# An X-ray Polaroid® filter for the IXO Narrow Field Imager

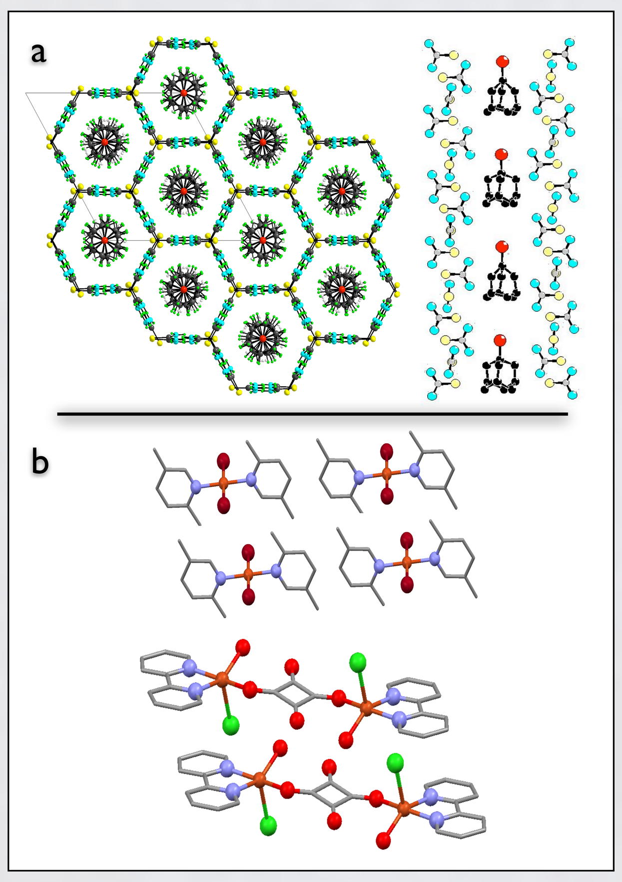
N.P. Bannister[1]✉, K.D.M. Harris[2], S.P. Collins[3], G.A. Solan[4], A. Martindale[1], M. Roy[1], A. Armitage[4], B.A. Palmer[2], R. Willingale[1], G.W. Fraser[1]

[1]Department of Physics & Astronomy, University of Leicester, University Road, Leicester LE1 7RH, UK
[2]School of Chemistry, Cardiff University, Park Place, Cardiff CF10 3AT, UK
[3]Diamond Light Source Ltd, Rutherford Appleton Laboratory, Chilton, Didcot, Oxon OX11 0QX, UK
[4]Department of Chemistry, University of Leicester, University Road, Leicester LE1 7RH, UK

