Experimental report

04/04/2016

Proposal: **4-01-1398** **Council:** 4/2014

Title: Spin dynamics in the quantum spin-ice $Pr_2Zr_2O_7$

Research area: Physics

This proposal is a new proposal

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Samples: $Pr_2Zr_2O_7$

Instrument	Requested days	Allocated days	From	To
IN5	7	6	11/09/2014	17/09/2014

Abstract:

The pyrochlore compound $Pr_2Zr_2O_7$ is very likely a "quantum spin ice" candidate, with similar physics as encountered in the celebrated $Tb_2Ti_2O_7$. Recently, neutron experiments have provided new insight into the properties of the later material, and shown that a strong magneto-elastic coupling between acoustic phonons and CEF transitions is likely at play, giving rise to effective interactions between quadrupoles on the top of exchange interactions. In this context, we would like to carry out a 7 days experiment on IN5 (with the dilution fridge and a cryomagnet) to determine if similar observations and conclusions hold in the case of $Pr_2Zr_2O_7$.

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Rare earth pyrochlore magnets $R_2T_2O_7$ are model systems in the field of geometrical frustration. $Tb_2Ti_2O_7$ has especially attracted much attention, as it might be a "quantum spin ice" with strongly correlated moments still fluctuating at 50 mK [1,2,3]. Recently, neutron experiments have however provided some new insight into this issue, and shown that a strong magneto-elastic coupling plays here a major role, giving rise to effective interactions between quadrupoles on the top of exchange interactions [4,5]. At the heart of this physics is the non-Kramers nature of the Tb ions. In contrast with Kramers ions, their ground state crystal field doublet is not protected from perturbations, especially from distortions which couple to quadrupoles and lift the degeneracy of those doublets.

In this context, $Pr_2Zr_2O_7$ is precious (see [6]). Indeed, like Tb3+, Pr3+ is a non Kramers ion, and its magnetic anisotropy is found to be Ising-like (along the <111> axes). Despite a negative Curie Weiss temperature, reflecting AF interactions, it does not order down to 50 mK. Xac measurements (performed at the Néel Institute) show evidence for a freezing at very low temperatures.
Our INS experiment has been carried out at IN5 in a complex set-up involving a cryoàmagnet (field along 110) and a dilution insert. This experiment allowed us to observe a quasi-elastic signal, with a peculiar spectral weight forming "Pinch-points" in Q-space (near (111), and related points), confirming the results presented in [6]. The Q spectral weight of this quasi-elastic signal depends on the magnetic field. In zero field, it displays no intensity along (h,h,0) and is maximum along the (h,h,h) and (0,0,l) directions (Fig 1). At 2.5 T, the signal is visible only along the (0,0,l) direction (Fig 1). Further, a large and non-dispersive mode emerges from the background around 0.4 meV (Figure 2). From experiments carried out at 4F2 (LLB), we have shown that the energy of the latter increases with increasing field (Fig 2).

Our recent analysis of those data provides new clues to understand these features. Our point is that $Pr_2Zr_2O_7$ is not a "quantum spin ice" but rather a new class of materials dominated by a strong effective coupling between ***quadrupoles*** leading to "ferromagnetic" correlations between those quantities. Whatever the amplitude and sign of the coupling between ***dipoles*** (in a certain extent though), our analysis allows to understand qualitatively the experimental results. The pinch-point pattern is especially shifted to the inelastic channel (figure 1 and 2).

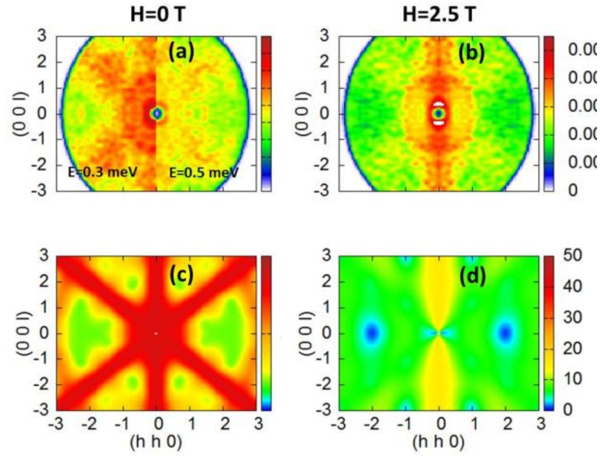

Figure 1: Upper panel : IN5 data taken at 50 mK. Lower panel : simulations based on our analysis.

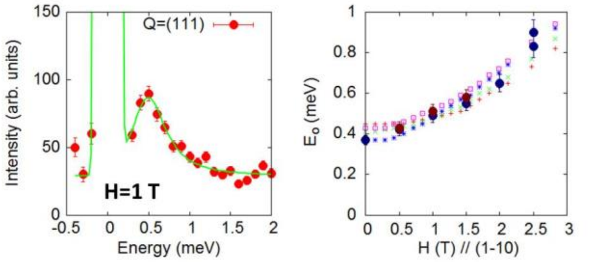

Figure 2: Lower panel : (left) 4F2 raw data at 1T and 50 mK. (right) : large symbols denote the field dependence of the mode that emerges under field (H//[110]). Small symbol show our calculations for different relevant sets of parameters.

References :
(1) L. Balents Science 464,199,(2010), J Gardner & al Rev Modern Phys 82,53 (2010)
(2) J. Gardner & al PRL 82,1012, (1999)
(3)H. Molavian, M Gingras & B Canals PRL 98, 157204 (2007)
(4)S Petit & al PRB 86, 174403 (2012)
(5)S Guitteny & al PRL 111, 087201 (2013) T Fennell & al PRL 2013
(6)K.Kimura & al, Nature Comm 4:1934 (2013)
(7)T. Fennell & al, Science 326, 415 (2009)
(8)C. Castelnovo, R. Moessner and SLSondhi, Nature, 399,333 (1999)