# Experimental report

05/02/2018

**Proposal:** **5-42-415** **Council:** 4/2016

**Title:** Search for magnetic skyrmions in apolar metal Y3Co8Sn4

**Research area:** Physics

**This proposal is a new proposal**

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**Samples:** Y3Co8Sn4

| Instrument | Requested days | Allocated days | From | To |
|---|---|---|---|---|
| IN3 | 1 | 1 | 17/11/2016 | 18/11/2016 |
| D33 | 3 | 3 | 18/11/2016 | 21/11/2016 |

**Abstract:**

Recently there has been a surge of interest in skyrmion spin textures. However, to date only few skyrmion hosting materials are known, and the skyrmions are almost always of the same chiral vortex-type. Here we propose a polarized SANS investigation of the long wavelength incommensurate magnetic structures of the polar crystal Y3Co8Sn4. This material potentially hosts a triple-q state, or a skyrmion crystal in the bulk, where the skyrmions may be of a new type. However, based on available data, it is not possible to assign the nature of the incommensurate magnetic modulation, i.e. if it is of helical or cycloidal type, and hence if the suspected skyrmion state is respectively of the common vortex-type or of a new Neel-type. Here we aim to resolve this controversy in a three-day polarized SANS experiment on D33.

# Experimental Report 5-42-415:
# Search for magnetic skyrmions in a polar metal $Y_3Co_8Sn_4$

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## Introduction

Recently, multiply periodic states similar to the atomic ordering in crystals have been identified in a wide variety of physical context. In magnetic systems, such multiply periodic states are often called multiple-*q* spin orders, and are attracting attention as the source of nontrivial magnetic topology and associated emergent phenomena[1]. In particular, the triple-*q* state represented by the superposition of helical spin textures can be often considered as the crystallized form of magnetic skyrmion (i.e. vortex-like swirling spin texture with topologically-protected particle nature)[2]. In bulk materials, such triple-*q* skyrmion orders have exclusively been found in noncentrosymmetric magnets, in which the relativistic Dzyaloshinskii-Moriya (DM) interaction is the key for the skyrmion formation. On the other hand, the latest theories further predict the emergence of various multiple-*q* magnetic orders from different physical origins, such as frustrated exchange interaction in triangular lattice system and spin-charge coupling in itinerant hexagonal system[3], while their experimental realization in the actual materials has rarely been achieved.

To realize the potential multiple-*q* helimagnetism, the search for appropriate material systems to fulfill the corresponding condition is essential. Our target material $Y_3Co_8Sn_4$ is a member of $R_3M_8Sn_4$ ($R$ being Y or rare earth element and $M$ being 3$d$ transition metal element) family characterized by the polar hexagonal crystal structure (space group: $P6_3mc$) with itinerant nature of magnetism[4-6]. This material family is unique because all of the above-mentioned mechanisms are allowed to become active in principle, depending on the relative magnitude of each interaction. We have successfully grown high quality single crystals of $Y_3Co_8Sn_4$, which undergoes a ferromagnetic transition around 55 K and exhibits the easy-plane anisotropy perpendicular to the [001] axis. We performed a small-angle neutron scattering (SANS) experiment on the crystal at PSI. For the (001) plane under zero magnetic field, we found that two incommensurate spin modulation vectors of different magnitude, i.e. six-fold magnetic Bragg reflections at $q_{out}$ ~ 0.081 $Å^{-1}$ and ring-shaped weak magnetic reflections at $q_{in}$ ~ 0.040 $Å^{-1}$, appear below $T_1$ = 18 and $T_2$ = 26 K, respectively. The magnetic field dependence of the SANS patterns showed that the $q_{out}$ keeps the six-fold symmetry for both in-plane and out-of-plane orientations of $H$, pointing to the formation of the triple-$q$ state. In contrast, the ring-shaped pattern of $q_{in}$ was turned into the two-fold spots under in-plane $H$, indicating the multiple-domain of single-$q$ state.

In this D33 experiment, we investigated the detail of magnetic structure described by $q_{out}$ and $q_{in}$ by using a polarized SANS technique. By using polarized neutrons in a geometry, where the neutron polarization ($\boldsymbol{S}_\mathbf{n}$) is parallel to the incident beam ($\boldsymbol{k}_\mathbf{in}$), the longitudinal (parallel to $\boldsymbol{S}_\mathbf{n}$) and transversal (perpendicular to $\boldsymbol{S}_\mathbf{n}$) spin components can be independently evaluated as the corresponding scattering will purely show a non-spin-flip (NSF) or spin-flip (SF) response, respectively.

