TT 85: Superconductivity: Yu-Shiba-Rusinov and Andreev Physics

Time: Thursday 15:00–17:15 Location: CHE/0089

TT 85.1 Thu 15:00 CHE/0089

Tip-gated quantum phase transition via valence change in a single Yu-Shiba-Rusinov impurity — •Xingsen Chen[1], Junyi Zhang[2], and Hao Zheng[1] — [1]Tsung-Dao Lee Institute, Shanghai Jiao Tong University, Shanghai, China — [2]Johns Hopkins University, Baltimore, USA

We report the real-space visualization of a quantum phase transition driven by a valence change in a single magnetic impurity coupled to a superconductor. Using a scanning tunneling microscope on a proximitized $Bi_2Te_3/NbSe_2$ substrate, we employ tip-induced band bending to precisely gate the energy level of a single Fe-based impurity cluster across the Fermi energy.

This tuning induces the formation of Yu-Shiba-Rusinov states inside the superconducting gap. Their evolution and zero-energy crossing signal a quantum phase transition. By correlating the YSR state transition with a concurrent high-energy valence transition, we identify the mechanism as a single-electron valence change of the Fe impurity (Fe^{2+}/Fe^{3+}), rather than conventional Kondo screening. Theoretical modelling using a multi-orbital Anderson impurity model confirms that the transition is governed by resonant hybridization and charge fluctuations at the mixed-valence point.

Our work establishes tip-gating as a powerful method for in-situ control of atomic-scale quantum phases and reveals a distinct mechanism for quantum phase transitions in superconducting hybrids.

TT 85.2 Thu 15:15 CHE/0089

Rare-earth spin chains on superconducting Nb(110) surface — •Yu Wang[1], Artem Odobesko[1], and Matthias Bode[1,2] — [1]Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Wilhelm Conrad Röntgen-Center for Complex Material Systems (RCCM), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Coupled Yu-Shiba-Rusinov (YSR) states in 1D magnetic chains can yield topologically protected edge modes. While well explored for $3d$ transition metals, studies on $4f$-shell rare-earth metals (REMs) remain scarce. Owing to their localized and shielded $4f$ orbitals, REMs such as Ce, Eu, Gd, Tb, and La provide a promising platform for weakly hybridized magnetic chains on superconductors.

We present a comparative study of YSR excitations in REM adatoms and chains on Nb(110). Building on previous Gd results [1-2], we extend the analysis to Tb and other REM chains along [1$\bar{1}$0] and [001]. Spectra reveal orientation-dependent edge behavior: [1$\bar{1}$0] chains host trivial end states, whereas [001] chains show zero-bias features consistent with non-trivial edge modes. The results highlight the impact of $4f$ magnetism on YSR band formation and topological superconductivity.

[1] Y. Wang *et al.*, arXiv:2506.19514 (2025)
[2] Y. Wang *et al.*, arXiv:2311.09742 (2023)

TT 85.3 Thu 15:30 CHE/0089

Yu-Shiba-Rusinov spectroscopy of triangular molecular trimer on superconducting surface — •Vladislav Pokorný[1], Martin Žonda[2], and Chao Li[3,4] — [1]FZU - Institute of Physics, Czech Academy of Sciences, Na Slovance 2, 182 00 Prague 8, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, 121 16 Prague 2, Czech Republic — [3]Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland — [4]Institute of Atom Manufacturing, Nanjing University, Suzhou 215163, China

We present a study of a molecular trimer constructed from tetrabromotetraazapyrene molecules deposited on a superconducting Pb(111) surface in a triangular geometry. Scanning tunneling spectroscopy reveals a pair of split Yu-Shiba-Rusinov (YSR) states within the superconducting gap as a result of the spinful nature of the molecules [1]. The system is described using a superconducting three-impurity Anderson model with a single superconducting bath. The model is solved using the numerical renormalization group technique, which provides a quantitative description of the experimental result, revealing the doublet nature of the ground state as a result of the intersite capacitive coupling and explains the behavior of the YSR states. We also briefly discuss the possible source of the peak splitting.

[1] C. Li et al., arXiv:2508.05575 (2025).

TT 85.4 Thu 15:45 CHE/0089

Stochastic resonance realized with a superconducting magnetic impurity state — •Philipp Maier[1], Björn Kubala[1,2], Joachim Ankerhold[1], and Ciprian Padurariu[1] — [1]Institute for Complex Quantum Systems and IQST, Ulm University — [2]German Aerospace Center (DLR), Ulm

The phenomenon of stochastic resonance (SR) was originally studied in the context of climatic changes and has since been observed in a variety of classical and quantum systems. Here, we theoretically investigate the emergence of SR in superconducting junctions to infer the rates of quantum electronic tunneling processes [1, 2].

We focus on a system where one electrode hosts a Yu-Shiba-Rusinov (YSR) state – a discrete bound state within the superconducting gap induced by the magnetic exchange interaction between a magnetic impurity and its superconducting host.

Applying the framework of full counting statistics (FCS), we demonstrate that SR manifests as a reduction of the Fano factor and a resonance of the tunneling current. Crucially, the frequency of this resonance reveals information about the rate of microscopic electronic processes, such as the process responsible for quasiparticle-occupation parity breaking.

