Experimental report

12/08/2021

Proposal: 7-01-525 **Council:** 4/2020

Title: A New Low-Energy Excitation in Charge Density Wave Ordered YBa2Cu3O6.5

Research area: Physics

This proposal is a new proposal

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Local contacts: Alexandre IVANOV

Samples: YBaCu3O6.5

Instrument	Requested days	Allocated days	From	To
IN8	7	6	23/03/2021	30/03/2021
IN3	1	1	14/03/2021	15/03/2021

Abstract:

Raman spectroscopy performed on the charge density wave (CDW) ordered underdoped YBa2Cu3O6.5 (YBCO) has demonstrated the existence of a novel excitation associated with the superconducting state and/or the CDW order. At present, the nature of this excitation is unclear, however, there are some interesting possibilities: It may be the Higgs (or amplitude) mode of the superconducting condensate. Here we propose to study the mode by inelastic neutron scattering to determine its dispersion and the effect of magnetic field

EXPERIMENT 7-01-525 ON IN8 IN MARCH 2021 AND EXPERIMENT TEST-3199 ON IN8 IN MAY 2021
A NEW LOW-ENERGY EXCITATION IN CHARGE DENSITY WAVE ORDERED $YBa_2Cu_3O_{6.5}$

A. Abstract

$YBa_2Cu_3O_{6.5}$ is a high-temperature cuprate superconductor which develops a charge-density wave (CDW) at low temperature and exhibits a double-layer structure made up by CuO_5-half-octahedra. X-ray diffraction in magnetic field has established the competition between the superconducting and the charge-density wave order parameters [1]. The magnetic excitations in $YBa_2Cu_3O_{6.5}$ are known to be of paramagnonic nature centred around the antiferromagnetic points with hourglass-shaped dispersion and a resonance at about 20 meV [2–4].
Recently, a novel excitation was observed in Raman spectroscopy inside the superconducting and charge-ordered phases at about 7 meV with an usual field dependence. It was suggested that this might correspond to a phonon back-folded by the CDW, an unknown magnetic excitation or the Higgs mode of the superconducting fluid which can only be probed in Raman spectroscopy by taking spectral weight from another excitation such as the amplitude mode of the CDW [5, 6].
The aim of these experiments was to examine if this excitation can also be observed by neutrons scattering and to characterise it's dispersion and field dependence. We observe a new excitation at $6.5 - 7$ meV centred around the Brillouin zone centre with a small reduction the lifetime in high magnetic fields and unusual variation in intensity along [00L]. This excitation could be of magnetic nature and represent an ferromagnetic analogue to the antiferromagnetic resonance or might as suggested represent the Higgs mode of the superconducting fluid.

B. Experimental details

These experiments [7] where performed on the three-axis spectrometer IN8 equipped with an 10 T-vertical cryomagnet for experiment 7-01-525 and with an orange cryostat for experiment TEST-3199. As monochromator and analyser Si(111) and PG(002) were used, respectively. Measurements at a variety of fields and temperatures as well as a collimated/low-flux setup to avoid phonons and minimize background and an uncollimated/high-flux setup for mapping multiple Brillouin zones.
Both experiments were performed on a melt-grown $YBa_2Cu_3O_{6.5}$ single crystal which was mounted for the experiment 7-01-525 with [00L] vertically and for the experiment Test-3199 with [H00] vertically.

C. Preliminary Results

We observed a novel excitation at energies between 6.5 meV and 7 meV (see Figure 1c)) which we affiliate with the excitation observed in Raman and which might also be related to an unknown excitation observed in reflectivity [8]. The excitation is centred at the Brillouin zone centres in the *ab*-plane with a suppression of spectral weights towards the Brillouin zone boundaries. In Figure 1a) we show measurements with a collimated setup for high resolution at 0 T and 10 T where the high field data show a slight broadening of the peak widths which suggest a shortening of the excitation's lifetime with increasing field. This suggest that the excitation is affiliated with the superconducting fluid than with an ferromagnetic resonance where one would expect an increase in coherence for fields large enough to overcome possible easy-axis in-plane and hard-axis out-of-plane anisotropies [9, 10]. The excitation has further a clear temperature dependence which is depicted in Figure 1b) where the difference between the data at 1.5 K and 70 K is taken under consideration of the Bose factor. The excitation appears stronger at lower temperatures.
We further observe an unusual L-dependent variation in intensity shown in Figure 1b) which might arise from the double-layered structure rather than the lattice periodicity as has been observed for the antiferromagnetic paramagnons [10–12].
The excitation is well observable in lower Brillouin zones and is not observable in higher in-plane Brillouin zones. This might be because of loss in intensity due to form factors or due to masking by phonons. Both would contradict the picture of a back-folded phonon where an increase in intensity $\propto Q^2$ is generally expected.

