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Rapid Colour Tomographic Imaging

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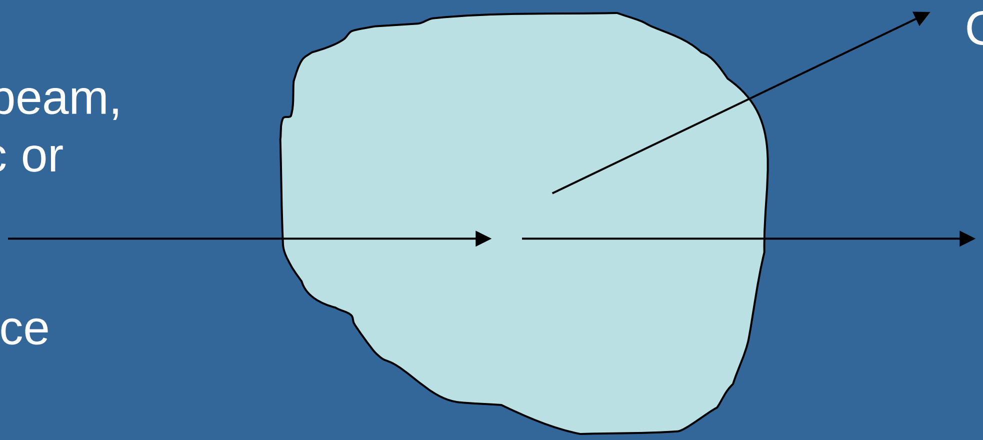
Awareness and Localization of Explosives-Related Threats (ALERT) ADSA Workshop 09: New Methods for Explosive Detection for Aviation Security
October 22-23, 2013 Northeastern University, Boston, MA

Forming images with bright or dark field scattered X-rays

Incident X-ray beam, monochromatic or polychromatic, synchrotron or laboratory source



Scattered X-rays, dark field, diffraction, fluorescence, Compton information

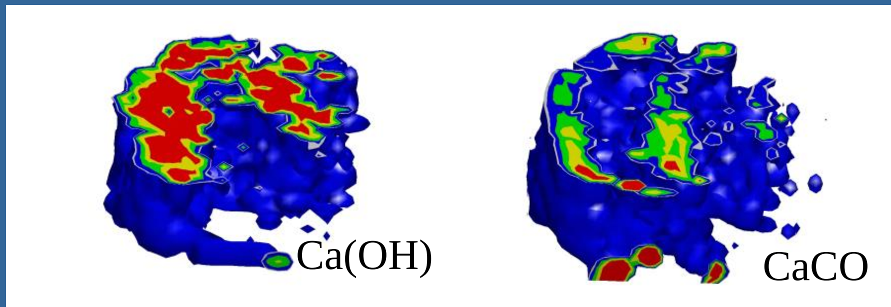
Transmitted X-rays, bright field, standard tomography

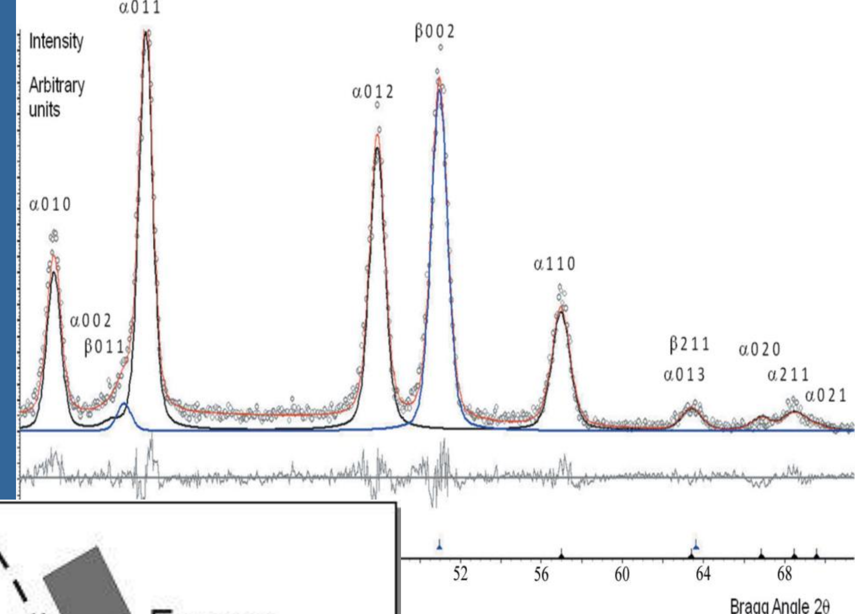
Thin samples require one projection, very fast
Thicker samples require rotation or translation or combination to recover a 3D image

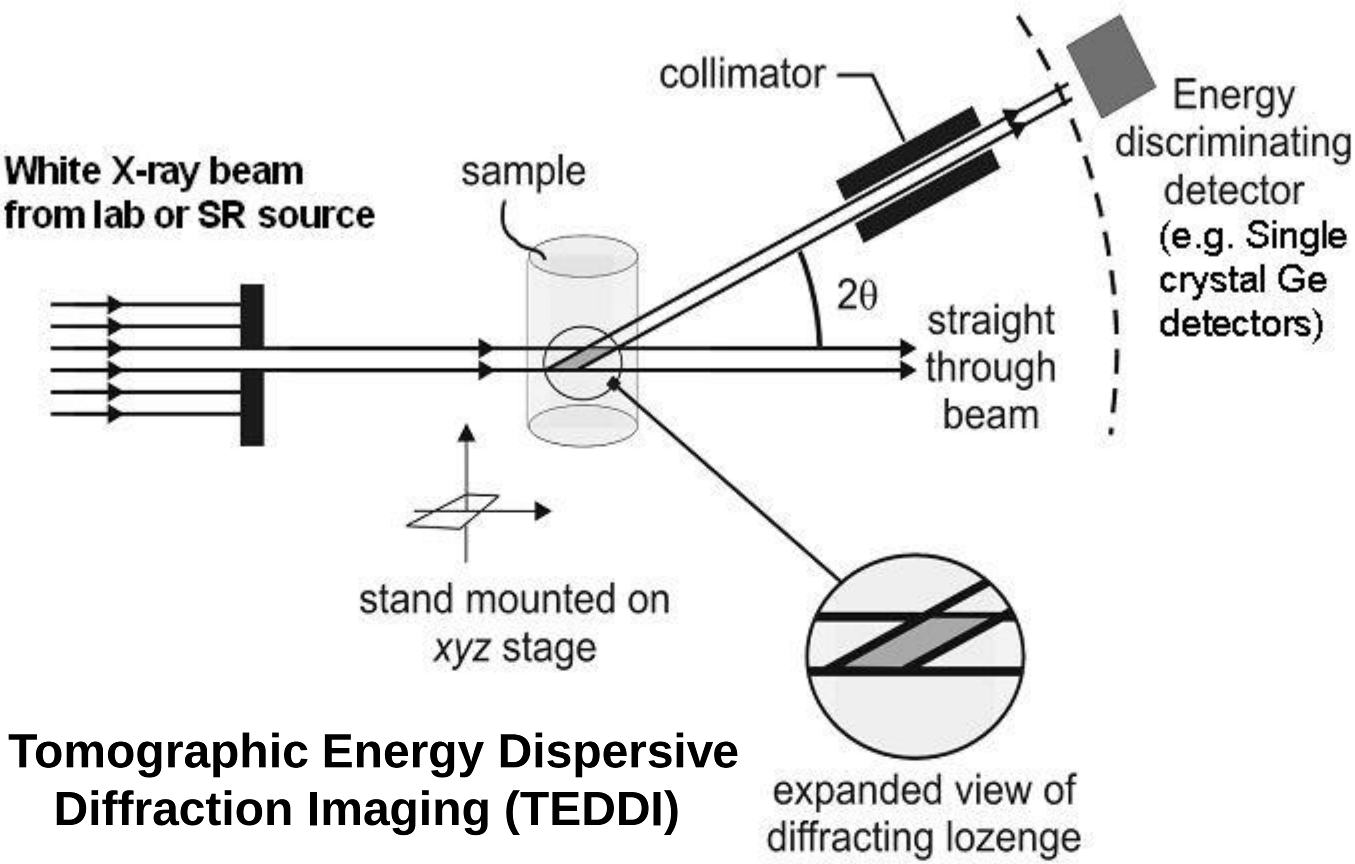
It is difficult in practice to collect the scattered signals, the signal to noise tend to be poor. The signals can be 10^4 or 10^5 times weaker than the transmitted beam used for conventional tomography.

