Disordered Insulator in an Optical Lattice

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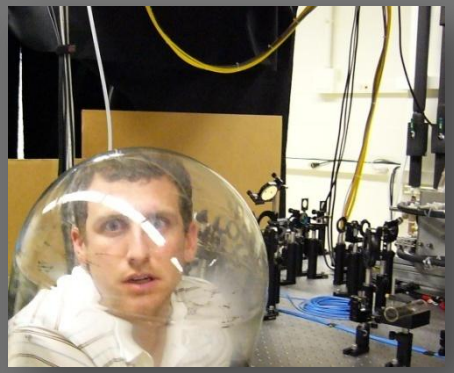
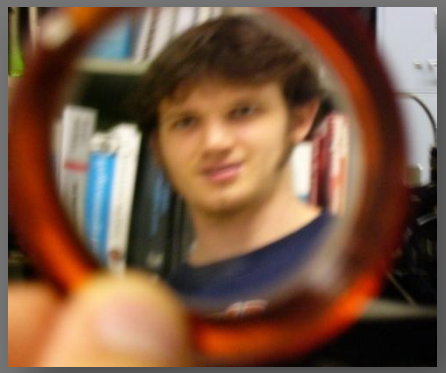
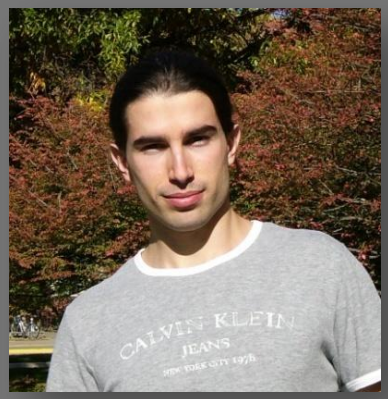
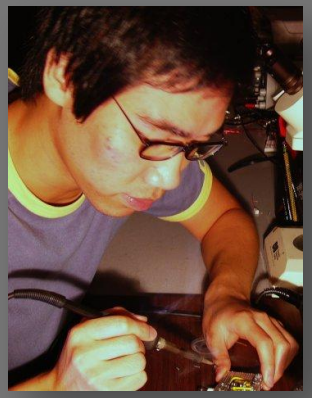
Josh Zirbel


Matt Pasienski


David McKay



Stan Kondov


David Chen


Carrie Meldgin


Will McGehee


Paul Koehring

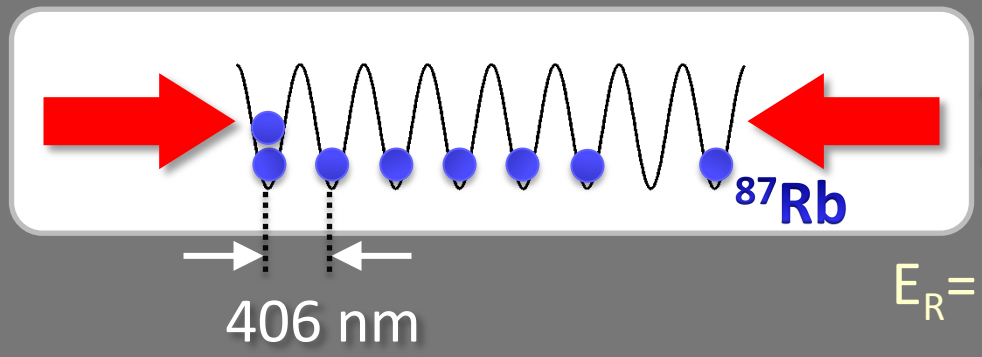
Outline

- Disordered Bose-Hubbard model
- Creating a disordered lattice
- Transport measurements: SF–IN transition
- Updates:

  compressibility, spin-dependent lattices

1 atom / site in the center of the lattice

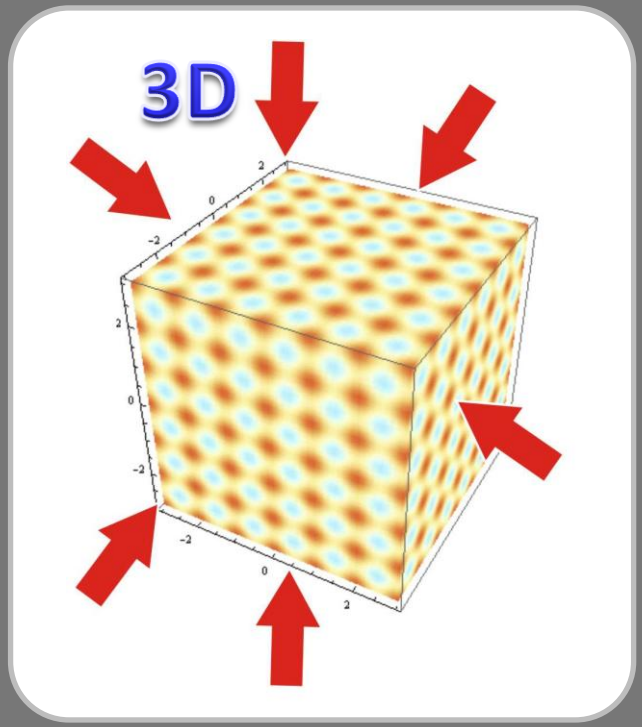
Optical lattices: clean BH model



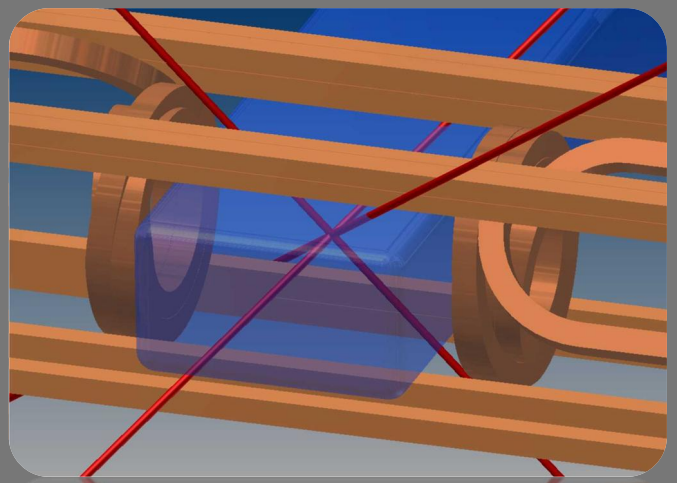
$E_R = k_B 170$ nK

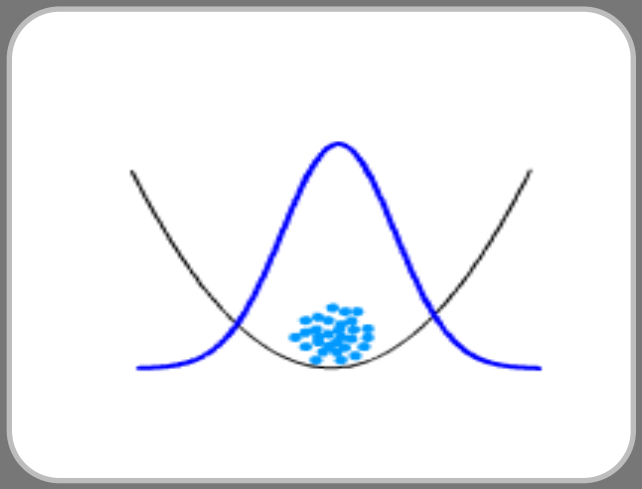
$$H = -t\sum_{\langle ij\rangle}\left(b_i^\dagger b_j + b_j^\dagger b_i\right) + \frac{U}{2}\sum_i n_i\left(n_i - 1\right)$$

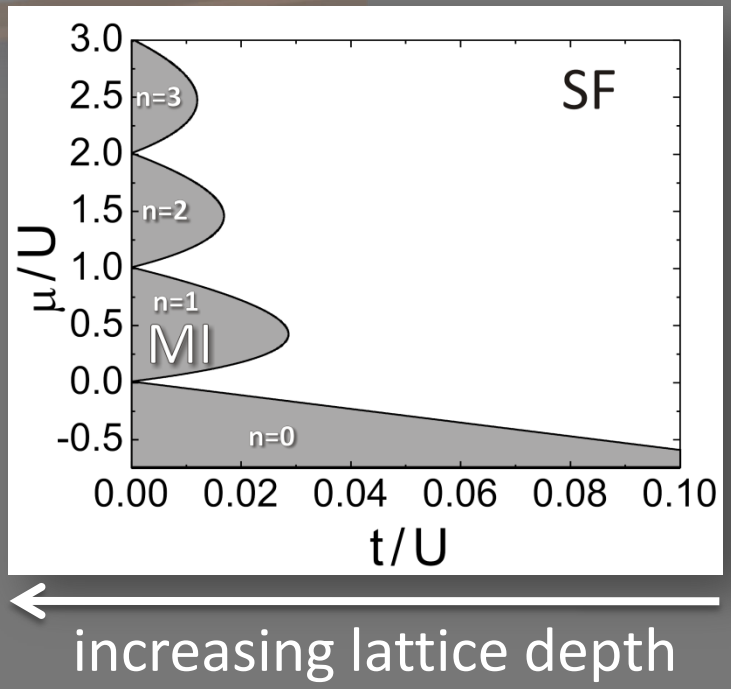
t/U controlled by lattice depth



Clean BH model





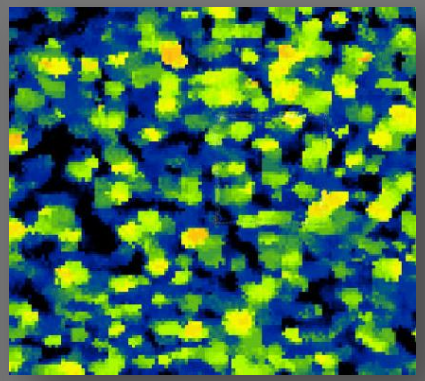
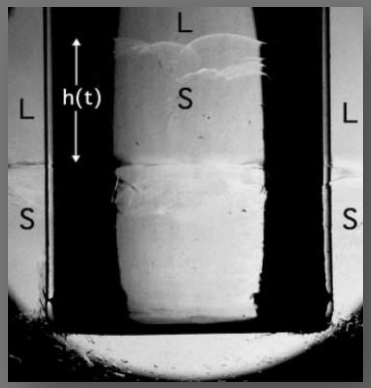


