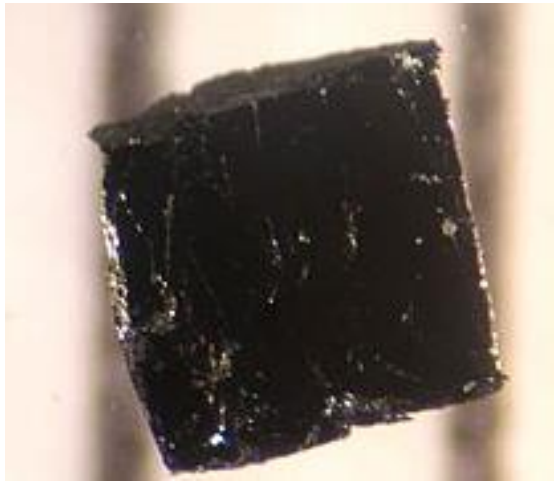
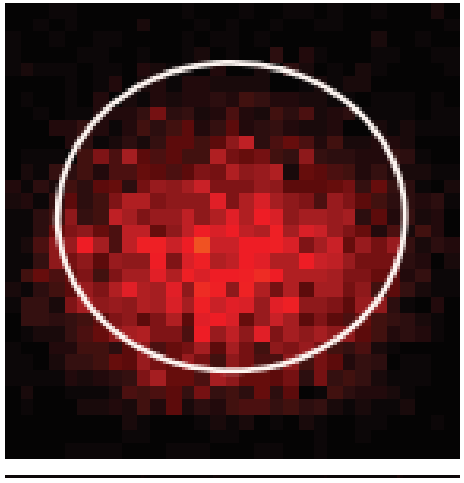
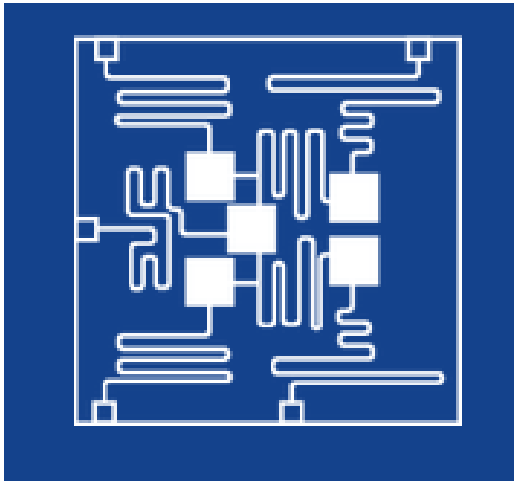
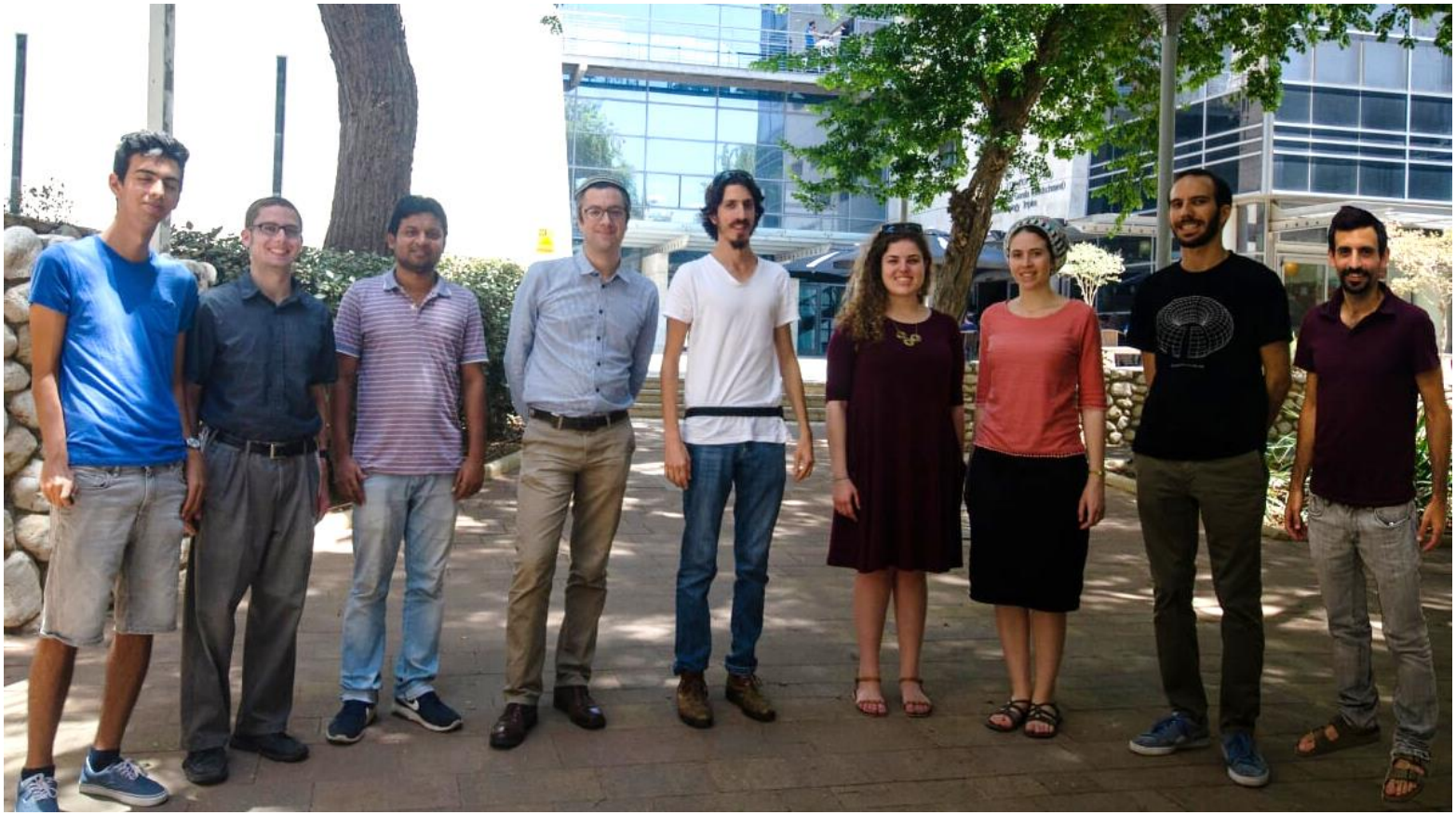
Three grand quantum challenges







