Experimental report

28/08/2024

Proposal: **CRG-3132** **Council:** 4/2024

Title: Magnons at the skyrmion-paramagnetic phase transition in MnSi

Research area: Physics

This proposal is a new proposal

Main proposer: **Tobias WEBER**

Experimental team: Tobias WEBER

Local contacts: Karin SCHMALZL

Samples: MnSi
MnSi #2

Instrument	Requested days	Allocated days	From	To
IN12	7	6	14/06/2024	20/06/2024
ORIENTEXPRESS	1	1	31/05/2024	01/06/2024

Abstract:

The magnons in the topologically non-trivial skyrmion phase of MnSi form a complex structure of energetically closely spaced Landau levels. For this proposal we wish to investigate how the magnons evolve into the topologically trivial paramagnetic phase at high temperatures.

This proposal will help us finish our years-long study of the magnon dynamics at the different phase transitions starting from the skyrmion phase. Of these we could recently complete an investigation into the skyrmion/conical transition at ThALES (ILL) and TASP (PSI) and now wish to do the same with the skyrmion/paramagnetic transition.

Magnons at the skyrmion-paramagnetic phase transition in MnSi

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The itinerant-electron compound MnSi features several magnetically ordered phases below temperatures T of ca. 29 K. These are the helical [1], conical [2], the field-polarised ferromagnetic [3], and the skyrmion phase [4, 5]. Paramagnetic phases set in at $T > 29\,\mathrm{K}$ [6].

As part of a broader investigation into the stability of the magnon modes at the border of the skyrmion phase, this experiment focused on the skyrmion-paramagnetic transition for increasing temperatures. The experiment was conducted using horizontal collimations of 30 minutes both before and after the MnSi sample. In order to remove higher-order contamination, a cooled Beryllium crystal was used in the instrument's k_f axis. The sample was placed in a horizontal Oxford magnet [7], providing a field of $B = 195\,\mathrm{mT}$ along the $[1\bar{1}0]$ axis.

Fig. 1 shows elastic scans around the (110) nuclear Bragg peak. The skyrmion satellite peaks and their out-of-plane projections are clearly visible at $T = 28.3\,\mathrm{K}$.

The left panel of Fig. 2 depicts how the magnon modes of the skyrmion lattice, here at $Q = (0.935\,1.065\,0)$ and $T = 28.3\,\mathrm{K}$, decay first into paramagnetic excitations ($T = 29.4 - 39.9\,\mathrm{K}$) and finally vanish for high temperatures ($T = 79\,\mathrm{K}$). The curve shown for the $T = 28.3\,\mathrm{K}$ data is a (preliminary) resolution-convolution of the instrumental resolution and the theoretical linear spin-wave model [5, 8], all other curves are simple Lorentzian fits, which have been found to describe the paramagnons well. The results show that upon leaving the skyrmion phase by heating up, the complicated magnetic modes of the skyrmion phase begin to lose their internal structure and continuously transform into the simple paramagnetic excitations. As the paramagnons move to lower and lower energies, their intensities increase due to the Bose factor. The intensities found at around $E = 0$ have their maximum at ca. $T = 35\,\mathrm{K}$ and then decrease again until only nuclear-incoherent scattering is left at $T > 79\,\mathrm{K}$.

The right panel of Fig. 2 shows the temperature-dependent evolution of the magnons at $Q = (1.07\,0.93\,0)$. The magnon modes in the skyrmion phase are visible, but not as pronounced as before, because here positive energy transfer corresponds to transverse defocusing of the instrument. This served as a check against possible spurions in the focusing scans. As before, the $T = 28.3\,\mathrm{K}$ curve is a (preliminary) resolution-convolution of the model [5, 8], all other curves are Lorentzian fits.

The non-reciprocal nature of the magnetic excitations found in all the ordered phases is retained in the paramagnetic phase, but becomes less pronounced as the temperatures approach the non-magnetic phase. Fig. 3 shows the time reversal asymmetry that is obtained by inverting the direction of the magnetic field: The same dispersion is only recovered when flipping both the reduced momentum transfer and the magnetic field direction. This result confirms an earlier study [6].

Experiment conducted at *IN12* [9] by T.W., with K.S. as local contact; DOIs: 10.5291/ILL-DATA.CRG-3132 (exp.) and 10.5281/zenodo.5718363 (model sources).

