Welcome CIL online training

CIL
CORE IMAGING LIBRARY
UKRI Science and Technology Facilities Council
Scientific Computing

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

- Check out our HackMD: https://hackmd.io/@ccpi/cil-online-25
    - And answer the icebreaker questions for today!
- Make sure you zoom name is correct
- Check your video and microphone (you will need them later)

CIL Discord

CIL GitHub

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

Scientific Computing @ STFC
Technical University of Denmark (DTU)

Finden

Our goals with this course

- Learn how to build your own objective function
- Learn how to customise your own optimisation problems including using callbacks
- See some deep dives into advanced capabilities in CIL
- Support you in trying out CIL with our Jupyter notebook demos on the cloud
- Set you up to continue exploring CIL for your own data

Training Program

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

Building your own optimisation problem using the block framework– 1:15-2:30 – Jakob

- Demo: 2_Iterative/02_tikhonov_block_framework.ipynb
- Block framework example lecture
- Notebook: 4_Deep_Dives/03_htc_2022.ipynb
- **Break**

Customising your optimisation method- 2:45-3:45 – Margaret

- Demo notebook: 4_Deep_Dives/01_callbacks.ipynb
- Notebook: 4_Deep_Dives/04_preconditioner_stepsize.ipynb
- **Break**

Time to explore and discuss – 4:00-4:45 – Margaret

- Notebook: 1_Introduction/exercises/03_where_is_my_reader.ipynb
- Notebook: 4_Deep_Dives/02_phase_retrieval.ipynb
- Notebook: 3_Multichannel/02_Dynamic_CT.ipynb
- Notebook: 4_Deep_Dives/06_directional_TV.ipynb

Conclusions and further support 4:45-5 – Jakob

Your feedback from Mentimeter

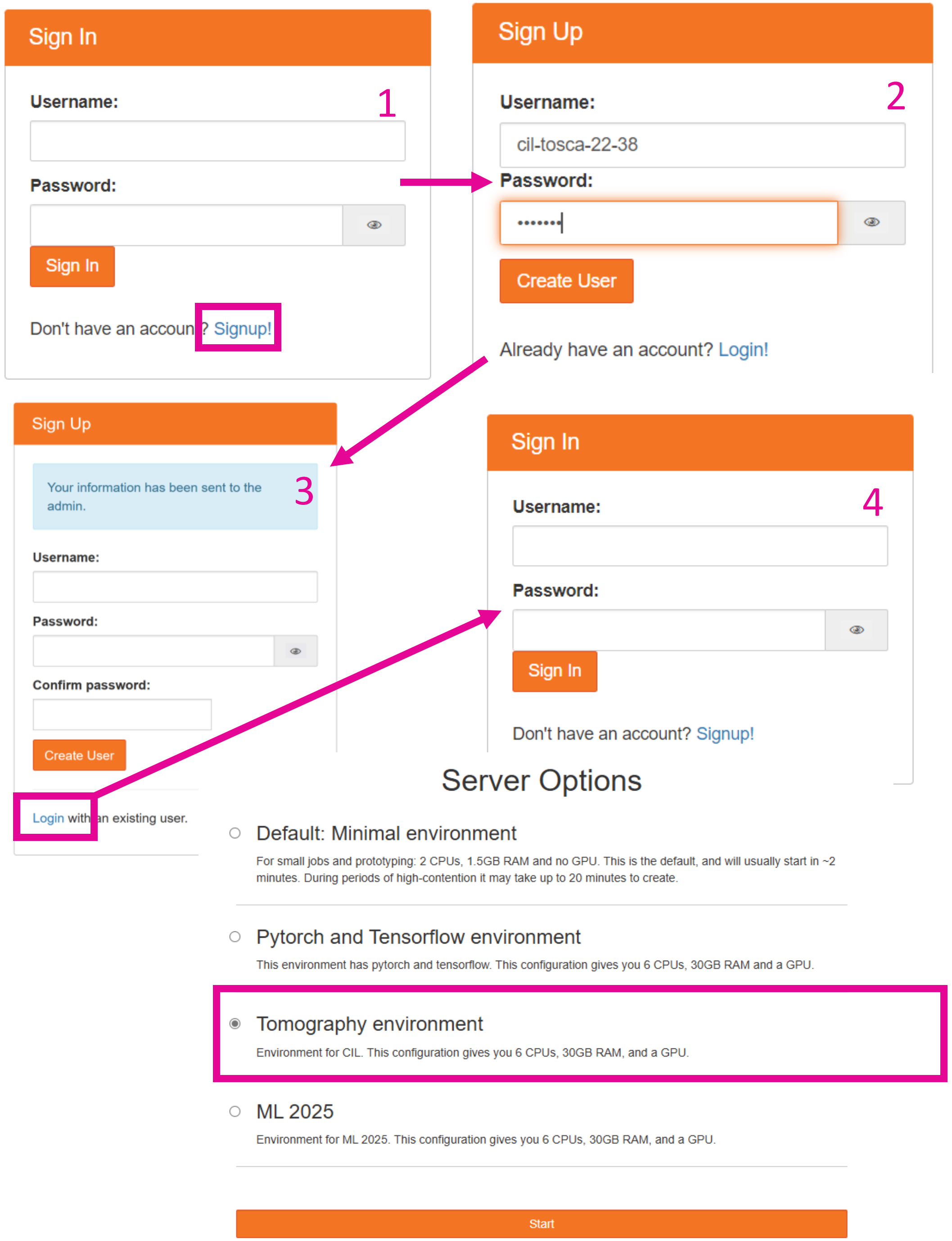
Name one thing we could improve about today's course?

9 11

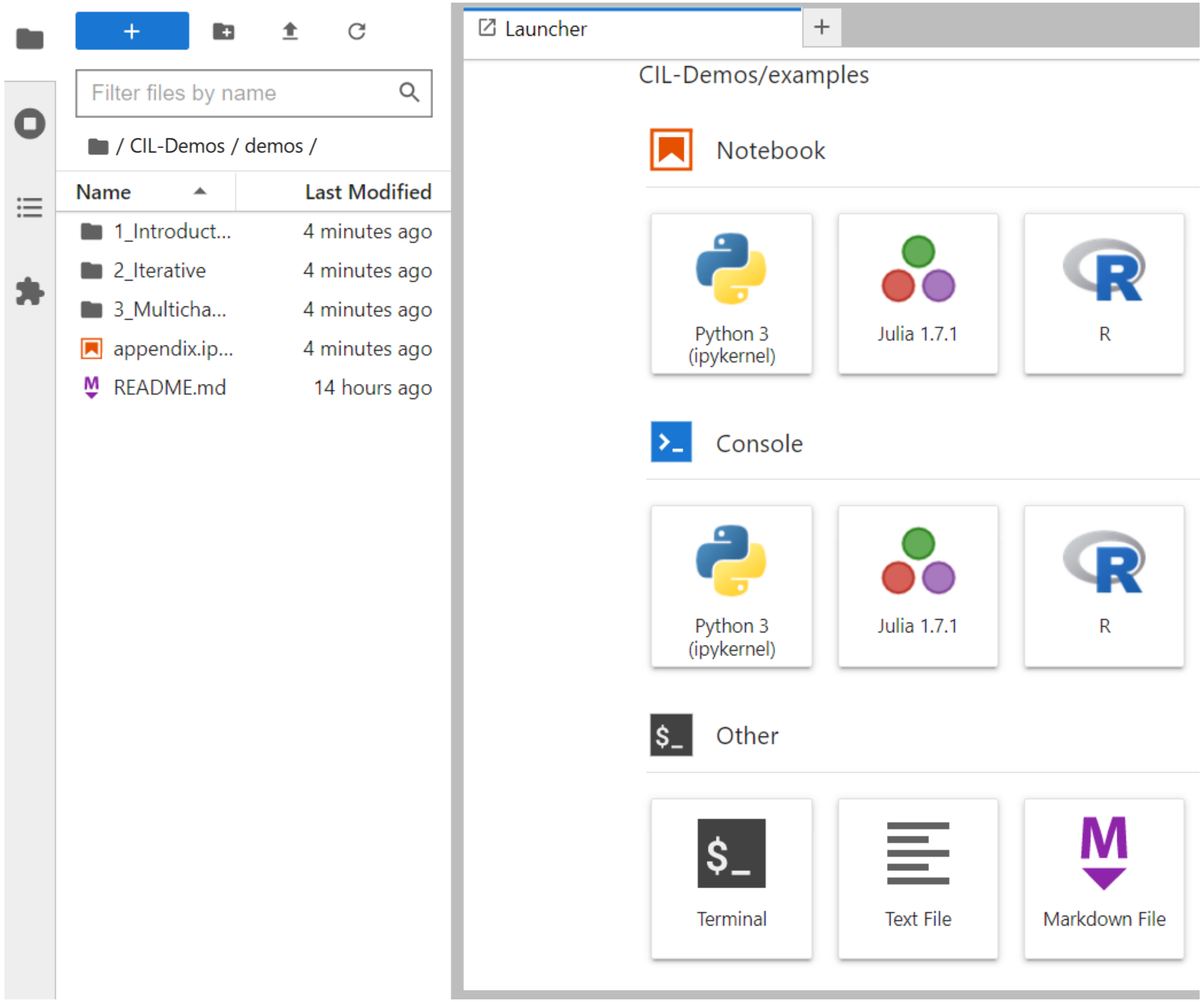
- More background math of some methods
- More math
- More implementation details
- more maths explanations
- Maybe more explanation on what each operator/regularizer/functions does
- More indpepth comparison (plusses and minus) of CIL in comparison to other tools.
- More walk-thoughts if possible
- Maybe we could concentrate a bit more on the mathematical methods, because we haven't used these before.
- More notebook interaction from the instructors.
- If felt a bit like clicking through and not really understanding
- Instead of covering so much content, is it possible to make a simple module to provide a test of all the things first at a bit lower difficult level and then build on it on the next day?

Log in to JupyterHub

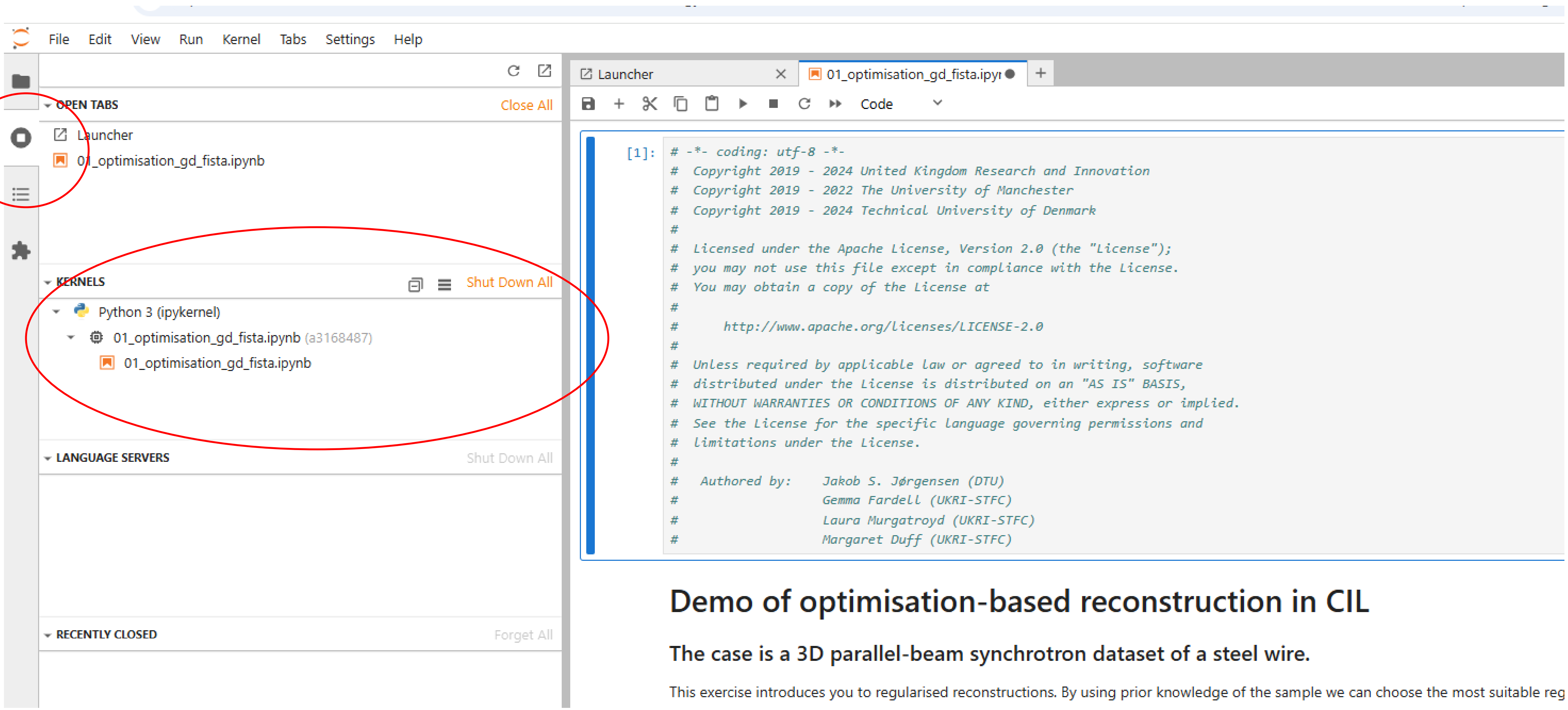
- Go to: https://tinyurl.com/cil-online-25 and write your name next to a **username** to claim it for the exercises
- Go to: https://training.jupyter.stfc.ac.uk/
- **Sign up with the username** you claimed and a password of your choice.
- No password reset option, so remember your password!
- Then log in with the username and password you set.
- Select the **Tomography environment** server and press "start":



Once you've logged in …

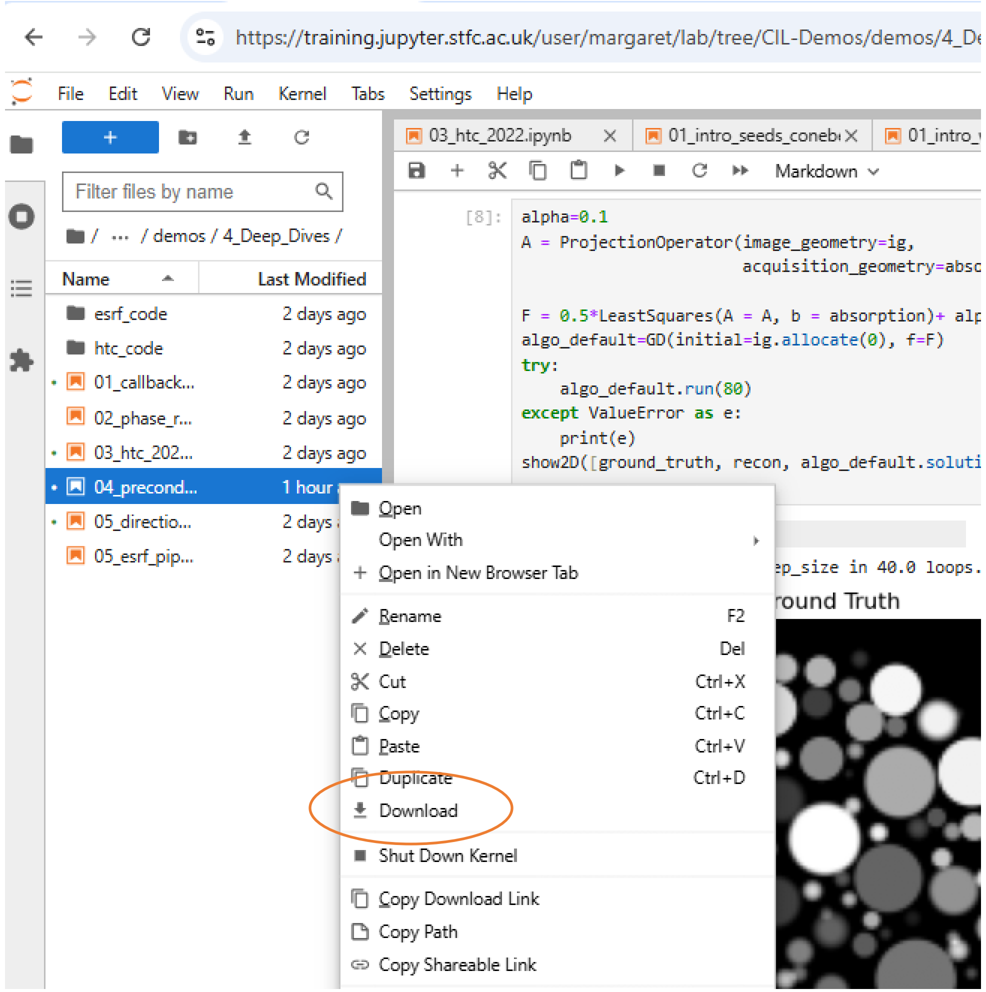


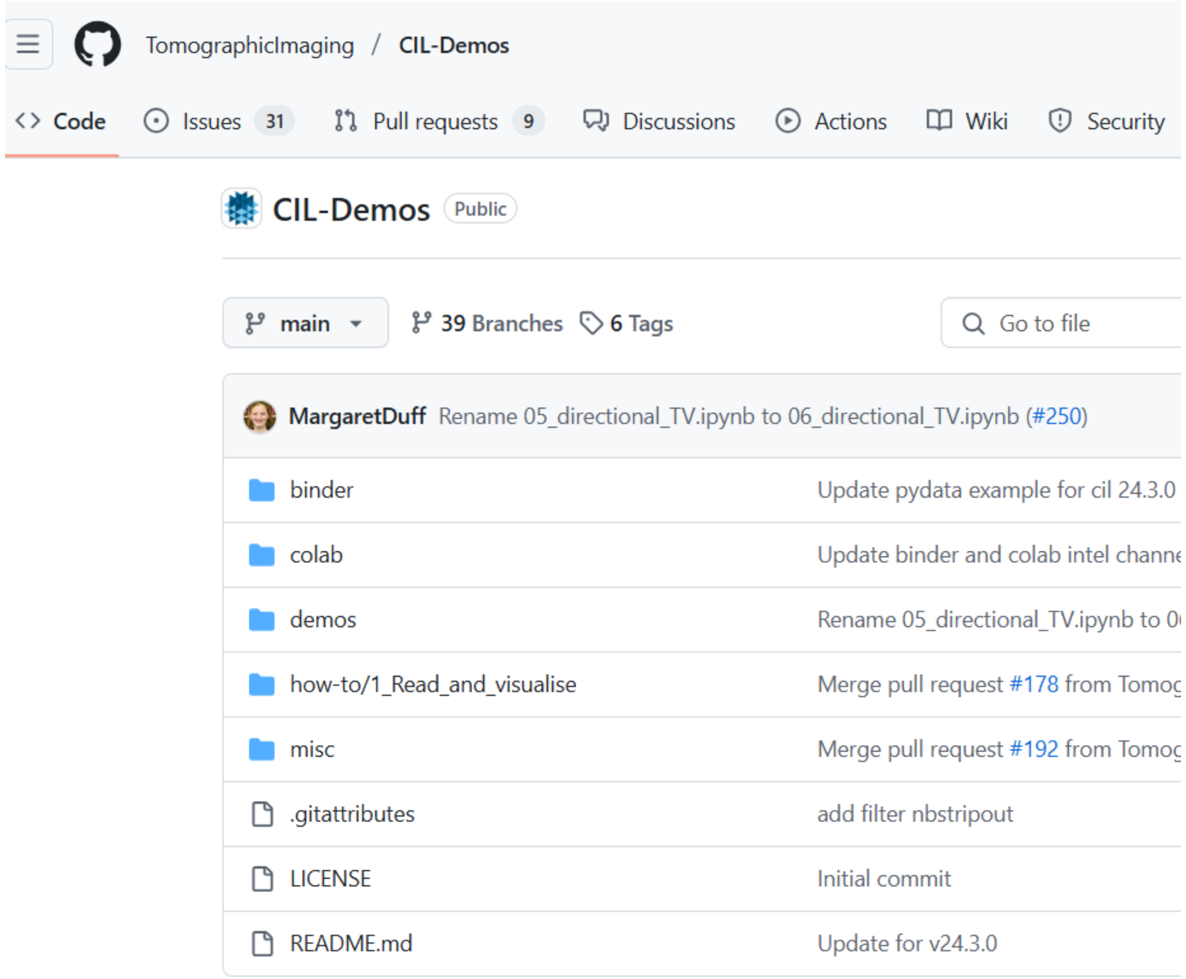
Killing kernels – IMPORTANT



tomography@stfc.ac.uk

Jupyterhub access – until 5pm UK tomorrow

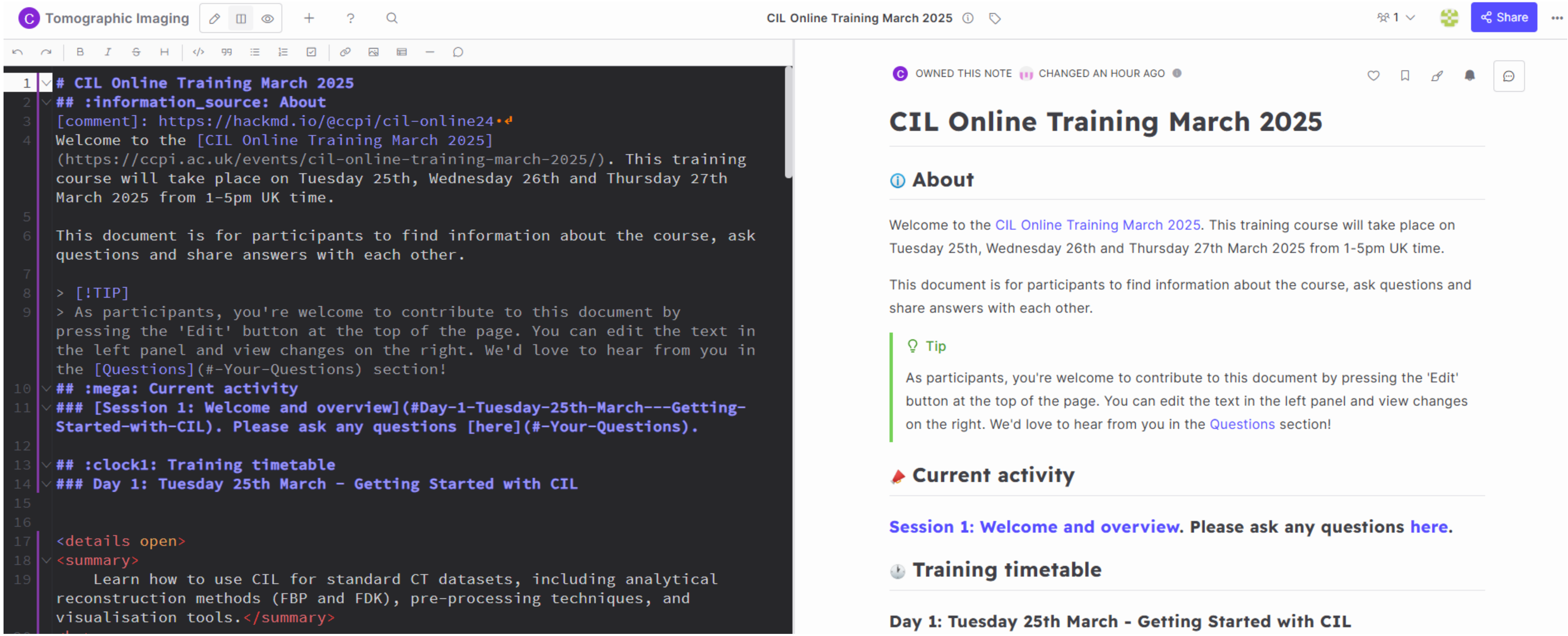




https://github.com/TomographicImaging/CIL-Demos

HackMD

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



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Conclusions and further support 4:45-5 – Jakob

Block Framework

Demonstration

Go to:
CIL-Demos/demos/2_Iterative/02_tikhonov_block_framework.ipynb

Learning Objectives:
1. Construct and manipulate BlockOperators and BlockDataContainer, including direct and adjoint operations and algebra.
2. Use Block Framework to solve Tikhonov regularisation with CGLS algorithm.
3. Apply Tikhonov regularisation to tomographic reconstruction and explain the effect of regularisation parameter and operator in regulariser.

