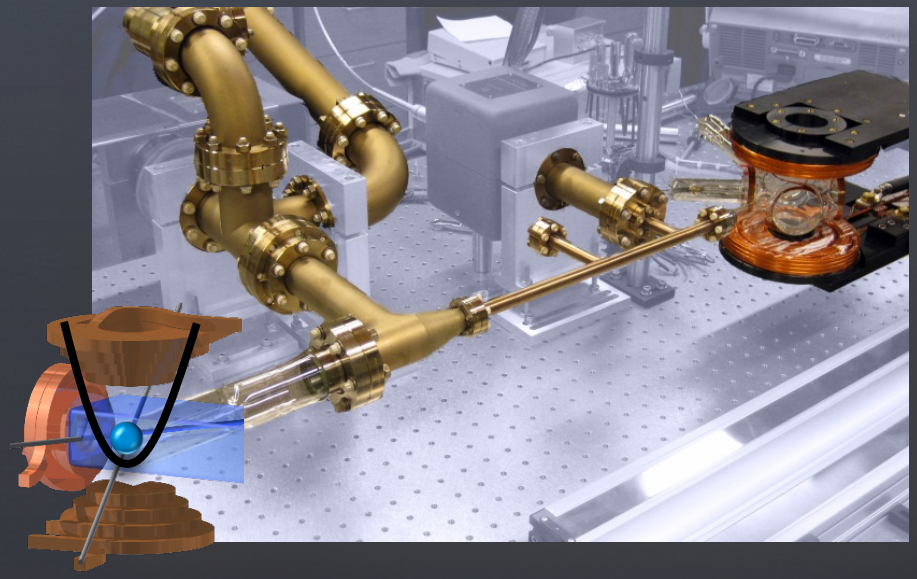
Disordered Quantum Gases

{ What is the nature of disordered, strongly interacting quantum matter?