Many-body quantum dynamics group

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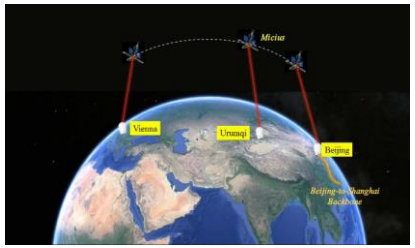
Quantum technologies

Quantum is the next ~~big thing~~ nano

Quantum communication



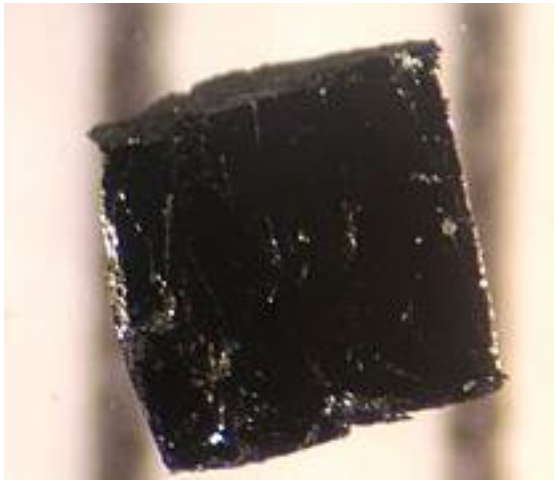
Quantum sensing

Quantum computing

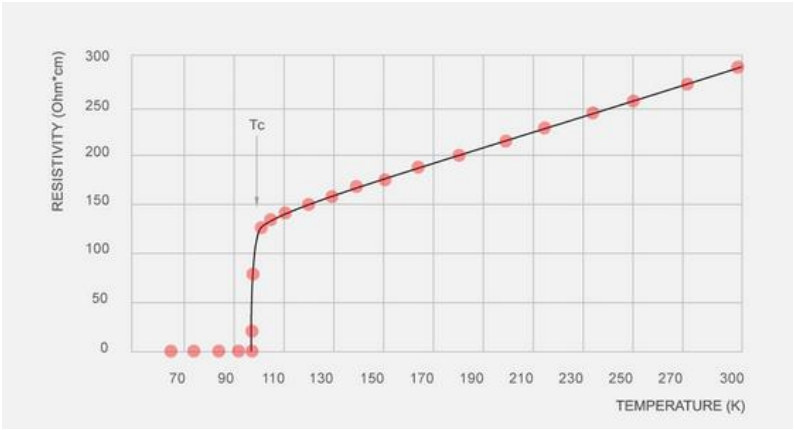
Quantum simulation

Challenge 1 : Quantum Materials

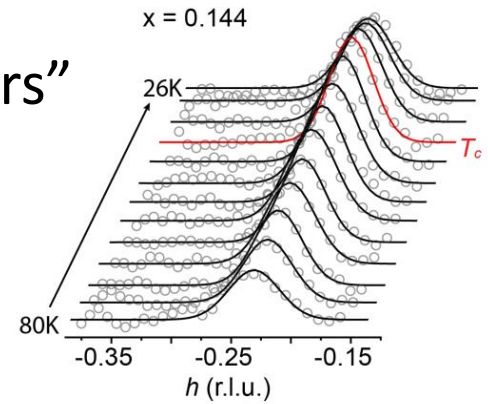
BSCCO-2223



Superconductivity

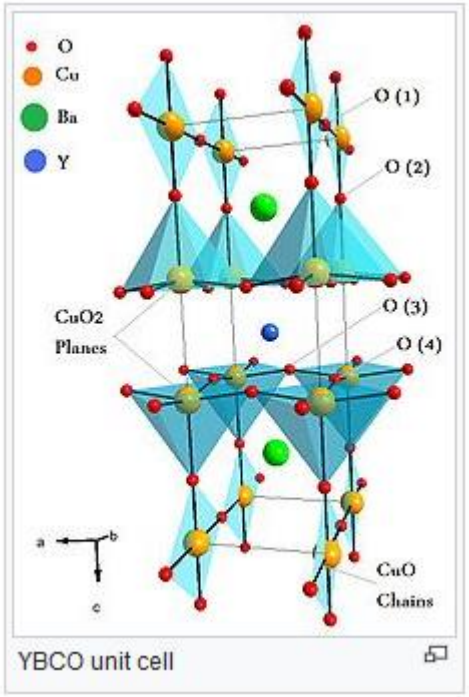


Coexisting “orders”

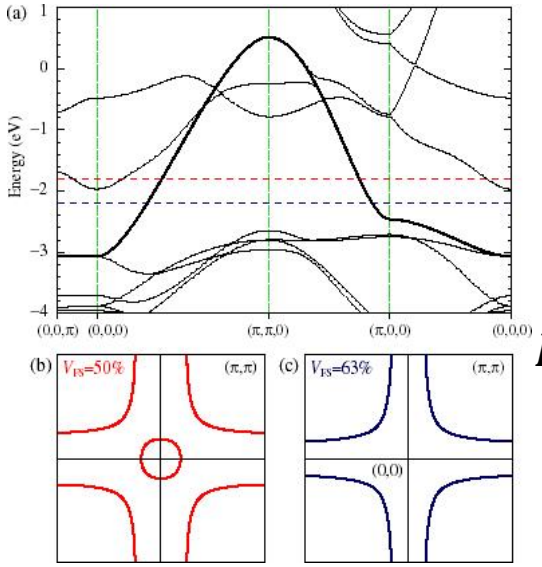


Common approach

Crystal (atoms)



Band structure (free electrons)



Add interactions

Hubbard model

$$H = \sum_k \epsilon_k \, c_k^+ c_k + \sum_i \frac{U}{2} n_i (n_i - 1)$$

PROBLEM: Find the ground state of H

What can we do?

