Novel electronic phases and competing interactions in the heavy fermion compound URu_2Si_2

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The heavy fermion compound URu_2Si_2 undergoes a second order transition at $T_o = 17.5$ K into an ordered phase whose identity has eluded researchers for three decades [1]. This so-called hidden order (HO) phase coexists with a type of unconventional superconductivity (SC) that is found below $T_c \approx 1.5$ K. The features in the electrical resistivity, specific heat and magnetic susceptibility associated with the HO phase transition are reminiscent of a charge or spin density wave that forms a gap over about 40% of the Fermi surface below T_o, with the remainder of the Fermi surface gapped by the SC below T_c [2]. The compound URu_2Si_2 has been studied extensively using many experimental techniques (e.g., transport, thermal, magnetic, and spectroscopic measurements), and numerous theoretical models have been proposed for the HO phase [1]. In this talk, we review selected experimental studies of URu_2Si_2 in which competing interactions have been tuned by varying the composition of elemental substituents, applied pressure, and magnetic field, yielding a rich variety of novel electronic phases and phenomena. For example, application of pressure depresses the T_c of the SC'ing phase and induces a transition from the HO phase to an antiferromagnetic (AFM) phase at a critical pressure $P_t \approx 1.5$ GPa [1,3]. Substitution of isoelectronic Fe for Ru suppresses SC and induces a transition from the HO phase to an AFM phase, accompanied by a more than two-fold increase in the temperature of the HO/AFM phase boundary, similar to what occurs in pure URu_2Si_2 under pressure. This led to the suggestion that the HO-AFM phase transition in $URu_{2-x}Fe_xSi_2$ is driven by "chemical pressure" P_{ch} associated with the reduction of the unit cell volume upon substitution of smaller Fe atoms for Ru atoms [4], which is supported by recent experiments on single crystals of $URu_{2-x}Fe_xSi_2$ prepared in our laboratory. The experiments reveal that the T-P_{ch} phase diagram and variation of the U magnetic moment with P_{ch} for $URu_{2-x}Fe_xSi_2$ are consistent with the T-P phase diagram and evolution of the U magnetic moment with P in URu_2Si_2 [5]. Single crystals of $URu_{2-x}Fe_xSi_2$ provide an opportunity to study the transition from the HO to the AFM phase at atmospheric pressure with methods such as ARPES or STM that cannot be readily performed on URu_2Si_2 under high pressure. These studies will yield information about the electronic structure of the HO and AFM phases in URu_2Si_2 and, hopefully, clues to the identity of the order parameter of the elusive HO phase. Support of the US DOE, NNSA, and NSF is gratefully acknowledged.

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