

Field-rigid Ising antiferromagnetism with giant metamagnetic transition fields in van der Waals UOTe

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van der Waals antiferromagnets provide a route to thickness-controlled magnetic order, but few combine high-temperature Ising order with conducting, correlated, and topological electronic structure. Here we show that UOTe realizes this combination. Magnetic susceptibility reveals a strongly anisotropic paramagnetic response, while neutron diffraction establishes *c*-axis antiferromagnetic order below $T_N \approx 150$ K with an order-parameter exponent $\beta = 0.14$, close to the two-dimensional Ising value. Torque magnetometry further shows that the ordered state remains well described by a uniaxial antiferromagnet below the high-field metamagnetic transition. Pulsed-field magnetization up to 73 T shows that the ordered state survives to very large fields applied along the *c* axis before entering a broad metamagnetic regime that begins near 50 T and remains unsaturated at the highest measured field. Angle-dependent proximity detector oscillator measurements show that the metamagnetic instability is set by the field component along the ordered moment direction, providing direct evidence for Ising-like field rigidity. UOTe therefore establishes a field-rigid Ising antiferromagnet with giant metamagnetic transition fields in a compensated van der Waals metal, where high-temperature *c*-axis order, quasi-two-dimensional magnetic criticality, Kondo-associated uranium 5*f* hybridization, metallic transport, and symmetry-enabled topology coexist in a single material.

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I. INTRODUCTION

In strictly two-dimensional magnets with short-range exchange and continuous spin symmetry, thermal fluctuations preclude finite-temperature long-range order, as established by the Mermin-Wagner theorem [1]. This restriction is not violated, but avoided when magnetic anisotropy breaks continuous spin-rotational symmetry and reduces the relevant symmetry of the ordered state, allowing magnetic order to persist in quasi-two-dimensional materials [2]. Layered van der Waals magnets therefore provide a direct materials setting in which dimensionality, magnetic anisotropy, interlayer coupling, spin-orbit interaction, and electronic structure can be tuned against one another and tested through field response [2–9].

Over the past two decades, a large variety of layered and van der Waals antiferromagnets have been explored. The transition-metal phosphorus trichalcogenide family MPX_3 is among the best-established examples, providing mechanically exfoliable, largely insulating layered antiferromagnets where localized 3*d* moments, superexchange, magnetic anisotropy, and field-driven spin reorientation can be studied in a controlled setting [10–22]. $FePS_3$ is the clearest Ising-like limit in this family, with easy-axis van der Waals antiferromagnetism that survives to the atomically thin limit and produces a strongly constrained magnetic response [15,23–

28]. The broader layered-antiferromagnet landscape now includes weak-anisotropy semiconductors such as $CrCl_3$ and $CrPS_4$, Kitaev-proximate or orbital-active halides such as α - $RuCl_3$, VBr_3 , FeI_2 , and related trihalides, topological Mn-Bi-Te chalcogenides, rare-earth oxyhalides and tritelluride metals, and layered Dirac systems such as $EuMnBi_2$ [29–46]. These systems show that layered antiferromagnetism can couple magnetic anisotropy and field-driven spin textures to itinerant carriers, orbital character, lattice symmetry, topology, and collective electronic reconstruction.

Uranium compounds add the further complexity of spatially extended 5*f* orbitals, where local-moment magnetism, spin-orbit coupling, intra-atomic correlations, ligand hybridization, and itinerant electronic structure can coexist within the same material. While these intertwined effects have been extensively studied in three-dimensional uranium magnets [47–56], layered uranium magnetic systems have only recently begun to attract broader attention [57–60].

UOTe is one of the first uranium-based van der Waals compounds. It orders antiferromagnetically near $T_N \approx 150$ K in the layered Te-U-O-U-Te lattice shown in Fig. 1(a), with uranium moments aligned along the crystallographic *c* axis in a fully compensated $\downarrow\uparrow\downarrow\downarrow$ magnetic structure [57]. ARPES and DFT + *U* identify UOTe as an antiferromagnetic Dirac semimetal, while resonant photoemission reveals a temperature-dependent U 5*f* flat band and hybridization with

