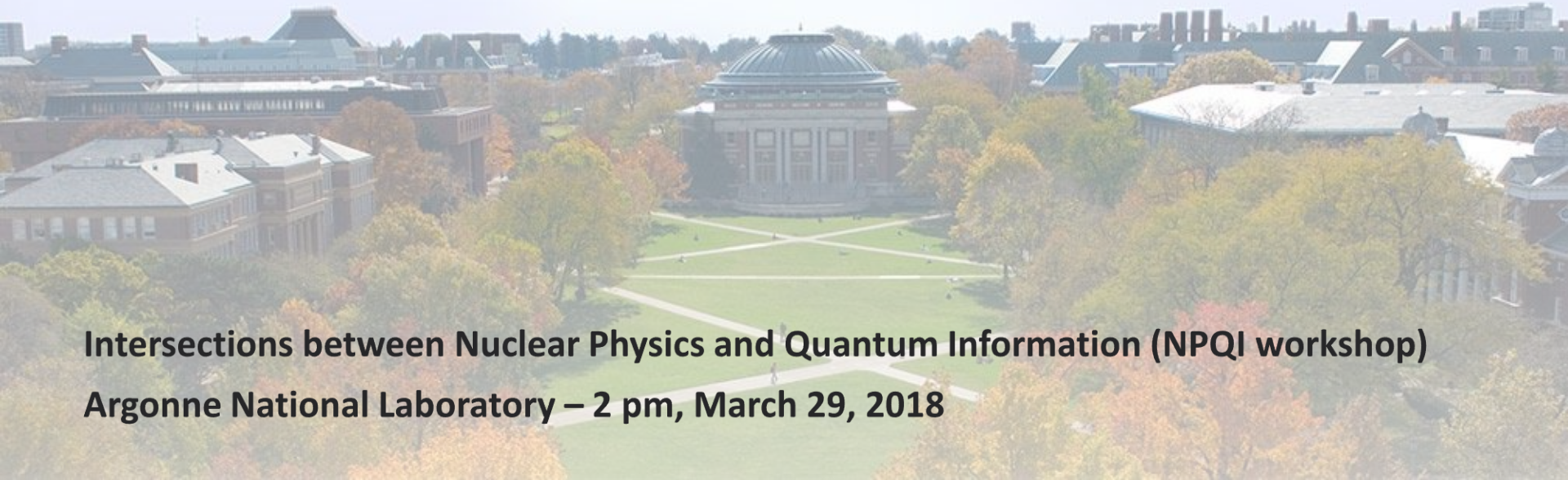
Overview of QIS and Quantum Emulation studies at University of Illinois

>> *Prospects for studying dynamical gauge fields with cold atoms and molecules*

Bryce Gadway [Paul Kwiat, Virginia Lorenz, Brian DeMarco]
University of Illinois at Urbana-Champaign



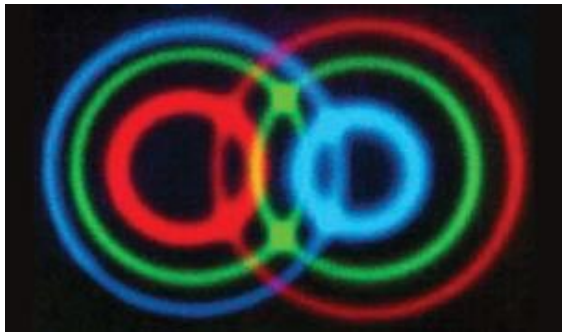
Intersections between Nuclear Physics and Quantum Information (NPQI workshop)

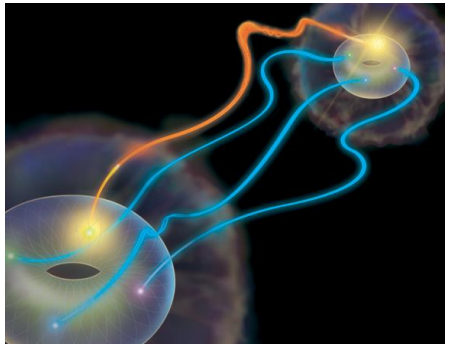
Argonne National Laboratory – 2 pm, March 29, 2018

Kwiat Group: Quantum Information Science

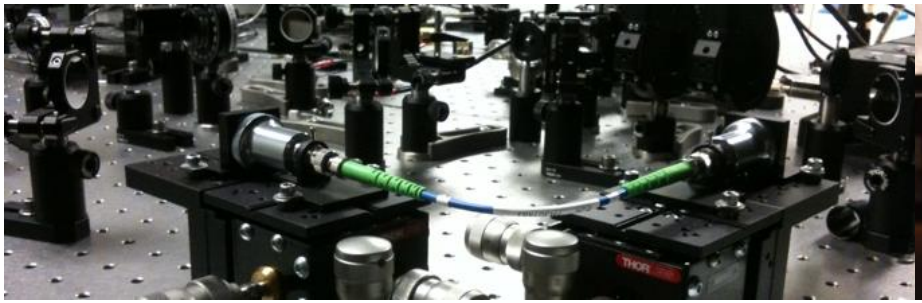
<u>Improving quantum technologies</u>
Development of entangled photon and single-photon sources
Development of single-photon detectors
Improving efficiency of photon collection in noisy environments

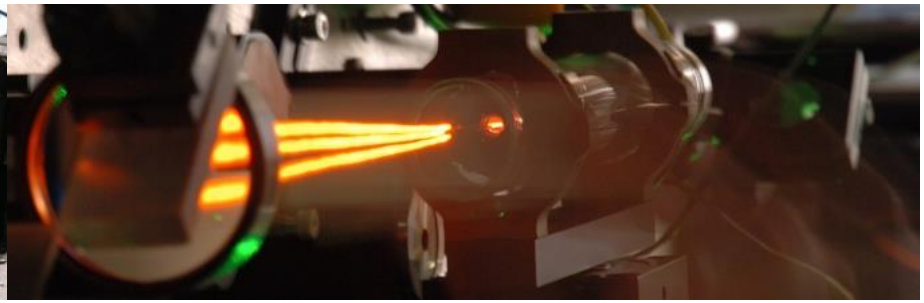
<u>More fundamental studies</u>
Bell-like tests of nonlocal realism
Superdense encoding of quantum information
Teleportation and quantum communications
Few- and single-photon detection by humans

