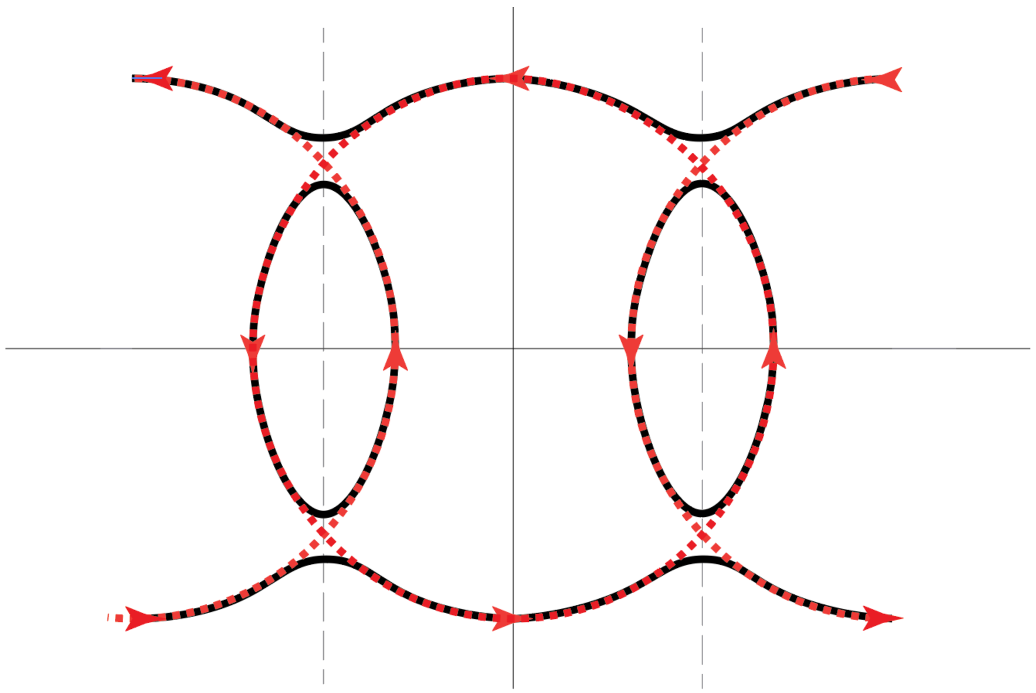
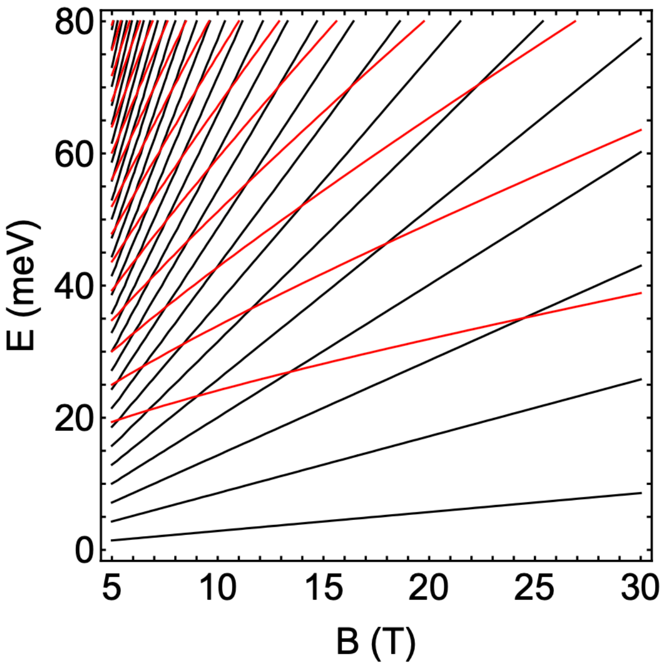


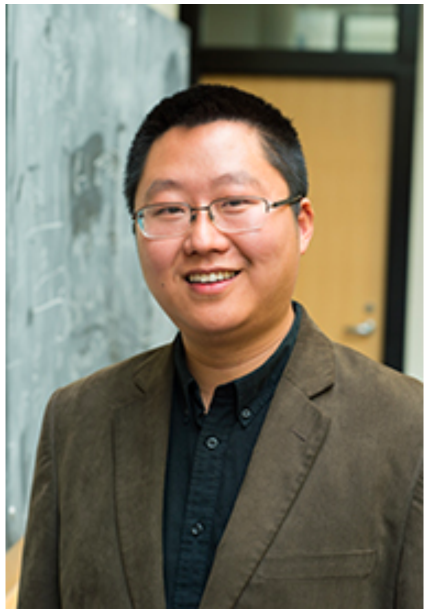


Moiré Landau fans and magic zeros

Capri Summer School 2022

Nisarga Paul

Phil Crowley, Trithep Devakul, Liang Fu



Phil Crowley

Trithep Devakul

Liang Fu

NP, PJD Crowley, T Devakul, L Fu, arXiv:2202.05854

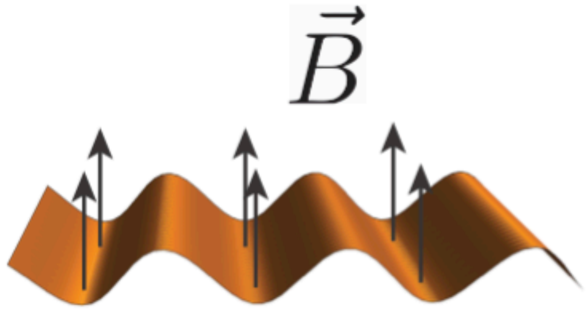
Setting

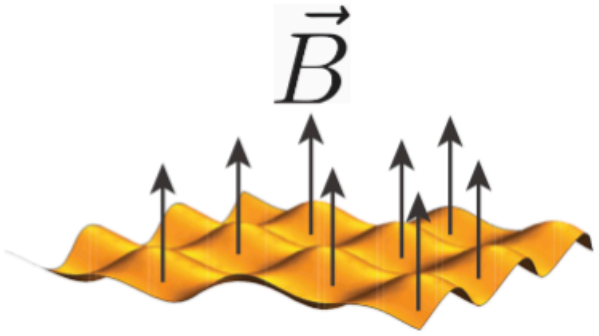
- Let us consider electrons in a moiré potential and magnetic field

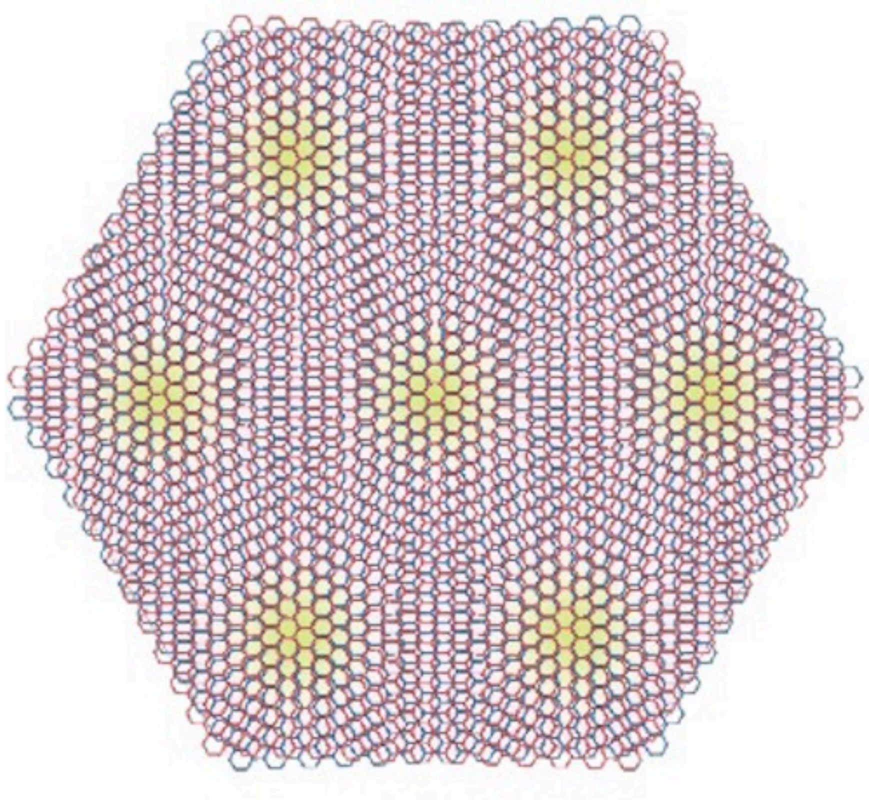
$$H = H_0(\mathbf{p} - e\mathbf{A}) + V(\mathbf{r})$$

- Let $V(\mathbf{r})$ be the periodic moiré effective potential

$$V(\mathbf{r}) = \sum_{\mathbf{q}} V(\mathbf{q}) e^{i\mathbf{q}\cdot\mathbf{r}} + c.c.$$





