Reconstruction methods and software for X-ray and neutron tomography

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CIL
CORE IMAGING LIBRARY

CCPi
TOMOGRAPHIC IMAGING

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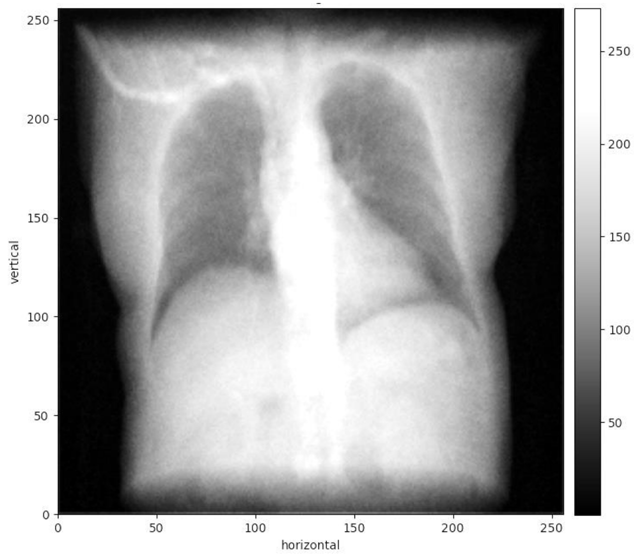
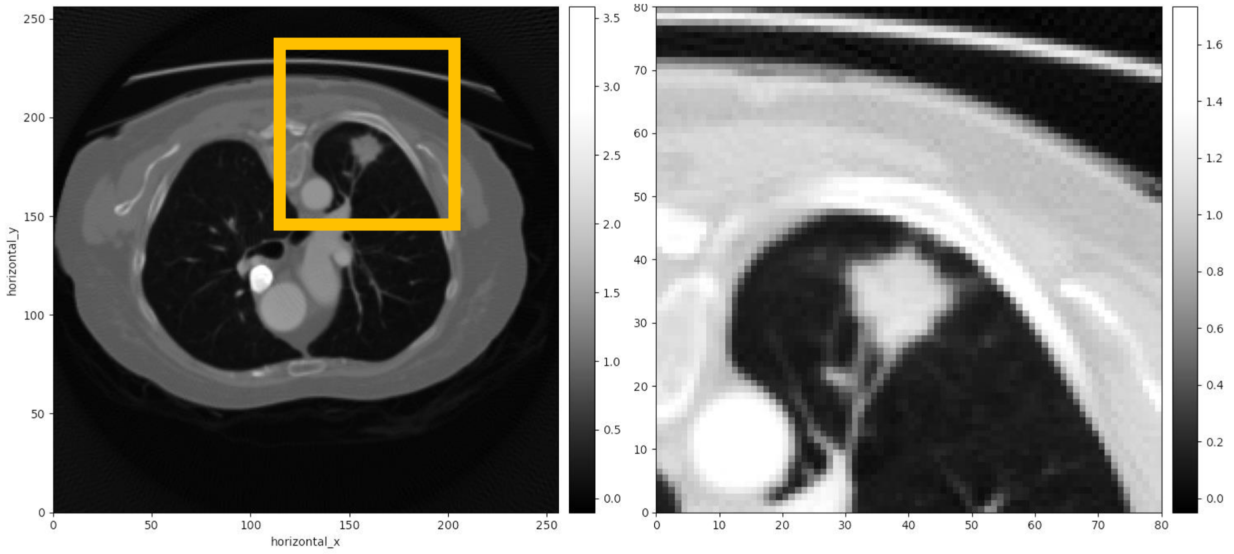
UKRI Science and Technology Facilities Council
Scientific Computing

Good reconstruction from bad data?

Good data



Good reconstructed 3d image

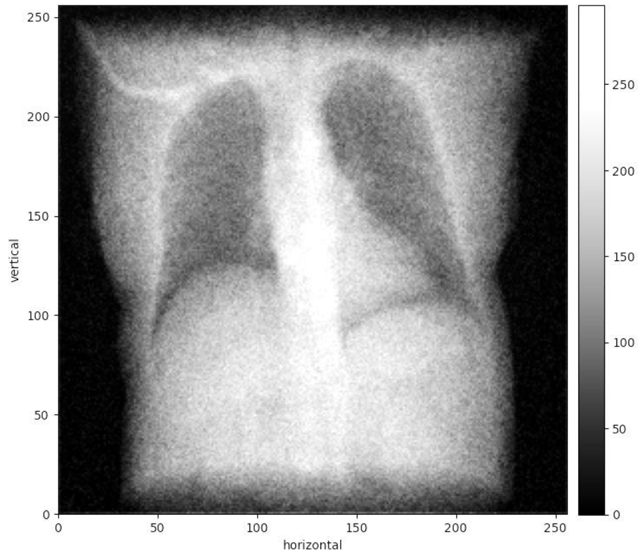


Filtered back-projection (FBP)

???