This is a shame since all the really useful information for phase identification, fingerprinting structural information is contained in the scattered beam.

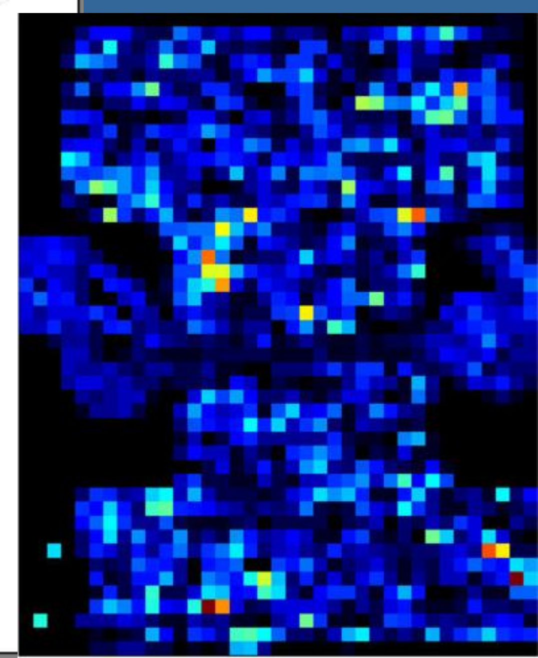
The next slide shows the first attempt to extract this information by a technique called Tomographic Energy Dispersive diffraction Imaging (TEDDI). Note this method needs long collimators to define the gauge volume







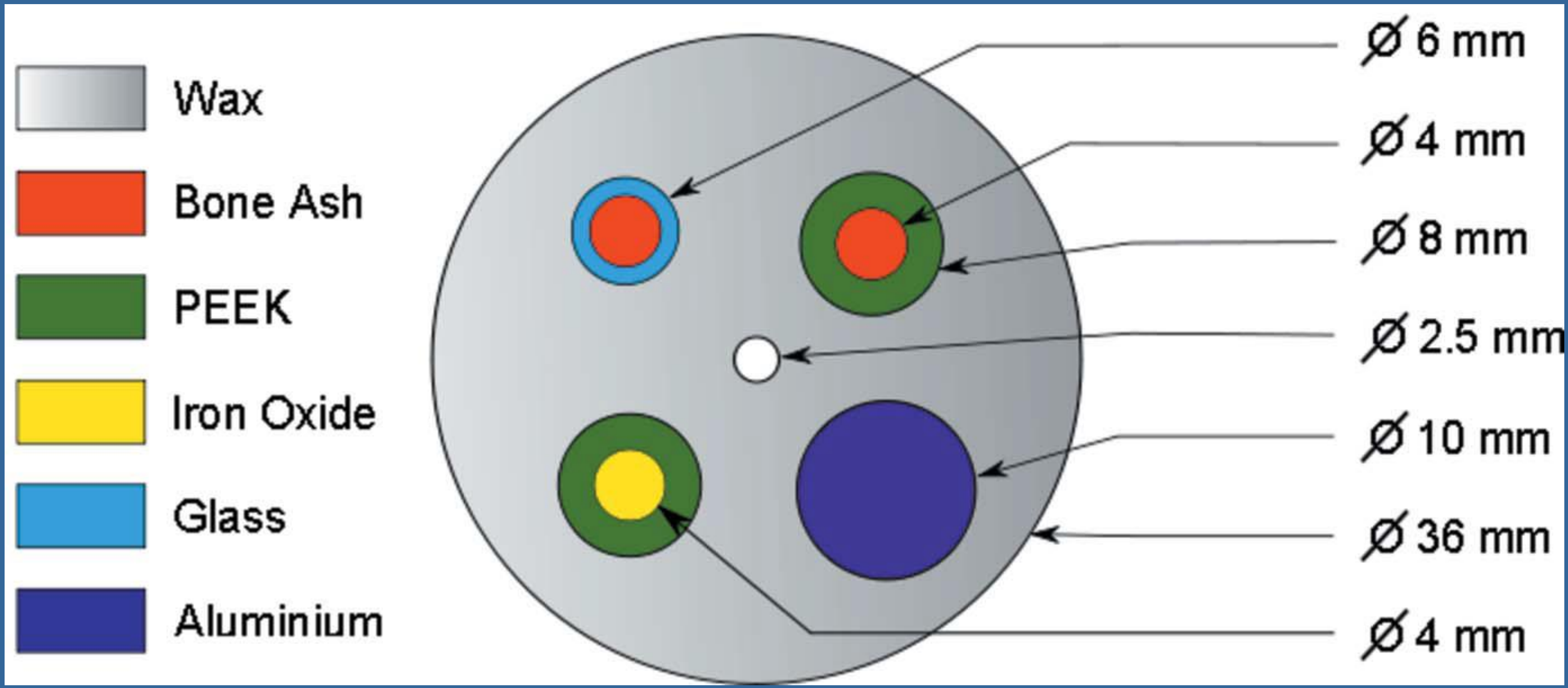
Tomographic Energy Dispersive Diffraction Imaging (TEDDI)



The next slides show the same TEDDI geometry but also using tomographic reconstruction. This is very informative but very slow. The maps too 16-20 hours to collect and several weeks of student processing time!