D. Conclusions and publication of this work

A novel excitation is observed at the Brillouin zone centres at lower Q with a slight loss of lifetime in increasing fields. The excitation shows an uncommon out-of-plane intensity variation. These two aspects favour either a ferromagnetic resonance with a strong anisotropy competing with the applied field or a Higgs mode picture affiliated with the

superconducting fluid.
This work is planned to be published and will contribute to the PhD thesis of Alexander Petsch.

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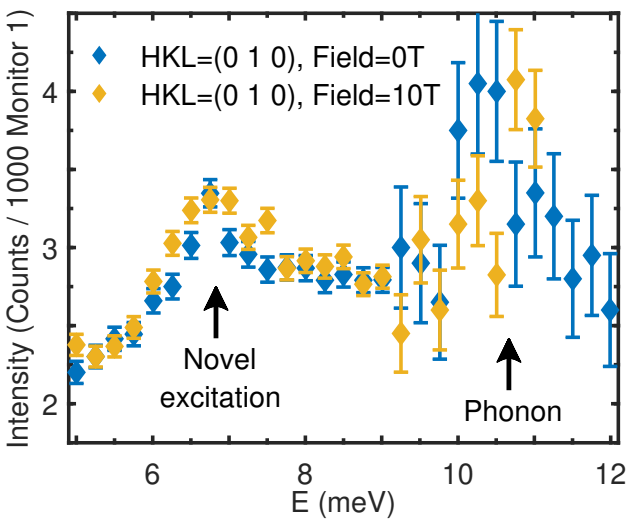
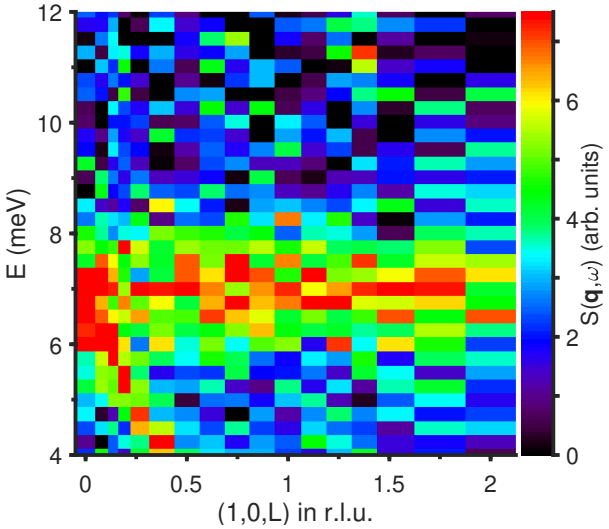
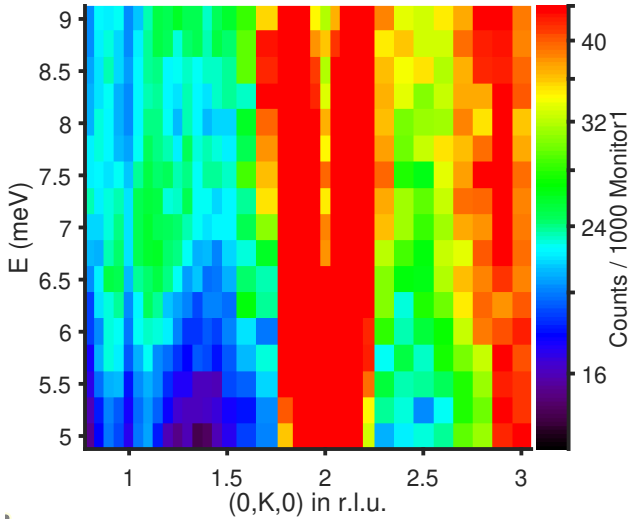


(a) The constant **Q**-cut at (010) and 1.5 K shows significant broadening of the novel excitation at 10 T with respect to zero field which implies a shortened excitation's lifetime.



(b) Difference between 1.5 K data and 70 K scattering functions S(**Q**,$\hbar\omega$) with Bose factor correction in the (1,0,L)-$\hbar\omega$ plane.



(c) Data from longitudinal measurements which show clearly the optical phonon modes as well as the weak novel excitation at about 6.5 meV to 7 meV.