Visualizing the Emergence of Heavy Fermions and their Exotic Properties

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In metallic compounds containing elements with f-electrons, the interaction between f-electrons and surrounding itinerant electrons leads to the development of composite electron-like particles with a very heavy effective mass at low temperatures. These composite particles are fundamental to the appearance of unconventional superconductivity and other exotic behaviors observed in actinide- and rare-earth-based compounds. Recently, there has been a major breakthrough in the application of scanning tunneling microscopy (STM) techniques to study of heavy fermions [1-2]. In this talk, I will review these recent developments and will describe how we used the STM techniques to detect for the first time the emergence of heavy fermions with lowering of temperature in a prototypical family of heavy-electron materials. [2] These experiments demonstrate the sensitivity of the tunneling process to the composite nature of these heavy particles, which arises from quantum entanglement of itinerant and f-electrons. Scattering and interference of the composite particles is used to resolve their energy–momentum structure and to extract their mass enhancement, which develops with decreasing temperature. The lifetime of the emergent heavy particles reveals a direct relationship between their energy and temperature dependence, a consequence of proximity to a zero-temperature quantum phase transition. These experiments open a new window to probe the apparent non-Fermi liquid behavior in heavy fermions compounds, as well as decades-old puzzles of superconductivity and other complex ordering phenomena involving heavy electrons.

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[1] P. Aynajian, E. H. deSilva Neto, A. Gyenis, R. E. Baumbach[†], J. D. Thompson[†], Z. Fisk[‡], E. D. Bauer and A. Yazdani, *Nature* **486**, 201 (2012).