Ground state phase diagram of a hard-core boson model in a honeycomb optical lattice

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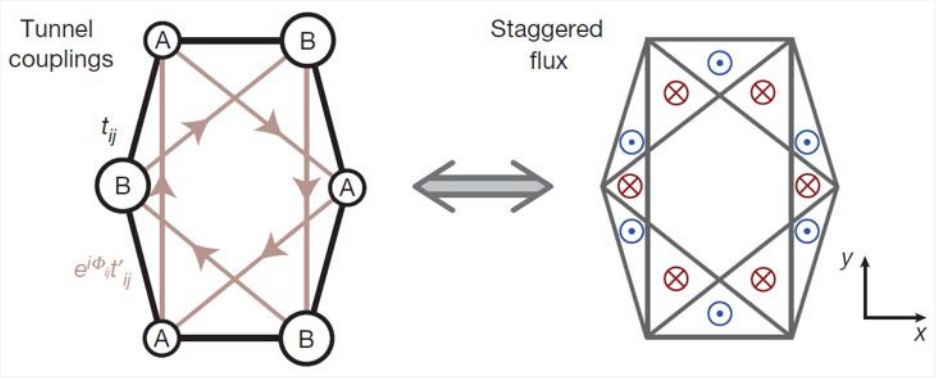
Experimental realization of the Haldane model



G. Jotzu et al., Nature **515,** (2014).

breaking

Inversion symmetry

Time-reversal symmetry

Quantum Hall effect

We study a system of

dipolar hard-core bosons in a honeycomb optical lattice

$$H_{\mathrm{HBHM}} = J_1 \sum_{\langle i,j \rangle} (a_i^\dagger a_j + h.c.) + J_2 \sum_{\langle\langle i,j \rangle\rangle} (e^{i\phi} a_i^\dagger a_j + h.c.)$$
$$+ V \sum_{\langle i,j \rangle} n_i n_j \left(-\mu \sum_i n_i\right)$$

NN repulsive interaction

Complex NNN hopping

Geometrical frustration

$$H_{\mathrm{HBHM}} \longrightarrow Z_{\mathrm{HBHM}} = \int [d\delta\rho_{bi}][d\delta\rho_{hi}][d\theta_{bi}][d\theta_{hi}][d\lambda_i] e^{-S_{\mathrm{HBHM}}}$$

$$a_i = h_i^\dagger b_i$$

$$(b_i^\dagger b_i + h_i^\dagger h_i)|\mathrm{Phys}\rangle = |\mathrm{Phys}\rangle$$

$$b_i = \sqrt{\rho_{bi} + \delta\rho_{bi}}\; e^{i\theta_{bi}}$$

$$h_i = \sqrt{\rho_{hi} + \delta\rho_{hi}}\; e^{i\theta_{hi}}$$

$$S_{\mathrm{HBHM}} = \int d\tau [S_\tau + S_H + S_I + \sum_i U_\tau(\delta\rho_{bi}^2 + \delta\rho_{hi}^2)]$$

$$S_\tau = \sum_i [i(\partial_\tau\theta_{bi} + \lambda_i)\delta\rho_{bi} + i(\partial_\tau\theta_{hi} + \lambda_i)\delta\rho_{hi}] \quad S_I = V\sum_{\langle i,j\rangle} \rho_{bi}\rho_{bj}$$

$$S_H = 2\; J_1 \sum_{\langle i,j\rangle} \sqrt{\rho_{bi}\rho_{hi}\rho_{bj}\rho_{hj}}\cos(\theta_i - \theta_j) + 2J_2 \sum_{\langle\langle i,j\rangle\rangle} \sqrt{\rho_{bi}\rho_{hi}\rho_{bj}\rho_{hj}}\cos(\theta_i - \theta_j - \phi)$$

$$\begin{aligned} S_{\mathrm{HBHM}} = \sum_{\ell=0}^{N_\tau - 1} \Big[& \sum_i -\frac{1}{2U_\tau\Delta\tau}[\cos(\theta_{bi,\ell+1} - \theta_{bi,\ell} + \lambda_{i,\ell}) + \cos(\theta_{hi,\ell+1} - \theta_{hi,\ell} + \lambda_{i,\ell})] \\ & + \frac{1}{2}J_1\Delta\tau \sum_{\langle i,j\rangle} \sin(2\chi_{i,\ell})\sin(2\chi_{j,\ell})\cos(\theta_{i,\ell} - \theta_{j,\ell}) \\ & + \frac{1}{2}J_2\Delta\tau \sum_{\langle\langle i,j\rangle\rangle} \sin(2\chi_{i,\ell})\sin(2\chi_{j,\ell})\cos(\theta_{i,\ell} - \theta_{j,\ell} - \phi) \\ & + V\Delta\tau \sum_{\langle i,j\rangle} \sin^2(\chi_{i,\ell})\sin^2(\chi_{j,\ell}) - \mu\Delta\tau\sum_i \sin^2(\chi_{i,\ell}) - \Delta\tau\sum_i \ln(\sin(2\chi_{i,\ell}))\Big] \end{aligned}$$

(2 + 1)D XXZ model