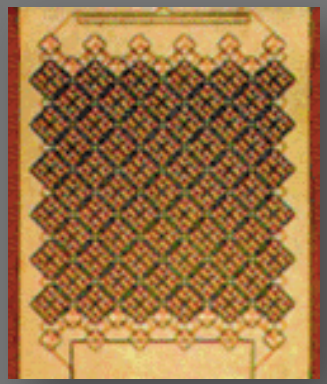
Weak lattice:
- Superfluid (SF)

Strong lattice:
- Mott-insulator (MI)

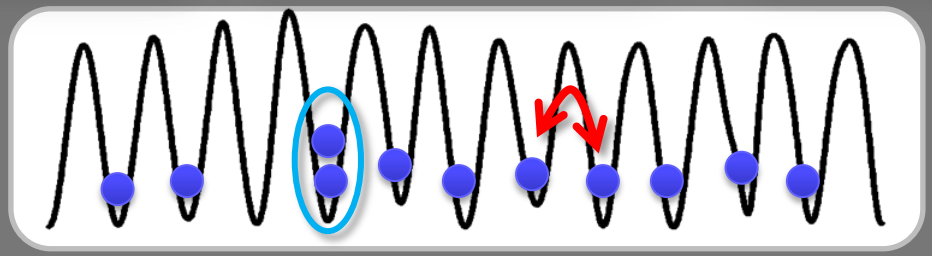
The Disordered BH model

Disordered bosonic materials



disordered lattice

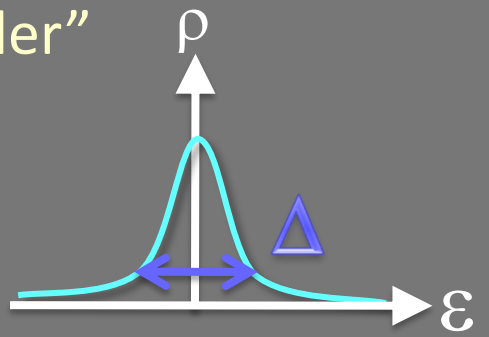


ε_i: site energies
"diagonal disorder"

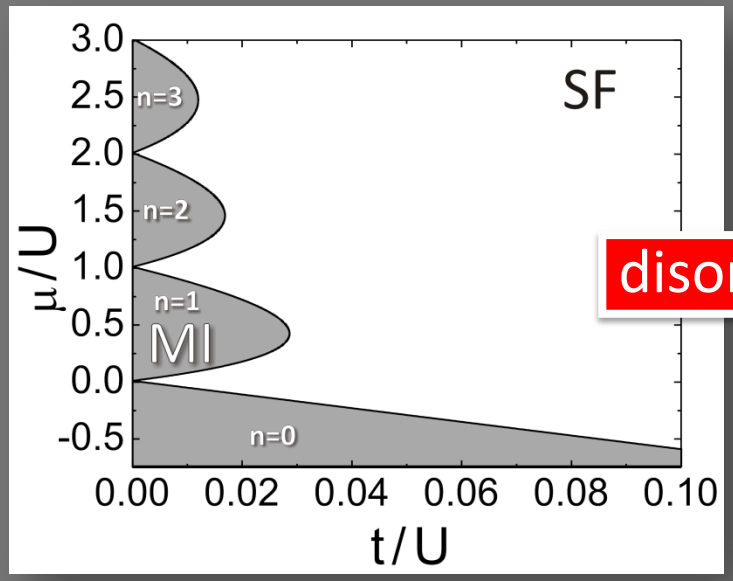
U_i: interaction energy

t_{ij}: tunneling energy
"off-diagonal disorder"

$$H = \sum_i n_i \varepsilon_i - \sum_{\langle ij \rangle} t_{ij} \left(b_i^\dagger b_j + b_j^\dagger b_i \right) + \frac{1}{2} \sum_i U_i n_i \left(n_i - 1 \right)$$



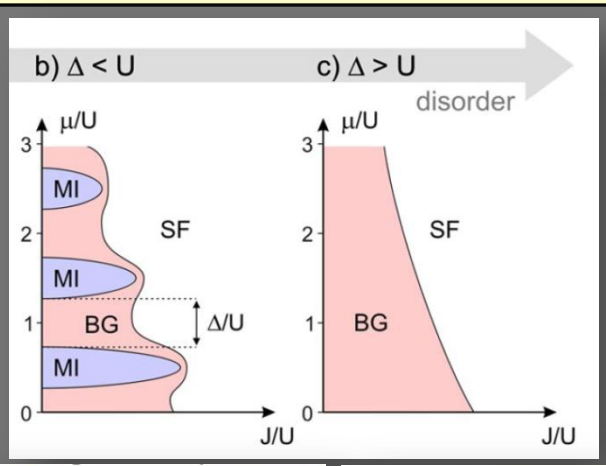
Disordered BH model: theory

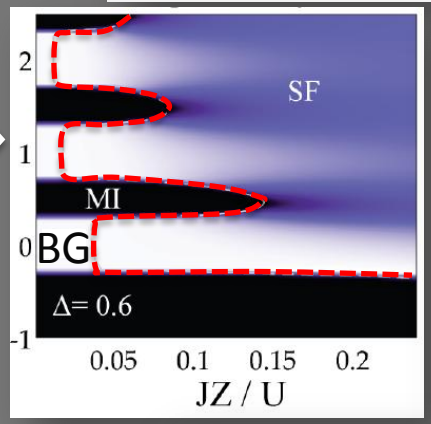


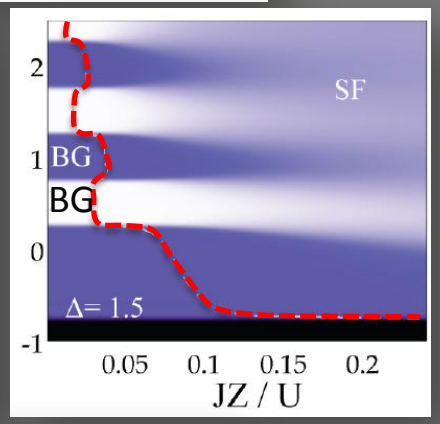
"filling"

