Two-Face of Interaction Blockade: Anisotropic Superfluidity of Bosons in Kagome Superlattice

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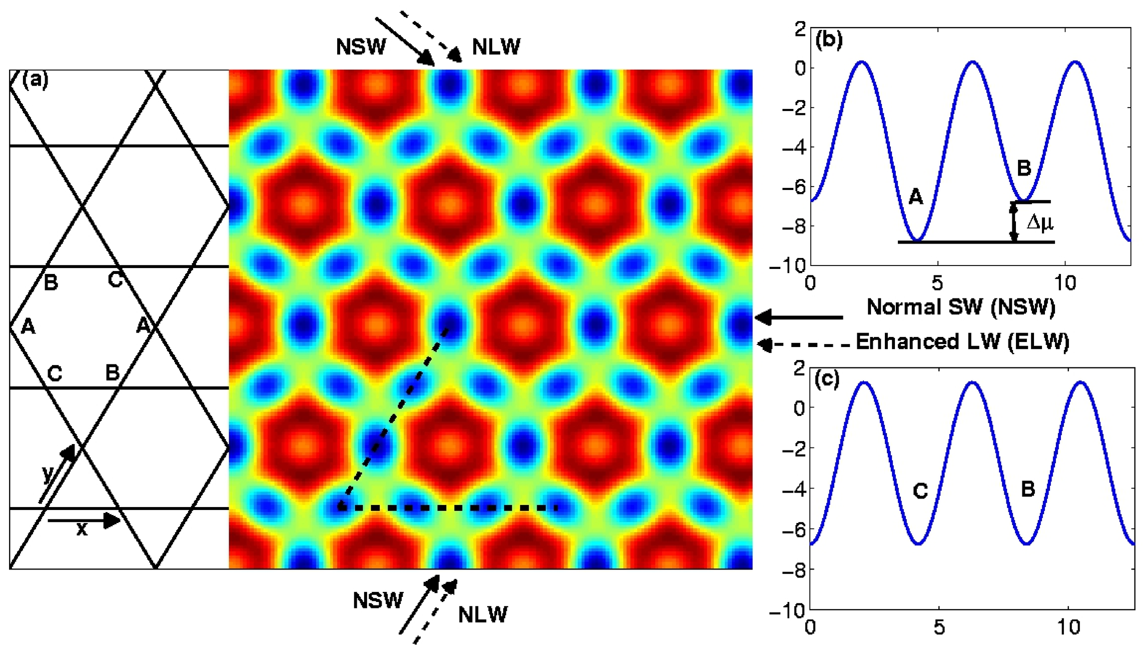
Abstract

We studied the generalized Bose-Hubbard model in the optical Kagome superlattice induced by enhancing the long wavelength laser in one direction. By using the quantum Monte Carlo simulation and the multi-component Landau theory, we found not only the Mott insulator and superfluid phase, but also the striped solid phase with different filling factors emerge in this system, and we also show the related phase diagrams. Due to the interaction blockade effects of the striped order, the resulting superfluid density turns out to be anisotropic and thus, reveals its tensorial property. Counterintuitively, the bias of the anisotropy is alternating between *x* and *y* direction while detuning the particle numbers.

Model



The optical Kagome Lattice is formed by six lasers[1]:
3 Short wavelength (SW) (532nm)
3 Long wavelength (LW) (1064nm)
One of LW laser is enhanced.

$$\gamma = V_{ELW}/V_0$$

The optical potential is:

$$V_c/V_0 = \gamma^2 + 4\gamma\cos(k_x x)\cos(k_y y) - 1 + 2\cos(2k_x x) - 2\cos(4k_x x) - 4\cos(2k_x x)\cos(2k_y y) \qquad k_x = \sqrt{3}k/4,\ \ k_y = 3k/4$$

The system is described by generalized Bose-Hubbard Model :

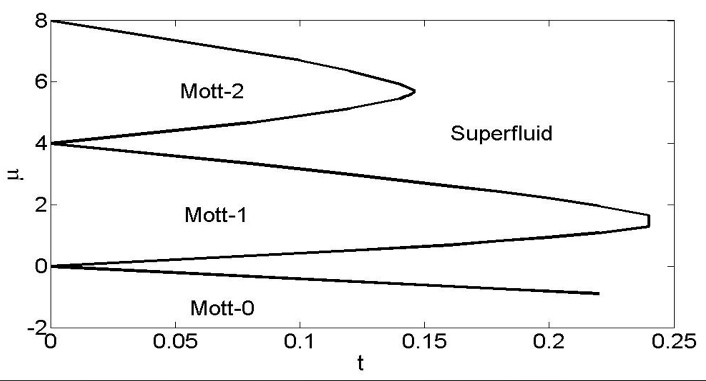
$$H = -t\sum_{\langle i,j\rangle}(a_i^\dagger a_j + a_j^\dagger a_i) + \frac{U}{2}\sum_i n_i(n_i-1) - \mu\sum_i n_i - \Delta\mu\sum_{i\in A} n_i$$

