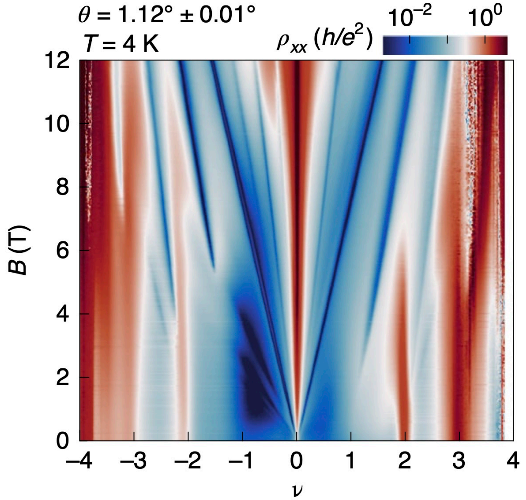


Spin-valley symmetry breaking and Chern insulators in twisted graphene structures

Louk Rademaker (Genève)

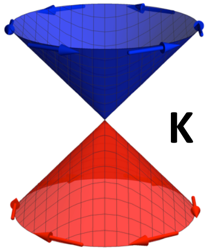
TYC Moiré-Twistronics workshop 2021

UNIVERSITÉ DE GENÈVE

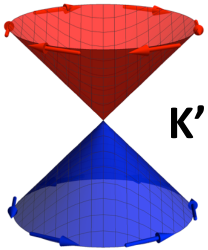
Topology in tBG

Topology = No Wannierization

Monolayer Graphene

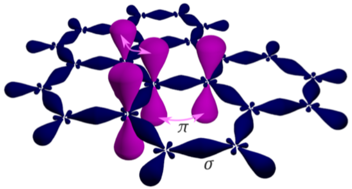


K

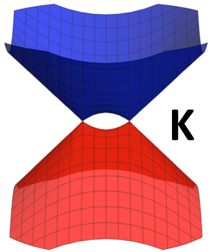


K'

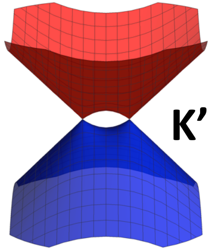
Both chiralities:



Twisted Bilayer Graphene



K

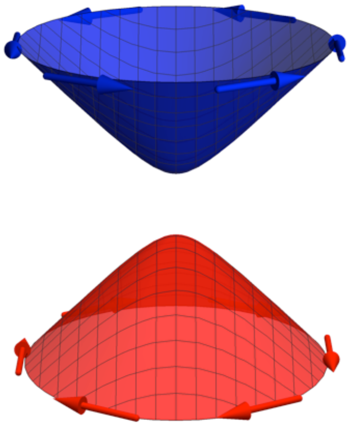


K'

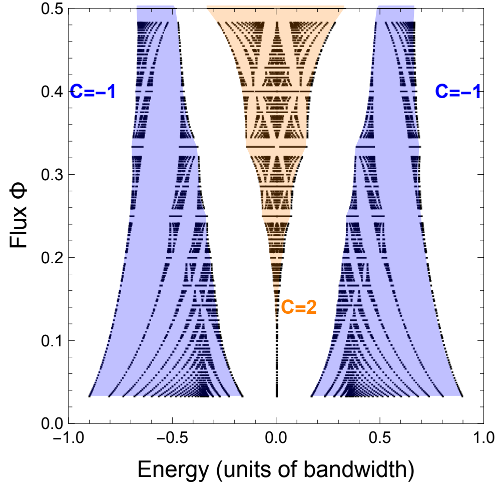
Same chirality per valley:
Fragile Topology

