Nonequilibrium Physics of Spinor Quantum Fluids

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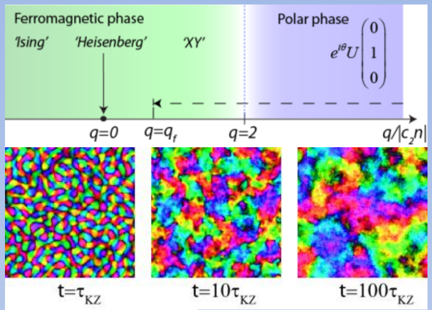

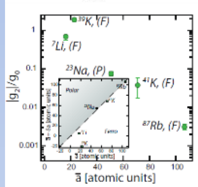

Fig 1. (Top) Phase diagram of a F=1 spinor Bose gas versus the quadratic Zeeman energy q. (Middle) Spin Textures at different times after a quench. (Bottom) The ratio between spin dependent and density dependent interactions for different atomic species.

Introduction

The focus of our research is on the many-body quantum physics of spinor gases. These multi-component quantum fluids offer rich prospects for studying non-equilibrium dynamics, the physics of topological defects, and spatially ordered spin textures. We are implementing a multi species spinor gas apparatus capable of rapid generation of large, spatially extended quantum degenerate ensembles and are developing techniques for the time resolved nondestructive imaging of these gases to perform quantitative studies of the dynamics of these systems.

In addition to our progress towards spinor studies of Rb-87 which we outline here, we have begun efforts towards the laser cooling of Li-7, which our calculations indicate has much larger spin dependent interactions, providing the possibility of study of spin-charge interplay.

Strategies for All-Optical Evaporation to Degeneracy

We load rubidium atoms directly from a MOT into a near resonant lattice, where degenerate Raman Sideband cooling [1] cools 6 x 10^8 atoms down to the vibrational ground state of the lattice in 15 ms. After adiabatic expansion from the lattice, we measure a temperature of 800 nK and a phase space density Γ of about 0.01. Currently we are optimizing the loading of the dilute Raman cooled cloud into an optical dipole trap (ODT) and evaporating to degeneracy. Below we outline previous strategies and how our recipe will improve upon current state-of-the-art all-optical evaporation [2].

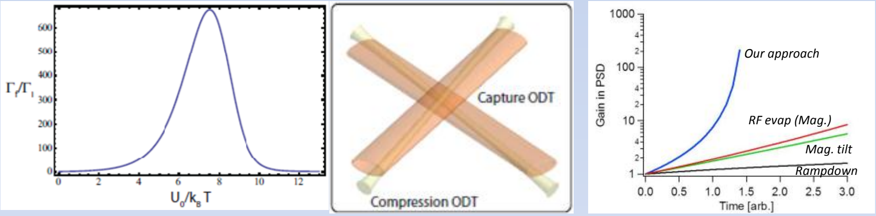

Fig. 2 (Top) Phase space density enhancement as a function of compression optical dipole trap depth in units of the initial temperature. (Middle) Geometry of the mode-matching catch ODT and compression ODT. (Bottom) Gain in PSD vs time for different methods of evaporating in an ODT.

Current Methods for Evaporation in a ODT

1. Ramping down ODT power
- Reliant on large initial collision rate
- Impossible to achieve runaway evaporation
- Compromise between speed and atom number

2. Constant ODT power with magnetic tilt
- Reliant on large initial collision rate
- Trap frequencies remain nearly constant, so faster rate of evaporation (but not as fast as RF evaporation)

Our approach – Compression ODT plus magnetic tilt

-Compression ODT increases collision rate of Raman cooled gas, so faster rate of evaporation

- Evaporation mainly from the 'Capture ODT' , so more efficient cooling and less atom loss.

