Optical Switching of a Moiré Chern Ferromagnet

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Outline

1. Moiré magnetism and correlated topological phases
2. Optical control of quantum phases
3. Optical switching of Chern states in twisted $MoTe_2$ bilayers
4. Conclusion and outlook

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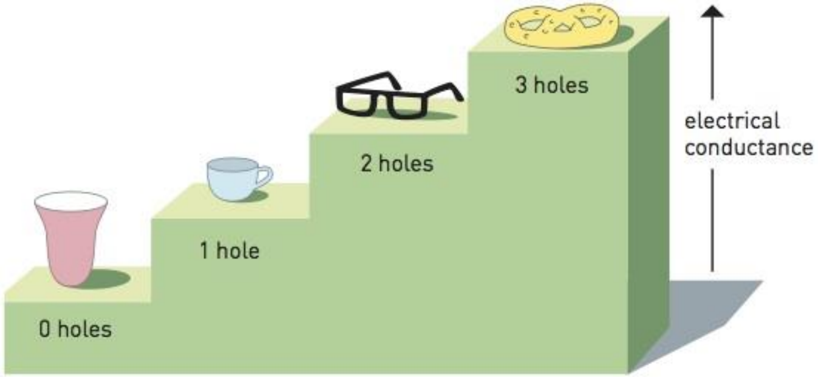
Topology in 2D Moiré Systems – Quantization

Topological Invariants underpin a variety of quantized phenomena

Sphere
Cow = Ball

Torus
Mug = Donut



- **Berry Curvature**

Karplus & Luttinger,
Physical Review **1954**

$$\dot{r} = \frac{1}{h}\nabla_k \varepsilon_k - \dot{k}\times\Omega(k)$$

Anomalous Velocity

$$\Omega(k) = \nabla_k \times < u_k | i\nabla_k | u_k >$$

TKNN, PRL **1982**

Chern Number

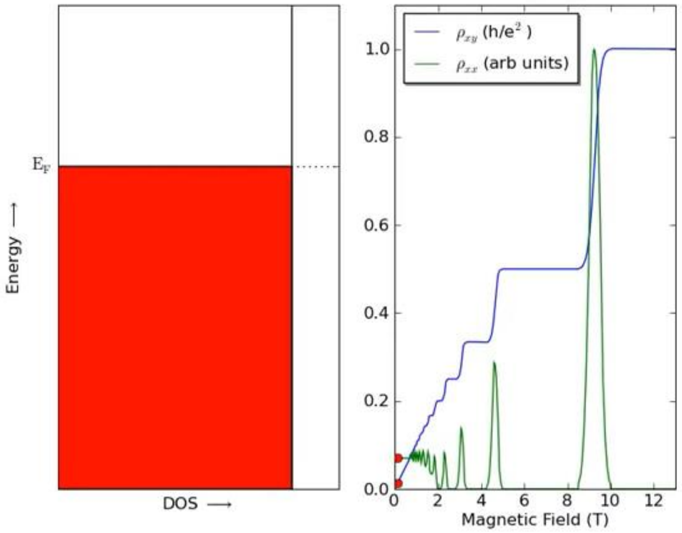
$$C = \frac{1}{2\pi}\int_{BZ} \Omega(k) d^2k \qquad \rho_{xy} = \frac{h}{Ce^2}$$

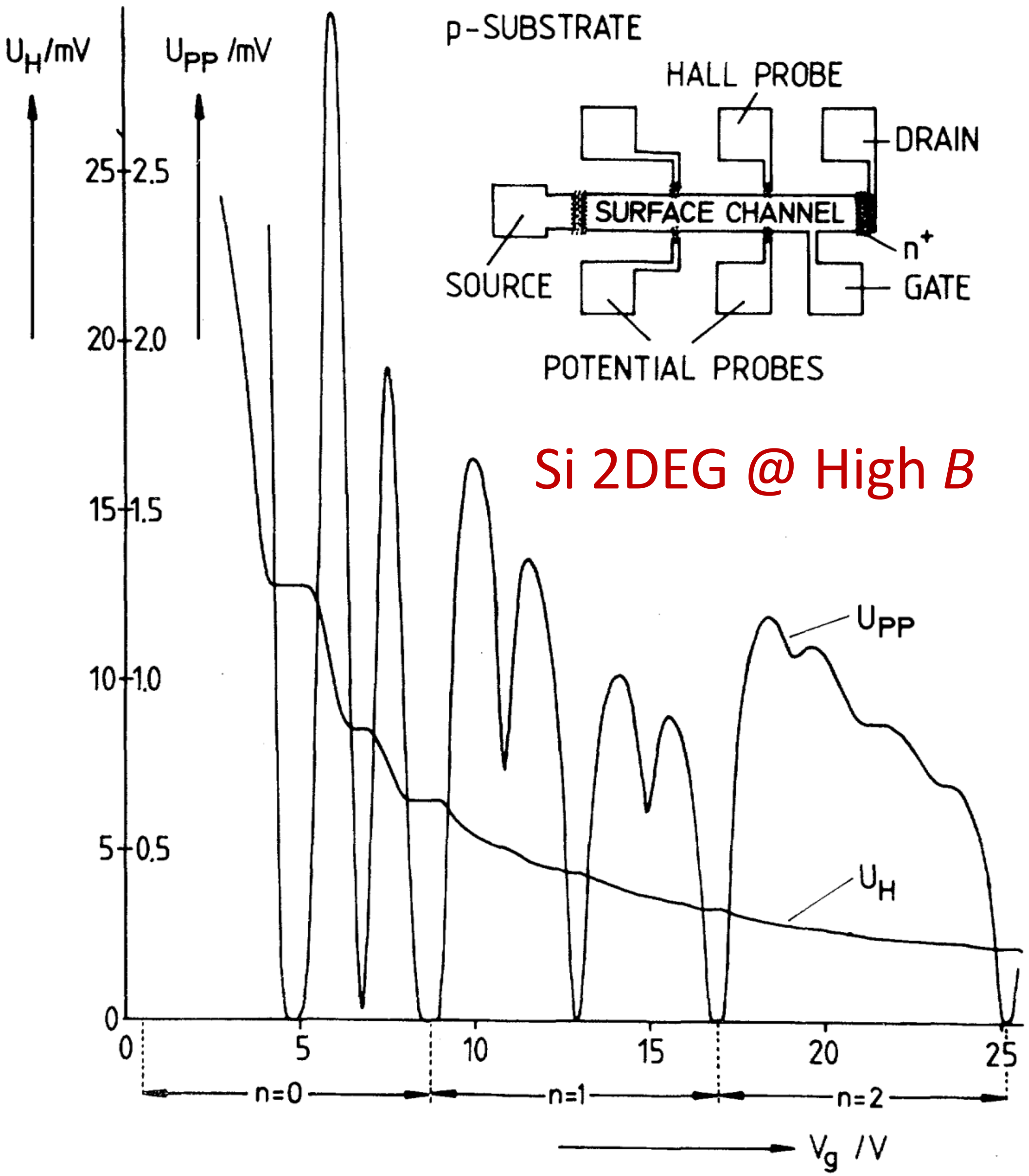
‘Magnetic Field’ in *k* space

First Experimental Realization of Quantum Hall Effect

$$E_n = \hbar\omega_c\left(n + \tfrac{1}{2}\right), \quad \omega_c = \frac{eB}{m}$$

An excellent example:
Landau Levels @ Large *B*





Si 2DEG @ High *B*

$$\sigma_{xy} = C\frac{e^2}{h}$$

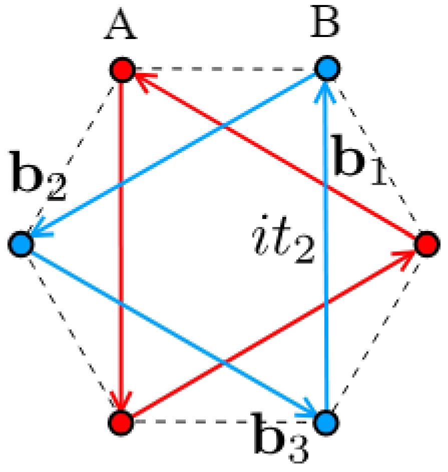
Klaus von Klitzing et.al., PRL **1980**, 45 (6), 494-497

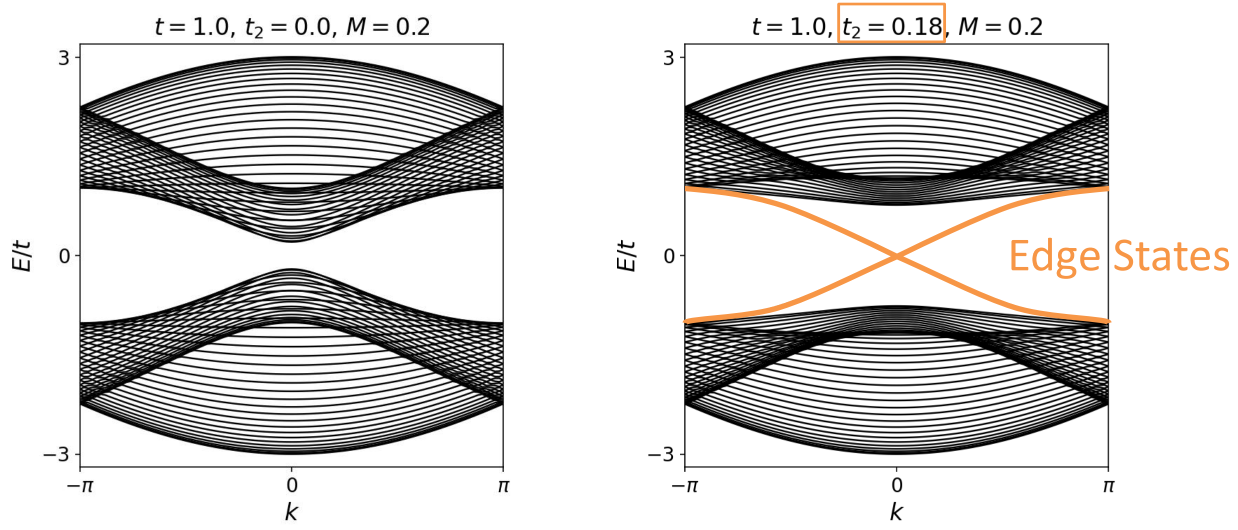
Topology in 2D Moiré Systems – Haldane Model

