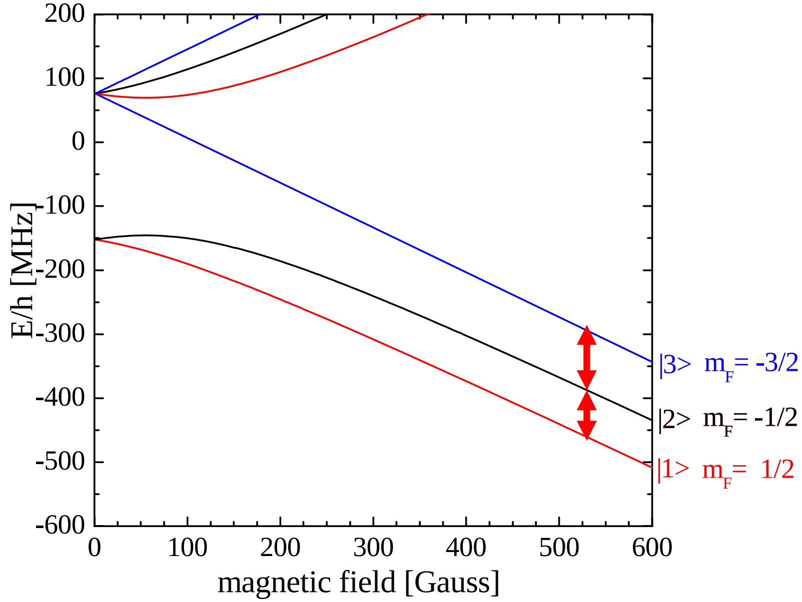
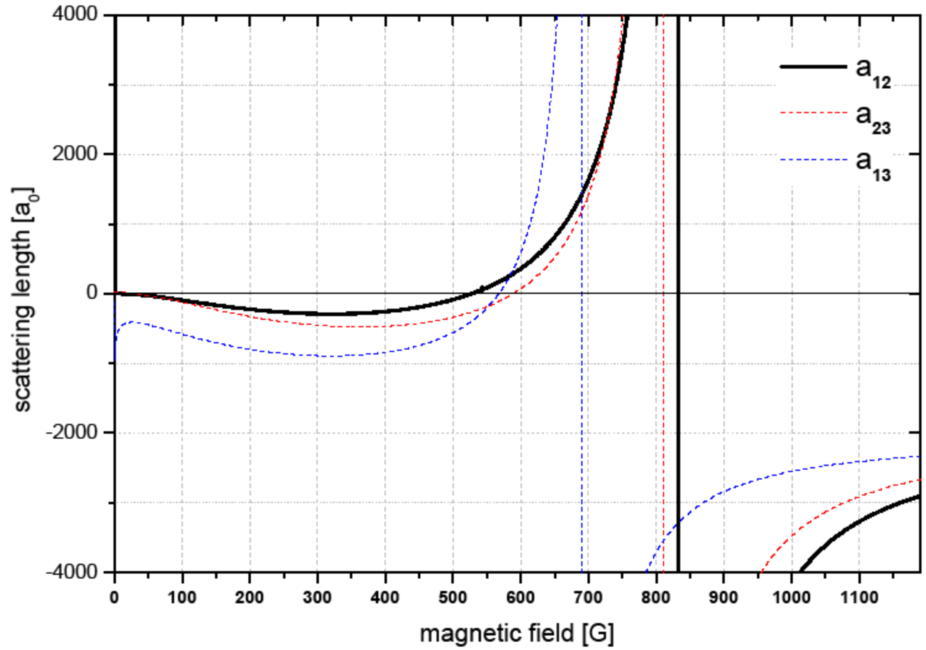
Outline – Second Part

- Two-component Fermi gases
- How to create a 3-component mixture
- First experiments
- Probing a strongly interacting system
- Conclusion and outlook

^{6}Lithium

Three hyperfine states with Feshbach resonances for each combination:





Transitions beetween the states can be driven via radio-frequency (RF)-fields!

