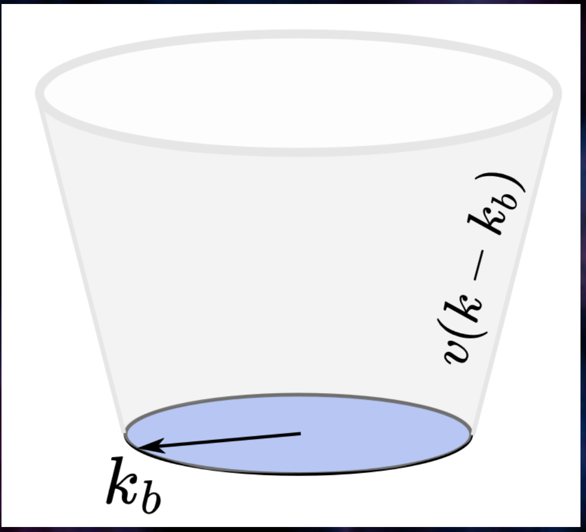
Interacting Models For Moire Matter
FCI in Rhombohedral Graphene
and
The Berry Trashcan



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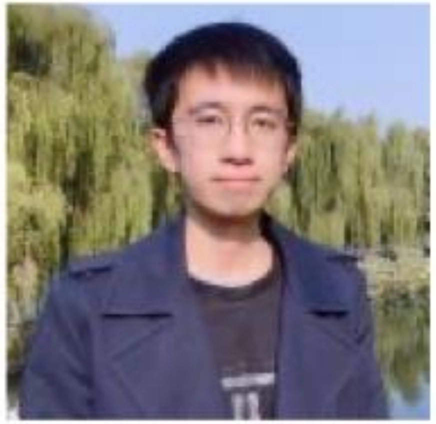
Nicolas Regnault



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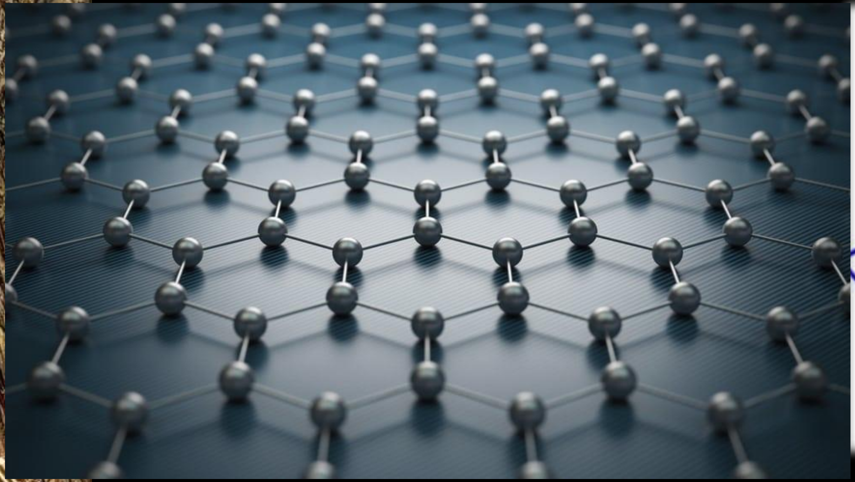
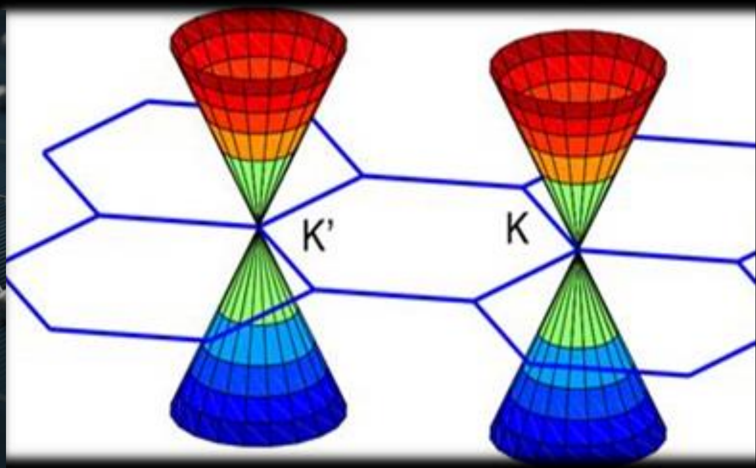
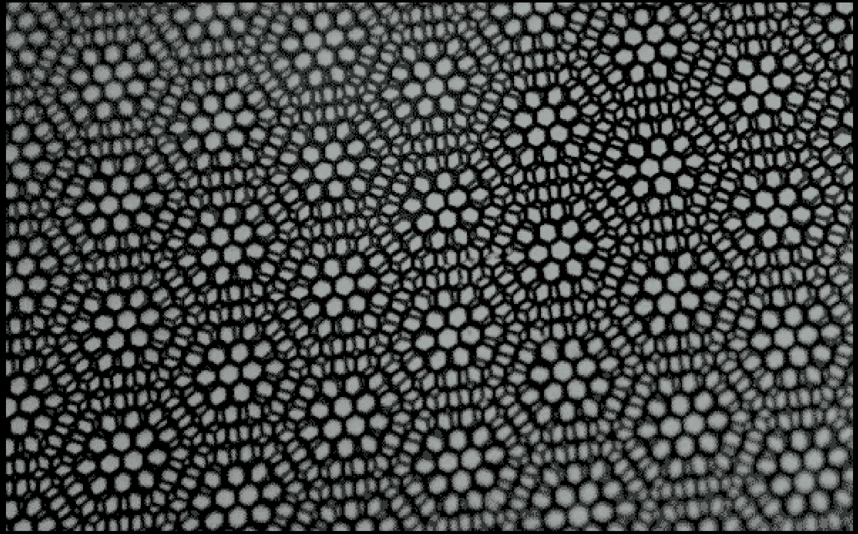
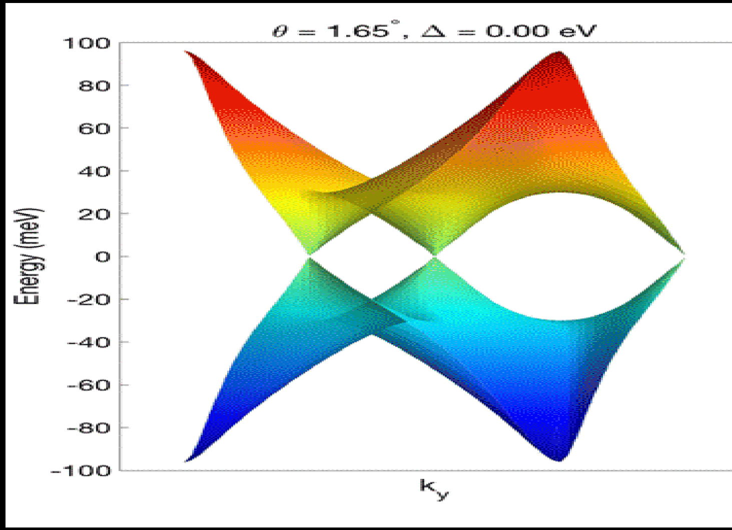




Moire

Pandora's box and the infinite phase space of engineered materials



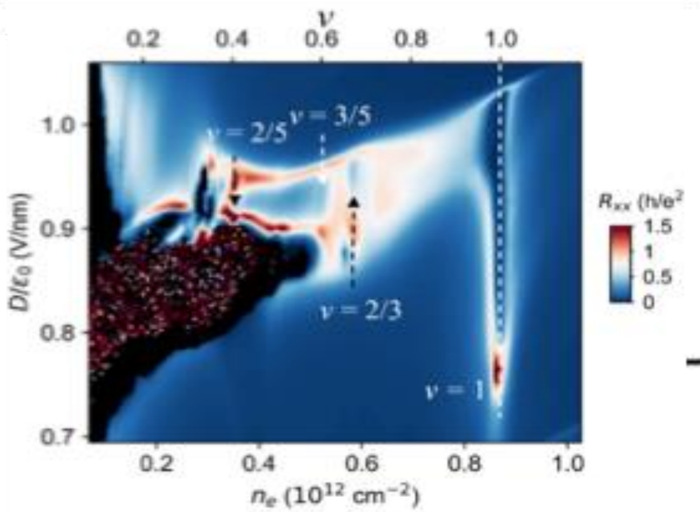


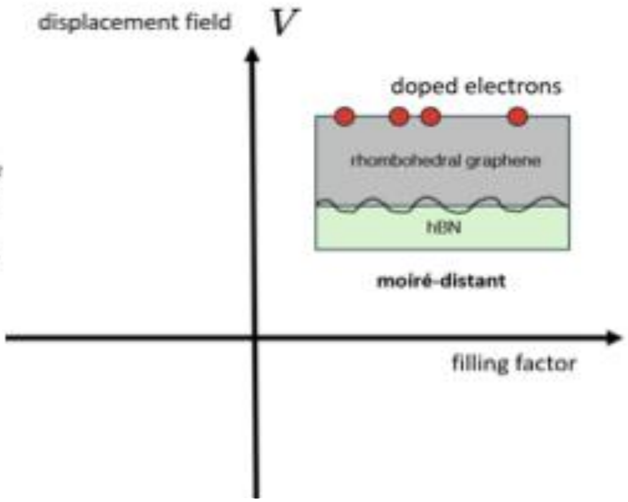
Fractional quantum anomalous Hall effect in multilayer graphene

Zhengguang Lu, Tonghang Han, Yuxuan Yao, Aidan P. Reddy, Jixiang Yang, Junseok Seo, Kenji Watanabe, Takashi Taniguchi, Liang Fu & Long Ju

Nature 626, 759–764 (2024) | Cite this article

$\theta = 0.77$ R5G/hBN





With moiré:

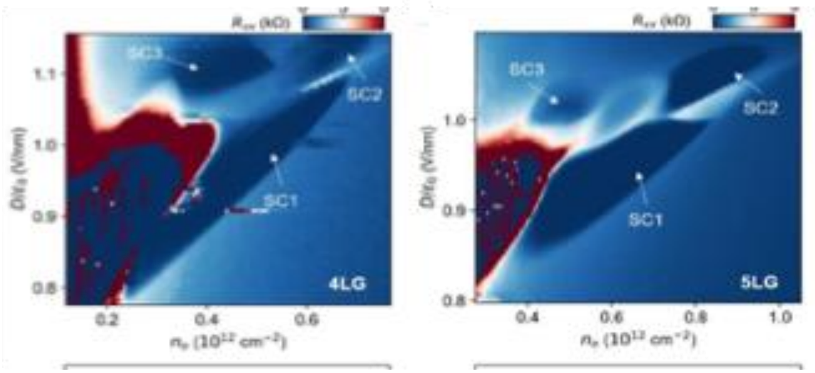
- anomalous Hall effect
- trivial $C = 0$ and Chern $C = 1$ insulators at $\nu = 1$
- fractional Chern insulators at $\nu = \frac{2}{5}, \frac{3}{5}, \frac{2}{3}, \ldots$

Signatures of chiral superconductivity in rhombohedral graphene

Tonghang Han, Zhengguang Lu, Zach Hadjri, Lihan Shi, Zhenghan Wu, Wei Xu, Yuxuan Yao, Armel A. Cotten, Omid Sharifi Sedeh, Henok Weldeyesus, Jixiang Yang, Junseok Seo, Shenyong Ye, Muyang Zhou, Haoyang Liu, Gang Shi, Zhenqi Hua, Kenji Watanabe, Takashi Taniguchi, Peng Xiong, Dominik M. Zumbühl, Liang Fu & Long Ju

Nature 643, 654–661 (2025) | Cite this article

R4G R5G



No moiré:

- anomalous Hall effect
- signatures of chiral superconductivity
- NO Chern of Fractional Chern

See also Torma, Heikilla, Zhang, Das Sarma, Guinea, Shizeng, others for mechanisms

Strategy

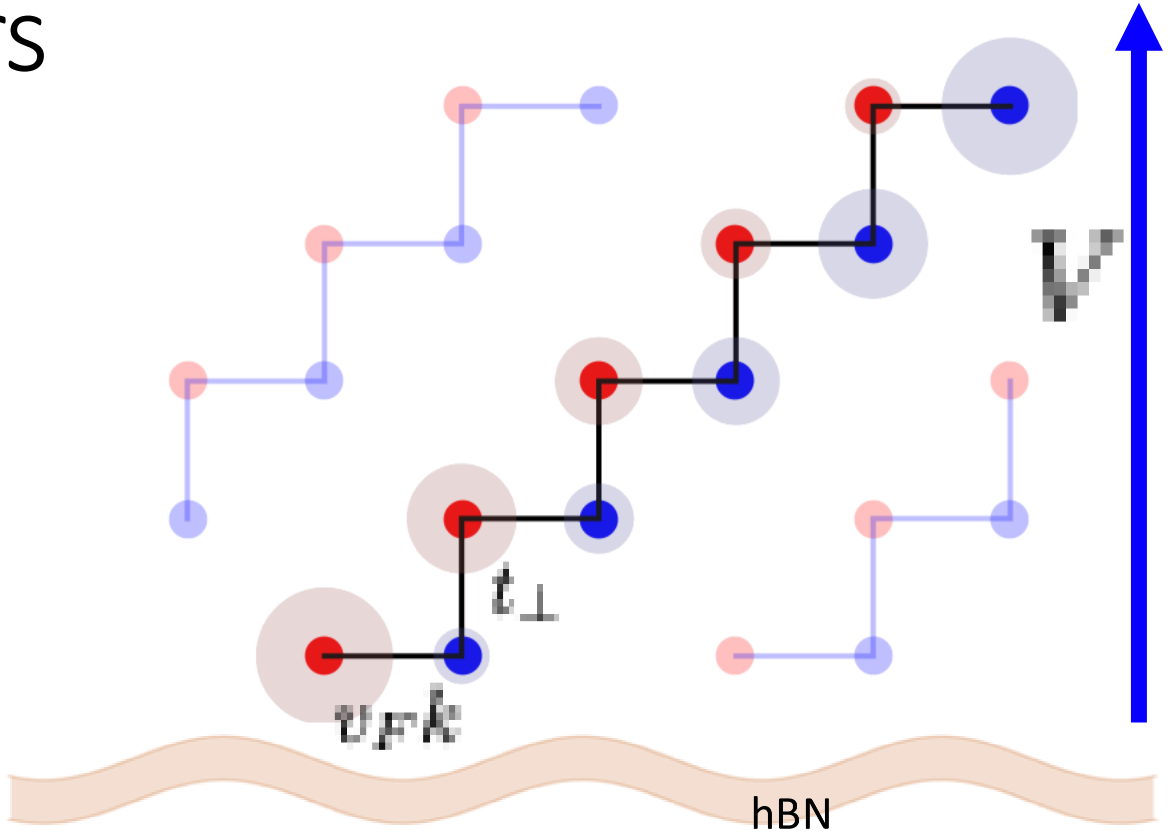
1. Model Rhombohedral Graphene Single Particle, completely new system
2. Get Rid of Details (can we?)
3. Model Interactions
4. See what phases emerge with a) Repulsive b) Attractive Interactions
5. Go beyond mean field, if necessary (it **is** necessary)
6. Find out Moire is necessary to explain CI/FCI (i.e. no AHC)
7. Once Moire added, can we explain CI/FCI? – Moire capacitor effect
8. Find if SC emerges naturally under attraction

