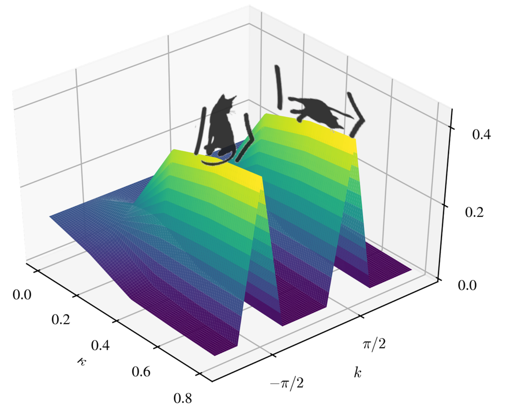
CAT STATES IN A KINETICALLY-DRIVEN SUPERFLUID



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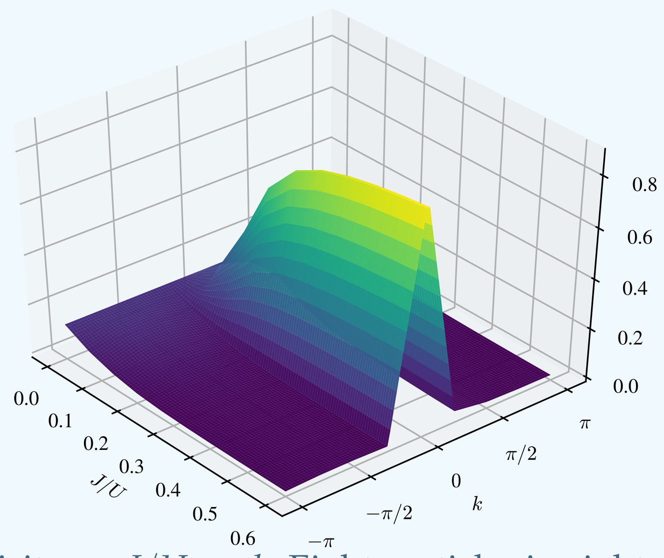
OVERVIEW AND MOTIVATION

- Ultracold atoms trapped in optical lattices offer a powerful toolbox for studying many-body systems through quantum simulation. Possibility to study condensed matter systems and new phases of matter, e.g. Bose-Einstein condensates (BEC).
- The Bose–Hubbard (BH) model gives a description of the physics of interacting bosons on a lattice. Explicit time dependence by driving in time any term of the Hamiltonian of the system in order to explore new and interesting effects.
- Floquet engineering consists of rapidly oscillating a parameter of a Hamiltonian periodically in time, which, following the elimination of the high-frequency degrees of freedom, produces a time-independent effective Hamiltonian.
- Cat states: coherent quantum superposition between two o more macroscopic different parts. Particular and extreme form of entanglement. The preparation of such a states is difficult due to decoherence. Applications: test for macroscopic realism, atom interferometry, precision measurements, quantum information task and quantum metrology.
- Goal: To extent the study of the properties of our exotic cat state and to test its robustness.

BOSE-HUBBARD MODEL

$$\mathcal{H} = \underbrace{-J\sum_{x=1}^{L}\left(a_x^{\dagger}a_{x+1} + \text{H.c.}\right)}_{\text{kinetic}} + \underbrace{\frac{U}{2}\sum_{x=1}^{L} n_x(n_x-1)}_{\text{interaction}}$$