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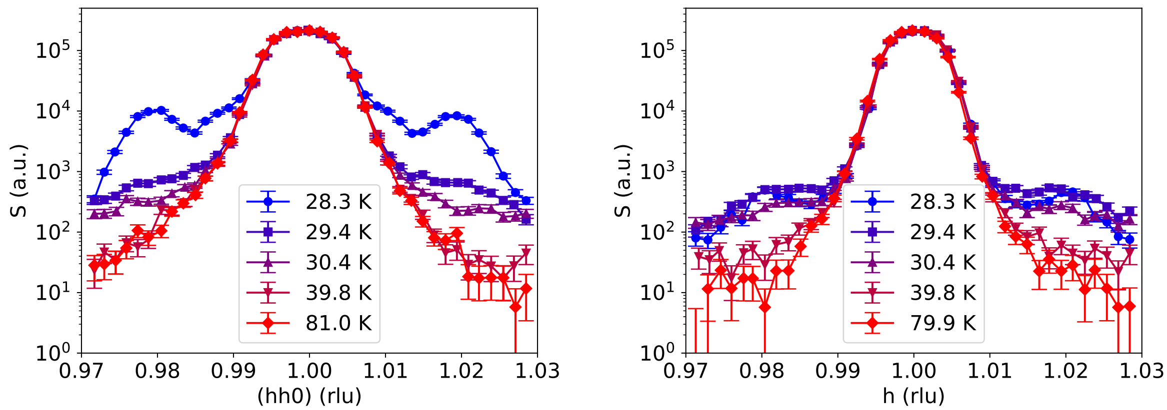

Figure 1. Elastic scans. Left: Longitudinal scan around (110). Right: Transverse scan around (110).

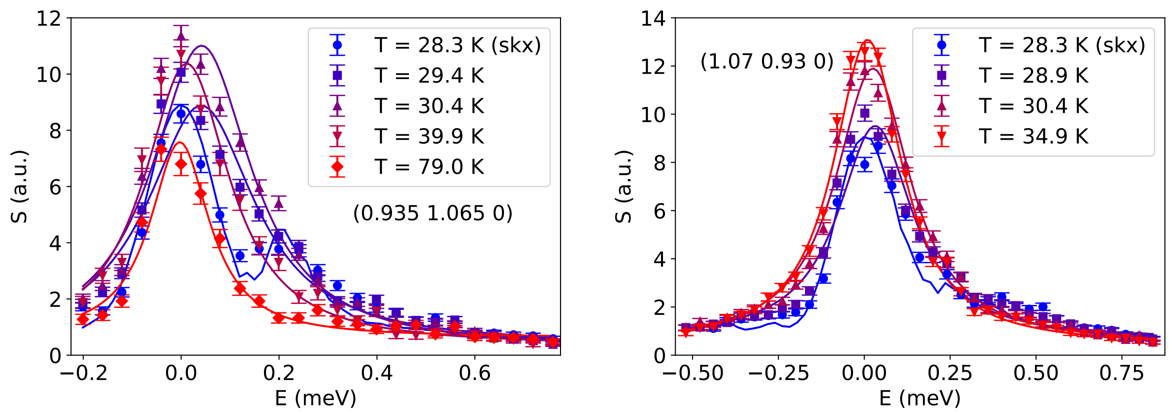

Figure 2. Temperature-dependent evolution of the magnon modes starting from the skyrmion phase at $T_{skx} = 28.3\,\mathrm{K}$ and going up to the nonmagnetic phase at 79 K (left) and the paramagnetic phase at 34.9 K (right). The complicated magnon structure in the skyrmion phase is gradually lost when icreasing the temperature. The solid lines at $T_{skx} = 28.3\,\mathrm{K}$ are (preliminary) resolution-convolution simulations of the magnon model [5, 8], all the other solid lines are simple Lorentzian fits.

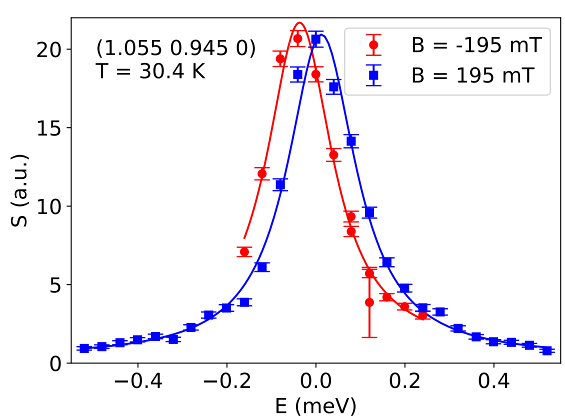

Figure 3. The non-reciprocity that is characteristic of the ordered magnetic phases is retained throughout the paramagnetic phase. It manifests itself via a time-reversal asymmetry. The solid lines are Lorentzian fits.