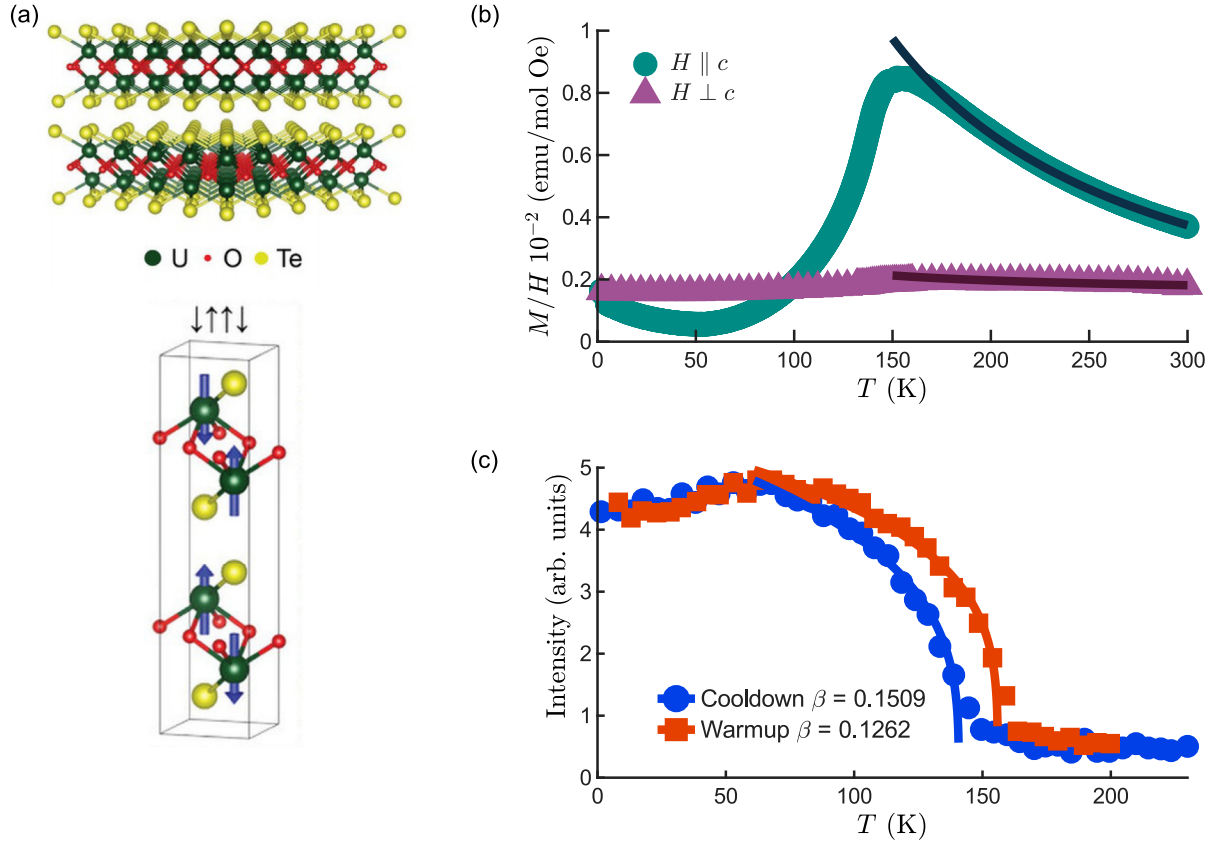


FIG. 1. (a) Crystal and magnetic structure of UOTe. Top, cross-sectional view of the layered structure, showing the Te-terminated van der Waals gaps between neighboring structural units. Bottom, magnetic structure showing the doubled magnetic unit cell with the $\downarrow\uparrow\uparrow\downarrow$ arrangement. (b) Temperature dependence of the magnetic susceptibility measured in an applied field of 1000 Oe for $H \parallel c$ and $H \parallel ab$. Solid lines show Curie–Weiss fits to the high-temperature response. A strong magnetic anisotropy is observed between the two field orientations. (c) Temperature dependence of the magnetic Bragg peak intensity at $\mathbf{Q} = (1, 0, 0.5)$. Data were collected in 5 K steps, with each point integrated for 1 min after a 1 min equilibration period. Solid lines are fits to a critical scaling form, and the extracted values of β are listed in the legend. The fitted values are close to the two-dimensional Ising limit. The neutron diffraction measurements are the same dataset reported in Ref. [57]; here they are reanalyzed to extract the magnetic critical behavior.

Dirac-like conduction states, establishing the coexistence of antiferromagnetism, topology, and Kondo interaction within the same electronic structure [57]. Its magnetic structure preserves combined parity and time-reversal symmetry, $\mathcal{PT}$, in the bulk and odd-layer limit, but breaks this symmetry in even layers; bilayer calculations predict a fully compensated antiferromagnetic Chern-insulating state with nonzero Chern number despite zero net magnetization [57]. UOTe therefore provides a setting in which strongly anisotropic uranium $5f$ antiferromagnetism can be tested in a correlated, topological van der Waals lattice.

Compared with canonical $3d$ van der Waals Ising antiferromagnets such as FePS_3 , UOTe occupies a distinct microscopic regime in which strong spin-orbit coupling, spatially extended uranium $5f$ orbitals, electronic correlations, metallic transport, and nontrivial band topology coexist. Whereas the Ising anisotropy in localized-moment systems is commonly discussed in terms of crystal electric field effects, single-ion anisotropy, and anisotropic exchange interactions, the microscopic origin of the strong Ising anisotropy in UOTe remains to be established. The coexistence of strong spin-orbit coupling, crystal electric field effects, anisotropic exchange

interactions, and hybridization between the uranium $5f$ states and conduction electrons nevertheless provides several natural microscopic mechanisms capable of producing the observed field-rigid Ising behavior.

Here we show that this ordered state is unusually rigid against magnetic field. Susceptibility and neutron diffraction establish a strongly anisotropic antiferromagnet with c -axis moments and critical behavior close to the two-dimensional Ising limit. Torque magnetometry shows that the low-field state behaves as a uniaxial antiferromagnet, while pulsed-field magnetization and angle-dependent proximity detector oscillator measurements show that the high-field metamagnetic instability occurs only at large fields and is governed by the c -axis component of the applied field. Rather than undergoing a single conventional spin-flip transition, UOTe enters a broad, hysteretic, and internally structured metamagnetic regime. The coexistence of a large hysteretic metamagnetic response with uranium $5f$ hybridization and strong spin-orbit coupling suggests that the high-field evolution is not simply a localized-spin reversal, but may involve coupled spin, orbital, lattice, and electronic degrees of freedom in a correlated van der Waals metal.

