第二十届全国磁学会议

Spin-orbital altermagnetism

Zi-Ming Wang,[1,2,*] Yang Zhang,[3,*,†] Song-Bo Zhang,[4,5,‡] Jin-Hua Sun,[6] Elbio Dagotto,[3] Dong-Hui Xu,[1,7,§] and Lun-Hui Hu[2,3,‖]

[1] Department of Physics and Chongqing Key Laboratory for Strongly Coupled Physics, Chongqing University, Chongqing 400044, China

[2] Center for Correlated Matter and School of Physics, Zhejiang University, Hangzhou 310058, China

[3] Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA

[4] Hefei National Laboratory, Hefei, Anhui 230088, China

[5] International Center for Quantum Design of Functional Materials (ICQD), University of Science and Technology of China, Hefei, Anhui 230026, China

[6] Department of Physics, Ningbo University, Ningbo 315211, China

[7] Center of Quantum Materials and Devices, Chongqing University, Chongqing 400044, China

†Email: yzhang@utk.edu ‡Email: songbozhang@ustc.edu.cn

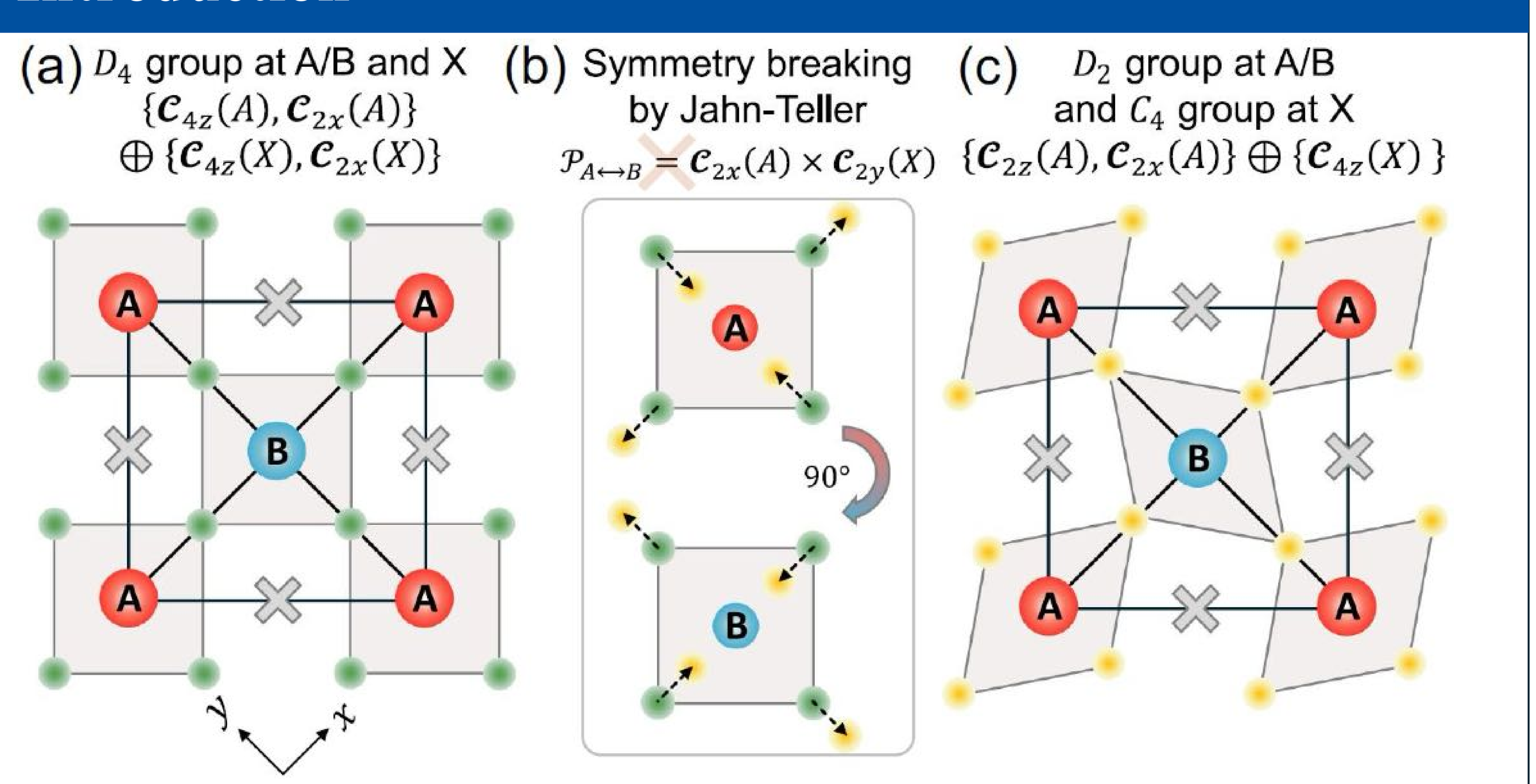
§Email: donghuixu@cqu.edu.cn ‖Email: lunhui@zju.edu.cn