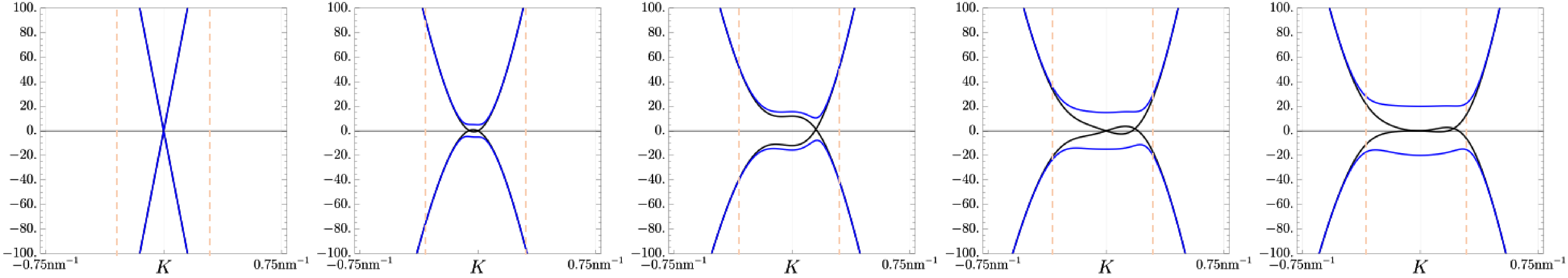
9. Go out have beer

10. Come back ask what is attraction mechanism

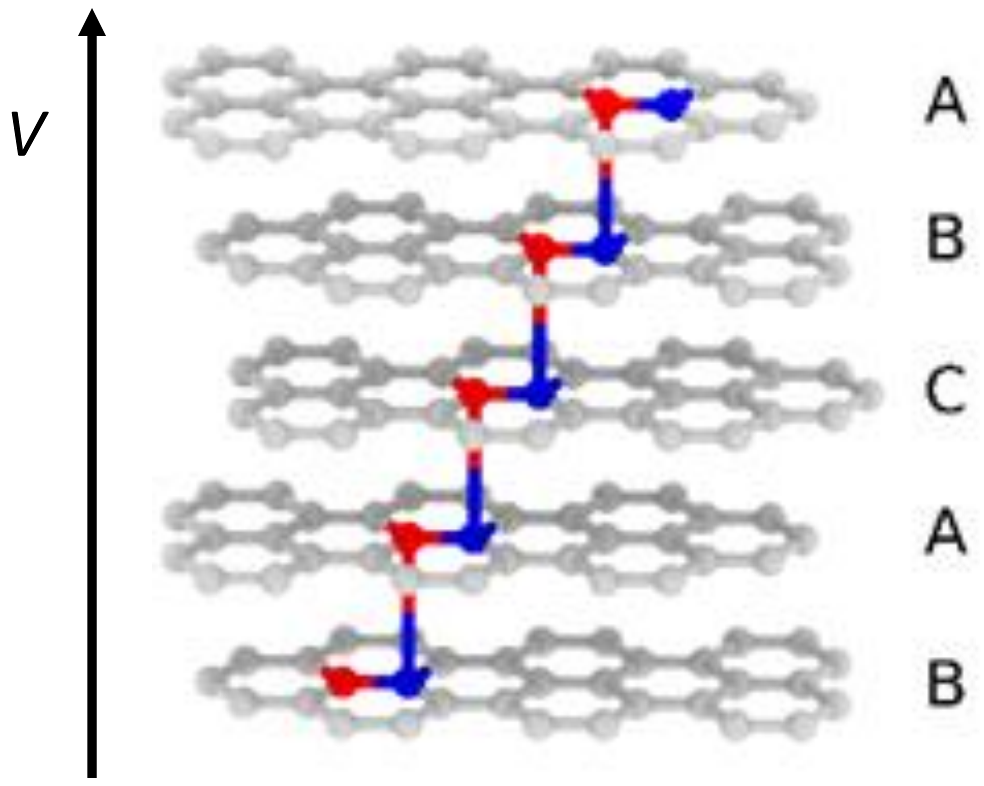
Rhombohedral multilayers

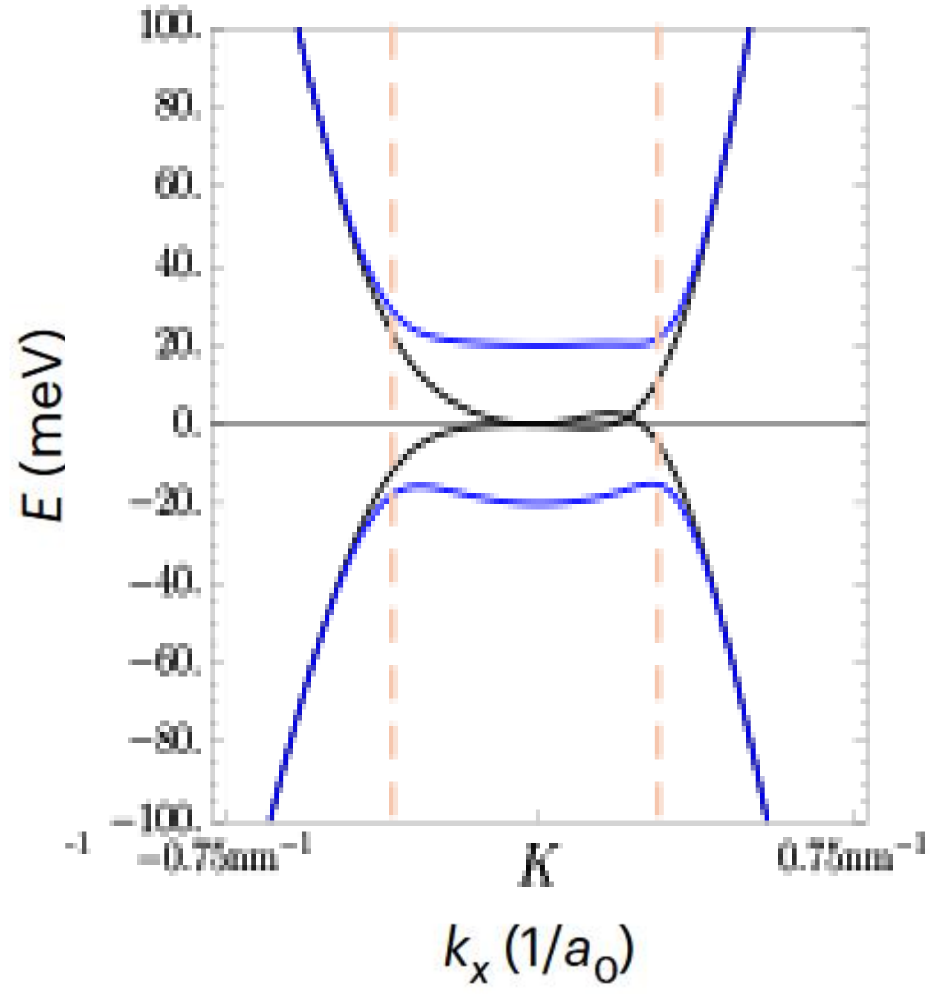
- Moiré engineering produces flat bands, but graphene has its own!
- SSH model out-of-plane
  - Surface states when $\frac{t_\perp}{|v_F k|} > 1 + \frac{1}{L}$





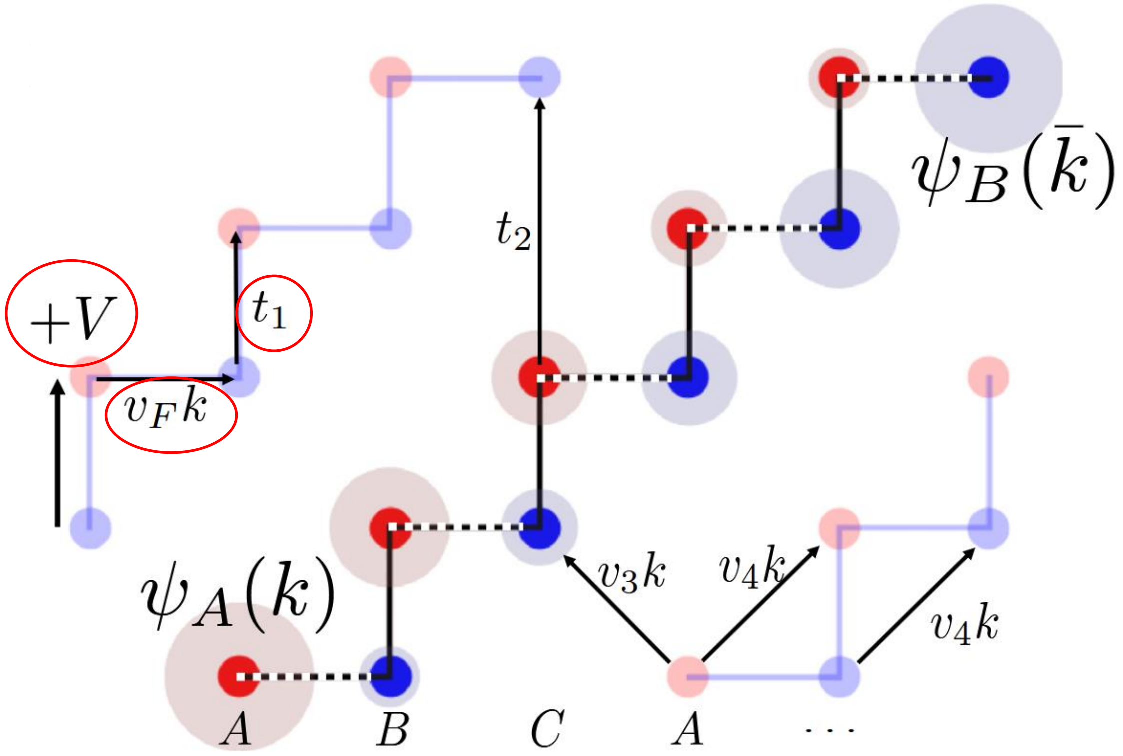
Rhombohedral Graphene Single Particle Model



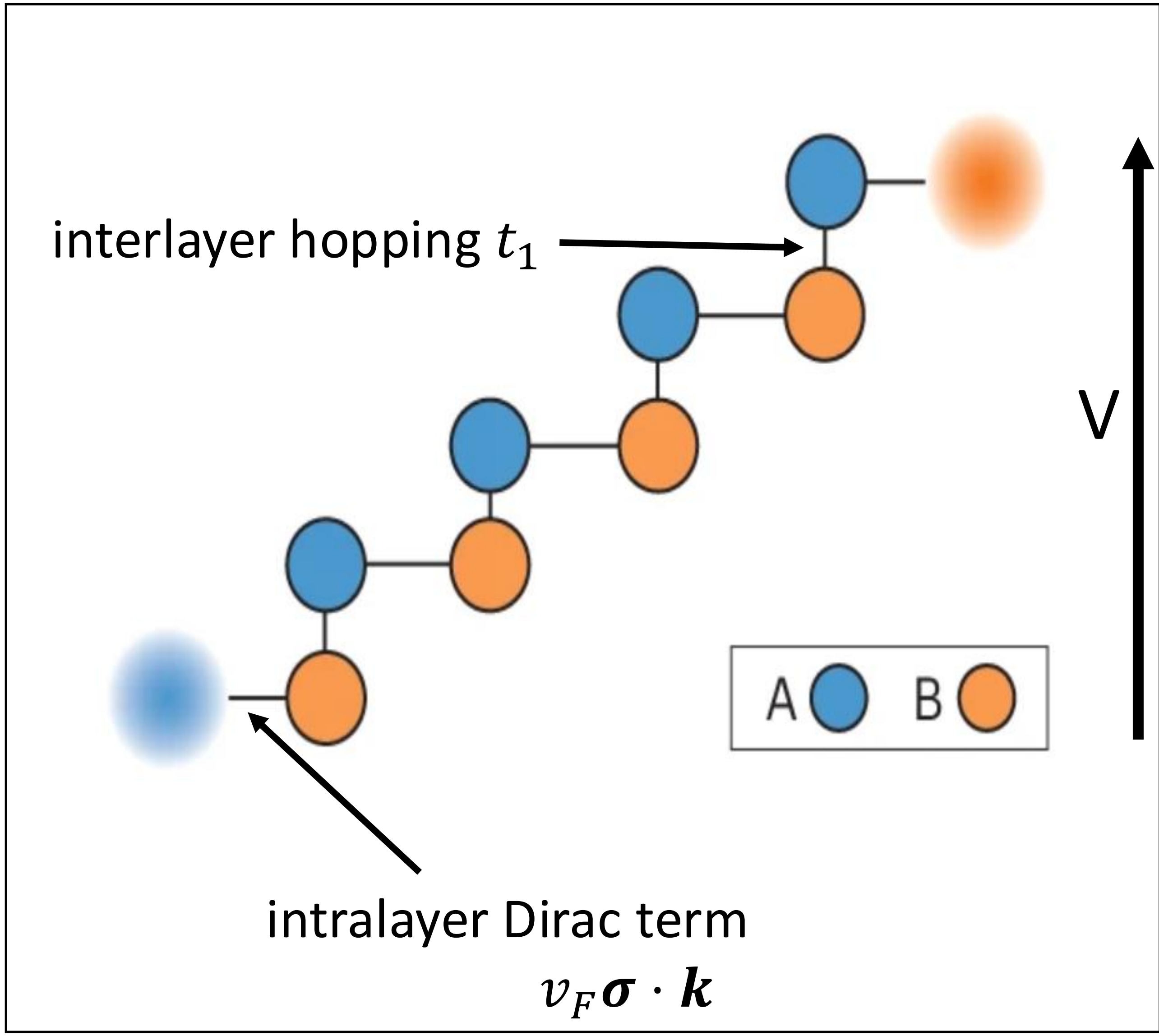


Too many details in the BS, anything simpler?

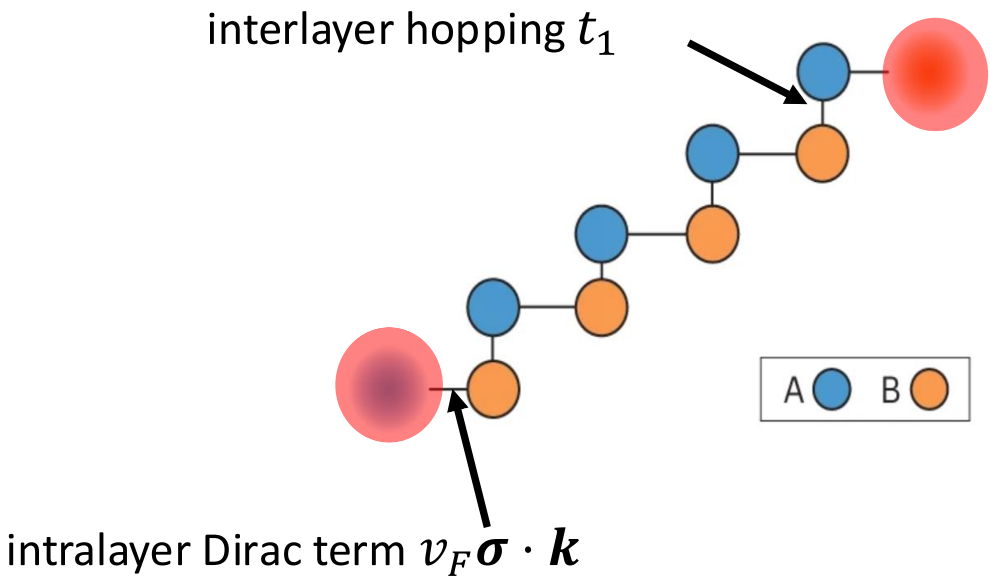
Focus on valley K, keep dominant terms

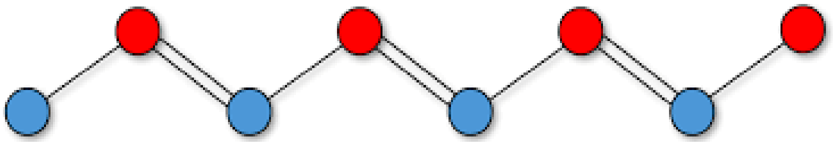


keep only dominant
v_F, t_1, V terms



Resemblance to (finite) Su-Schrieffer-Heeger chain





$$H(\boldsymbol{k}) = \begin{bmatrix} 0 & v_F k_- & 0 & 0 & \cdots \\ v_F k_+ & 0 & t_1 & 0 & \cdots \\ 0 & t_1 & 0 & v_F k_- & \cdots \\ 0 & 0 & v_F k_+ & 0 & \ddots \\ \vdots & \vdots & \vdots & \ddots & \ddots \end{bmatrix}$$

$$k_\pm = k_x \pm i k_y$$

1. low-energy edge modes localized at **1A** and ***n*B** for $k < k_b \sim t_1 / v_F$

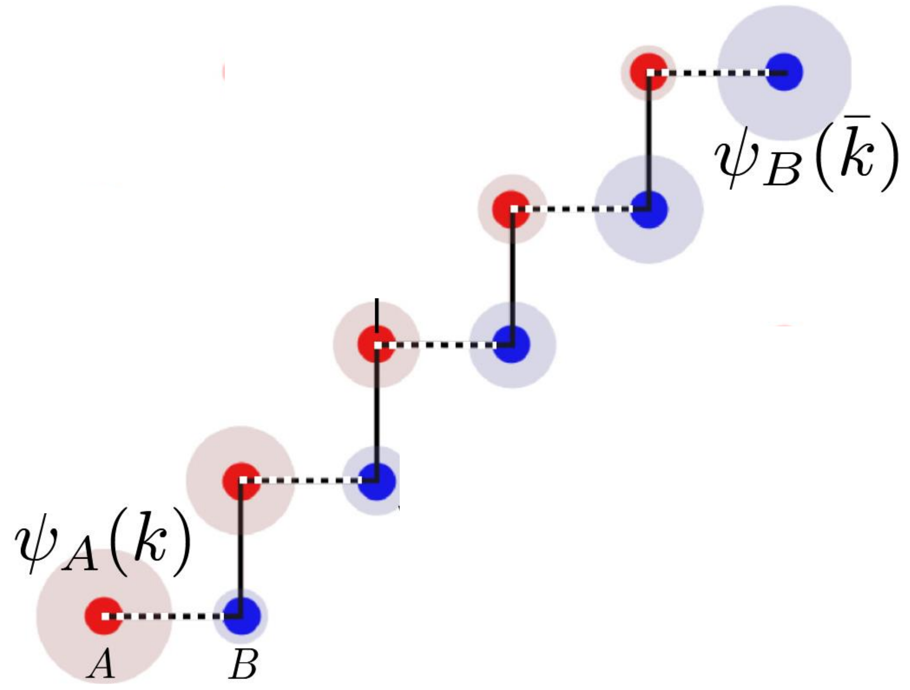
2. other 'dimer' states split by $\simeq \pm t_1$

$$t_1 \simeq 360\text{meV}, v_F \simeq 540\text{meVnm} \;\rightarrow\; k_b \simeq 0.7\text{nm}^{-1} \rightarrow n_{edge} \simeq (1 \rightarrow 3) \times 10^{12}\text{cm}^{-1}$$

Low-energy non-dimer states captured by **chiral basis**

Exact as $k \rightarrow 0$

$k_{\pm} = k \pm ik_y$



$$\begin{bmatrix} (-v_F k_+/t_1)^4 \\ (-v_F k_+/t_1)^3 \\ (-v_F k_+/t_1)^2 \\ -v_F k_+/t_1 \\ 1 \end{bmatrix} \qquad \begin{bmatrix} 1 \\ -v_F k_-/t_1 \\ (-v_F k_-/t_1)^2 \\ (-v_F k_-/t_1)^3 \\ (-v_F k_-/t_1)^4 \end{bmatrix}$$

holomorphic $\psi_A(\boldsymbol{k})$
on A sublattice

exponentially localized to bottom layer

anti-holomorphic $\psi_B(\boldsymbol{k})$
on B sublattice

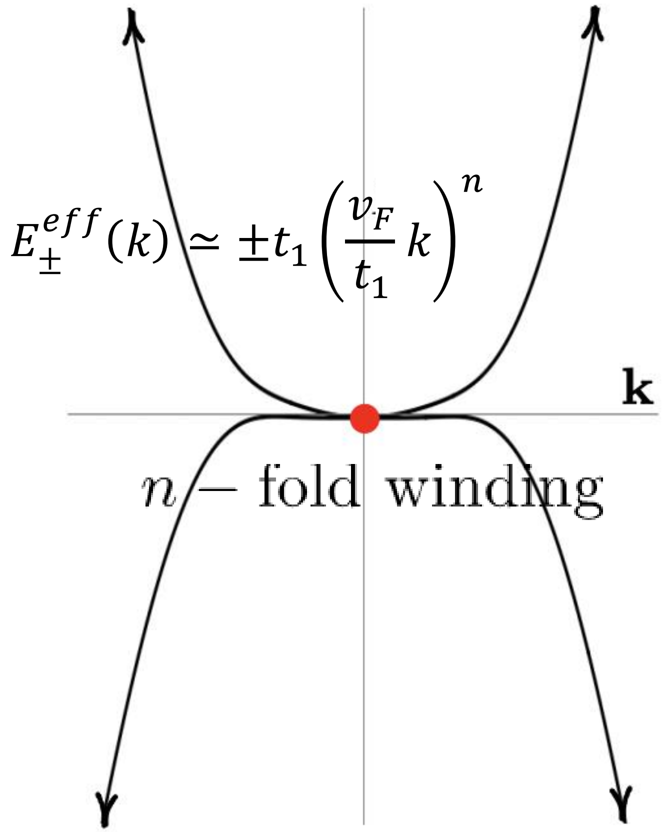
exponentially localized to top layer

Projection to the low-energy states

Zhang et al, PRB (2010)

$$H^{eff}(\boldsymbol{k}) = < \psi_i(\boldsymbol{k}) | \mathrm{H}(\boldsymbol{k}) | \psi_j(\boldsymbol{k}) >, \quad i, j = A, B$$

$$= \begin{bmatrix} 0 & \dfrac{v_F^n k_-^n}{t_1^{n-1}} \\ \dfrac{v_F^n k_+^n}{t_1^{n-1}} & 0 \end{bmatrix}$$



approximate nth order Dirac cone

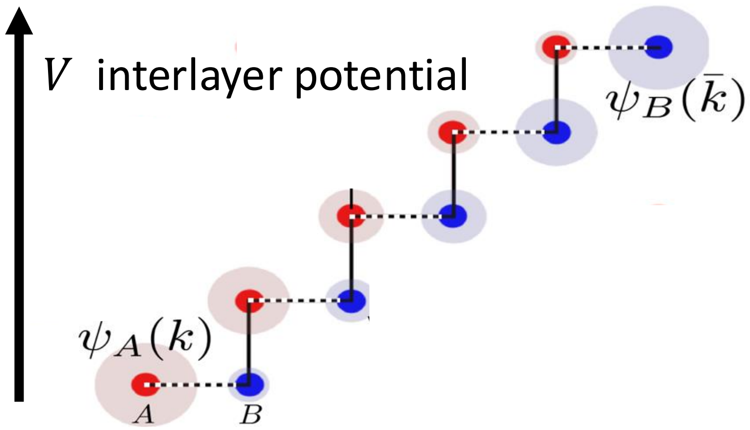
singularity of $n\pi$ Berry phase at $k = 0$

