Welcome to the CIL online training

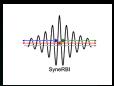Thank you for joining, while we wait to get started:

- Check out our HackMD: https://hackmd.io/@ccpi/cil-online-25

- Make sure you zoom name is correct

- Check your video and microphone (you will need them later)

CIL Discord

CIL GitHub

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Hands-on training for the Core Imaging Library (CIL)

an open-source reconstruction platform for challenging and novel data.

Gemma Fardell – STFC

Jakob Sauer Jørgensen – DTU

Laura Murgatroyd – STFC

Danica Sugic – STFC

Hannah Robarts - STFC

Evangelos Papoutsellis – Finden

Edoardo Pasca – STFC

Margaret Duff – STFC

Franck Vidal – STFC

Casper da Casta-Luis - STFC

CIL Team

Laura | Gemma | Franck | Evangelos | Jakob | Edoardo | Margaret | Danica | Casper | Hannah

Scientific Computing @ STFC
Technical University of Denmark (DTU)
Finden

Welcome to the CIL Online Training

- **Day 1 - March 25th - 13:00 - 17:00 GMT**

  Getting Started with CIL
  Learn how to use CIL for standard CT datasets, including analytical reconstruction methods (FBP and FDK), pre-processing techniques, and visualisation tools.

- Day 2 - March 26th - 13:00 - 17:00 GMT

  Iterative Reconstruction Techniques with CIL

  Explore iterative reconstruction methods, going beyond SIRT and CGLS, and incorporating regularisation for improved results.
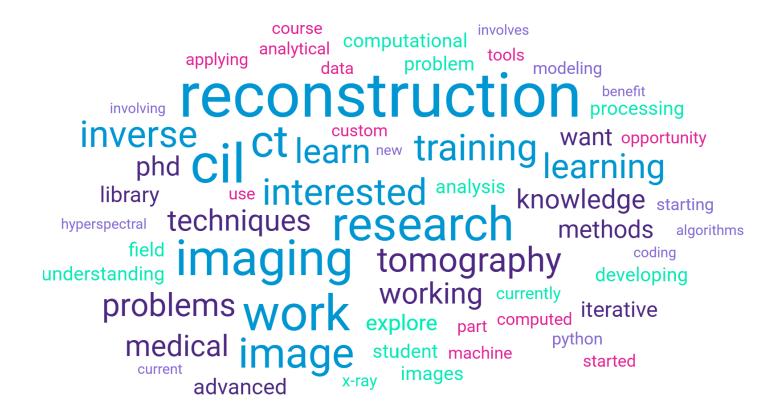
- Day 3 - March 27th - 13:00 - 17:00 GMT

  Advanced Topics in CIL

  Dive into advanced capabilities, including building custom optimisation problems, using callbacks and preconditioners, and creating objective functions.

What you want to get out of this course

Our goals for Day 1

- Give an overview of CT data pre-processing and FBP reconstruction with CIL

- Support you in trying out CIL with our Jupyter notebook demos on the cloud

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Day 1 Training Program

Welcome to the CIL Online Training – 1:00 – 1:15 (Lead: Hannah)
- Course overview and HackMD
- Icebreaker

Geometry, Data Reading and FBP/FDK Reconstruction – 1:15-2:10 (Lead: Franck)
- Introduction to CT , FBP and CIL
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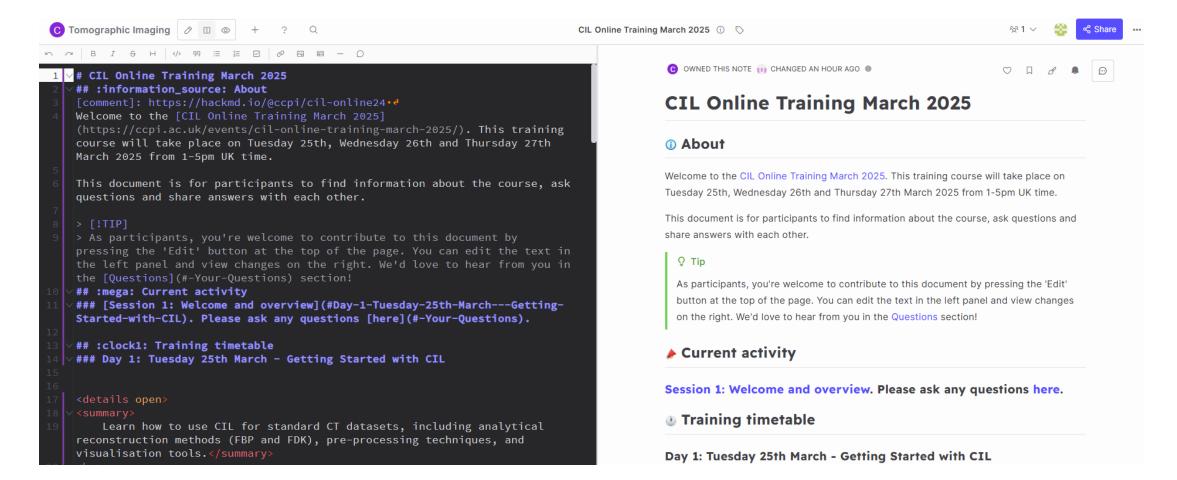- Option D: CIL Geometry
- Takeaways from exploration

Conclusions 4:50-5:00 (Lead: Laura)
- Feedback
- Preview of tomorrow's course

HackMD

https://hackmd.io/@ccpi/cil-online-25

Mentimeter

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CT and FBP

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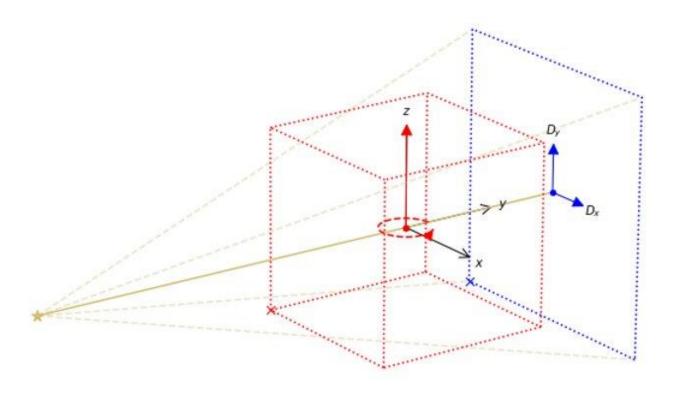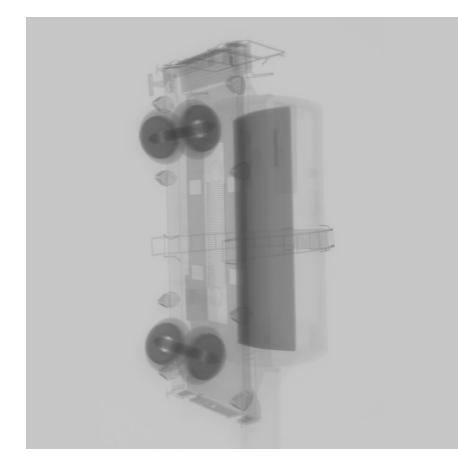
Tomography