Lazzari et al. *J. Synchrotron Rad.* (2012). 19, 471-477

Full XRD CT with a test object



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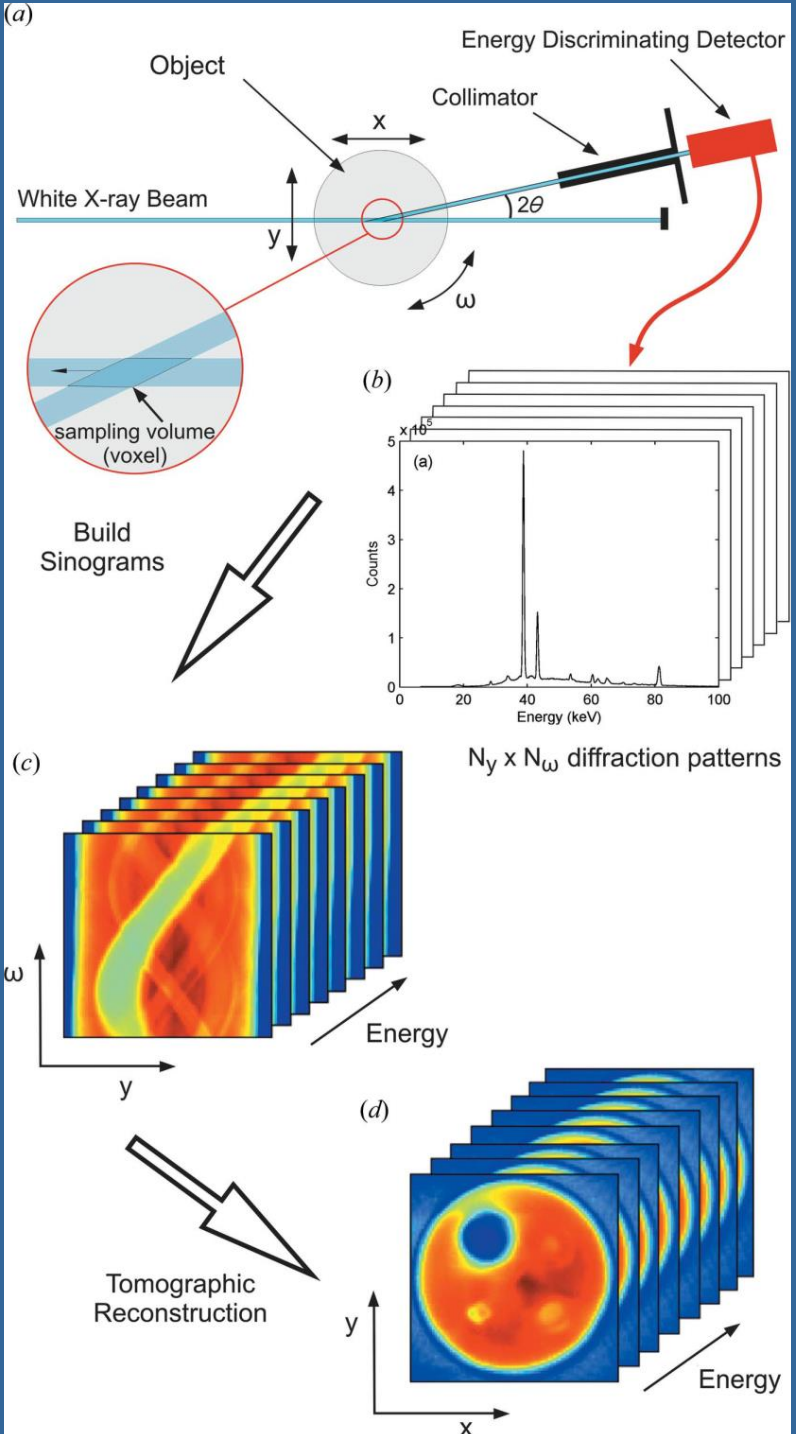
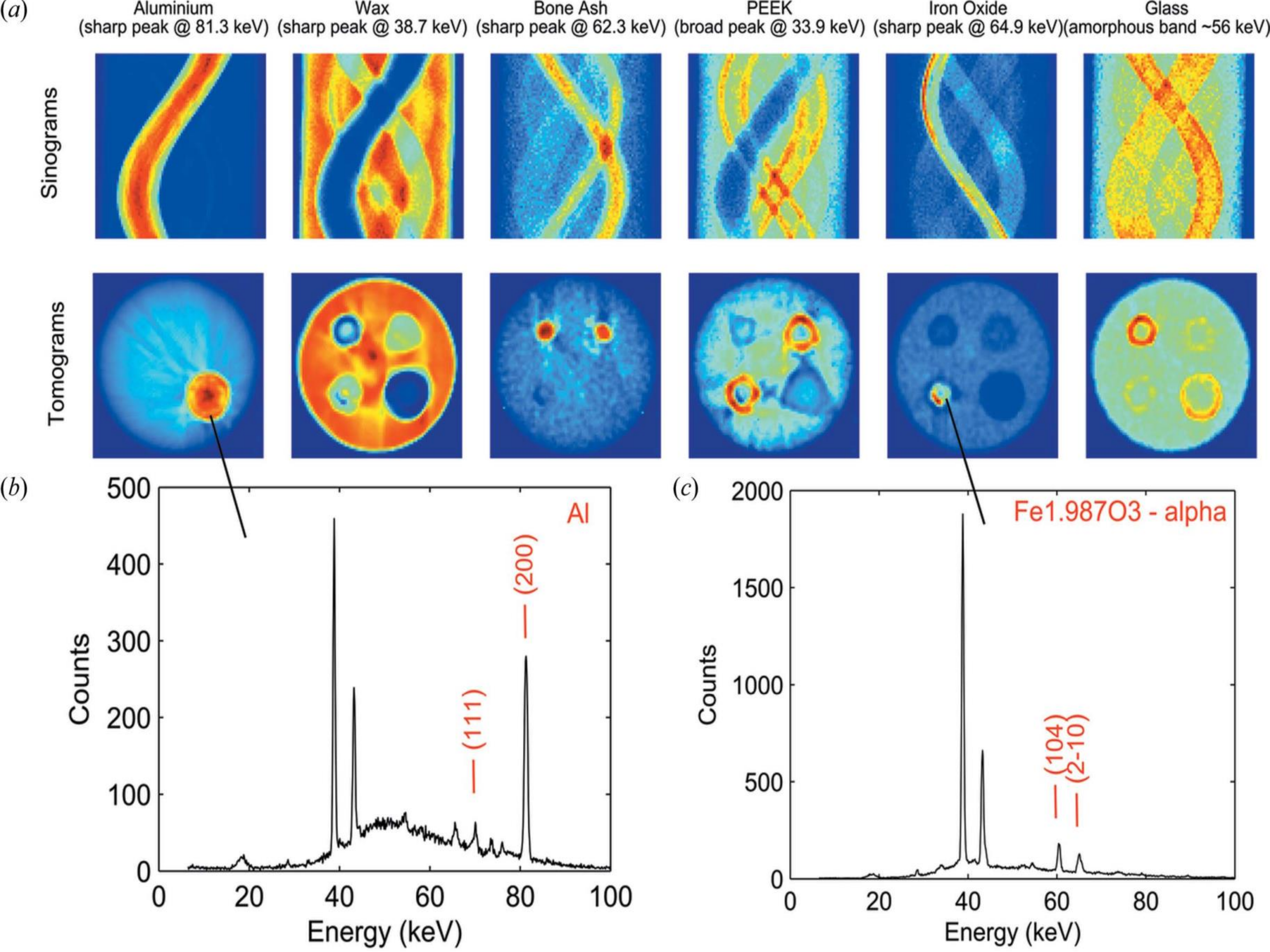
Schematic of the basic experimental set-up for energy-dispersive X-ray diffraction computed tomography. The voxel is continuously scanned through the sample in the x direction whilst collecting data. This constitutes the collection of one diffraction pattern. This is repeated for a number of translations (Ny) and rotations (Nω) as shown, from which sinograms are built. Tomograms are reconstructed from this data set.