Add Displacement Field

low-energy states polarizable by displacement field D

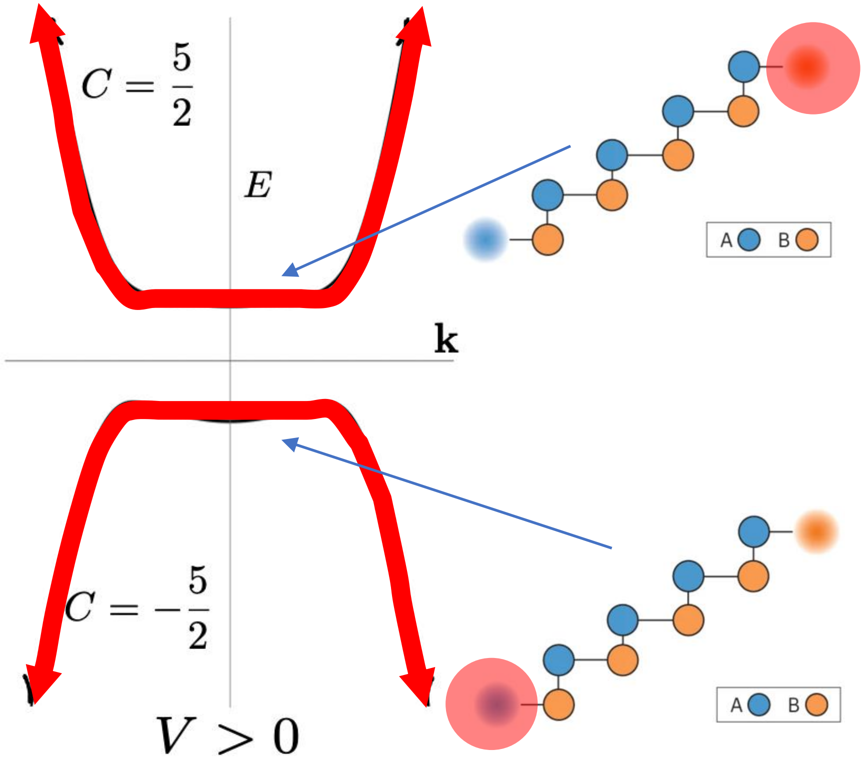
→ regions of **flat dispersion**

broken I symmetry → **finite Berry curvature**

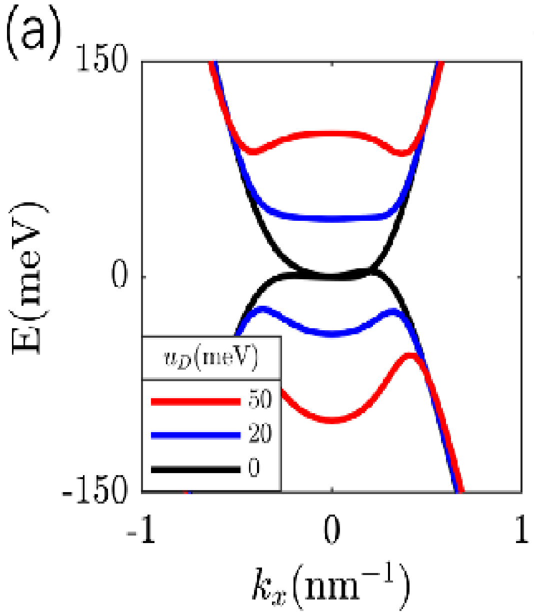


$$H^{eff}(\boldsymbol{k}) = \begin{bmatrix} -\frac{n-1}{2}V & \frac{v_F^n k_-^n}{t_1^{n-1}} \\ \frac{v_F^n k_+^n}{t_1^{n-1}} & \frac{n-1}{2}V \end{bmatrix}$$

$$E_\pm^{eff}(k) \simeq \pm t_1 \sqrt{\left(\frac{v_F}{t_1}k\right)^{2n} + \left(\frac{(n-1)V}{t_1}\right)^2}$$



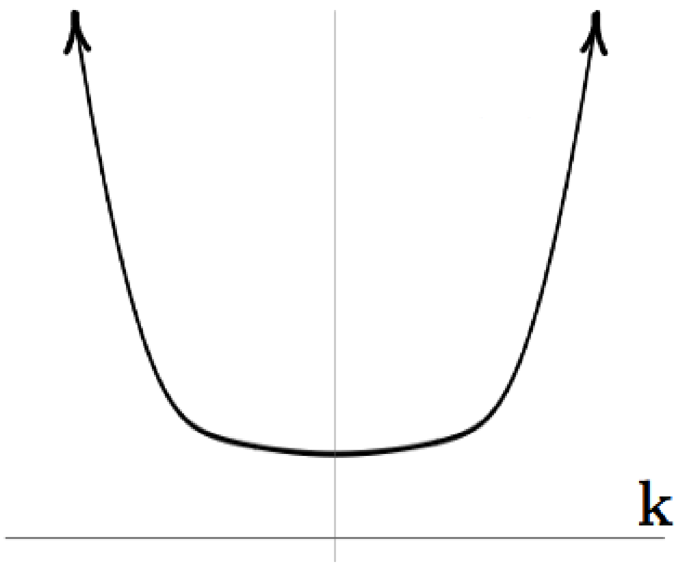
R5G
(higher-order hoppings)



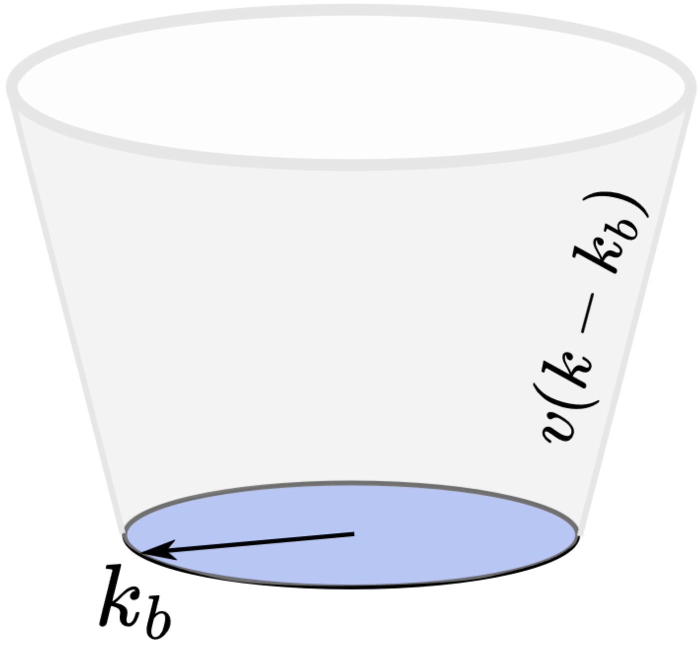
Han et al, Nature (2024)

The Kinetic Model Of n > 3 Is A Trashcan

BAB, Kwan, arXiv (2025)



Physics happens in the conduction band with flat bottom



can extract analytically:

trashcan velocity v

$$v = v_F\left(\frac{2\sqrt{10}\left(n^2-1\right)\sqrt{\frac{1}{7n^2+2}}}{9n}+\frac{1}{n}\right)$$

$$v \simeq 0.45 v_F$$

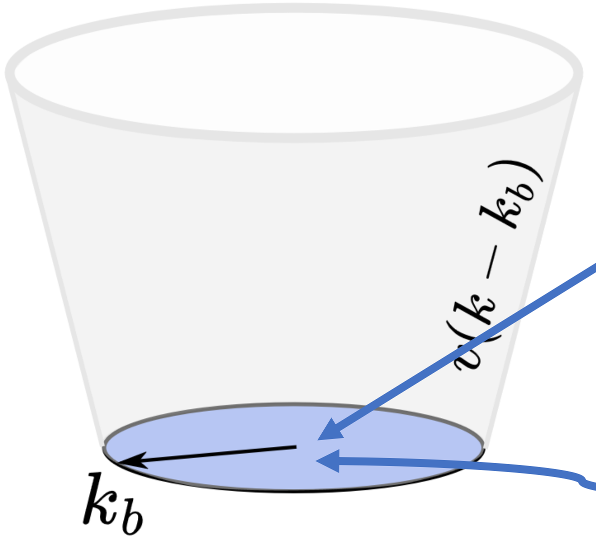
trashcan radius k_b

$$k_b = \frac{t_1}{v_F}\frac{\left(n^2-1\right)\left(4\sqrt{10(7n^2+2)}-15\right)}{18\left(7n^2+\frac{2}{9}\left(n^2-1\right)\sqrt{10(7n^2+2)}+2\right)}$$

$$k_b \simeq 0.51\frac{t_1}{v_F}$$

Wavefunctions of the Trashcan Bottom: Constant Berry Curvature

For $V > 0$, conduction band is $\psi_B(\boldsymbol{k})$



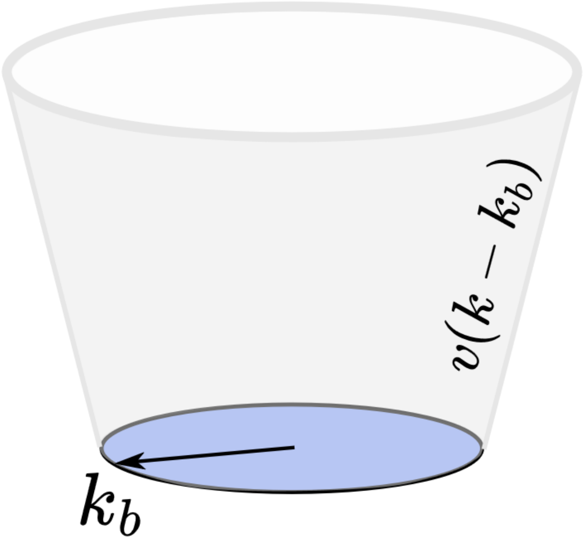
$$M_{\boldsymbol{k},\boldsymbol{q}} = \langle \psi_B(\boldsymbol{k}+\boldsymbol{q}) | \psi_B(\boldsymbol{k}) \rangle \approx e^{-\frac{v_F^2}{2t_1^2}(q^2 + 2i\boldsymbol{q}\times\boldsymbol{k})}$$

$$\Omega(k) = 2\beta, \qquad \beta = \frac{v_F^2}{t_1^2}$$

n=5: Berry flux enclosed by trashcan basin $\simeq 0.52\pi$

'GMP algebra', exact for $\frac{v_F k}{t_1} \ll 1$: $[\bar{\rho}_{\mathbf{q}_1}, \bar{\rho}_{\mathbf{q}_2}] = -2i \sin\left(\Omega \frac{\mathbf{q}_1 \wedge \mathbf{q}_2}{2}\right) \bar{\rho}_{\mathbf{q}_1+\mathbf{q}_2}$

Berry Trashcan Interacting Model



trashcan dispersion

chiral B basis creation operator

GMP form factors

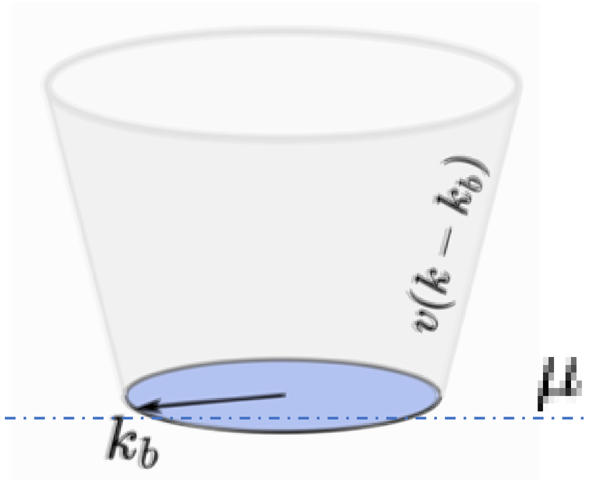
$$H = \sum_{k} E(\boldsymbol{k}) \gamma_{\boldsymbol{k}}^{\dagger} \gamma_{\boldsymbol{k}} + \frac{1}{2\Omega_{tot}} \sum_{\boldsymbol{q},\boldsymbol{k},\boldsymbol{k'}} V_{\boldsymbol{q}} M_{\boldsymbol{k},\boldsymbol{q}} M_{\boldsymbol{k'},-\boldsymbol{q}} \gamma_{\boldsymbol{k}+\boldsymbol{q}}^{\dagger} \gamma_{\boldsymbol{k'}-\boldsymbol{q}}^{\dagger} \gamma_{\boldsymbol{k'}} \gamma_{\boldsymbol{k}}$$

$$V_{\boldsymbol{q}} M_{\boldsymbol{k},\boldsymbol{q}} M_{\boldsymbol{k'},-\boldsymbol{q}} = V_{\boldsymbol{q}} e^{-\beta q^2} e^{-i\beta \boldsymbol{q} \times (\boldsymbol{k} - \boldsymbol{k'})}$$

$V_{\boldsymbol{q}}$ is a density-density interaction, usually Coulomb and likely screened (due to gates, etc.)

What do interactions do?

4 trashcans: 2 valleys (K, K') and 2 spins



At finite filling < $\pi\, k_b^2$, almost exact spin and flavor valley and spin ferromagnetism

Can be obtained in Hartree Fock and is exact

Breaks time-reversal

In one trashcan, system is gapless.

Goal: Study addition of moire

Goal: Study repulsive interactions, at fractional or integer filling

Goal: Study attractive interactions

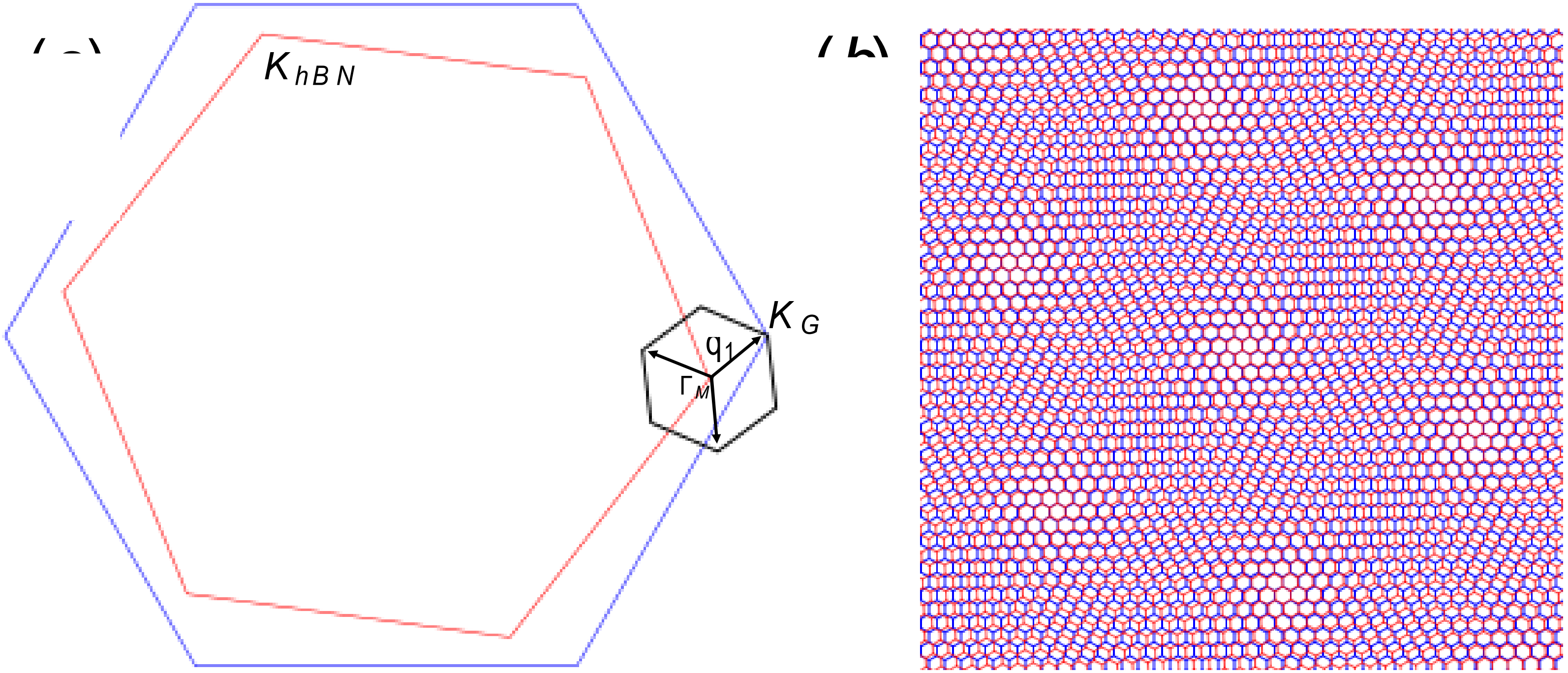
Goal: Hartree-Fock, ED, analytic solutions possible?

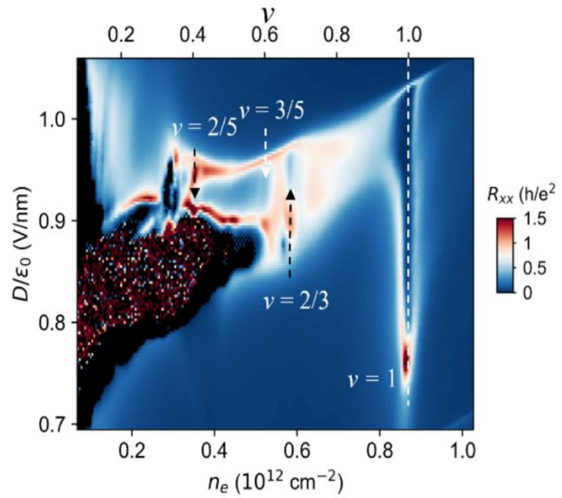
Most of the above is not understood.

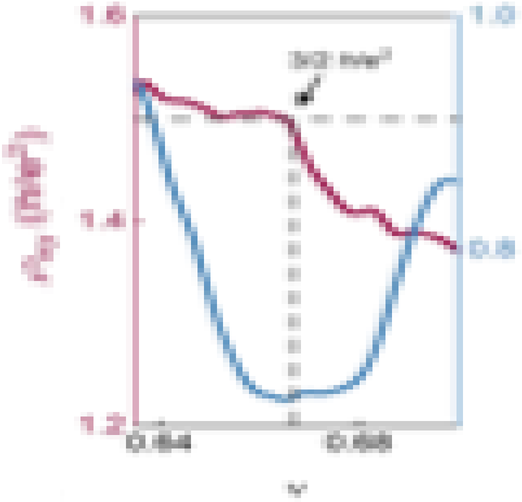
Add Moire?