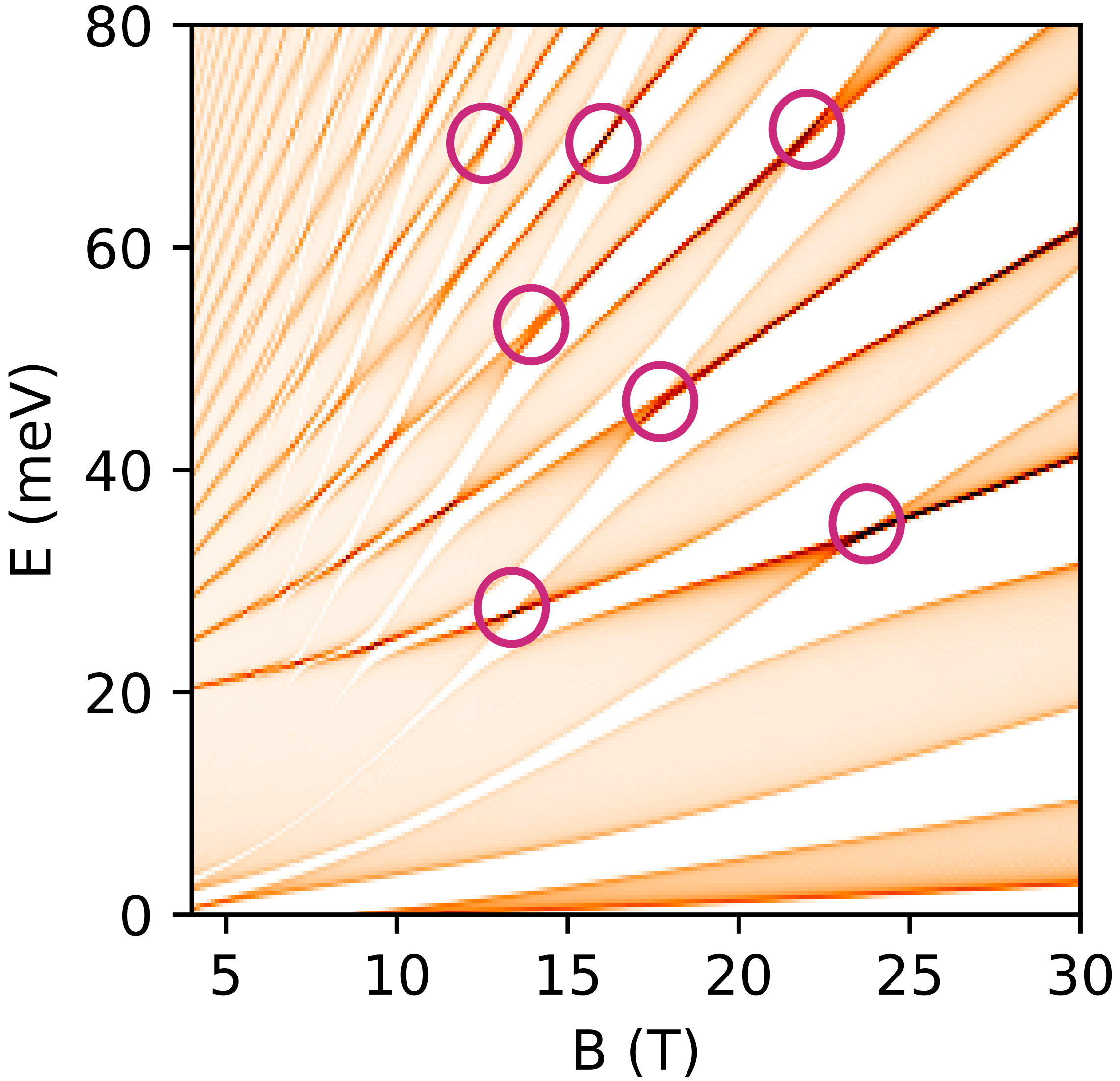


Exact diagonalization Landau spectrum

- Exact diagonalization spectrum for a simple case:

$$H = \frac{(\mathbf{p} - e\mathbf{A})^2}{2m} + V_0 \cos qx$$

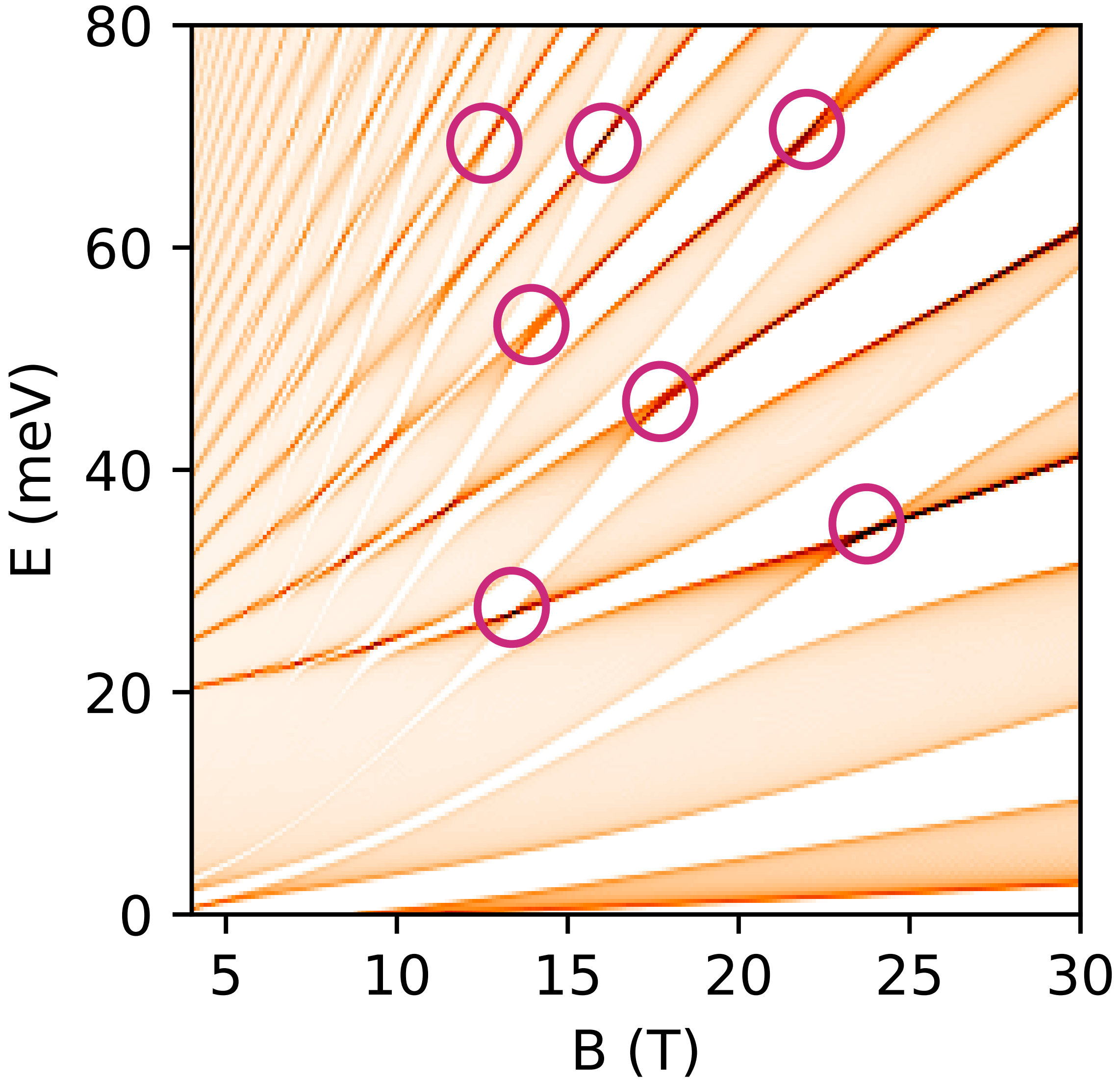
- Landau levels broaden but remain flat at discrete points



$V_0 = 15\ meV,\ m = 0.2 m_e,\ q = 2\pi/13\ nm^{-1}$

How robust are these flat bands?

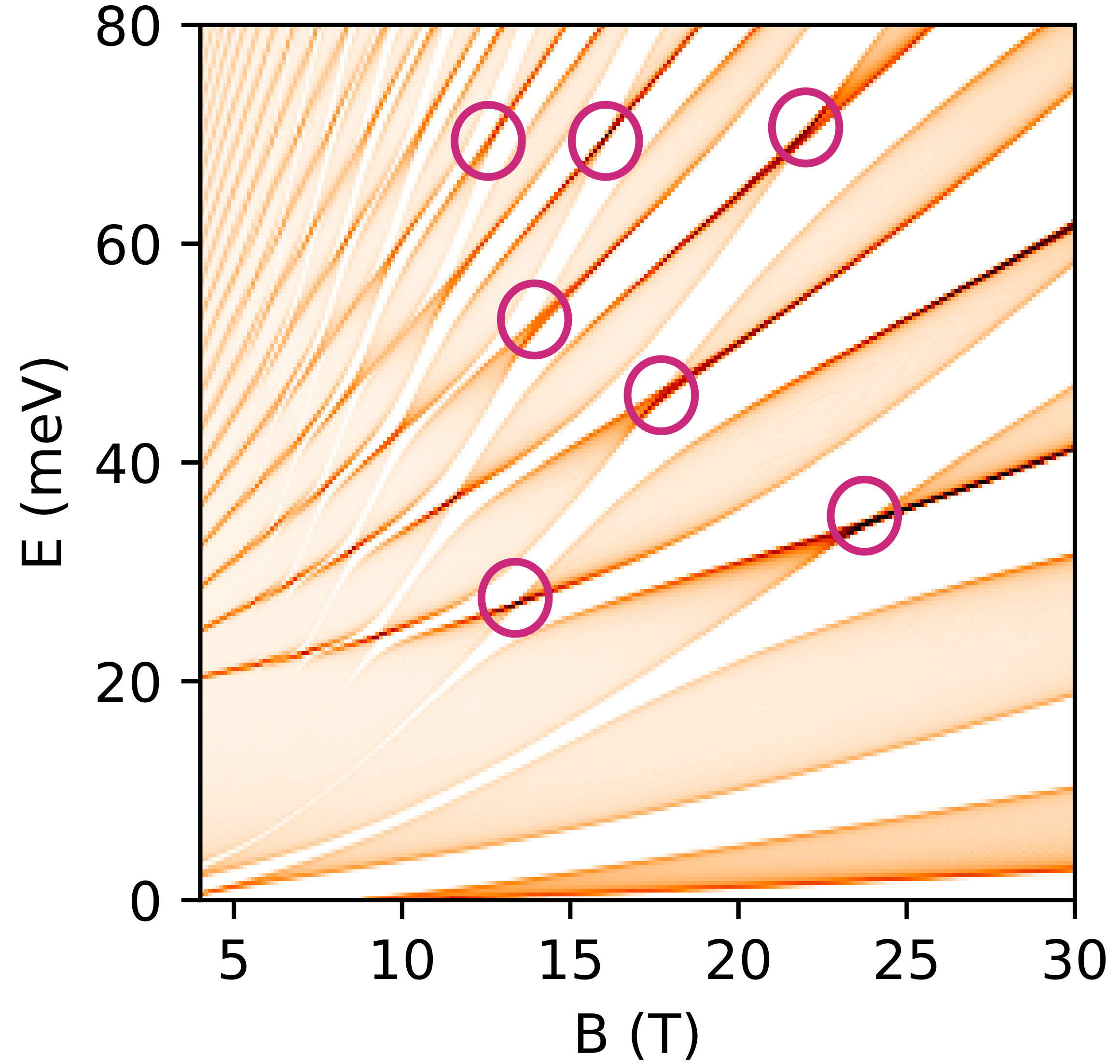
- Seen in perturbation theory ($V_0 \ll \omega_c$)
- Also nonperturbative (ED and semiclassics)
- Generic dispersion $H_0(\mathbf{p})$ (semiclassics)



