

Experimental report

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Proposal: 4-03-1768

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Title: Ultra-low energy excitations in spin-density-wave masked ferromagnetic Nb_{1-y}Fe_{2+y}

Research area: Physics

This proposal is a new proposal

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Samples: NbFe₂

Instrument	Requested days	Allocated days	From	To
WASP	4	3	05/12/2023	08/12/2023

Abstract:

Our previous neutron scattering of ferromagnetic (FM) Nb_{1-y}Fe_{2+y} revealed that chemical composition (y) tuning leads to a FM quantum-critical point masked by an emerging spin-density wave (SDW). Samples with y=+0.02 appear to show critical scattering across the substantial temperature range where the SDW is stable. Unusually, critical scattering has been observed along an extended line in reciprocal space. We propose to check, whether these previous results obtained by time-of-flight and triple-axis spectrometer measurements can be confirmed using neutron spin-echo spectroscopy with its ultra-high energy resolution. The results would form an important test for, e.g., order-by-disorder models that predict the emergence of modulated order at the border of ferromagnetism. We apply for 4 days of beamtime at WASP.

Ultra-low energy excitations in spin-density-wave masked ferromagnetic $\text{Nb}_{1-y}\text{Fe}_{2+y}$

1. SCIENTIFIC BACKGROUND

The transition metal Laves phase compound $\text{Nb}_{1-y}\text{Fe}_{2+y}$ presents a rare opportunity to study the border of itinerant ferromagnetism (FM) at low temperature at ambient pressure. Slight iron excess of the order of 1% induces FM, whereas the stoichiometric compound exhibits spin density wave (SDW) order, and slightly Nb-rich $\text{Nb}_{1-y}\text{Fe}_{2+y}$ remains a paramagnet (PM) down to low temperatures and displays signatures of Fermi-liquid breakdown [1]. Empirical observation in other materials as well as theoretical arguments [2, 3] suggest that the masking of itinerant FM quantum critical points (QCPs) by SDW order may be intrinsic in many clean systems. The SDW in $\text{Nb}_{1-y}\text{Fe}_{2+y}$ could be connected to many exciting phenomena including field-induced quantum-critical lines, quantum tri critical points [4] and quantum multi-critical points. A detailed investigation of the magnetic excitations of $\text{Nb}_{1-y}\text{Fe}_{2+y}$ is crucial to advance our understanding of the mechanisms leading to emerging SDW order masking the FM QCP. It is expected that any critical magnetic fluctuations will play the most important role in shaping the physics of masked FM quantum criticality. In previous triple-axis spectrometer based experiments the presence of critical magnetic fluctuations along a line in $\mathbf{Q}$ space that includes the FM and SDW ordering wave vectors has been suggested.

2. AIMS OF THE EXPERIMENT

The lowest- E magnetic fluctuations were to be measured with high E resolution to determine whether fluctuations that look critical in lower E resolution experiments remain gapless in experiments with high- E resolution or whether lower- E resolution in previous experiments was hiding low- E gaps in the excitation spectrum.

3. EXPERIMENTAL SET UP

We were allocated three days of beamtime at WASP. An iron-rich $\text{Nb}_{0.98}\text{Fe}_{2.02}$ sample with $T_N = 38$ K and $T_C = 32$ K was mounted via an Al holder with Cd shielding to an Orange Cryostat. Sample orientation turned out to be more challenging than expected due to a small extra crystallite, but the main crystal was eventually orientated as planned with the a^* and c^* axes in the scattering plane. Using an incoming neutron wavelength range centred at 5 Å and with a relative width $\Delta\lambda/\lambda = 18\%$ we were able to cover the crucial $\mathbf{Q}$ range from (0 0 1.8) to (0 0 2.2), which includes $\mathbf{Q}_{\text{FM}}$ and $\mathbf{Q}_{\text{SDW}}$. We were also able to reach the related $\mathbf{Q}$ range from (0 0 0.1) to (0 0 0.2). This setting allowed to resolve spin-echo times, which corresponds to an E resolution of 1 μeV . Measurements of HoTi were used to determine the instrumental resolution and empty measurement was done to determine the instrumental background.

