Spin-Imbalanced Unitary Fermi Gas in a Uniform Trapping Potential

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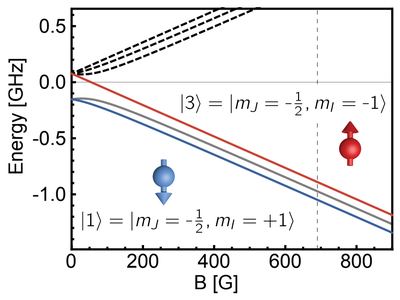
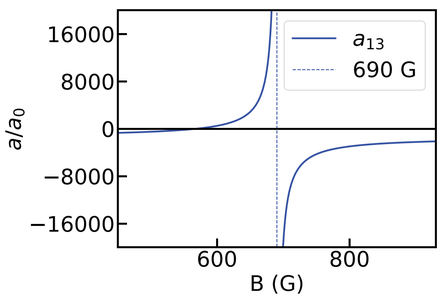
Unitary Fermi Gas in a Box Potential

Unitary Fermi Gas

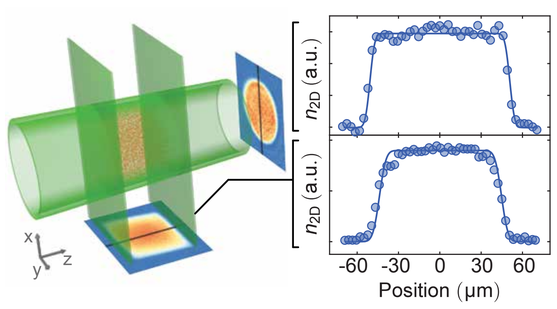
- Relevant to systems ranging from neutron stars to high-T_c superconductors
- Unitary Fermi gas is scale-invariant
- Realize unitarity with $|1\rangle - |3\rangle$ Feshbach resonance in ^{6}Li
- Create tunable spin mixture with Landau-Zener RF transfer
- Evaporatively cool spin mixture to below T_F





Box Potential [1]

- Hollow blue-detuned beams realize (quasi) flat potential
- Reduces influence of trap averaging & targets smaller range of densities
- Momentum imaging possible via residual axial harmonic trap



Imaging Optically Dense Atomic Clouds

Polarization Rotation Imaging (PRI) [2,3,4]

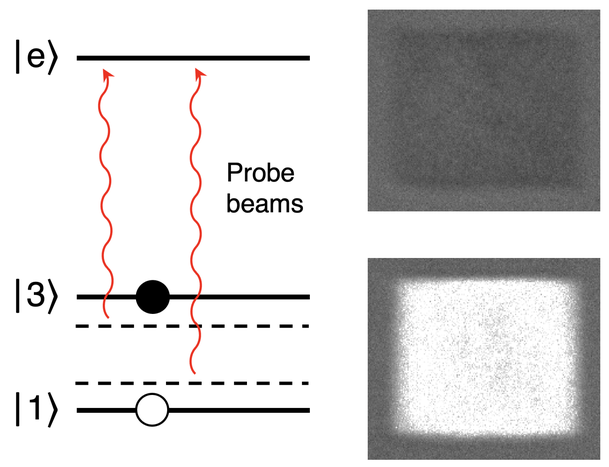
- Phase shift + absorption of detuned imaging light → atomic density
- Orthogonal polarizations $|H\rangle$ and $|V\rangle$. Only $|H\rangle$ interacts with the atoms
- Atoms act on imaging light as

$$A = \begin{pmatrix} ae^{i\Delta\phi} & 0 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} e^{-\frac{\alpha d}{2}} e^{-i\frac{\delta}{\Gamma}\alpha d} & 0 \\ 0 & 1 \end{pmatrix}$$

- An RCP generates interference. Measured signal is

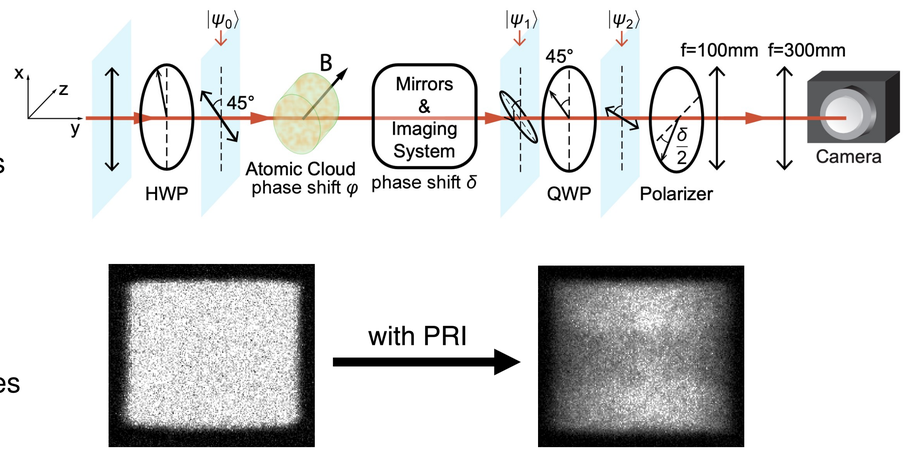
$$\frac{2I_f}{I_0} = 2|RCP \cdot A \cdot |D\rangle|^2 \propto \frac{\alpha d}{2} + \frac{\delta}{\Gamma}\alpha d + \mathcal{O}(\alpha d^2)$$

- αd is solved numerically from exact solution for I_f
- For imaging $|1\rangle$ and $|3\rangle$, solve two coupled equations



Why not absorption imaging?

