Experimental report

22/09/2022

Proposal: **4-01-1585** **Council:** 4/2018

Title: Spinon-phonon interaction in the low-dimensional SrCuO2

Research area: Physics

This proposal is a continuation of 4-04-481

Main proposer: **Dalila BOUNOUA**

Experimental team: Dalila BOUNOUA
Sylvain PETIT
Francoise DAMAY
David MSIKA

Local contacts: Tobias WEBER
Mechthild ENDERLE

Samples: SrCuO2

Instrument	Requested days	Allocated days	From	To
IN20	7	6	19/10/2018	25/10/2018

Abstract:

Among them, the Mott insulating spin chains system SrCuO2 was shown to exhibit a strikingly high and anisotropic magnetic heat conduction, which peaks at around 600 WK-1m-1 at 37K. Indeed, heat in SrCuO2 is conveyed by phonon and fractional S= 1/2 magnetic excitations, namely, spinons. Heat conduction by spinons occurs only along the spin chains direction and has been proven to be ballistic. The interplay between magnetic and lattice quasi-particles and chemical or structural defects during the heat transport process gives rise to various two-quasi-particles and quasi-particle-defects scattering mechanisms that govern the resulting heat conduction properties. A deep understanding of these different interaction paths is thus fundamental in order to have a clear insight of the heat transport process. However, such a microscopic description of the system is still lacking. We propose to examine the possible coupling between spinon and phonons resulting from spinon-LA phonon interaction, using polarized neutron scattering on IN20.

Exp report on 4-01-1585 : Spinon-phonon interaction in $SrCuO_2$

Scientific context: $SrCuO_2$ crystallizes in the orthorhombic space group *Cmcm*. The spin chains are formed by alternating Cu-O-Cu ions along the c-axis with nearly 180° bonding angles. The Cu^{2+} ions are square planar coordinated within the CuO_4 plaquettes contained in the [b,c] plane, and the whole structure can be described as alternating stacks of ribbons of zigzag Cu-O chains, along (H 0 0) and (0 K 0), separated by Sr atoms along (0 K 0).

This compound exhibits an anisotropic magnetic contribution to the heat transport, along the spin chains direction, where heat is carried by spinons. The magnetic excitations spectrum of $SrCuO_2$ consists of a two-spinon continuum centered at L=0.5 in r.l.u. The spin excitation spectrum is gapless in the pure compound, whereas in the doped materials spinon-defects scattering has been shown to govern the low energy region of the two-spinon continuum giving rise to the opening of spin pseudo-gap of about 7 meV, as a consequence of the chains segmentation by impurities [1-2]. The reduced chain lengths, and hence spinon mean free path cause a drastic reduction of the magnetic heat conduction. Phonon-defects scattering instead has been shown to decrease the phonon mean free paths and their group velocities resulting in a decrease of heat conduction by phonons [4]. Both of the aforementioned mechanisms dominate the low temperature region of the heat conduction, up to nearly 120K.

However, only little is known about **spinon-phonon** scattering, which is supposed to control the high temperature region of the heat conduction process. Indeed, such interactions result, experimentally, in the same value for the heat conduction in the pure as well as in the doped compounds [3] above 230K, regardless of the presence of defects. On the other hand, our previous INS measurements of the phonons modes in the pure and above-mentioned doped $SrCuO_2$ compounds highlighted a strong scattered intensity around the spin excitation spectrum, at Q(0 0 2.5), on the longitudinal phonon (Q,$\boldsymbol{\omega}$) maps for phonon modes propagating in the direction of chains Q(0 0 L) with L=[2.0-3.0]. This scattered intensity is located around the region where the longitudinal acoustic phonon and the spin excitations spectrum cross (**Fig 1.a**). This suggests a possible spinon- LA phonon interaction at around 20 meV. Note that the transverse phonon (Q, $\boldsymbol{\omega}$) maps measurements along Q(2 0 L) with L=[0.0-1.0] depict the absence of such a scattered intensity around Q(2 0 0.5) despite the fact that the TA phonon mode crosses the spinon spectrum at L=0.5 (**Fig 1.b**). This observation is reproducible in the pure as well as in the doped materials, which gives support for a possible dominant spinon-phonon scattering in this energy region, excluding any contribution from the defects (i.e. nonmagnetic impurities). This, further, hints at a possible polarization-dependent interaction between spinon and phonon degrees of freedom which might be intimately coupled.

