Experimental report

22/05/2019

Proposal: **4-01-1568**

Council: 4/2017

Title: Spin fluctuations and quantum criticality in iron doped MnSi

Research area: Physics

This proposal is a resubmission of 4-01-1254

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Samples: Mn(0.87)Fe(0.13)Si

Instrument	Requested days	Allocated days	From	To
IN3	0	1	04/09/2018	05/09/2018
THALES	7	7	04/09/2018	11/09/2018

Abstract:

In recent years complex forms of magnetic order based on spin chirality in noncentrosymmetric systems has attracted great interest in condensed matter physics. Among many systems, MnSi is ideally suited to study the properties of unconventional magnetic states. Recent measurements on the spin structure and its dynamical properties of MnSi and Mn(0.9)Fe(0.1)Si yielded evidence for the presence of a chiral spin liquid phase characterized by a constant integrated magnetic intensity in a temperature range of 1K above the ordering temperature. With the proposed experiment we would like to extend our studies to higher iron concentrations close to the quantum critical point, where the magnetic phase transition is suppressed to zero temperature. The expected results will show if the chiral spin liquid phase survives close to the quantum critical point and, therefore test the generality of this phase as a precursor to helical magnetic order in Mn(1-x)Fe(x)Si.

EXPERIMENTAL REPORT

INSTRUMENT	DATES OF THE EXPERIMENT	NUMBER OF THE EXPERIMENT
Thales – cold triple-axis spectrometer	4. - 11.09.2018	4-01-1568

TITLE OF THE EXPERIMENT
Spin fluctuations and quantum criticality in iron doped MnSi

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Here, we report on our investigation of magnetic scattering in $Mn_{1-x}Fe_xSi$. In MnSi at ambient conditions, we find helimagnetic order below a transition temperature $T_C = 29.3\,\mathrm{K}$ in MnSi [1] as a result of the interplay of ferromagnetic exchange, Dzyaloshinski-Moriya (DM) interaction and the crystal potential. The magnetic moments of the Mn ions align parallel in planes perpendicular to the modulation vector $\boldsymbol{r}_h$ of the helix, where the latter is parallel to the cubic [111] axis. The pitch of the helix is 180 Å, i.e., much longer that the cubic lattice parameter $a = 4.55$ Å. Magnetic order in MnSi can be suppressed by Fe substitution with a critical concentration of about 17%. In fact, we have very recently performed a detailed susceptibility [1] and small-angle neutron scattering (SANS) study [2] of $Mn_{1-x}Fe_xSi$.
The aim of the current investigation was three-fold: (1) Search for the signature of the chiral spin-liquid phase in MnSi just above T_C, (2) follow its evolution with Fe substitution and (3) search for magnetic scattering beyond the critical concentration $x_c \approx 0.17$.
Stoichiometric MnSi was studied in a first experiment on IN14 [Ex. Rep. 4-01-1117] and indeed, we observed a particular temperature dependence of the integrated magnetic intensity which stays constant in a temperature range $T_C < T \leq T_C$+1K and only decreases at further increasing temperatures. The constant intensity is present in the same temperature range in which a chiral skyrmion-like phase was observed in polarized neutron and neutron spin-echo measurements [3].
In the current measurements on Thales, we investigated samples with three different doping levels, x = 0.09, 0.11 and 0.23. According to our recently published phase diagram of $Mn_{1-x}Fe_xSi$ [1] these doping levels are just below and at the crossover concentration x^* = 0.11 as well as well above the critical substitution level $x_c \approx 0.17$ for which the magnetic ordering vanishes. Below x = 0.11 we observe similar behavior to stoichiometric MnSi with clear boundaries between the helical, conical, and

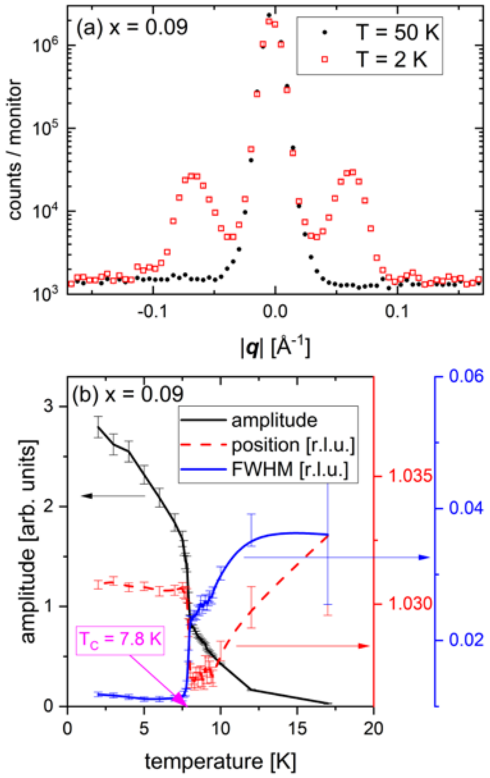

FIG. 1. $Mn_{0.91}Fe_{0.09}Si$
(a) Momentum scans of the helimagnetic superlattice peaks at T = 2 K along the [110] direction in reciprocal space shown in absolute units [$Å^{-1}$]. Data at T = 50 K denote the background due to lattice Bragg peak and incoherent scattering. (b) Results from the analysis of scans as shown in (a). The phase transition is observed at T_C = 7.8 K.

