



ATOMIC FERMIONS IN 1D OPTICAL LATTICE

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Motivation

- The Mott metal-insulator transition (MMIT) is a fundamental concept in strongly correlated many-body systems. The MMIT with bosonic atoms has been demonstrated.
- How can we detect the emergence of fermionic Mott-insulator phases in real experiments?

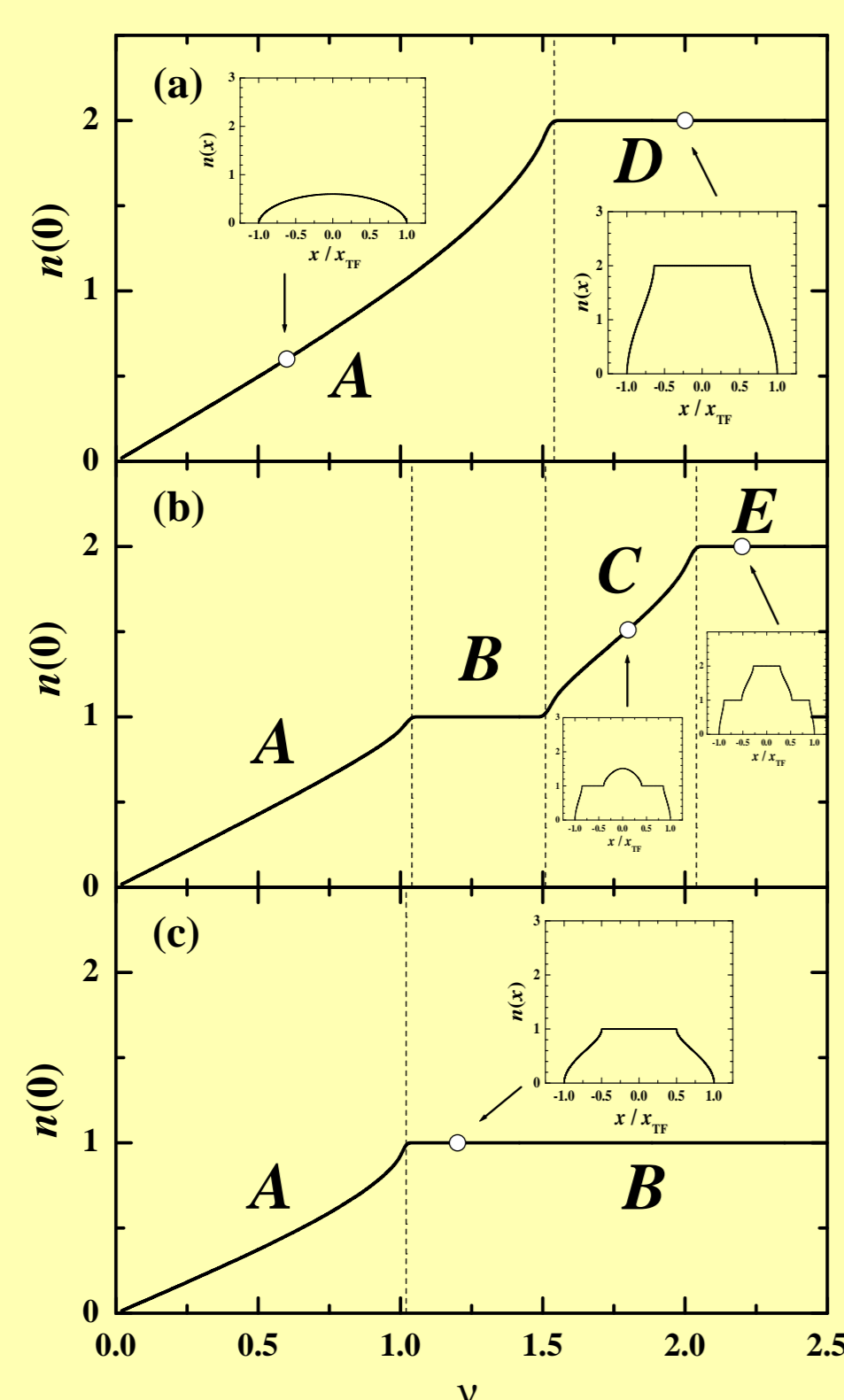
Phase Diagram

- 1D Hubbard model:

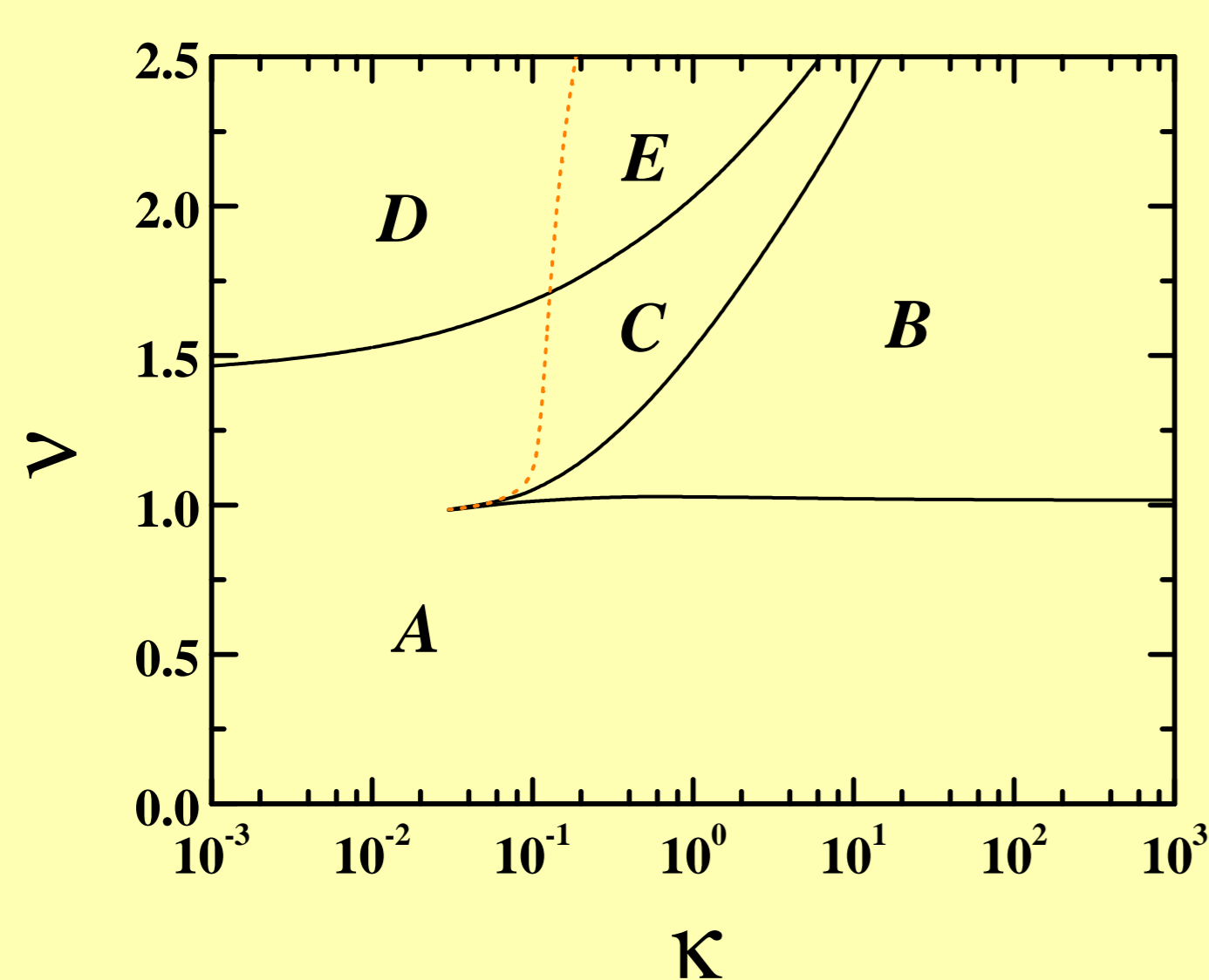
$$\mathcal{H}_0/t_h = u \sum_i n_{i\uparrow} n_{i\downarrow} - \sum_{i\sigma} (c_{i\sigma}^\dagger c_{i+1\sigma} + h.c.).$$

$$\mathcal{H} = \mathcal{H}_0 + \sum_{i\sigma} \frac{m\omega_0^2}{2} d^2 i^2 n_{i\sigma}.$$