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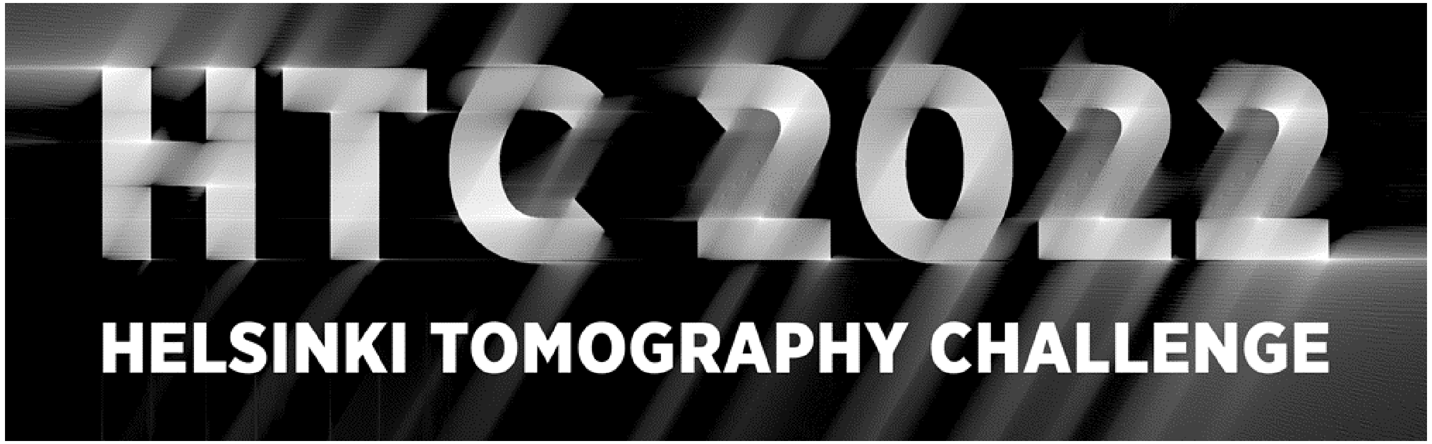
Example of block framework and modularity



Competition (CIL team finished 3rd)
https://www.fips.fi/HTC2022.php

Article describing methods:
A directional regularization method for the limited-angle Helsinki Tomography Challenge using the Core Imaging Library (CIL)
https://www.aimsciences.org/article/doi/10.3934/ammc.2023011

Special award session, Inverse Days 2022

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Scientific Computing

HELSINKI TOMOGRAPHY CHALLENGE 2022 – FINNISH INVERSE PROBLEMS SOCIETY

CERTIFICATE OF AWARD

Presented to JAKOB SAUER JØRGENSEN, EDOARDO PASCA, GEMMA FARDELL, EVANGELOS PAPOUTSELLIS, AND LAURA MURGATROYD for participating as a team in the Helsinki Tomography Challenge 2022 held at the Department of Mathematics and Statistics of the University of Helsinki and getting the THIRD place.

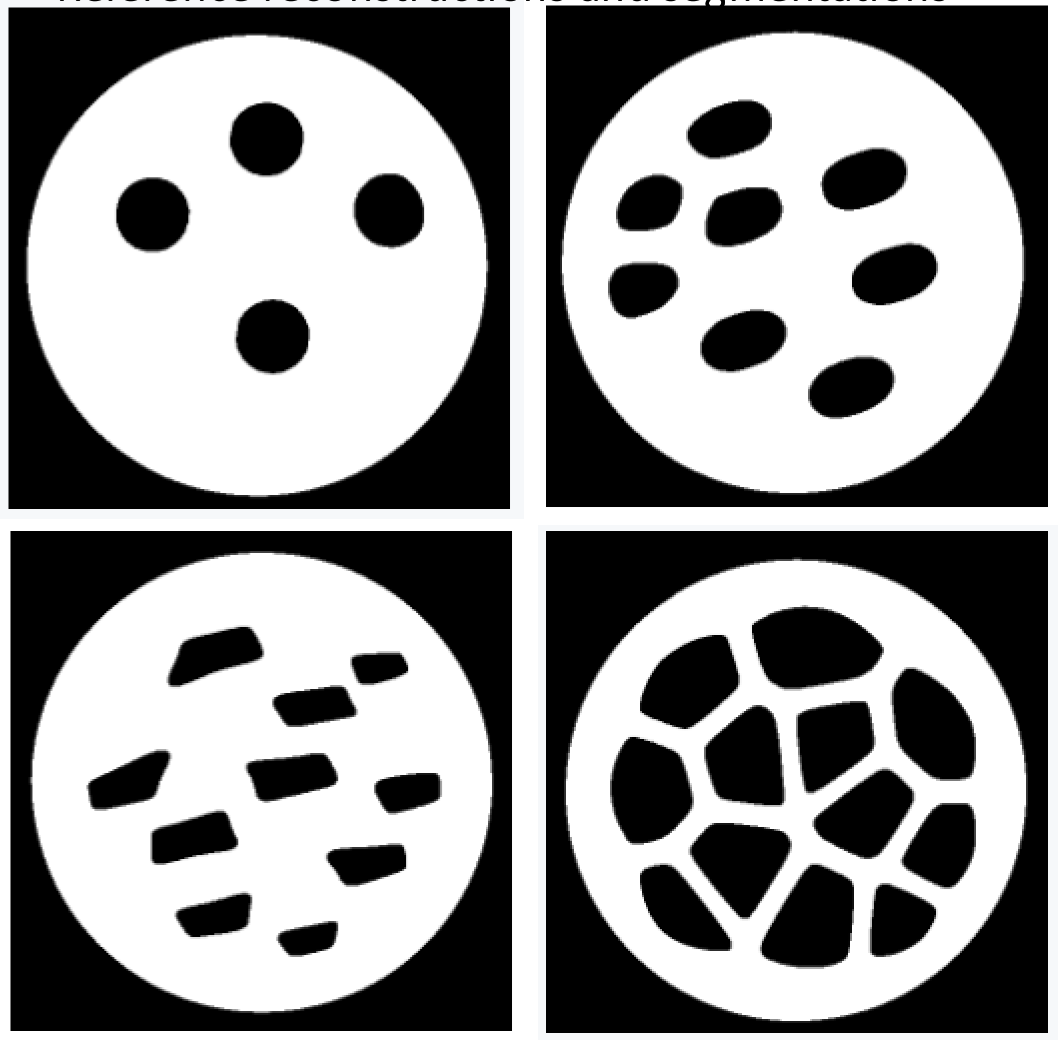
Fernando Moura
Organizing committee
Helsinki, November 24th 2022

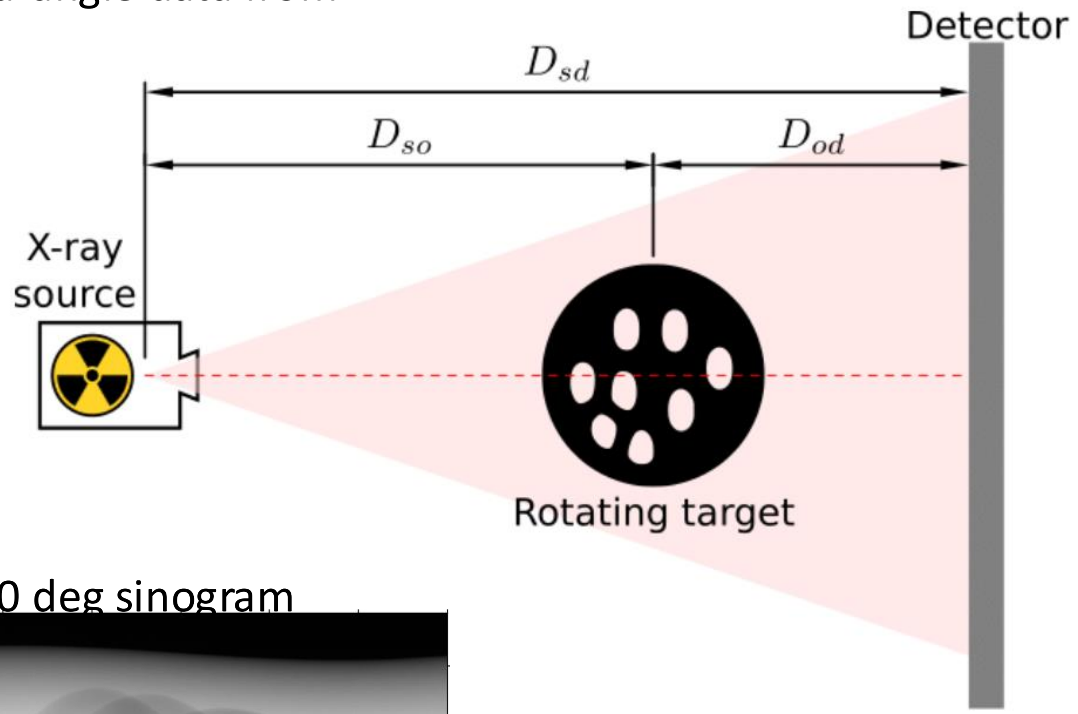
fips Finnish Inverse Problems Society

UNIVERSITY OF HELSINKI

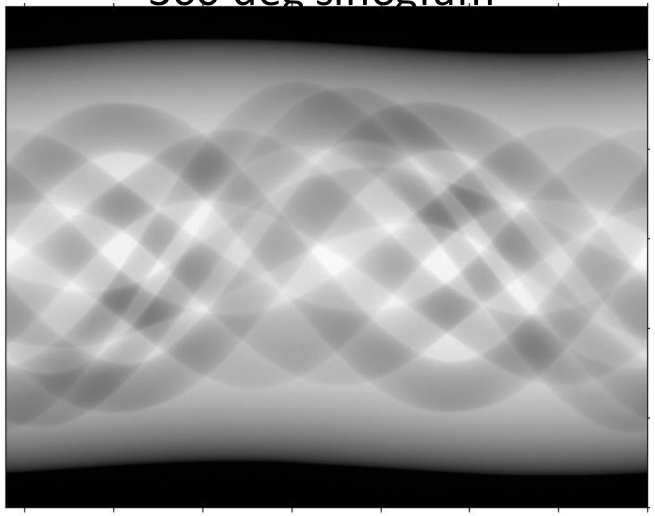
Test data provided and scan setup

- Four 360 degree measured sinogram data sets to generate limited-angle data from
- Reference reconstructions and segmentations

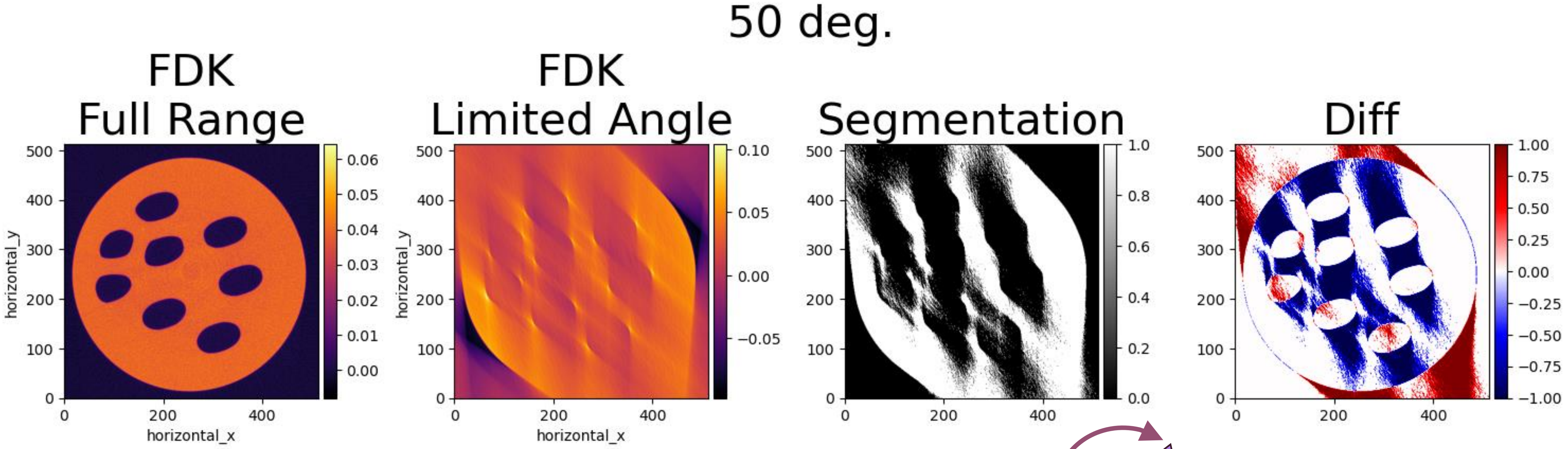


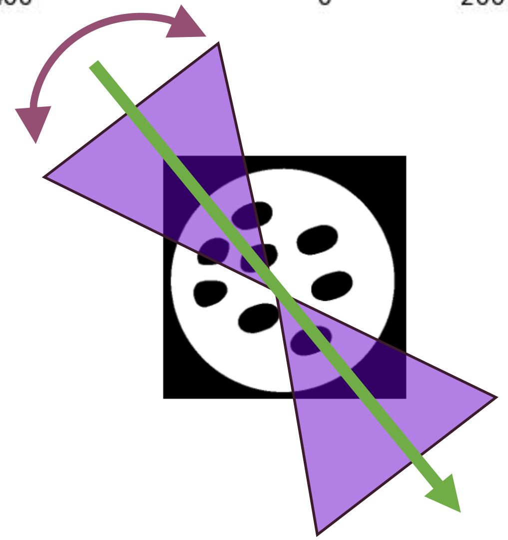


360 deg sinogram



Motivation





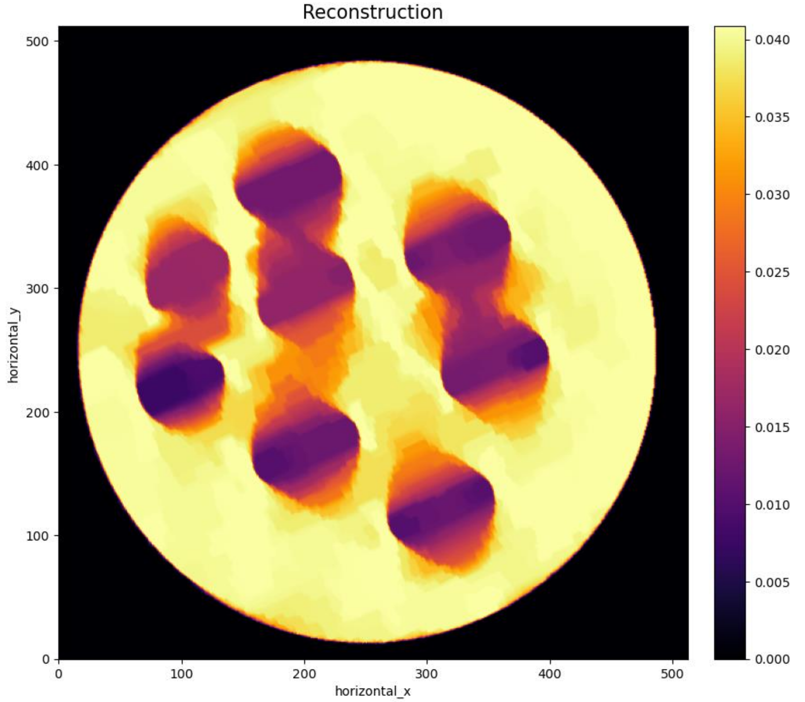
- See how far "conventional" CT pre-processing plus variational methods could go
- Use existing general purpose CIL tools as much as possible – limited time for new dev

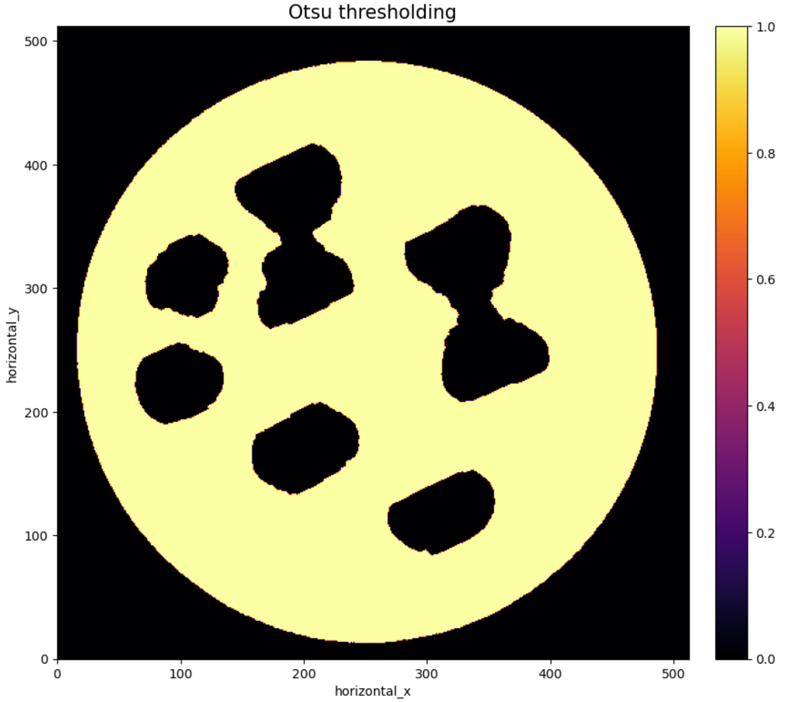
Segmentation

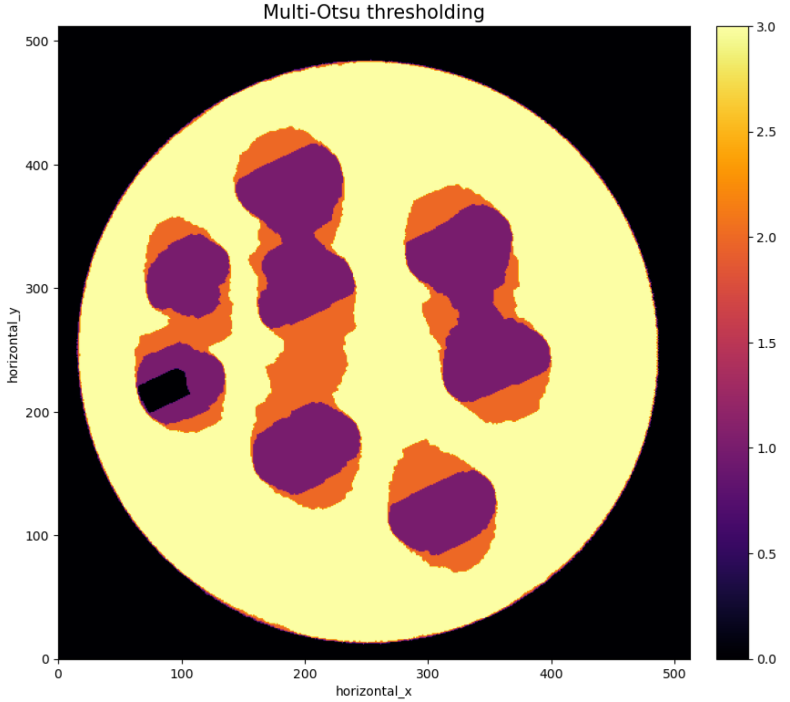
- 'blind' segmentation of the test data
- Not our expertise!
- Otsu triple-threshold worked consistently for the test data at 30 degrees

- Otsu thresholded segmentation
  - Identifies signal peak

- Otsu triple-thresholded segmentation
  - Strong signal
  - Messy signal
  - Messy background
  - Strong background