$V_0 = 15\ meV,\ m = 0.2 m_e,\ q = 2\pi/13\ nm^{-1}$

Motivation: new setting for strong interactions

- Flat bands can host various strongly correlated phases
- Hilbert space of these flat bands generally distinct from Landau level subspace of free electrons
- Translation-symmetry-enriched FQH physics?
- Bandwidth easily tunable



$V_0 = 15\ meV,\ m = 0.2m_e,\ q = 2\pi/13\ nm^{-1}$

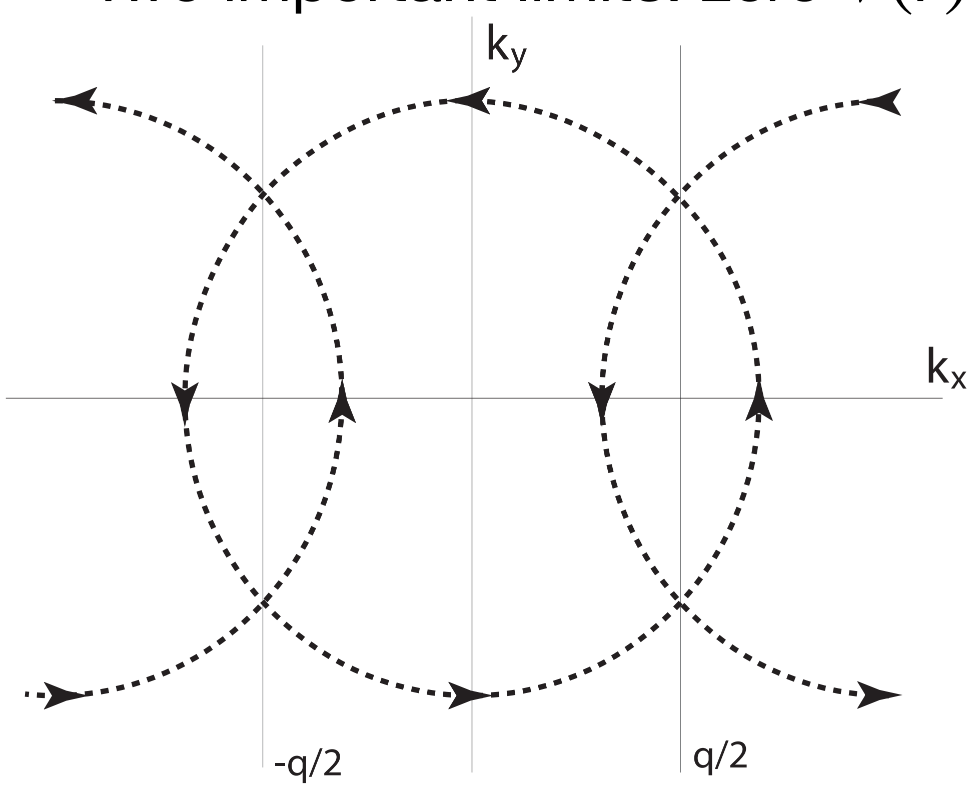
Semiclassical explanation of zeros

- Semiclassical equations of motion for a Bloch wavepacket:

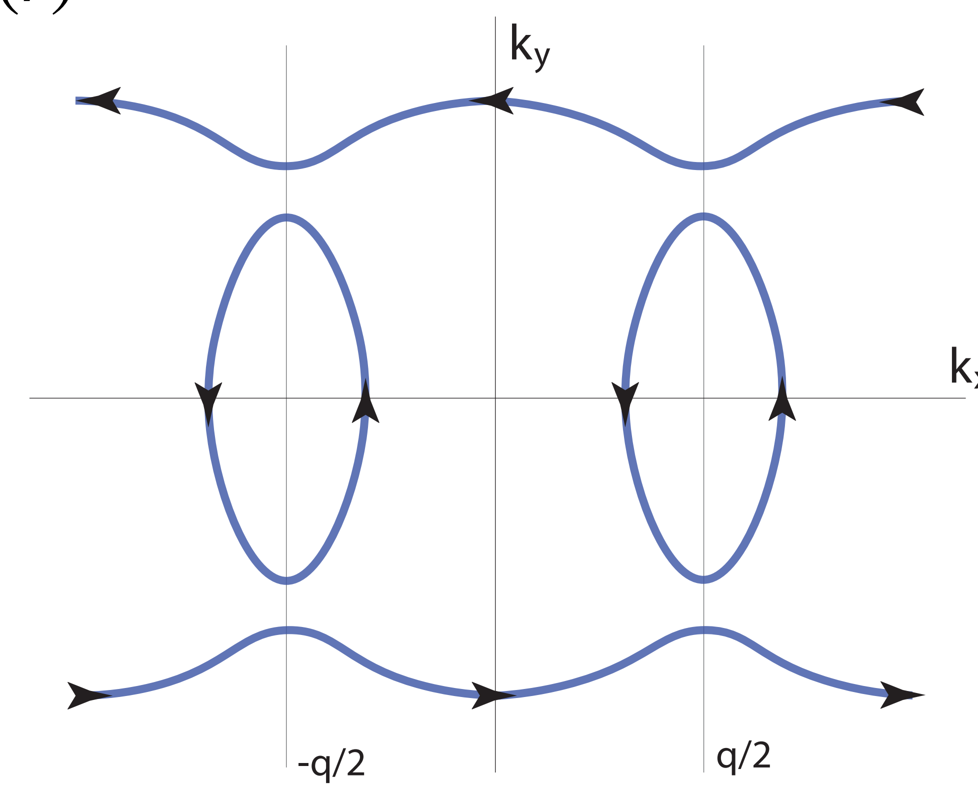
$$\dot{\mathbf{p}} = -e\dot{\mathbf{r}} \times \mathbf{B}$$
$$\dot{\mathbf{r}} = \nabla E(\mathbf{p})$$