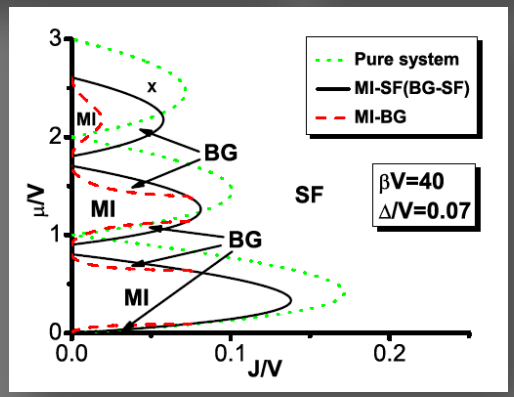
disorder

increasing lattice depth







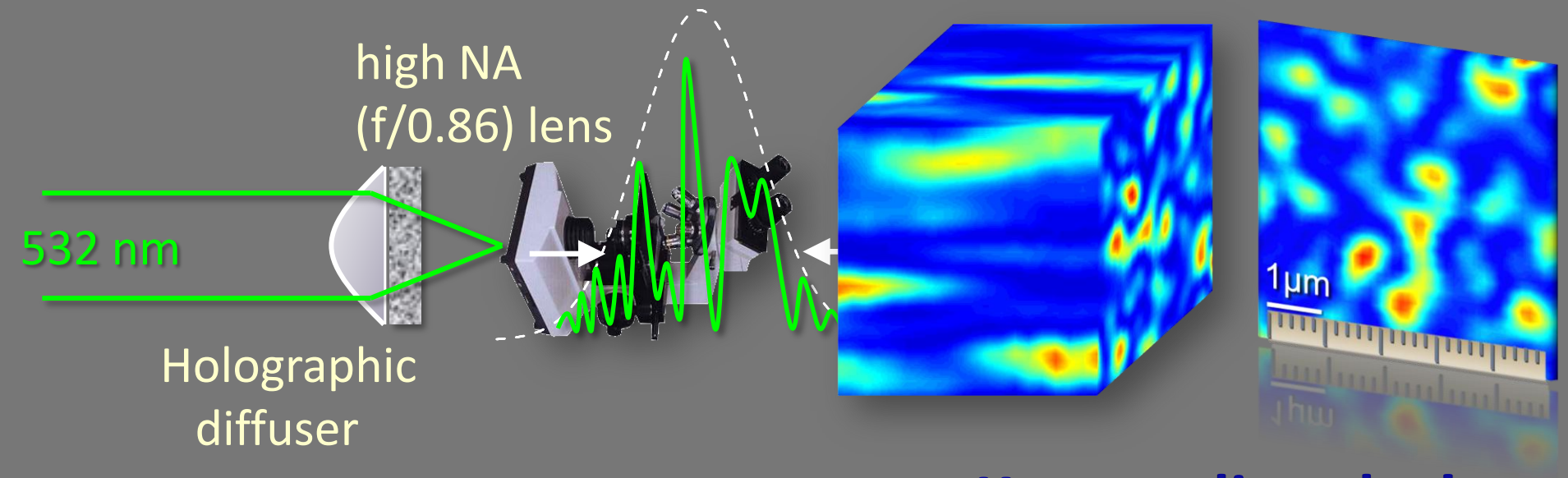


SF: superfluid MI: Mott-insulator

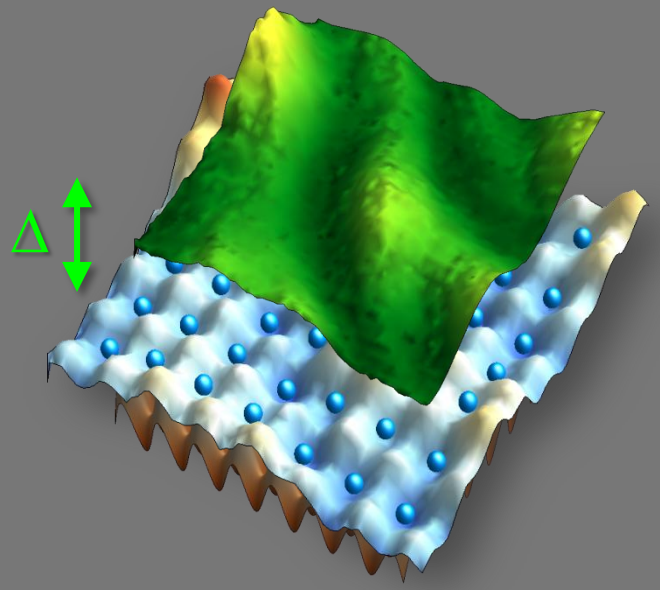
BG: Bose-glass (gapless, compressible IN)

MG: Mott-glass (gapless, incompressible IN)

Controllable disorder: speckle



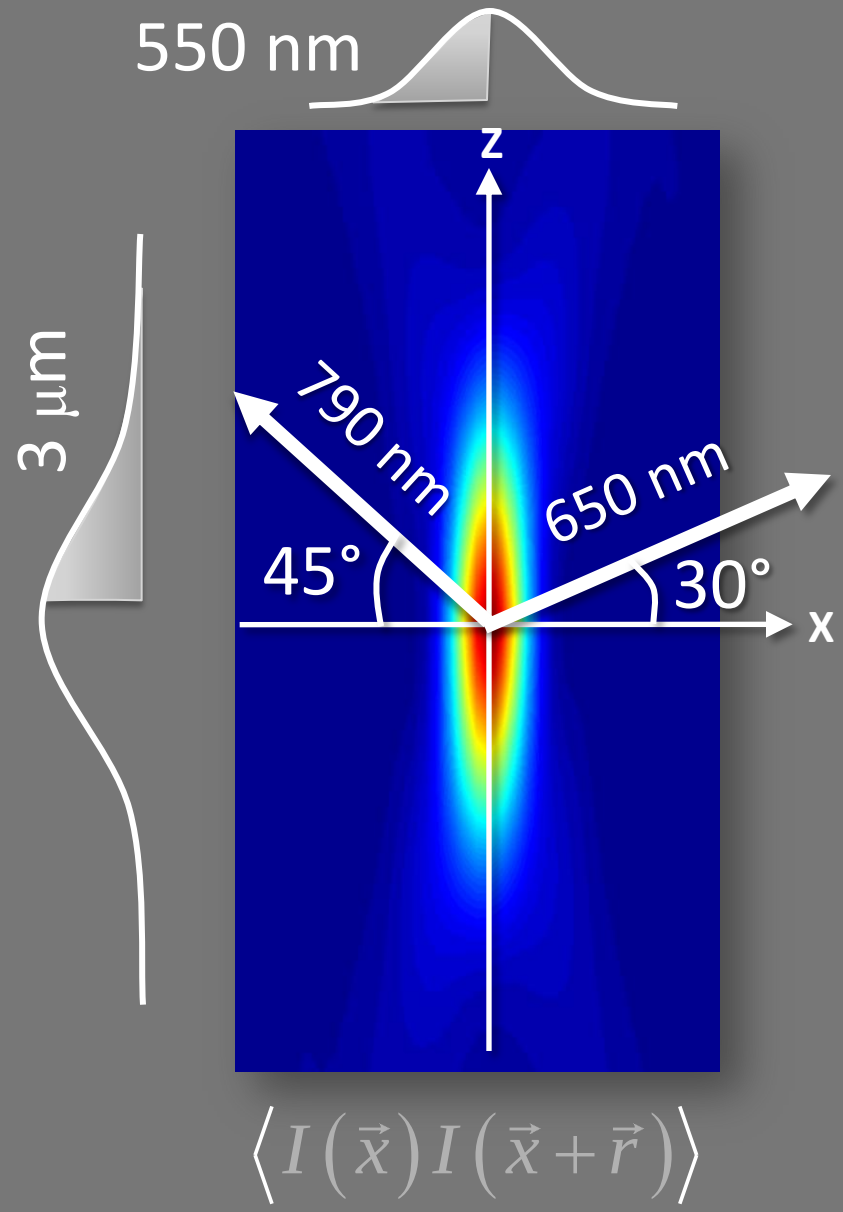
Known disorder!



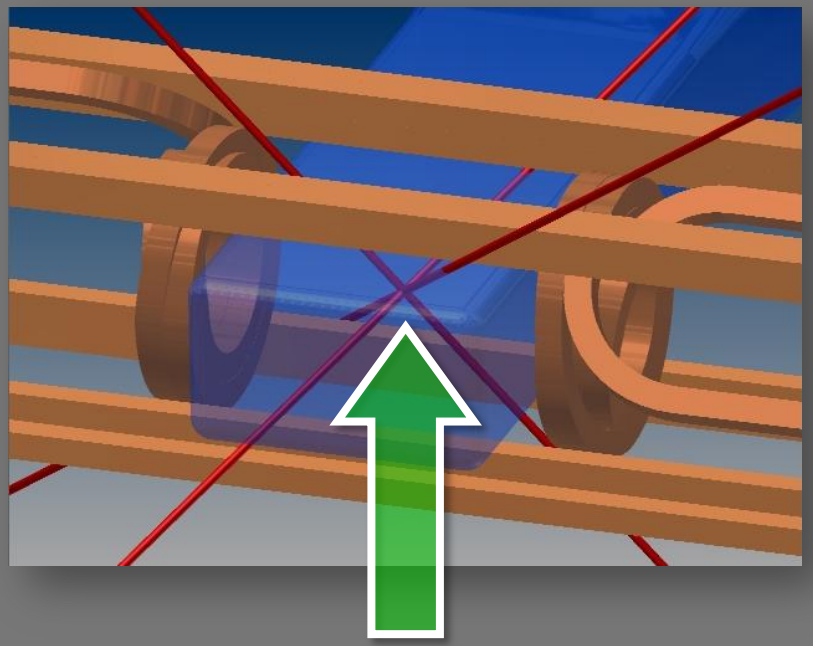
Potentials add to
produce disordered lattice

Aspect, Ertmer, Engels,Hulet, Inguscio…*

Fine-grain 3D disorder



$$\langle I(\vec{x})I(\vec{x}+\vec{r})\rangle$$

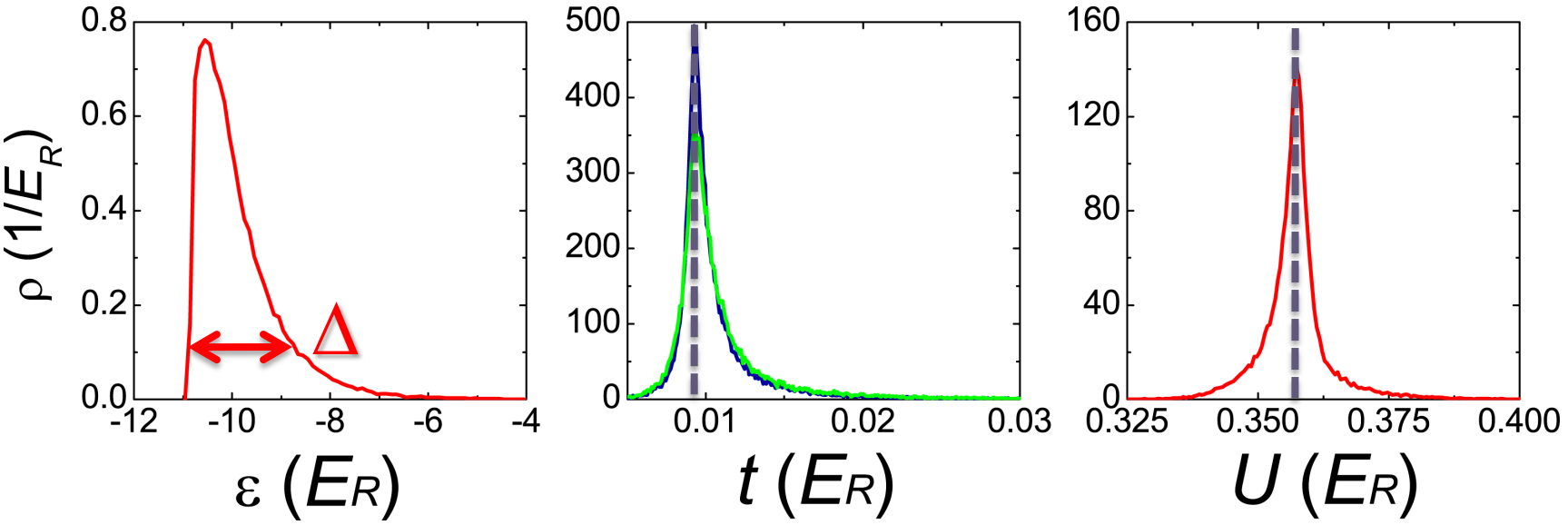


Fine grained disorder:

- Assumed in theory
- Required to realize disorder in t and U

BH parameters

Calculation by Ceperley's group using known potential

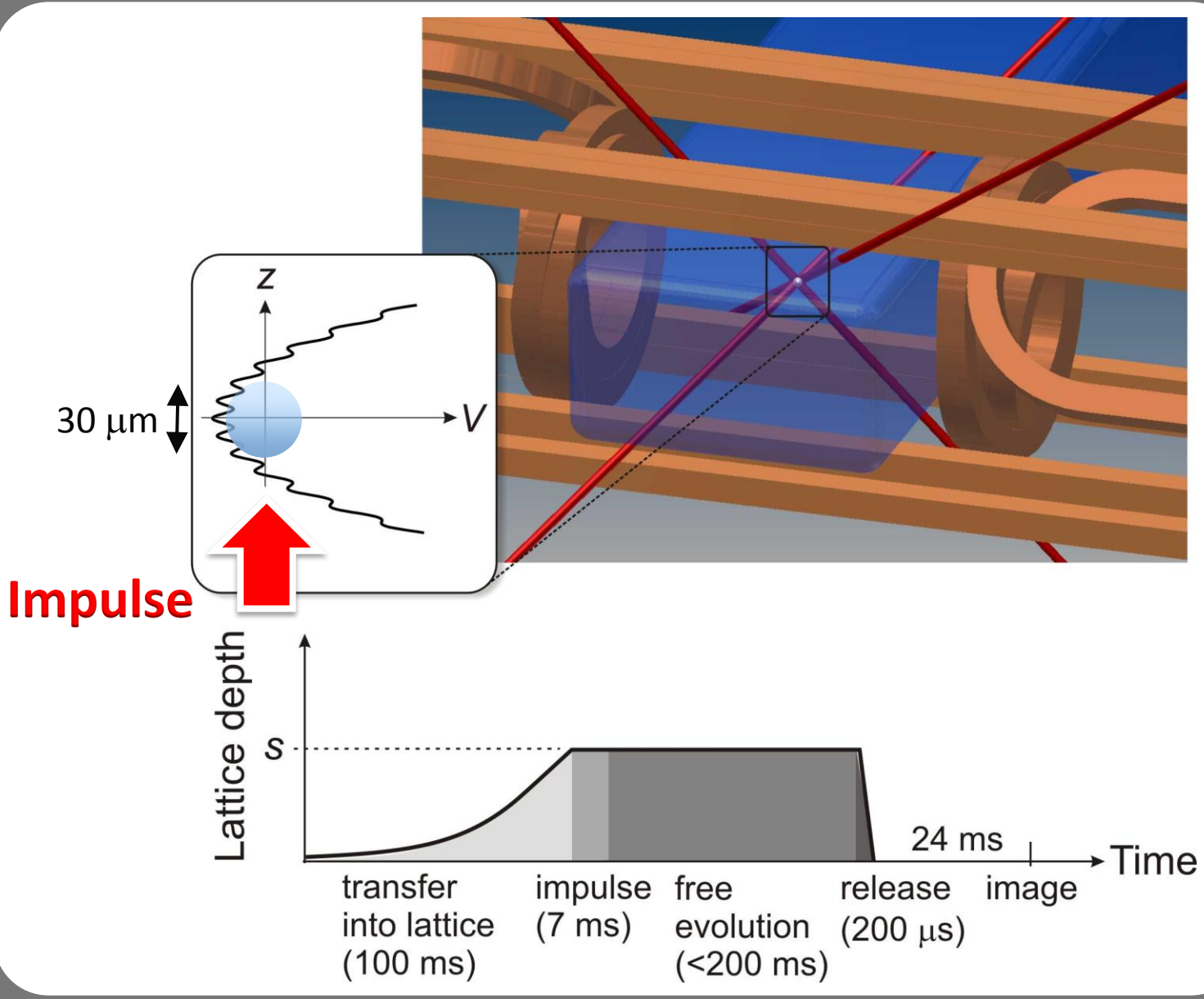


Disordered "material" in which microscopic disorder completely determined

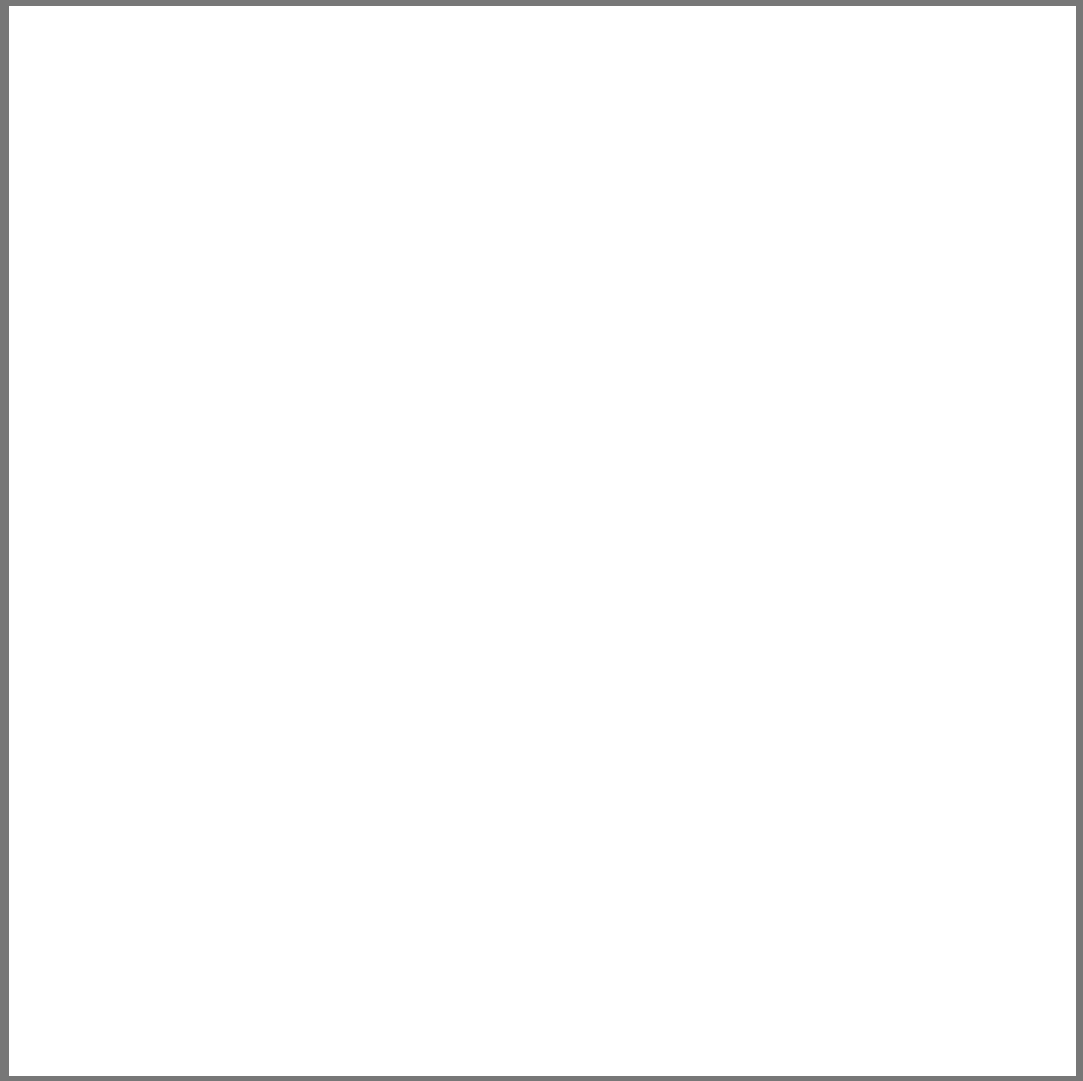
Transport Measurements

resistivity $\rho \propto \frac{V}{I}$

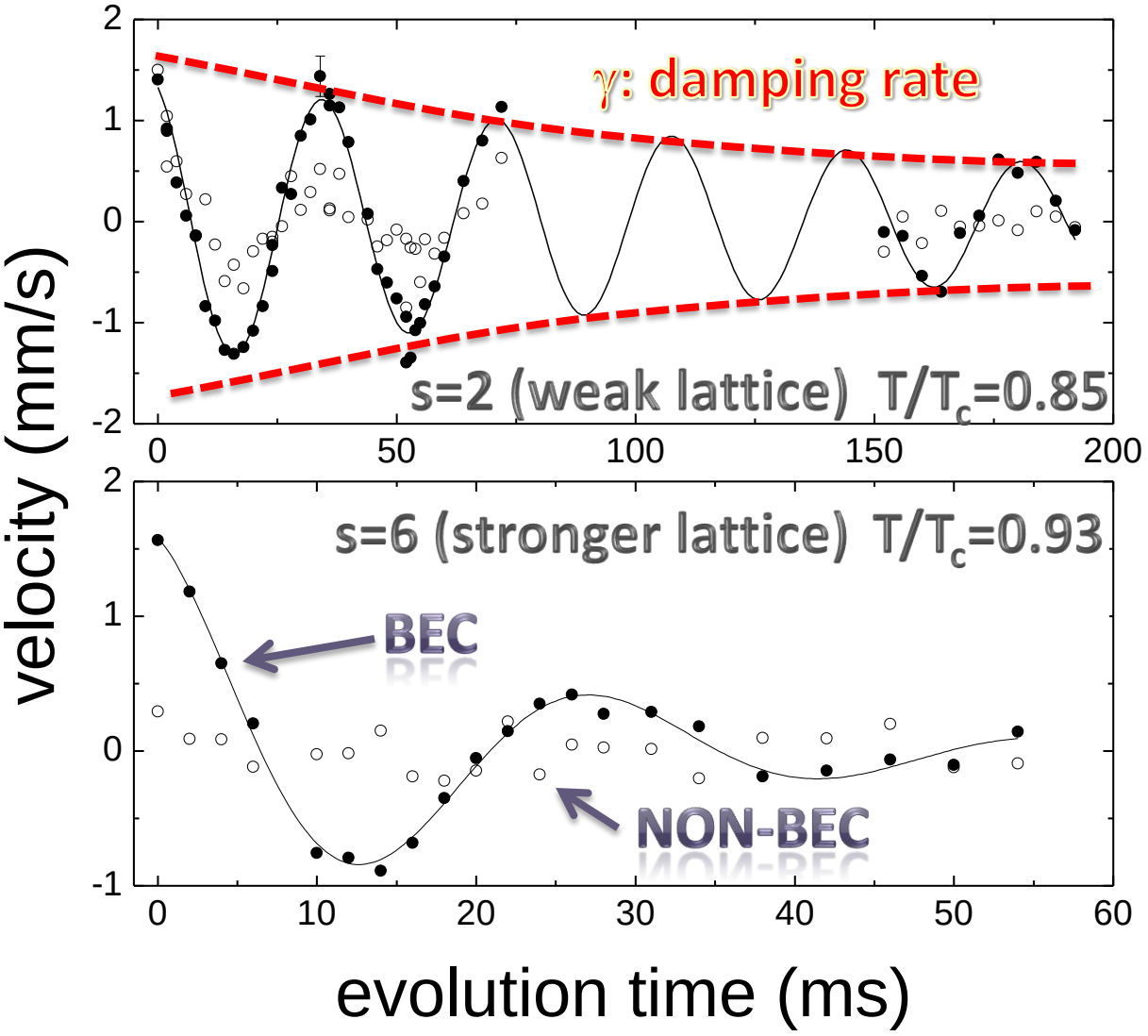
Transport


z
V
30 μm
Impulse
Lattice depth
s
24 ms
Time
transfer into lattice (100 ms)
impulse (7 ms)
free evolution (<200 ms)
