

Quantum Geometry of Altermagnetic Magnons Probed by Light

Rundong Yuan^{1,*}, Wojciech J. Jankowski^{1,†}, Ka Shen^{2,3}, and Robert-Jan Slager^{4,1,‡}

¹TCM Group, Cavendish Laboratory, *University of Cambridge*, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

²The Center for Advanced Quantum Studies, School of Physics and Astronomy, and
Institute for Advanced Study, *Beijing Normal University*, Beijing 100875, China

³Key Laboratory of Multiscale Spin Physics, Ministry of Education, *Beijing Normal University*, Beijing 100875, China

⁴Department of Physics and Astronomy, *University of Manchester*, Oxford Road, Manchester M13 9PL, United Kingdom



(Received 6 August 2025; accepted 5 August 2026; published 1 September 2026)

Magnons with momentum-dependent chirality are a key signature of altermagnets. We identify bicircular light as a smoking-gun optical probe for chiral altermagnetic magnons, selectively targeting their quantum geometry induced by an alternation of magnonic chirality. We show that in d -wave altermagnets, under a canting magnetic field, the altermagnetic magnons realize a nontrivial quantum geometry, resulting in an enhancement of the nonlinear second-order light-magnon interactions. We find that the scattering of bicircular pulses probes the present magnonic quantum geometry, even if the magnonic topology is trivial. Hence, our findings establish bicircular Raman response as an optical effect of choice to identify altermagnetic magnons. As such, we propose a universal experimental protocol to distinguish altermagnets from antiferromagnets by detecting their magnon chirality patterns with light, independently of the underlying magnon topology.

DOI: [10.1103/12cl-b9jj](https://doi.org/10.1103/12cl-b9jj)

Introduction—Excitations in ordered media, such as magnets, provide insights into the physical character of the underlying order. Magnons, the quanta of spin waves, carry spin-precessional information, such as chirality, in magnetic materials [1–3]. The dynamical chirality of magnons can be defined as the sum of the expectation value of right-handed (RH) and left-handed (LH) spin-precessional angular momentum once the magnetic polarization is aligned by single-ion anisotropy or an external magnetic field [4]. Because of time-reversal symmetry (TRS) breaking in ferromagnets, only RH magnons exist upon exciting a ferromagnetic ground state, resulting in chiral propagation of magnons [5–7] and magnon spin currents with only one sign under a fixed magnetic field [8–10]. The LH magnon chirality is recovered in antiferromagnetic (AFM) ground states, given their pseudo-TRS [4,11–13].

In a recently proposed classification of magnetic materials [14–16], altermagnets, the excitations of their magnetic order, i.e., altermagnetic (AM) magnons, possess chiral

properties despite a vanishing net magnetic moment of the system, even without any chiral Dzyaloshinskii-Moriya interactions that split energies of RH and LH magnons in conventional antiferromagnets [4,16–23]. Unlike conventional antiferromagnets, the altermagnets break TRS by their spin space groups, and thus lift electronic band degeneracies according to their magnetic polarizations [16–19,24–27]. Similarly, in altermagnets, the RH and LH magnons are energetically lifted on low-symmetry points of magnon band structures [16–20]. This splitting of AM magnons, and their chirality, are induced by the asymmetric exchange interactions due to the alignment of nonmagnetic atoms between magnetic atoms [16–19]. The chirality of magnetic excitations distinguishes altermagnets from antiferromagnets [16], and thus gives insight into the classification of magnetic order on a lattice, which makes the detection of magnon chirality of AM magnon bands highly desirable [18,28].

The chiral magnons in altermagnets have been investigated theoretically in various types of altermagnets such as d -wave altermagnet RuO_2 [17], Mn_2SeTe [29], etc., and g -wave altermagnets $\alpha\text{-MnTe}$ [19], CrSb [30], $\alpha\text{-Fe}_2\text{O}_3$ [31], etc. A full classification of magnons can be dictated by the spin space group classifications [32–36], following similar strategies for (magnetic) space groups [37–42]. Experimentally, the energy splitting of magnons has been observed by inelastic neutron scattering in the g -wave altermagnets $\alpha\text{-MnTe}$ and $\alpha\text{-Fe}_2\text{O}_3$ [29,43]. Notably, the splitting of magnon bands was found to be absent in AM MnF_2 [28]. Electrical detection of magnon chirality has

*Contact author: ry306@cam.ac.uk

†Contact author: wjj25@cam.ac.uk

‡Contact author: rjs269@cam.ac.uk

Published by the American Physical Society under the terms of the [Creative Commons Attribution 4.0 International](https://creativecommons.org/licenses/by/4.0/) license. Further distribution of this work must maintain attribution to the author(s) and the published article's title, journal citation, and DOI.

been conducted in $\alpha\text{-Fe}_2\text{O}_3$ [44], but the excitation energy (~ 10 GHz) is much lower than the splitting of chiral magnon bands, and thus makes their observations unlikely to originate from altermagnetism. To our best knowledge, a direct probe of the split chirality at a certain frequency of AM magnons remains elusive until now. It should be stressed that the energy scale of chiral magnons is much higher than the range of electrical probes [44–49], whereas inelastic neutron scattering and conventional Brillouin light scattering experiments are not sensitive to AFM or AM magnon chirality [50–53].

Centrally to this Letter, quantum geometry, consisting of the quantum metric and Berry curvature, can characterize the momentum-space Riemannian structure of Bloch wave functions arising from a given Hamiltonian [54,55]. Nontrivial geometry is found to give rise to Hall conductances [56–62], nonlinear transport [63,64], and higher-order optical responses [60,65–69] in various materials. In altermagnets, electronic quantum geometry has been reported to induce nontrivial topology [70–73], nonlinear electron transport [74,75], magnetic instability [76], and magneto-optical signatures [77–79]. On another note, bicircular light (BCL), which targets information of different symmetry by its phase slip and frequency tunability, has been utilized to probe quantum geometries [80–82]. For magnons, the nontrivial topology of AFM spin waves could also be captured by light-matter coupling (LMC) under a canting (perpendicular) magnetic field [68]. Although yet to be explored, LMC underpinned by the magnonic quantum metric, rather than the Berry curvature [68,83–86], promises to be pivotal for capturing geometrical properties of magnons. Whether a universal relation exists between magnon chirality distribution in altermagnets and magnonic quantum geometry is an open question, which we address here.

As shown in Fig. 1(a), we propose an optical probe of chiral AM magnons and their quantum geometry with bicircular light ($\gamma_R + \gamma_L$) in an altermagnet canted by a magnetic field. We validate our findings in systems with trivial magnonic Chern numbers [68], in a minimal d -wave AM Heisenberg model. After applying a canting magnetic field, a splitting of magnonic nodal line is found to appear at Γ -M high-symmetry line where the LH and RH magnons hybridize. We show that in the first Brillouin zone (BZ), the magnon chirality switches as a function of wave vector $\mathbf{k}$. As a consequence, the alternating chirality of AM magnons in the Bloch space gives rise to nontrivial geometry of magnon bands, alongside the presence of trivial band topology, which we reveal with accumulated phases in magnonic Wilson loop. We deduce an enhancement of LMC through quantum metric in the dominant second and subleading fourth-order terms. Within our approach, the quantum geometry of AM magnons is revealed to be accessible by nonlinear bicircular Raman spectroscopy. Such effects are found to be unique to AM