Two-component Fermi gas

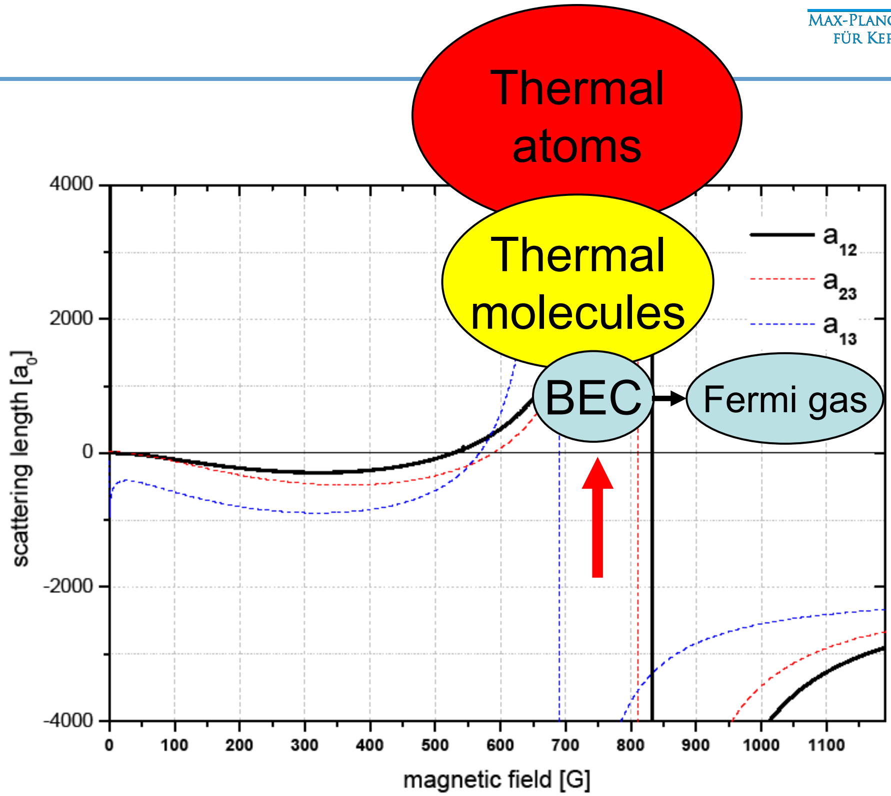
Evaporation at B = 760G:

$\Rightarrow$ a_0 large and positive:

$\Rightarrow$ Molecule formation when T ~ E_b

$$E_b = \frac{\hbar}{ma^2} \quad (\sim 3\,\mu K \text{ at } 760\,G)$$

Close to resonance the molecules are stable and can form a BEC!



Molecules can easily be transformed into Cooper pairs by ramping across the Feshbach resonance (BEC-BCS crossover)

Creating 3-component Fermi gases

Basic Idea:

- Create degenerate 2-component Fermi gas
- Drive RF-transitions to populate the third state

Unfortunately, it is not that easy:

Ultracold gases are metastable objects…

Stability of ultracold gases

- Formation of molecules from free atoms is energetically favorable
- This is a three-body process
- Therefore ultracold gases are stable if they are dilute and weakly interacting

But the crossover is in the strongly interacting regime ($a \rightarrow \infty$)?

