Multi-Channel tomographic reconstruction using the Core Imaging Library

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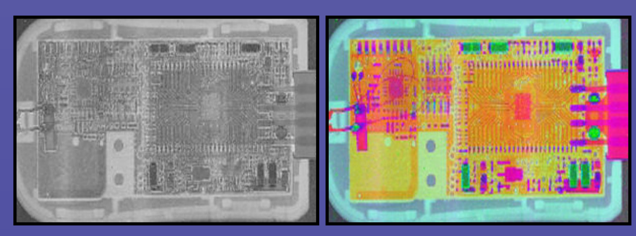
Overview & Goal

- The Collaborative Computational Project in Tomographic Imaging (CCPi) aims to provide the UK tomography community with a toolbox of algorithms that increases the quality and level of information that can be extracted by computed tomography.
- Moving beyond existing single-channel image reconstruction, we unlock the full power of spectral imaging and exploit Multi-Channel Tomography modalities towards to chemical imaging, structure and material decomposition.



USB spectral X-ray projection. Each color represents a different material.

Optimisation Framework

- Plethora of functions, operators and algorithms implementing a generic (smooth/non smooth) optimisation problem (2D - 4D) for tomographic reconstruction.
- Different formulations and algorithms, i.e., "mix and match" data fidelities, regularisers and constraints.
- Better choice of energy based reconstruction algorithms can guide the informed user and enable improved quantification and qualification for image information extraction.

Operator Class
- Gradient (Symmetrised)
- Convolution Operator
- Multi - spectral
- Dynamic CT

Function Class
- Total (Generalised) Variation
- Nonlocal Total Variation
- Direction Total Variation
- Total Nuclear Variation
- L^1, L^2 norms, Kullback-Leibler

CCPi - Framework

- Object-oriented framework for optimisation-based tomography reconstruction problems.
- Algorithms with CPU/GPU implementations: (a) FISTA, (b) ADMM, (c) CGLS, (d) PDHG
- Data readers & processors for various instruments:
  - (a) HEXITEC (spectroscopic, single photon counting, pixel detectors), IMAT (Neutron imaging & Diffraction instrument), Nikon Metrology X-ray CT.
  - (b) Utilities for tomographic data: flat/dark field correction, padding, re-binning, normalisation, calculation of centre of rotation.

```python
# Setup and run the CGLS algorithm
cgls = CGLS(u_init, A, g)
cgls.run(10)

# Setup and run the FISTA algorithm
f = alpha * Norm2Sq(Gradient)
g = 0.5 * Norm2Sq(A, g)
fista = FISTA(u_init, f, g)
fista.run(2000)

# Setup and run the PDHG algorithm
operator = BlockOperator(Gradient, A)
f = BlockFunction( alpha * MixedL21Norm(),
                   KullbackLeibler(g)     )
g = IndicatorBox(lower=0)
pdhg = PDHG(f, g, operator, tau, sigma)
pdhg.run(3000)
```

$$\min_{x} \mathcal{F}(Kx) + \mathcal{G}(x)$$

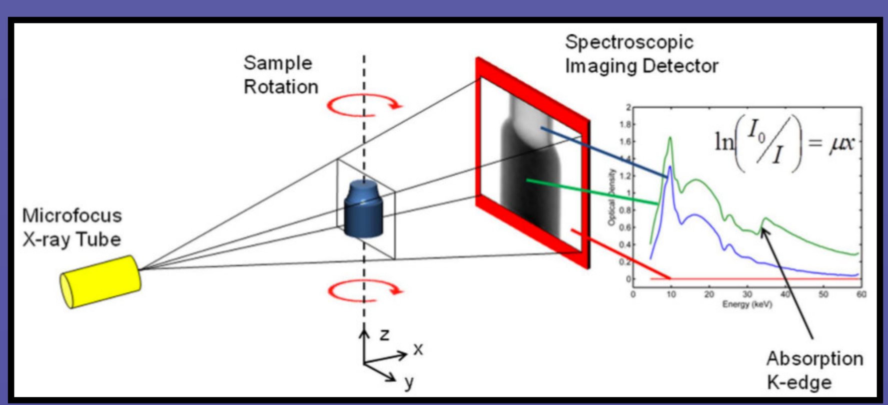
$$\min_{u} \frac{1}{2}\|Au - g\|^2$$

$$\min_{u} \frac{1}{2}\|Au - g\|^2 + \alpha\|\nabla u\|_{2,1}$$

$$\min_{u,w} \int Au - g\,log(Au + \eta) + \alpha\,\|\nabla u - w\|_{2,1} + \beta\,\|\mathcal{E}w\|_{2,1}$$