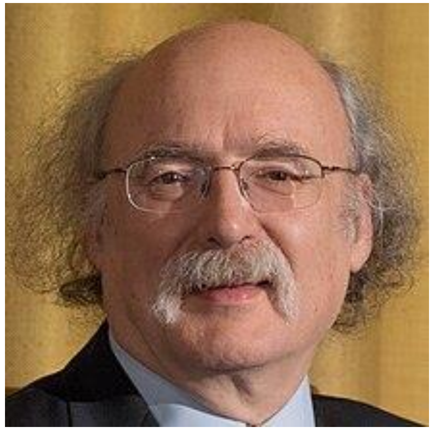
Anomalous = Zero *B*

Lattice Analogue to IQH

$$H = -t\sum_{\langle i,j\rangle} c_i^\dagger c_j - t_2 \sum_{\langle\langle i,j\rangle\rangle} e^{i\phi_{ij}} c_i^\dagger c_j + M\sum_i \xi_i c_i^\dagger c_i,$$



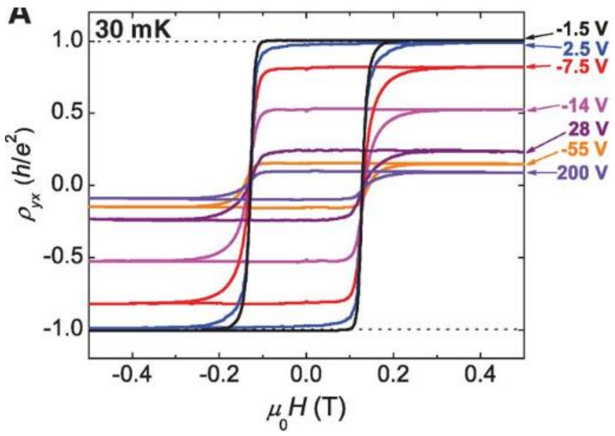




Duncan Haldane,
PRL **1988**, 61 (18).

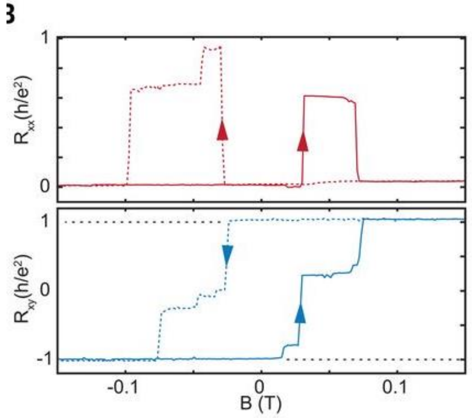
Integer Quantum Anomalous Hall Effect

Cr-doped $(Bi,Sb)_2Te_3$



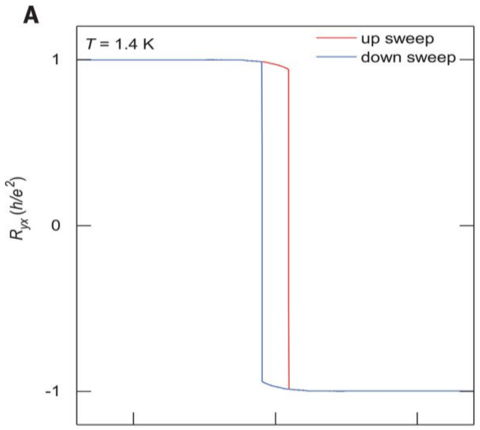
C. Chang et.al., Science **2013**

TBG aligned to h-BN



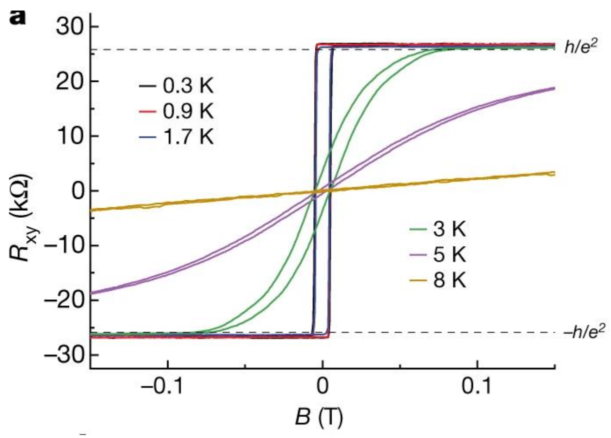
M. Serlin et.al., Science **2019**

5L-$MnBi_2Te_4$



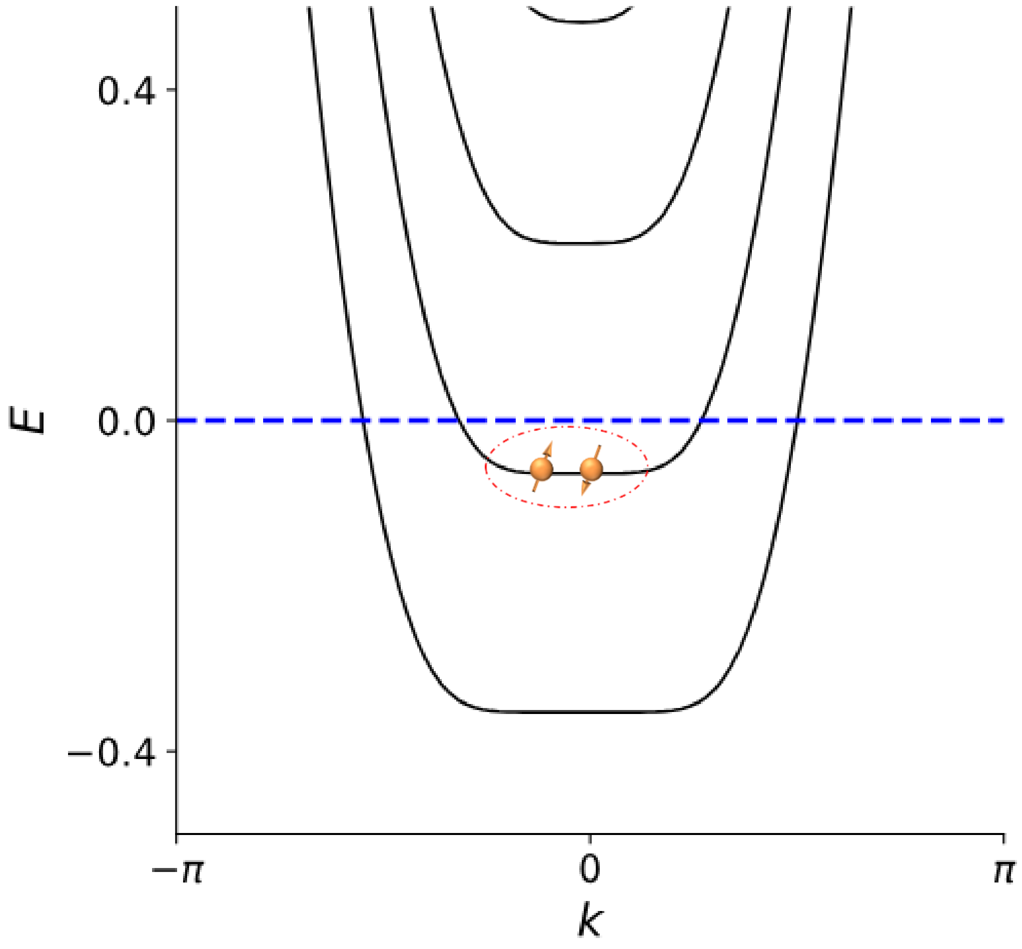
Y. Deng et.al., Science **2020**

AB-stacked $MoTe_2/WSe_2$



T. Li et.al., Nature **2021**

Fractional Quantum Hall Effect



Integer Quantum Hall
Integer Chern Insulator (ICI)
+
Electron Interactions
=
Gap Opening
at fractional filling factor
Fractional Chern Insulator (FCI)

Fractional Quantum Anomalous Hall Effect

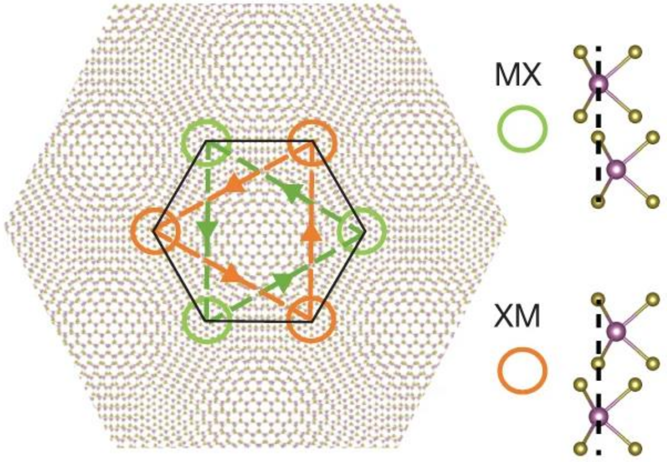
Anomalous = Zero B

Spontaneous TRB by Exchange Interactions (Ferromagnetism)

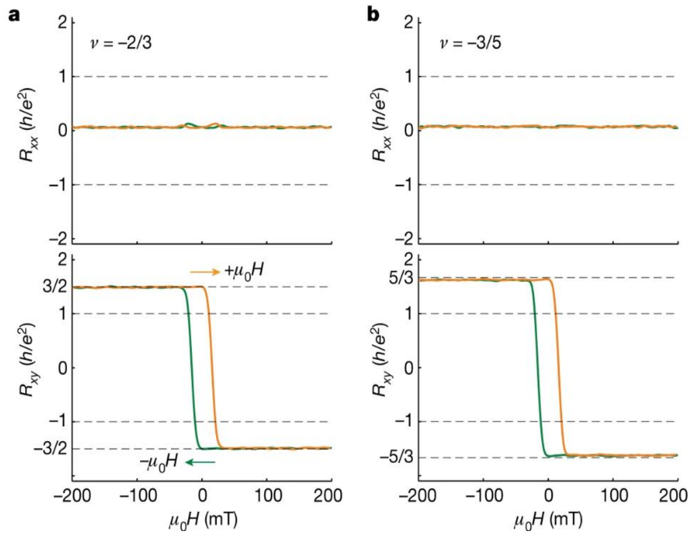
+

Strong Electron Correlations (Moiré Flat Band)

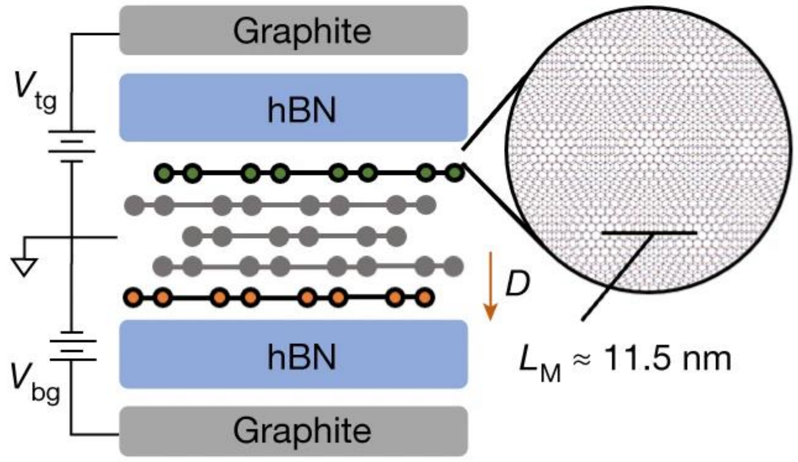
Twisted $MoTe_2$ Bilayer



J. Cai et.al., Nature **2023**
H. Park et.al., Nature **2023**



BN-proximitized ABC-Graphene



Z. Lu et.al., Nature **2024**

Interplay of topology and correlation in moiré materials leads to rich correlated topological phases!