- $E(\mathbf{p})$ includes the effect of periodic potential $V(r)$

- Two important limits: zero $V(r)$ and strong $V(r)$



$V(r) = 0$

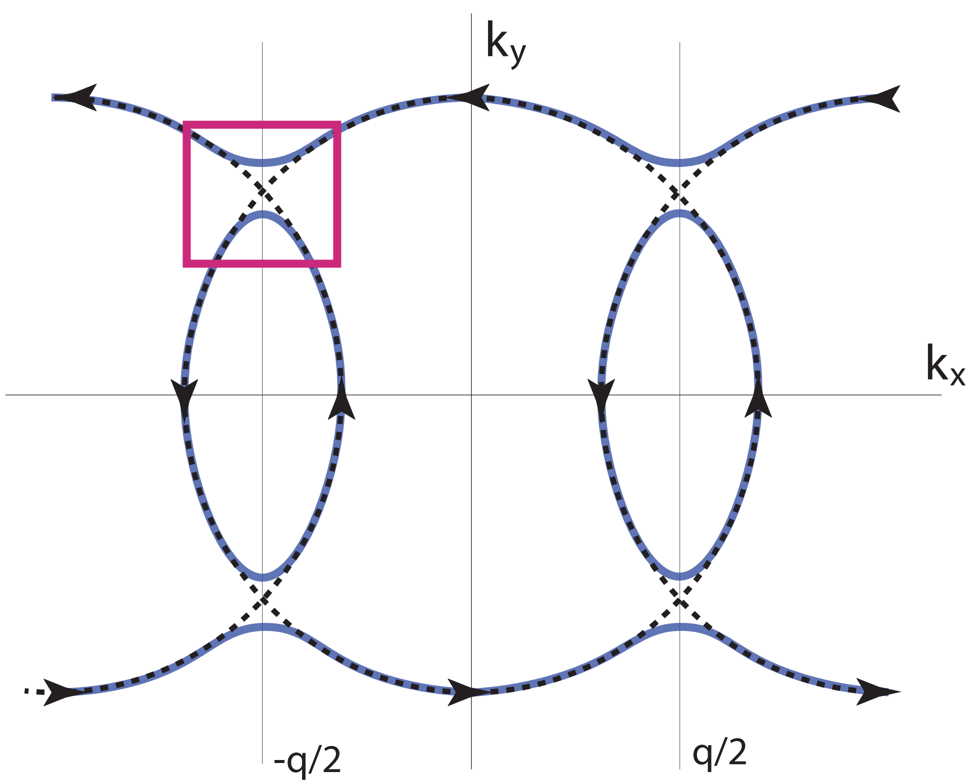


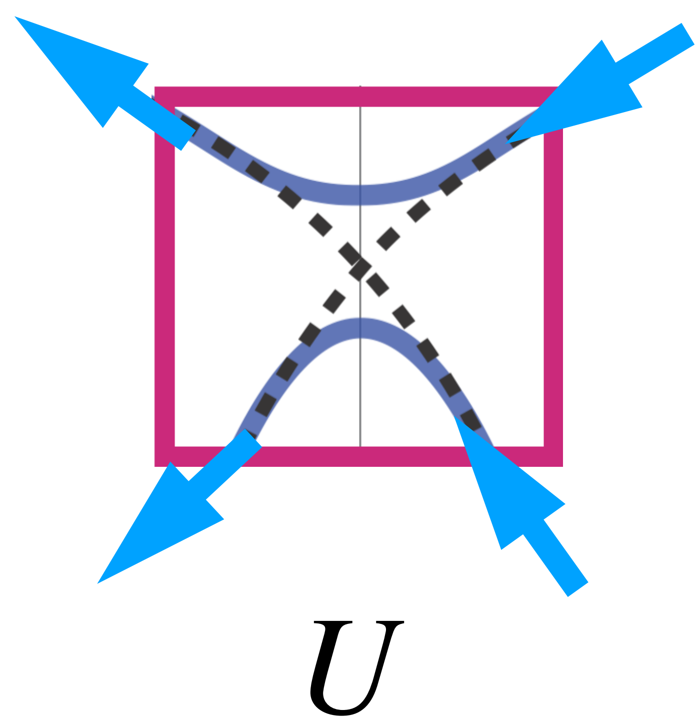
$V(r) \neq 0$

repeated zone scheme

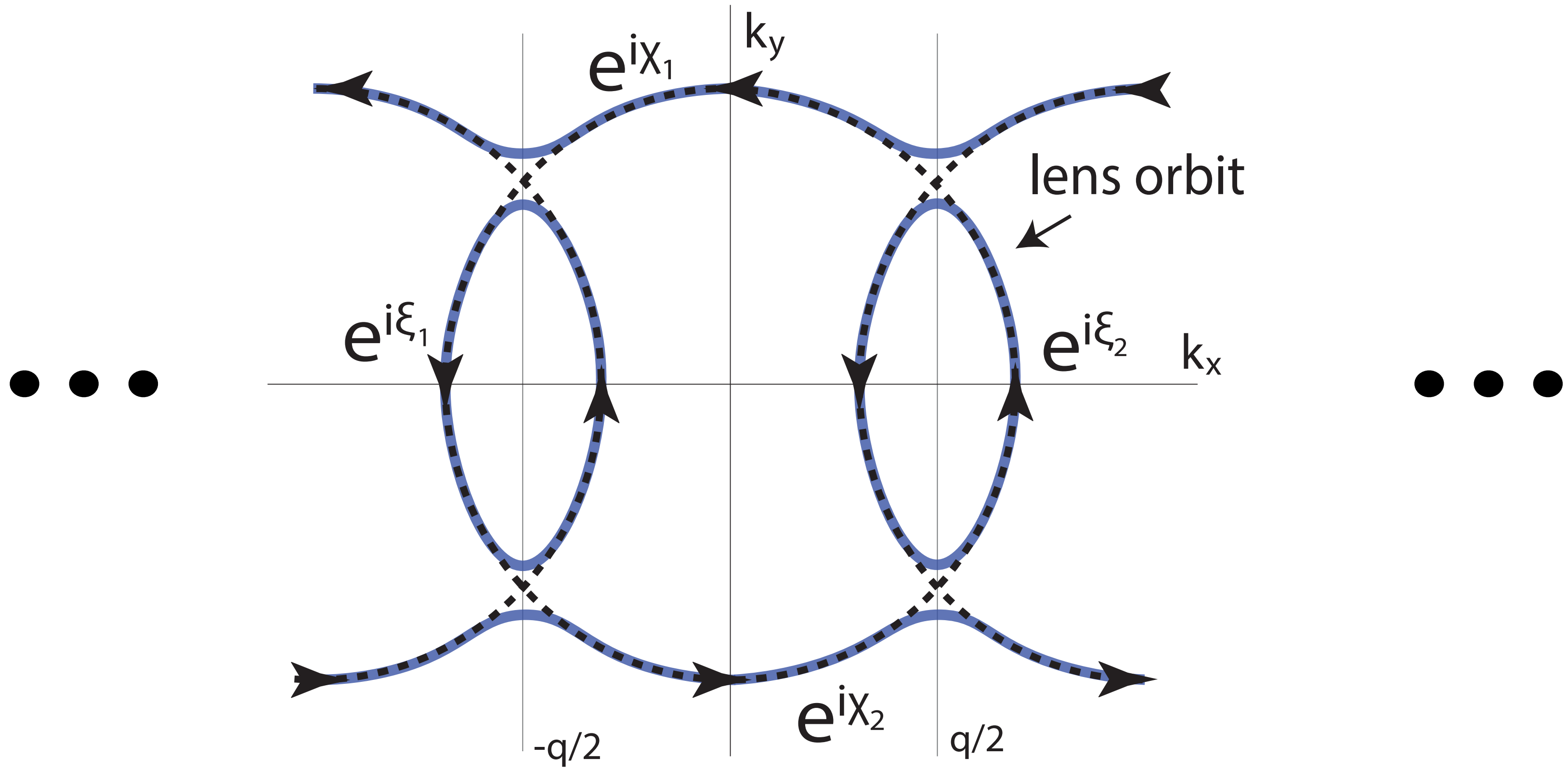
Magnetic breakdown

- The intermediate regime is $E_F \omega_c \sim V_0^2$
- In this regime, electrons near junctions may scatter
- We may treat each junction as a Landau-Zener crossing





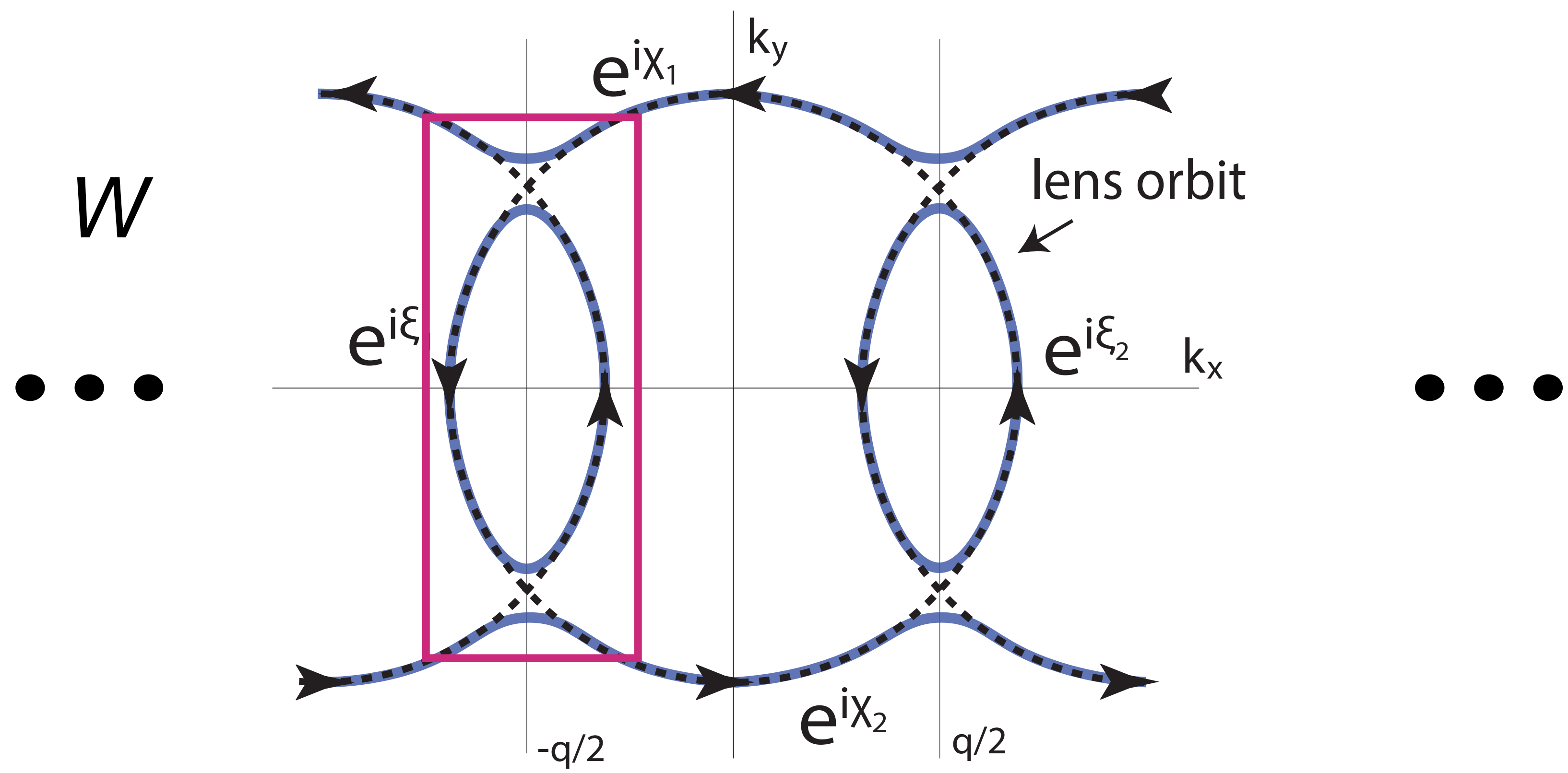
Network model



- Electrons propagate unidirectionally
- Scatter by U at junctions
- Pick up phases along links