Beer-Lambert Law

$$\frac{I}{I_0} = \exp \int_{L_i} -\mu(s)ds$$

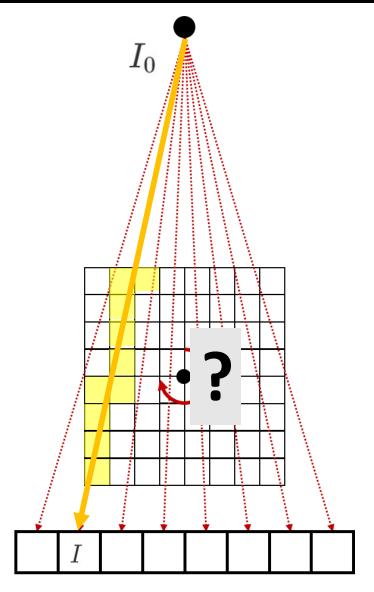$$b_i = -\log \frac{I_i}{I_0} = \int_{L_i} \mu(s)ds$$

X-ray source

I_0

Measurement volume

Reconstructed volume:
- map of linear attenuation coefficients (μ)
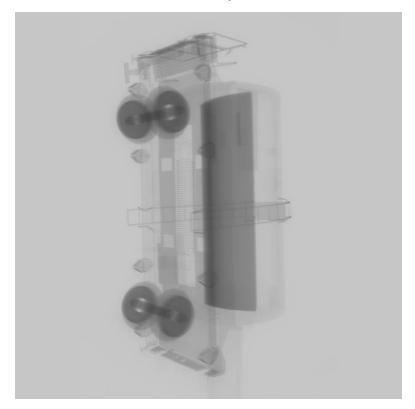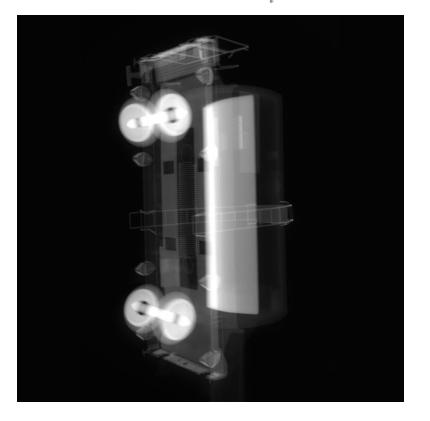- often expressed in cm^{-1}

?

X-ray detector

I
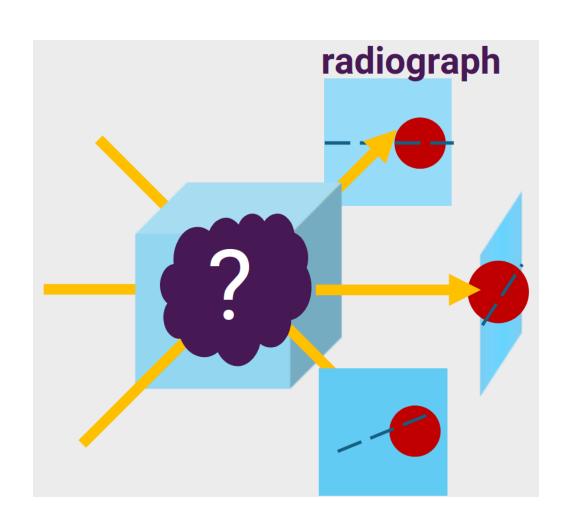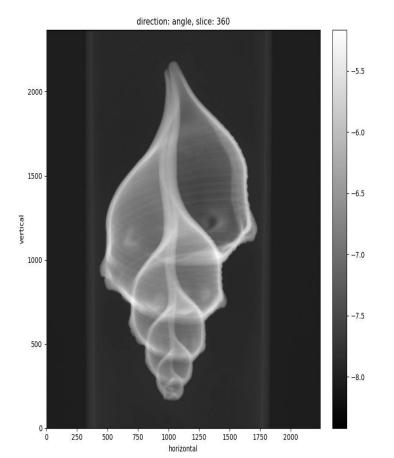
Minus log

$$\frac{I}{I_0} = \exp \int_{L_i} -\mu(s)ds$$

$$b_i = -\log \frac{I_i}{I_0} = \int_{L_i} \mu(s)ds$$

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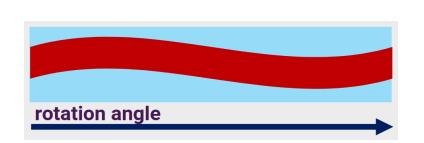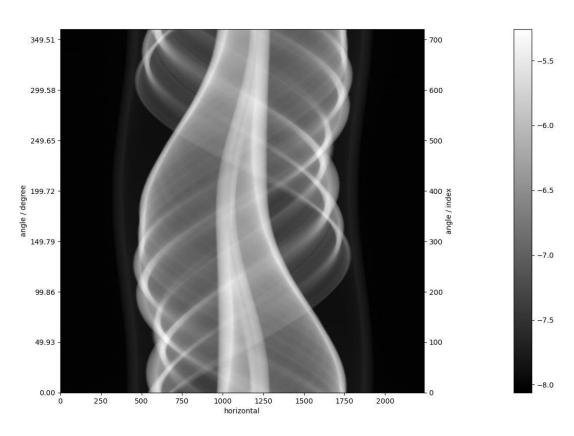
Take many projections

An x-ray radiograph of a shell measured at the University of Helsinki [1]

[1] Kamutta, E., Mäkinen, S., & Meaney, A. (2022). Cone-Beam Computed Tomography Dataset of a Seashell (1.1.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.6983008
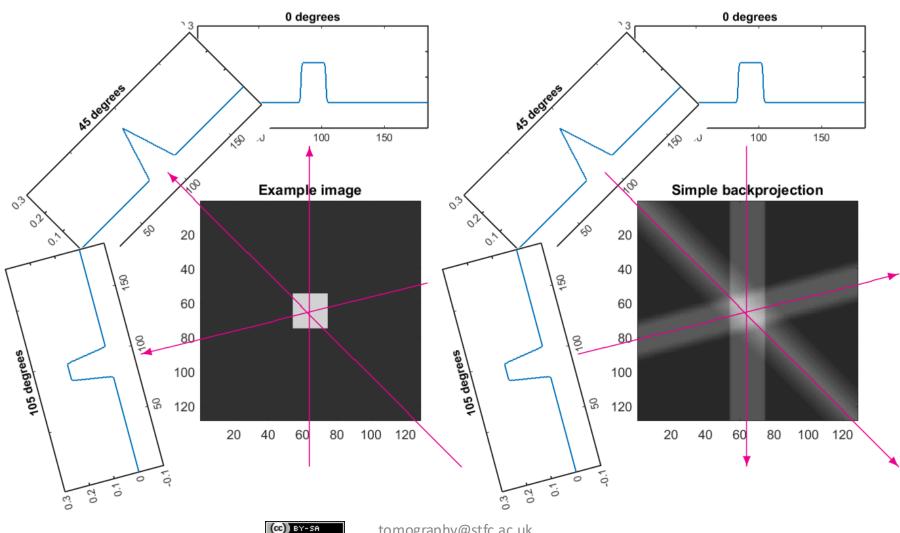
tomography@stfc.ac.uk