Brian DeMarco
University of Illinois



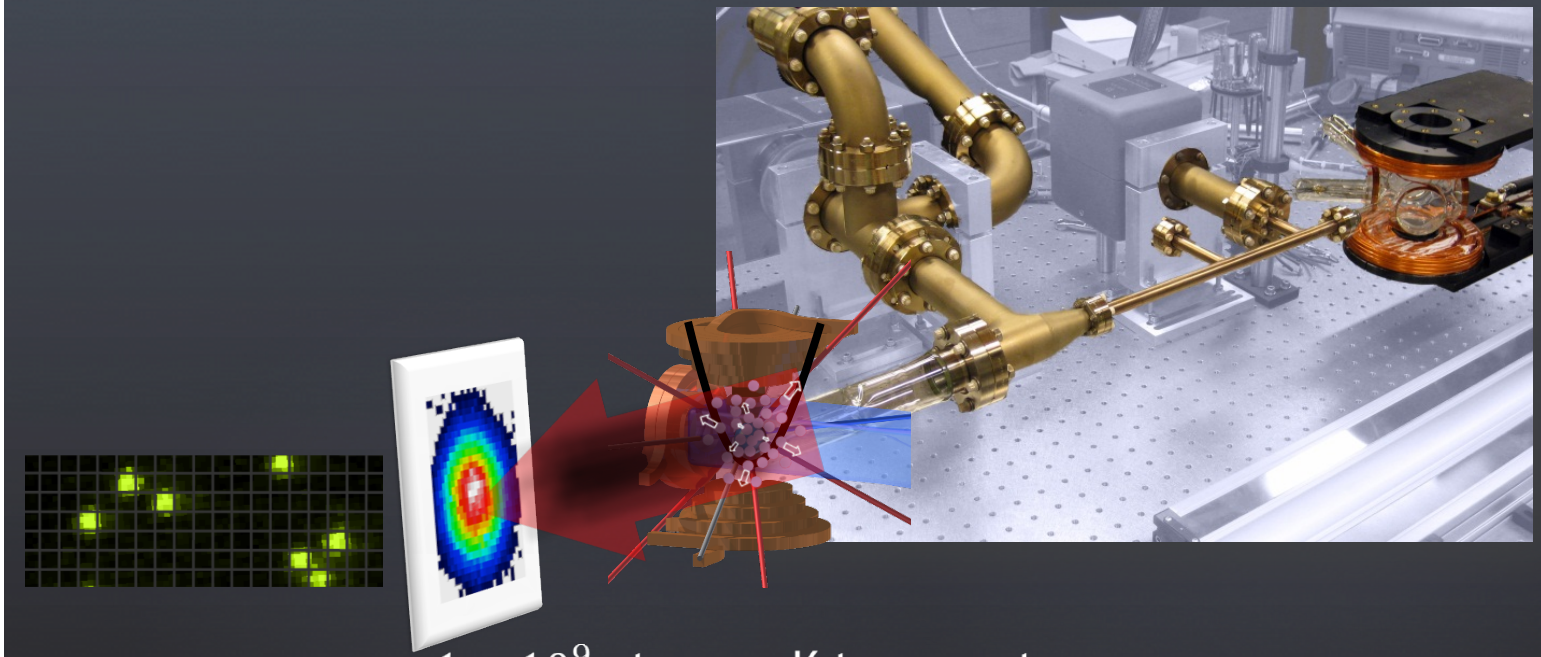
$1 - 10^9$ atoms, nK temperatures

$10 - 100\ \mu m$ in diameter

Bosons (^{87}Rb, ^{23}Na,…), fermions (^{40}K, ^{6}Li, …)

Interact through collisions: contact potential $4\pi a\,\hbar^2\delta^3(\vec{r}_i - \vec{r}_j)/m$

(attractive, repulsive, tunable)



$1 - 10^9$ atoms, nK temperatures

$10 - 100\ \mu m$ in diameter

Bosons (^{87}Rb, ^{23}Na,…), fermions (^{40}K, ^{6}Li, …)

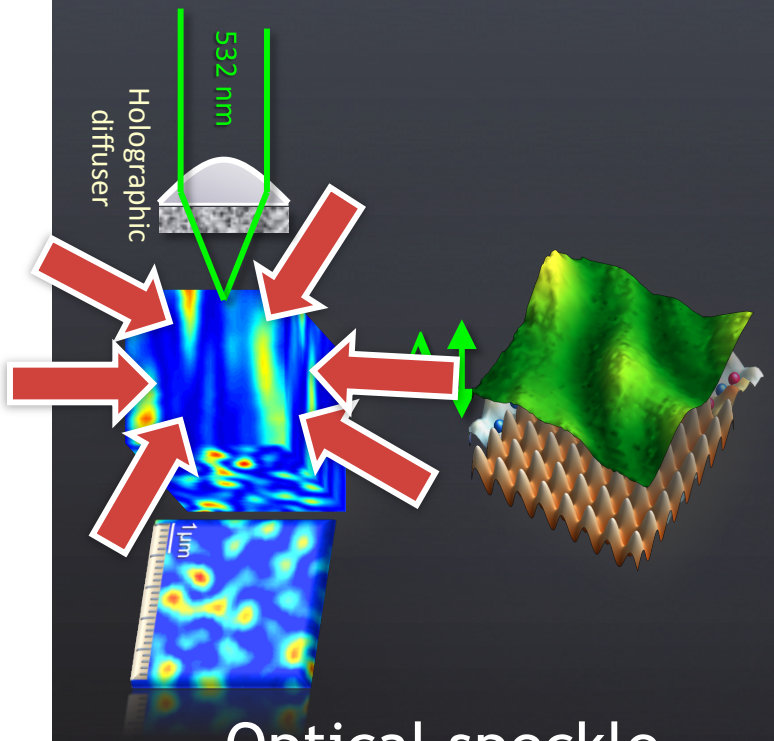
Interact through collisions: contact potential $4\pi a\,\hbar^2\delta^3(\vec{r}_i - \vec{r}_j)/m$
(attractive, repulsive, tunable)