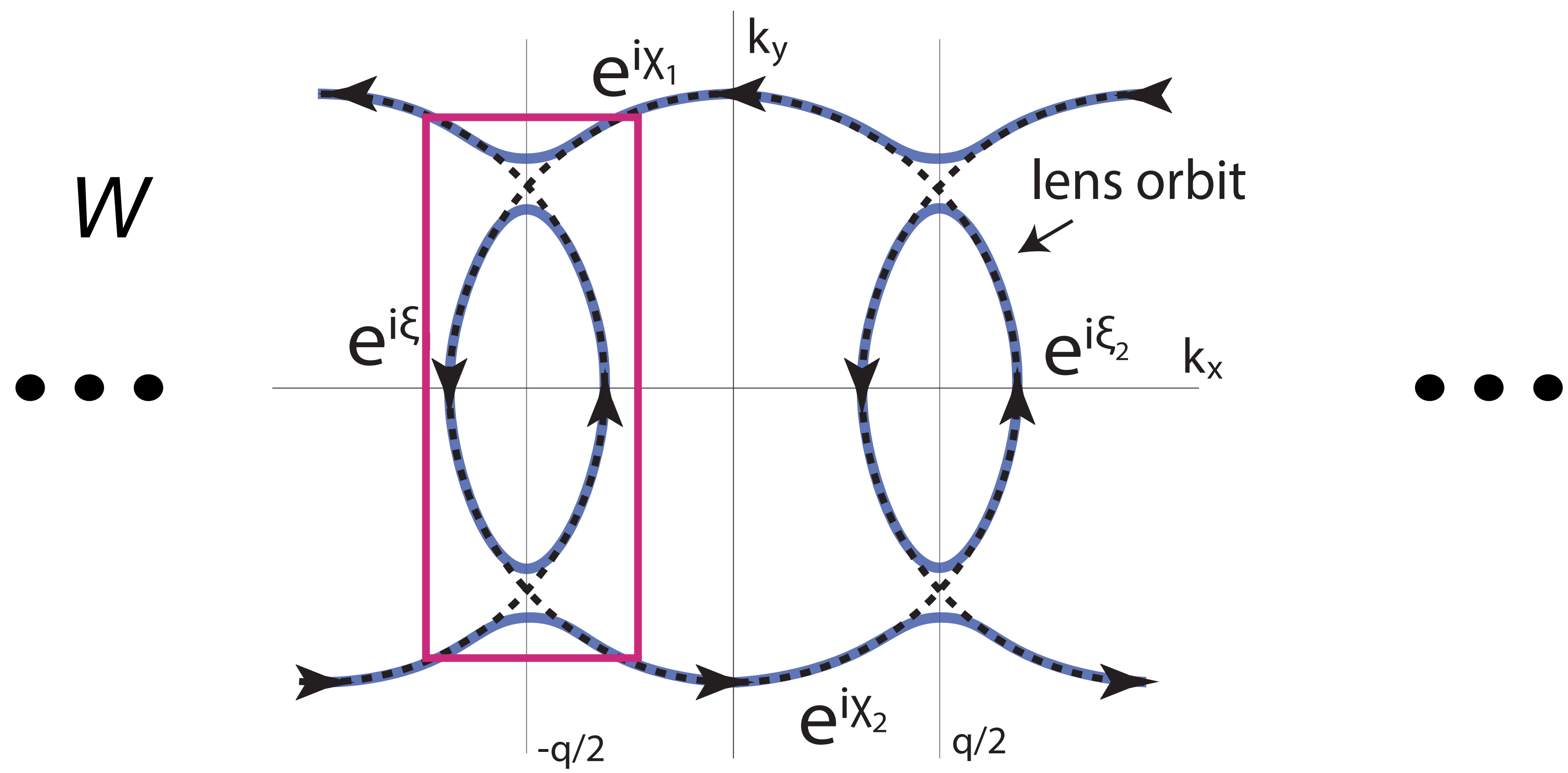
Pippard 1962

Network model, cont'd



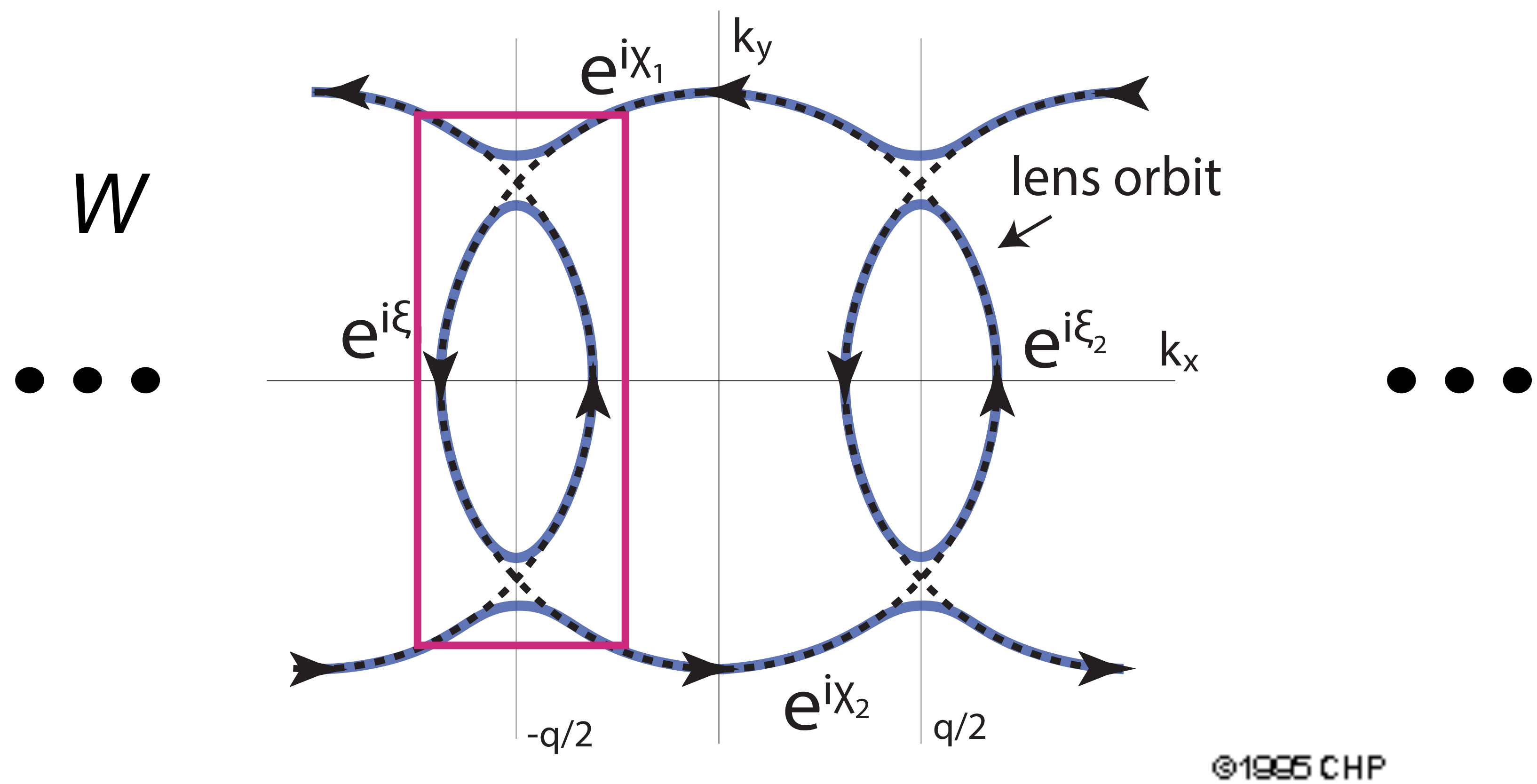
- Consider the scattering matrix W across lens orbit

Network model, cont'd



- Consider the scattering matrix W across lens orbit
- Key point: when W is diagonal, each zone decouples and network supports an extensive set of localized modes, i.e. a flat band

Network model, cont'd



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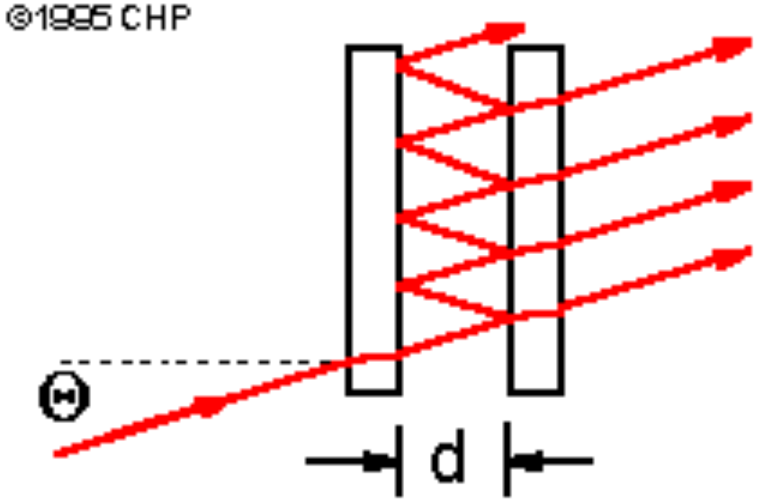
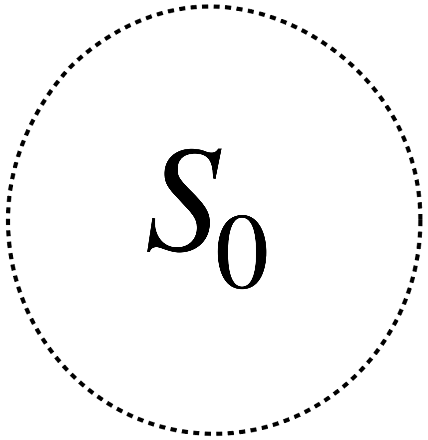