Outline

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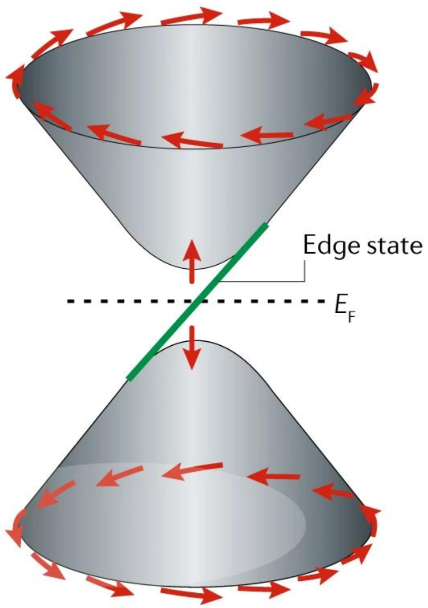
When FM Meets Topology in 2D Moirés

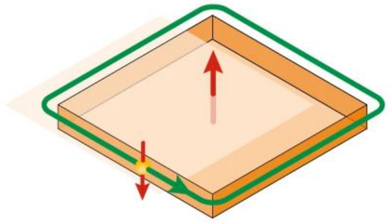
✓ In a **Chern insulator (CI)**, Chern number represents the **topology invariant** of the band structure under smooth deformations:

$$C = \frac{1}{2\pi}\int_{BZ} d^2k\ \Omega(k)$$

✓ Twisted $MoTe_2$ bilayer emerges with **moiré Chern ferromagnet**.



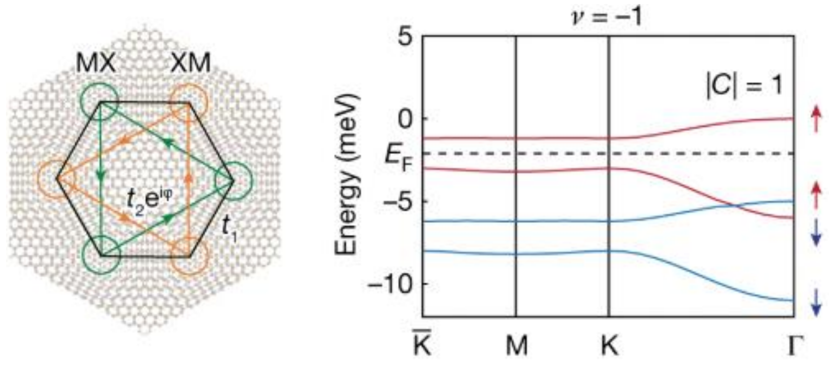
$$\sigma_{xy} = C\,\frac{e^2}{h}$$

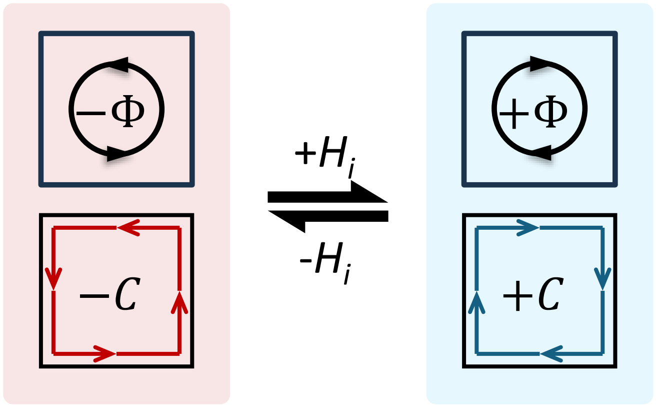


$$C = \Delta M\,\frac{\Phi_0}{\Delta\mu}$$

FM for CI: $\Omega(k) \neq -\Omega(-k) \rightarrow C \neq 0$

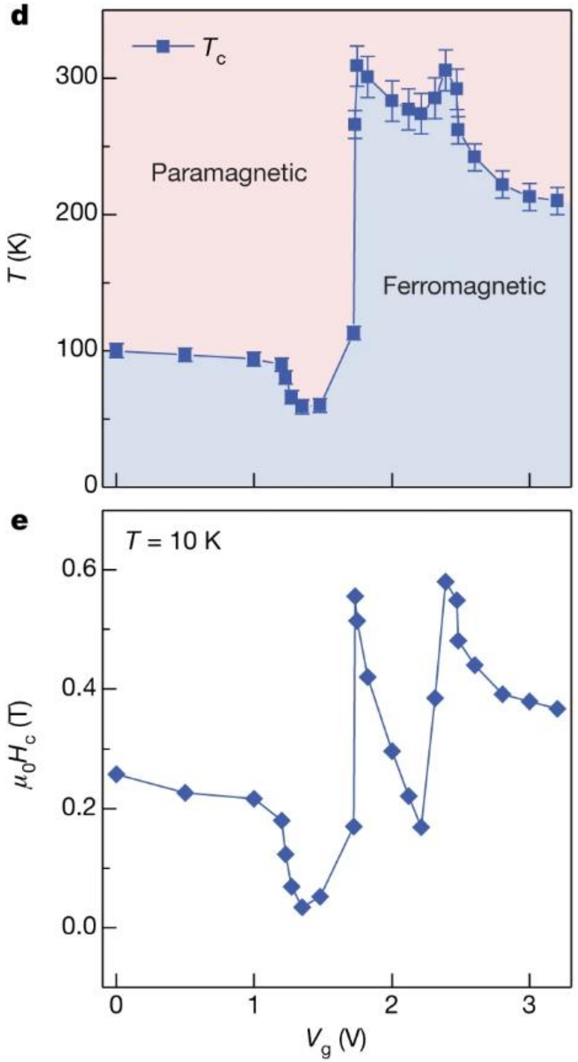
Nat Rev Phys 1, 126-143 (2019)
Rev. Mod. Phys. 95, 011002 (2023)





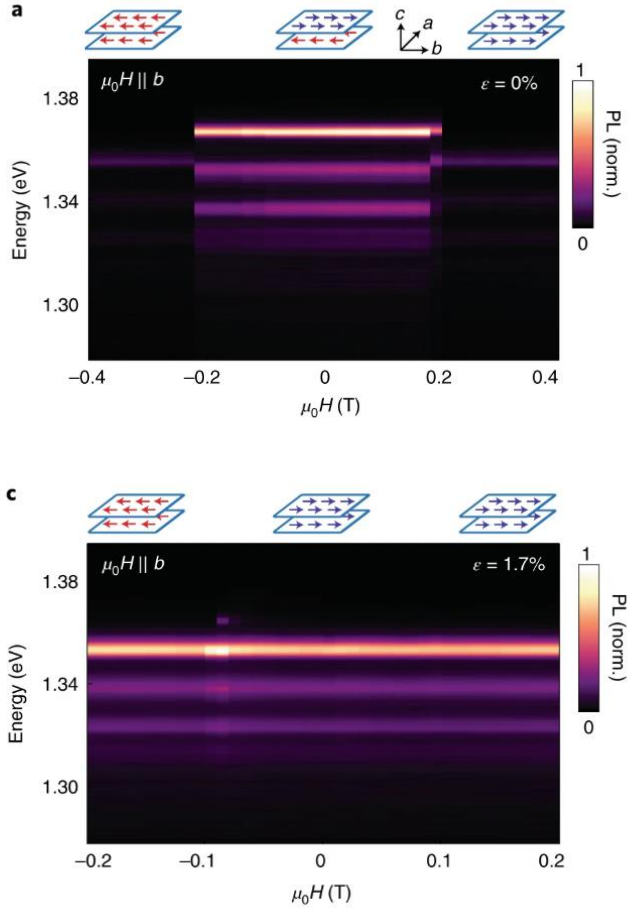
Available FM Control Techniques

Electrical Control
Fe_3GeTe_2



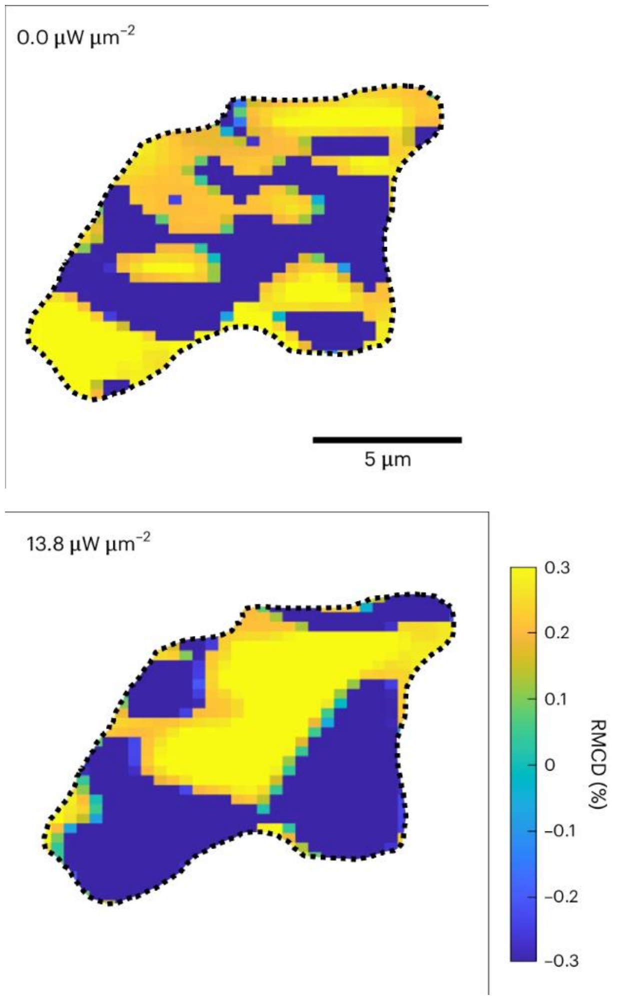
Nature 563, 94-99 (2018)