email: npb@star.le.ac.uk

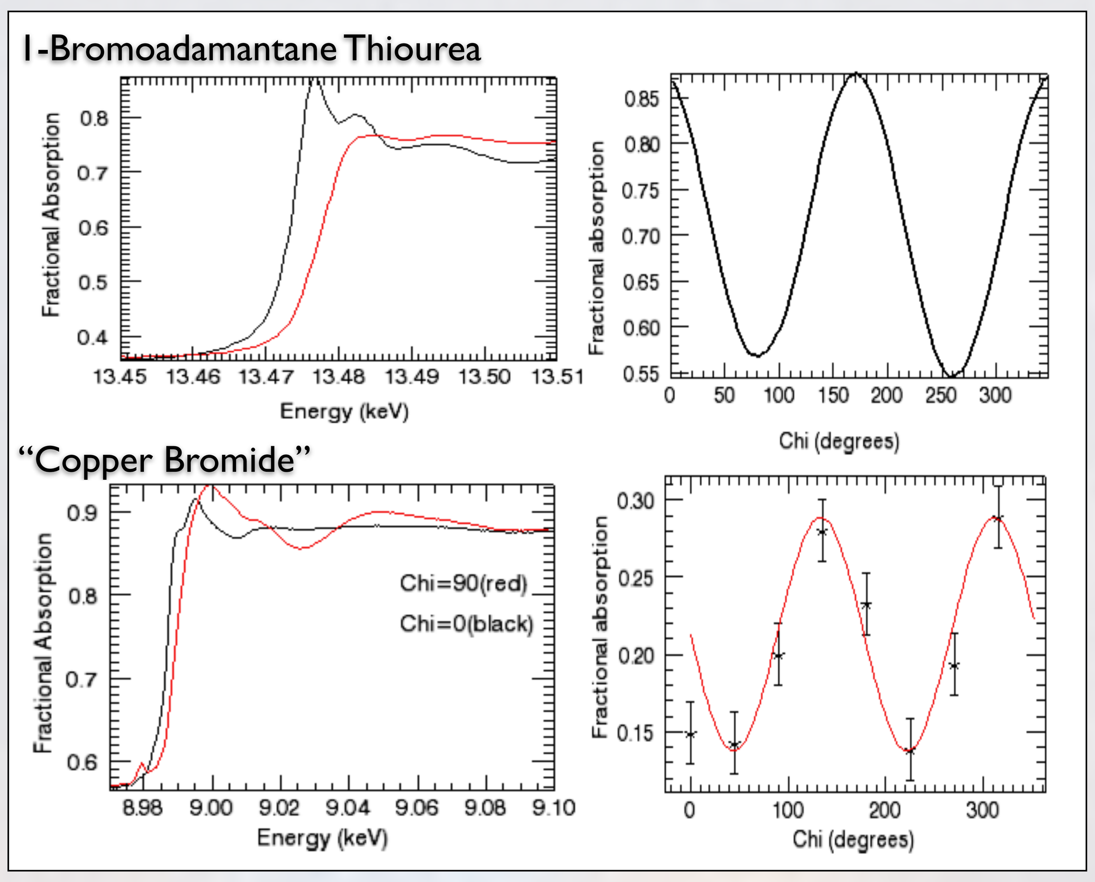
## Abstract

Astrophysical X-ray polarimetry remains as unexplored now as it was 30 years ago. Narrow bandwidth or low scattering efficiency in current technologies have rendered polarisation observations insensitive to all but the brightest sources. Consequently only one unambiguous measurement of polarisation in a cosmic X-ray source has been made to date: that of 19% linear polarisation at 2.6 keV for the Crab nebula. The very large effective area of the International X-ray Observatory compared to that of previous observatories opens the possibility of the first new results in astronomical X-ray polarimetry for over three decades. We describe a simple, low-mass X-ray filter technology which can add polarimetry capability to the existing Narrow Field Imager. We summarise results from our current laboratory proof-of-concept studies, provide estimates of the minimum detectable polarisation for a selection of sources and discuss the astrophysical observations that could be made by IXO using this device.



