Image Reconstruction with CIL

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Manchester

Edoardo Pasca, Franck Vidal, Nalin Gupta

STFC Tomography and Imaging

CCPi TOMOGRAPHIC IMAGING Bring together expertise in computational research for tomography and imaging

- Open-source software development, maintenance and distribution
- Methods development
- Community building
- Training and user support network

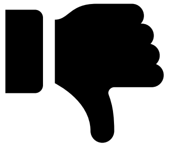
Plan for this workshop

- Introduce tomography and the Core Imaging Library (CIL)
  - Standard reconstruction methods for CT
  - The importance of data (pre) processing

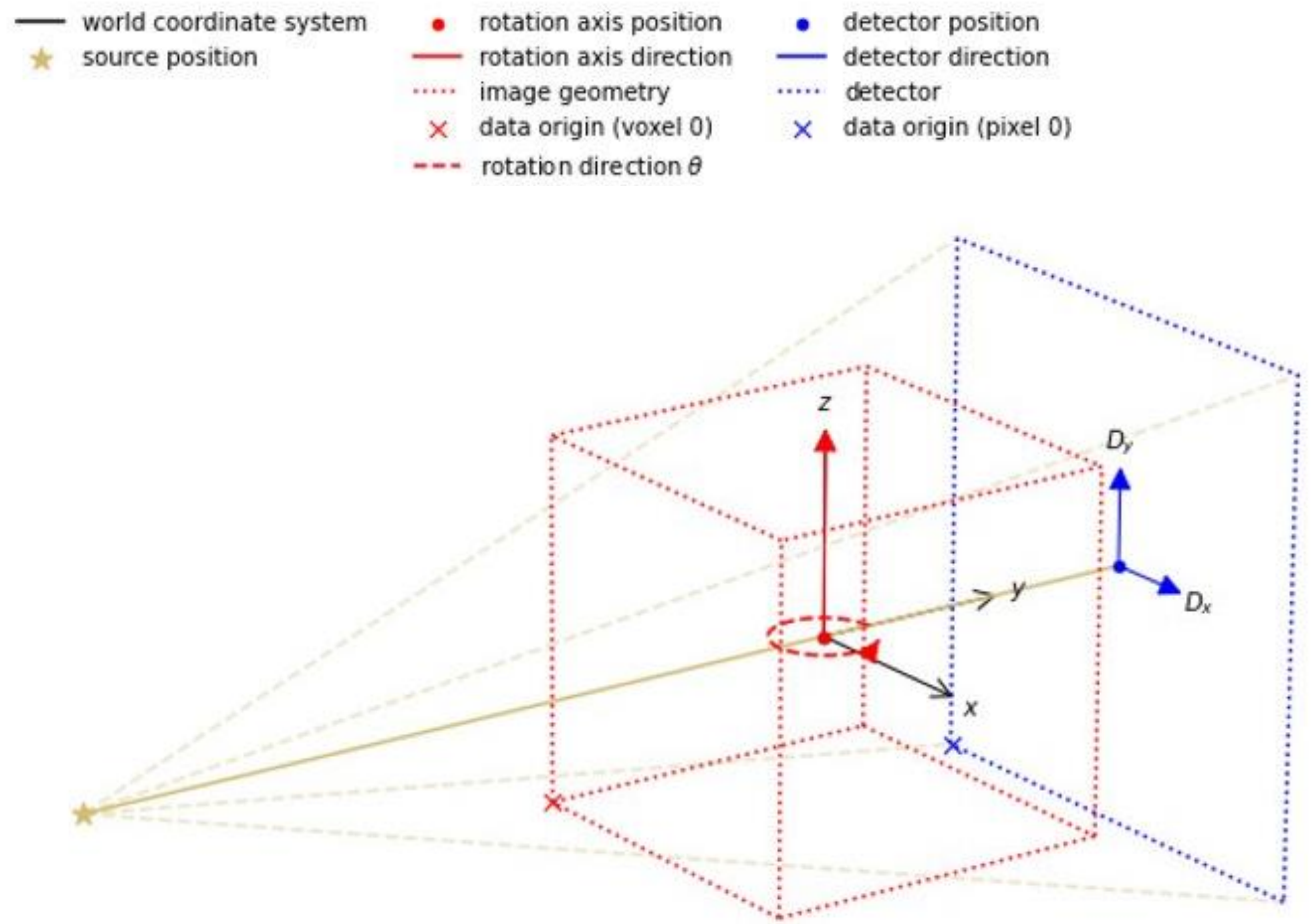
- Introduction to imaging inverse problems
  - Variational regularisation
  - CIL optimisation toolkit