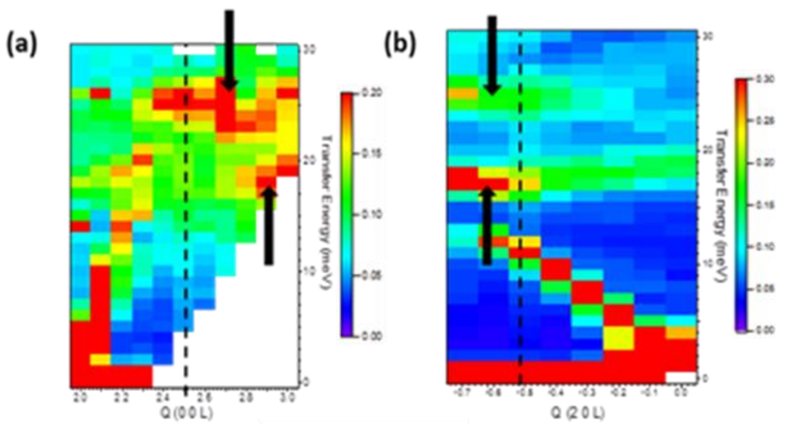

Fig.1. (a) Longitudinal phonons modes of $SrCuO_2$, propagating along Q (0 0 L), with L=[2.0,3.0]. Measured at T=4 K on the TAS 2T1. The figure shows the LA and the LO modes (indicated by the black arrrow). The black dashed lines show the position of the spin excitations spectrum. **(b)** Transverse phonons modes propagating along Q (2 0 L), with L=[0, 1]. Measured at T=4 K on the TAS 2T1. Theblack dashed lines show the position of the spin excitations spectrum. The black arrows show the TO modes at 18 and 25 meV which correspond to B3u TO modes.

Report : the aim of the experiment was to use polarized neutron scattering to probe a possible spinon-phonon interaction in the excitation spectrum of $SrCuO_2$ and get a more complete description of the microscopic heat transport mechanism in $SrCuO_2$.

The sample was aligned in the (1,0,0)/(0,0,1) scattering plane such as to access wavevectors of the form (H,0,L). The sample was cooled down to 10K using an orange cryostat. The longitudinal polarization analysis XYZ-PA was performed using Helmholtz coils. Incoming and outgoing beam polarizations were realized using Heusler crystals. The instrument was operated at a fixed k_F=2.662A^{-1}.

The flipping ratio homogeneity was checked using a Ge(111) single crystal giving $FR_X \approx FR_Y \approx FR_Z \approx 20$.
Constant energy scans were collected across (00L), along the spin chains direction in the $SF_{X,Y,Z}$ and $NSF_{X,Y,Z}$ channels at few energy values : 10, 13, 17 and 20 meV corresponding to the region where the strong scattering occurs on the (Q, $\boldsymbol{\omega}$) map in Fig.1.a.

Fig.2-4. shows the raw data collected at 10, 13 and 17 meV, respectively. A possible contribution from the two spinon continuum can be seen at L=1.5 and L=2.5 on the scans collected in the SF channel as indicated by the yellow lines.