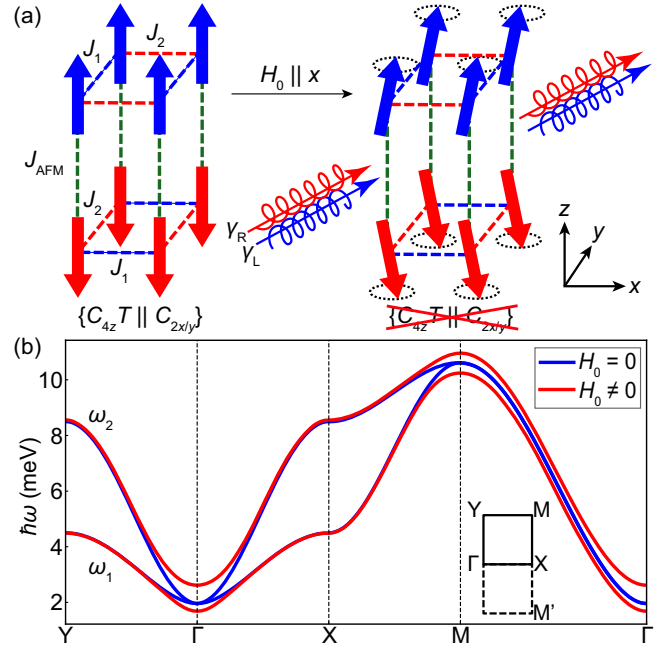


FIG. 1. Modeling AM magnons with split chirality. (a) Minimal spin model for d -wave AM magnons, canted by an external magnetic field. The spin structures before (left) and after (right) applying a canting field. The AM magnons are bicircularly probed by photons of opposite handedness ($\gamma_{L/R}$). (b) Magnon band structure with external canting field (red lines) and without (blue lines). Here, we set $S = 1$, with $J_{1,2} = 1 \pm 0.5$ meV, $J_{\text{AFM}} = 2.0$ meV, $K = 0.8$ meV. $H_0 \neq 0$ to match the energy scale of 2.0 meV. The definitions of the parameters are further detailed in the End Matter.

systems, and are absent in AFM ones, as we further demonstrate.

Modeling AM magnons—We start from a minimal d -wave AM spin-lattice tight-binding model to investigate the AM magnons [20]. We consider an AM Heisenberg model canted by an external magnetic field without Dzyaloshinskii-Moriya interactions; see End Matter for technical details. The model includes magnetic crystalline anisotropy to stabilize the magnetizations. As shown in the left panel of Fig. 1(a), the considered spin Hamiltonian preserves a $C_{4z}T||C_{2x/y}$ symmetry without an external magnetic field, as expected for a d -wave AM spin model, where x/y denote x or y direction. Setting AM splitting $\Delta J = 0$, we can restore pseudo-TRS in the model and yield an AFM ground state. In the following, we will also show that the nontrivial geometrical effects are present regardless of the scale of exchange interactions, but only rely on the AM symmetry.

We use a Holstein-Primakoff (HP) transformation for our AM model [87]: $S_{x,i}^\dagger + iS_{y,i}^\dagger = \sqrt{2S}a_i$, $S_{x,i}^\dagger - iS_{y,i}^\dagger = \sqrt{2S}a_i^\dagger$, $S_{x,i}^\dagger + iS_{y,i}^\dagger = \sqrt{2S}b_i$, and $S_{x,i}^\dagger - iS_{y,i}^\dagger = \sqrt{2S}b_i^\dagger$, where a_i, b_i ($a_i^\dagger, b_i^\dagger$) are magnon annihilation (creation) operators at the lattice sites i . Transforming the basis

into Bloch space as $a_i = 1/\sqrt{N} \sum_{\mathbf{k}} a_{\mathbf{k}} e^{-i\mathbf{k} \cdot \mathbf{r}_i}$ with position vectors $\mathbf{r}_i$, and analogously for the b_i , we obtain the quadratic bosonic Hamiltonian in the basis $\psi_{\mathbf{k}} = (a_{\mathbf{k}}^\dagger, b_{\mathbf{k}}^\dagger, a_{-\mathbf{k}}, b_{-\mathbf{k}})$, with a linear-wave approximation. We only consider the in-plane wave vector $\mathbf{k} = (k_x, k_y)$ of magnons. The eigenmodes are obtained by a bosonic Bogoliubov–de Gennes (BdG) transformation, $\psi_{\mathbf{k}} = U \phi_{\mathbf{k}}$, in which $\phi_{\mathbf{k}}^\dagger = (\alpha_{\mathbf{k}}^\dagger, \beta_{\mathbf{k}}^\dagger, \alpha_{-\mathbf{k}}, \beta_{-\mathbf{k}})$ denotes the eigenmode basis. U diagonalizes the Hamiltonian $\mathcal{H}(\mathbf{k})$ by $U^\dagger \mathcal{H}(\mathbf{k}) U = \hbar \Omega(\mathbf{k})$ with the magnonic eigenfrequency matrix $\Omega(\mathbf{k}) = \text{diag}[\omega_1(\mathbf{k}), \omega_2(\mathbf{k}), \omega_1(-\mathbf{k}), \omega_2(-\mathbf{k})]$ [88], and $\omega_i(\mathbf{k})$, with $i = 1, 2$, denote the energies of magnons with a wave vector $\mathbf{k}$. The transformation matrix U is normalized by $\bar{U} U^\dagger = I$, where $\bar{U}^\dagger \equiv \tau_3 U^\dagger \tau_3$ is the paraunitary conjugate of U in BdG transformation (see End Matter). The model supports $\omega_i = \omega_{\bar{i}}$, where $\bar{i}$ denotes the index with a opposite wave vector, as it obeys the C_{2z} symmetry, which culminates in $(C_{4z}T)^2 = 1$. This indicates a trivial topology of considered magnon bands, since the symmetry obstructs the existence of nontrivial Pfaffian operators at high-symmetry points [89]. Moreover, our model can be adiabatically transformed into a nonrelativistic AFM model, while preserving the $C_{4z}T$ symmetry, meaning that both belong to the same topological class. It has been investigated that the nonrelativistic AFM magnons have trivial topology [21,61,62], which is consistent with the model studied hereby that realizes topologically trivial magnons.

In Fig. 1(b), we show the magnon band structure of the d -wave AM model with and without the perpendicular magnetic field (red and blue lines). The high-symmetry points are defined in the right-lower panel of Fig. 1(b). Consistent with previous findings [17,20], we find split chirality for magnon bands. Without an external magnetic field, a magnonic nodal line appears at the Γ -M high-symmetry line, and a Dirac-type band touching appears at the Γ point. The perpendicular field lifts the degeneracy at the nodal line and at the Γ point, which aligns with our expectation, since the field breaks the $C_{4z}T || C_2$ symmetry, as shown in Fig. 1. As will be shown below, the canting field is essential for the identification of magnonic quantum geometry.

Chirality and quantum geometry of AM magnons—Since the split AM magnon bands are chiral [17], it is important to quantify their chirality p_j , which is shown in Figs. 2(a) and 2(b). The chirality of AM magnons can be inferred from their angular momentum $\langle S_z^j \rangle = \langle S_a^z \rangle_j - \langle S_b^z \rangle_j$, where $\langle \dots \rangle_j$ denotes the expectation value associated with magnon band index j . Subscripts a/b denote the spin precession of sublattice $a^{(\dagger)}/b^{(\dagger)}$, which provide constant and definite (opposite) angular momenta. Since the equilibrium magnetization vanishes, one can further define the normalized chirality upon HP and BdG transformations,

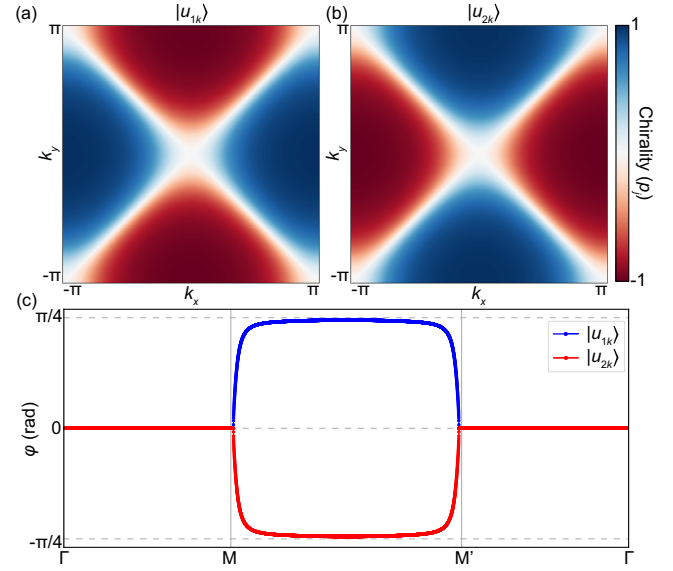


FIG. 2. Interplay of magnonic chirality and quantum geometry in altermagnets. (a),(b) The chirality of lower and upper magnon bands $|u_{1\mathbf{k}}\rangle \equiv [U(\mathbf{k})]_1$, $|u_{2\mathbf{k}}\rangle \equiv [U(\mathbf{k})]_2$. The magnon chirality over momentum space (p_j) is presented, with the blue and red colors representing the RH and LH chirality, respectively. (c) Magnonic Wilson lines along IBZ. The blue and red curves denote Wilson lines for $|u_{1\mathbf{k}}\rangle$ and $|u_{2\mathbf{k}}\rangle$. The parameters are the same as in Fig. 1.

