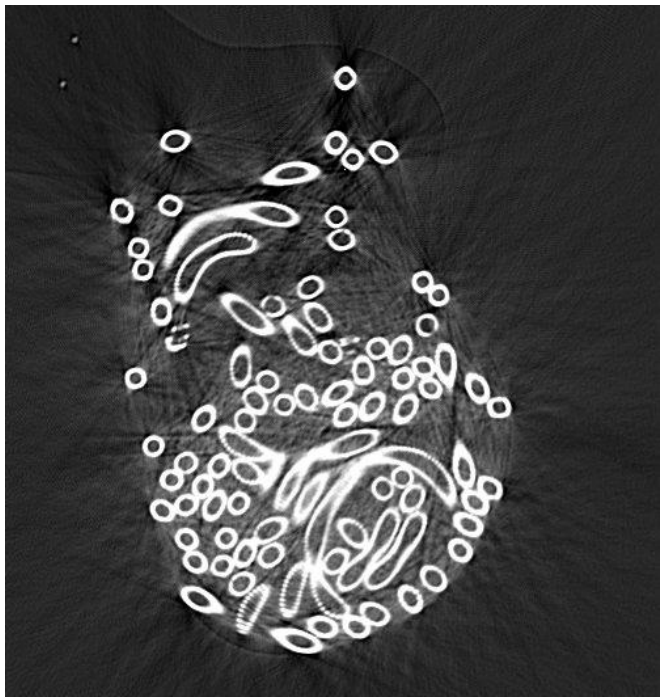
CT slices



Segmented slices

Original Image with Beam hardening

AI corrected image

Segmentation after ring artefacts correction

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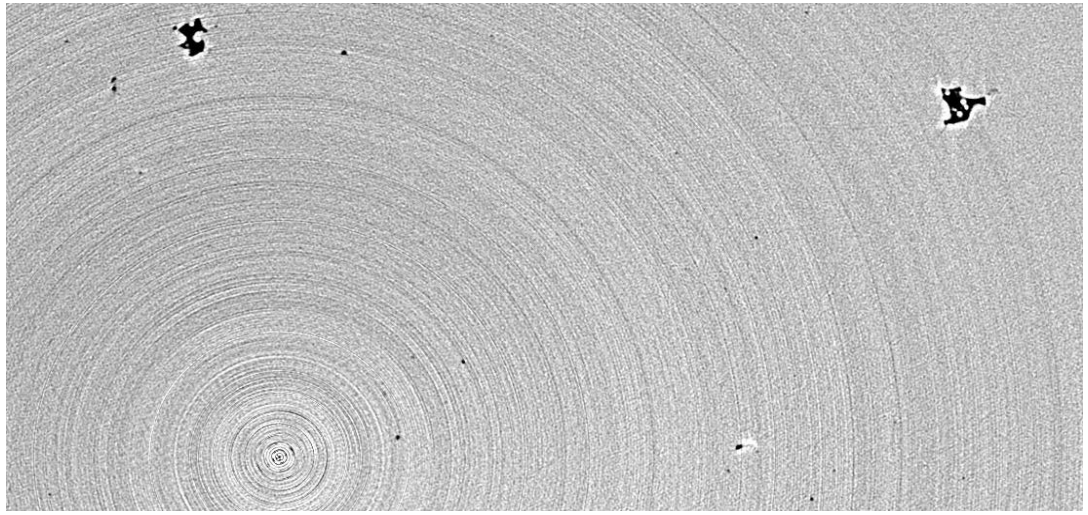
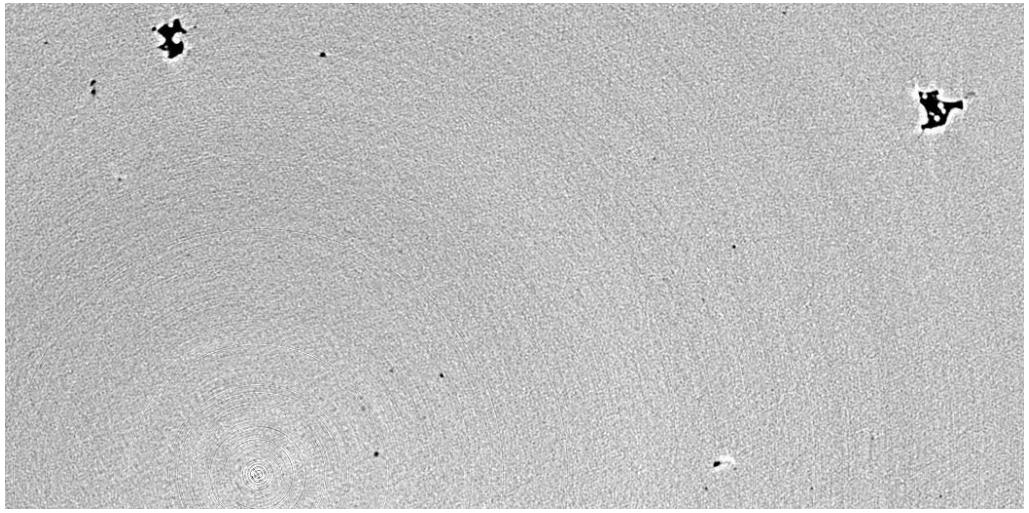
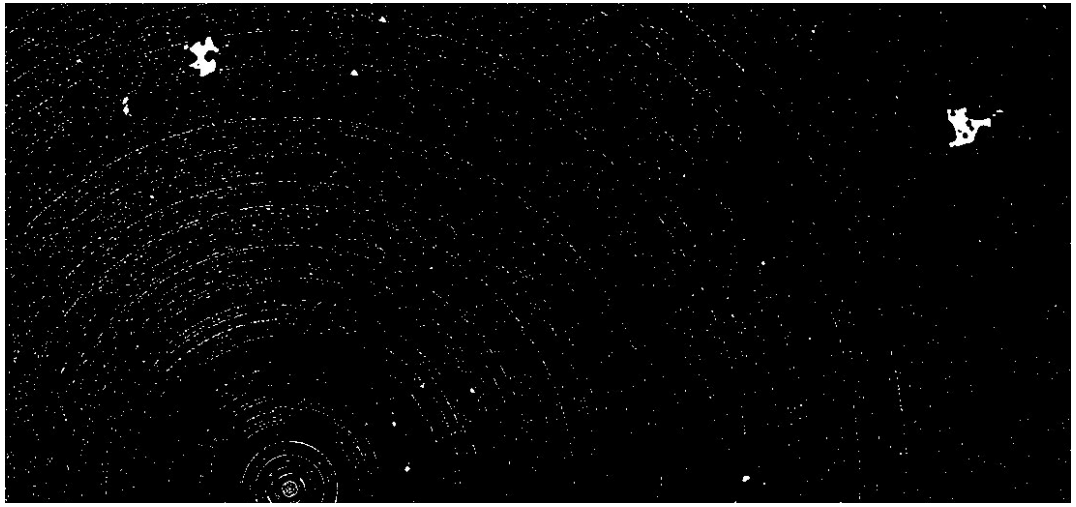
CT slices





