

Anisotropic anomalous Hall effect in distorted kagome GdTi_3Bi_4 Avdhesh K. Sharma¹, Bo Tai¹, Subhajit Roychowdhury^{1,2}, Premakumar Yanda¹, Ulrich Burkhardt¹, Xiaolong Feng¹, Claudia Felser^{1,*}, and Chandra Shekhar^{1,†}¹Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany²Department of Chemistry, Indian Institute of Science Education and Research Bhopal, Bhopal 462 066, India

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Topological kagome magnets offer a rich landscape for exploring the intricate interplay of quantum interactions among geometry, topology, spin, and correlation. GdTi_3Bi_4 crystallizes in layered Ti-based kagome nets intertwined with zigzag Gd chains along the a axis and orders antiferromagnetically below ~ 15 K. Here, we present the temperature- and field-dependent electrical transport of GdTi_3Bi_4 in different directions. The material exhibits anomalous Hall conductivity (AHC) of $410 \Omega^{-1} \text{cm}^{-1}$ at 2 K for $\mu_0 H \parallel c$, and it is completely absent for $\mu_0 H \parallel a$, despite the similar magnetizations observed in both orientations. This behavior is quite contradictory, as the anomalous Hall effect (AHE) typically scales with the magnetization. Through first-principles calculations, it is demonstrated that in the presence of time-reversal symmetry broken by the Gd $4f$ sublattice and spin-orbit coupling, the magnetization direction controls the orbital mixing in the Ti t_{2g} bands, relocating Berry-curvature hot spots and producing the observed orientation-selective AHC. The results establish GdTi_3Bi_4 as a platform for investigating new avenues of the AHE, such as directional AHE, and thus shed light on the intricate coupling between magnetic and electronic structures, paving the way for exploring novel quantum phenomena.

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Introduction. The intrinsic anomalous Hall effect (AHE) has emerged as a key probe of quantum phenomena in magnetic topological materials, arising from a pseudomagnetic field generated by momentum-driven Berry curvature (BC), which further originates from the topology of the band structure and its invariants [1–3]. A finite net magnetization with broken time-reversal symmetry (TRS) is a prerequisite criterion, although the AHE in materials with complex magnetic spin textures and nontrivial topological band structures is always promising to investigate [4–6]. A kagome lattice, composed of interconnected triangles arranged in a hexagonal pattern, presents a unique atomic structure in which each atom is surrounded by four neighboring atoms within the plane [7]. This distinctive geometry provides a unique platform in which Dirac cones, flat bands, and Van Hove singularities naturally coexist, enabling a strong source of BC once symmetry is lowered [8–16].

Over the past few years, several kagome series such as AV_3Sb_5 (where A can be K, Cs, or Rb) and RM_6X_6 (where R is a rare-earth element, M is a transition metal, and X signifies a p -block element) have exhibited conventional and unconventional AHEs and other related quantum phenomena

due to the presence of either finite or inherent magnetic moment [14,17–23]. However, the origin of the AHE remains a topic of debate in AV_3Sb_5 series, with the loop current proposed as a source of the AHE in the absence of long-range magnetic ordering [23–25]. Among the RM_6X_6 series, a number of predominantly ferromagnetic (FM) compounds exhibit the AHE [26,27], in addition to the anomalous Nernst effect in YMn_6Sn_6 [10] and Chern magnetism in TbMn_6Sn_6 [15]. However, the AHE without the presence of such magnetism is observed in ScV_6Sn_6 , which persists up to the charge density wave (CDW) transition [11,28]. Recently, diverse electronic and magnetic properties were discovered in titanium-based bilayer kagome metals RTi_3Bi_4 . The crystal structure is formed by slightly distorted Ti kagome layers, interleaved with zigzag R chains within the RBi bilayers [29]. It offers a tunable magnetic order through the R site while keeping the kagome-derived electronic states largely intact. Across the series, many physical properties such as spin density waves, Van Hove singularities, stripelike magnetization plateaus, and even charge-spin intertwined density waves have been observed, underscoring the pivotal role of the one-dimensional magnetic chain of the R and Ti kagome lattice [30–38]. A key signature of rare-earth elements is the emergence of magnetization plateaus or steplike transition under the application of magnetic fields. In the case of GdTi_3Bi_4 , this phenomenon occurs as a result of the reconfiguration of localized moments into stripelike or fractional magnetization states. This supports the formation of an unconventional charge-spin intertwined density wave, which appears to be limited to the c axis. Furthermore, the emergence of two distinct antiferromagnetic (AFM) order states has been observed, exhibiting a deviation of $\pm 7^\circ$ from the a axis [32,38]. Such

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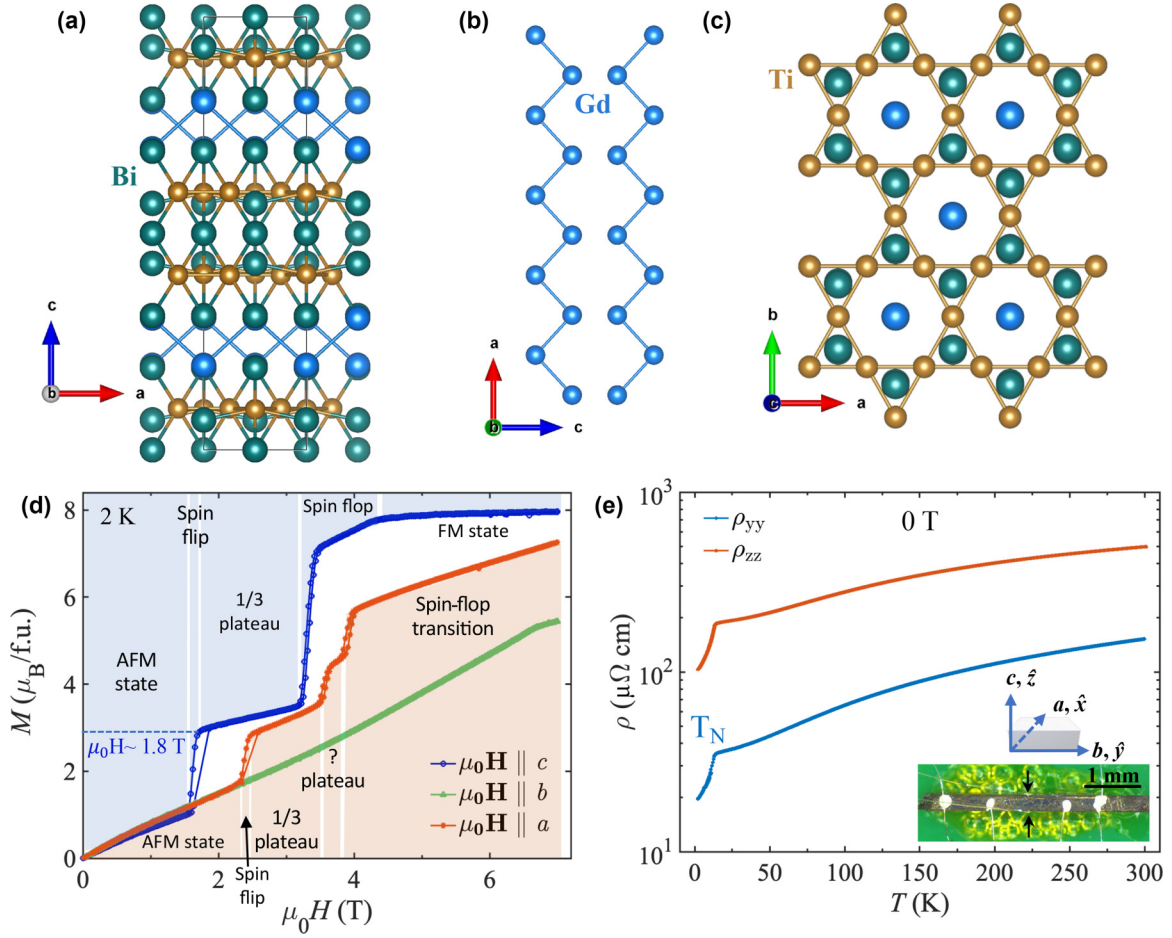