$$p_j \equiv \sum_{i,\text{RH}} |U_{ij}^{-1}|^2 - \sum_{i,\text{LH}} |U_{ij}^{-1}|^2, \quad (1)$$

which represents the difference between the amplitude of RH and LH magnons [17]. Here, $p_j > 0$ ($p_j < 0$) represents an RH (LH) magnon chirality, and $p_j = 0$ represents a linear polarization. On the high-symmetry line Γ -M, one can observe that although the magnon bands are lifted, the chirality of both bands is similarly linear in our model. What is more, the distribution of chirality p_j over the first BZ behaves distinctly in AM and AFM; see Supplemental Material (SM) for details [90].

We emphasize that the LH and RH characters of magnons are directly captured by the amplitudes in the original basis ($a_{\mathbf{k}}/b_{\mathbf{k}}$) of the system, i.e., in the column of the BdG matrix that denotes the eigenvectors of magnons in the Bloch space. Meanwhile, given the alternating feature of p_j in momentum space, it is worth inspecting quantum-geometric consequences of the distribution of magnon chirality, since the quantum geometry relies on the differential features of the eigenvectors [54,55]. To characterize the geometry and topology of the modeled AM magnons, we calculate the gauge-invariant magnonic Wilson loop [Fig. 2(c)] along a closed path surrounding the irreducible Brillouin zone (IBZ), whose quantization is guaranteed by the $C_{4z}T$ symmetry in our model [89,91,92]. The Wilson loop is deduced from the phases of the Wilson line:

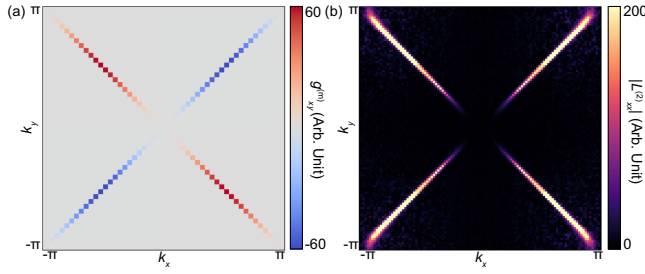


FIG. 3. Quantum metric and nonlinear light-magnon coupling in a d -wave altermagnet. (a) The quantum metric of magnons $g_{ab}^{(m)}$ in the lower band of the canted minimal d -wave AM model, over the first Brillouin zone. The component of magnonic metric $g_{xy}^{(m)}$ peaks at the chirality (p_j) crossover boundary. (b) The momentum-space features of the second-order LMC term $L_{xx}^{(2)}$. $L_{ab}^{(2)}$, which is enhanced by the magnonic quantum metric, is maximal at the magnon chirality crossover regions. The parameters are the same as in Fig. 1, except that H_0 matches the energy of 0.5 meV.

$W(\mathbf{k}) = \prod_{\partial\text{IBZ}} \bar{U}^\dagger(\mathbf{k}_{i+1})U(\mathbf{k}_i)$, where $\mathbf{k}_i$ denote the wave vectors at different points of the Wilson loop contour. Importantly, we use a different definition from fermionic Wilson loop, since the overlap of neighbor bosonic BdG eigenvector should be represented by $\bar{U}(\mathbf{k}_1)U(\mathbf{k}_2)$. The magnonic Wilson loop eigenvalue moves from $\phi = 0$ to $\phi = \pm\pi/4$, and back to $\phi = 0$, which indicates the eigenvectors of the magnon bands accumulate a Berry phase, which is subsequently dissolved around the loop over the boundary of IBZ; see Fig. 2(c). The phase accumulated along the Wilson loop is also found to be parameter-independent (see SM [90]), indicating that the nontrivial quantum geometry is protected by the model symmetry [89,91,92], rather than arising from specific parameter choices. The magnonic Wilson loops are not winding around the IBZ, in agreement with our previous discussion of topology. Meanwhile, in an AFM model, the Wilson loop does not possess any nontrivial accumulated phases (see SM [90]).

We confirm that the AM magnons with trivial Chern number carry nontrivial quantum geometry, by an explicit evaluation of the quantum metric tensor; see Fig. 3(a). The quantum geometry of magnons is captured by magnonic quantum geometric tensor, $Q_{ab}^{(m)} = g_{ab}^{(m)} - (i/2)\Omega_{ab}^{(m)}$ [68]. Here, we use the superscript (m) to denote the magnonic nature of the quantum geometric tensor considered. In particular, the magnonic Berry curvature $\Omega_{ab}^{(m)}$, which naturally presents in topologically nontrivial magnons such as Chern magnons, can be characterized by dichroic Raman scattering [68]. For topologically trivial magnons, the presence of any Berry curvature is not underpinned by Chern topology. Here, the characteristic signature arising from the unique alternation of chirality of AM magnons across BZ [17] is the nontrivial magnonic quantum metric $g_{ab}^{(m)}$. The enhancement of the magnonic quantum metric is guaranteed

by the lower bound associated with the derivative of magnon chirality, as described in the End Matter. The canting field that split the magnon nodal line is found to be essential here given the definition of the magnonic metric [see End Matter, Eq. (B1)]. Given that the quantum metric $g_{ab}^{(m)}$ can also be probed by the LMC [64,69], we focus on the metric-induced optical features associated with the nonlinear magnonic LMC in the following.

Light-magnon interaction in altermagnets—We now construct a methodology to probe the quantum geometry in AM magnons with light. At optical frequencies, the magnonic LMC can be described by the Fleury-Loudon (FL) mechanism [68,93], where the photon electric field couples to spin-dependent electric dipoles. Although magnons do not naturally admit a direct Peierls substitution [94,95], the FL term generates an effective coupling, $\mathcal{H}(\mathbf{k}, \mathbf{A}) = \mathcal{H}(\mathbf{k} - \mathbf{A})$ (see SM [90]), with $\mathbf{A} = (A_x, A_y)$ the vector potential of light. Accordingly, under the long-wavelength approximation, i.e., $\mathbf{A} \cdot \mathbf{d}_{ij} \ll 1$, with $\mathbf{d}_{ij}$ denoting the position vector from spin i to j , the light-magnon coupling can be expanded as [68,93] $\mathcal{H}(\mathbf{k}, \mathbf{A}) = \mathcal{H}(\mathbf{k}) + L_a^{(1)}A_a + L_{ab}^{(2)}A_aA_b + \dots$, and the second-order LMC Hamiltonian is given by

$$L_{ab}^{(2)} = -\Omega g_{ab}^{(m)} + U_a^\dagger \bar{U} \Omega \bar{U}^\dagger U_b - \Omega_a \bar{U}^\dagger U_b + U^\dagger \bar{U}_a \Omega_b + \frac{1}{2}(U^\dagger \bar{U}_{ab} \Omega + \Omega_{ab} - \Omega \bar{U}^\dagger U_{ab}) + (a \leftrightarrow b), \quad (2)$$

where the subscripts a, b in the right-hand side give $U_a \equiv \partial_{k_a} U$, $U_{ab} \equiv \partial_{k_a} \partial_{k_b} U$, and analogously $\Omega_a \equiv \partial_{k_a} \Omega$, $\Omega_{ab} \equiv \partial_{k_a} \partial_{k_b} \Omega$. The further contributions are negligibly small, whereas are also calculated up to the fourth order for completeness; see SM [90]. One finds that the quantum metric enters in the first term of $L_{ab}^{(2)}$, thus confirming that the emergent quantum metric in the magnon bands can enhance the nonlinear LMC [68]. In Fig. 3, we show the distribution of quantum metric and LMC strength as a function of wave vector around the first BZ. In Fig. 3(a), the metric is found maximal at the lifted Γ -M line. The absolute value of $L_{xx}^{(2)}$ in the perturbative Hamiltonian is also calculated for the first diagonal term, as shown in Fig. 3(b). Although Eq. (2) contains additional terms beyond the quantum metric, our calculations reveal a direct correspondence between the maxima of the quantum metric and the LMC strength, confirming the interplay between nontrivial quantum geometry and nonlinear Raman response of AM magnons. Furthermore, in a PT -symmetric AFM model with trivial magnon topology, where the alternation of magnon RH and LH chirality is prohibited, a simultaneous vanishing of the quantum metric and the LMC terms is observed (see SM [90]). We also note that the canting field is introduced only to lift the degeneracy on Γ -M high-symmetry line, rather than to generate the LMC

terms. Indeed, the LMC strength decreases with an increasing canting field (see SM [90]). We then establish the BCL scattering as an experimental probe for the LMC in altermagnets, given its tunability on the polarizations of the incident light, which allows to target $L_{ab}^{(2)}$.