## Experimental Method

Single crystal sample of $Y_3Co_8Sn_4$ were synthesized by arc-melting stoichiometric amounts of pure Y, Co, and Sn pieces, followed by slow cooling in a silica tube under vacuum. In the SANS experiments with longitudinal polarization analysis using the D33, the incident neutron beam with a wavelength of 4.6 Å is polarized using an Fe-Si transmission polarizer and can be reversed by means of an RF spin flipper. The neutron spin state after the sample was analyzed using a nuclear spin-polarized $^3$He cell. Both $\boldsymbol{S}_\mathbf{n}$ and $\boldsymbol{k}_\mathbf{in}$ were directed along the [001] axis. In this configuration, the SF (NSF) signal detects the spin component normal (parallel) to the [001] axis, which is referred to as $S_{xy}$ ($S_z$).The neutron spin polarization was preserved by means of magnetic guide fields of ~5 mT on the intermediate flight path between polarizer and analyzer. Temperature scans were performed in the warming process after zero field cooling (ZFC).

## Results

Figures 1(a),(b) show the polarized SANS patterns of the SF and NSF channels measured at 1.5 K under zero magnetic field. The magnetic reflections were clearly observed in the SF channel but not in the NSF one for both $q_{out}$ and $q_{in}$. This proves that neither $q_{out}$ nor $q_{in}$ have $S_z$ component at the ground states, and therefore the magnetic moments

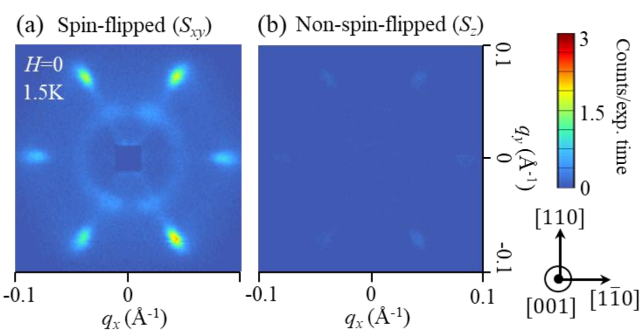


Figure 1: Polarized SANS patterns of (a) spin-flipped (SF) and (b) non-spin-flipped (NSF) channels measured at 1.5 K under zero magnetic field, which detects in-plane and out-of-plane spin components ($S_{xy}$ and $S_z$), respectively.

always lie within the (001) plane. Temperature development of each spin component for $q_{out}$ and $q_{in}$ is summarized in Figs. 2(a),(b). Note that the $S_z$ component of $q_{in}$ gradually increases above 14 K, which may reflect the spin fluctuation toward the critical temperature $T_2$.

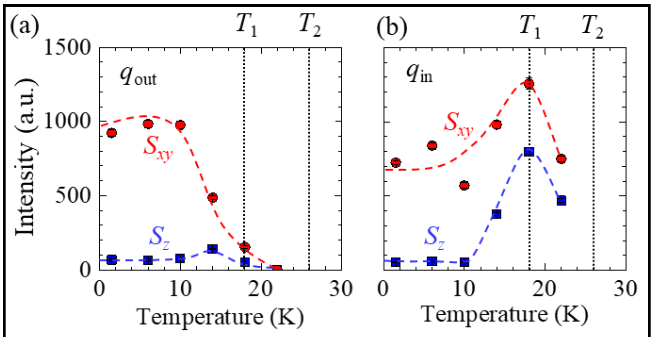


Figure 2: Temperature variations of the scattering intensity of SF and NSF channels (corresponding to $S_{xy}$ and $S_z$, respectively) for (a) $q_{out}$ and (b) $q_{in}$.

The emergence of multiple-$q$ magnetic order has been predicted theoretically from various distinctive mechanisms, such as (1) DM interaction in noncentrosymmetric system, (2) frustrated exchange interactions in triangular lattice system, and (3) spin-charge coupling in itinerant hexagonal system. If the DM mechanism is responsible for the present case, the polar symmetry of crystal structure should favor the cycloidal spin texture with magnetic moments confined within the [100]-[001] plane, and application of $H$ || [001] will lead to the formation of Néel-type skyrmion lattice state with triple-$q$ nature. Here, both of these magnetic orders should contain nonzero magnitude of $S_z$ component. However, the presently-observed confinement of the spins within the (001) plane is clearly inconsistent with this scenario; therefore, the DM interaction is not the main source of the incommensurate magnetism in $Y_3Co_8Sn_4$. Another potential source is the frustrated exchange interactions, but this is also unlikely because the Curie-Weiss temperature determined from the temperature dependence of the inverse magnetic susceptibility agrees well with $T_c$. Then, we are now considering the spin-charge coupling mechanism in itinerant magnets as the origin of the triple-$q$ and single-$q$ magnetic orders in the present compound. This result suggests that the traditional DM mechanism is not the only approach to realize the multiple-$q$ orders and will trigger further investigation of itinerant hexagonal magnets as a unique material platform to explore the topological spin textures.

## References


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