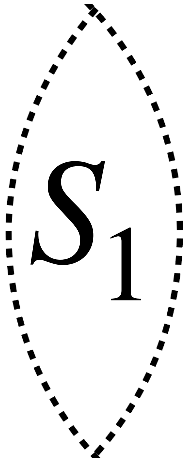
Fabry-Perot interferometer

Flat band conditions

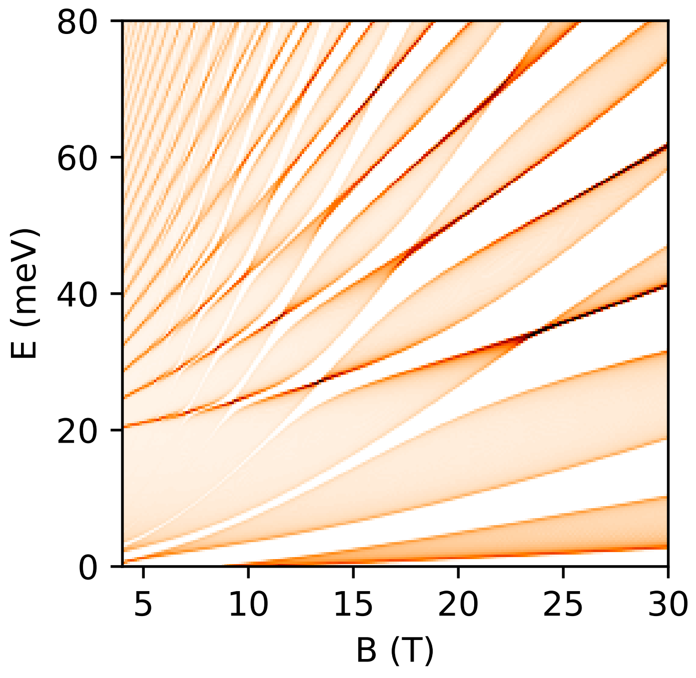


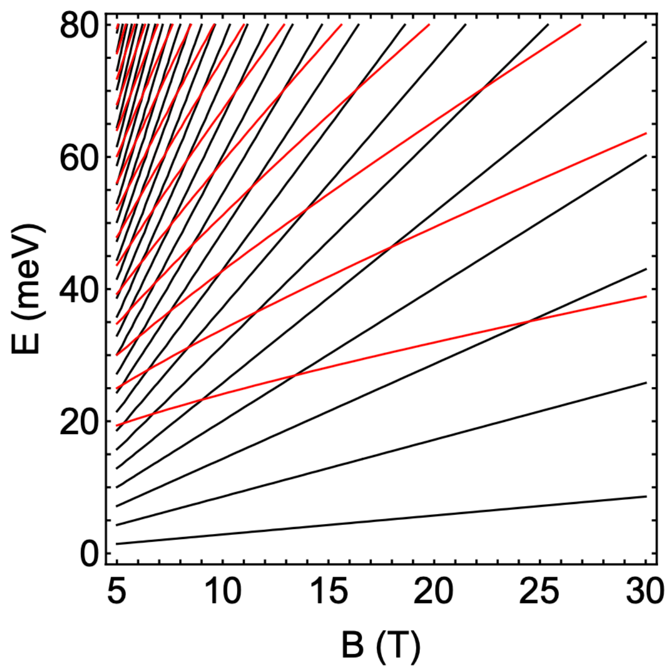
- The flat band conditions:

$$l_B^2 S_0 = 2\pi(n+\gamma)$$
$$l_B^2 S_1 = 2\pi(n'+\gamma)$$



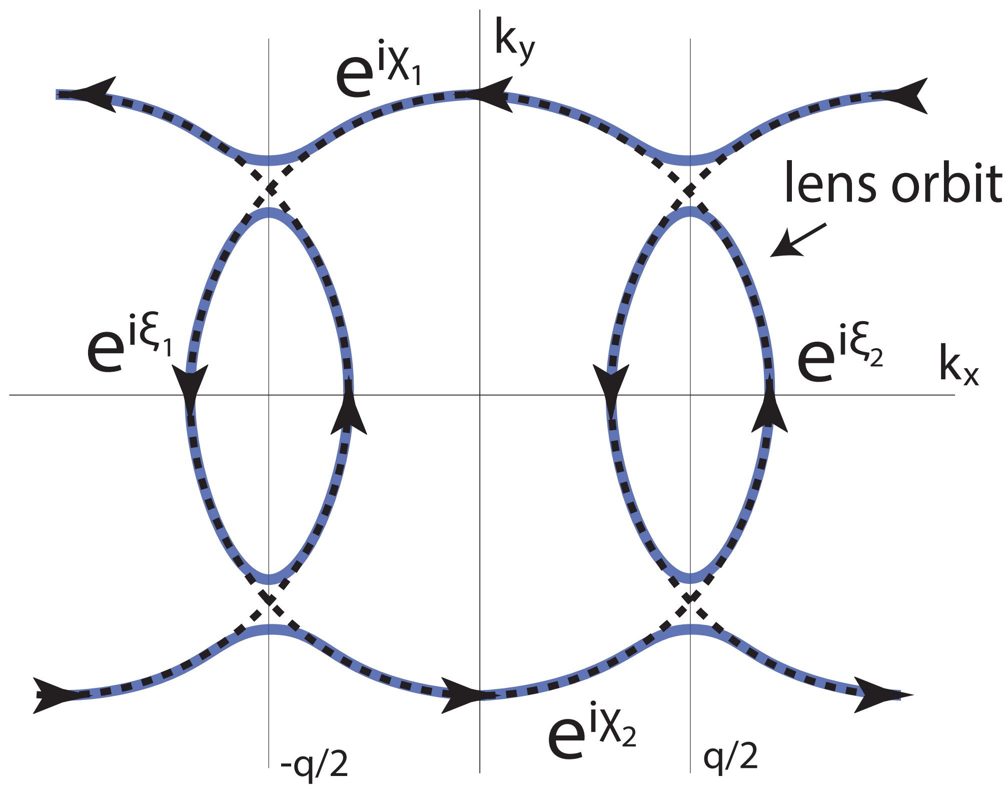
- The flat bands occur at the intersections of two Landau fans