Jung, …, MacDonald PRB (2014)

Herzog-Arbeitman, Wang, Liu, Tam,…., Quansheng Wu, Jiabin Yu, arXiv:2311.12920







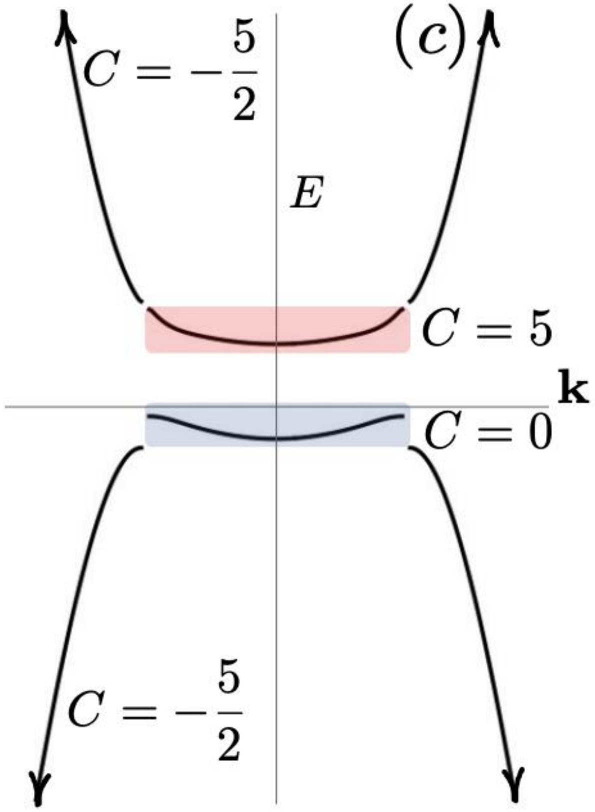
MIT Group (Ju)
Peking Group (Lu)

Similar story with $MoTe_2$? Moire folds the band, scatters, opens single particle Chern number gaps (Chern Insulator), then fractional fill this band for FCI? Not so fast

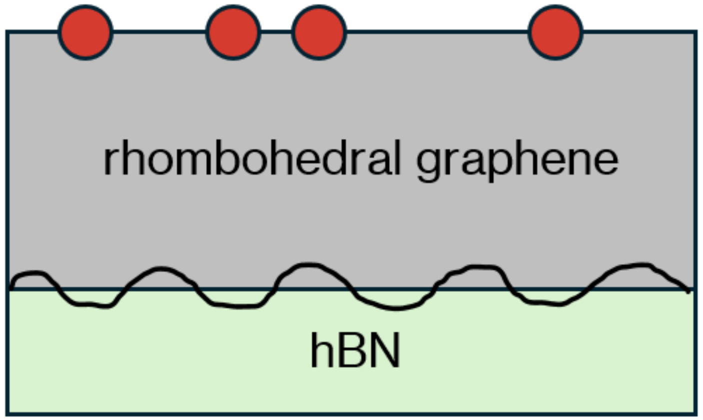
First Puzzle: Nothing Happens in Trashcan When Moire Added

doped electrons are away from aligned hBN and moire!

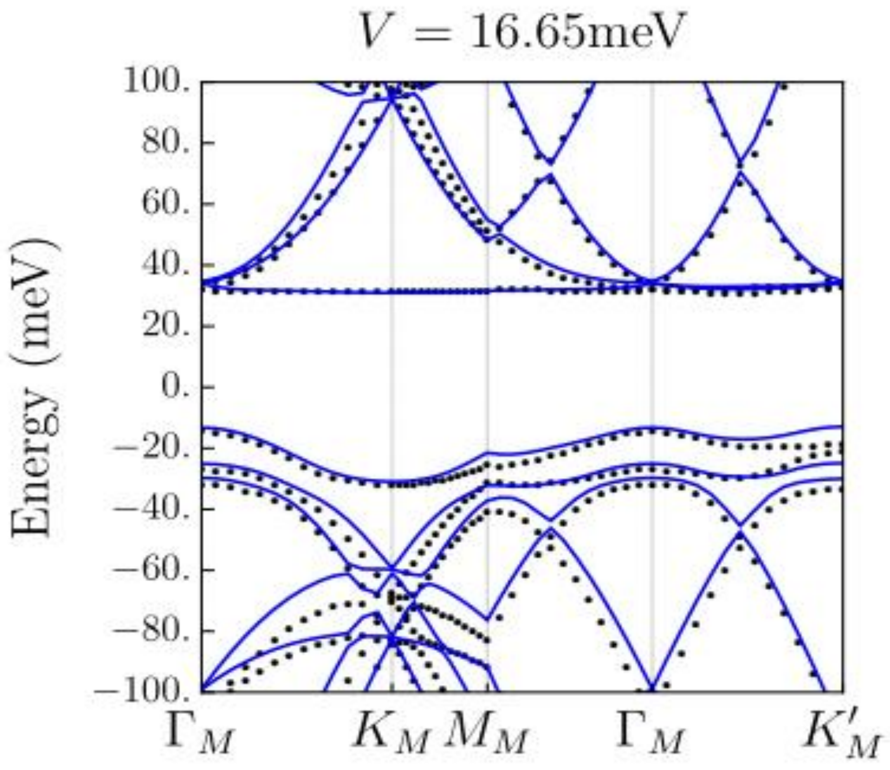
$$+V_\xi(\mathbf{r})$$



$$V > 0, V_\xi(\mathbf{r}) \neq 0$$



1. Moire barely opens any single particle gaps (0.1 mev)
2. Electron band has wrong Chern number (5)
3. Valence band is close to moire, opens gaps but has Chern number 0
4. All experimental action happens in conduction band

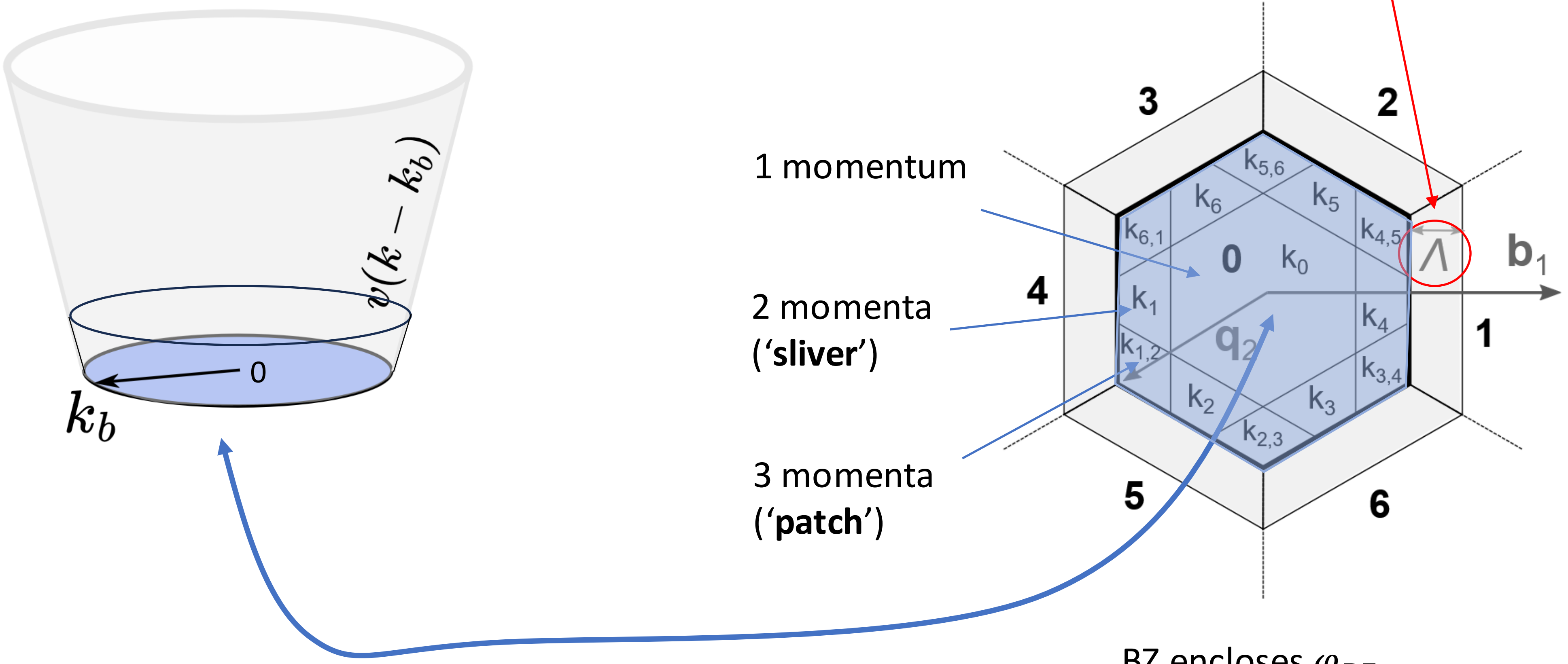


Can we open gap without Moire? In Hartree Fock, We can!

Berry Trashcan allows for analytic Hartree Fock calculation

Interaction projected in the Berry Trashcan

sharp dispersion leads to tight cutoff outside 1^{st} BZ
'thin-sliver approximation'

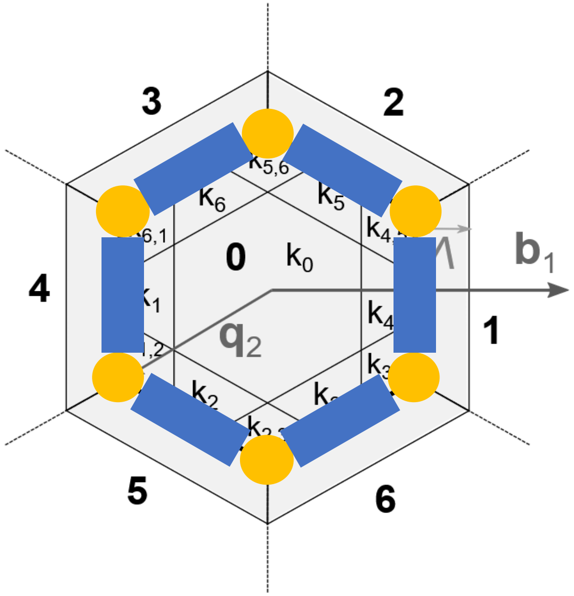


BZ encloses φ_{BZ}
Berry curvature

Analytical Solution of Berry Trashcan Hartree Fock Wigner Crystal

- **patch treatment**

  see also Soejima et al, Dong et al, Crepel et al



only consider small patches at BZ corners at K_M and K'_M

small patches → set $\boldsymbol{k} \simeq \boldsymbol{q}_2$ etc

C mod 3

- **Patch + slivers** along $K_M - M_M$ lines

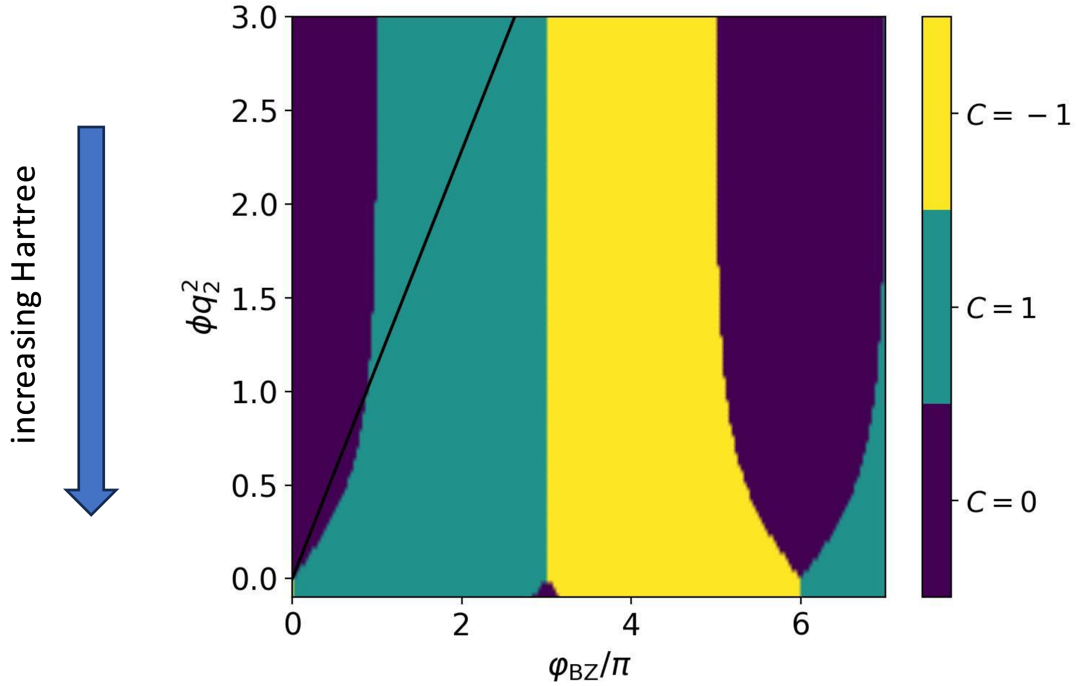
ability to get HF wavefunction around entire BZ
→ obtain **full Chern number *C***

Hartree | Fock

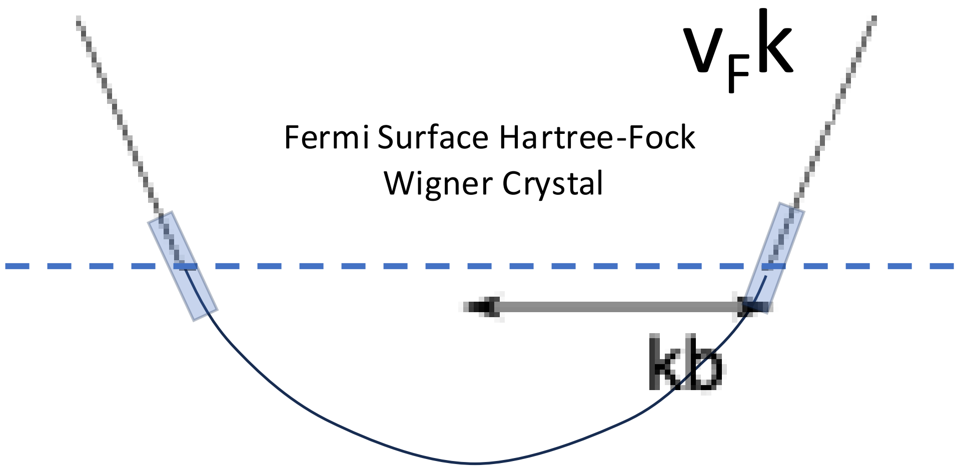
$$E^{\mathrm{HF}} \propto e^{-\phi b_1^2} \cos\left(\frac{\varphi_{\mathrm{BZ}} + 2\pi C}{3}\right) - e^{-\phi q_2^2} \cos\left(\frac{\varphi_{\mathrm{BZ}} - 2\pi C}{3}\right)$$

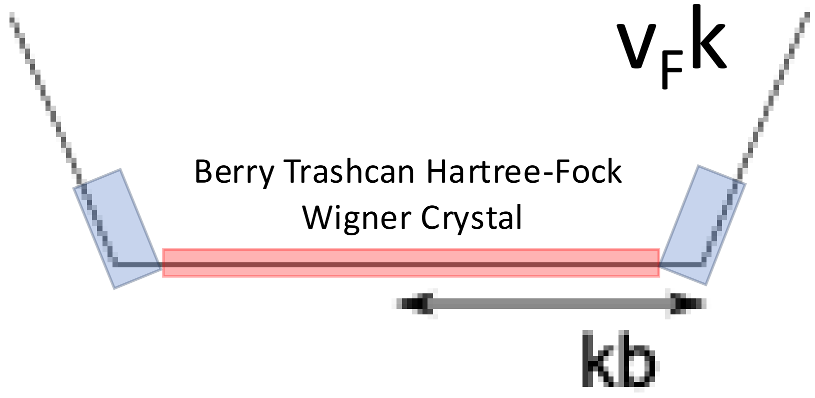
For small φ_{BZ}:

- Hartree prefers $C = 1 \; mod \; 3$ over $C = 0 \; mod \; 3$
- Fock prefers $C = 0 \; mod \; 3$ over $C = 1 \; mod \; 3$



Hartree Fock Wigner Crystal might fare worse for trashcan than the usual fermi sea



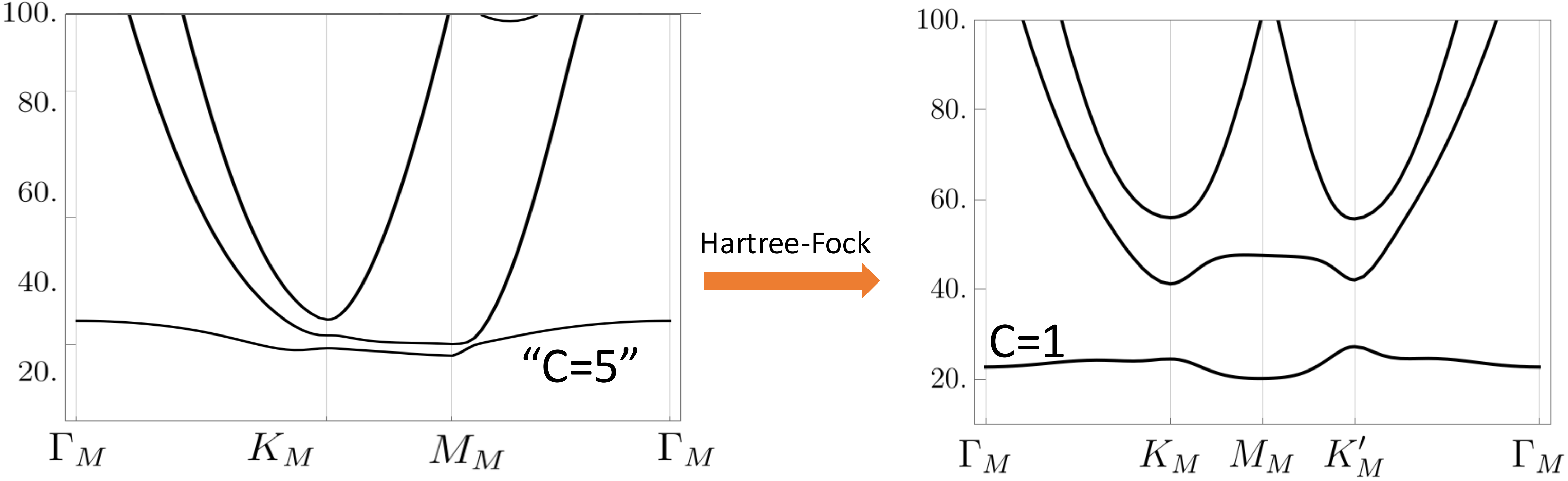


Does not consider red to blue scattering
As important as blue to blue

The Hartree-Fock route to a C=1 band

Dong, ..., Parker, PRL 133, 206503 (2024)
Zhou, Yang, Zhang PRL.133,206504 (2024)
Guo,.., Liu, PRB 110, 075109 (2024)
Dong, Patri, Senthil, PRL 133, 206502 (2024)

