Experimental Report

Proposal: **5-42-378** **Council:** 4/2014

Title: Stuffed quantum spin ice

This proposal is a new proposal

Researh Area: Physics

Main proposer: **GOFF Jonathan P.**

Experimental Team: GOFF Jonathan P.
BOWMAN David

Local Contact: NILSEN Goran

Samples: Yb2Ti2O7

Instrument	Req. Days	All. Days	From	To
D7	14	12	17/09/2014	29/09/2014

Abstract:

It has been proposed that the prototypical quantum spin ice material Yb2Ti2O7 exhibits a Higgs transition from a magnetic Coulomb liquid to a ferromagnetic phase at Tc ~ 0.21K. However, the situation is complicated, since the magnetic ground state appears to be highly sample dependent. It has recently been proposed that the stuffing of titanium sites by ytterbium ions is responsible for the variation in magnetic properties of nominally stoichiometric samples. We propose to study the low-temperature spin correlations of large single crystals of Yb2(Ti2-xYbx)O7-x/2 stuffed in a controlled manner to compositions of x ~ 0, 0.05 and 0.2. The diffuse magnetic scattering in the spin-flip channel will be measured for each composition using polarised neutrons in a dilution refrigerator at T ~ 0.3K using D7. The transition to the ferromagnetic phase will be studied down to T ~ 0.05K, and a magnetic field of 1T will be applied to give a single domain. Our results will be compared with Monte Carlo simulations based on the defect structures in the stuffed compounds.

The nature of the ground state of $Yb_2Ti_2O_7$ is hotly contested [1-4]. Based on experimental results both a ferromagnetic low temperature state [5-6], and a dynamic ground state with no long range order [7-10] have been proposed. An inelastic neutron scattering study in the field-induced ferromagnetic phase revealed substantial XY character, however the dominant exchange interaction is the Ising component, making $Yb_2Ti_2O_7$ an exchange analogue to the spin ices, a so called "quantum spin ice" [11]. In this scenario quantum-mechanical tunnelling between different ice configurations leads to electric and magnetic monopoles, where linearly dispersing excitations are the photons of the emergent electromagnetism [12-14]. Alternatively, a polarized neutron scattering study implies a ferromagnetic Higgs phase achieved by a Bose-Einstein condensation of spinons [5]. These differences in the reported ground states have been interpreted as due to $Yb_2Ti_2O_7$ being close to a first order transition between a Coulomb and a Higgs phase, with changes in the intrinsic defects in nominally stoichiometric samples being sufficient to drive $Yb_2Ti_2O_7$ through the phase transition.

There is evidence that the main defects in as-grown $Yb_2Ti_2O_7$ are the light stuffing of Ti sites by excess Yb [3]. We have, therefore, studied the spin correlations in a deliberately stuffed single crystal of composition $Yb_2(Ti_{1.5}Yb_{0.5})O_{6.75}$, and compared it to a nominally stoichiometric single crystal of composition close to $Yb_2Ti_2O_7$.

The single crystals were aligned with [1,-1,0] vertical, and mounted in a dilution refrigerator with a base temperature of about $T \sim 50$mK. Uniaxial polarization analysis was employed with a guide field of $B \sim 0.01$T. In some cases a field of $B \sim 2.5$T was applied along [1,-1,0] in order to study the systems in a saturated ferromagnetic state with no diffuse neutron magnetic scattering.

Figure 1 shows the diffuse neutron scattering in the non-spin-flip and spin-flip channels for the nominally stoichiometric sample at $T \sim 0.05$K and $B \sim 0.01$T. There are rods of magnetic scattering along the <111> directions in both channels and these correspond to 2D correlations in the kagome planes. Broad magnetic scattering is also seen near {220} in the spin-flip channel, and this corresponds to the ferromagnetic clusters reported in Ref [8]. As the temperature is raised the pattern remains qualitatively similar, but the scattering broadens due to a decrease in correlation lengths, and the correlations have disappeared by $T \sim 5$K. The $B \sim 2.5$T field also eliminates the diffuse magnetic scattering.

The temperature dependence differs from Ref [8] where short-range ferromagnetic correlations are observed below $T \sim 400$mK and only 2D correlations are observed above this temperature. No spontaneous long-range ferromagnetism of the type reported in Ref [5] below $T \sim 210$mK is observed at any temperature here. The ferromagnetic correlations do not extend over a sufficient range to depolarize the beam.

Figure 2 shows the corresponding diffuse neutron scattering from stuffed $Yb_2(Ti_{1.5}Yb_{0.5})O_{6.75}$. Stuffing radically changes the diffuse scattering. In this case the non-spin-flip channel is mainly structural, and only short-range ferromagnetic correlations are detected in the spin-flip channel near {220}. Comparison with data taken in a saturating field where there is no diffuse scattering shows that there are also uncorrelated spins at low field.