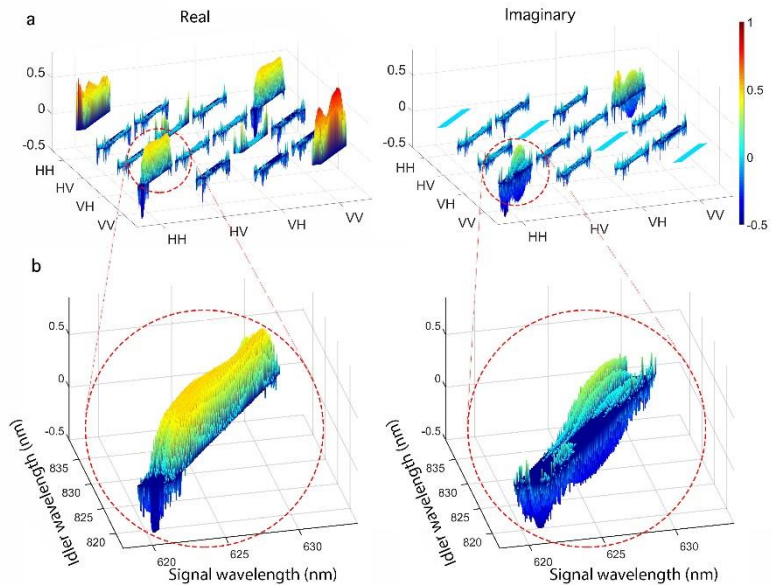




Lorenz Group: Quantum Optics and Spectroscopy





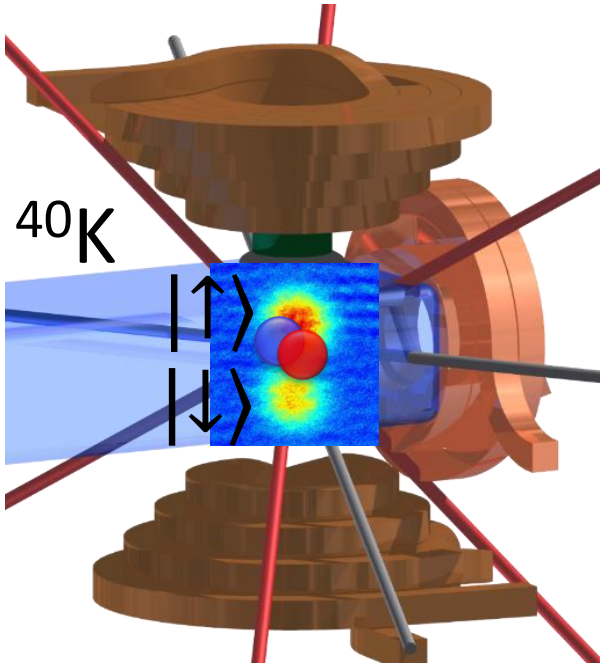


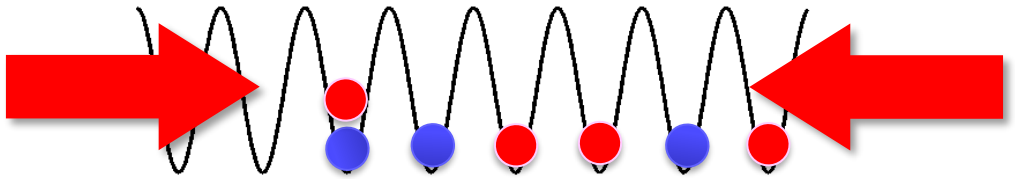
Motivation: quantum information applications, fundamental studies

- Engineering photonic quantum states for quantum applications
- High-resolution, high-efficiency measurement techniques for characterization of photonic quantum states in multiple degrees of freedom
- Quantum memories for telecom broadband photonic quantum states, fundamental studies of influence of light-matter interaction on photon-pair properties