Segmented slices



Original Image with ring artefacts

AI corrected image

Segmentation after noise reduction

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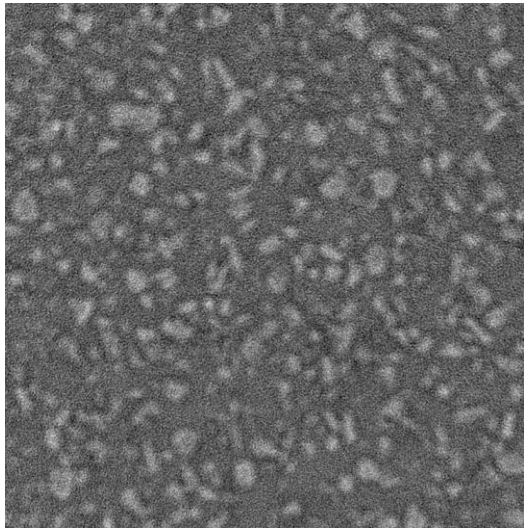
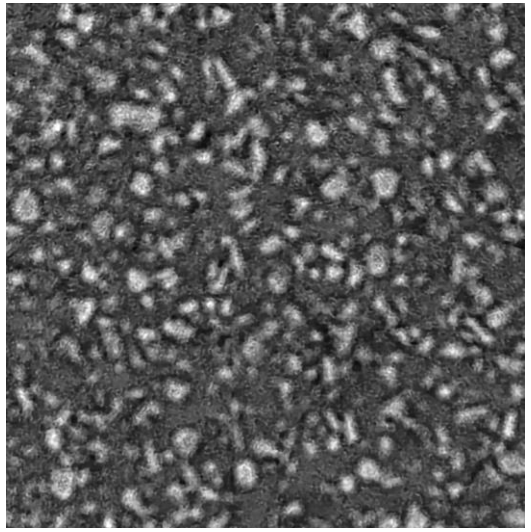
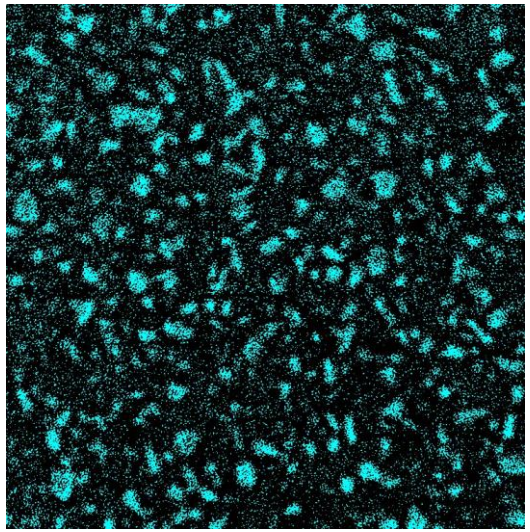
CT slices

