ESRF	**Experiment title: X-ray resonant scattering study of magnetic field control of multiferroic $TbMnO_3$**	**Experiment number**: HE3068
Beamline: ID20	**Date of experiment**: from: 25/02/09 to: 03/03/09	**Date of report**: 15/04/09
Shifts: 18	**Local contact(s)**: L. Paolasini	*Received at ESRF:*

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Report:

Since the discovery of anomalously large magnetoelectric effects, ie a coupling between magnetic and ferroelectric order parameters, there has been a considerable resurgence of interest in multiferroics. It had been assumed that the apparent incompatibility between the chemical conditions for magnetism and ferroelectricity would result in few multiferroics being identified, but a new class have been discovered taking advantage of symmetry breaking magnetic structures, such as helices. $TbMnO_3$ is representative of this class of magnetolectric ferroelectrics, and displays switching of electric polarisation by magnetic field application. In order to develop these materials for potential spintronics applications it is essential to develop a fundamental understanding of the governing microscopic physics. To this end we have been carrying out experiments on ID20 using circularly polarised incident X-rays with a full polarimetry analysis of the scattered beam after applying an electric field to the sample to control the cycloidal domain state, and so far we have successfully learnt new details of the Tb ordering [1] in zero magnetic field. ***This latest experiment built on our experience of using the new technical setup, but in addition we have applied a magnetic field, with the intention of investigating the magnetic structure in the electric polarisation flop phase.***

The single crystal sample prepared in Oxford and cut with an *a*-face normal, was that used in our previous experiments. The sample was mounted in the ID20 electrified stick, such that +/-800 V could be applied to the sample along the *c* axis, which was in turn inserted into the Oxford Instruments cryomagnet, allowing us to apply magnetic fields up to 10 T parallel to the *b* axis. The high flux of ID20 was essential for performing the low intensity non-resonant measurements using the phase plate, whilst the polarimetry analysis was performed using a LiF analyser crystal.

After electric field cooling the sample, we initially applied a magnetic field of 3 T, and then performed stokes scans for circular left and circular right incident light. 3 T is below the critical magnetic field at which the polarisation should flop and should lie within the same phase as that at zero field, however we observed a marked difference in the scattering between 0 and 3 T, with the scattered light becoming more linear and the intensities in the two incident channels being more comparable in overall magnitude. The effect appeared to be reversible, since on returning to zero magnetic field we recovered the same Stokes parameters as before. The change in the Stokes scans may be indicative of the magnetic field breaking the glide plane symmetry, and canting the moments so introducing a ferromagnetic component, such that Thomson scattering may now occur at magnetic reflections.

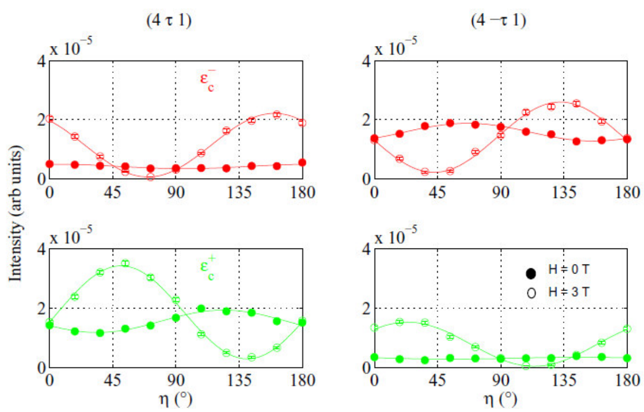

Figure 1: Stokes scans of (4 ±τ 1) after E-field cooling into cycloidal phase in zero and 3 T magnetic fields for circular left and circular right incident X-rays.

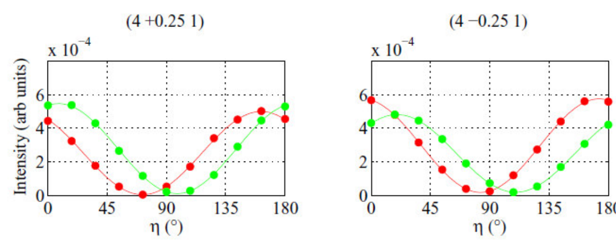

Figure 2: Stokes scans of (4 ±1/4 1) after E-field cooling into cycloidal phase in 10 T magnetic field for circular left and circular right incident X-rays.

Above 8 T, we entered the polarisation flop phase, in which the magnetic wavevector becomes commensurate. Stokes scans performed over the reflections (4 ±1/4 1) for H=10 T revealed that the scattered X-rays are highly linear, in contrast to those at H=0 T. The scattered intensities for circular left and circular right are very similar although some difference remains which conforms to a similar ±k symmetry as in zero field. The data appear to be inconsistent with a possible ↑↑↓↓ spin structure as has been proposed previously [2], whilst analysis is ongoing to see whether it is indicative of the alternative proposed structure, namely the cycloid flopping into the *ab* plane [3].

[1] F. Fabrizi, H. C. Walker et al., submitted to Phys. Rev. Lett.
[2] T. Arima et al., Phys. Rev. B 72, 100102(R) (2005).
[3] N. Aliouane et al., condmat 0902.1890