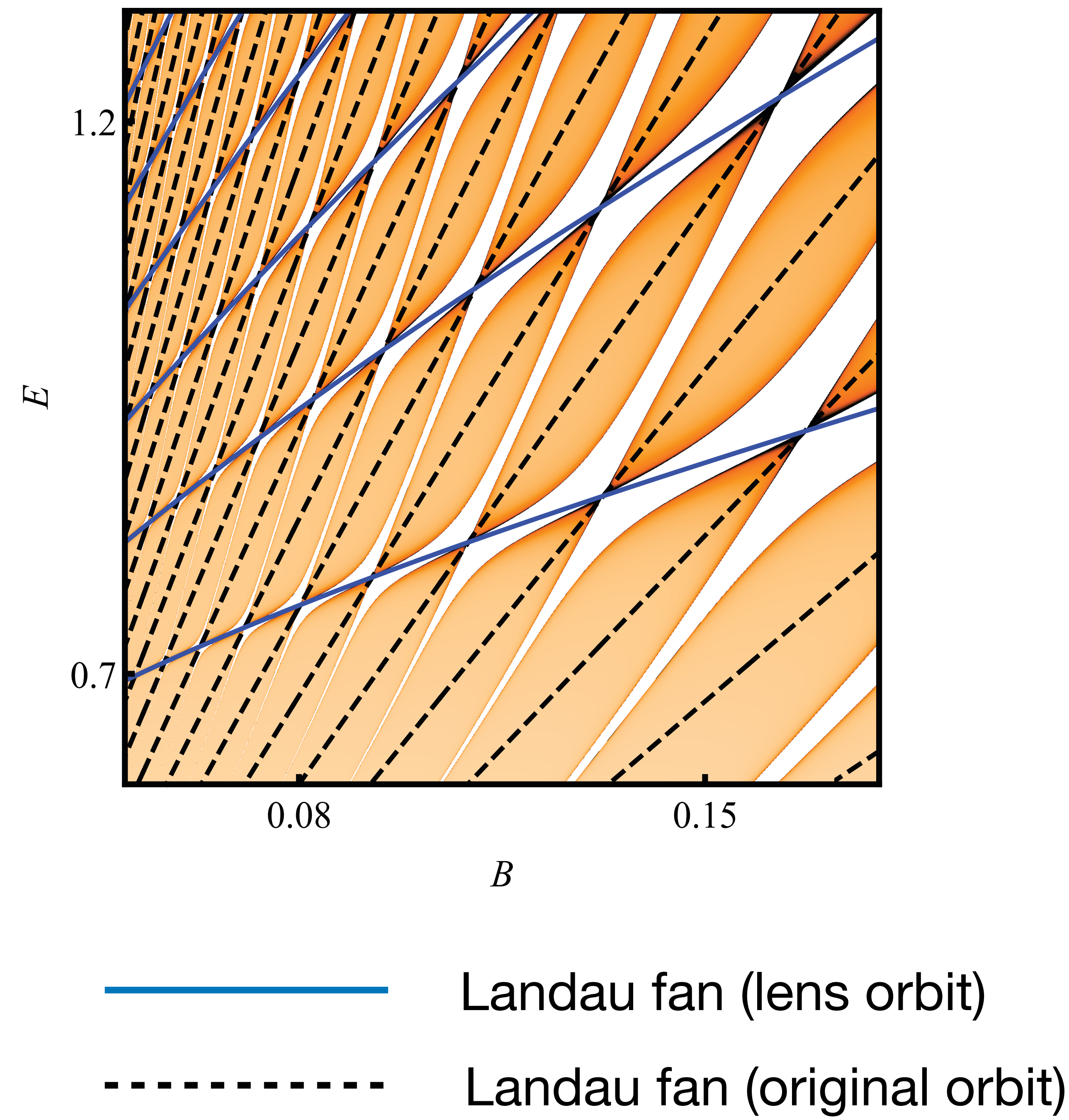


Network model

$$V(r) = V_0 \cos qx$$

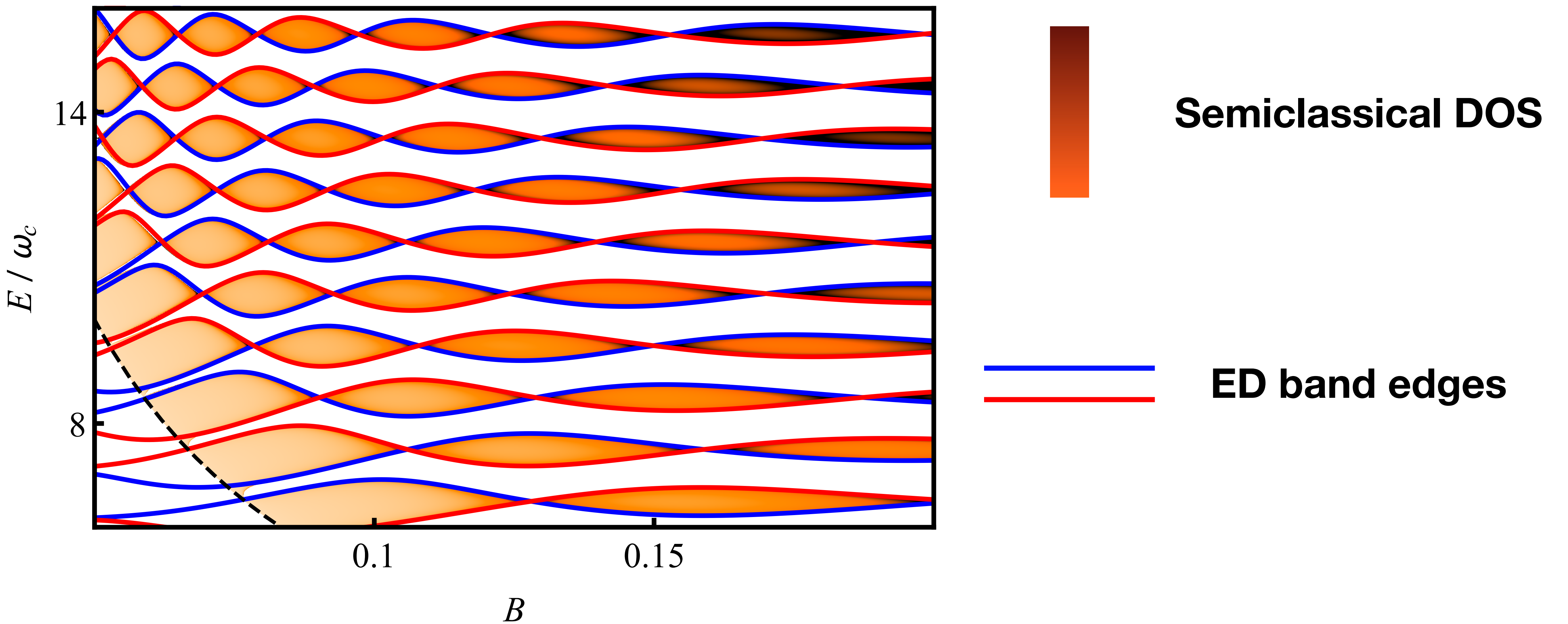


Semiclassical DOS

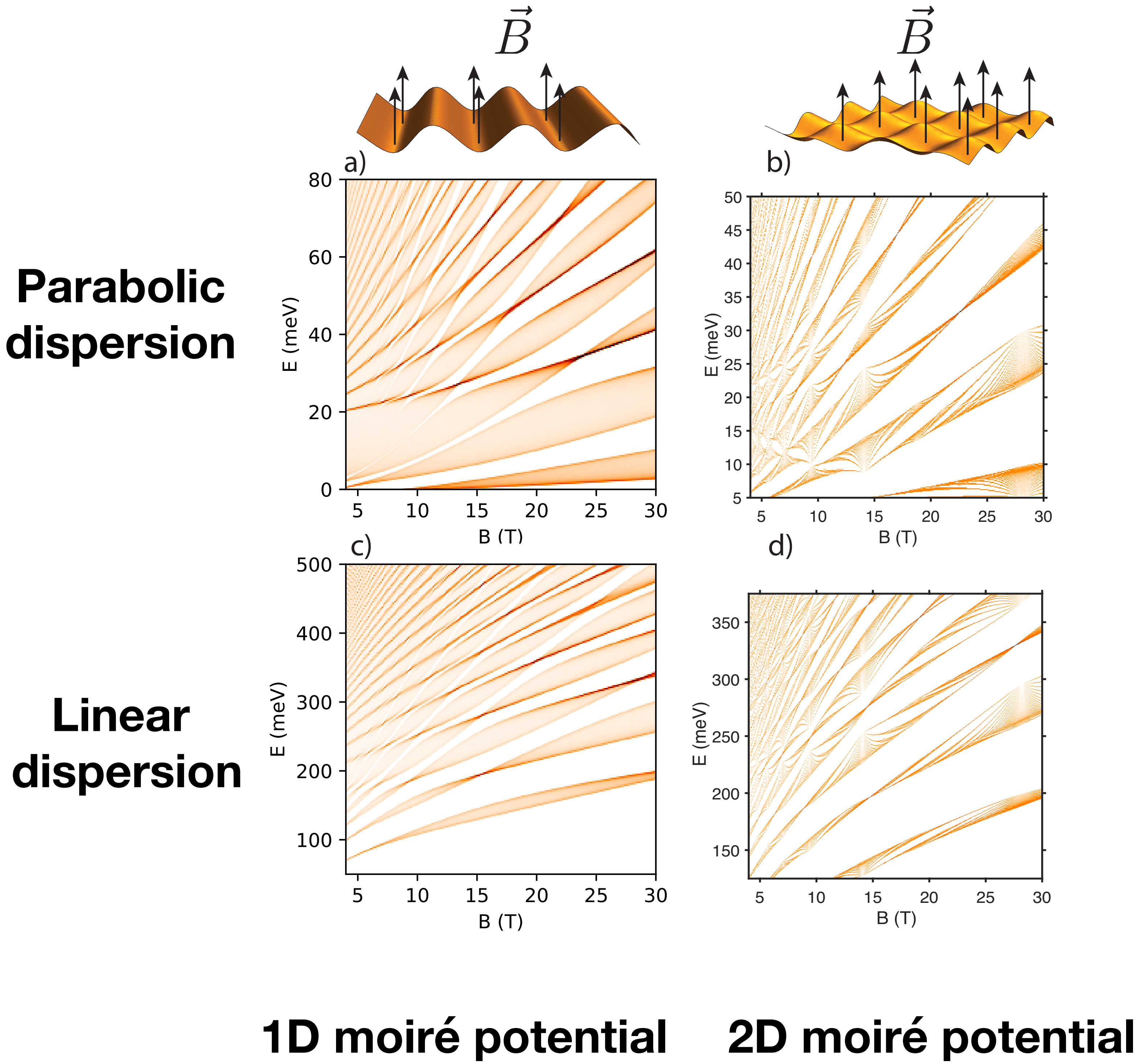


$V_0 = 0.4,\ \omega_c \sim 0.1,\ q = 2$

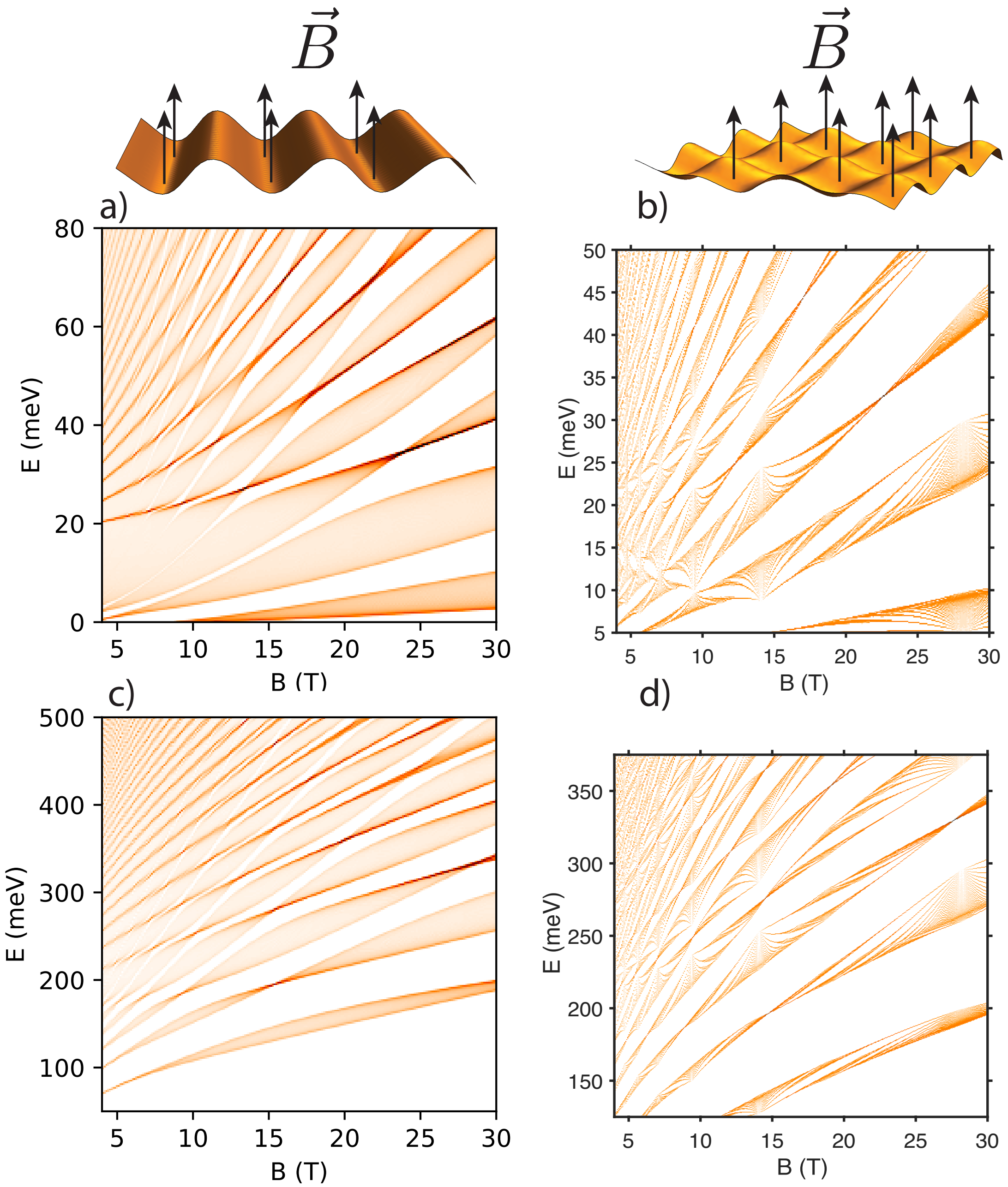
Semiclassics vs exact diagonalization



$V_0 = 0.2, \ \omega_c \sim 0.1, \ q = 2$



$\vec{B}$
$\vec{B}$
a)
b)
c)
d)
Parabolic dispersion
Linear dispersion
E (meV)
B (T)
1D moiré potential
2D moiré potential