II. METHODS

Single crystals of UOTe were synthesized by chemical vapor transport in a two-zone furnace. High-purity tellurium (99.9999%, Alfa Aesar) and depleted uranium metal (New Brunswick Laboratory) were combined in an equimolar ratio and loaded into an evacuated quartz ampoule together with iodine as the transport agent (1 mg cm^{-3}). The sealed tube was placed across a temperature gradient of 1030°C at the source and 970°C at the sink for seven days. After the transport reaction, the furnace was cooled to ambient temperature, yielding shiny, platelike UOTe single crystals suitable for physical property measurements.

Magnetization measurements were carried out using a vibrating sample magnetometer (VSM). A magnetic field of 1000 Oe was applied during data acquisition. The temperature was varied from 2 K to 300 K for fields oriented within the ab plane and from 2 K to 400 K for fields applied along the crystallographic c axis.

Torque magnetometry measurements were conducted at the High Magnetic Field Laboratory in Tallahassee, Florida, in fields up to 41.5 T and temperatures down to 350 mK. Crystals with a nominal thickness below $100 \mu\text{m}$ and approximate lateral dimensions of $200 \mu\text{m} \times 200 \mu\text{m}$ were selected under optical inspection. Each crystal was fixed with GE varnish onto a piezoresistive torque cantilever and measured in magnetic fields up to 41.5 T at a base temperature of 350 mK.

Single-crystal neutron diffraction measurements were performed on the HB-3A DEMAND four-circle diffractometer at the High Flux Isotope Reactor, Oak Ridge National Laboratory [61,62]. A Si (220) monochromator was used to select a neutron wavelength of $1.542 \text{ \AA}$. Several UOTe single crystals were coaligned on a Si substrate to form a composite sample with a total mass of approximately 0.1 g and a mosaic spread of $\pm 5^\circ$. The sample assembly was mounted on the four-circle goniometer and cooled to 5 K using a closed-cycle helium refrigerator. Data reduction was performed using the RETIA software package [63]. Symmetry analysis was carried out using the BILBAO CRYSTALLOGRAPHIC SERVER [64], and magnetic-structure refinements were performed with the FULLPROF suite [65].

Pulsed-field magnetization and proximity detector oscillator (PDO) measurements were carried out at the Pulsed Field Facility of the National High Magnetic Field Laboratory at Los Alamos National Laboratory in magnetic fields up to 73 T and temperatures down to 570 mK. Magnetization was measured using a compensated-coil extraction magnetometer [66]. An oriented single-crystal sample was placed in a 1 mm diameter ampoule that could be moved in and out of the compensated coil. The voltage induced in the coil by the time-dependent pulsed magnetic field, $H(t)$, is proportional to dM/dt [66]. To obtain the magnetization, $M(H)$, the voltage signal recorded with the sample inside the coil was integrated with respect to time, and the corresponding integrated background signal measured with the empty coil was subsequently subtracted. PDO measurements were performed using plate-like single crystals with their large faces spanning the ab plane, mounted on the detection coil inside a rotator. The sample was rotated from $H \parallel c$ toward $H \parallel ab$ to determine the angular evolution of the field-induced transition.

III. RESULTS

A. Magnetization and Curie-Weiss analysis

We first establish the magnetic anisotropy from the temperature-dependent susceptibility for fields applied parallel to the crystallographic c axis and within the ab plane. As shown in Fig. 1(b), the response is strongly anisotropic over the full measured temperature range, with $\chi(T)$ for $H \parallel c$ substantially larger than for $H \parallel ab$. Both field orientations show a clear anomaly at T_N , marking the onset of antiferromagnetic order. The much larger response for $H \parallel c$ identifies the crystallographic c axis as the magnetic easy axis already in the paramagnetic regime.

To quantify the paramagnetic response above T_N , we fit the susceptibility to a Curie-Weiss form with a temperature-independent background,

$$\chi(T) = \chi_0 + \frac{C}{T - \theta_{\text{CW}}},$$

where χ_0 is the temperature-independent contribution, C is the Curie constant containing the effective moment μ_{eff} , and θ_{CW} is the Curie-Weiss temperature. For $H \parallel c$, the fit gives $\theta_{\text{CW}}^c = -30 \text{ K}$, $\mu_{\text{eff}}^c = 3.2 \mu_B$, and $\chi_0^c = -2.2 \times 10^{-3}$. For $H \parallel ab$, the Curie-Weiss temperature was fixed to the value obtained for $H \parallel c$, giving $\theta_{\text{CW}}^{ab} = -30 \text{ K}$, $\mu_{\text{eff}}^{ab} = 0.64 \mu_B$, and $\chi_0^{ab} = 1.7 \times 10^{-3}$.

