Experimental report

02/09/2022

Proposal: **4-01-1630**

Council: 4/2019

Title: Spin Wave Dispersion in Magnetic Weyl Semimetal Candidate $Co_3Sn_2S_2$

Research area: Physics

This proposal is a new proposal

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Samples: $Co_3Sn_2S_2$

Instrument	Requested days	Allocated days	From	To
IN8	6	6	22/06/2021	28/06/2021
THALES	0	4	24/09/2021	28/09/2021

Abstract:

$Co_3Sn_2S_2$ has a highly frustrated kagome lattice structure and is one of several magnetic Weyl semimetal candidates. Recent transport studies have observed large anomalous Hall effect, magnetoresistance, and chiral anomalies consistent with the presence of Weyl fermions, suggesting the presence of topological phenomena. To fully understand the magnetism in $Co_3Sn_2S_2$, we propose an inelastic neutron scattering experiment to study the spin wave dispersion and determine if there is a spin gap at the Dirac points. Additionally, we will determine if the system can be described well by a Heisenberg Hamiltonian or if additional interactions will be needed to understand the behavior. Our observations will provide new understanding of the mechanisms causing exotic topological phenomena and cast light on potential applications in novel spintronic devices.

Report on the proposal (4-01-1630)

Title: Spin Wave Dispersion in Magnetic Weyl Semimetal Candidate Co3Sn2S2

Experimental team: Philippe Bourges, Kelly Neubauer, Pengcheng Dai, Su Yixi

Abstract: In the proposal 4-01-1630, we planned to study the temperature dependence of the spin wave dispersions in Co3Sn2-xS2 with x=0.12. Previous transport measurements indicated a maximal anomalous Hall effect (AHE) near x=0.12 despite a reduced moment size. The enhanced AHE has been attributed to Berry curvature associated with the Weyl semimetal phase, yet recent studies revealed a more complicated picture of the magnetism in this system. Therefore, to develop a microscopic understanding of the interplay of the AHE and magnetism in this system we studied the spin wave excitations in this system.

The concept of topology has been predicted and experimentally identified amongst materials with little or no electron correlations and is arguably a success in the pursuit of materials by design [1, 2]. In contrast, topology in strongly correlated materials is much less explored due to a lack of identified material platforms and the theoretical difficulty in developing descriptions that incorporate topology and electron correlations. The role of magnetism on topologically protected states has implications for both our fundamental understanding of properties and the technological applications of quantum materials such as dissipationless spintronics [3, 4]. The magnetic semimetal $Co_3Sn_2S_2$ is particularly interesting because the interplay between magnetism and topology leads to giant anomalous Hall effect (AHE), where charge carriers acquire a velocity component orthogonal to an applied electric field without an external magnetic field, with a small, ordered moment [5, 6]. The magnetic Co ions in $Co_3Sn_2S_2$ form a two-dimensional (2D) kagome lattice, composed of corner sharing triangles and hexagons, separated by nonmagnetic S and Sn layers with another Sn intercalated between the Co-S layer [Fig. 1(a)]. Depending on the nature of the magnetic order, the observed AHE may have different microscopic interpretations [7-12].

Through measurements at THALES and IN-8, we considered the effect of spin dynamics to the AHE. In previous work on Weyl semimetal candidate $SrRuO_3$, the observed non-monotonic temperature dependence of the AHC $\sigma_{xy}(T)$, induced by Barry curvatures near Weyl points, is associated with temperature dependence of the spin gap $E_g(T)$ in FM spin waves via:

$$E_g(T) = \frac{a_g M(T)/M_0}{1 + b(\frac{M(T)}{M_0})(\frac{\sigma_{xy}(T)}{\sigma_0})} \qquad (1),$$

where $M(T)$ and M_0 are the magnetization at temperature T and saturation moment, respectively; a_g and b are nearly temperature independent constants, and σ_0 is a constant related to lattice parameter of the system [13]. Similarly, the spin wave stiffness $D_H(T)$ has a large temperature dependence that follows:

$$D_H(T) = \frac{a_D M(T)/M_0}{1 + b(\frac{M(T)}{M_0})(\frac{\sigma_{xy}(T)}{\sigma_0})} \qquad (2).$$

Our inelastic neutron scattering experiments confirm the strong interplay between spin dynamics and AHC [9, 10]. Figure 4(a) shows the constant-**Q** scans at (0,0,3), revealing clear spin gap at different temperatures. The resulting temperature dependence of the spin gap shown in blue dashed line can be fitted by eq. (1) with $a_g = 3.65$ meV and $b = 0.60$, while fitting with $a_g = 2.36$ meV and $b = 0.0$ in black dashed line fitted is clearly worse in Fig. 4(b). Therefore, like in the parent compound, the temperature dependence of the AHE must be included to best fit the data.