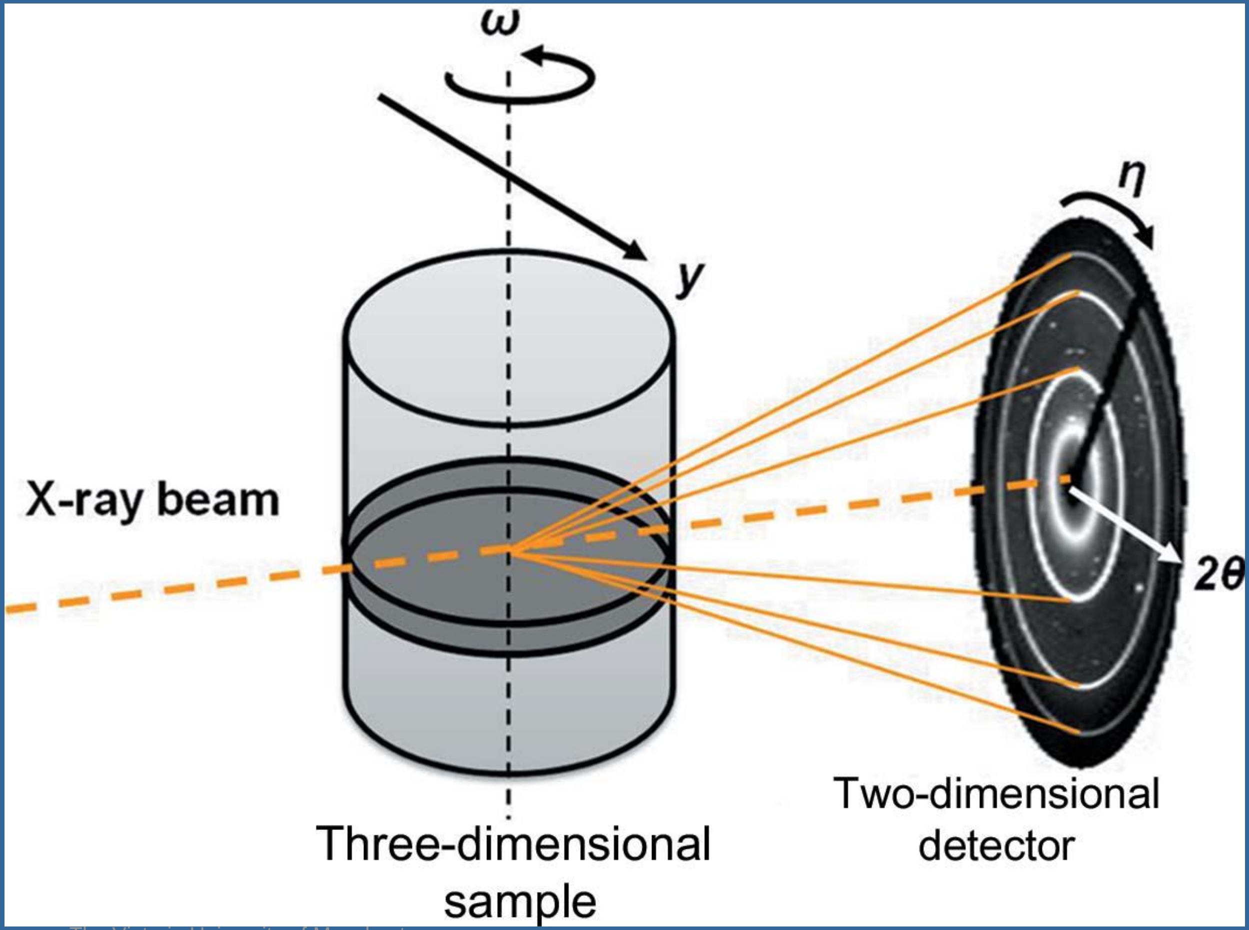



(a)
Aluminium
(sharp peak @ 81.3 keV)
Wax
(sharp peak @ 38.7 keV)
Bone Ash
(sharp peak @ 62.3 keV)
PEEK
(broad peak @ 33.9 keV)
Iron Oxide
(sharp peak @ 64.9 keV)
Glass
(amorphous band ~56 keV)
Sinograms
Tomograms
(b)
Al
(200)
(111)
Counts
Energy (keV)
0
100
200
300
400
500
20
40
60
80
(c)
Fe1.987O3 - alpha
(104)
(2-10)
Counts
Energy (keV)
0
500
1000
1500
2000
20
40
60
80
100

We can also get diffraction tomograms by using a monochromatic beam and a conventional area detector. This gives you the ability to look at samples with very fine spatial resolution, also the ability to examine nanocrystalline materials and to look at crystalline structure.

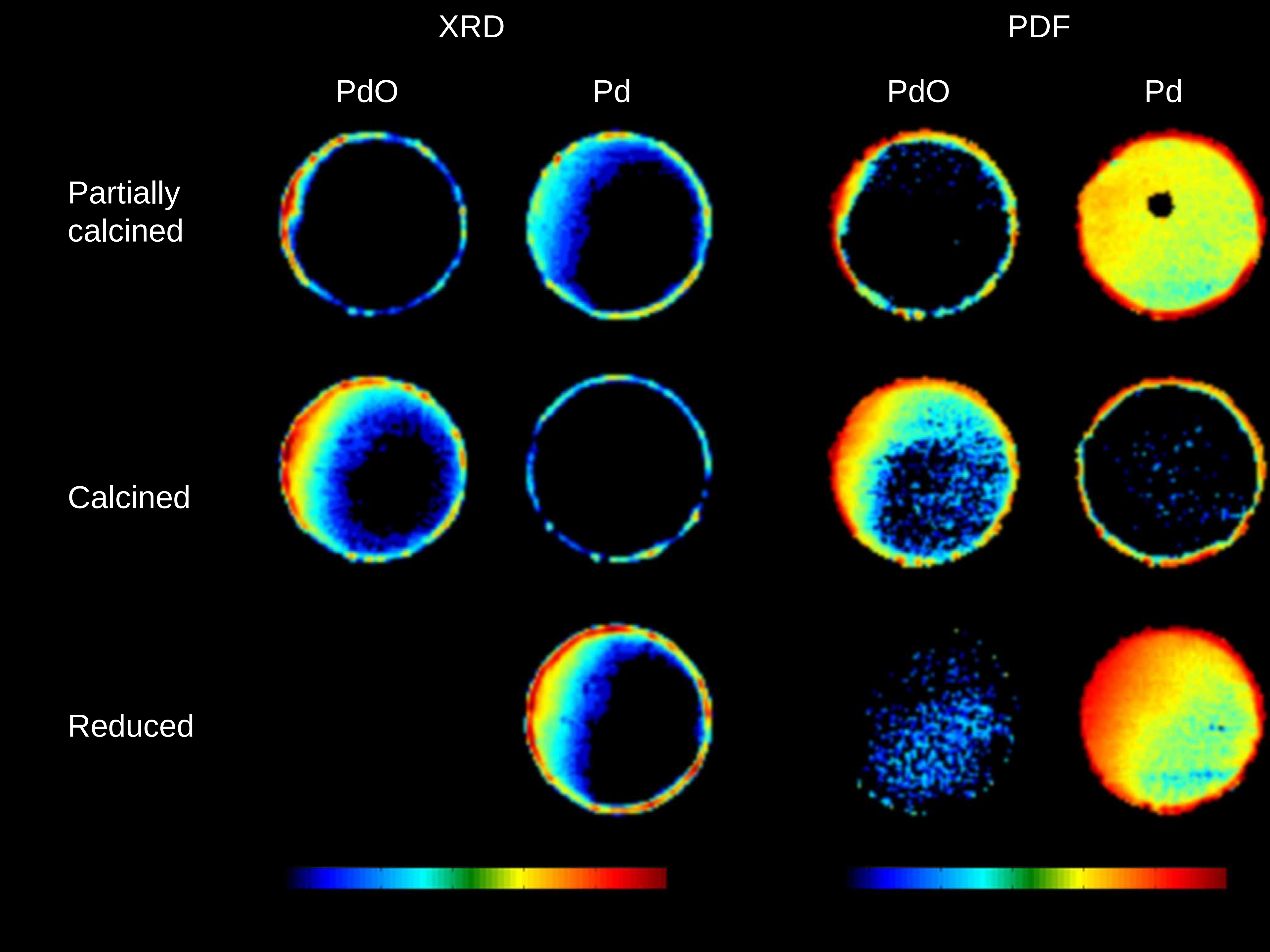
This is academically very interesting but needs a synchrotron source and even longer scan times than Tomographic TEDDI method.