$$H = \sum_k \epsilon_k \, c_k^+ c_k + \frac{1}{2} U n_i (n_i - 1)$$

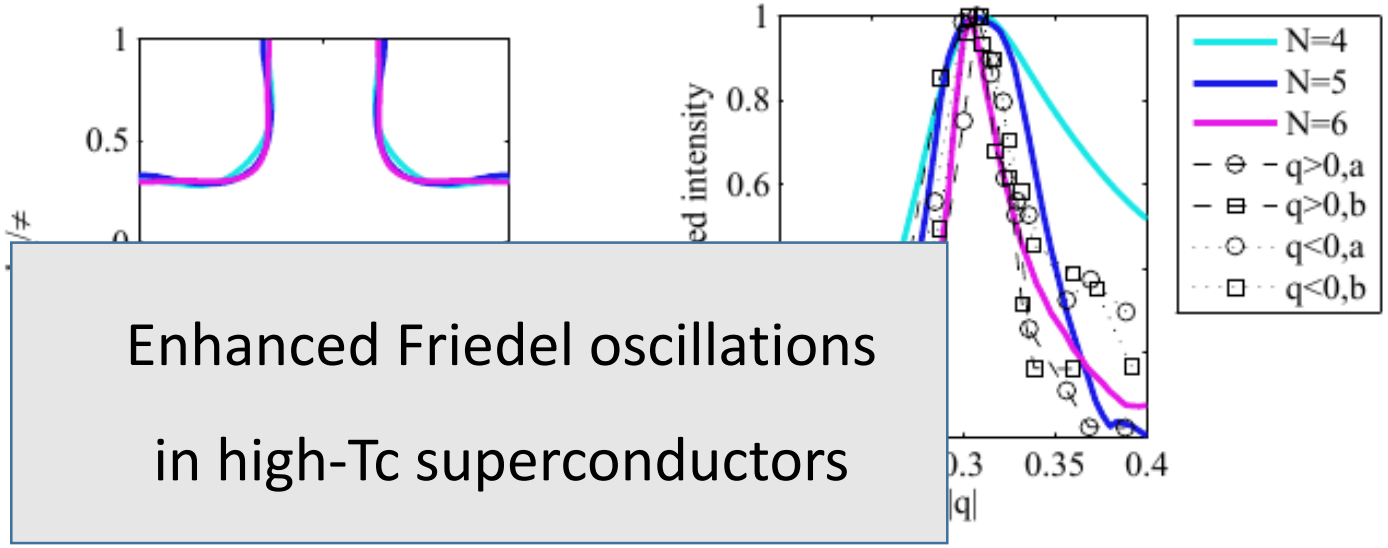
David Dentelski

Mean field $\quad n_i^2 \approx \langle c^+ c^+ \rangle \, c \, c$

$$\Delta = \frac{U}{2} \langle c \, c \rangle$$

$$H = \sum_k \epsilon_k \, c_k^+ c_k + (\Delta \, c_k c_k + \Delta^* c_k^+ c_k^+)$$

Fluctuations (impurities)



Enhanced Friedel oscillations

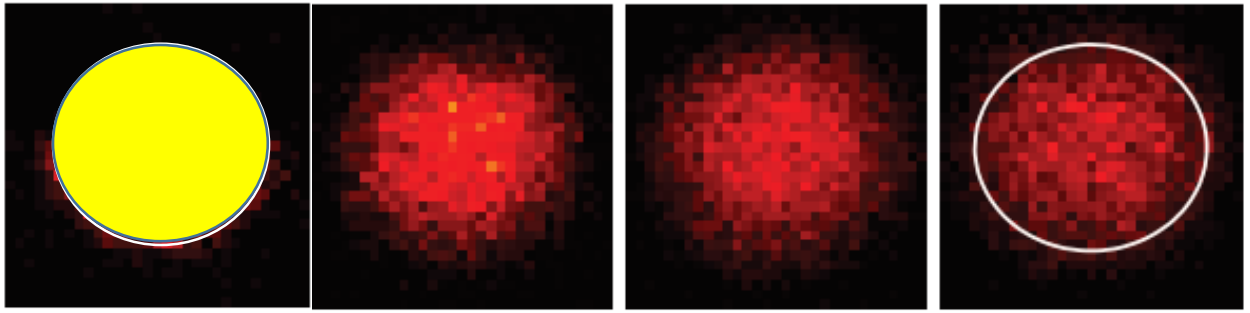
in high-Tc superconductors

Dalla Torre, Dentelski, He, Demler, PRB (2018)