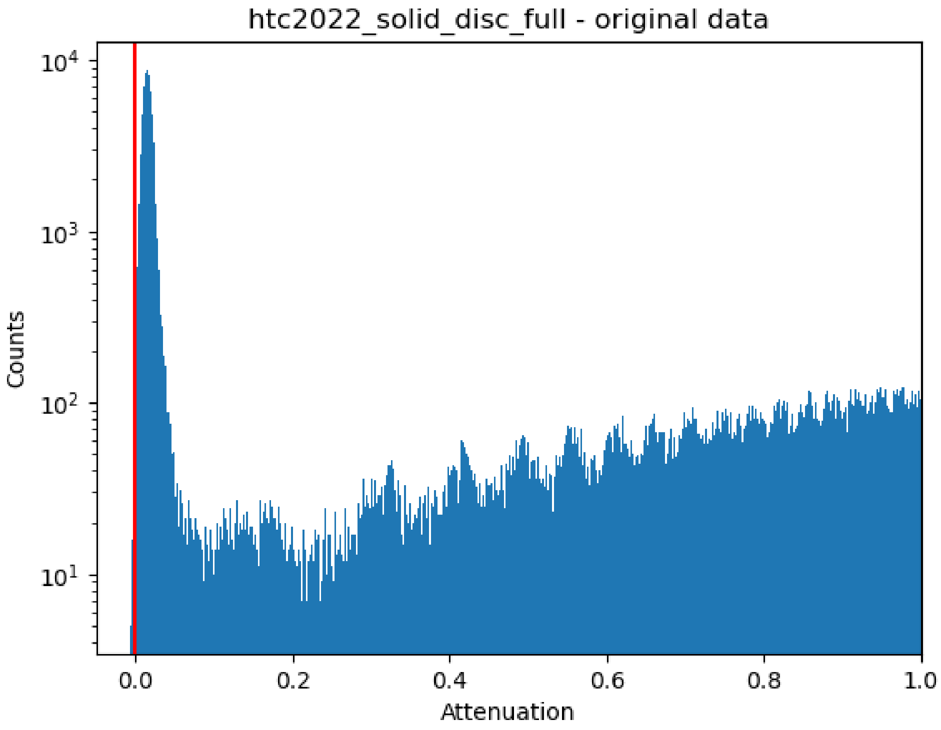


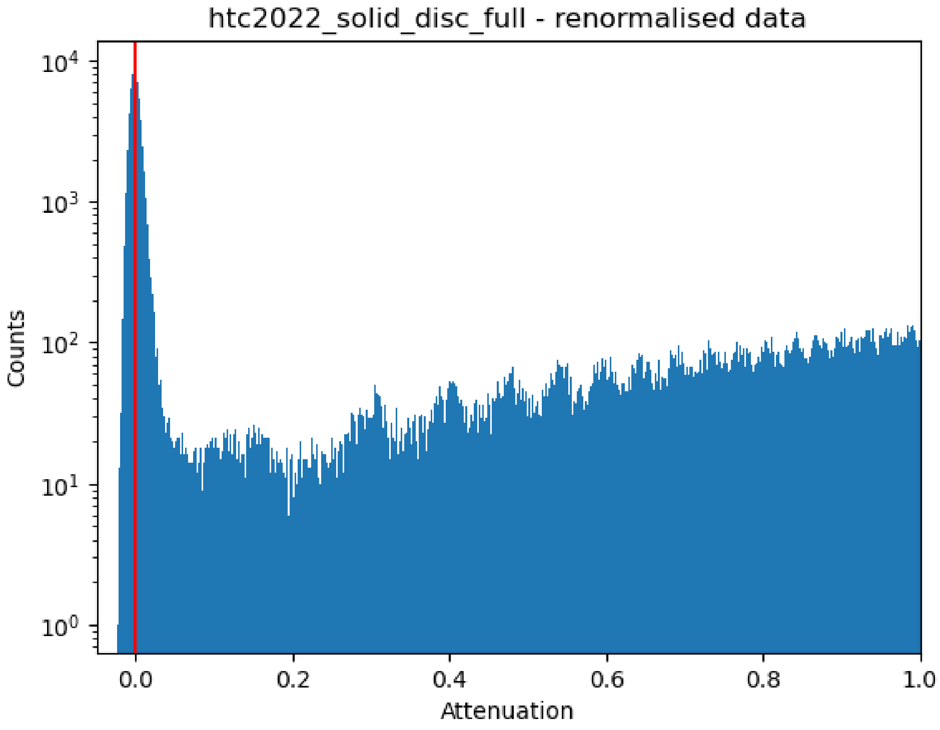




Renormalization of sinogram

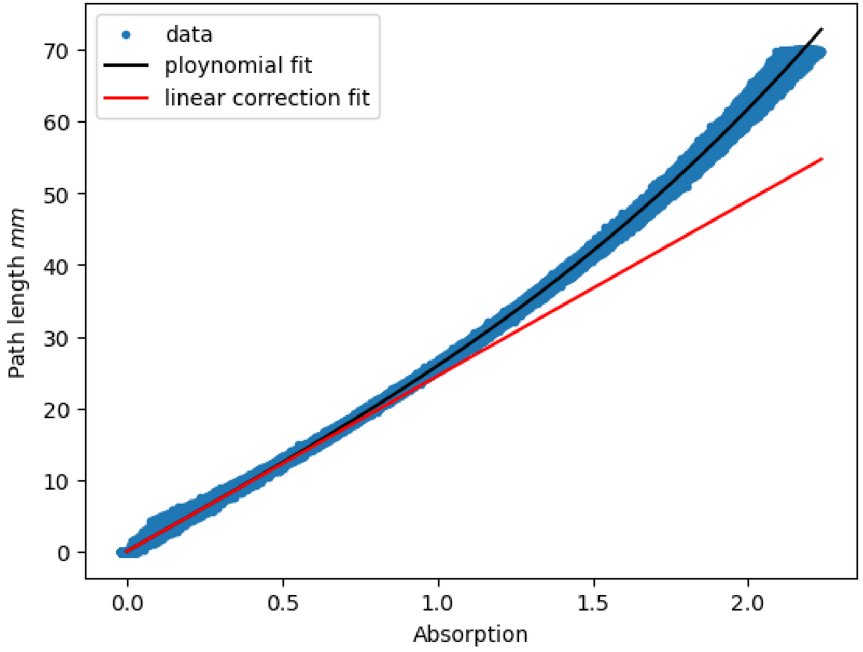
- Background attenuation should have a mean at zero
- Test data had an offset i.e. the normalization image was brighter than the data
  - Convert data back to I/I0, renormalize for a peak at 1, convert back to absorption

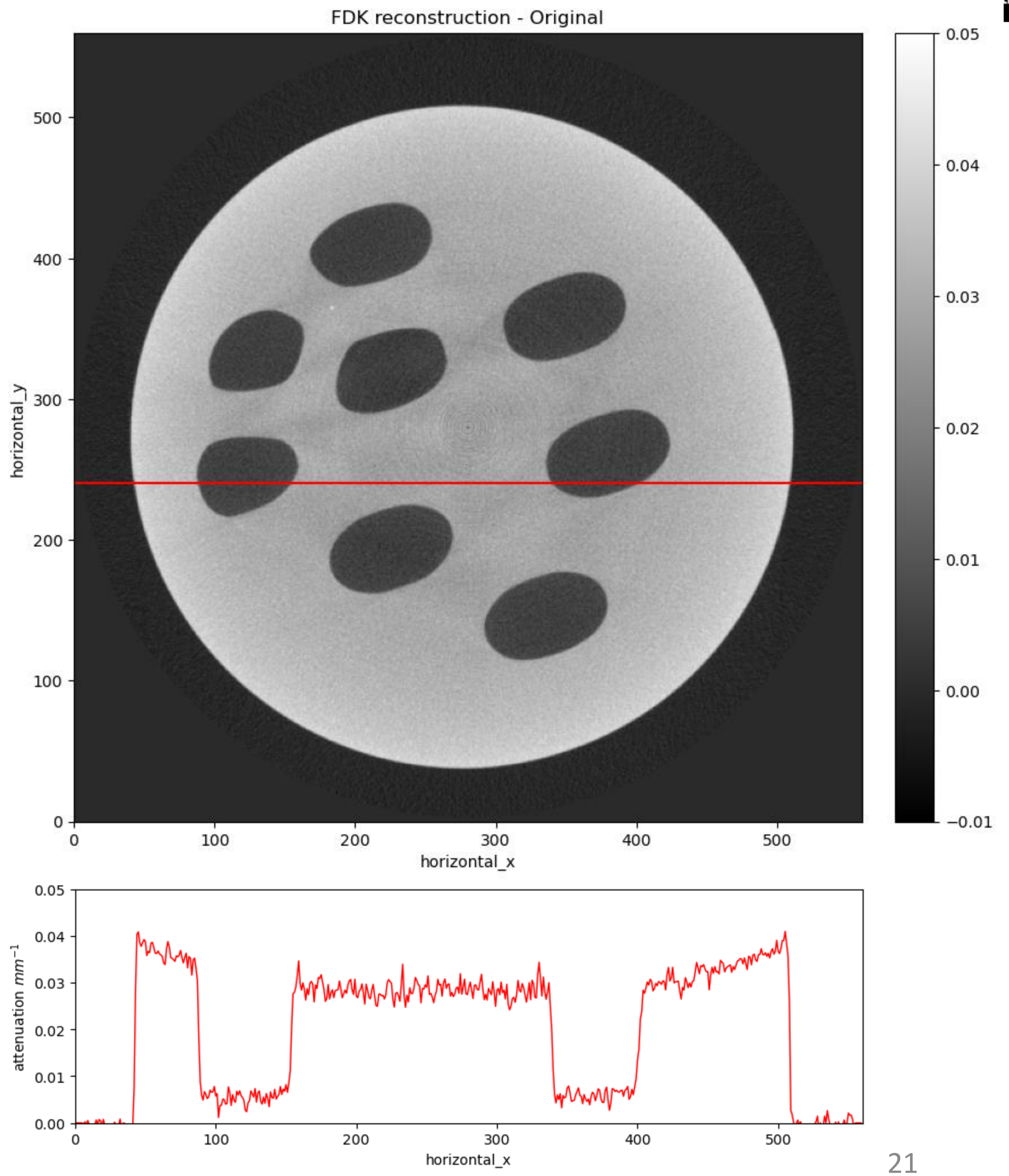




Beam hardening correction

- Lower energy rays are preferentially absorbed leading to a non-linear measurement
- Single material scan can be linearised to an effective monochromatic energy
- Correction to the linear attenuation of acrylic at 24.7 KeV, mu = 0.0409 mm^{-1}





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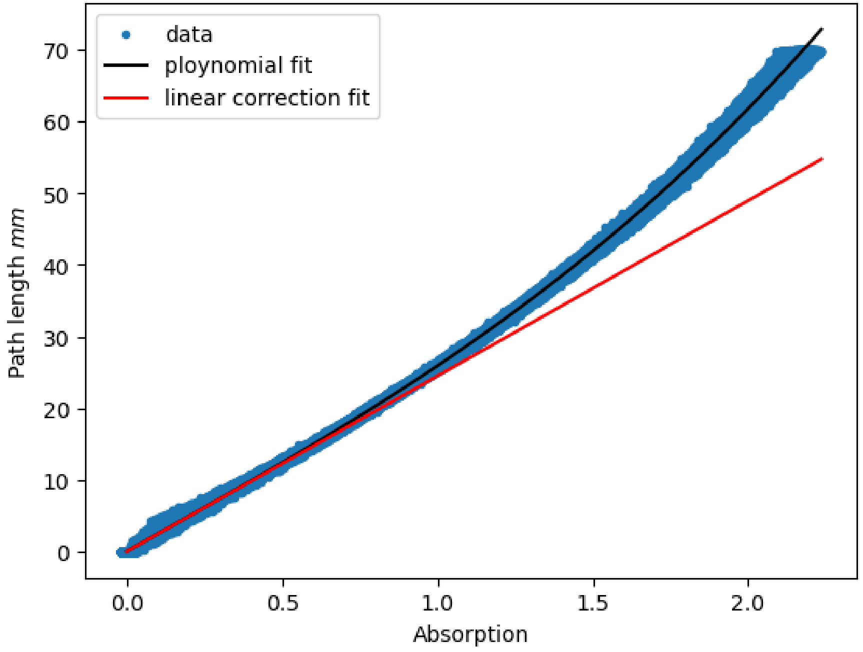
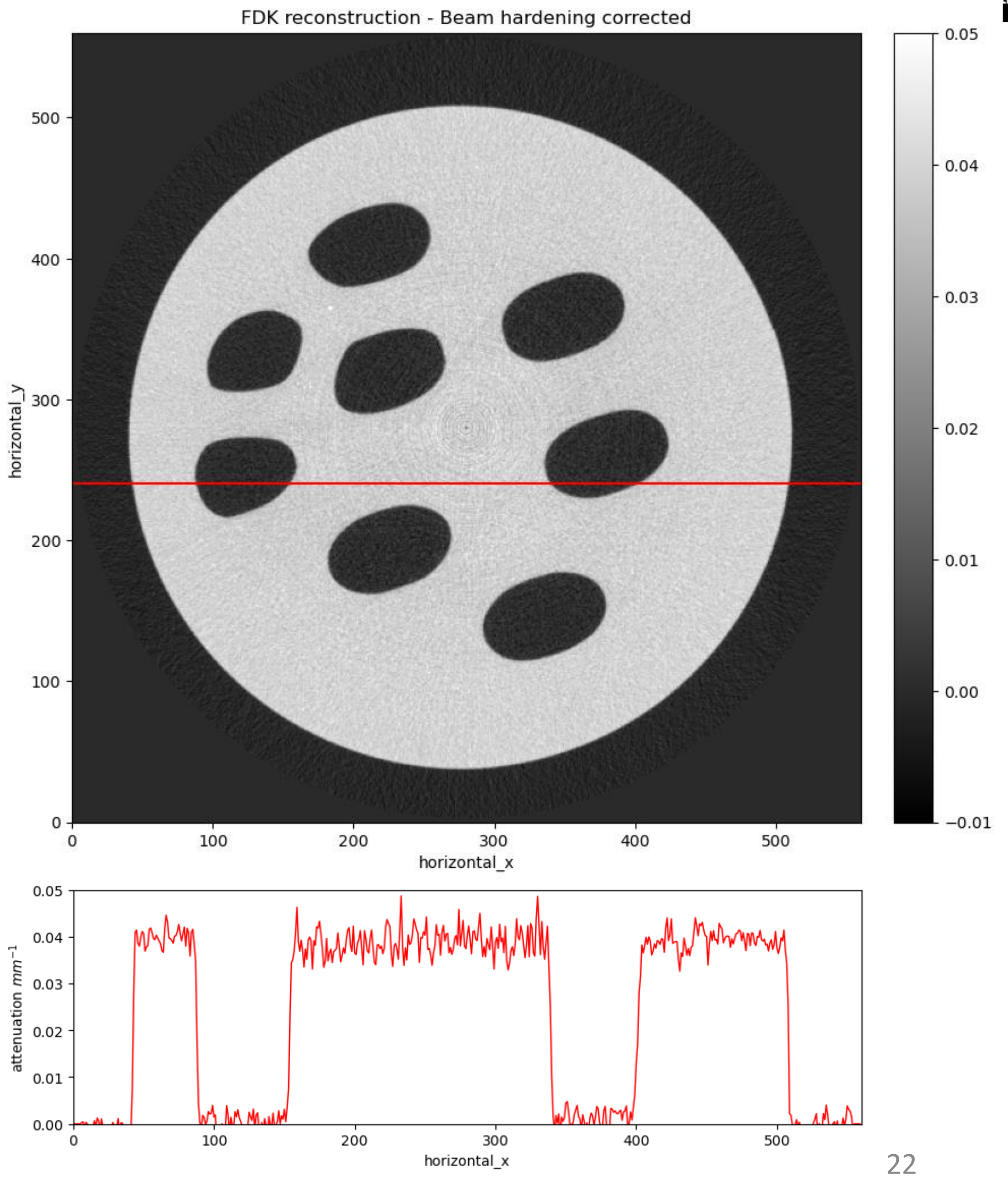
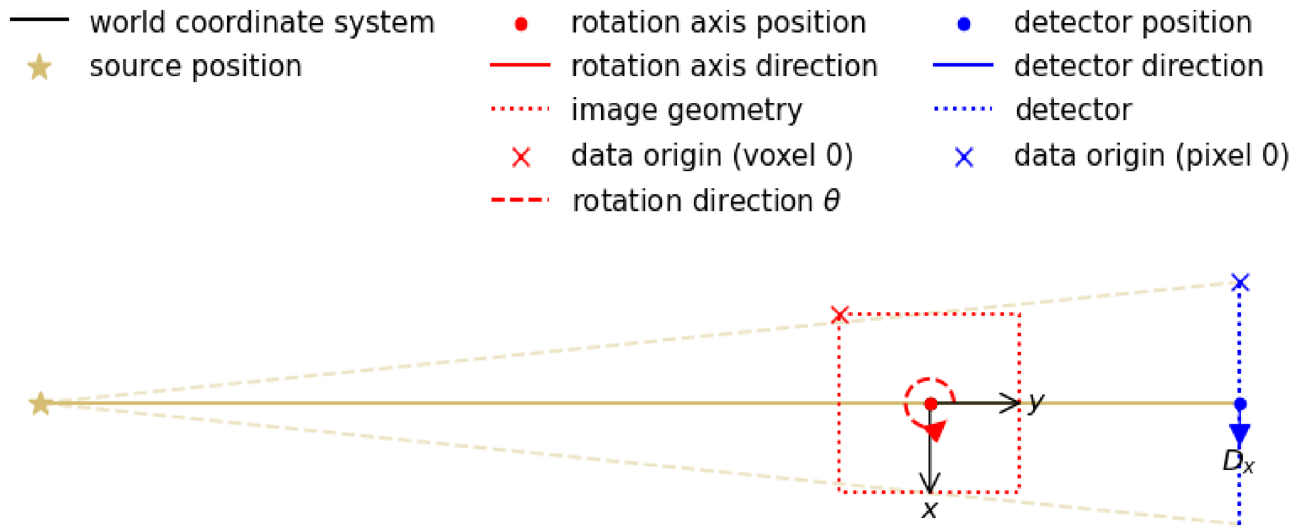
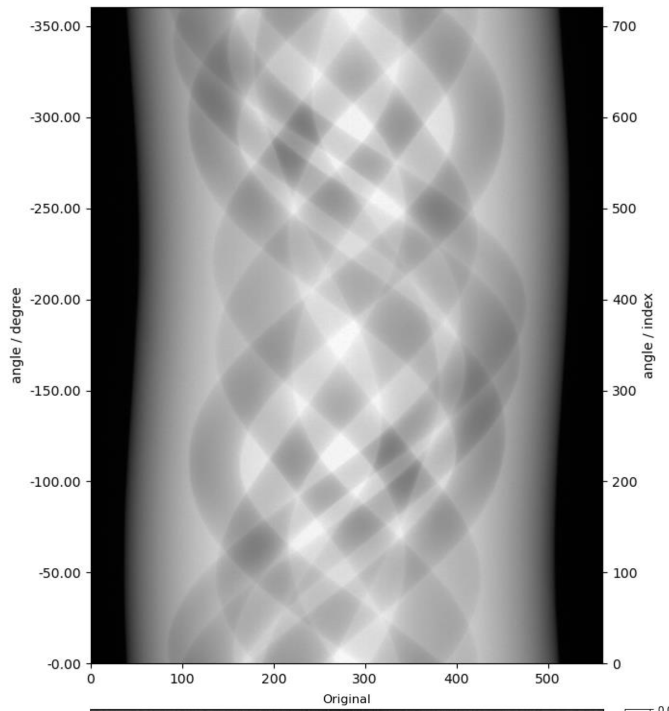


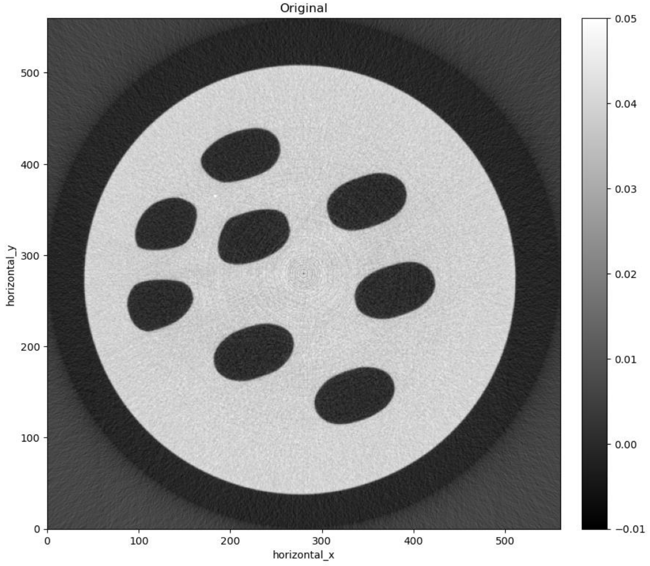


Zero-padding

- The reconstruction window extends outside the field of view
- Causes a non-zero background outside the radius of the detector
- Zero-Padding the acquisition data corrects this







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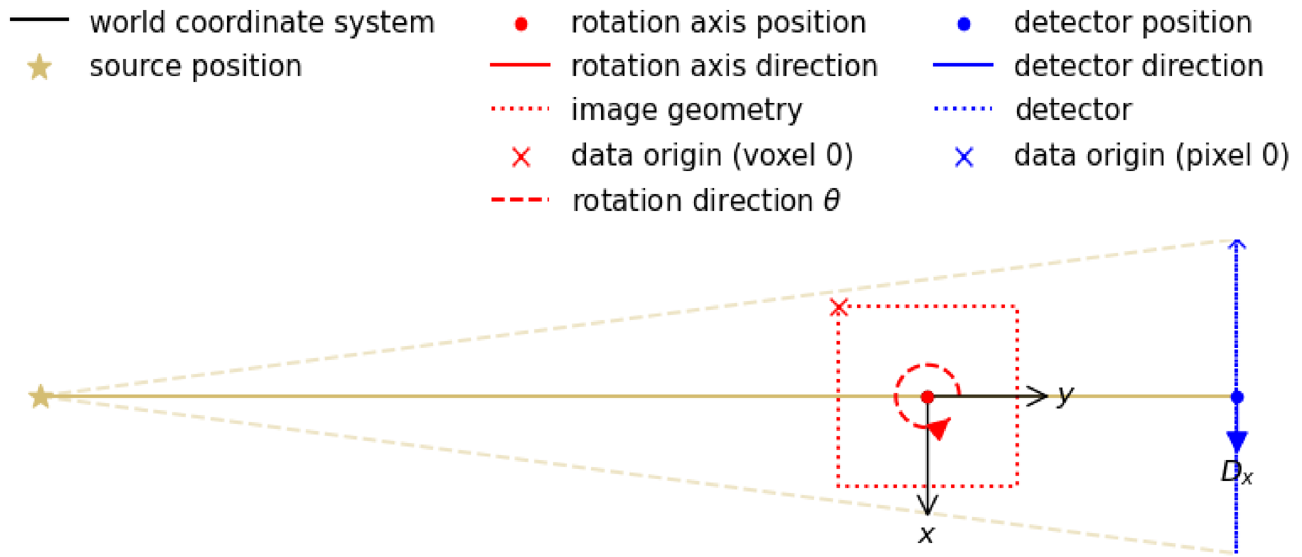
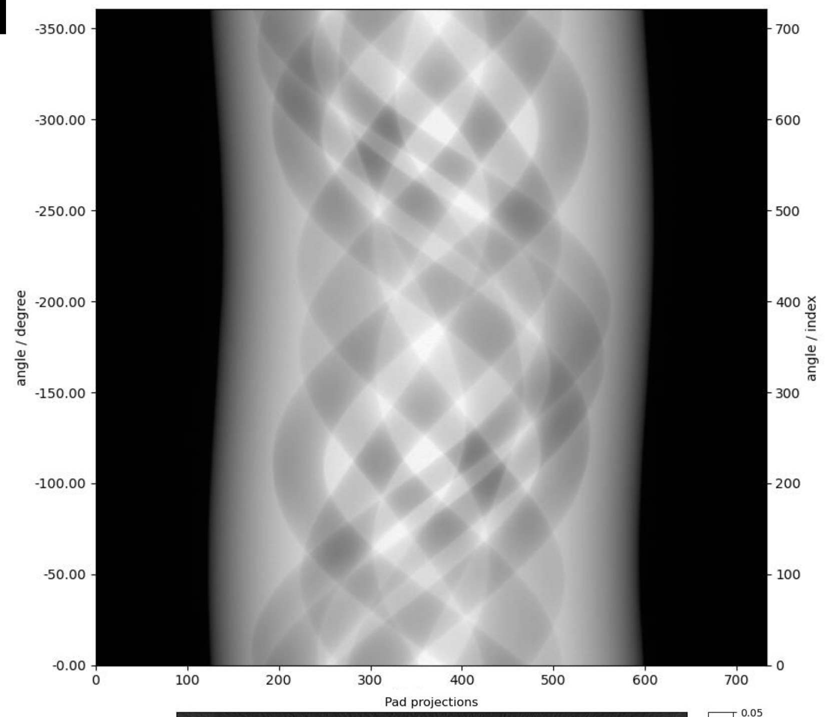
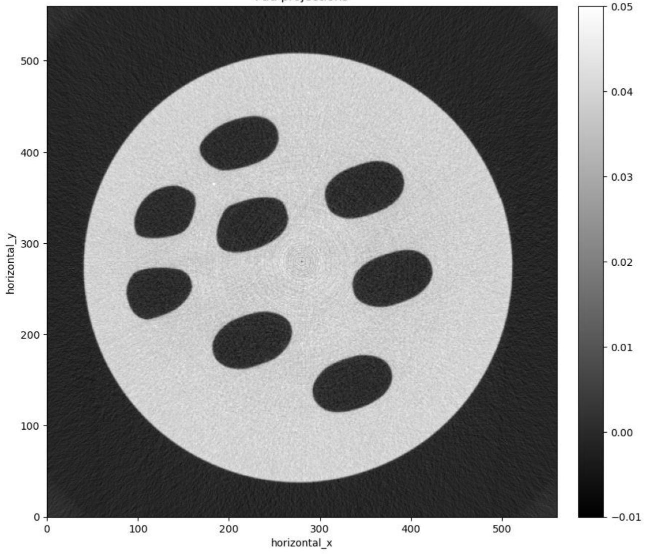