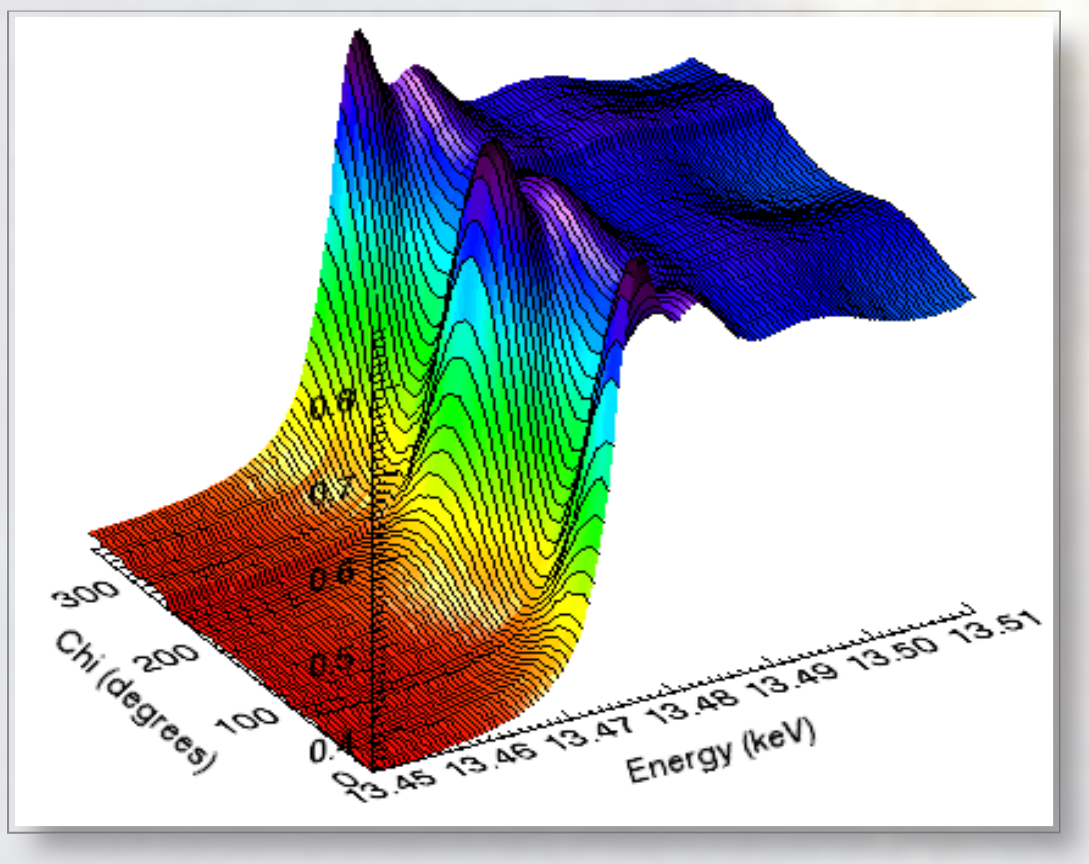

## Principle

The distribution of electronic states in an X-ray dichroic material is different in the two principal axes of the crystal, so that the X-ray absorption properties differ according to the orientation of the electric field vector in a beam of polarised X-rays. Crystals which possess this directionality act like X-ray "Polaroid®". They can be engineered by adopting a host-guest structure (a) in which the bonds of the "active" material are forced into alignment by being held in place within a tunnel-like "host" matrix. An alternative approach (b) uses complex coordination chemistry to generate crystals with high degrees of alignment. Both approaches are used in our work.




## Verification

Left column: synchrotron measurements of two dichroic crystals, showing a significant variation in X-ray absorptivity when the principal axis is parallel (black) and perpendicular (red) to the direction of the X-ray electric field vector. Right column: Measurements of the X-ray flux transmitted through the crystals show the characteristic modulation curve of a polarimeter, achieved at X-ray energies with low mass, compact, simple transmissive elements.




## Requirements

The dichroic response occurs within a narrow region (a few tens of eV) of the absorption edge in the crystal. Excellent detector energy resolution (ΔE < 5eV) is therefore required, and the performance of the Narrow Field Imager (NFI) proposed for IXO is well matched to these requirements. In common with previous polarimeter designs, large effective areas and long exposure times are required for sensitive polarisation measurements of significant numbers of objects.