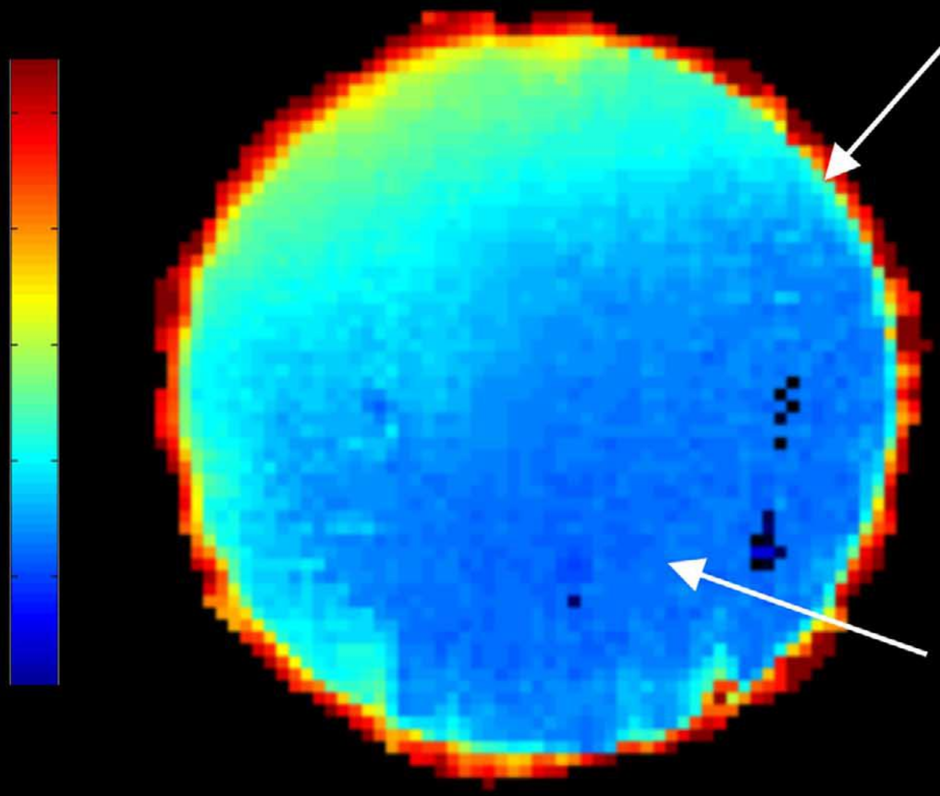
M. A lvarez-Murga et al.
J. Appl. Cryst. (2012). 45, 1109–1124

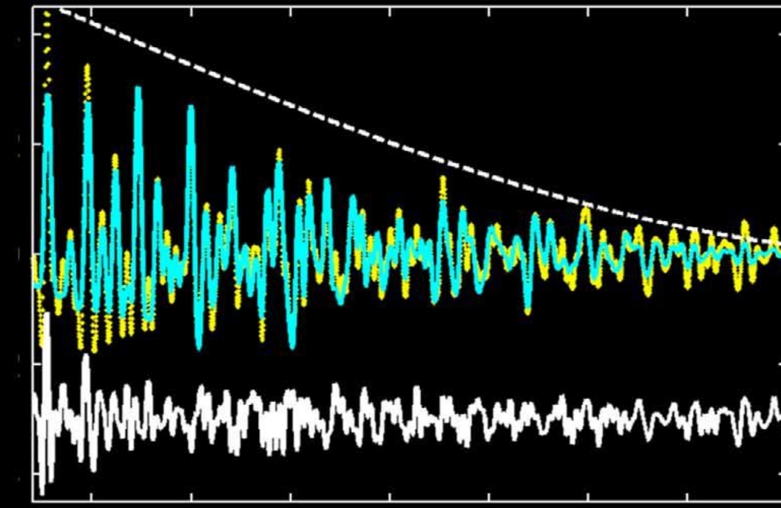


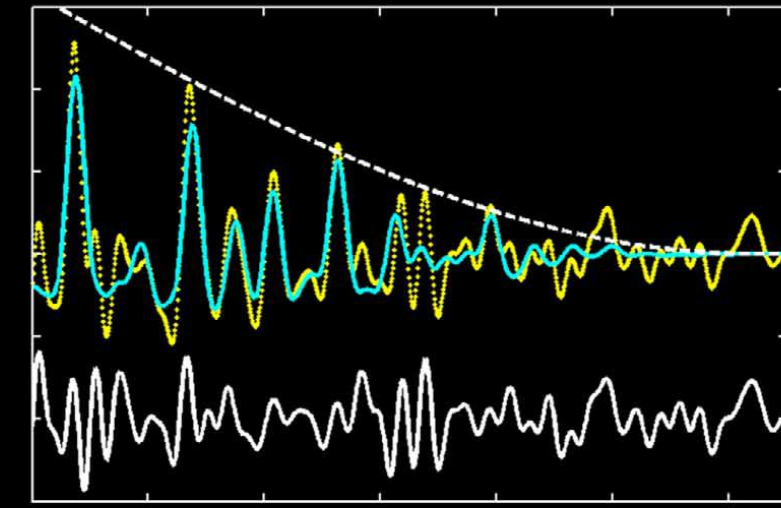
Can also use this approach for PDF Analysis

Jacques et al.
Nature Comm 2013
DOI:
10.1038/ncomms3536


XRD
PDF
PdO
Pd
PdO
Pd
Partially calcined
Calcined
Reduced







Distribution of particle sizes of fcc Pd within the catalyst body under reducing conditions. Portions Of the PDF data for selected pixels at the edge and interior of the catalyst body (yellow data points) with an fcc model fit (cyan) and difference (white).

In order to really speed up the process we need large numbers of solid state detectors all looking simultaneously at the sample. This is very difficult.

Silicon pixellated detectors are ubiquitous but far too low in energy efficiency or stopping power for higher energy X-rays.