FIG. 1. (a) Crystal structure of GdTi₃Bi₄. (b) Zigzag chain of Gd atoms along the *a* axis. (c) Ti kagome lattice visualized along the *c*-axis. (d) Isothermal magnetization for $\mu_0 H \parallel a$, *c*, and *c* at 2 K. (e) Temperature-dependent resistivity at log scale along the *b* (ρ_{yy}) and *c* (ρ_{zz}) crystallographic axes at zero magnetic field. The inset shows an image of four-probe electrical contacts on the sample used to measure the resistivity and Hall voltage contacts, shown by arrows.

field-induced textures sometimes produce a substantial BC and AHE, as seen in the rare-earth based compounds [39–42]. However, the manner in which the localized spins of *R* influence the electronic bands remains largely unexplored in the context of the connection between magnetism and topology, as reflected in their electrical transport properties.

In this study, we conduct axis-dependent magnetoelectrical transport investigations of single crystals of GdTi₃Bi₄ followed by a theoretical analysis. We explicitly observe a large anomalous Hall conductivity (AHC) of $410 \Omega^{-1} \text{ cm}^{-1}$ at 2 K with $\mu_0 H \parallel c$; it is completely absent for $\mu_0 H \parallel a$. However, the magnetic behavior is similar in both directions, including the 1/3 magnetic plateau and other minor plateaus. Fully relativistic calculations in saturated FM configurations with $\mu_0 H \parallel c$ or $\mu_0 H \parallel a$ reproduce the strong anisotropy and trace it to spin-orbit coupling (SOC) gapped anticrossings near the Fermi energy E_F . Our findings highlight that the intertwining of magnetism and structure via TRS breaking due to the exchange field of Gd 4*f* sublattice and orbital mixing controlled by SOC is vital for elucidating the axis-dependent anomalous transport observed in kagome compounds.

Results and discussion. High-quality single crystals of GdTi₃Bi₄ were synthesized using the Bi self-flux method

[29]. Unlike the other kagome prototypes AV₃Sb₅ and RM₆X₆, GdTi₃Bi₄ displays a more complex crystal structure [Fig. 1(a)] [20,22]. It features a layered crystal structure with space group *Fmmm* and lattice parameters $a = 5.858 \text{ \AA}$, $b = 10.299 \text{ \AA}$, and $c = 24.726 \text{ \AA}$. The unit cell comprises a Ti-based kagome layer perpendicular to the *c* axis and Gd-based zigzag chains along the *a* axis. Interestingly, Ti kagome layers show an additional anisotropic distortion, resulting in orthorhombic crystal symmetry rather than hexagonal. Figure 1(b) emphasizes the presence of Gd-based zigzag chains aligned parallel to the *a* axis, with nearest Gd-Gd spacing of $\sim 3.970 \text{ \AA}$. Zigzag chains are fundamental motifs in low-dimensional magnetism, as they typically host both comparable nearest neighbor (J_1) and next nearest neighbor (J_2) interactions, which introduces magnetic frustration [43,44]. Such systems exhibit magnetization plateaus at fractional values (e.g., 1/3) of the saturation magnetization and strongly influence the magnetoelectrical transport property of the material, as discussed in following sections.

After the successful growth of single crystals, preliminary characterizations were carried out to confirm the composition, structure, and orientation (Fig. S1) [45]. Temperature-dependent field-cooled magnetic susceptibility χ_c at 50 mT

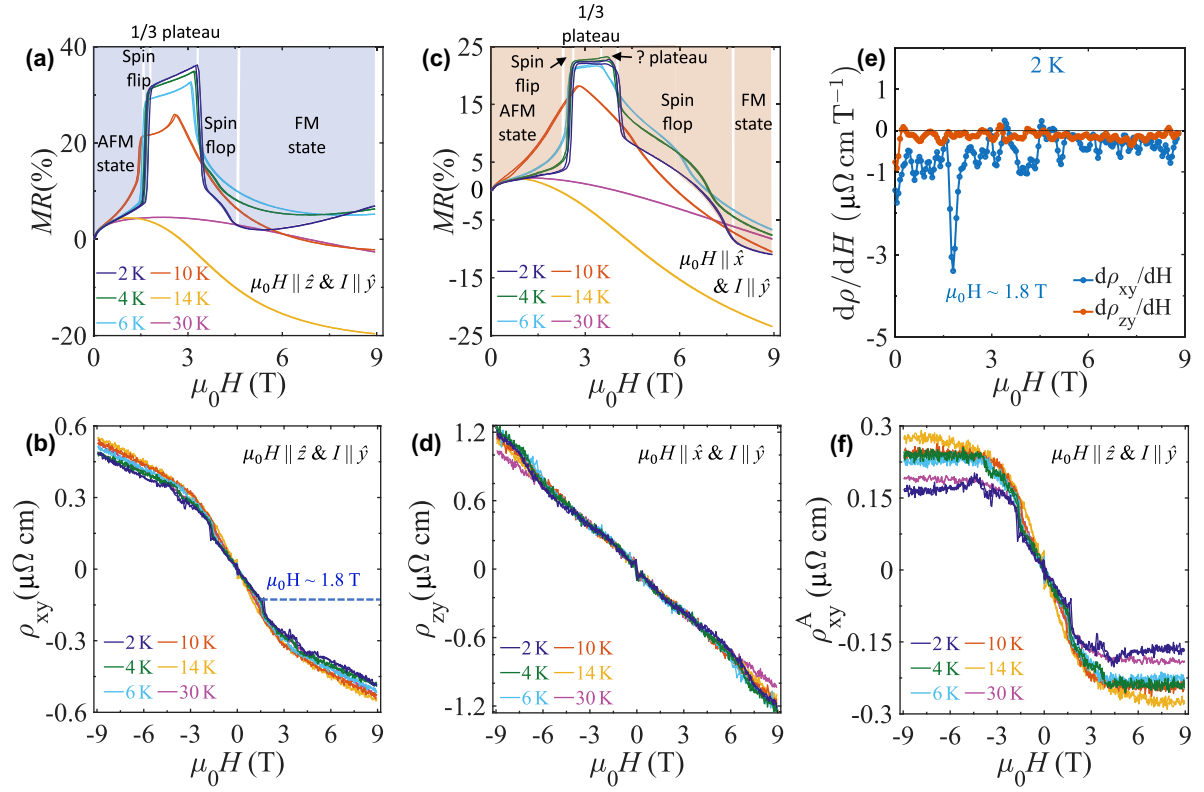


FIG. 2. Field dependence of (a) the resistivity and (b) Hall resistivity at various temperatures for $I \parallel \hat{y}$ and $\mu_0 H \parallel \hat{z}$. Field dependence of (c) the resistivity and (d) Hall resistivity at various temperatures for $I \parallel \hat{y}$ and $\mu_0 H \parallel \hat{x}$. (e) Comparison of the first derivative of the Hall resistivities of two different directions (ρ_{zy} and ρ_{xy}) at 2 K. (f) Extracted anomalous Hall resistivity ρ_{xy}^A from (b).

