Random artificial gauge field
in 2D optical lattices

Jan Major, Marcin Płodzień, Omjyoti Dutta, Jakub Zakrzewski

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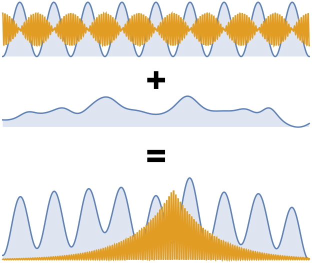
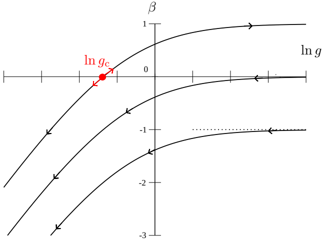
Outline

1. Introduction: Anderson localization, optical lattices
2. Creating the model
3. Results





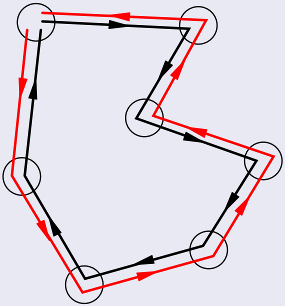
Exponential localization:
$\psi(x) \sim e^{-(x - x_0)/\lambda}$.

$$\beta = \frac{\mathrm{d} \ln g}{\mathrm{d} \ln L}$$

Is there a mobility edge in 2D?

Time symmetric model

Weak localization correction:



$$\lambda \approx \ell e^{\frac{\pi}{2} k\ell}$$

Time symmetric model

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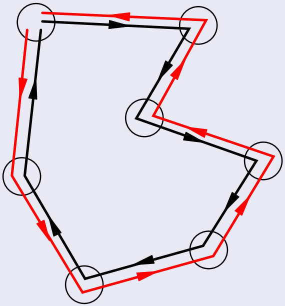

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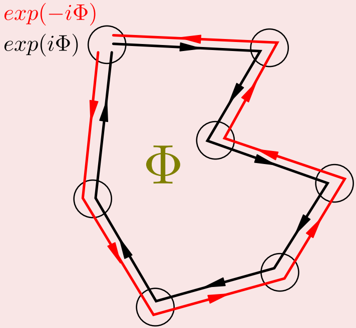
Time symmetry broken

Correction vanishes:



Higher order corrections:

$$\lambda \approx \ell e^{\zeta (k\ell)^2}$$

- By varying lattice depth one can modulate tunnelings (and interactions – but it could be neglected).
- Control over interactions using Feshbach resonances. It is possible to modulate interactions by varying magnetic field in time $B(\tau)$.
- Interactions for two species (and between them) can be changed independently.
- Two species do not have to see the same depth of the lattice:
  - different detunings,
  - two differently polarized lattices.

Poisson distribution of atoms

We prepare particles in deep superfluid state $t^{\mathrm{f}} \gtrsim U^{f}$, after fast quench the occupancies are given by Poisson distribution:

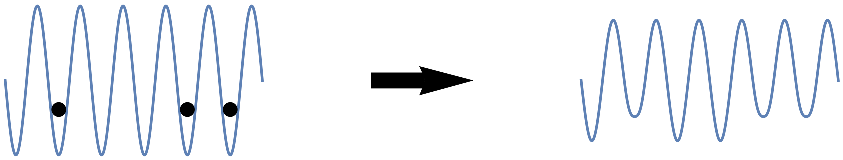
$$P(n^{\mathrm{f}}) = e^{-\rho^{\mathrm{f}}} \frac{(\rho^{\mathrm{f}})^{n^{\mathrm{f}}}}{n^{\mathrm{f}}!}.$$

Discrete disorder

To system with “frozen” particles we add new type of atoms.

$$H_{\mathrm{DD}} = \sum_{i} (V n_i^{\mathrm{f}}) n_i - \sum_{\langle ij \rangle} t a_i^{\dagger} a_j$$

effective on site energy:
$\varepsilon_i = V n_i^{\mathrm{f}}$.



$$H(\tau) = \sum_d \left(t_0 + t_1^d f_\omega(\tau)\right) \sum_{\langle ij\rangle_d} a_i^\dagger a_j + \sum_i \left((V_0 + V_1 \sin\omega\tau) n_i^{\mathrm{f}}\right) n_i$$