The anisotropy of the fitted Curie constants can be expressed as an effective anisotropic g -factor ratio using $C_i \propto g_i^2$ for a fixed moment manifold:

$$\frac{g_c}{g_{ab}} = \sqrt{\frac{C_c}{C_{ab}}} = 4.97.$$

As a dimensionless measure of the uniaxial character of the paramagnetic response, “Ising-ness” can be defined as

$$\mathcal{A}_g = \frac{(g_c/g_{ab})^2 - 1}{(g_c/g_{ab})^2 + 1} = \frac{C_c - C_{ab}}{C_c + C_{ab}}.$$

This quantity is zero for an isotropic Curie response and approaches unity when the transverse Curie response vanishes. For UOTe, the fitted Curie constants give $\mathcal{A}_g = 0.922$, indicating that strong anisotropy is already present above T_N .

B. Neutron diffraction and critical behavior

Having established the strong easy-axis susceptibility, we next track the development of antiferromagnetic order directly through neutron diffraction. The neutron diffraction measurements were previously reported in Ref. [57]; here, the same dataset is reanalyzed to determine the magnetic critical behavior. The temperature dependence of the magnetic Bragg peak intensity at $\mathbf{Q} = (1, 0, 0.5)$ is shown in Fig. 1(c). The intensity increases continuously on cooling below T_N , consistent with the onset of long-range antiferromagnetic order. Near T_N , the data were fit to the standard order-parameter form

$$I(T) \propto \left(1 - \frac{T}{T_N}\right)^{2\beta},$$

where the Bragg intensity is proportional to the square of the ordered moment.

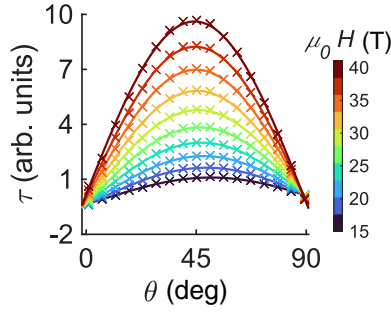


FIG. 2. Angular cuts through the torque data. Representative angular cuts extracted from the torque data at fixed magnetic fields. Solid lines are fits to the $\sin(2\theta)$ angular dependence expected for a uniaxial two-sublattice antiferromagnet, $\tau \propto \Delta\chi H^2 \sin(2\theta)$. The agreement shows that the angular response remains consistent with a simple uniaxial antiferromagnetic state throughout the measured field range.

Fitting the critical region from 61 to $T_N = 148$ K gives a best-fit exponent of $\beta = 0.1385$. As a stability check, we averaged fits over lower-temperature cutoffs from 31 to 81 K,

giving $\beta = 0.1278$ and $T_N = 147.7$ K. The cutoff range extends up to 81 K because the neutron intensity is nearly saturated below this temperature, whereas the rapid growth toward T_N occurs above it. Details of the fitting procedure are provided in the Supplemental Material [67]. The extracted exponent is close to the two-dimensional Ising value of $1/8$, consistent with quasi-two-dimensional Ising critical behavior.

C. Torque magnetometry

To test whether the ordered state retains a simple uniaxial response below the high-field metamagnetic transition, we measured the magnetic torque as a function of field and angle. Across the full accessible field range up to 41 T, the data are well described by the angular dependence expected for a uniaxial two-sublattice antiferromagnet [27,68],

$$\tau \propto \Delta\chi H^2 \sin(2\theta),$$

where $\Delta\chi = \chi_c - \chi_{ab}$ is the susceptibility anisotropy. The torque amplitude therefore tracks the difference between the c -axis and in-plane magnetic responses. Representative angular cuts in Fig. 2 follow the same form across the measured field range.