Sinogram: How the attenuation changes as we rotate the object
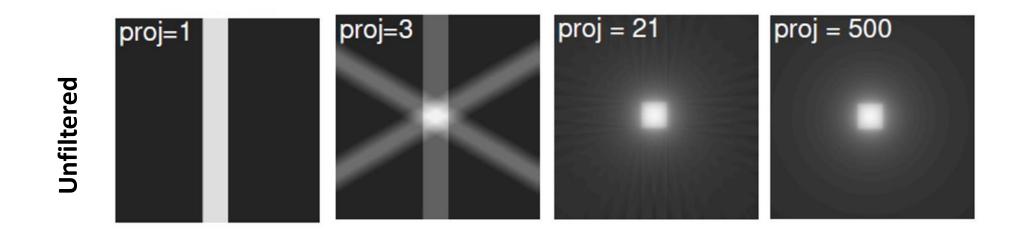
The shell has a much more complex sinogram

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Filtered Back Projection (FBP)

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Filtered Back Projection (FBP)

Courtesy J. Jørgensen

tomography@stfc.ac.uk

Filtered Back Projection (FBP)

Courtesy J. Jørgensen

Filtered Back Projection (FBP)
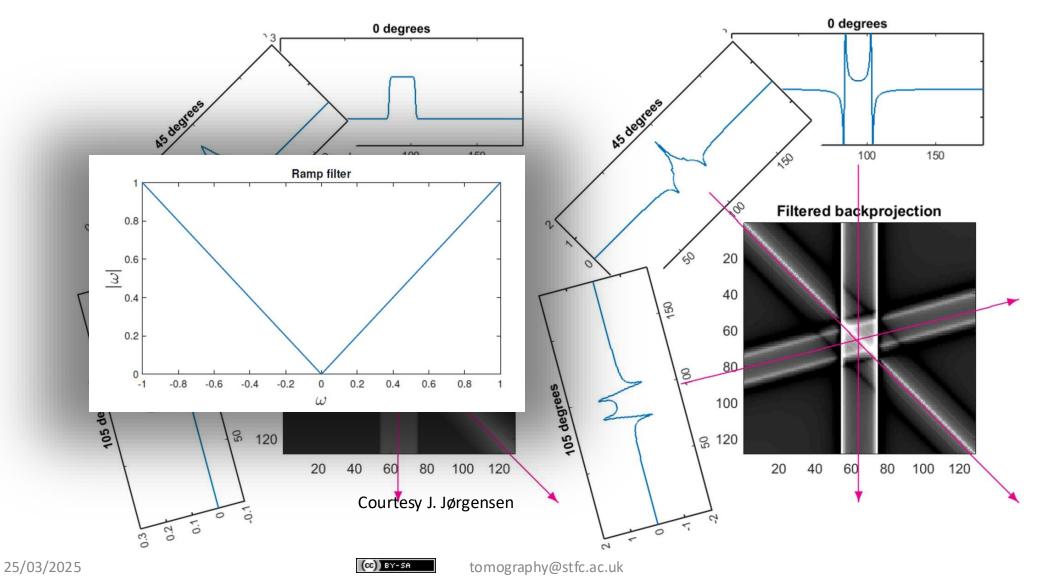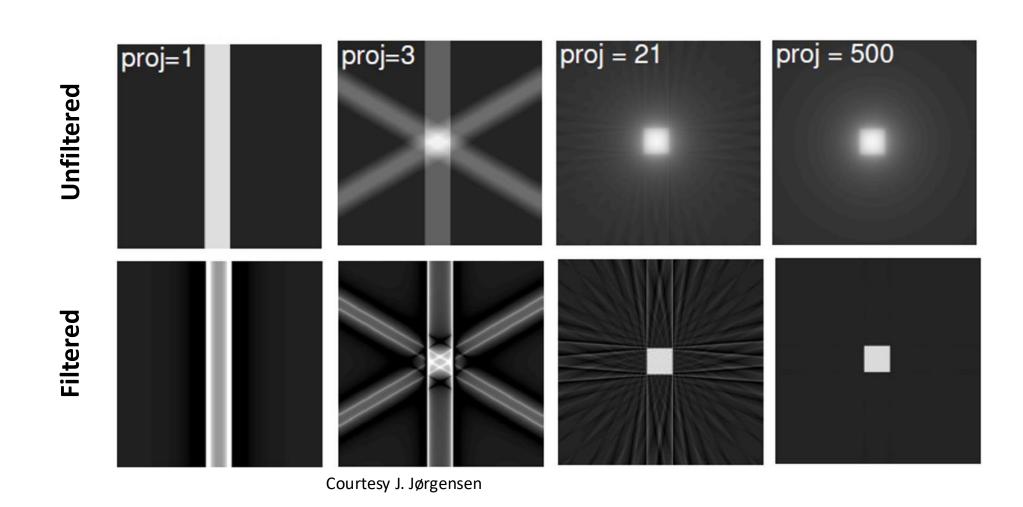

Courtesy J. Jørgensen

Filtered Back Projection (FBP)

Pros

- Fast as based on FFT and backprojection

- Few parameters

- Typically works very well

- Reconstruction behaviour well understood

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What is the Core Imaging Library?

- A Python library for **processing** and **reconstruction** of tomography data.

- Optimised standard methods, such as **Filtered Back Projection**

- Special emphasis on *challenging data sets*: noisy, non-standard, incomplete, multi-channel, …

- Highly modular to allow creation of bespoke pipelines.

- Apache v2 license.