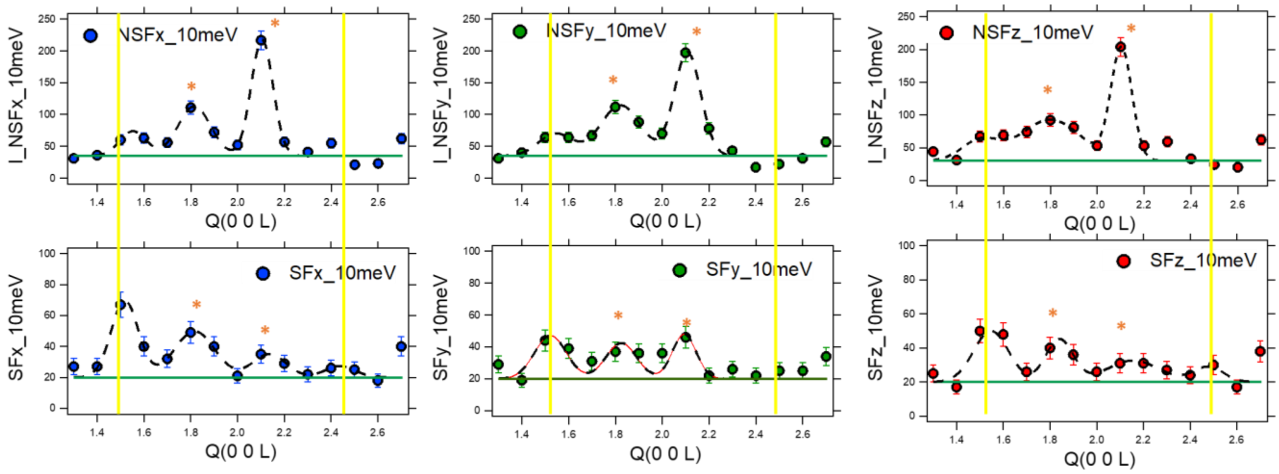

Fig.2. *Constant energy scans along the (0,0,L) spin chains direction in the $SF_{X,Y,Z}$ and $NSF_{X,Y,Z}$ channels at* $10meV$

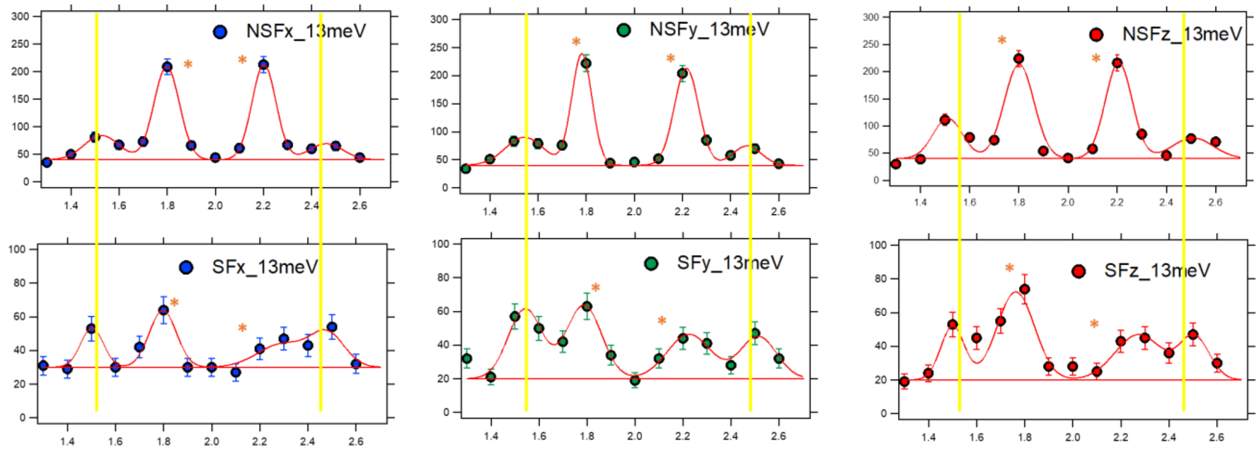

Fig.3. *Constant energy scans along the (0,0,L) spin chains direction in the $SF_{X,Y,Z}$ and $NSF_{X,Y,Z}$ channels at* $13meV$

Fig.2. further shows the signature of the longitudinal acoustic phonons at 10 meV at L=2$\pm\delta$ (indicated by the orange asterisks) in the data collected in the NSF channel. The intensity of both phonons branches follows the expected Q^2 dependence from phonons scattering. Interestingly, the modes located at the same L-values on the SF scans exhibit the opposite tendency with an intensity decreasing upon increasing Q. This hints at a possible magnetic nature of the modes observed in the SF channel rather than a simple polarization leakage from the

strong acoustic phonon scattering. The same observation can be made on the scans collected at 13 meV Fig.3. This highlights the possible existence of a hybrid magnetic-nuclear response as a signature of the spinon-phonon coupling occurring at those energies.

Fig.4. shows the data collected at 17 meV. The NSF scans only show broad phonon modes, corresponding to the strong scattering occurring in the (Q, $\boldsymbol{\omega}$) maps in Fig.1. The SF scan instead exhibit a more structured L-dependence with scattering occurring at L=1.5 and 2.5 that might arise from the two spinon continuum.

