

# Staggered Dzyaloshinskii-Moriya and canting angle in centrosymmetric altermagnetic and ferromagnetic phases: influence on the anomalous Hall effect and Weyl points

M. Benny,<sup>1</sup> X. Gong,<sup>1</sup> K. Jamroszczyk,<sup>1</sup> A. Fakhredine,<sup>2</sup> G. Cuono,<sup>3</sup> R. Islam,<sup>4</sup> J. Skolimowski,<sup>1</sup> and C. Autieri<sup>1,5</sup>

<sup>1</sup>*International Research Centre Magtop,  
Institute of Physics, Polish Academy of Sciences,  
Aleja Lotników 32/46, PL-02668 Warsaw, Poland*

<sup>2</sup>*Institute of Physics, Polish Academy of Sciences,  
Aleja Lotników 32/46, 02668 Warsaw, Poland*

<sup>3</sup>*Consiglio Nazionale delle Ricerche (CNR-SPIN),  
Unità di Ricerca presso Terzi c/o Università "G. D'Annunzio", 66100 Chieti, Italy*

<sup>4</sup>*Lomare Technologies Limited London Street, London EC3R 7LP, UK*

<sup>5</sup>*SPIN-CNR, UOS Salerno, IT-84084 Fisciano (SA), Italy*

We present a simple methodology to compute the anomalous Hall conductivity (AHC) as a function of the canting angles in ferromagnets and altermagnets[1], starting from a nonmagnetic Hamiltonian obtained from first principles calculations that preserves the full symmetry of the crystal structure. Magnetism is introduced by including on site spin- splitting, spin-orbit coupling, and spin canting angles. As a representative material, we study SrRuO<sub>3</sub>, which supports spin canting and exhibits a sign change of the AHC[2]. In the ferromagnetic phase, the low-energy AHC is found to be close to zero at the Fermi level, in agreement with experimental observations. We show that the dependence of the AHC on the relevant physical parameters is most pronounced in the central region of the electronic bandwidth. We determine the symmetry-allowed components of the AHC for different magnetic orders in the large family of transition-metal perovskite ABO<sub>3</sub> compounds with space group 62, including the spontaneous in-plane anomalous Hall effect. Within density functional theory, we evaluate the range of spin canting angles for SrRuO<sub>3</sub> and demonstrate that it is suppressed by increasing electronic correlations. By analyzing the AHC as a function of the canting angle, we find that the collinear magnetic configurations give the main contribution to the AHC, while the canting of the spins plays a secondary role in determining the magnitude of the AHC in non collinear ferromagnets and altermagnets. However, canting can become relevant and induce a sign change of the AHC when the collinear magnetic state exhibits an AHC close to zero. Finally, we investigate the locations of Weyl points in the Brillouin zone and their evolution as a function of the canting angle.

## References:

[1] L. Smejkal, J. Sinova, and T. Jungwirth, Phys. Rev. X 12, 040501 (2022).

[2] M. Kim and B. I. Min, Phys. Rev. B 91, 205116 (2015).

[3] M. Benny, X. Gong, K. Jamroszczyk, A. Fakhredine, G. Cuono, R. Islam, J. Skolimowski and C. Autieri, Staggered Dzyaloshinskii-Moriya and canting angle in centrosymmetric altermagnetic and ferromagnetic phases: influence on the anomalous Hall effect and Weyl points (Manuscript in Preparation).