Experimental report

04/10/2022

Proposal: **4-05-804**

Council: 4/2020

Title: The magnetic field dependence of the director state in the quantum spin hyperkagome compound Yb3Ga5O12

Research area: Physics

This proposal is a new proposal

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Samples: Yb3Ga5O12

Instrument	Requested days	Allocated days	From	To
IN5	5	7	19/05/2021	27/05/2021

Abstract:

The 2D antiferromagnetic Heisenberg model on the kagome lattice is the archetypal frustrated system and remains highly studied. However, in recent years, 3D pyrochlore or garnet lattices with significant anisotropy have shown emergent states of matter such as monopole excitations in spin ice materials and long range multipolar director states in $Gd_3Ga_5O_{12}$ (GGG). These phenomena reveal that the combination of a 3 dimensional crystal structure and magnetic frustration are powerful indicators of exotic states of matter. The aim of this proposal is to study the magnetic field behaviour of the low lying spin waves in single crystal $Yb_3Ga_5O_{12}$ (YbGG), isostructural to GGG, in the short ranged ordered director state. In YbGG the director state is subtly different to the GGG counterpart and is particularly interesting since Yb^{3+} ions is an effective $S = 1/2$ moment thus enabling quantum effects to manifest. We intend to employ IN5 to access the Q dependence of the low lying excitations in YbGG at 100 mK and for $0 < B < 3.5$ T. Perturbing the director state of YbGG will greatly increase our understanding of the director state and determine the effect of quantum spins on this state.

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In this proposal two teams were requested to perform the an experiment together since the scientific aims and techniques of their proposals were very similar. We provide a report of this joint experiment,

In $Yb_3Ga_5O_{12}$, the Yb^{3+} ions are magnetic and situated on equivalent 3D networks of triangles in a system known as the hyperkagome lattice [1]. In $Yb_3Ga_5O_{12}$ the magnetic ions are frustrated and have a low transition temperature of 54 mK [2] making it an interesting material to study both for fundamental interest and as a good candidate for magnetic refrigeration [3]. Furthermore, it has been shown to play host to some interesting emergent behaviour such as the director state [4].

The experiment was performed on a single crystal sample that was mounted on a copper mount, the sample was installed in a dilution refrigerator which was used to provide temperature control for the experiment. The data is all taken with an apparent sample temperature of approximately 40 mK but is expected to be somewhat higher. A measurement at 5 K was used to provide a background correction. The sample was oriented with the crystallographic [111] direction perpendicular to the neutron beam (and therefore parallel to the applied magnetic field). The scattering planes are **u**= [-z,z,0] and **v**=[x,x,-2x]. Some time was lost due to a power cut which stopped the dilution refrigerator, the system warmed to 40 K before it returned to base temperature around 9 hours later.

Test measurements were performed with an incident wavelength of 5 Å and consisted of a magnetic field scan in a field of 0.5 T and then integer tesla steps 1 - 6 T, at a single scattering angle. This revealed the location of the field dependent inelastic mode and how it moves with magnetic field (see figure 1) elucidating the energy range required for the experiment. Extracted peak locations extrapolated from fitting to a gaussian are consistent with a Zeeman splitting of moments with magnitude 1.72 μ_B – consistent with previously reported values.

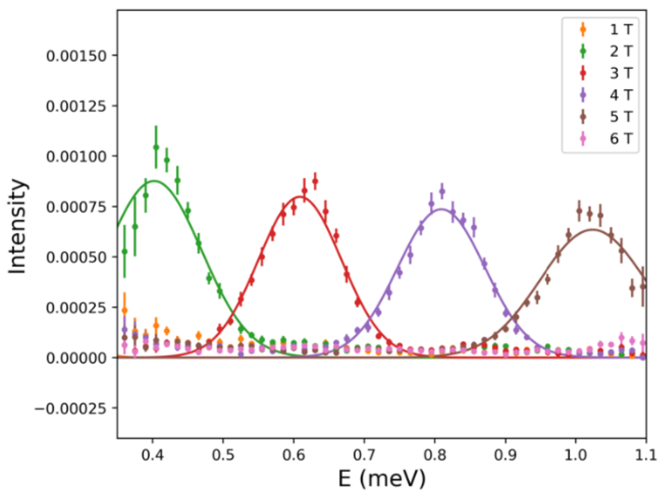

Figure 1. Field dependence of observed intensity band with gaussian fits at Q=(0.4,0.4,-1.8).

The full available Q range was then measured using both 5 Å (for higher field measurements) and 7 Å for 0.5 T (and a 5 T background measurement). Cuts across **u** and **v** show a broad band of intensity which is broader than the instrumental resolution and which is at its middle relatively featureless. However iso-energy cuts through the top and bottom of the band show some dispersion see figure 2.

