Experiments on ultracold three-component Fermi gases

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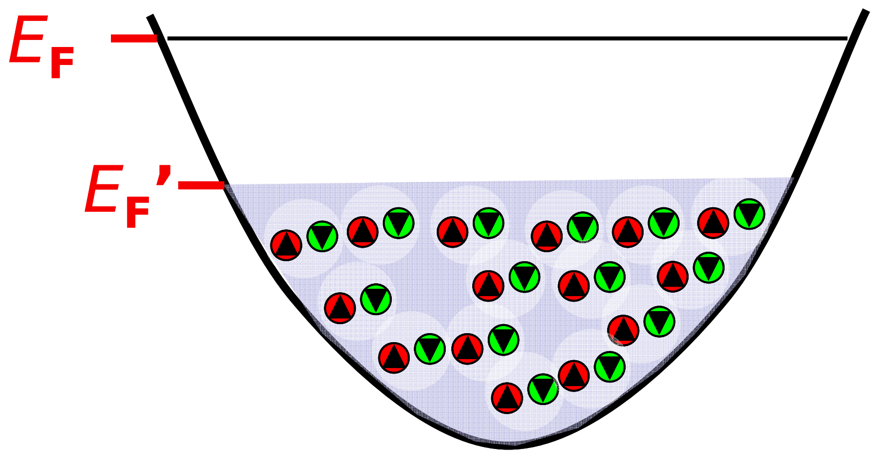
Outline

- Motivation
- The ^{6}Li System
- An Efimov Trimer of Fermions
- Work in progess
- Conclusion

Is the gas stable for resonant interactions?

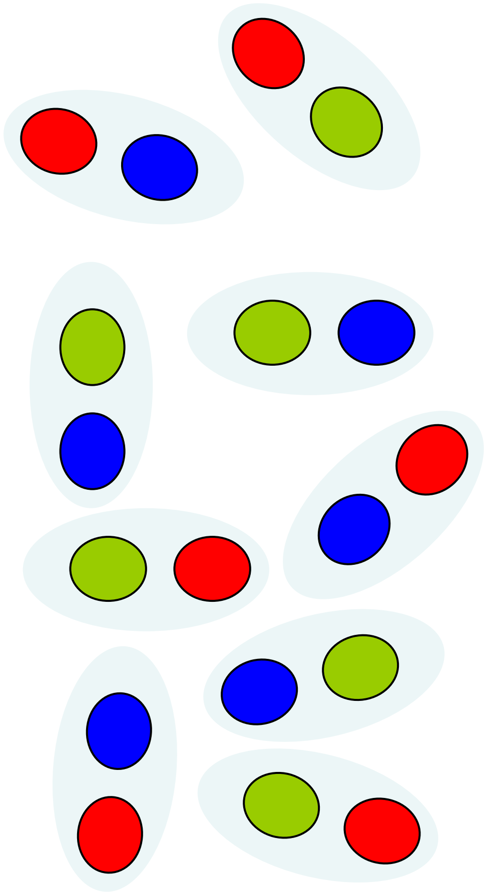
Attractive interactions counteract Fermi pressure:



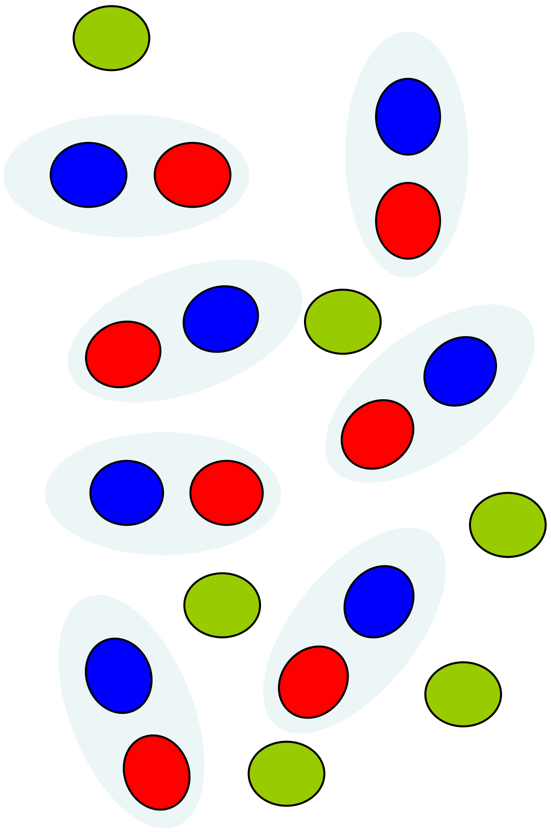
At infinite scattering length:
the Fermi energy is rescaled by a universal factor:

$E_F' \approx 0.42\ E_F$ for two components, how about three?