Reconstruction: Exploit prior knowledge

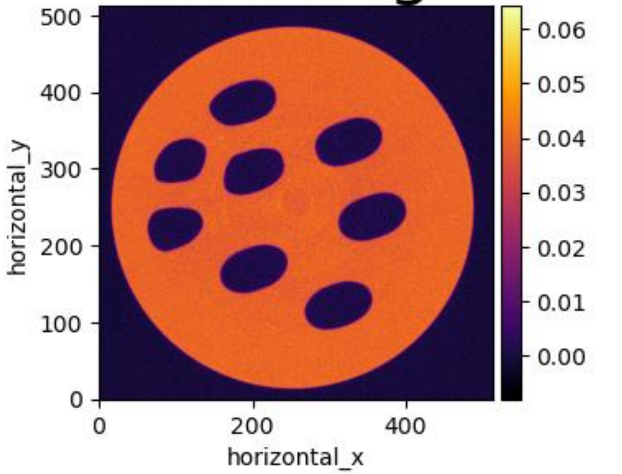
Construct optimization problem to express what we know:

- Single homogeneous material
- Sharp edges

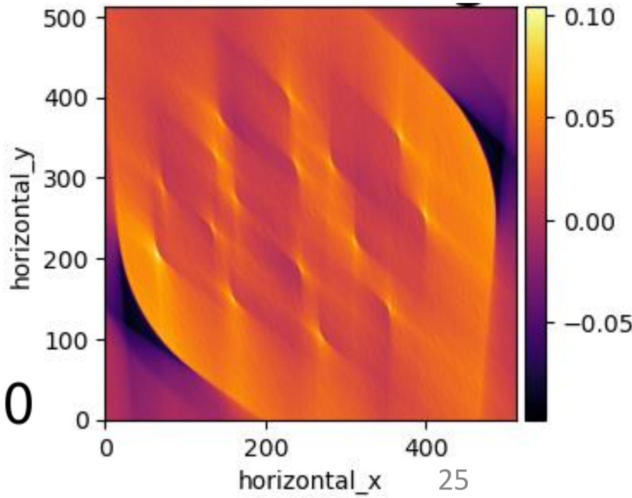
- Object is approximately disk shaped
- Zero attenuation outside the object
- Constant value of 0.0409 mm^{-1} inside the object

- Edges perpendicular to projection angles are the most difficult (micro-local analysis)

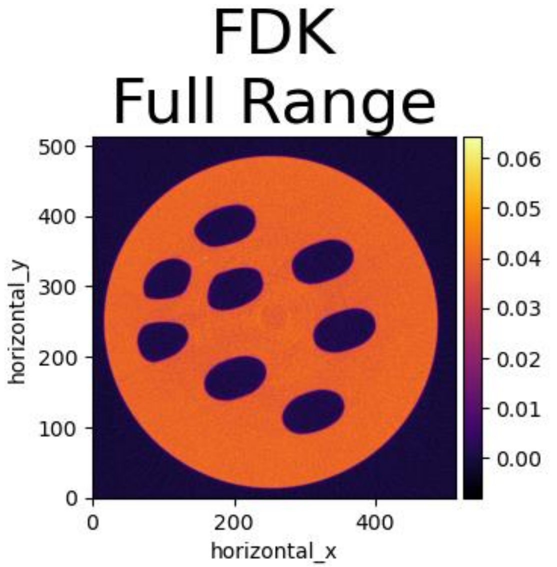
FDK
Full Range



Score: 0.430

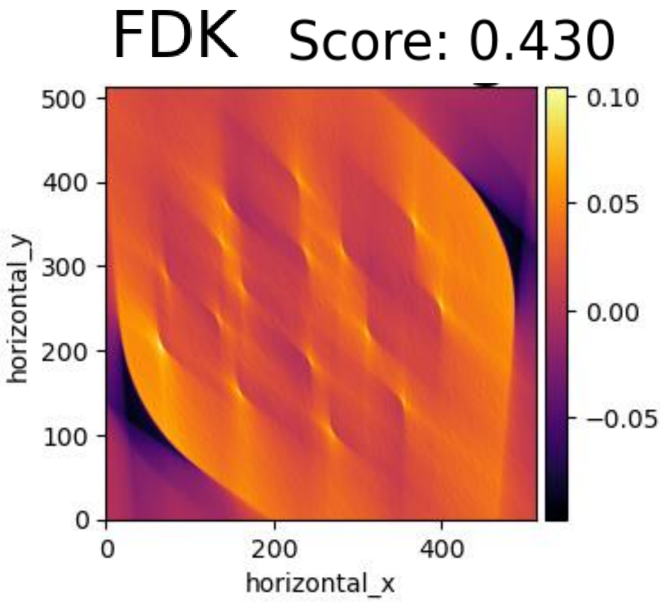


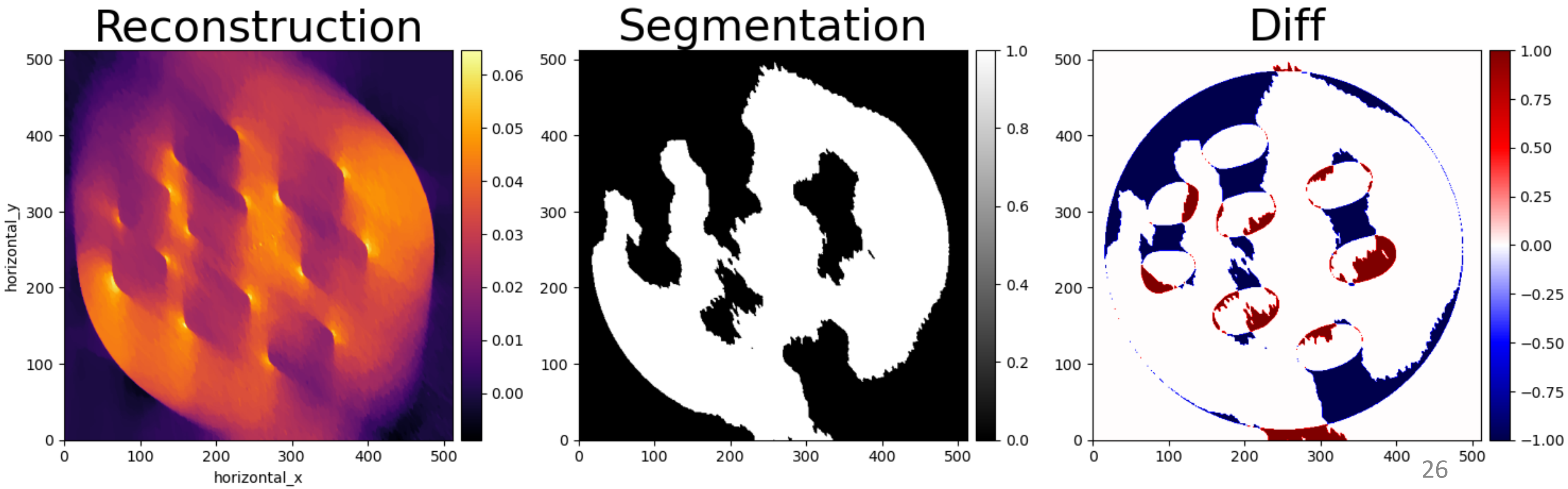
Prior knowledge: homogeneous material with sharp edges



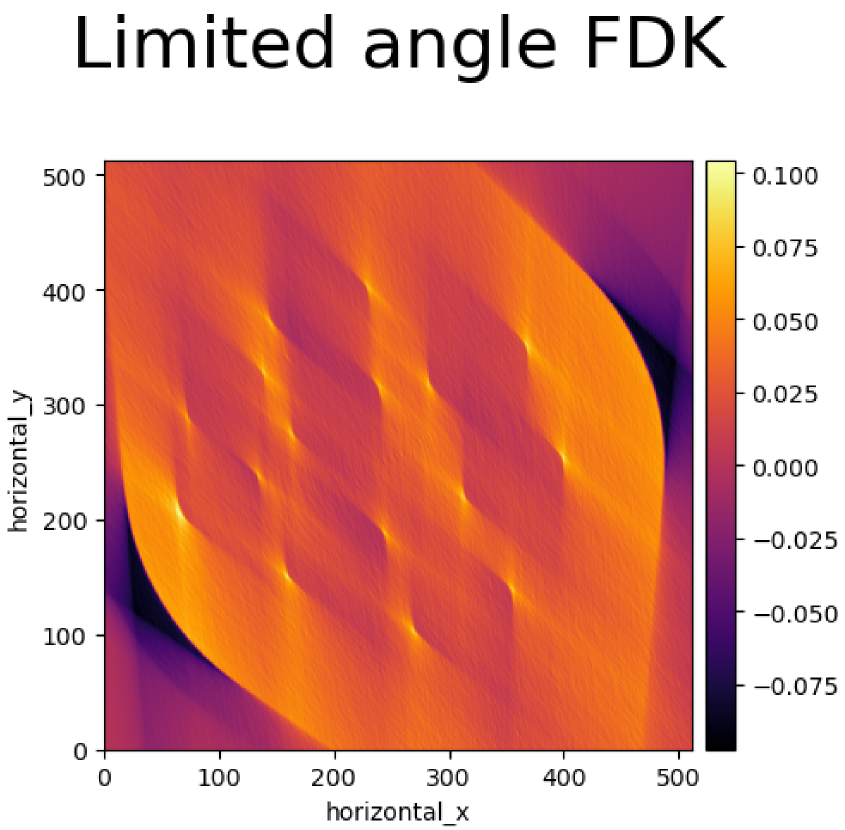
$$\min_{\mathbf{u}} \quad a_1\|\mathbf{A}\mathbf{u}-\mathbf{b}\|_2^2 + a_2\mathrm{ITV}(\mathbf{u})$$

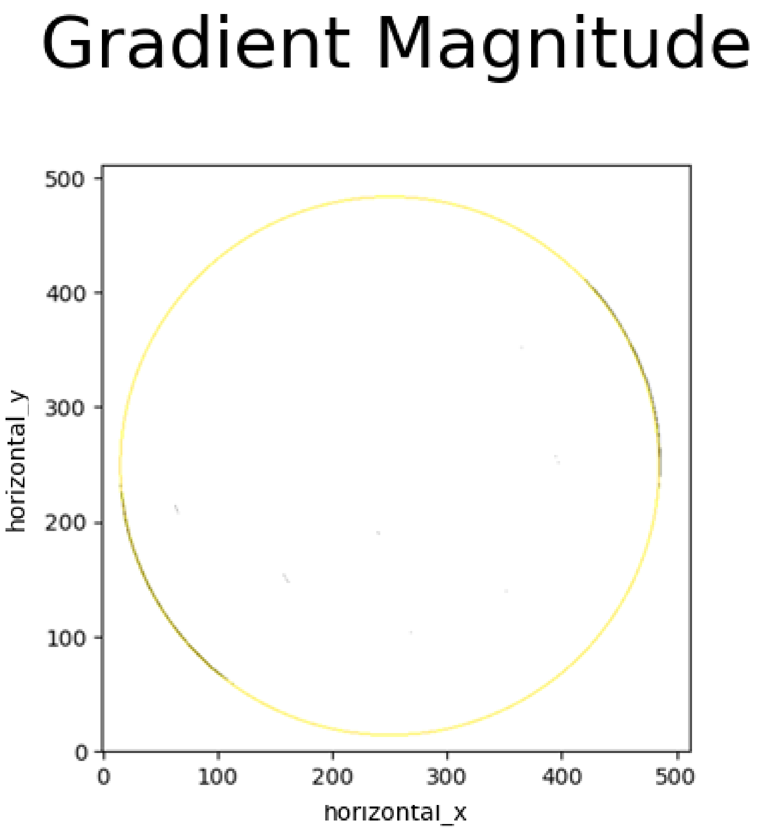
Score: 0.713

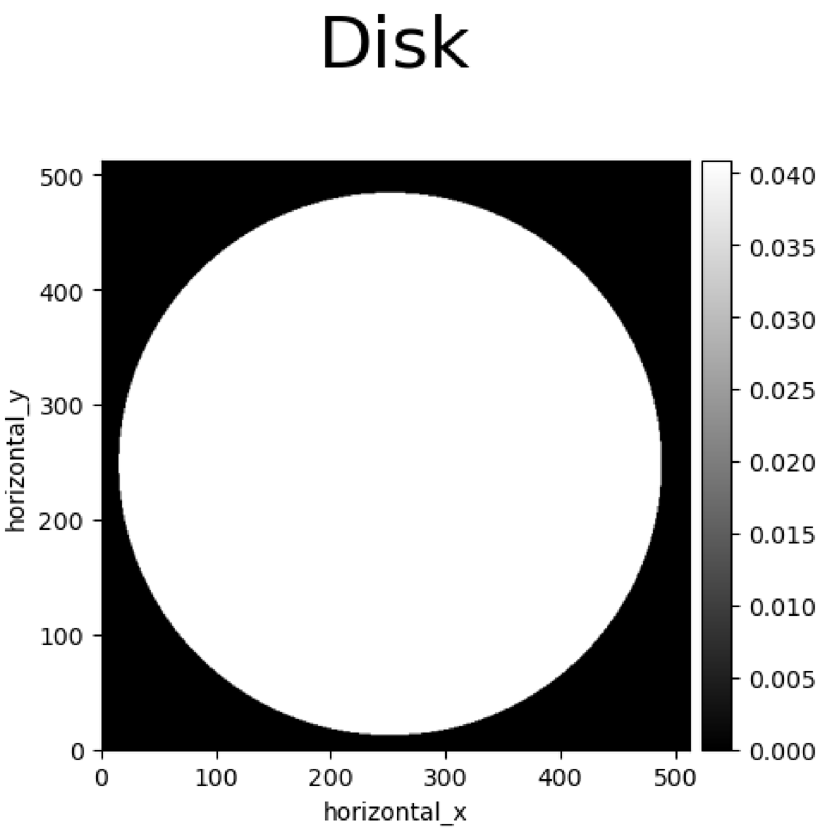




Prior knowledge: approximately disk shaped





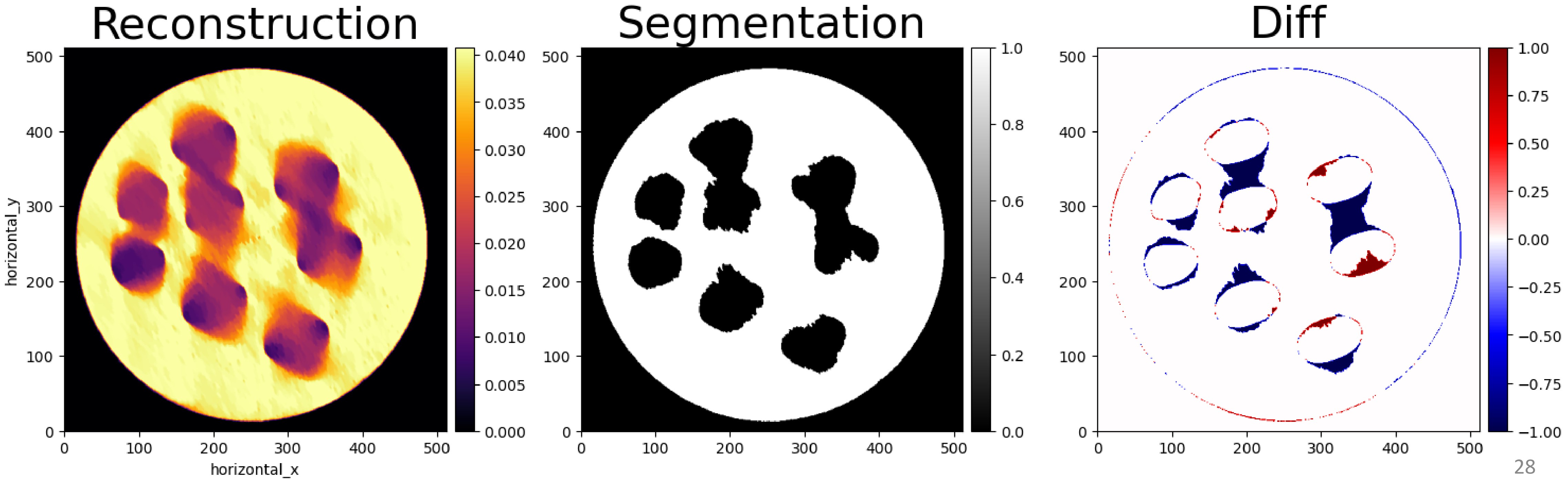


I.D. Coope *Circle fitting by linear and nonlinear least squares in 2D*
https://link.springer.com/article/10.1007/BF00939613

Disk shape with known attenuation as constraints

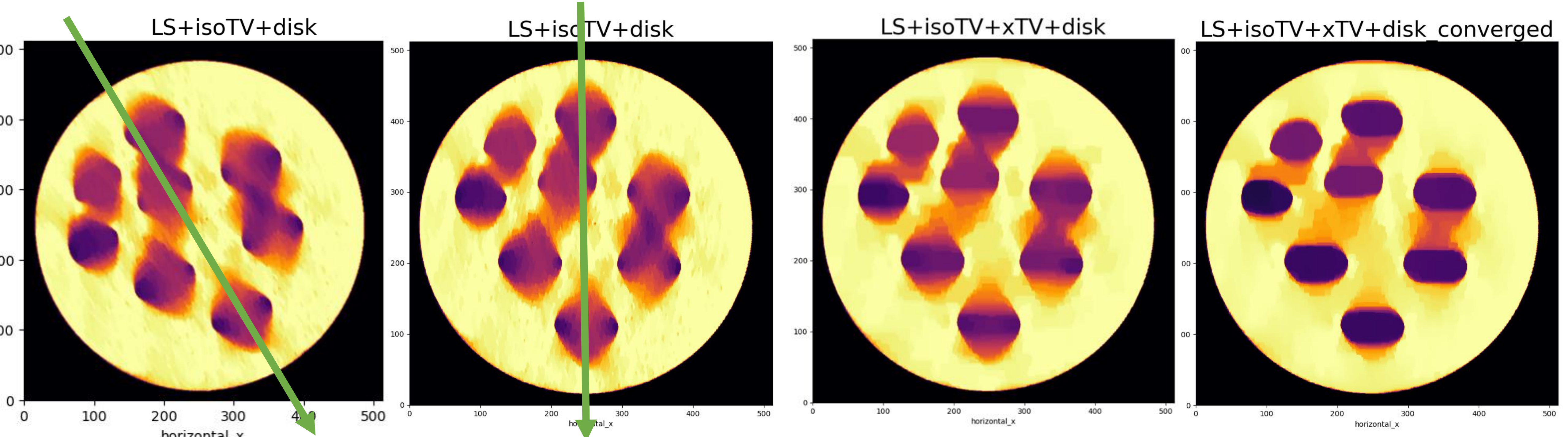
$$\begin{aligned} \min_{\mathbf{u}} \quad & a_1 \|\mathbf{A}\mathbf{u} - \mathbf{b}\|_2^2 + a_2 \mathrm{ITV}(\mathbf{u}) \\ \text{s.t.} \quad & \mathbf{0} \leq \mathbf{u} \leq v\mathbf{m} \end{aligned}$$

Score: 0.919



Anisotropic TV

- Blurred edges along central projection direction
- Rotate to align with coordinate axis
- Apply single-directional TV to encourage edges in blurred direction
- Remember to check convergence!
- Rotate back

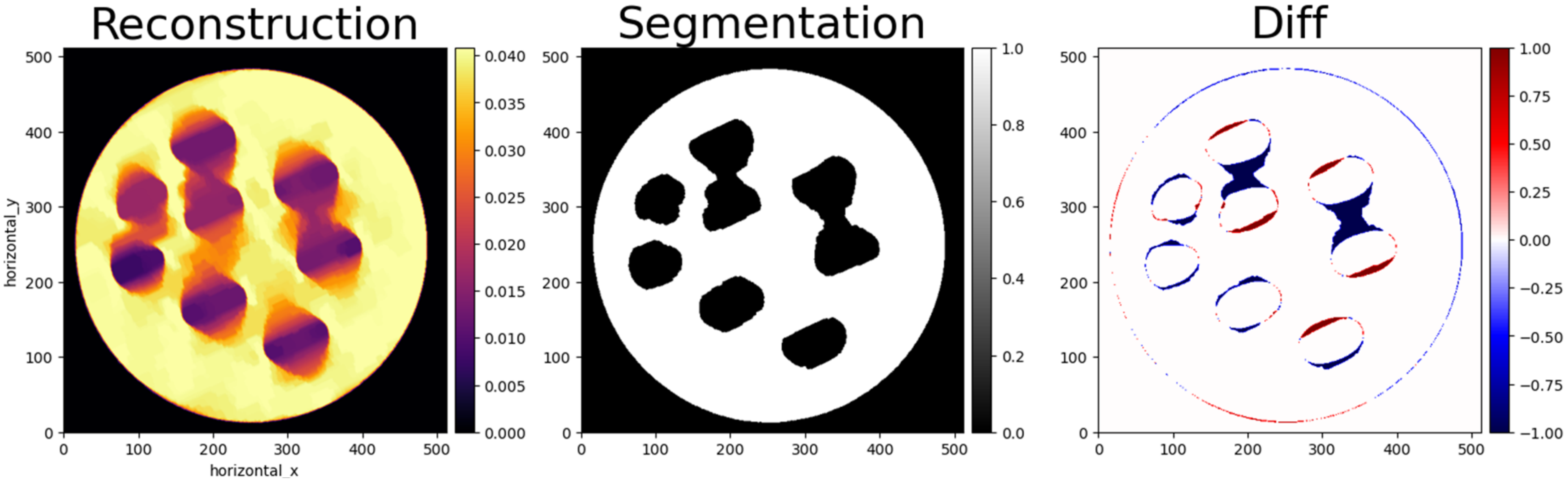


LS + ITV + mask + ATV

$$\min_{\mathbf{u}} \quad a_1\|\mathbf{A}\mathbf{u}-\mathbf{b}\|_2^2 + a_2\mathrm{ITV}(\mathbf{u}) + a_3\mathrm{ATV}_x(\mathbf{u})$$

$$\text{s.t.} \quad \mathbf{0} \leq \mathbf{u} \leq v\mathbf{m}$$

Score: 0.934

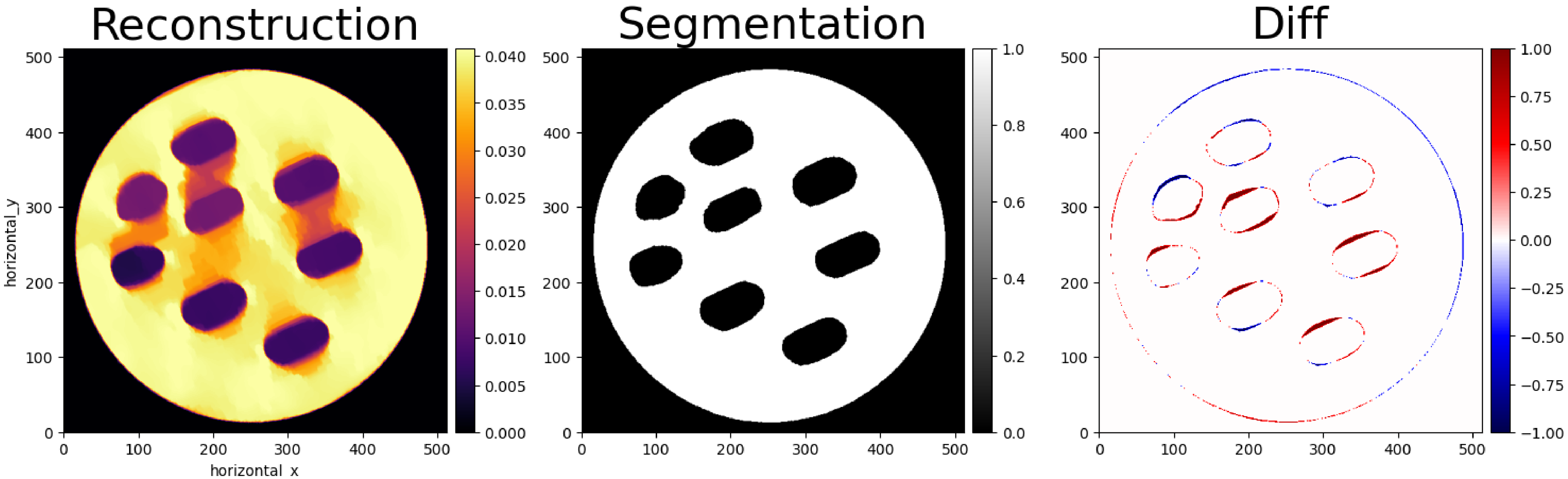


Jørgensen, J.S., Papoutsellis, E., Murgatroyd, L., Fardell, G. and Pasca, E., 2023. A directional regularization method for the limited-angle Helsinki Tomography Challenge using the Core Imaging Library (CIL). *Applied Mathematics for Modern Challenges*, *1*(2), pp.143-169.