[1] M. Hänze et al., Sci. Adv. 7 (2021)
[2] T. Wagner et al., Nat. Phys. 15 (2019)

TT 85.5 Thu 16:00 CHE/0089

Analytical and ab-initio characterization of YSR-state binding energies under magnetic-moment misalignment — •Ilias Klepetsanis[1,2] and Samir Lounis[3] — [1]Forschungszentrum Jülich & JARA, Germany — [2]University of Duisburg-Essen and CENIDE, Germany — [3]Martin-Luther University Halle-Wittenberg, Institut für Physik and Halle-Berlin-Regensburg Cluster of Excellence CCE Halle, Germany

Complex spin textures interfaced with superconducting surfaces give rise to a rich variety of phenomena, ranging from the emergence of intricate in-gap states –such as Yu-Shiba-Rusinov (YSR) states– to the realization of topological superconductivity hosting Majorana modes. At the core of these effects lie competing and intertwined interactions involving Cooper pairing, spin-spin coupling, and spin-orbit-driven mechanisms. In this work, we systematically and analytically identify how the binding energies of YSR states in atomic nanostructures depend on the orientation of their magnetic moments. We distinguish between different underlying mechanisms, including those that are independent of spin-orbit coupling (SOC) and those that arise from SOC-driven magnetic misalignment. Results obtained using an Anderson-impurity model coupled to the Bogoliubov-de Gennes (BdG) formalism are compared with both DFT-BdG calculations for Fe nanostructures on a superconducting $BiAg_2$ surface and available scanning tunnelling microscopy measurements.

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15 min. break

TT 85.6 Thu 16:30 CHE/0089

Emergence of new zero modes bound to vortices in extended topological Josephson junctions — •Adrian Reich[1], Kiryl Piasotski[1,2], and Alexander Shnirman[1,2] — [1]Institute for Theoretical Condensed Matter Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany

We theoretically study planar Josephson junctions formed on the surface of a three-dimensional topological insulator (Fu-Kane proposal) and examine the experimentally relevant parameter regimes in which the effective velocity of the emergent one-dimensional Majorana modes approaches zero. We show that the frequently employed Fu-Kane effective theory breaks down in this case. As parameters like the chemical potential or the width of the junction are tuned, instances of vanishing effective velocity mark the emergence of additional "Dirac cones" at zero energy and finite momentum. If the junction is subjected to an external magnetic field, Josephson vortices may then bind a number of zero modes in addition to the topological Majorana mode. The additional zero modes are "symmetry-protected" and can be lifted by a broken mirror symmetry (which is to be expected in realistic scenarios) as well as by an in-plane magnetization (or Zeeman field). We note that the ensuing presence of additional low-energy Andreev states can significantly contribute to measured quantities like the Josephson current or microwave absorption spectra.

TT 85.7 Thu 16:45 CHE/0089

Local Observation of Andreev Billiards in an In-Plane Magnetic Field — •Jens Brede, Adrian Greichgauer, and Yoichi Ando — University of Cologne

Quasiparticles in a normal metal can be confined by a surrounding superconductor through Andreev reflection at the N/S interface. For subgap energies, electrons are retroreflected as holes that retrace their paths, forming closed semiclassical trajectories. When their accumulated phase reaches 2π, these trajectories create Andreev bound states (ABS), observed as subgap features in the local density of states (LDOS). We probe these ABS using STM at 400 mK in the two-dimensional electron gas of the Cu(111) surface state, confined to quasi-rectangular islands by superconducting Nb. We observe a hard superconducting gap and, with increasing in-plane magnetic field, nearly periodic LDOS gap closings. The period scales roughly linearly with the island dimension perpendicular to the field direction. A simple model that incorporates the vector potential into the semiclassical trajectories qualitatively reproduces the experimental behavior.

TT 85.8 Thu 17:00 CHE/0089

Assessing effective models of double quantum dot Andreev molecules — •Kacper Wrześniewski[1], Peter Zalom[2], Tomasz Tomáš Novotný[3], and Ireneusz Weymann[1] — [1]Institute of Spintronics and Quantum Information, Faculty of Physics and Astronomy, Adam Mickiewicz University in Poznań, Poland — [2]Institute of Physics, Czech Academy of Sciences, Praha, Czech Republic — [3]Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Praha, Czech Republic

We investigate the phase diagram of a parallel double-quantum-dot Andreev molecule, in which the two quantum dots are coupled to a common superconducting lead. Using the numerical renormalization group (NRG) method, we analyze the evolution of the ground state across a broad parameter space, including level detuning, superconducting gap size, lead couplings, and interdot hopping. The resulting phase diagrams exhibit singlet, doublet, and a relatively uncommon triplet ground state, the latter serving as a clear signature of strong lead-mediated interactions between the quantum dots.

To evaluate the reliability of simplified theoretical descriptions, we benchmark the applicability of several effective models, including the atomic limit and zero-bandwidth approximations. Our results reveal notable limitations of these approaches: with the exception of the extended zero-bandwidth approximation, the effective models fail to reproduce the triplet ground state. These findings provide valuable guidance for interpreting experimental data and for the design of superconducting devices based on quantum dots.