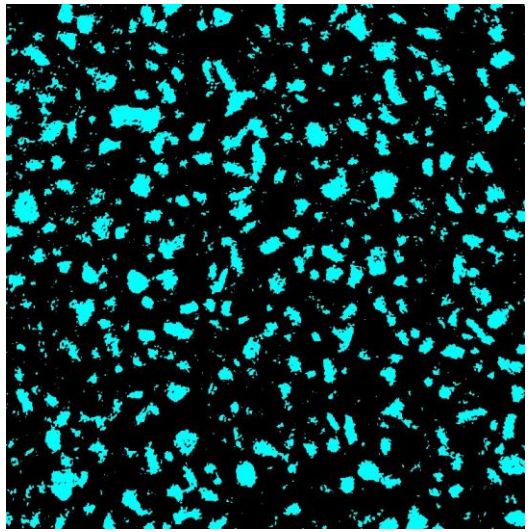




Segmented slices



Original Image

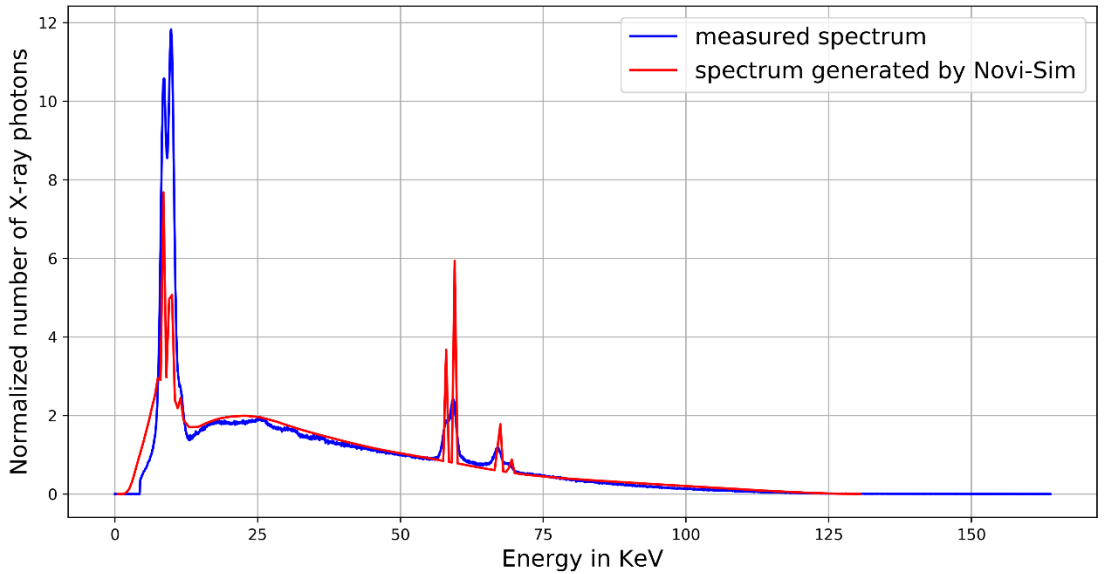


AI corrected image

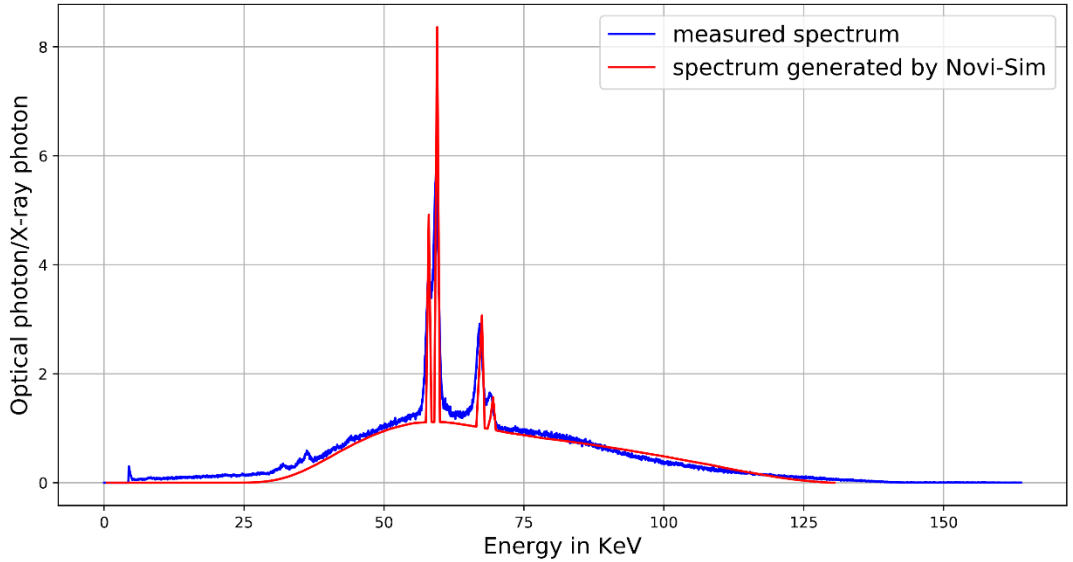
Lightning Round

How well do simulations and experiments match?

Simulated X-ray tube spectra vs measured spectra



With no filter

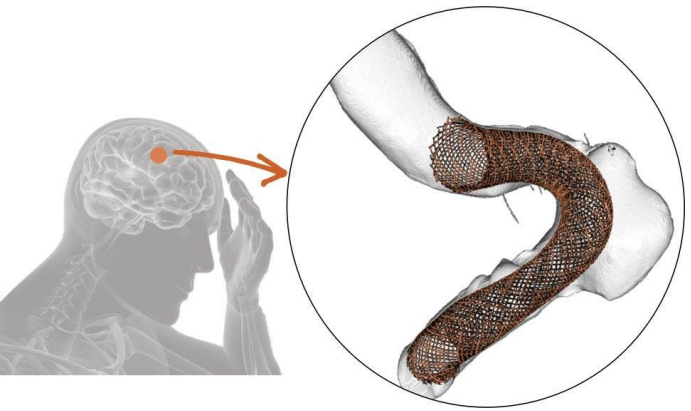


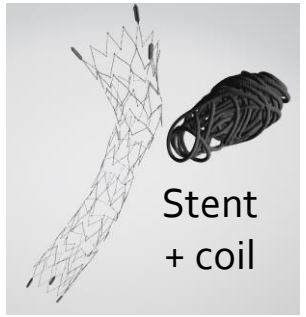
With a Cu filter of 0,5 mm

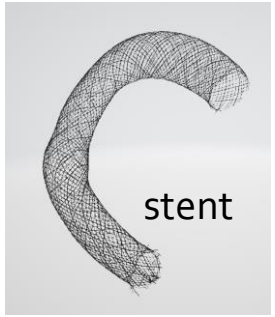
Normalized spectrum emitted by a sealed X-ray tube in reflection, measured with a spectrometer **(Courtesy of SIMAP Lab, L. Salvo)**