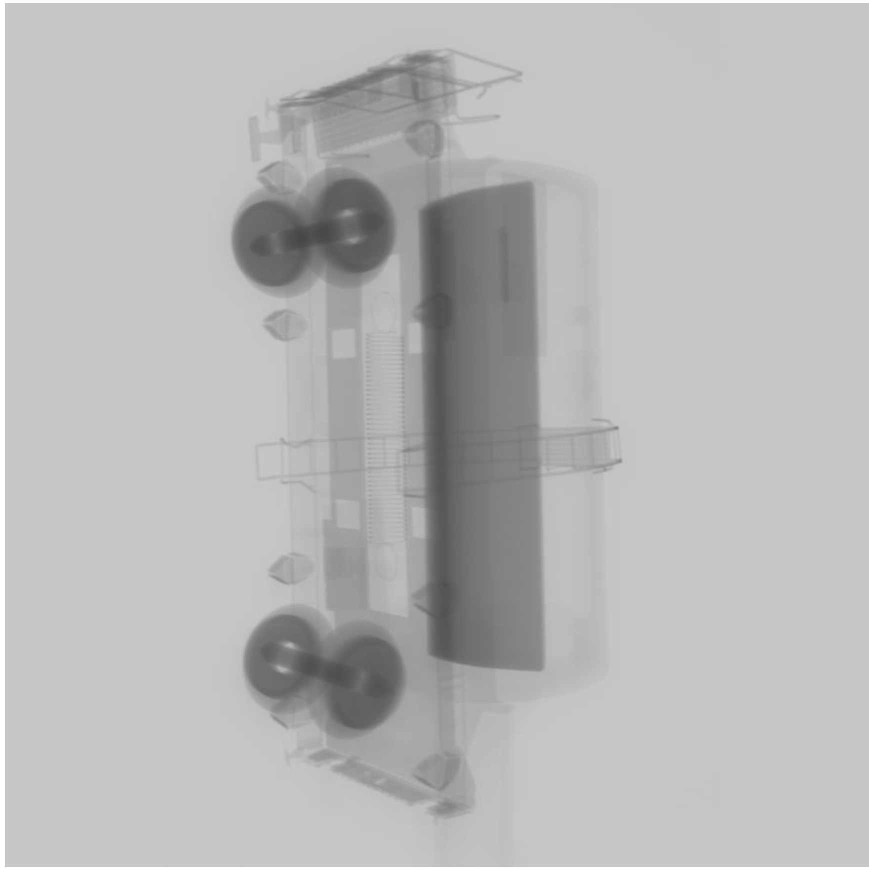
Confidence level check

- Computed tomography
- Python and juypter notebooks
- Inverse imaging problems



Tomography


world coordinate system
source position
rotation axis position
rotation axis direction
image geometry
data origin (voxel 0)
rotation direction θ
detector position
detector direction
detector
data origin (pixel 0)
z
y
x
D_y
D_x



Beer-Lambert Law

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

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

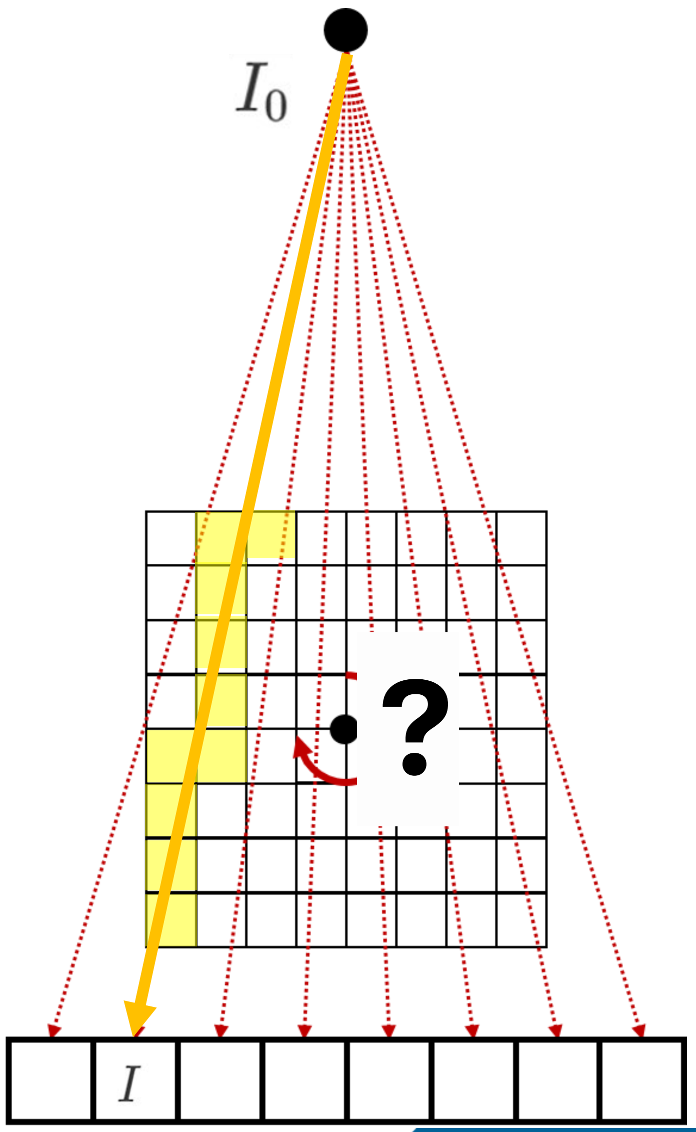
X-ray source

Measurement volume

Reconstructed volume:

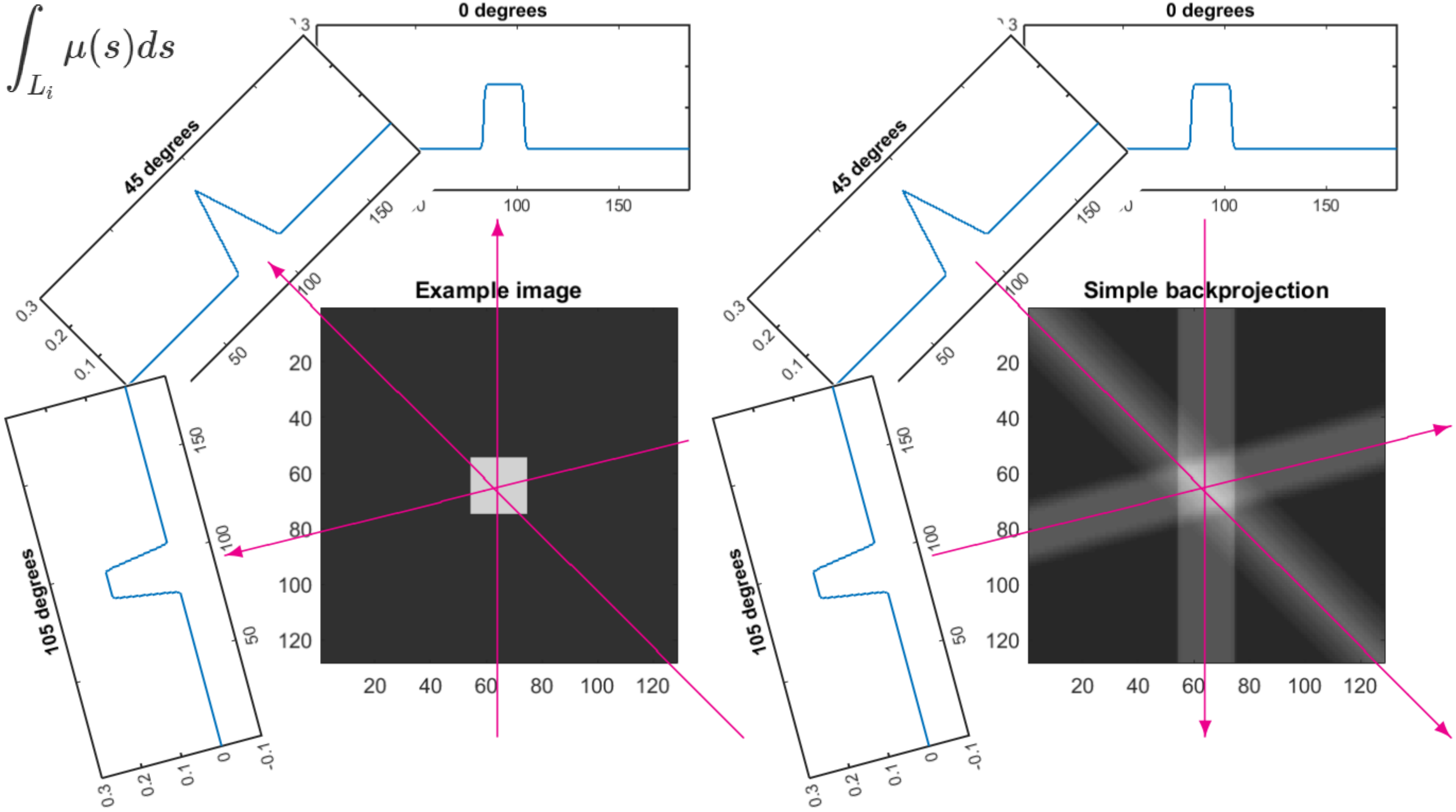
- map of linear attenuation coefficients (μ)
- often expressed in cm^{-1}

X-ray detector

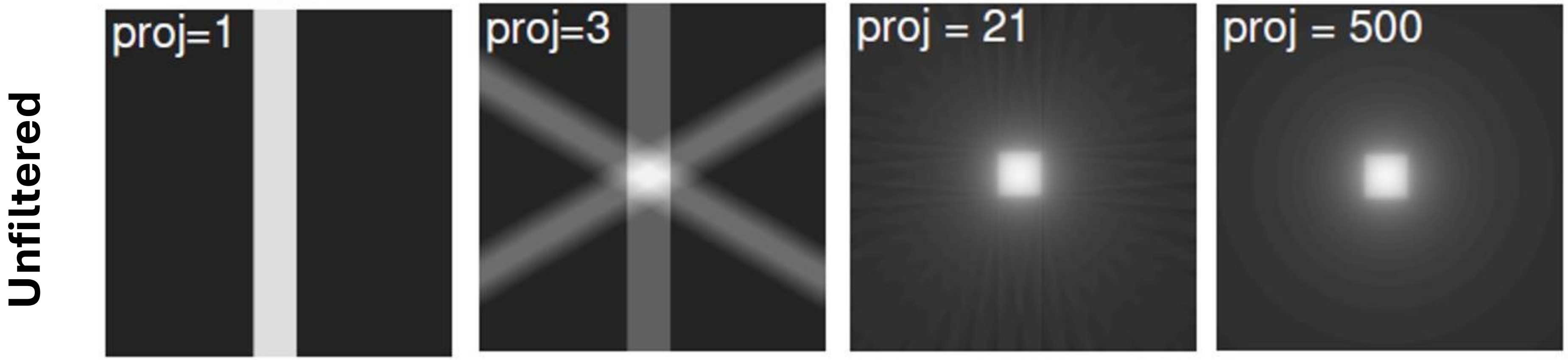


Filtered Back Projection (FBP)