LS + ITV + mask + ATV (converged!)

$$\begin{array}{ll} \min_{\mathbf{u}} & a_1\|\mathbf{A}\mathbf{u}-\mathbf{b}\|_2^2 + a_2\mathrm{ITV}(\mathbf{u}) + a_3\mathrm{ATV}_x(\mathbf{u}) \\ \text{s.t.} & \mathbf{0} \le \mathbf{u} \le v\mathbf{m} \end{array}$$

Score: 0.973



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Primal Dual Hybrid Gradient (PDHG) method in CIL

CIL offers a range of optimization algorithms, incl GD, FISTA, ADMM and **PDHG:**

$$\min_{\mathbf{u}} \quad f(\mathbf{Ku}) + g(\mathbf{u})$$

$$\text{where} \quad f(\mathbf{Ku}) = \sum_i f_i(\mathbf{K}_i \mathbf{u})$$

Rewrite our optimization problem for PDHG:

$$\min_{\mathbf{u}} \quad a_1 \|\mathbf{Au} - \mathbf{b}\|_2^2 + a_2 \|\mathbf{Du}\|_{2,1} + a_3 \|\mathbf{D_x u}\|_1 + \chi_{[\mathbf{0}, v\mathbf{m}]}(\mathbf{u})$$

$$f = \begin{pmatrix} a_1 \|\cdot - \mathbf{b}\|_2^2 \\ a_2 \|\cdot\|_{2,1} \\ a_3 \|\cdot\|_1 \end{pmatrix} \quad \mathbf{K} = \begin{pmatrix} \mathbf{A} \\ \mathbf{D} \\ \mathbf{D_x} \end{pmatrix} \quad g = \chi_{[\mathbf{0}, v\mathbf{m}]}$$

Solving with CIL – "near-math" syntax

$$f = \begin{pmatrix} a_1 \|\cdot - \mathbf{b}\|_2^2 \\ a_2 \|\cdot\|_{2,1} \\ a_3 \|\cdot\|_1 \end{pmatrix}$$

```
F = BlockFunction( a1*L2NormSquared(data),
                   a2*MixedL21Norm(),
                   a3*L1Norm() )
```

$$\mathbf{K} = \begin{pmatrix} \mathbf{A} \\ \mathbf{D} \\ \mathbf{D_x} \end{pmatrix}$$

```
K = BlockOperator( ProjectionOperator(ig, ag),
                   GradientOperator(ig),
                   FiniteDifferenceOperator(ig,'horizontal_x') )
```

$$g = \chi_{[\mathbf{0}, v\mathbf{m}]}$$

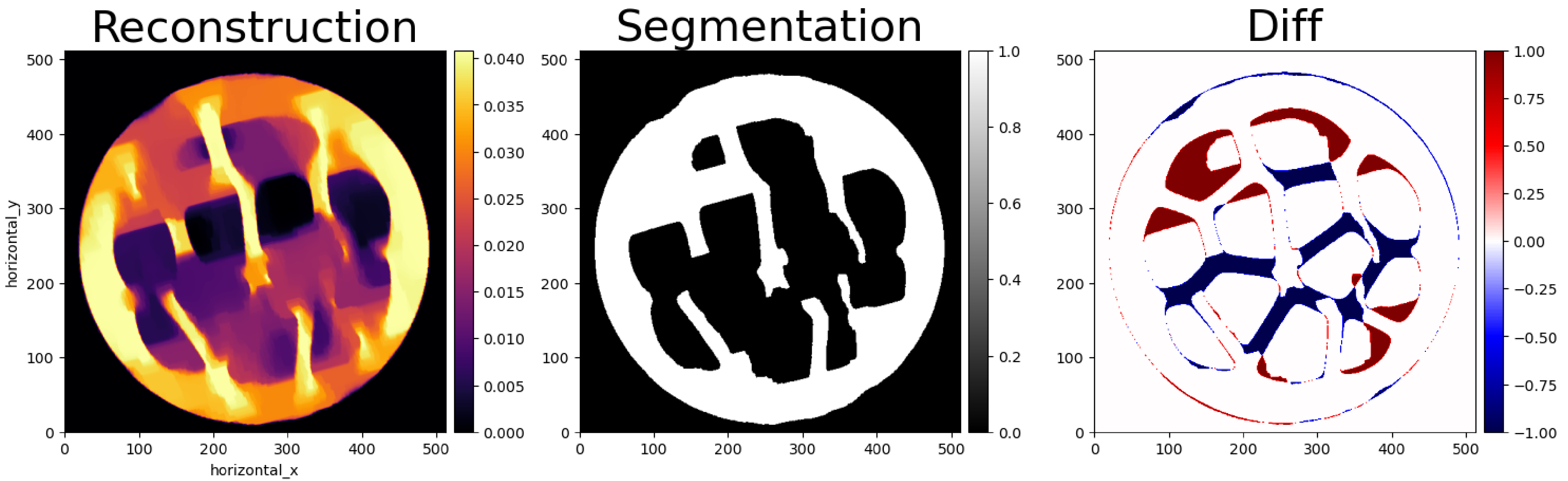
```
G = IndicatorBoxPixelwise( lower=0.0,
                           upper=v*m )
```

$$\min_{\mathbf{u}} \quad f(\mathbf{Ku}) + g(\mathbf{u})$$

```
algo = PDHG( initial=ig.allocate(0.0),
             f=F,
             g=G,
             operator=K)
algo.run(2000)
```

Results on even fewer angles...

30 deg.



Ideas to explore if more time

- Improved segmentation – area we spent least time
- Enforce acrylic value in outermost circular band
- Combine with L1-norm sparsity regulariser to force zero values

Time to explore in break out rooms

Demo: CIL-Demos/demos/2_Iterative/02_tikhonov_block_framework.ipynb

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2. Use Block Framework to solve Tikhonov regularisation with CGLS algorithm.
3. Apply Tikhonov regularisation to tomographic reconstruction and explain the effect of regularisation parameter and operator in regulariser.

Explore: CIL-Demos/demos/4_Deep_Dives/03_htc_2022.ipynb

See examples of:

- incorporating prior knowledge of a problem in a variational regularisation framework
- utilising the flexibility and near-math syntax of the CIL optimisation toolkit to prototype different reconstruction objectives
- the CIL Block Framework and PDHG optimisation algorithm

- Go to: https://tinyurl.com/cil-online-25 write your name next to a **username** to claim it for the exercises
- CIL Jupyter notebook server: https://training.jupyter.stfc.ac.uk/
- **Sign up with the username** you claimed and a password of your choice.

Summary and questions

We have seen:

- How to incorporate prior knowledge of a problem in a variational regularisation framework
- How CIL can be used to flexibly prototype different reconstruction objectives
- How to use the block framework in CIL to build up more complex optimisation objectives

Break

Training Program

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

Building your own optimisation problem using the block framework– 1:15-2:30 – Jakob

- Demo: 2_Iterative/02_tikhonov_block_framework.ipynb
- Block framework example lecture
- Notebook: 4_Deep_Dives/03_htc_2022.ipynb
- **Break**

Customising your optimisation method- 2:45-3:30 – Margaret

- Demo notebook: 4_Deep_Dives/01_callbacks.ipynb
- Notebook: 4_Deep_Dives/04_preconditioner_stepsize.ipynb
- **Break**

Time to explore and discuss – 3:45-4:45 – Margaret

- Notebook: 1_Introduction/exercises/03_where_is_my_reader.ipynb
- Notebook: 4_Deep_Dives/02_phase_retrieval.ipynb
- Notebook: 3_Multichannel/02_Dynamic_CT.ipynb
- Notebook: 4_Deep_Dives/06_directional_TV.ipynb

Conclusions and further support 4:45-5 – Jakob

Customising your optimisation method

Callbacks

User code

```
algo = PDHG( initial=ig.allocate(0.0),
             f=F,
             g=G,
             operator=K)


algo.run(2000)
```

Internal code

```
def set_up(self, *args, **kwargs):
    '''Set up the algorithm'''
```

```
for _ in iters:
    try:
        self.__next__()
        for callback in callbacks:
            callback(self)
    except StopIteration:
        break
```

```
def update(self):
    '''A single iteration of the algorithm'''
```

Callbacks

CIL CORE IMAGING LIBRARY
UKRI Science and Technology Facilities Council
Scientific Computing

User code

```
algo = PDHG( initial=ig.allocate(0.0),
             f=F,
             g=G,
             operator=K)


algo.run(2000,
callbacks=[Exciting_possibility_1,
               Exciting_possibility_2 ])
```

Printing information

Saving data

Calculating metrics

Stopping the iterations

Internal code

```
def set_up(self, *args, **kwargs):
    '''Set up the algorithm'''
```

```
for _ in iters:
    try:
        self.__next__()
        for callback in callbacks:
            callback(self)
    except StopIteration:
        break
```

```
def update(self):
    '''A single iteration of the algorithm'''
```

Customising your optimisation algorithm

Demo : CIL-Demos/demos/4_Deep Dives/01_callbacks.ipynb

- Explore the default behaviour of callbacks in CIL
- Demonstrate customisable callbacks in CIL for reporting and early stopping
- Complex callback example for calculating a dictionary of metrics evaluated on a region of interest