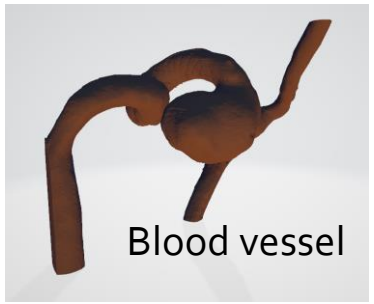
Comparison with experimental data

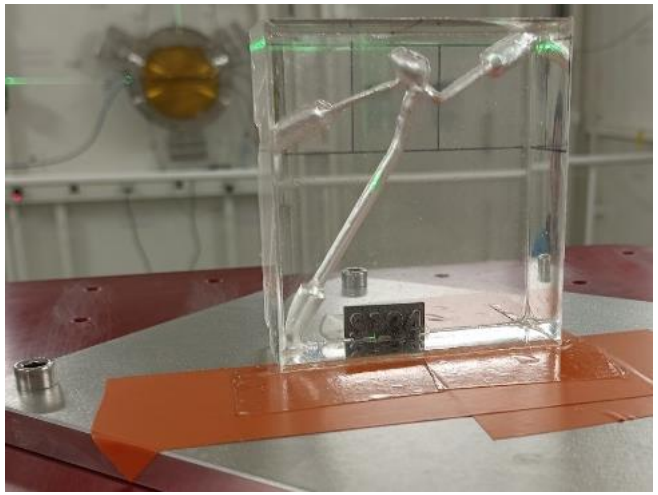
Aneurysm model





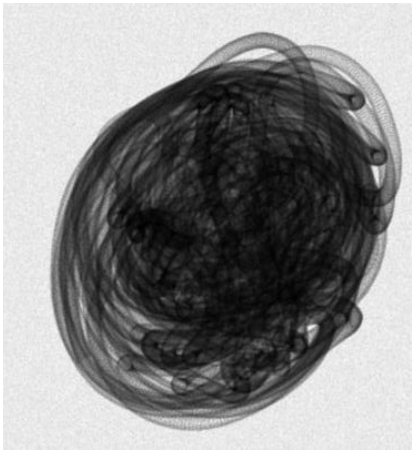


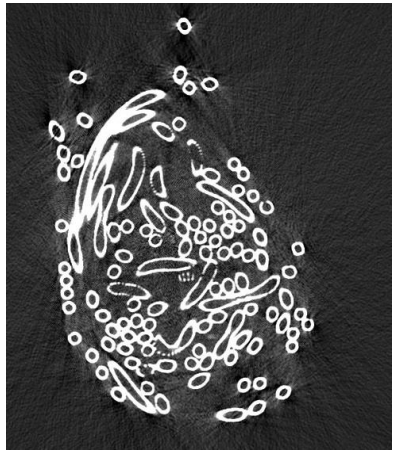




Stent and coil in silicone blocs
(blood vessels replica)