We are almost exclusively interested in the energy ranges from 60 – 300 keV (or higher) to get through large objects. That means we need high Z material for the detectors, pixellated, with excellent energy resolution and highly uniform in response. The HEXITEC project has done hjust that as you can see in the next slides.

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HEXITEC Detector

1 mm CdTe; 80 × 80 pixels on 250 µm pitch; active area: 2 × 2 cm^2

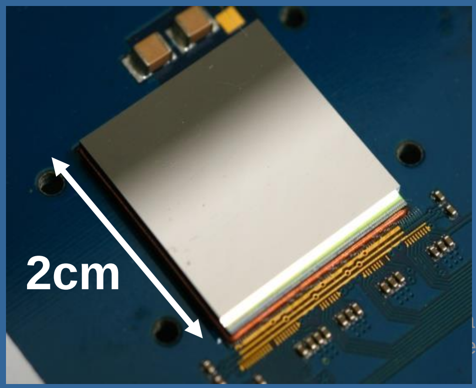
Energy range: 5 – 200 keV

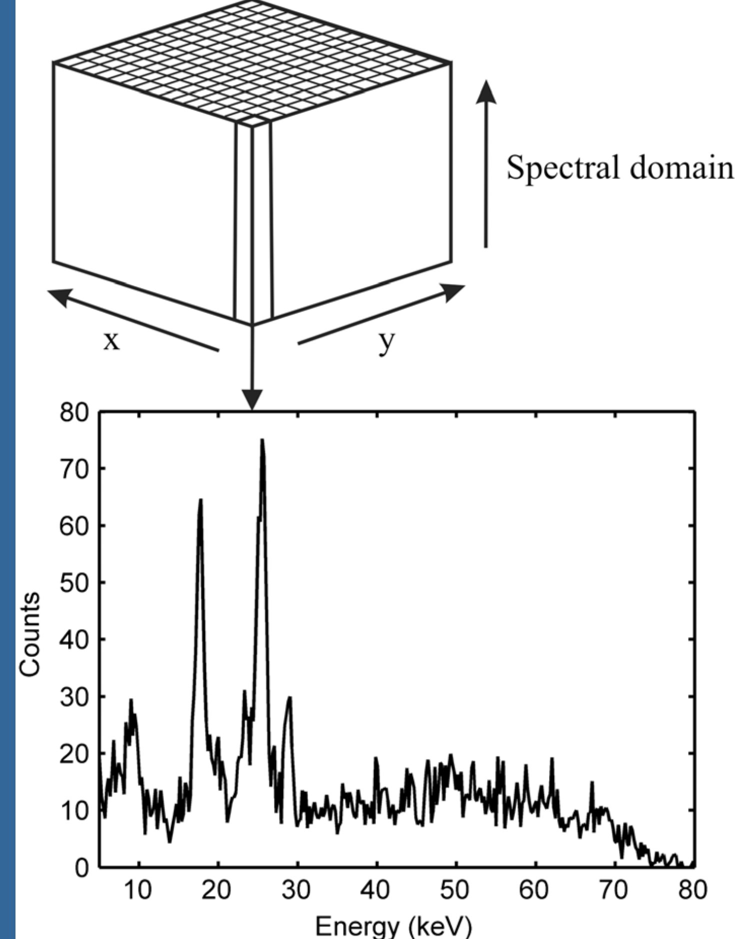
Energy resolution: ≤800 eV @ 60 keV

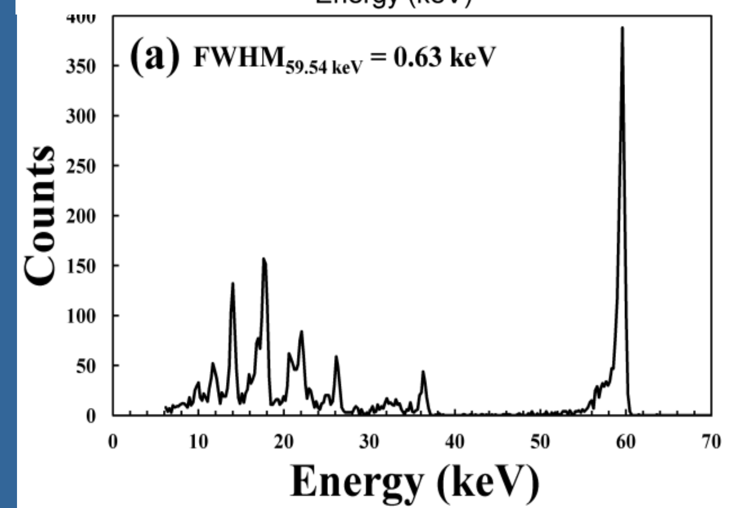
Rolling row readout @ 20MHz

Events extracted in soft/firmware → really understand the data

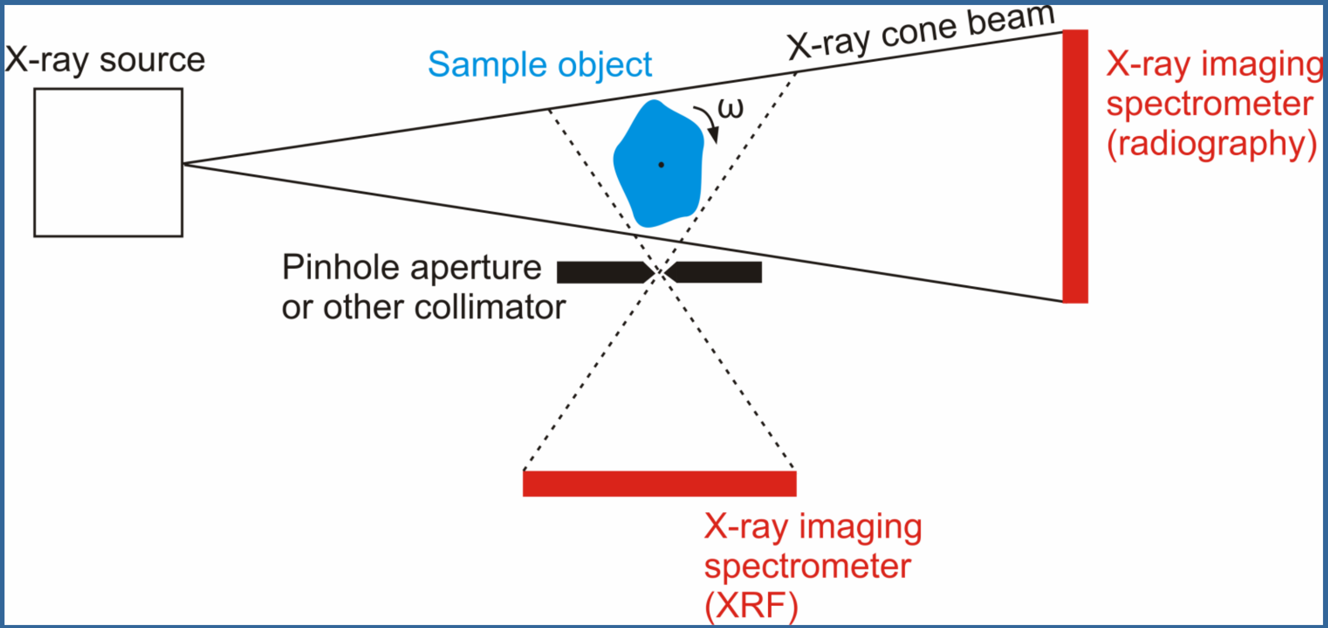
10 Mphotons/sec/80x80 (charge sharing)