DeMarco group

Optical lattice quantum emulation

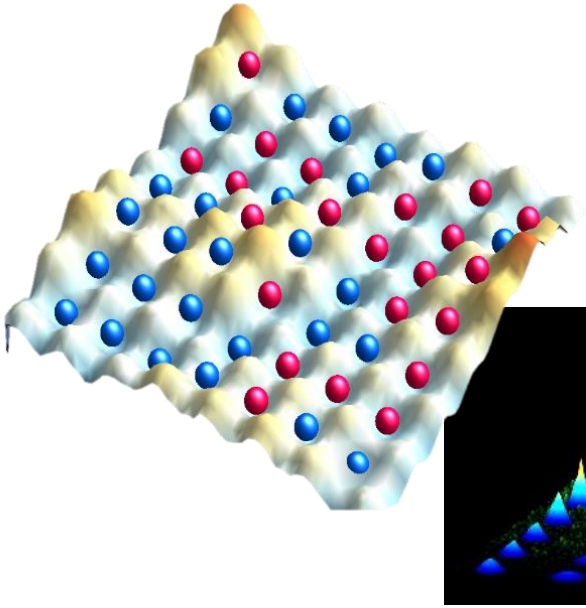




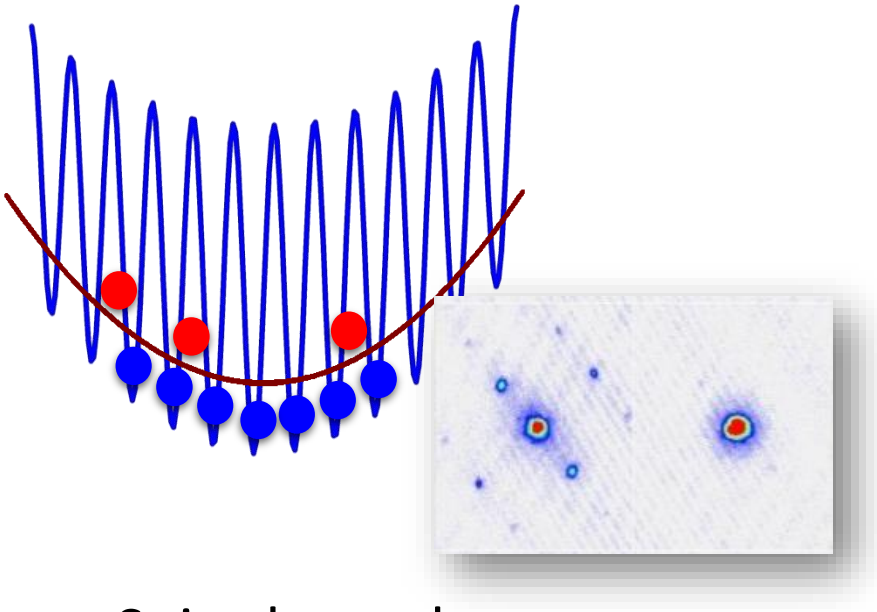
$$H = -t \sum_{\langle ij \rangle} c_i^\dagger c_j + U \sum_i n_{\downarrow i} n_{\uparrow j}$$

Hubbard model

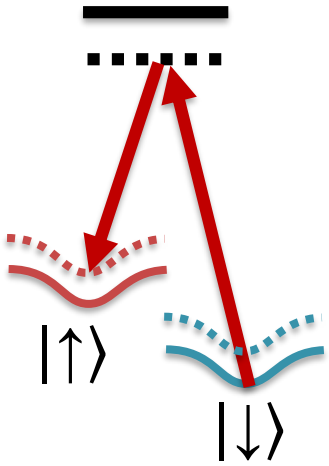
Minimal model for strongly interacting quantum matter

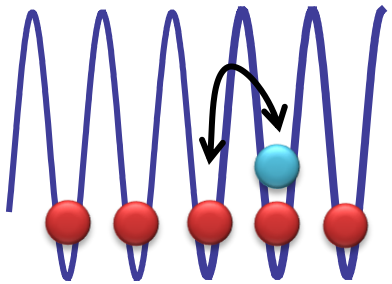


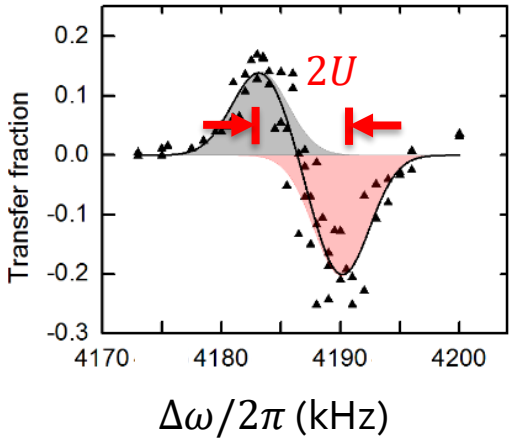
Disorder



Spin-dependent
lattices & potentials





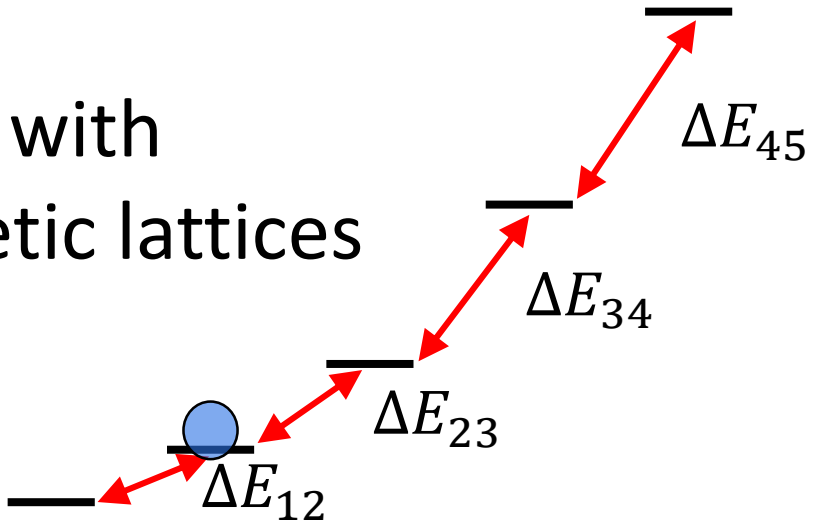


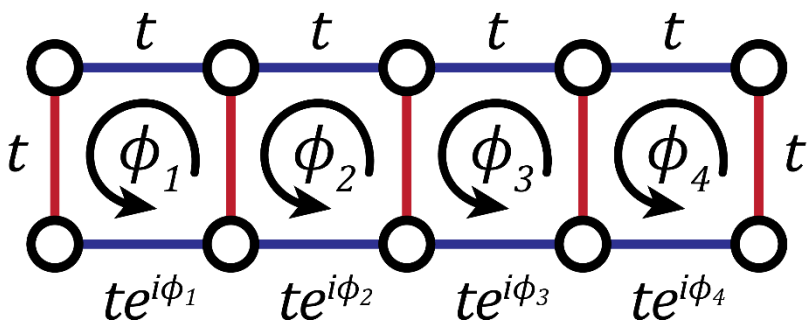
Correlated Tunneling

Gadway group

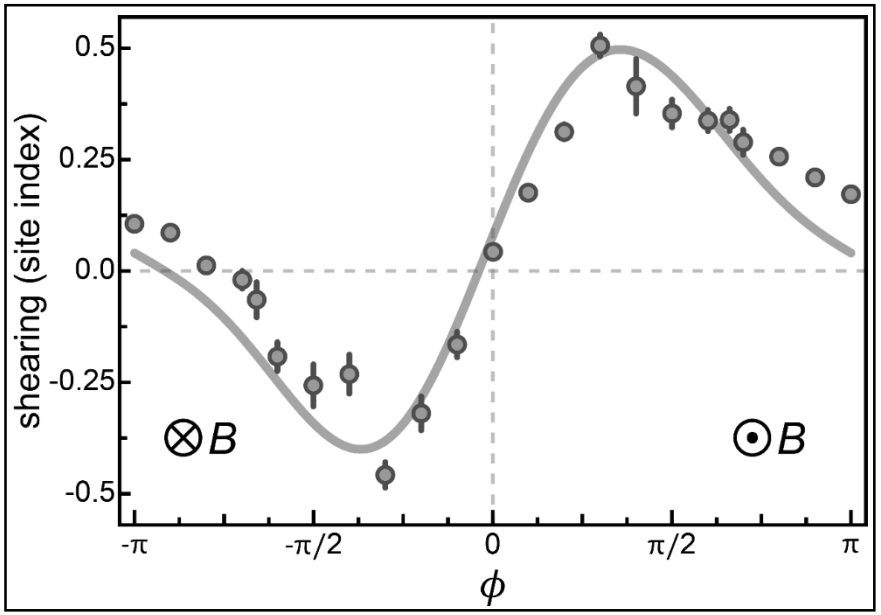
Quantum simulation with non-standard, synthetic lattices