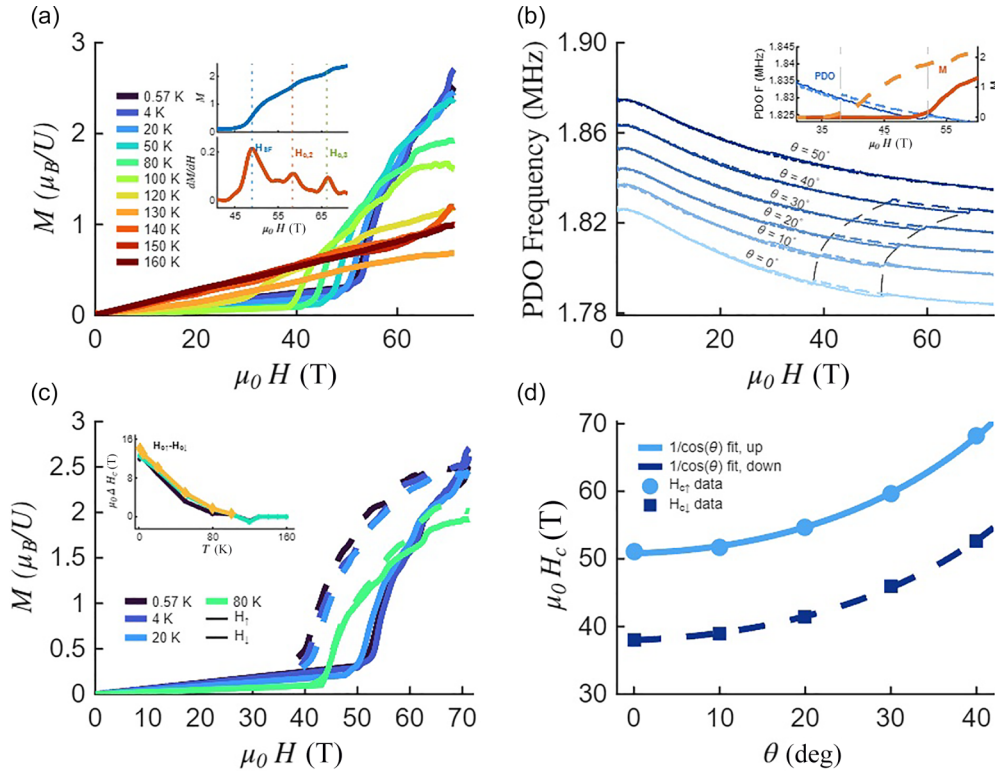


FIG. 3. (a) Magnetization of UOTe as a function of field for temperatures from 570 mK to 160 K, measured in pulsed fields up to 73 T. The data were normalized using vibrating sample magnetometer measurements from earlier experiments. The inset shows an expanded view of the metamagnetic transition and its field derivative, highlighting the three derivative peaks used to track the field evolution of the metamagnetic response. (b) PDO frequency shift as a function of field at 570 mK for field angles measured with respect to the c axis. A clear transition is observed, and the inset compares the PDO response with the magnetization data near the onset of the metamagnetic transition. The critical field increases with angle from 0° to 50° , beyond which the transition is not resolved up to 73 T. (c) Upsweep and downsweep magnetization at selected temperatures from 570 mK to 80 K, showing the evolution and closing of the hysteresis loop with increasing temperature. The inset shows the hysteresis width extracted from the derivative peak positions on upsweep and downsweep traces for the three tracked features. (d) Angular dependence of the critical field determined from PDO measurements on upsweep and downsweep for $H \parallel c$. Solid lines are fits to a $1/\cos(\theta)$ form, indicating scaling with the c -axis component of the applied field.

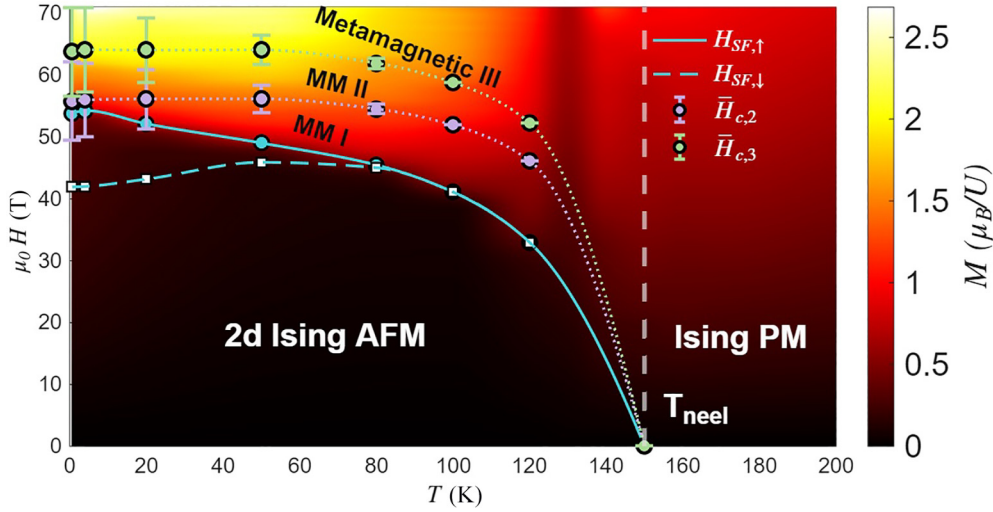


FIG. 4. Magnetic field-temperature phase diagram of UOTe constructed from pulsed-field magnetization and PDO measurements, together with neutron scattering, magnetic susceptibility, and torque magnetometry. Above $T_N \approx 150$ K, UOTe is in the paramagnetic state. Below T_N , at least three field-induced branches emerge from the metamagnetic transition region and define the evolution of the ordered state with temperature and field. The blue boundary marks the metamagnetic transition onset, with separate upswing and downswing values shown where hysteresis is resolved. The green and pink branches correspond to the higher-field derivative features identified from the magnetization data. Vertical bars denote the upswing and downswing values, and solid lines indicate the average field position of each feature. The regions labeled MM I, MM II, and Metamagnetic III denote phenomenological metamagnetic regimes separated by these field scales rather than microscopically determined magnetic phases.

No additional anomalies are resolved in the torque response up to 41 T. Instead, the signal remains smooth and retains the same uniaxial angular dependence throughout, consistent with a stable easy-axis antiferromagnetic state below the onset of the high-field metamagnetic regime.

D. Pulsed-field magnetization

Having established that the ordered state remains uniaxial up to 41 T, we next probe the field range where the antiferromagnetic state is destabilized. Figure 3(a) shows the pulsed-field magnetization for $H \parallel c$ from 570 mK to 160 K. From 570 mK to 120 K, $M(H)$ remains only weakly field dependent over a broad low-field interval, consistent with the rigid easy-axis response inferred from susceptibility, neutron diffraction, and torque magnetometry. At higher fields, the magnetization enters a pronounced metamagnetic regime. At base temperature, the onset occurs near 50 T, but the metamagnetic transition does not appear as a single sharp spin-flip transition. Instead, $M(H)$ evolves through a broad sequence of rapid increases and intermediate shoulders. The high-field evolution remains incomplete at 73 T, showing that the field-driven reconstruction extends over more than 20 T and does not reach full saturation within the available field window.