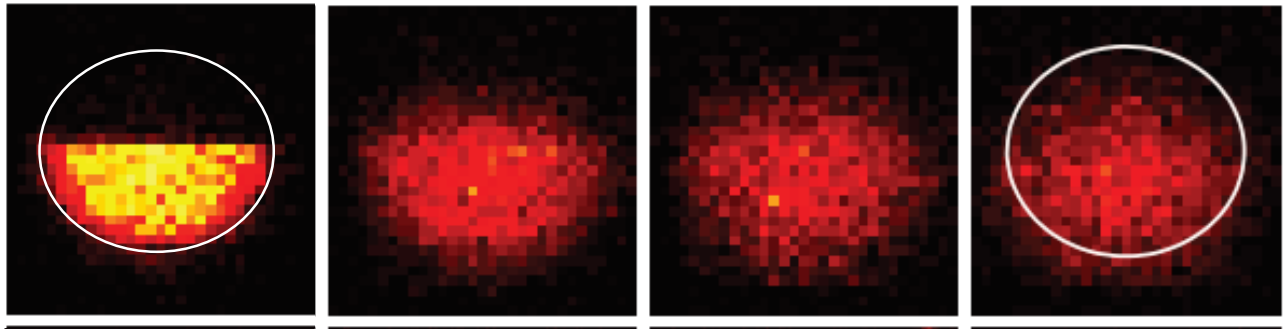
Challenge 2 – Quantum simulators

time

Without disorder



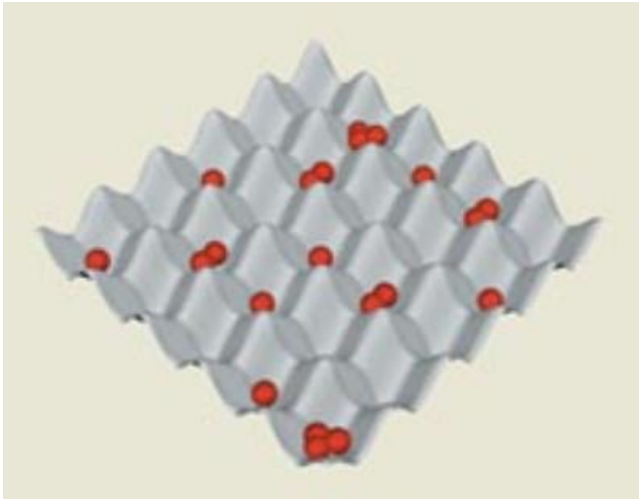
With disorder



Bloch group (2016)

Common approach

Optical lattice



Bose-Hubbard model

$$H = J\sum_{\langle i,j\rangle} b_i^+ b_j + H.c. + \sum_i \frac{U}{2} n_i(n_i - 1) + \mu_i n_i$$

Anderson localization

with interactions (MBL)?

PROBLEM: Find the eigenvalues of H

What can we do?