along $\mu_0 H \parallel c$ exhibits a peak at approximately 14.73 K, indicating a paramagnetic to AFM transition [Fig. S2(a)] [45]. Figures S2(b)–S2(d) shows isothermal magnetization measurements conducted along different axes, and Fig. 1(d) shows isothermal magnetization along different directions at 2 K, with the a and c axes being the easy axes. Magnetization for field along the c axis reaches saturation, $M_s \sim 7.9 \mu_B/\text{f.u.}$, which is in close alignment with the theoretical moment of Gd^{3+} ions. Notably, a distinct metamagnetic transition below 8 K is discernible at a critical field of approximately $\mu_0 H_C \approx 1.8 \text{ T}$ (c axis) and 2.5 T (a axis). These transitions are at approximately 1/3 of M_s . Both directions show a spin-flip transition before the 1/3 plateau, followed by spin flop. For $\mu_0 H \parallel a$, additional plateau-like behavior appears before the FM state is reached. We call it the unknown plateau in this study. Overall magnetization varies similarly for both $\mu_0 H \parallel a$ and $\mu_0 H \parallel c$, even though magnetization saturation is approaching until 7 T for the a axis. This similarity but difference in magnetization hints at the direct link with the zigzag chain of Gd along the a direction. In GdTi_3Bi_4 , weak interlayer AFM coupling leads to the realization of the 1/3 plateau at comparatively low fields for $\mu_0 H \parallel c$. The presence of similar multiple metamagnetic transitions was previously observed in HoAgGe as well and was attributed to the existence of canted AFM states [42,46]. Such states exert a significant influence on transport properties, highlighting the importance of understanding the magnetic behavior. As sketched in the inset of Fig. 1(e), the a , b , and c axes of

the material are equivalent to $\hat{x}$, $\hat{y}$, and $\hat{z}$ in measurements, respectively.

To examine the complex relationship between magnetism and transport properties, the measurement of the transverse resistivity and Hall resistivity of GdTi_3Bi_4 crystals was carried out across 2–30 K under varying temperatures and $\mu_0 H \parallel \hat{z}$ and $\hat{x}$. Figure 1(e) shows zero-field resistivities (ρ_{yy} , ρ_{zz}) in logarithmic scale versus temperature. The decrease in resistivity with decreasing temperature is indicative of metallic behavior, while the hump near 14.7 K marks the paramagnetic to AFM transition. Below the magnetic transition, a sharp decrease in the resistivity indicates lower scattering, and this decline is particularly pronounced in the case of a transition to an AFM state. The resistivity along $\hat{z}$ has been found to be ~ 3 times higher in comparison to that of $\hat{y}$. This resistivity anisotropy indicates that GdTi_3Bi_4 is indeed a layered material whose layers are not highly isolated and are electrically connected [47]. These resistivities at different magnetic fields are shown in Figs. S3(a) and S3(b), indicating the suppression of T_N with field due to the predominance of the Zeeman energy over the antiferromagnetic exchange energy [45].

The application of $\mu_0 H \parallel \hat{z}$ and $\hat{x}$ enabled the discernment of the AFM ground state to 1/3 plateau spin-flip to FM spin-flop transitions from the field-dependent resistivity plots at different temperatures. The magnetoresistance (MR) data ($\text{MR}(H) = [\rho_{yy}(H) - \rho_{yy}(0)]/\rho_{yy}(0)$) display a complex behavior at low temperatures [Figs. 2(a) and 2(c)]. Specifically,

at 2 K for $\mu_0 H \parallel \hat{z}$, MR initially increases gradually before exhibiting sharp transitions at approximately 1.8, 3.3, and 4.4 T which correspond to the metamagnetic transitions observed in the magnetization data. These abrupt shifts in resistivity can be attributed to the presence of canted spin states. These features are only evident below 15 K due to the occurrence of spin-flip transitions. As the temperature increases, the peaks gradually shift to lower fields and eventually disappear above T_N . The magnetization data corroborate these findings and offer a potential explanation that is rooted in metamagnetic phase transitions. A similar MR behavior was observed for $\mu_0 H \parallel \hat{x}$, as shown in Fig. 2(c). It can be concluded that the magnetic properties of the material are the primary factor influencing its electronic band structure and its topology, which can be accessed through the transport measurements [5,40,48].

Figure 2(b) presents the Hall resistivity at different temperatures (2 to 30 K) as a function of the applied magnetic field when $\mu_0 H \parallel \hat{z}$ and $I \parallel \hat{y}$. In magnetic systems, the Hall resistivity ρ_{xy} is typically composed of two distinct contributions: $\rho_{xy} = R_0 \mu_0 H + R_s M$, where the first and second terms represent the ordinary and anomalous Hall resistivities, respectively [3]. By isolating these contributions, we obtained the anomalous Hall resistivity ρ_{xy}^A , as depicted in Fig. 2(f). ρ_{xy}^A exhibits stepwise increments with $\mu_0 H$, followed by saturation and subsequent increments, which mirror the behavior observed in the magnetization curve. After extrapolating the saturation to zero field at 2 K, the typical value of ρ_{xy}^A is $\sim 0.18 \mu\Omega \text{ cm}$ [Fig. 2(f)]. In contrast, after we switch $\mu_0 H \parallel \hat{x}$ in the same piece of sample, ρ_{zy} shows completely linear behavior [Fig. 2(d)]. This can be seen better in the first derivative of the Hall resistivities with respect to the field for 2 K, as shown in Fig. 2(e). The substantial alteration in slope manifests as a dip when $\mu_0 H \parallel \hat{z}$, and this dip is absent when $\mu_0 H \parallel \hat{x}$. Interestingly, the field value of the dip corresponds to the 1/3 plateau, where anomalous behavior in the Hall resistivity exclusively emerges in the $\mu_0 H \parallel \hat{z}$ case. This feature has been thoroughly examined in subsequent discourse, accompanied by theoretical insights. In another study, the Hall signal had similar features except for a pronounced peak at ~ 3 T, which could be due to a microscopic origin [30]. The temperature-dependent variation of both mobility μ and carrier concentration n in different directions is shown in Figs. S3(c) and S3(d) [45]. The comparable μ and n along both axes indicate that the underlying dominant scattering mechanisms are similar. The presence of a cusplike feature in the magnetoresistance and a kink in the Hall resistivity for both field orientations near zero field is attributed to a weak antilocalization effect, which is commonly observed in compounds with large SOC [49,50].

The presence of an anisotropic AHE in one direction and its absence in another direction despite analogous magnetization is rarely observed in materials. To the best of our knowledge, there is no extant experimental study that claims to have observed this phenomenon. This alteration may be attributable to the intertwining of magnetism and the zigzag configuration of Gd atoms along the a axis. Recent observations revealed the presence of a direction-dependent spin-charge intertwined density wave and stripe magnetization in this ma-

terial when an external magnetic field is applied along the c -axis direction [30,32]. A similar intertwining phenomenon was also observed in another kagome material, Mn_3Sn , suggesting a potential link to the magnetization [51]. We further elucidate the origin of the observed AHE along the c axis in Fig. 3.

