

DESCRIPTION

- We study: spinless fermions in a flux threaded AB2 chain with Coulomb interaction
- We present:
 - Exact diagonalization in the limit $V \rightarrow \infty$ and $V = 0$
 - Mean field approach in the intermediate regime
 - Algorithm for finding flat eigenstates in arrays of rings

MODEL

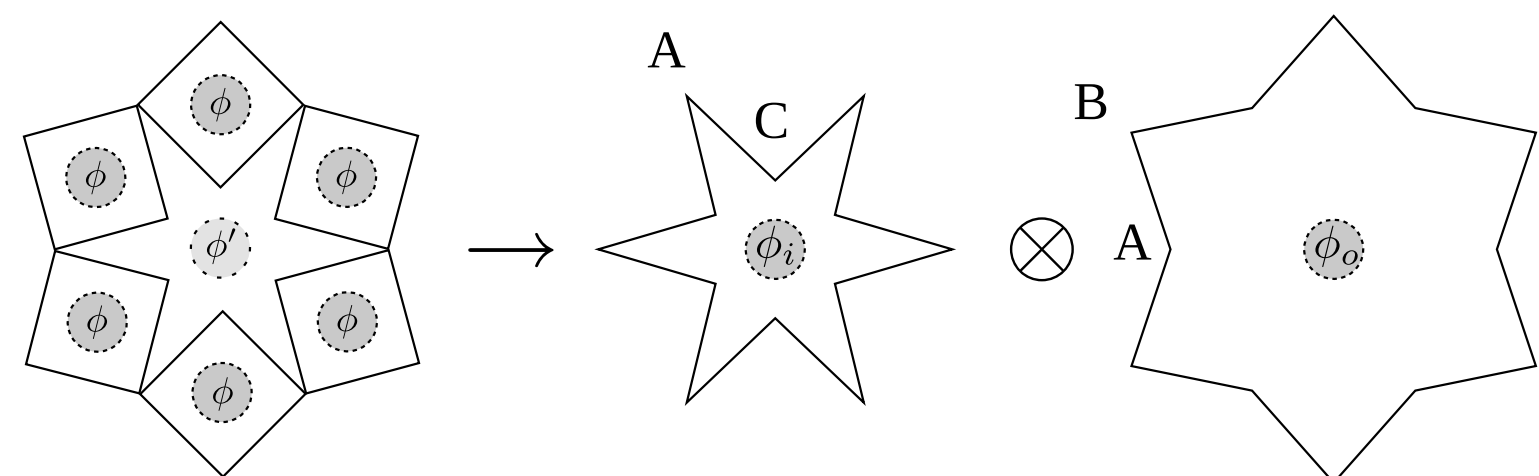


Fig. 1: The model

Interacting spinless fermions Hamiltonian:

$$H = H_0 + V \sum_j (n_j^A + n_{j+1}^A) (n_j^B + n_j^C)$$

$$H_0 = -t \sum_{j=1}^{N_c} \left[e^{i\phi_o/2N_c} (A_j^\dagger B_j + B_j^\dagger A_{j+1}) + e^{-i\phi_i/2N_c} (C_j^\dagger A_j + A_{j+1}^\dagger C_j) \right] + \text{H.c.}$$

