Experimental report

22/01/2024

Proposal:	**4-02-625**	**Council:**	4/2023
Title:	Polarisation analysis of magnetic excitations in the SDW phase of Sr1.5Ca0.5RuO4		
Research area:	Physics		

This proposal is a new proposal

Main proposer:	**Felix WIRTH**
Experimental team:	Felix WIRTH
Local contacts:	Paul STEFFENS

Samples: Sr1.5Ca0.5RuO4

Instrument	Requested days	Allocated days	From	To
THALES	5	6	16/11/2023	22/11/2023

Abstract:

Magnetic excitations in a spin-density wave (SDW) phase have been rarely studied although the coupling between static and dynamic moments can imply peculiar modes such as the Fincher-Burke mode in Cr. Sr1.5Ca0.5RuO4 exhibits SDW order appearing at the q-positions, where pure Sr2RuO4 shows dominant magnetic fluctuations. We propose to perform polarized INS experiments across the SDW ordering in Sr1.5Ca0.5RuO4 profiting from the excellent experimental conditions in this material. We thereby hope to separate longitudinal and transversal modes (with respect to the static order) as function of temperature.

Experimental Report

Instrument	THALES
Proposal Number	4-02-625
Proposal	Polarization analysis of magnetic excitations in the SDW phase of $Sr_{1.5}Ca_{0.5}RuO_4$
Experimentalist	Felix Wirth, Yvan Sidis, Markus Braden
Local Contact	Paul Steffens

$Sr_{1.5}Ca_{0.5}RuO_4$ exhibits magnetic incommensurate order of spin-density-wave (SDW) type [1] appearing at the ***q*** position, where pure Sr_2RuO_4 shows strong magnetic fluctuations arising from Fermi-surface nesting in the 1D bands of *xz* and *yz* orbital character [2,3,4]. By applying polarization analysis on *Thales* we wished to separate the magnetic excitations according to their polarization. A large cylindrical single crystal of $Sr_{1.5}Ca_{0.5}RuO_4$ was grown with the floating-zone technique yielding a total mass of ~4 g. This crystal was cut into four pieces that were coaligned for this experiment, see Fig. 1, with the ***c*** direction perpendicular to the scattering plane. We used focusing Heusler crystals as polarizing monochromator and analyzer, and a Helmholtz-coil setup permitted to adjust the neutron polarization direction at the sample. To suppress higher order contaminations, we inserted a velocity selector and a Beryllium filter with most scans performed with fixed k_f=1.50Å^{-1}. The polarization quality of the experiment was examined on the (110) nuclear Bragg peak and yielded flipping ratios between 23 and 27, with the best values obtained for ***z*** polarization due to a better performance of the spin flipper between sample and analyzer. The flipping ratio analysis along the energy scan shown in Fig. 1 illustrates that at the feed of the gaussian distribution flipping ratios are reduced, which will affect the polarization analysis in the vicinity of a very strong signal. Due to the high flipping ratios, a correction of the inelastic data can be neglected sufficiently away from the elastic line. We use the usual coordinate system in polarized experiments with ***x*** parallel to the scattering vector ***Q***, ***y*** in the scattering plane and perpendicular to the scattering vector ***Q***, and ***z***=***x***×***y***.

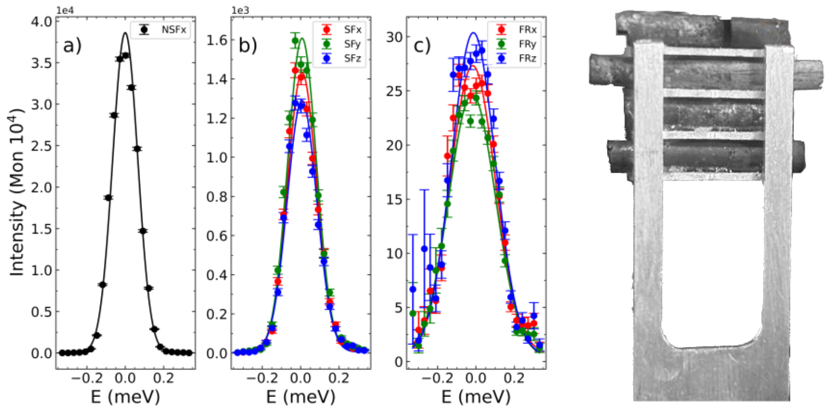


Fig. 1 Polarization analysis at the nuclear Bragg reflection (110); flipping ratios are of the order 23 to 27 but vary for different directions due to inequal performance of the flipper. Foto of the crystal mouting.