- Actively developed on GitHub: https://github.com/TomographicImaging/CIL
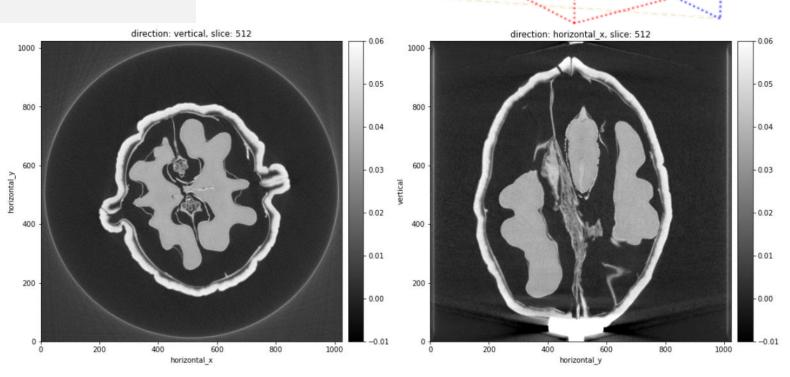
Core Imaging Library for CT and other inverse problems


```
data = ZEISSDataReader(filename).read()

data = TransmissionAbsorptionConverter()(data)

show_geometry(data.geometry)

recon = FDK(data).run()

show2D(recon)
```
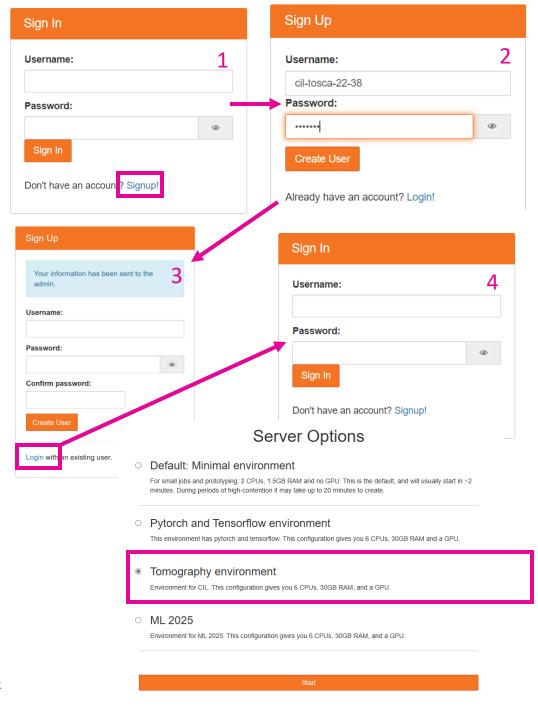
- Data readers/writers
- Pre-processing tools
- Image reconstruction
- *Near math* optimisation syntax
- Visualisation
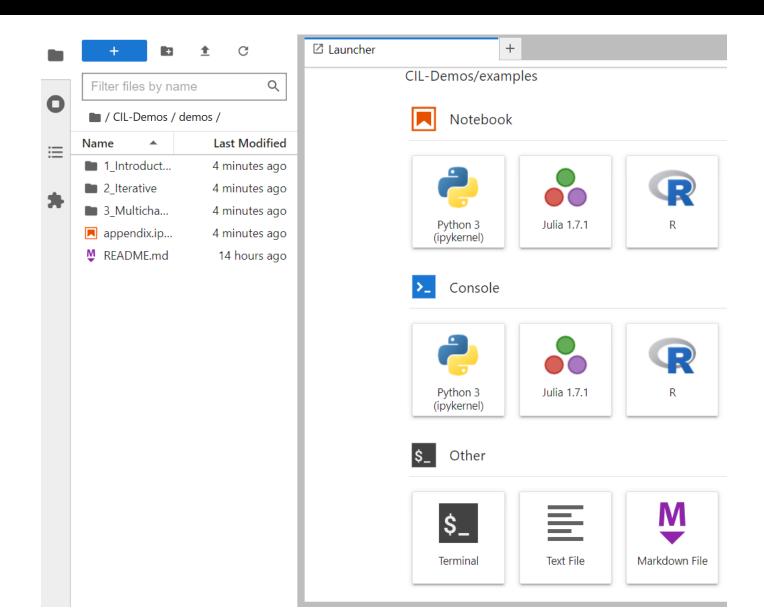- 2D, 3D and 4D data
- TIGRE and ASTRA backend

ccpi.ac.uk/CIL

Log in to JupyterHub

- Go to: https://tinyurl.com/cil-online-25
  and write your name next to a **username** to claim it for the exercises

- Go to: https://training.jupyter.stfc.ac.uk/

- **Sign up with the username** you claimed and a password of your choice.

- No password reset option, so remember your password!

- Then log in with the username and password you set.

- Select the **Tomography environment** server and press "start":
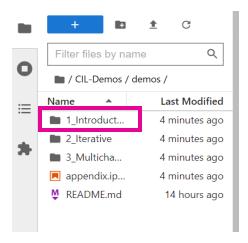
tomography@stfc.ac.uk

Once you've logged in …

Example: Getting started

CIL-Demos/examples/1_Introduction /exercises/00_intro_to_jupyter.ipynb
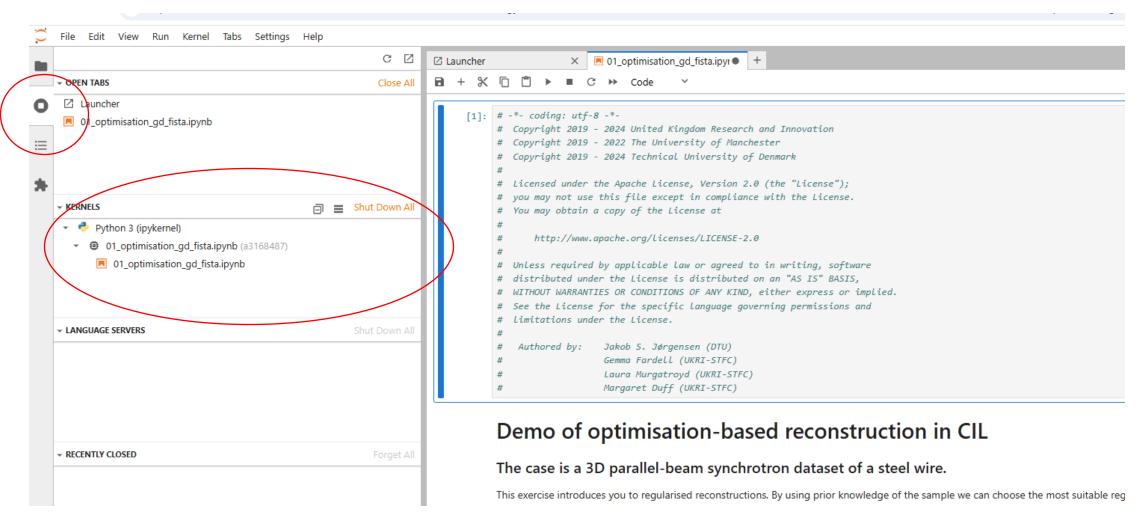
Learning Objectives:
- Learn how to use jupyter notebooks
- Check which CIL version we're running on
- Import and display an example CIL dataset

Killing kernels – IMPORTANT

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Example: Walnut reconstruction!

In breakout rooms:
- Introduce yourselves and your background
- Run through the walnut notebook together (one person may screen share)
- Work together to add a question to the hackmd:

    https://hackmd.io/GMitAYuFRN2dJ4md7CPa4A#Questions-about-01_intro_walnut_conebeamipynb

CIL-Demos/examples/1_Introduction /01_intro_walnut_conebeam.ipynb

Learning Objectives:
- Load and investigate a ZEISS data set.

- Apply CIL's TransmissionAbsorptionConverter.

- Compute FDK reconstruction using CIL and compare with a reconstruction made from fewer projections.

- Write out the reconstructed image to a TIFF stack.

CIL Online Training March 2025
About
Current activity: Session 1: Welc...
Training timetable
Training platform instructions
Mentimeter
Your Questions
General CIL and CT questions
Technical questions
1_Introduction
1_Introduction / exercises
2_Iterative
3_Multichannel
3_Deep_Dive
Resources

Questions?