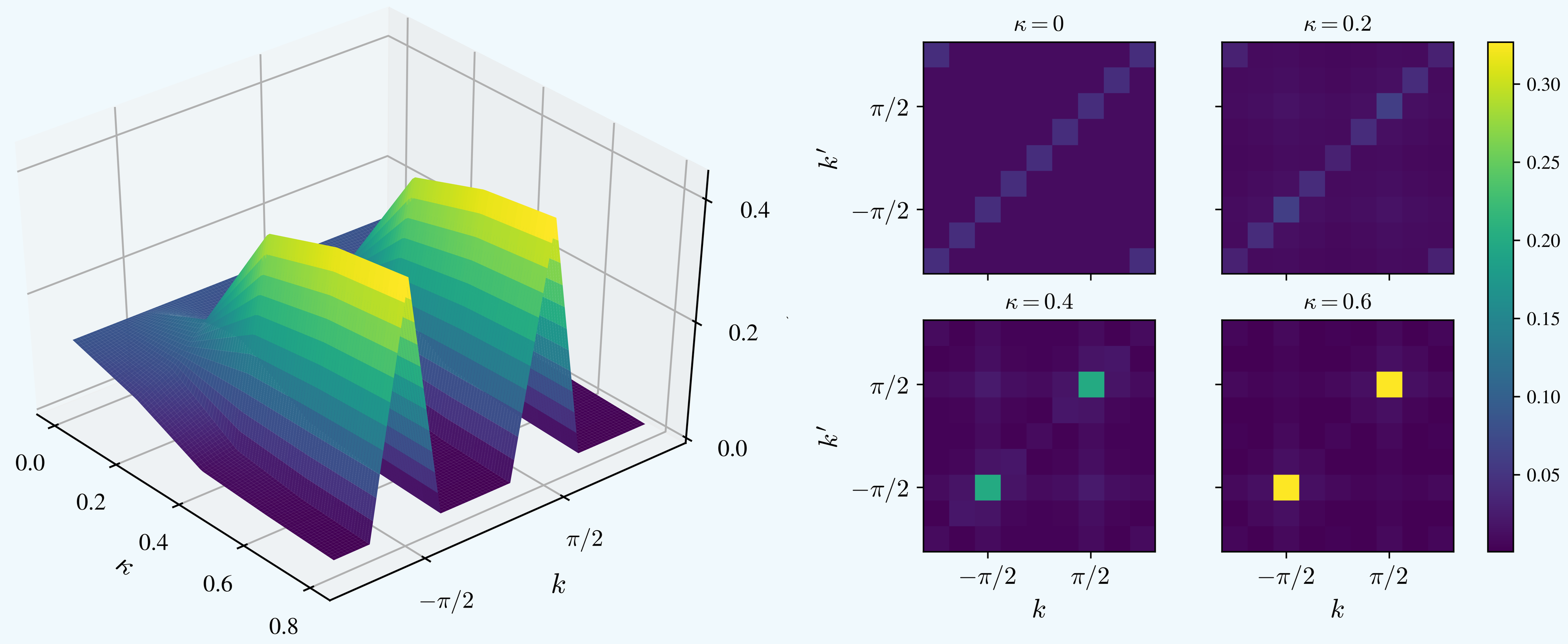
UNDRIVEN



Momentum denisity vs. J/U vs. k. Eight particles in eight sites of a ring.

- Hopping to nearest neighbors.
- Transition phase.
- For $J = 0$, interaction domains. Mott insulator.
- As $J\uparrow$, kinetic domains. Superfluid, BEC forms at $k = 0$.

KINETICALLY DRIVEN



(Left) Momentum density versus κ vs. k. (Right) 2-Particle momentum density (2-PMD) for several κ. Eight particles in eight sites of a ring.

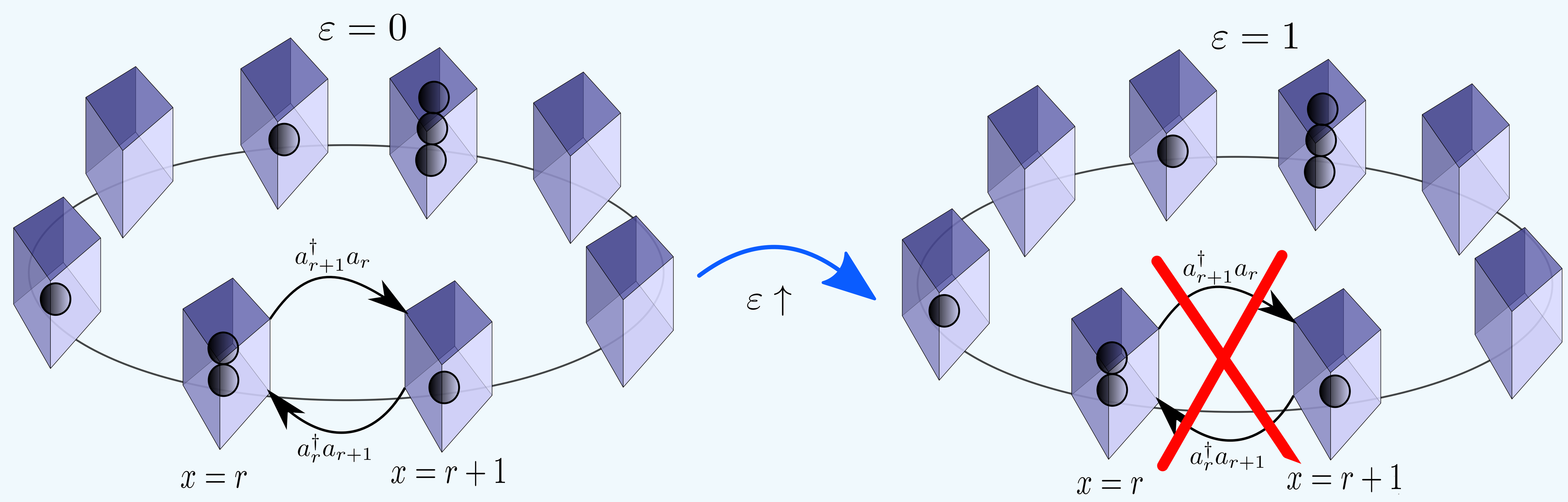
- Time-periodic modulation of the hopping amplitude, $J \to f(t) = J\cos(\omega t)$.
- Kinetic and interaction terms merge in a unique term in the effective Hamiltonian. Correlated hoppings appear!
- Transition phase remains. For $\kappa = 0$, Mott insulator. As $\kappa\uparrow$, superfluid.
- Fragmented condensate at $k = \pm\pi/2$.
- The absence of cross peaks in the 2-PMD reveals that the ground state is a Schrödinger cat state.