- Method: exact solution.
- The different phases:
 - A: pure metallic phase; B: Mott insulator domain in center; C: metallic phase at center surrounded with Mott insulator plateaus; D: band insulator at center; E: band insulator at center surrounded by metallic regions, in turn surrounded by Mott insulators.
- Characteristic parameters
 - Interaction strength: $\kappa = u^2 / (16N\omega)$
 - filling factor: $\nu = 2\sqrt{N\omega}/\pi$
 - Central density for $\kappa = 0.01$ (a), 1 (b), and 100 (c):



- Phase diagram:



Collective Oscillations

- Luttinger liquid model:

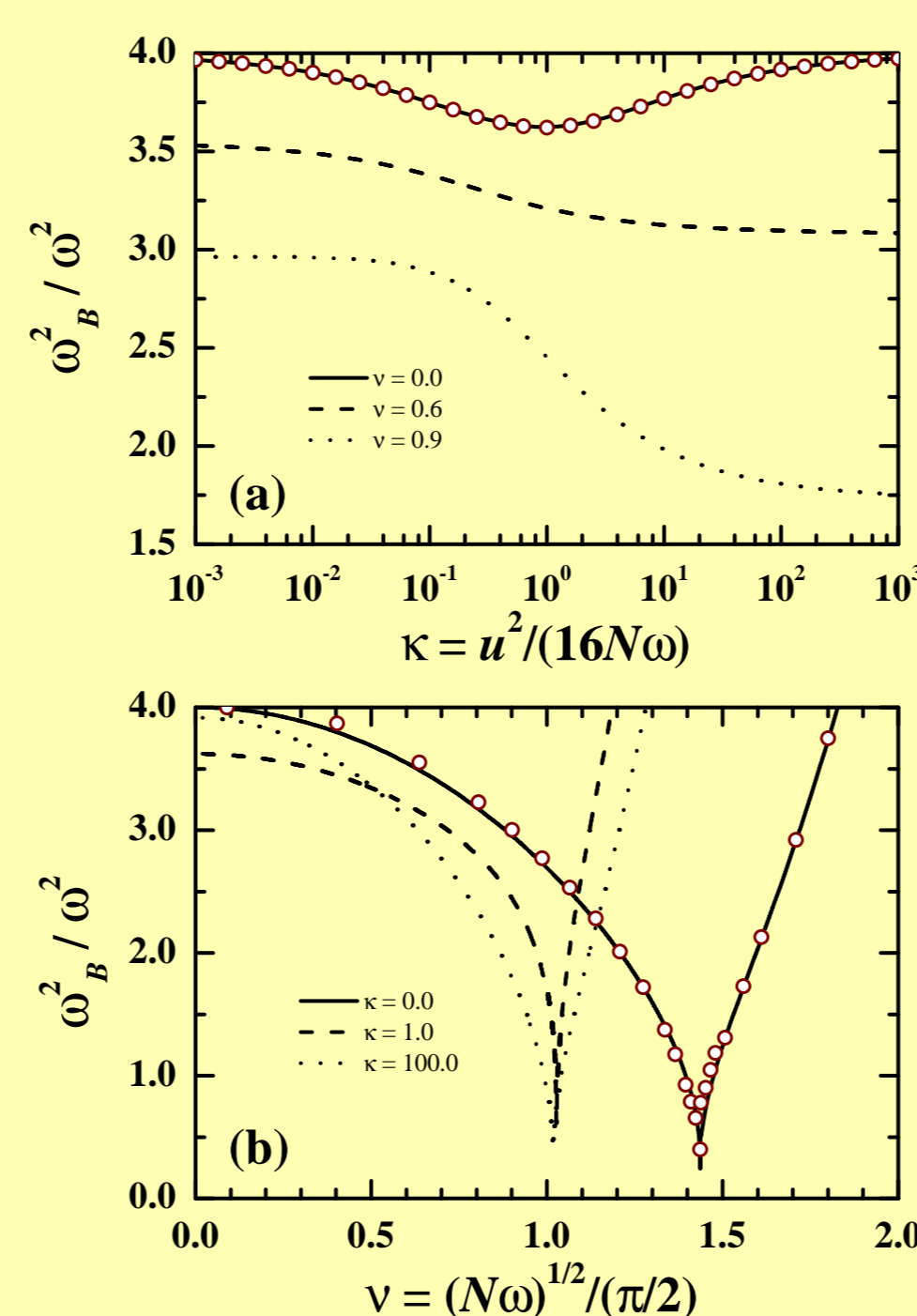
$$\mathcal{H}_{LL} = \sum_{\nu} \int dx \left[\frac{u_{\nu} K_{\nu}}{2} \Pi_{\nu}^2 + \frac{u_{\nu}}{2K_{\nu}} \left(\frac{\partial \phi_{\nu}}{\partial x} \right)^2 \right].$$