- Mean-field shows C=1 insulators at integer filling

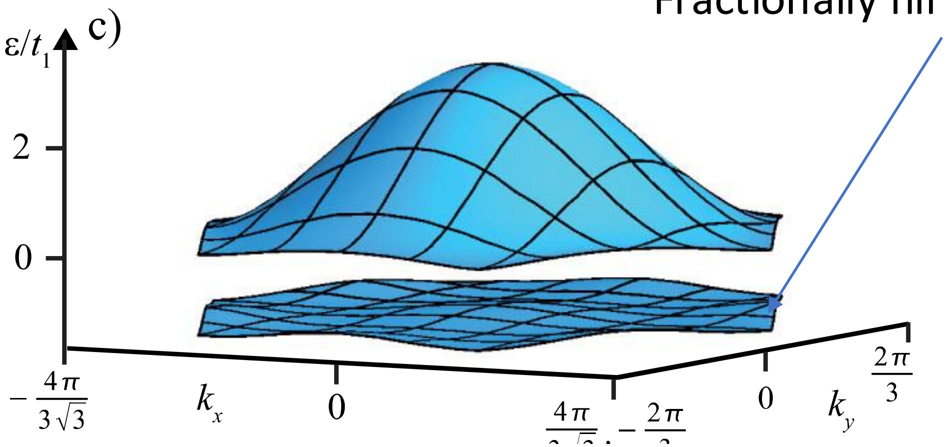


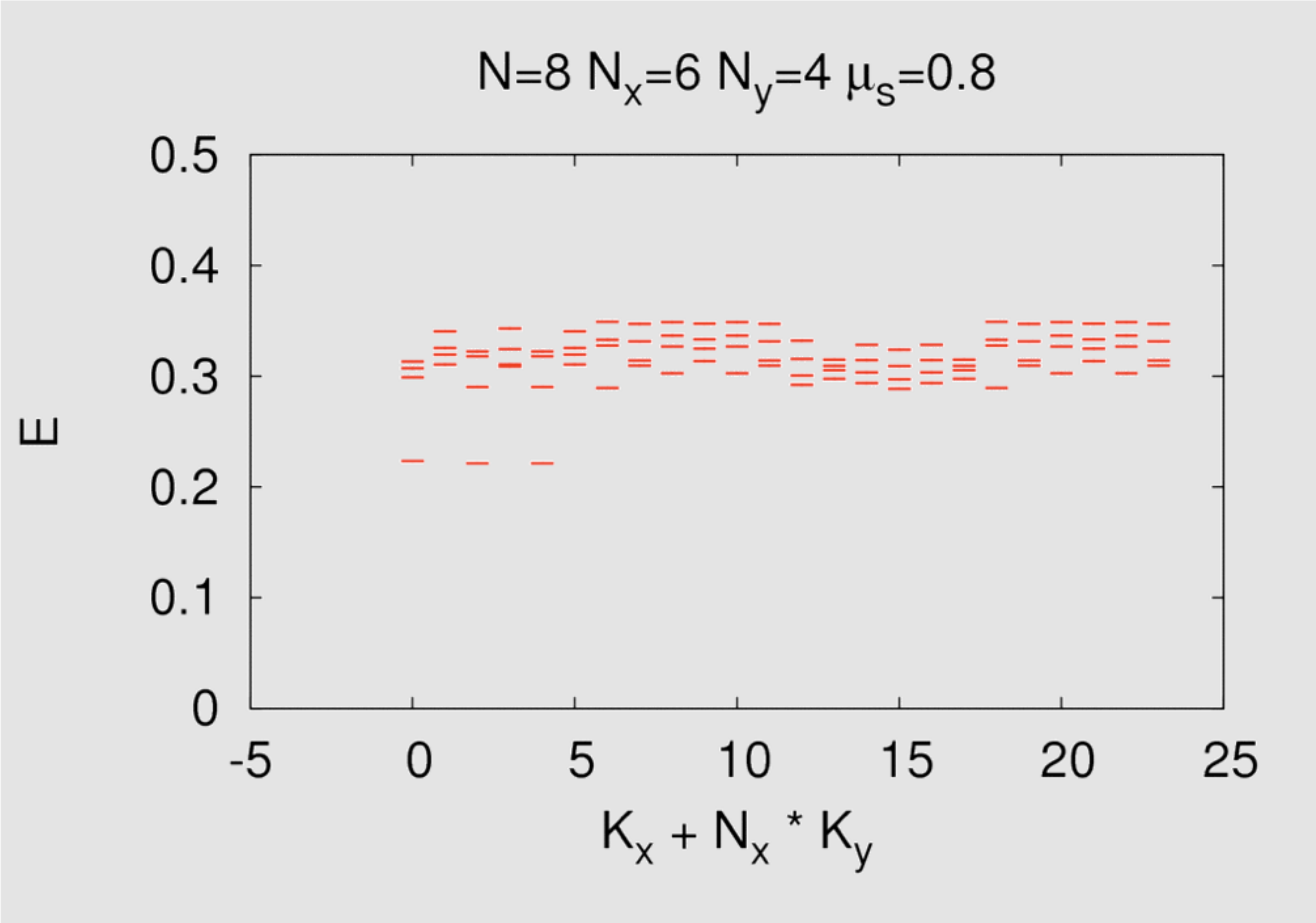
- Harvard/Berkeley, MIT, Johns Hopkins: Anomalous Hall Crystal
- Within HF, C=1 band is adiabatically connected to moiré-less limit
- But experiment clearly shows no FCI without hBN
- Kwan, Yu et al, MFCI III 2312.11617 showed instabilities, subtraction schemes, moire
- See Parameswaran cm journal club

Guo,.., Liu, PRB 110, 075109 (2024)
Huang, Li Sarma, Zhang, PRB 110 115146 (2024). Yong Baek Kim, others

Fractionally Filled Chern Insulator With Strong Interactions

Fractionally fill the “flat Chern band”





Post-Hartree-Fock

Yu, Arbeitman ..., Bernevig, arXiv:2407.13770

Li, BAB, Regnault, arXiv:2504.20140

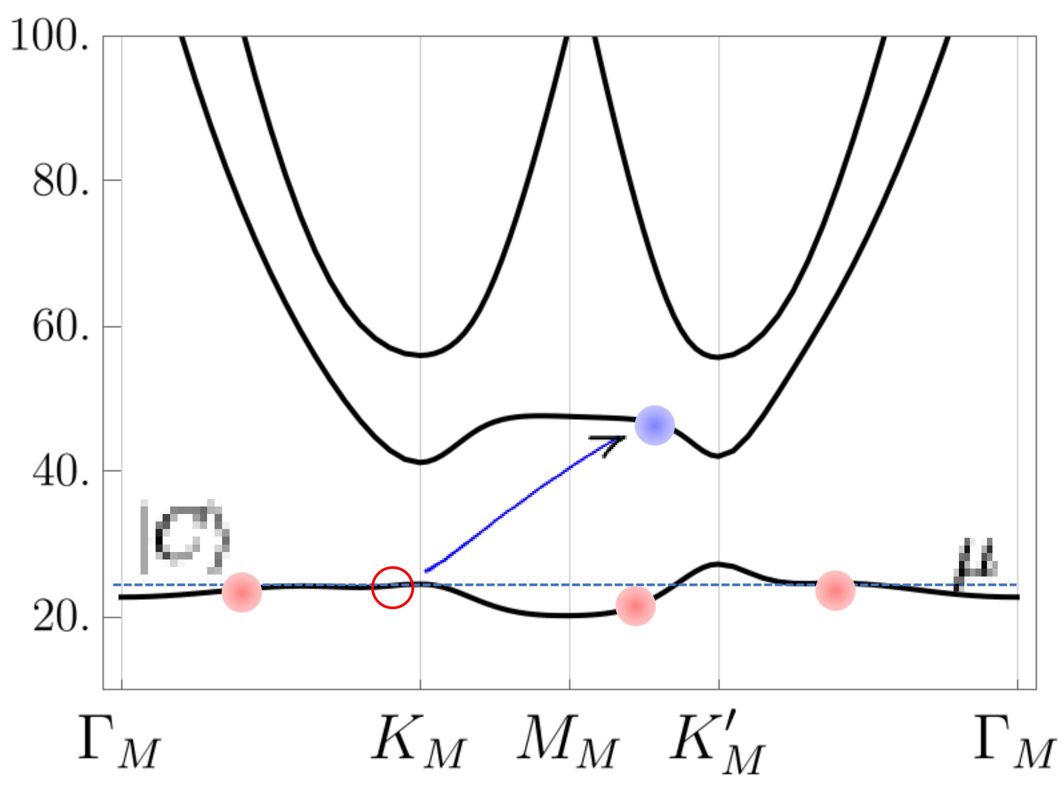
The ED problem is decomposed into two parts in the HF **basis**:

- Intra-band doping (1-band projection)

$$|C\rangle = \prod_i c^\dagger_{\text{intra}} |0\rangle$$

- Inter-band excitations (cut-off *n*)

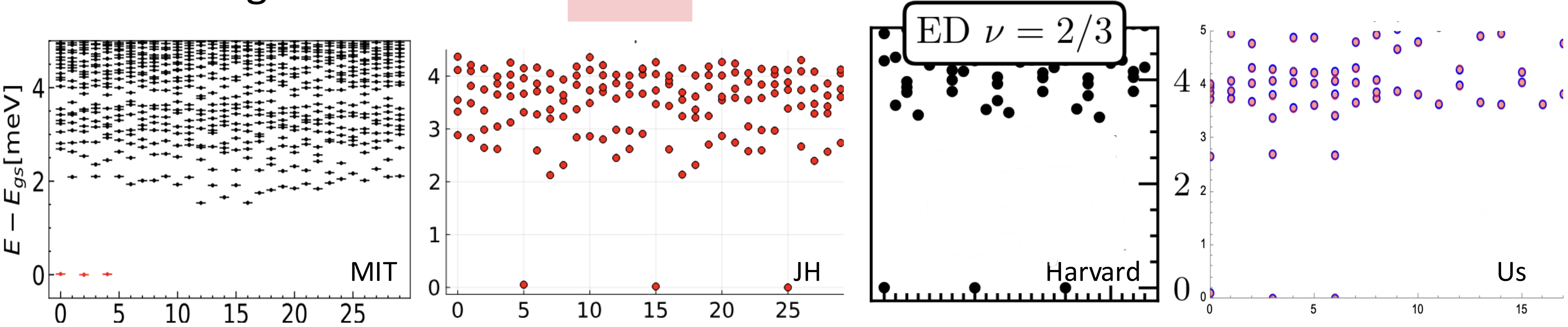
$$\prod_{i\leq n} c^\dagger_{\text{inter}} c_{\text{intra}} |C\rangle$$



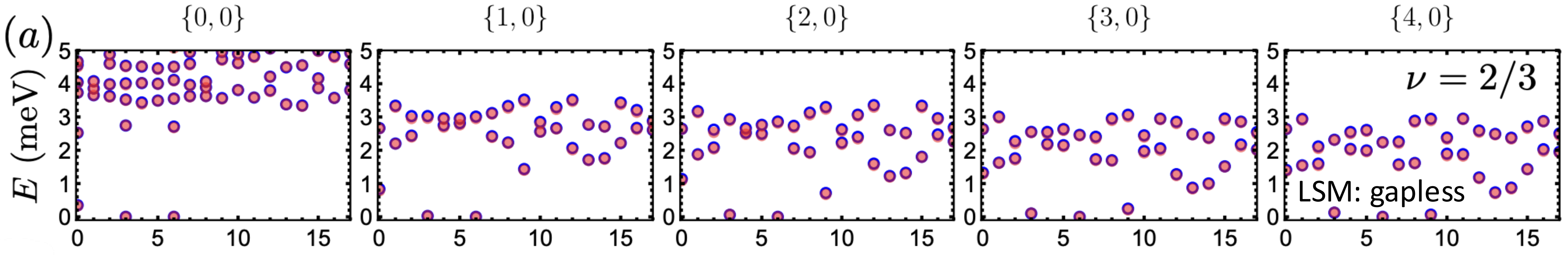
- "band-max" truncation *n*, along with orbital truncation, allows 3-band ED

Fate of the FCI in the full Hilbert Space

- Clear signatures of FCI within the Chern band:



- What is the effect of fluctuations outside the HF band?



- Conclusion: FCI is unstable to fluctuations

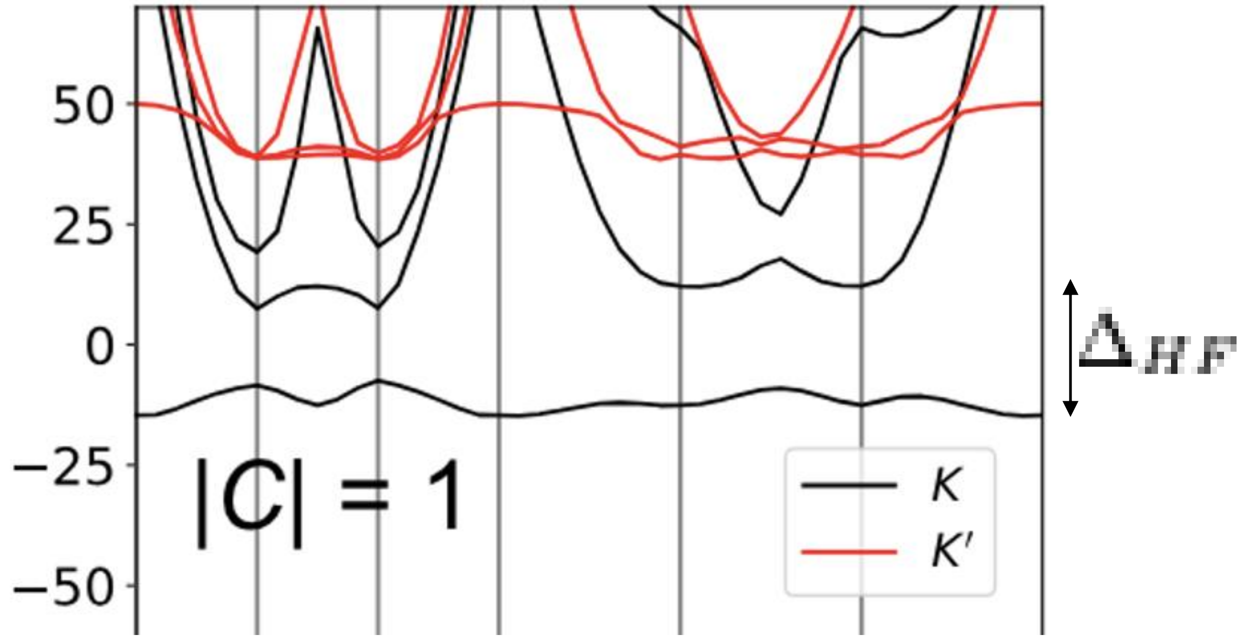
(MFCI IV)

Yu, Arbeitman ..., Reganult, BAB, arXiv:2407.13770

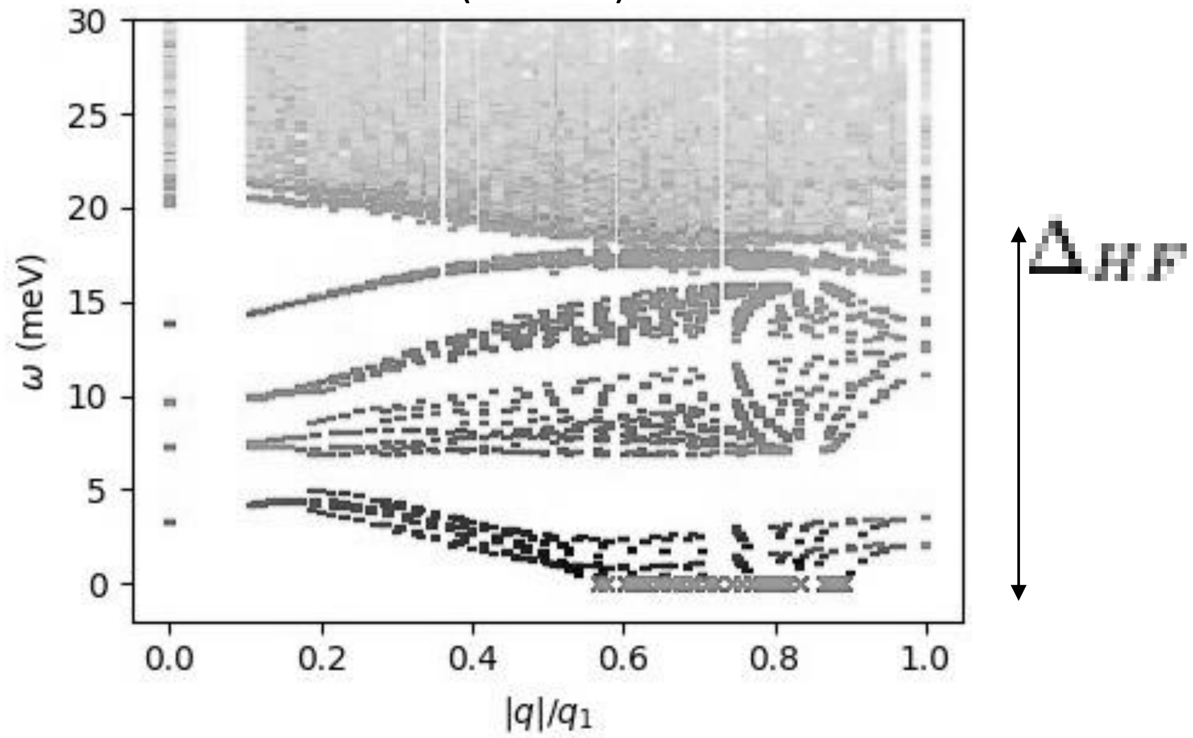
The root of the problem

- Not only is the proposed FCI unstable, the parent state is unstable!
- Easily seen from time-dependent HF calculations (MFCI III, see also MIT, Hopkins)