Phase diagram

$\Delta\mu = 0$

The Bose-Hubbard Model in the Kagome Lattice , there exists Mott insulator – Superfluid phase transition

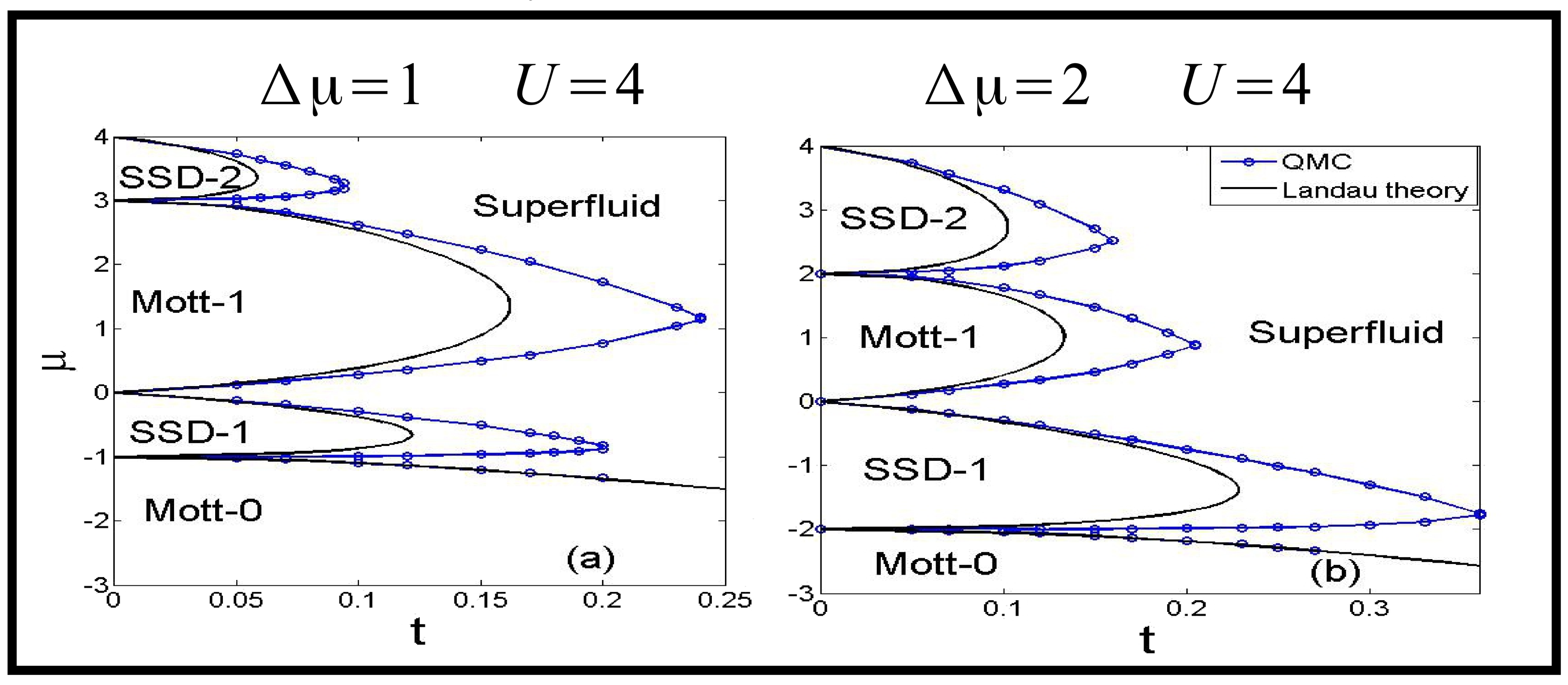
The phase diagram from quantum Monte Carlo simulation at U=4



$\Delta\mu \neq 0$ The striped solid phase (SSD) emerges and the phase diagram is determined by QMC and Landau theory[3]

SSD-n: the density in A sublattice is n, in B and C lattices is n-1;