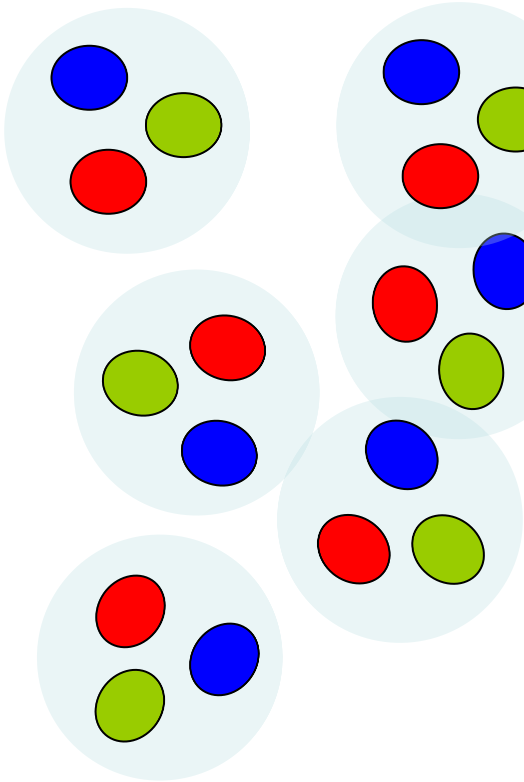
Different phases possible?



