The exact properties of ultracold polarons

Jia Wang[a], Xia-Ji Liu[a] and Hui Hu[a]

[a]*Centre for Quantum Technology Theory, Swinburne University of Technology, Melbourne 3122, Australia*

Polaron, arguably the most celebrated quasiparticle, consists of an impurity dressed with elementary excitations of a many-body background. Polaron plays an essential role in understanding the properties of a wide variety of quantum materials and holds great potential for improving the designs of quantum optoelectronic devices. Ultracold gases provide a perfect experimental platform for investigating the associated impurity problem, thanks to the unprecedented controllability and rich atomic physics toolbox. Here, we investigate systems of a heavy impurity in ultracold gases where exact solutions exist and provide a unique basis to develop a profound understanding.

If the background medium is a non-interacting Fermi gas, polaron resonances reduce to singularities because of the well-known Anderson's "orthogonality catastrophe" (OC). OC refers to the fact that the many-particle states with and without impurity interactions are orthogonal since multiple particle-hole excitations can be excited without costing recoil energy. We extend the non-perturbative functional determinant approach (FDA) to investigate the impurity's nonlinear response in multidimensional spectroscopy. We observe the correlations and many-body dynamics between these Fermi singularities [1].

On the other hand, if the background gas is Fermi superfluid with excitation gaps, the energy cost for pair breaking prevents OC. It allows the existence of polaron quasiparticles in the exactly solvable heavy impurity limit. Hence, we rigorously confirm the remarkable features such as dark continuum, molecule-hole continuum, and repulsive polaron. For a magnetic impurity scattering at finite temperature, we predict additional resonances related to the subgap Yu-Shiba-Rusinov bound state, whose positions can be used to measure the superfluid pairing gap. Surprisingly, we find undamped repulsive polarons for a nonmagnetic impurity at zero temperature [2, 3].

[1] Jia Wang, arXiv: 2207.10501 (2022).

[2] Jia Wang, Xia-Ji Liu, and Hui Hu, *Phys. Rev. Lett.* **128**, 175301 (2022).

[3] Jia Wang, Xia-Ji Liu, and Hui Hu, *Phys. Rev. A* **105**, 043320 (2022).