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Superfluid Bloch Dynamics in an Incommensurate Lattice

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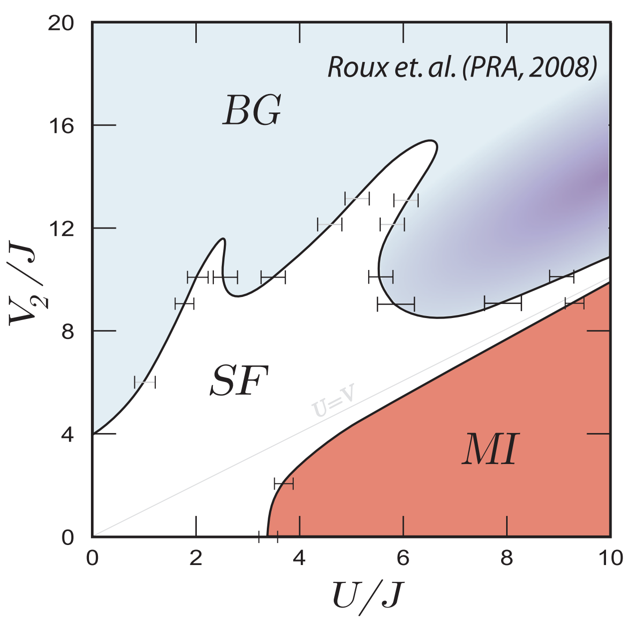
Motivation

Interplay between interactions and disorder



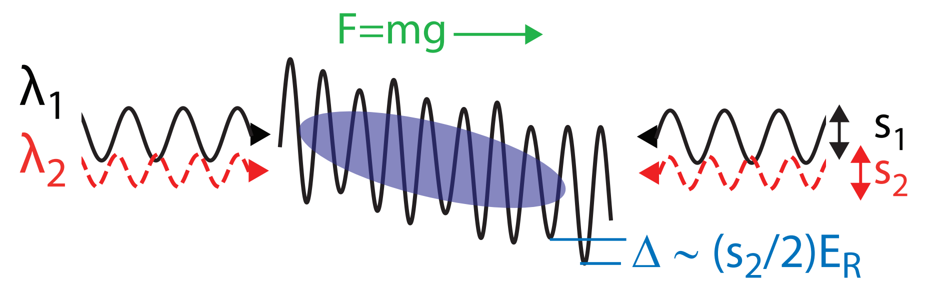
Disorder and interactions can influence the properties of condensed-matter systems in profound ways: Anderson localization; Mott insulator; Bose glass
Giamarchi and Schulz (PRB,1988)
Fisher et al (PRB,1989)

Disorder and interactions can *compete* or *cooperate*, depending on the interaction strength: Bose glass formation vs. screened-disorder superfluidity
Scarlettar et al (PRL,1991);
Deissler et al (Nat. Phys. 2010)

Effects on dynamical properties? For Bloch oscillations in disordered lattice potentials: prediction of reduction/enhancement of damping
Schulte et al (PRA,2008); Walter et al (PRA,2010)

BEC in a Tilted, Incommensurate Optical Lattice

Bichromatic optical lattice (1D)

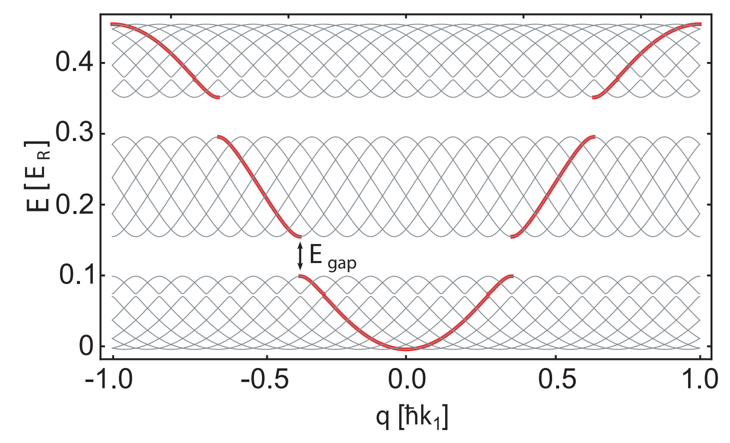


$\lambda_1 = 1064$ nm
$\lambda_2 = 785.2$ nm

$$V(z) = s_1 E_R \cos(2\pi/\lambda_1 z)^2 + s_2 E_R \cos(2\pi/\lambda_2 z)^2 + mgz \quad (E_R = h^2/2M\lambda_1^2)$$

$\lambda_1/\lambda_2 = \beta = 1.355...$
beat period exceeds size of BEC: effective quasi-disorder