Step size rule – examples for gradient descent

Step size rule – examples for gradient descent

$$u_{k+1} = u_k - \beta \nabla \mathrm{L}(\mathrm{u_k})$$

Step size rule – fixed step size

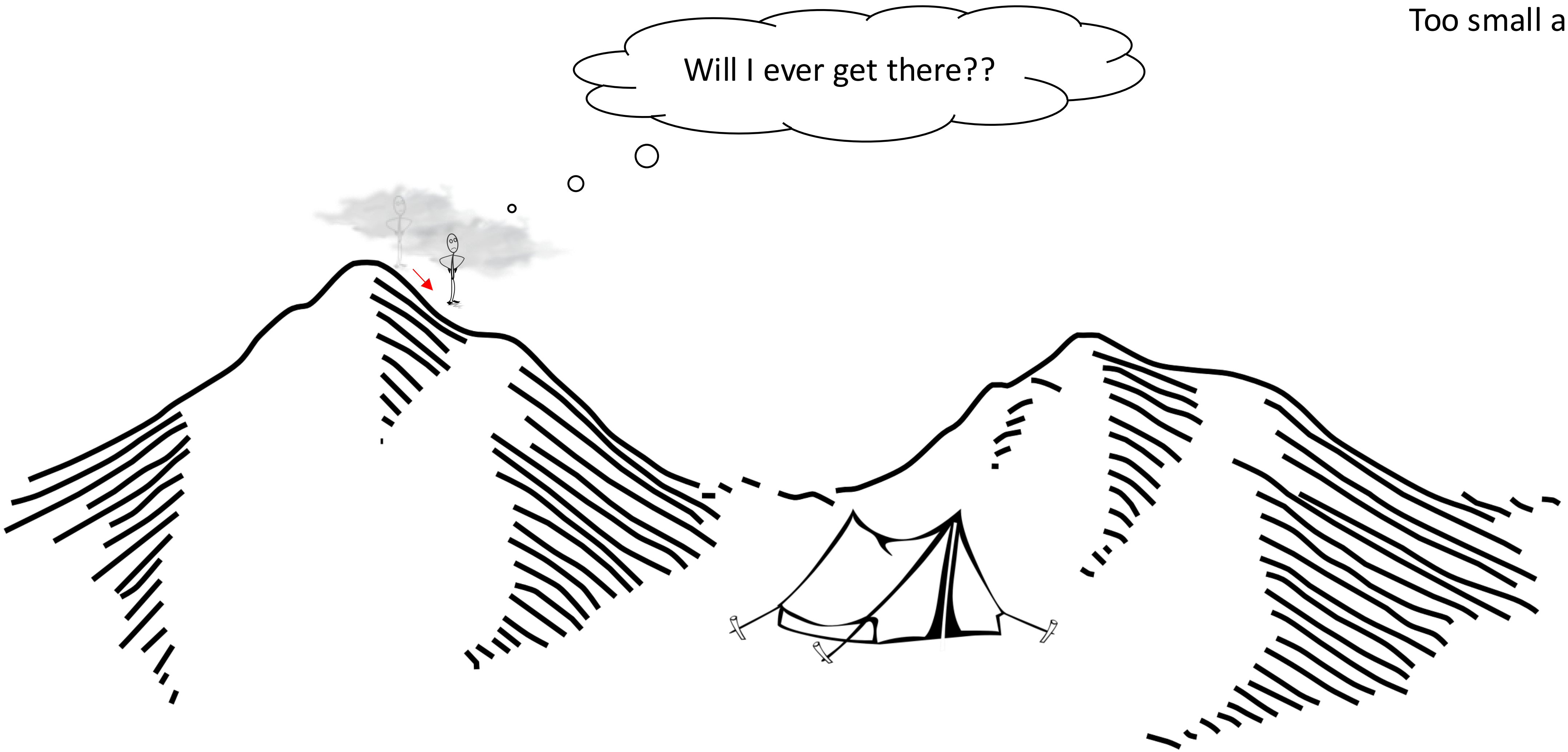
Too small a step size

Step size rule – fixed step size

Too small a step size

Step size rule – fixed step size

Too small a step size

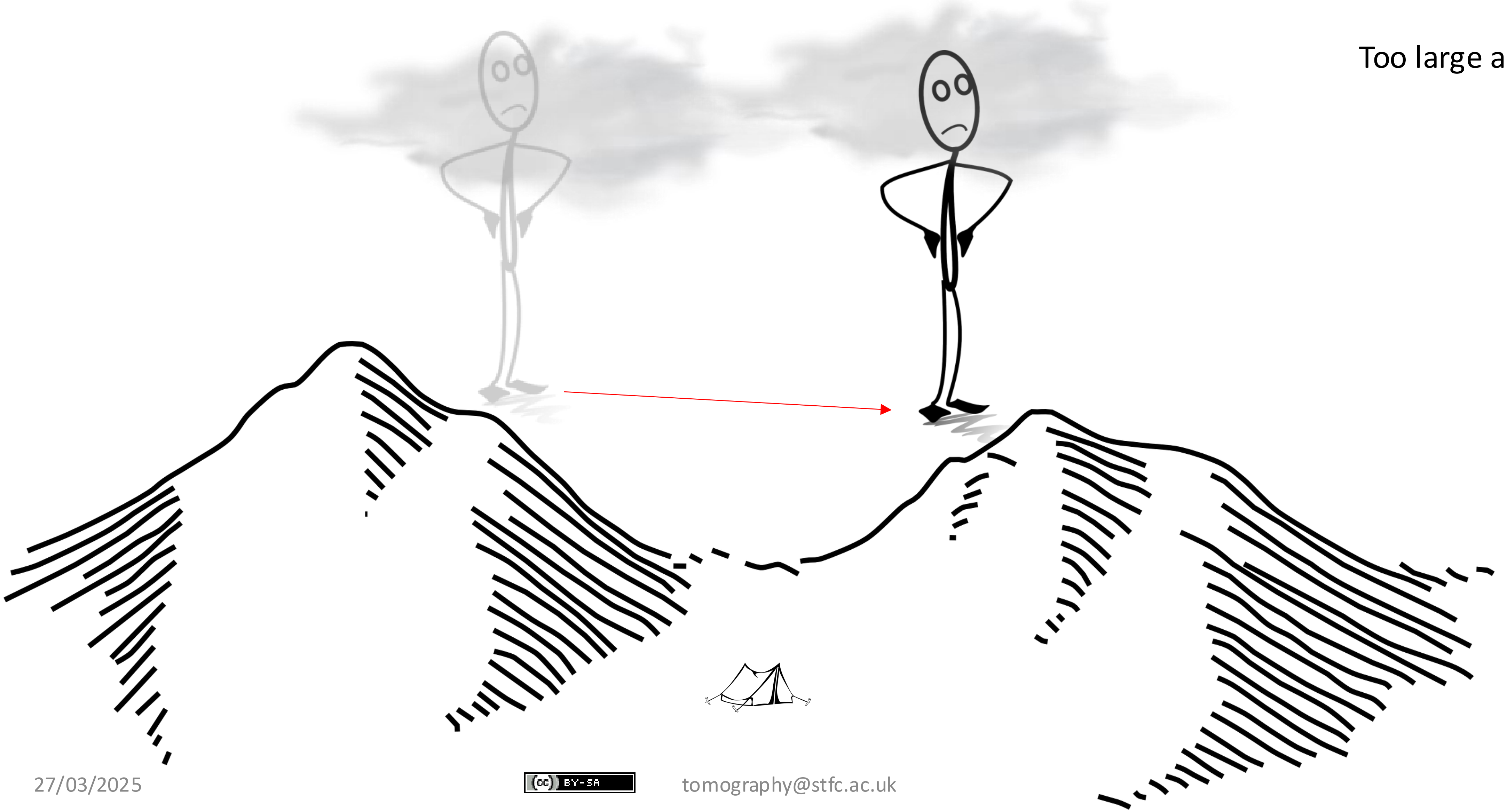


Step size rule – fixed step size

Too large a step size

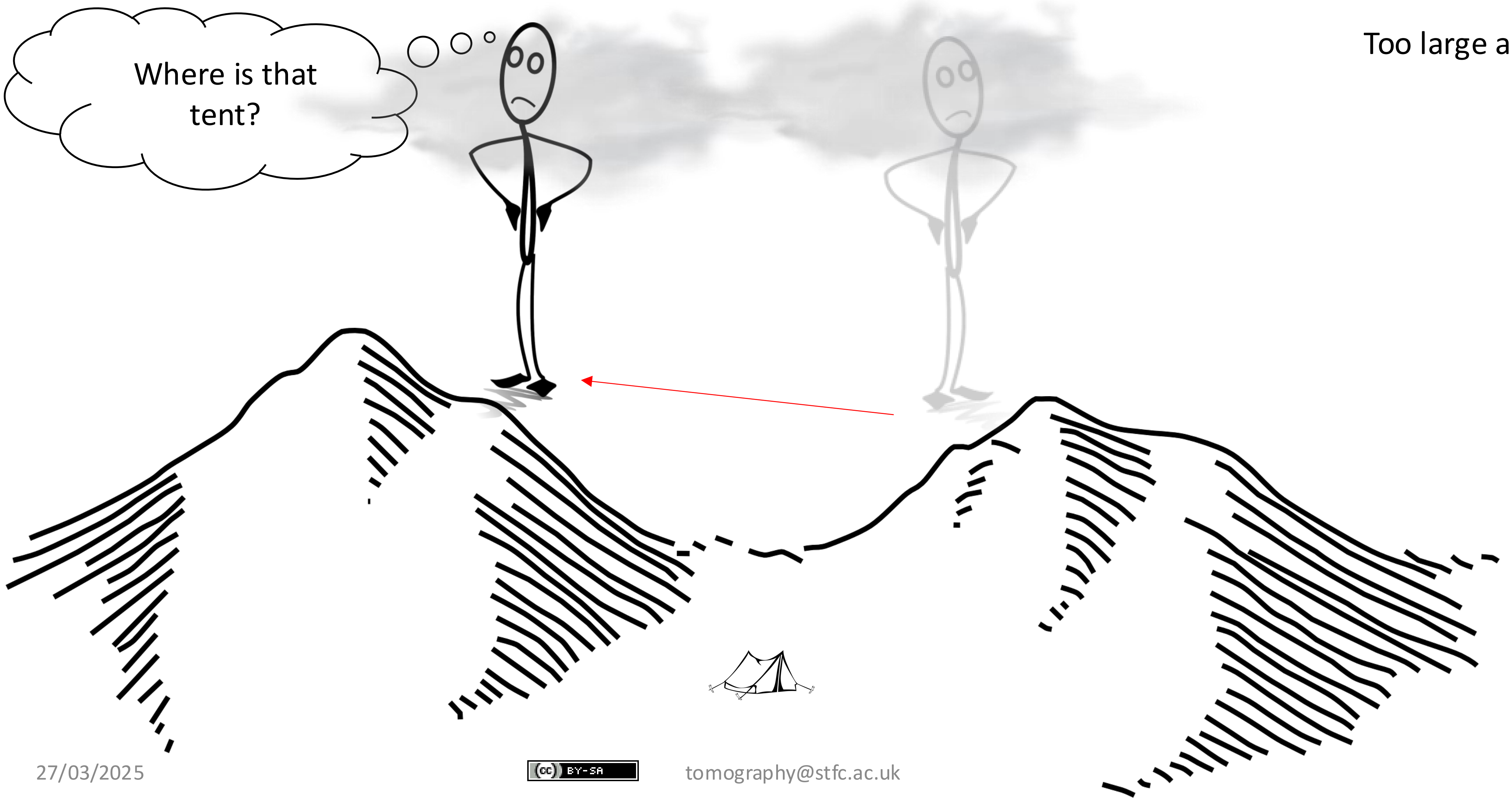
Step size rule – fixed step size

Too large a step size

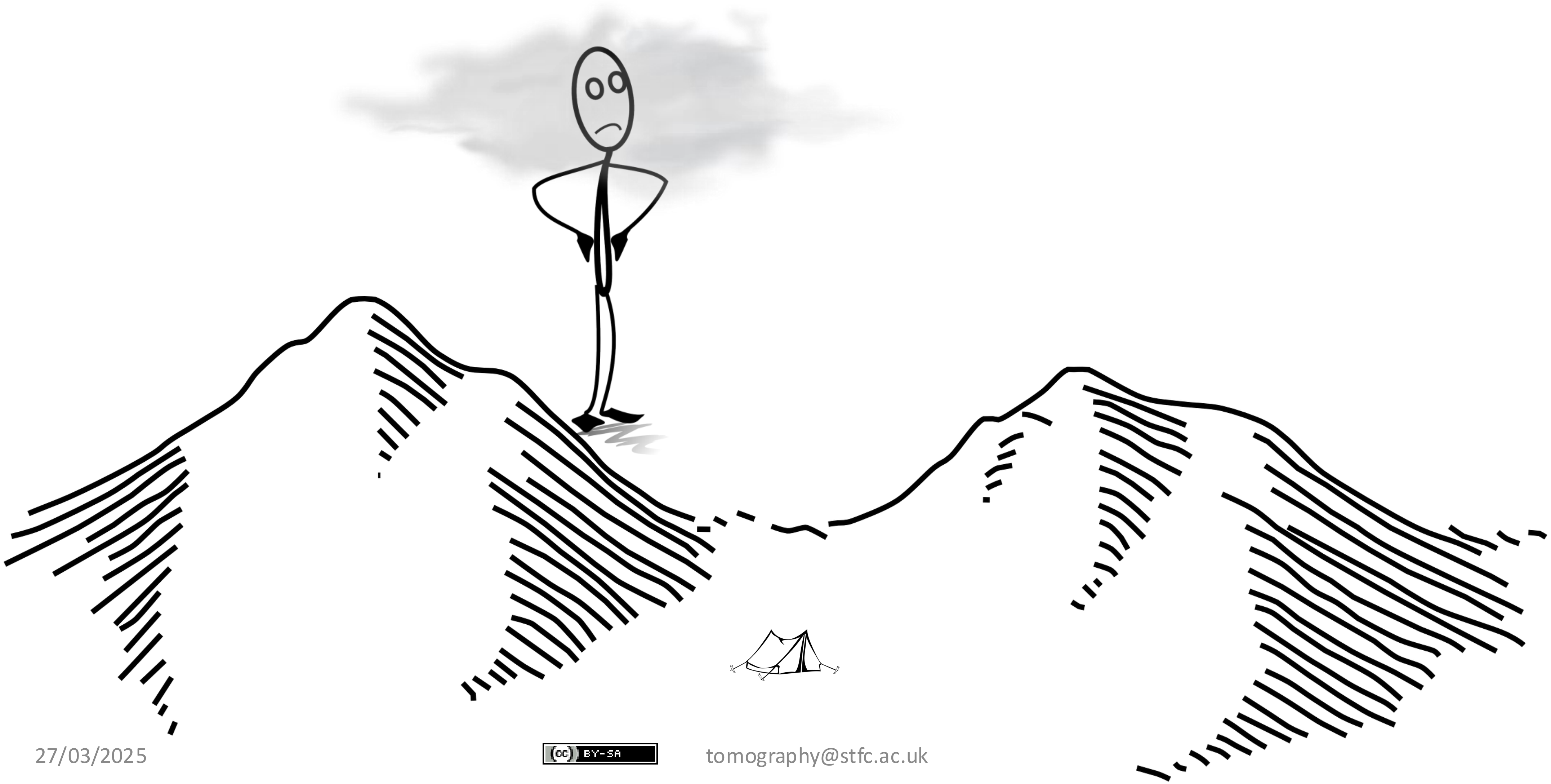


Step size rule – fixed step size

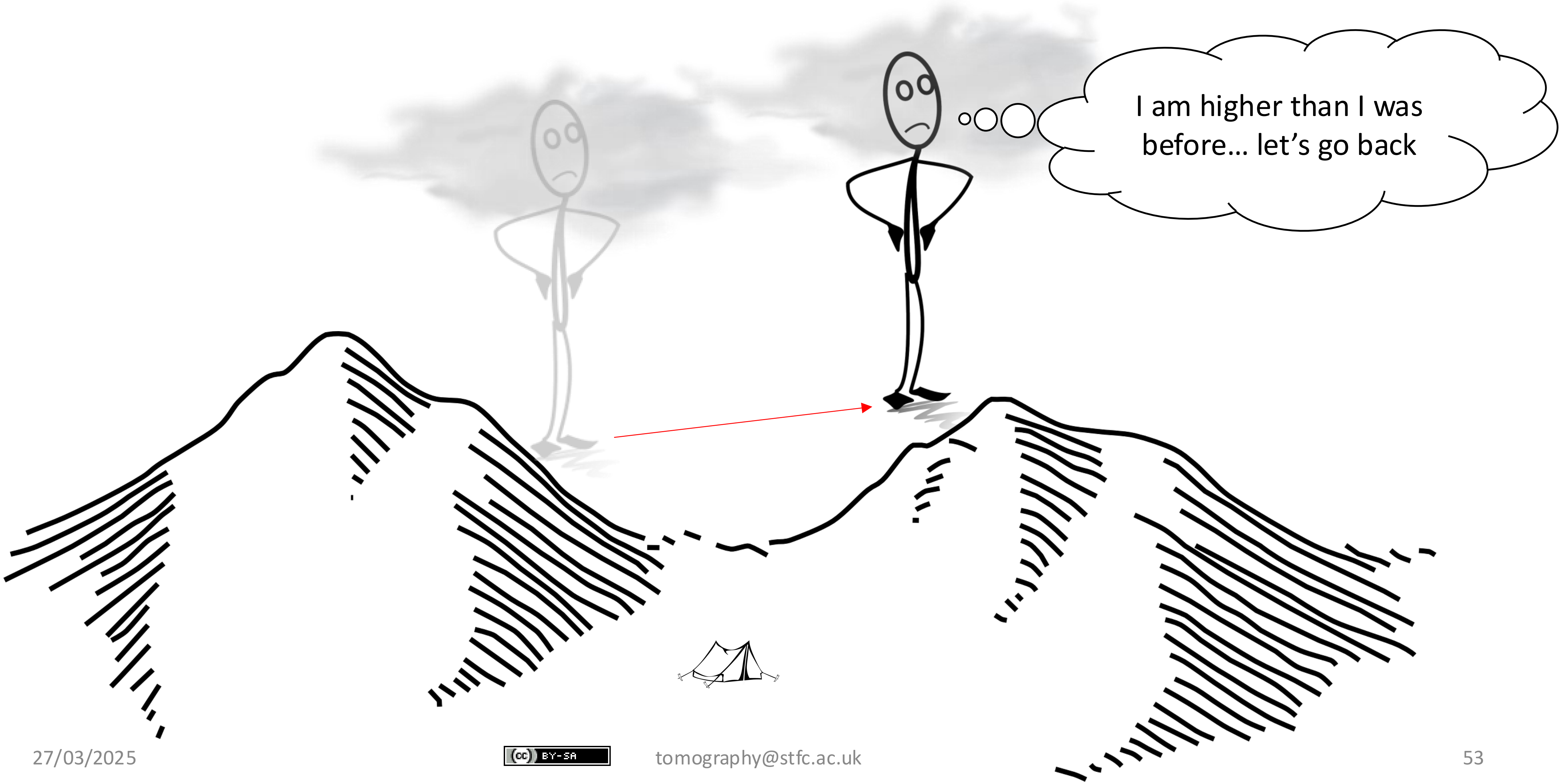
Too large a step size



Step size rule – line search

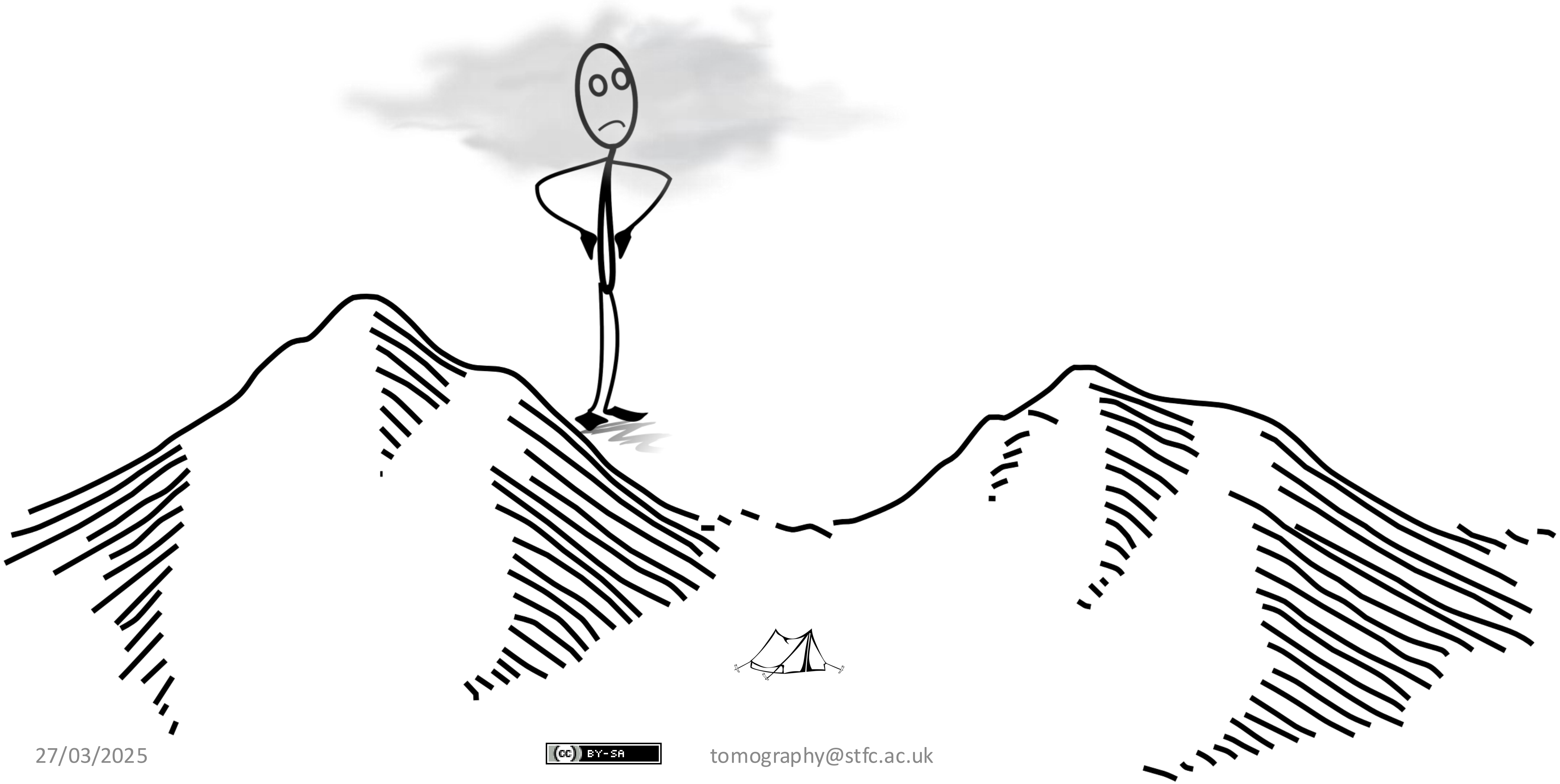


Step size rule – backtracking line search

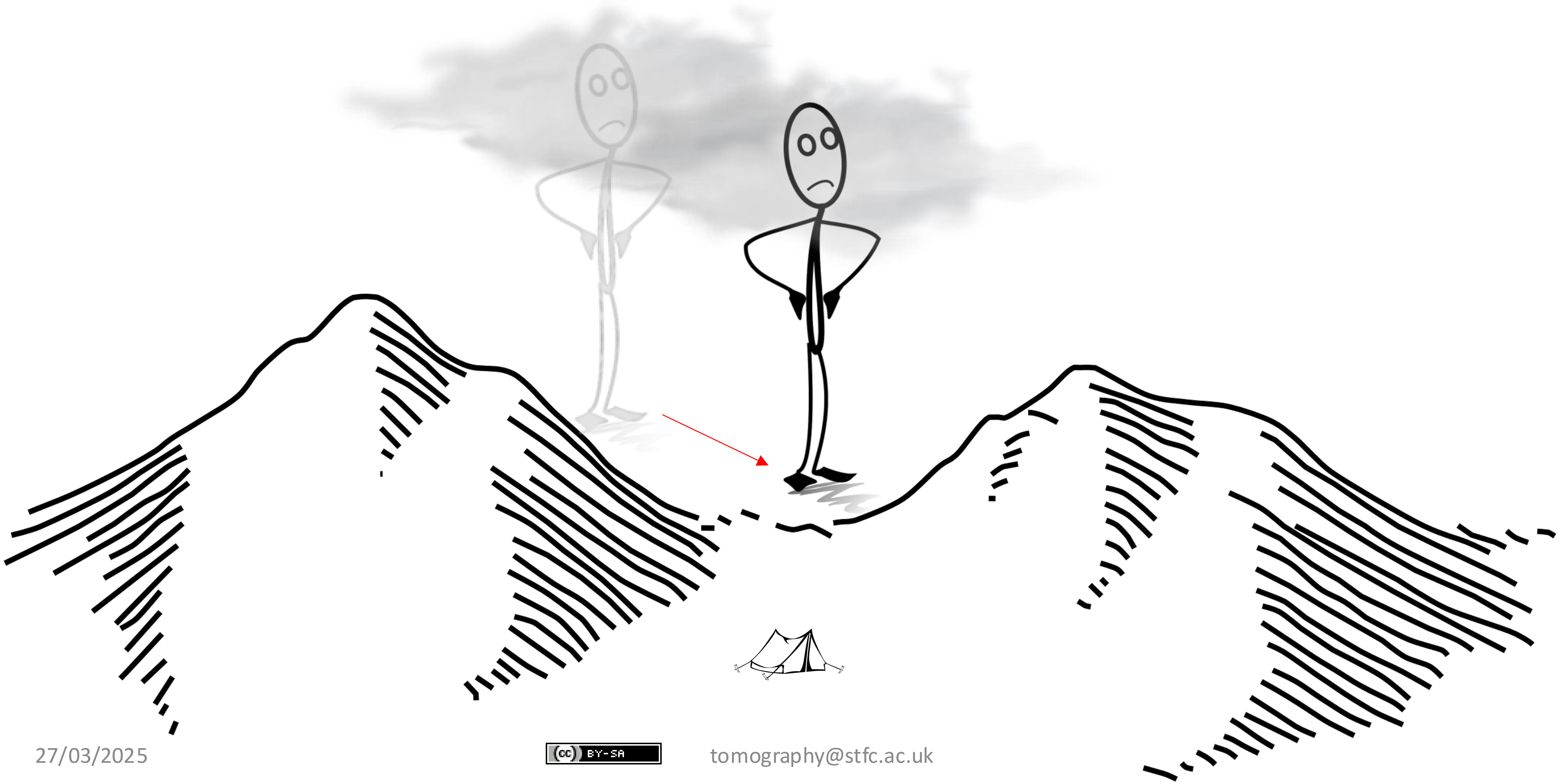


tomography@stfc.ac.uk

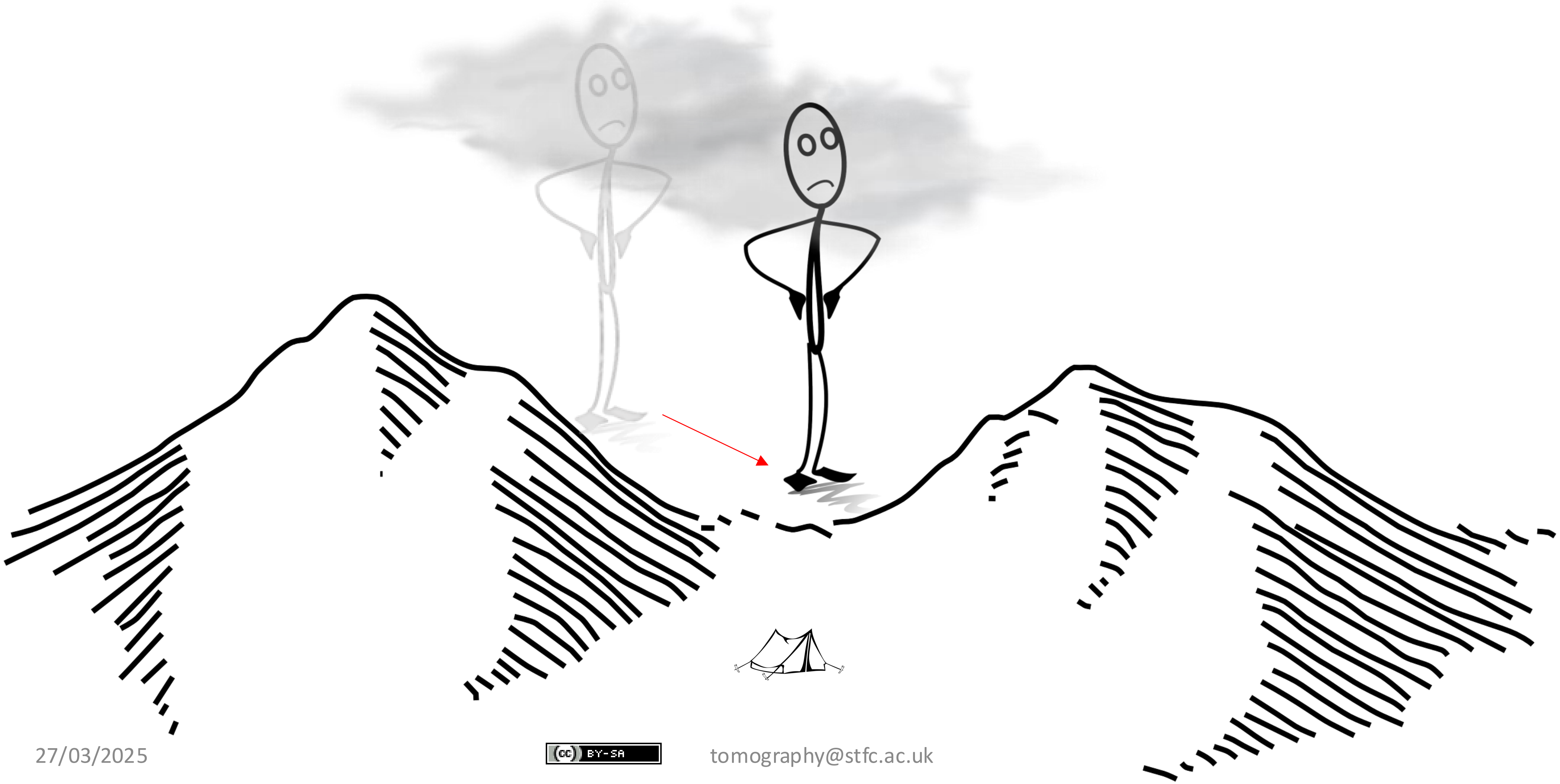
Step size rule – backtracking line search



Step size rule – backtracking line search



Step size rule – backtracking line search



Customising your optimisation algorithm

Demo : CIL-Demos/demos/4_Deep Dives/01_callbacks.ipynb

- Explore the default behaviour of callbacks in CIL
- Demonstrate customisable callbacks in CIL for reporting and early stopping
- Complex callback example for calculating a dictionary of metrics evaluated on a region of interest

Option 2: CIL-Demos/demos/4_Deep_Dives/04_preconditioner_stepsize.ipynb

- Explore and compare a range of step size methods in CIL
- Learn how to implement your own step size rule in CIL
- Learn about the concept of preconditioning for gradient descent based methods
- Explore the preconditioners currently available in CIL

- Go to: https://tinyurl.com/cil-online-25 write your name next to a **username** to claim it for the exercises
- CIL Jupyter notebook server: https://training.jupyter.stfc.ac.uk/
- **Sign up with the username** you claimed and a password of your choice.

Training Program

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- Notebook: 3_Multichannel/02_Dynamic_CT.ipynb
- Notebook: 4_Deep_Dives/06_directional_TV.ipynb

Conclusions and further support 4:45-5 – Jakob

Summary and questions

We have seen:

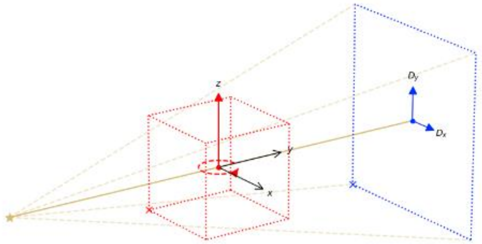
- How to use a callback to customise your CIL algorithm
- How to set custom step sizes and why this might be important
- How to use the block framework in CIL to build up more complex optimisation objectives

Time to explore and discuss

Time to explore

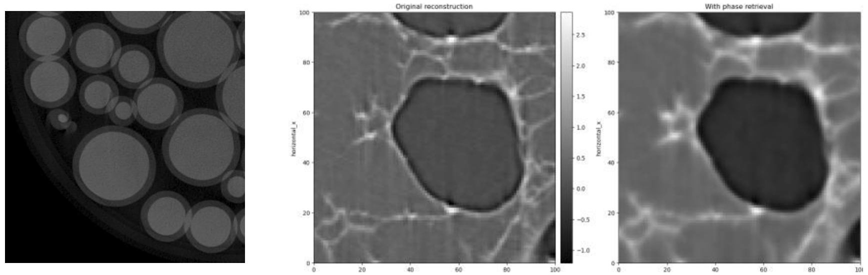
Notebook: 1_Introduction/excercises/03_where_is_my_reader.ipynb

- Load and investigate a dataset stored as a tiff using `TIFFStackReader`
- Create the CIL geometry using `AcquisitionGeometry.Create_Cone2D`
- Combine the data and geometry to form an `AcquisitionData`
- Find the Centre of rotation to complete the data geometry description



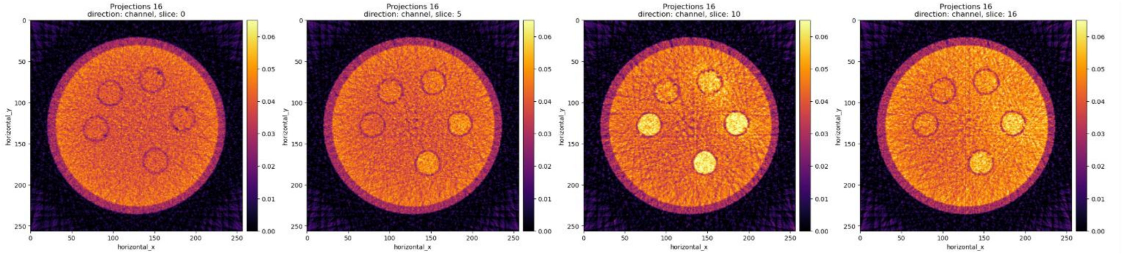
Notebook: 4_Deep_Dives/02_phase_retrieval.ipynb

- Intro to phase contrast imaging, propagation based phase contrast and phase retrieval
- Demonstration of the CIL Paganin Processor and Generalised Paganin method in CIL
- Demonstration of the effect of propagation distance on phase retrieval methods in CIL



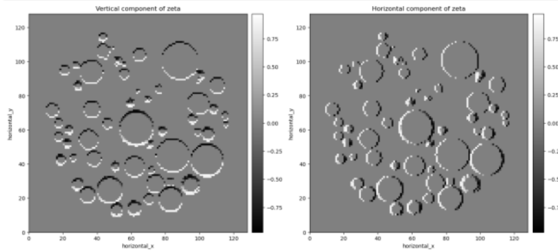
Notebook: 3_Multichannel/02_Dynamic_CT.ipynb

- Create a geometry for dynamic tomographic tomographic data
- Compare FBP reconstructions for every time-channel with spatio-temporal total variation
- Introduction to directional total variation



Notebook: 4_Deep_Dives/06_directional_TV.ipynb

- Introduce the dTV regulariser
- Demonstrate the dTV regularisation using the CCPi regularisation toolkit, seeing examples of over and under regularisation
- Use the CIL BlockFramework and PDHG to define and minimise a CIL objective function for using dTV for denoising.