- $\partial_x \phi_{\nu}(x)$: density or spin density fluctuations;
- $\Pi_{\nu}(x)$: density or spin density currents;
- u_{ν} : density or spin velocities;
- K_{ν} Luttinger exponents.

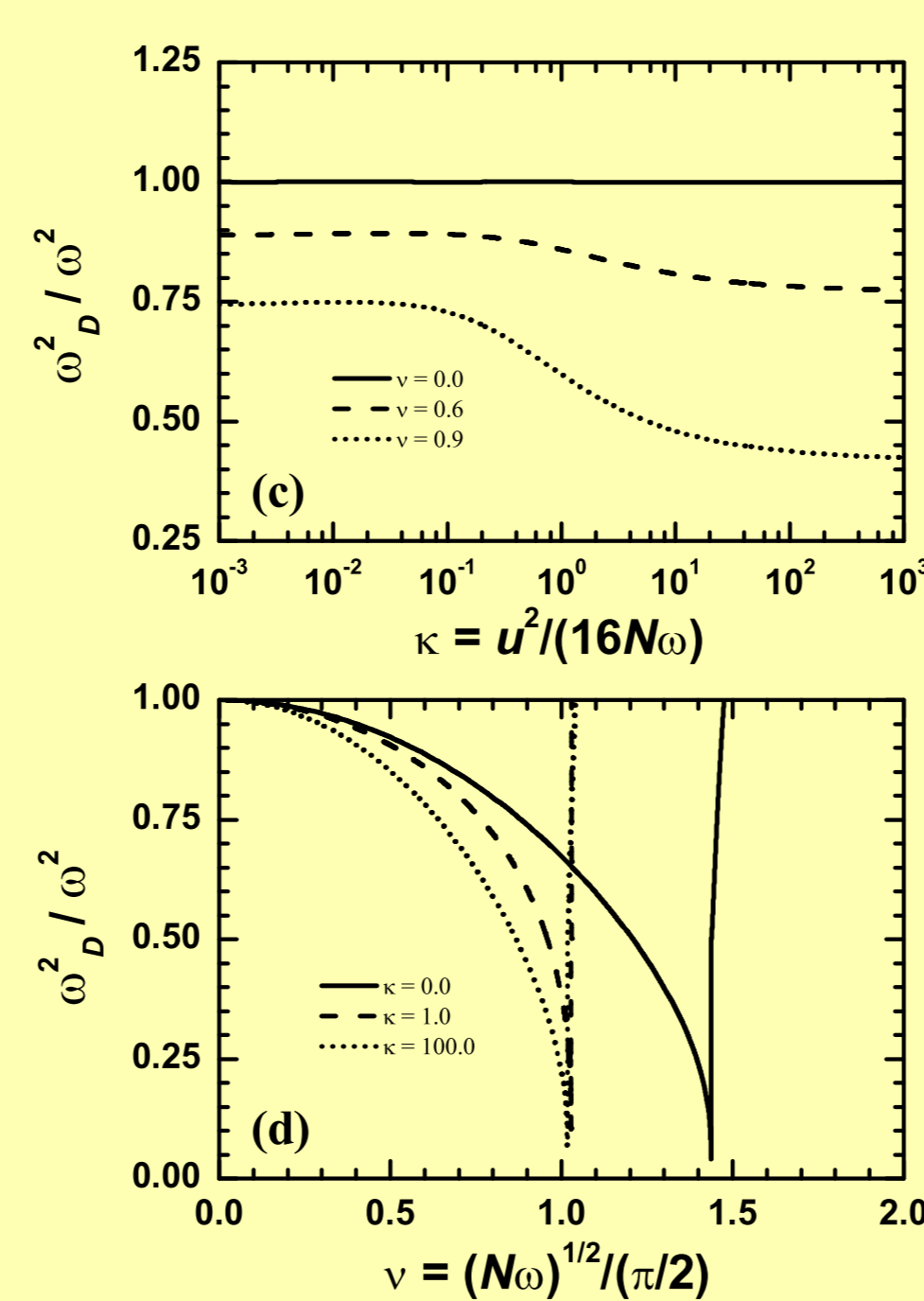
- Hydrodynamic equation:

$$\frac{\partial^2 \delta n_{\nu}}{\partial \tau^2} = \frac{\partial}{\partial x} \left[u_{\nu}(x) K_{\nu}(x) \frac{\partial}{\partial x} \left(\frac{u_{\nu}(x)}{K_{\nu}(x)} \delta n_{\nu} \right) \right].$$

- Focus on the density modes
- boundary conditions: current vanishes
- Breathing mode:

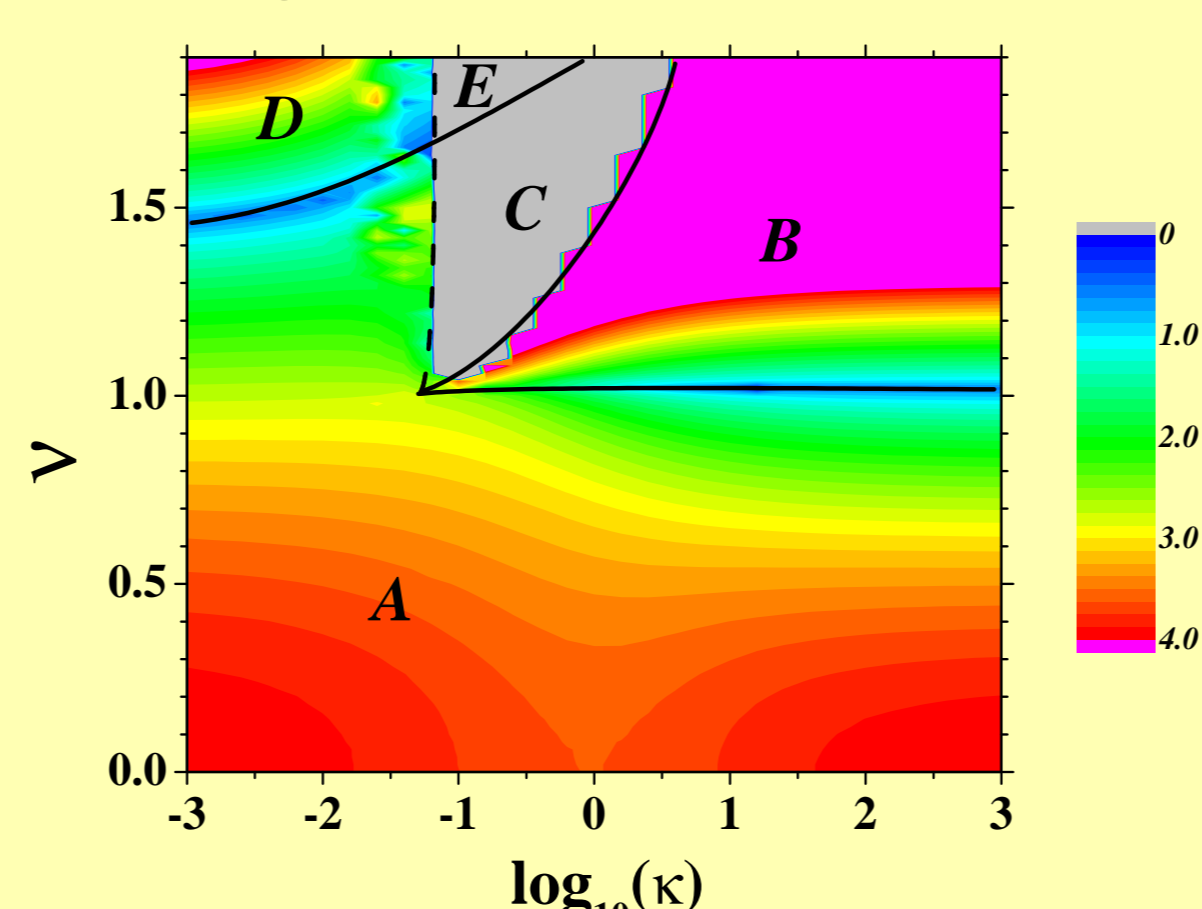


- Dipole mode:



- A sharp dip in the phase boundary.