w/ cold atoms & molecules



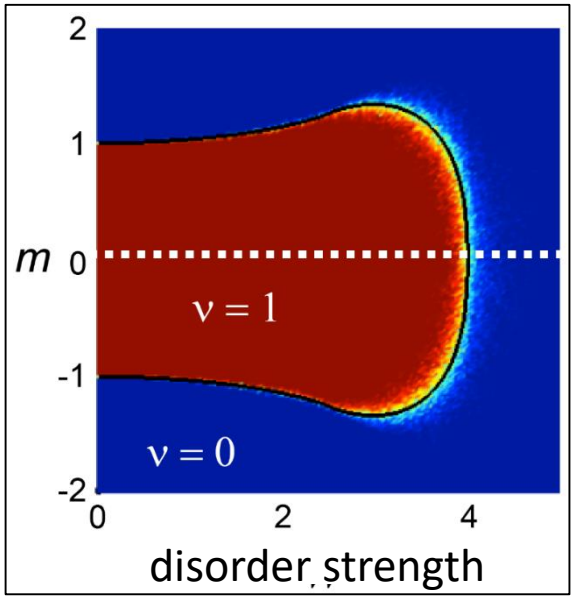


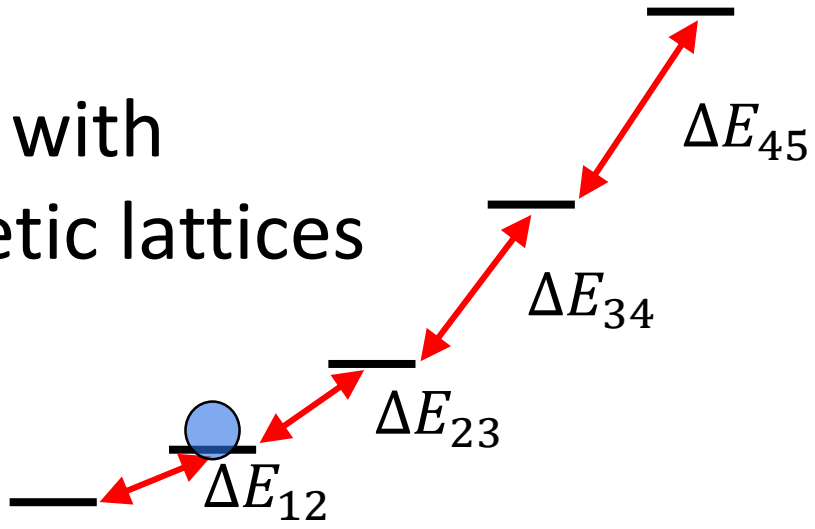
Designer *classical* gauge fields



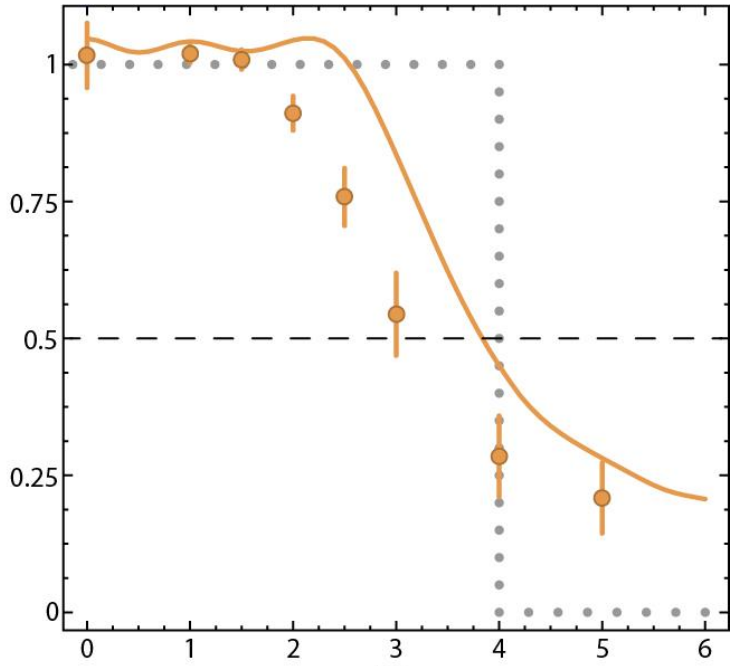
Gadway group

Quantum simulation with non-standard, synthetic lattices





winding number



Interplay of:

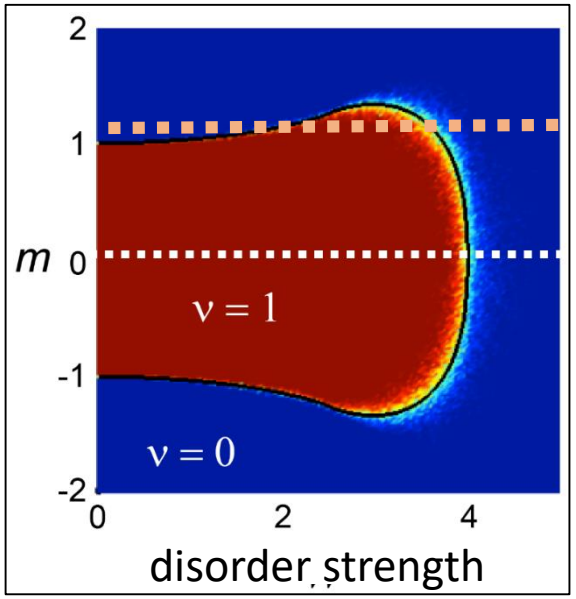
- topology & disorder

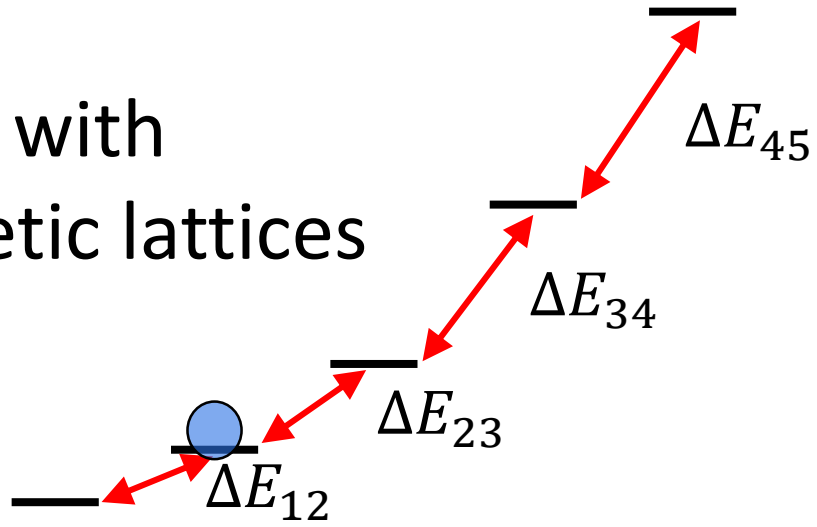
- topology & interactions

- disorder & interactions

Gadway group

Quantum simulation with non-standard, synthetic lattices





Interplay of:

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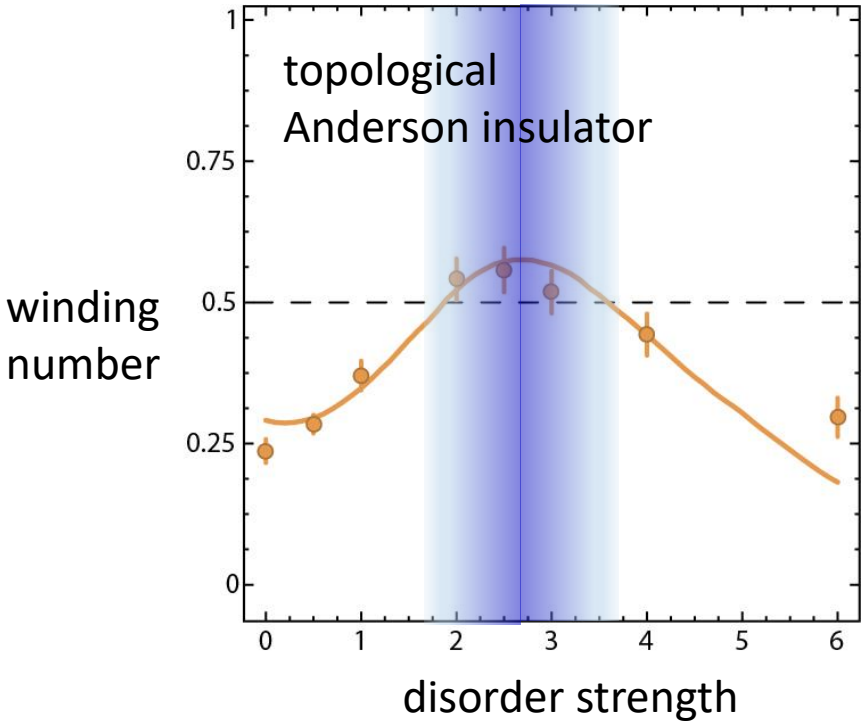
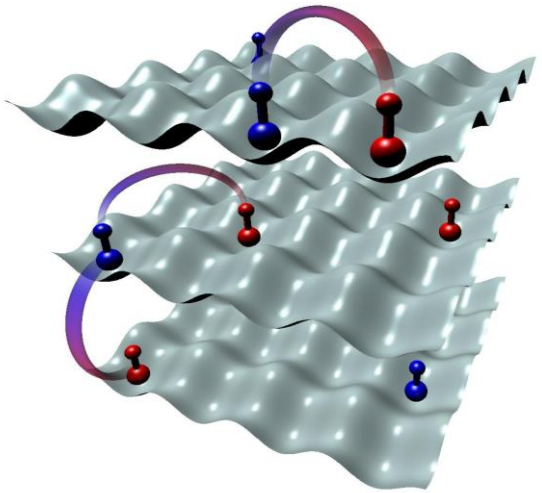


Gadway / DeMarco – ultracold molecules



Harnessing dipolar exchange interactions
for the emulation of lattice gauge theories

Gadway / DeMarco – ultracold molecules

Requires extreme control, not very forgiving for cold atoms
→ molecules are a natural fit