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

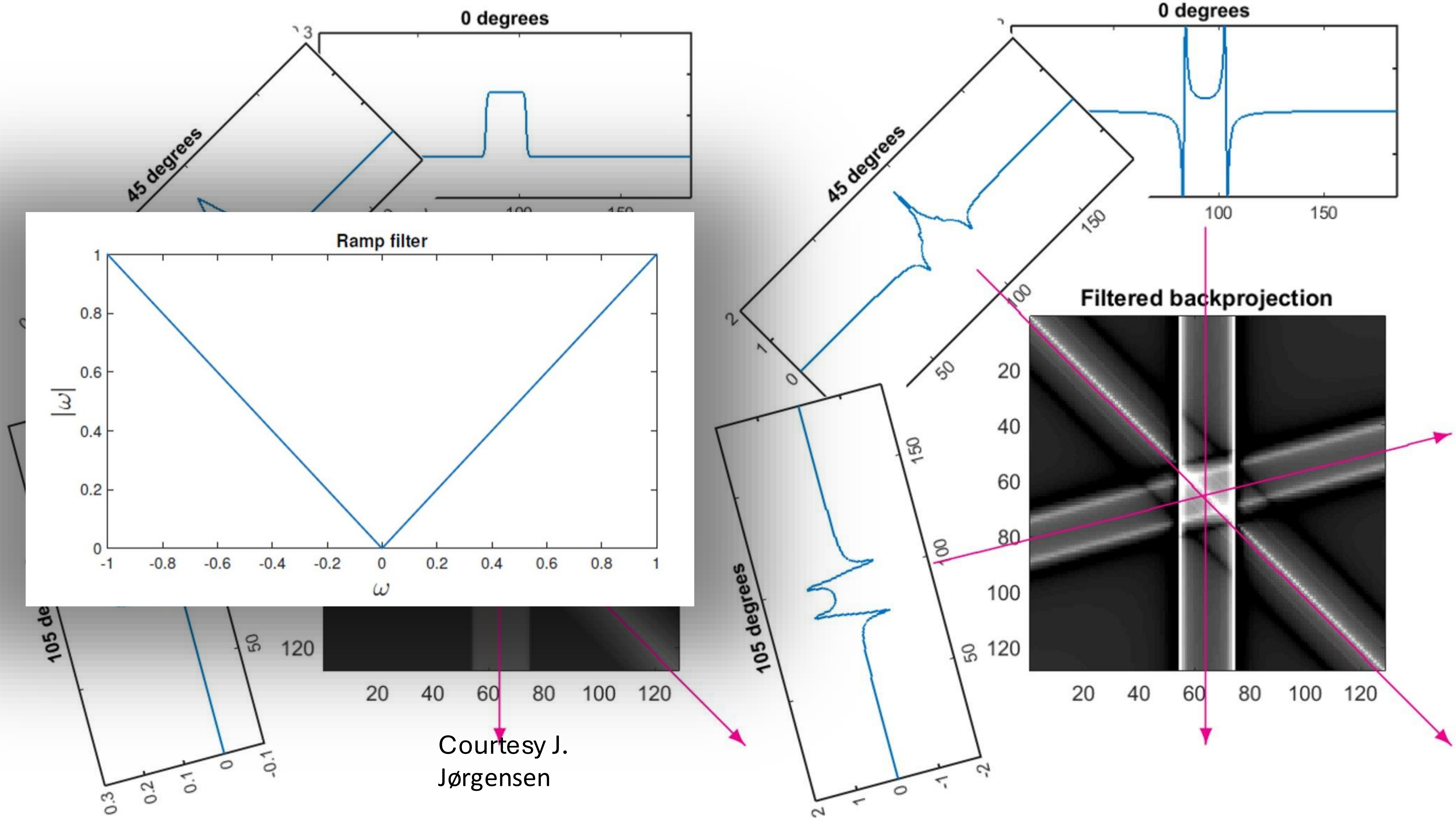


Filtered Back Projection (FBP)



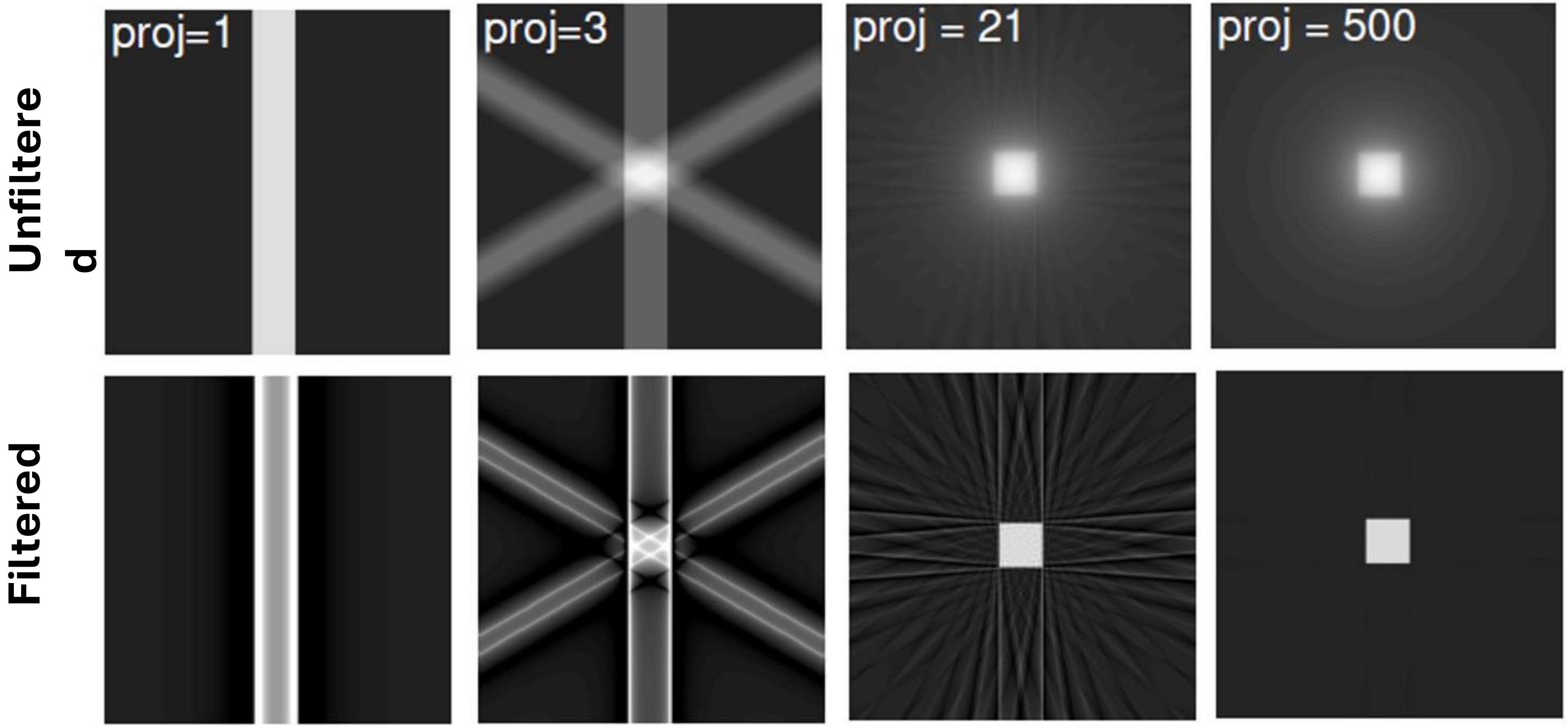
Courtesy J. Jørgensen

Filtered Back Projection (FBP)