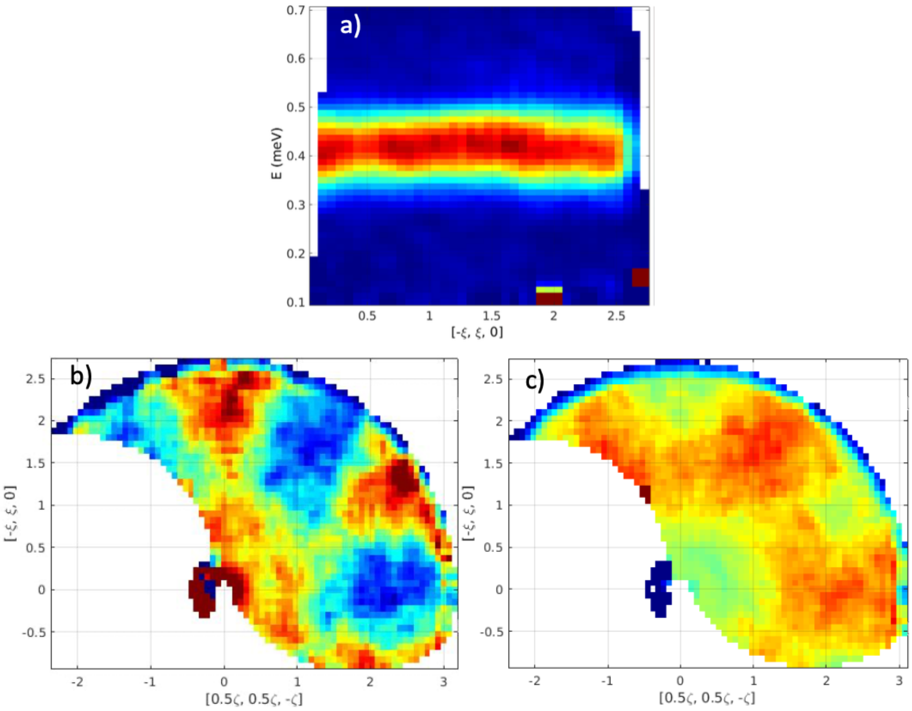

*Figure 2. a) Scattering intensity along **u** in a field of 2 T. b) Iso-energy slice of the 2 T intensity at E=0.33 meV. c) Iso-energy slice of the 2 T intensity at E=0.47 meV.*

Our theoretical calculations predict the presence of multiple bands close together (relative to the instrumental resolution) meaning that extracting the detailed magnon spectra is difficult. To attempt to do so we have fitted to the data using gaussians that have a width determined by the instrumental resolution, yielding a good fit using 3 peaks (figure 3 a) for the 5 T data and 2 peaks for the 2 T data. Complicating matters further is that many more peaks (e.g., figure 3b with 10) are required to fit the 0.5 T data which used the higher resolution 7 Å configuration. This analysis is still ongoing.

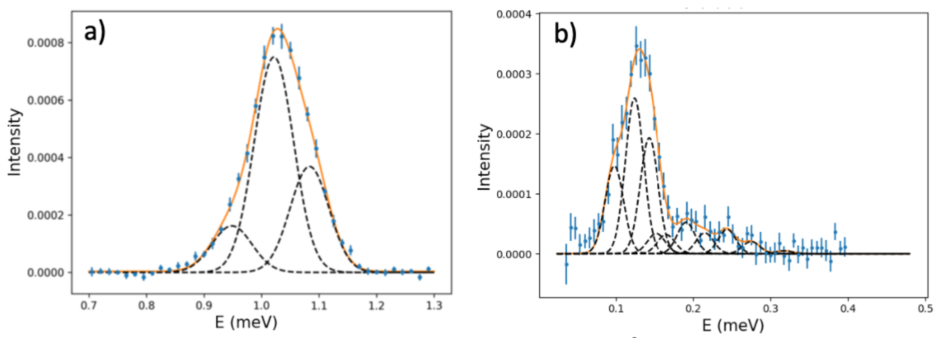

Figure 3. a) Energy dependent scattering intensity in 2 T for 5 Å with 3 resolution fixed peaks at Q=(0.9,0.9,-1.8). b) In 0.5 T for 7 Å with 10 resolution fixed peaks at Q=(0.5,0.5,-1).

[1] Lhotel, Elsa, et al. "Spin dynamics of the quantum dipolar magnet $Yb_3Ga_5O_{12}$ in an external field." Physical Review B 104.2 (2021): 024427. [2] Filippi, J., et al. "Magnetic properties of ytterbium gallium garnet between 44 mK and 4K." Journal of Physics C: Solid State Physics 13.7 (1980): 1277.
[3] Brasiliano, Diego Augusto Paixao, et al. "YbGG material for Adiabatic Demagnetization in the 100 mK–3 K range." Cryogenics 105 (2020): 103002. [4] Jacobsen, Henrik, et al. "Spin dynamics of the director state in frustrated hyperkagome systems." Physical Review B 104.5 (2021): 054440.