$$\phi_o = \phi' + N_c \frac{\phi}{2},$$

$$\phi_i = \phi' - N_c \frac{\phi}{2}.$$

T-B LIMIT

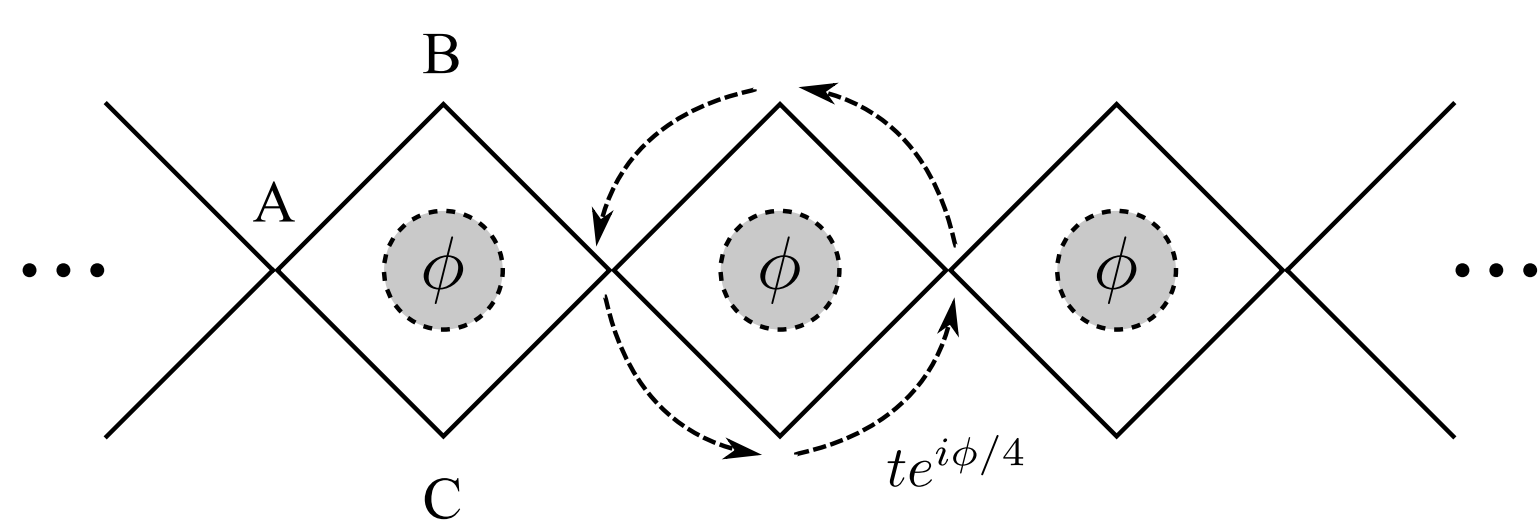


Fig. 2: AB₂ chain t-b model

$$H = -t \sum_j A_j^\dagger \left(e^{i\phi/4} B_j + e^{-i\phi/4} C_j \right) + A_{j+1}^\dagger \left(e^{-i\phi/4} B_j + e^{i\phi/4} C_j \right) + \text{H.c.}$$

Eq. 1: t-b Hamiltonian

Flat band states:

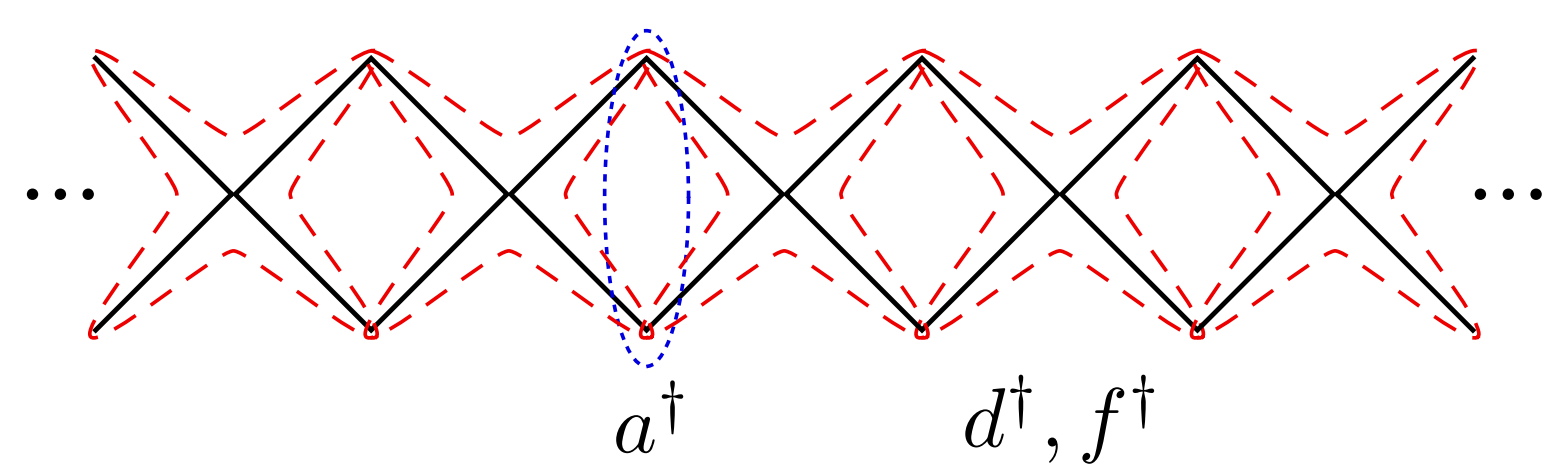


Fig. 3: Eigenstates for $\phi = 0$.

