Hidden Order State in URu_2Si_2

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The so-called "hidden order" state in the heavy-fermion superconductor URu_2Si_2 has been a mystery since its discovery more than 20 years ago. On cooling large anomalies appear at T_0 = 17.5 K in transport and thermodynamic measurements, but the microscopic origin of this transition is still unclear. In the SPSMS we made a strong effort in the last years to get more insight into the nature of this state by determining precisely the high pressure phase diagram and performing a new set of detailed neutron scattering experiments under high pressure in combination with thermal expansion measurements. The results of these experiments allow us to clarify the inelastic neutron response in the different phases, HO and the large moment antiferromagnetic state (LMAF) under high pressure, to get a microscopic signature of the HO state.

URu_2Si_2 is a heavy fermion system which attracts a lot of attention in the strongly correlated electron system community due to its still mysterious transition at T_0=17.5 K to the so called hidden order state, and due to the coexistence of this state with a superconducting state at low temperatures. To precise the high pressure phase diagram of URu_2Si_2, we performed accurate resistivity and ac calorimetric measurements on the same single crystal under the highly hydrostatic pressure conditions of argon in a diamond anvil pressure cell. The obtained phase diagram is shown in Fig. 1. In both properties we observe the transition from the HO ground state to a large moment antiferromagnetic state above a critical pressure p_x = 0.5 GPa. Furthermore, from these measurements it is obvious that the $T_0(p)$ and $T_x(p)$ lines meet at a characteristic pressure of p* = 1.3 GPa. Above p* only the antiferromagnetic transition appears. Bulk superconductivity is suppressed above p_x. The low pressure HO state is dominated by an opening of a gap at the Fermi surface due to nesting. This nesting behaviour is preserved up to highest pressure of 5 GPa.

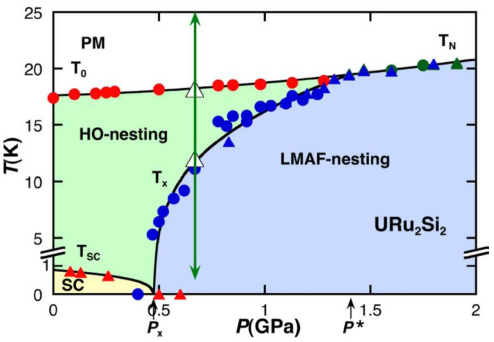

Fig. 1: P-T phase diagram of URu_2Si_2 from resistivity (circles) and ac calorimetry (triangles) measurements with the low pressure HO phase and above p_x the high pressure antiferromagnetic phase (LMAF). Superconductivity is suppressed in the LMAF state. Triangles correspond to the transitions observed in the combined thermal expansion and neutron scattering experiment.

To get a microscopic signature of the HO state we performed neutron scattering experiments at a fixed pressure p = 0.67 GPa in the pressure window $p_x < p < p^*$ as a function of temperature along the green line in Fig. 1. This allows studying the successive paramagnetic, HO and LMAF phases on cooling. At zero pressure below T_0 the two main inelastic magnetic excitations appear at wave vectors Q_0 = (1 0 0) and Q_1 = (1.4 0 0). Remarkably both excitations are sharp and their temperature evolution can explain the shape of the specific heat anomaly.

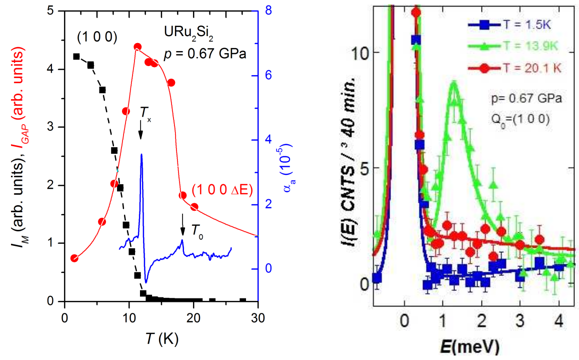

Fig. 2: (Left) Temperature dependence of the magnetic Bragg peak intensity at Q_0 (squares) and of the integrated dynamic susceptibility at Q_0. The thermal expansion (in blue) shows clearly the transitions at T_0 and T_x. (Right) Energy scans at Q_0 in the PM (T=20.1 K) HO (T=13.9 K) and AF (T=1.5 K) phases.

In Fig. 2 (left) we show the temperature dependence of the elastic signal at Q_0, the integrated inelastic signal at Q_0, together with the thermal expansion measured simultaneously in the pressure cell. Clearly we can see that the inelastic signal at Q_0 increases below T_0 in the HO state, however when entering in the LMAF state, below T_x, the elastic signal at Q_0 increases and the inelastic signal is strongly suppressed. The right panel of Fig. 2 shows energy scans at Q_0 in the different phases PM, HO and LMAF, respectively. In the paramagnetic regime the signal is weak and strongly damped, a resonance at the energy E = 1.25 meV appears in the HO state and in the LMAF state neither quasi-elastic nor an inelastic response can be detected at Q_0. Measurements at the other characteristic wave vector Q_1 indicate that above T_0 the response is mainly quasi-elastic, in the HO state the signal becomes inelastic, and this response at Q_1 persists in the LMAF state with a shift to higher energies, in contrast to the excitations at Q_0. With these measurements we have shown that Q_0 is the significant wavevector in the HO state, which could give a hint on the order parameter, and the fact that the resonance at Q_0 and superconductivity both collapse at p_x opens interesting perspectives.

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