We have identified isolated oxygen vacancies as the dominant defects in other pyrochlores [15], and we plan to complete our studies of the effects of defects on the magnetic ground state of $Yb_2Ti_2O_7$ by comparing as-grown nominally stoichiometric (black), pristine annealed in oxygen (orange), and reduced in hydrogen (black) samples.

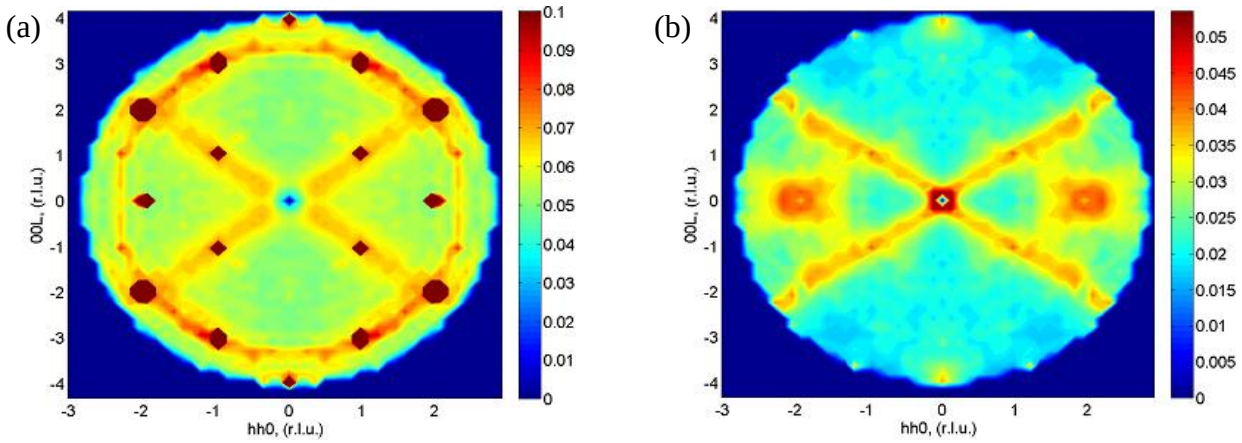

Fig. 1. The diffuse magnetic scattering observed from $Yb_2Ti_2O_7$ at T ~ 0.05K and B ~ 0.01T (a) non-spin-flip and (b) spin-flip scattering. There are rods of scattering along the <111> directions from 2D spin correlations and broad magnetic peaks close to {220} from ferromagnetic clusters.

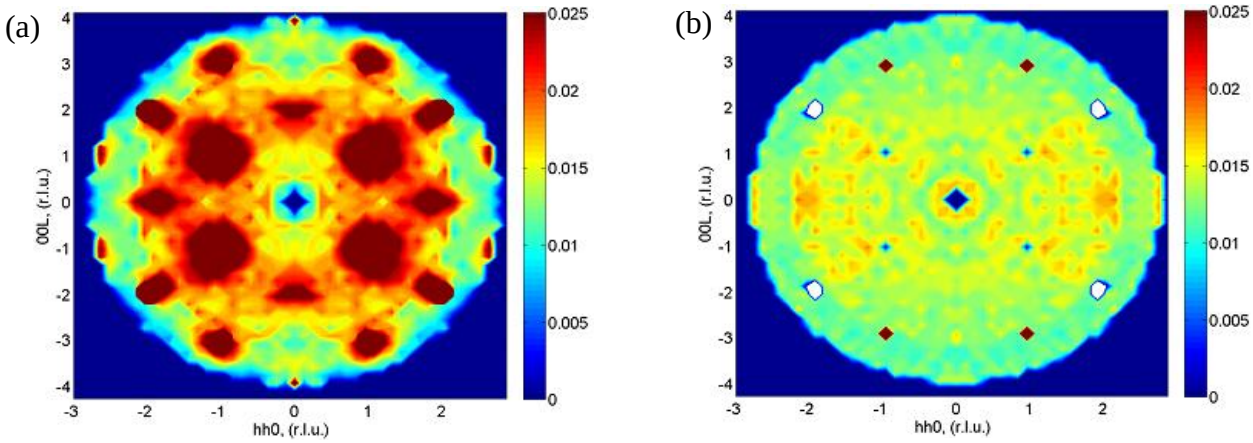

Fig. 2. The diffuse magnetic scattering observed from $Yb_2(Ti_{1.5}Yb_{0.5})O_{6.75}$ at T ~ 0.05K and B ~ 0.01T (a) non-spin-flip and (b) spin-flip scattering. There are broad magnetic peaks close to {220} from ferromagnetic clusters and there is also scattering from uncorrelated spins.

References

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