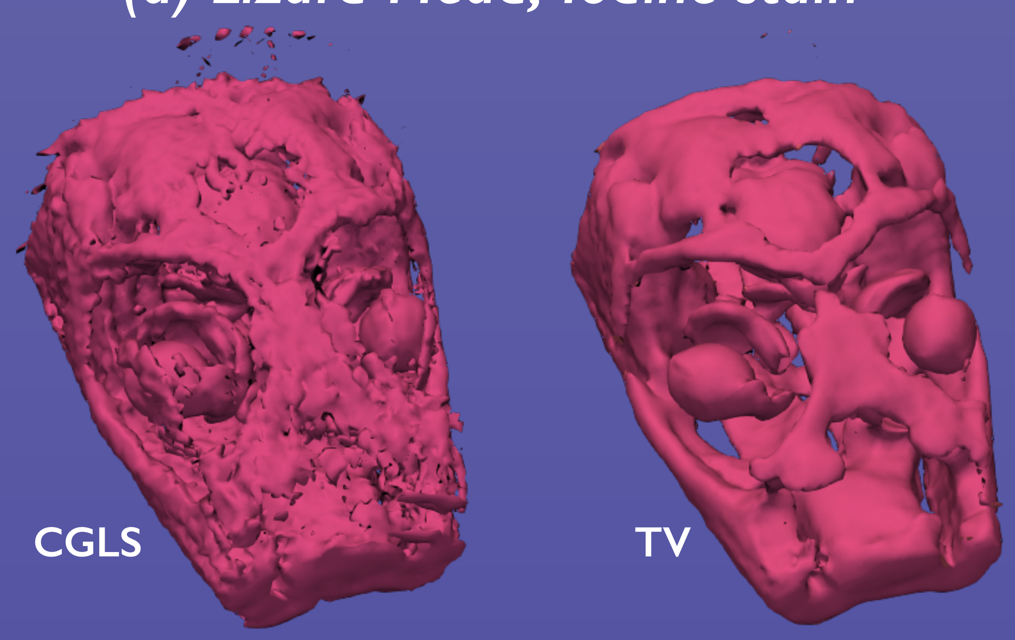
$$\min_{u} \|Au - g\|_1 + \alpha\,\|\nabla u\|_{2,1} + \beta\,\|\nabla^2 u\|_{2,1}$$