Standard procedure for $H(\tau) = H_0 + H' f(\tau)$

Transformation to a rotating frame: $\mathcal{U} = \exp(iH' \int f(\tau))$ and time averaging:

$$H_{\mathrm{eff}} = \langle \mathcal{U} H(t) \mathcal{U}^\dagger \rangle_T, \text{ leaves errors of order } 1/\omega^4.$$

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Impossible to use – time dependent parts do not commute. Instead:

$$\mathcal{U} = \exp\left(i \frac{V_1 \cos\omega\tau}{\omega} \sum_i n_i^{\mathrm{f}} n_i\right).$$

We get:

$$H_{\mathrm{eff}} = \sum_d \sum_{\langle ij\rangle_d} J_{ij}^d[f_\omega] a_i^\dagger a_j + (V_0 n_i^{\mathrm{f}}) n_i, \quad \text{with error of order } \frac{1}{\omega^2}.$$

Harmonic modulation: $f_\omega(\tau) = \cos\omega\tau$

$$J^d_{ij}[\cos] = t_0\mathcal{J}_0(\tfrac{V_1}{\omega}(n^{\mathrm{f}}_j - n^{\mathrm{f}}_i)) + it^d_1\mathcal{J}_1(\tfrac{V_1}{\omega}(n^{\mathrm{f}}_j - n^{\mathrm{f}}_i))$$

Not only flux disorder!

For $t_1 = \pm\sqrt{2}$, there exists approximation:

$$J^d_{ij}[f_\omega] \approx t_0 \exp\left(\pm i\tan^{-1}\left(\frac{V_1}{\omega}\left(n^{\mathrm{f}}_j - n^{\mathrm{f}}_i\right)\right)\right)$$

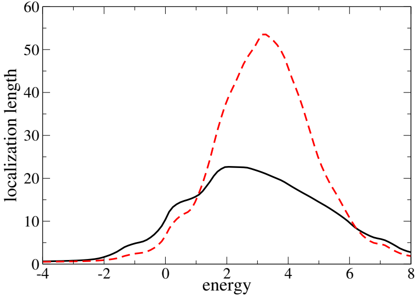
- Saturation – “infinite” modulation amplitude
- Nonlinear – nontrivial flux even for symmetric lattice modulation

Delta modulation: $f_\omega(\tau) = Ш(\tau) = \sum_i \delta(\tau - \frac{2\pi}{\omega}i)$

$$J^d_{ij}[Ш_\omega] = t_0 \exp\left(\pm\frac{V_1}{\omega}\left(n^{\mathrm{f}}_j - n^{\mathrm{f}}_i\right)\right)$$

- Only flux disorder
- Nontrivial flux only for different modulation in different lattice directions

No extended states, monotonic dependence on energy ⇒ we concentrate only on max. localization length in band



Parameters:

- $V = 1.5t_0$
- $\rho^{\mathrm{f}} = 2.5$ (compared with folded normal distribution)

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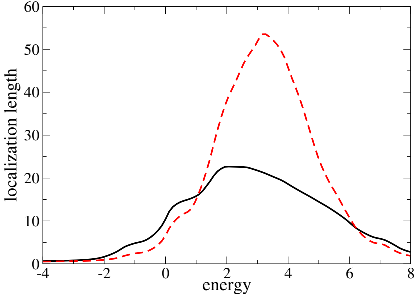
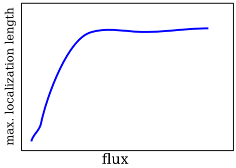


Expectation:



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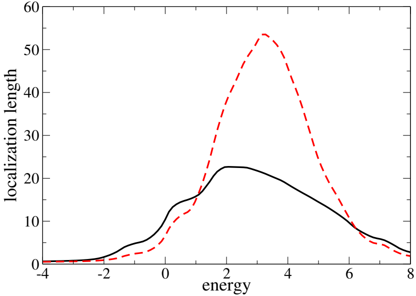

