

## **Augmented multipoles: classification of order parameter and cross-correlated phenomena**

Akimitsu Kirikoshi

Department of Physics, Hokkaido University

### **Abstract:**

The interplay between electronic degrees of freedom, such as a charge, spin, and orbital in solids, has drawn the attention of researchers in various fields of condensed matter physics. The concept of multipoles has been developed to describe unconventional parity-breaking and spin-orbital entangled states [1]. According to spatial inversion and time-reversal symmetry, four types of multipoles, electric, magnetic, magnetic toroidal, and electric toroidal, are defined, which constitute a complete basis set [2]. The advantage of using these multipole bases is the systematic classification of complex electronic order parameters under crystallographic (magnetic) point groups, which provides possible cross-correlated responses and transports [3,4,5].

In this talk, we discuss the following topics of the application of augmented multipoles. (a) Microscopic mechanism for intrinsic nonlinear anomalous Hall effect under odd-parity magnetic orderings [6]. (b) Characteristic responses induced under ferroaxial ordering [7]. (c) Classification of the pairing state in the superconducting state [8].

### **References:**

- [1] H. Kusunose and S. Hayami, *J. Phys.: Condens. Matter* **34**, 464002 (2022).
- [2] H. Kusunose, R. Oiwa, and S. Hayami, *J. Phys. Soc. Jpn.* **89**, 104704 (2020).
- [3] S. Hayami, M. Yatsushiro, Y. Yanagi, and H. Kusunose, *Phys. Rev. B* **98**, 165110 (2018).
- [4] H. Watanabe and Y. Yanase, *Phys. Rev. B* **98**, 245129 (2018).
- [5] M. Yatsushiro, S. Hayami, and H. Kusunose, *Phys. Rev. B* **104**, 054412 (2021).
- [6] A. Kirikoshi and S. Hayami, *Phys. Rev. B* **107**, 155109 (2023).
- [7] A. Kirikoshi and S. Hayami, *J. Phys. Soc. Jpn.* **92**, 123703 (2023).
- [8] A. Kirikoshi and S. Hayami, arXiv:2312.02410.