The field-dependent AHC σ_{yx}^A was estimated by employing the equation $\sigma_{yx}^A(H) = \frac{\rho_{xy}^A(H)}{(\rho_{xy}^A(H))^2 + \rho_{yy}^2(H)}$. As displayed in Fig. 3(a), the calculated σ_{yx}^A at 4 K yields a value of $585 \Omega^{-1} \text{ cm}^{-1}$, extrapolated from high field. The AHE is a quantum phenomenon that arises for multiple reasons, but the three main reasons are the Berry phase, skew scattering from disorder in the system, and side jump scattering due to spin-orbit coupled impurities [3]. The Berry phase contribution is intrinsic, arising from the band structure of the material. The skew scattering is theoretically proportional to the resistivity ($\rho_{xy}^A \propto \rho_{yy}$). On the other hand, the contribution of the Berry phase and side jump scattering together is proportional to the square of the resistivity ($\rho_{xy}^A \propto \rho_{yy}^2$). Thus, the AHE can be written as the sum of both dependences as $\rho_{xy}^A = a\rho_{yy} + b\rho_{yy}^2$. Linear fitting of ρ_{xy}^A/ρ_{yy} versus ρ_{yy} from 4 to 14 K [Fig. 3(c)] confirms that the main contribution of the AHE is from the BC and side jump mechanisms. The slope of the fit yields an intrinsic AHC of $\sim 360 \Omega^{-1} \text{ cm}^{-1}$, closely matching the experimental value. Notably, the data at 2 K deviate from a linear fit. This deviation is indicative of a potential change in the underlying electronic structure, which may be attributed to a transition from $3Q$ charge order to $2Q$ charge order [32]. Furthermore, variation of the AHC with temperature also clearly shows the rise from 2 to 4 K, followed by a substantial decline at temperatures exceeding 15 K [Fig. 3(b)]. This behavior shows that not only is the AHE direction sensitive, but its magnitude and scaling behavior are also sensitive to ordering parameters. The angle-dependent AHE demonstrates a decline in value with increasing angle, as shown in Fig. 3(d). It is evident that the perpendicular component of the field with respect to the current is the sole contributing factor to the Hall resistivity. Consequently, as the angle between $\mu_0 H$ and I decreases, the Hall resistivity decreases. Moreover, a full logarithmic plot of σ_{yx}^A versus σ_{yy} for a range of materials is shown in Fig. S5 [8,9,45,52–59]. In general, the analysis reveals the presence of three distinct regimes in the classification of the AHE contribution. In the high-conductivity regime ($\sigma_{yy} > 10^6 \Omega^{-1} \text{ cm}^{-1}$), the linear contribution to $\sigma_{yx}^A \sim \sigma_{yy}$ is dominated by skew scattering, while in the bad metal regime ($\sigma_{yy} < 10^4 \Omega^{-1} \text{ cm}^{-1}$), σ_{yx}^A decreases with decreasing σ_{yy} at a rate that is faster than linear. On the other hand, within the intrinsic or scattering-independent regime ($10^4 \Omega^{-1} \text{ cm}^{-1} < \sigma_{yy} < 10^6 \Omega^{-1} \text{ cm}^{-1}$), σ_{yx}^A is roughly independent of σ_{yy} [3]. Thus, it can be concluded from Fig. S5 that GdTi_3Bi_4 lies in the intrinsic regime, thereby signifying that the observed AHE is indicative of an intrinsic contribution such as BC, which depends on the band structure of the material.

In the high-field saturated FM state, the TRS is broken, and the system carries a uniform nonzero net magnetization ($M \neq 0$) aligned with the external field, superimposed on

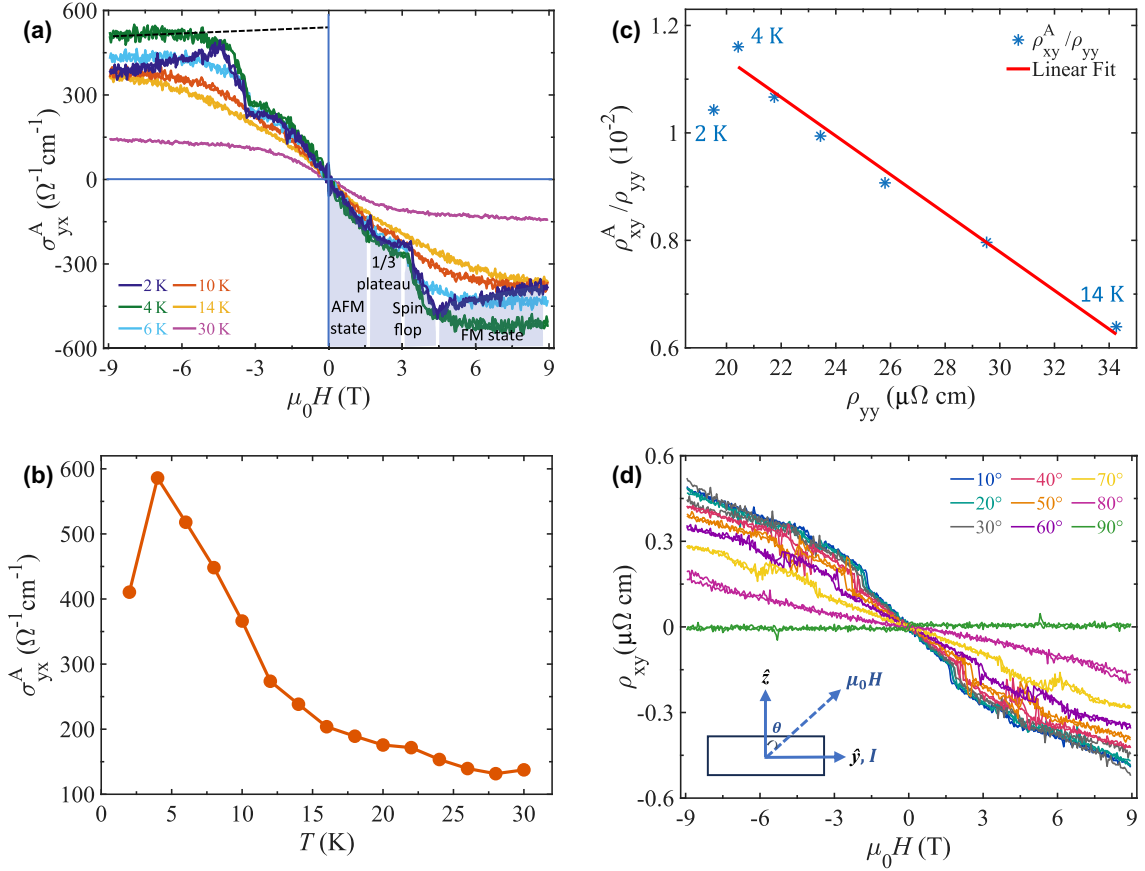


FIG. 3. (a) Anomalous Hall conductivity σ_{yx}^A of GdTi₃Bi₄ at several temperatures. (b) Variation of σ_{yx}^A with temperature. (c) Linear fitting of the ratio of ρ_{xy}^A/ρ_{yy} versus ρ_{yy} in the temperature range 4–14 K. (d) Hall resistivity at different angles at 2 K. The inset shows the rotating angle between $\mu_0 H$ and I .