(I) Enhanced Information Extraction for HEXITEC Spectroscopic X-ray

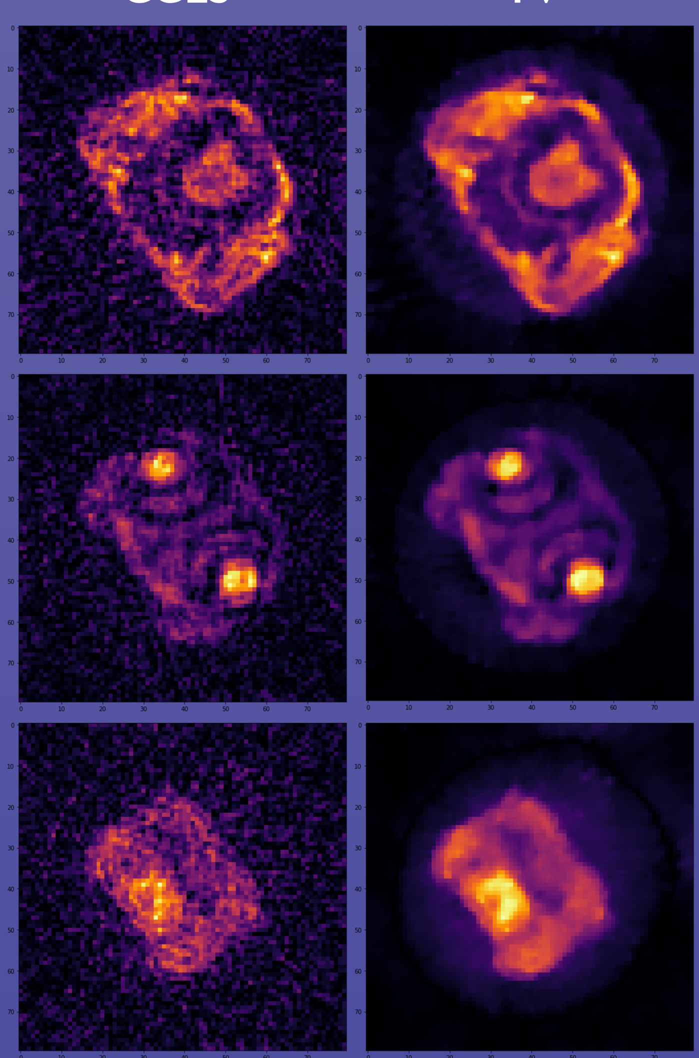


- Voxel Size : $(250\mu m)^3$
- Volume Resolution : 80 x 80 x 80
- Energy range : 2 - 200 keV
- Dimensions : 21cm x 5cm x 5cm

(a) Lizard Head, Iodine stain

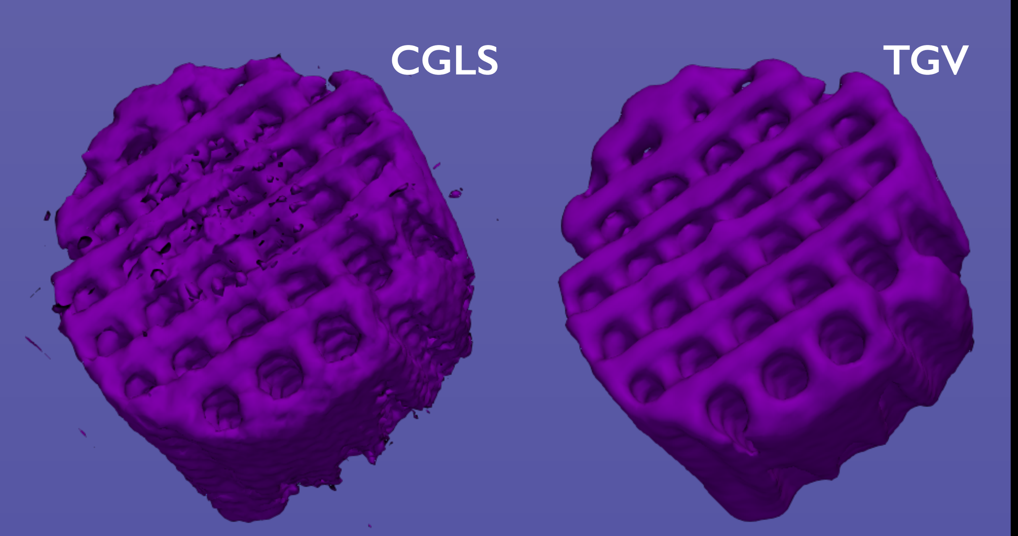


White-beam volume rendering after 4D reconstruction using TomViz

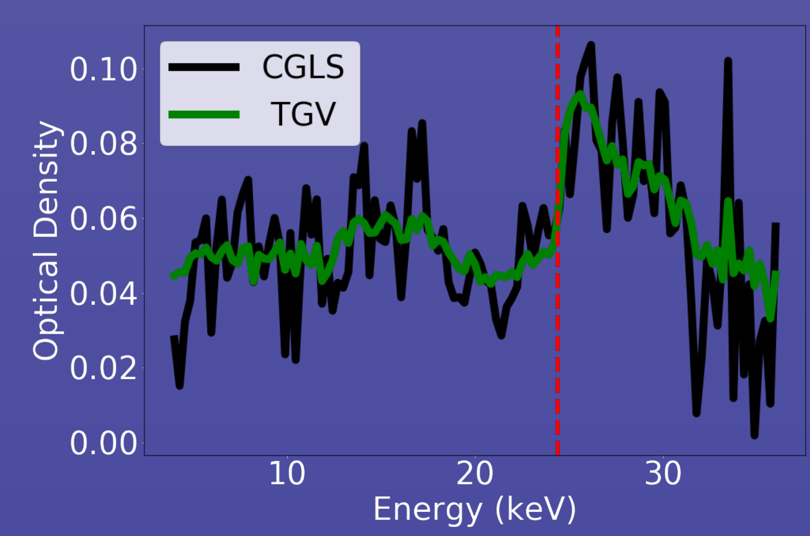


Extraction of Iodine map: Subtract white-beam reconstructions before and after Iodine's K-edge (33,16keV).