Fig. 2 shows the elastic scattering in the SDW phase near $\boldsymbol{Q}_{inc}$=(0.305, 0.305, 0). In agreement with previous analyzes [1] the ordered magnetic moments completely align along the ***c*** direction with the full magnetic scattering appearing in SFy and no signal existing in SFz. The onset of the static order is observed at 22 K and there is no difference in measurements with different final k_f values corresponding to different energy resolution. The magnetic ordering is thus static on the ps time scales of these experiments, which contrasts to incommensurate quasistatic ordering in isostructural nickelates or manganates that exhibit clear signatures of a cluster glass [5].

Fig. 3 presents the polarization analysis of the inelastic response at $\boldsymbol{Q}_{inc}$=(0.3, 0.3, 0) and (0.7, 0.3, 0) at 1.6 K well below the magnetic transition. At both positions the magnetic scattering appears in the SFy channel indicating that the fluctuations at the incommensurate ordering vector are also *c* polarized. From the SF channels we calculate the magnetic scattering functions σ_y and σ_z. There is no indication for a difference between the two $\boldsymbol{Q}_{inc}$ positions besides that arising from the Ru form factor, so that we can merge the two data sets. By applying the Bose factor, we finally obtain the imaginary part of the dynamic susceptibility for the two directions in panel 3 (f). The weak signal polarized perpendicular to the ***c*** direction cannot be unambiguously characterized due to the lack of statistics; it is strongly suppressed compared to χ_c'' and can be equally well described by a relaxor although yielding an unphysically high energy or by a gaussian peak at finite energy.

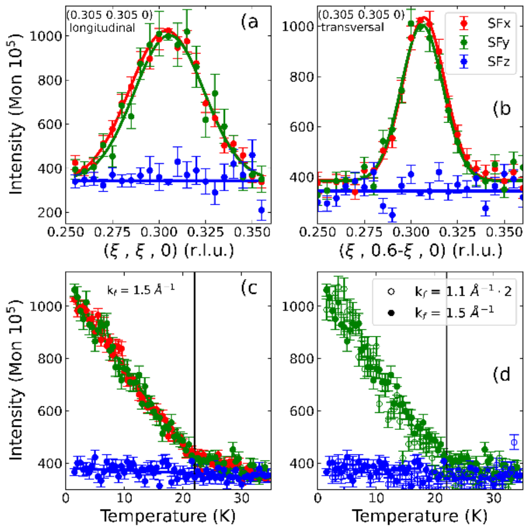


Fig. 2 Polarization analysis at the ***Q*** position of the incommensurate SDW. The signal completely stems from the ***z*** component and sets in at 22 K. The scaling of data taken with k_f=1.5 and 1.1Å^{-1} shows that the order is static on these time scales.

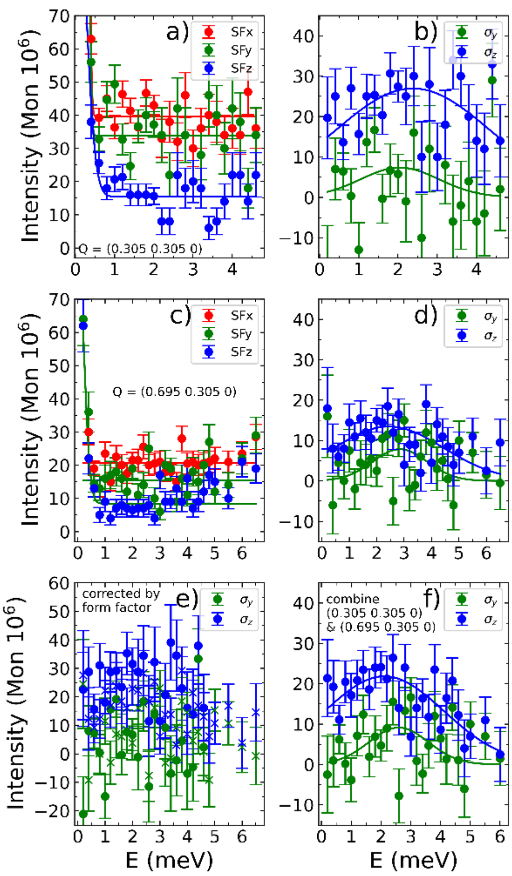
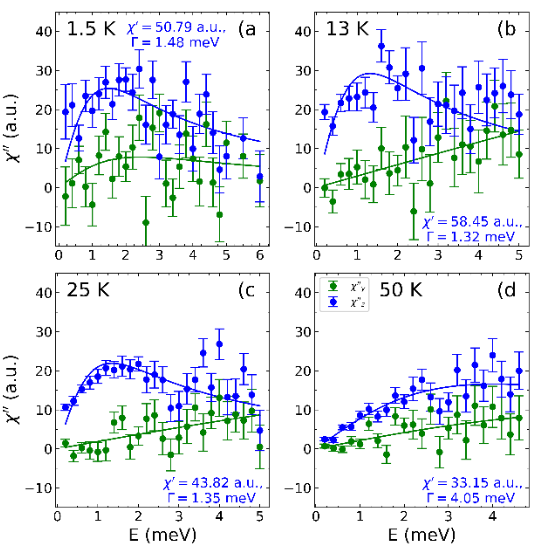