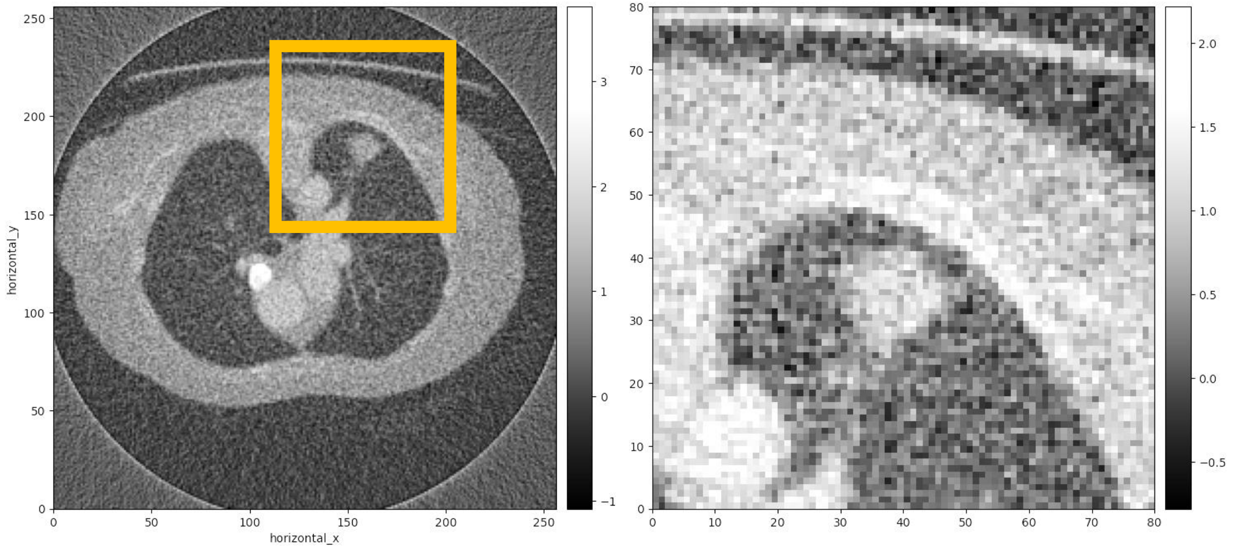
Mathematical modelling
Computational methods
Open-source software

Bad data



Filtered back-projection (FBP)

Bad reconstructed 3d image



Ingredients in improving reconstruction

Mathematical modelling

- Understand the specifics of why the data is bad or non-standard
- Formulate any side information such as “image should have sharp edges”

Computational methods

- Develop dedicated reconstruction algorithms
- Incorporate characteristics of data and any side information

Open-source software

- Make methods available as high-quality scientific software
- Work with facilities to apply and deploy methods to benefit users