an AFM background. The intrinsic AHC originates from BC and is governed by the spin-quantization axis under SOC. To evaluate it in two saturated configurations, all local moments are constrained to be collinear with $M \parallel a$ or $M \parallel c$ (constrained FM) [3,60,61]. First-principles spin-polarized density functional theory (DFT) calculations were performed using the Vienna Ab initio Simulation Package (vasp) with the Perdew-Burke-Ernzerhof functional in the generalized gradient approximation and the Dudarev DFT+U scheme ($U_{\text{eff}} = U - J = 6$ eV for Gd $4f$ and all others are 0 eV) [62–65]. Figures 4(a) and 4(c) show the band structures for the FM state along $\hat{z}$ and $\hat{x}$, respectively. The band colors encode the z and x components of the BC, $\Omega(k)$, on the color scale shown in Fig. 4(b); yellow (blue) denotes large positive (negative) curvature. The right panels show the energy-dependent AHC obtained with the Kubo-Berry formalism. At $E = E_F$, the calculated intrinsic AHC for $\mu_0 H \parallel \hat{z}$ is much larger than that for $\mu_0 H \parallel \hat{x}$ (by a factor of 3.6), and its sign and scale are comparable to the experimental AHC for $\mu_0 H \parallel \hat{z}$, demonstrating that the dominant contribution is intrinsic. BC slices [Figs. 4(b) and 4(d)] further highlight how the Hall response evolves when the magnetization is rotated. For $\mu_0 H \parallel \hat{z}$, Ω_z on the T - Y - U_0 - C_0 plane manifests both broader positive bands and deeper negative lobes, with the negative region clearly predominating in terms of areal coverage [Fig. 4(b)]. The

Brillouin zone is shown in Fig. S6 [45]. Integrating the signed Berry curvature over this slice yields a net value of 169.75 (in units consistent with the three-dimensional Kubo-Berry integration). In contrast, in Fig. 4(d) (Ω_x on the same plane as $\mu_0 H \parallel \hat{x}$), the curvature generates narrow yellow and blue stripes of opposite sign and almost equal area; the net signed integral is only 16.62, indicating much stronger cancellation. Consequently, their contributions cancel in the Brillouin-zone integral, and only a modest σ_{yz}^A remains, where σ_{yz}^A is set by an extended, nearly single sign Ω_z pattern. By comparing orbital-projected band structures with Berry-curvature colored bands, we find that for $\mu_0 H \parallel \hat{z}$ the BC hot spots near E_F trace SOC-gapped anticrossings within the Ti t_{2g} manifold, predominantly $\{d_{xz}, d_{yz}\}$ along Y - C_0 and U_0 - T . In contrast, for $\mu_0 H \parallel \hat{x}$, the active SOC matrix elements couple d_{xz} to d_{z^2} and d_{yz} to d_{xy} . However, the d_{z^2} weight is shifted above E_F , resulting in the avoided crossings that fall away from E_F . This leads to a significantly weaker Ω_x and σ_{yz}^A (E_F). Therefore, despite the negligible local moment of Ti, the exchange field from the Gd $4f$ sublattice breaks TRS for the Ti-derived Bloch states. In the presence of SOC, the active-matrix elements are found to be contingent upon the spin-quantization axis ($\mu_0 H \parallel \hat{x}$ vs $\mu_0 H \parallel \hat{z}$), elucidating the underlying reason for the substantial AHC for $\mu_0 H \parallel \hat{z}$ and its strong suppression for $\mu_0 H \parallel \hat{x}$.

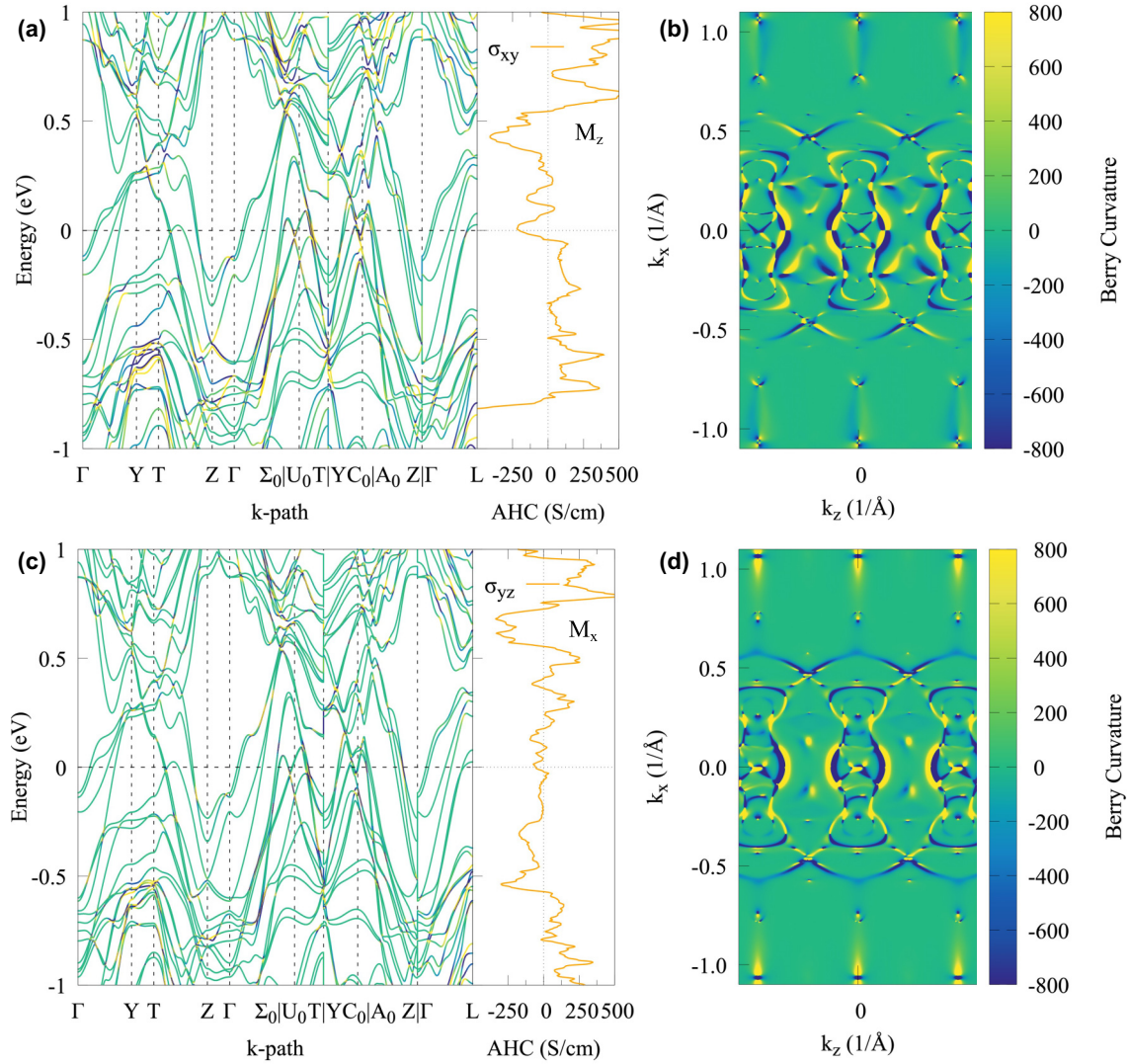


FIG. 4. (a) Berry-curvature colored band structure for the saturated FM state with $\mu_0 H \parallel \hat{z}$ (left; bands colored by $W_z = \Omega_z$) and intrinsic $\sigma_{xy}^A(E_F)$ from the Kubo-Berry formalism (right; E_F indicated). (b) Constant-energy slice of $W_z(k)$ on the T - Y - U_0 - C_0 plane at $E = E_F$. (c) Same as (a), but for $\mu_0 H \parallel \hat{x}$: left, bands colored by $W_x = \Omega_x$; right, intrinsic $\sigma_{yz}^A(E_F)$. (d) Same as (b), but for $\mu_0 H \parallel \hat{x}$: constant-energy slice of $W_x(k)$ on the T - Y - U_0 - C_0 plane at $E = E_F$.

