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Percolating states in the topological Anderson insulator

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We investigate the presence of percolating states in disordered two-dimensional topological insulators. In particular, we uncover a close connection between these states and the so-called topological Anderson insulator, which is a topologically nontrivial phase induced by the presence of disorder. The decay of this phase could previously be connected to a delocalization of bulk states with increasing disorder strength. We identify this delocalization to be the result of a percolation transition of states that circumnavigate the hills of the bulk disorder potential.

Topological Anderson Insulators

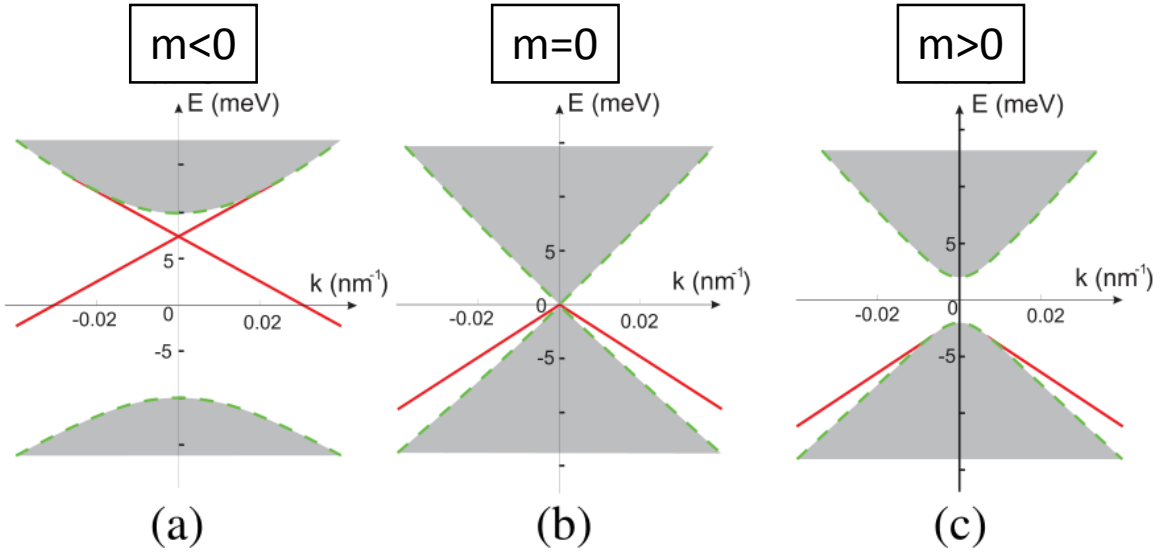
BHZ model for HgTe quantum well:

$$H_{\text{eff}}(k_x,k_y) = \begin{pmatrix} h(\vec{k}) & 0 \\ 0 & h^*(-\vec{k}) \end{pmatrix},$$