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)
```

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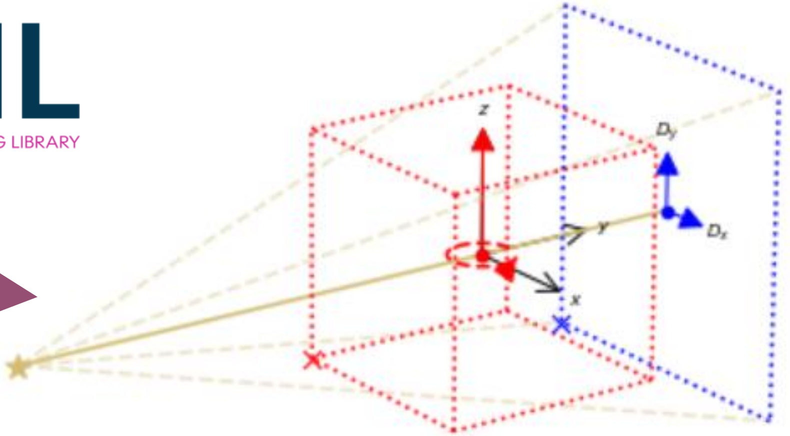
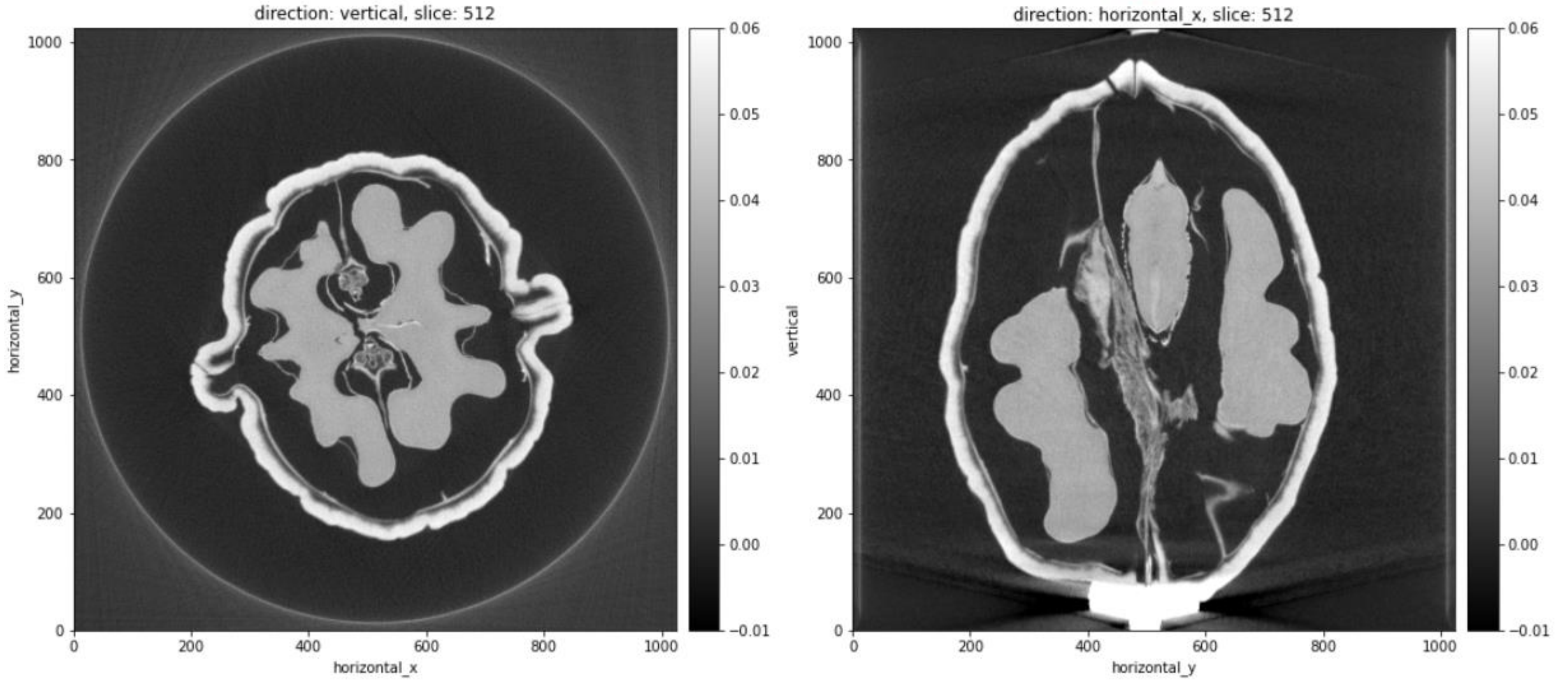


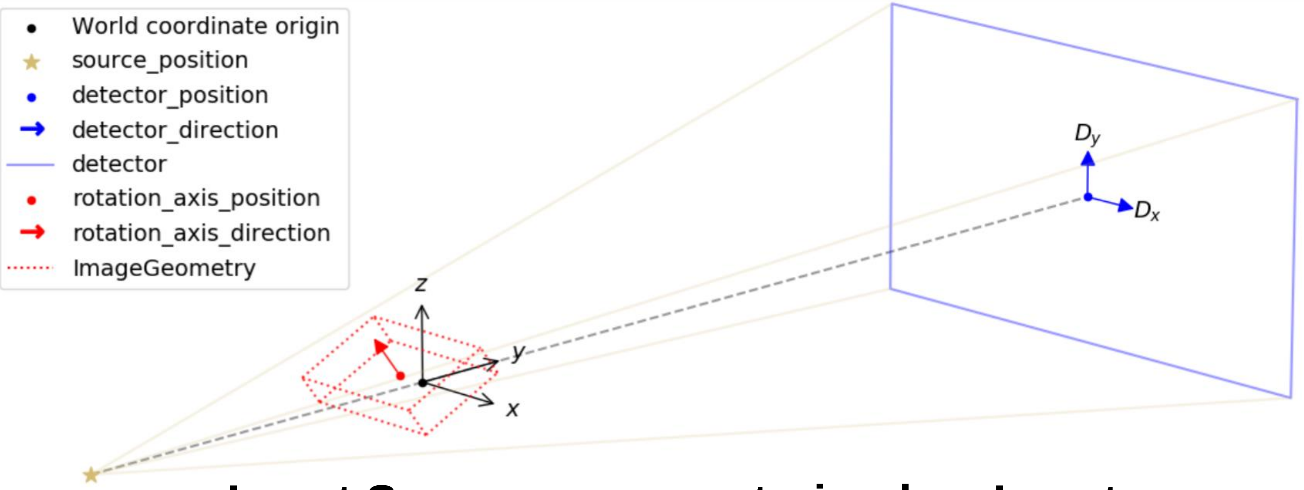
- Data readers/writers
- Pre-processing tools
- GPU-acceleration
- 2D, 3D, 4D – cone & parallel beam
- Many reconstruction algorithms
- Bad and non-standard CT data
- Visualisation

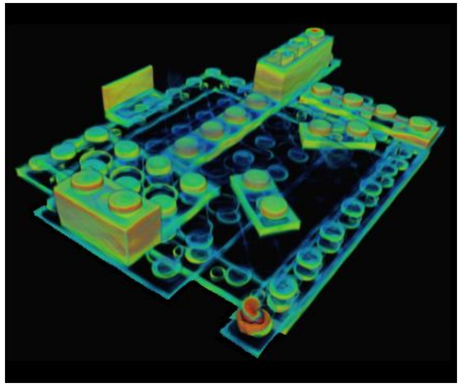
ccpi.ac.uk/CIL



Jørgensen et al. 2021: *Core Imaging Library - Part I: a versatile Python framework for tomographic imaging*, Phil. Trans. R. Soc. A, **379**, 20200193: https://doi.org/10.1098/rsta.2020.0192

Example: Non-standard scan - laminography

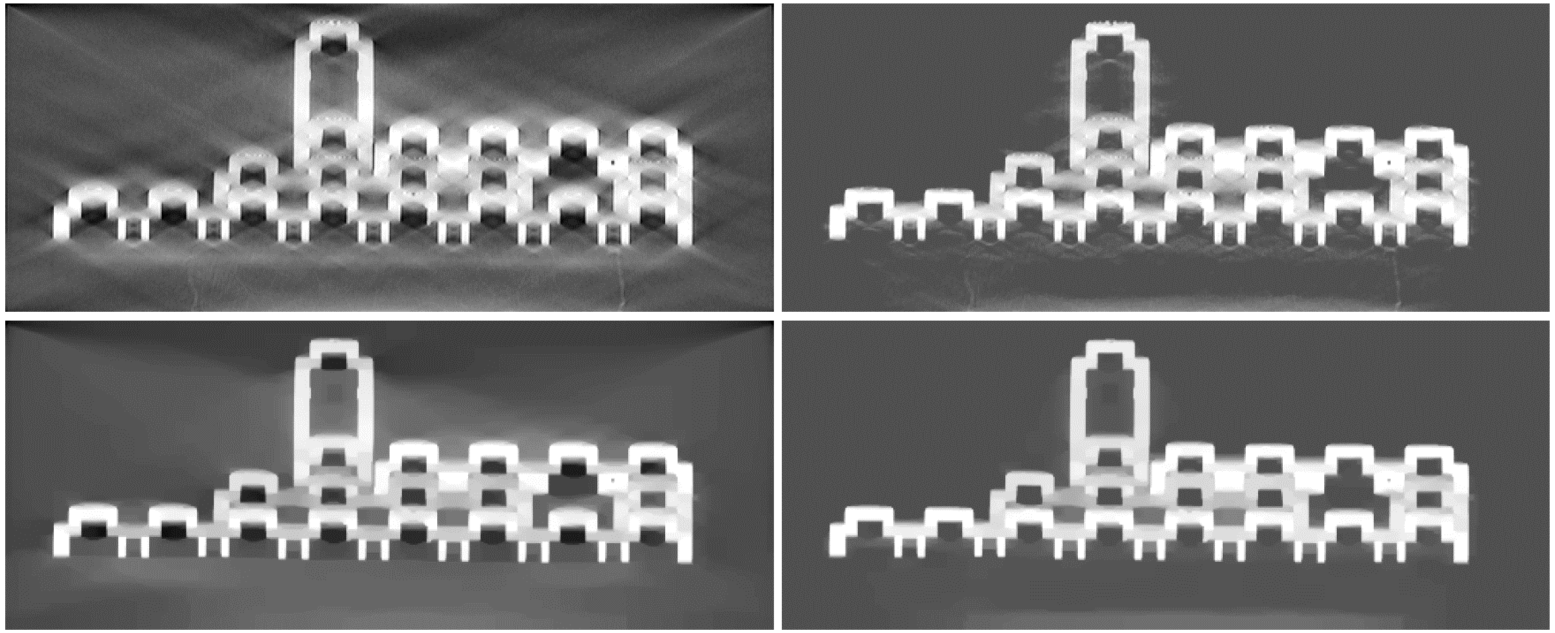




Least Squares, unconstrained | Least squares, nonnegativity

No regu.

TV regu.



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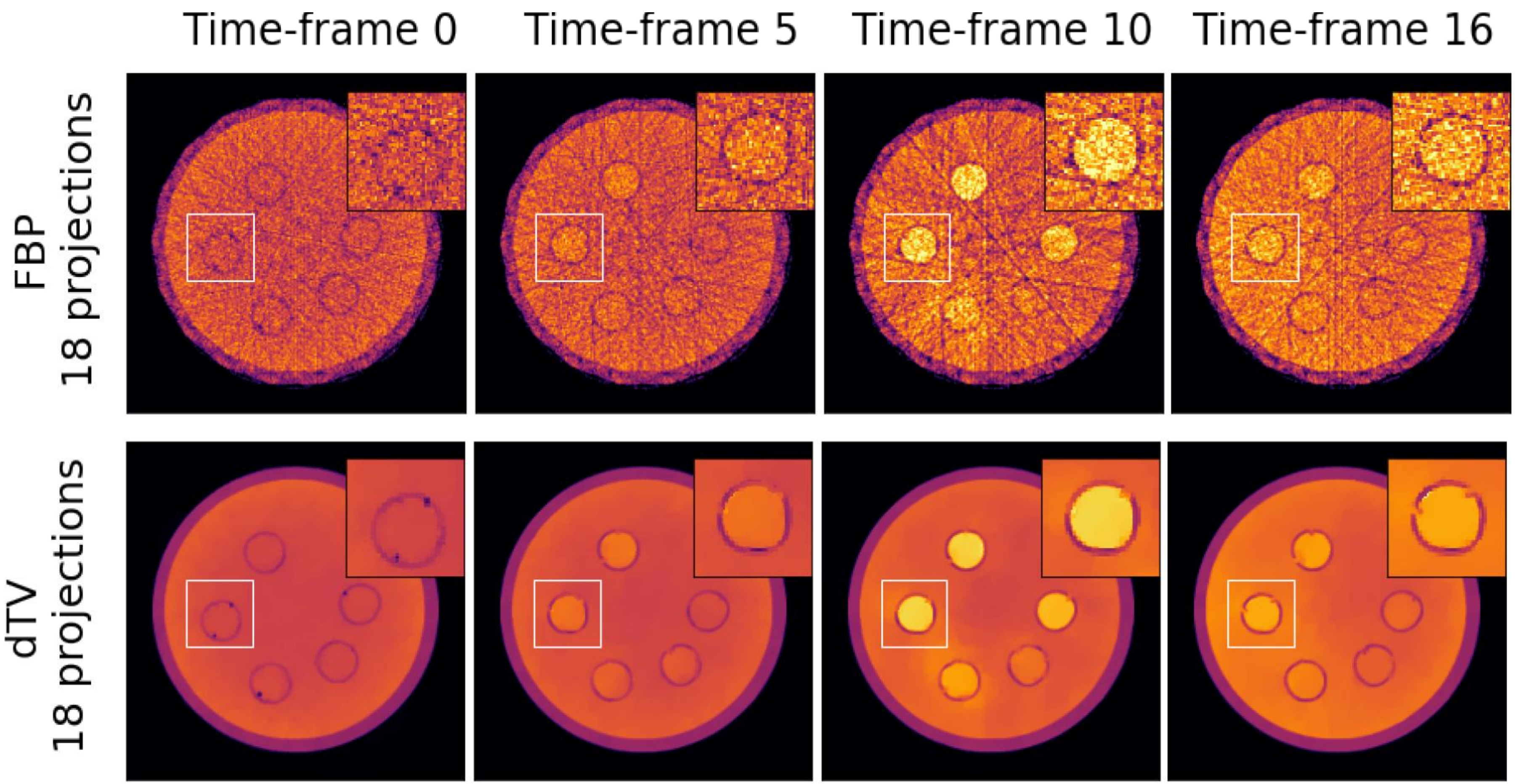
Example: Fast time-resolved CT