CIL User Showcase

- 001 – Multibang regularisation
- 002 – Deblurring with CIL
- 003 – 1D integral inverse problem
- 004 – Dynamic CT example
- 005 – Dynamic MR example (with SIRF)
- 006 – CT simulation with gVXR
- 007 – Hyperspectral regularisation
- 008 - Poisson noise models for the data discrepancy term
- 009 – Offset CT reconstruction of an apple
- 010 – Bruker Skyscan reader and reconstruction
- 011 – Phase contrast Exciscope data
- 012 – Wavelet sparsity control regularization
- 013 – anisotropic regularization for FILD measurements
- 014 – GVXR simulation and CIL CPU reconstruction
- One more currently in review!

https://github.com/TomographicImaging/CIL-User-Showcase

Next steps

Questions

tomography@stfc.ac.uk

Feedback

CCP*i* = CCP in Tomographic Imaging, 2012 -

- The Collaborative Computational Projects (CCPs)
- UK Network of expertise in key computational research fields
- CCPs foster exchange by organising workshops, training, conferences …
- Enable large-scale scientific software development, maintenance and distribution.
- Long term funding by EPSRC with a 5 years renewal cycle, currently until fall 2026
- CCPs supported by Computational Science Centre for Research Communities (CoSeC)
- https://www.ccpi.ac.uk

https://www.jiscmail.ac.uk/cgi-bin/webadmin?A0=CCPI-MEMBERS

User show and tell and user drop-in

Next one:
10th April

- Every other Thursday 1-2pm UK, online
- Two informal talks from users and/or CIL developers
- Followed by user drop-in session (2pm-2:30pm) – come ask your CIL and tomography questions!
- Advertised on Discord and on email list.

https://ccpi.ac.uk/events/ccpi-show-tell-and-user-support-drop-in/

Tell us about your work!

If you publish or present - or win a prize - for work done using CIL, please:

- Tell us about it – tomography@stfc.ac.uk

- Give an (informal) talk at our show and tell

- Cite CIL --> citations help us secure funding for more CIL!

Citing CIL

If you use CIL in your research, please include citations to **both** the software on Zenodo, and a CIL paper:

E. Pasca, J. S. Jørgensen, E. Papoutsellis, E. Ametova, G. Fardell, K. Thielemans, L. Murgatroyd, M. Duff and H. Robarts (2023)
Core Imaging Library (CIL)
Zenodo [software archive]
DOI: https://doi.org/10.5281/zenodo.4746198

https://github.com/TomographicImaging/CIL

Where to go from here?

Use CIL
- In your work
- Teaching, etc.
- Please cite CIL

Contribute – on GitHub or by email
- Bug reports, documentation suggestions, etc.
- Feature requests
- Bug fixes
- New features

Tell others
- Students, postdocs, professors, ...
- (Tell **us** if you do **not** see yourself using CIL, and why)

Collaborate – and publish – with us
- We can help set up CIL for your problem
- Integrate new tools, algorithms, etc. in CIL
- Collaborations drive new code development

Conclusion

- CIL is a Open Source mostly Python library for all your tomographic needs:
  - I/O
  - pre-processing
  - Reconstruction
  - Visualisation

- Developer Support, user driven, long term funding

- https://www.ccpi.ac.uk/CIL

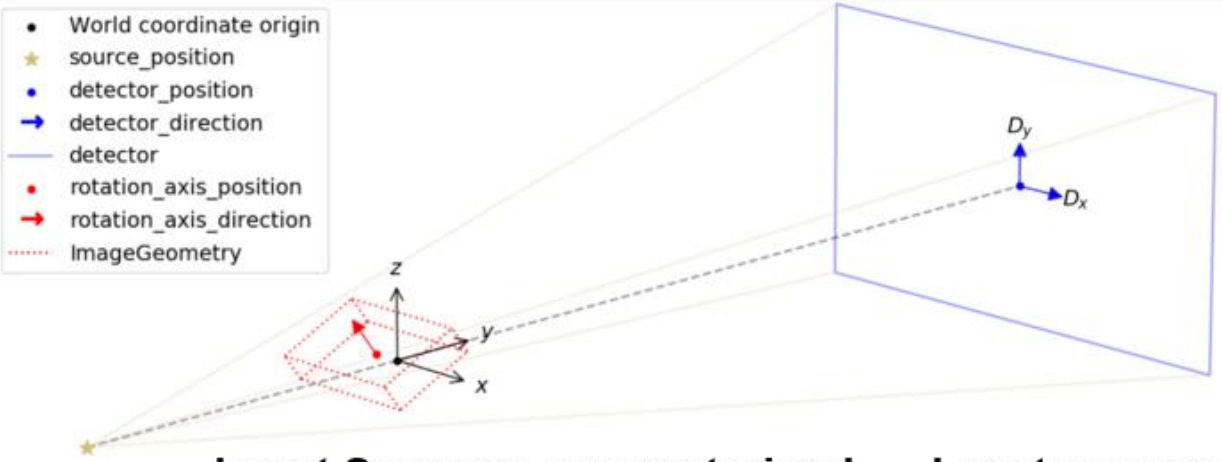
Join our Discord community:

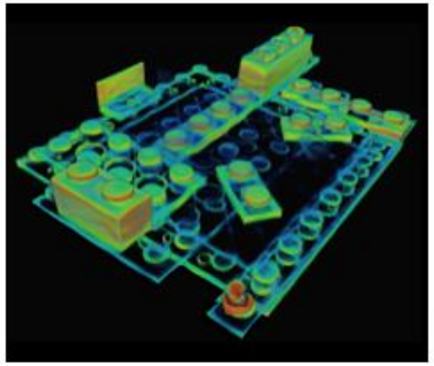
tinyurl.com/cil-discord

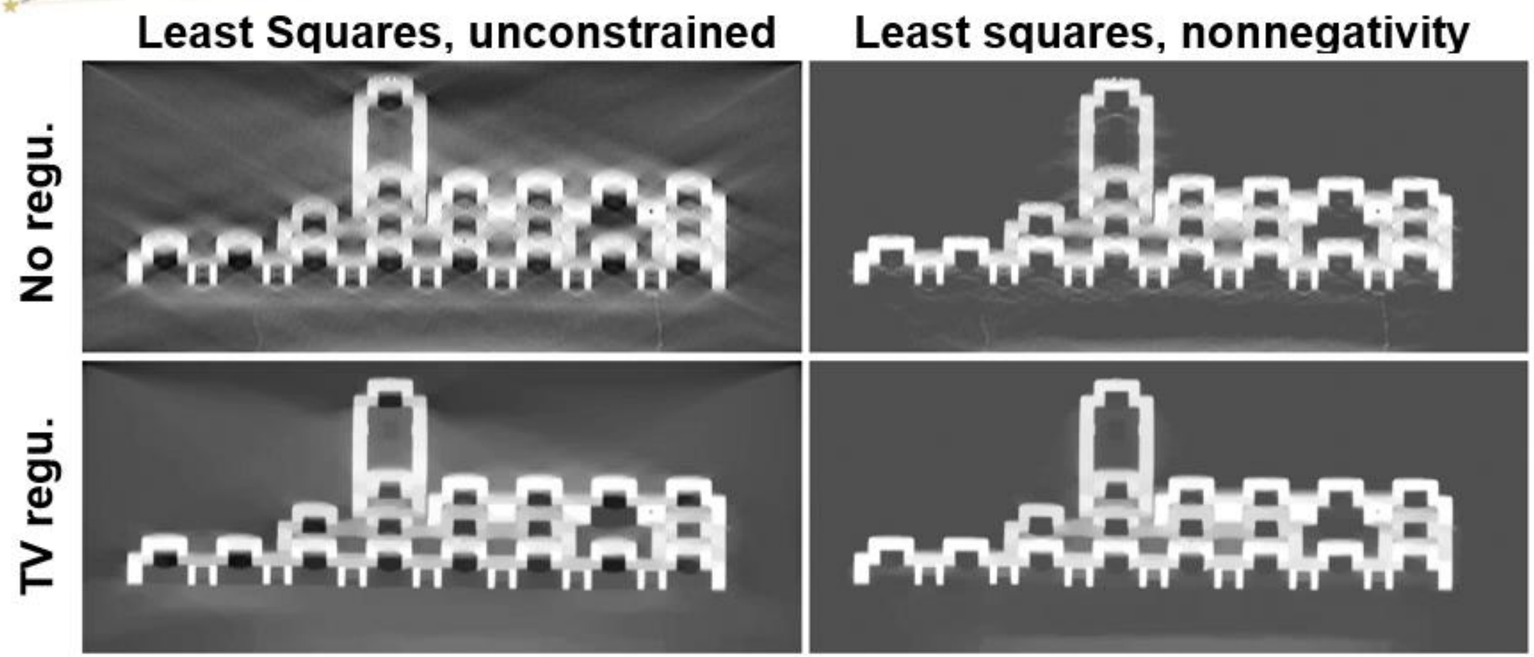
tomography@stfc.ac.uk

Spare slides

CIL example - non-standard scan





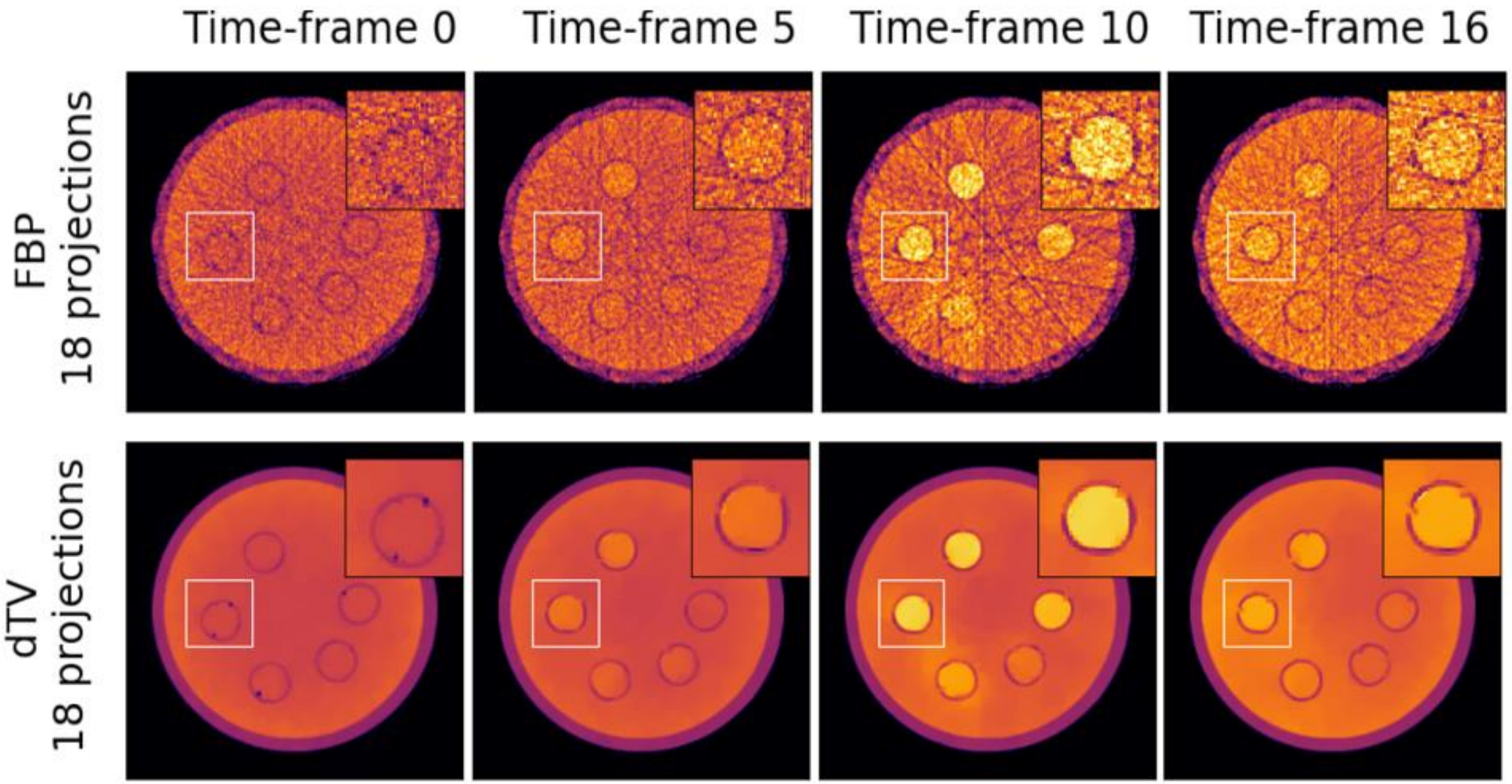


Jørgensen et al. 2021: *Core Imaging Library - Part I: a versatile Python framework for tomographic imaging*, Phil Trans A. https://doi.org/10.1098/rsta.2020.0192

CIL example - few-view dynamic CT

Filtered back-projection

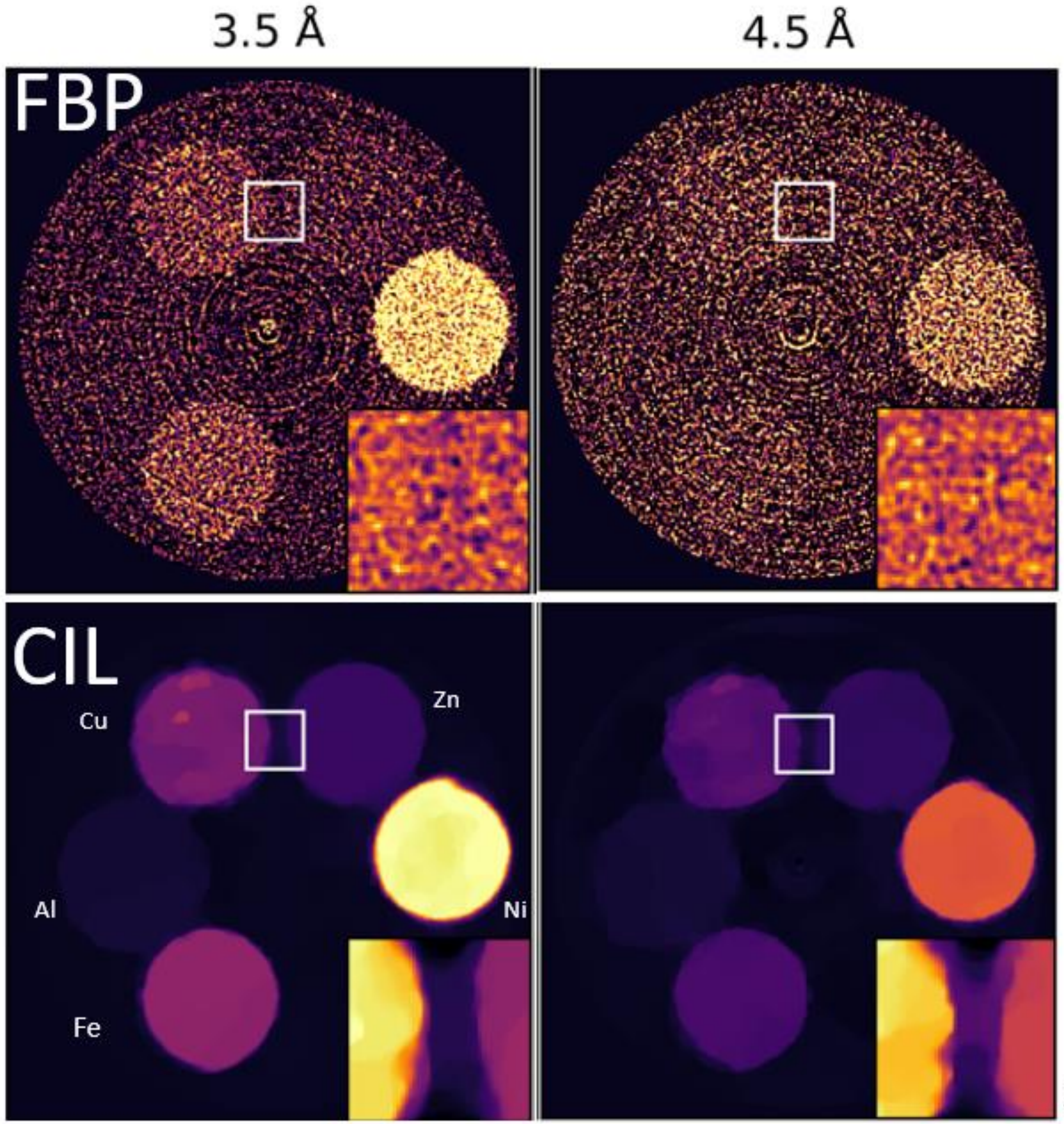
Directional TV propagating edges from pre and post scan



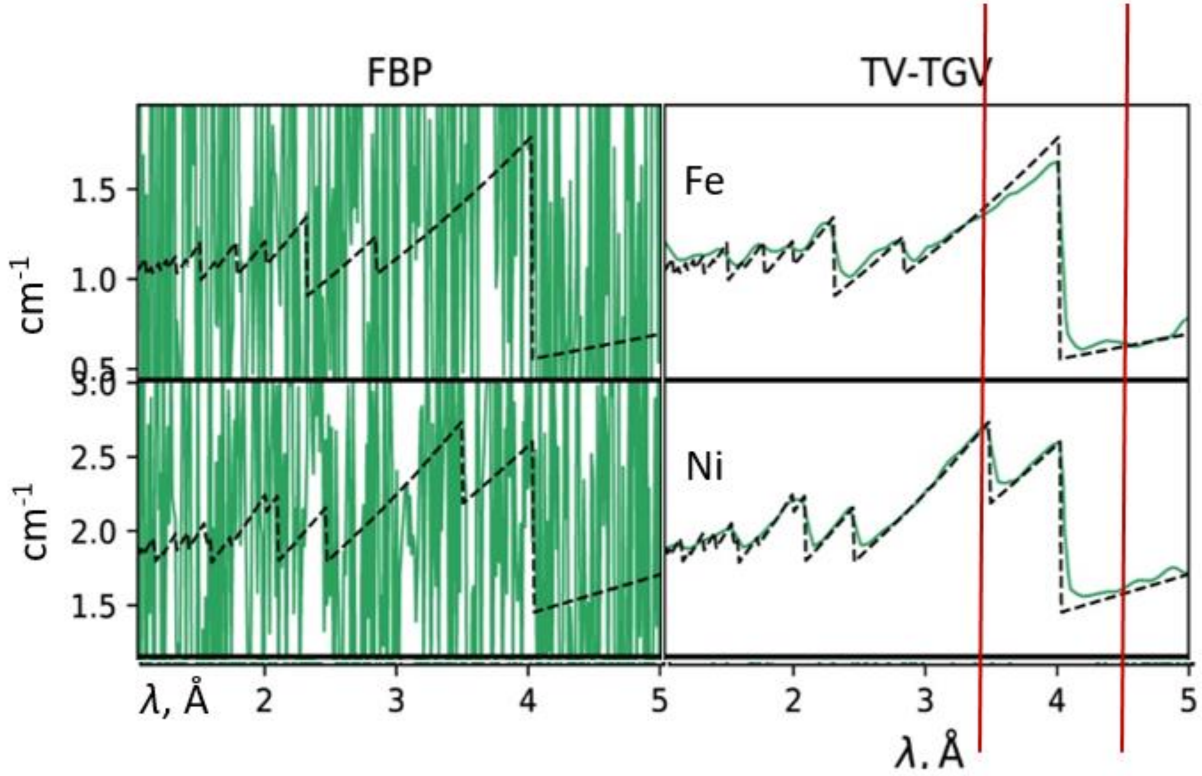
Papoutsellis et al. 2021: *Core Imaging Library - Part II: multichannel reconstruction for dynamic and spectral tomography*, Phil. Trans. R. Soc. A, **379**, 20200193: https://doi.org/10.1098/rsta.2020.0193

FIPS dataset: Tommi Heikkilä, Hanna Help and Alexander Meaney: "Gel phantom data for dynamic X-ray tomography" https://doi.org/10.5281/zenodo.4540623

Energy-resolved neutron CT



- Proposed spatio-spectral TV-TGV regularization
- Enables clear identification of Bragg edges in 3D



Ametova et al. 2021: *Crystalline phase discriminating neutron tomography using advanced reconstruction methods*, J. Physics D, https://doi.org/10.1088/1361-6463/ac02f9

CIL community

CIL
CORE IMAGING LIBRARY
Science and Technology Facilities Council
Scientific Computing

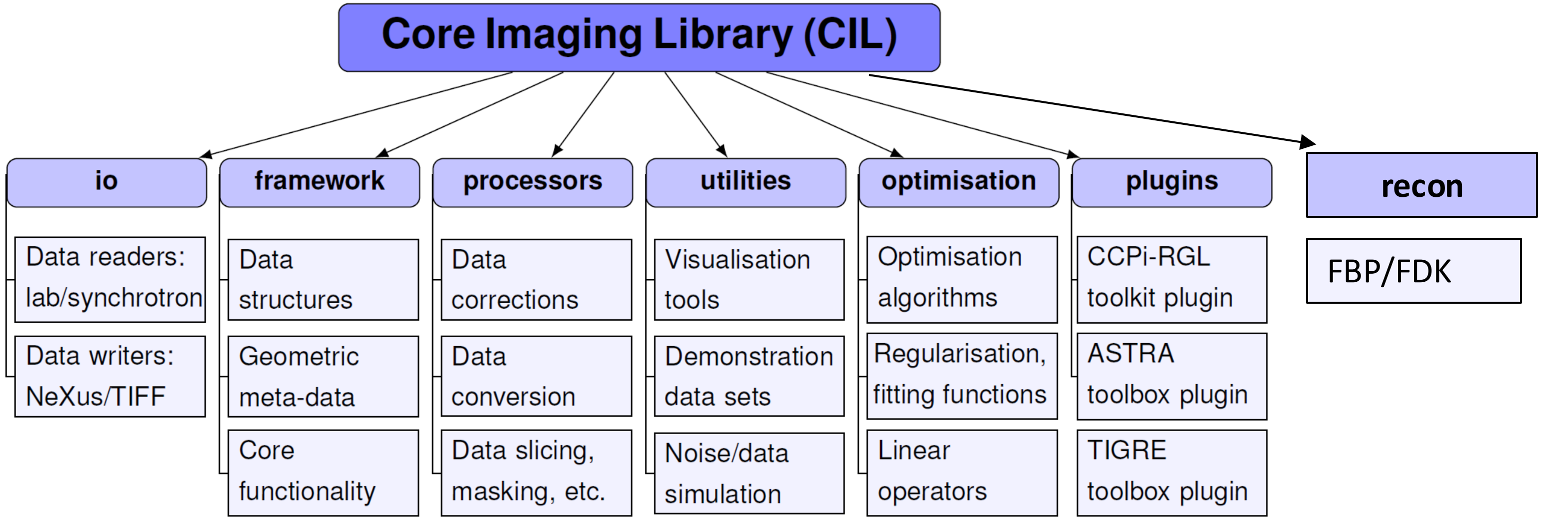
CIL “Bring Your Own Data” Hackathon
Isaac Newton Institute
Cambridge, UK – Mar 2023

First CIL User Meeting
Rutherford Appleton Laboratory
Harwell, UK – Nov 2023

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.