Lattice band structure (β=1.36) effectively incommensurate

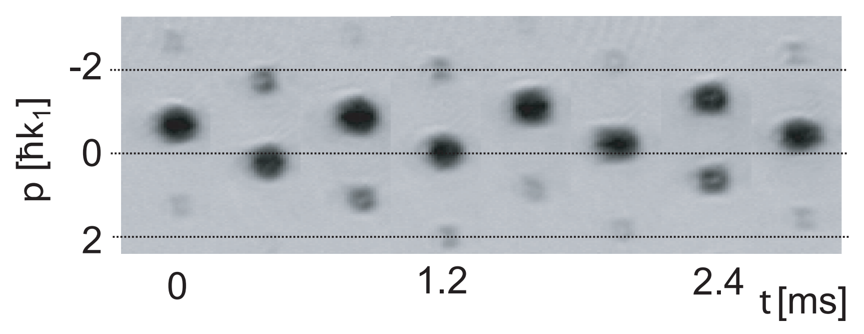


ground band of primary lattice (s_1=3)

secondary lattice (s_2=0.1) opens minigaps

$E_{gap} = (1/2)\, s_2 E_R \sim \Delta$

s_2=0 Bloch Oscillations

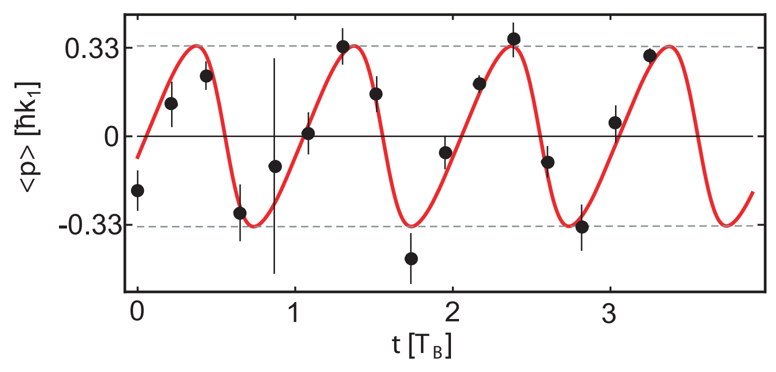


Quasimomentum
$q(t) = F/\hbar\, t$

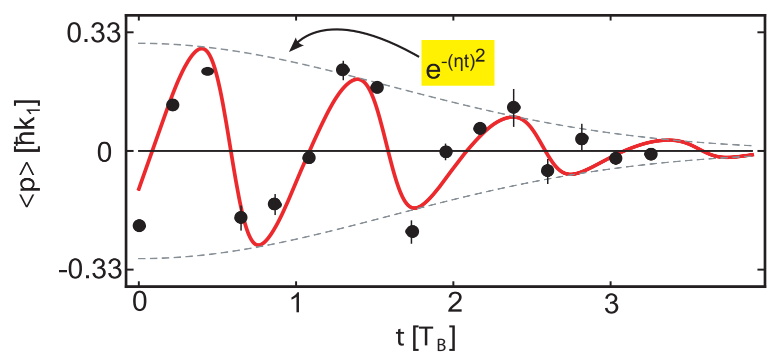
Momentum
$\langle p(t)\rangle = \frac{m}{\hbar}\frac{dE(q)}{dq}$

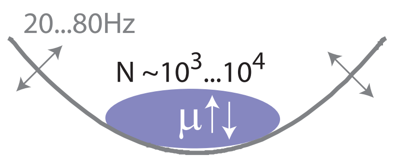
oscillation period
$T_B = h/(Fd) \approx 0.9$ ms

• $\mu/E_R = 0.07$



• $\mu/E_R = 0.46$



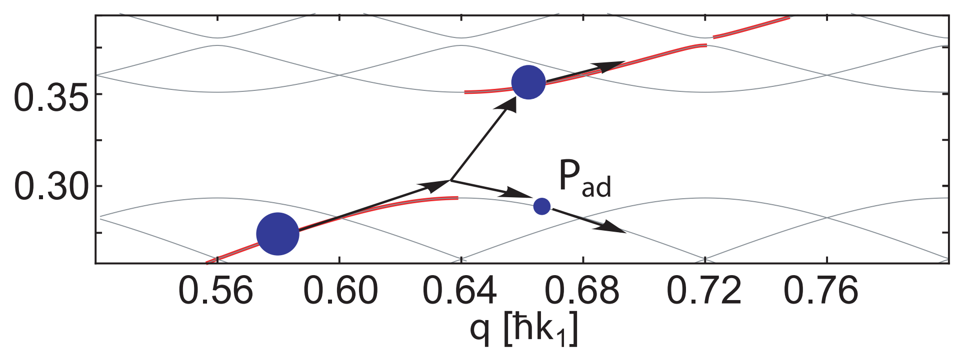


Interaction-driven damping
(nonlinearities, dynamical instability, quantum chaos)
Buchleitner & Kolovsky (PRA,2003)
Witthaut et al (PRE, 2005)
Kolovsky et al (PRA,2009)
Fattori et al (PRL,2008)
Gustavsson et al (PRL,2008)