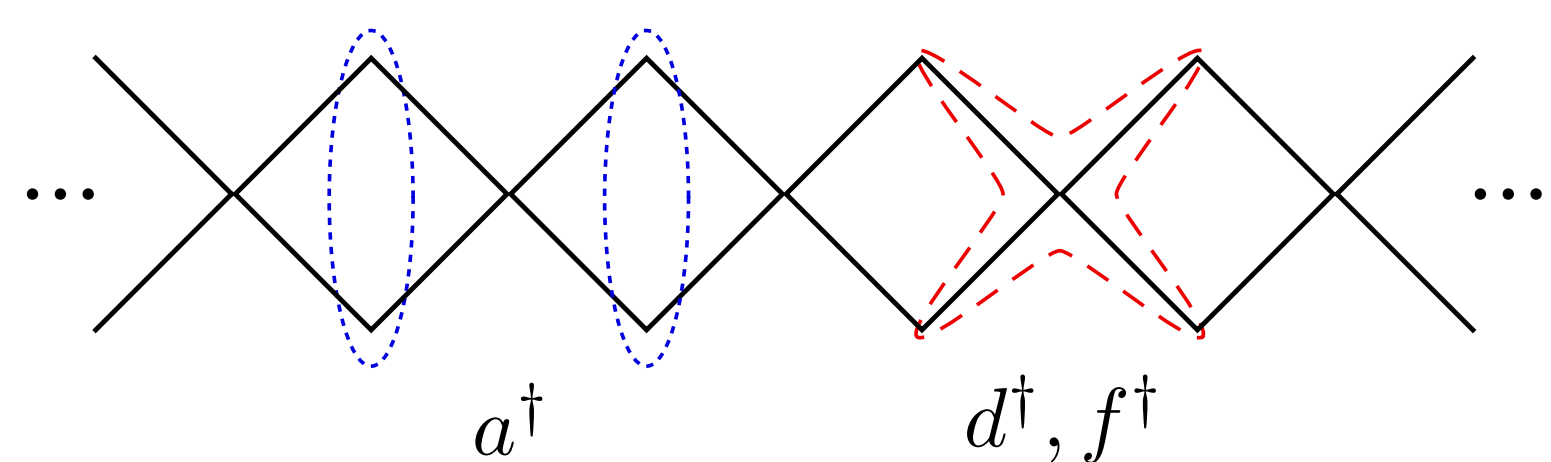


Fig. 4: Localized eigenstates for $\phi = \pi$

T-B LIMIT

For general ϕ : Possible to find a two cells *non-orthogonal* localized eigenbasis for $a_j^\dagger$.

Dispersion relation:

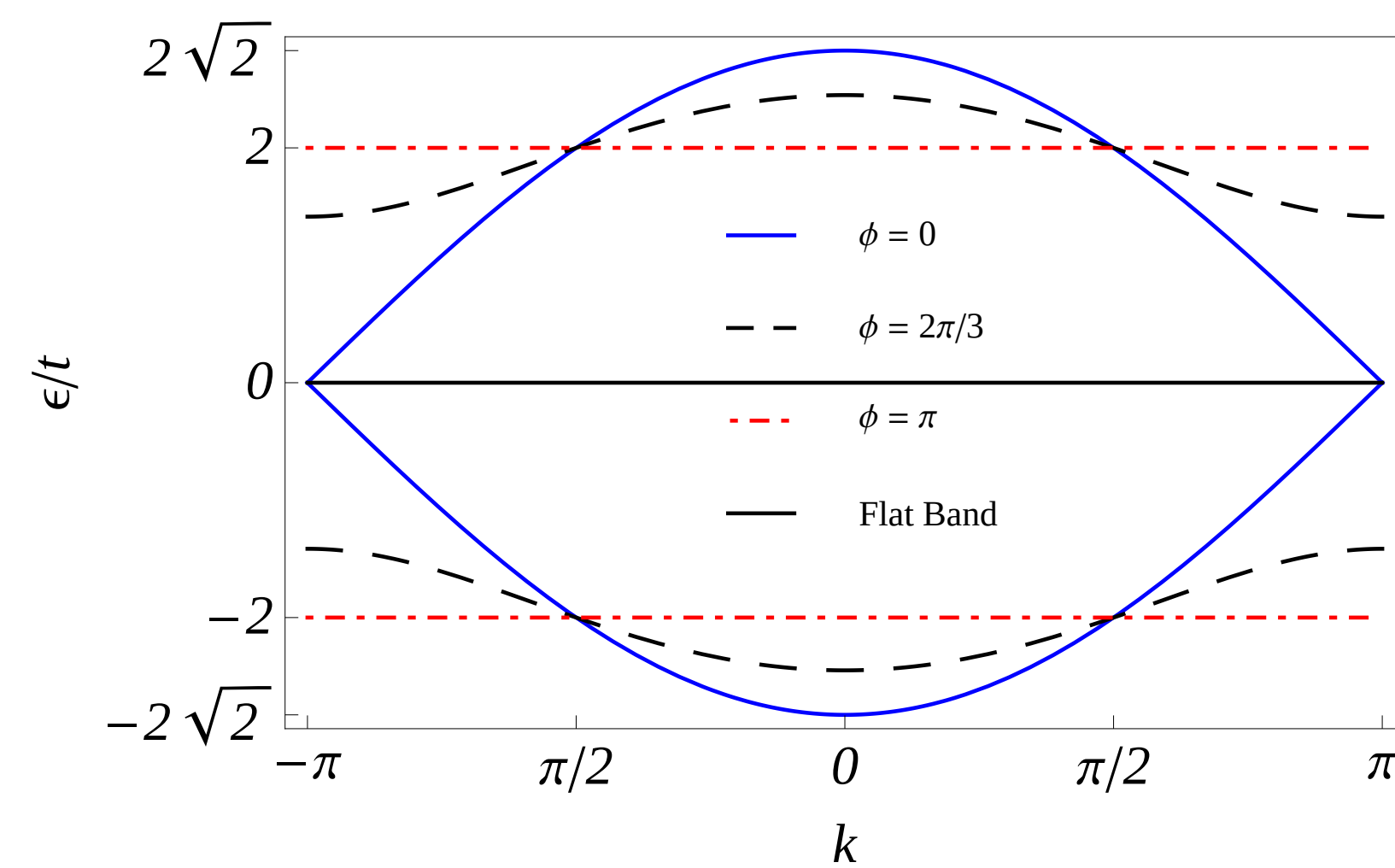


Fig. 5: Dispersion relation

MF RESULTS

$$\Delta\rho = \frac{\rho_A - 2\rho_B}{\rho_A + 2\rho_B}.$$

Eq. 2: Order parameter

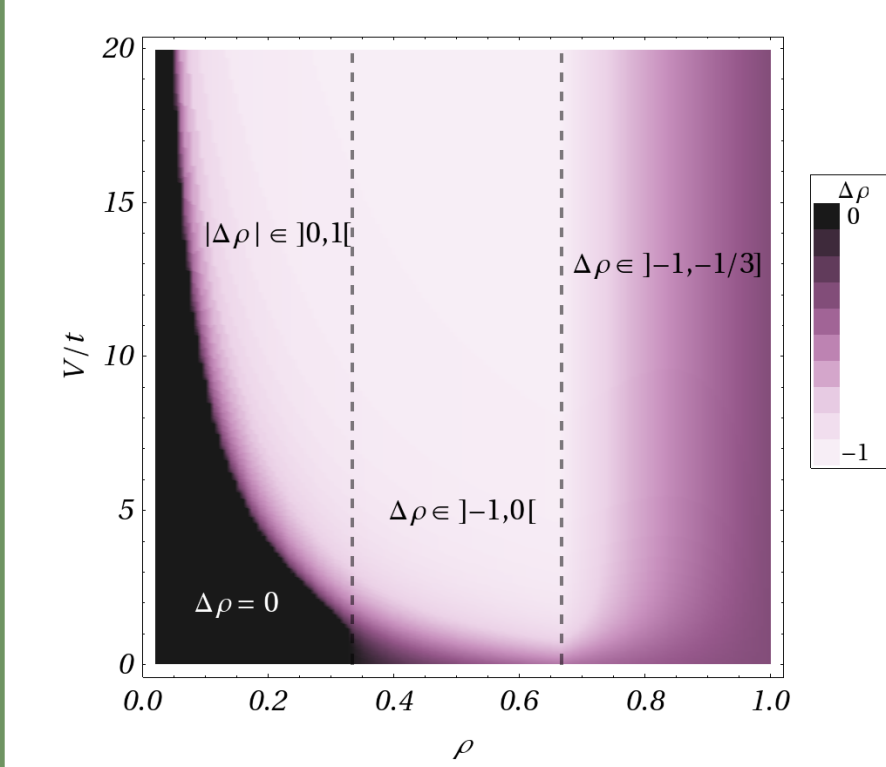


Fig. 6: Phase diagram