The internal structure of this metamagnetic regime is resolved more clearly in the field derivative, shown in the inset of Fig. 3(a). Three distinct peaks appear in dM/dH , defining characteristic fields associated with the onset, intermediate evolution, and upper portion of the metamagnetic transition. These features shift systematically with temperature and provide the field scales used to construct the phase diagram in Fig. 4. Between 120 K and 160 K, the response crosses over toward a more nearly linear susceptibility, consistent with the

loss of the low-temperature metamagnetic structure as the system approaches and exceeds the antiferromagnetic transition.

A second important feature is the pronounced hysteresis between upsweeps and downsweeps at low temperature, shown in Fig. 3(c). We define the hysteresis width of each derivative feature as

$$\Delta H_i(T) = H_i^\uparrow(T) - H_i^\downarrow(T),$$

where $H_i^\uparrow$ and $H_i^\downarrow$ are the corresponding peak positions in dM/dH on the upswing and downswing, respectively. At base temperature, the overall hysteretic width across the metamagnetic region is approximately 14 T. As shown in the inset of Fig. 3(c), the hysteresis decreases steadily with increasing temperature and disappears near 100 K.

Taken together, the pulsed-field magnetization shows that the antiferromagnetic state of UOTe survives to exceptionally large c -axis fields before reconstructing through a broad, hysteretic, and multistage metamagnetic regime. This behavior is distinct from a conventional narrow spin-flip transition and establishes that the high-field state is not fully saturated by 73 T.

E. Angle-dependent PDO measurements

The angle-dependent PDO measurements provide a direct test of whether the high-field instability is controlled by the total magnetic field or by the field component along the Ising axis. Figure 3(b) shows the PDO frequency shift at 570 mK for fields rotated away from $H \parallel c$. The inset compares the PDO response for $H \parallel c$ with the magnetization measured in the same field orientation, showing that the PDO anomalies coincide with the onset and evolution of the high-field metamagnetic transition identified in $M(H)$. As the field is

tilted toward the ab plane, the anomaly shifts systematically to higher total field while retaining the same overall form. This behavior is the defining expectation for an easy-axis instability governed by the c -axis field projection.

The extracted critical fields are summarized in Fig. 3(d). Both upsweep and downsweep values follow

$$H_c(\theta) = \frac{H_c(0)}{\cos \theta},$$

so

$$H_c(\theta) \cos \theta \approx H_c(0).$$

Thus, the metamagnetic transition occurs when the c -axis component of the applied field reaches the same critical value, independent of the transverse field component within the measured angular range. No separate anomaly associated with the in-plane field component is resolved. As the field is rotated farther toward $H \parallel ab$, the required total field increases according to the $1/\cos \theta$ form and the transition moves beyond the 73 T field window above approximately 50° . Together, the angle-resolved PDO data show that the high-field metamagnetic transition is locked to the easy axis. This uniaxial-field scaling demonstrates that the field-induced instability is governed by the ordered-moment direction, providing direct experimental evidence for the exceptional field rigidity of the Ising state in UOTe.

IV. DISCUSSION

The results establish UOTe as a field-rigid Ising antiferromagnet whose anisotropy is visible above T_N , inherited by the ordered state, and retained into the high-field regime. Above T_N , the Curie-Weiss anisotropy gives $g_c/g_{ab} = 4.97$ and $\mathcal{A}_g = 0.922$, close to the Ising limit $\mathcal{A}_g = 1$. Neutron diffraction shows that the ordered moments align along c , the magnetic Bragg intensity follows critical behavior close to the two-dimensional Ising value, and torque magnetometry shows that the ordered state remains well described by a uniaxial antiferromagnet up to 41 T. The angle-dependent PDO measurements provide the most direct high-field test: the metamagnetic anomaly follows $H_c(\theta) = H_c(0)/\cos \theta$, showing that the instability is controlled by the c -axis field component $H \cos \theta$ rather than by the total applied field. Taken together, the susceptibility, neutron diffraction, torque, magnetization, and PDO data show that UOTe is not merely anisotropic, but locked to the Ising axis over a wide range of temperature and field.

The microscopic origin of this Ising anisotropy remains unresolved, but the present data constrain the relevant ingredients. In localized $3d$ van der Waals Ising antiferromagnets such as FePS_3 , strong anisotropy is commonly discussed in terms of crystal electric field effects, single-ion anisotropy, anisotropic exchange, and magnetoelastic coupling [16,69]. UOTe occupies a different regime because the ordered moment derives from uranium $5f$ states, where strong spin-orbit coupling, crystal electric field splitting, spatially extended orbitals, anisotropic exchange, and hybridization with itinerant bands can all contribute. The persistence of the strong c -axis anisotropy from the paramagnetic susceptibility through the ordered state and into the high-field

response shows that it is intrinsic to the anisotropic, spin-orbit-coupled uranium $5f$ electronic manifold rather than arising only from the specific zero-field magnetic structure. The present measurements do not, however, distinguish whether the dominant anisotropy energy originates from crystal-field-induced single-ion anisotropy, anisotropic $5f$ - $5f$ exchange, direction-dependent hybridization with itinerant states, or their combined action. Its measured g_c/g_{ab} ratio does not reach the nearly locked limits found in some rare-earth or uranium heavy-fermion systems, such as YbAlO_3 , YbRh_2Si_2 , or URu_2Si_2 [70–73], but it is much larger than in many conventional finite-transverse Ising-chain or van der Waals antiferromagnet comparisons. UOTe therefore occupies an unusual intermediate regime: the moments are strongly Ising-like, while the electronic structure remains metallic, hybridized, and topological. Determining the relative contributions of the microscopic terms responsible for this anisotropy will require future theory and spectroscopic probes.