Probing AM magnons with bicircular light—We now show how BCL can be used to probe the nontrivial magnonic geometry of AM magnons within realistic experimental setups. The BCL field takes the form $\mathbf{A}(t) = \mathbf{A}_L e^{i(\eta\omega t + \alpha)} + \mathbf{A}_R e^{-i\omega t}$ [80,81], including left and right circularly polarized light components ($\mathbf{A}_L$ and $\mathbf{A}_R$) with frequencies $\eta\omega$ and ω . For $\alpha = 0$, the nonlinear LMC of AM magnons to linearly polarized light is retrieved from the bicircular coupling. The combinations of left and right circularly polarized beams, yielding linearly polarized light, have been previously proven successful in probing nontrivial electronic quantum geometry [96]. The nonlinear Raman response is estimated by $P_{BC} \propto \sum_i |(\bar{U} H_R U)_{ii}|^2 \delta(\omega_i - \omega_{sc} + \omega_{in})$, where ω_{in} and ω_{sc} are the incident and scattered light frequencies, and H_R is the Raman scattering Hamiltonian given by $H_R \propto \sum_{ij} (\mathbf{A}_{sc}^* \cdot \mathbf{d}_{ij})(\mathbf{A}_{in} \cdot \mathbf{d}_{ij}) \mathcal{H}(\mathbf{k})$, where $\mathbf{A}_{in}$ and $\mathbf{A}_{sc}$ denote field of incident and scattered light (see also SM [90]). To propose a credible realization for experiments, we set $\eta = 1$ and assume that the incident and scattered photons have the same polarizations. We can reconstruct $L_{ab}^{(2)}$ on filtering out the first-order contribution $L_a^{(1)}$, which is distinctly sensitive to phase delay α of BCL (see SM [90]). In Fig. 4, we show how the magnonic LMC cross section P_{BC} [68] measured as a function of α allows to probe the magnonic metric $g_{ab}^{(m)}$, which captures the momentum-space chirality crossovers unique to the AM magnons. Transforming LMC terms to a circular basis (see SM [90]), one finds that the dependence of cross section P_{BC} on phase difference α consistently captures the interplay between the Raman response and the polarizations of the incident and scattered light, which reflects the AM magnon chirality. A single-beam linearly polarized laser, having an equal superposition of left and right circularly polarized components, can in principle also detect such an AM LMC signal. However, it does not permit tracking the signal as a function of the relative phase introduced in our proposal. Notably, we also observe that the AFM phase lacks similar features (see Fig. 4), consistent with degenerate LH and RH chirality (see SM [90]). Physically, our formalism probes the two-magnon processes via Raman scattering, which is insensitive to the wave vector of magnons, and thus cannot resolve detailed magnon dispersions, unlike inelastic neutron scattering measurements [93,97].

Discussion and conclusions—We discuss the applicability of our results. On the material side, the LMC effects of AM magnons could be realized in various types of AM materials, given that our proposed experimental signatures do not rely on a specific lattice. In materials

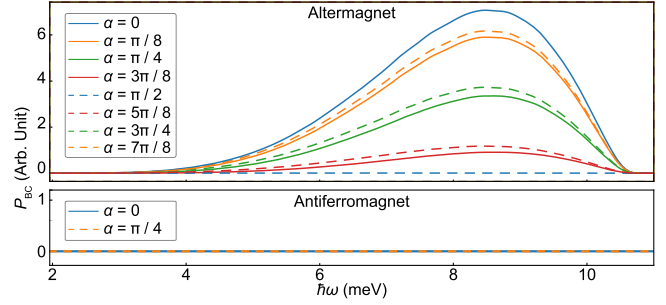


FIG. 4. Cross section of magnonic LMC with bicircular light. Bicircular light of frequency ω_{in} with phase shift α between left- and right-circular components is inelastically scattered to frequency ω_{sc} , experiencing a Raman shift $\omega = \omega_{in} - \omega_{sc}$. Resolution of the light-AM magnon cross section P_{BC} capturing the scattering of AM magnons from light against α and ω allows to retrieve $L_{ab}^{(2)}$ enhanced by the magnonic quantum metric $g_{ab}^{(m)}$ reflecting the chirality pattern. The parameters are the same as in Fig. 3.

with strong spin-orbit coupling, non-FL contributions can dominate the magnonic Raman response [98], and the candidate materials should therefore be chosen to avoid such regime. Suitable examples include the d -wave altermagnets RuO_2 [17] and MnF_2 [28], as well as LuFeO_3 [99,100], and the g -wave altermagnet $\alpha\text{-Fe}_2\text{O}_3$ [31,43]. Their magnon energy scale is typically around 0–100 meV, as reported in the above references. Depending on the different lattice symmetries, e.g., g , f , i wave, we expect analogous enhancements of LMCs with different symmetries over $\mathbf{k}$ space to be manifested in the scattering of BCL. We note that other types of AM models, such as honeycomb and checkerboard altermagnets [70–72], can also accumulate nontrivial magnonic Berry phases and realize topological magnons. We expect that such nontrivial quantum geometry can likewise be observed using BCL. Additionally, magnon-magnon interactions in altermagnets are expected to renormalize the magnon bands and induce chirality-dependent anisotropic damping, which may provide additional signatures of the altermagnetic order [101–103]. Extending the magnonic LMC theories beyond linear spin-wave theory, e.g., including three-magnon processes, remains a promising direction for future works. Our results show that the LMC effects can clearly distinguish altermagnets from conventional antiferromagnets due to a qualitative difference between the AM and AFM magnons, as reflected by their distinct quantum geometries. Our findings provide an optical criterion for confirming the presence of AM order with its unique spin excitations.

Note added—We recently became aware of Ref. [104], where Liu *et al.* use topological ferromagnetic magnons to showcase probing magnonic quantum geometry with LMC.

Acknowledgments—We thank Bo Peng, Habib Rostami, Haiming Yu, and Yuelin Zhang for fruitful discussions.

We further thank Ting Qiu for spotting typos. R. Y. acknowledges the support by CSC Scholarship No. 202408060249 and Cambridge Commonwealth, European, and International Trust. W. J. J. acknowledges funding from the Rod Smallwood Studentship at Trinity College, Cambridge. K. S. acknowledges support from the National Natural Science Foundation of China (Grants No. 12374100 and No. 12550004) and the Fundamental Research Funds for the Central Universities. R.-J. S. acknowledges funding from an EPSRC ERC underwrite Grant No. EP/X025829/1 and a Royal Society exchange grant IES/R1/221060 as well as Trinity College, Cambridge.

Data availability—The data that support the findings of this article are not publicly available. The data are available from the authors upon reasonable request.