Conclusion. In summary, our study presents a systematic direction dependent investigation of the magnetic and electrical transport properties of GdTi_3Bi_4 single crystals. GdTi_3Bi_4 with a T_N of approximately 15 K displays the metamagnetic transition under $\mu_0 H \parallel c$ and a , usually present in one-dimensional zigzag chain systems due to weak inter-layer AFM couplings. We observed that the large anomalous Hall conductivity of $410 \Omega^{-1} \text{cm}^{-1}$ at 2 K is observed when $\mu_0 H \parallel \hat{z}$ and it is absent when $\mu_0 H \parallel \hat{x}$ despite the presence of similar field-dependent magnetic behavior. This is an intrinsic AHC, which further originates from the BC. The obtained results reveal a clear distinction in the roles of the different components. Gd $4f$ is responsible for breaking TRS and establishing the magnetization direction, while the SOC in the Ti-derived bands converts the orientation into BC and controls the intrinsic AHC. This study serves as a foundation for future research to clarify the mechanistic breakdown of the AHE. Extending such in-

vestigations to other kagome materials, especially RTi_3Bi_4 compounds, has the potential to uncover additional exotic topological phenomena, in which the interplay between topology, electron correlation, and magnetism assumes paramount importance.

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Data availability. The data that support the findings of this article are not publicly available upon publication because it is not technically feasible and/or the cost of preparing, depositing, and hosting the data would be prohibitive within the terms of this research project. The data are available from the authors upon reasonable request.

- [1] R. Karplus and J. M. Luttinger, Hall effect in ferromagnetics, *Phys. Rev.* **95**, 1154 (1954).
- [2] G. Bergmann, The anomalous Hall effect, *Phys. Today* **32**(8), 25 (1979).
- [3] N. Nagaosa, J. Sinova, S. Onoda, A. H. MacDonald, and N. P. Ong, Anomalous Hall effect, *Rev. Mod. Phys.* **82**, 1539 (2010).
- [4] H. Chen, Q. Niu, and A. H. MacDonald, Anomalous Hall effect arising from noncollinear antiferromagnetism, *Phys. Rev. Lett.* **112**, 017205 (2014).
- [5] S. Nakatsuji, N. Kiyohara, and T. Higo, Large anomalous Hall effect in a non-collinear antiferromagnet at room temperature, *Nature (London)* **527**, 212 (2015).
- [6] L. Šmejkal, A. H. MacDonald, J. Sinova, S. Nakatsuji, and T. Jungwirth, Anomalous Hall antiferromagnets, *Nat. Rev. Mater.* **7**, 482 (2022).
- [7] I. Syőzi, Statistics of kagomé lattice, *Prog. Theor. Phys.* **6**, 306 (1951).
- [8] E. Liu, Y. Sun, N. Kumar, L. Muechler, A. Sun, L. Jiao, S.-Y. Yang, D. Liu, A. Liang, Q. Xu, *et al.*, Giant anomalous Hall effect in a ferromagnetic kagome-lattice semimetal, *Nat. Phys.* **14**, 1125 (2018).
- [9] A. K. Nayak, J. E. Fischer, Y. Sun, B. Yan, J. Karel, A. C. Komarek, C. Shekhar, N. Kumar, W. Schnelle, J. Kübler, *et al.*, Large anomalous Hall effect driven by a nonvanishing Berry curvature in the noncolinear antiferromagnet Mn_3Ge , *Sci. Adv.* **2**, e1501870 (2016).
- [10] S. Roychowdhury, A. M. Ochs, S. N. Guin, K. Samanta, J. Noky, C. Shekhar, M. G. Vergniory, J. E. Goldberger, and C. Felser, Large room temperature anomalous transverse thermoelectric effect in kagome antiferromagnet YMn_6Sn_6 , *Adv. Mater.* **34**, 2201350 (2022).
- [11] H. W. S. Arachchige, W. R. Meier, M. Marshall, T. Matsuoka, R. Xue, M. A. McGuire, R. P. Hermann, H. Cao, and D. Mandrus, Charge density wave in kagome lattice intermetallic ScV_6Sn_6 , *Phys. Rev. Lett.* **129**, 216402 (2022).
- [12] F. H. Yu, D. H. Ma, W. Z. Zhuo, S. Q. Liu, X. K. Wen, B. Lei, J. J. Ying, and X. H. Chen, Unusual competition of superconductivity and charge-density-wave state in a compressed topological kagome metal, *Nat. Commun.* **12**, 3645 (2021).
- [13] S. Regmi, T. Fernando, Y. Zhao, A. P. Sakhyia, G. Dhakal, I. Bin Elius, H. Vazquez, J. D. Denlinger, J. Yang, J.-H. Chu, *et al.*, Spectroscopic evidence of flat bands in breathing kagome semiconductor Nb_3I_8 , *Commun. Mater.* **3**, 100 (2022).