$$H = J\sum_{\langle i,j\rangle} b_i^+ b_j + H.c. + \sum_i \frac{U}{2} n_i(n_i - 1) + \mu_i n_i$$

Atanu Rajak

Density-phase $\quad b \to e^{i\theta} \quad \mathrm{n_i} \to p_i \quad [\mathrm{p_i}, \theta_j] = \delta_{i,j}$

$$H = \sum_i \frac{p_i^2}{2m} + \mu_i p_i + J\sum_{\langle i,j\rangle} \cos(\theta_i - \theta_j)$$

Modified Frenkel-Kontorova model

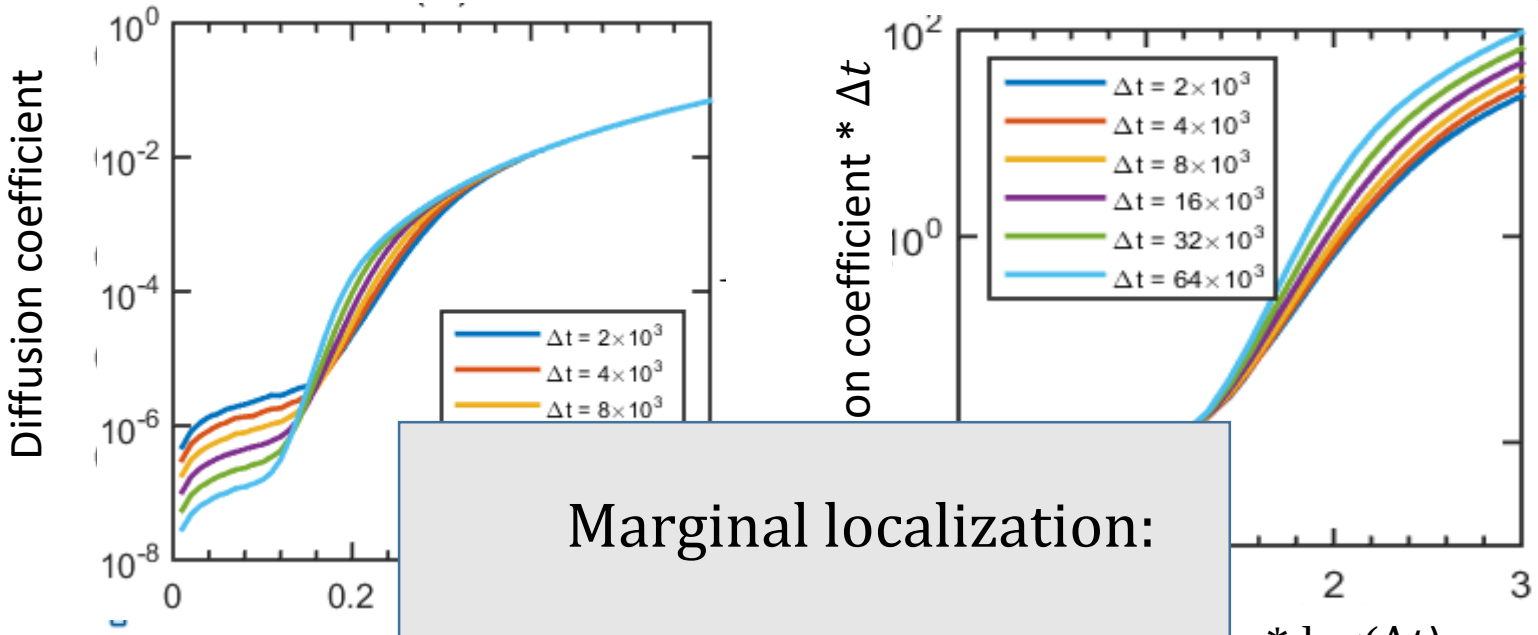
Semiclassical approximation

Rajak, Citro, Dalla Torre (J. Phys B, 2019)

What can we do?