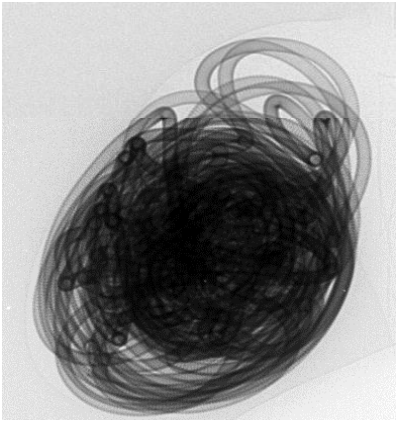
Simulation

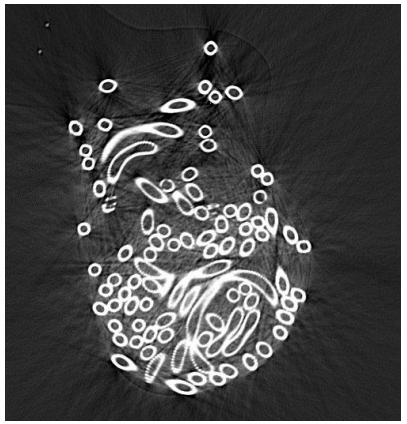




Radiography **Tomography**

BM18 ESRF



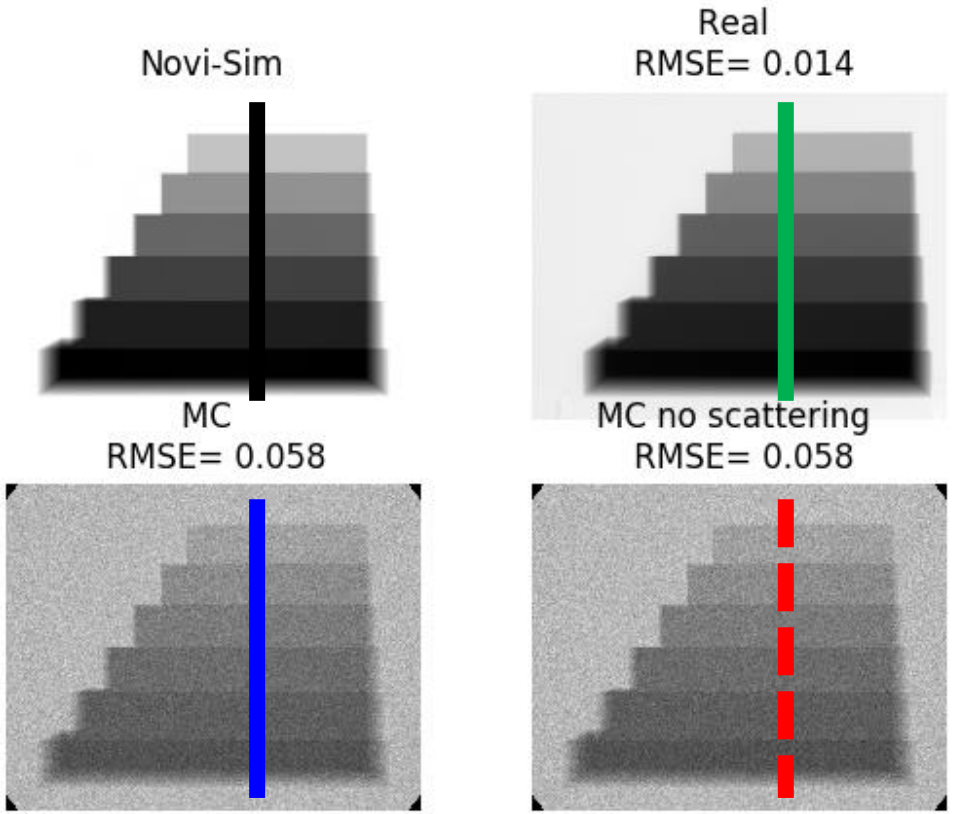


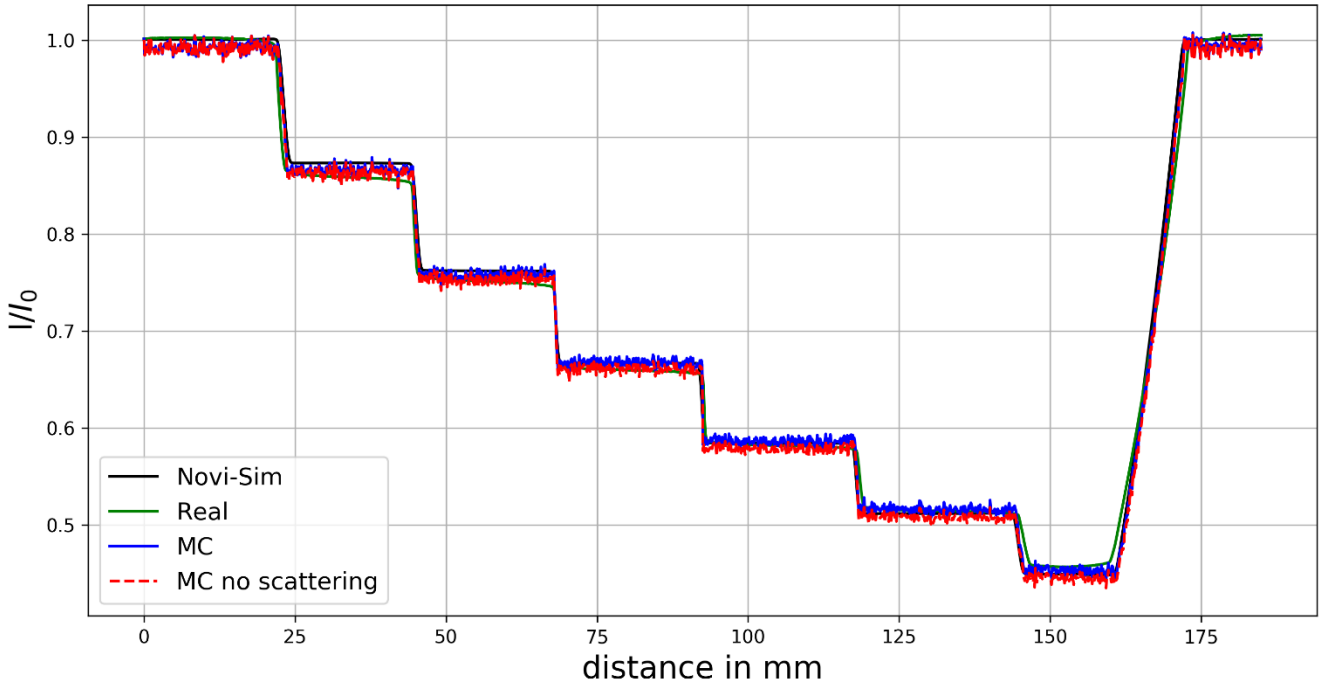
Absorption contrast validation – An example

- ✓ Staircase phantom, multiple thicknesses, in Aluminum and PMMA
- ✓ Dimensions: 3 x 1,5 cm² for the base
- ✓ Lab type source (**DeskTom - RX Solutions – CMTC, UGA**), object scanned at 150 kV
- ✓ Novi-Sim results are compared to experimental and MC simulations results

*RMSE: root mean squared error calculated inside the region where the profiles is plotted