- [14] B. R. Ortiz, S. M. L. Teicher, Y. Hu, J. L. Zuo, P. M. Sarte, E. C. Schueller, A. M. M. Abeykoon, M. J. Krogstad, S. Rosenkranz, R. Osborn, *et al.*, CsV_3Sb_5 : A $\mathbb{Z}_2$ topological kagome metal with a superconducting ground state, *Phys. Rev. Lett.* **125**, 247002 (2020).
- [15] J. X. Yin, W. L. Ma, T. A. Cochran, X. T. Xu, S. T. S. Zhang, H. J. Tien, N. Shumiya, G. M. Cheng, K. Jiang, B. Lian, *et al.*, Quantum-limit Chern topological magnetism in TbMn_6Sn_6 , *Nature (London)* **583**, 533 (2020).
- [16] A. K. Sharma, S. Chatterjee, P. Yanda, C. Felser, and C. Shekhar, Topological quantum materials: Kagome, chiral, and square-net frameworks, *arXiv:2507.12410*.
- [17] H. Chen, B. Hu, Y. H. Ye, H. T. Yang, and H. J. Gao, Superconductivity and unconventional density waves in vanadium-based kagome materials AV_3Sb_5 , *Chin. Phys. B* **31**, 097405 (2022).
- [18] H. Chen, H. Yang, B. Hu, Z. Zhao, J. Yuan, Y. Xing, G. Qian, Z. Huang, G. Li, Y. Ye, *et al.*, Roton pair density wave in a strong-coupling kagome superconductor, *Nature (London)* **599**, 222 (2021).
- [19] L. Nie, K. Sun, W. Ma, D. Song, L. Zheng, Z. Liang, P. Wu, F. Yu, J. Li, M. Shan, *et al.*, Charge-density-wave-driven electronic nematicity in a kagome superconductor, *Nature (London)* **604**, 59 (2022).
- [20] B. R. Ortiz, L. C. Gomes, J. R. Morey, M. Winiarski, M. Bordelon, J. S. Mangum, I. W. H. Oswald, J. A. Rodriguez-Rivera, J. R. Neilson, S. D. Wilson, *et al.*, New kagome prototype materials: Discovery of KV_3Sb_5 , RbV_3Sb_5 , and CsV_3Sb_5 , *Phys. Rev. Mater.* **3**, 094407 (2019).
- [21] D. C. Fredrickson, S. Lidin, G. Venturini, B. Malaman, and J. Christensen, Origins of superstructure ordering and incommensurability in stuffed CoSn -type phases, *J. Am. Chem. Soc.* **130**, 8195 (2008).
- [22] W. Ma, X. Xu, J.-X. Yin, H. Yang, H. Zhou, Z.-J. Cheng, Y. Huang, Z. Qu, F. Wang, M. Z. Hasan, *et al.*, Rare earth engineering in RMn_6Sn_6 ($R = \text{Gd-Tm, Lu}$) topological kagome magnets, *Phys. Rev. Lett.* **126**, 246602 (2021).
- [23] F. H. Yu, T. Wu, Z. Y. Wang, B. Lei, W. Z. Zhuo, J. J. Ying, and X. H. Chen, Concurrence of anomalous Hall effect and charge density wave in a superconducting topological kagome metal, *Phys. Rev. B* **104**, L041103 (2021).
- [24] S.-Y. Yang, Y. Wang, B. R. Ortiz, D. Liu, J. Gayles, E. Derunova, R. Gonzalez-Hernandez, L. Šmejkal, Y. Chen, S. S. P. Parkin, *et al.*, Giant, unconventional anomalous Hall effect in the metallic frustrated magnet candidate, KV_3Sb_5 , *Sci. Adv.* **6**, eabb6003 (2020).
- [25] M. H. Christensen, T. Birol, B. M. Andersen, and R. M. Fernandes, Loop currents in AV_3Sb_5 kagome metals: Multipolar and toroidal magnetic orders, *Phys. Rev. B* **106**, 144504 (2022).
- [26] D. Chen, C. C. Le, C. G. Fu, H. C. Lin, W. Schnelle, Y. Sun, and C. Felser, Large anomalous Hall effect in the kagome ferromagnet LiMn_6Sn_6 , *Phys. Rev. B* **103**, 144410 (2021).
- [27] B. Lv, R. Zhong, X. Luo, S. Ma, C. Chen, S. Wang, Q. Luo, F. Gao, C. Fang, W. Ren, *et al.*, Anomalous Hall effect in kagome ferromagnet YbMn_6Sn_6 single crystal, *J. Alloys Compd.* **957**, 170356 (2023).
- [28] C. Yi, X. Feng, N. Mao, P. Yanda, S. Roychowdhury, Y. Zhang, C. Felser, and C. Shekhar, Quantum oscillations revealing topological band in kagome metal ScV_6Sn_6 , *Phys. Rev. B* **109**, 035124 (2024).
- [29] B. R. Ortiz, H. Miao, D. S. Parker, F. Yang, G. D. Samolyuk, E. M. Clements, A. Rajapitamahuni, T. Yilmaz, E. Vescovo, J. Yan, *et al.*, Evolution of highly anisotropic magnetism in the titanium-based kagome metals LnTi_3Bi_4 ($\text{Ln} : \text{La} \cdots \text{Gd}^{3+}, \text{Eu}^{2+}, \text{Yb}^{2+}$), *Chem. Mater.* **35**, 9756 (2023).
- [30] E. Cheng, N. Mao, X. Yang, B. Song, R. Lou, T. Ying, S. Nie, A. Fedorov, F. Bertran, and P. Ding, Striped magnetization plateau and chirality-reversible anomalous Hall effect in a magnetic kagome metal, *arXiv:2409.01365*.
- [31] J. Guo, L. Zhou, J. Ding, G. Qu, Z. Liu, Y. Du, H. Zhang, J. Li, Y. Zhang, F. Zhou, *et al.*, Tunable magnetism and band structure in kagome materials RETi_3Bi_4 family with weak interlayer interactions, *Sci. Bull.* **69**, 2660 (2024).