CIL Module Structure and Contents

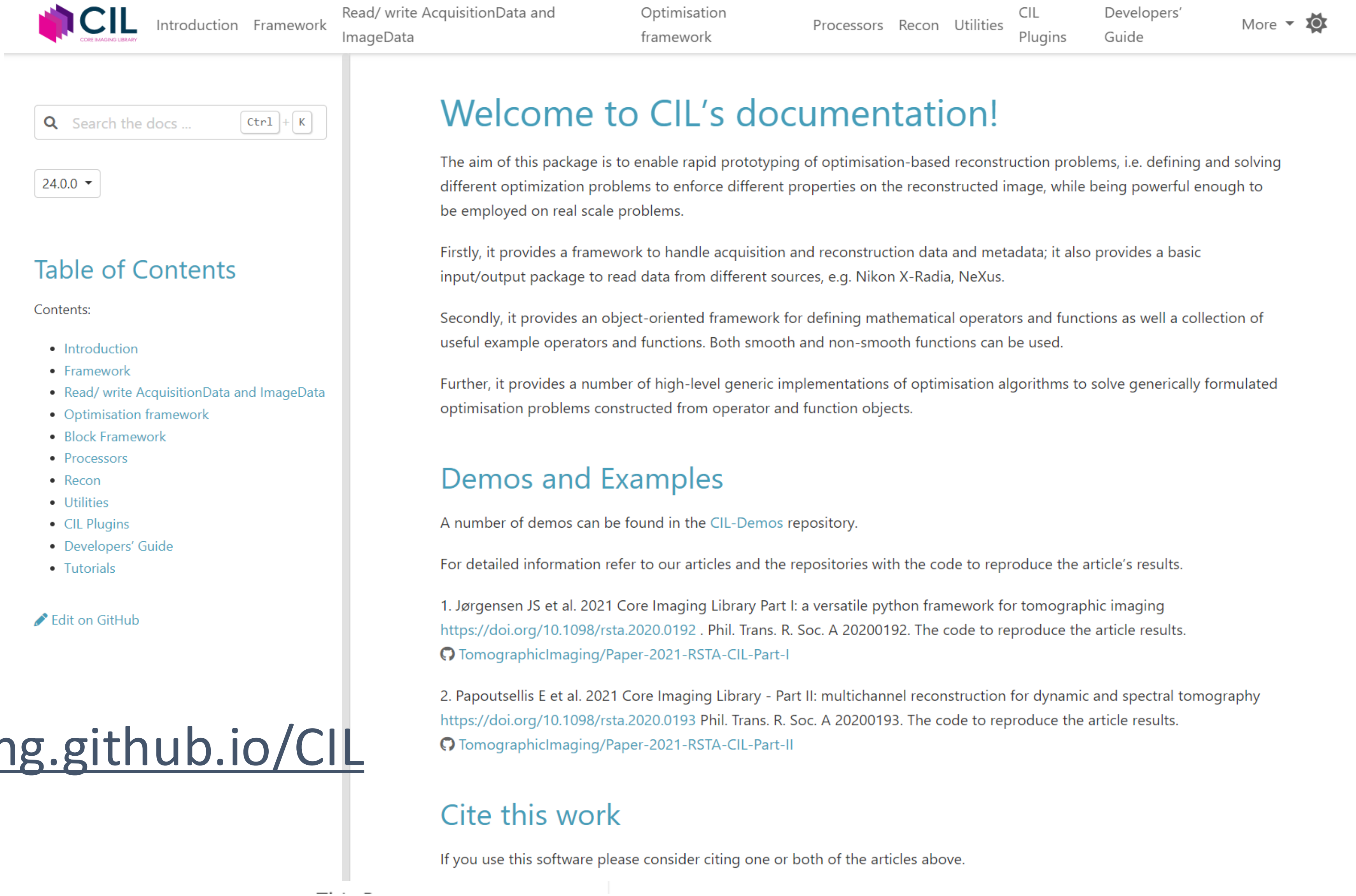


Jørgensen et al. 2021: *Core Imaging Library - Part I: a versatile Python framework for tomographic imaging*, Phil. Trans. R. Soc. A, **379**, 20200192: https://doi.org/10.1098/rsta.2020.0192

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.

Documentation

Scientific Computing


Introduction Framework Read/ write AcquisitionData and ImageData Optimisation framework Processors Recon Utilities CIL Plugins Developers' Guide More

Search the docs ... Ctrl + K

24.0.0

Table of Contents

Contents:

Edit on GitHub

Welcome to CIL's documentation!

The aim of this package is to enable rapid prototyping of optimisation-based reconstruction problems, i.e. defining and solving different optimization problems to enforce different properties on the reconstructed image, while being powerful enough to be employed on real scale problems.

Firstly, it provides a framework to handle acquisition and reconstruction data and metadata; it also provides a basic input/output package to read data from different sources, e.g. Nikon X-Radia, NeXus.

Secondly, it provides an object-oriented framework for defining mathematical operators and functions as well a collection of useful example operators and functions. Both smooth and non-smooth functions can be used.

Further, it provides a number of high-level generic implementations of optimisation algorithms to solve generically formulated optimisation problems constructed from operator and function objects.

Demos and Examples

A number of demos can be found in the CIL-Demos repository.

For detailed information refer to our articles and the repositories with the code to reproduce the article's results.

1. Jørgensen JS et al. 2021 Core Imaging Library Part I: a versatile python framework for tomographic imaging https://doi.org/10.1098/rsta.2020.0192 . Phil. Trans. R. Soc. A 20200192. The code to reproduce the article results. TomographicImaging/Paper-2021-RSTA-CIL-Part-I

2. Papoutsellis E et al. 2021 Core Imaging Library - Part II: multichannel reconstruction for dynamic and spectral tomography https://doi.org/10.1098/rsta.2020.0193 Phil. Trans. R. Soc. A 20200193. The code to reproduce the article results. TomographicImaging/Paper-2021-RSTA-CIL-Part-II

Cite this work

If you use this software please consider citing one or both of the articles above.

https://tomographicimaging.github.io/CIL

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

Algebraic Iterative Methods

regularising by number of iterations

CGLS

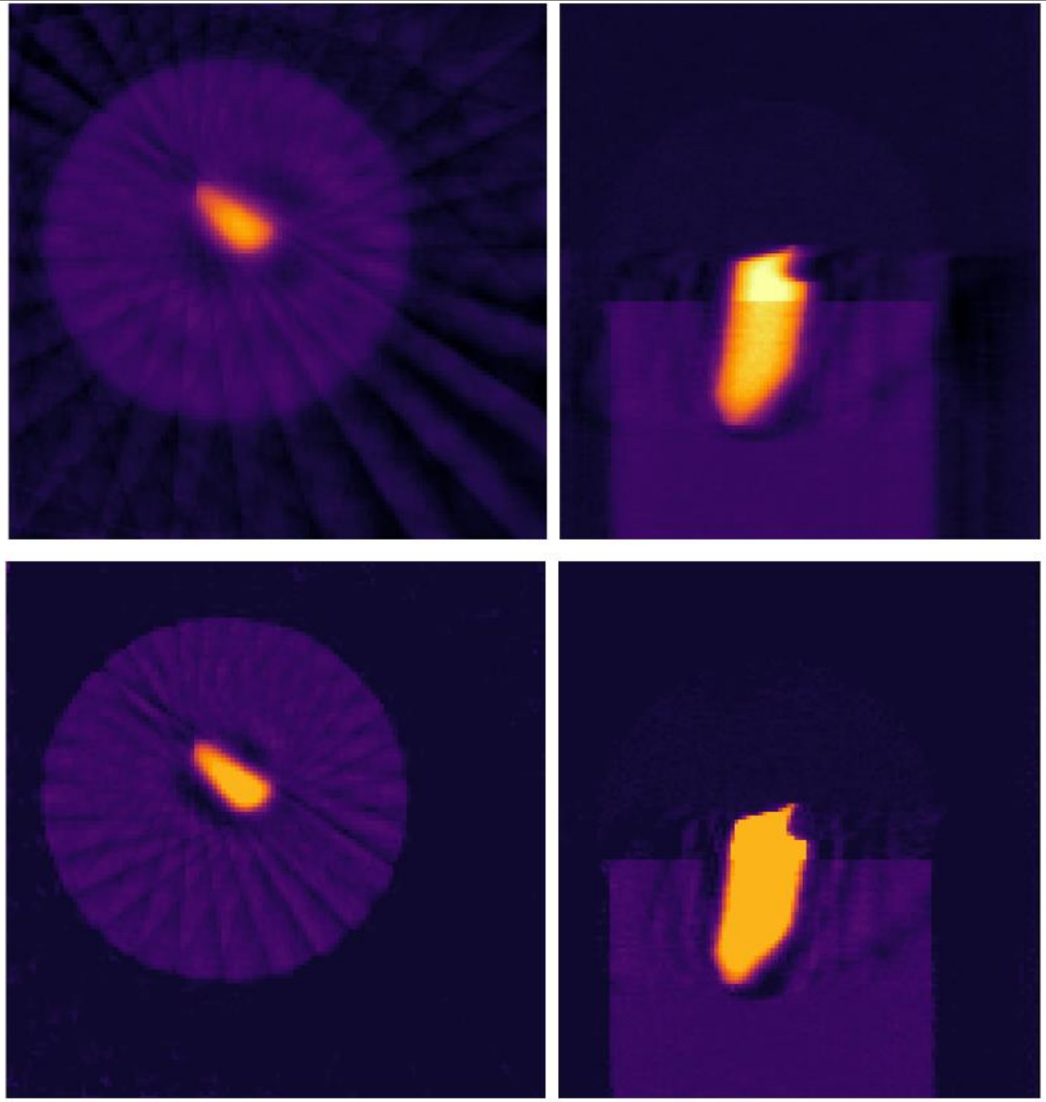
$$u^{\star} = \arg\min_{u} \| Au - b \|_2^2$$

Typically 10s of iterations

SIRT

As above and allowing lower and upper bounds on pixel values, here Non-negative and <= 0.9

Typically 100s of iterations



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CIL Publications

CIL
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Scientific Computing

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

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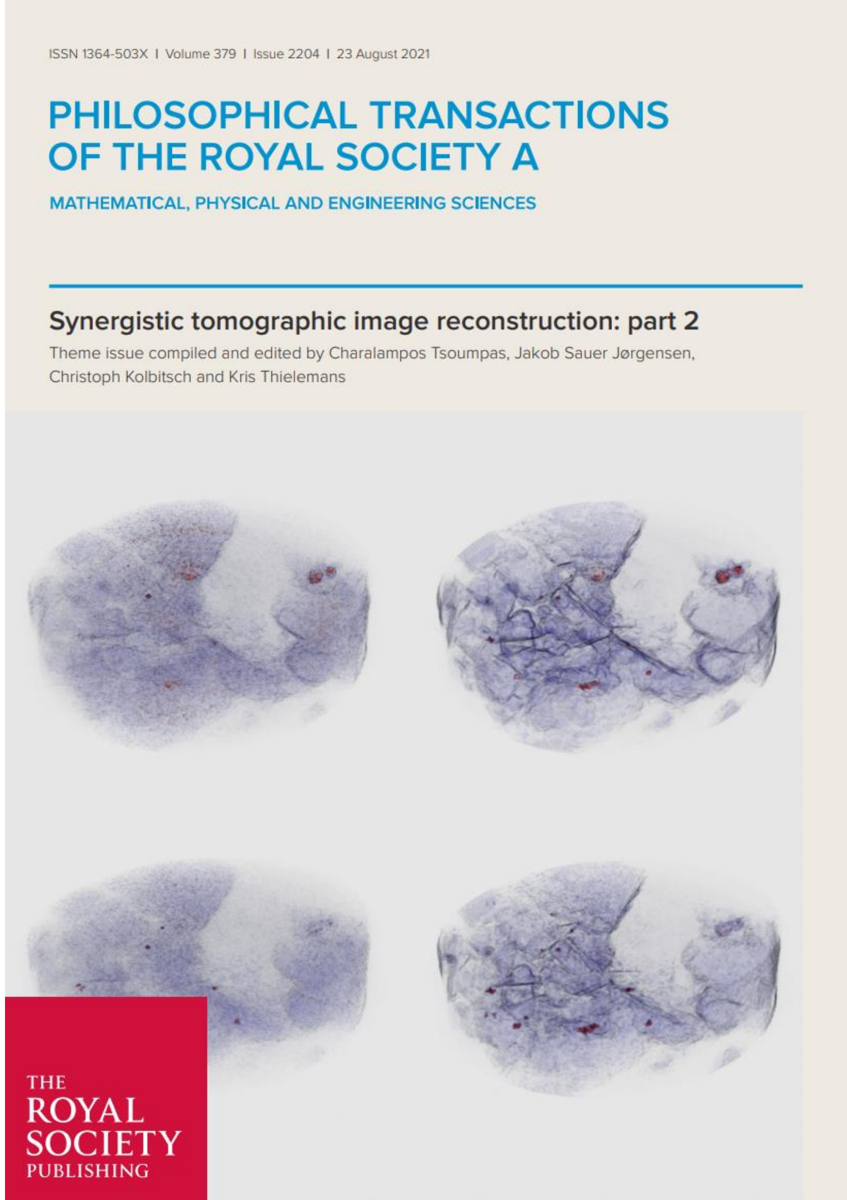
Jørgensen et al.: *A directional regularization method for the limited-angle Helsinki Tomography Challenge using the Core Imaging Library (CIL),* Applied Mathematics for Modern Challenges, Volume **1**, Issue 2: 143-169. (2023) [10.3934/ammc.2023011](https://doi.org/10.3934/ammc.2023011)

Ametova et al.: *Crystalline phase discriminating neutron tomography using advanced reconstruction methods*, J. Phys. D: Appl. Phys. **54** 325502 (2021) DOI [10.1088/1361-6463/ac02f9](https://doi.org/10.1088/1361-6463/ac02f9)

Warr R. et al.: *Enhanced hyperspectral tomography for bioimaging by spatiospectral reconstruction* Sci Rep **11,** 20818 (2021) DOI: [10.1038/s41598-021-00146-4](https://doi.org/10.1038/s41598-021-00146-4)

Brown R. et al.: *Motion estimation and correction for simultaneous PET/MR using SIRF and CIL* Phil. Trans. R. Soc. A.**379** 20200208 (2021) DOI:[10.1098/rsta.2020.0208](https://doi.org/10.1098/rsta.2020.0208)



CCP*i* = CCP in Tomographic Imaging

- The Collaborative Computational Projects (CCPs)
- UK Network of expertise in key computational research fields
- CCP's foster exchange by organising workshop, training, conferences ...
- Enable large-scale scientific software development, maintenance and distribution.
- Long term funding by EPSRC with a 5 years renewal cycle
- CCP's are supported by the Computational Science Centre for Research Communities (CoSeC).
- https://www.ccpi.ac.uk

Conclusion

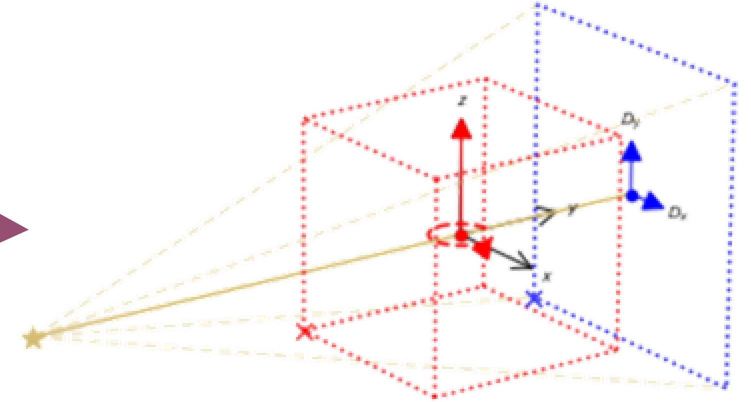
- CIL is a Open Source mostly Python library for all your tomographic needs:
  - I/O
  - pre-processing
  - Reconstruction
  - Visualisation
- Developer Support, user driven, long term funding
- Join the community Discord
- https://www.ccpi.ac.uk/CIL

Discord community:
discord.gg/ky7yCqRcYn

tomography@stfc.ac.uk

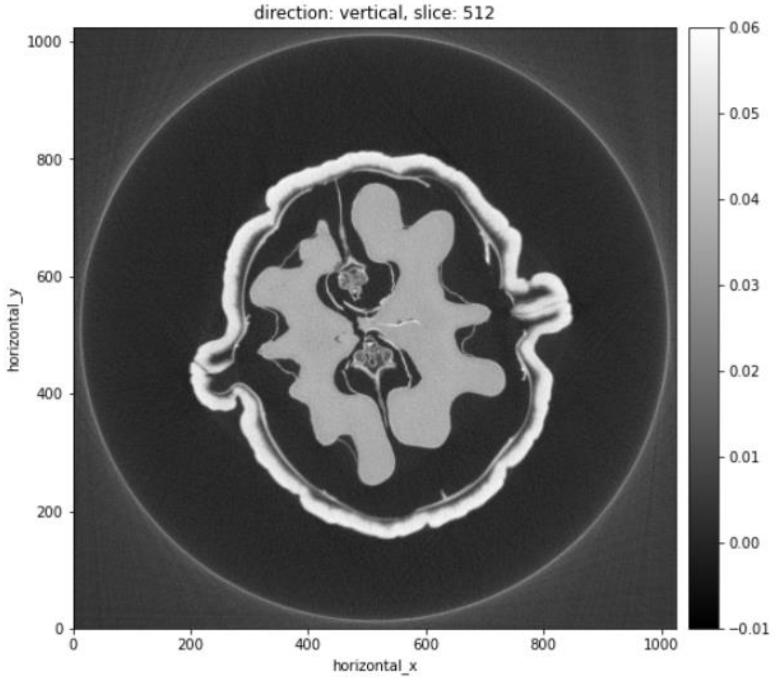
Core Imaging Library for CT and other inverse problems

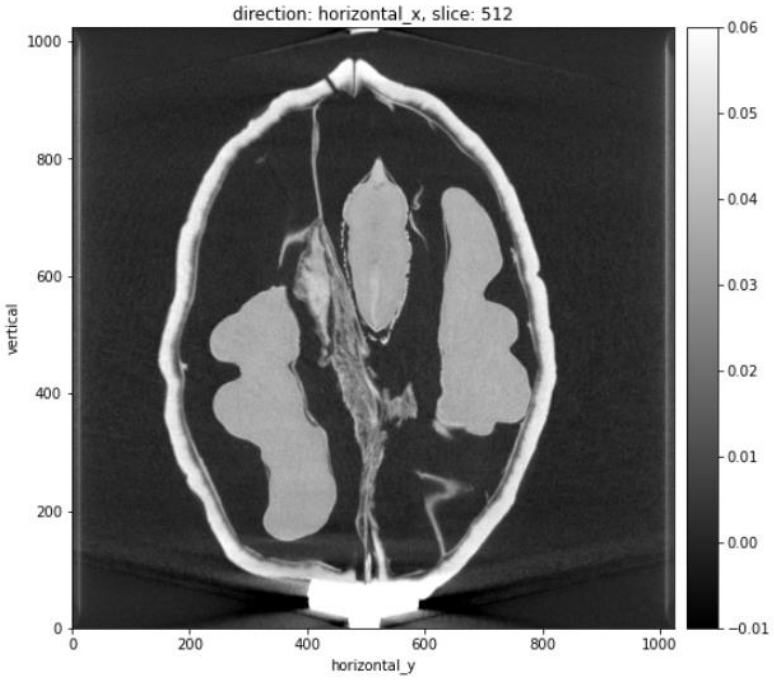
```
data = ZEISSDataReader(filename).read()
data = TransmissionAbsorptionConverter()(data)
show_geometry(data.geometry)
recon = FDK(data).run()
show2D(recon)
```



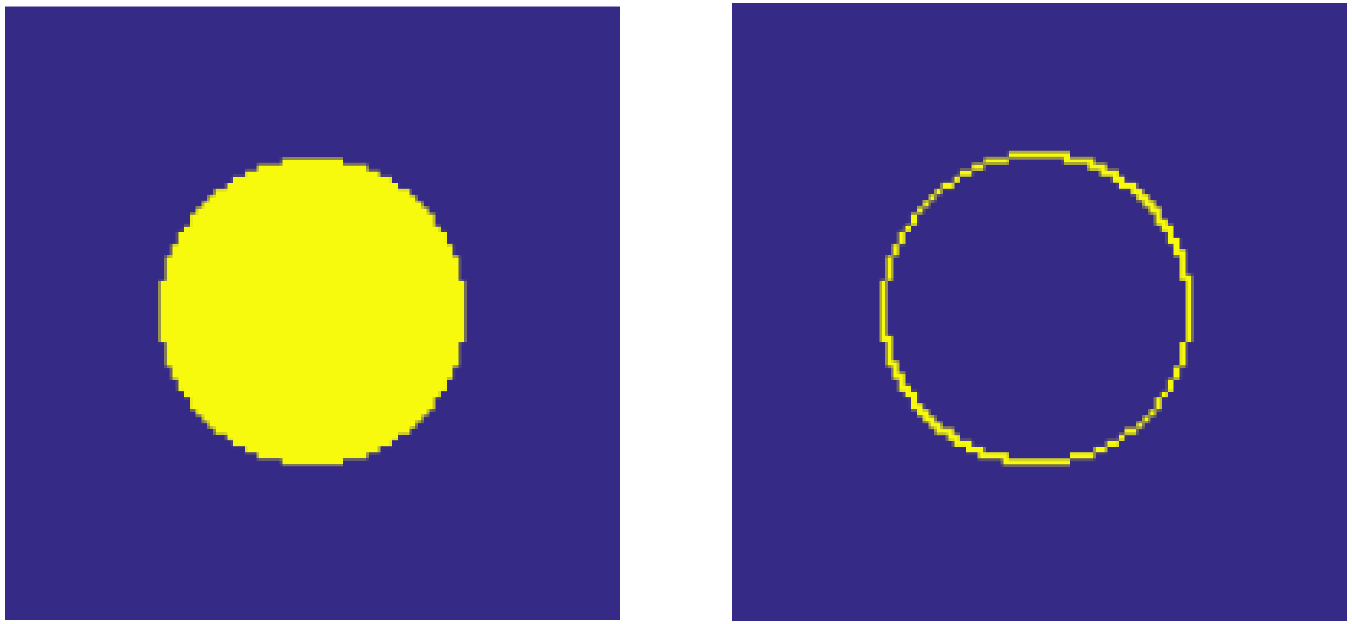
- Data readers/writers
- Pre-processing tools
- Image reconstruction
- *Near math* optimisation syntax
- Visualisation
- 2D, 3D and 4D data
- TIGRE and ASTRA backend

ccpi.ac.uk/CIL





What is Total Variation?



- Measures variation of an image
- Sum of gradient magnitude image

$$\mathrm{TV}(u) = \sum_j \|D_j u\|_2$$

- Prior: few homogeneous regions with simple boundaries
- Quite successful in tomography, in particular for reduced data

tomography@stfc.ac.uk