Courtesy J. Jørgensen

Filtered Back Projection (FBP)



Courtesy J. Jørgensen

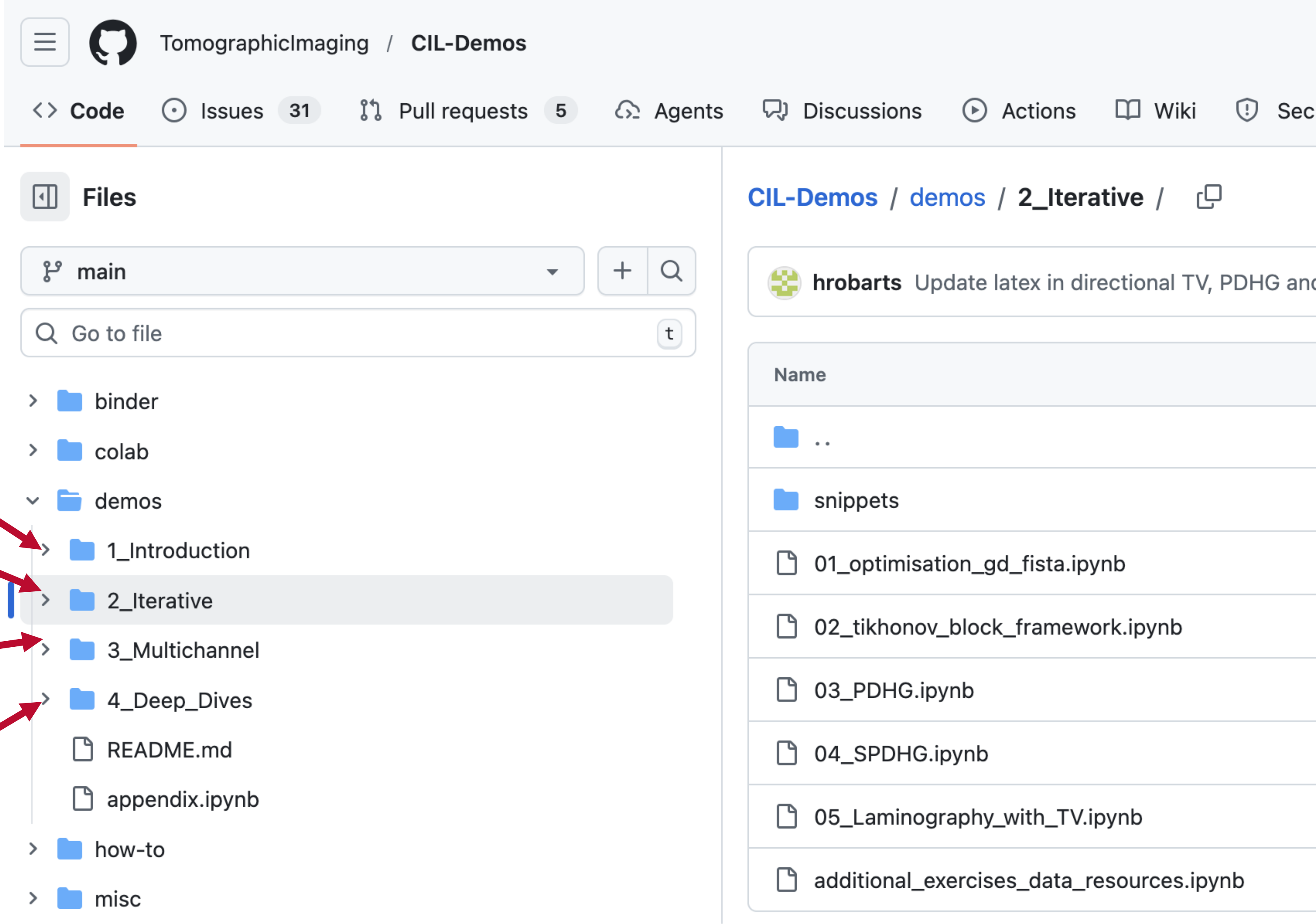
CIL-Demos

Mainly X-Ray CT specific processing

Mainly iterative methods

Hyperspectral/colour processing

Focused training on topic or processing



Example reconstruction - walkthrough

CIL-Demos/demos/1_introduction/**01_intro_walnut_conebeam.ipynb**

- Load and investigate a dataset
- Convert from Transmission to Absorption
- Compute a FDK reconstruction