Filtered back-projection

Directional TV propagating edges from pre and post scan



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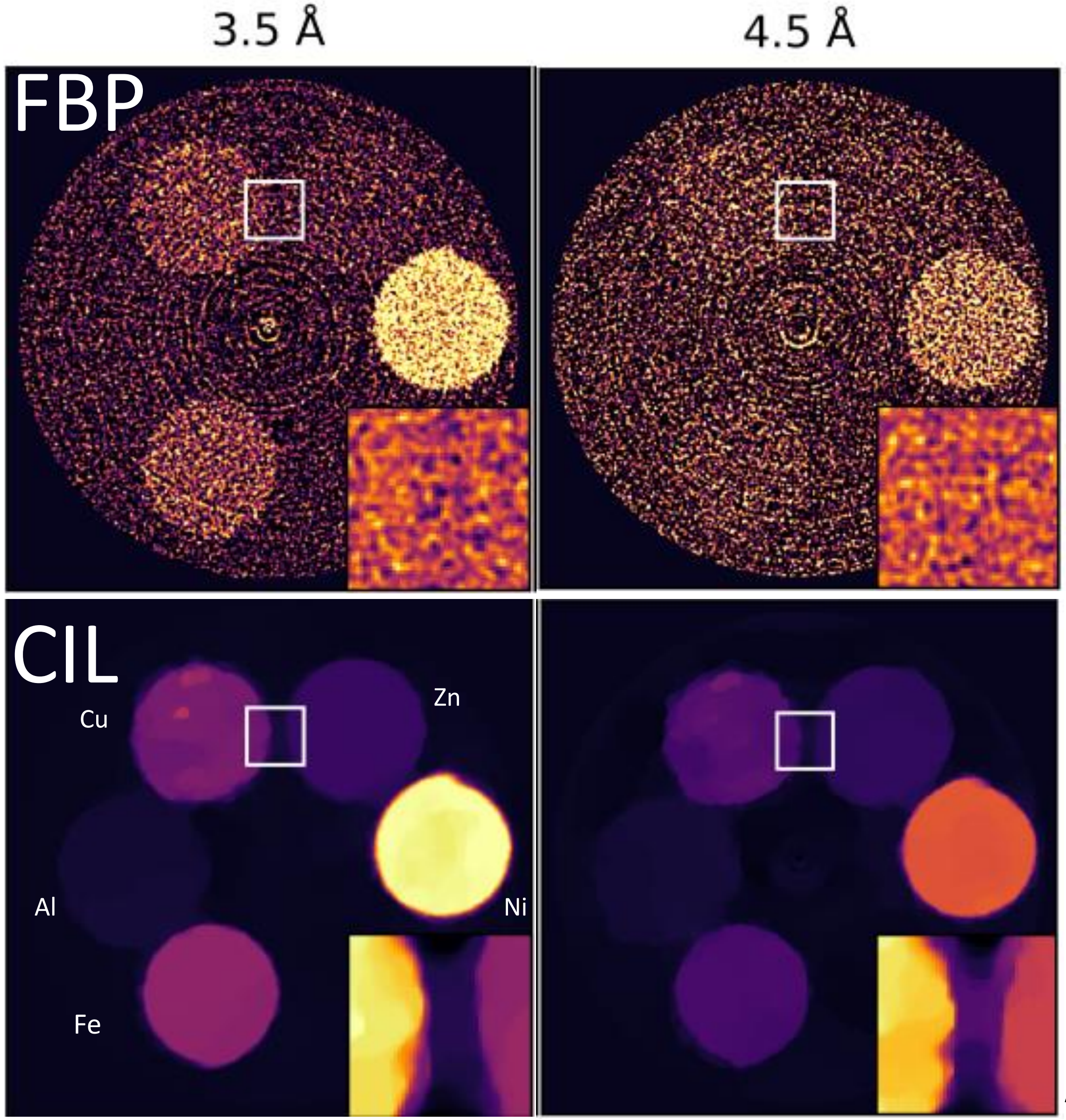
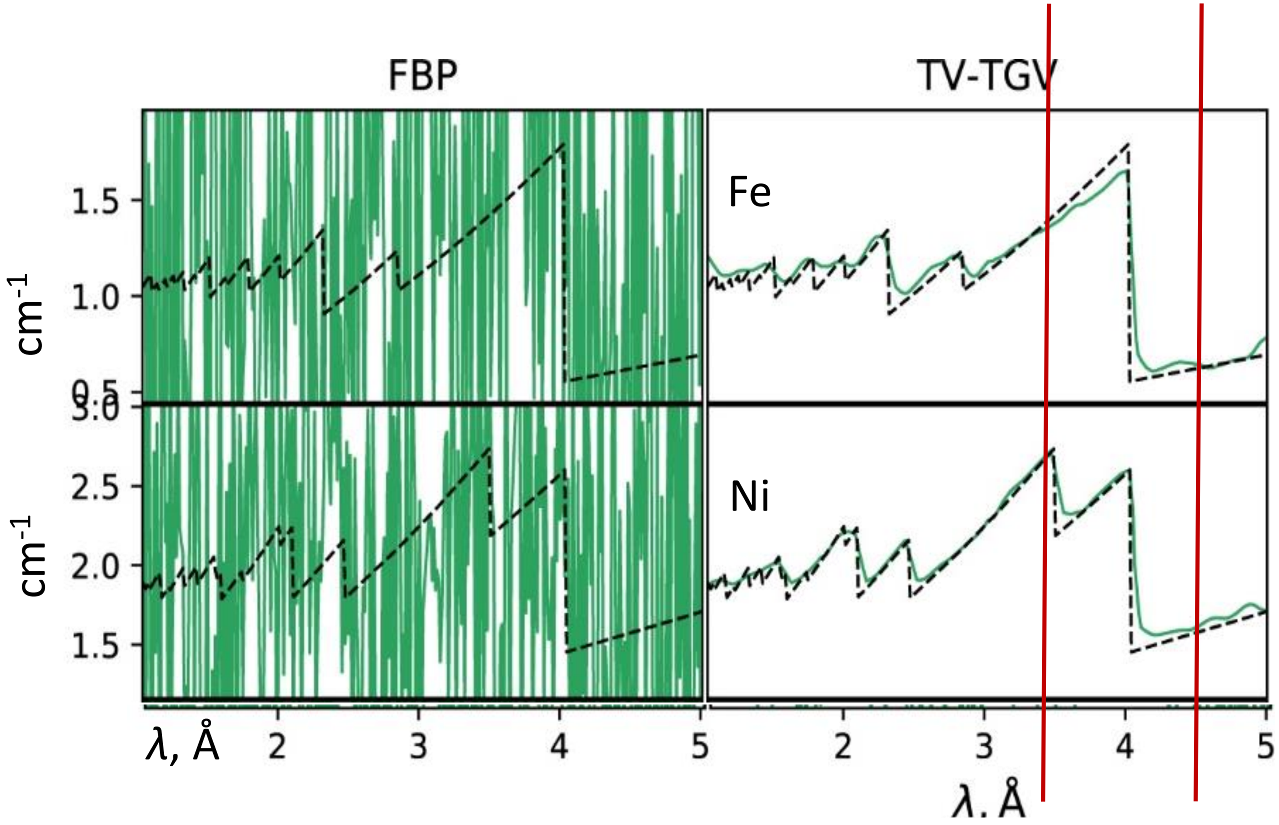
Papoutsellis et al. 2021: *Core Imaging Library - Part II: multichannel reconstruction for dynamic and spectral tomography*, Phil. Trans. R. Soc. A, **379**, 20200193: https://doi.org/10.1098/rsta.2020.0193

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

Example: Hyperspectral neutron CT



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

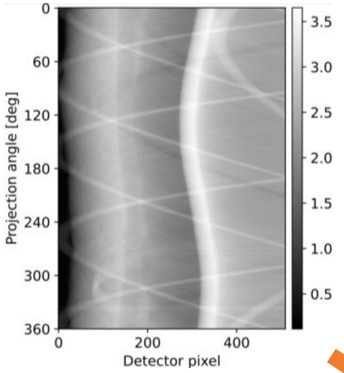


Ametova et al. 2021: *Crystalline phase discriminating neutron tomography using advanced reconstruction methods*, J. Physics D, https://doi.org/10.1088/1361-6463/ac02f9

Uncertainty Quantification with CUQIpy

Forward model & data

$\mathbf{A}$ $\quad$ $\mathbf{b}$



Parameter assumptions