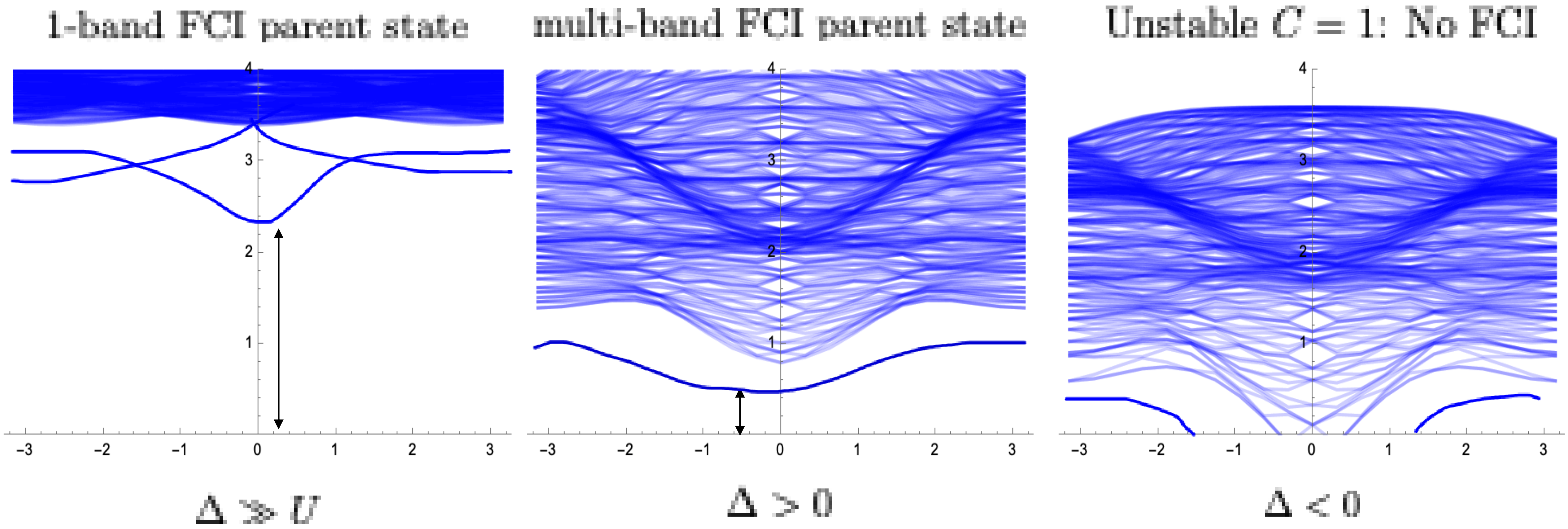
Charge modes



Collective (neutral) modes

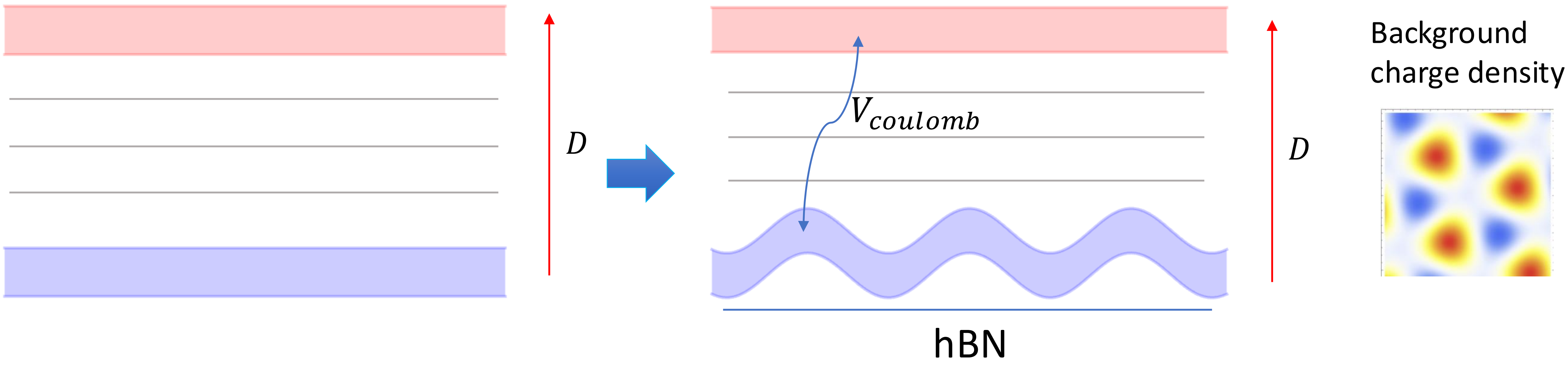


Parent State Possibilities



How do we obtain a stable C=1 state in rhombo?

Moire is crucial for FCI, but thru interactions: Moire Capacitor Effect



Kwan, ..., Regnault, B. A. B , arXiv:2312.11617

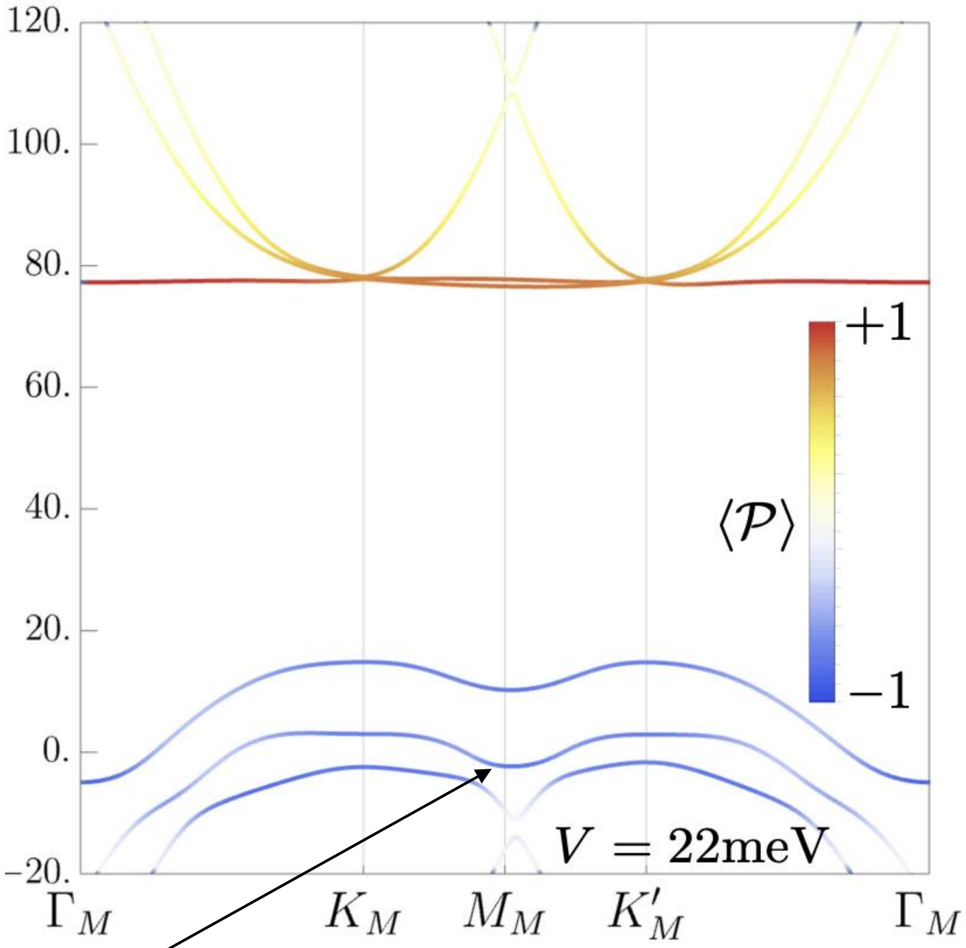
- D field leads to charge concentration like a capacitor
- hBN coupling → background charge density modulation
- Enhanced moire in conduction band from Coulomb interaction with holes
- Cannot get stable FCI without moire capacitor effect

(See Kolar, ..., Lewandowski for description of 3D multi-layer Coulomb)

Twisting the Dirac Sea

$$H_{int} = \frac{1}{2}\int d^2r d^2r' \, V_{ll'}(\mathbf{r}-\mathbf{r}')\delta\rho_l(\mathbf{r})\delta\rho_{l'}(\mathbf{r}')$$

+



(See Kolar, ..., Lewandowski for description of 3D multi-layer Coulomb)

$$\mathscr{H}_{\text{low-energy}} = \prod_{\text{conduction}} c^\dagger \, |\text{valence}\rangle_\Lambda$$

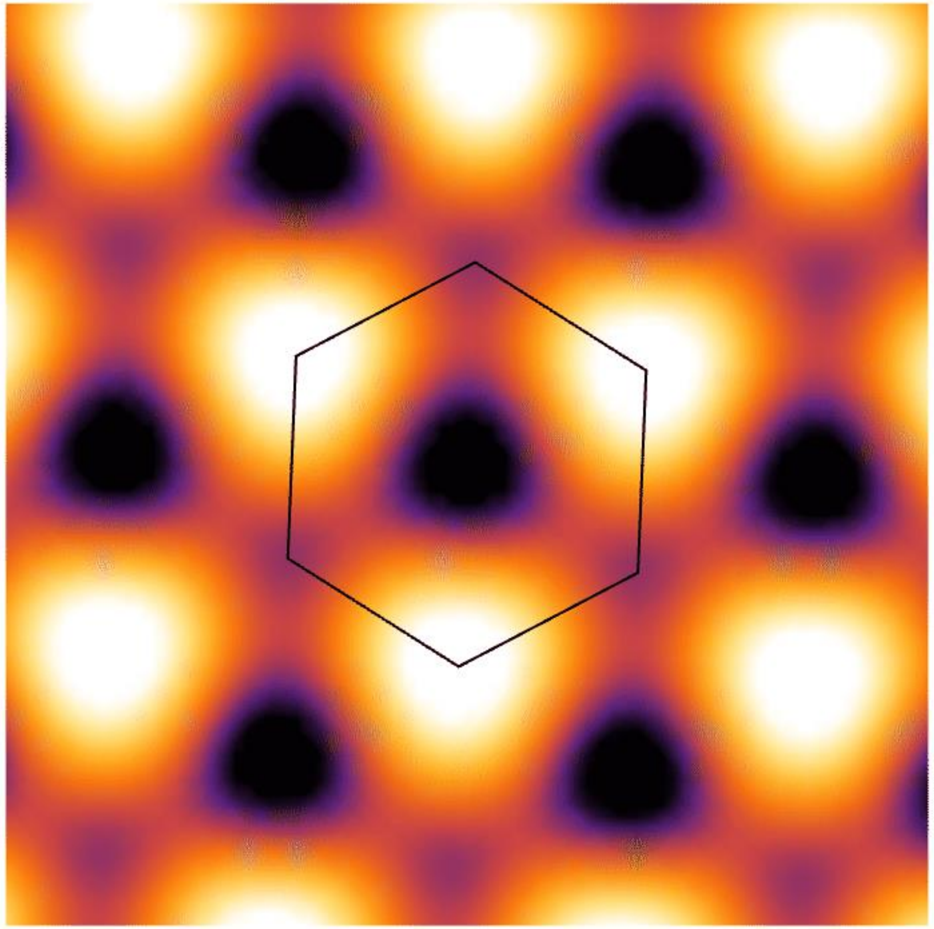
$$H_{eff} = H_0 + H_{int} + H_{HF}[\delta P_{\text{val.}}]$$

Revisiting the Role of the hBN Moiré

Mystery (another)

- Experiment: FCIs appear only with hBN moiré

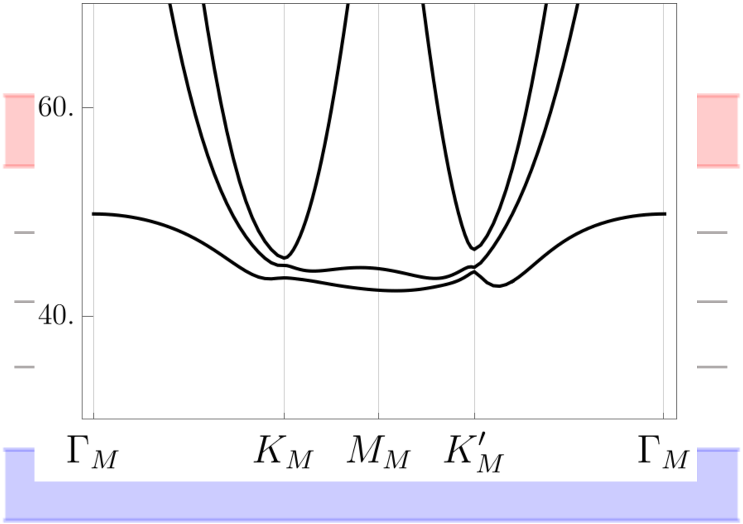
- Theory: bare hBN hybridization negligible on conduction bands



$\rho_{valence}(\mathbf{r})$

“Moiré Capacitor Effect”

$$V_H(\mathbf{r}, z) = \int d^2r' dz' \;\; \rho_{\text{valence}}(\mathbf{r}', z') V_{\text{Coulomb}}(\mathbf{r} - \mathbf{r}', z - z')$$



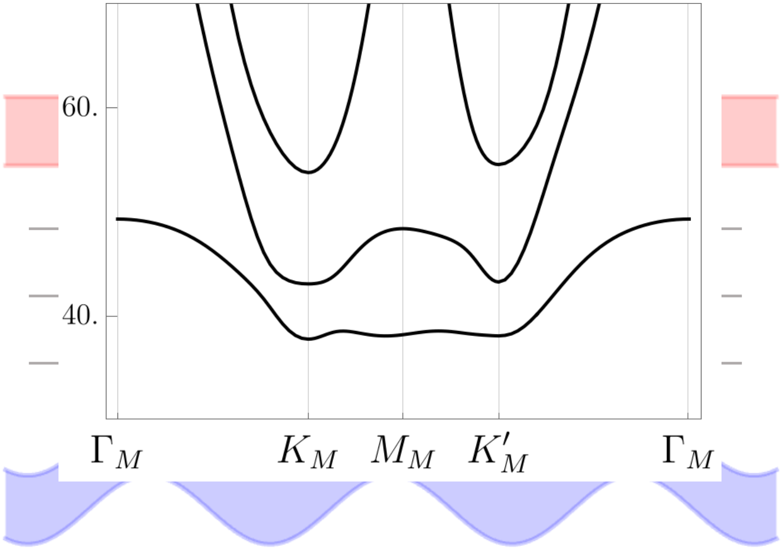
$$V_H = \rho \frac{d}{\epsilon_\perp}$$

$$V_H = \rho(\mathbf{r}) \frac{d}{\epsilon_\perp}$$

{-1, 1, -1}

{1, -1, 0}

{-1, 0, 1}

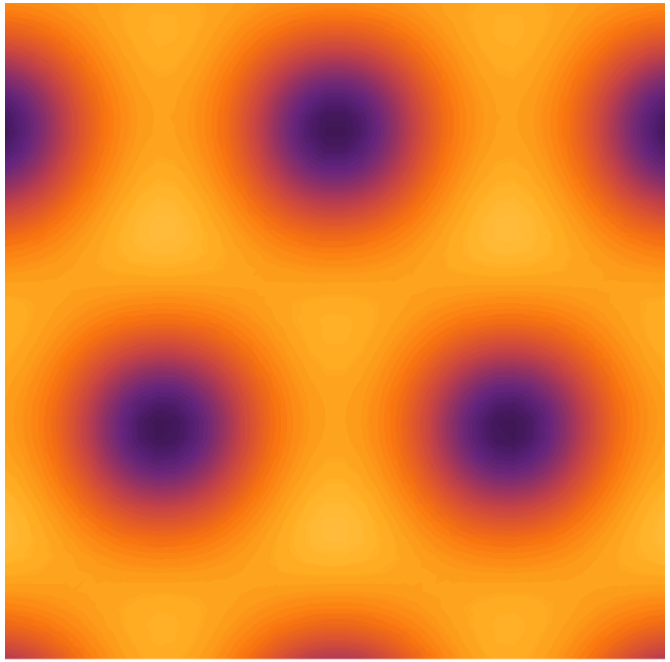


$$P(\mathbf{k}) = \oint_{z<0} \frac{dz}{2\pi i} \frac{1}{z - h(\mathbf{k}) - V_M} = \oint \frac{dz}{2\pi i} \left(\frac{1}{z - h(\mathbf{k})} + \frac{1}{z - h(\mathbf{k})} V_M \frac{1}{z - h(\mathbf{k})} + \ldots \right) \quad \propto \frac{V_M}{4V} \frac{e^2}{\epsilon_\perp |\mathbf{G}_M|}$$

Stability through Electrostatics

- To pin and stabilize the C=1 insulator, we inspect its density

$\rho_{C=1}(\mathbf{r})$

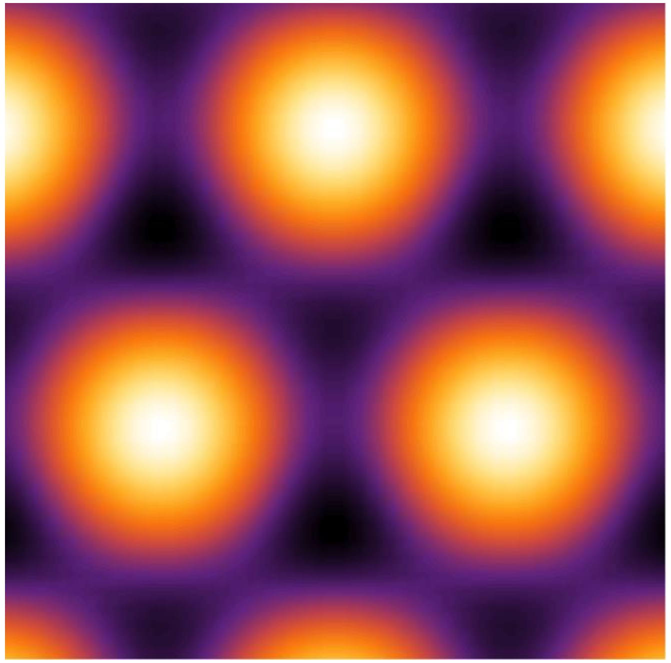


smooth rhombo parent band

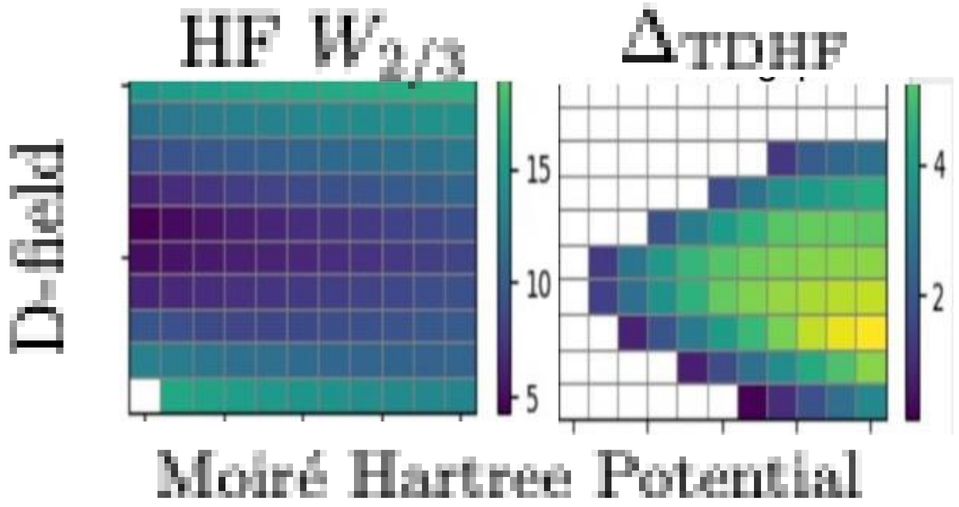
$$c^\dagger_{\mathbf{k}} = \sum_\alpha U_\alpha(\mathbf{k}) c^\dagger_{\mathbf{k},\alpha}$$

$$\gamma^\dagger_{\mathbf{k},C} = \sum_{\mathbf{G}} f(\mathbf{k}+\mathbf{G}) e^{iC\theta(\mathbf{k}+\mathbf{G})} c^\dagger_{\mathbf{k}+\mathbf{G}}$$