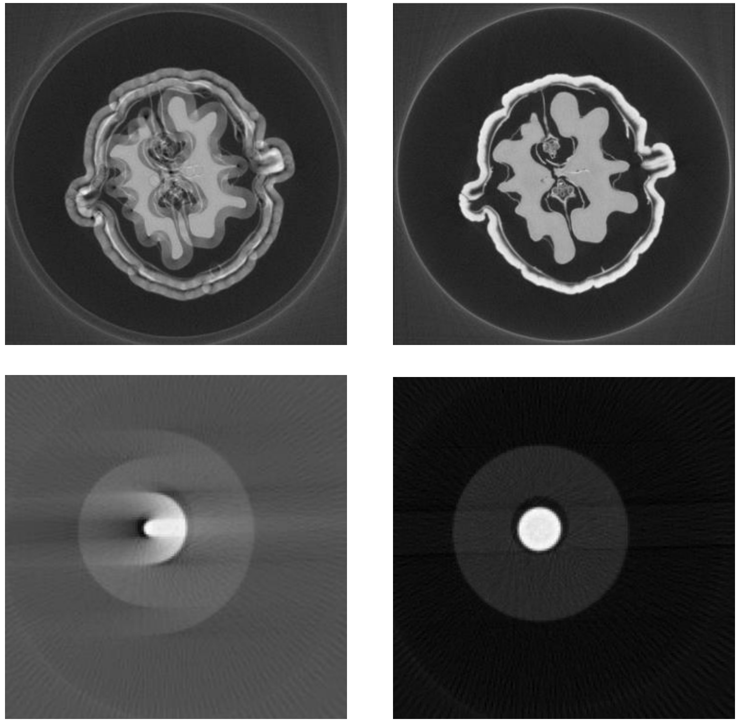
Example reconstruction

CIL-Demos/demos/1_introduction/**01_intro_sandstone_parallel_roi.ipynb**

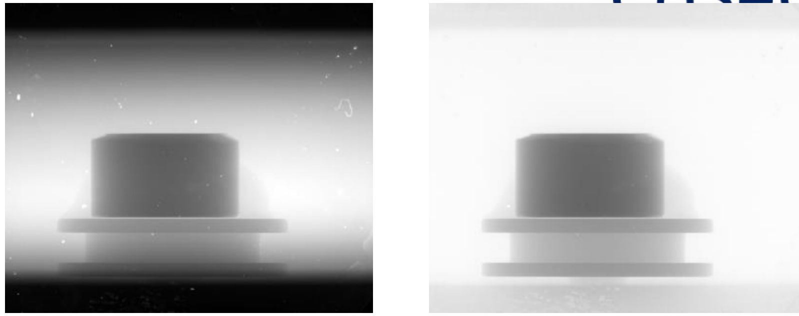
- Load and investigate a synchrotron ROI dataset
- Determine geometric information and set up data structures
- Apply basic pre-processors
- Compute a FBP reconstruction