MINOR CHANGES

- Signal shape: The cat structure remains for other non-sinusoidal drivings: square, triangle and sawtooth (zero time average periodic functions).
- Switching protocol: The effective Hamiltonian is totally independent on the initial phase of the driving.
- External flux: Introducing a Peierls phase connensurate with the reciprocal lattice shifts the peaks, but the cat remains.

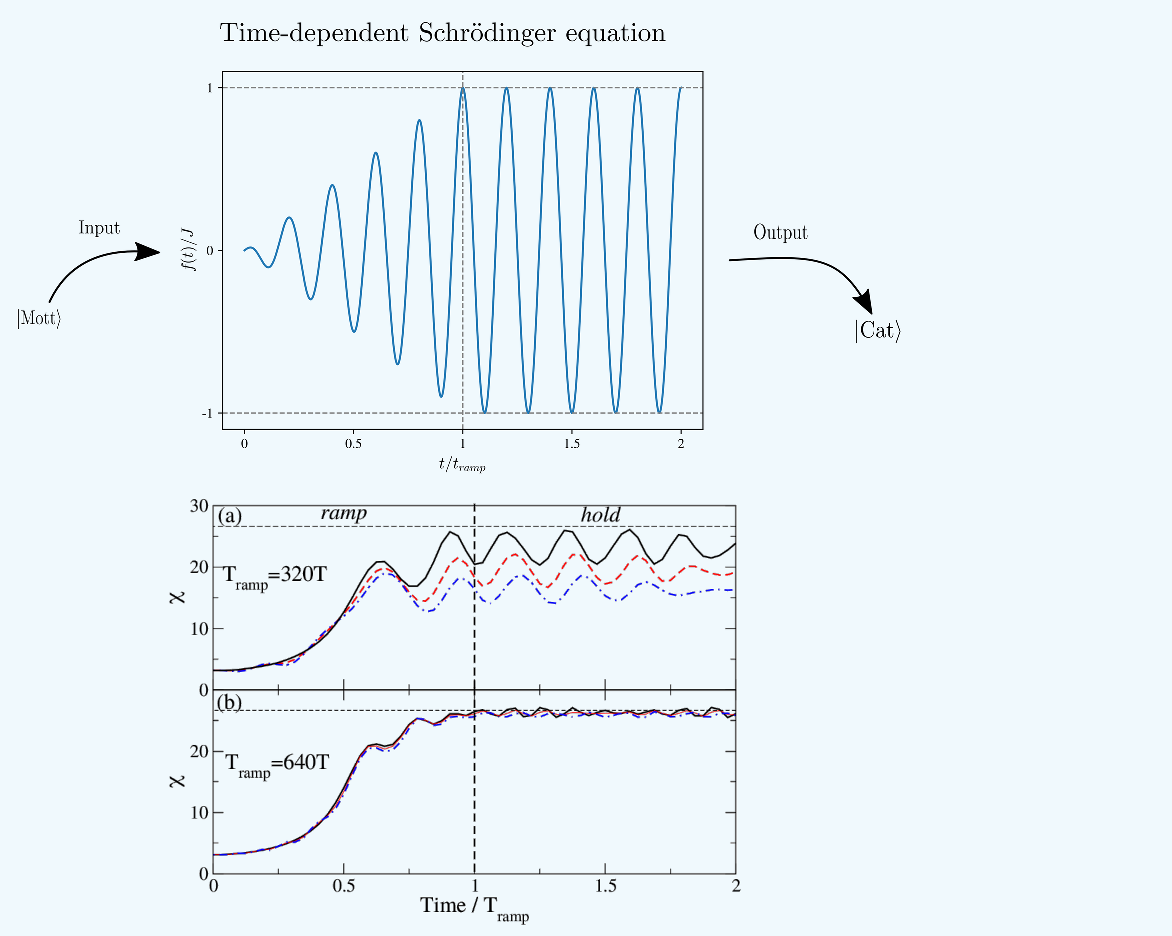
CURRENT WORK: SUPERFLUIDITY

- Exotic superfluidy due to the correlations of the kinetically-driven BH.
- Proven by general theorems: Tomonaga-Luttinger liquid theory.
- Look for signs of superfluidity by adding an impurity in the ring.



Off-diagonal impurity in the ring mediated by ε. As ε increases, the link between two adjacent sites is broken.

ADIABATIC PREPARATION



(Top) Starting from the Mott state, the hopping amplitude $J\cos(\omega t+\varphi)$ is ramped-up slowly and the state is evolved to the Cat state. (Bottom) Momentum density at $\pi/2$ versus time to measure the protocol fiability. $\varphi = 0$(*black*), $\pi/2$ (blue) and $\pi/4$ (red).

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