Mechanical Control
CrSBr



Nat. Nanotechnol. 17, 256-261 (2022)

Optical Control
Fe_3GeTe_2

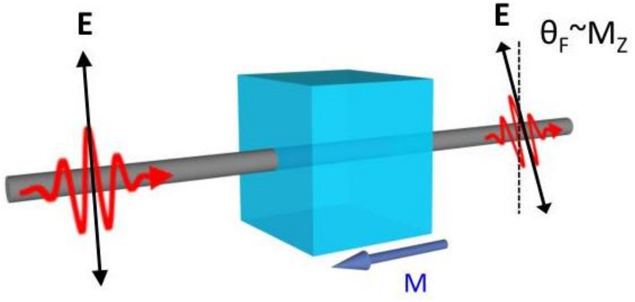


Nat. Phys. 21, 1118-1124 (2025)

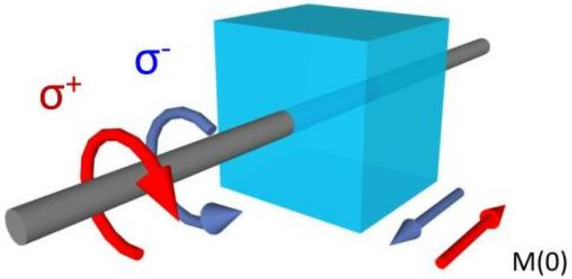
Current Optical FM Control Mechanisms

Inverse Faraday Effect (IFE):

$$H_{eff} = \varepsilon_0 \beta [E \times E^*] = \frac{2\beta}{c} I$$



Faraday effect



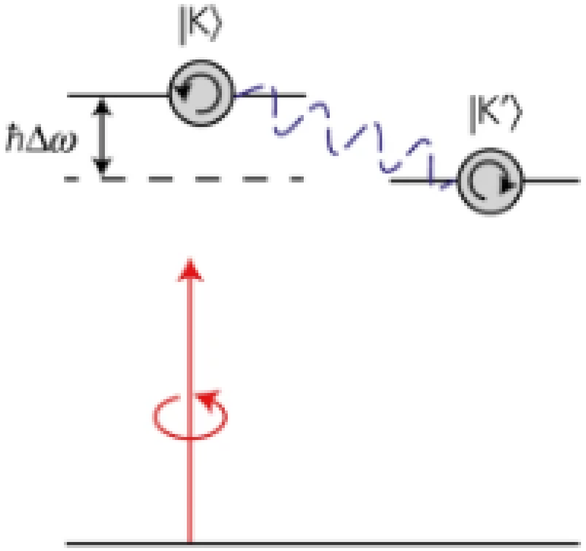
Inverse Faraday effect

Phys. Rev. Lett. 15, 190 (1965)

AC Stark Shift:
Oscillating electric field amplitude of the light shifts electronic energy levels.

$$\Delta E \propto \frac{|E|2}{\Delta}$$

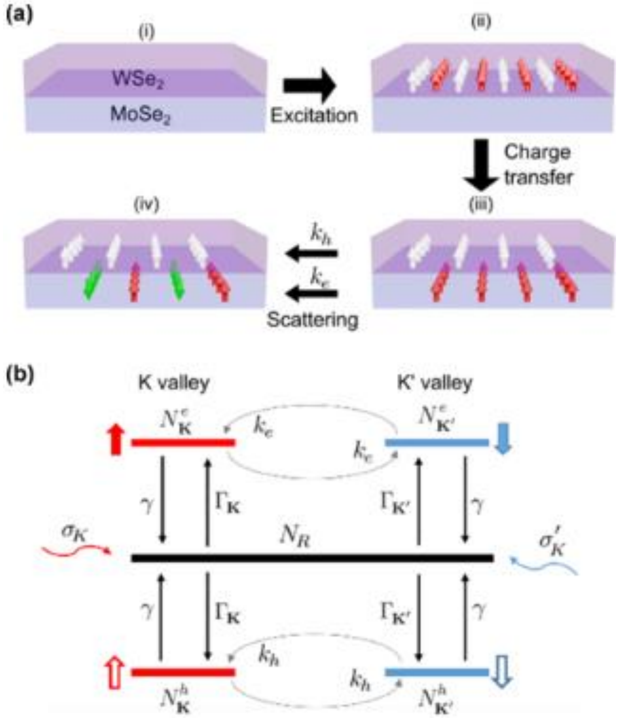
, where Δ is the detuning from resonance.



Nature Phys 13, 26-29 (2017)

Spin Pumping/spin injection:
Quantum selection rules build up a net spin population imbalance in the system.

$$B \propto -\frac{2(\gamma+\gamma_e+\gamma_h)}{(\gamma+2\gamma_e)(\gamma+2\gamma_h)}(\Gamma_K - \Gamma_{K'})$$



Phys. Rev. B 98, 241410(R) (2018)

Article

Optical control of integer and fractional Chern insulators

https://doi.org/10.1038/s41586-025-09777-3
Received: 24 April 2025
Accepted: 20 October 2025
Published online: 28 January 2026

William Holtzmann[1,5], Weijie Li[1,5], Eric Anderson[1], Jiaqi Cai[1], Heonjoon Park[1], Chaowei Hu[1], Takashi Taniguchi[2], Kenji Watanabe[3], Jiun-Haw Chu[1], Di Xiao[1,4], Ting Cao[4] & Xiaodong Xu[1,4]✉

Optical control of topology, particularly in the presence of electron correlations, is an interesting topic with broad scientific and technological impact[1–4]. Twisted

Article

Optical switching of a moiré Chern ferromagnet

https://doi.org/10.1038/s41586-025-10048-4
Received: 15 July 2025
Accepted: 12 December 2025
Published online: 28 January 2026

Xiangbin Cai[1,2,10], Haiyang Pan[1,2,10], Yuzhu Wang[2,10], Abdullah Rasmita[1,2], Shunshun Yang[1], Yan Zhao[1,2], Wei Wang[3], Ruihuan Duan[4], Ruihua He[1], Kenji Watanabe[5], Takashi Taniguchi[6], Zheng Liu[1,4], Jesús Zúñiga-Pérez[1,7], Bo Yang[2]✉ & Weibo Gao[1,2,8,9]✉

Optical control offers a non-contact, high-precision and ultrafast route to manipulating

Article

Optical control over topological Chern number in moiré materials

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Published online: 28 January 2026

O. Huber[1], K. Kuhlbrodt[1], E. Anderson[2], W. Li[2], K. Watanabe[3], T. Taniguchi[4], M. Kroner[1], X. Xu[2], A. Imamoğlu[1]✉ & T. Smoleński[5]✉

Controlling quantum matter with light offers a promising route to dynamically tune its many-body properties, ranging from band topology[1,2] to superconductivity[3].

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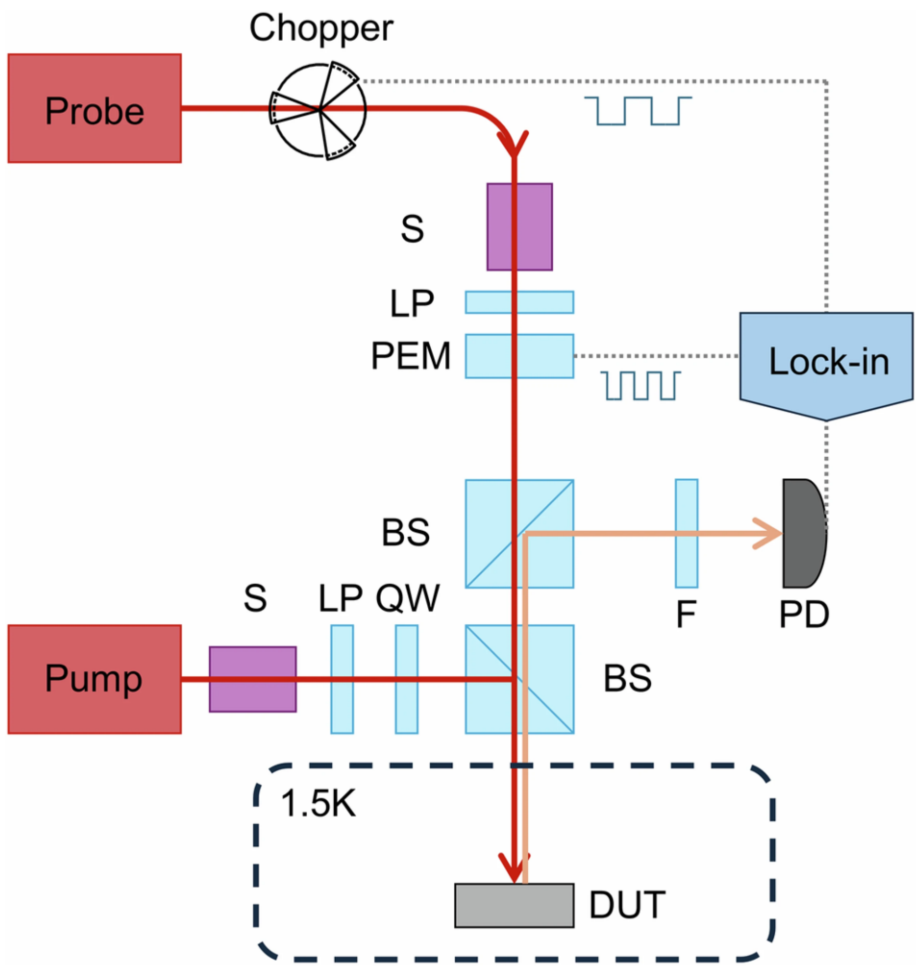
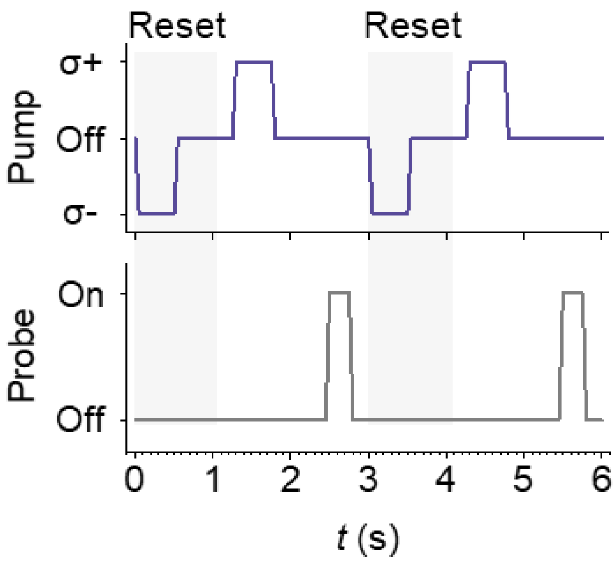
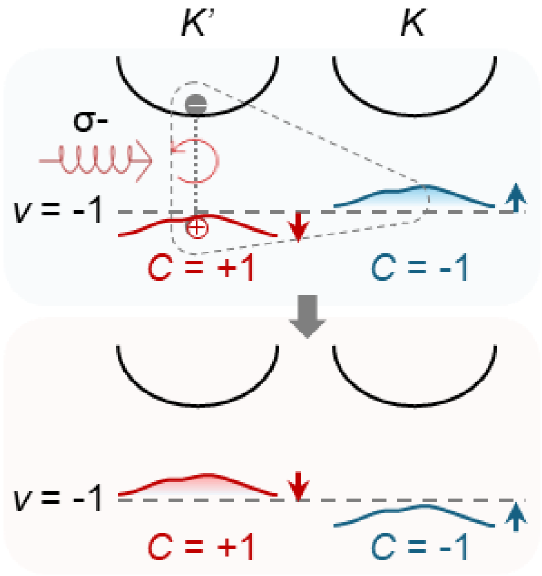
"Poor Man's" Pump-Probe FM Control