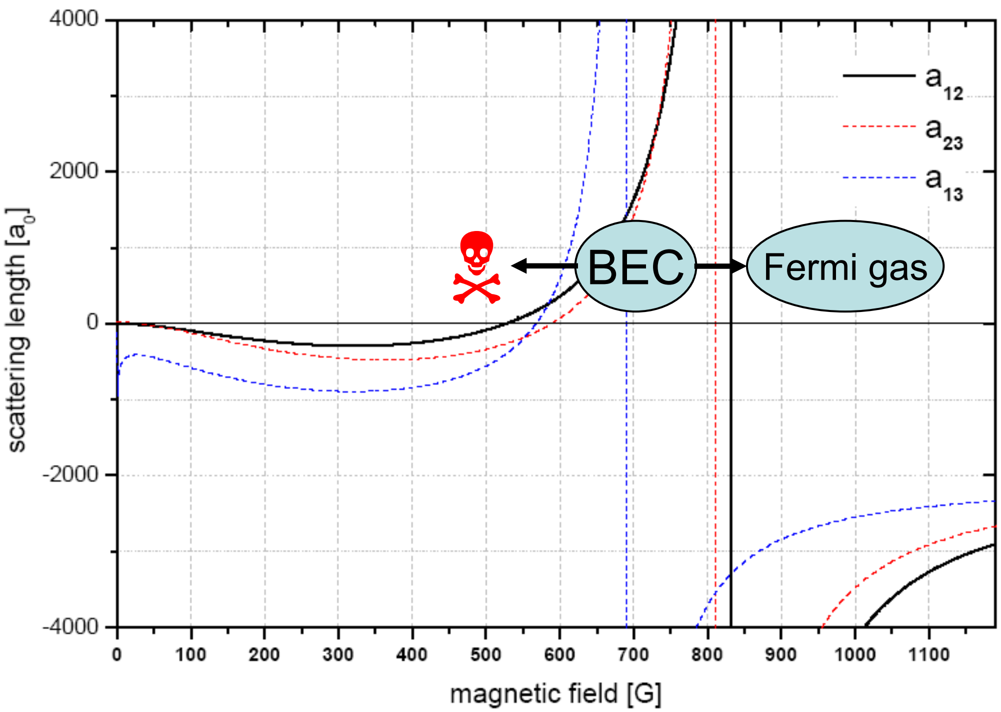
Those are Fermions!

$\Rightarrow$ Pauli blocking strongly supresses three-body losses:

Strongly interacting systems with 3 non-identical Fermions decay within milliseconds

$\Rightarrow$ It is impossible to create a thermalized three-component sample close to resonance

Creating stable 3-component mixtures

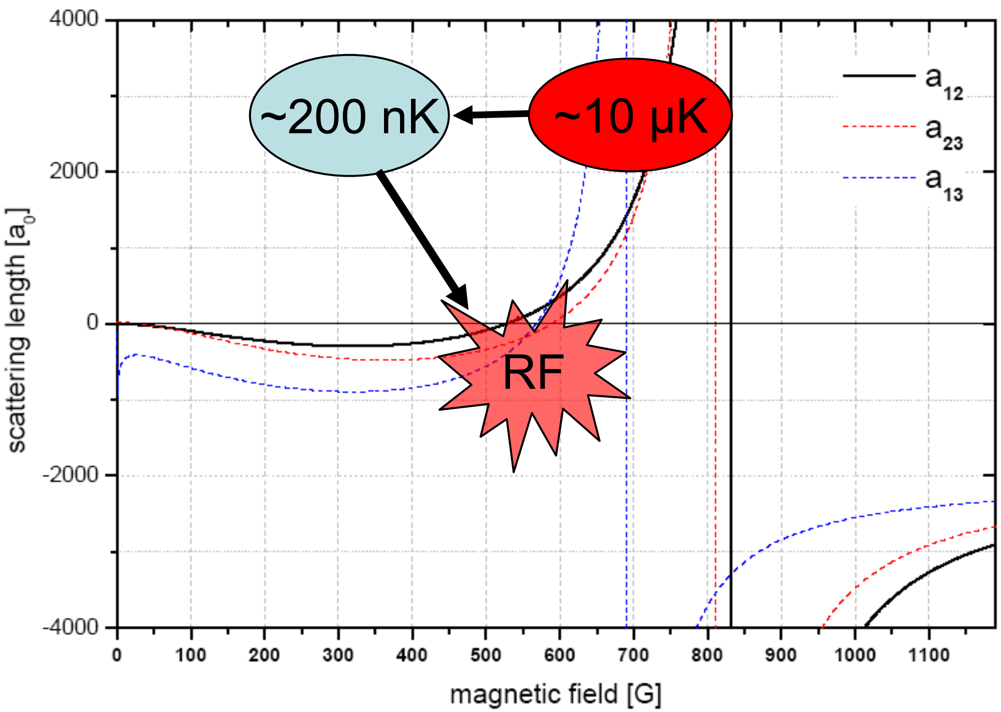


Solution: Create mixture where all scattering lengths are small…

…But the problem is how to get there:

Result: Balanced 123 mixtures with long lifetimes

Creating stable 3-component mixtures

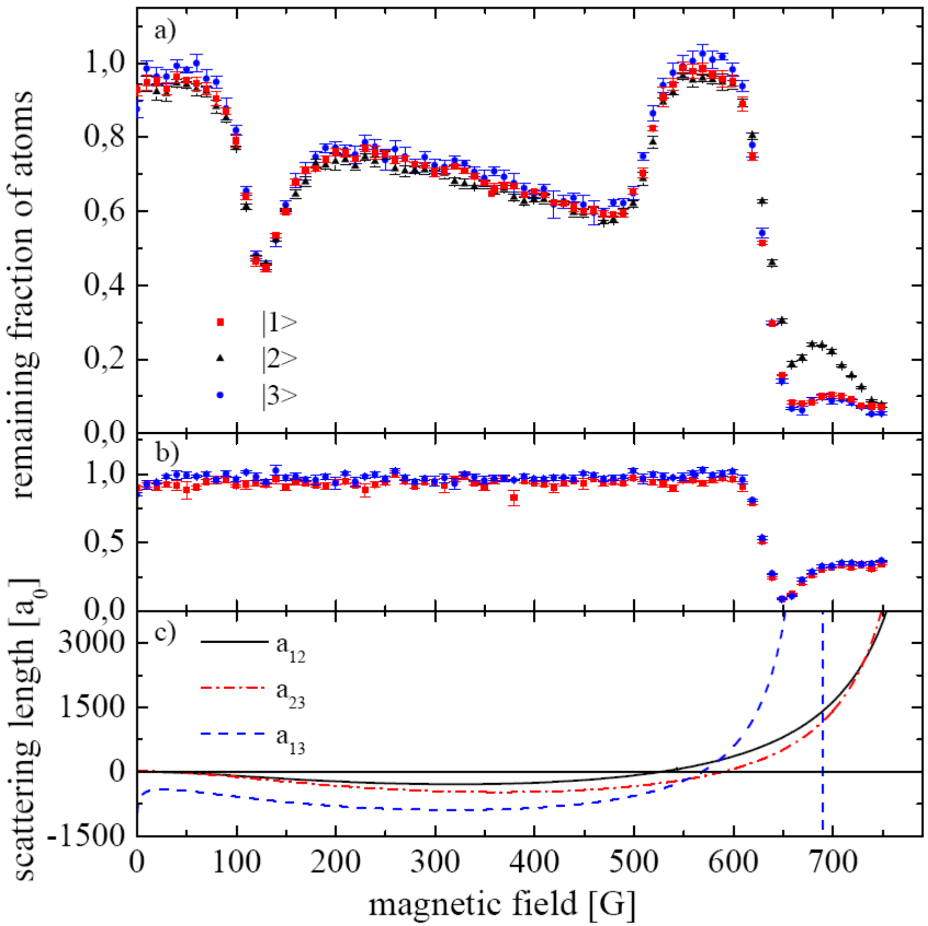


1. Evaporative cooling of a |1>-|2> mixture to T ~ 10 µK at B = 755 G
2. Finish evaporation at B = 300 G to avoid molecule formation
3. Ramp to B = 532 G (zero-crossing of a_{12})
4. Simultaneously apply 200 ms RF pulse on both transition frequencies

