Experimental report

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Proposal: **INTER-413** **Council:** 4/2018

Title: Longitudinal polarisation analysisof the skyrmion dynamics in MnSi

Research area:

This proposal is a new proposal

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Samples: MnSi

Instrument	Requested days	Allocated days	From	To
THALES	2	2	11/06/2018	13/06/2018

Abstract:

ILL experimental report INTER-413: Longitudinal polarisation analysis of the non-reciprocal skyrmion dynamics in MnSi

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Using the longitudinal polarisation analysis option at the cold-neutron triple-axis spectrometer Thales we succeeded in initially investigating the separation of the non-reciprocal skyrmion dynamics in MnSi into spin-flip and non-spin-flip channels. The experiments further show that Thales is ideally suited for continuing these lines of research in future experiments.

I. BACKGROUND

The chiral and itinerant compound MnSi is well-known for featuring a rich magnetic phase diagram below temperatures of $T_c = 29.5\,\mathrm{K}$, most importantly the skyrmion phase.[1] The non-centrosymmetric $\mathrm{P2_13}$ space group of MnSi has profound consequences for spin-wave dynamics in all ordered magnetic phases of MnSi. It introduces a Dzyaloshinskii-Moriya term which – at certain directions in reciprocal space – either causes magnons to be created at different (absolute) energies than they are annihilated or leads to different spectral weights for magnon creation compared to annihilation. The dynamical structure factor $S(q, E, B)$ in all phases is asymmetric ("non-reciprocal") with respect to changing the sign of either the reduced momentum transfer $q_{||}$, the energy transfer E, or the magnetic field B. Here, $q_{||}$ refers to the component of the reduced momentum transfer along the direction of B. Such an asymmetric behaviour could be observed for the field-polarised,[2,3] the paramagnetic,[4] the conical,[5] and the skyrmion[6] phases of MnSi.

II. EXPERIMENT

Utilising two days of internal beam time at Thales,[7] we performed an initial investigation into the separation into spin-flip and non-spin-flip channels of the non-reciprocal magnons in the skyrmion phase. The measurements were performed in the $hk0$ scattering plane around the nuclear (110) reflection with the magnetic field oriented along [110]. In this configuration, the skyrmion plane is spanned by the $[1\bar{1}0]$ and [001] reciprocal vectors and the hexagonal skyrmion lattice pins along [001] (Fig. 1 left). The magnetic Brillouin zone of the skyrmion lattice has an extent of $k_h = 0.027\,\mathrm{rlu}$, the helix pitch. Due to the coarser resolution in the l direction and the sloped nature of the instrumental resolution ellipsoid, projections of the four 30 degree out-of-plane skyrmion satellites can be observed in both spin-flip channels in transverse scans (Fig. 1 right) at the approximate positions Q = (0.98 1.02 0), (0.99 1.01 0), (1.01 0.99 0), and (1.02 0.98 0) rlu. The non-spin-flip channel (not depicted) shows no signal except for incoherent-elastic scattering.

We performed three const-Q scans at reduced momentum transfers of $q_{||} = \pm 3.5\,\mathrm{k_h}$ (Fig. 2), a position which we had already determined beforehand as being optimal for observing the dynamical structure factor's non-reciprocity.[6] For the first case, $B > 0$ and $q > 0$, as shown in the top left panel of Fig. 2, all skyrmion dynamics in the scanned range appears in the "SF-+" spin-flip channel, and none in the "SF+-" spin-flip or the "NSF" non-spin-flip channels. The asymmetry of the structure factor $S(q, E, B)$ here manifests itself in a larger spectral weight for magnon creation ($E > 0$) than annihilation ($E < 0$).

In the second case, as shown in the top right panel of Fig. 2, flipping the sign of the reduced momentum transfer leads to a larger spectral weight for magnon annihilation than creation. The effect appears not as pronounced as in the first case due to the Bose factor being lower for annihilation. It is furthermore of note that all low-E signal now appears in the "SF+-" spin-flip channel in contrast to the first case. Additionally, a magnon can be observed at around $E = 0.6\,\mathrm{meV}$ in the "SF-+" channel; it can be assumed by (a)symmetry that in the fist case (top left panel) this magnon would appear at $E = -0.6\,\mathrm{meV}$ and in the "SF+-" channel.

The third case, which is depicted in the bottom left panel of Fig. 2, has both the the signs of $q_{||}$ and B flipped compared to the first case. Previously,[5,6] we had assumed that flipping the signs of two dependent variables of S would reproduce the original structure factor, i.e. $S(-q, E, -B) = S(q, E, B)$. The present polarisation analysis shows that this is not strictly true, as all the intensity that can be observed in the "SF-+" spin-flip channel in the first case instead appears in the "SF+-" channel in the third case (and vice versa).

III. CONCLUSION

We could successfully perform polarisation analysis of the skyrmion dynamics in MnSi. The information gained during the experiment is very important for the future development of the universal theory modeling helimagnon and skyrmion excitations.[8] Furthermore, the present measurements prove the feasibility of polarisation studies in the skyrmion phase, but also in the conical and field-polarised phases. With its high intensity and good resolution, Thales proved to be the perfect instrument for the task.