$$\mathbf{b} \sim \mathcal{N}(\mathbf{A}\mathbf{x}, \sigma^2_{\text{noise}}\mathbf{I})$$
$$\mathbf{x} \sim \mathcal{N}(\mathbf{0}, \delta^2\mathbf{I})$$
$$\delta \sim \text{Gamma}(a, b)$$

Bayesian inverse problem modelling framework

$$p(\mathbf{x}, \delta|\mathbf{b}) \propto p(\mathbf{b}|\mathbf{x})\, p(\mathbf{x}|\delta)\, p(\delta)$$

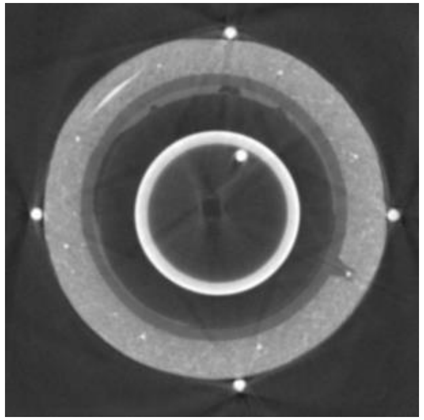
Posterior $\quad$ Likelihood $\quad$ Priors

Computational UQ engine

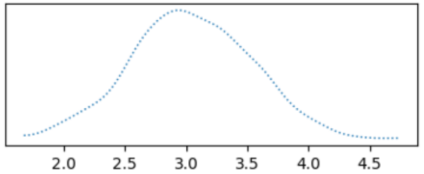
- Efficient posterior sampling using structure
- High-level interface for non-experts
- Full control for experts
- Hierarchical problem support
- Catalogue of test problems, priors, …

Parameter estimates

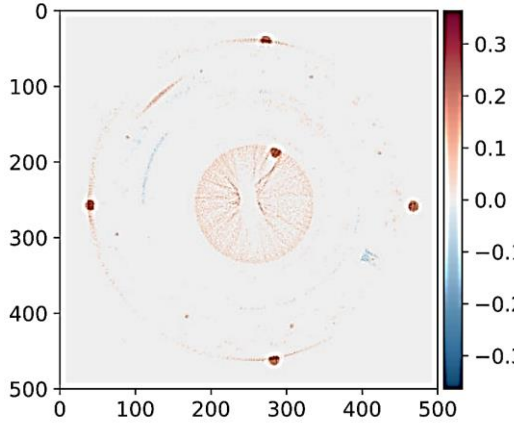
$\mathbf{x}$



δ



UQ information



https://github.com/CUQI-DTU/CUQIpy

Summary and links

Improved reconstruction

- Mathematical modelling, computational methods & open-source software

Computational Uncertainty Quantification for Inverse Problems in python