Visit our homepage at cquctcmp.com

1. Introduction

Altermagnetism is a newly discovered magnetic phase, characterized by nonrelativistic spin splitting that has been experimentally observed. Here, we introduce a framework dubbed "spin-orbital altermagnetism" to achieve spin-orbital textures in altermagnetic materials. We identify two distinct classes of spin-orbital altermagnetism: intrinsic and extrinsic. The intrinsic type emerges from symmetry-compensated magnetic orders with spontaneously broken parity-time symmetry, while the extrinsic type stems from translational symmetry breaking between sublattices, as exemplified by the Jahn-Teller-driven structural phase transition. In addition to directly measuring the spin-orbital texture, we propose spin conductivity and spin-resolved orbital polarization as effective methods for detecting these altermagnets. Additionally, a symmetry-breaking mechanism induces weak spin magnetization, further revealing the peculiar feature of spin-orbital altermagnetism. We also utilize the staggered susceptibility to illustrate a potential realization of this phase in a two-orbital interacting system. Our Letter provides a new platform to explore spin-orbital locked physics, extending the materials classes that may display complex spin textures from the standard 4d − 5d compounds to 3d compounds.

2. Introduction



Mean-field Hamiltonian

$$\mathcal{H}_{\mathrm{MF}}(\boldsymbol{k}) = \mathcal{H}_0(\boldsymbol{k}) s_0 + \Delta_1 \tau_0 \sigma_z s_z + \Delta_2 \tau_x \sigma_z s_z + \Delta_3 \tau_x \sigma_0 s_z + \Delta_4 \tau_z \sigma_0 s_z + \Delta_5 \tau_z \sigma_z s_z$$

Spinless $\mathcal{H}_0(\boldsymbol{k})$ includes the Jahn–Teller effect and orbital hybridization

	Symmetry							
AFM order	$\mathscr{P}_{A\leftrightarrow B}$	$\{\mathscr{C}_2 \Vert \mathscr{P}_{A\leftrightarrow B}\}$	$\mathscr{C}_{4z}(X)$	$\{\mathscr{C}_2 \Vert \mathscr{C}_{4z}(X)\}$	$\mathscr{M}_{A\leftrightarrow B}$	$\{\mathscr{C}_2 \Vert \mathscr{M}_{A\leftrightarrow B}\}$	With $\mathscr{P}_{A\leftrightarrow B}$	w/o $\mathscr{P}_{A\leftrightarrow B}$
$\mathscr{O}_1$: $\tau_0\sigma_z s_z$	X	✓	X	✓	X	✓		d-wave AM $\sigma^z_{xx} \neq 0$
$\mathscr{O}_2$: $\tau_x\sigma_z s_z$	X	✓	✓	X	X	✓	Néel AFM $\sigma^z_{\mu\nu} = 0$	SO g-wave AM $\sigma^z_{\mu\nu} = 0$
$\mathscr{O}_5$: $\tau_z\sigma_z s_z$	X	✓	✓	X	✓	X		Weak FM
$\mathscr{O}_3$: $\tau_x\sigma_0 s_z$	✓	X	X	✓	X	✓		Intrinsic SO d-wave AM $\sigma^z_{xy} = \sigma^z_{yx} \neq 0$
$\mathscr{O}_4$: $\tau_z\sigma_0 s_z$	✓	X	X	✓	✓	X		Intrinsic SO d-wave AM $\sigma^z_{xx} = -\sigma^z_{yy} \neq 0$