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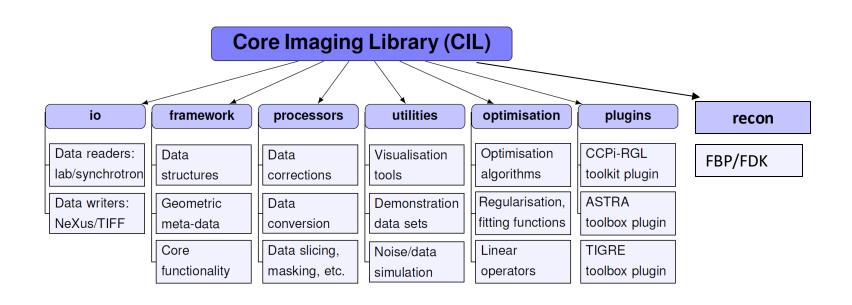- Preview of tomorrow's course

Who is CIL for?

- CT experimentalists
  - **Optimised** standard algorithms for large data
  - Batch processing
  - To utilise reconstruction algorithms for **poor data quality** or to handle novel imaging modalities

- Image processing specialists
  - To easily implement new reconstruction algorithms
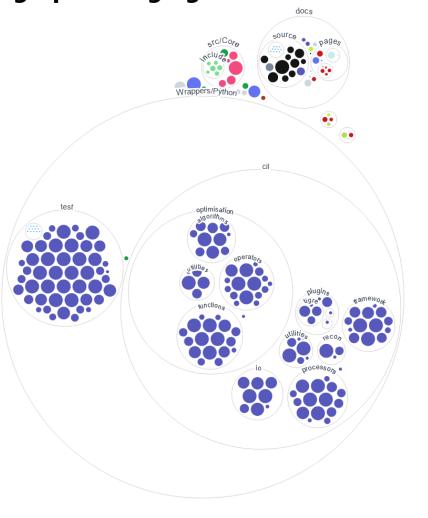 - **Assess** them against existing ones.

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CIL Module Structure and Contents

Jørgensen et al. 2021: *Core Imaging Library - Part I: a versatile Python framework for tomographic imaging,* Phil. Trans. R. Soc. A, **379**, 20200192: https://doi.org/10.1098/rsta.2020.0192

The **cil.plugins** module contains wrapper code for other software and third-party libraries that need to be installed separately to be used by CIL.

TomographicImaging/CIL

Documentation

https://tomographicimaging.github.io/CIL

25/03/2025

Exercise: Reconstruct a dataset yourself!

CIL-Demos/examples/1_Introduction/exercises/01_intro_seeds_conebeam.ipynb

Learning Objectives:
- Learn how to use jupyter notebooks
- Check which CIL version we're running on
- Import and display an example CIL dataset

Uncomment the following line and run the cell to see the solution, to run the lines you'll need to run the cell a second time

```
In [ ]:    # %load './snippets/01_exA.py'
```

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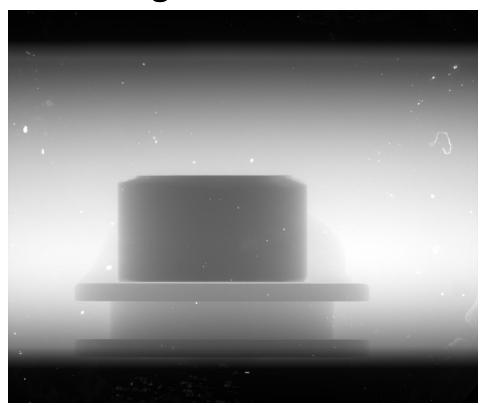- Option D: CIL Geometry
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Preparing raw data for the reconstruction

Raw image

- Detectors are not perfect
- Defects build up over time
- Non uniform spread of intensity across the detector
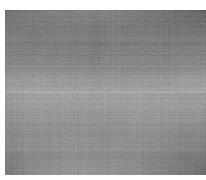
How we do we correct for this?

Image	Sample	Beam
raw	with	on
dark field	without	off
flat field	without	on

raw

dark field

flat field

tomography@stfc.ac.uk
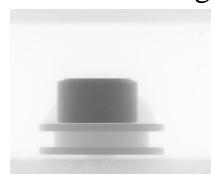
Flat-field correction: How does it work?
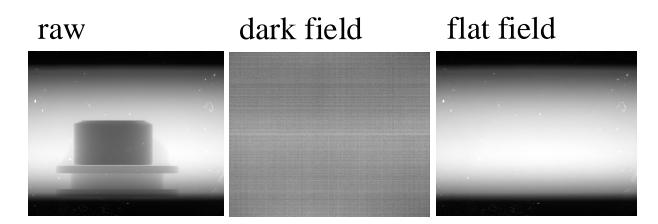
$$\text{corrected image} = \frac{\text{raw} - \text{dark field}}{\text{light field} - \text{dark field}}$$

corrected image

cil.processors.Normaliser(flat_field, dark_field)

Image	Sample	Beam
raw	with	on
dark field	without	off
flat field	without	on

raw   dark field   flat field

Flat-field correction
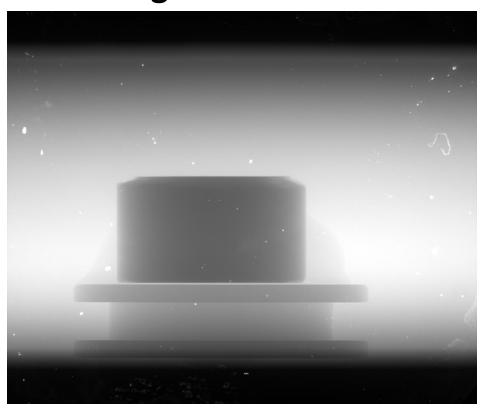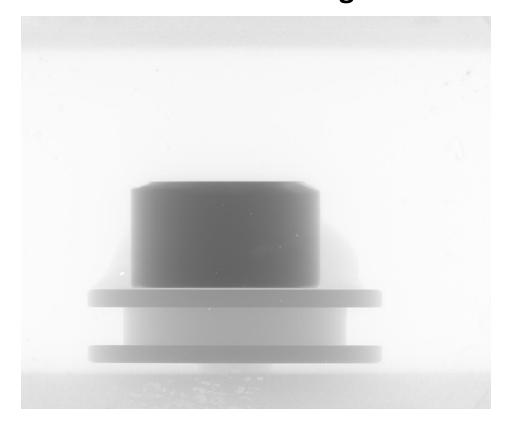
Raw image

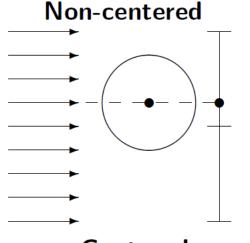**Flat-field corrected image**

tomography@stfc.ac.uk
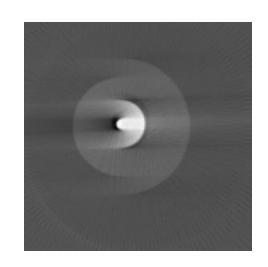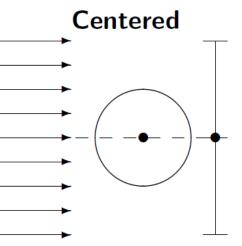
Centre of Rotation Correction

- CoR: The projection of the axis of rotation onto the detector
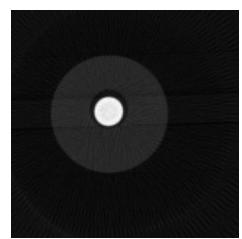
- Reconstruction assumes axis of rotation is horizontally centred on detector