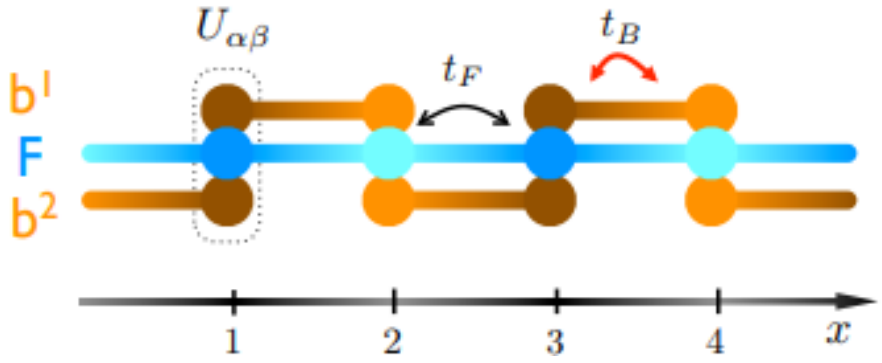
Quantum field theory

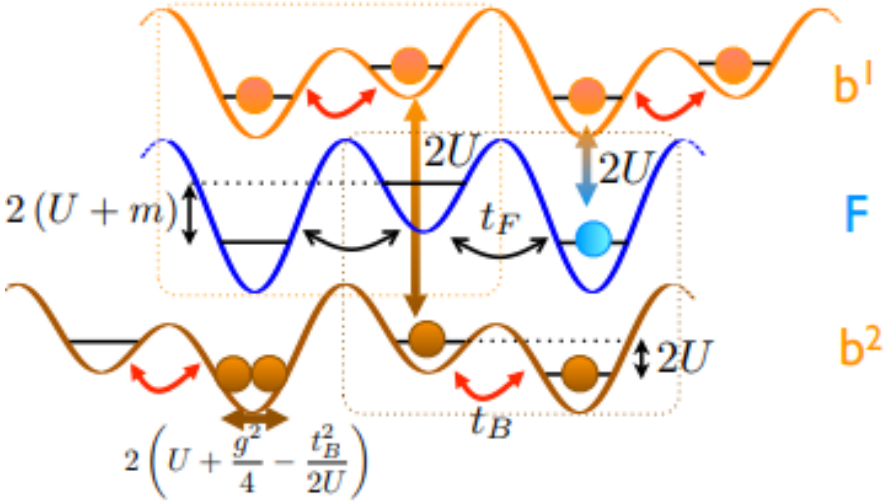
Lattice gauge theory

Quantum link model

- Multiple species (2 bosons, 1 fermion)
- Spin-dependent tunneling / site energies
- Control of all interactions [must be stable]
- Keep entropy low

→ gauge invariance only at low T, low S/N

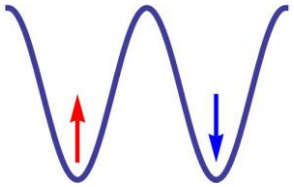




Banerjee, et al. PRL 109, 175302 (2012)

Emulating LGTs with ultracold molecules

atoms → molecules



particle hopping → spin "hopping" by dipolar exchange

correlated hopping (low S/N, low t/U) → naturally imposed by dipolar exchange

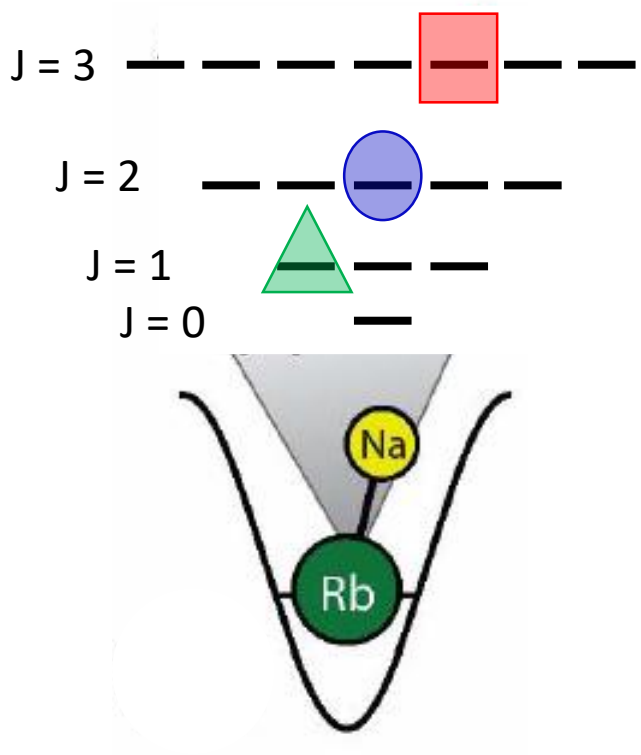
spin-dependent potentials → local "magnetic fields" / light shifts