3. Spin-orbital texture and spin-resolved orbital weight

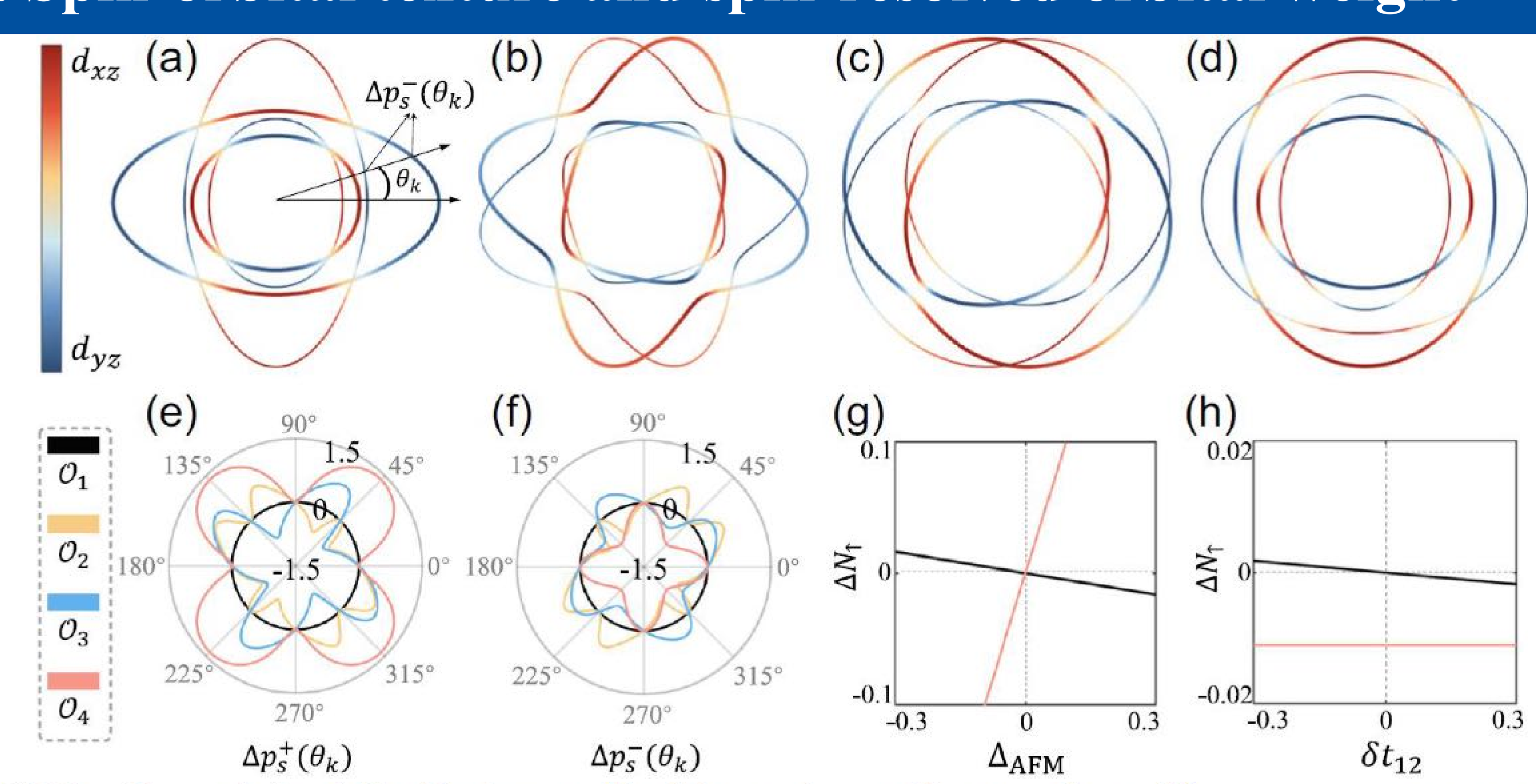
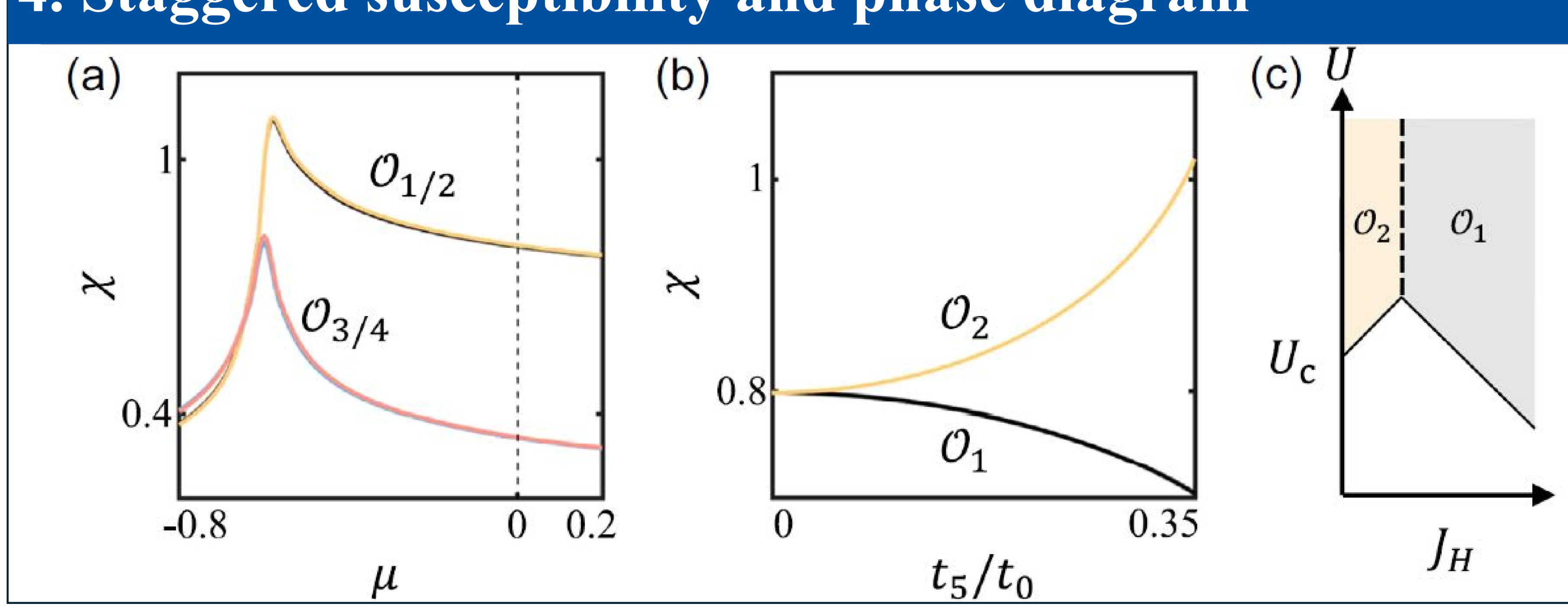