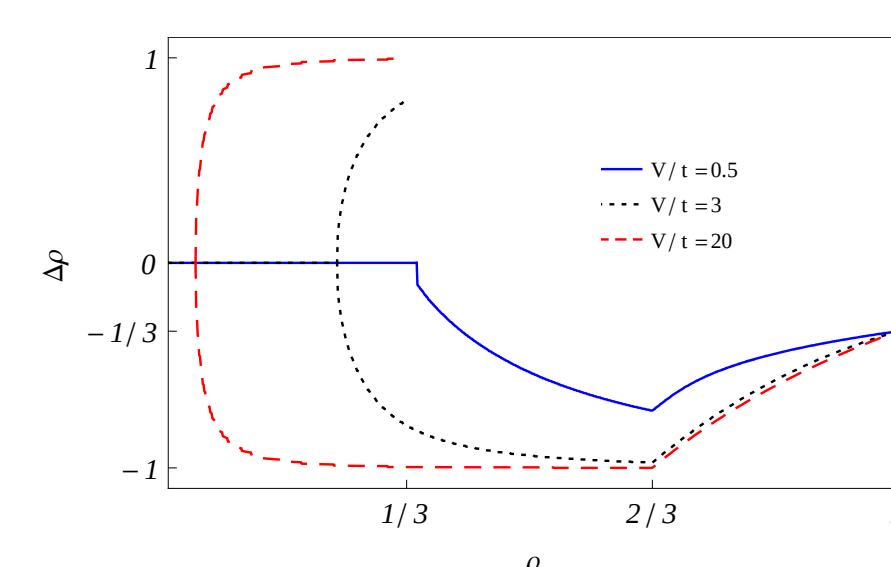
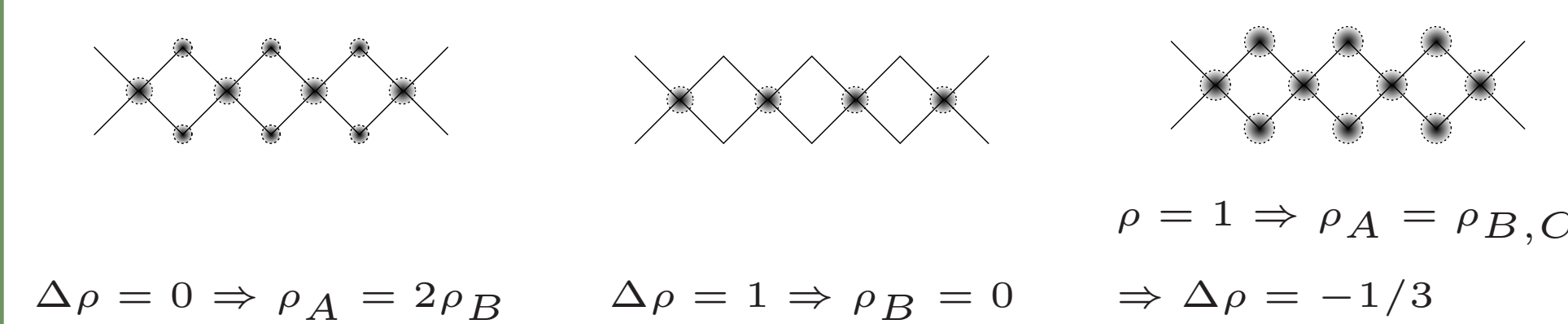


Fig. 7: Order parameter



FLAT STATES

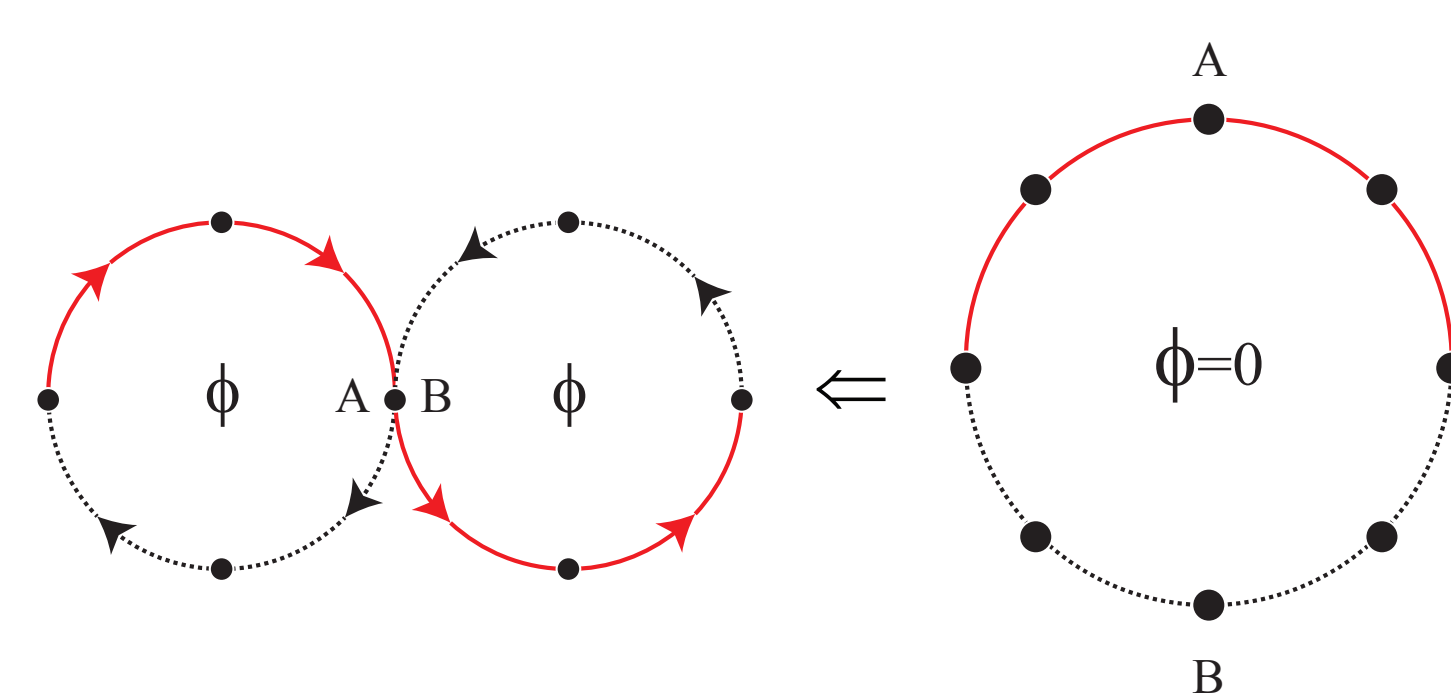


Fig. 8: Obtaining a zero Peirls phase - standing waves.