start with "low" entropy by motion → motion frozen out, initial spin entropy = 0

gauge invariance / Gauss' law imposed by hand

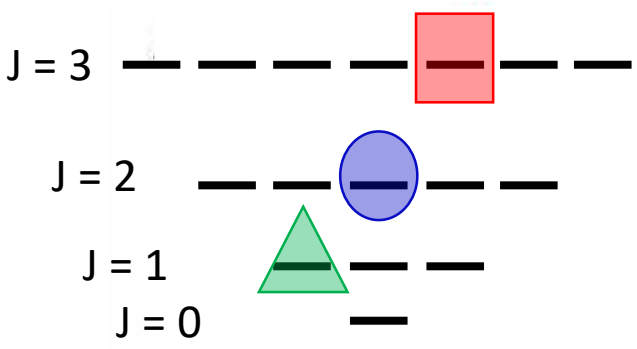
Emulating LGTs with ultracold molecules

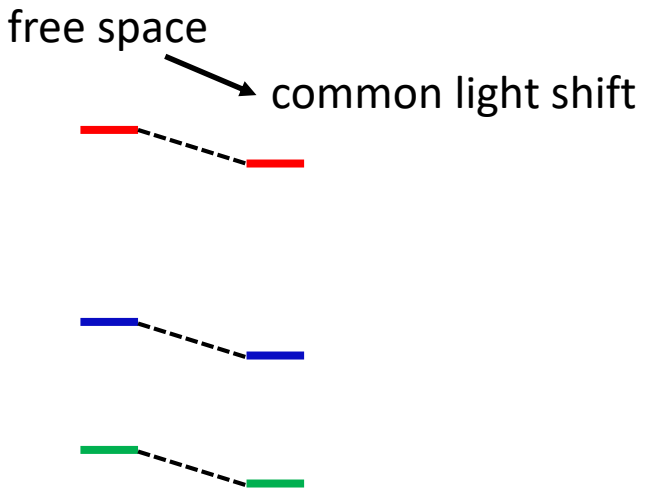
internal rotational states

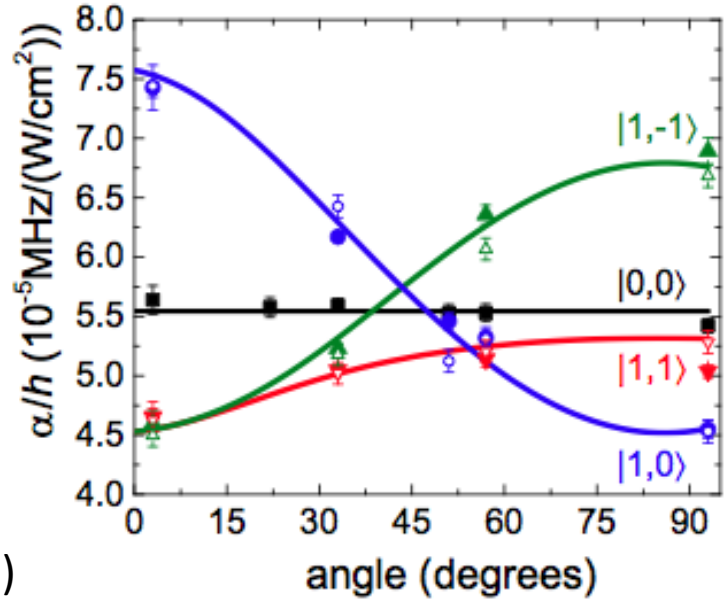


Emulating LGTs with ultracold molecules

internal rotational states



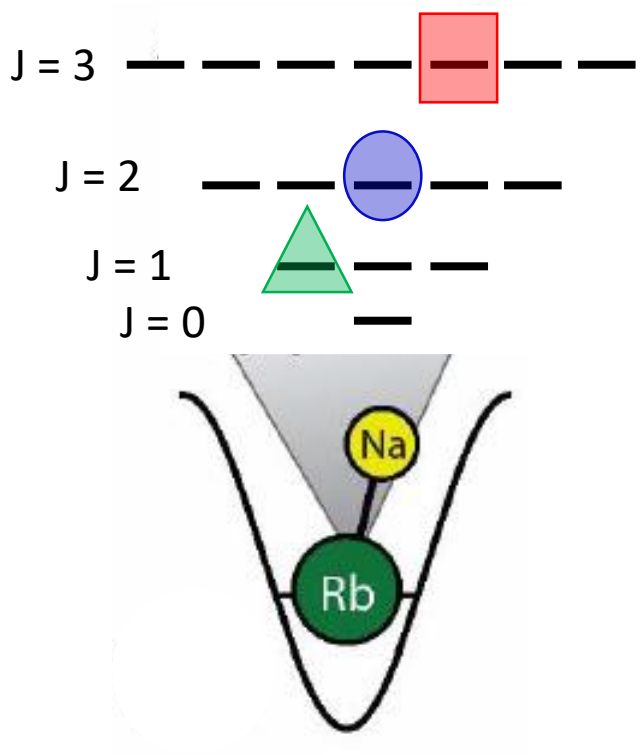


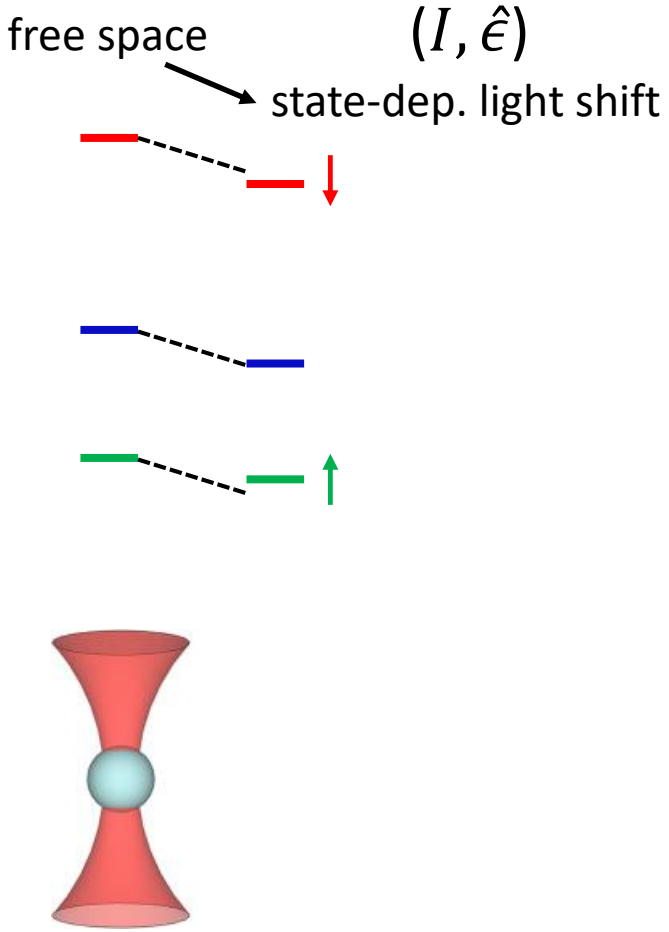


anisotropic polarizability
Neyenhuis, *et al*. PRL (2012)