release (200 μs)
image

Motion



Observable: center-of-mass velocity



We measure:
- Damping rate (resistance)

We change:
- Lattice depth (t/U)
- Temperature
- Disorder strength

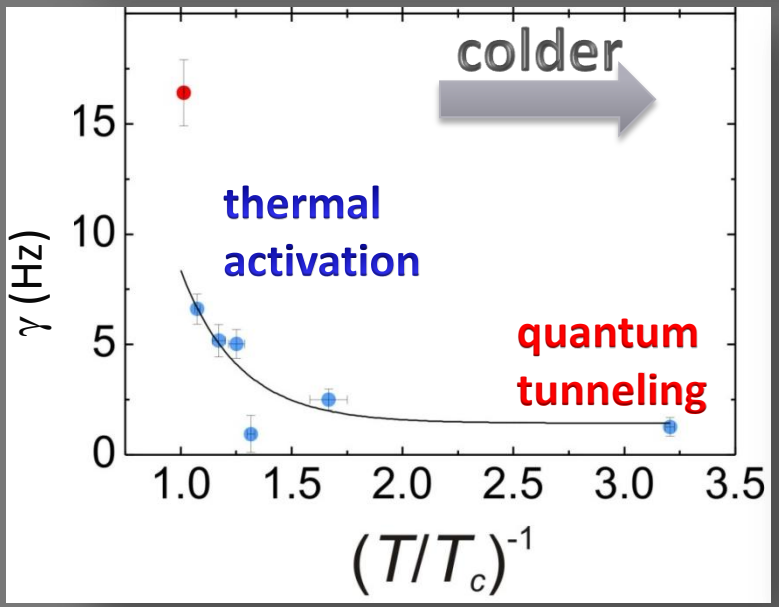
Clean system: phase slips

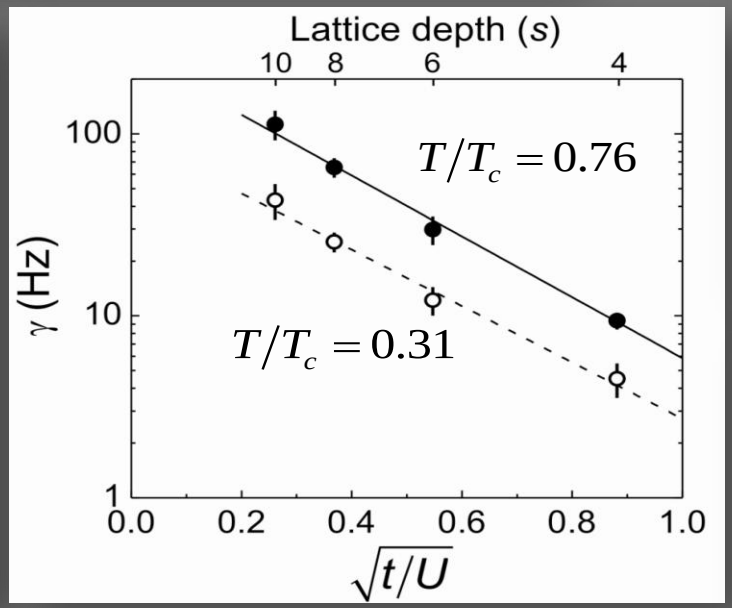
nature Vol 453 | 1 May 2008 | doi:10.1038/nature06920

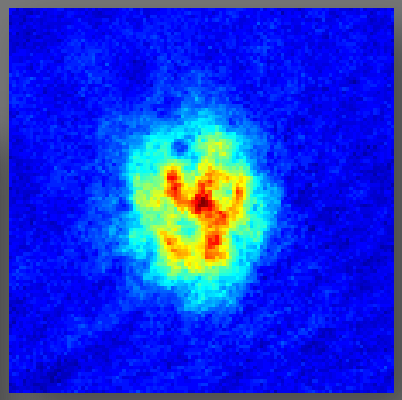
LETTERS

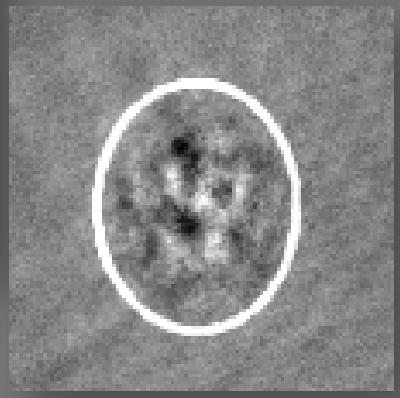
Phase-slip-induced dissipation in an atomic Bose–Hubbard system

