ESRF	**Experiment title:** Electric field control of magnetism in multiferroics studied with X-ray scattering	**Experiment number**: HE-2905
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Shifts: 21	**Local contact(s)**: Luigi Paolasini	*Received at ESRF:*

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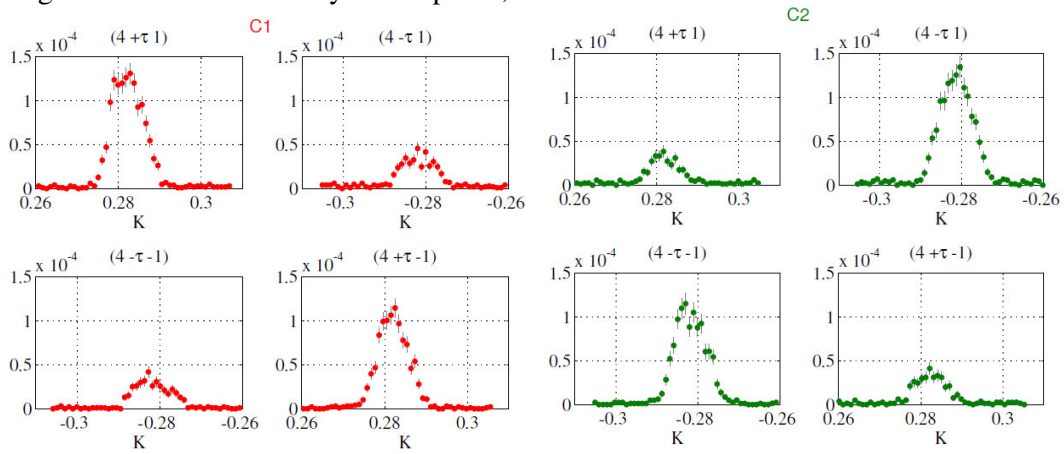
Report: ***Magnetoelectric multiferroics*** are materials in which magnetism and ferroelectricity coexist and interact, endowing them with a range of interesting properties that are a considerable challenge to understand at the microscopic level, but which suggest a number of potential practical applications in the fields of spintronics, data storage, etc. [1]. The chemical requirements for ferroelectricity and magnetism are typically mutually exclusive. However, recently a new route to multiferroicity has been discovered, involving the breaking of inversion symmetry (required for ferroelectricity) through the formation of complex magnetic structures [2]. The distorted perovskites $REMnO_3$ (RE=Tb and Dy) are a family of such multiferroics, in which ferroelectricity develops at the phase transition from a collinear to a spiral magnetic structure, with a concomitantly gigantic magnetoelectric effect. This allows, for example, the electric polarization in $TbMnO_3$ to be switched by applied magnetic fields [3]. So far these magnetoelectric ferroelectrics display these properties only at low temperatures, and therefore the development of a microscopic theory of the coupling mechanism is clearly of vital importance to the technological advancement of these materials. The unique properties of X-ray resonant scattering (XRS), including its elemental specificity, and exquisite sensitivity to the multipolar order parameters that are predicted to characterise the combined ferroelectric/magnetic state [4], make it ideal for working towards such a goal. ***In this highly successful experiment we continued on from our previous in-house research, demonstrating the ability of an Electric field to produce an almost mono-chiral domain, and the power of using circular polarized X-rays to probe these states.***

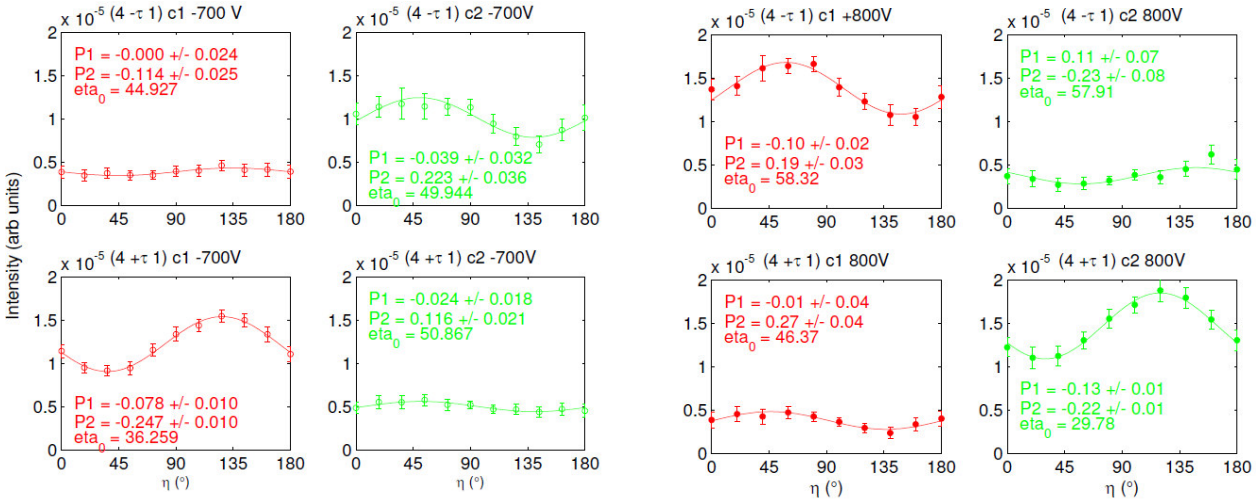
A single crystal sample was prepared in Oxford, and cut with an *a*-face normal. Non-resonant measurements were performed on the ID20 beamline using the phase plate and newly developed electric-field stick in an orange cryostat, to enable low temperature measurements after cooling the sample with up to +/- 800 V applied across the sample parallel to *c*. ID20 with its high flux and innovative experimental set up is unique in allowing us to investigate the cycloidal order in $TbMnO_3$ using circular polarised light. To gain an understanding of the magnetoelectric order parameters it was essential to perform polarisation analysis and this was done using an Au (222) analyser crystal. As far as we are aware, this is the first time that cycloidal order has been investigated using circularly polarised X-rays.

Initially we investigated how, after field cooling with -700 V applied across the sample, the magnetic signal strength varies as a function of the handedness of the incident circular polarisation state and the specific magnetic reflection in the cycloidal phase, and the results are shown below:



There is a clear imbalance in the magnetic signal intensity between (4 ±τ ±1) and circular left and right, which is absent in the higher temperature collinear phase.

To learn more about the details of the magnetic ordering we measured Stokes scans for the different reflections with circular left and circular right X-rays incident on the sample in the cycloidal phase. In the collinear phase there is no difference for the different handedness or different reflections, in striking contrast with the cycloidal phase data. Below are the data obtained in this experiment compared with those from a previous in-house measurement when the sample was cooled with +800 V applied across the sample:



This figure demonstrates that we have successfully switched the magnetic chiral domain structure by reversing the applied electric field. More specifically the large size of the Stokes parameter P2 in all cases demonstrates that there is possibly significant Thomson scattering at the same wave-vector, indicating a charge distortion associated with the cycloidal order. Once we include Thomson scattering in our model, we can show that for a particular chiral domain we would expect that reversing both the circular handedness, and the sign of tau, should result in no change in P1, whilst the sign of P2 should be reversed, which is what we have observed within our errorbars. Analysis is still ongoing, but we expect to submit a paper to Physical Review Letters detailing these results.

References:

[1] M. Fiebig, J. Phys. D 38, R123 (05)
[2] H. Katsura et al., Phys. Rev. Lett. 95, 057205 (05)
[3] T. Kimura et al., Nature 426, 55 (03)
[4] T. Arima et al., J. Phys. Soc. Jpn 74, 1419 (05)