mixture of pairs



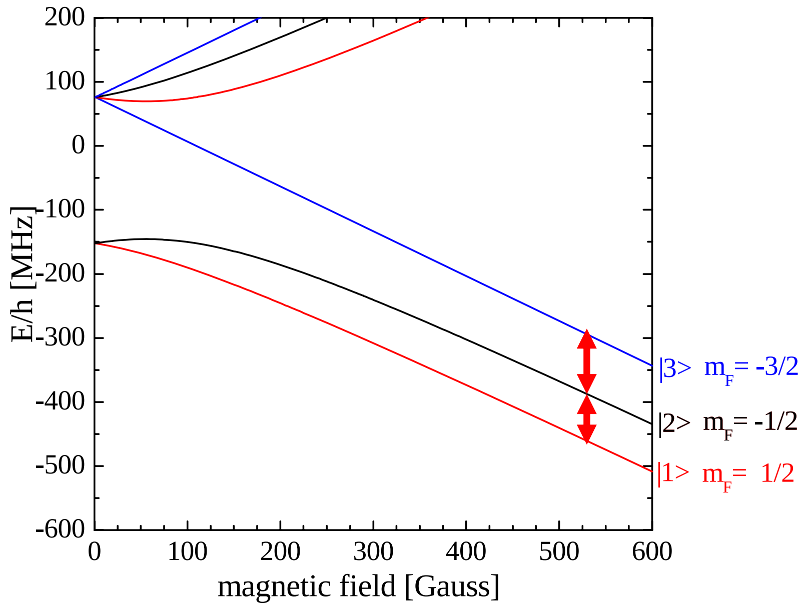
color superfluid

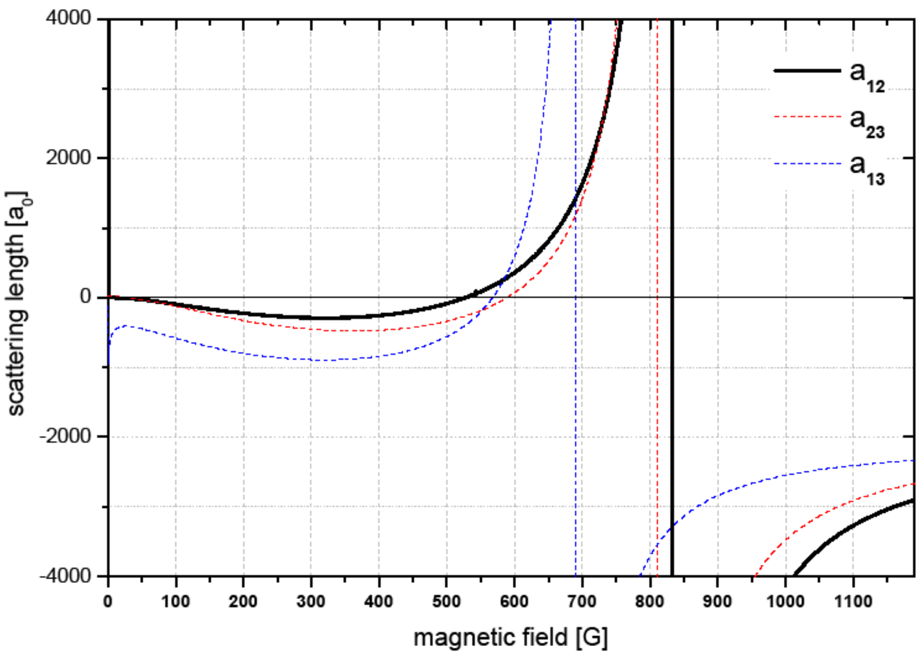


gas of trimers

Our System: ^{6}Li

Three hyperfine states with Feshbach resonances for each combination:

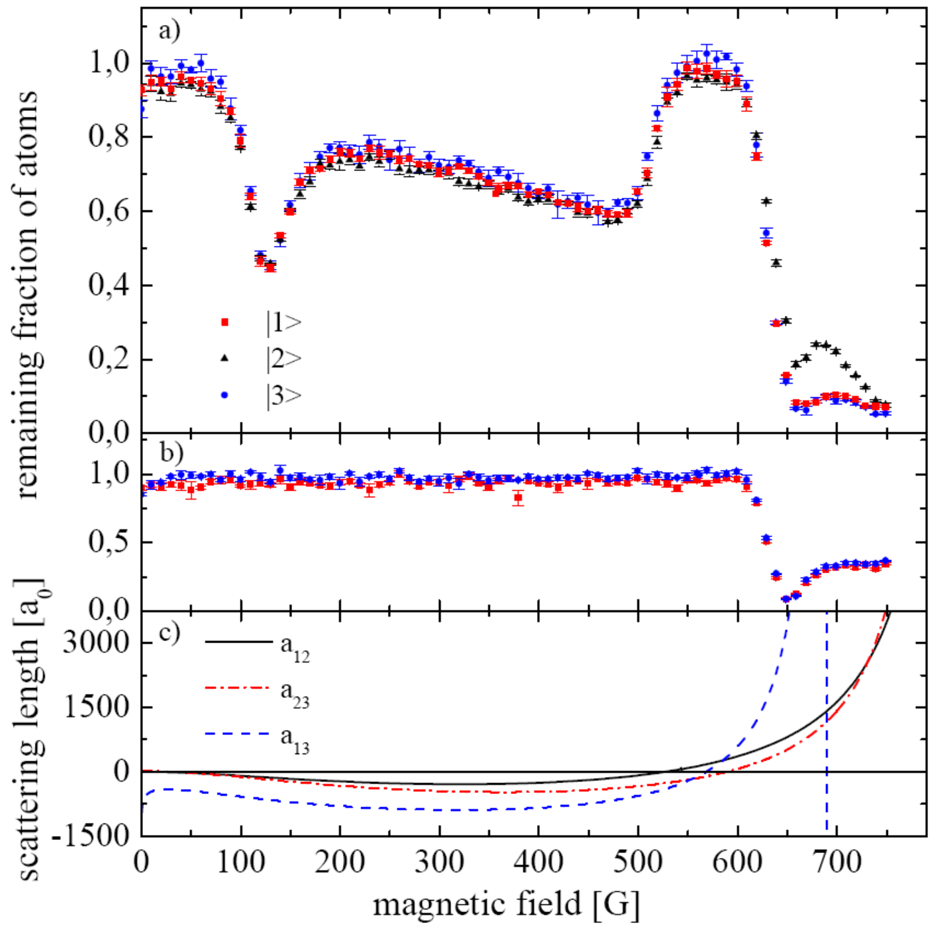




Transitions beetween the states can be driven via radio-frequency (RF)-fields!