FIG. 2. (a)–(d) Spin-split Fermi surfaces for $\mathcal{O}_{1/2/3/4}$, respectively, with the thick (thin) lines denoting the $s_z = \uparrow (\downarrow)$ bands. The color scheme represents the orbital weight on the Fermi surfaces. (e),(f) Corresponding spin-orbital textures $\Delta p_s^{\pm}(\theta_k)$ for the + (inner Fermi surfaces) and − bands (outer Fermi surfaces), respectively, as illustrated in (a). (g),(h) Spin-resolved orbital polarization as a function of the altermagnetic gap $\Delta_{\mathrm{AFM}} = \Delta_1$ (black) and $\Delta_{\mathrm{AFM}} = \Delta_4$ (red), and JT distortion strength δt_{12}, respectively.

4. Staggered susceptibility and phase diagram



5. Reference

Z.-M. Wang, Y. Zhang*, S.-B. Zhang*, J.-H. Sun, E. Dagotto, D.-H. Xu*, and L.-H. Hu*, Spin-orbital altermagnetism, Phys. Rev. Lett. 135, 176705 (2025).

Light-Induced Odd-Parity Magnetism in Conventional Antiferromagnetism

Shengpu Huang, Zheng Qin, Fangyang Zhan, Dong-Hui Xu*, Da-Shuai Ma*, Rui Wang*

Institute for Structure and Function & Department of Physics & Chongqing Key Laboratory for Strongly Coupled Physics, Chongqing University, Chongqing 400044, People's Republic of China

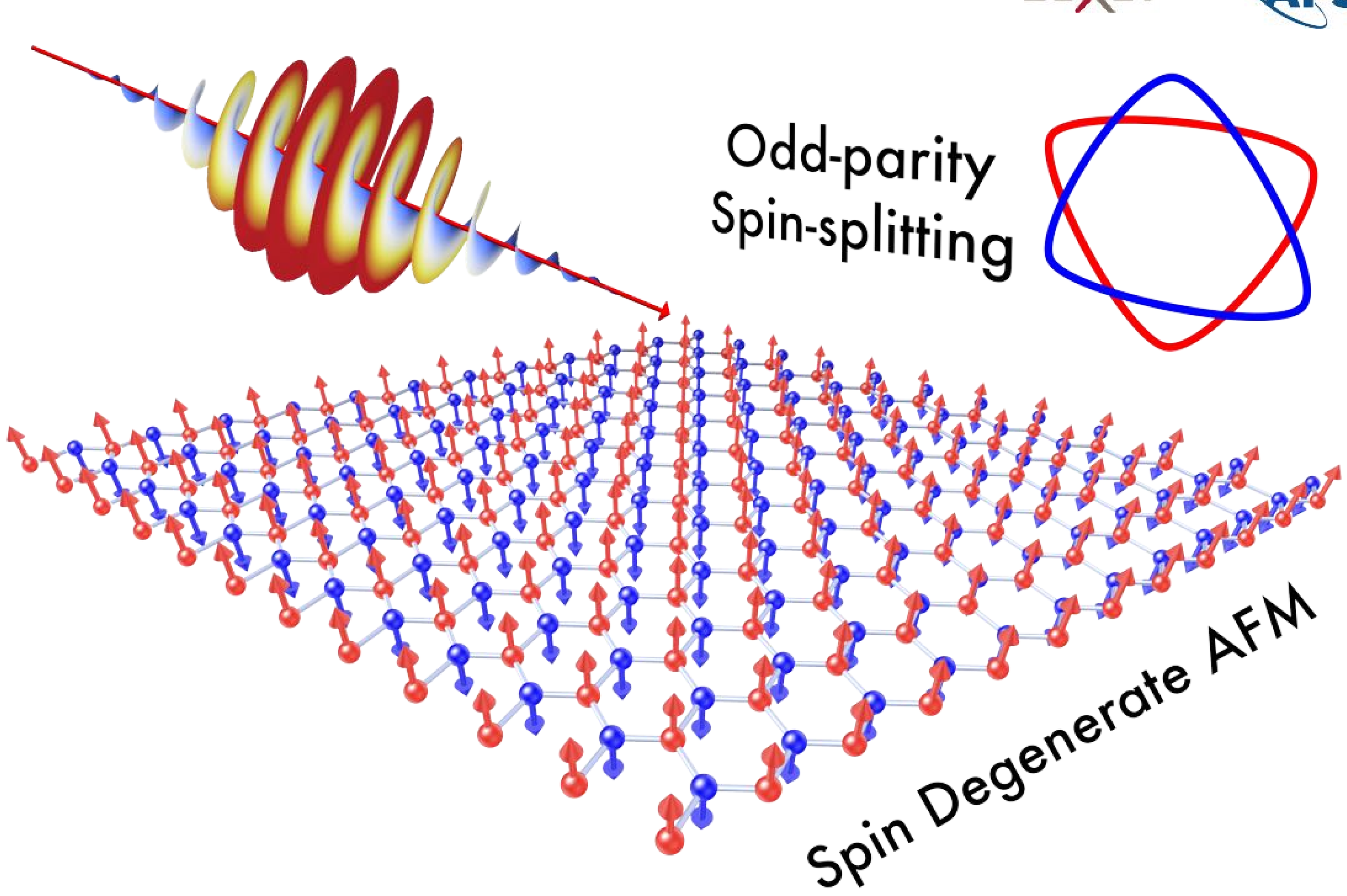
Hi from cquctcmp.com

Abstract

Phys. Rev. Lett. 136, 126703 (2026)