ACKNOWLEDGEMENT

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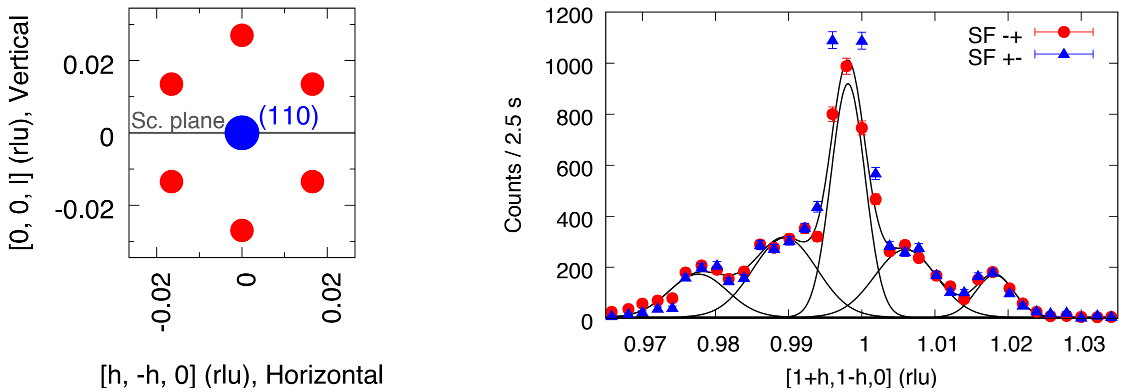

Figure 1. Left: The skyrmion plane is spanned by $[1\bar{1}0]$ and [001] and the hexagonal lattice pinned along [001]. The scattering plane is marked in the figure and is perpendicular to the skyrmion plane. Right: Four out-of-plane magnetic skyrmion satellites can be observed in both spin-flip channels.

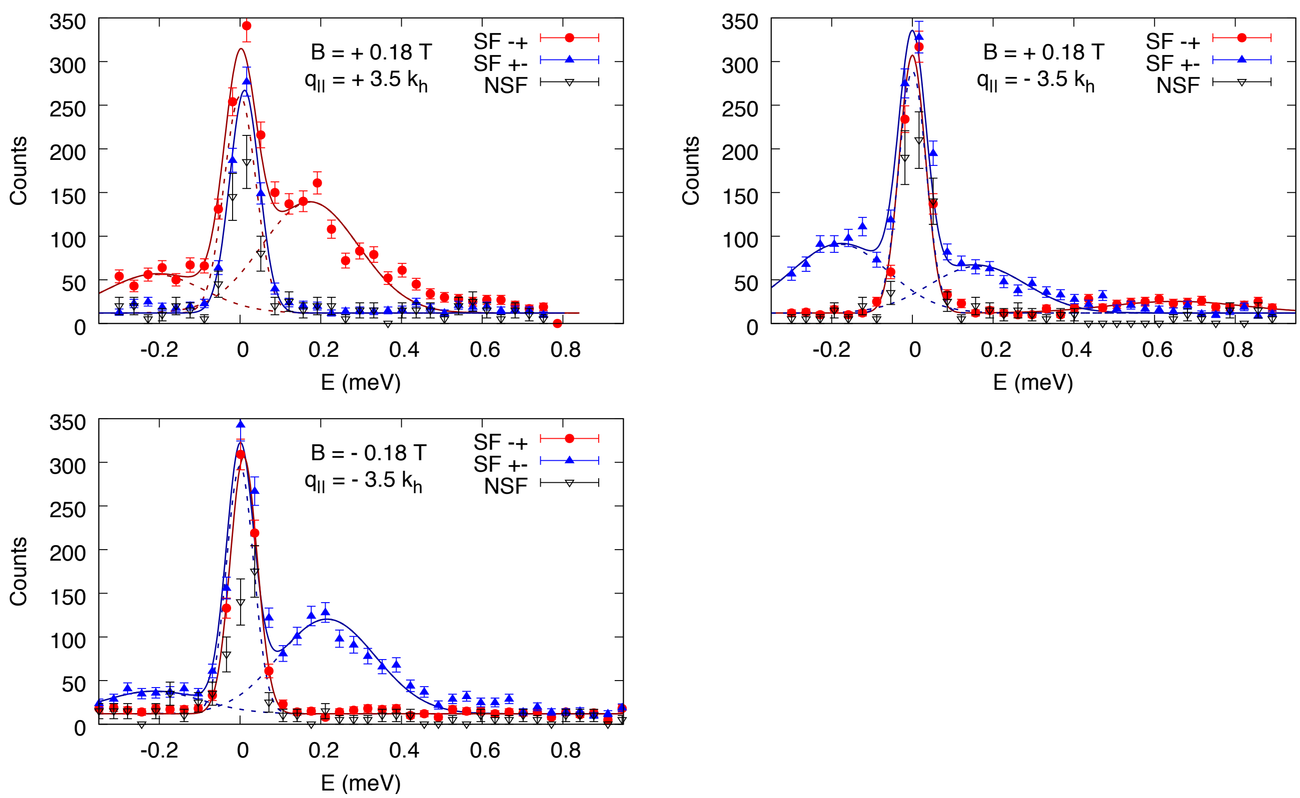

Figure 2. Const.-Q scans show that the non-reciprocal dynamical structure factor manifests itself in different spectral weights for magnon creation $E > 0$ compared to annihilation $E < 0$. All low-E spectral weight is concentrated in one of the two spin-flip channels. The sign of the reduced momentum transfer q, but not the sign of the magnetic field B, chooses which spin-flip channel is populated.