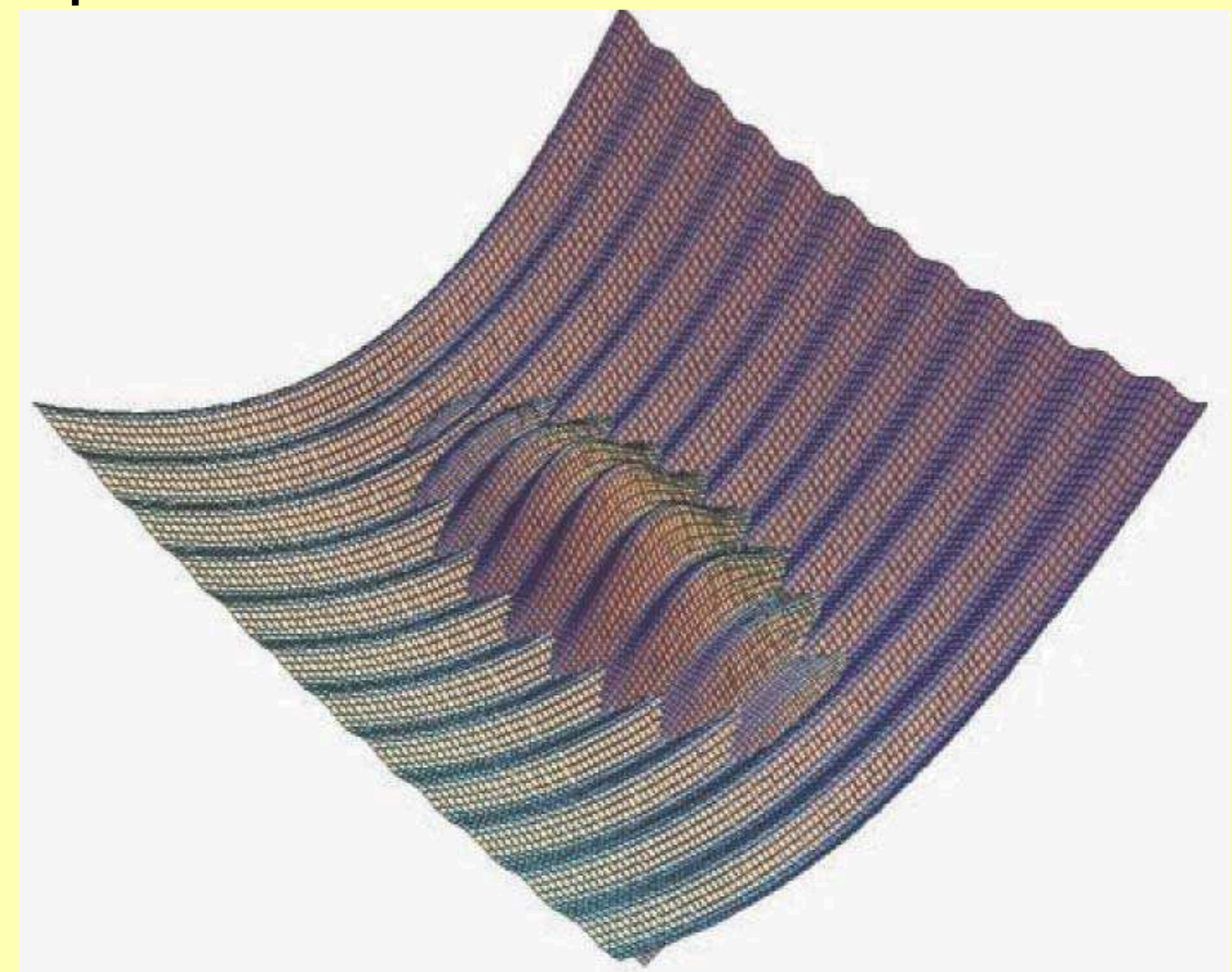
- Breathing mode frequency as ν and k :



- The blue regions with small frequency indicate a phase transition.