First experiments

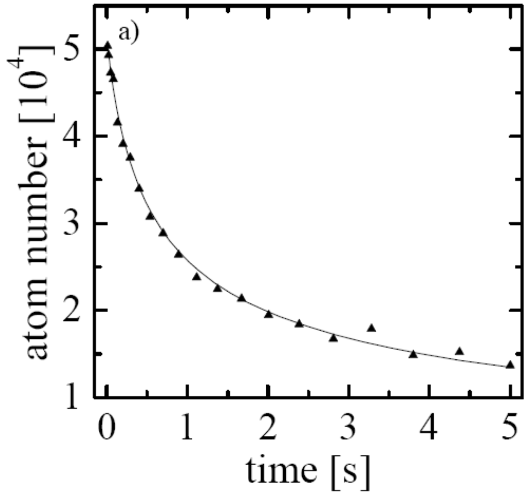
Holding the mixture for 250 ms at different magnetic fields:

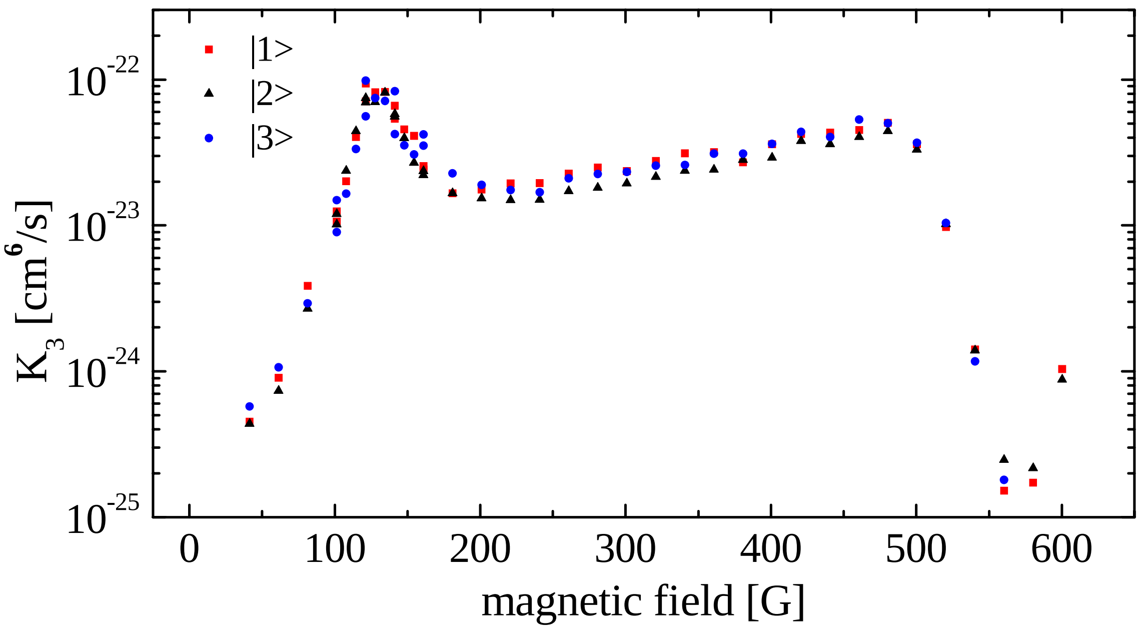


- Mixture is stable if all two-particle scattering lengths are small
- Rapid decay close to the two-particle Feshbach resonances
- Decay is the same for all components
- Three-body process

Quantitative analysis of the three-body loss

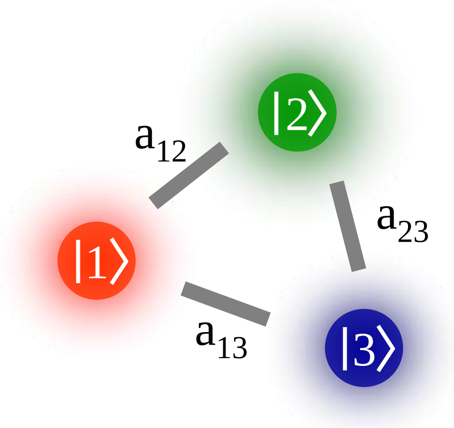
$$\dot{n}(\mathbf{r},t) = -K_3\, n^3(\mathbf{r},t)$$