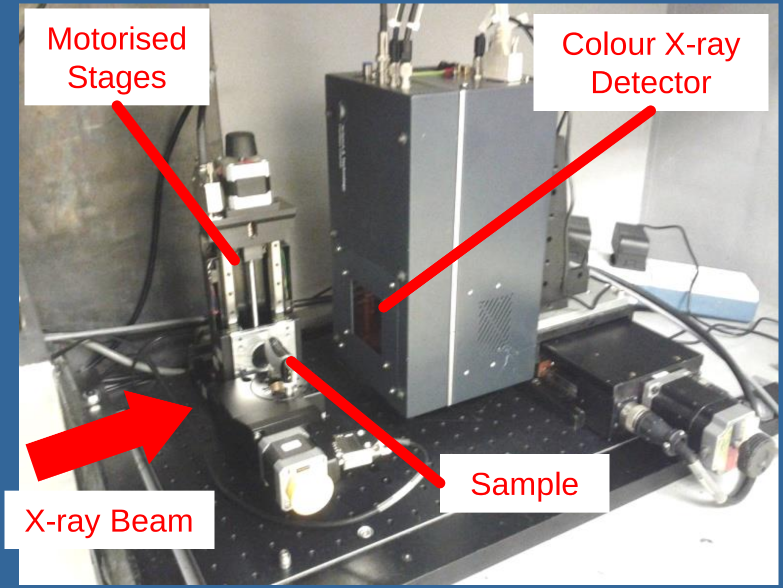






The next slides shows the very simple set up in the lab with images being collected in minutes from conventional sources.





Laboratory X-ray system

225 keV tungsten target

HEXITEC detector

80 x 80 array

500 eV resolution

250 micron square pixel

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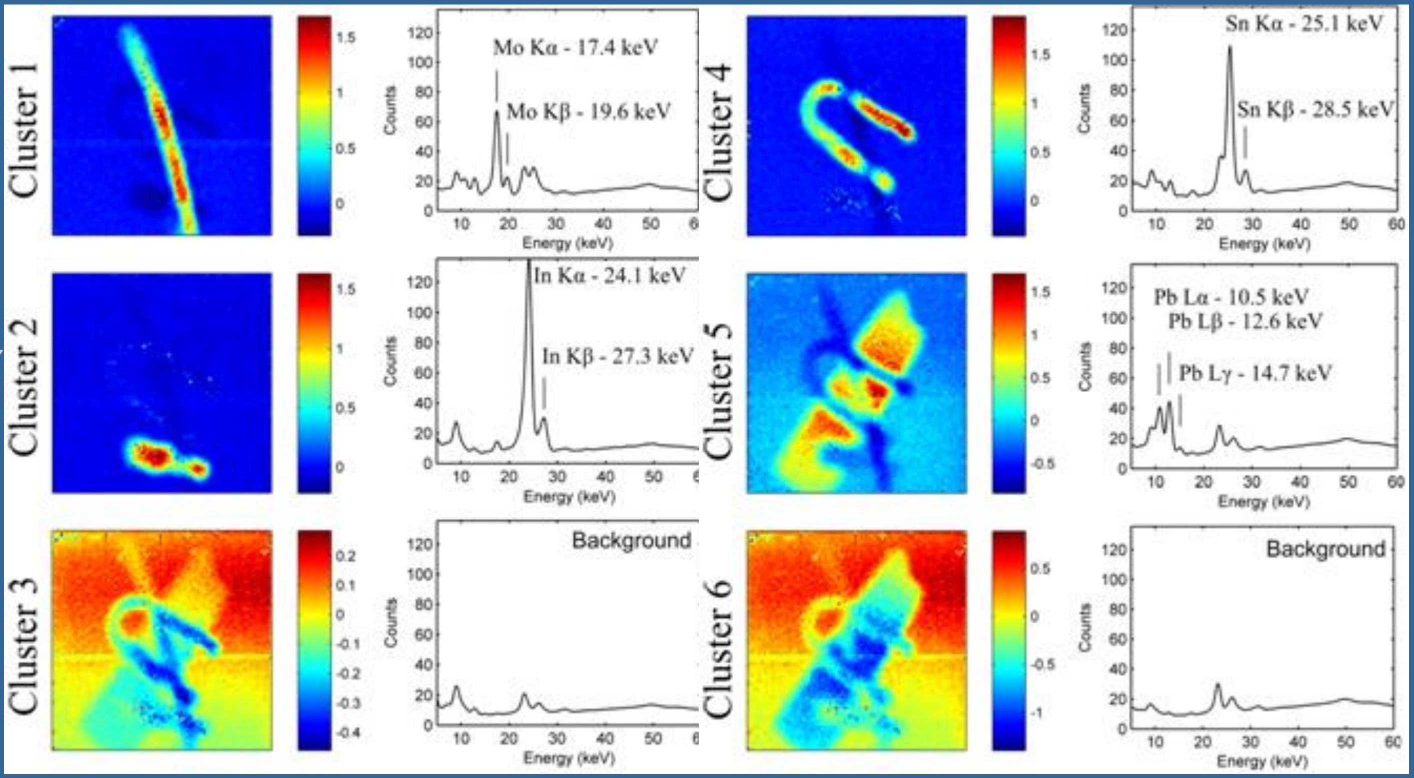
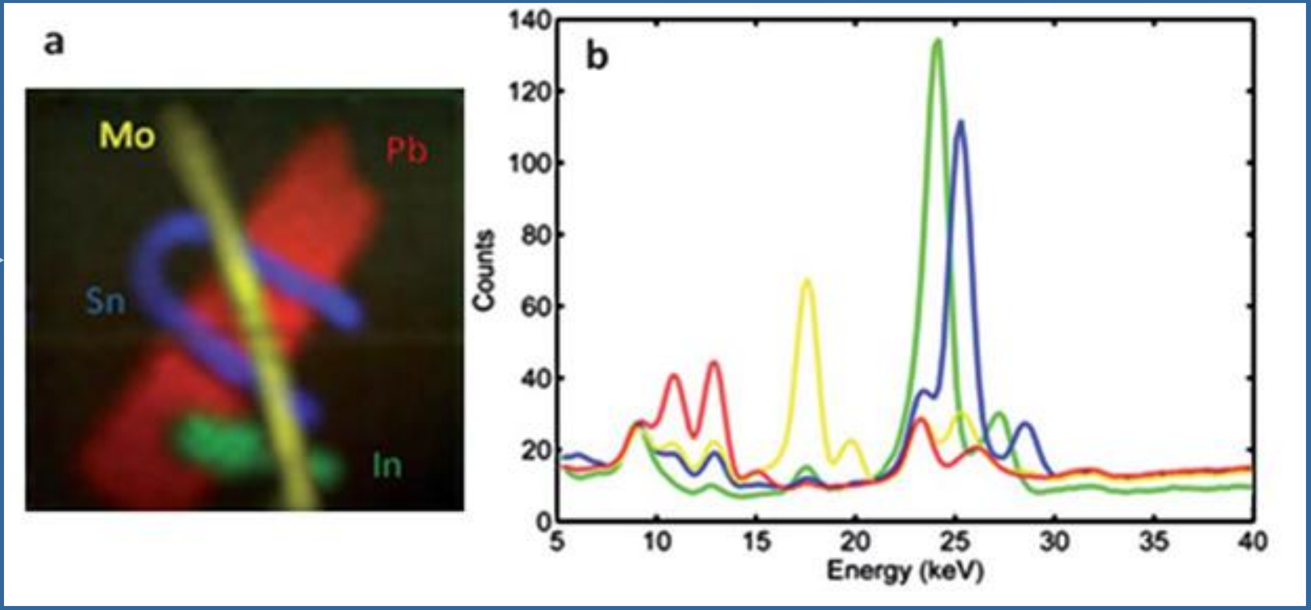
Multivariate analysis, bright field energy sensitive radiograph