Result: Balanced 123 mixtures with long lifetimes

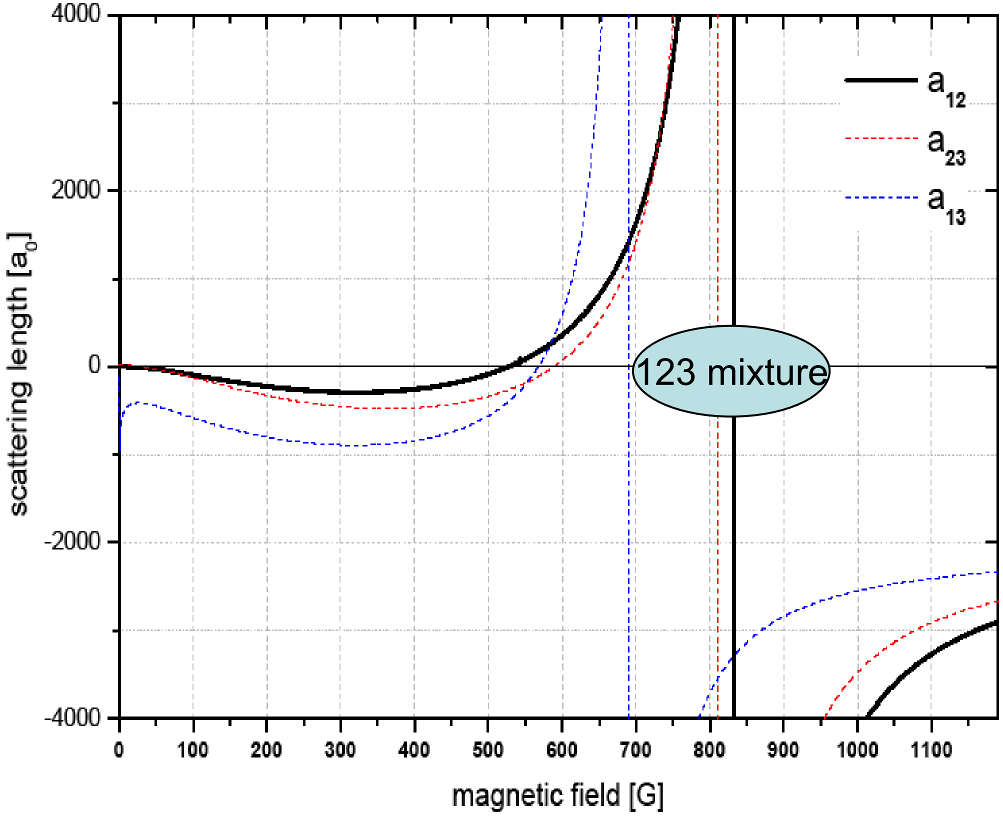
First experiments

Holding the mixture for 250 ms at different magnetic fields:



- Mixture is stable if all two-particle scattering lengths are small
- Rapid decay close to the two-particle Feshbach resonances
- Decay is the same for all components
- Three-body process

Probing strongly interacting systems

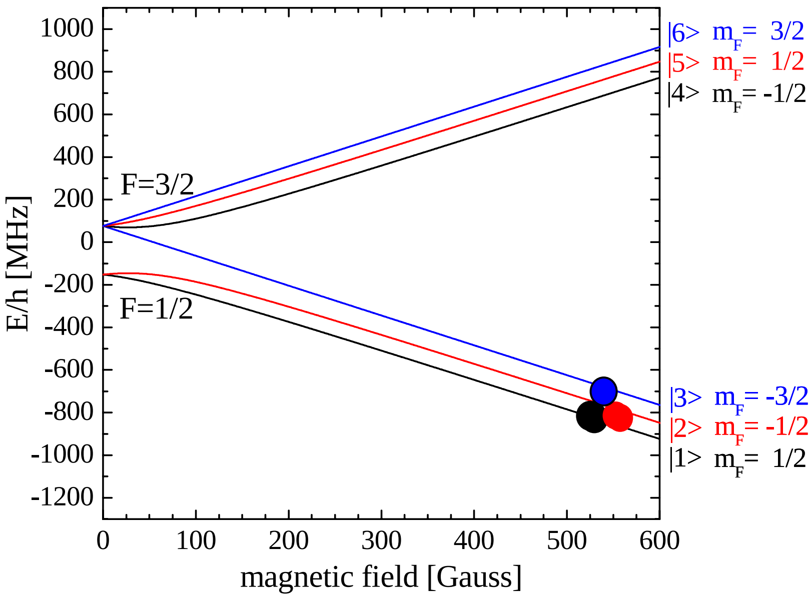


- Prepare a thermalized 3-component gas with small interactions
- Go to the strongly interacting regime
- Observe the system and try to deduce information about the equation of state

Signatures for pairing and/or superfluidity

- Energy gap
- Phase separation
- Oscillation Frequencies of collective modes
- Vortices