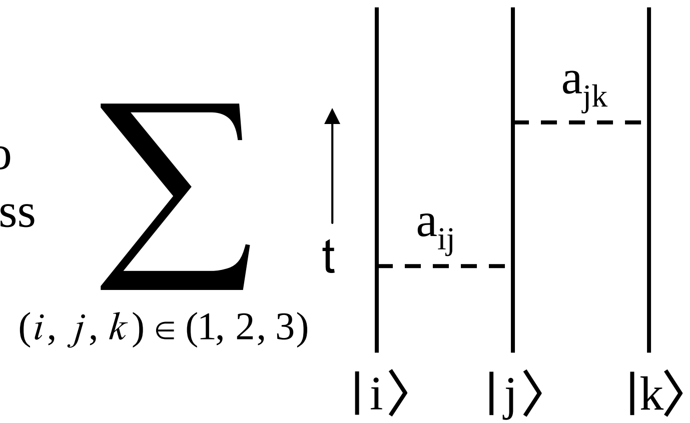


Effective scattering length

Assume a three-body event to consist of two independent two-body collisions:

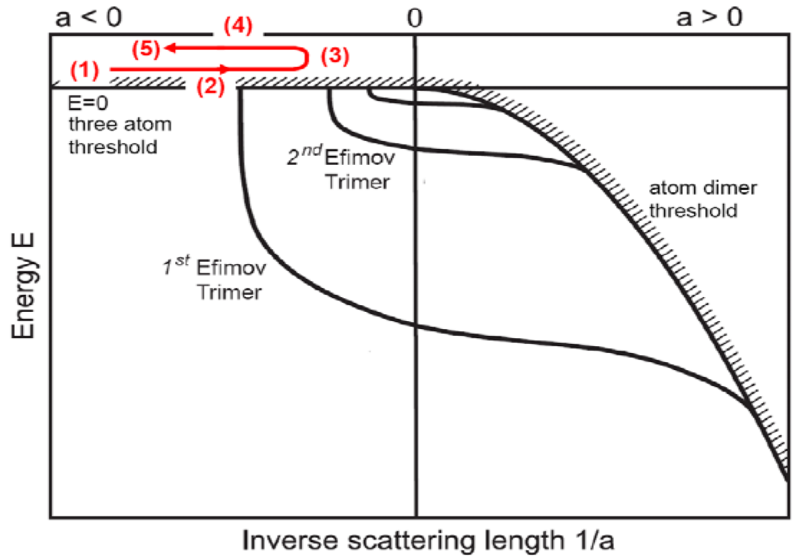


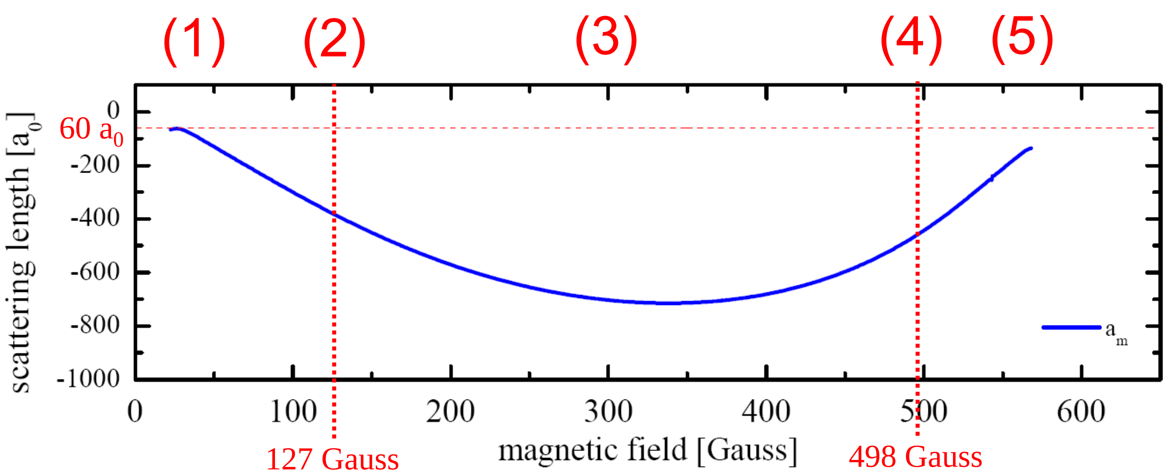
three contributions to the three-body process



$$a_m = \sqrt[4]{\frac{1}{3}\left(a_{12}^2 a_{23}^2 + a_{12}^2 a_{13}^2 + a_{13}^2 a_{23}^2\right)}$$