Xiangbin Cai et al., Nature 650, 580-584 (2026)

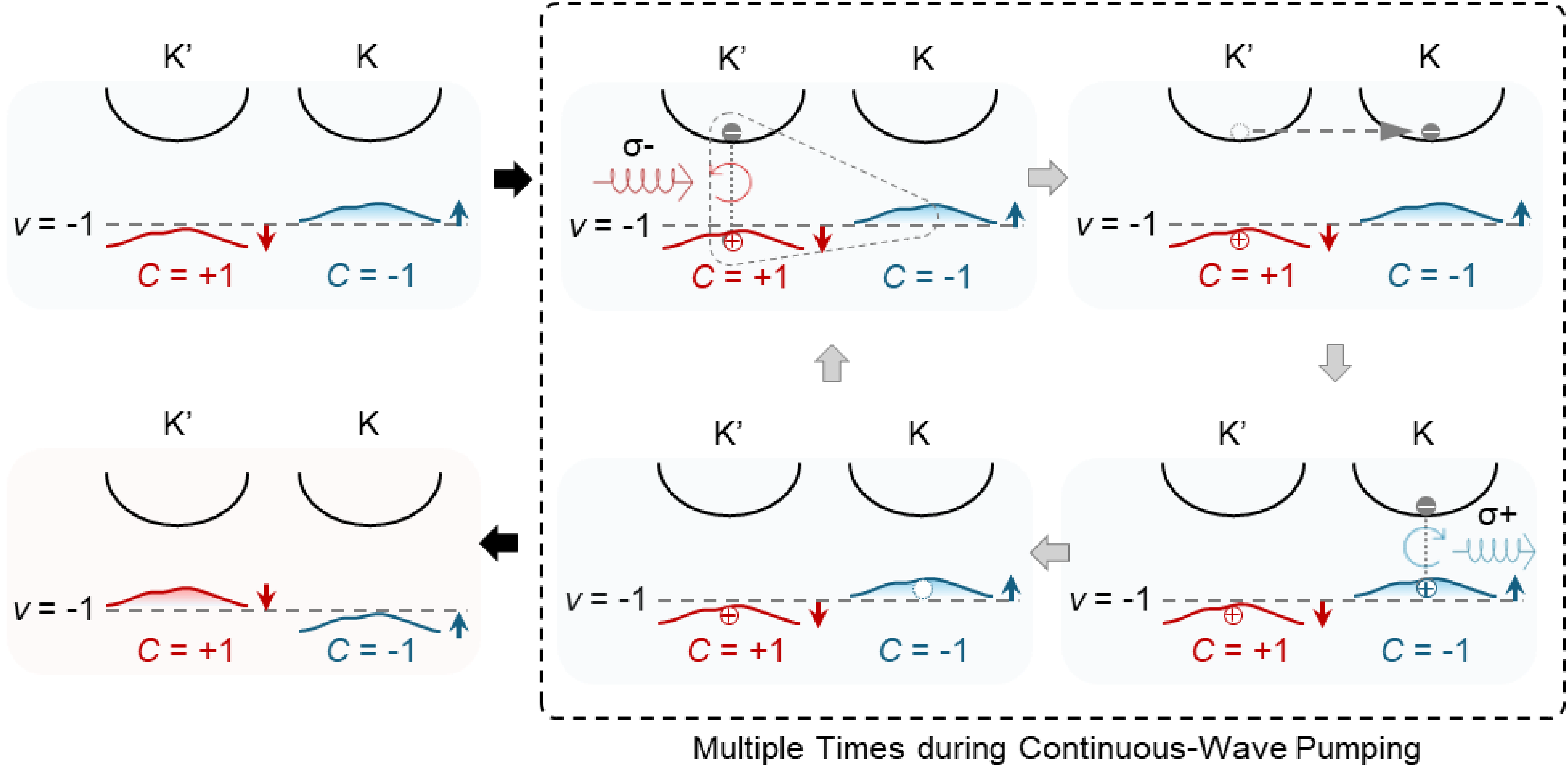




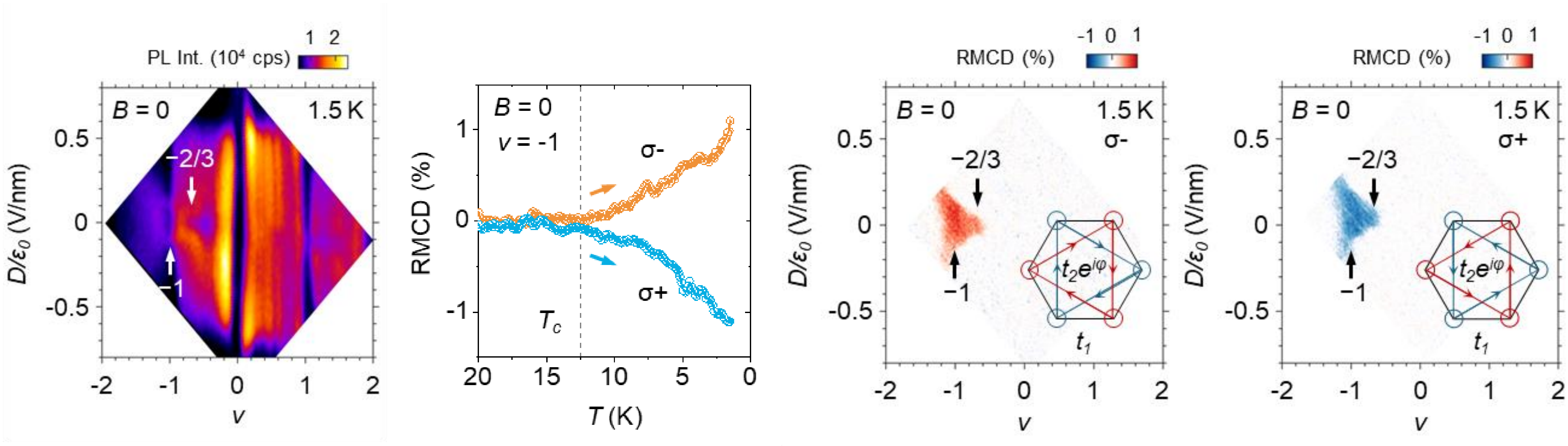
Each pump-probe cycle:

1. Gates ramp
2. Initialization with σ−
3. Dark time
4. Pump with σ+
5. Dark time
6. RMCD Probe.

Mechanism

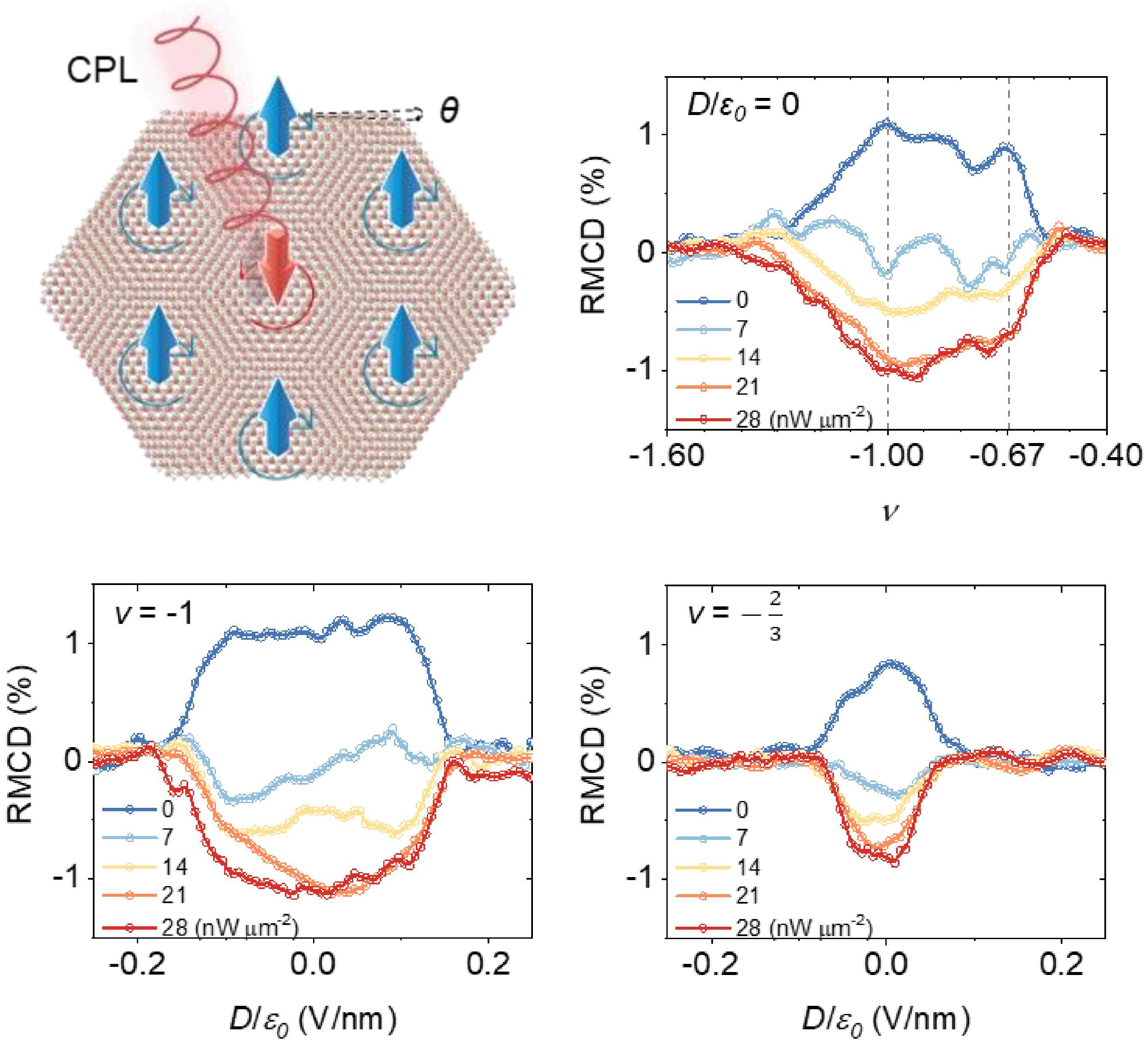

K'
K
v = -1
C = +1
C = -1
K'
K
σ-
v = -1
C = +1
C = -1
K'
K
v = -1
C = +1
C = -1
K'
K
σ+
v = -1
C = +1
C = -1
K'
K
v = -1
C = +1
C = -1
K'
K
v = -1
C = +1
C = -1
Multiple Times during Continuous-Wave Pumping

Zero-Field Initialization of Moiré Chern Ferromagnet



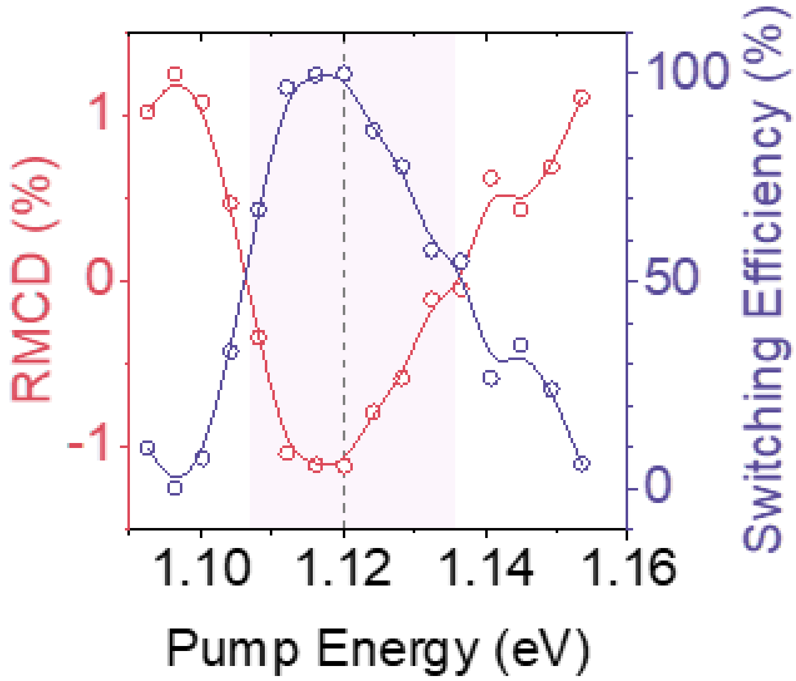
- Trion sensing of correlated gapped states
- CPL helicity dependence of moiré Chern ferromagnet orientations

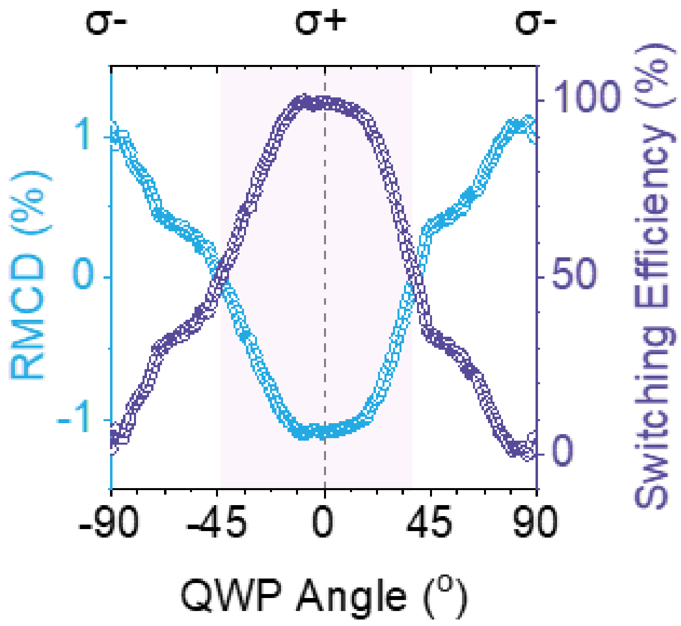
Direct Optical Switching of Correlated FM



- Direct switching of the magnetization state in MCFs below the Curie temperature
- Pump power, charge density and electric field dependence.

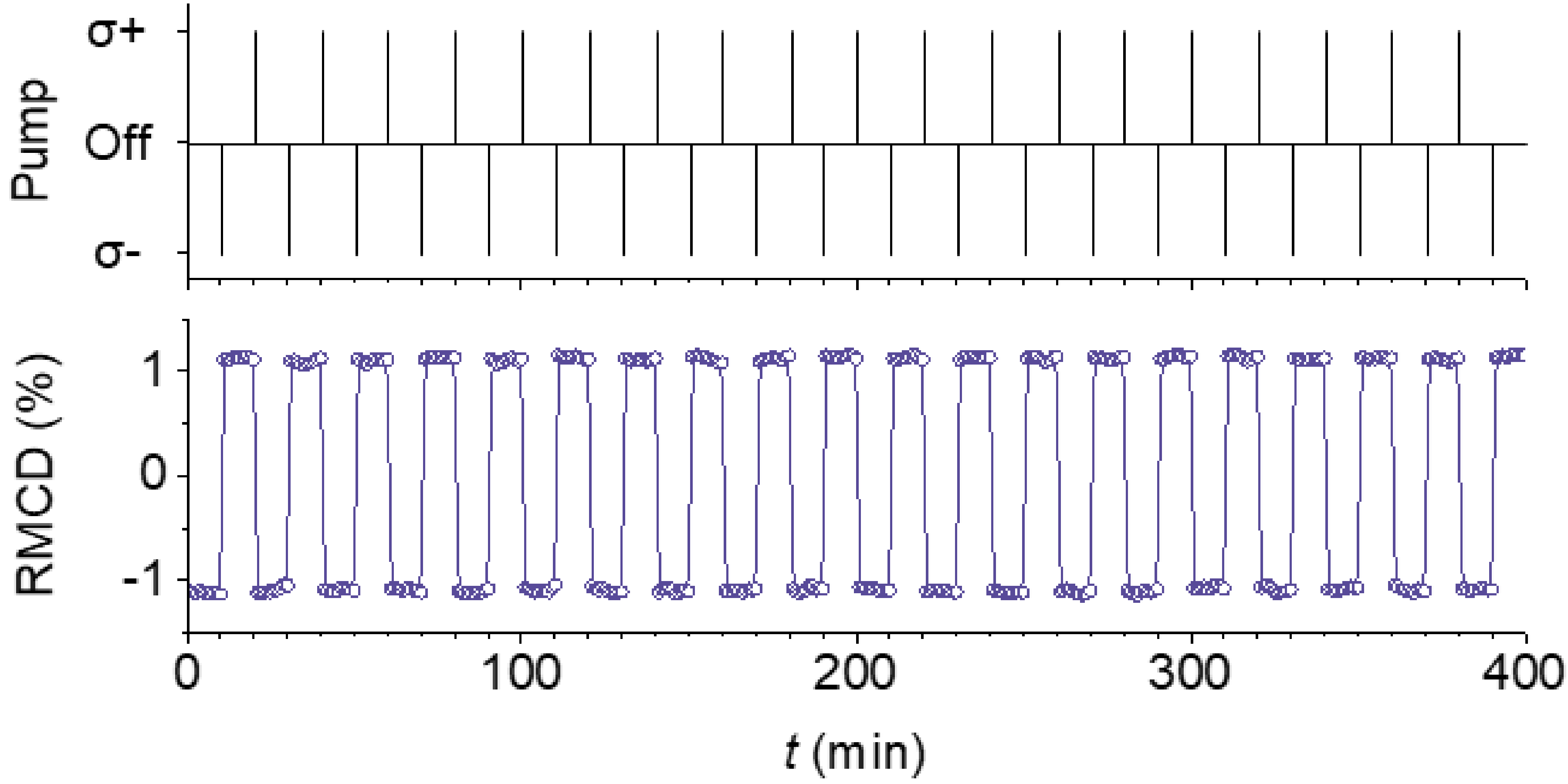
Sensitivity to BOTH Excitation Energy and Polarization





- Pump photon energy range matches the absorption energy of hole-doped twisted $MoTe_2$ bilayers
- Resonant linearly polarized light pumping suppresses FM, while no perturbation for linearly polarized HeNe laser