- CUQIpy: cuqi-dtu.github.io/CUQIpy

CUQIpy

Core Imaging Library (CIL)

- Main site: ccpi.ac.uk/cil
- Demos: github.com/TomographicImaging/CIL-Demos
- Discord: discord.gg/9NTWu9MEGq
- Article: https://doi.org/10.1098/rsta.2020.0192

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Open in Colab

Ongoing work and future plans

- Deploy at facilities: ESRF, Diamond, NXRF, DTU 3DIM, ISIS, … **ESS?**
- Bad data or new modality? Talk to us!
- Open to collaborations, applications, student projects, etc.
- Community events incl software training: https://ccpi.ac.uk/events/first-cil-user-meeting/

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Other inverse problems - Colour image inpainting

Colour image inpainting and salt/pepper denoising using L1-norm data fidelity and total generalized variation (TGV)

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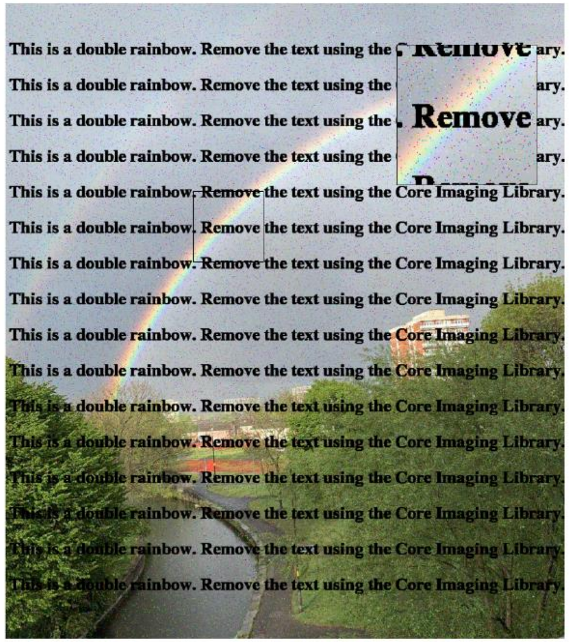
Ground truth

Corrupted image



L1 + TGV

