Experimental Report

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Proposal: **INTER-286** **Council:** 4/2014

Title: Internal time on IN12

This proposal is a new proposal

Researh Area:

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Samples: MnSi

Instrument	Req. Days	All. Days	From	To
IN3	7	7		
IN12	5	9	11/07/2014	16/07/2014
			02/10/2014	06/10/2014

Abstract:

Stabilization of Magnetic Order in Chiral Magnets

Max Kugler

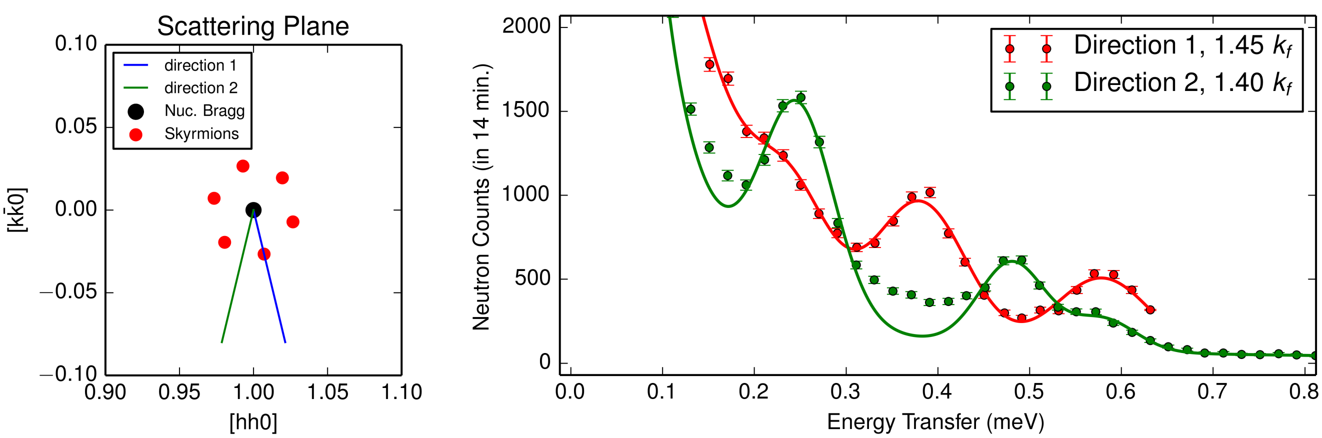
The intermetallic compound MnSi is of great interest as a magnetic model system exhibiting helical spin ordering and topologically non-trivial spin correlations. In particular, an unusual two dimensional skyrmion lattice exists in small applied magnetic fields at the border between paramagnetism and long-range helimagnetic order. The skyrmion crystal can be treated as a phase coherent superposition of three spin spirals which are aligned in an equilateral triangle. It forms a 2D hexagonal lattice perpendicular to the applied field composed of magnetic vortices (skyrmions). These vortices are stable due to their topology and therefore of high technological interest for data storage. With the discovery of the skyrmion lattice in 2009 it was shown that the skyrmion phase is stabilized relative to the conical phase by thermal magnetic fluctuations [1] – the skyrmimagnons.

From a preliminary TAS measurement [2] one knows that there are at least two spin-wave branches associated with the skyrmion crystal for finite momentum transfers q. On the other hand, there are three excitations in the case $q = 0$, accessible via microwave response [3]. Within this experiment we observed the third missing skyrmimagnon and showed that these spin-waves can be well investigated by optimizing the instrumental focusing and using high-quality samples.

MnSi is a cubic crystal ($P2_13$) with a lattice constant of a = 4.558 Å and we used a cylindrical sample with a vertical field of 0.2 T along [001]. The skyrmions pin along ⟨100⟩ only in this special configuration otherwise always along ⟨110⟩. It follows that by performing scans around the common [110] nuclear Bragg peak the two symmetry directions within the skyrmion plane are symmetric around the transversal direction Q_y (±15°), see left figure. The instrumental resolution is also symmetric around that direction. If one observes a difference in the skyrmimagnon behavior along the two symmetry directions it has therefore to be intrinsic and cannot originate from resolution effects – we see such a difference.

We performed const-q scans at 27.9 K for both directions using a moderate collimation of open-30-30-open. We varied k_f = 1.35 … 1.45 Å^{-1} to identify possible spurious signals and to find a compromise between focusing and the energy cutoff given by the Be-Filter (the velocity selector was out of order). The right figure shows two example scans at the same momentum transfer q = 1.8 x k_h for both symmetry directions. The helix pitch k_h = 0.038 Å^{-1} is the distance between the nuclear and the skyrmion reflections. We can clearly resolve three skyrmimagnon branches. The much stronger elastic peak is due to incoherent scattering which partly hides the lower excitation branch in the case of direction 1. The lower and upper branches do not change their energy positions between the two propagation directions while the center branch gets much stiffer for direction 2 compared to direction 1. The lower branch obtains more spectral weight for direction 2 while the center peak drastically shrinks. The upper branch does not change spectral weight between both directions. The comparison of the weights of the modes cannot be seen very well in the shown scans because of the varying k_f and the additional spurious signals at *~0.4 meV* in the green drawn scan. These spurious signals partly arise along direction 2 and originate from elastic double scattering at $q = \sqrt{3} \times k_h$ which is close to the selected reciprocal position.

Because of the short beamtime at half reactor power we were not able to determine the dispersion relation of the three skyrmimagnons and the corresponding difference along different propagation directions. But we clearly showed that there are exactly three excitation branches matching the microwave response results. Furthermore, we have seen that the stiffnesses of the lower and upper branches are isotropic while this is not true for the center mode. Therefore, the lower and upper branches show a similar characteristic while the center mode has to be something different. This again matches the microwave results at $q = 0$ where the lower and upper modes correspond to a counter-clockwise and clockwise rotating skyrmion while the center mode corresponds to a periodic growth and shrinking of the skyrmion center (breathing mode). This experiment opens the door for a systematic investigation of the spin-waves associated with this novel class of magnetic texture.



<u>Left:</u> Scattering plane with the vertical field along [001]. The magnetic skyrmion reflections (red) align in a sixfold symmetry around the nuclear [110] Bragg reflection defining two symmetry directions (blue and green) for the associated spin-waves – the skyrmimagnons.

<u>Right:</u> Two example const-q scans for the same momentum transfer $q = 1.8 \times k_h$ along both directions. We observe three skyrmimagnon branches where the upper and lower one behave nearly isotropic. In contrast, the stiffness of the center mode varies strongly for different propagation directions. The elastic peaks are due to incoherent scattering, partly hiding the lower branch in the red curve. The spurious points in the green data set around ~0.4 meV are due to elastic double scattering.

References:

[1] S. Mühlbauer *et al.*, Science 323, 915 (2009).

[2] M. Janoschek *et al.*, JPCS 200, 032026 (2010).

[3] Y. Onose *et al.*, PRL 109, 037603 (2012).