4. EXPERIMENTAL RESULTS

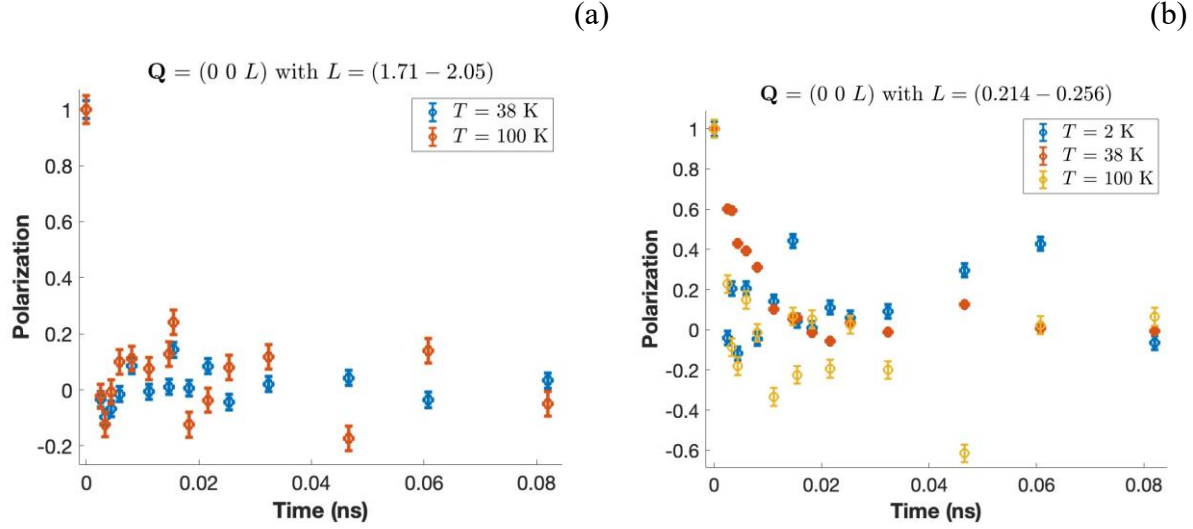


Fig1. Polarisation decay with time at (a) high- Q and (b) low- Q positions. There appears to be little polarization surviving for substantial amounts of time except in the low Q range (b) near $T_N=38\text{K}$. All shown data has been corrected for background and for instrumental resolution.

One part of the measurements was done across a range of high- Q value positions from $(0\ 0\ 1.5)$ to $(0\ 0\ 2.1)$ by using three different sample rotation positions that in combination allowed to cover this Q range with the WASP detector bank. The relative resolution $dQ/Q = 18\%$, which in this Q range corresponds to 0.27 - 0.36 r.l.u. in the c^* direction, allowed to gain integrated signals over larger sections of the Q range, e.g., the range from $(0\ 0\ 1.71)$ to $(0\ 0\ 2.05)$ that include Q_{FM} and Q_{SDW} (see Fig. 1a). Measurements were taken at $T_N = 38\text{ K}$ and in the paramagnetic (PM) state at 100 K. In both cases the signal collapses instantly within the time resolution of the measurement suggesting the absence of magnetic excitations between 1 μeV and the largest energy values that can be resolved, which from the density of data points in time is about 150 μeV .

The other part of the measurement was done across a range of low Q value positions from $(0\ 0\ 0.1)$ to $(0\ 0\ 0.2)$ by using two different sample rotation positions. The relative resolution dQ/Q of 0.018 - 0.036 r.l.u. in the c^* direction allowed to study the Q dependence in more detail. E.g., data of the range from $(0\ 0\ 0.214)$ to $(0\ 0\ 0.256)$ (shown in Fig. 1b) is more strongly influenced by SDW fluctuations than FM fluctuations. Measurements at $T = 2\text{ K}$, 38 K, 43 K, 100 K, and 200 K (not all shown) have been obtained. The instant collapse of the signals at $T = 2\text{ K}$ and $T = 100\text{ K}$ again suggests the absence of magnetic excitations between 1 and 150 μeV . The data also shows a substantial amount of scatter, which at 2 K could at least partially arise from depolarization effects in the FM state. However, data at $T_N = 38\text{ K}$ shows a more gradual decay over a characteristic time of about 0.01 ns that would correspond to quasielastic scattering with a linewidth Γ of about 70 μeV .

A combined interpretation of the findings could be that the dilution of the SDW signal within the wider signal across the high Q value range makes it difficult to detect, while it can be revealed with the higher absolute resolution low Q measurements. This would suggest that the excitations become soft near Q_{SDW} but become gapped by at least 150 μeV elsewhere.

5. CONCLUSION AND OUTLOOKS

The planned measurements of low E excitations of NbFe_2 in a wide Q range and at different temperatures across the FM, SDW and PM phases were carried out at WASP. Few signals were detected suggesting a gapped excitation spectrum but quasielastic scattering from soft SDW excitations with a linewidth Γ of about 70 meV were detected at 38 K, which would be plausible near a continuous SDW phase transitions. Full data analysis and potentially the collection of further data with higher statistics will be necessary to confirm this initial interpretations of the data.

6. REFERENCES

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