From fragile to robust topology

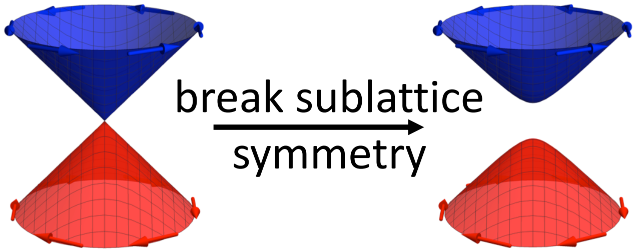
Sublattice symmetry breaking



Large magnetic field



Part I: Sublattice symmetry breaking



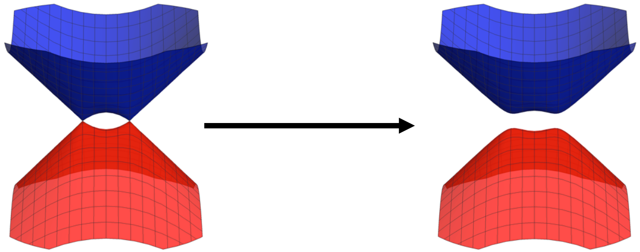
C = + ½

C = – ½

chirality promoted to **Chern numbers**

monolayer graphene has **C=0**

Twisted bilayer graphene:



C = + 1

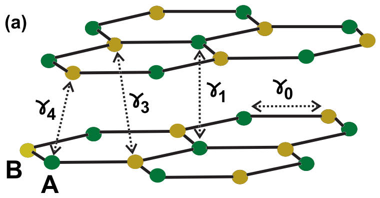
C = – 1

Nonzero Chern number **per valley**!

Twisted Mono-Bilayer Graphene (tMBG)

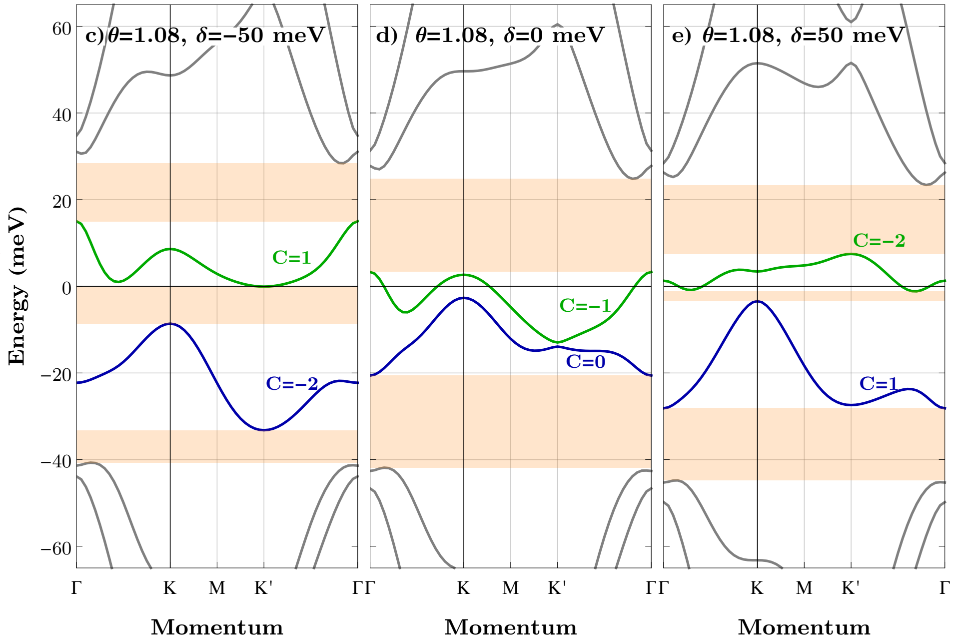
Twisted bilayer graphene
continuum model

$$H^{(\xi)} = \begin{pmatrix} H_1 & U^\dagger & \\ U & H_2 & \\ & & \end{pmatrix}$$