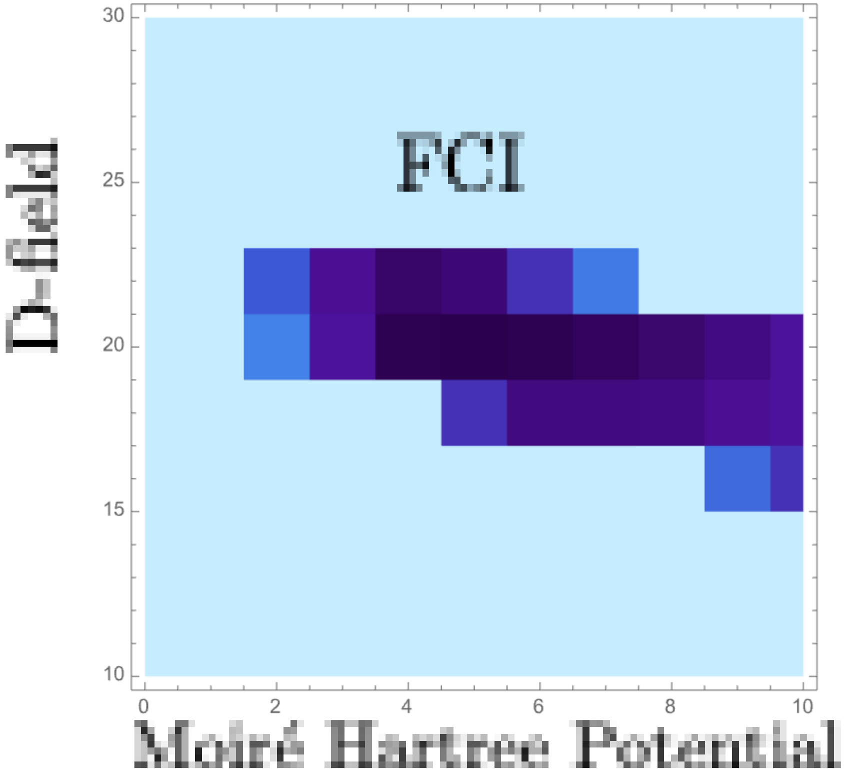
$\rho_{\text{valence}}(\mathbf{r})$

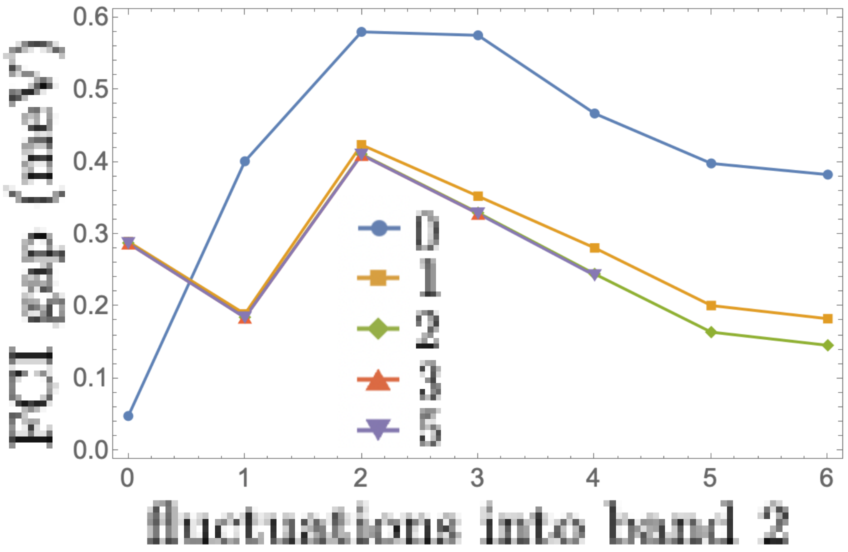


Quantitative Theory of multi-band FCIs



Large-scale multi-band ED calculations at nu=2/3 (Hilbert space > 100mil)





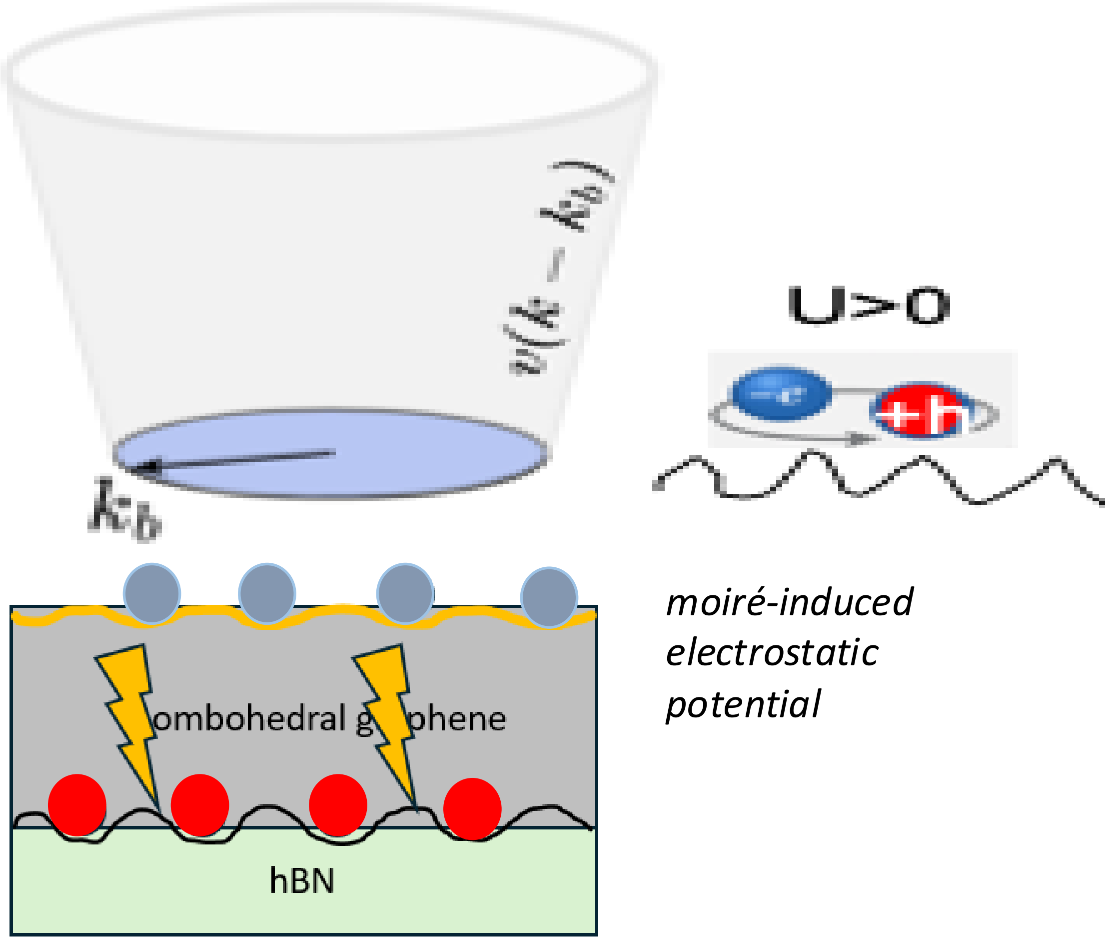
"fluctuating" Laughlin state

- 30% density outside C=1 band at K point

- Band-mixing *strengthens* the FCI

Chern Number of the CI: same sign as the Berry Curvature inside the Berry Trashcan

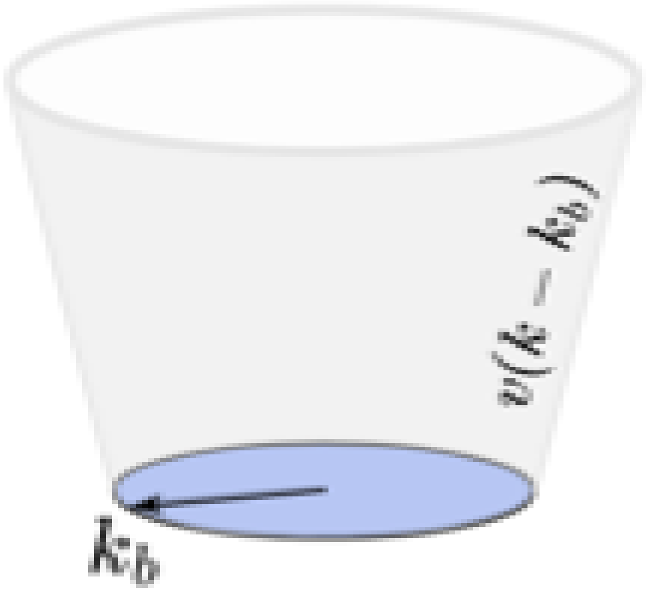
Before gapping

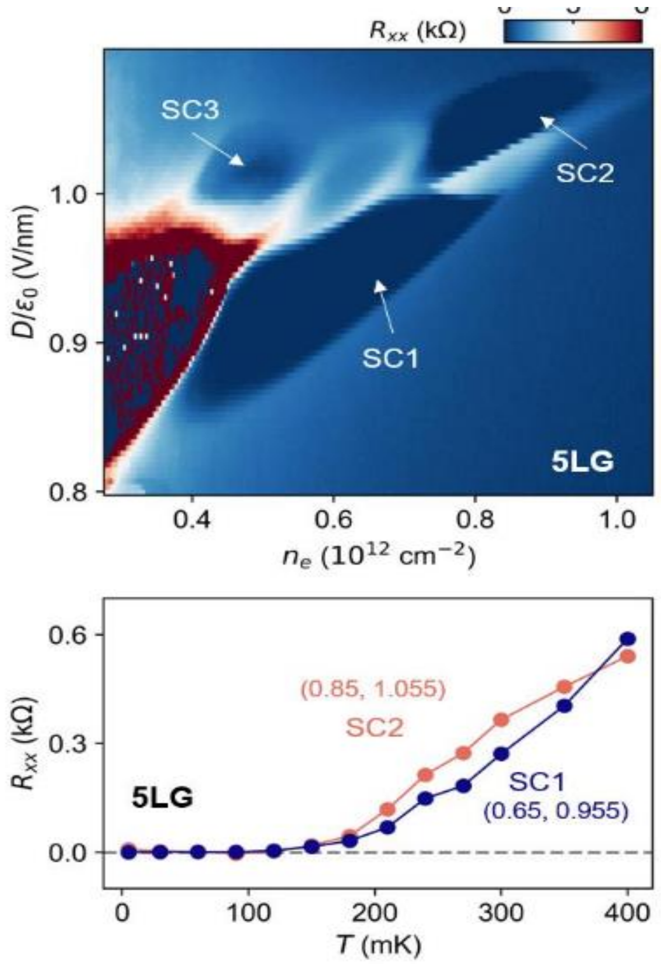


Next Step: A Fully Analytical Theory of Time Dependent Hartree Fock of the Berry trashcan should show:

1. Instability Without Moire
2. Stability With Moire + which factors are essential.

Moire-less samples show superconductivity





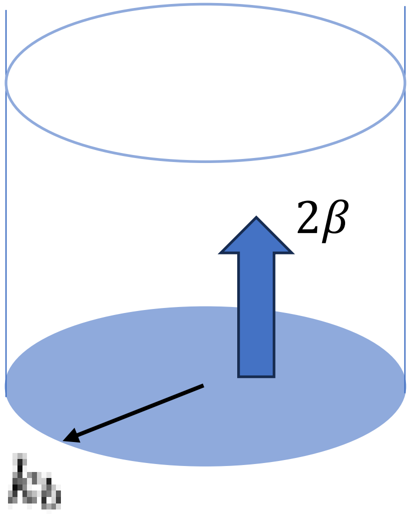
1. Superconductivity for same density as Berry Traschan bottom
2. Implies same polarization of 4 valley/spin into 1
3. Implies single flavor, finite momentum superconductivity

??????

4. What is the origin of the attraction (remember we start w repulsive interactions - valley/spin polarization)
5. What superconductivity does the Berry Traschan exhibit with attraction?

Berry Trashcan Attractive Model

- $v_F \to \infty$ (confinement to flat circular trashcan bottom of radius k_b)



GMP form factors

$$H = \frac{1}{2\Omega_{tot}} \sum_{\boldsymbol{q},\boldsymbol{k},\boldsymbol{k}'} V_{\boldsymbol{q}} M_{\boldsymbol{k},\boldsymbol{q}} M_{\boldsymbol{k}',-\boldsymbol{q}} \gamma^\dagger_{\boldsymbol{k}+\boldsymbol{q}} \gamma^\dagger_{\boldsymbol{k}'-\boldsymbol{q}} \gamma_{\boldsymbol{k}'} \gamma_{\boldsymbol{k}}$$

$$V_{\boldsymbol{q}} = U e^{-(\alpha-|\beta|)q^2}$$

U<0

$$\frac{1}{2\Omega_{tot}} \sum_{\boldsymbol{q},\boldsymbol{k},\boldsymbol{k}'} e^{-\alpha \boldsymbol{q}^2 - i\beta(\boldsymbol{q}\times(\boldsymbol{k}-\boldsymbol{k}'))} \gamma^\dagger_{\boldsymbol{k}+\boldsymbol{q}} \gamma^\dagger_{\boldsymbol{k}'-\boldsymbol{q}} \gamma_{\boldsymbol{k}'} \gamma_{\boldsymbol{k}}$$

For $\alpha = \beta$ interaction $V_q = -const$ is onsite **attraction** in real-space

Put in BY HAND. Still (1) system superconducts or phase separates? (2) what superconductivity k_x, k_y, $k_x + I k_y$, $k_x - I k_y$, $(k_x + I k_y)^3$, $(k_x - I k_y)^3$ etc

Exact Solution Berry Trashcan Attractive Model

Exact solution for 2-electron GS is chiral p-wave pair (angular momentum $m = 1$)

$$\hat{O}_2 = \sum_{\boldsymbol{k}} k_+^m e^{-\alpha|\boldsymbol{k}|^2} \hat{\gamma}_{\boldsymbol{k}}^\dagger \hat{\gamma}_{-\boldsymbol{k}}^\dagger$$

$k_+ = k_x + ik_y$

Ansatz for more electrons:

$$|\phi_{2N}^A\rangle \propto O_{2,m=1}^{\dagger N}|\text{vac}\rangle$$

$$|\phi_{2N+1}^A\rangle \propto \gamma_0^\dagger O_{2,m=1}^{\dagger N}|\text{vac}\rangle$$

Chirality of the superconductor is identical to the chirality of the Chern insulator in Moire

More non-trivially: To the first order of αk_b^2:

***Exact restricted spectrum-generating algebra** of order 1*

(RSGA-1)

$$R_q = \sum_{k}^{\{k,k-q\}} k_{-}\gamma_{q-k}\gamma_{k},$$

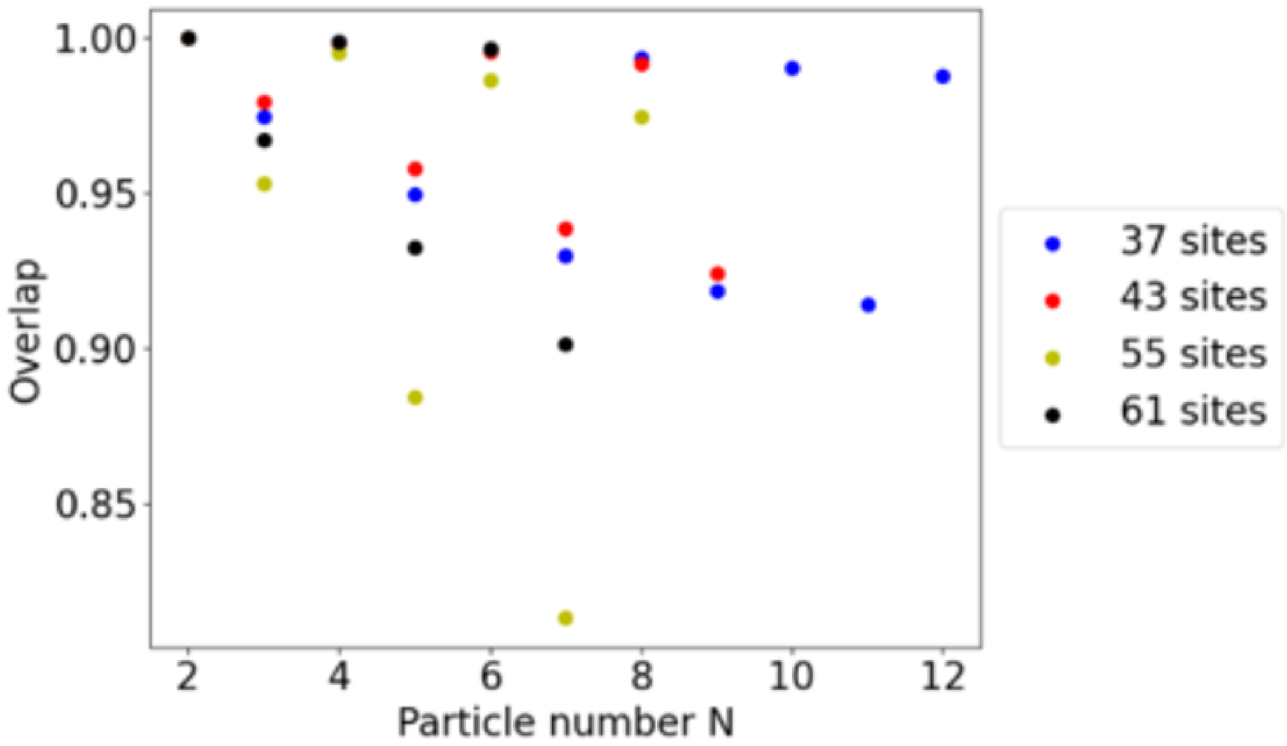
$$\hat{H}^{\rm int} \approx \frac{\alpha U}{\Omega_{\rm tot}} \sum_q R_q^\dagger R_q$$