The high-field response is not a conventional spin-flip transition of rigid local moments. Once the metamagnetic transition onset field is reached near 50–55 T, $M(H)$ evolves through a broad sequence of changes extending over more than 20 T, with multiple resolved maxima in dM/dH , large hysteresis, and no saturation up to 73 T. The angular PDO data show that this evolution is still governed by the c -axis field component, so a simple transverse-field canting instability is disfavored. A plausible interpretation is that the field sequentially destabilizes several closely competing Ising-like configurations. Starting from the layered $\downarrow\uparrow\downarrow$ magnetic structure, the system could pass through inequivalent layer-reversal pathways, domain-dependent reversal processes, partially polarized layer-resolved states, magnetoelastic relaxation, or electronic reconstruction coupled to the uranium $5f$ bands. The present measurements determine the thermodynamic field scales associated with this reconstruction, but they do not uniquely determine the microscopic magnetic structures in the MM I, MM II, and MM III regimes. We therefore treat these labels phenomenologically as field regimes separated by reproducible anomalies in magnetization and PDO rather than as microscopically solved magnetic phases.

The hysteresis provides an additional constraint on the free-energy landscape of the metamagnetic transition. At 570 mK, the separation between upsweep and downsweep derivative features spans an overall field width of about 14 T, and this hysteresis collapses on warming toward 100 K, as shown in the inset of Fig. 3(c). Such a large irreversible field window is difficult to reconcile with reversible canting and instead points to first-order-like dynamics, metastability, and competing local minima separated by sizable barriers. The relevant collective energy scale is not only the single-moment Zeeman estimate $g\mu_B H$, but also the magnetic work required to drive the ordered state through the reconstruction, $W_{\text{mag}} \sim \mu_B \int M(H) dH$, with hysteretic loss associated with the loop area $\mu_B \oint M(H) dH$. A rough single-moment comparison already shows that the field scale is substantial: $H_m \sim 55$ T corresponds to $g\mu_B H_m \sim 6.4$ meV for $g = 2$, while $T_N \approx 150$ K corresponds to $k_B T_N \sim 12.9$ meV. The metamagnetic transition is therefore not a small perturbation on the ordered

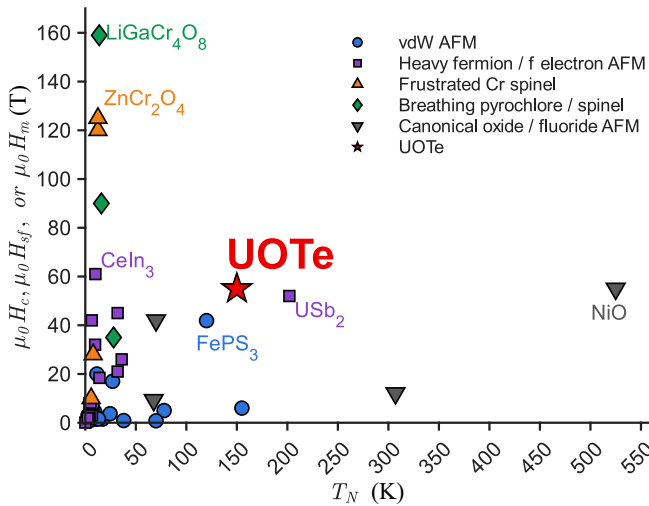


FIG. 5. Comparison of characteristic field scales in antiferromagnets. The characteristic field scale is plotted as a function of Néel temperature for a representative set of antiferromagnetic materials. The vertical axis denotes the reported spin-flip field, spin-flop field, metamagnetic transition field, or other relevant critical field, labeled here as H_c , H_{sf} , or H_m . The comparison is intended to highlight the relative magnitudes of the reported characteristic field scales across different antiferromagnets rather than to imply a common microscopic mechanism or a common underlying energy scale. The comparison includes compounds from van der Waals antiferromagnets, heavy-fermion and other f -electron antiferromagnets, frustrated chromium spinels, breathing pyrochlore or spinel antiferromagnets, and canonical oxide or fluoride antiferromagnets. Literature values used to construct the comparison are taken from Refs. [16,17,20,22,31–35,37–42,51,74–90].

state, and the hysteresis indicates that the reconstruction involves appreciable irreversible magnetic work.

