Quantum Magnetism with ^{7}Li

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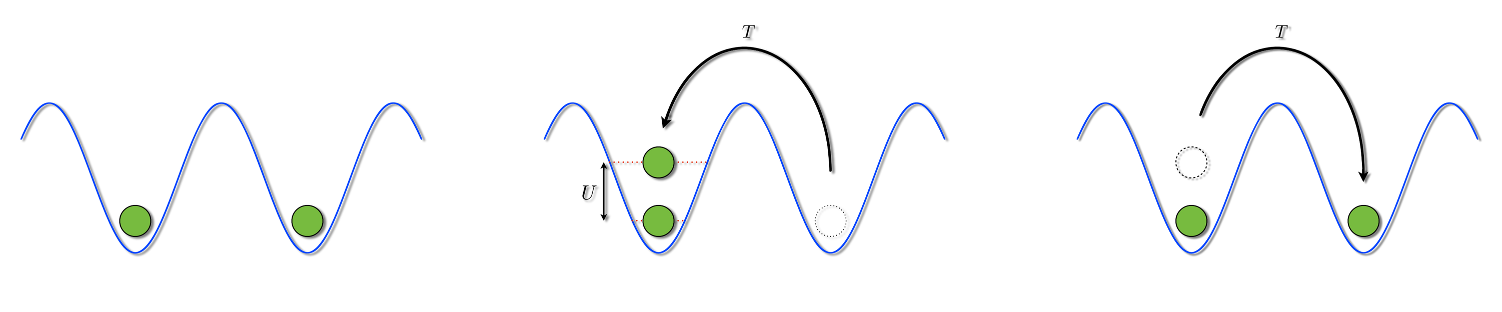
Introduction

The Need 4 Speed

Two-component Bose-Hubbard Hamiltonian

$$H = -\sum_{\langle ij\rangle,\sigma=\uparrow,\downarrow}\left(t_\sigma a^\dagger_{i\sigma}a_{j\sigma} + h.c.\right) + \frac{1}{2}\sum_{i,\sigma=\uparrow,\downarrow} U_\sigma n_{i\sigma}(n_{i\sigma}-1) + U_{\uparrow\downarrow}\sum_i n_{i\uparrow}n_{i\downarrow}$$

Super-exchange dominated spin-interactions $J = t^2/U$



(a) Neighboring atoms (b) Virtual Excitation of energy U (c) Particle tunnels back

Advantages of our experimental setup:

(1) Light mass of Li-7 $\quad E_R = \frac{\hbar^2 k^2}{2m} \quad t \approx E_R \cdot \frac{4}{\sqrt{\pi}}(V_0/E_R)^{3/4} e^{-\sqrt{V_0/E_R}}$

(2) Green optical lattice

(3) Feshbach resonance $\quad U \approx a\sqrt{\frac{8}{\pi}}k(V_0/E_R)^{3/4}E_R$

$\Rightarrow$ Higher critical temperature for magnetic ordering ($k_B T_c \sim t^2/U$)

$\Rightarrow$ Faster spin dynamics within experimentally relevant timescales

Experimental Realization

Experimental Model

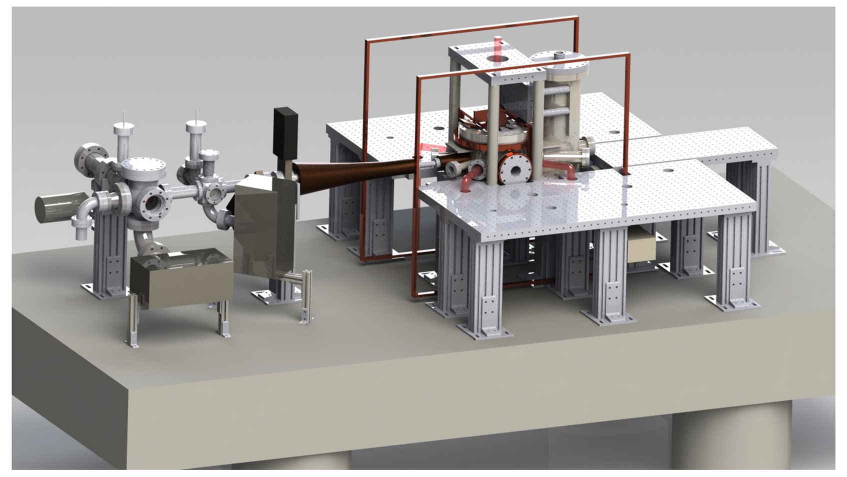
- Two-component Hamiltonian realized by ^{7}Li atoms in two hyperfine states placed in an optical lattice
- Freely tunable experimental parameters:
  - Energy ratio t/U by optical lattice depth
  - On-site interaction energy U by a Feshbach resonance
  - Spin separating potential by a magnetic field gradient
  - Temperature by evaporation time