$O_2 = R_0$

$$[\hat{H}^{\rm int}, \hat{O}_2^\dagger]|{\rm vac}\rangle = E_2 \hat{O}_2^\dagger |{\rm vac}\rangle$$

$$[[\hat{H}^{\rm int}, \hat{O}_2^\dagger], \hat{O}_2^\dagger] = 0,$$

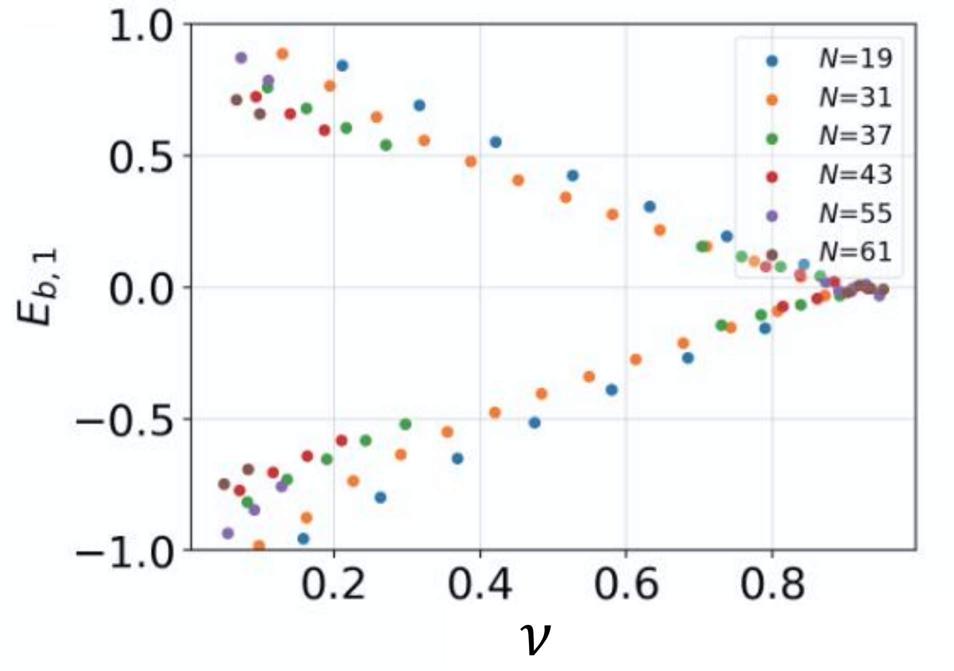
overlap of ansatz with ED wavefunction



Evidence for superconductivity: binding energies

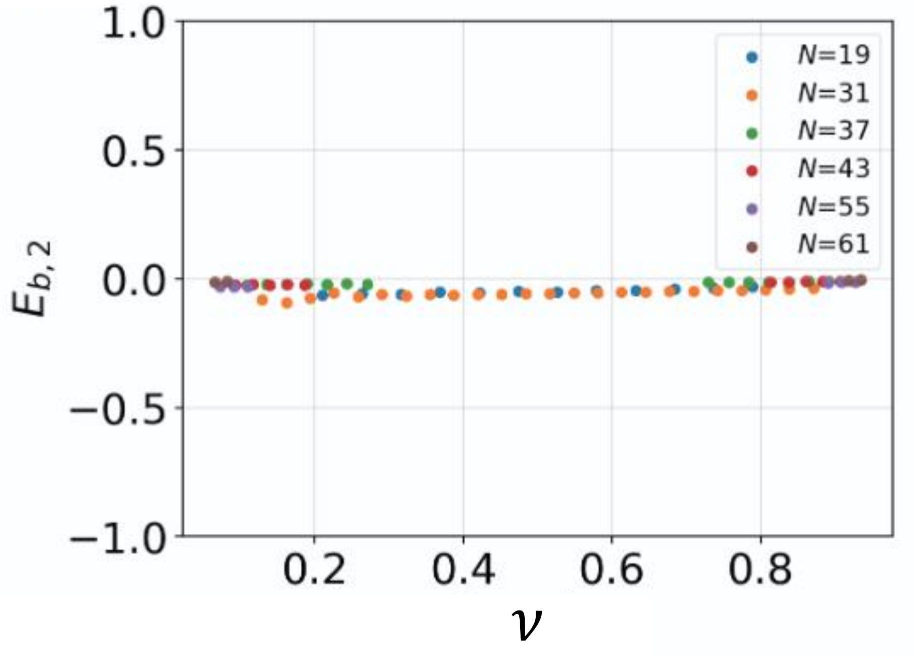
$$E_{b,m}(N_e) \equiv E(N_e - m) + E(N_e + m) - 2E(N_e)$$

Even/odd effect in $E_{b,1}$ corresponds to binding into 2e pairs



filling of trashcan bottom

$E_{b,2} \rightarrow 0$ corresponds to condensation of 2e pairs

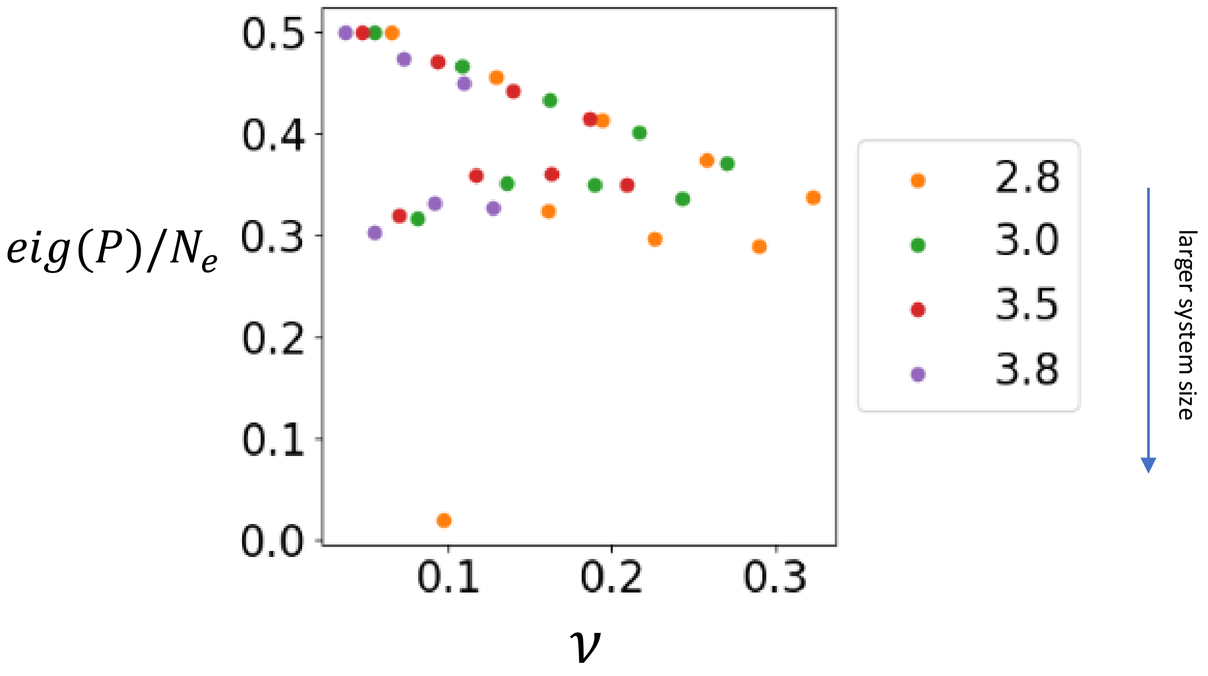


all ED calculations performed on system with $\frac{\pi}{2}$ Berry flux

Evidence for superconductivity: off-diagonal long-range order

$$P_{\boldsymbol{k},\boldsymbol{k}'} = \frac{\langle GS|\psi_{\boldsymbol{k}}\psi_{-\boldsymbol{k}}\psi^\dagger_{-\boldsymbol{k}'}\psi^\dagger_{\boldsymbol{k}'}|GS\rangle}{\langle GS|GS\rangle}$$

superconductivity implies that P/N_e has finite eigenvalue in thermodynamic limit

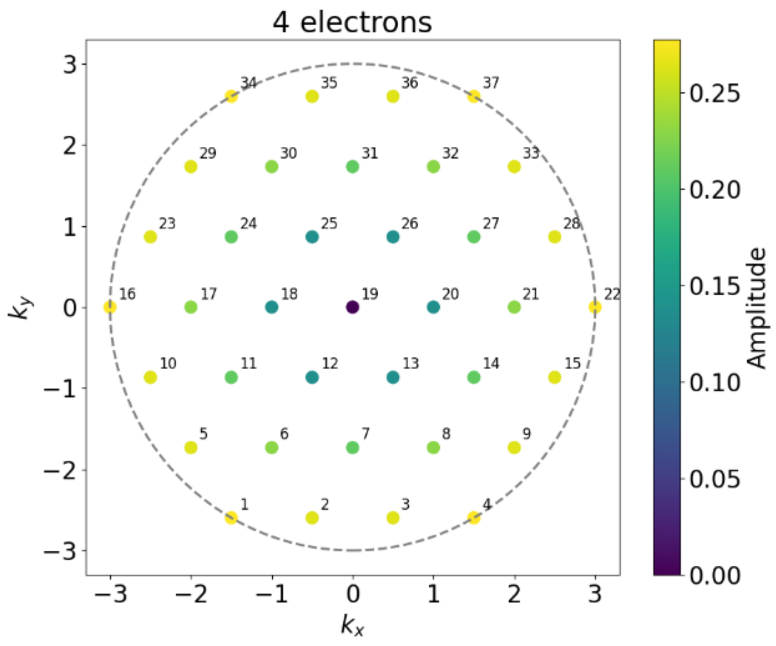


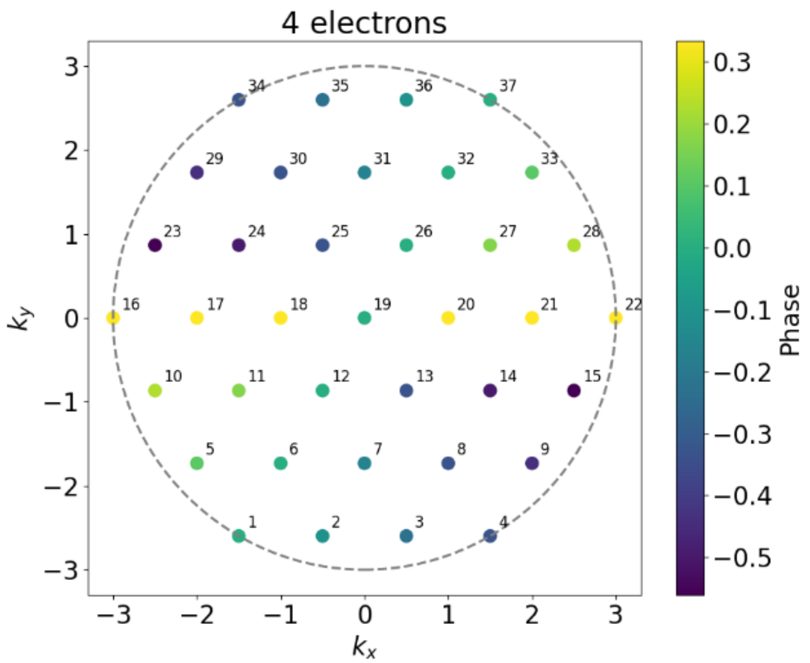
only showing highest eigenvalue of P

Evidence for superconductivity: off-diagonal long-range order

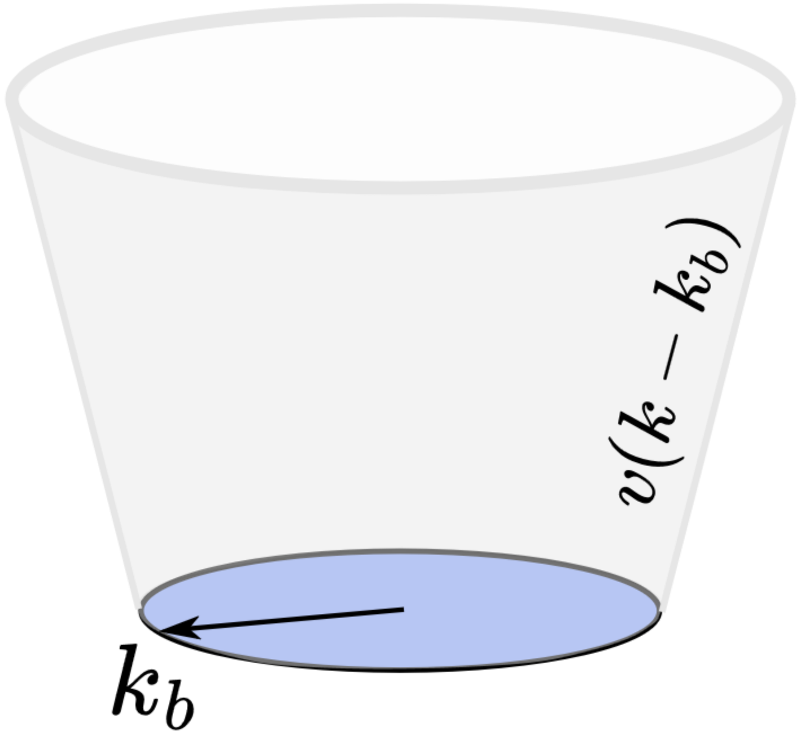
$$P_{\boldsymbol{k},\boldsymbol{k'}} = \frac{\langle GS|\psi_{\boldsymbol{k}}\psi_{-\boldsymbol{k}}\psi^\dagger_{-\boldsymbol{k'}}\psi^\dagger_{\boldsymbol{k'}}|GS\rangle}{\langle GS|GS\rangle}$$

pairing eigenvector consistent with chiral p-wave





Where is the attraction coming from?



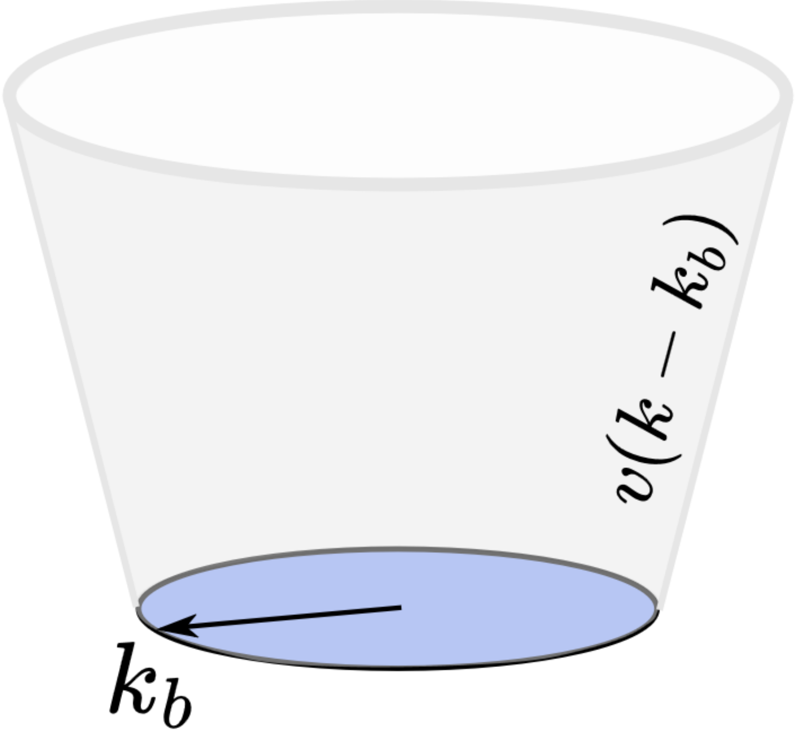
If Berry trashcan model is correct

1. Luttinger Kohn not favored
2. Hence spin fluctuations or
3. Phonons

How to overcome Coulomb?

Turns out there is a large degeneracy with just Coulomb
Attraction can act in this space

Berry Trashcan model



futire directions:

- add moiré potential
  → connect to R*n*G/hBN and FCI physics
- relax symmetries and assumptions
  → improve quantitative agreement
- obtain collective modes analytically
  → understanding of local stability (important for FCI!)
- exact diagonalization of Wigner crystals
  → stability beyond mean-field
- superconductivity (see next)

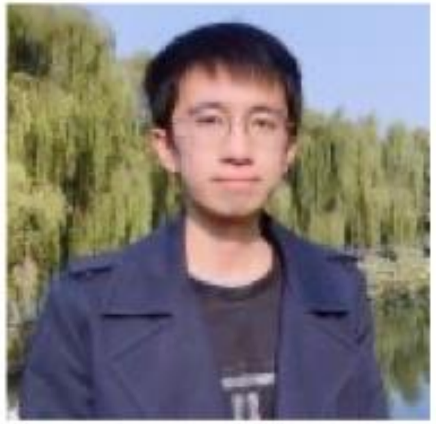
Jonah Herzog-Arbeitman

Heqiu Li

Yves Kwan

Jiabin Yu

Nicolas Regnault



Mingrui Li

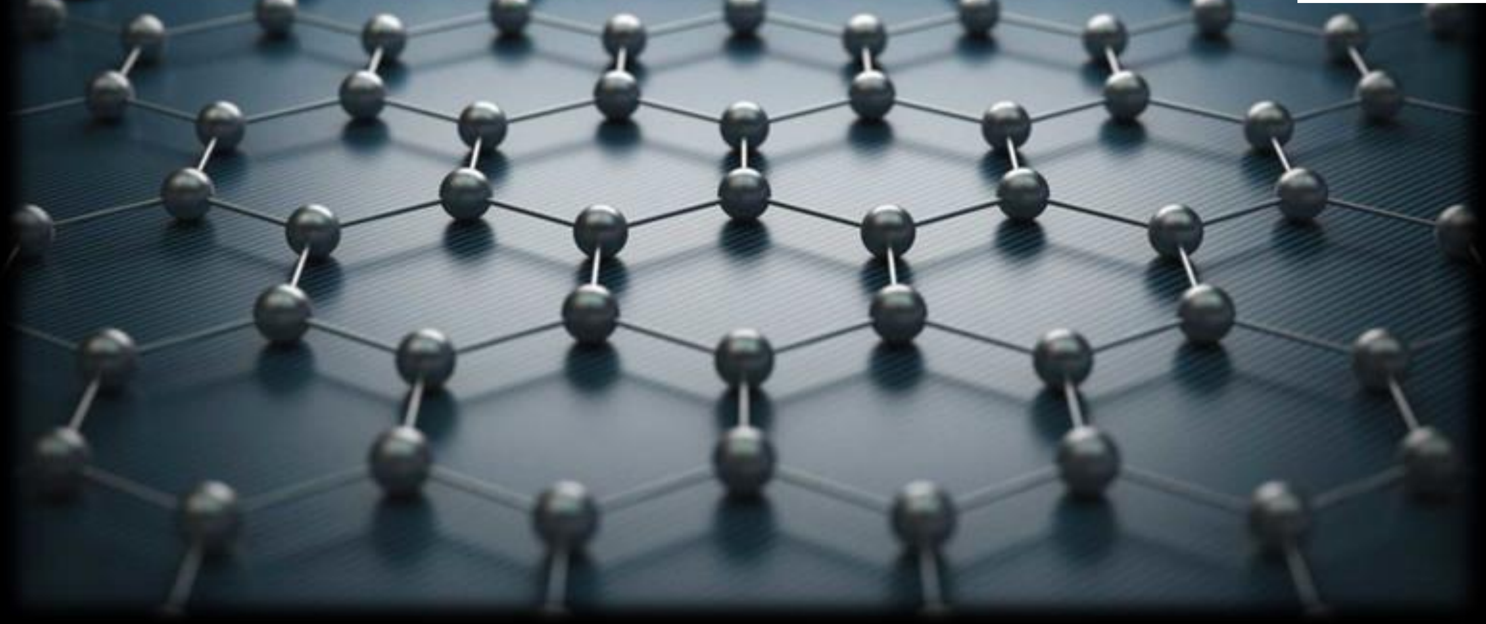
Andreas Feuerpfeil

Quansheng Wu,
Hongming Weng

New FTI collaboration
w Titus Neupert
group, G Wagner,
Andrea Dogino
Xiaobo Lu

Oskar Vafek

Frontiers in Quantum Material Engineering and Classification
The “Alchemists“ of Today



→ One atomic layer of carbon atoms
→ True 2D material
→ Scotch tape