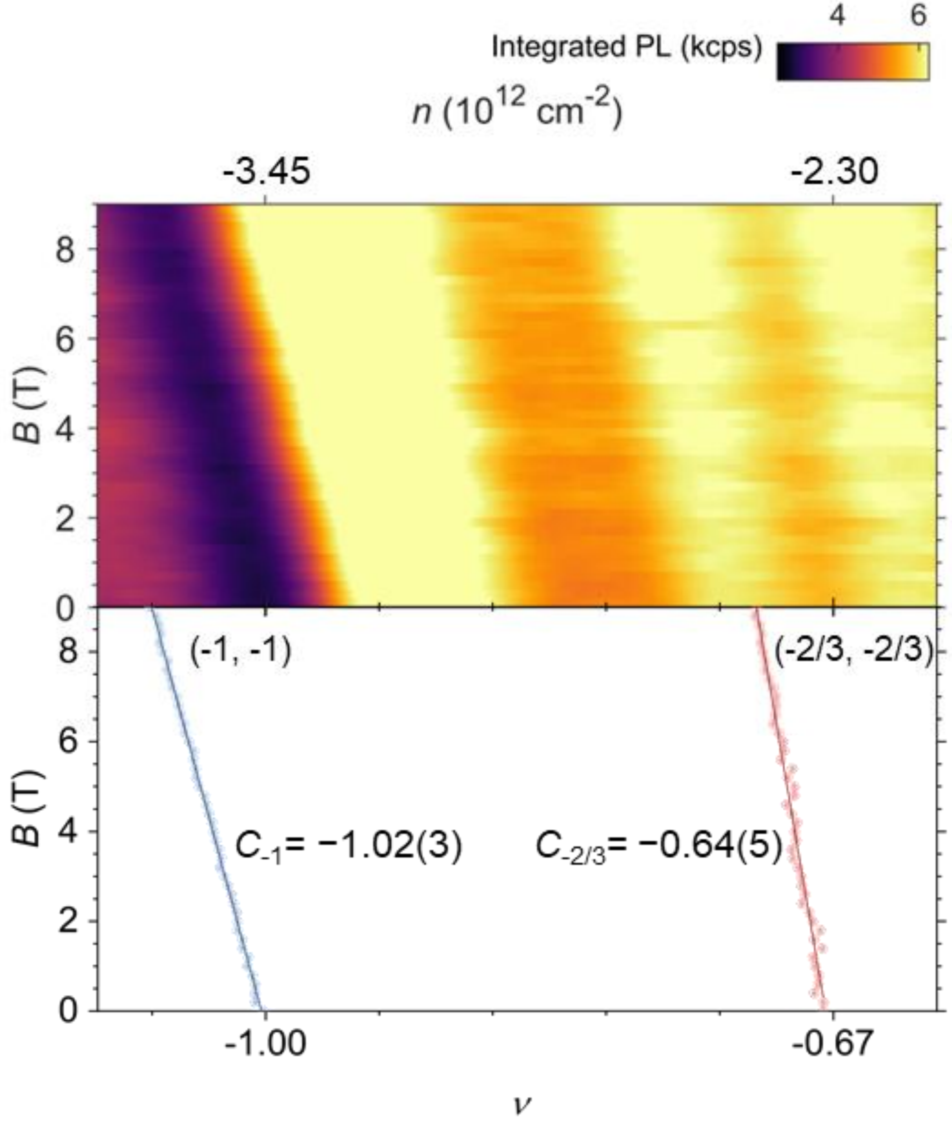
Robustness of Optical Phase Transition



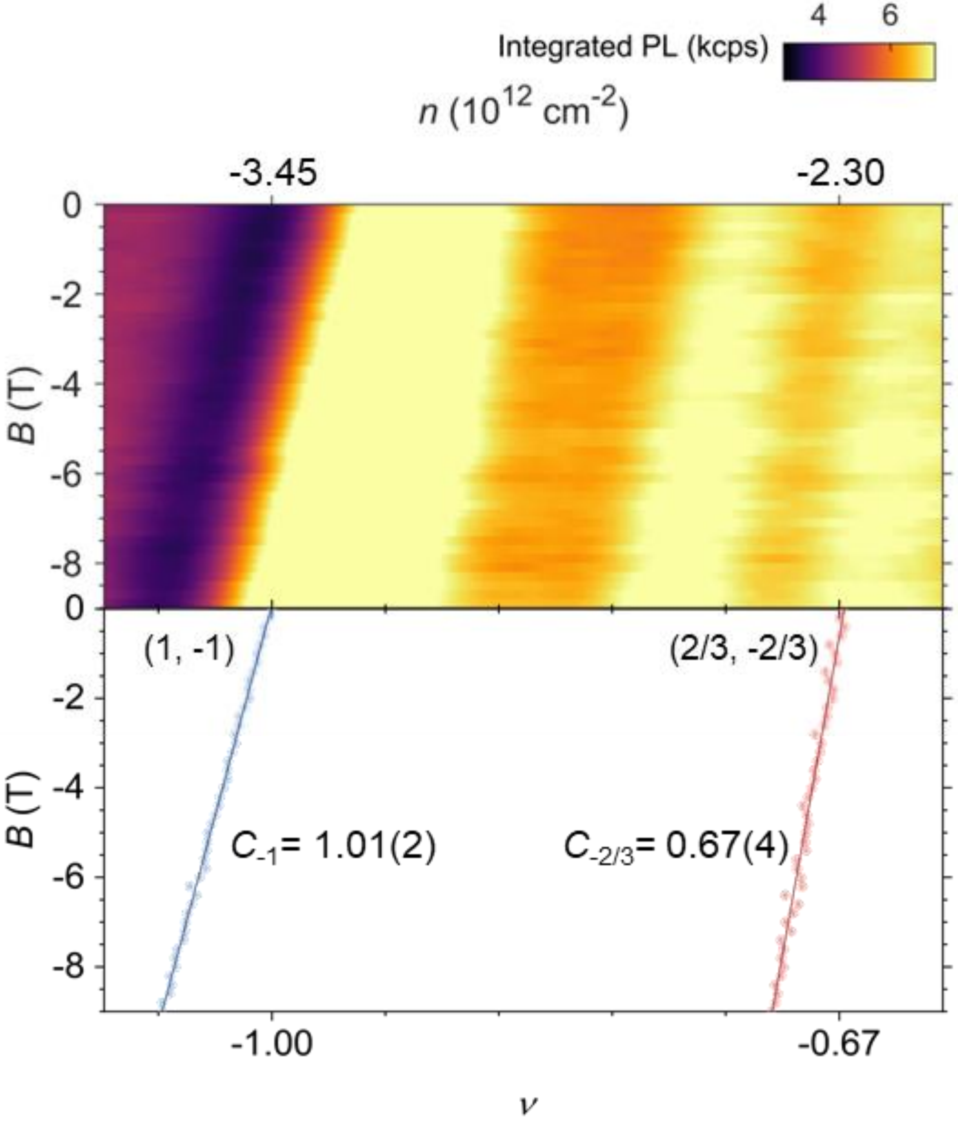
- Small critical pump powers for complete FM flipping: 20 nW μm^{-2} for $\nu = -1$ and 18 nW μm^{-2} for $\nu = -2/3$