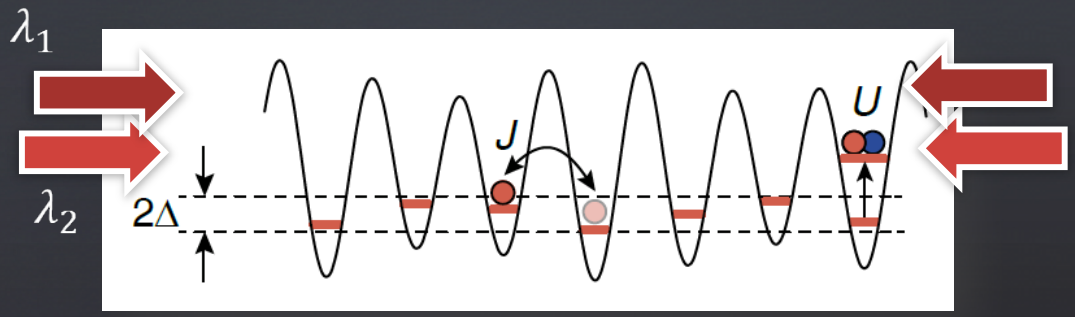
Manipulated using lasers & optical potentials

Data from images

Test-bed for theory & numerics, discovery of new phenomena

Optical disorder





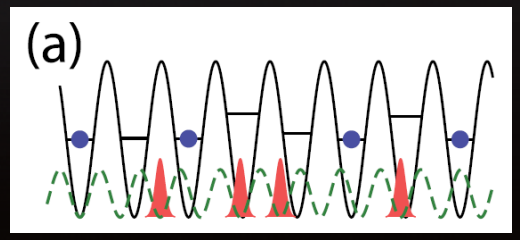
Bloch, arXiv: 1501.05661 (2015)

