Measuring many-body topological invariants using polarons

Fabian Grusdt

Physics Department and Research Center OPTIMAS,
University of Kaiserslautern, Germany

Graduate School of Materials Science in Mainz,
Kaiserslautern, Germany
Control over individual anyons?

- electrons
- ultracold atoms
- photons

Motivation

- Stormer, RMP 71,4 (1999)
- Aidelsburger et al., arXiv:1407.4205
- Hafezi et al., Nature Photonics 7 (2013)
### Motivation

#### Outline:

**Following talk!**

- Interferometric measurement of topological invariants
- Topological Polarons & many-body invariants
Interferometric approach for measuring topological invariants

2D

\[ C = \frac{1}{2\pi} \int_{-\pi}^{\pi} dk_y \partial_{k_y} \varphi_{Zak}(k_y) \]

1D

\[ \varphi_{Zak} = \int_{-\pi}^{\pi} dk_x A(k_x) \]

Xiao, Rev. Mod. Phys. 82 (2010)

Berry (1984)

key idea: measure geometric phases!
Zak phase of Bloch bands:

\[ \varphi_{\text{Zak}} = \int dk \langle u(k) | i\partial_k | u(k) \rangle \]

quantized by inversion symmetry

\[ \varphi_{\text{Zak}} = 0, \pi \]


Su-Schrieffer-Heeger model:

\[ \hat{H} = -t_1 \sum_{n \text{ odd}} \hat{a}_n^\dagger \hat{a}_{n+1} + \text{h.c.} \]

\[ -t_2 \sum_{n \text{ even}} \hat{a}_n^\dagger \hat{a}_{n+1} + \text{h.c.} \]

Su et al., PRL 42 (1979)
Measurement of Zak phase:

Atala et al., Nature Phys. 9, 2013

BEC in Su-Schrieffer-Heeger model:

\[ \varphi_{\text{Zak}} = 0.97(2)\pi \]
Multi-band Chern number:

\[ C = \frac{1}{D} \frac{1}{2\pi} \int_0^{2\pi} dk_y \partial_{k_y} \text{Im} \log \det \hat{W}(k_y) \]

D: number of bands

Wilson loops — multiband generalization of Berry phase

\[ \hat{W}(k_y) = \mathcal{P} \exp \left[ -i \int_0^{2\pi} dk_x \hat{A}_x(k_x) \right] \]

Abelian case:

\[ C = \int_0^{2\pi} dk_y \partial_{k_y} \varphi_{\text{Zak}}(k_y) \]

\[ \varphi_{\text{Zak}} / 2\pi \]

pedagogical overview:

numerical implementation:
Yu et al., PRB 84 (2011)

\[ k_y / 2\pi \]
2D — Z2 topological insulator (TI)

Time-reversal (TR) invariant TI

Z2 topological insulator:  
Kane & Mele, PRL 95 (2005)

\[
\varphi_\theta(k_y) = \varphi^{I}_{\text{Zak}}(k_y) - \varphi^{II}_{\text{Zak}}(k_y)
\]

TR polarization:  
Fu & Kane, PRB 74 (2006)

Z2 topological invariant:  

\[
\nu_{2D} = \Delta \varphi_\theta \equiv \varphi_\theta(\pi) - \varphi_\theta(0) \mod 4\pi \in \{0, 2\pi\}
\]

Not sufficient to measure these Zak phases!!
Problem: measurement of $\varphi_{\text{Zak}} \mod 2\pi$ only.

Solution: measure winding of TR polarization!

$\varphi_{\text{Zak}}(k_y)$ is discontinuous!

Not sufficient to measure these Zak phases!!
Solution: Continuous TR polarization

Example: Kane-Mele model:

Grusdt, Abanin & Demler, PRA 89 (2014)
Interferometric approach to measuring topological invariants

Ramsey Interferometry + Bloch oscillations

Many-body invariants can also be measured:
Collaborators:

Eugene Demler

Dmitry Abanin

Norman Yao
Thanks for your attention!