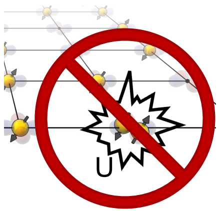


AB-stacked
bilayer graphene

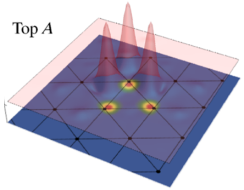
tMBG bandstructure per valley



Interactions in topological bands



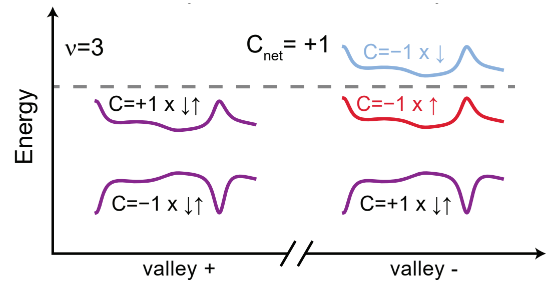
No Wannierization = **No Hubbard U**

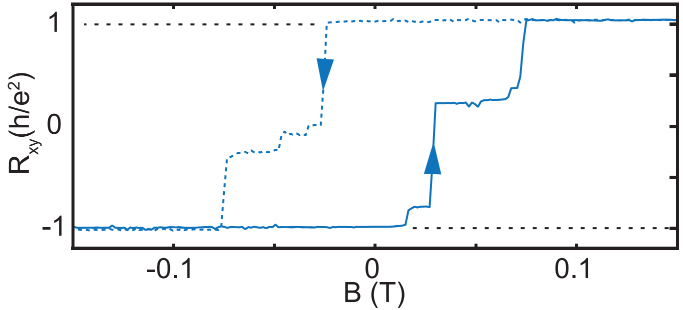


Nonlocal orbitals = **Ferromagnetic coupling** (*spin-valley Hund's*)

[Kang, Vafek, PRX '18, PRL '19]

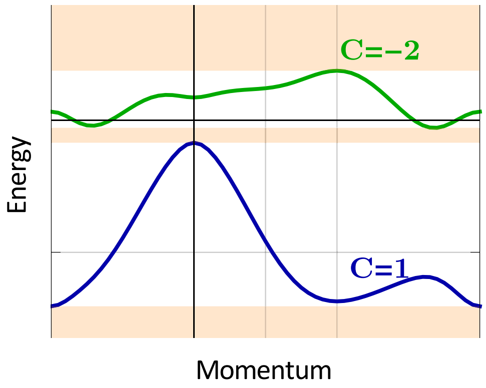
Spontaneous
spin/valley
polarization
[Serlin '20]



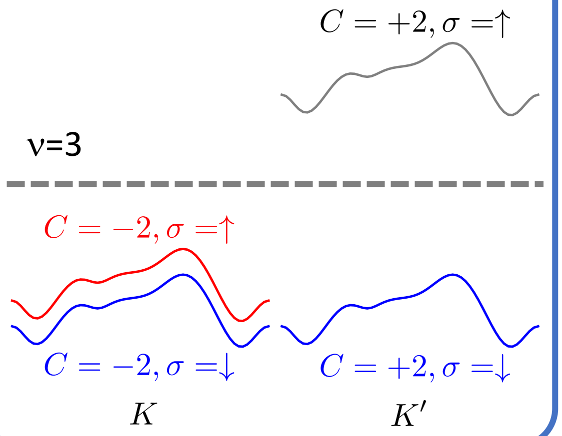


Quantum Anomalous Hall effect in tMBG

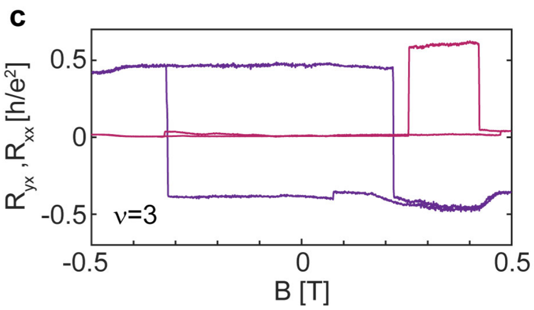
Twisted **mono-bilayer** graphene has **Chern** bands



Mean field theory predicts **Quantum Anomalous Hall**



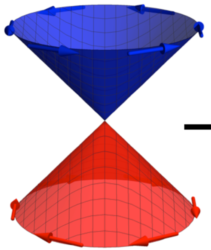
Confirmed in **experiment**



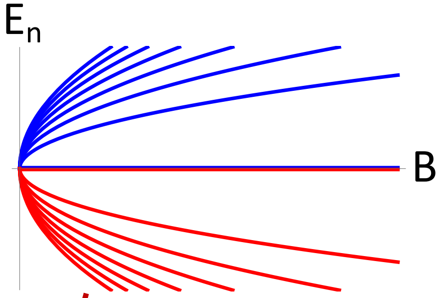
[**Rademaker**, Protopopov, Abanin, PRR 2020]

[Polshyn 2020]