- [32] X. Han, H. Chen, Z. Cao, J. Guo, F. Fei, H. Tan, J. Guo, Y. Shi, R. Zhou, and R. Wang, Discovery of unconventional charge-spin-intertwined density wave in magnetic kagome metal GdTi_3Bi_4 , [arXiv:2503.05545](#).
- [33] B. R. Ortiz, H. Zhang, K. Górnicka, D. S. Parker, G. D. Samolyuk, F. Yang, H. Miao, Q. Lu, R. G. Moore, A. F. May, *et al.*, Intricate magnetic landscape in antiferromagnetic kagome metal TbTi_3Bi_4 and interplay with $\text{Ln}_{2-x}\text{Ti}_{6+x}\text{Bi}_9$ (Ln: Tb...Lu) shurikagome metals, *Chem. Mater.* **36**, 8002 (2024).
- [34] R. Zhang, B. Yu, H. Tan, Y. Cheng, F. Shen, J. Yang, D. Mu, X. Han, A. Zong, *et al.*, Observation of orbital-selective band reconstruction in an anisotropic antiferromagnetic kagome metal TbTi_3Bi_4 , *Phys. Rev. X* **15**, 031012 (2025).
- [35] K. Guo, Z. Ma, H. Liu, Z. Wu, J. Wang, Y. Shi, Y. Li, and S. Jia, 1/3 and other magnetization plateaus in the quasi-one-dimensional Ising magnet TbTi_3Bi_4 with zigzag spin chain, *Phys. Rev. B* **110**, 064416 (2024).
- [36] Z. Zheng, L. Chen, X. Ji, Y. Zhou, G. Qu, M. Hu, Y. Huang, H. Weng, T. Qian, and G. Wang, Anisotropic magnetism and band evolution induced by ferromagnetic phase transition in titanium-based kagome ferromagnet SmTi_3Bi_4 , *Sci. China: Phys., Mech. Astron.* **67**, 267411 (2024).
- [37] P. Park, B. R. Ortiz, M. Sprague, A. P. Sakhyia, S. A. Chen, M. Frontzek, W. Tian, R. Sibille, D. G. Mazzone, and C. Tabata, Spin density wave and Van Hove singularity in the kagome metal CeTi_3Bi_4 , *Nat. Commun.* **16**, 4384 (2025).
- [38] J. Guo, S. Zhu, R. Zhou, R. Wang, Y. Wang, J. Sun, Z. Zhao, X. Dong, J. Cheng, H. Yang, *et al.*, Tunable bifurcation of magnetic anisotropy and bi-oriented antiferromagnetic order in kagome metal GdTi_3Bi_4 , *Phys. Rev. Lett.* **134**, 226704 (2025).
- [39] C. Shekhar, N. Kumar, V. Grinenko, S. Singh, R. Sarkar, H. Luetkens, S.-C. Wu, Y. Zhang, A. C. Komarek, E. Kampert, *et al.*, Anomalous Hall effect in Weyl semimetal half-Heusler compounds RPtBi (R = Gd and Nd), *Proc. Natl. Acad. Sci. USA* **115**, 9140 (2018).
- [40] T. Suzuki, R. Chisnell, A. Devarakonda, Y. T. Liu, W. Feng, D. Xiao, J. W. Lynn, and J. G. Checkelsky, Large anomalous Hall effect in a half-Heusler antiferromagnet, *Nat. Phys.* **12**, 1119 (2016).
- [41] N. Kikugawa, S. Uji, and T. Terashima, Anomalous Hall effect in the magnetic Weyl semimetal NdAlGe with plateaus observed at low temperatures, *Phys. Rev. B* **109**, 035143 (2024).
- [42] S. Roychowdhury, K. Samanta, S. Singh, W. Schnelle, Y. Zhang, J. Noky, M. G. Vergniory, C. Shekhar, and C. Felser, Enhancement of the anomalous Hall effect by distorting the kagome lattice in an antiferromagnetic material, *Proc. Natl. Acad. Sci. USA* **121**, e2401970121 (2024).
- [43] T. Hikihara, T. Momoi, A. Furusaki, and H. Kawamura, Magnetic phase diagram of the spin-1/2 antiferromagnetic zigzag ladder, *Phys. Rev. B* **81**, 224433 (2010).
- [44] K. Okunishi and T. Tonegawa, Magnetic phase diagram of the $S = 1/2$ antiferromagnetic zigzag spin chain in the strongly frustrated region: Cusp and plateau, *J. Phys. Soc. Jpn.* **72**, 479 (2003).
- [45] See Supplemental Material at <https://link.aps.org/supplemental/10.1103/bnvq-rbdc> for the characterization data for GdTi_3Bi_4 , the mobility and carrier concentration, the AHCs of various materials compared with GdTi_3Bi_4 , and an illustration of the Brillouin zone of GdTi_3Bi_4 .
- [46] K. Zhao, H. Deng, H. Chen, K. A. Ross, V. Petřiček, G. Günther, M. Russina, V. Hutanu, and P. Gegenwart, Realization of the kagome spin ice state in a frustrated intermetallic compound, *Science* **367**, 1218 (2020).
- [47] Y. Xiang, Q. Li, Y. Li, W. Xie, H. Yang, Z. Wang, Y. Yao, and H.-H. Wen, Twofold symmetry of c -axis resistivity in topological kagome superconductor CsV_3Sb_5 with in-plane rotating magnetic field, *Nat. Commun.* **12**, 6727 (2021).
- [48] Y. Pan, C. Le, B. He, S. J. Watzman, M. Yao, J. Gooth, J. P. Heremans, Y. Sun, and C. Felser, Giant anomalous Nernst signal in the antiferromagnet YbMnBi_2 , *Nat. Mater.* **21**, 203 (2022).
- [49] D. M. Vu, W. Shon, J.-S. Rhyee, M. Sasaki, A. Ohnishi, K.-S. Kim, and H.-J. Kim, Weak antilocalization and two-carrier electrical transport in $\text{Bi}_{1-x}\text{Sb}_x$ single crystals ($0\% \leq x \leq 17.0\%$), *Phys. Rev. B* **100**, 125162 (2019).
- [50] C. Shekhar, C. E. ViolBarbosa, B. Yan, S. Ouardi, W. Schnelle, G. H. Fecher, and C. Felser, Evidence of surface transport and weak antilocalization in a single crystal of the $\text{Bi}_2\text{Te}_2\text{Se}$ topological insulator, *Phys. Rev. B* **90**, 165140 (2014).
- [51] Y. Chen, J. Gaudet, G. G. Marcus, T. Nomoto, T. Chen, T. Tomita, M. Ikhlas, H. S. Suzuki, Y. Zhao, W. C. Chen, *et al.*, Intertwined charge and spin density waves in a topological kagome material, *Phys. Rev. Res.* **6**, L032016 (2024).
- [52] J. Kübler and C. Felser, Weyl fermions in antiferromagnetic Mn_3Sn and Mn_3Ge , *Europhys. Lett.* **120**, 47002 (2017).
- [53] W. J. Xu, B. Zhang, Z. X. Liu, Z. Wang, W. Li, Z. B. Wu, R. H. Yu, and X. X. Zhang, Anomalous Hall effect in Fe/Gd bilayers, *Europhys. Lett.* **90**, 27004 (2010).
- [54] M. Lee, Y. Onose, Y. Tokura, and N. P. Ong, Hidden constant in the anomalous Hall effect of high-purity magnet MnSi , *Phys. Rev. B* **75**, 172403 (2007).
- [55] S. Sangiao, L. Morellon, G. Simon, J. M. De Teresa, J. A. Pardo, J. Arbiol, and M. R. Ibarra, Anomalous Hall effect in Fe (001) epitaxial thin films over a wide range in conductivity, *Phys. Rev. B* **79**, 014431 (2009).
- [56] N. Haham, Y. Shperber, M. Schultz, N. Naftalis, E. Shimshoni, J. W. Reiner, and L. Klein, Scaling of the anomalous Hall effect in SrRuO_3 , *Phys. Rev. B* **84**, 174439 (2011).
- [57] Z. B. Guo, W. B. Mi, Q. Zhang, B. Zhang, R. O. Aboljadayel, and X. X. Zhang, Anomalous Hall effect in polycrystalline Ni films, *Solid State Commun.* **152**, 220 (2012).
- [58] J. Kötzler and W. Gil, Anomalous Hall resistivity of cobalt films: Evidence for the intrinsic spin-orbit effect, *Phys. Rev. B* **72**, 060412(R) (2005).
- [59] T. Miyasato, N. Abe, T. Fujii, A. Asamitsu, S. Onoda, Y. Onose, N. Nagaosa, and Y. Tokura, Crossover behavior of the anomalous Hall effect and anomalous Nernst effect in itinerant ferromagnets, *Phys. Rev. Lett.* **99**, 086602 (2007).
- [60] D. Xiao, M.-C. Chang, and Q. Niu, Berry phase effects on electronic properties, *Rev. Mod. Phys.* **82**, 1959 (2010).
- [61] Y. Yao, L. Kleinman, A. H. MacDonald, J. Sinova, T. Jungwirth, D.-S. Wang, E. Wang, and Q. Niu, First principles calculation of anomalous Hall conductivity in ferromagnetic bcc Fe, *Phys. Rev. Lett.* **92**, 037204 (2004).
- [62] D. Hobbs, G. Kresse, and J. Hafner, Fully unconstrained noncollinear magnetism within the projector augmented-wave method, *Phys. Rev. B* **62**, 11556 (2000).

- [63] J. P. Perdew, K. Burke, and M. Ernzerhof, Generalized gradient approximation made simple, [Phys. Rev. Lett. **77**, 3865 \(1996\)](#).
- [64] S. L. Dudarev, G. A. Botton, S. Y. Savrasov, C. J. Humphreys, and A. P. Sutton, Electron-energy-loss spectra and the structural stability of nickel oxide: An LSDA+U study, [Phys. Rev. B **57**, 1505 \(1998\)](#).
- [65] H. J. Monkhorst and J. D. Pack, Special points for Brillouin-zone integrations, [Phys. Rev. B **13**, 5188 \(1976\)](#).