

Unconventional Magnetism

Congjun WU

Department of Physics, Westlake University, P.R. China

Email: wucongjun@westlake.edu.cn

Over two decades ago a mechanism for generating what was later termed unconventional magnetism (UM) [1] was proposed by Wu and Zhang [2] in analogy to unconventional superconductivity. It is based on quantum phase transitions of the Landau-Pomeranchuk Fermi surface instability, spontaneously generating spin-multipole ordering and momentum-dependent spin splitting. Later theoretical investigation was systematically developed [3]: The symmetry and topological defects were analyzed by composed operations of non-equivalent orbital and spin rotations, i.e., spin-space group type operations in later literatures; properties proposed for experiment tests include temperature-dependent spin splitting detectable by ARPES and Shubnikov–de Haas oscillations, coupling between strain and magnetization, and resonance modes in inelastic neutron scattering spectra, etc. UM was generalized to orbital band systems to explain the nematic metamagnetism observed in Sr₃Ru₂O₇ [4].

From the symmetry perspective, altermagnetism corresponds to the collinear version of UM (alpha-phase) in even partial-wave numbers. It is worth mentioning that the distorted Fermi surfaces in the d-wave state and the spin current generation by charge current shown in the presentation in 2007 [1] are the same as the now-iconic illustration of altermagnetism. In addition, UM states can exhibit non-collinear spin multipole orders (beta-phase) and exist in odd partial-wave channels maintaining time-reversal symmetry beyond altermagnetism. These deep connections offer insights into their shared theoretical underpinnings. As for a recent development, we reconcile conflicting experimental and theoretical reports in RuO₂ by attributing it to the proximity to a quantum phase transition [5] and a phase-sensitive method to explore unconventional magnetic symmetries via the two-impurity Kondo effect [6].

References:

- [1] Online talk given by C. Wu at the KITP, UCSB in 2007, <https://online.kitp.ucsb.edu/online/coldatoms07/wu1/>
- [2] C. Wu and S. C. Zhang, PRL 93, 36403 (2004).
- [3] C. Wu, K. Sun, E. Fradkin, and S. C. Zhang, PRB 75, 115103 (2007).
- [4] W.C. Lee, C. Wu, Phys. Rev. B 80, 104438 (2009).
- [5] Z. Qian, Y. Yang, Shi Liu, C. Wu, Phys. Rev. B 111.174425 (2025)
- [6] Q. Qin, T. Sato, M. Raczkowski, J. van den Brink, C. Wu, F. F. Assaad, arXiv:2601.07138 .