Agenda

9:00 Wolfgang Ketterle: Introduction

9:10 Synthetic gauge fields and spin orbit coupling
   Colin Kennedy: Synthetic Gauge Fields and Engineering New Lattice Models
   Ian Spielman: Cold atoms and not just quantum simulators any more

9:50 Exotic new phenomena
   Eugene Demler: Exotic phenomena with impurities
   Ashwin Vishwanath: New topological phases with interacting bosons

10:30 COFFEE BREAK

11:00 New schemes for cooling and state preparation
   Dan Stamper-Kurn: Using magnons to measure and lower temperature
   Andrew Daley: Adiabatic state preparation and quantum magnetism

11:40 New systems and new probes
   Jun Ye: Spectroscopic observation of SU(N)-symmetric interactions
   in Sr orbital magnetism.
   Markus Greiner: Probing many-body entanglement

12:20 Martin Zwierlein: Summary and Outlook
New Phenomena with impurities

Mobile magnetic impurity in Fermi superfluids

Sarang Gopalakrishnan, Norm Yao, Misha Lukin, Eugene Demler (Harvard), Ivar Martin (Argonne), Colin Parker (Chicago)
+ ongoing work with Gergely Zarand (TU Budapest)
Mobile magnetic impurity in Fermi superfluids

Sarang Gopalakrishnan, Colin Parker, Eugene Demler
Enhancing interaction by suppressing kinetic energy

Example: fractional quantum Hall effect

Example: spin orbit coupled BEC
Quantum quasicrystals of spin-orbit coupled bosons
Using mobile magnetic impurities in Fermi superfluids to realize exotic states
Bound states on magnetic impurities in superconductors

BCS pairing \rightarrow Mexican hat

DOS singularity \left(1/\sqrt{E}, \text{“1D-like”}\right) at bottom of quasiparticle band, weak-coupling bound state with polynomial energy

\[
E \sim \Delta \frac{1 - (\pi N(E_F)J)^2}{1 + (\pi N(E_F)J)^2}
\]

Impurity must be magnetic, otherwise quasiparticles decouple from it at low energies

interspecies coupling
Bound states on magnetic impurities in superconductors

Yu, Acta Phys. Sin. 21, 75 (1965)

Salkola, Balatsky, Schrieffer, PRB 55:12648 (1997)
Probing the Local Effects of Magnetic Impurities on Superconductivity

Ali Yazdani,* B. A. Jones, C. P. Lutz, M. F. Crommie,†
D. M. Eigler

Science 275:1767 (1997)

Local density of states near
Parity changing transition

Salkola, Balatsky, Schrieffer, PRB 55:12648 (1997)

Analogous to Kondo singlet formation
Possible realization: Cs impurities in Li fermionic condensate

e.g. Cheng Chin’s group
other possible mixtures
in experiments by
W. Ketterle, M. Zwierlein

- Heavy Cs impurities in light Li fermionic condensate
- Interactions between Cs and the two hyperfine states of Li can be tuned independently via heteronuclear Feshbach resonance: impurities are “magnetic”
- Infinite-mass limit: Shiba states bound to each Cs atom
  - Our question: **fate of a mobile Shiba state**
Bound state of Bogoliubov quasiparticle and impurity atom

Overall Hamiltonian

\[ H_0 = \sum_{k\sigma} \xi_k \gamma_{k\sigma}^\dagger \gamma_{k\sigma} + \frac{p^2}{2M} \]

\[ H_1 = J \sum_{kq\sigma} e^{iqr} (\gamma_{k+q,\sigma}^\dagger \gamma_{k,\sigma} + \gamma_{k,\sigma}^\dagger \gamma_{k+q,\sigma} + \text{h.c.}) \]

Odd sector: two-body problem with different dispersions:
Total momentum conserved, $\sim k_F$
Scattering across Mexican hat costs impurity recoil

$$\mathcal{E} \sim k_F^2/2M \gg J$$
Strong interaction: global minimum

As J increases, odd branch comes down in energy, eventually becomes global ground state (can be captured via T-matrix approach)
“Exotic” molecule

Mass of the relative coordinate

$$\frac{1}{\mu^\parallel} = \frac{1}{M} + \frac{1}{\infty}; \quad \frac{1}{\mu^\perp} = \frac{1}{M} + v_F^2 \Delta$$

What about the center-of-mass coordinate?

$$M^\parallel = \infty; \quad M^\perp = M + \Delta/v_F^2$$

Molecule itself has Mexican-hat dispersion: impurity momentum $\sim 0$, quasiparticle momentum $\sim k_F$ in any direction
Detection via RF

Tune to Cs-Li scattering length attractive for "up spins", repulsive for "down spins"

Implies existence of Feshbach molecule between impurity and down spins
Exotic many-body phases?

Reminiscent of electrons with spin-orbit coupling

\[ H = \sum_j \left\{ \frac{1}{2m} \left[ -\nabla_j^2 - \frac{2k_0}{i} (\nabla_j \times \hat{z}) \cdot \vec{\sigma}_j \right] + E_0 \right\} \]

in 2D and contact interaction, ground state: breaks rotational symmetry. Wigner crystal or nematic.
Berg, Rudner, Kivelson (2012)

Interaction between two Shiba states: Yao et al., 13092633

For contact interaction Wigner crystal with aspect ratio has energy per particle parametrically better than uniform phase