

Theory of Chiral Topological Superconductivity and Pair Density Wave Superconductivity in Twisted Bilayer WSe₂

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We theoretically explore possible orders induced by weak repulsive interactions in twisted bilayer transition metal dichalcogenides (e.g., WSe₂) in the presence of an out-of-plane electric field [1, 2]. Using renormalization group analysis, we predict that topological chiral superconducting states with Chern number $\mathcal{N} = 1, 2, 4$ (namely, $p + ip$, $d + id$, and $g + ig$) can appear over a large parameter region with a moiré filling factor around $\nu = 1$. At some special values of applied electric field and in the presence of a weak out-of-plane Zeeman field, spin-polarized pair-density-wave (PDW) superconductivity can emerge [1]. For very recent discovery of unconventional superconductivity in twisted WSe₂ homobilayers at filling $\nu = -1$, considerable interest has arisen in revealing its mechanism. We developed a three-band tight-binding model with non-trivial band topology. Incorporating both onsite Hubbard repulsion and next-nearest-neighbor attraction, we then performed a mean-field analysis of the microscopic model and obtained a phase diagram qualitatively consistent with the experiment results. For zero or weak displacement field, the ground state is a Chern number ± 2 topological superconductors in the Altland-Zirnbauer A-class (breaking time-reversal but preserving total S_z symmetry) with inter-valley pairing dominant $d_{xy} \pm i d_{x^2-y^2}$ -wave (mixing with a subdominant $p_x \mp i p_y$ -wave) component [2].

References:

[1] Yi-Ming Wu, Zhengzhi Wu, and Hong Yao, Phys. Rev. Lett. 130, 126001 (2023)

[2] Chuyi Tuo, Ming-Rui Li, Zhengzhi Wu, Wen Sun, and Hong Yao, Nature Communications 16, 9525 (2025)