Mott-n: the density in all sublattice is n

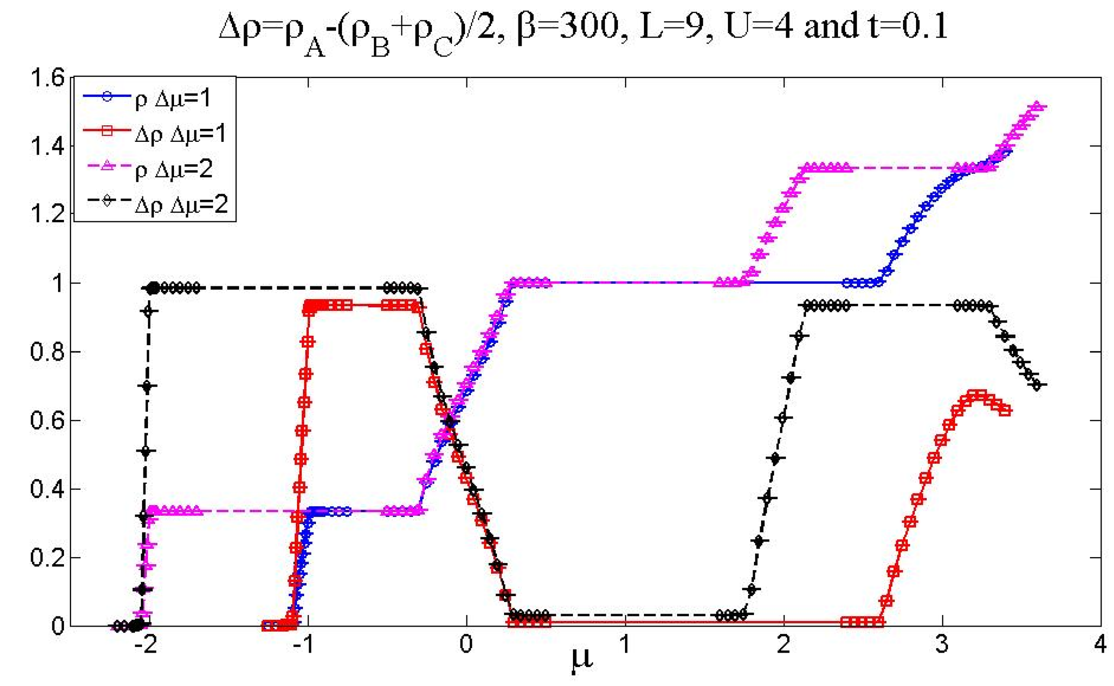


Phase range at t=0:

$$\text{SSD-n:}\quad U(n-1) - \Delta\mu \leq \mu \leq U(n-1)$$
$$\text{Mott-n:}\quad U(n-1) \leq \mu \leq Un - \Delta\mu$$

Numerical simulation

We use the Stochastic Series Expansion to simulate this system. The total density and the density difference between A and B, C sublattice show the SSD and Mott insulator phases.