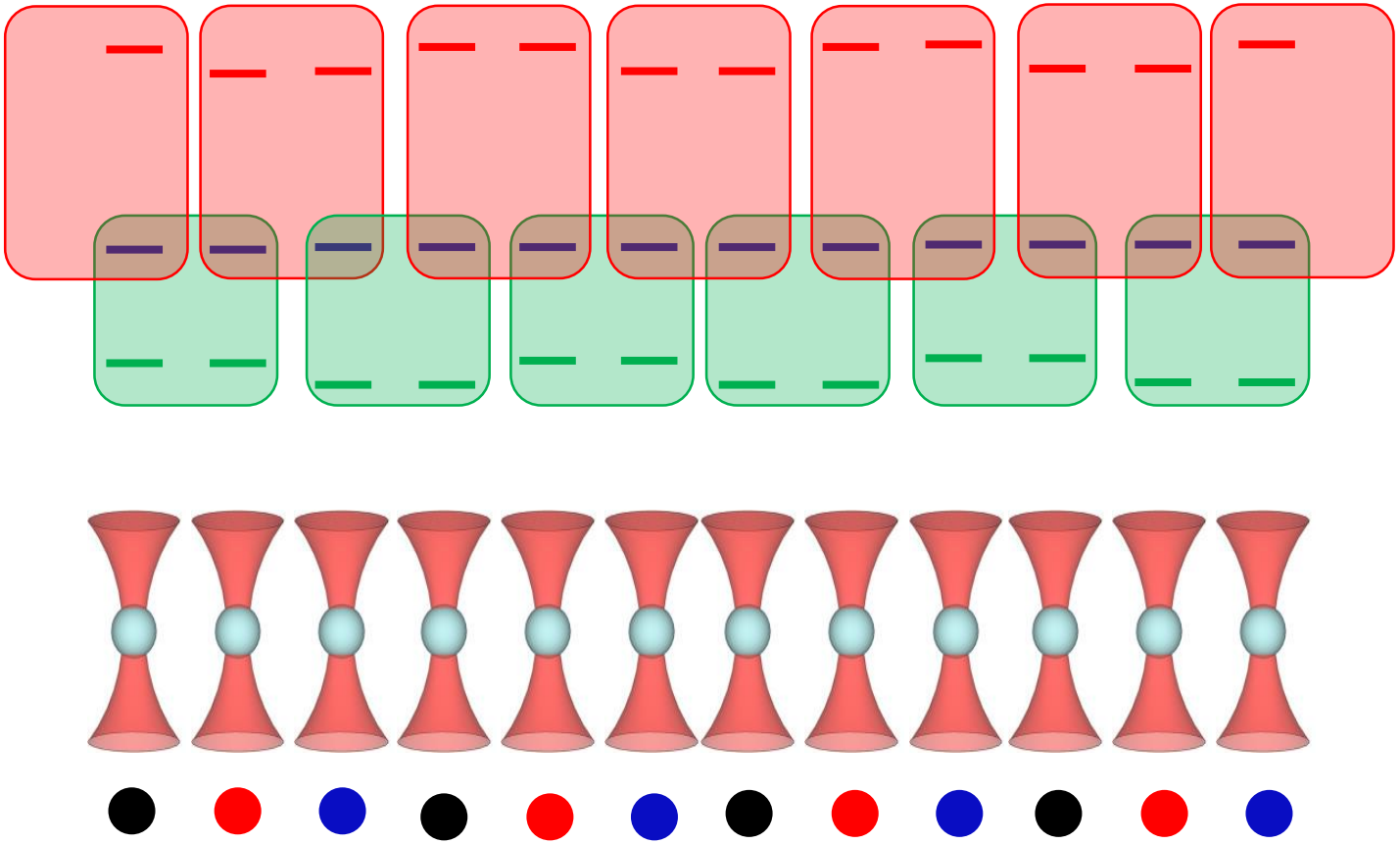
Emulating LGTs with ultracold molecules

internal rotational states



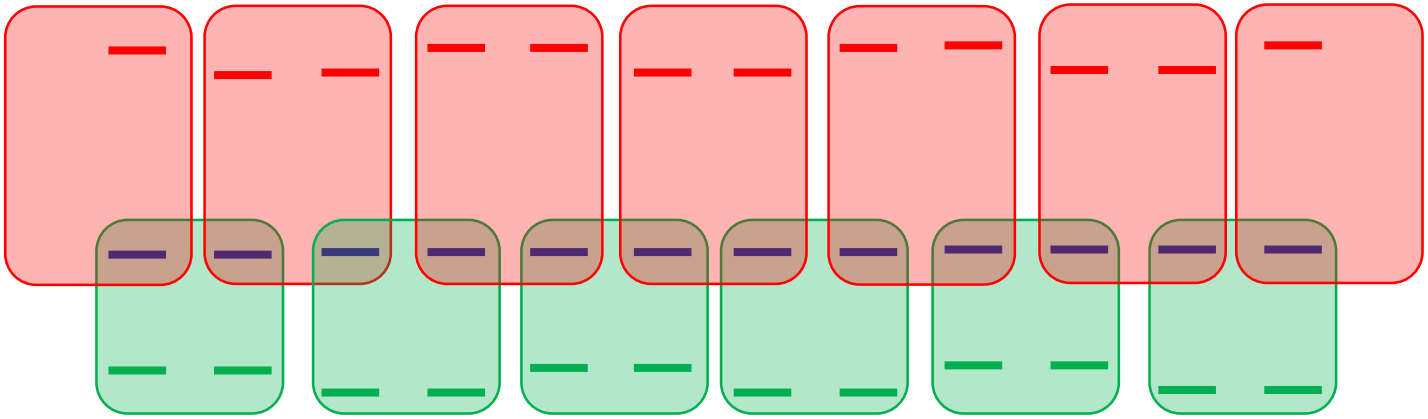


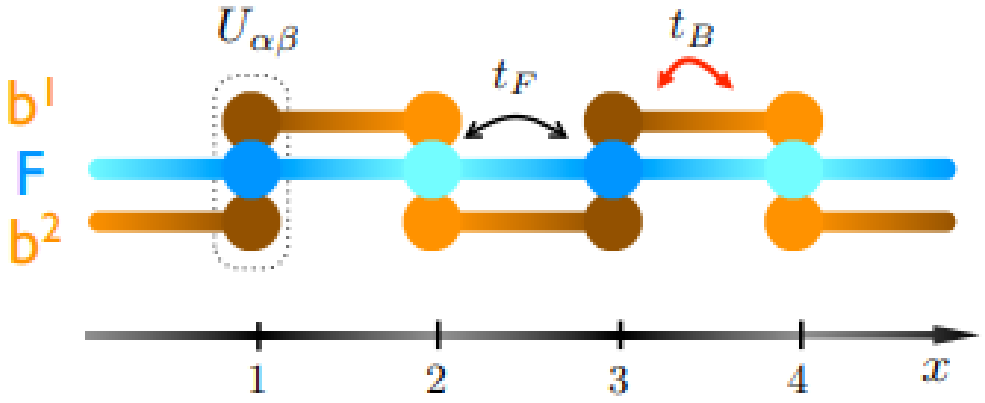
Emulating LGTs with ultracold molecules



$(I_1, \hat{\epsilon}_1)$, $(I_2, \hat{\epsilon}_2)$, $(I_3, \hat{\epsilon}_3)$

Emulating LGTs with ultracold molecules





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Thanks! Questions?