NÉEL INSTITUTE Grenoble

Topic for Master 2 internship – Academic year 2021-2022

Higgs Modes in Superconductors

General Scope :

When a spontaneous breaking of a continuous symmetry takes place, for instance when crossing the normal to **superconducting** transition, collective excitations of the order parameter emerge:
They are the phase modes and the massive **amplitude Higgs mode,** as illustrated Fig.1 in red.
There is growing interest in the search and the study of the fundamental collective Higgs mode, as an analogous in quantum many body systems of the particle physics Higgs boson and as a fingerprint of the properties of the superconducting state. Indeed, even if theoretically always here in any superconductors and even if presented as a textbook excitation, this 'dark' mode remains very elusive. In principle, it does not couple to any external probe. Our purpose is to identify this Higgs mode in various compounds, with different type of superconductivity (symmetry, mechanism, coupled electronic orders).

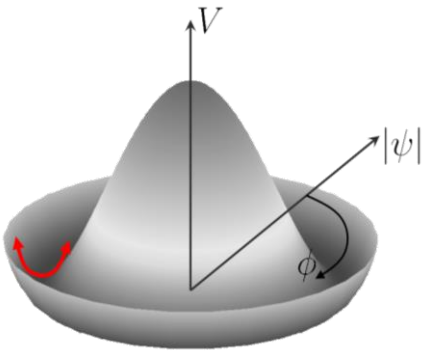

Fig. 1: Mexican-hat-shaped potential of the free energy as a function of the complex order parameter $|\psi| e^{i\phi}$. There are two types of fundamental collective mode around the new equilibrium state taken spontaneously in the line of minima. One, the amplitude mode in red, is known as a "dark" mode and is the analogous of the Higgs boson. In superconductor, it corresponds to coherent oscillatory pairings and depairings of the Cooper pairs of electrons.

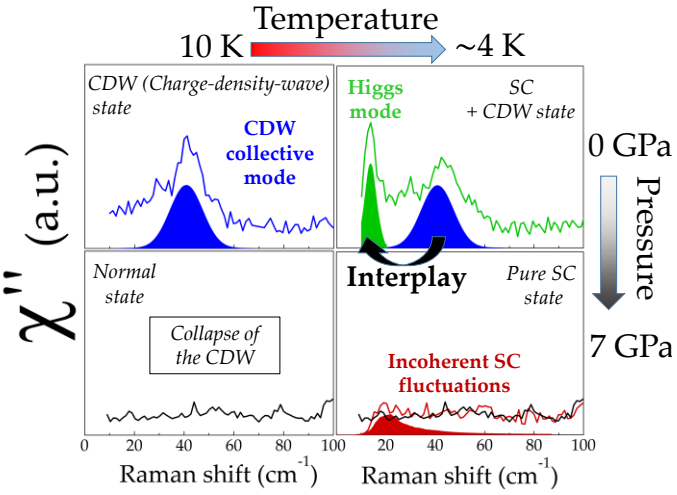

Fig. 2: Raman spectra of 2H-$NbSe_2$ under high pressure and at low temperature. Evidence of the requisite of the adjacent CDW state (in blue) for the Higgs mode (in green) observability: Pressure-induced concomitant collapse of the Higgs mode and CDW state.

Research topic and facilities available:

The compounds where a superconducting Higgs mode has been claimed to be present are the ones where superconductivity coexists with another type of electronic order, such as charge density wave (CDW). In these systems, like in $NbSe_2$ (see Fig. 2), the amplitude oscillations of the CDW order parameter (CDW mode) can be detected by Raman spectroscopy. When the system becomes superconductor, a new Raman peak emerges. It has been attributed to the Higgs mode. This is one of the very few examples of such Higgs mode measurements. The student will explore a new family of compounds to discover new Higgs mode which, as fingerprint of its underlying quantum order, may give access to properties of the electronic orders and their interplay. The student will perform symmetry dependent electronic Raman scattering experiment under extreme conditions, at low temperature and under high pressure, on a chosen family of superconductors.

Possible collaboration and networking: We already have a close theoretical collaboration with Lara Benfatto (Roma) on this topic. Collaborations with samples' growers (France and abroad), high

magnetic field facilities (Nijmegen), High pressure labs (Paris), Optics (Germany) is also established.
Networking: ERC project.

Possible extension as a PhD: YES. This study will be done in the context of a financed European ERC project.

Required skills: knowledge of condensed matter physics, curiosity, taste for delicate experiments.

Starting date: march-april 2022

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