The temperature scale of the hysteresis is also suggestive. Prior work identified a temperature-dependent uranium $5f$ flat band that develops below approximately 100 K and hybridizes with Dirac-like conduction states [57]. In the present measurements, the derivative structure sharpens and the hysteresis emerges over approximately the same temperature range. This correspondence does not prove that Kondo-associated hybridization causes the hysteretic metamagnetism, but it argues against treating the high-field transition as a purely localized-spin process independent of the electronic structure. Any microscopic description of UOTe must account for why the field-induced magnetic reconstruction, the onset of large hysteresis, and the development of uranium $5f$ hybridization occur on similar temperature scales. A plausible scenario is that hybridization reshapes the low-temperature free-energy landscape, allowing several nearby magnetic, orbital, lattice, or electronic states to compete under magnetic field.

The comparison in Fig. 5 places this field scale in a broader antiferromagnetic context, but it should be interpreted qualitatively because the plotted fields do not all represent the same microscopic process. Some materials show spin-flop transitions, others spin-flip transitions, metamagnetic transitions, saturation fields, or field-induced reconstructions.

The useful comparison is therefore not a one-to-one microscopic equivalence, but the relative scale of the magnetic field needed to destabilize or reorganize antiferromagnetic order. In high- T_N insulating oxides, large ordering temperatures coexist with spin-reorientation fields that may probe anisotropy or sublattice-reorientation scales rather than the full exchange energy [89,90]. In frustrated spinels and related geometrically frustrated antiferromagnets, large critical fields can occur despite much lower ordering temperatures because frustration suppresses T_N and produces many nearly competing spin-lattice configurations [77–80,82,83,85]. UOTe is unusual because it combines a high ordering temperature, a large c -axis metamagnetic transition field, a large magnetic-work scale, and pronounced hysteresis in a van der Waals metal with correlated uranium $5f$ electronic structure.

This combination makes the electronic structure especially important. Prior work established UOTe as an antiferromagnetic Dirac semimetal in which a Kondo-associated uranium $5f$ flat band hybridizes with Dirac-like conduction states, and in which the $\downarrow\uparrow\downarrow$ magnetic structure preserves $\mathcal{PT}$ symmetry in the bulk and odd-layer limit but breaks it in even layers [57]. Bilayer UOTe was consequently predicted to realize a fully compensated antiferromagnetic Chern-insulating state with nonzero Chern number despite zero net magnetization [57]. The present work adds the magnetic constraint required for that picture: the compensated antiferromagnetic state is not fragile. It remains easy-axis locked, quasi-two-dimensional, and stable to large magnetic fields before reconstructing through a broad high-field metamagnetic regime.

More broadly, UOTe occupies a materials regime that is difficult to access in conventional two-dimensional magnetic platforms. Localized van der Waals magnets such as FePS₃ provide reduced dimensionality and strong anisotropy, while topological antiferromagnets such as MnBi₂Te₄ link magnetic symmetry to band topology; correlated uranium magnets provide strong spin-orbit coupling and hybridized $5f$ electrons, but are generally not van der Waals materials. UOTe combines these ingredients in a single layered compound: compensated antiferromagnetism, uranium $5f$ hybridization, metallic Dirac-like carriers, strong spin-orbit coupling, van der Waals structure, and even-layer $\mathcal{PT}$ breaking. This makes it relevant not only for high-field magnetism but also for antiferromagnetic spintronics and topological antiferromagnetism, where zero-net-moment order, spin-orbit coupling, Berry curvature, and symmetry control can link magnetic structure to transport [91–94].

UOTe therefore establishes a distinct limit among van der Waals antiferromagnets. Its ordered state is thermally robust, strongly Ising-like, and rigid against magnetic field, yet it resides in a conducting uranium material with Kondo-associated $5f$ hybridization and nontrivial antiferromagnetic electronic structure. Rather than collapsing through a conventional spin-flip transition, the ordered state reconstructs through a broad, hysteretic metamagnetic transition with multiple internal field scales and no saturation up to 73 T. These results establish UOTe as a platform for studying how reduced dimensionality, strong spin-orbit coupling, electronic correlations, and topological band structure collectively shape high-field antiferromagnetic order.

V. CONCLUSION

We have shown that UOTe realizes a quasi-two-dimensional Ising antiferromagnetic state whose rigidity persists from the paramagnetic regime into extreme magnetic fields. Susceptibility, neutron diffraction, and torque magnetometry establish a strongly uniaxial ordered state with moments locked to the crystallographic c axis and critical behavior close to the two-dimensional Ising limit. Pulsed-field magnetization and angle-dependent PDO measurements then show that this state survives to giant magnetic fields, with the metamagnetic boundary controlled by the c -axis field component rather than by the total applied field. The field-induced reconstruction is broad, hysteretic, and internally structured, with no full saturation by 73 T, indicating that the high-field evolution is not a simple spin flip of rigid local moments.

These results place UOTe in a distinct regime among antiferromagnets. Its large metamagnetic transition field appears in a van der Waals uranium material that is conducting, Kondo-interacting, and topologically nontrivial rather than in a localized insulating magnet or a conventional three-dimensional oxide. The emergence of strong hysteresis below the same temperature scale associated with the U 5*f* flat band further links the magnetic reconstruction to the correlated electronic background. UOTe therefore provides a rare platform in which reduced-dimensional Ising order, high-field antiferromagnetic stability, metallic transport,

Kondo-associated hybridization, and symmetry-enabled topology coexist within a single compensated magnetic state.

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DATA AVAILABILITY

There are no publicly available research data or software supporting this manuscript. Requests for further information or data should be sent to the authors.

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