Optical speckle

Incommensurate lattices

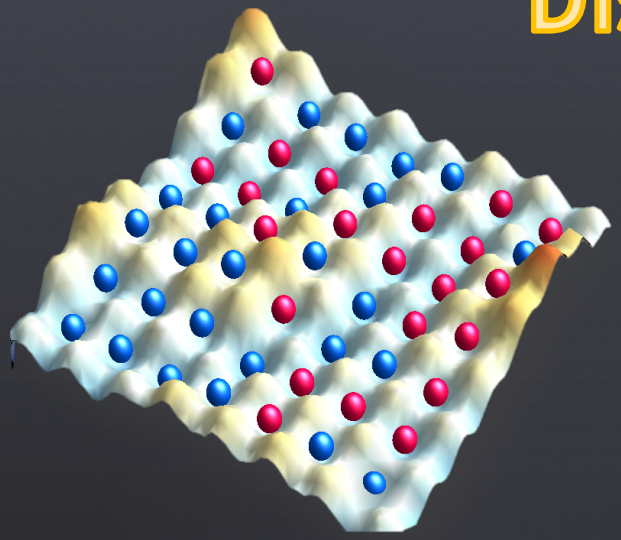
Precisely known, tunable

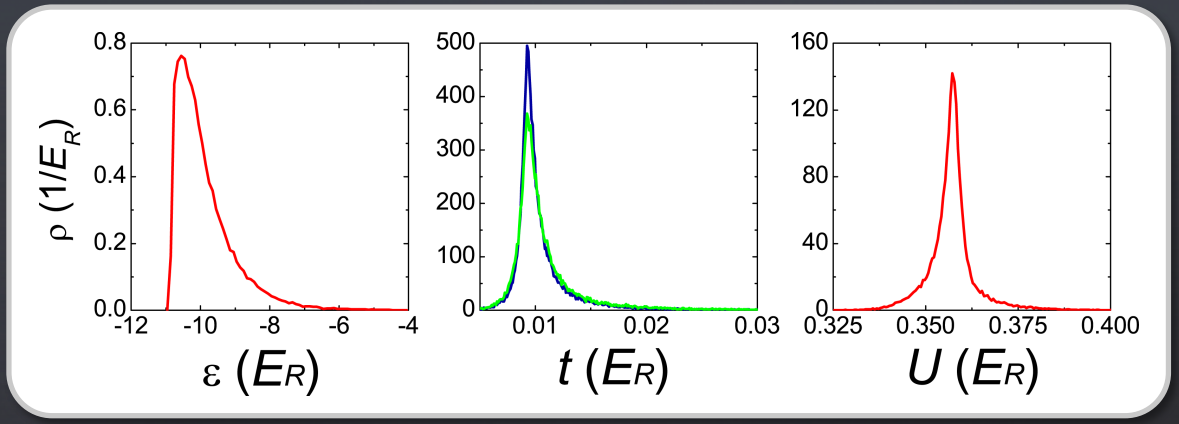
Also: atomic impurities

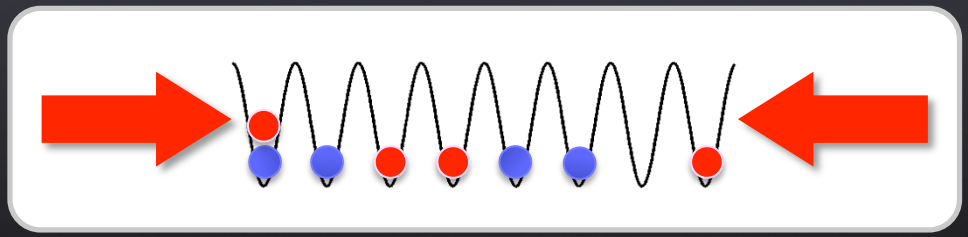


Most significant impact:

Disordered Hubbard models







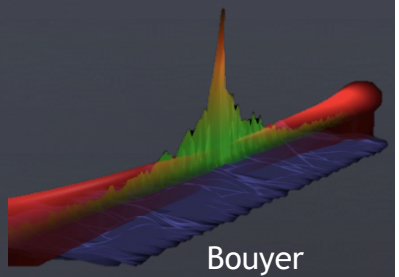
$$H = \sum_i n_{i,\sigma}\varepsilon_i - \sum_{\langle ij \rangle} t_{ij} b_i^\dagger b_j + \sum_i U_i n_i (n_i - 1)/2$$

Simplest paradigms for understanding interplay of disorder and strong interactions

Importance

Spectacular fundamental phenomena

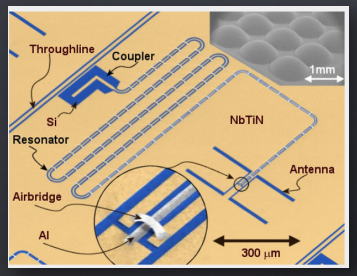
Open fundamental questions: especially dynamics