Data processing methods

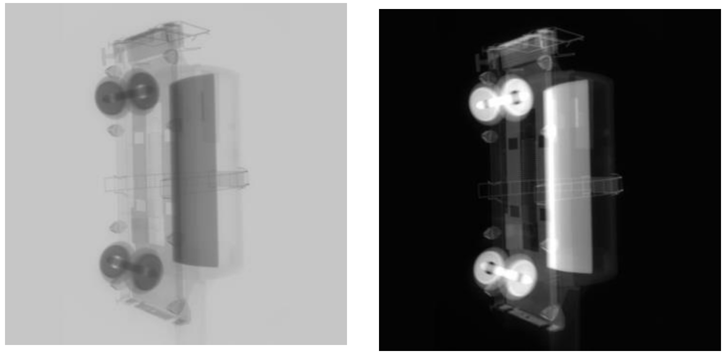
Centre of Rotation correction



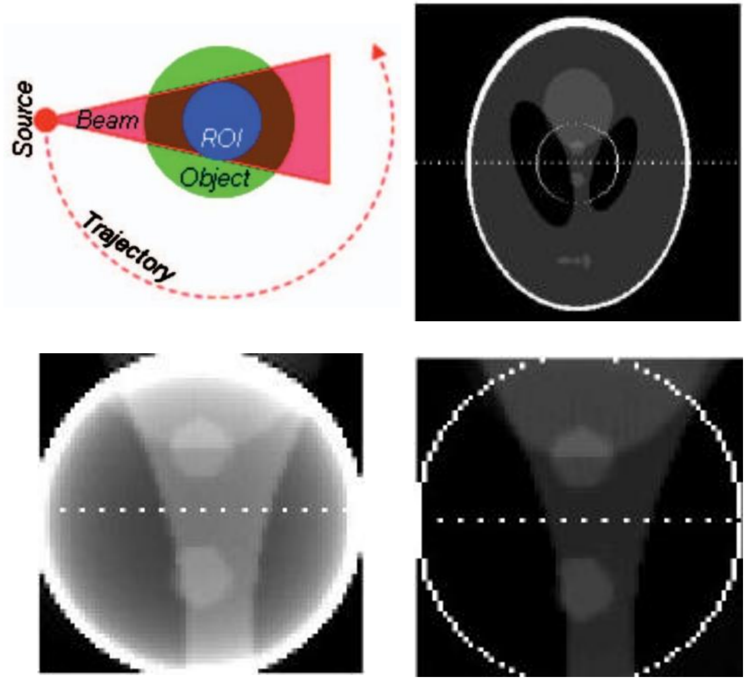
Flat-field correction



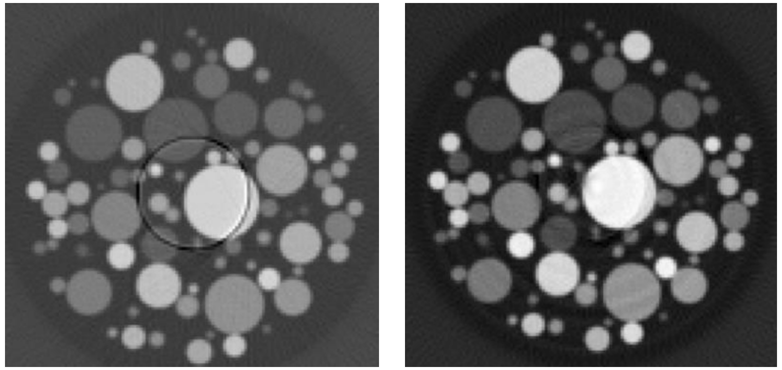
Convert to absorption



Region of interest scans



Ring removal

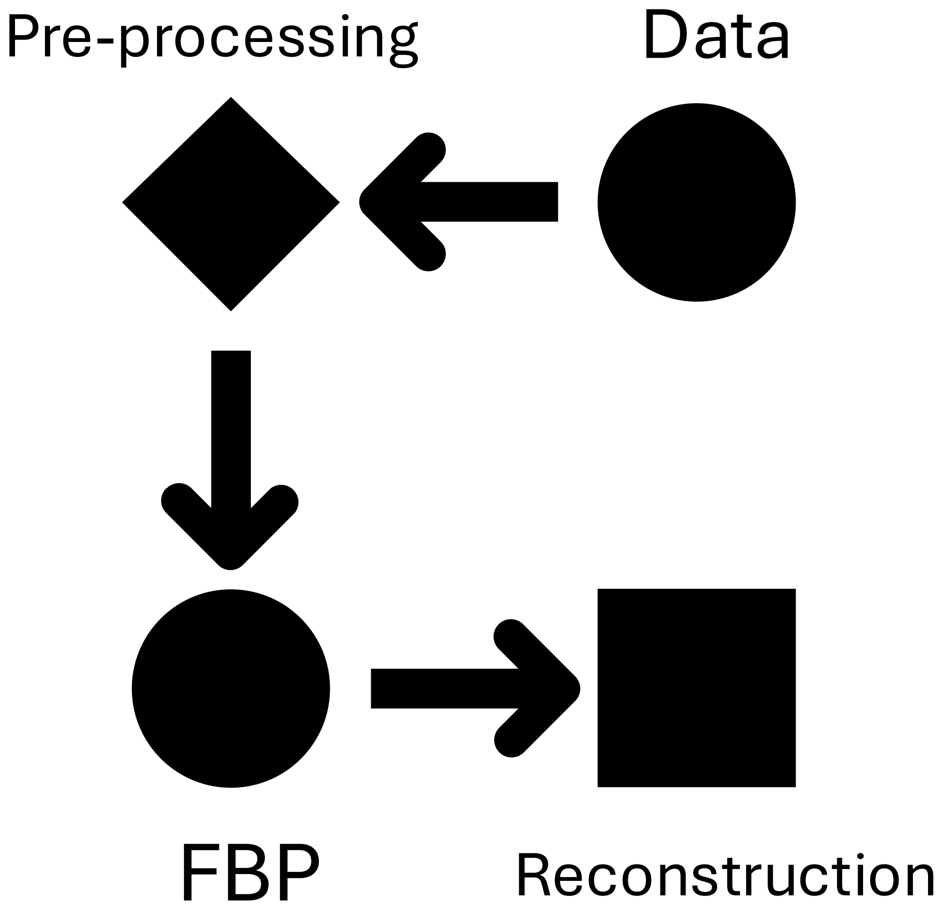


Wrap up

Filtered back-projection is very good!

- If your data is good it should work well
- Do any necessary pre-processing

If your data is not good… consider other methods



Filtered Back Projection (FBP)