- Offset introduces blurring and artifacts

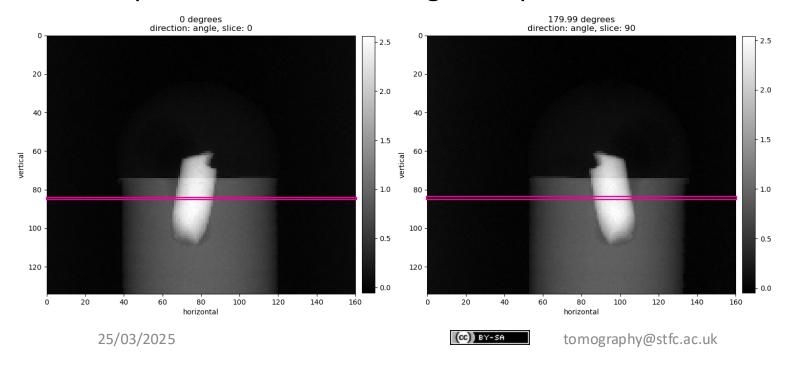- We correct for this by updating our geometry

Parallel Beam

Centre of Rotation in CIL – X Correlation
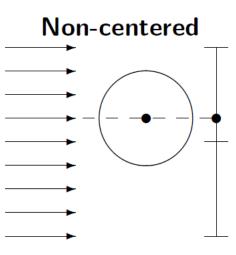
cil.processors.CentreOfRotationCorrector.**xcorrelation(***slice_index='centre'*,   *projection_index=0, ang_tol=0.1)*

- For **parallel beam** geometry
- Requires two rows 180 degrees apart

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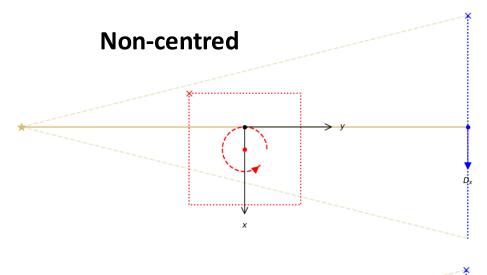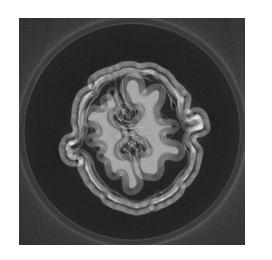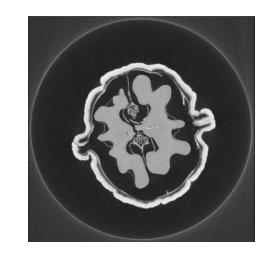
Centre of Rotation Correction

Cone/Fan Beam

Non-centred

Centred

tomography@stfc.ac.uk
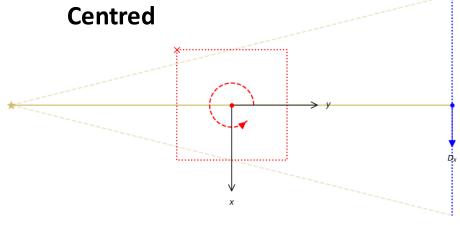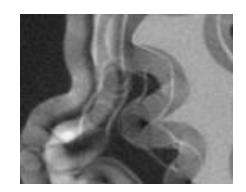
Centre of Rotation in CIL – Image Sharpness
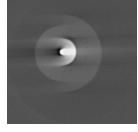
cil.processors.CentreOfRotationCorrector.**image_sharpness**(slice_index='centre', backend='tigre', tolerance=0.005, search_range=None)

Reconstructs with FBP/FDK a single slice and adjusts the centre of rotation offset to maximise the sharpness

By default the search range is ¼ width of the detector panel

- For parallel beam or centre-slice cone beam
- Works best with full 360 degree data
- Can only be used on datasets that can be reconstructed with FBP/FDK

https://tomographicimaging.github.io/CIL/nightly/processors/#cil.processors.CentreOfRotationCorrector.image_sharpness
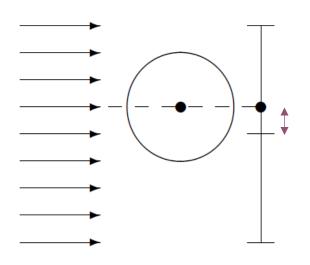
Centre of Rotation Correction in CIL - Manual
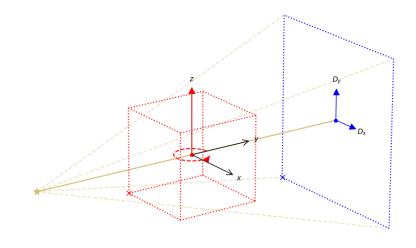
AcquisitionGeometry's **.get_centre_of_rotation()**

```
{'offset': (0.1, 'units distance'), 'angle': (0.0, 'radian')}
```

.set_centre_of_rotation(offset**)**

In CIL, the centre of rotation offset is defined as the offset from the centre of the detector panel

Region of Interest Correction

The object is too large to fit in the field of view, or we want a close view of a specific ROI
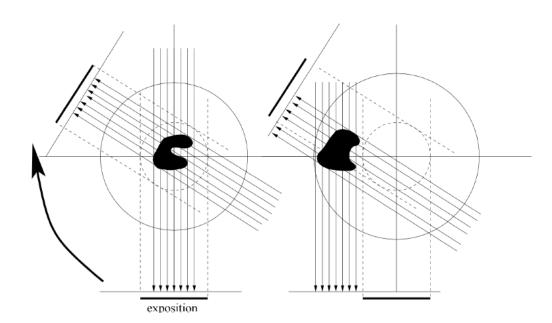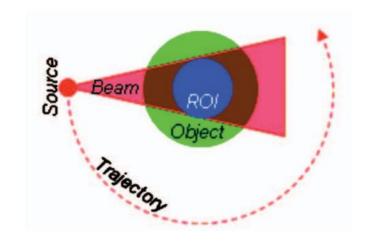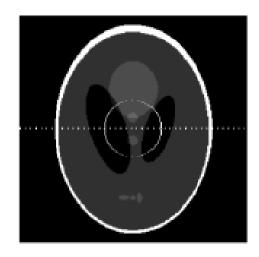
Figure: Bilgot et al., IEEE Nuc. Sci. Symp. Conf. Rec. (2009), 4080–4085.
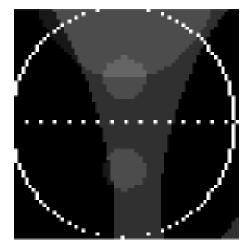
The projections are **truncated** – don't cover entire width of object and are **contaminated** by data exterior to the ROI.