Direct Optical Switching of Topological Invariant

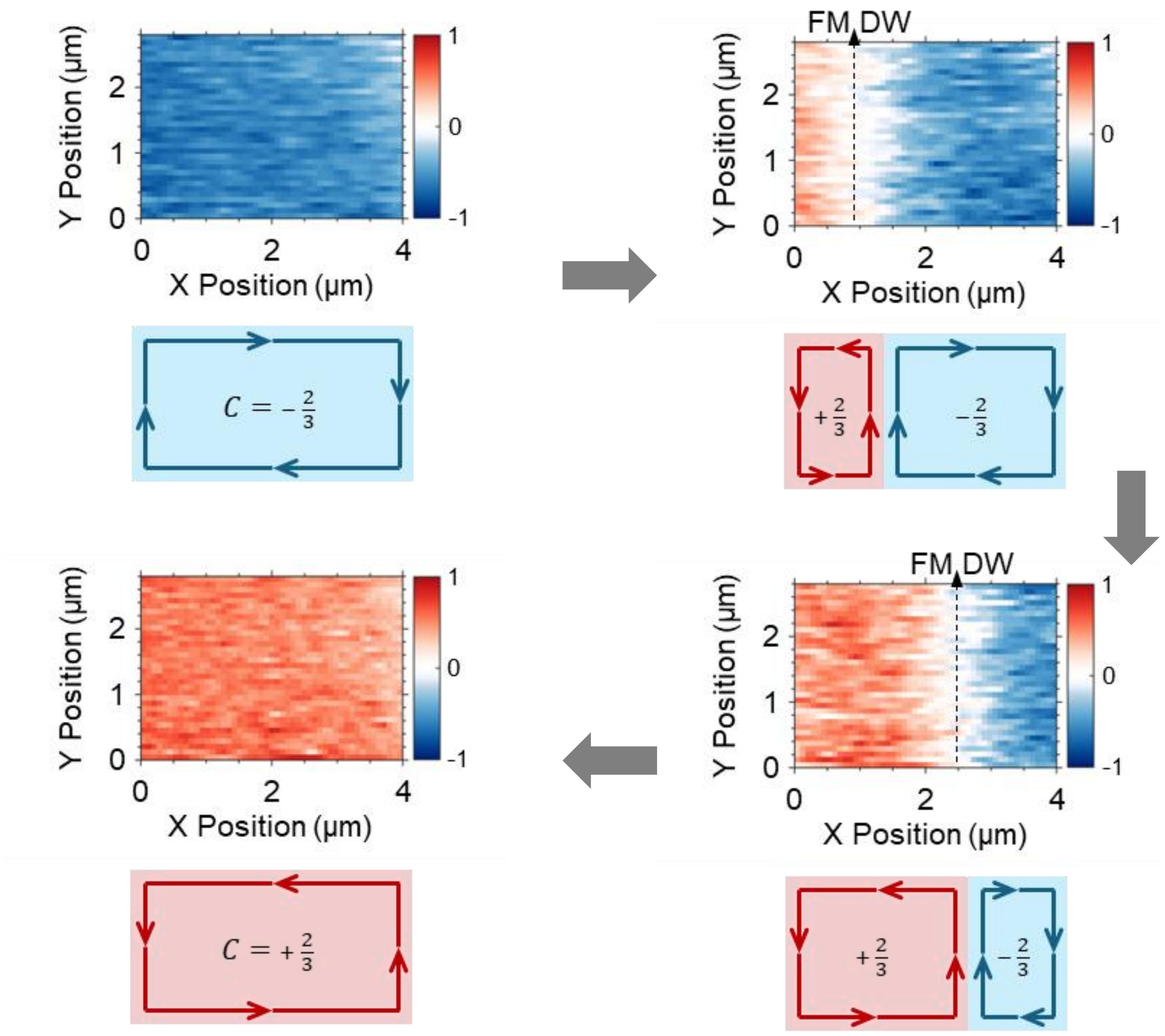
After σ+ excitation



After σ- excitation

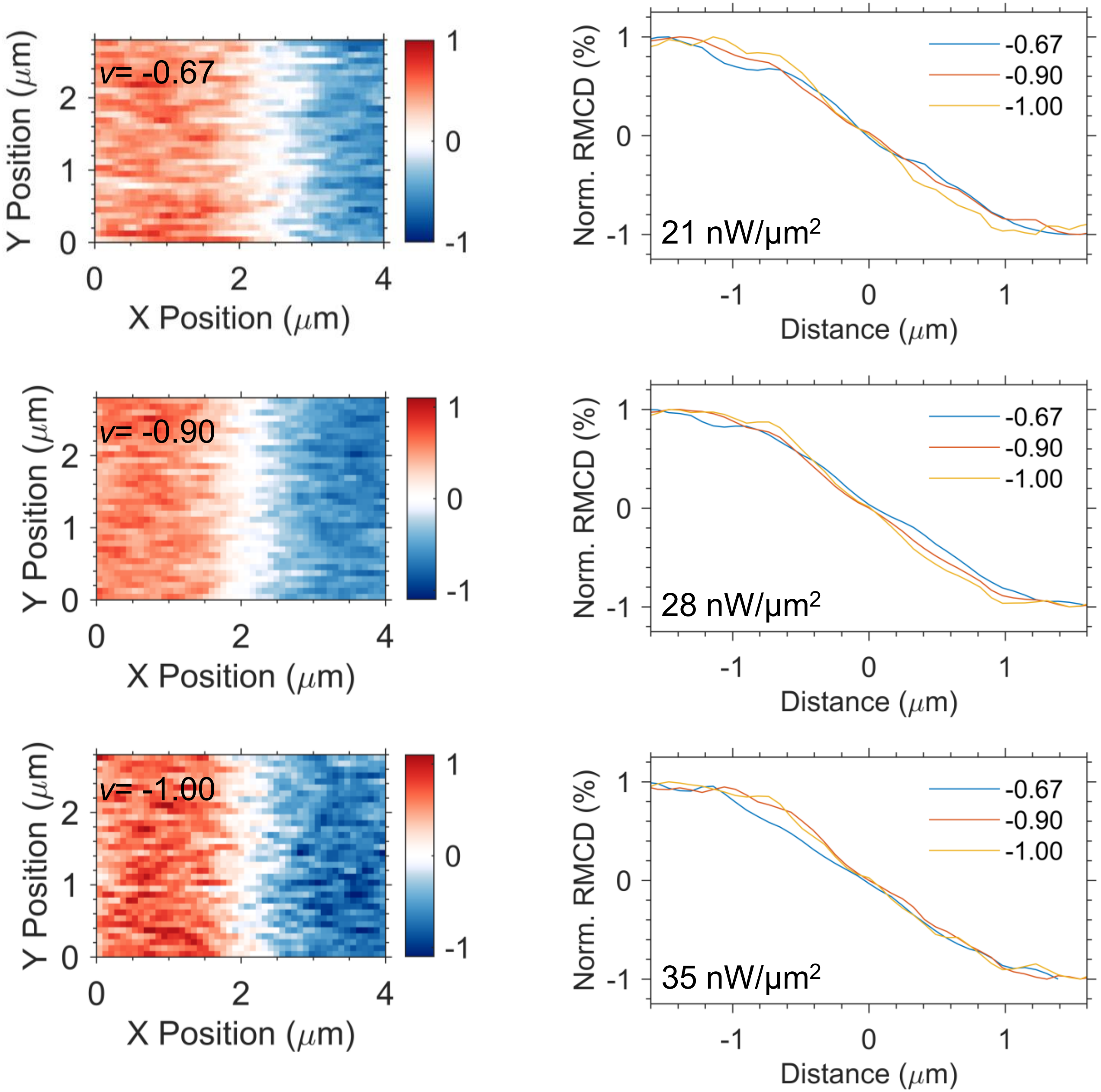


Domain Wall Control for Programmable Chern Junction



- High spatial precision for deterministic writing of FM domain walls using light at zero magnetic field
- Unique quantum phase with co-propagating chiral edge currents carrying fractional charges interacting with each other at the domain wall

Domain Wall Width



- ➢ Feasibility of FM domain-wall fabrication for varied filling states (FCI, metal and ICI)
- ➢ Beam-size-limited or spin-defect-pinned domain-wall widths

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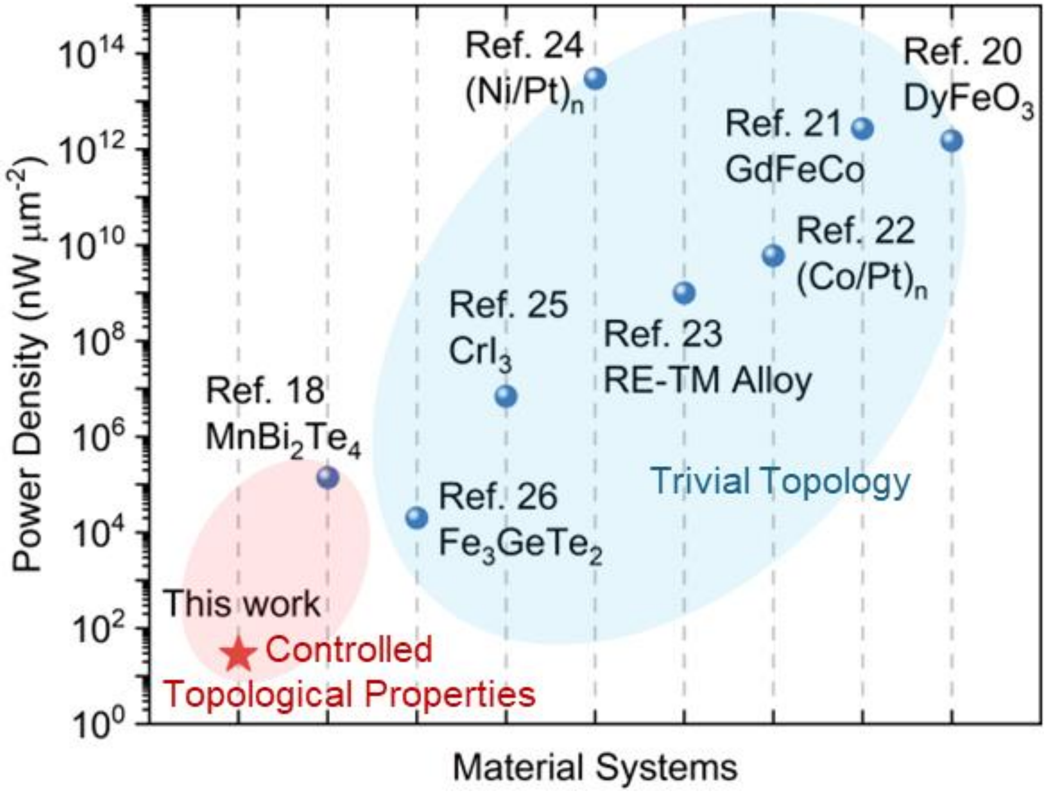
Take Home Message

✓ **Direct all-optical control of integer and fractional Chern magnets, with record-high optical FM switching efficiency**

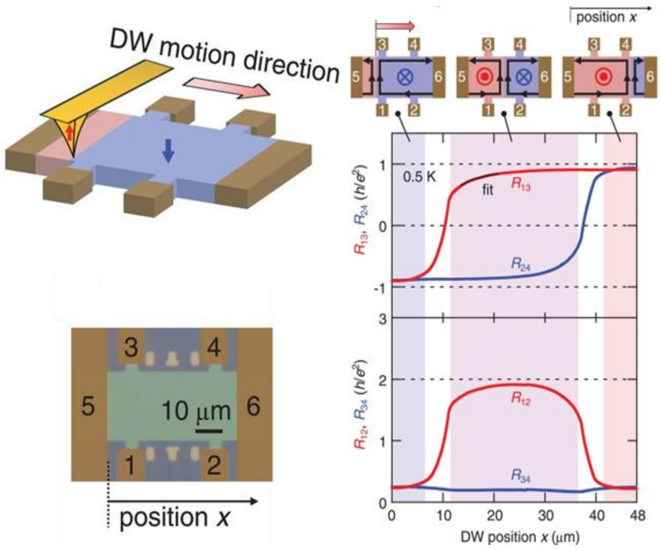
✓ **Optical FM switching mechanism in moiré Chern ferromagnets due to the spin-valley-locked flat Chern bands.**

✓ **Deterministic writing of FM domain walls for programmable Chern junctions and uncharted topological domain wall devices.**

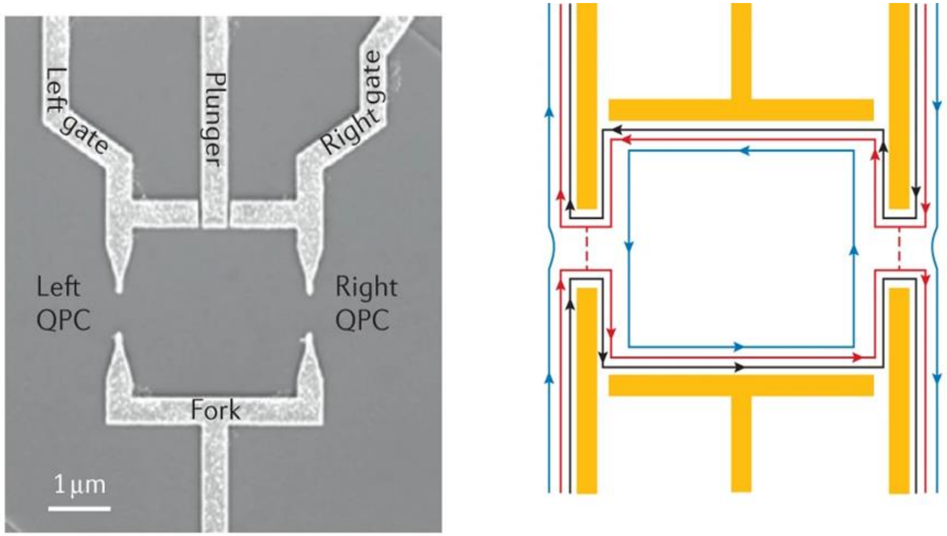


Outlook

- ➢ **Time-resolved data showing the switching speed.**
- ➢ **Transport (Hall) measurements to confirm Chern number reversal.**
- ➢ **Possible anyon interference in the DW by optically defined FP or MZ interferometers.**



Science 358, 1311-1314 (2017)



Nature Reviews Physics 3, 698-711 (2021)

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