Bouyer

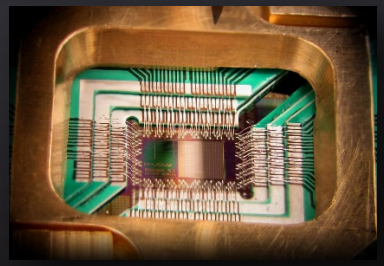
Practical applications

Disordered superconductors



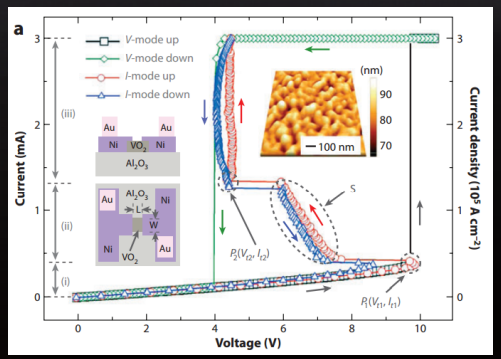
Delft

Optimization via quantum annealing



D-wave Systems

Mott-tronics

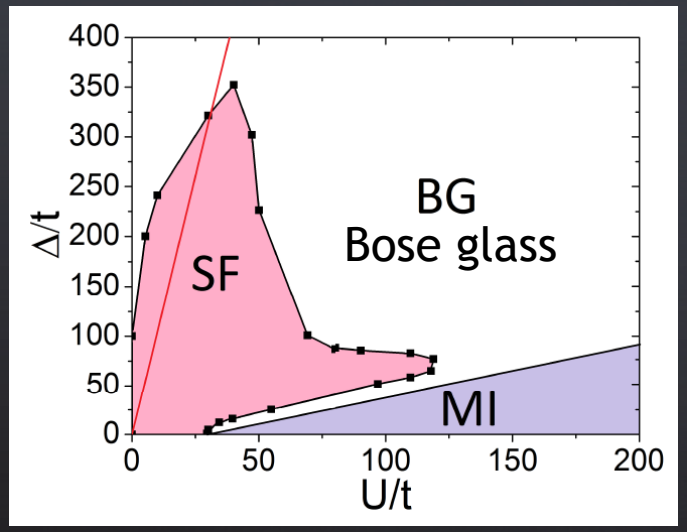


Lee et al., Appl. Phys. Lett. **92**:162903

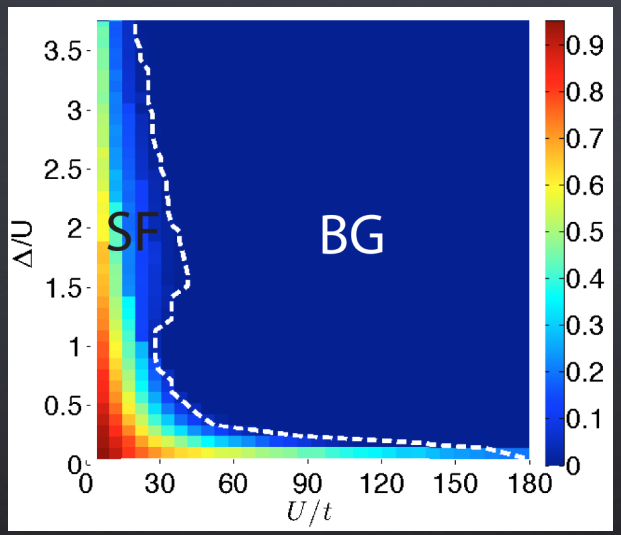
What's known

Disordered Bose-Hubbard Model

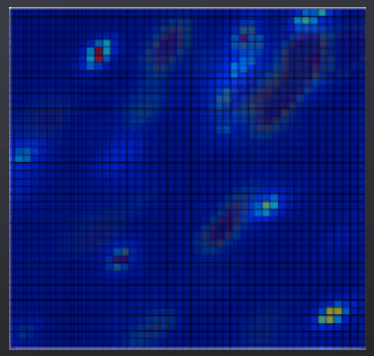
Equilibrium ground-state phase diagrams in 1D, 2D, 3D