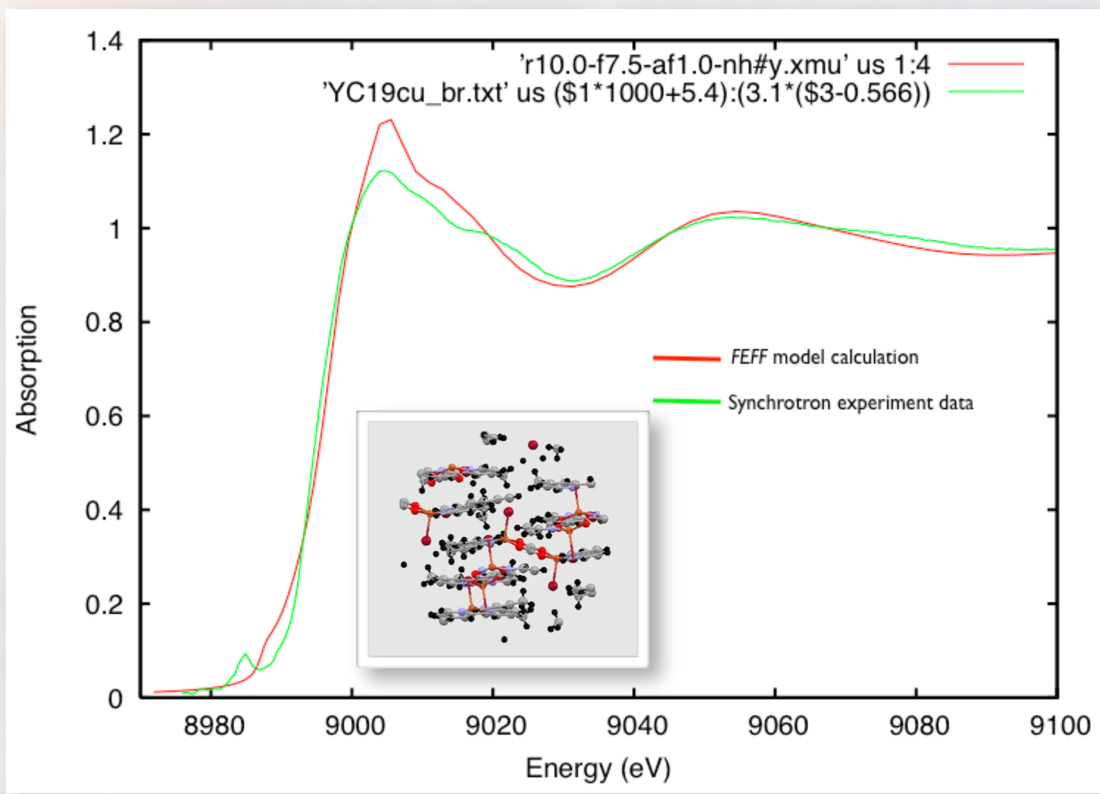
## Advantages

The figure (left) shows the amplitude of the modulation curve as a function of energy, for a 1-Bromoadamantane Thiourea crystal. While significant dichroism is observed within a few tens of eV of the Bromine K-edge, beyond approximately 100 eV from the edge, X-ray dichroism is no longer observed. X-ray dichroics are therefore self-normalising devices. The false modulation signatures which can be generated in any polarimeter by e.g. mechanical misalignment, or structural inhomogeneities, can be eliminated in the dichroic filter system by the application of a "polarisation flat field". In a device such as the NFI on IXO, this calibration is possible with no overhead in observation time, by using science data in channels corresponding to energies beyond the dichroic zone. In addition, dichroic filters are simple and compact, low mass (crystal mass ~ few grammes) devices which can add polarimetry capability to existing hardware (i.e. the IXO NFI) without the need for substantial extra complexity.

## Modeling

Central to the X-ray dichroic filter concept is the polarisation dependence of the crystal's X-ray absorption spectrum, primarily in the near-edge structure (XANES) region and extending out to a few hundred eV above the edge. The figure (right) shows the results of initial XANES calculations produced with the *FEFF* self-consistent real space multiple scattering (RSMS) code, comparing synchrotron data for one of our Cu-Br compounds (structure shown inset), with the calculated response of this crystal. *FEFF* uses as input a large number of physical parameters, for example the molecular structure and disorder of the material, to calculate the XANES and EXAFS features in the X-ray absorption spectrum of the crystal.

In the next phase of our work, this approach will be used to direct the development of efficient dichroic crystals. Targeting elements which produce absorption edges in the 1 - 5 keV range (exploiting the most significant region in IXO's effective area), we will begin with a basic (non-optimal) molecule developed in the laboratory. Then, by reproducing the molecule in *FEFF* and studying the dichroic performance computationally, we will identify modifications to the crystal structure that lead to improved dichroic performance. We will then embark on the laboratory production of crystals with structures as close as possible to the computationally derived design. Also, by comparing synchrotron data with the model calculations, we will obtain detailed information on the electronic and physical structure of the polarising molecules and provide additional diagnostics with which to verify that the crystals produced in the laboratory have the intended structure.




| Material (Edge) | Energy (keV) | MDP(%) Crab | MDP(%) 3C273 | MDP(%) NGC4151 |
|---|---|---|---|---|
| I (L) | 4.6 | 0.36 | 10.62 | 1.89 |
| Cl (L) | 2.8 | 0.19 | 6.08 | 0.97 |
| Br (L) | 1.6 | 0.06 | 2.34 | 0.33 |
| F (K) | 0.7 | 0.03 | 1.31 | 0.15 |
| Cl (K) | 0.2 | 0.01 | 0.48 | 0.40 |

## Sensitivity

Using results from our current laboratory programme, we have estimated the Minimum Detectable Polarisation (MDP) which can be achieved in a 100 ksec observation in the original XEUS configuration, assuming the TES-based Narrow Field Imager as the focal plane device. Three example objects are considered, with spectra generated in XSPEC using model parameters given in literature. These preliminary estimates are based on dichroic performance obtained at higher energies and include highly conservative assumptions regarding filter performance. More detailed modeling is now in progress, and we will be extending our experimental work to lower energies using the IXO instrument response in the next phase of the programme.

## References

Bannister et al., Dichroic Filters For Astronomical X-Ray Polarimetry. Experimental Astronomy, 21, 1, pp 1-12, 2006.

Martindale et al., Narrow Band X-ray Polarising Filters. Proc.SPIE, Vol 6686, 2007.

## Further Information

An electronic version of this poster is available at:

http://www.star.le.ac.uk/~npb/ixo_pol.pdf

For further information contact N.P. Bannister (Email: npb@star.le.ac.uk)