Critical phenomena and transport in correlated hybrid nanostructures

Transport properties of correlated hybrid nanostructures, involving molecules and atoms as well as their artificial counterparts, coupled to external contacts are the subject of extensive theoretical and experimental studies not only due to various fundamental aspects and new physical phenomena, but also because of possible applications in nanoelectronics and quantum technologies for storing and processing information. However, to further progress the development of quantum technologies or to propose any working device, it is of crucial importance to fully understand the system's behavior under different conditions, involving both equilibrium and out-of-equilibrium situations as well as the stationary and transient regimes. In this regard, a special attention has been recently paid to the time-dependent phenomena and dynamical quantum critical behavior triggered upon a controllable change of the system's parameters, which may lead to dynamical phase transitions – a counterpart of conventional phase transitions but taking place in time. Up to now, such phase transitions have been mainly studied in the case of global parameter changes, and only very recently it has been demonstrated that the concept of dynamical phase transitions can be extended to mesoscopic hybrid systems involving nanoscale objects. In such systems, local perturbations can be performed in a fully controllable fashion, allowing for more flexible exploration of dynamical phenomena in artificial heterostructures. One of the simplest mesoscopic hybrid systems involves a quantum dot attached to superconductor, as shown in the figure. In such setup, upon a sudden switching on of the coupling to superconductor, the system exhibits dynamical phase transitions associated with stationary transition between the corresponding distinct (singlet and doublet) states of the system. In this context, an extension of the concept of dynamical quantum criticality and reliable knowledge of time-dependent properties of more realistic and complex hybrid nanostructures is an important goal. The main objective of this project is therefore to search for signatures of dynamical phase transitions, shed new light and provide accurate predictions for the dynamical and transport behavior of complex hybrid nanostructures, involving, among others, large-spin molecules or multi-level quantum dots interacting with superconducting reservoirs as well as hybrid artificial molecules or multiple quantum dot systems, which enable the realization of the so-called Yu-Shiba-Rusinov molecules, dimers or trimers. Such systems are relevant in the context of novel applications in quantum technologies and our investigations will address various fundamental questions relevant to broad physics community, which still remain unexplored. The considerations performed in this project will be based upon very accurate numerical methods, such as time-dependent numerical renormalization group method, which allow for obtaining high-quality quantitative results with all the correlations and interactions taken into account in an essentially exact manner. The planned investigations and calculations will thus provide very reliable results for the time-dependent and transport phenomena that will be of relevance to both theoretical and experimental works. Moreover, our theoretical predictions shall foster further investigations of physical properties of hybrid nanoscale systems and devices. Finally, because the research in the highly specialized areas, as described in this proposal, is very important not only for fundamental science but also for high-tech industry and innovation, the execution of the project will contribute to the development of new competitive and environmental-friendly technologies.

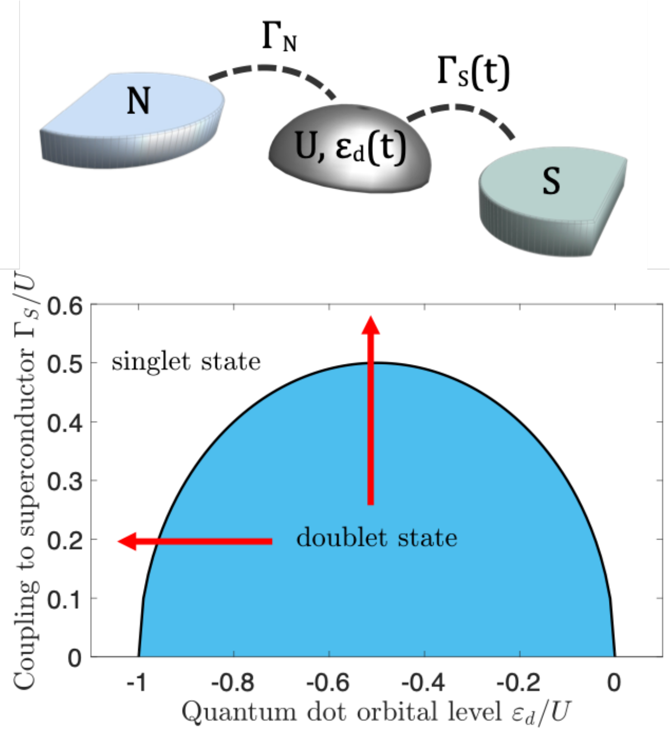

Figure: (Top) Schematic of a hybrid mesoscopic system exhibiting dynamical quantum phase transitions. It consists of a quantum dot (middle) coupled to superconducting (S) and normal (N) contacts. (Bottom) The stationary phase diagram of the system. The dynamical phase transition occurs when tuning the system between doublet and singlet phases (as indicated by red arrows).