$$\langle p(t)\rangle = \frac{m}{\hbar}\frac{dE(q)}{dq}\, e^{-(\eta t)^2}$$

s_2>0 Bloch Oscillations

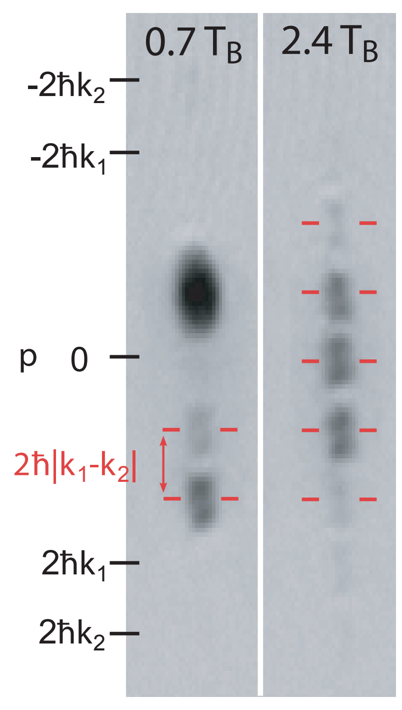
Landau Zener (LZ) tunneling



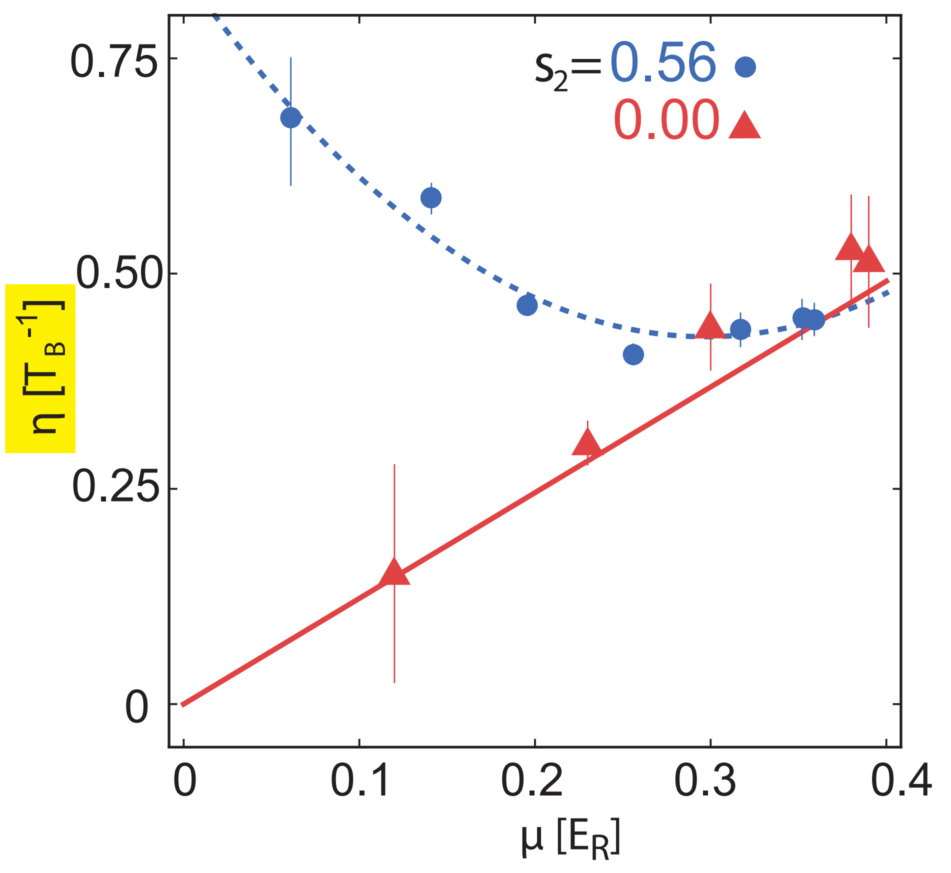
Probability to traverse a minigap adiabatically is

$$P_{ad} = \exp\left[\frac{-2\pi E_{gap}^2}{F(dE/dq|_{gap})}\right]$$

Nonadiabatic transitions, combined with Bragg reflections, lead to breakup of momentum space wave-function and rapid dephasing.