Figure 4(c) shows the in-plane spin wave dispersions at 5 K and 200 K compared to the parent compound results of Ref. [9]. The temperature dependences of spin wave stiffness, obtained by fitting the spin wave dispersion with $E \approx E_g(T) + D_H(T)q^2$ where E is energy of spin waves and q the momentum transfer away from the zone center, is shown in Figs. 4(d). The black and blue dashed lines are fits of the $D_H(T)$ by eq. (2) with zero and finite b, respectively. Although finite b fits the data slightly better, the differences with zero b is not large.

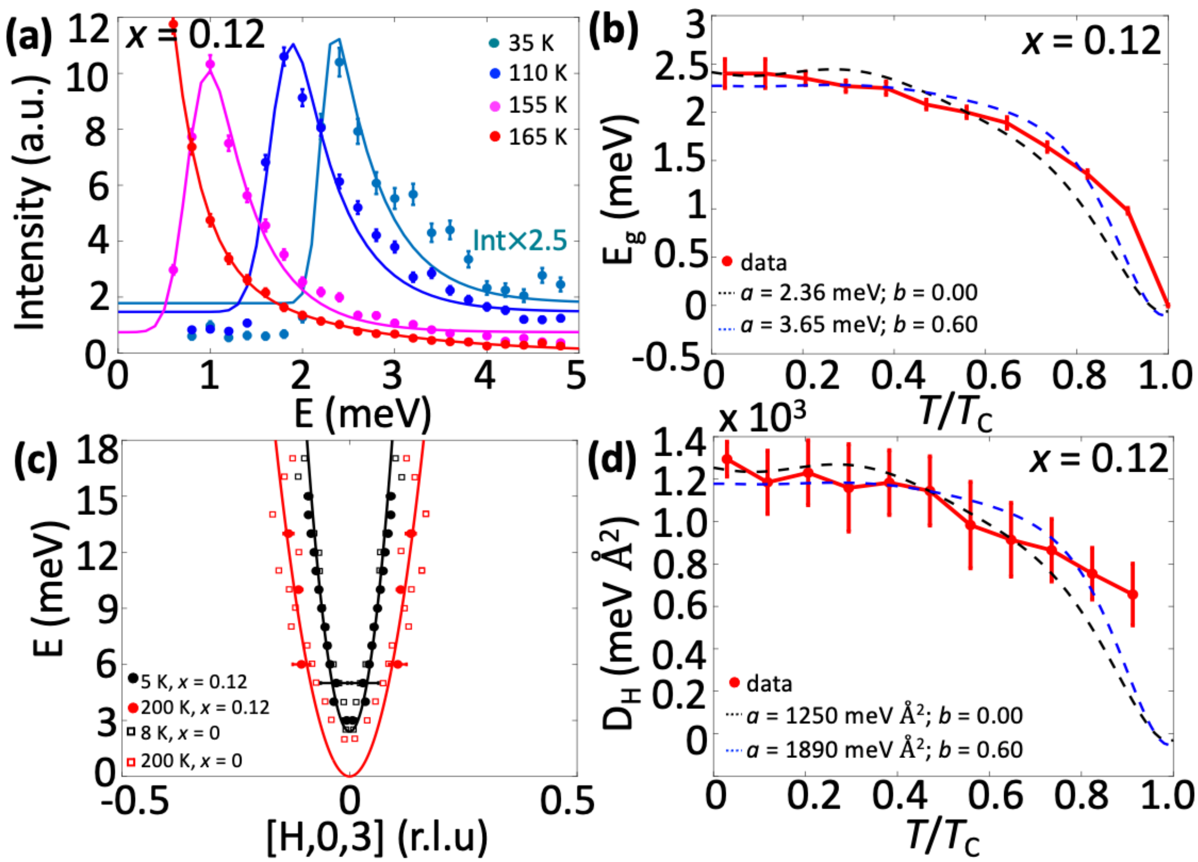

Fig. 1. (a) Select energy dependence of the spin excitations at T = 35, 110, 155, and 165 K (see supplementary information for fit details). (b) Temperature dependence of the spin wave gap and fitting results with different parameters with $T_C = 165$ K. (c) Dispersion curve of the spin wave excitations along [H,0,3] at 5 and 200 K fit to a q^2-dependence and compared to $x = 0$ data from [9] as shown in square points. After data analysis, [9] claims a gapless spectrum at 200 K. (d) Temperature dependence of the in-plane spin-wave stiffness D_H and fitting results with different parameters and $T_C = 165$ K. D_H was determined using fixed E_g determined from energy scans (Fig. 4(a)) and then fitting the dispersions along H (Fig. 4(c)).

Our inelastic neutron scattering experiments on $x = 0.12$ reveal that spin dynamics in the doped compound behave similarly as the undoped $Co_3Sn_2S_2$. These results along with previous elastic neutron measurements helped us establish the magnetic structures and dynamics of the Co3Sn2-xInxS2 system as a function of In doping and to further understand the interplay of magnetism and AHE.

References:

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