D. McKay[1], M. White[1], M. Pasienski[1] & B. DeMarco[1]



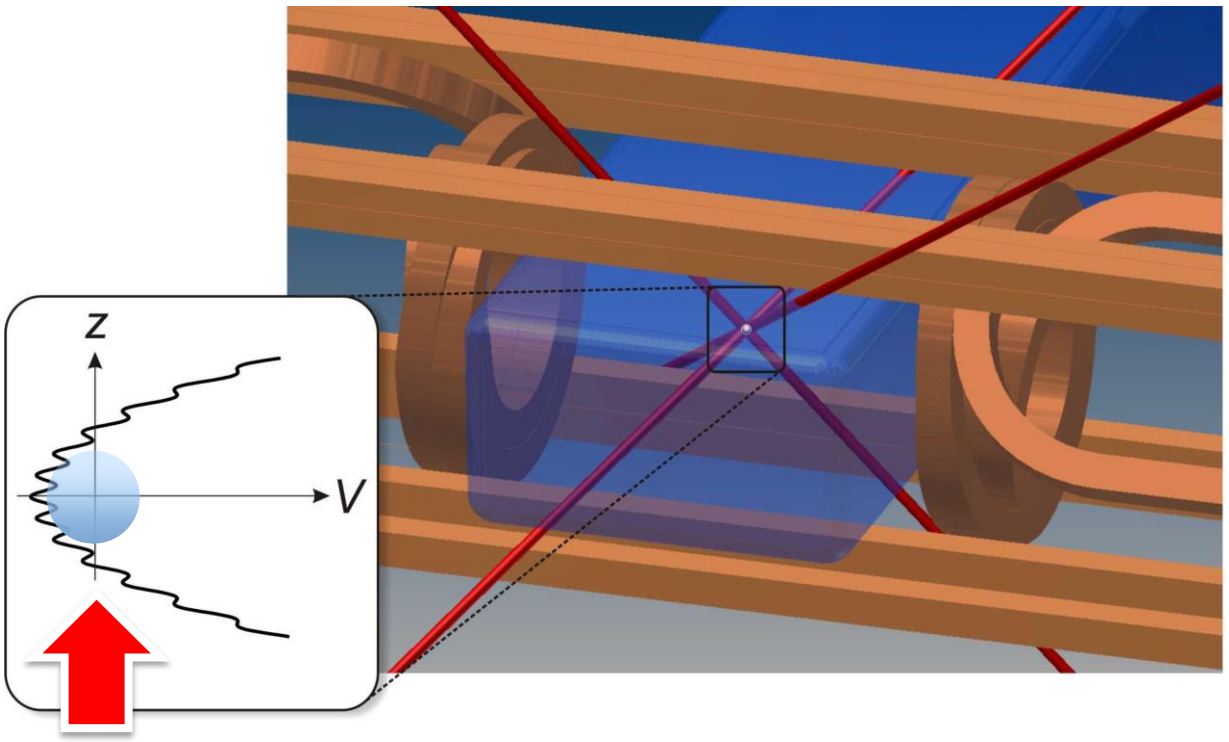


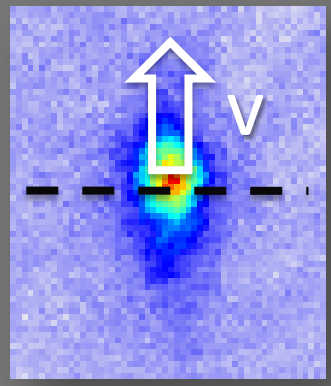




Resolving an insulator

Apply impulse, measure total center-of-mass velocity



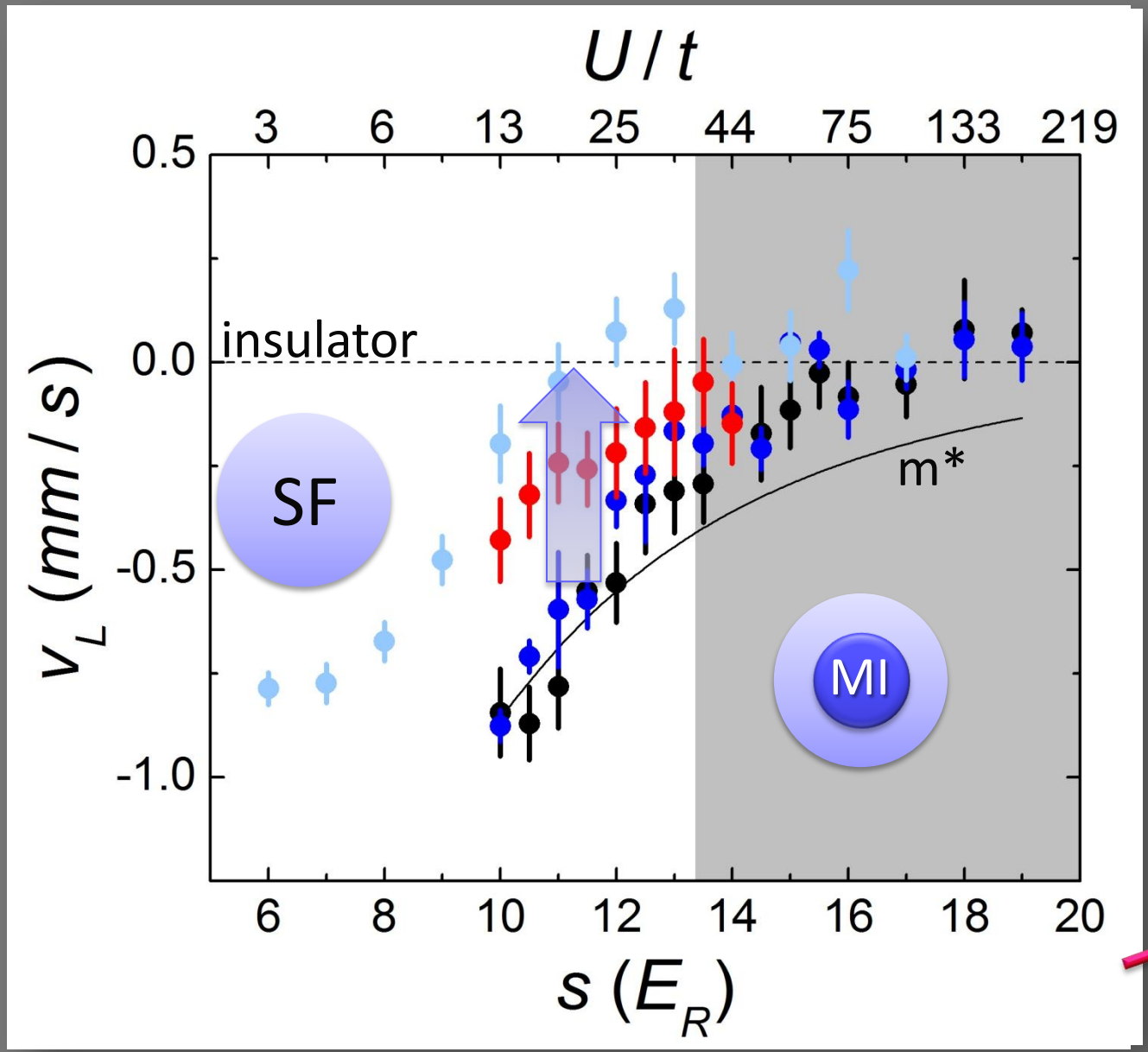


$$v_0 = \frac{N_C v_C + N_{NC} v_{NC}}{N}$$

For a damped,
SHO in the limit $\gamma \gg 1/t \gg \omega$:

$$v_0 = \frac{Ft}{m^*} e^{-\gamma t}$$

Disorder-induced SF-IN transition

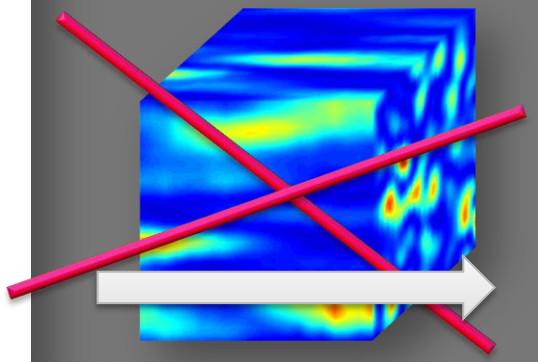


Δ=3 E_R

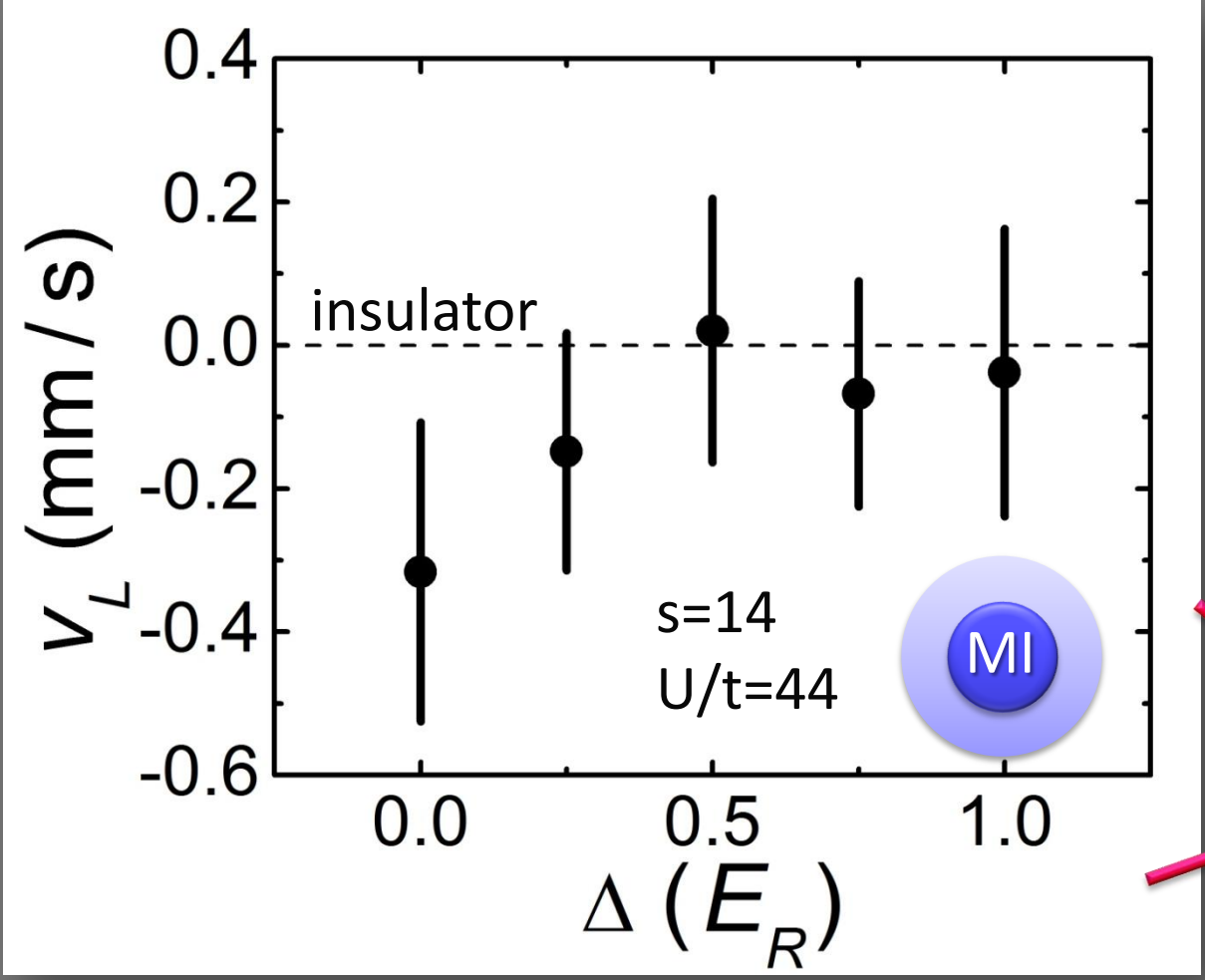
Δ=0.75 E_R

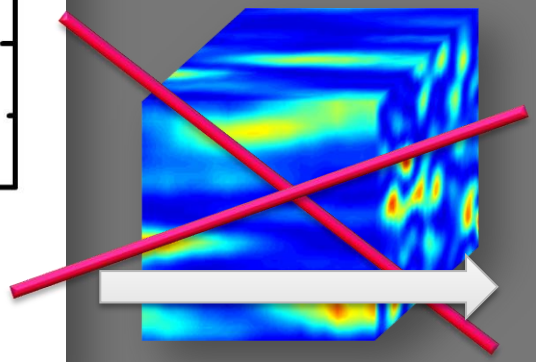
Δ=0 E_R

Δ=0 E_R hot



Disorder mediated IN-to-SF?