Part II: Large magnetic field



replace p
by p - eA

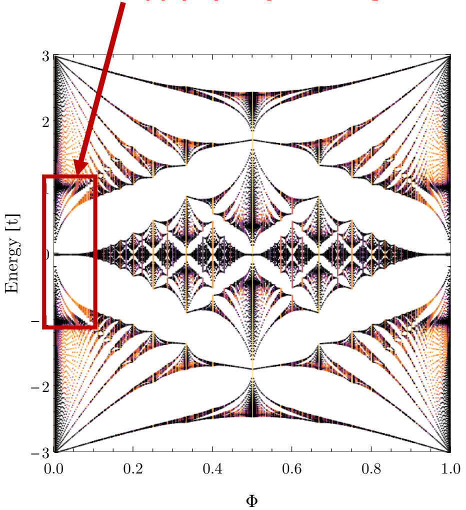


Dirac **Landau levels**

$$E_n \sim v_F \mathrm{sgn}(n)\sqrt{nB}$$

Each LL has **C = 2x2 = 4**

Including **lattice** gives
Hofstadter butterfly

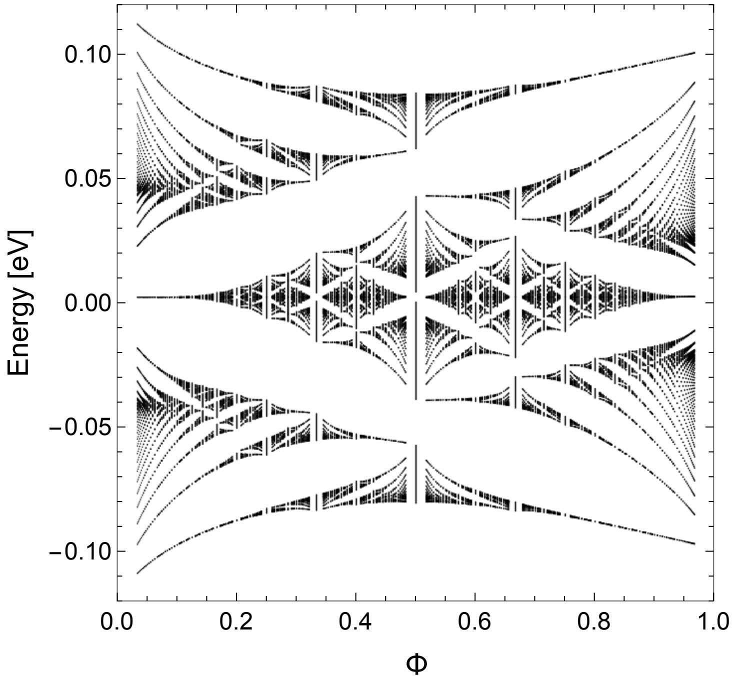


Hofstadter butterfly of tBG (1)

Continuum model = **Landau levels** $\varphi_{n,k_x}(k_y)$ + **Moiré interlayer coupling**