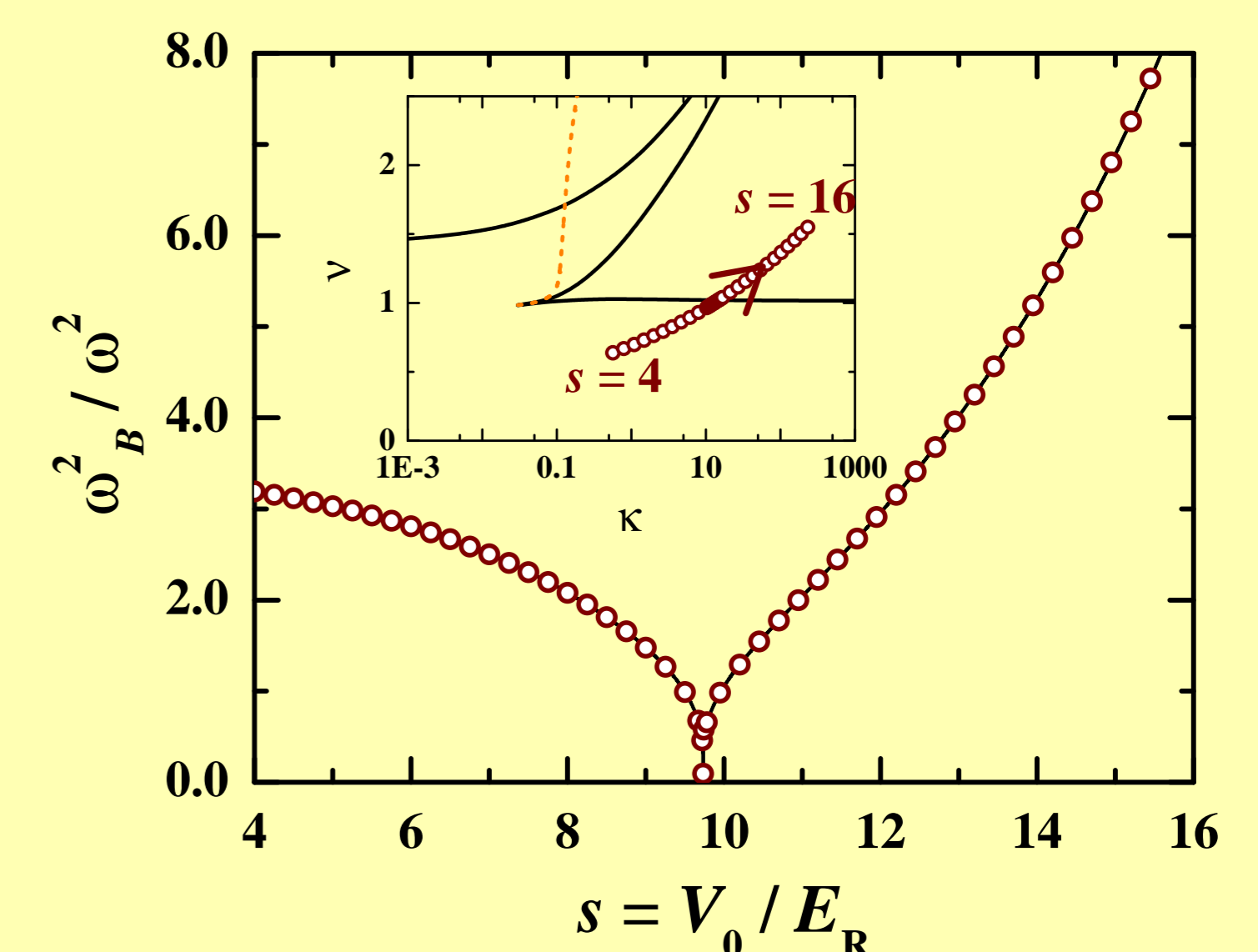
Experimental proposal

- Optical lattice



- Experimental parameters:

- Number of Fermions: $N=15$;
- Trapping frequency: $\omega_0 = 120\pi\text{Hz}$
- Wavelength: $2d = 854\text{nm}$
- Interaction: $a_{3D} = 26a_B$ for ^{40}K
- Experimental scheme:



- The frequency dip of the breathing mode signals the entrance into the Mott-insulator phase

Summary

- Present a phase diagram in 1D optical lattice.
- The collective modes provides a signature of the Mott metal-insulator transition.
- A detailed experimental implementation is proposed.
- How about the damping rates of collective modes?

References

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