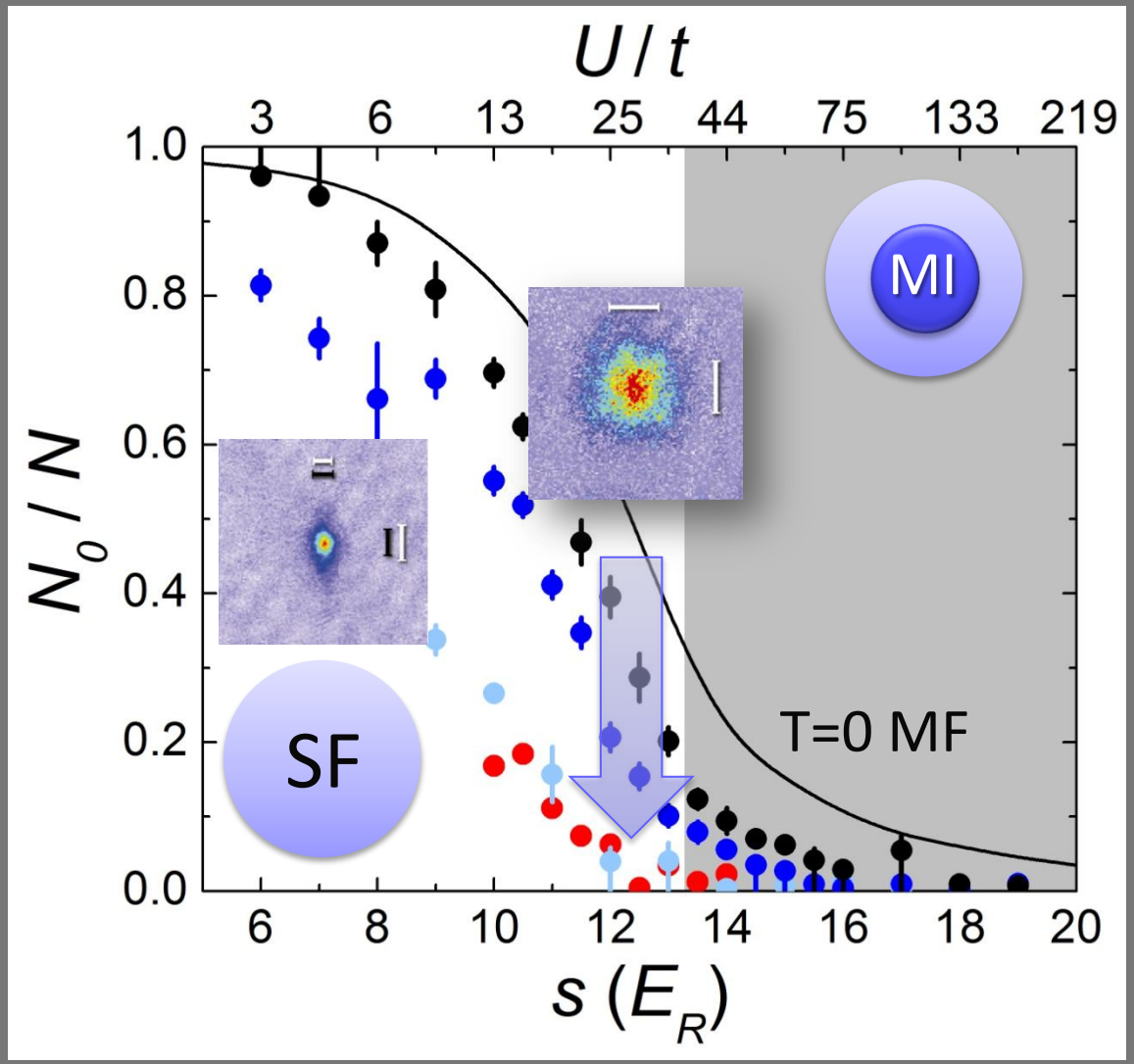




More disorder always leads to more dissipation

Disorder-induced SF-IN transition

Destruction of condensate ➡ insulator



Δ=0 E_R

Δ=0.75 E_R

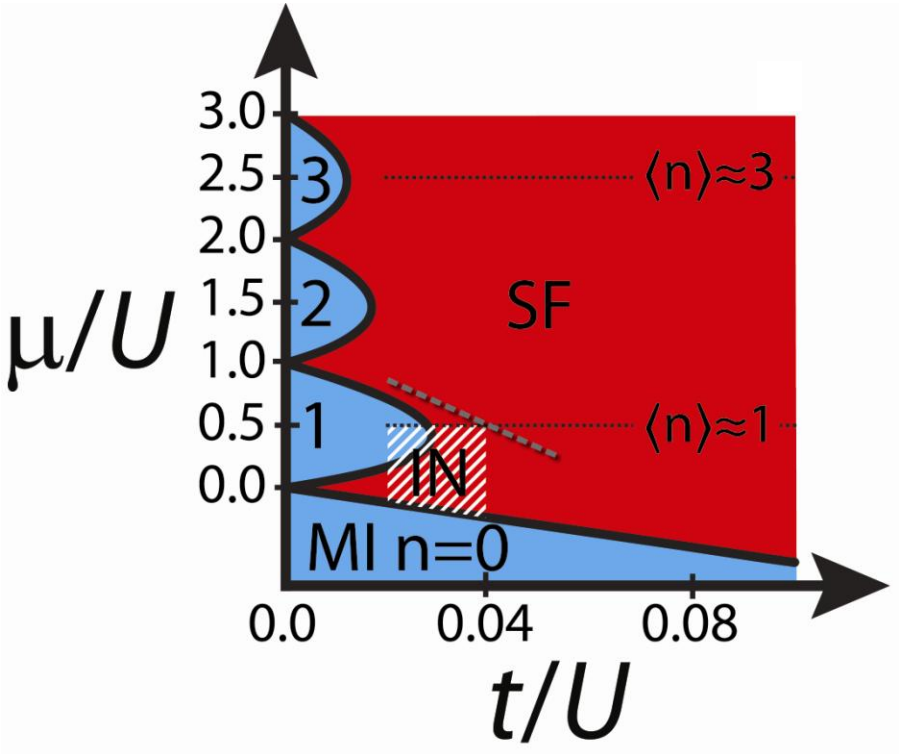
Δ=3 E_R

Δ=0 E_R hot

Conclusions

- Disorder-induced insulator for “strong” disorder
- No evidence for disorder-induced MI⇨SF transition

Nature Physics doi:10.1038/nphys1726 (2010)



- Temperature low enough?
- LDA?
- Finite system?
- Equilibrium?

Gurarie, Pollet, *et al*. doi 10.1103/Phys Rev B **80**, 214519 (2009)

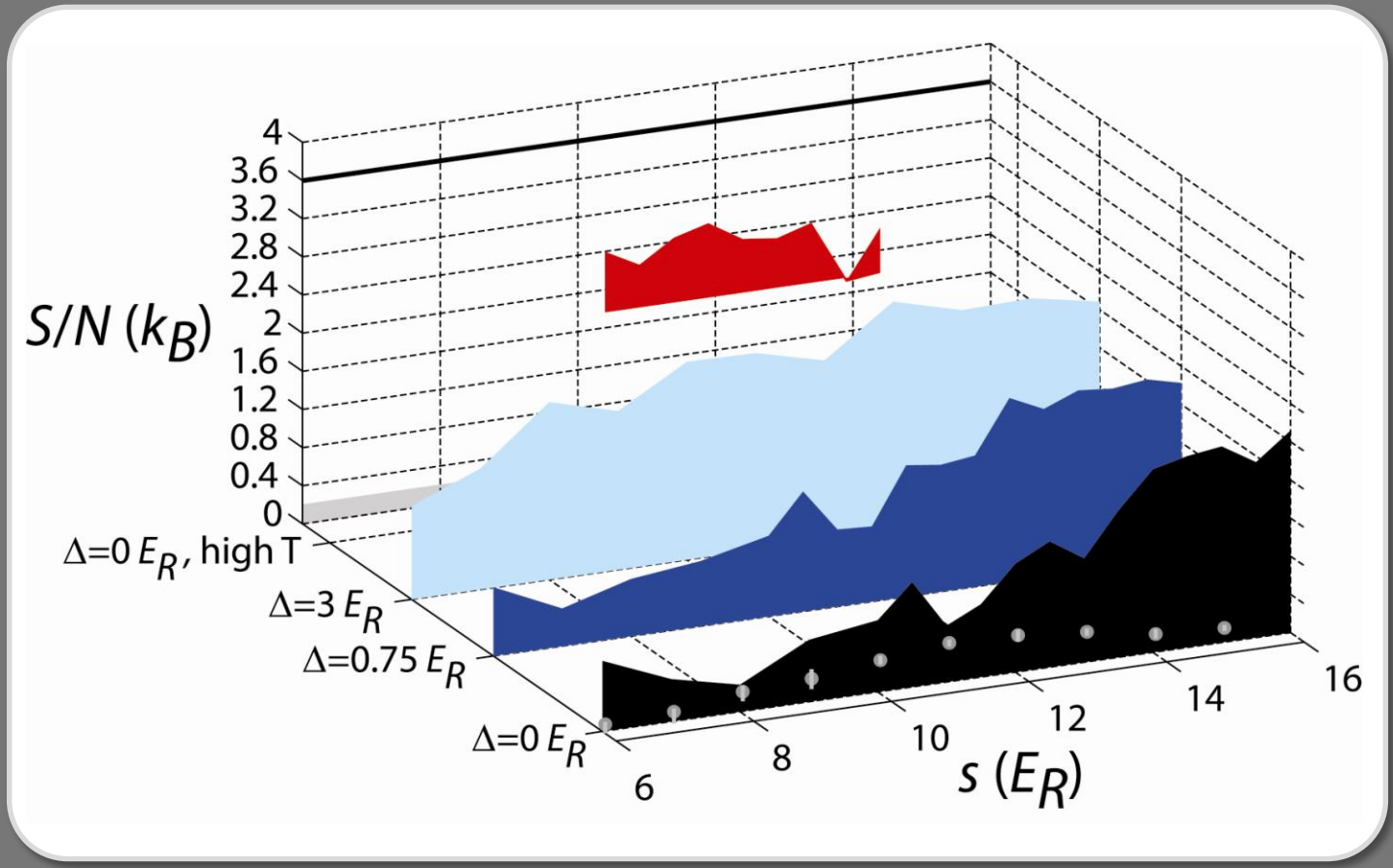
Bounds on entropy

Upper bound: entropy after slow (15 ms) turn off

*separate measurements indicate this is not truly adiabatic!