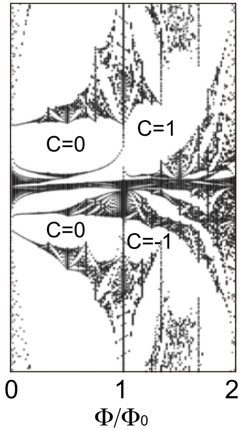
$$e^{-i\mathbf{Q}\cdot\mathbf{r}}$$

transitions n, k_x to $m, k_x + Q_x$

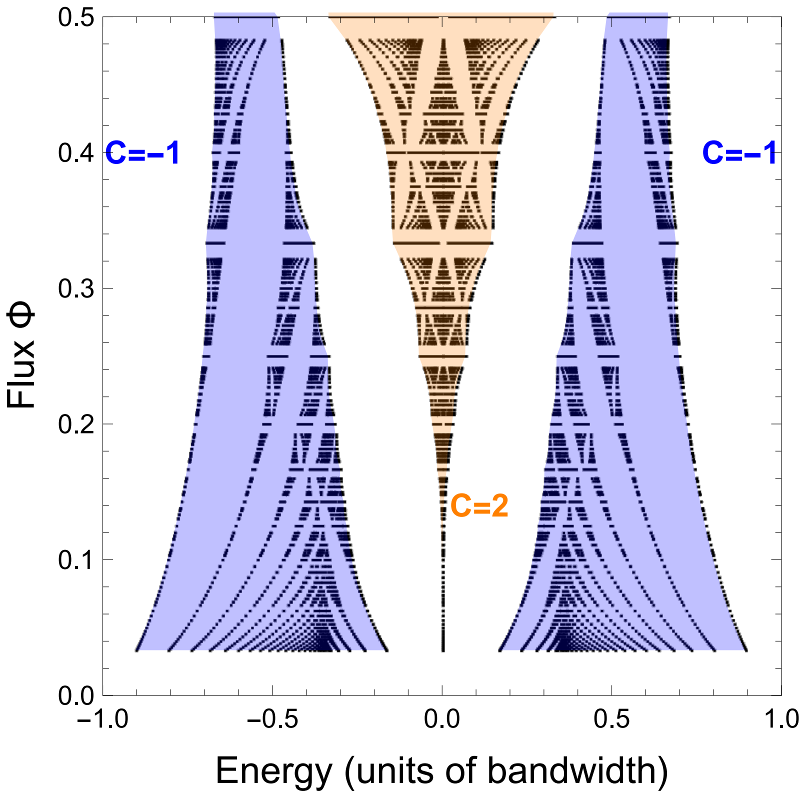


Note: butterfly is completely **different** when computed using **tight-binding** models

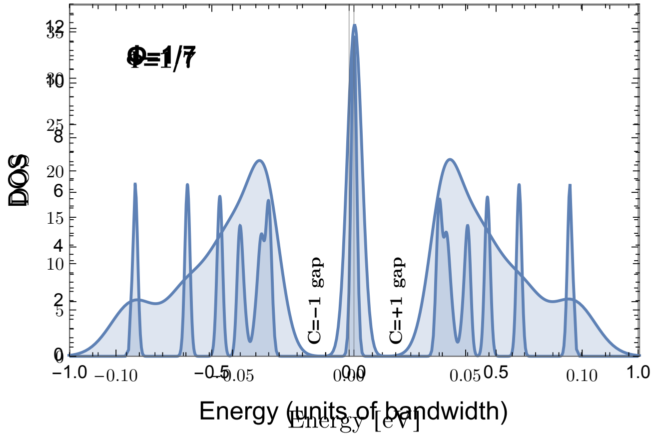
[Lian PRB '20]



Hofstadter butterfly of tBG (2)



Disorder and temperature **spread** the Hofstadter subbands



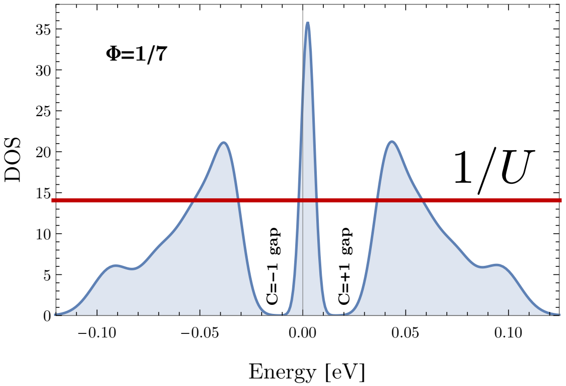
Splits the butterfly in **three subbands** with C=-1, +2, -1 **per spin/valley**

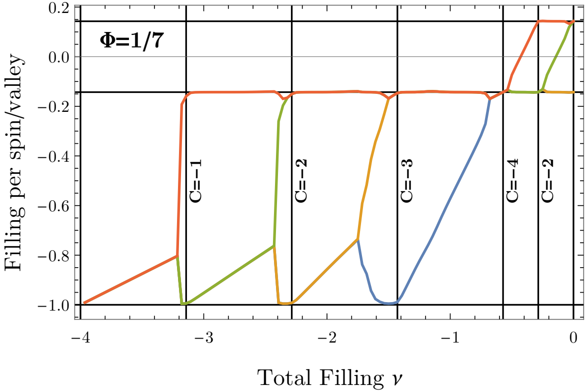
Hofstadter subband ferromagnetism

Spin/valley polarized states can be understood with the **Stoner** mechanism

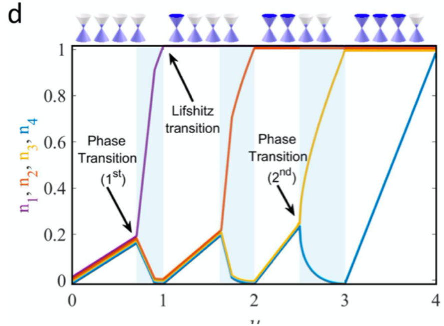
Polarization happens when $U\rho(\mu) = 1$