Periodically driven FK model $$H = \frac{1}{2m}\sum_i p_i^2 + J(t)\sum_{\langle i,j\rangle}\cos(\theta_i - \theta_j)$$

Atanu Rajak

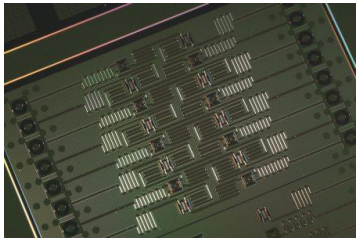


Marginal localization:

$$\Delta t = \exp(-1/\text{interaction})$$

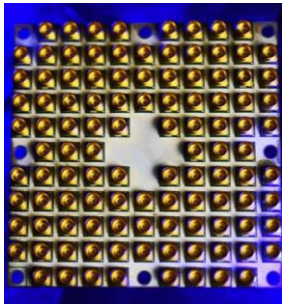
Challenge 3 – Quantum computers

IBM



50 qubit
(November 2017)

intel

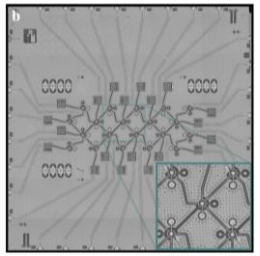


50 qubit
(Jan 2018)

Google

70 qubit
(March 2018)

rigetti



128 qubit
(May 2018)

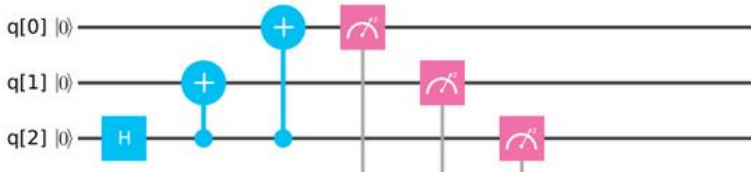
Currently available (March 19):

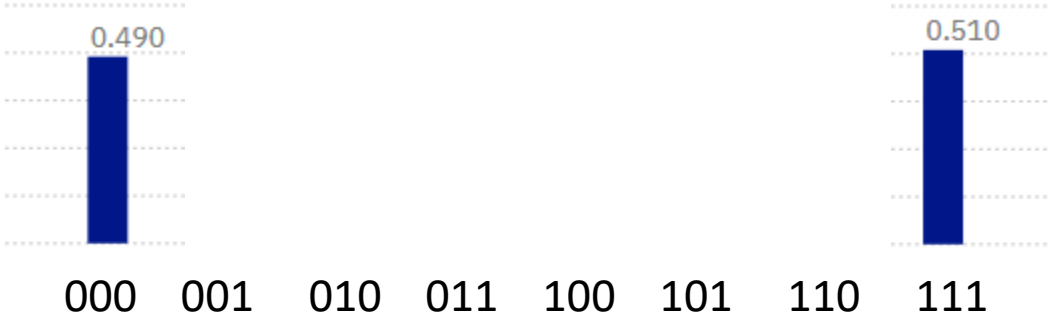
14 qubit by IBM (free)

20 qubit by IBM ($$$)

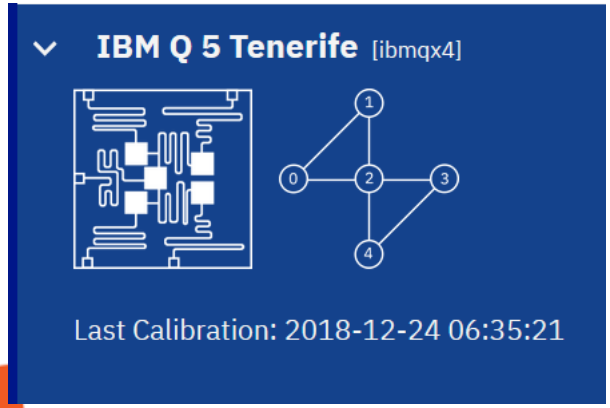
Noisy Intermediate-Scale Quantum (NISQ) Computers