Pollet



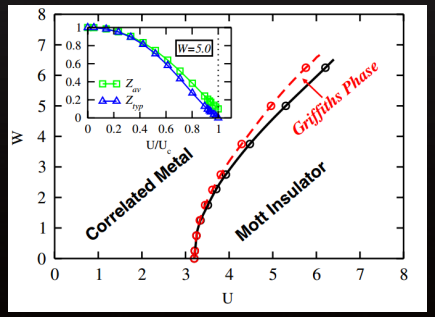
Ray, Ceperley



Trap, varied fillings, non-zero T for large N accessible to QMC

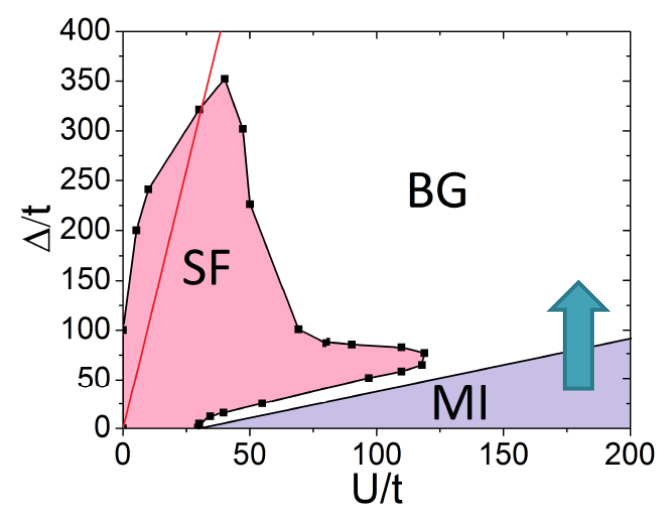
Disordered (Fermi)-Hubbard Model

Much less is certain! Ex: $U > 0$, mean field



Dobrosavljevic

What's unknown / Questions



Mott insulator (MI)-BG transition:
Griffiths transition

How do Griffiths
transitions play out in nature?

Phase diagram of DFH model

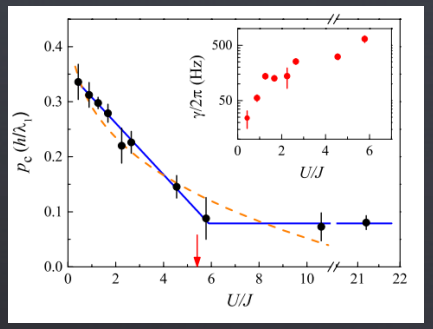
$U < 0,\ U > 0$ Superfluid phases?

Properties of Many-body localized (MBL) phases?

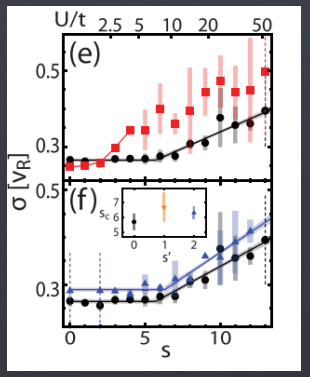
Excited States,
Dynamics, Out-of-equilibrium behavior

Progress / Highlights

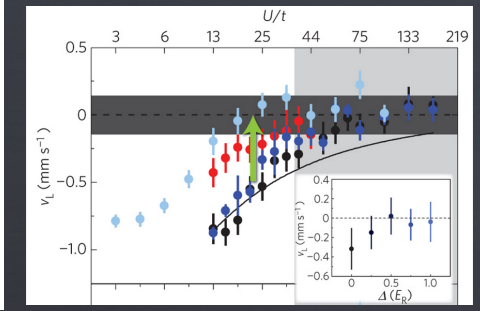
1D & 3D SF-BG transition



Inguscio

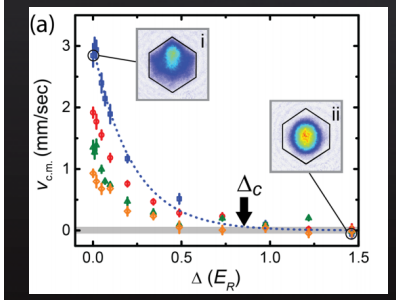


Schneble

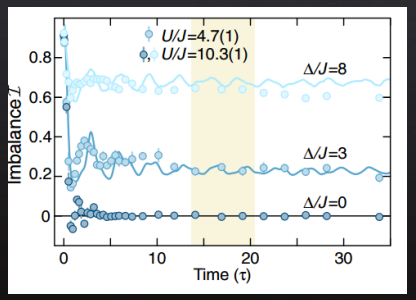


DeMarco

MBL (fermions, strongly correlated M-IN transition)