- [1] V. V. Kruglyak, S. O. Demokritov, and D. Grundler, Magnonics, *J. Phys. D* **43**, 264001 (2010).
- [2] A. V. Chumak, V. I. Vasyuchka, A. A. Serga, and B. Hillebrands, Magnon spintronics, *Nat. Phys.* **11**, 453 (2015).
- [3] A. Barman, G. Gubbiotti, S. Ladak, A. O. Adeyeye, M. Krawczyk, J. Gräfe, C. Adelmann, S. Cotozana, A. Naemi, V. I. Vasyuchka *et al.*, The 2021 magnonics roadmap, *J. Phys. Condens. Matter* **33**, 413001 (2021).
- [4] R. Cheng, J. Xiao, Q. Niu, and A. Brataas, Spin pumping and spin-transfer torques in antiferromagnets, *Phys. Rev. Lett.* **113**, 057601 (2014).
- [5] R. Damon and J. Eshbach, Magnetostatic modes of a ferromagnet slab, *J. Phys. Chem. Solids* **19**, 308 (1961).
- [6] J. Chen, T. Yu, C. Liu, T. Liu, M. Madami, K. Shen, J. Zhang, S. Tu, M. S. Alam, K. Xia, M. Wu, G. Gubbiotti, Y. M. Blanter, G. E. W. Bauer, and H. Yu, Excitation of unidirectional exchange spin waves by a nanoscale magnetic grating, *Phys. Rev. B* **100**, 104427 (2019).
- [7] T. Yu, Y. M. Blanter, and Gerrit E. W. Bauer, Chiral pumping of spin waves, *Phys. Rev. Lett.* **123**, 247202 (2019).
- [8] K. Ando, S. Takahashi, J. Ieda, Y. Kajiwara, H. Nakayama, T. Yoshino, K. Harii, Y. Fujikawa, M. Matsuo, S. Maekawa, and E. Saitoh, Inverse spin-Hall effect induced by spin pumping in metallic system, *J. Appl. Phys.* **109**, 103913 (2011).
- [9] S. Maekawa, S. O. Valenzuela, E. Saitoh, and T. Kimura, *Spin Current* (Oxford University Press, New York, 2017).
- [10] J. Wang, H. Wang, J. Chen, W. Legrand, P. Chen, L. Sheng, J. Xia, G. Lan, Y. Zhang, R. Yuan, J. Dong, X. Han, J.-P. Ansermet, and H. Yu, Broad-wave-vector spin pumping of flat-band magnons, *Phys. Rev. Appl.* **21**, 044024 (2024).
- [11] J. Li, C. B. Wilson, R. Cheng, M. Lohmann, M. Kavand, W. Yuan, M. Aldosary, N. Agladze, P. Wei, M. Sherwin, and J. Shi, Spin current from sub-terahertz-generated antiferromagnetic magnons, *Nature (London)* **578**, 70 (2020).
- [12] T. Wimmer, A. Kamra, J. Gückelhorn, M. Opel, S. Geprägs, R. Gross, H. Huebl, and M. Althammer, Observation of antiferromagnetic magnon pseudospin dynamics and the Hanle effect, *Phys. Rev. Lett.* **125**, 247204 (2020).
- [13] P. Vaidya, S. A. Morley, J. van Tol, Y. Liu, R. Cheng, A. Brataas, D. Lederman, and E. del Barco, Subterahertz spin pumping from an insulating antiferromagnet, *Science* **368**, 160 (2020).
- [14] L. Šmejkal, J. Sinova, and T. Jungwirth, Beyond conventional ferromagnetism and antiferromagnetism: A phase with nonrelativistic spin and crystal rotation symmetry, *Phys. Rev. X* **12**, 031042 (2022).
- [15] C. Song, H. Bai, Z. Zhou, L. Han, H. Reichlova, J. H. Dil, J. Liu, X. Chen, and F. Pan, Altermagnets as a new class of functional materials, *Nat. Rev. Mater.* **10**, 473 (2025).
- [16] L. Šmejkal, J. Sinova, and T. Jungwirth, Emerging research landscape of altermagnetism, *Phys. Rev. X* **12**, 040501 (2022).
- [17] L. Šmejkal, A. Marmodoro, K. H. Ahn, R. González-Hernández, I. Turek, S. Mankovsky, H. Ebert, S. W. D'Souza, O. Šipr, J. Sinova, and T. Jungwirth, Chiral magnons in altermagnetic RuO₂, *Phys. Rev. Lett.* **131**, 256703 (2023).
- [18] Z. Liu, M. Ozeki, S. Asai, S. Itoh, and T. Masuda, Chiral split magnon in altermagnetic MnTe, *Phys. Rev. Lett.* **133**, 156702 (2024).
- [19] L. M. Sandratskii, K. Carva, and V. M. Silkin, Direct ab-initio calculation of magnons in altermagnets: Method, spin-space symmetry aspects, and application to MnTe, *Phys. Rev. B* **111**, 184436 (2025).
- [20] Z. Jin, T. Gong, J. Liu, H. Yang, Z. Zeng, Y. Cao, and P. Yan, Strong coupling of chiral magnons in altermagnets, *Phys. Rev. Lett.* **135**, 126702 (2025).
- [21] A. Mook, J. Henk, and I. Mertig, Edge states in topological magnon insulators, *Phys. Rev. B* **90**, 024412 (2014).
- [22] A. Mook, J. Henk, and I. Mertig, Magnon Hall effect and topology in kagome lattices: A theoretical investigation, *Phys. Rev. B* **89**, 134409 (2014).
- [23] R. Cheng, M. W. Daniels, J.-G. Zhu, and D. Xiao, Antiferromagnetic spin wave field-effect transistor, *Sci. Rep.* **6**, 24223 (2016).
- [24] S. Reimers, L. Odenbreit, L. Šmejkal, V. N. Strocov, P. Constantinou, A. B. Hellenes, R. Jaeschke Ubierno, W. H. Campos, V. K. Bharadwaj, A. Chakraborty, M. Jourdan *et al.*, Direct observation of altermagnetic band splitting in CrSb thin films, *Nat. Commun.* **15**, 2116 (2024).
- [25] J. Ding, Z. Jiang, X. Chen, Z. Tao, Z. Liu, T. Li, J. Liu, J. Sun, J. Cheng, J. Liu *et al.*, Large band splitting in *g*-wave altermagnet CrSb, *Phys. Rev. Lett.* **133**, 206401 (2024).
- [26] J. Krempaský, L. Šmejkal, S. W. D'Souza, M. Hajlaoui, G. Springholz, K. Uhlířová, F. Alarab, P. C. Constantinou, V. N. Strocov, D. Usanov *et al.*, Altermagnetic lifting of Kramers spin degeneracy, *Nature (London)* **626**, 517 (2024).
- [27] O. Fedchenko, J. Minár, A. Akashdeep, S. W. D'Souza, D. Vasilyev, O. Tkach, L. Odenbreit, Q. Nguyen, D. Kutnyakhov, N. Wind *et al.*, Observation of time-reversal symmetry breaking in the band structure of altermagnetic RuO₂, *Sci. Adv.* **10**, eadj4883 (2024).