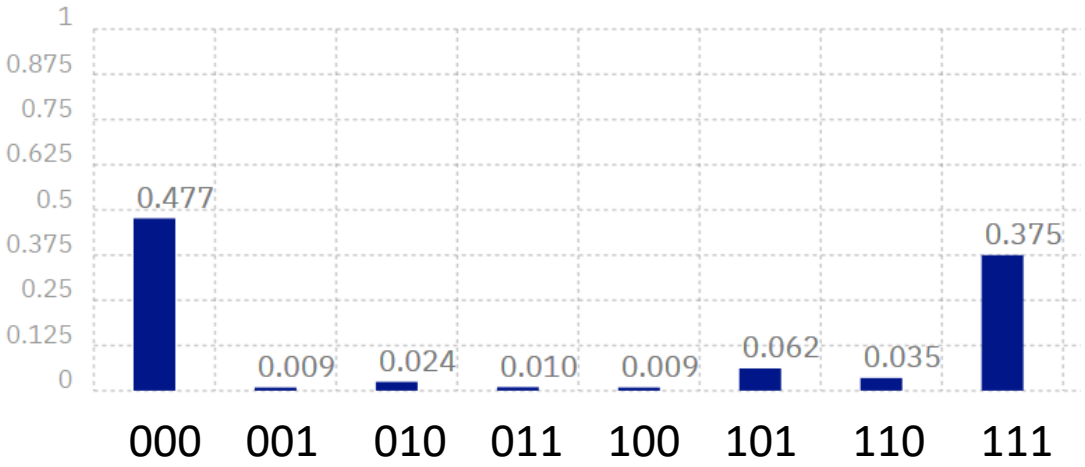
Theory: ("cat state")





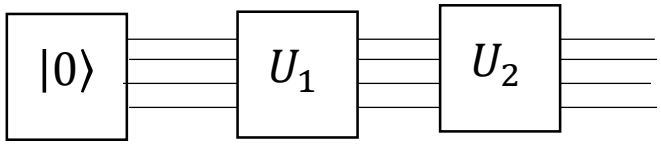
IBM Quantum Experience (2017)





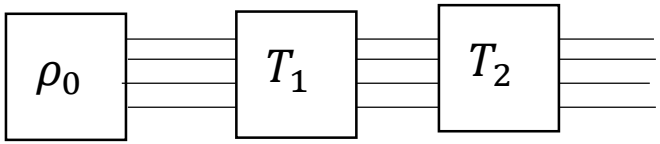
Common approach

Unitary evolution: $|\psi_n\rangle = U_n\,|\psi_{n-1}\rangle$



readout

Noisy evolution: $\rho_n = \sum_\alpha B_n^{(\alpha)}\ \rho_{n-1}\bar{B}_n^{(\alpha)}$ $\qquad \sum_\alpha B_n^{(\alpha)}\bar{B}_n^{(\alpha)} = 1$



readout

PROBLEM: Describe the evolution of ρ

What can we do?

Daniel Atzitz

Symmetry-resolved purity of an SPT phases

1. Algorithm to measure the **purity** of a state

2. A simple example of an **SPT** state

3. **Results**: simulation and experiments

Atzitz, Sela, Dalla Torre (in preparation)

Symmetry-resolved purity of an SPT phases

1. Algorithm to measure the purity of a state

$$Tr[\rho^2] = \sum_{i,j} \langle i|\rho|j\rangle\langle i|\rho|j\rangle$$

$$\langle SWAP_{AB}\rangle = Tr[\rho^A \rho^B SWAP_{AB}] = \sum_{i,j} \langle i_A j_B|\rho^A \rho^B SWAP_{AB}|i_A j_B\rangle$$

$$= \sum_{i,j} \langle i_A j_B|\rho^A \rho^B|j_A i_B\rangle = \sum_{i,j} \langle i_A|\rho^A|j_A\rangle\langle i_A|\rho^B|j_B\rangle$$

Daley, Pichler, Schachenmayer, Zoller, PRL (2012)

Symmetry-resolved purity of an SPT phases

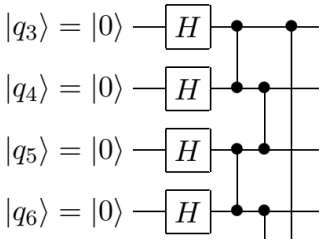
Bat-el Friedman

2. A simple example of an **SPT** state

Unitary transformation

$$H = -\sum_i \sigma_i^x \quad \Rightarrow \quad H = -\sum_i \sigma_{i-1}^z \sigma_i^x \sigma_{i+1}^z$$

