Universal Suppression of Superfluid Weight by Disorder

- Independent of Quantum Geometry and Band Dispersion -

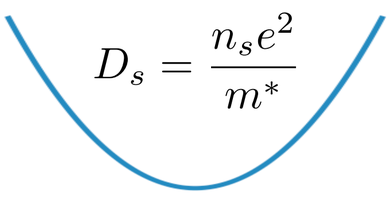
A. Lau[1], S. Peotta[2], D. I. Pikulin[3], E. Rossi[4], T. Hyart[1,2]

[1]MagTop, IF PAN, Warsaw, Poland
[2]Department of Applied Physics, Aalto University, Finland
[3]Microsoft Quantum, Redmond, USA
[4]Department of Physics, William & Mary, Williamsburg, USA

Decomposition of Superfluid Weight D_s

Definition: Transport coefficient characterizing a superconductor

parabolic band



$$D_s = \frac{n_s e^2}{m^*}$$

isolated flat band

$$D_s^{\mu\nu} \sim \int \frac{d^d k}{(2\pi)^d}\, g_{\mu\nu}(\mathbf{k})$$

$g_{\mu\nu}$ - quantum metric

in general

conventional contribution
(most superconductors)

geometric contribution
(topological materials)

$$D_s^{\mu\nu} = D_{s,\mathrm{conv}}^{\mu\nu} + D_{s,\mathrm{geom}}^{\mu\nu}$$

What is the effect of disorder on D_s?

- Anderson: superconductivity robust against non-magnetic disorder
- Superfluid weight suppressed in conventional superconductors
- Formation of islands → superconductor-insulator transition

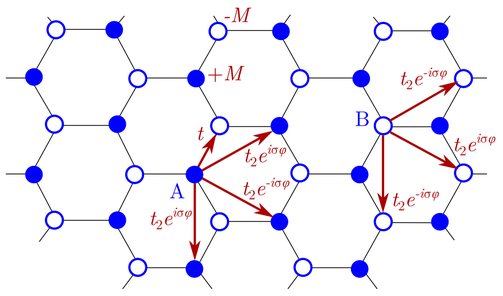
Effect of disorder on flat-band superconductors?

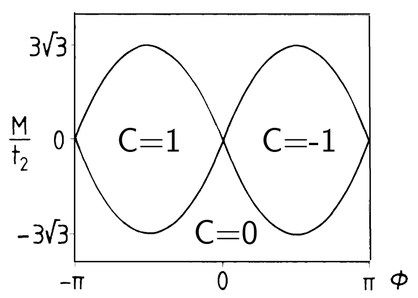
How does disorder affect superfluidity when the geometric contribution is large?

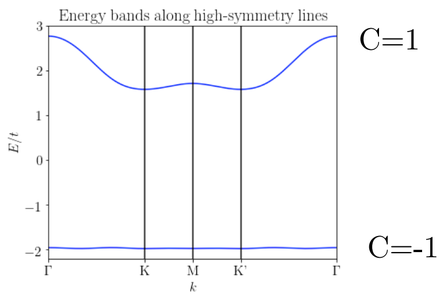
Does nontrivial topology lead to stronger disorder resilience?

Flat Kane-Mele Model

- Two time-reversed copies of Haldane's famous model
- Spin-Chern number C
- Additional hopping terms to flatten the lower band:

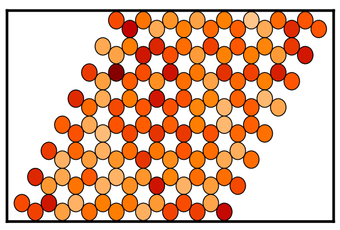






Mean-field theory for disordered clusters

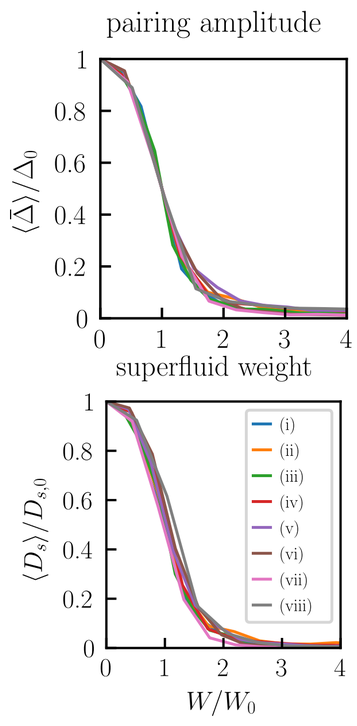
- Disordered clusters with up to 128 sites and periodic boundary conditions
- Time-reversal invariant singlet pairing
- Solve mean-field equations self-consistently:



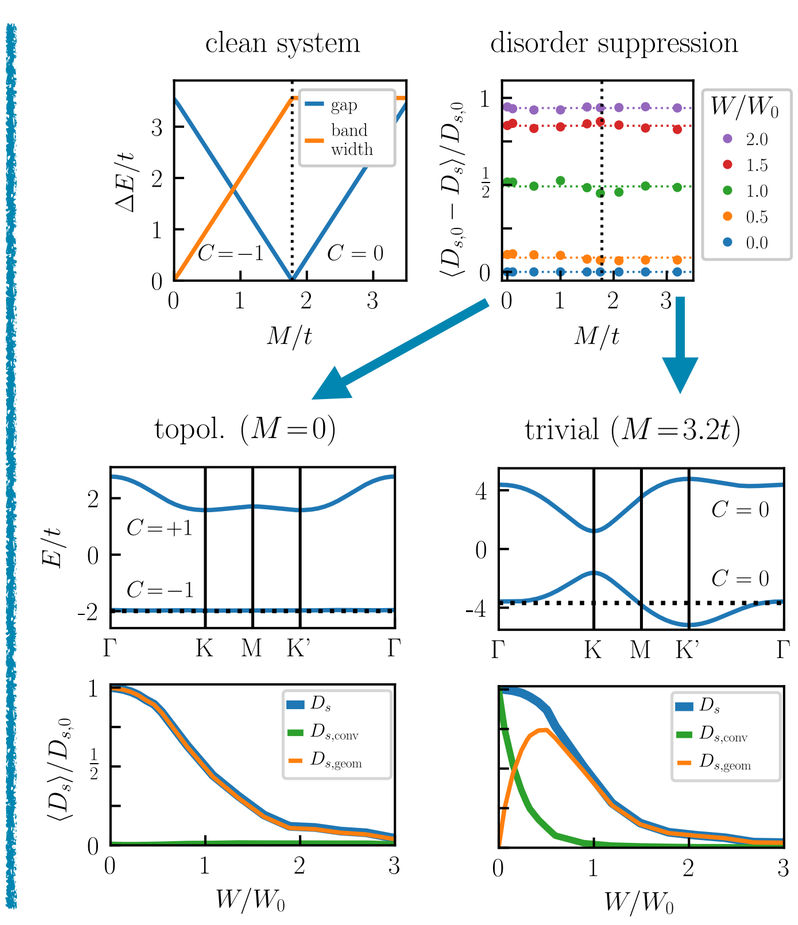
$$\Delta_\alpha = \frac{1}{\mathcal{N}} \sum_i U \langle c_{i\alpha\uparrow} c_{i\alpha,\downarrow} \rangle,\ \nu = \frac{1}{N\mathcal{N}} \sum_{i,\alpha,\sigma} \langle c^\dagger_{i\alpha\sigma} c_{i\alpha\sigma} \rangle$$

Compute full, conventional, and geometric superfluid weight

Universal Suppression of Superfluid Weight



(i) flat topological
(ii),(iii) topological with dispersion
(iv) semimetallic
(v) trivial with dispersion
(vi)-(viii) trivial square lattice models



Take-home messages

- First study of disorder in flat-band superconductors:
  → relevant for twisted bilayer graphene
- Suppression of superfluid weight and pairing amplitude is **universal** across various models
- Band topology/geometry does **not** affect superfluidity in the presence of disorder
- Flat-band superconductors are as resilient to disorder as conventional (non-flat band) superconductors

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