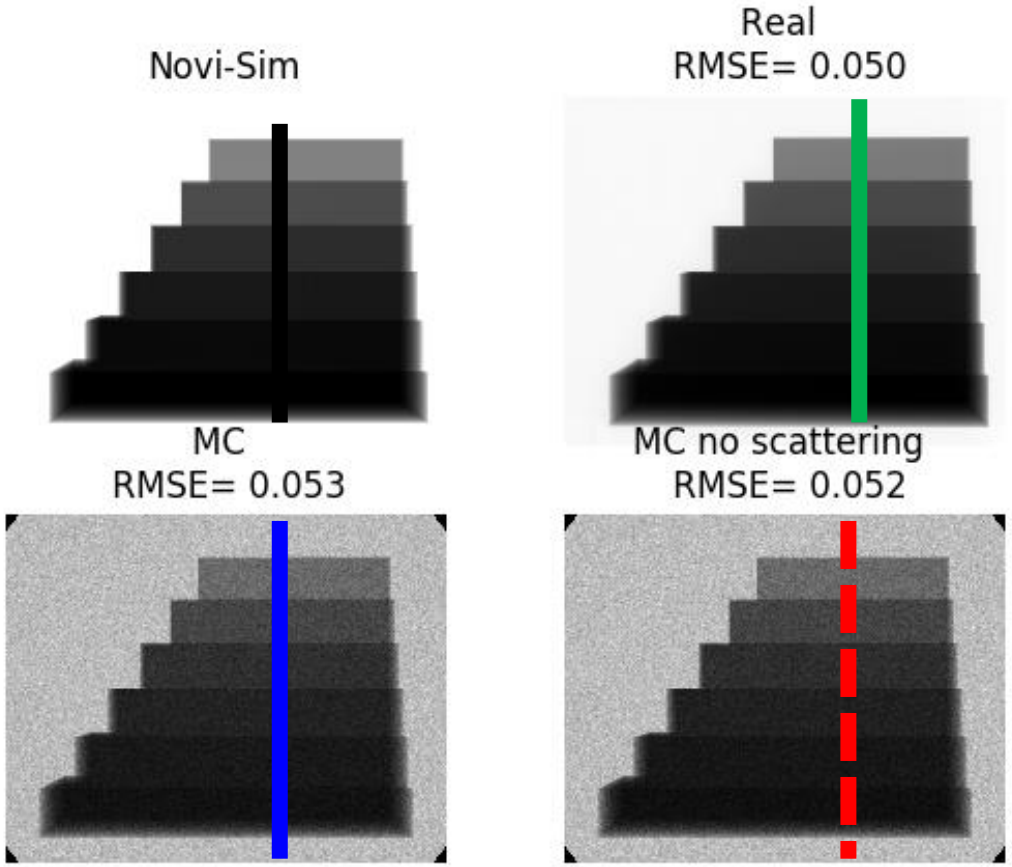
PMMA sample results

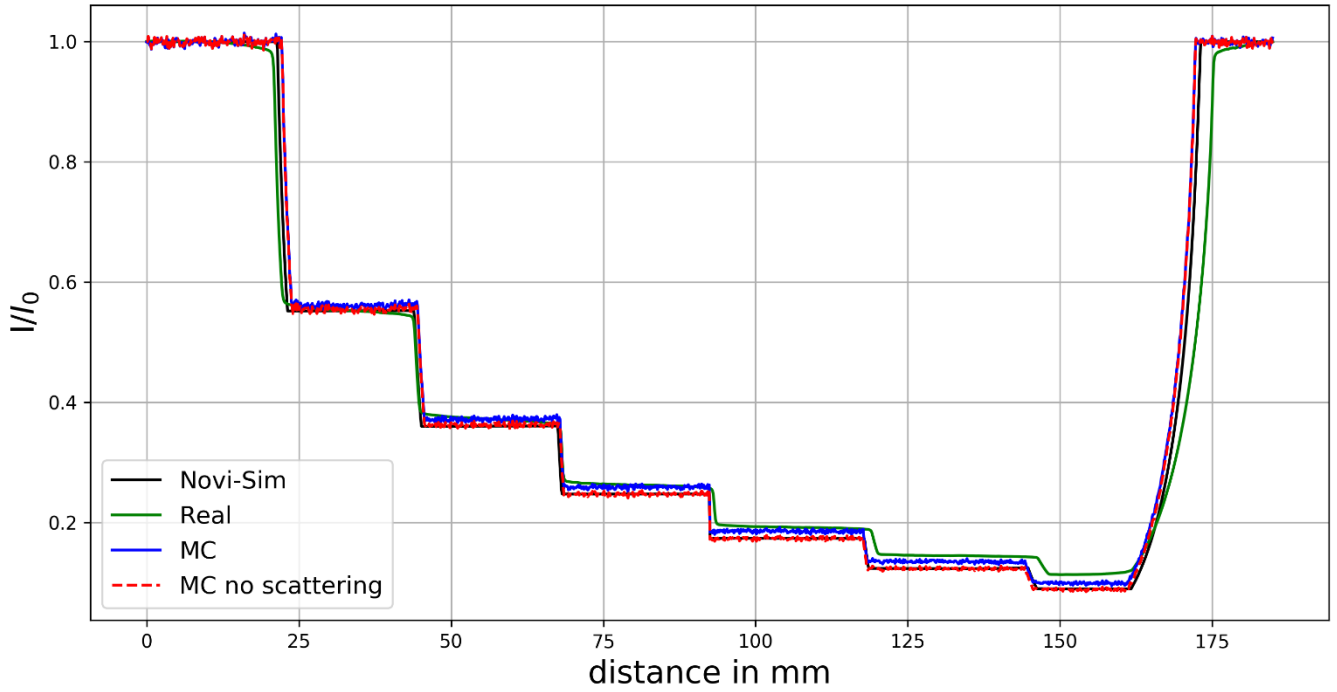




Absorption contrast validation – An example

Aluminum sample results

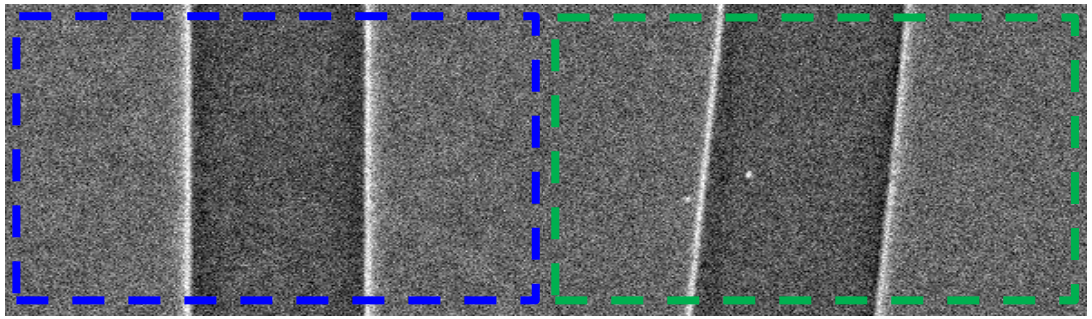




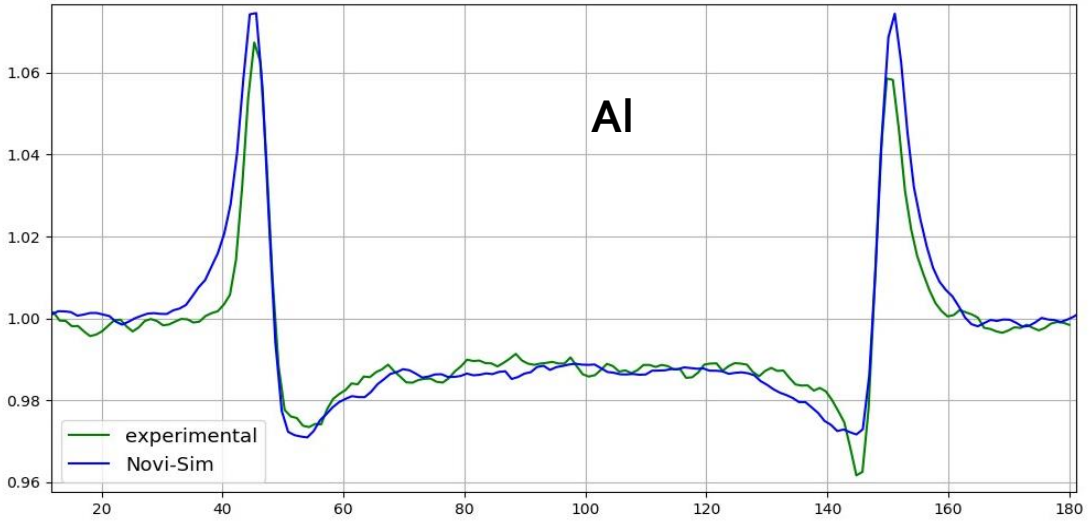
✓ Lab type source (**DeskTom - RX Solutions – CMTC, UGA**), object scanned at 150 kV