Non topological



Topological

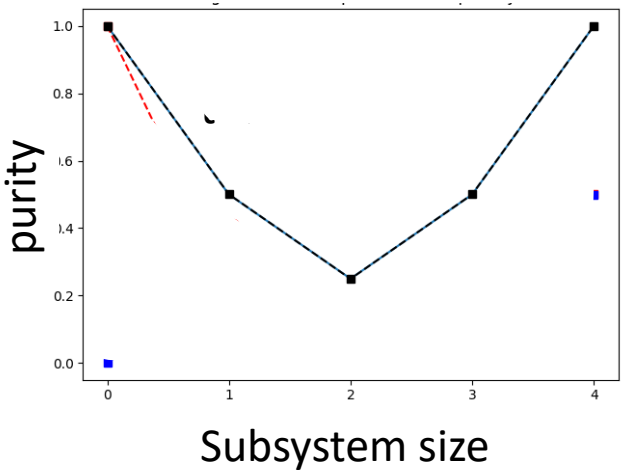
Choo, von Keyserlingk, Regnault, Neupert (PRL, 2018)

See also: Friedman, Rajak, Dalla Torre (EPL, 2019)

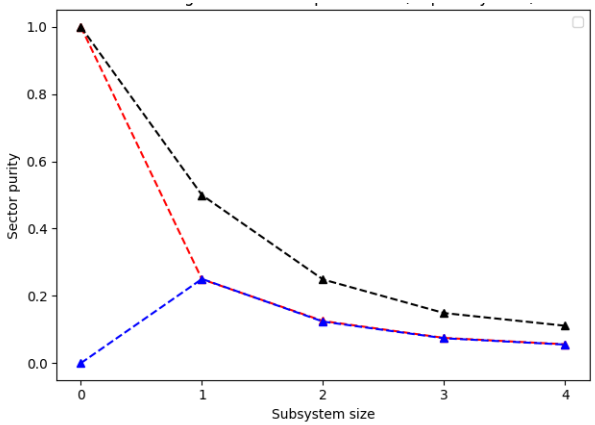
Symmetry-resolved purity of an SPT phases

3. **Results**: simulation and experiments

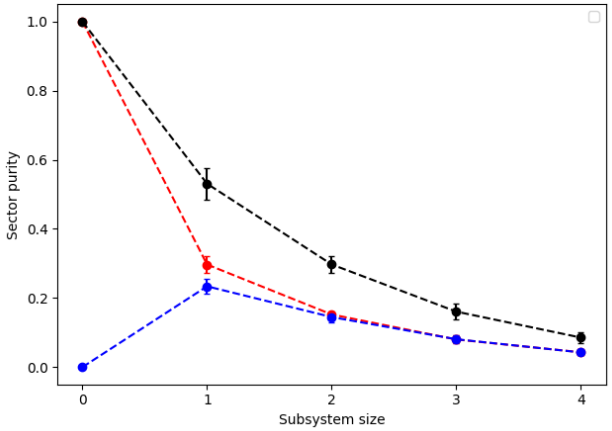
Unitary circuit



Noisy simulation



Quantum computer



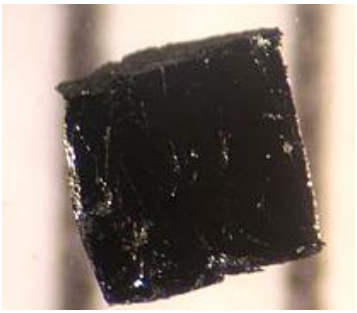
Atzitz, Sela, Dalla Torre (in preparation)

See also: Goldstein, Sela PRL 2018

Three grand quantum challenges

1. Quantum materials

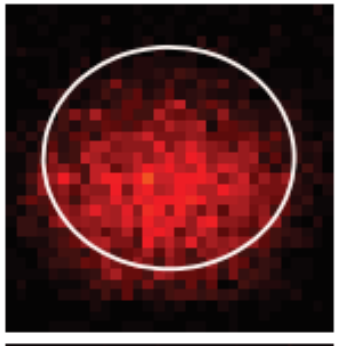
High temperature superconductors



Find the ground state of H

2. Quantum simulations

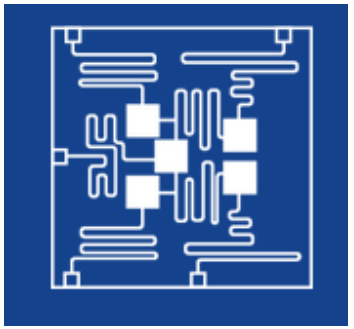
Many body localization (MBL)



Find the eigenstates of H

3. Quantum computers

Near term intermediate scale quantum (NISQ)



Find the evolution of ρ