Algorithm to generate flat eigenstates:

- Choose two consecutive rings ("opening" them generates a larger ring)
- Peirls phase is now zero in larger ring
- Do a gauge transformation for the larger ring - states with opposite momenta are now degenerate
- Now construct standing waves for the larger ring (eigenstates of a $\phi = 0$ ring)
- Rings are decoupled, so these are flat band eigenstate for the whole system

FLAT STATES

Example in the Lieb lattice:

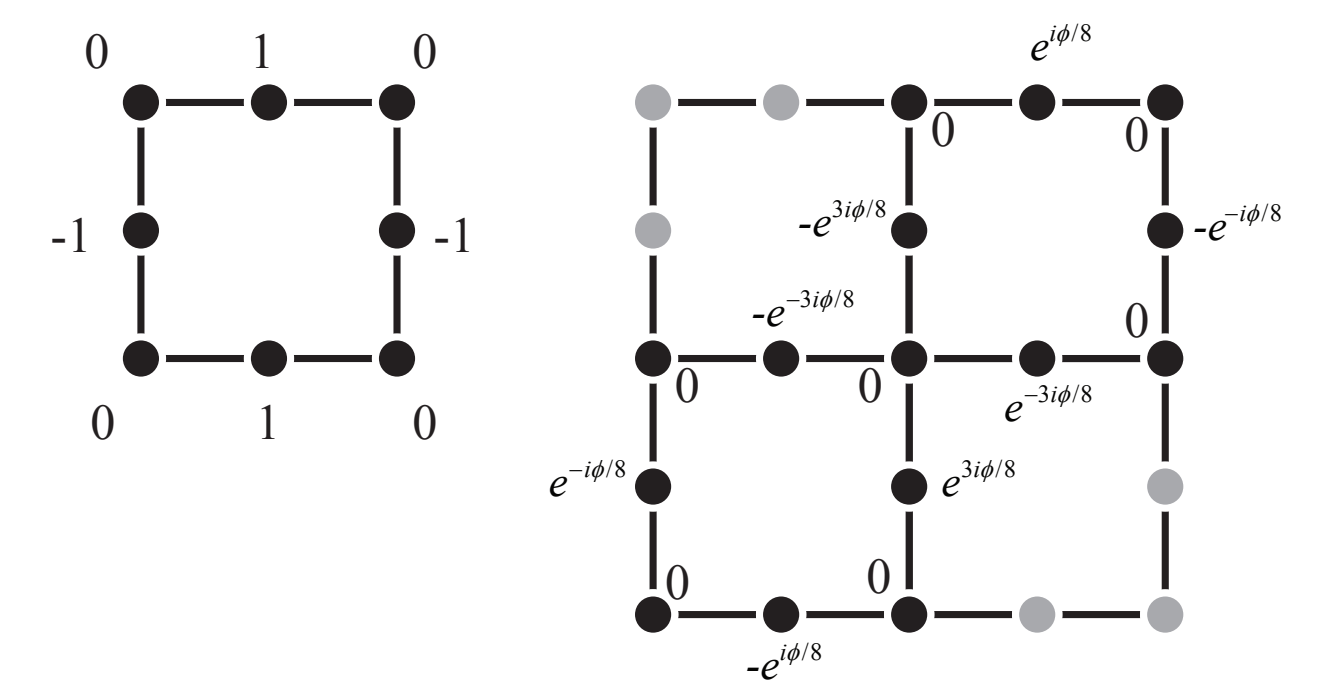


Fig. 9: Localized state in a Lieb lattice, without (left) and with flux(right).