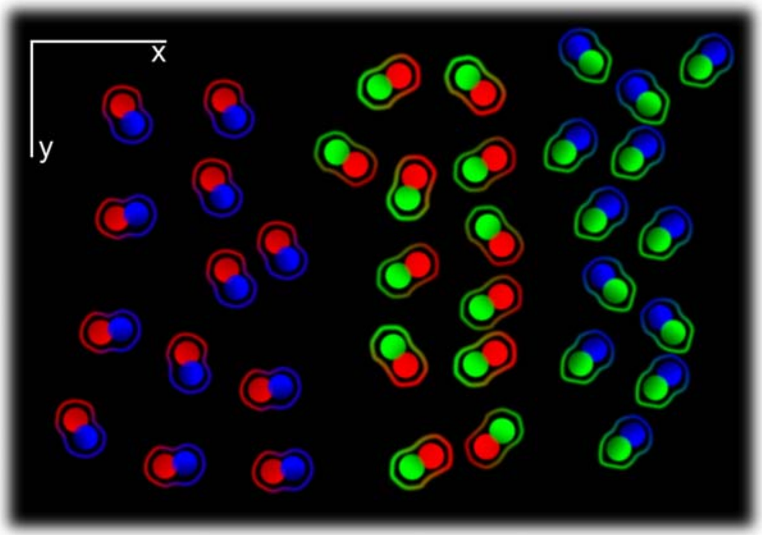
Signatures for pairing and/or superfluidity

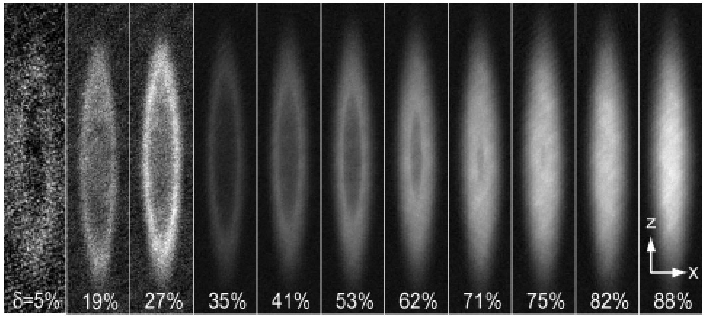


RF-Spectroscopy:

- Quantitative measurement of the pairing energy
- Can be done on short timescales

Signatures for pairing and/or superfluidity





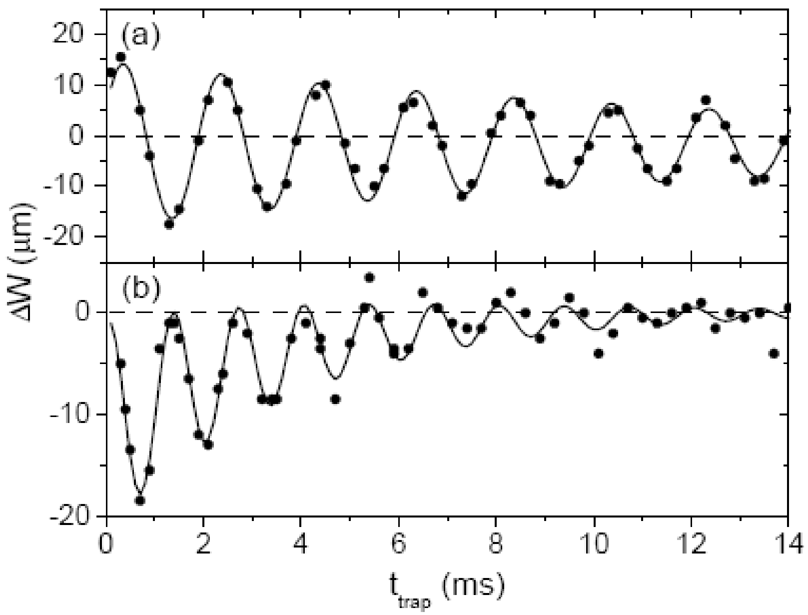
Phase Separation in an imbalanced two-component system, MIT 2005

Phase separation:

- Directly observable via in-situ imaging
- Qualitative knowledge of what to expect
- System has to form equilibrium