Experimental Sequence

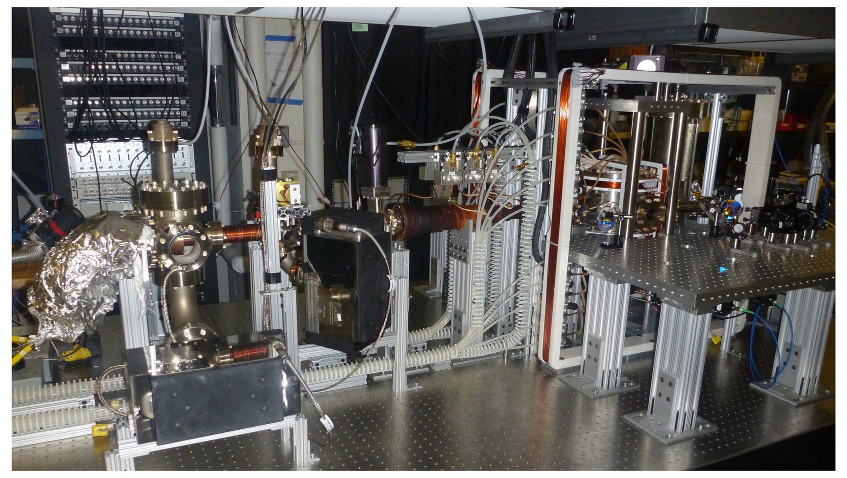
1. Zeeman-slowing and Magneto-optical trapping
2. Grey Molasses followed by Evaporative cooling in a Plug trap
3. BEC in an IR dipole trap, interactions enhanced by a Feshbach resonance
4. Green lattice supported by an IR dipole trap