STRONG LOCALIZATION LIMIT

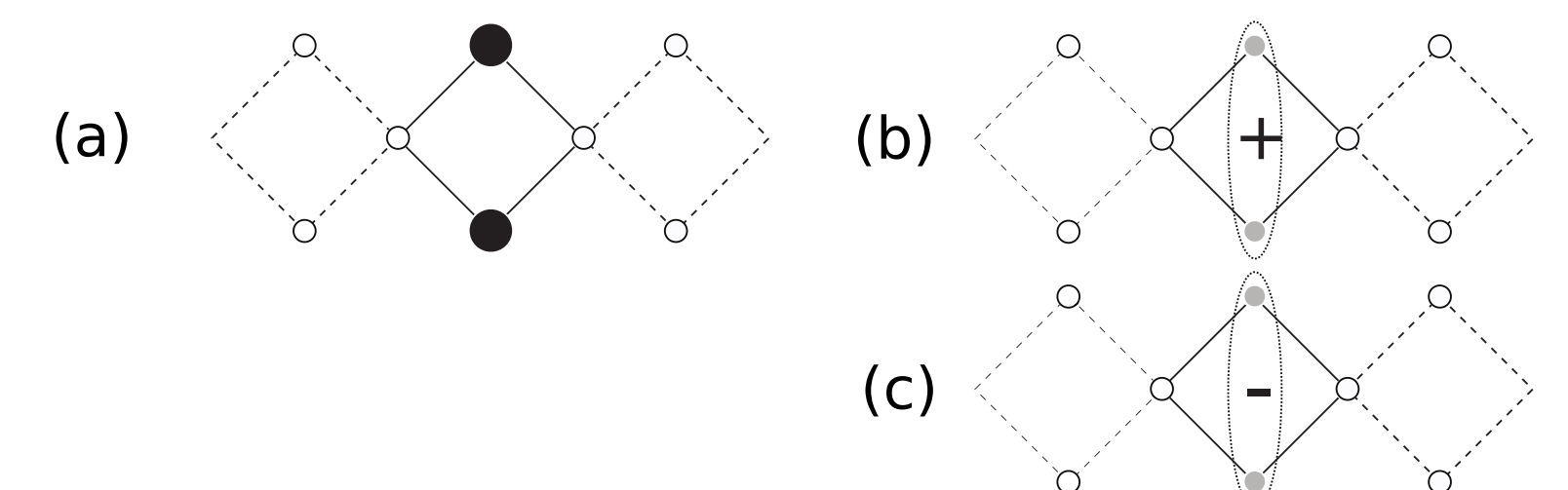


Fig. 10: (a) 2-particle localized states. (b) Bound ($B_{+,i}^\dagger$) - itinerant 1-part. states. (c) Anti-bound ($B_{-,i}^\dagger$) - loc. 1-part. states

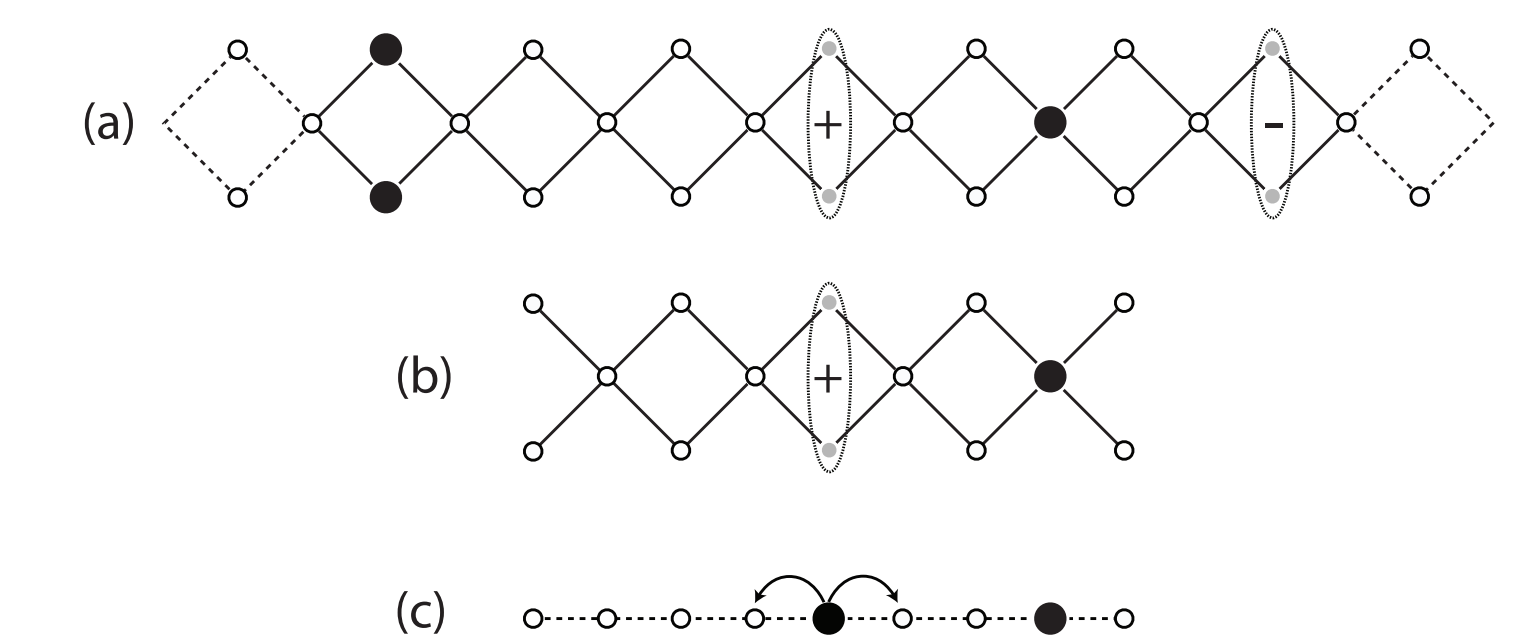


Fig. 11: (a) State with loc. and itin. particles; (b) Open boundary region where itin. fermions in state (a) may move. The open boundary regions terminate on B/C sites. (c) Corresponding state of the t-V chain.