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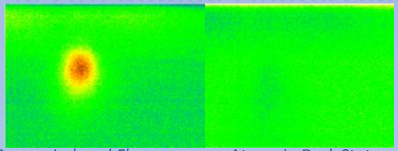
[1] W. S. Bakr, et al, Nature 462, 74 (2009).
[2] C. Hung, et al, Phys. Rev. A. 78 011604 (2008)
[3] J. F. Sherson, et al, Nature 467, 68 (2010)
[4]V. Vuletic, C. Chin, A. J. Kerman, and Steve Chu, Phys. Rev. Lett. 81 5768 (1998)
[5] R. Barnett, A. Polkovnikov and M. Vengalattore Phys. Rev. A 84, 023606 (2011)

In Situ Raman Fluorescence Imaging



Raman Induced Fluorescence
Image of 10^8 atoms averaged over 10 runs

Atoms in Dark State
After 20 ms of degenerate Raman sideband cooling

Recent experimental progress [1,2] in single site fluorescence imaging of atoms in an optical lattice using optical molasses has opened up the possibility of studying individual atoms in macroscopic ensembles. Here we present preliminary results for a proof-of-principle experiment where we capture the fluorescence from the optical pump beam during degenerate Raman sideband cooling [3] to image 10^8 atoms in a 1-D lattice.

Advantages of this technique:

•Works for atomic species such as Li, K where polarization gradient cooling does not work

•Can access shallow optical lattice depths such as in the vicinity of the Superfluid to Mott Insulator transition, limited by field stability {we measure < 4mG without feedback} and by power broadening due to the optical pump beam and off-resonant scattering rate of the optical lattice.

•By rapidly changing the polarization of the optical pumping beam, the dark state [1,0,0,0,…] can be mapped onto the state [1, ϕ, ϕ^2, ….] and the atoms reimaged.

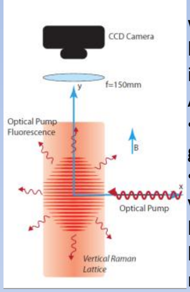


Fig 4. In situ Raman fluorescence beam geometry and imaging set-up.

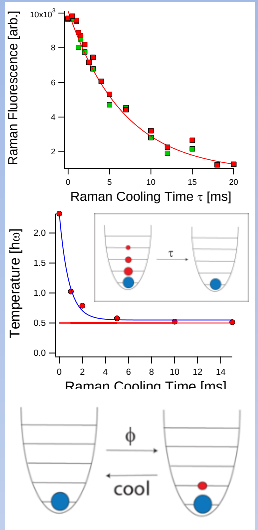


Fig 3. (Top) Decay of Raman fluorescence as atoms go into the dark state. (Middle) Raman cooling rate.(Inset) Atoms being pumped into dark state during Raman cooling. (Bottom) Effect of polarization change on dark state.

Non equilibrium physics of spinor fluids

Our theoretical studies of the non-equilibrium dynamics of spinor condensates focus on the dynamics following quenches from the polar to the ferromagnetic phase. A reason for particular interest is that numerical simulations of the system(using the Truncated Wigner approximation) and early experimental studies suggest that the system (which is not integrable) does not thermalize over experimental time scales, and instead asymptotes to prethermalized phase [5].

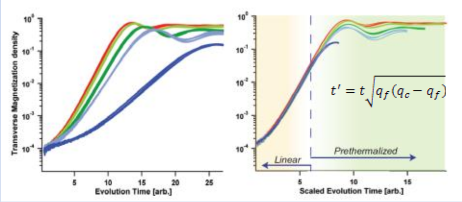


Fig. 6(Left) The growth of the magnetization density after an instantaneous quench to $q_f = 0.5\, q_c$ (red), $q_f = 0.58\, q_c$ (lt. green), $q_f = 0.72\, q_c$ (dk. green), $q_f = 0.8\, q_c$ (lt. blue), $q_f = 0.95\, q_c$ (dk. blue) versus evolution time. (Right) The same data versus time scaled according to the inset equation showing universal collapse onto the same curve at short evolution times (linear regime), but are distinct at later evolution times (Prethermalized regime).

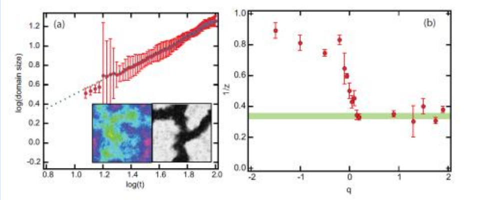


Fig. 5 (Left) TWA simulations of the system showing the growth of the characteristic size scale of ferromagnetic domains to be a power law $l = t^{1/z}$. (Right) The dynamical critical exponent showing dramatic change as a function of the final quadratic Zeeman energy q, indicating that the conserved parameters and the thermalization dynamics of the magnons change as the symmetry of the system changes from easy axis to easy plane. (To be published)

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