Lower bound: entropy before turning on lattice

Clean lattice: Estimate from N_0/N using finite temperature LDA+site-decoupled MFT



Conclusions

On the horizon:

- Measuring compressibility / center of lattice
- Implement isotropic disorder

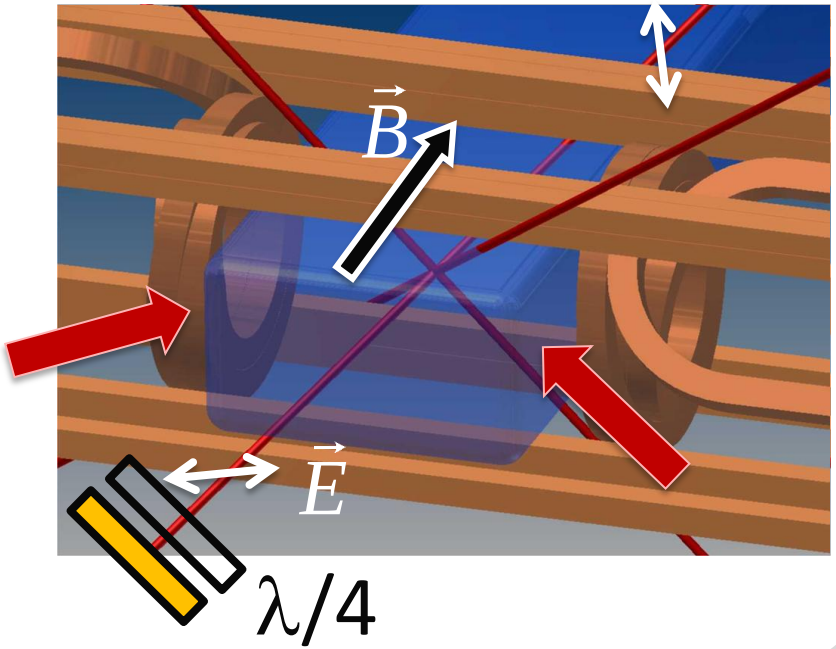
Other projects:

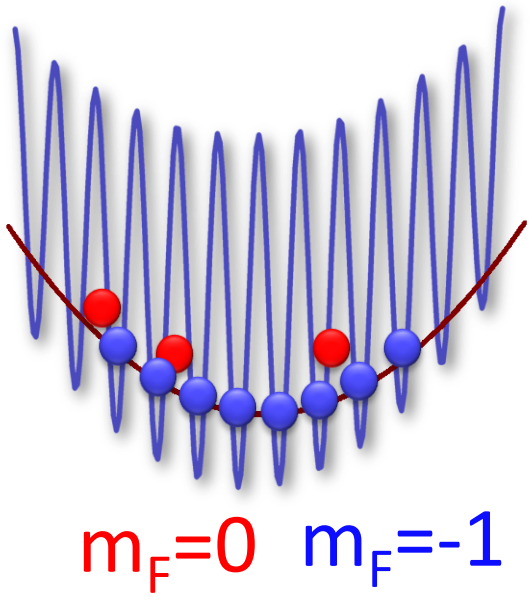
- Measuring temperature in a lattice (PRA **79**, 063605 (2009))
- Spin-dependent lattices (NJP 12, 055013 (2010))
- Non-equilibrium dynamics in 2D and 3D lattices
- Simulating thermopower in Mott-Hubbard materials

There is a lot we still don't understand! Help!

- Detailed dirty transport measurements
- Phase slips in finite 3D systems
- …

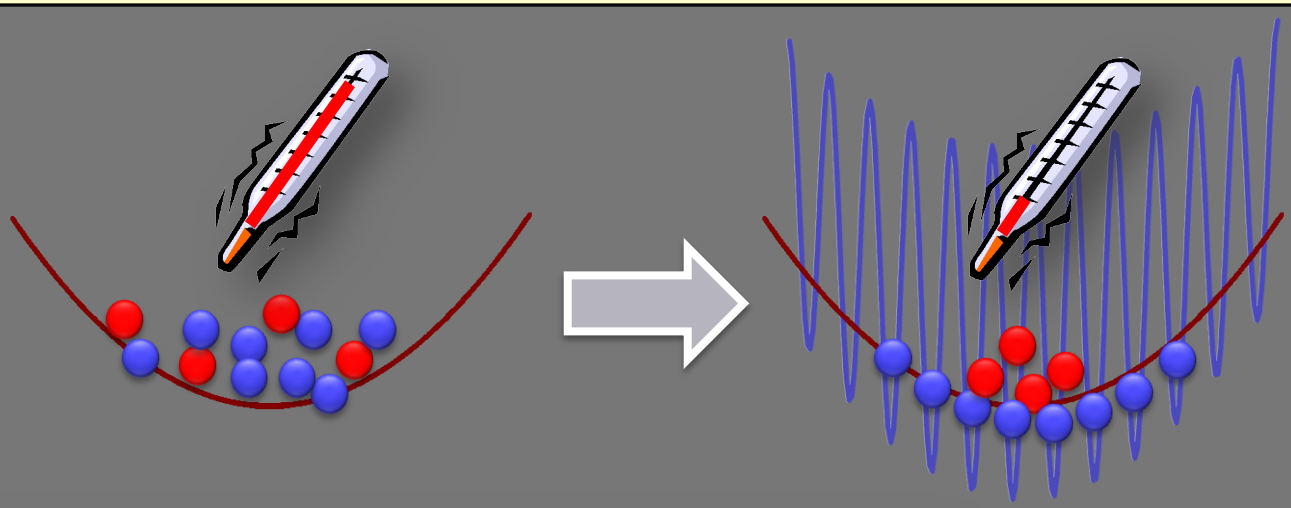
Spin-Dependent Lattices

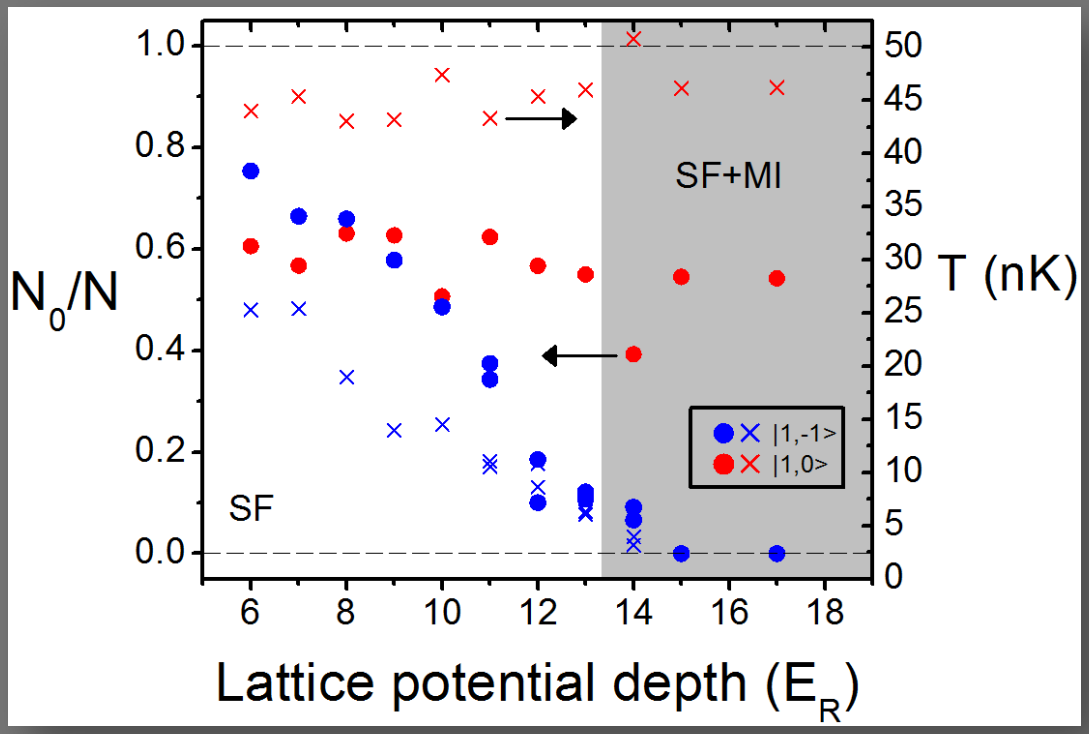




Use m=0 atoms for thermometry, cooling, phonon bath…

Loss of thermal contact





- Not macro-/micro-scopic phase separation
- Detailed thermalization measurements using selective heating

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"Cooling in strongly correlated optical lattices: prospects and challenges"

arXiv:1010.0198v1

To appear in *Reports on Progress in Physics*