Supplemental material: Spontaneously polarized half-gapped superconductivity

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I. X-RAY AND NEUTRON DIFFRACTION

Room temperature powder x-ray diffraction on crushed single crystals shows that CVT-grown UTe$_2$ forms in the correct crystal structure and is single phase, with no sign of impurity phases. Low-temperature neutron diffraction confirms that there are no structural or magnetic phase transitions down to 5 K.

II. ELECTRICAL RESISTIVITY

The low temperature resistivity can be fit to Fermi liquid term $AT^2$ (Fig. 4), with $A \sim 0.64 \mu\Omega$-cm/K$^2$ for $a$-axis and $1.55 \mu\Omega$-cm/K$^2$ for $b$-axis. Values of RRR range from 18 to 30. These do not exhibit a large variation across different batches of single crystals synthesized via CVT.

The Kondo-coherent state exhibits strongly-renormalized Fermi liquid properties: 1) resistivity $\rho = AT^2$, with $A \sim 1 \mu\Omega$-cm/K$^2$, 2) specific heat $C = \gamma T$ with $\gamma = 120$ mJ/mol-K$^2$, and 3) the Kadowaki - Woods ratio $A/\gamma^2 \sim 1\times10^{-4} \mu\Omega$-cm/K$^2/(\text{mJ/mol-K}^2)^2$, similar to many heavy fermion metals.

III. MAGNETIZATION

The Arrott plots (Fig. 6) in the low field range (0 - 0.1 T) at different temperatures show that the system is not in the critical regime of a mean-field classical (finite-temperature) ferromagnetic phase transition. Extending this analysis beyond mean field using the Arrott-Noakes equation of state is also unsuccessful.

The magnetization data are well-described by the Belitz-Kirkpatrick-Vojta (BKV) theory of metallic ferromagnetic quantum critical point. To determine critical exponents, the low temperature magnetization data was fitted to power law behavior, with $\gamma = 0.51$ (Fig. 7). The consideration of a constant susceptibility $M/H$, consistent with a large Pauli paramagnetic response from the heavy Fermi liquid, is necessary to conform to established theories of ferromagnetic critical behavior. A constant term in $M/H$, or equivalently a linear term in $M(H)$, is subtracted from the measured $M(H)$ data. After the subtraction, for temperatures less than 9 K and fields less than 3 T, the resultant curves collapse onto a single curve when $M/T^\beta$ is plotted vs. $H/T^{\beta+\gamma}$ (main text, Fig. 1), using BKV critical exponents ($\beta$
\( \gamma = 0.5, \delta = 1.5 \). Note that scaling is also possible absent this correction. Without constant \( M/H \) subtraction, \( M/T^\beta \) vs. \( H/T^{\beta+\gamma} \) data can also collapse onto a single curve, for temperatures less than 9 K and fields less than 7 T (Fig. 8). However the corresponding exponents will be \( \beta = 4.16, \gamma = 0.51, \delta = 1.12 \). The small value of \( \delta \) reflects the almost-linear \( M(H) \), but the very large value of \( \beta \) cannot be reconciled with known theories.

IV. SPECIFIC HEAT

The low-temperature \( T^3 \) phonon contribution to the specific heat is estimated by fitting to linear function to \( C/T \) vs \( T^2 \) (Fig. 9). It can also be seen that there are no signatures of magnetic phase transitions or unusual temperature-dependence above the superconducting \( T_c \).

The deviation from BCS behavior of the superconducting transition in UTe\(_2\) is emphasized in Fig. 10, in which it is clear that exponential temperature dependence expected for an isotropic gap is absent in this material. Instead, the specific heat below \( T_c \) follows a power law, with \( n \sim 3.2 \), reflecting the presence of point nodes, which arise from a momentum-dependent gap structure typical of nonunitary states.

The large residual \( \gamma \) is a robust feature and does not show obvious sample variation as seen in Fig. 11. This fact is in sharp contrast to the strong sample dependence observed in other materials considered to house spin-triplet superconductivity.

\( C/T \) data in the magnetic fields applied along \( a \)-axis are shown in Fig. 12. The residual \( \gamma \) increases systematically upon increasing magnetic field, further indicating this is an intrinsic property of the compound, as magnetic field will enhance spin unbalance. Entropy calculated from specific heat data for superconducting and normal state are shown in Fig. 13. The normal state data are obtained by applying a magnetic field of 7 T along the \( a \)-axis to suppress superconductivity. The superconducting jump releases 10% more entropy than expected, which can be ascribed to magnetic excitations arising from the spin-polarized ungapped normal Fermi liquid.
FIG. 1. Laue diffraction pattern of [011] direction demonstrating good crystallinity.

FIG. 2. (a) Powder x-ray diffraction data of UTe$_2$ showing good quality of the sample with no visible peaks from impurities. (b) Low-temperature neutron diffraction data of UTe$_2$ confirming that there are no structural or magnetic phase transitions down to 5 K.

V. NMR

No change of the peak position has been observed in the $^{125}$Te-NMR spectra between normal and superconducting states, as shown in Fig. 14.
FIG. 3. Temperature dependence of electronic resistivity data in zero magnetic field with electric current applied along $a$ and $b$-axis. The lines are the fit to Fermi liquid term $AT^2$.

FIG. 4. Temperature dependent resistivity data in magnetic fields applied along (a) $a$ and (b) $c$ axis up to 9 T. The current is applied along $a$-axis.
FIG. 5. The calculated superconducting coupling strength as a function of applied magnetic field in three directions is enhanced when field is applied along the $b$-axis, as expected from pairing due to ferromagnetic fluctuations.

FIG. 6. Arrott plot, $M^2$ as a function of $H/M$, at different temperatures above $T_c$. It can be seen that UTe$_2$ does not have a conventional finite-temperature ferromagnetic transition.
FIG. 7. Temperature dependence of magnetization with magnetic field of 0.1 T applied in $a$ axis. The red line is the fit to the power law $AT^{-0.51} + M_0/H$ in the low temperature region. The constant term $M_0$ is necessary to obtain a good fitting.

FIG. 8. $M/T$ as a function of $H/T^{1.12}$ for different temperatures. All the data collapse onto a single line.
FIG. 9. $C/T$ data as function of $T^2$. There is a linear region above $T_c$, from which phonon contribution to the specific heat is obtained by fitting to a linear function. The red line is the fit. No magnetic order is detected above $T_c$.

FIG. 10. Semilog plot of $C^*_e/\gamma T_c$ ($C^*_e$ is the electric contribution to specific heat minus the residue term at the zero temperature limit) as a function of $T_c/T$. Orange line is the fit to the BCS type of behavior. Red line is the fit to a power law with $n = 3.2 \pm 0.1$. 
FIG. 11. $C/T$ data for different samples. The residue $\gamma$ in the superconducting state does not show obvious sample variation.

FIG. 12. $C/T$ data in different magnetic fields applied along $a$-axis. $H_{c2}$ is approximately 6 T in this direction. The large normal state $C/T$ is that of a heavy Fermi liquid.
FIG. 13. Entropy calculated from specific heat data for superconducting and normal state. The normal state data are obtained by applying magnetic field of 7 T along the $a$-axis to suppress superconductivity.

FIG. 14. $^{125}$Te NMR spectra in both the normal and the superconducting states of UTe$_2$ at $f = 15.1$ MHz.