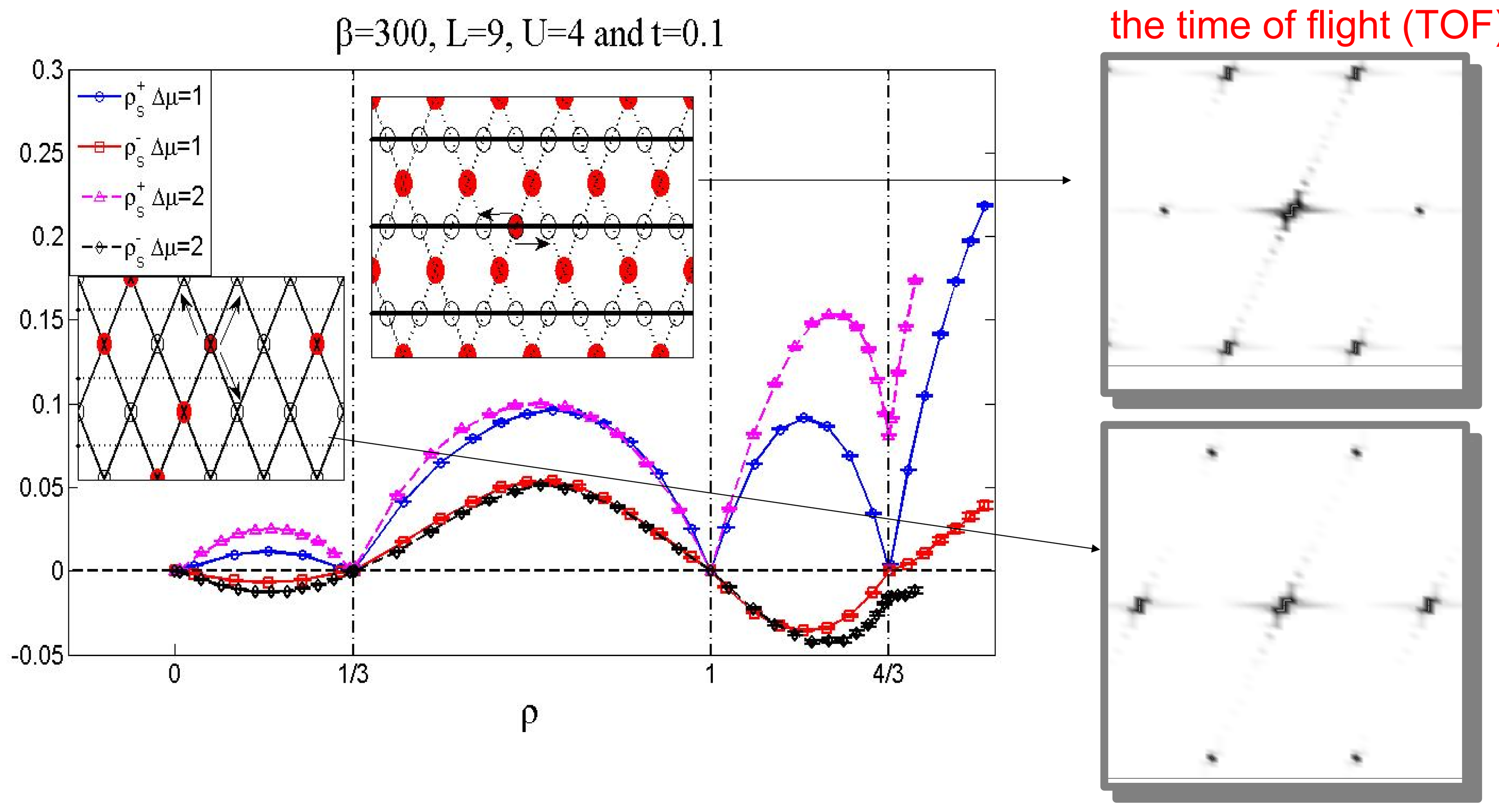


In order to detect the superfluid density in x and y direction, we define them with winding numbers:

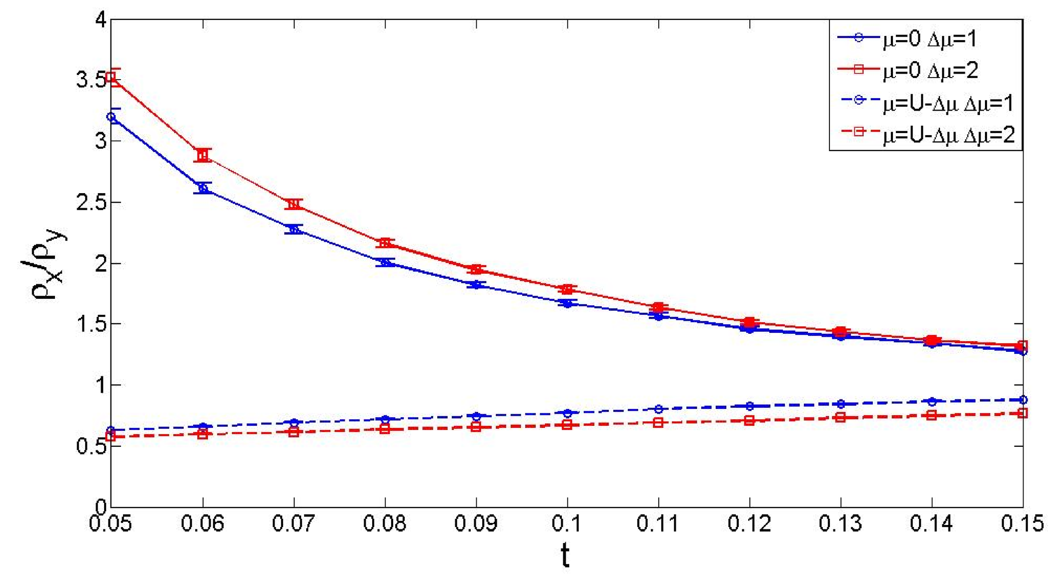
$$\rho_s^x = \frac{W_x^2}{4\beta t},\quad \rho_s^y = \frac{W_y^2}{4\beta t},\quad \rho_s^+ = (\rho_s^x + \rho_s^y)/2,\quad \rho_s^- = \rho_s^x - \rho_s^y.$$

And we found the alternative anisotropic properties of the superfluid density. It indicates the tensorial property of the superfluid density.

Schematic photo of the time of flight (TOF)



At last, we analyze the bias of the superfluid density:



Conclusion

1. We find a simple method to build the optical Kagome superlattice and also show the related extended Bose-Hubbard Model.
2. By using both quantum Monte Carlo simulation and the Landau theory, we got the phase diagram of both normal Kagome lattice and superlattice. In the superlattice system, we found the striped solid phase with fractional density filling factor.
3. By analyzing the superfluid density in *x* and *y* direction, we found distinct anisotropic properties of the superfluid density which underline its tensorial property.

Reference

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