- [28] V. C. Morano, Z. Maesen, S. E. Nikitin, J. Lass, D. G. Mazzone, and O. Zaharko, Absence of altermagnetic magnon band splitting in MnF_2 , *Phys. Rev. Lett.* **134**, 226702 (2025).
- [29] H. Yu, W. Feng, F. Zheng, and Y. Yao, Chiral magnons in an altermagnetic Janus Mn_2SeTe monolayer, *Comput. Mater. Today* **4**, 100021 (2024).
- [30] Y. F. Zhang, X. S. Ni, K. Chen, and K. Cao, Chiral magnon splitting in altermagnetic CrSb from first principles, *Phys. Rev. B* **111**, 174451 (2025).
- [31] R. Hoyer, P. P. Stavropoulos, A. Razpopov, R. Valentí, L. Šmejkal, and A. Mook, Altermagnetic splitting of magnons in hematite $\alpha\text{-Fe}_2\text{O}_3$, *Phys. Rev. B* **112**, 064425 (2025).
- [32] X. Chen, Y. Liu, P. Liu, Y. Yu, J. Ren, J. Li, A. Zhang, and Q. Liu, Unconventional magnons in collinear magnets dictated by spin space groups, *Nature (London)* **640**, 349 (2025).
- [33] Y. Jiang, Z. Song, T. Zhu, Z. Fang, H. Weng, Z.-X. Liu, J. Yang, and C. Fang, Enumeration of spin-space groups: Toward a complete description of symmetries of magnetic orders, *Phys. Rev. X* **14**, 031039 (2024).
- [34] Z. Xiao, J. Zhao, Y. Li, R. Shindou, and Z.-D. Song, Spin space groups: Full classification and applications, *Phys. Rev. X* **14**, 031037 (2024).
- [35] X. Chen, J. Ren, Y. Zhu, Y. Yu, A. Zhang, P. Liu, J. Li, Y. Liu, C. Li, and Q. Liu, Enumeration and representation theory of spin space groups, *Phys. Rev. X* **14**, 031038 (2024).
- [36] H. Schiff, A. Corticelli, A. Guerreiro, J. Romhányi, and P. A. McClarty, The crystallographic spin point groups and their representations, *SciPost Phys.* **18**, 109 (2025).
- [37] J. Kruthoff, J. de Boer, J. van Wezel, C. L. Kane, and R.-J. Slager, Topological classification of crystalline insulators through band structure combinatorics, *Phys. Rev. X* **7**, 041069 (2017).
- [38] H. C. Po, A. Vishwanath, and H. Watanabe, Symmetry-based indicators of band topology in the 230 space groups, *Nat. Commun.* **8**, 50 (2017).
- [39] B. Bradlyn, L. Elcoro, J. Cano, M. G. Vergniory, Z. Wang, C. Felser, M. I. Aroyo, and B. A. Bernevig, Topological quantum chemistry, *Nature (London)* **547**, 298 (2017).
- [40] A. Bouhon, G. F. Lange, and R.-J. Slager, Topological correspondence between magnetic space group representations and subdimensions, *Phys. Rev. B* **103**, 245127 (2021).
- [41] H. Watanabe, H. C. Po, and A. Vishwanath, Structure and topology of band structures in the 1651 magnetic space groups, *Sci. Adv.* **4**, eaat8685 (2018).
- [42] L. Elcoro, B. J. Wieder, Z. Song, Y. Xu, B. Bradlyn, and B. A. Bernevig, Magnetic topological quantum chemistry, *Nat. Commun.* **12**, 5965 (2021).
- [43] Q. Sun, J. Guo, D. Wang, D. L. Abernathy, W. Tian, and C. Li, Observation of chiral magnon band splitting in altermagnetic hematite, *Phys. Rev. Lett.* **135**, 186703 (2025).
- [44] L. Sheng, A. Duvakina, H. Wang, K. Yamamoto, R. Yuan, J. Wang, P. Chen, W. He, K. Yu, Y. Zhang, J. Chen, J. Hu, W. Song, S. Liu, X. Han, D. Yu, S. J.-P. Ansermet and Maekawa, D. Grundler, and H. Yu, Control of spin currents by magnon interference in a canted antiferromagnet, *Nat. Phys.* **21**, 740 (2025).
- [45] H. Wang, R. Yuan, Y. Zhou, Y. Zhang, J. Chen, S. Liu, H. Jia, D. Yu, J.-P. Ansermet, C. Song, and H. Yu, Long-distance coherent propagation of high-velocity antiferromagnetic spin waves, *Phys. Rev. Lett.* **130**, 096701 (2023).
- [46] A. El Kanj, O. Gomonay, I. Boventer, P. Bortolotti, V. Cros, A. Anane, and R. Lebrun, Antiferromagnetic magnon spintronic based on nonreciprocal and nondegenerated ultra-fast spin-waves in the canted antiferromagnet $\alpha\text{-Fe}_2\text{O}_3$, *Sci. Adv.* **9**, eadh1601 (2023).
- [47] J. Chen, Z. Jin, R. Yuan, H. Wang, H. Jia, W. Wei, L. Sheng, J. Wang, Y. Zhang, S. Liu *et al.*, Observation of coherent gapless magnons in an antiferromagnet, *Phys. Rev. Lett.* **134**, 056701 (2025).
- [48] J. Chen, M. Xu, J. Wang, K. Wagner, L. Sheng, H. Jia, W. Wei, H. Zhang, Y. Zhang, H. Wang *et al.*, Deterministic switching of antiferromagnetic spin textures by nonlinear magnons, *Nat. Commun.* **16**, 5794 (2025).
- [49] Y. Su, C. Hu, F. Pan, J. Chen, and C. Song, Enhancement of magnon transport length in easy-plane antiferromagnets, *Appl. Phys. Lett.* **127**, 142402 (2025).
- [50] F. Moussa, M. Hennion, J. Rodriguez-Carvajal, H. Moudden, L. Pinsard, and A. Revcolevschi, Spin waves in the antiferromagnet perovskite LaMnO_3 : A neutron-scattering study, *Phys. Rev. B* **54**, 15149 (1996).
- [51] T. Weber, J. Waizner, P. Steffens, A. Bauer, C. Pfleiderer, M. Garst, and P. Böni, Polarized inelastic neutron scattering of nonreciprocal spin waves in MnSi , *Phys. Rev. B* **100**, 060404(R) (2019).
- [52] Y. Nambu, J. Barker, Y. Okino, T. Kikkawa, Y. Shiomi, M. Enderle, T. Weber, B. Winn, M. Graves-Brook, J. M. Tranquada *et al.*, Observation of magnon polarization, *Phys. Rev. Lett.* **125**, 027201 (2020).
- [53] M. Hamdi, F. Posva, and D. Grundler, Spin wave dispersion of ultra-low damping hematite ($\alpha\text{-Fe}_2\text{O}_3$) at GHz frequencies, *Phys. Rev. Mater.* **7**, 054407 (2023).
- [54] M. V. Berry, The quantum phase, five years after, in *Geometric Phases in Physics*, Advanced Series in Mathematical Physics, edited by A. Shapere and F. Wilczek (World Scientific, Singapore, 1989), Vol. 5, pp. 7–28.
- [55] J.-P. Provost and G. Vallée, Riemannian structure on manifolds of quantum states, *Commun. Math. Phys.* **76**, 289 (1980).
- [56] Q. Niu, D. J. Thouless, and Y. S. Wu, Quantized Hall conductance as a topological invariant, *Phys. Rev. B* **31**, 3372 (1985).
- [57] C. L. Kane and E. J. Mele, $\mathbb{Z}_2$ topological order and the quantum spin Hall effect, *Phys. Rev. Lett.* **95**, 146802 (2005).
- [58] N. Nagaosa, J. Sinova, S. Onoda, A. H. MacDonald, and N. P. Ong, Anomalous Hall effect, *Rev. Mod. Phys.* **82**, 1539 (2010).
- [59] J. Sinova, S. O. Valenzuela, J. Wunderlich, C. H. Back, and T. Jungwirth, Spin Hall effects, *Rev. Mod. Phys.* **87**, 1213 (2015).
- [60] A. Bouhon, A. Timmel, and R.-J. Slager, Quantum geometry beyond projective single bands, [arXiv:2303.02180](https://arxiv.org/abs/2303.02180).