Algorithm to solve the problem:

- Distribute localized fermions (if any) $\rightarrow$ create open boundary regions
- Solve remaining problem for itinerant fermions by mapping into the t-V chain
- To solve t-V chain: Bethe Ansatz or Dias method for strong coupling [2]

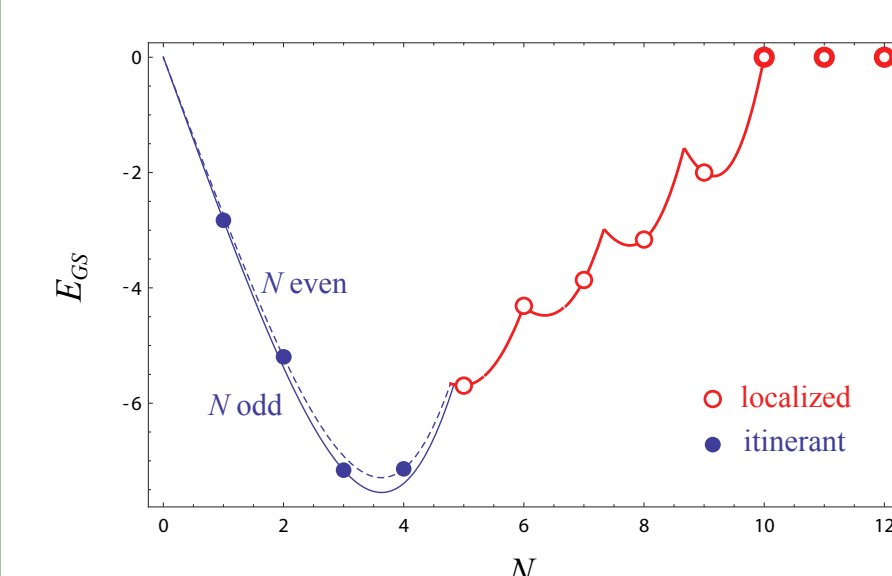


Fig. 12: E_{GS} for $N_c = 6$

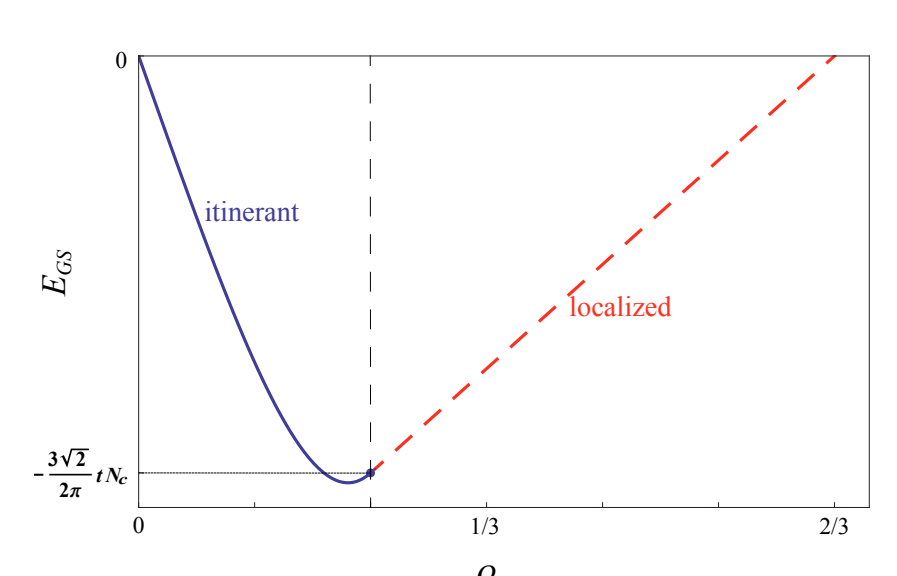


Fig. 13: E_{GS} (therm. lim.)

- At $\rho = 2/9$ (reduced chain half-filled) phase separation occurs - larger delocalization zone (reduced kinetic energy)
- Itinerant band as close as possible to half-filling (all negative energy states filled)

SUMMARY

- Flat, dispersionless band for any value of ϕ
- Localized energy eigenbasis for any ϕ (flat band)
- Algorithm for finding flat states in arrays of quantum rings
- For V interaction we have obtained an interesting phase diagram
- Exact solution in the strong coupling limit ($V \rightarrow \infty$) presented. Phase separation for $\rho > 2/9$.

FUNDING

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REFERENCES

- [1] A. A. Lopes, R. G. Dias, Interacting spinless fermions in a diamond chain *Phys. Rev. B*. **84**, 085124 (2011).
- [2] R. G. Dias, Exact solution of the strong coupling $t - V$ model with twisted boundary conditions *Phys. Rev. B*. **62**, 7791–7801 (2000)