Machine Table

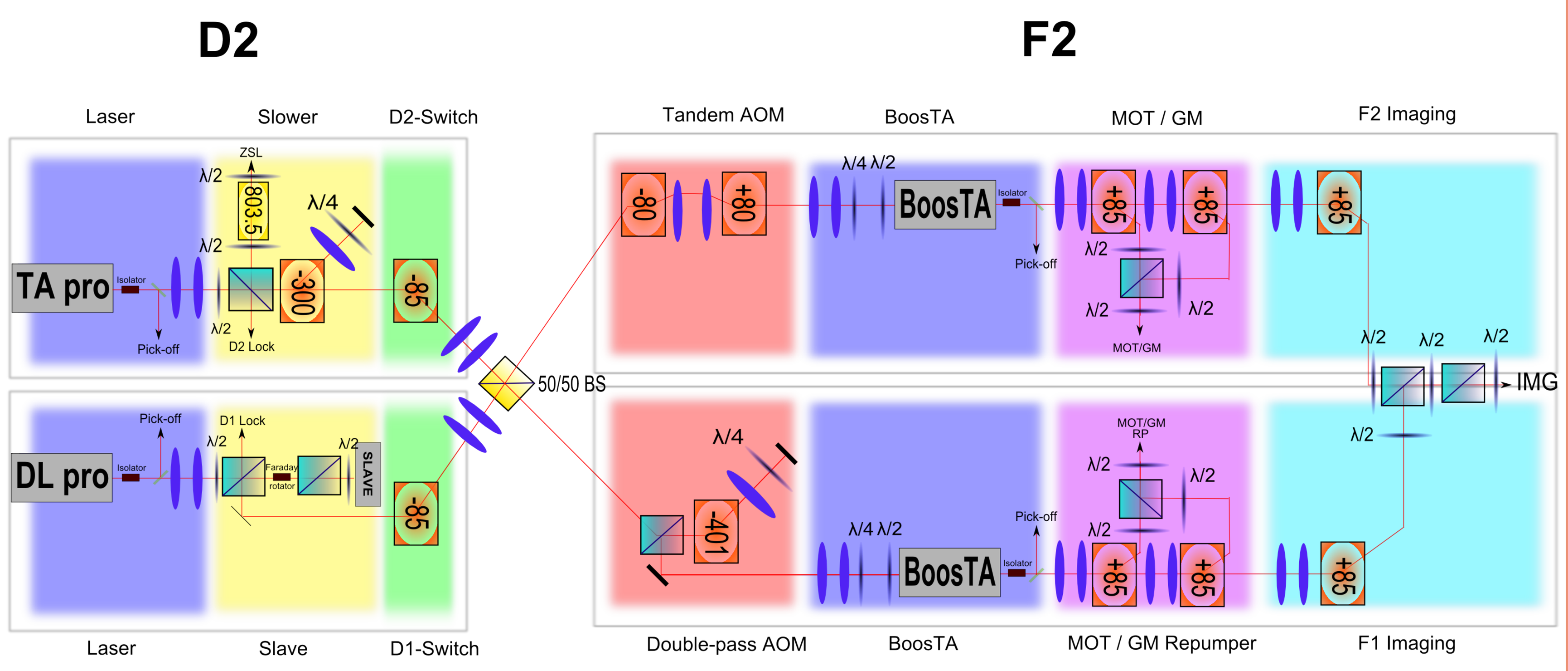
Design



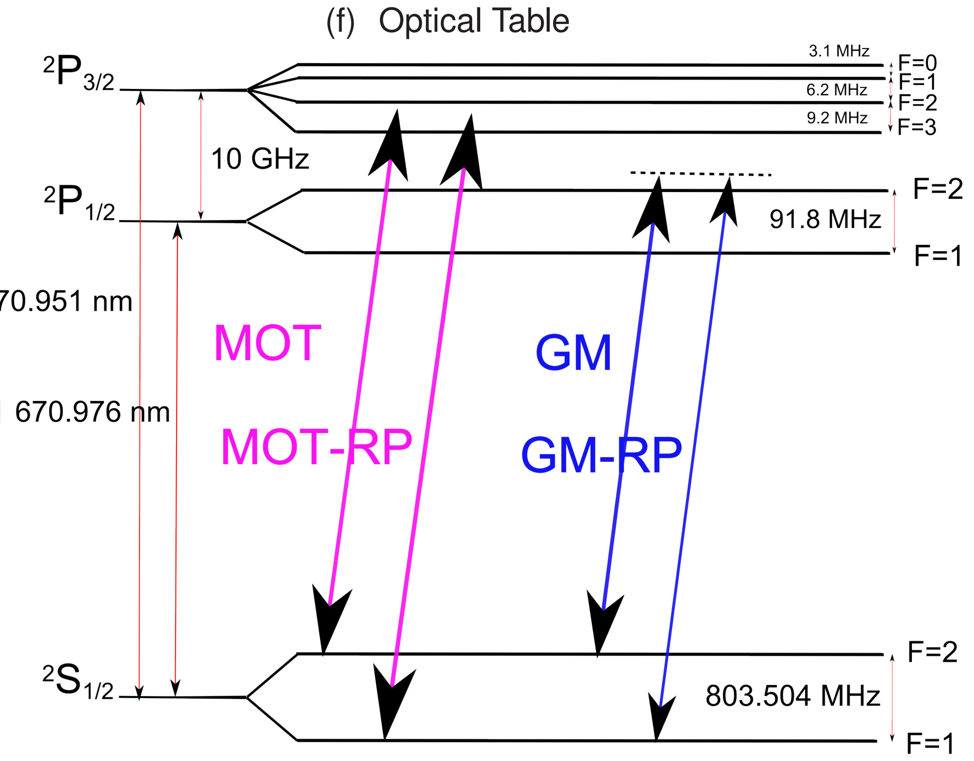
Realization



Gray Molasses Cooling



(f) Optical Table



(g) Energy Level Diagram

A grey Molasses sub-Doppler cooling scheme has been recently realized in ^{7}Li in the Salomon group:

Grier, A.T., Ferrier-Barbut, I., Rem, B.S., Delehaye, M., Khaykovich, L., Chevy, F., Salomon, C., *Lambda-enhanced Sub-Doppler Cooling of Lithium Atoms in D1 Gray Molasses*, arXiv:1304.6971