DOS per spin/valley



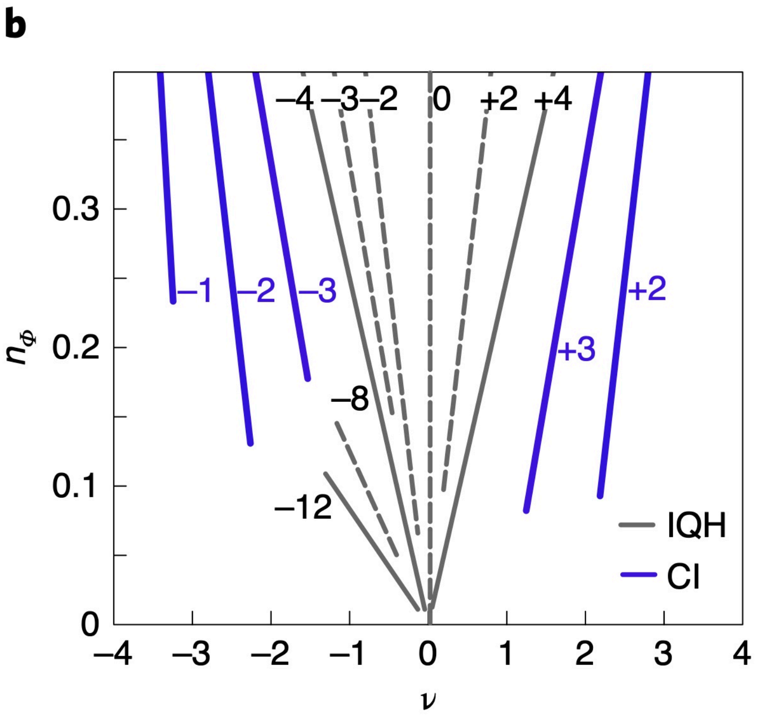


Sequence of Chern insulators with
C=-1, -2, -3, -4, -2, 0

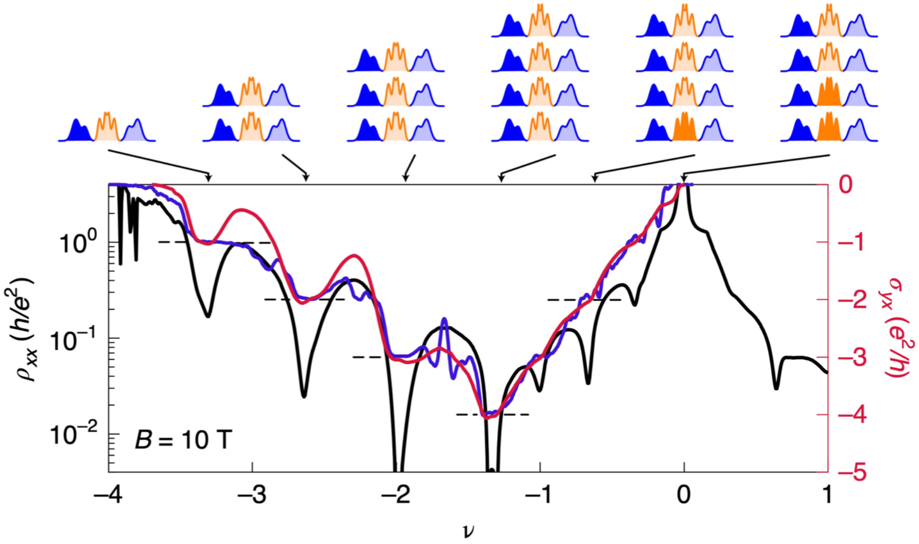


[Zondiner 2020]