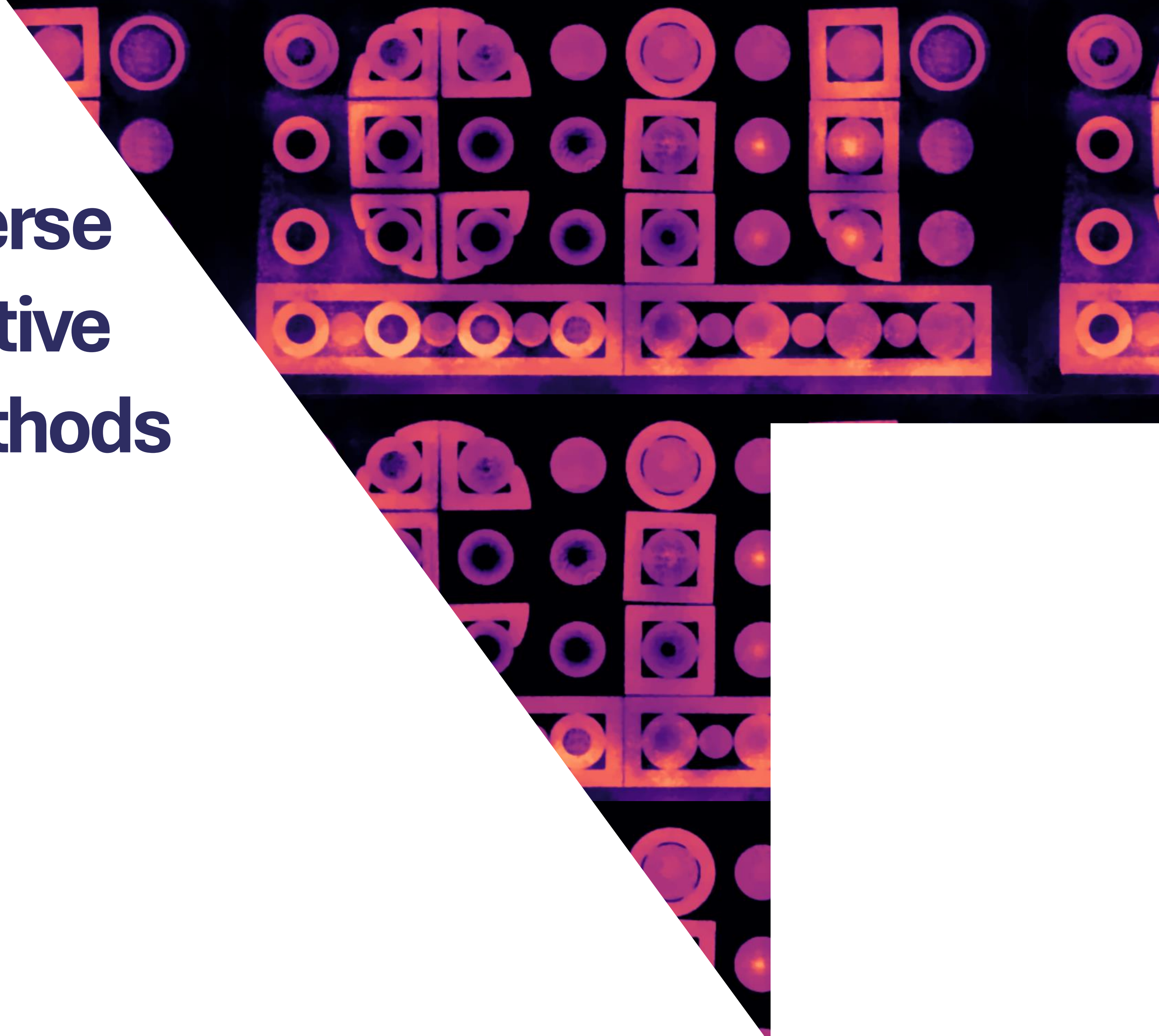
Pros

- Fast as based on FFT and backprojection
- Few parameters
- Typically works very well
- Reconstruction behaviour well understood

Cons

- Number of projections needed proportional to acquisition panel size
- Full angular range required (**limited angle** problem)
- Modest amount of noise tolerated
- Fixed scan geometries
- Cannot make use of prior knowledge such as non-negativity

Introduction to inverse problems and iterative reconstruction methods



Inverse problem example - CT

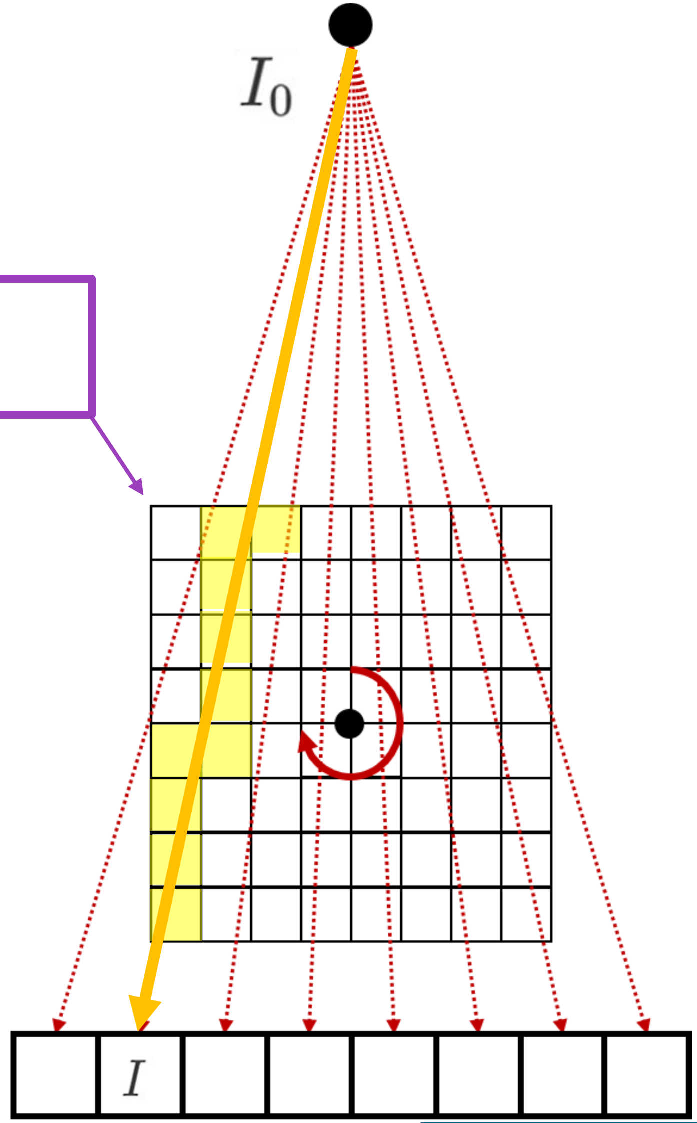
$$\frac{I}{I_0} = \exp \int_{L_i} -\mu(s) ds$$

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

$$b_i = \sum_j a_{ij} u_j \rightarrow Au = b$$

Extremely large set of linear equations!

- Assume object is constant in each pixel
- u_j value of pixel j
- a_{ij} path length of ray i in pixel j



Why iterative methods?

- Direct inversion (e.g., FBP) subject to noise and incomplete data
- Iterative methods allow to incorporate noise models, priors etc.
- Most CT iterative reconstructions use regularization

Regularisation parameter

$$u^\star = \underset{u}{\operatorname{argmin}} \{\mathcal{D}(Au, b) + \alpha \cdot \mathcal{R}(u)\}$$

Data discrepancy term

Regularisation term

Iterative reconstruction – over to you!

CIL-Demos/blob/main/demos/2_Iterative/01_optimisation_gd_fista.ipynb

- Load a dataset and reconstruct with FBP
- Set-up a least-squares problem to solve using CIL's algorithms, a projection operator and objective function
- Add regularisation to the least-squares problem and compare the results: Tikhonov, Non-negativity, L1-Norm, Total-Variation
- Solve the optimisation problem with the appropriate algorithm: Gradient Descent, FISTA, PDHG

Extension options:

- https://github.com/TomographicImaging/CIL-Demos/blob/main/demos/3_Multichannel/02_Dynamic_CT.ipynb
- or https://github.com/TomographicImaging/CIL-Demos/blob/main/demos/4_Deep_Dives/03_htc_2022.ipynb