Phase contrast validation – An example

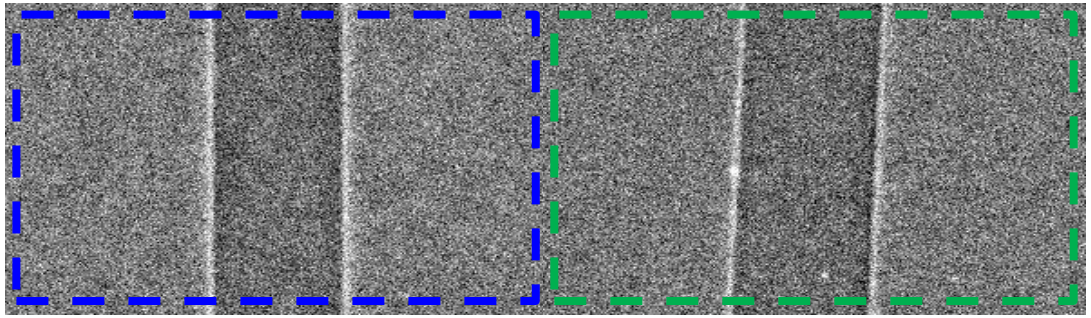
1(a) Simulated 1(b) Experimental



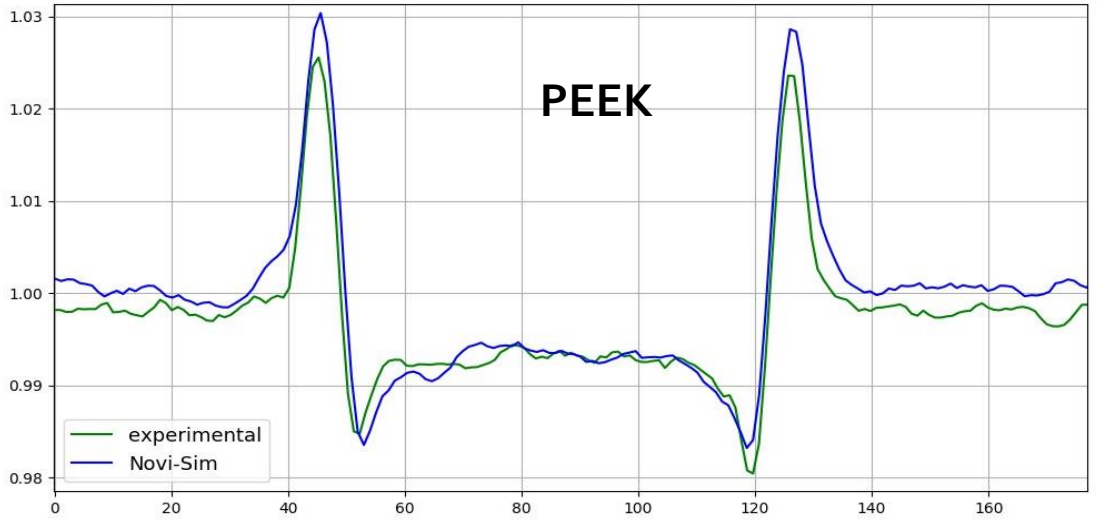
1(c)



2(a) 2(b)



2(c)

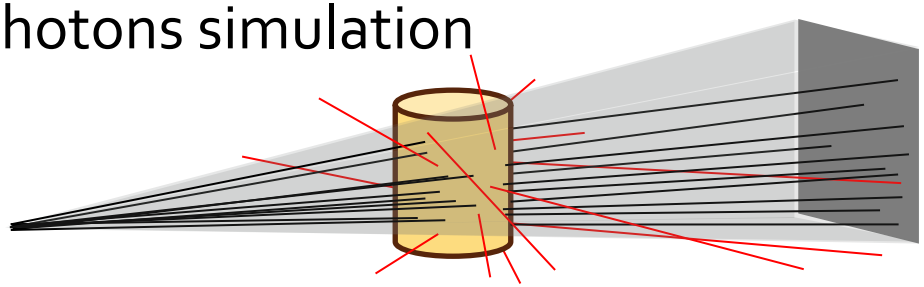


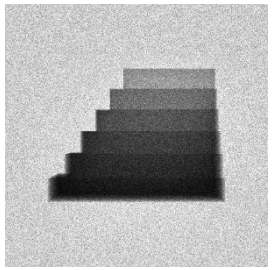
What is the future of CT simulations?

CT simulations perspectives

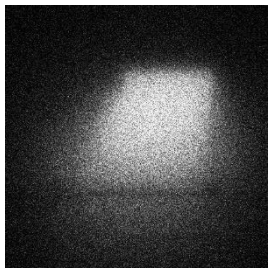
- Faster simulation (GPU)

- Scatter photons simulation





Radiography

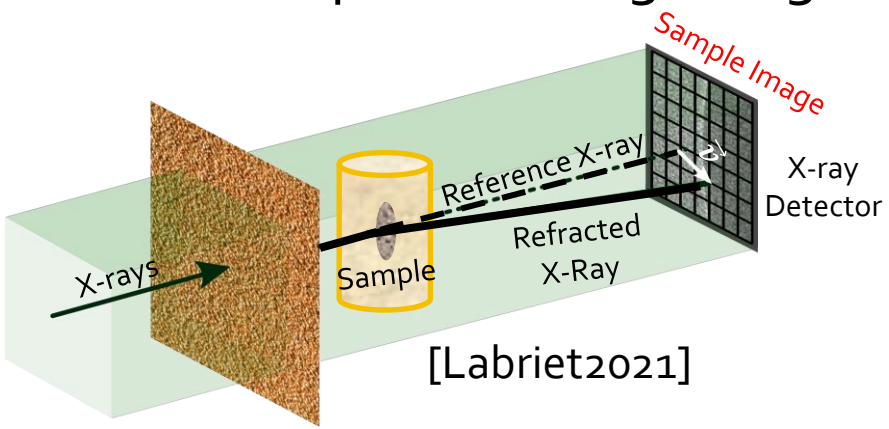


Scatter signal

[Neffati2023]