Fig. 3 Polarization analysis of the inelastic response at the (0.3,0.3,0) and (0.7,0.3,0). From the three SF channels in (a) and (c) we calculate the components of the scattering function in (b) and (d) that are compared in (e). As there is no difference visible besides the formfactor effect, we can merge the data (f).

Fig. 4 The procedure described for Fig. 3 was applied to the data at all temperatures and the Bose factor was corrected to obtain the susceptibility along and perpendicular to *c*.



The strong suppression of transversal modes is surprising. For the transverse fluctuations in a simple SDW system one expects steep magnons that extend till the scattering continuum related with the gap opened by the SDW, 2Δ, see references [6,7]. In $Sr_{1.5}Ca_{0.5}RuO_4$ the picture is fundamentally different: strong spin-orbit coupling seems to be the dominating energy scale suppressing these transversal excitations at low energy in the ordered state. On the other hand, we do not observe a gap in the longitudinal (***c*** polarized) channel, which, however, can be attributed to the multi-domain nature of the SDW state that must be expected for the condensation of the magnetic instability at an in-plane propagation vector. Assuming 2Δ~$3.6k_BT_c$, a value of 2Δ~6meV is obtained, beyond the studied energy range.

Following the same analysis, we obtain χ_c'' and $\chi_\perp''$ at the four studied temperatures displayed in Fig. 4. We describe these susceptibilities by single relaxor spectra $\chi''(E)= \chi'(E=0)\cdot\Gamma E/(\Gamma^2+E^2)$ with the characteristic energy Γ and the amplitude given by the real part of the susceptibility at E=0. These fit results for χ_c'' are shown in Fig. 5. The susceptibility χ_c'' shows the expected softening of the characteristic energy Γ and the increase of the amplitude upon cooling and approaching the magnetic transition. The characteristic energies are smaller than in pure Sr_2RuO_4 [3] already well above the transition. The suppression of the in-plane susceptibility by the spin-orbit coupling is most remarkable. The data is fully consistent with a full suppression of this signal below 2meV. The relaxor fits yield characteristic energies for this component that are well above the studied energy range, generating a strong correlation with the amplitude and preventing a reliable determination of these parameters.

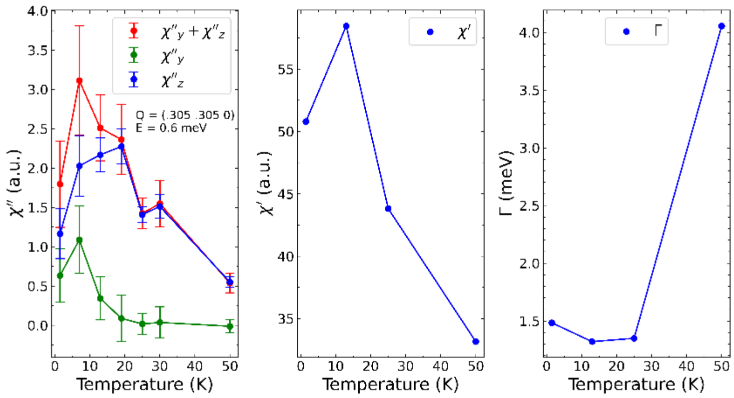


Fig. 5 (a) Temperature dependence of the anisotropic susceptibilities χ_c'' and $\chi_\perp''$ at 0.6 meV as a function of temperature. (b) and (c) present the amplitude and the characteristic energies of the relaxor fits to χ_c'' as a function of temperature.

In conclusion, we have studied the elastic and dynamic magnetic correlations in $Sr_{1.5}Ca_{0.5}RuO_4$ by polarized inelastic neutron scattering on *Thales*. Due to the large sample volume and the recent progress on *Thales*, the experiment was quite efficient yielding data of good statistics. The static signal is fully polarized perpendicular to the RuO_2 layers as a result of strong spin orbit coupling. This strong anisotropy is also observed for the inelastic response yielding almost complete suppression of the magnetic fluctuations parallel to the planes in full contrast to the usual finding in a SDW state. Qualitatively this anisotropy reflects that seen in pure Sr_2RuO_4 but it is even enhanced in this substituted compound, in which the ***c*** polarized susceptibility condenses to static order.

References

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