Signatures for pairing and/or superfluidity

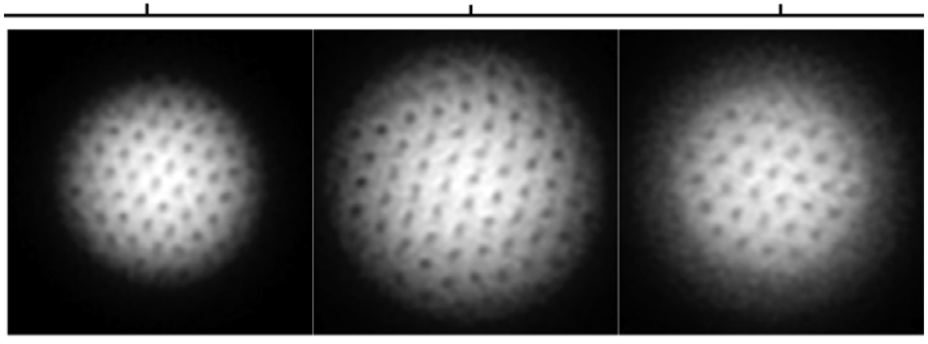
Collective Oscillations:



Quadrupole mode for hydrodynamic and collisionless two-component gas (Innsbruck 2007)

- Easy to excite and observe
- Can be done on relatively short timescales
- Effects might be small
- No quantitative expectations

Signatures for pairing and/or superfluidity

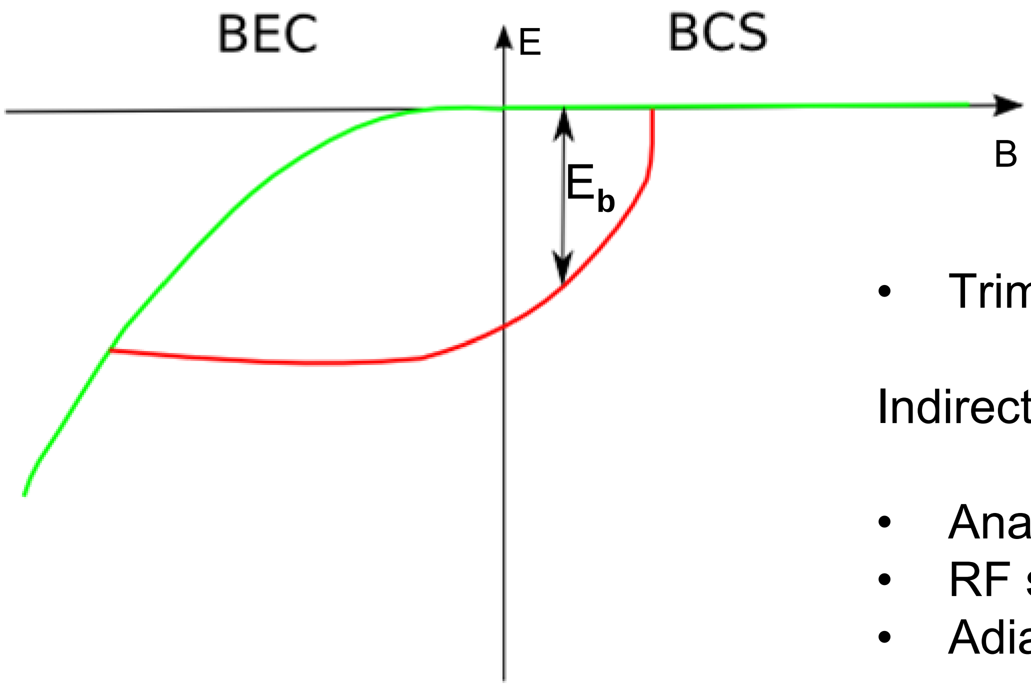


Vortices in a two-component Fermi gas (MIT 2005)

Vortices:

- Definite proof of superfluidity
- Rotation can already be introduced into the weakly interacting gas
- Only local density changes neccessary to form vortex lattice
- Impressive pictures
- **Very** difficult to observe

Signatures for trimer formation



- Trimers Cannot be observed directly

Indirect methods:

- Analyzing trap loss
- RF spectroscopy
- Adiabatic ramping

Conclusion

So far there has been only very little work on three-component Fermi systems…

…But this is about to change