A wire test object made from Pb, Mo Sb and In wire

Fluorescence image from a dark field projection



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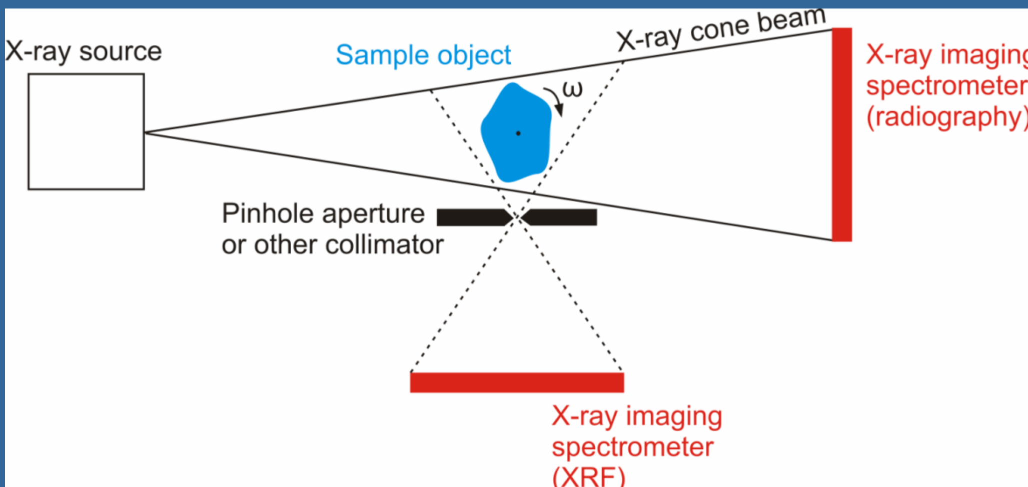

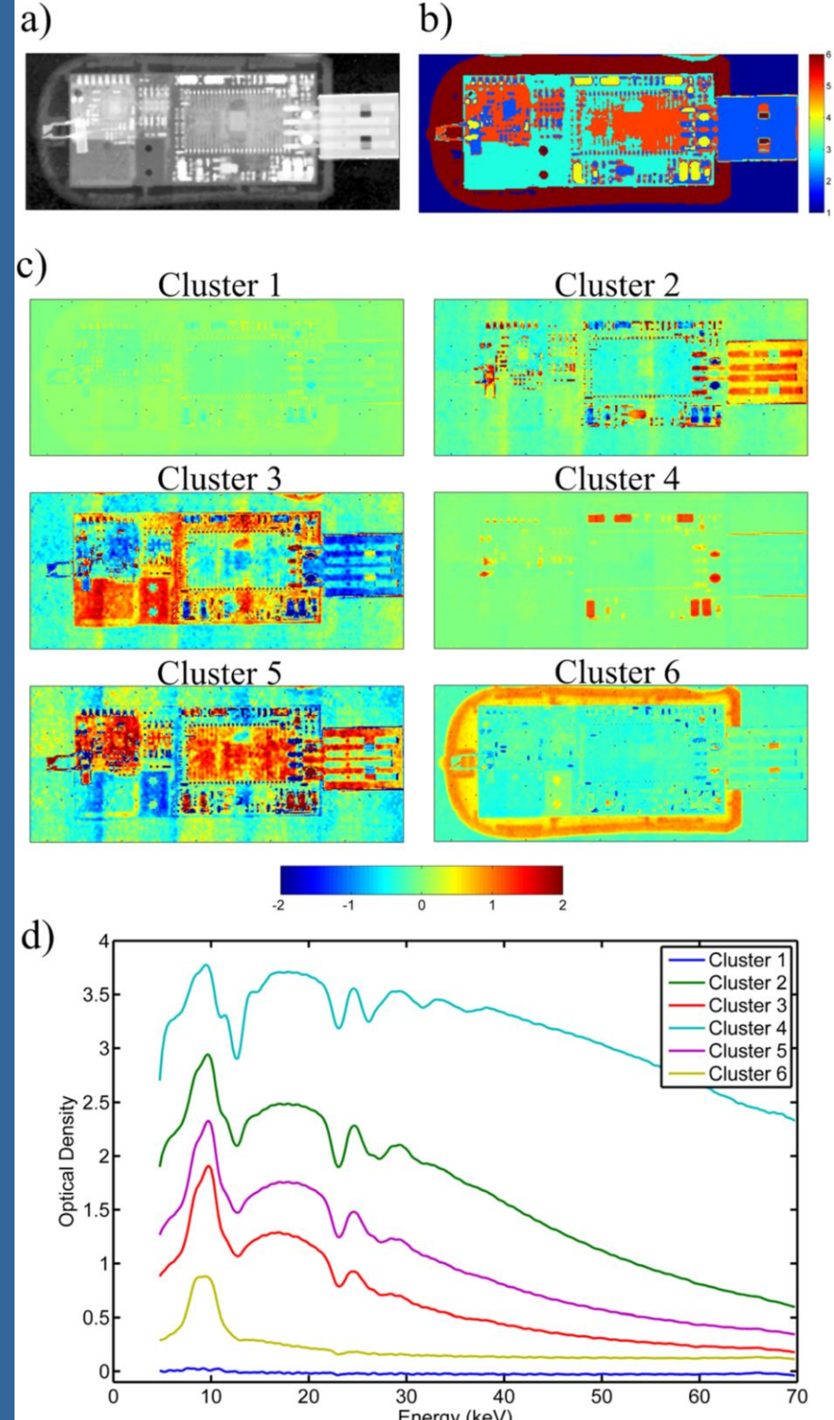

We have very recently shown how diffraction signals can be projected through pinholes onto a HEXITEC detector module to give the whole plane structural image all at once (data collection in seconds).

We can also carry out full diffraction CT in n times the projection data collection time. This gives the possibility of retro flitting colour sensors onto existing CT and imaging modalities to provide extra identification of threat substances to reduce the number of false positives.

Applications:

Battery charge/discharge chemistry
Fuel cell membrane chemical imaging
Fracking shale in situ
Pharma crystallisation
In situ catalysis, hetero
Water supply contamination
Medical biopsy
Security scanning
Stress –strain scanning in whole components

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Main credits to:
Simon Jacques
Chris Egan
Paul Seller
Matt Wilson
Matt Veale
Beamline staff at Diamond and ESRF

Thank you for the invitation and thank you for listening