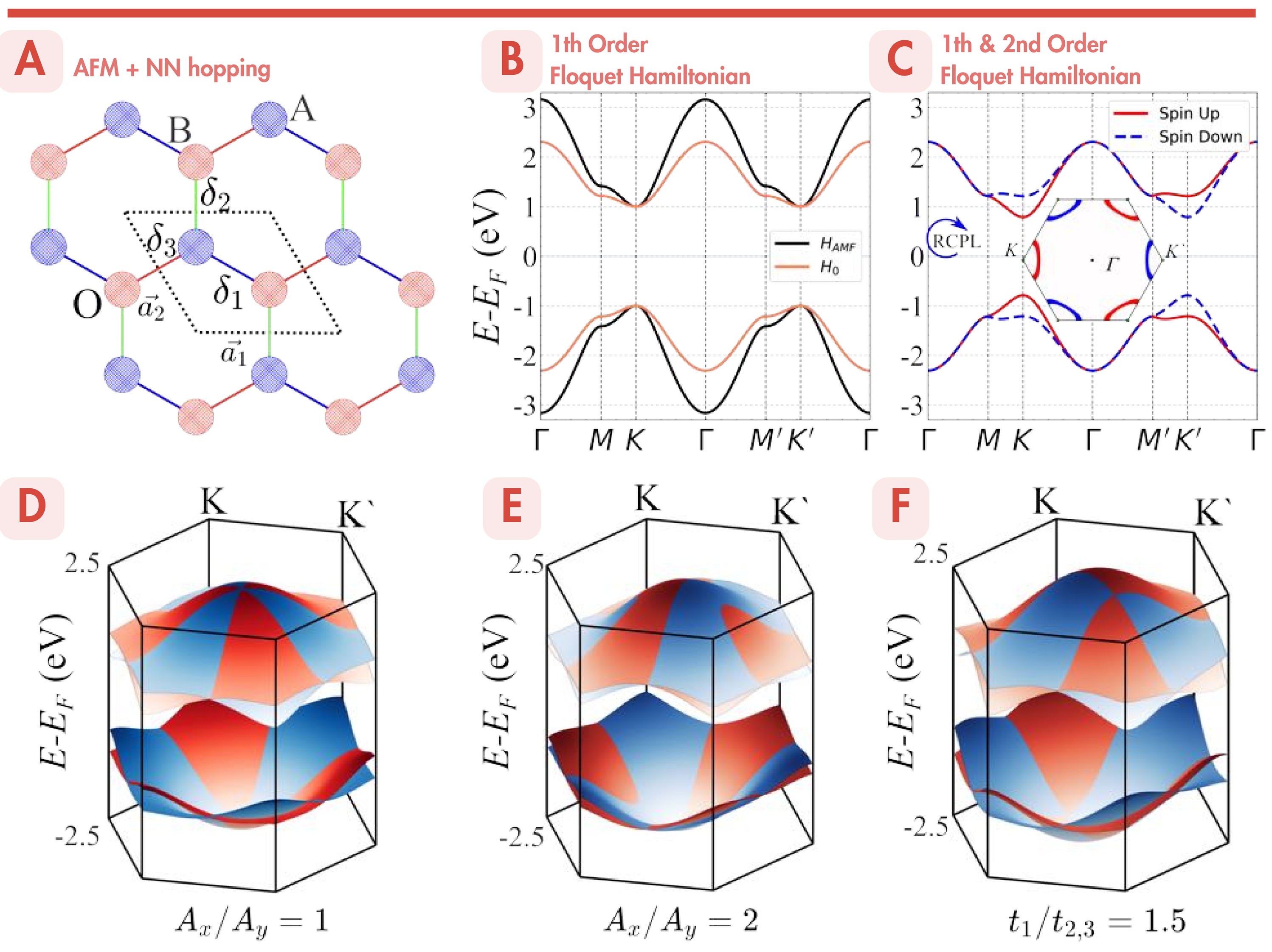
Visit our homepage at **cquctcmp.com**

arXiv APS



Recent studies have drawn growing attention on nonrelativistic odd-parity magnetism in the wake of altermagnets. Nevertheless, odd-parity spin splitting is often believed to appear in noncollinear magnetic configurations. Here, using symmetry arguments and effective model analysis, we show that Floquet engineering offers a universal strategy for achieving odd-parity magnetism in two-dimensional (2D) collinear antiferromagnetism under irradiation of periodic driving light fields such as circularly polarized light (CPL), elliptically polarized light (EPL), and bicircular light. The symmetry requirements and three distinct lattice models of potential candidates are established. Strikingly, the light-induced odd-parity spin splitting can be flexibly controlled by adjusting the crystalline symmetry or the polarization state of incident light, enabling the reversal or conversion of spin splitting. By combining first-principles calculations and Floquet theorem, we present illustrative examples of 2D collinear antiferromagnetic (AFM) materials to verify the light-induced odd-parity magnetism. Our Letter not only offers a powerful approach for uniquely achieving odd-parity spin splitting with high tunability, but also expands the potential of Floquet engineering in designing unconventional compensated magnetism.

Lattice Model



A A hexagonal lattice model with Collinear AFM order and NN-hopping (w/o SOC).

$$H = t\sum_{\langle i,j\rangle} c_i^\dagger c_j + \sum_i c_i^\dagger[\mu_\zeta\sigma_0 + \boldsymbol{m}_\zeta\cdot\boldsymbol{\sigma}]c_i + h.c.$$

B-C Lattice model under Floquet light field (CPL circularly polarized light)

$$H^{\alpha-\beta}_{mn}(\vec{k},\omega) = \sum_{\vec{R}_i} e^{i\vec{k}\cdot\vec{R}_j}\left(\frac{1}{T}\int_0^T t_j^{mn}\times e^{i\frac{e}{\hbar}\vec{A}(t)\cdot\vec{d}_{mn}}e^{i(\alpha-\beta)\omega t}dt\right)$$