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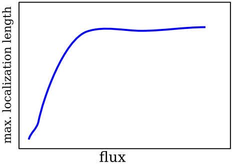
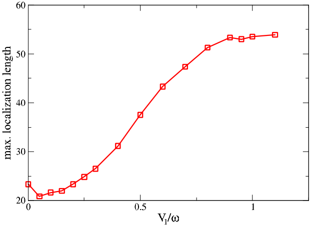


Reality:



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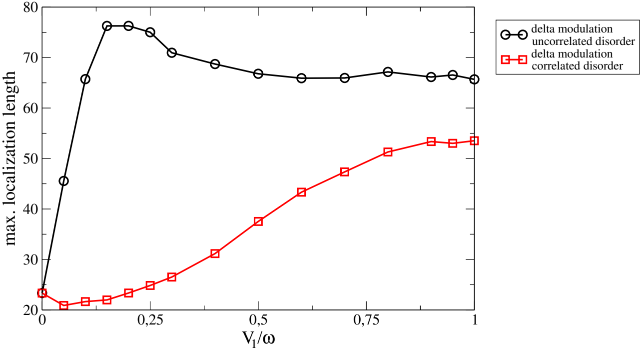
The on-site disorder is correlated with flux disorder (they are taken from the same distribution of frozen particles).

Using two frozen species to get rid of correlation ("experimentally demanding")

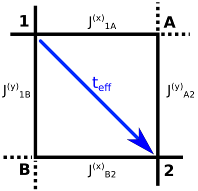
- diagonal disorder $V_0^{\mathrm{I}} \neq 0,\ V_1^{\mathrm{I}} = 0$
- flux disorder $V_0^{\mathrm{II}} = 0,\ V_1^{\mathrm{II}} \neq 0$

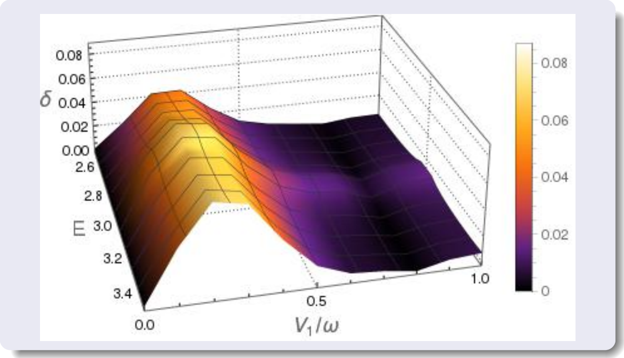


Transport through one plaquette:

$$t_{\text{eff}} = \frac{1}{E - V_0 n^{\text{f}}_A} J^{\text{y}}_{2A} J^{\text{x}}_{A1} + \frac{1}{E - V_0 n^{\text{f}}_B} J^{\text{x}}_{2B} J^{\text{y}}_{B1},$$

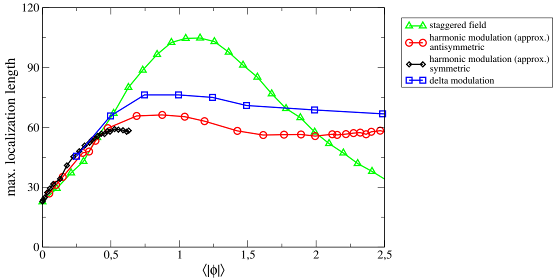
$$\delta = \langle \log t_{\text{eff}} \rangle_{\text{uncorr.}} - \langle \log t_{\text{eff}} \rangle_{\text{corr.}}$$





Introducing flux disorder mutually:

- breaks the time reversal symmetry $\Rightarrow$ localization length should rise
- introduces a new source of disorder $\Rightarrow$ localization length should fall



For uncorrelated disorder the localization length scales similarly with mean absolute flux, regardless the distribution of fluxes.
Comparing with staggered field:

- For $\langle|\Phi|\rangle \lesssim 0.5$ breaking of the symmetry.
- For $\langle|\Phi|\rangle \gtrsim 0.5$ flux disorder strengthens localization.

- It seems to be possible to create random magnetic field model in 2D optical lattice.
- Due to correlations between diagonal and flux disorder transport is hindered.
- After removing correlation (on the cost of complicating the system) the localization length behaves as expected.

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Thank you