Possible Experiments

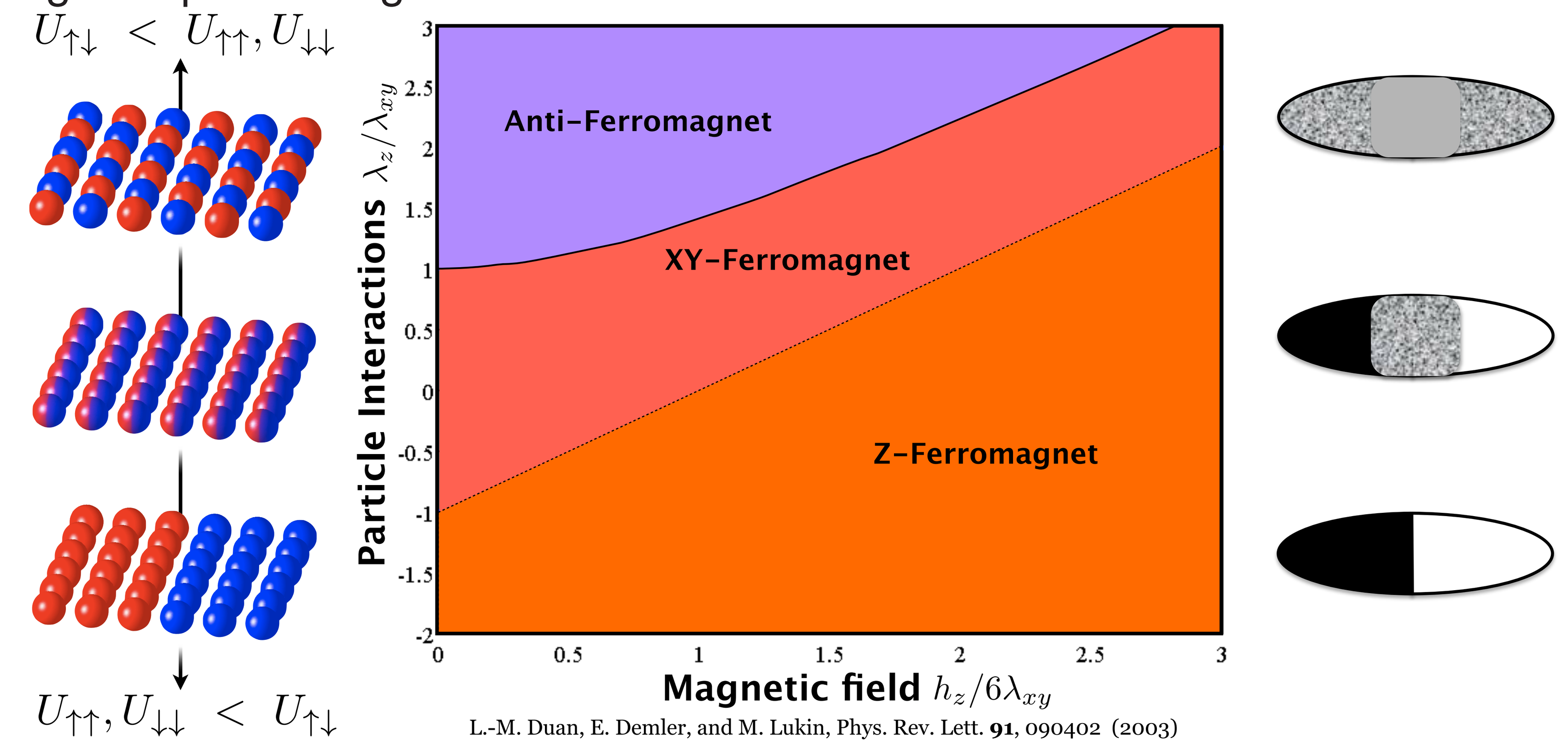
Quantum Simulation

- Anisotropic Heisenberg Model (XXZ model)

$$H = \sum_{<i,j>}[\lambda_z s_i^z s_j^z - \lambda_{xy}(s_i^x s_j^x + s_i^y s_j^y)] - B_z\sum_i s_i^z$$

$$\lambda_z = \frac{t_\uparrow^2 + t_\downarrow^2}{2U_{\uparrow\downarrow}} - \frac{t_\uparrow^2}{U_{\uparrow\uparrow}} - \frac{t_\downarrow^2}{U_{\downarrow\downarrow}} \qquad \lambda_{xy} = \frac{t_\uparrow t_\downarrow}{2U_{\uparrow\downarrow}}$$

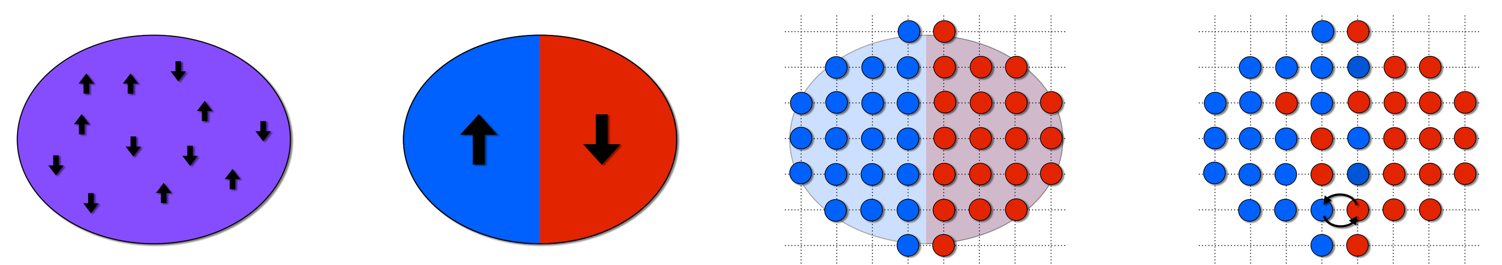
- Magnetic phase diagram



L.-M. Duan, E. Demler, and M. Lukin, Phys. Rev. Lett. **91**, 090402 (2003)

Spin Dynamics

- Spin transport by super-exchange interactions



(h) Prepare a 50-50 spin mixture (i) Separate spins by magnetic field gradient (j) Apply optical lattice (k) Allow spins to mix (by decreasing magnetic field gradient)

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