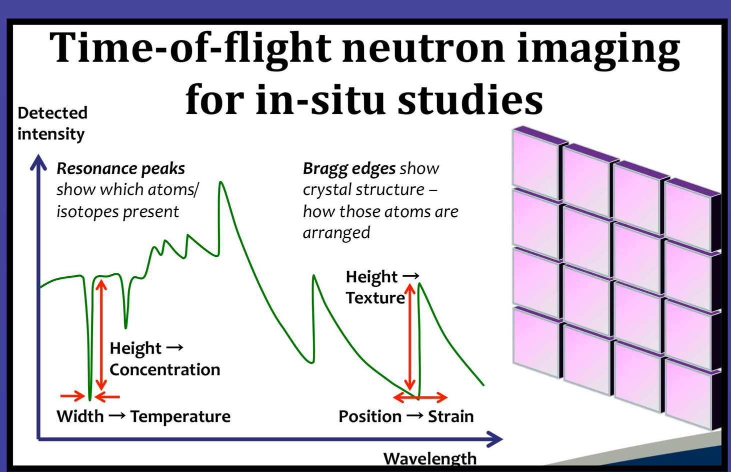
(b) Palladium on Carbon



White-beam volume rendering after 4D reconstruction using TomViz

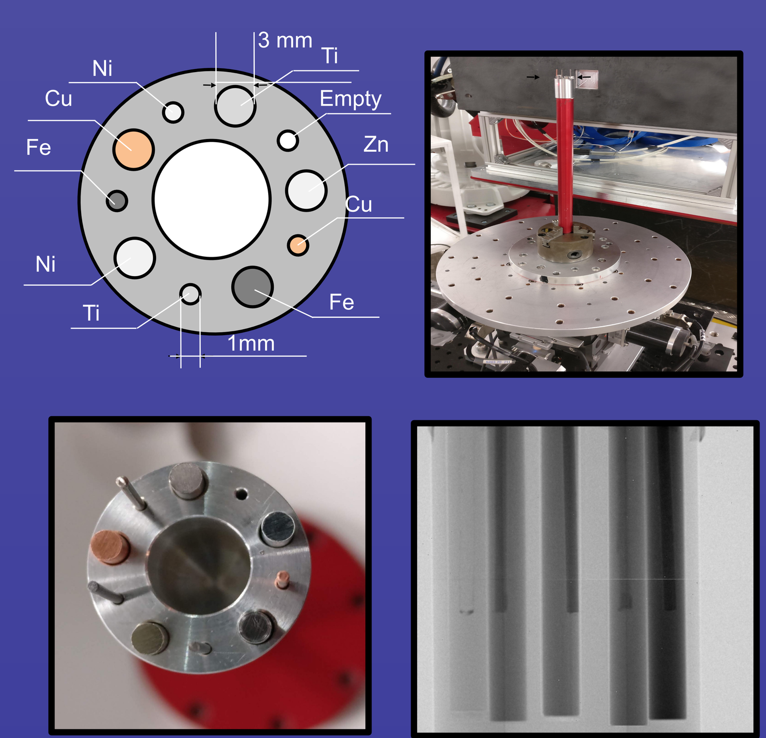


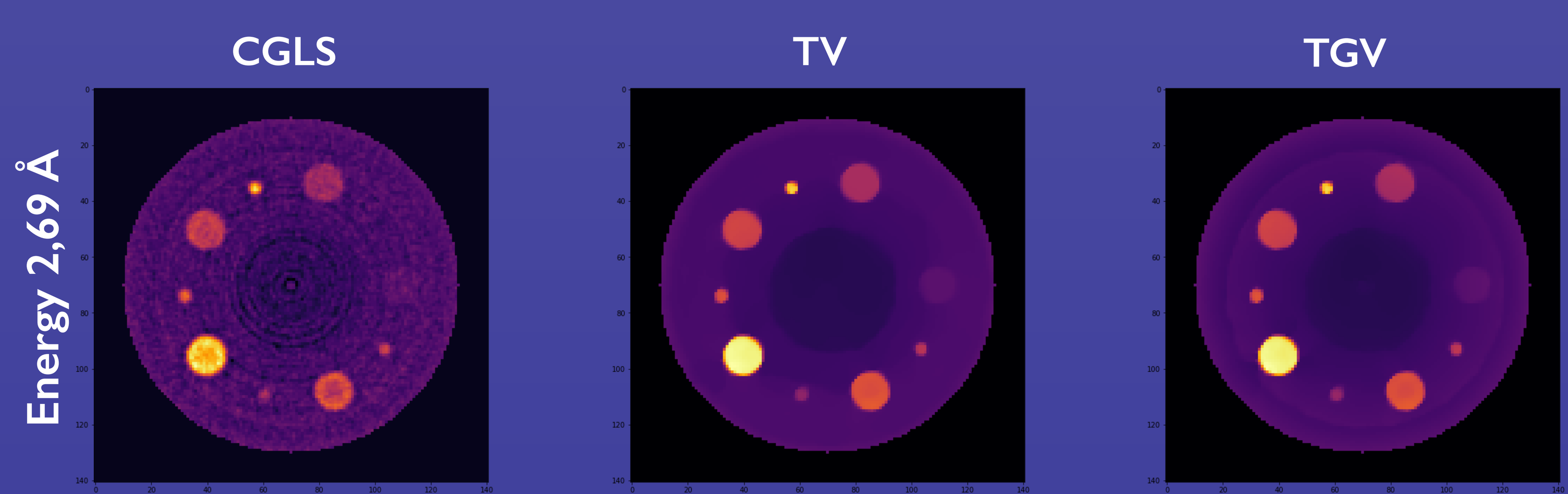
(II) Enhanced Information Extraction for Neutron Imaging at ISIS Neutron and Muon Source



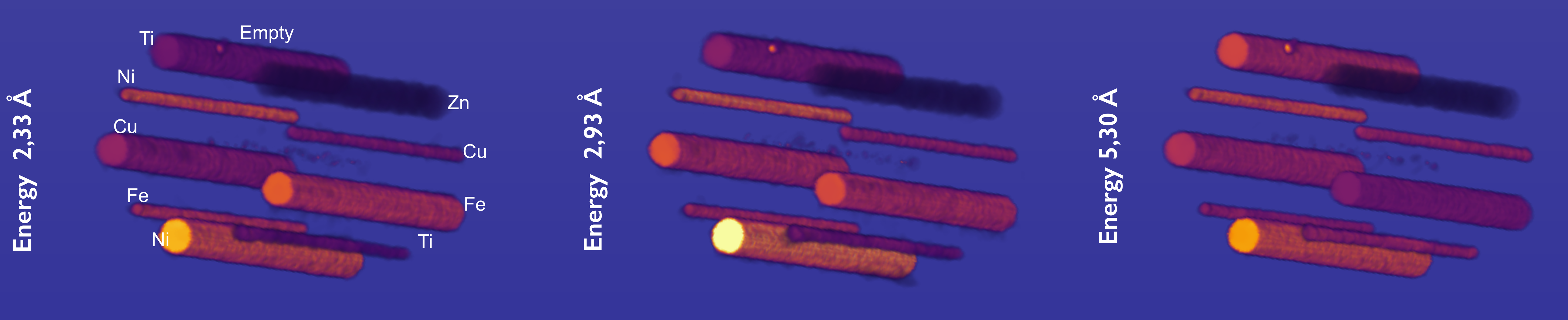
- 512 x 512 pixels, 0.055mm pixel size
- 2312 energy channels, Wavelength range/ resolution: 1.7-6.6 Å / $(1.4\text{-}2.8)\times10^{-3}$ Å
- 30 min exposure time
- 186 projections with Golden Ratio scheme
- Extremely low count data (<50 counts/pixel/ energy)
- Non-uniform wavelength sampling with missing data between shutter periods

Data acquisition





Downsampled 2D + energy reconstruction, rebinned to 162 energy channels



Total variation 4D reconstruction, rebinned to 412 energy channels

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