CIL supplies LinearOperators for denoising, deblurring and inpainting problems and users may write a LinearOperator wrapper for their own problem.

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

What is the Core Imaging Library (CIL)?

- CIL is an open-source Python library for solving **Imaging Inverse Problems**
- Special emphasis on tomography applications with **challenging data sets**: low-count, non-standard geometries, incomplete, multi-channel
- **Highly flexible** and modular set of tools for different imaging problems
- **Near-math** specification and solution of **optimization problems**
- **Simple** to get started – **powerful** enough for large, real applications

- Funded by the **C**ollaborative **C**omputational **P**roject in Tomographic **I**maging **(CCPi)**
- Apache v2 license – highly permissive.
- Actively developed on GitHub: https://github.com/TomographicImaging/CIL

Who is CIL for?

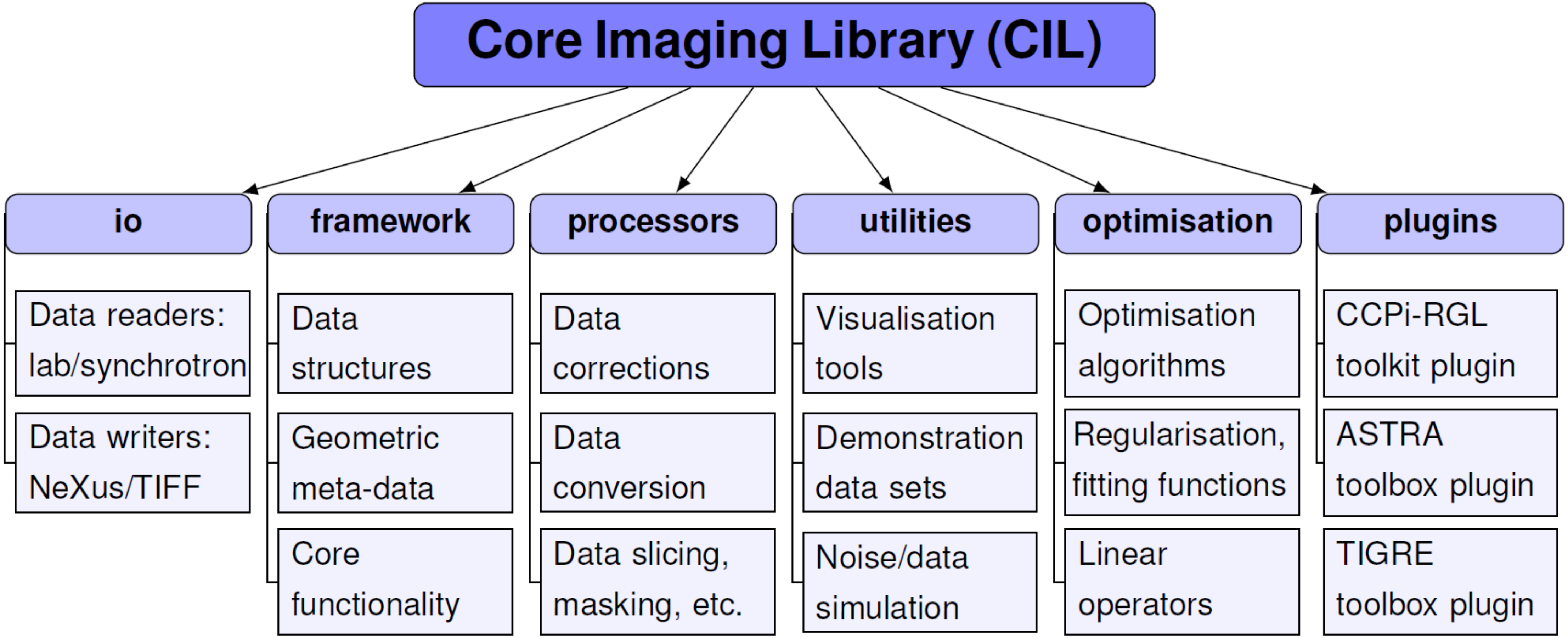