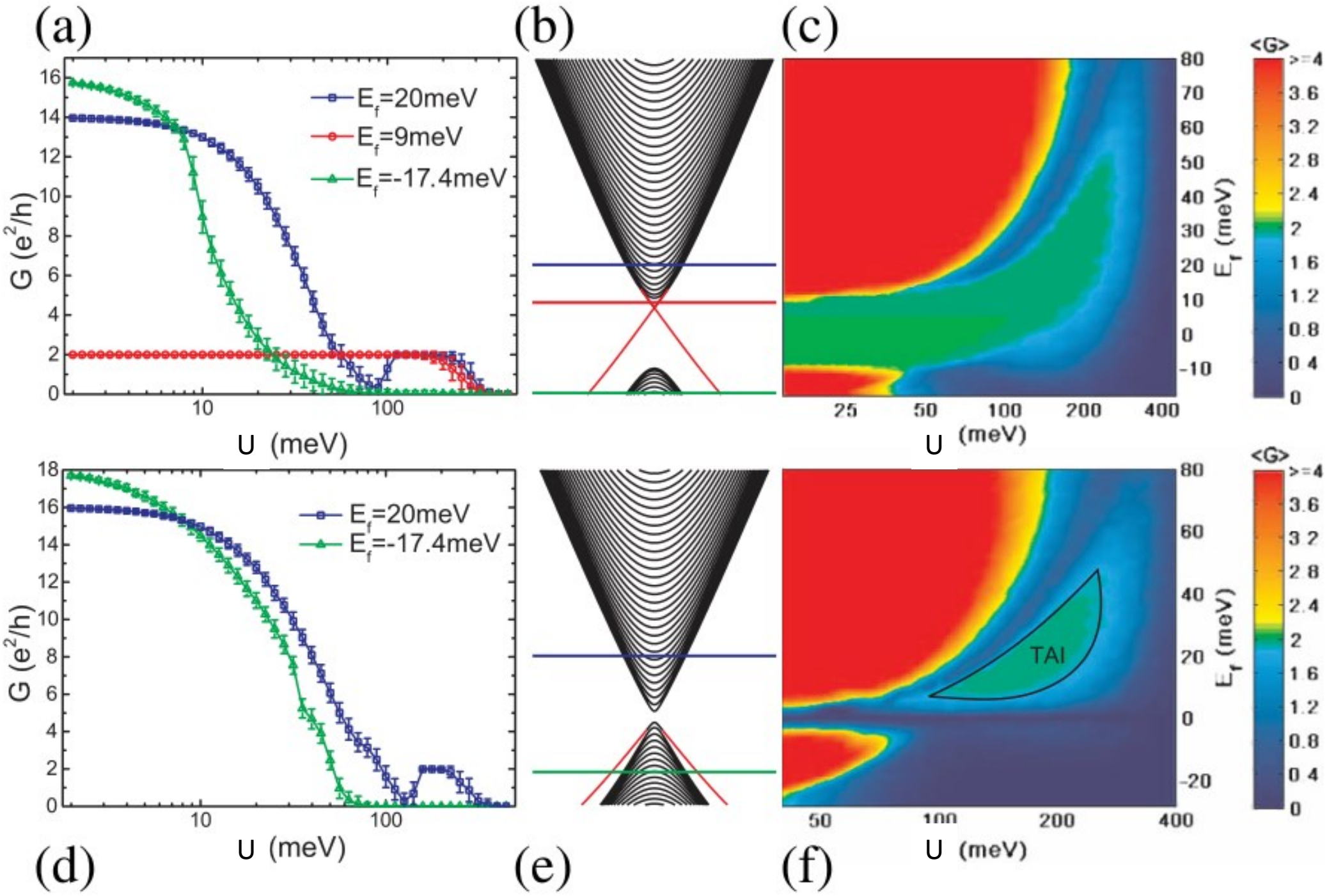
with

$$h(\vec{k}) = \mathbb{1}\epsilon(\vec{k}) + d_i(\vec{k})\sigma^i, \quad \epsilon(\vec{k}) = C - D\left(k_x^2 + k_y^2\right),$$

$$d_i = [Ak_x, -Ak_y, M(\vec{k})]^T, \quad M(\vec{k}) = m - B\left(k_x^2 + k_y^2\right),$$



J. Li, R. Chu, J. Jain, S. Shen, PRL 102, 136806 (2009)


(a)
(b)
(c)
G (e²/h)
U (meV)
E_f=20meV
E_f=9meV
E_f=-17.4meV
E_f (meV)
<G>
TAI
(d)
(e)
(f)

Theory

Self-consistent Born approximation:

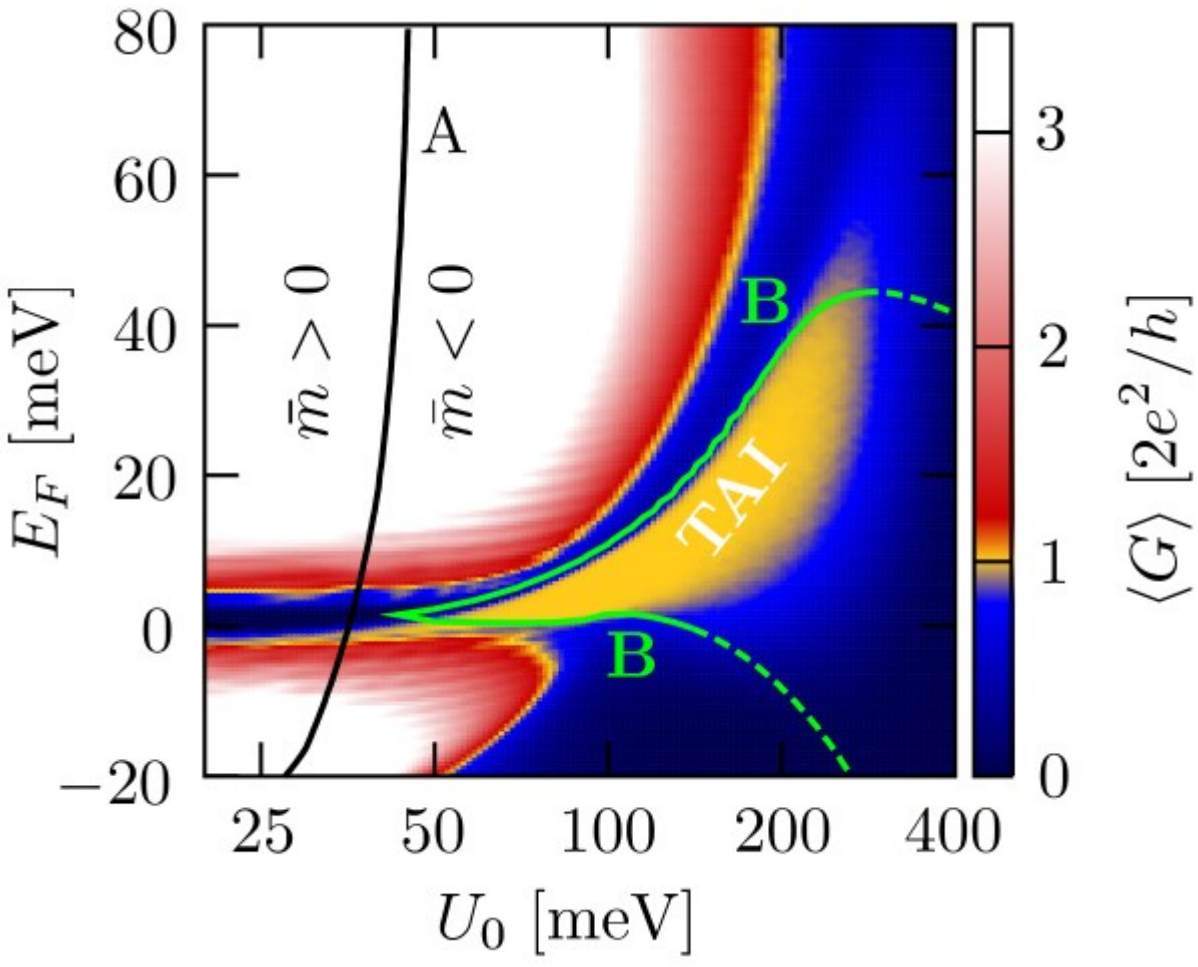
$$\bar{m} = m + \lim_{k\to 0} \mathrm{Re}\Sigma_z, \qquad \bar{\mu} = E_F - \lim_{k\to 0} \mathrm{Re}\Sigma_0.$$

$$\Sigma = \tfrac{1}{12} U_0^2 (a/2\pi)^2 \int_{\mathrm{BZ}} d\boldsymbol{k} [E_F + i0^+ - H_0(\boldsymbol{k}) - \Sigma]^{-1}.$$

Renormalization of topological mass and chemical potential:

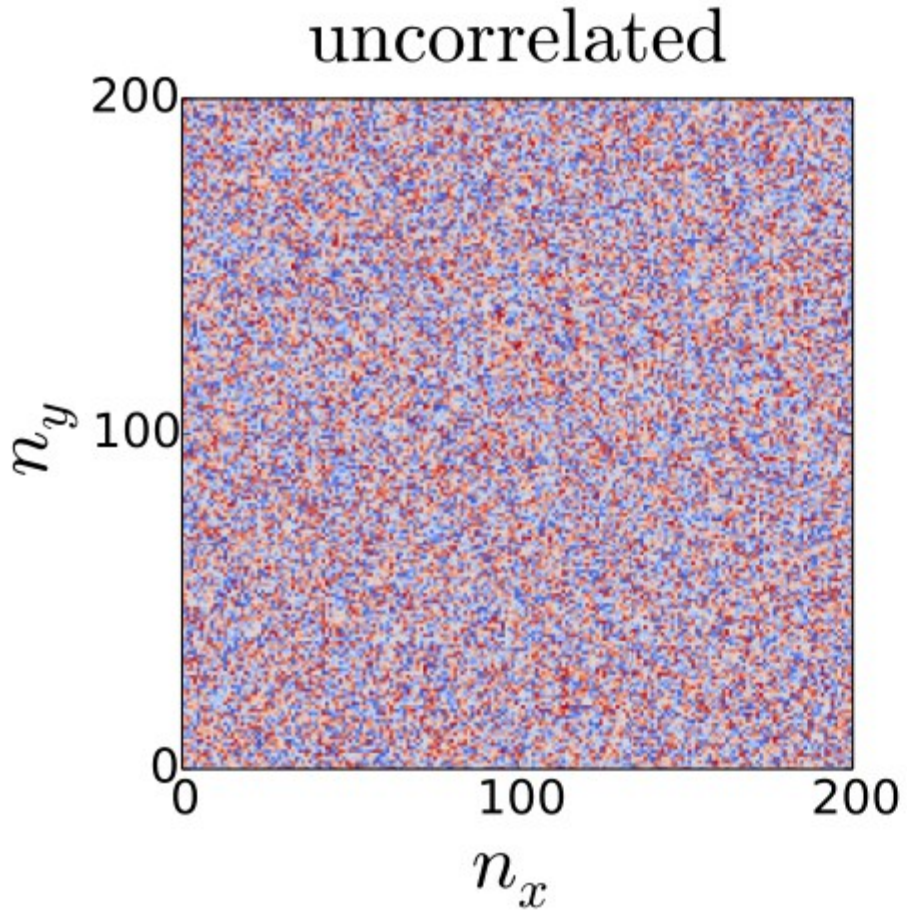
$$\bar{m} = m - \frac{U_0^2 a^2}{48\,\pi\hbar^2} \frac{-B}{B^2 - D^2} \log \left| \frac{B^2 - D^2}{E_F^2 - m^2} \left(\frac{\pi\hbar}{a} \right)^4 \right|$$

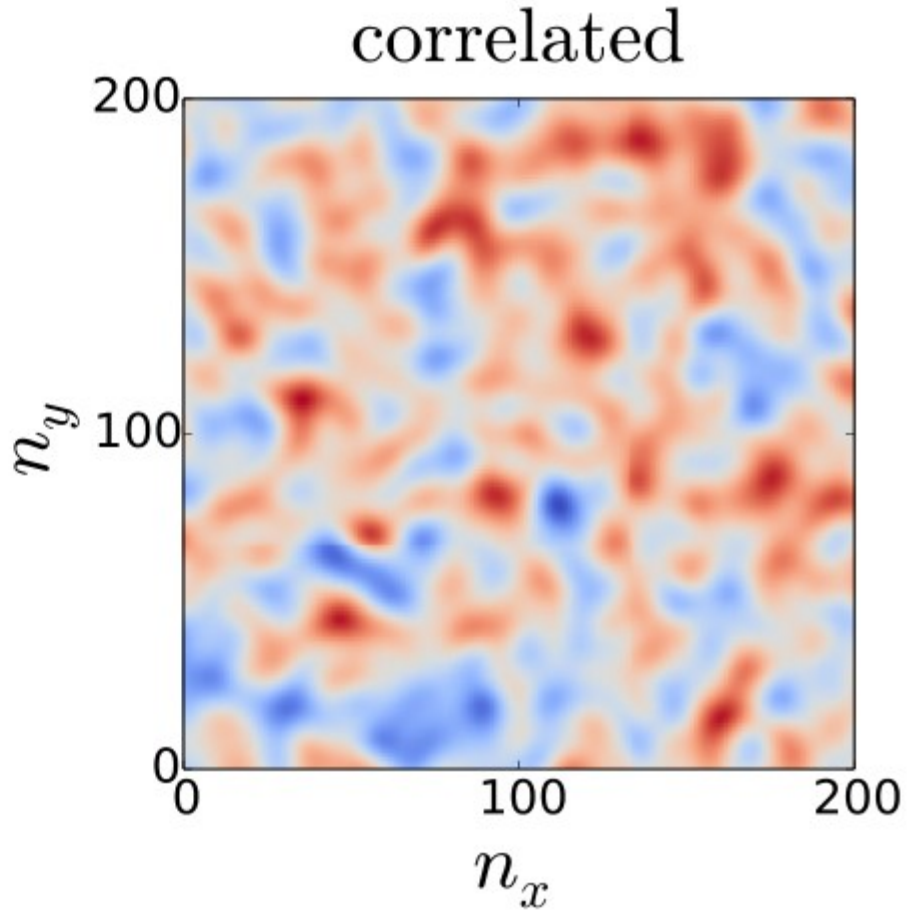
$$\bar{\mu} = E_F - \frac{U_0^2 a^2}{48\,\pi\hbar^2} \frac{-D}{B^2 - D^2} \log \left| \frac{B^2 - D^2}{E_F^2 - m^2} \left(\frac{\pi\hbar}{a} \right)^4 \right|$$



