

# Kondo cloud in magnetic molecules coupled to superconductor

Quantum physics has completely revolutionized our understanding of the universe during the past century. Nevertheless, quantum phenomena/correlations in matter, with very few exceptions such as superconductivity, exist in extremely small length and time scales rendering them a Herculean task to study experimentally. Therefore, the direct detection and studies of quantum correlations at larger scales will be invaluable in the deeper understanding of quantum physics in general. One prominent phenomena where quantum correlations exist in an unusually large length scale is the Kondo effect. This many-body effect relies on the screening of the spin of a magnetic impurity by the conduction electrons in bulk materials as well as mesoscopic structures. The screening is manifested through the formation of a cloud of conduction electrons that are quantum correlated in nature, known as the Kondo cloud, which was predicted to reach length scales of micrometres. After many years of unsuccessful attempts to detect the Kondo cloud, very recently, Ivan V. Borzenets et al. [Nature 579, 210 (2020)] confirmed the presence of Kondo cloud using the Fabry-Perot oscillations in a mesoscopic system. This milestone achievement paves the way for exploring the spatial properties of different strongly-correlated states in nanoscale devices. In particular, it opens up the field for further research into the behavior of Kondo cloud in various mesoscopic systems, such as molecular junctions, nanowires or single-electron transistors. Theoretical investigations into such systems are imminent for the efficient development of the experimental part of the field.

Thus, the main objective of this project is to fulfil the newly created knowledge gap in the reliable theoretical predictions for the properties of Kondo cloud, especially in the context of large-spin molecules attached to superconducting electrodes. It is worthwhile to note the significance of introducing a superconducting environment to the system, which can be attributed to the recent theoretical developments in the properties of the Kondo cloud i.e., when a spin one-half impurity is attached to a superconductor, a quantum phase transition between the screened and unscreened phases occurs as the superconducting energy gap becomes comparable with the Kondo temperature. Interestingly enough, screening clouds were shown to exist even for the unscreened phase of the system. Moreover, large-spin molecules such as molecular magnets trapped in a mesoscopic system, unlike simple quantum dot systems, possess additional intrinsic parameters such as exchange interaction and magnetic anisotropy, which can greatly influence the screening processes and thus, the spatial extension of the Kondo-correlated states. Consequently, the realization of this project will provide new insights into the interplay between the exchange and spin-orbit interactions as well as Kondo correlations in the studied systems.

The state-of-art numerical techniques in the field, particularly based on renormalization group methods, will be employed along the duration of the project to estimate the spatial extension of the Kondo cloud. Thus, this project will improve our fundamental understanding of the strongly correlated/entangled states in quantum impurity systems, which according to the recent experimental developments, can be experimentally studied. Moreover, the knowledge about the spatial correlations gained from this project will contribute greatly to the fields of nanoelectronics, molecular electronics, molecular spintronics, quantum information technologies. Especially, the possibilities lie in the development of novel technologies in the nanoscale aimed at the storage and processing of quantum information.