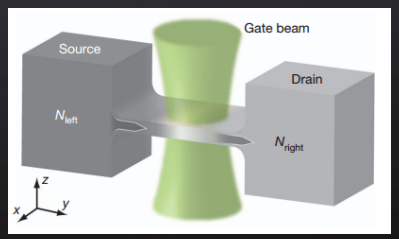


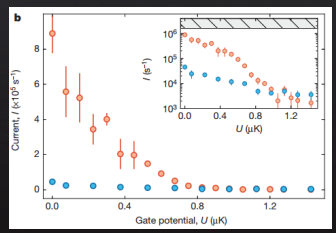
DeMarco



Bloch

2D paired-SF Diffusion





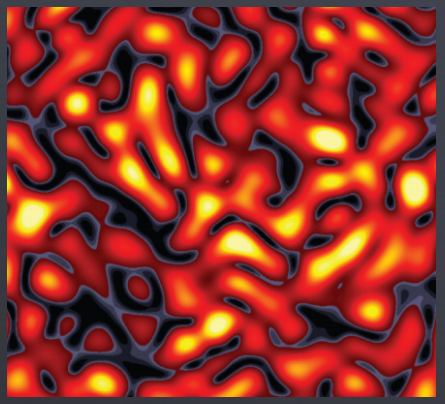
Esslinger

Anderson localization, Coherent back scattering, …

See also work by Aspect, Hulet, Rolston, …

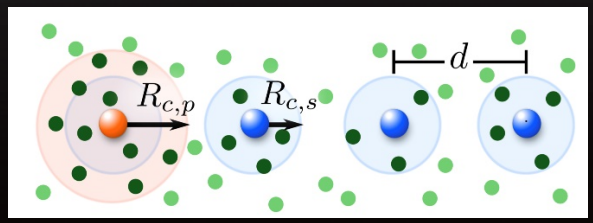
Challenges

2D Localization



Measuring temperature

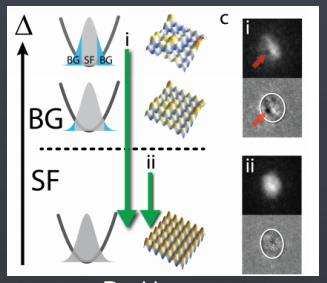
More complex interactions



Wüster

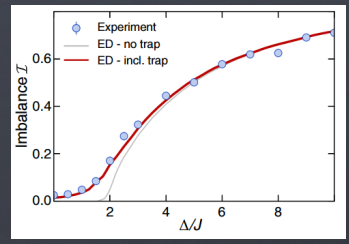
Opportunities

Dynamics;
Annealing;
Quenching;
Critical Properties



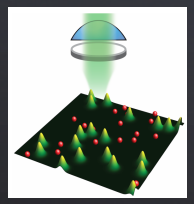
DeMarco

Ergodicity;
Equilibrium

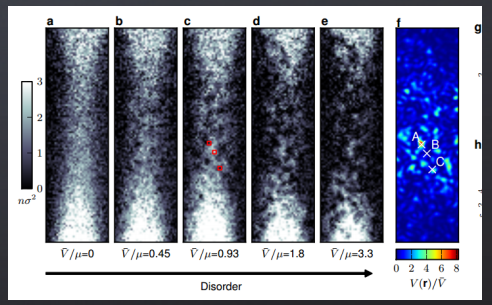


Bloch

2D


DeMarco

Fermions,
paired superfluids



Esslinger

Non-zero temperature

Magnetic impurities / disorder

Measurement is fully controlled

"Material" is fully characterized and tunable

Closed quantum systems

All dynamical timescales accessible