Spin-valley polarization in experiments

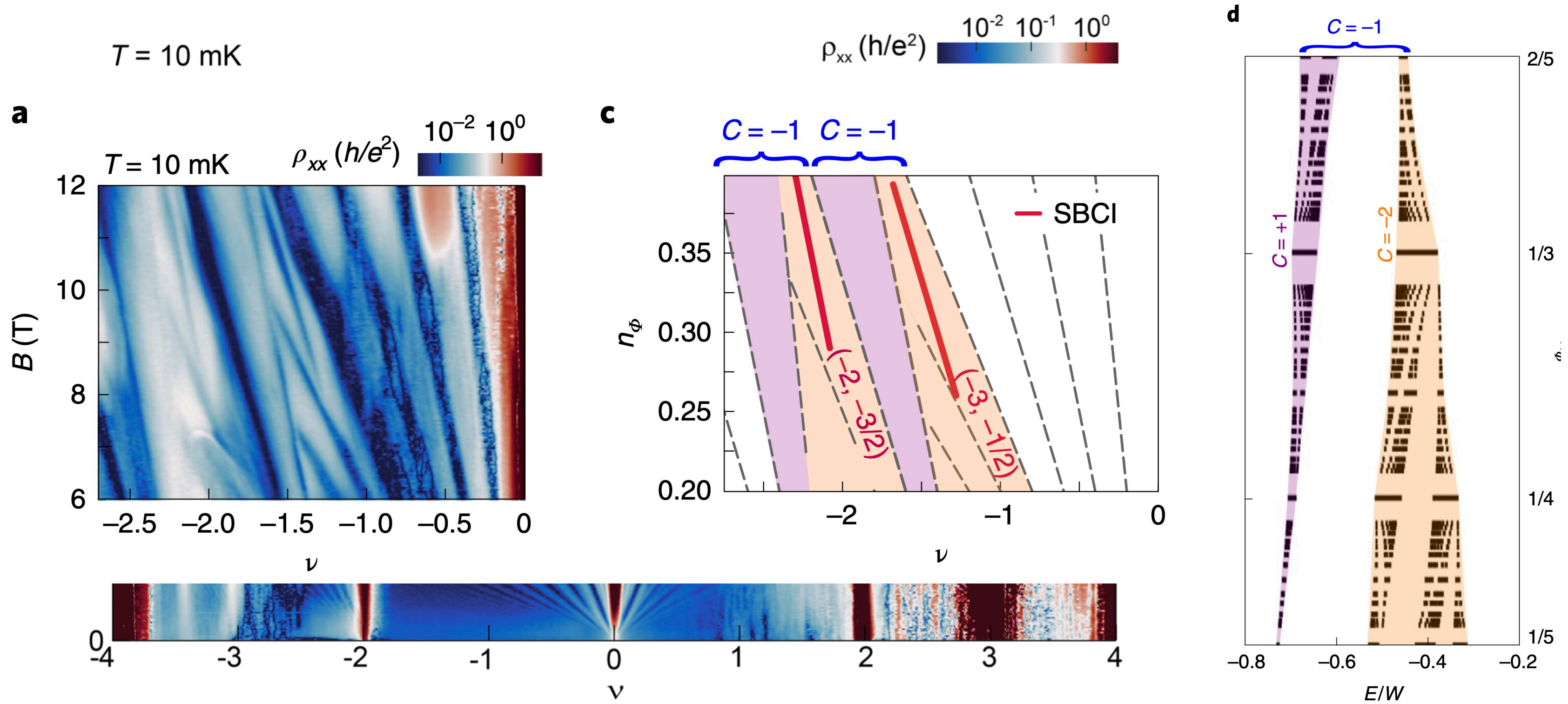


Spontaneous spin/valley **polarization** of the Hofstadter subbands

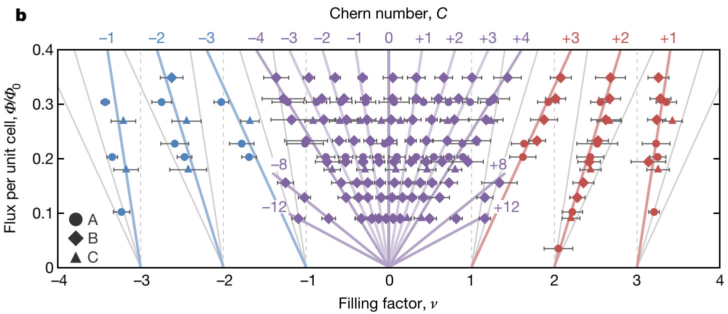


Ref: Saito, Ge, **Rademaker**, et al., Nature Phys. 2021

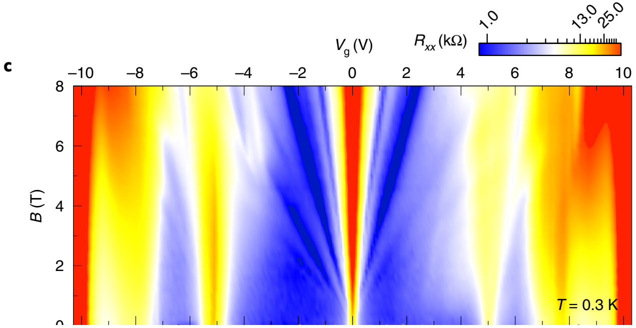
Symmetry-broken Chern Insulators



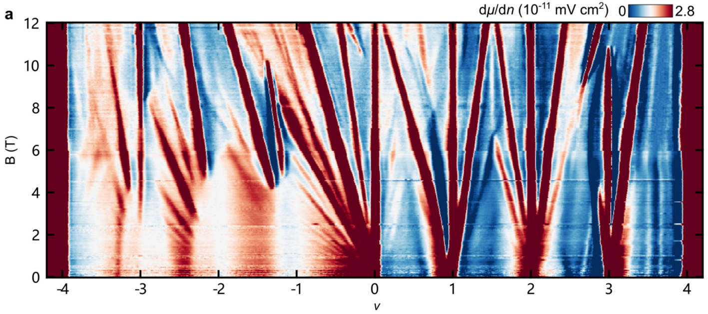
Spin-valley polarization throughout



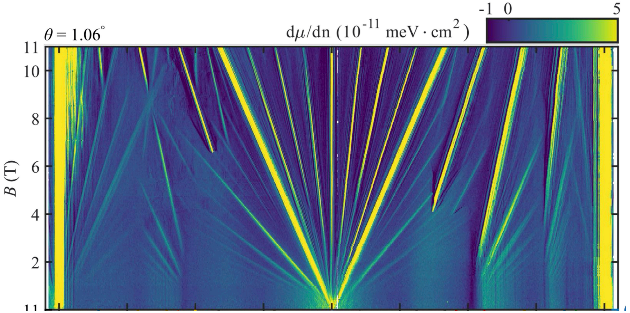
Nuckolls, Nature 2020



Wu, Nat. Mater. 2021



Xie, arXiv:2107.10854



Yu, arXiv:2108.00009

Collaborators

Santa Barbara