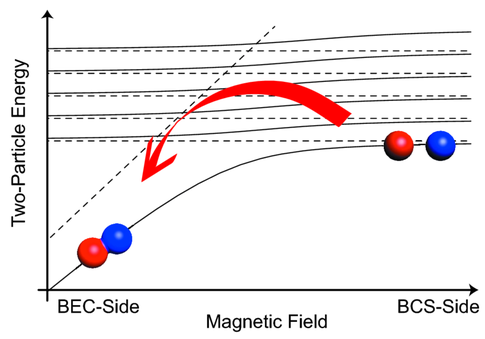
- Resonant absorption imaging gives blacked out images for high-OD clouds
- Detuned absorption imaging results in distortions due to dispersive effects
- PRI gives better contrast with detuned imaging light
- PRI allows for higher imaging intensities for better S/N

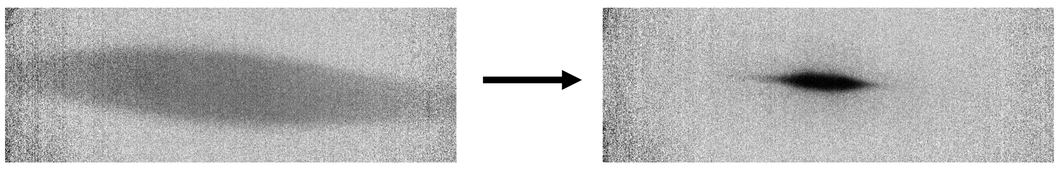


Clogston-Chandrasekhar limit measurement

Rapid Ramp procedure [2]

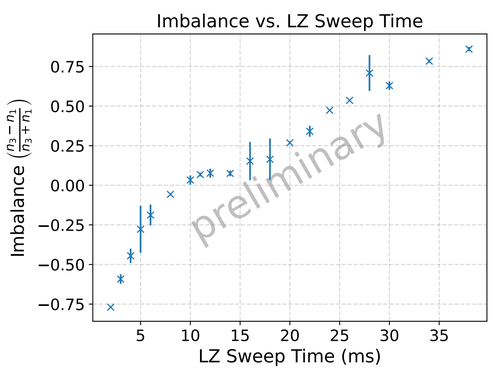
- A rapid B-field ramp to the BEC side adiabatically converts correlated pairs into molecules
- Pair condensation after RR is (indirect) evidence for superfluidity in the box

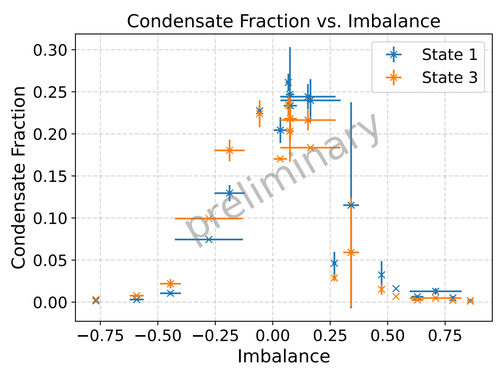




Measuring the Clogston-Chandrasekhar limit

- Clogston limit: Beyond a critical spin-imbalance, superfluidity is no longer supported
- Measured in harmonic trap [5], not yet in uniform trap

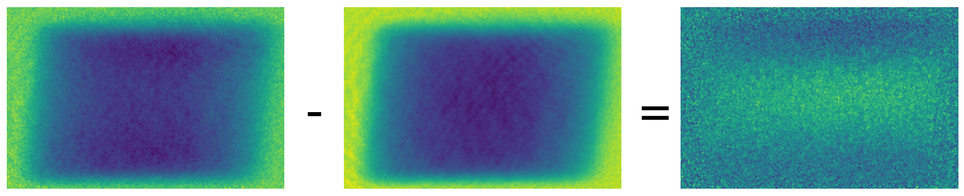




Outlook

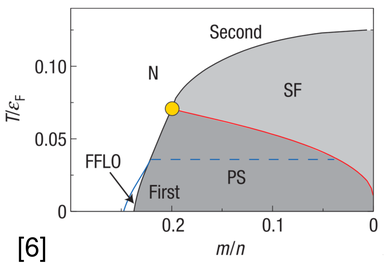
First sound in spin-imbalanced system

- Sound with spin-imbalance? **Yes**
- How do hydrodynamic quantities change with spin-imbalance?



Second sound in spin-imbalanced system

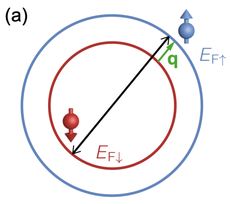
- Direct evidence for superfluidity in the box trap
- New transport phenomena?

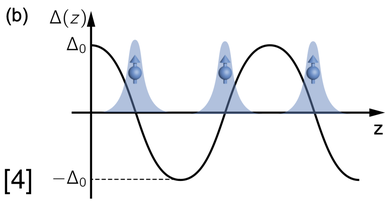


[6]

Observing the FFLO state

- Indirect evidence exists in 1D [7]
- Still elusive in 3D





[4]

References

[1] B. Mukherjee et al., *PRL*, 2017
[2] M. W. Zwierlein, W. Ketterle, *La Rivista del Nuovo Cimento*, 2008
[3] P. Patel, PhD Thesis, 2021
[4] Z. Yan, PhD Thesis, 2021
[5] Shin, Yong-il, et al. *Nature*, 2008
[6] Partridge, G. B., et al., *Science*, 2006
[7] Liao, Yean-an, et al., *Nature*, 2010

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