- Automatic acquisition setup optimization

- Phase contrast simulation with speckle and grating methods

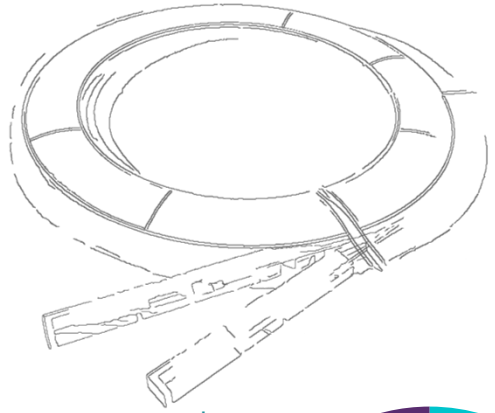


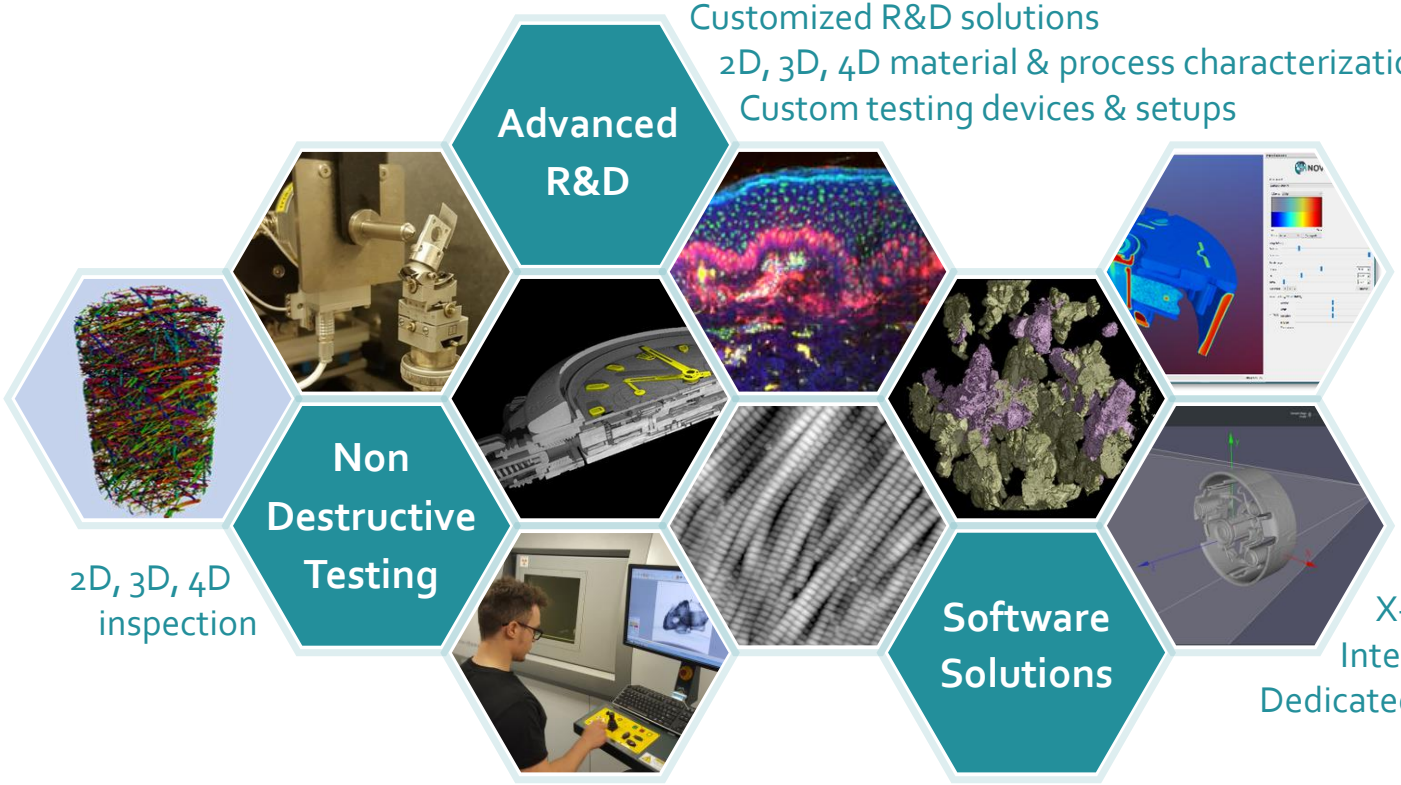
[Labriet2021]

[Neffati2023] Neffati, D,, et al, "Novi-Sim: A fast X-ray tomography simulation software for laboratory and synchrotron systems to generate training databases for deep learning applications", 12th Conference on Industrial Computed Tomography (2023)
[Labriet2021] Rouge-Labriet, H., et al. "Comparison of X-ray speckle-based imaging deflection retrieval algorithms for the optimization of radiation dose." Physics in Medicine & Biology (2021)

Who is Novitom?

- Service provider specialized in 3D imaging, structural imaging and chemical imaging based on advanced technologies such as synchrotron radiation.
- Software development for image analysis, simulation and data visualization.



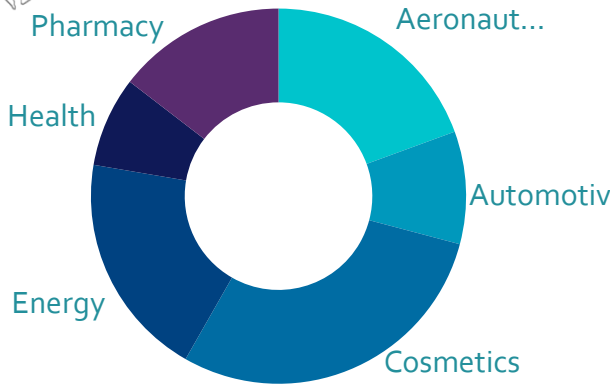


Customized R&D solutions
2D, 3D, 4D material & process characterization
Custom testing devices & setups

2D, 3D, 4D inspection

NOVI-SIM
X-RAY CT SIMULATOR

X-ray CT Simulator
Interactive 3D Viewer
Dedicated image analysis softwares



2011
Founded

18
Experts, PhD

12%
R&D investment

HYBRID EVENT

X-ray Micro Computed Tomography Seminar & Workshop

University of Southern California

Wednesday, September 27, 9 am – 12:30 pm PDT