$$H_{\mathrm{eff}}(\boldsymbol{k}) = \underbrace{H_0(\boldsymbol{k})}_{B} + \underbrace{\frac{[H_1(\boldsymbol{k}),H_{-1}(\boldsymbol{k})]}{\omega}}_{C} + \mathcal{O}\left(\frac{1}{\omega^2}\right)$$

Methodology
- SM of this work
- Phys. Rev. B 99, 075121 (2019)
- arXiv:2003.08252
- Quantum Frontiers 3, 21 (2024)

D f-wave spin-splitting

$$\omega H'(\boldsymbol{k}) = 8\sqrt{3}\eta J_1\left(\frac{A_0}{\sqrt{3}}\right)^2 t^2\prod_i \sin(k_i'/2)\sigma_0\tau_z = f(\boldsymbol{k})\sigma_0\tau_z$$

E-F Additional Anisotropy: f-wave to p-wave

E A elliptically polarized light (EPL)

F Mechanical Strain

The schematic of three material candidate categories of f-wave spin splitting: 1 *hexagonal lattice with Néel-type magnetic configuration (Category-I)* 2 *AFM bilayers composed of FM monolayers. (Category-II),* 3 *AFM bilayers composed of Ferrimagnetic monolayers (Category-III).*

CPL induced f-wave spin splitting in representative materials, i.e., AFM $MnPS_3$ monolayer (Category I), AFM $FeCl_2$ bilayer (Category II), and AFM $NiRuCl_6$ bilayer (Category III). **A - C** The side-view and bird-view of crystal structure and magnetic order of AFM $MnPS_3$ monolayer, AFM $FeCl_2$ bilayer, and AFM $NiRuCl_6$ bilayer. **D - F** The spin-resolved band structures (curves in red solid represent the spin-up state) along high-symmetry lines of the AFM $MnPS_3$ monolayer, AFM $FeCl_2$ bilayer, and AFM $NiRuCl_6$ bilayer under irradiation of CPL with a light intensity of $eA_0/\hbar$ = 0.3 Å^{-1} and the photon energy of this light $\hbar\omega$ = 10 eV. The light irradiation preserves the spin degeneracy along the high-symmetry line Γ-M while lifting the degeneracy at other arbitrary k-point. **G - I** The spin-resolved isoenergy surfaces with f-wave spin splitting.

Material Candidates