C. Groth, M. Wimmer, A. Akhmerov, J. Tworzydlo, C. Beenakker, PRL 103, 196805 (2009)

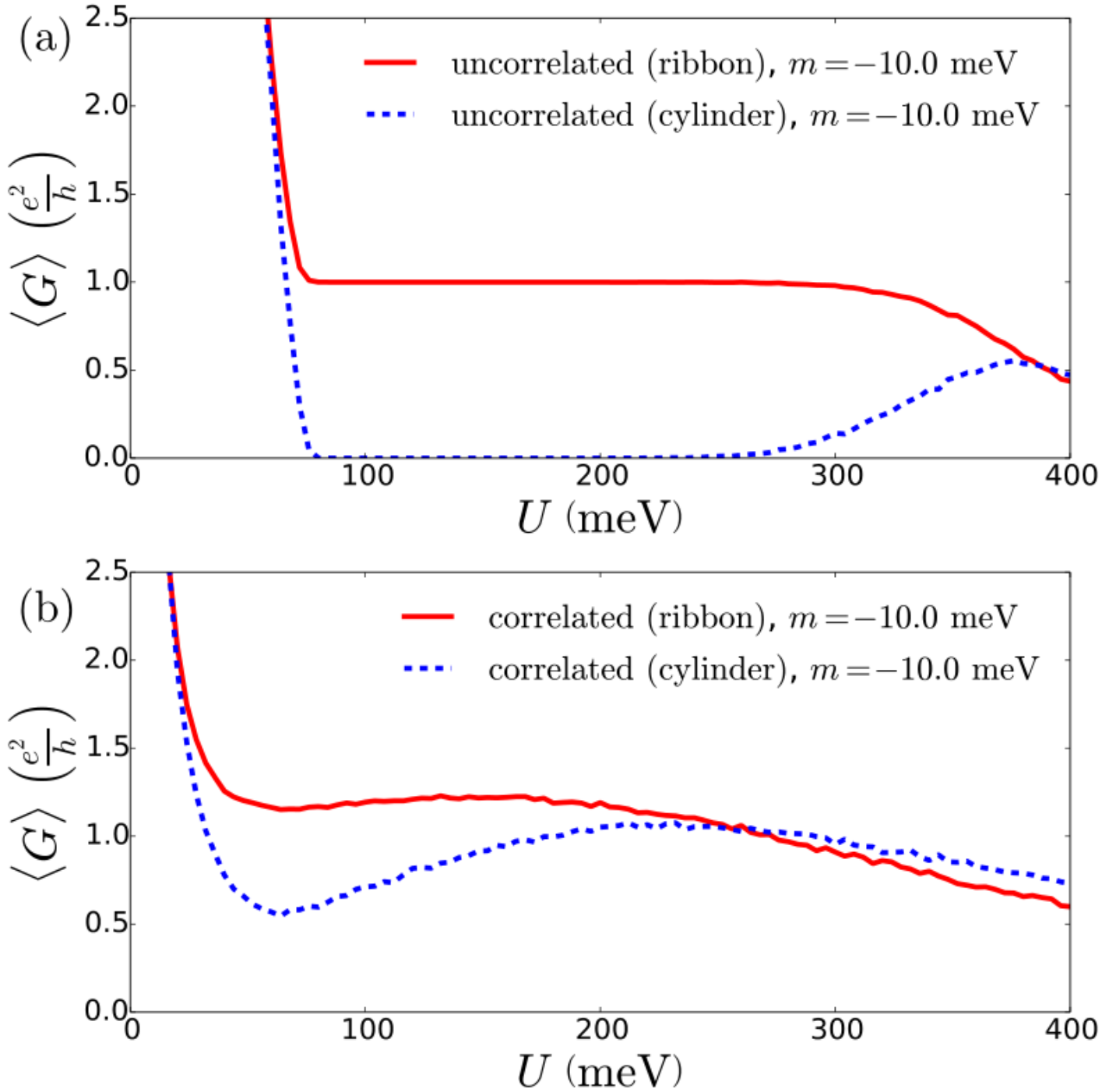
Spatially correlated disorder potential

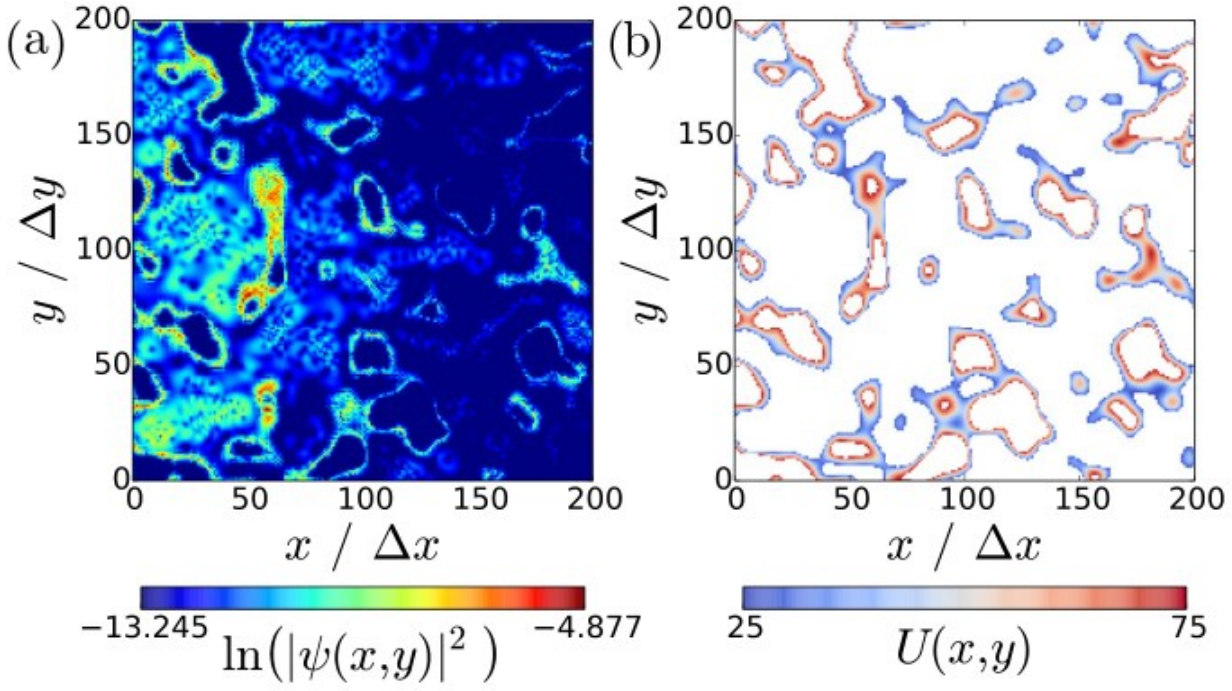


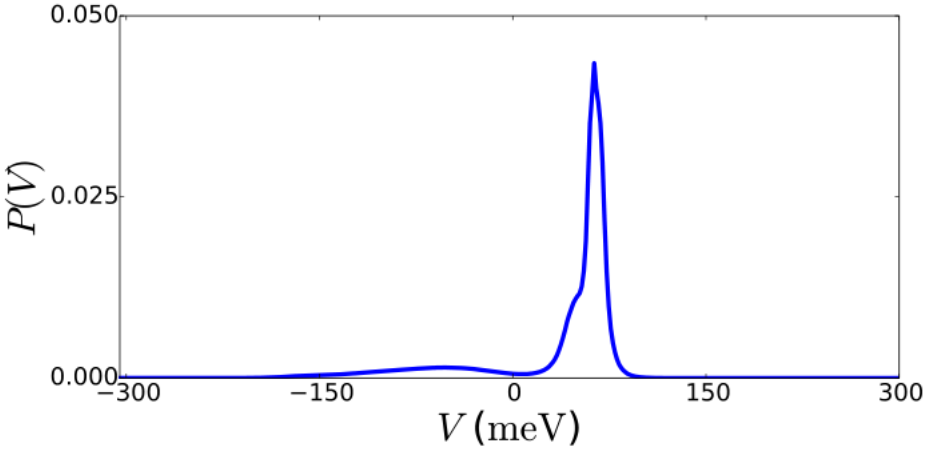


A. Girschik, F. Libisch, S. Rotter , PRB 88, 014201 (2013):

$$C(\vec{r}) = \langle V(\vec{x}) \cdot V(\vec{x}+\vec{r}) \rangle \propto \exp\left(-\frac{r^2}{2\xi^2}\right),$$