- [61] K. Nakata, S. K. Kim, J. Klinovaja, and D. Loss, Magnonic topological insulators in antiferromagnets, *Phys. Rev. B* **96**, 224414 (2017).
- [62] S. A. Owerre, Noncollinear antiferromagnetic Haldane magnon insulator, *J. Appl. Phys.* **121**, 223904 (2017).
- [63] N. Wang, D. Kaplan, Z. Zhang, T. Holder, N. Cao, A. Wang, X. Zhou, F. Zhou, Z. Jiang, C. Zhang, N. Wang *et al.*, Quantum-metric-induced nonlinear transport in a topological antiferromagnet, *Nature (London)* **621**, 487 (2023).
- [64] A. Gao, Y.-F. Liu, J.-X. Qiu, B. Ghosh, T. V. Trevisan, Y. Onishi, C. Hu, T. Qian, H. Tien, S.-W. Chen *et al.*, Quantum metric nonlinear Hall effect in a topological antiferromagnetic heterostructure, *Science* **381**, 181 (2023).
- [65] M. Schüler, U. De Giovannini, H. Hübener, A. Rubio, M. A. Sentef, and P. Werner, Local Berry curvature signatures in dichroic angle-resolved photoelectron spectroscopy from two-dimensional materials, *Sci. Adv.* **6**, eaay2730 (2020).
- [66] G. E. Topp, C. J. Eckhardt, D. M. Kennes, M. A. Sentef, and P. Törmä, Light-matter coupling and quantum geometry in moiré materials, *Phys. Rev. B* **104**, 064306 (2021).
- [67] J. Ahn, G. Guo, N. Nagaosa, and A. Vishwanath, Riemannian geometry of resonant optical responses, *Nat. Phys.* **18**, 290 (2022).
- [68] E. Viñas Boström, T. S. Parvini, J. W. McIver, A. Rubio, S. V. Kusminskiy, and M. A. Sentef, Direct optical probe of magnon topology in two-dimensional quantum magnets, *Phys. Rev. Lett.* **130**, 026701 (2023).
- [69] S. Kim, Y. Chung, Y. Qian, S. Park, C. Jozwiak, E. Rotenberg, A. Bostwick, K. S. Kim, and B.-J. Yang, Direct measurement of the quantum metric tensor in solids, *Science* **388**, 1050 (2025).
- [70] M.-H. Zhang, G. Xuan, and D.-X. Yao, Dirac points and Weyl phase in a honeycomb altermagnet, *Front. Phys.* **21**, 095208 (2026).
- [71] E. Syljuåsen, A. Qaiumzadeh, and A. Sudbø, Quantum geometry and magnon Hall transport in an altermagnet, *Phys. Rev. B* **112**, 064429 (2025).
- [72] X. Guo, M.-H. Zhang, and D.-X. Yao, Higher-order topological states in chiral split magnons of honeycomb altermagnets, *Chin. Phys. Lett.* **42**, 120703 (2025).
- [73] W. Lu, S. Feng, Y. Wang, D. Chen, Z. Lin, X. Liang, S. Liu, W. Feng, K. Yamagami, J. Liu *et al.*, Signature of topological surface bands in altermagnetic Weyl semimetal CrSb, *Nano Lett.* **25**, 7343 (2025).
- [74] Y. Fang, J. Cano, and S. A. A. Ghorashi, Quantum geometry induced nonlinear transport in altermagnets, *Phys. Rev. Lett.* **133**, 106701 (2024).
- [75] L. Han, X. Fu, C. Song, Y. Zhu, X. Li, Z. Zhu, H. Bai, R. Chu, J. Dai, S. Liang *et al.*, Discovery of a large magnetic nonlinear Hall effect in an altermagnet, [arXiv:2502.04920](https://arxiv.org/abs/2502.04920).
- [76] N. Heinsdorf, Altermagnetic instabilities from quantum geometry, *Phys. Rev. B* **111**, 174407 (2025).
- [77] W. Chen, X. Zhou, W.-K. Lou, and K. Chang, Magneto-optical conductivity and circular dichroism in d-wave altermagnets, *Phys. Rev. B* **111**, 064428 (2025).
- [78] Y. Li, Y. Liu, and C.-C. Liu, Unconventional magneto-optical effects in altermagnets, [arXiv:2512.03435](https://arxiv.org/abs/2512.03435).
- [79] Y. Li and C.-C. Liu, Quantum-metric-based optical selection rules, *Phys. Rev. Lett.* **136**, 046901 (2026).
- [80] T. Nag, R.-J. Slager, T. Higuchi, and T. Oka, Dynamical synchronization transition in interacting electron systems, *Phys. Rev. B* **100**, 134301 (2019).
- [81] T. V. Trevisan, P. V. Arribi, O. Heinonen, R.-J. Slager, and P. P. Orth, Bicircular light Floquet engineering of magnetic symmetry and topology and its application to the Dirac semimetal Cd_3As_2 , *Phys. Rev. Lett.* **128**, 066602 (2022).
- [82] Y. Ikeda, S. Kitamura, and T. Morimoto, Photocurrent induced by a bicircular light drive in centrosymmetric systems, *Phys. Rev. Lett.* **131**, 096301 (2023).
- [83] K. Shen, Magnon spin relaxation and spin Hall effect due to the dipolar interaction in antiferromagnetic insulators, *Phys. Rev. Lett.* **124**, 077201 (2020).
- [84] J. Liu, L. Wang, and K. Shen, Dipolar spin waves in uniaxial easy-axis antiferromagnets: A natural topological nodal-line semimetal, *Phys. Rev. Res.* **2**, 023282 (2020).
- [85] J. Liu, L. Wang, and K. Shen, Tunable topological magnon phases in layered ferrimagnets, *Phys. Rev. B* **107**, 174404 (2023).
- [86] B. Bermond, A. Defossez, and N. Goldman, A local quantized marker for topological magnons from circular dichroism, [arXiv:2504.17374](https://arxiv.org/abs/2504.17374).
- [87] T. Holstein and H. Primakoff, Field dependence of the intrinsic domain magnetization of a ferromagnet, *Phys. Rev.* **58**, 1098 (1940).
- [88] J. Colpa, Diagonalization of the quadratic boson Hamiltonian, *Physica (Amsterdam)* **93A**, 327 (1978).
- [89] I. Araya Day, A. Varentcova, D. Varjas, and A. R. Akhmerov, Pfaffian invariant identifies magnetic obstructed atomic insulators, *SciPost Phys.* **15**, 114 (2023).
- [90] See Supplemental Material at <http://link.aps.org/supplemental/10.1103/12cl-b9jj> for details on the light-magnon coupling and Fleury-Loudon Hamiltonian (Sec. I), comparison of altermagnetic and antiferromagnetic models, and light-magnon coupling at different external canted field magnitudes (Sec. II), and further analytical details on the relations between quantum metric and alternating magnon chirality, and the bicircular Raman response (Sec. III).
- [91] A. Alexandradinata, X. Dai, and B. A. Bernevig, Wilson-loop characterization of inversion-symmetric topological insulators, *Phys. Rev. B* **89**, 155114 (2014).
- [92] A. Bouhon, A. M. Black-Schaffer, and R.-J. Slager, Wilson loop approach to fragile topology of split elementary band representations and topological crystalline insulators with time-reversal symmetry, *Phys. Rev. B* **100**, 195135 (2019).
- [93] P. A. Fleury and R. Loudon, Scattering of light by one- and two-magnon excitations, *Phys. Rev.* **166**, 514 (1968).
- [94] M. Eckstein, J. H. Mentink, and P. Werner, Designing spin and orbital exchange Hamiltonians with ultrashort electric field transients, [arXiv:1703.03269](https://arxiv.org/abs/1703.03269).
- [95] J. Li, H. U. R. Strand, P. Werner, and M. Eckstein, Theory of photoinduced ultrafast switching to a spin-orbital ordered hidden phase, *Nat. Commun.* **9**, 4581 (2018).

- [96] W. J. Jankowski, A. S. Morris, A. Bouhon, F. N. Ünal, and R.-J. Slager, Optical manifestations and bounds of topological Euler class, *Phys. Rev. B* **111**, L081103 (2025).
- [97] B. N. Brockhouse, Scattering of neutrons by spin waves in magnetite, *Phys. Rev.* **106**, 859 (1957).
- [98] Y. Yang, M. Li, I. Rouschatzakis, and N. B. Perkins, Non-Loudon-Fleury Raman scattering in spin-orbit coupled Mott insulators, *Phys. Rev. B* **104**, 144412 (2021).
- [99] E. Galindez-Ruales, W. Yang, T. Dannegger, M. Kundu, J. Köhler, C. Schmitt, F. Fuhrmann, A. Akashdeep, D. M. Tran, X. Ma *et al.*, Altermagnetic magnon transport in the d -wave altermagnet LuFeO_3 , [arXiv:2508.14569](#).
- [100] Y. Yang, D. Wang, B. Yang, P. Wang, Y. Mu, Y. Tian, B. Zheng, W. Qin, K. Wang, B. Huang *et al.*, Altermagnet-driven magnon spin splitting Nernst effect, *Phys. Rev. Lett.* **136**, 026701 (2026).
- [101] A. T. Costa, J. C. G. Henriques, and J. Fernández-Rossier, Giant spatial anisotropy of magnon Landau damping in altermagnets, *SciPost Phys.* **18**, 125 (2025).
- [102] F. Garcia-Gaitan, A. Kefayati, J. Q. Xiao, and B. K. Nikolić, Magnon spectrum of altermagnets beyond linear spin wave theory: Magnon-magnon interactions via time-dependent matrix product states versus atomistic spin dynamics, *Phys. Rev. B* **111**, L020407 (2025).
- [103] Z. Jin, Z. Zeng, J. Liu, T. Gong, Y. Su, K. Chang, and P. Yan, Interaction-driven altermagnetic magnon chiral splitting, *Phys. Rev. Lett.* **136**, 086703 (2026).
- [104] Y. S. Liu, E. V. Boström, M. A. Sentef, and S. V. Kusminskiy, Light-matter-coupling formalism for magnons: Probing quantum geometry with light, [arXiv:2604.11931](#).
- [105] G. Chaudhary, M. Levin, and A. A. Clerk, Simple approach to characterizing band topology in bosonic pairing Hamiltonians, *Phys. Rev. B* **103**, 214306 (2021).
- [106] I. Tesfaye and A. Eckardt, Quantum geometry of bosonic Bogoliubov quasiparticles, *Phys. Rev. Res.* **7**, L042052 (2025).