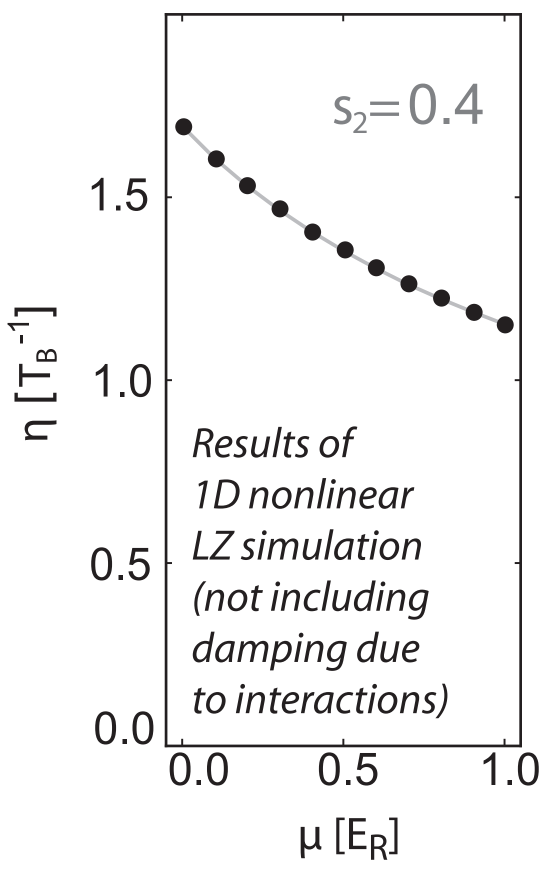


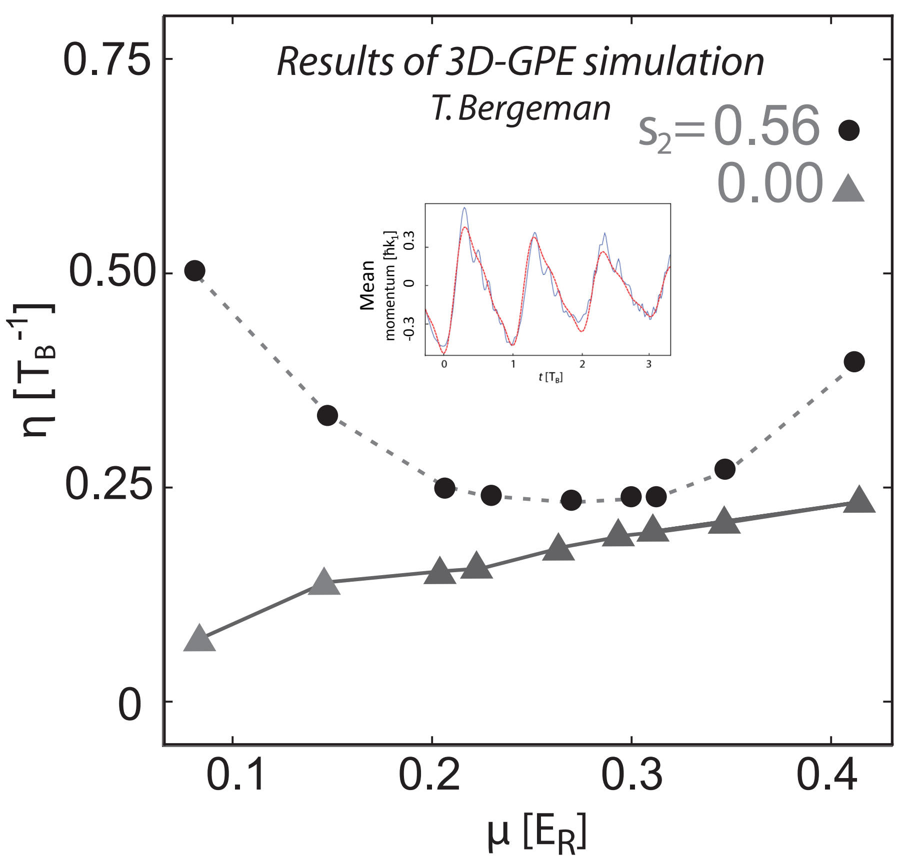
Combined Effect of Interactions and Disorder



• *disorder-free case:* more interactions mean **more** damping
• *disordered case:* more interactions can mean more, or **less,** damping

• (parabolic) fit yields minimum for $\mu = 0.29\, E_R \approx \Delta$





• interactions **renormalize the minigap** (reduction) and thus lead to a breakdown of adiabaticity

• **screening of disorder** potential; crossover to interaction-dominated damping near μ~Δ