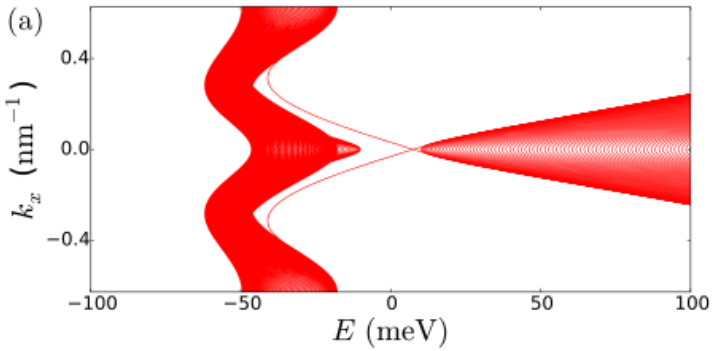

(a)
uncorrelated (ribbon), $m = -10.0$ meV
uncorrelated (cylinder), $m = -10.0$ meV
$\langle G \rangle \left(\frac{e^2}{h}\right)$
U (meV)
(b)
correlated (ribbon), $m = -10.0$ meV
correlated (cylinder), $m = -10.0$ meV
$\langle G \rangle \left(\frac{e^2}{h}\right)$
U (meV)

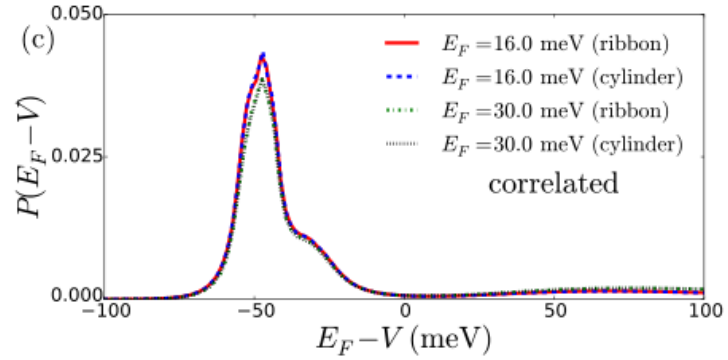




$$P(V) \propto |\Psi(x,y)| \times V(x,y)$$

Max between 25 meV and 75 meV





Conclusions

- **Topological Anderson insulator**: transition to topological insulator phase due to *strong disorder*
- Theoretically understood by self-consistent Born approximation
- Finally destruction of edge states for large disorder because of percolating states in the bulk