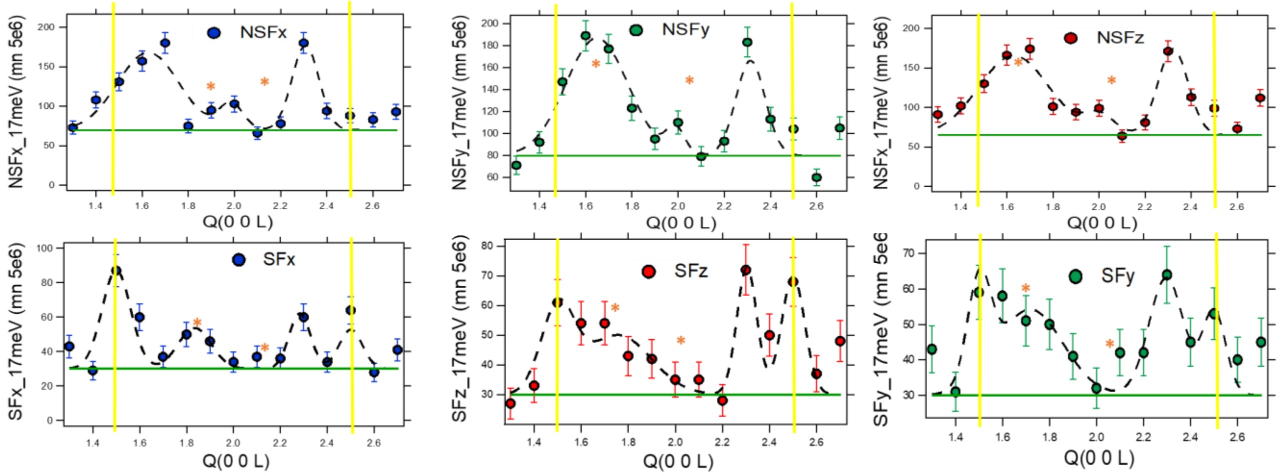

Fig.4. *Constant energy scans along the (0,0,L) spin chains direction in the $SF_{X,Y,Z}$ and $NSF_{X,Y,Z}$ channels at 17meV*

In order to estimate the leakage from the NSF to the SF channel we measured the flipping ratio on a quartz sample of similar shape as the sample in the same experimental conditions (orange cryostat, Helmholtz like coils, fixed K_F). We conducted XYZ polarization analysis on same (Q, $\boldsymbol{\omega}$) positions where we observe possible scattering from the two spinon-continuum and possible magnetic response on top of phonons. The data were collected at fixed k_F=2.662 and 4.1 $Å^{-1}$. The resulting flipping ratios are homogeneous in the three polarization directions and given in Tab.1.

k_F (A^{-1})	Energy (meV)	$FR_X \approx FR_Y \approx FR_Z$
4.1	0	11
	±2.5	10-11
	±10	7.5
2.662	0	15
	2.7	2.7

Tab.1. Flipping ratios obtained on a quartz sample

Owing to the poor quality of FR obtained at k_F=2.662 A^{-1}, quickly decreasing upon increasing the energy transfer, the conclusions that can be made on the experiment are only partial. The experiment needs to be repeated with optimized conditions and longer counting times focused on the region around 10-13 meV.

References

1. D. Bounoua, R. Saint-Martin, S.Petit, P. Berthet, F. Damay, Y. Sidis, F. Bourdarot, L. Pinsard-Gaudart. Phys. Rev. B, **95**, 224429 (2017).
2. Y. Utz, F. Hammerath, A. Mohan, C. Hess, S. Singh, D. Bounoua, R. Saint-Martin, L. Pinsard-Gaudart A. Revcolevschi, B. Büchner, and HJ. Grafe, Phys. Rev. B **96**, 115135 (2017).
3. D. Bounoua, R. Saint-Martin, S. Petit, F. Bourdarot and L. Pinsard-Gaudart, Phys B: Cond Matt (2017).
4. O. Shlagman and E. Shimshoni, Phys Rev B, **86**(7), 075442 , (2012).