Quantum Phase Transitions out of the Heavy Fermi liquid

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Recommended with a commentary by Matthew Fisher, University of California, Santa Barbara.

In the heavy fermion materials, the magnetic coupling between the conduction electrons and the local moments can lead to enormous mass enhancements. Following its discovery (in 1979), superconductivity in the heavy fermions was of primary focus. But attention has gradually refocused on the non-Fermi liquid character observed above the point where the Antiferromagnetic transition temperature tends to zero as a function of some tuning parameter. From the earliest discovery of this phenomena in a Cerium intermetallic compound, the importance of a quantum critical point in many of these materials, separating the heavy fermion state from a magnetic metal, has been emphasized. The standard theoretical framework which treats this quantum phase transition as a fermi surface spin-density-wave instability has been woefully inadequate in accounting for the measured non-fermi liquid character - leaving the field in somewhat of a theoretical conundrum.

One of the bolder proposals seeking to resolve this dilemma has appeared in a series of recent papers by T. Senthil, S. Sachdev and M. Vojta - succinctly summarized in the above paper. Their basic premise is that the magnetism is an ``afterthought", and that the phase transition is driven by a breakdown of the Kondo screening (present in the heavy fermion state), rather than the development of magnetism. Within their scenario, there would be two characteristic crossover length and energy scales on the magnetic side near the quantum phase transition. Specifically, above the magnetic ordering temperature but below a higher coherence scale, the system is predicted to be in an exotic regime with a small conduction electron fermi surface coexisting with a spin-liquid derived from the local moments. Magnetism then develops as an instability of the spin-liquid, driven by confinement.

As revealed in various simple toy models, phase transitions of this kind which involve two diverging length scales appear to be commonplace in quantum systems. But establishing the legitimacy (or not) of this intriguing scenario in the heavy fermion materials will require more detailed experimental signatures (and experiments). Possible spin-offs for other correlated materials, such as the cuprates, are worth contemplating.