Reconstruction of ROI will also be contaminated.
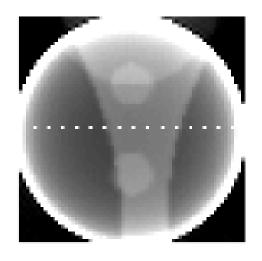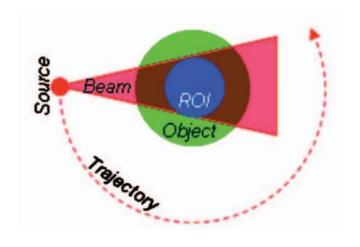
Region of Interest correction

Sample

Scan with whole sample in field of view (then cropped)

ROI scan: with only circle in field of view
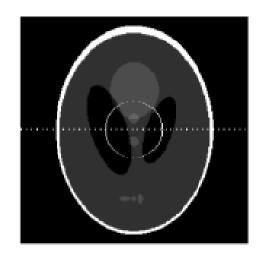
Large artifact in ROI scan – white ring
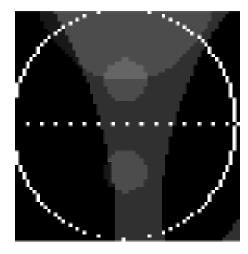
To correct this we **pad the data** an amount roughly the width of the object

cil.processors.Padder
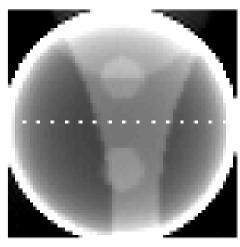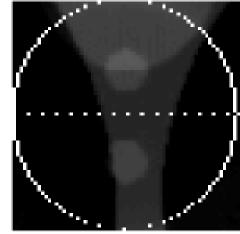
Region of Interest correction

Sample

Scan with whole sample in field of view (then cropped)
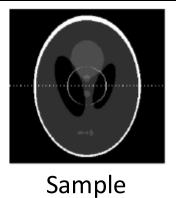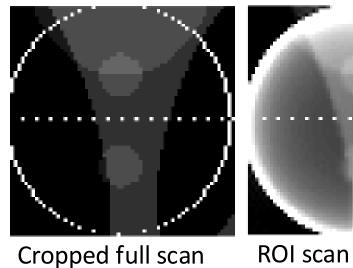
ROI scan: with only circle in field of view
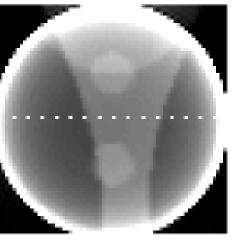
Corrected by padding ROI scan

Region of Interest correction

Sample

Cropped full scan

ROI scan

Region of Interest correction

Sample

Cropped full scan

ROI scan

Cropped full scan

Corrected ROI scan

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Region of Interest correction
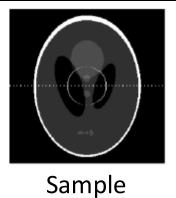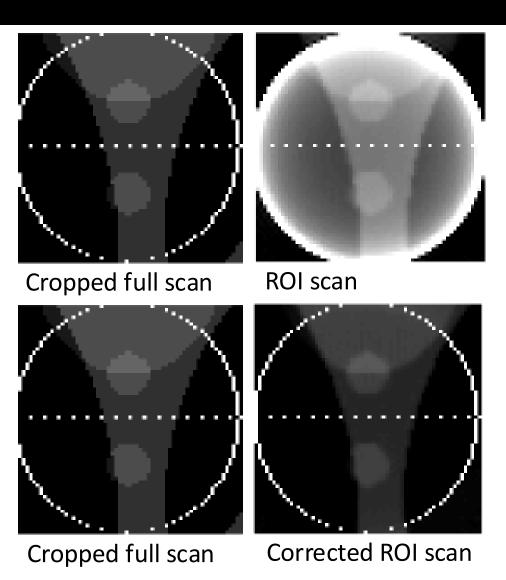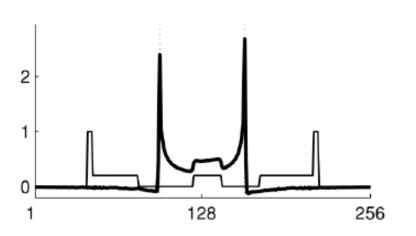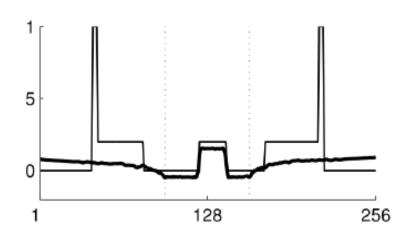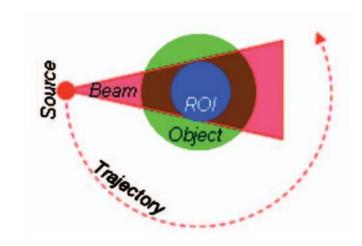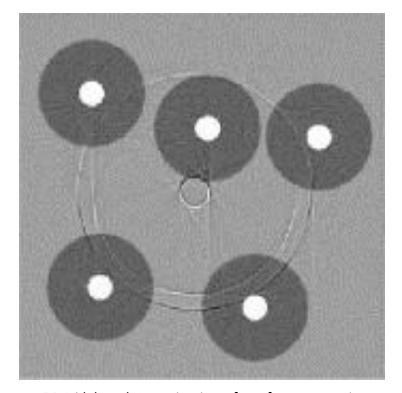
- Padding provides great improvement but can't fully recover intensities

- Contamination from outside the ROI provides even greater problem with iterative reconstruction.

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Many other artifacts

- Ring artifacts
- Cone beam artifacts
- Beam hardening
- Misalignment
- Motion
- And more!

F.P. Vidal et al. Investigation of artefact sources in synchrotron microtomography via virtual X-ray imaging, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Volume 234, Issue 3, 2005, Pages 333-348, ISSN 0168-583X, https://doi.org/10.1016/j.nimb.2005.02.003

Sandstone Data

The Scan:
- Parallel Beam
- 0 to 180 degrees
- ROI

Centre of Rotation – which algorithm would you expect to use?

Look out for centre of rotation and ROI artifacts!

Try out the Sandstone notebook

Go to:
CIL-Demos/demos/1_Introduction/02_intro_sandstone_parallel_roi.ipynb

Learning Objectives:
- Load and investigate a real data set.
- Determine geometric information of the data and set up CIL data structures.
- Apply CIL processors to pre-process the data, including normalisation, negative log, region-of-interest and centre of rotation correction.
- Compute FBP reconstruction using CIL and compare with reconstruction provided.

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Questions?