End Matter

Appendix A: Details of the AM spin Hamiltonians—Below we provide further technical details on the d -wave altermagnet model studied in this Letter [20]. In real space, the spin Heisenberg Hamiltonian $\mathcal{H}$ written in terms of the lattice spin operators $\mathbf{S}_i^\uparrow, \mathbf{S}_i^\downarrow$, which we consider in this Letter, reads,

$$\begin{aligned} \mathcal{H} = & - \left(\sum_{\langle ij \rangle_x} J_1 \mathbf{S}_i^\uparrow \cdot \mathbf{S}_j^\uparrow + \sum_{\langle ij \rangle_y} J_2 \mathbf{S}_i^\uparrow \cdot \mathbf{S}_j^\uparrow \right) \\ & - \left(\sum_{\langle ij \rangle_x} J_2 \mathbf{S}_i^\downarrow \cdot \mathbf{S}_j^\downarrow + \sum_{\langle ij \rangle_y} J_1 \mathbf{S}_i^\downarrow \cdot \mathbf{S}_j^\downarrow \right) \\ & - \sum_i J_{\text{AFM}} \mathbf{S}_i^\uparrow \cdot \mathbf{S}_i^\downarrow \\ & - \frac{1}{2} K \sum_i \left[(\mathbf{S}_i^\uparrow \cdot \hat{\mathbf{z}})^2 + (\mathbf{S}_i^\downarrow \cdot \hat{\mathbf{z}})^2 \right] \\ & - g\mu_B H_0 \sum_i \left(\mathbf{S}_i^\uparrow + \mathbf{S}_i^\downarrow \right) \cdot \hat{\mathbf{x}}, \end{aligned} \quad (\text{A1})$$

with $J_{1,2} = J \pm \Delta J$ the intrasublattice exchange coupling coefficient, $J_{\text{AFM}} < 0$ the intersublattice AFM exchange coupling coefficient, $K > 0$ the easy-axis magnetic anisotropy, $\hat{\mathbf{x}}, \hat{\mathbf{z}}$ the unit vectors in the x and z directions, the Bohr magneton μ_B , Landé g factor, and H_0 an external field along x direction, which cants the sublattices; see Fig. 1(a). ΔJ gives the scale of AM splitting of magnons, and $\langle ij \rangle_{x,y}$ denotes the nearest neighbors in the x, y directions, respectively. Under the HP transformation and a Fourier transformation, the corresponding momentum-space magnon Hamiltonian amounts to

$$\begin{aligned} \mathcal{H}(\mathbf{k}) = & (A_1 + A_2)\sigma_0\tau_0 + (A_1 - A_2)\sigma_0\tau_3 + B_1\sigma_1\tau_1 \\ & + B_2\sigma_0\tau_1 + B_3\sigma_1\tau_0. \end{aligned} \quad (\text{A2})$$

In the above, the model parameters read

$$\begin{aligned} A_{1,2} = & S[J_{1,2}(1 - \cos k_x) + J_{2,1}(1 - \cos k_y) \\ & + K(3\cos^2\theta - 1)/4 - \cos 2\theta J_{\text{AFM}}/2 \\ & + g\mu_B H_0 \sin \theta/2], \\ B_1 = & SJ_{\text{AFM}}(1 + \cos 2\theta)/2, \\ B_2 = & -SJ_{\text{AFM}}(1 - \cos 2\theta)/2, \\ B_3 = & -SK\sin^2\theta/4, \end{aligned} \quad (\text{A3})$$

where $\theta = \arctan[g\mu_B SH_0/(-2J_{\text{AFM}} + K)]$ is the canting angle induced by the external magnetic field H_0 , and $\sigma_{0,1,2,3}$ ($\tau_{0,1,2,3}$) denote the Pauli matrices operating on sublattice and wave vector degree of freedom, respectively.

Appendix B: Relation between magnon chirality and quantum metric—In the following, we provide further technical details on the unique quantum geometry of AM magnons retrieved and probed by light in this Letter. The magnonic metric $g_{ab}^{(m)}$ considered in the main text reads, in terms of magnon band eigenvectors $|u_i\rangle \equiv [U]_i$,

$$g_{ab}^{(m)} = \text{Re} \frac{([\bar{U}]_1 \tau_3 \partial_{k_a} \mathcal{H}(\mathbf{k}) [U]_2) ([\bar{U}]_2 \tau_3 \partial_{k_b} \mathcal{H}(\mathbf{k}) [U]_1)}{(\hbar\omega_1 - \hbar\omega_2)^2}, \quad (\text{B1})$$

which is consistent with Refs. [62,68]. We emphasize that the quantum geometry of magnons driven by the

considered BdG Hamiltonians is fundamentally a symplectic quantum geometry [62,68,105,106]. We now detail how the nontrivial metric texture [Fig. 3(a)], which reflects the chirality (p_j) alternation, and its coincidence with the $L_{ab}^{(2)}$ pattern [Fig. 3(b)] identified in the main text, arise. The enhancement of diagonal terms $g_{aa}^{(m)}$ [Fig. 3(a)] occurs under a local $\mathbf{k}$ -space condition: $|([\tilde{U}]_1 \tau_3 \partial_{k_a} \mathcal{H}(\mathbf{k}) [U]_2)|^2 \gg 1$. These matrix elements, equivalently translate to a local enhancement of matrix elements $|\tilde{U}^\dagger U_a|$ occurring in the LMC matrix elements, i.e., $L_a^{(1)}$ and $L_{ab}^{(2)}$, as defined in the main text, and consistently with the identifications of Ref. [68].

Crucially, the matrix elements $|\tilde{U}^\dagger U_a|$ closely reflect the magnon chirality features. On direct differentiation, the gradient $\partial_a p_j$, introduced by the unique alternation of AM magnonic chirality (p_j), by definition consists of the terms $(U_{ij}^{-1})^* \partial_a U_{ij}^{-1}$. The gradients of U_{ij}^{-1} inverses in the

individual magnon bands i , within the $(U_{ij}^{-1})^* \partial_a U_{ij}^{-1}$ terms, translate into the enhancements in the matrix elements $|\tilde{U}^\dagger U_a|$. A general inequality relating the quantum metric to the chirality alternation exists for collinear AM and AFM models in the limit $H_0 \rightarrow 0$,

$$|g_{aa}^{(m)}| \geq \left| \frac{\partial_a p_i}{2\Delta_{\mathbf{k}}} \right|^2, \quad (\text{B2})$$

with $\Delta_{\mathbf{k}}$ arising through Bogoliubov transformation, as derived in SM [90]. This inequality saturates for large-wave-vector magnons, which indicates that the enhancement of the quantum metric becomes a direct signature of alternating magnon chirality at the BZ boundary. To visualize these relations quantitatively, we presented the $\mathbf{k}$ -space resolved local patterns in Figs. 2(a) and 2(b) against the textures in Figs. 3(a) and 3(b), and in Sec. II of SM [90].