Parabolic dispersion

Linear dispersion

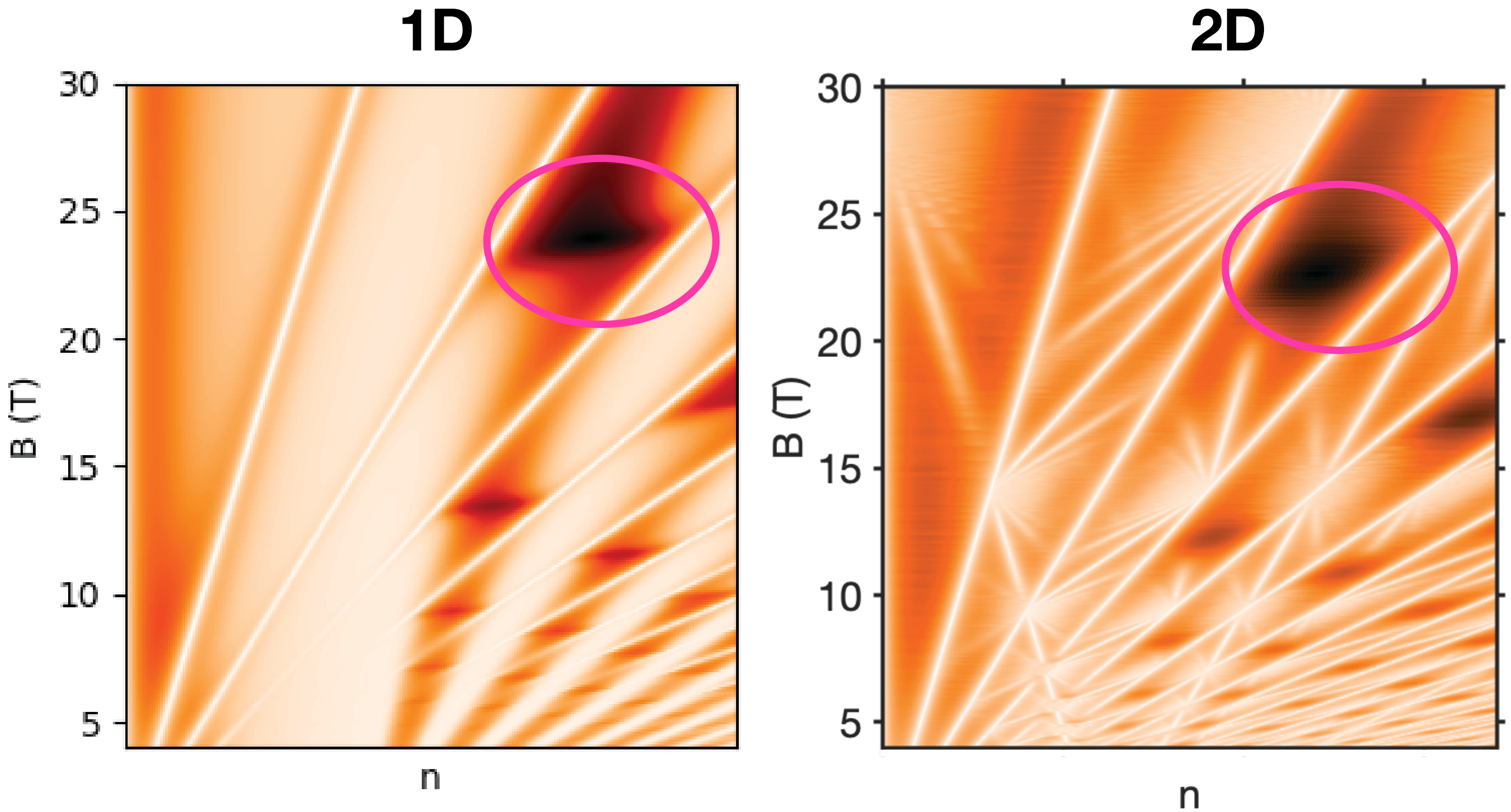
1D moiré potential **2D moiré potential**

Generalizations:

- Small q (many overlapping Fermi surfaces)
- 2D potentials

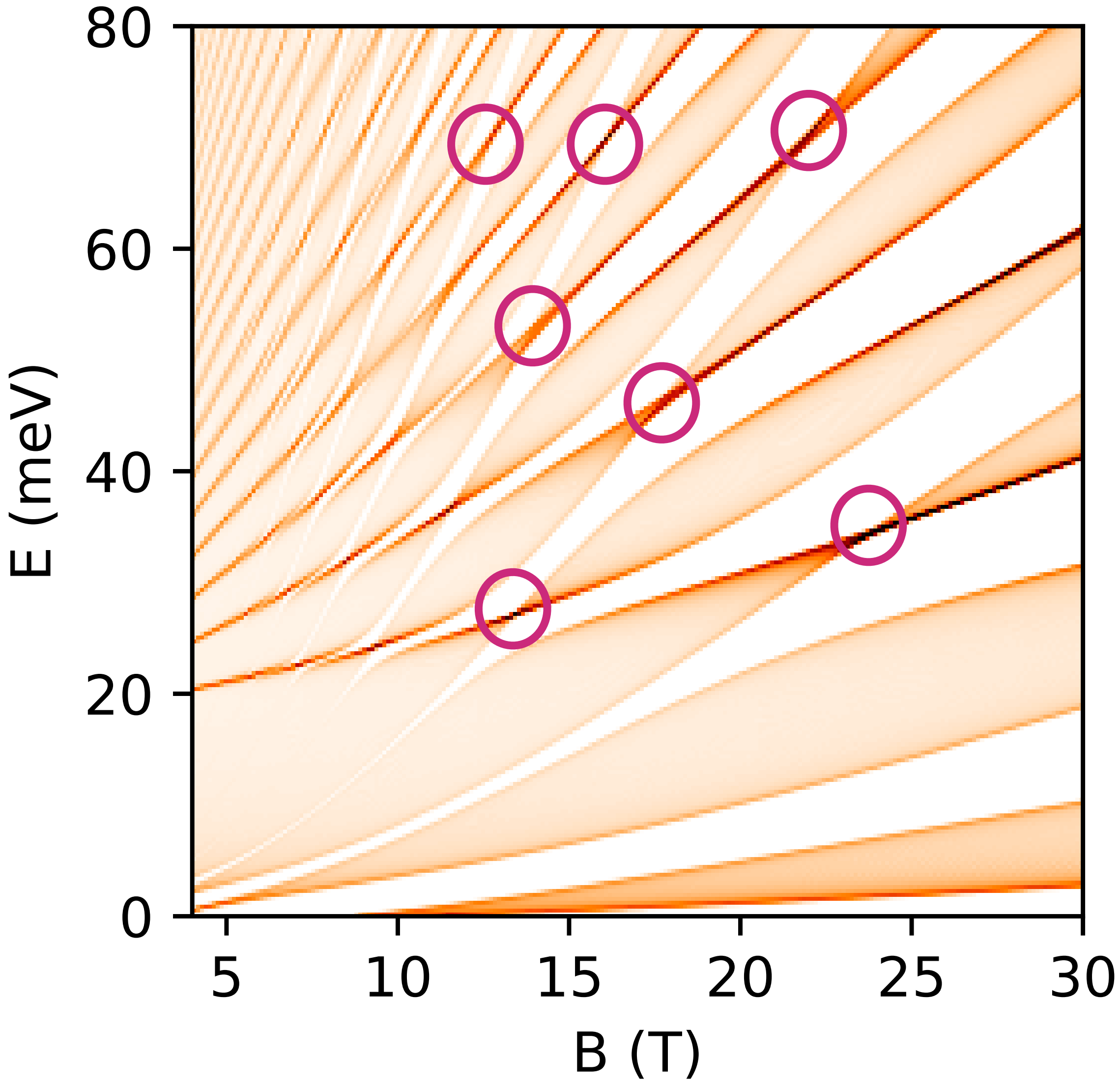
Observing magic zeros

- Patterned dielectric gating, i.e. artificial 1D or 2D potentials
- Moiré TMDs
- TBG only hosts magic zeros in the chiral limit
- Distinct compressibility features (ignoring interactions)



Future directions

- Studying transitions between FQH and metallic states
- Bandwidth highly tunable by adjusting magnetic field near a magic zero
- Translation symmetry-enriched FQH physics



Summary & conclusion

- Electrons in a uniform field and moiré potential exhibit flat Chern bands at discrete fields
- Semiclassical theory: intersecting Landau fans
- New settings for studying strong interactions at various fillings