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BREAK

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Day 1 Training Program

Welcome to the CIL Online Training – 1:00 – 1:15 (Lead: Hannah)

- Course overview and HackMD
- Icebreaker

Geometry, Data Reading and FBP/FDK Reconstruction – 1:15-2:10 (Lead: Franck)

- Introduction to CT , FBP and CIL
- Cloud login
- Introduction to jupyter
- Breakout rooms: Cone beam reconstruction: 1_Introduction/01_intro_walnut_conebeam.ipynb
- Summary

Writing your own code in CIL – 2:10-2:40 (Lead: Laura)

- CIL's structure and documentation
- 1_Introduction/Exercises/01_intro_seeds_conebeam.ipynb

Break 2:40-2:55

Pre-processing – 2:55-3:45 (Lead: Laura)

- Introduction to pre-processing in CIL
- Notebook: 1_Introduction/02_intro_sandstone_parallel_roi.ipynb

Break 3:45-4:00

Time to explore and discuss – 4:00-4:50 (Lead: Franck)

- Introduction
- Option A: Further Pre-processing of Synchrotron data
- Option B: Further Pre-processing of Cone beam data
- Option C: Phase contrast
- Option D: CIL Geometry
- Takeaways from exploration

Conclusions 4:50-5:00 (Lead: Laura)

- Feedback
- Preview of tomorrow's course

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Explore: Synchrotron Data
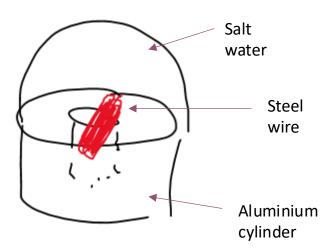
Preprocessing Synchrotron Data   **1_Introduction/03_preprocessing.ipynb**

- 3D parallel-beam X-ray CT dataset from Beamline I13-2, Diamond Light Source.
- 0.5 mm aluminium cylinder with a piece of steel wire embedded in a small drilled hole. A droplet of salt water was placed on top, causing corrosion to form hydrogen bubbles.

- Notebook concepts:
  - Centre of Rotation
  - FBP
  - Working with bad pixels
  - Slicing and binning data

Salt water

Steel wire

Aluminium cylinder

Explore: Cone beam data

Preprocessing Cone Beam Data   **1_Introduction/exercises/02_preprocessing_seeds_conebeam.ipynb**

- Same Seeds in the Box Nikon data as exercise 1

- Hands on exercise – writing CIL code yourself

- Concepts:
  - Centre of Rotation
  - FDK
  - Binning data

Paganin Phase Retrieval

4_Deep_Dives/02_phase_retrieval.ipynb

- Phase contrast imaging combines absorption data with phase information

- Can provide additional contrast for samples with similar materials

- Phase retrieval methods (e.g. Paganin) separate phase information and boost signal to noise (SNR)


```
processor = PaganinProcessor(delta=delta, beta=beta,
                             energy=energy, energy_units='keV',
                             full_retrieval=False)
processor.set_input(data_before)
data = processor.get_output()
```

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Explore: Geometry

Geometry

1_Introduction/00_CIL_Geometry.ipynb

- Learn how to set-up Acquisition geometries for:
  - Parallel beam – 2D and 3D
  - Cone beam – 2D and 3D
  - Offsets
  - Tilted detectors

Where is my Reader?

1_Introduction/exercises/03_where_is_my_reader.ipynb

- Hands-on exercise working with cone-beam CT data

- Read in TIFF data and construct geometry from known info about the experiment

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Explore!

Further Pre-processing	
Preprocessing Synchrotron Data	1_Introduction/03_preprocessing.ipynb
Preprocessing Cone Beam Data	1_Introduction/exercises/02_preprocessing_seeds_conebeam.ipynb
Paganin Phase Retrieval	4_Deep_Dives/02_phase_retrieval.ipynb

Geometry	
Where is my Reader?	1_Introduction/exercises/03_where_is_my_reader.ipynb
Geometry	1_Introduction/00_CIL_Geometry.ipynb

Regroup

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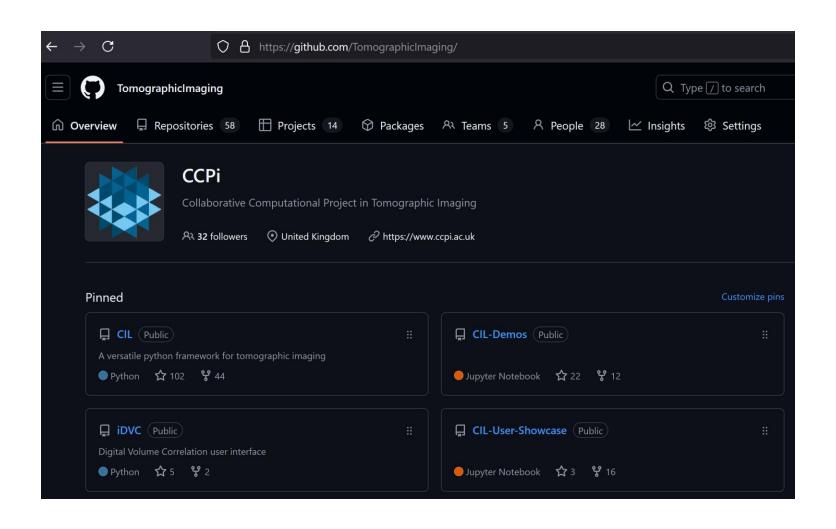**Time to explore and discuss – 4:00-4:50** (Lead: Franck)

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CIL on GitHub.com/TomographicImaging

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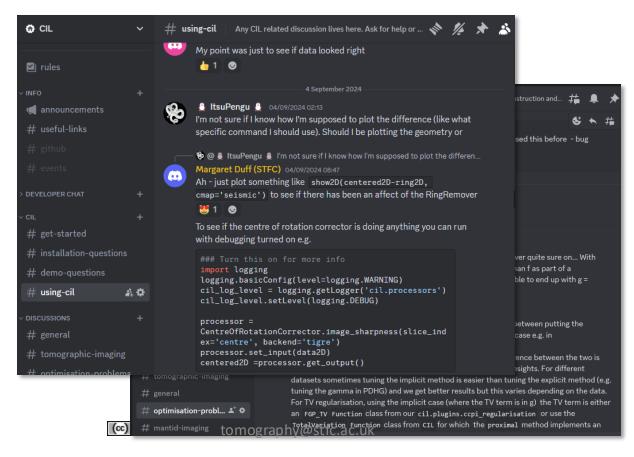# CCPi network: CIL User Community

User support through GitHub

And CIL discord with 200+ users

General and tailored support

Fortnightly User Drop-ins

CIL Discord

CIL GitHub

CCPi network: CIL User Community Events

Travel grants

In person and online training

CIL User Meeting – Feb 2026 at RAL

Data and software hackathons (2 per year)

CIL-Pytorch hackathon 7-9 April @ UCL

Fortnightly Show and Tell Meetings

For more details…
https://ccpi.ac.uk

tomography@

Feedback on Mentimeter

tomography@stfc.ac.uk

See you tomorrow : Introduction to iterative reconstruction

Welcome, intro and cloud set-up 1-1:15 – Edo

Intro to optimisation – 1:15-2:15 – Edo
- Intro lecture
- Time to explore: demos/1_Introduction/04_FBP_CGLS_SIRT.ipynb
- Extension: demos/1_Introduction/05_USB
- **Break**

Intro to regularisation 2:30-3:30 – Jakob
- Intro lecture
- Demo: binder/PyData22_deblurring.ipynb
- Notebook: 2_Iterative/Optimisation_gd_fista.ipynb
- **Break**

Time to explore and discuss – 3:45-4:45 – Jakob
- Notebook: 2_Iterative/05_Laminography_with_TV.ipynb
- Notebook: 3_Multichannel/03_Hyperspectral_reconstruction.ipynb

Conclusions 4:45-5 – Jakob and Margaret