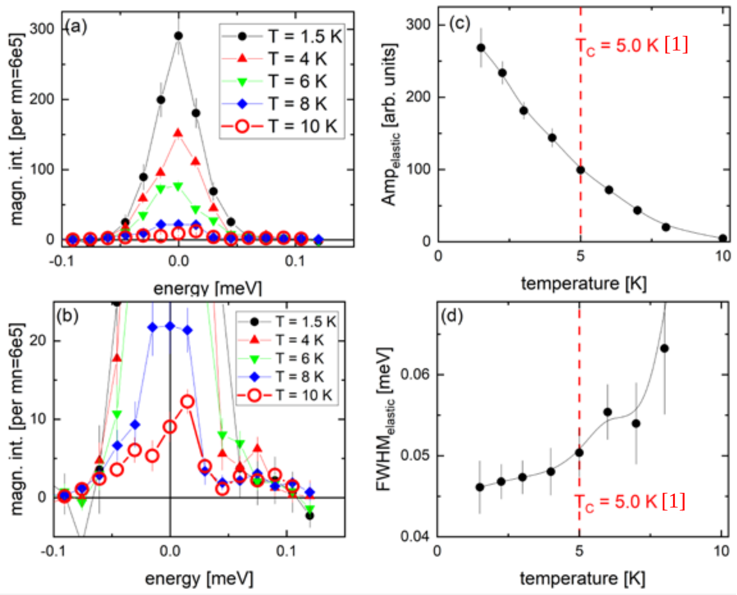

FIG. 2. $Mn_{0.89}Fe_{0.11}Si$
Analysis of energy scans at the helimagnetic ordering wave vector $\boldsymbol{Q}_h$ = (0.97, 0.97, 0). (a) Raw data after subtraction of background taken at T = 25 K. (b) Zoom into the low intensity region. (c)(d) Amplitude and linewidth of the approximated Gaussian function. The indicated transition temperature Tc=5.0 K was determined via magnetization measurements [1].

skyrmion lattice phase as well as an enhanced precursor phase. A notably different behavior sets in for $x \geq 0.11$, where certain characteristics of helimagnetic correlations persist, but without clear phase boundaries.

Our results for samples with x = 0.09 and 0.11 presented in Figures 1 and 2 reveal this qualitative change very nicely. The onset of long-range magnetic order at T_C = 7.8 K in $Mn_{0.91}Fe_{0.09}Si$ is clearly visible in all properties of the helimagnetic superlattice peak [Fig. 1(a)], i.e., the amplitude [Fig. 1(b)], the wave vector position [Fig. 1(c)] and the momentum width [Fig. 1(d)]. On the other hand, the transition in 11% substituted $Mn_{0.89}Fe_{0.11}Si$ is much more gradual without any sharp features at T_C = 5.0 K determined from ac susceptibility measurements [1]. Here, we show the analysis of energy scans at the helimagnetic ordering wave vector $\boldsymbol{Q}_h$ = (0.97,0.97,0) [Fig. 2(a)(b)]. Both, the amplitude of magnetic scattering [Fig. 2(c)] as well as the width in energy [Fig. 2(d)] evolve smoothly through T_C = 5 K.

Figure 3 shows the magnetic intensity of $Mn_{0.91}Fe_{0.09}Si$ obtained by taking into account the amplitude, the momentum width as well as the width in energy. Linear fits to the data below T_C and above T_C+1K (red lines) visualize that there is an offset of about 0.5K. Based on our results for stoichiometric MnSi, this indicates that the chiral skyrmion-like phase is still present in $Mn_{0.91}Fe_{0.09}Si$ but its temperature range is reduced from ΔT = 1K in MnSi to ΔT = 0.5K in $Mn_{0.91}Fe_{0.09}Si$. At x=0.11, the evolution is much more gradual and we can find no indication of the chiral skyrmion-like phase anymore.

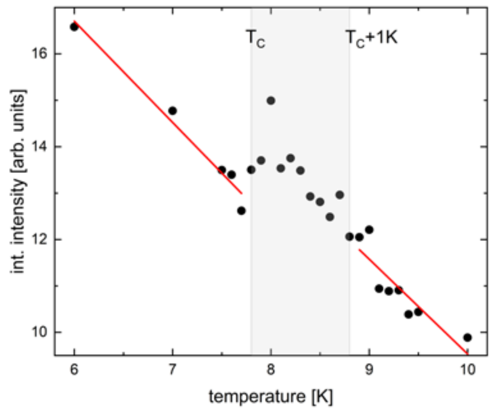

FIG. 3. $Mn_{0.91}Fe_{0.09}Si$
Integrated magnetic intensity as function of temperature.

Finally, we investigated a sample with x = 0.23. Here, we used a dilution insert and performed measurements similar to those presented above but down to T = 50 mK. We could not observe any hint for magnetic scattering in a wave vector range similar to that of the helimagnetic signatures at x < 0.17.

[1] L. J. Bannenberg *et al.*, Physical Review B **98**, 184430 (2018).
[2] L. J. Bannenberg *et al.*, Physical Review B **98**, 184431 (2018).
[3] C. Pappas *et al.*, Physical Review Letters **102** (2009).