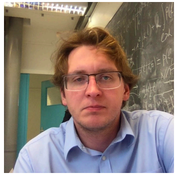
Yu Saito

Andrea Young

Jingyuan Ge

Kenji Watanabe, Takashi Taniguchi (Tsukuba)

Geneva



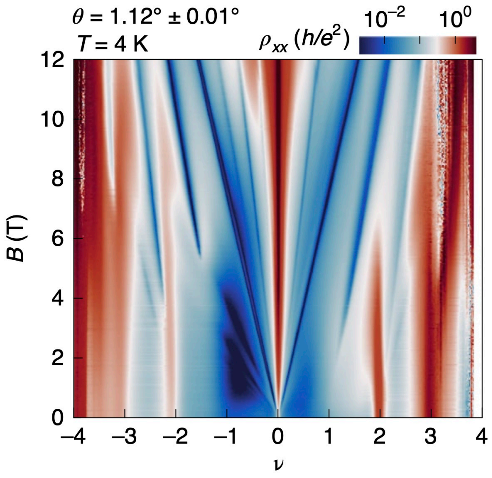
Ivan Protopopov

Dima Abanin

Santiago de Chile

Paula Mellado

Conclusions



tMBG and **tBG in a field** have topological bands

Spin/valley **polarization** causes **correlated Chern insulators**

Can be described by simple **Hartree-Fock** theory

Outlook:

Maybe twisted graphene is **not** similar to **cuprates/heavy fermions**

Correlated states are **not Mott** but ”simple” **Stoner ferromagnets**…