CT experimentalists and practical users

- Apply advanced algorithms for poor data quality or novel imaging modalities
- Optimised standard algorithms for large data
- Batch processing and custom-built open-source data processing

Mathematical imaging researchers

- Prototype new reconstruction algorithms
- Make **YOUR METHOD** available to community and deploy it to imaging facilities
- Try on real data and assess against existing methods

Overview



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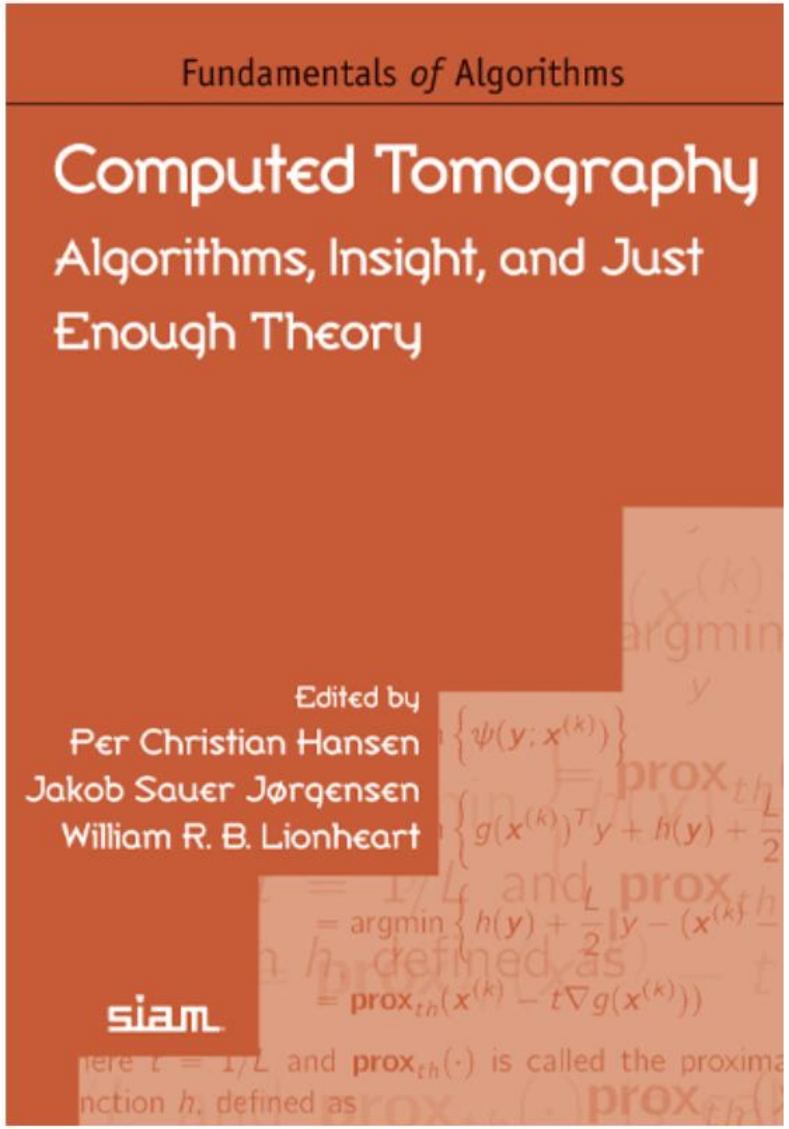
New book on CT reconstruction



Computed Tomography: Algorithms, Insight, and Just Enough Theory

Edited by Per Christian Hansen, Jakob Sauer Jørgensen, and William R. B. Lionheart
Published: 2021
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Order Code: FA18

With
Todd Quinto, Yiqiu Dong, Martin Andersen, Joost Batenburg and Jan Sijbers

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