An unusal Efimov scenario

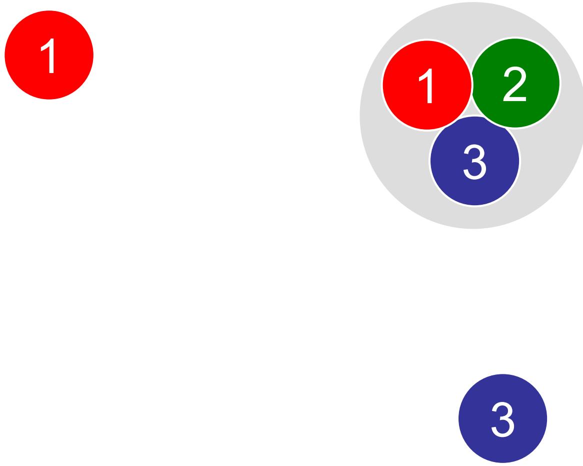




The trimer is extremely unstable!

$$K_3 = C(a_m, a_*, \eta_*)\,\frac{\hbar\, a_m^4}{m}$$

(E. Braaten, H.W. Hammer Physics Reports **428**, 259 (2006))



$C(a_m, a_*, \eta_*)$ has resonances at values of the scattering length where a three-body bound state crosses the continuum

Fit parameters:

a_* Position of the resonance

η_* Width of the resonance

The trimer state is only virtually occupied and decays into a deeply bound dimer and a free atom!

Effect of the dimer states

Fit $K_3(a_m, a_*, \eta_*)$ to peak at 127G:

Why is the right peak so much broader?

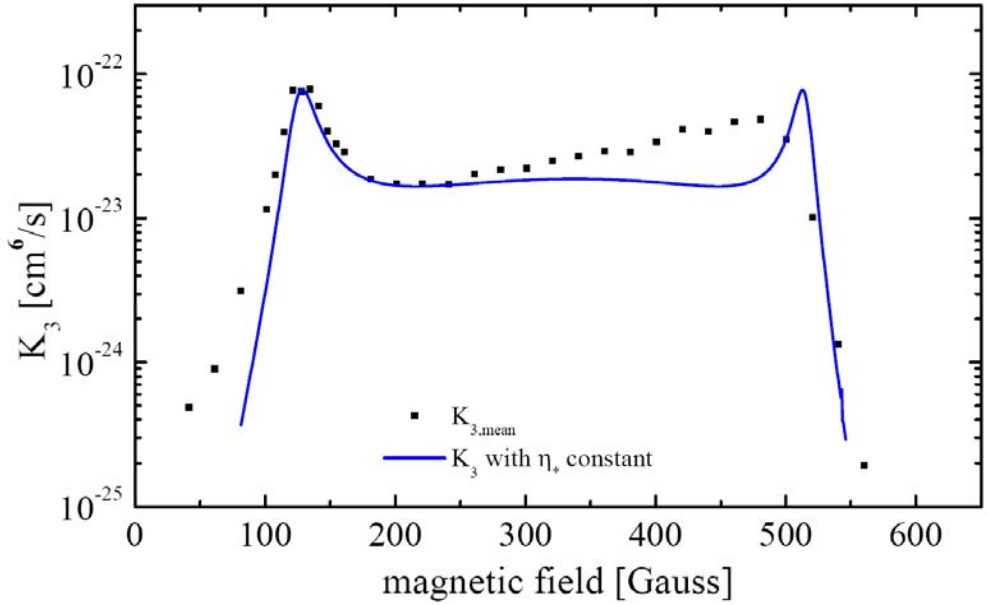
Non-universal effects?

remember:

$$\eta_*$$

fixes width (~lifetime) of trimer state

$\longrightarrow \eta_*$ might not be constant but depend on the properties of the dimer .



Effect of the dimer states

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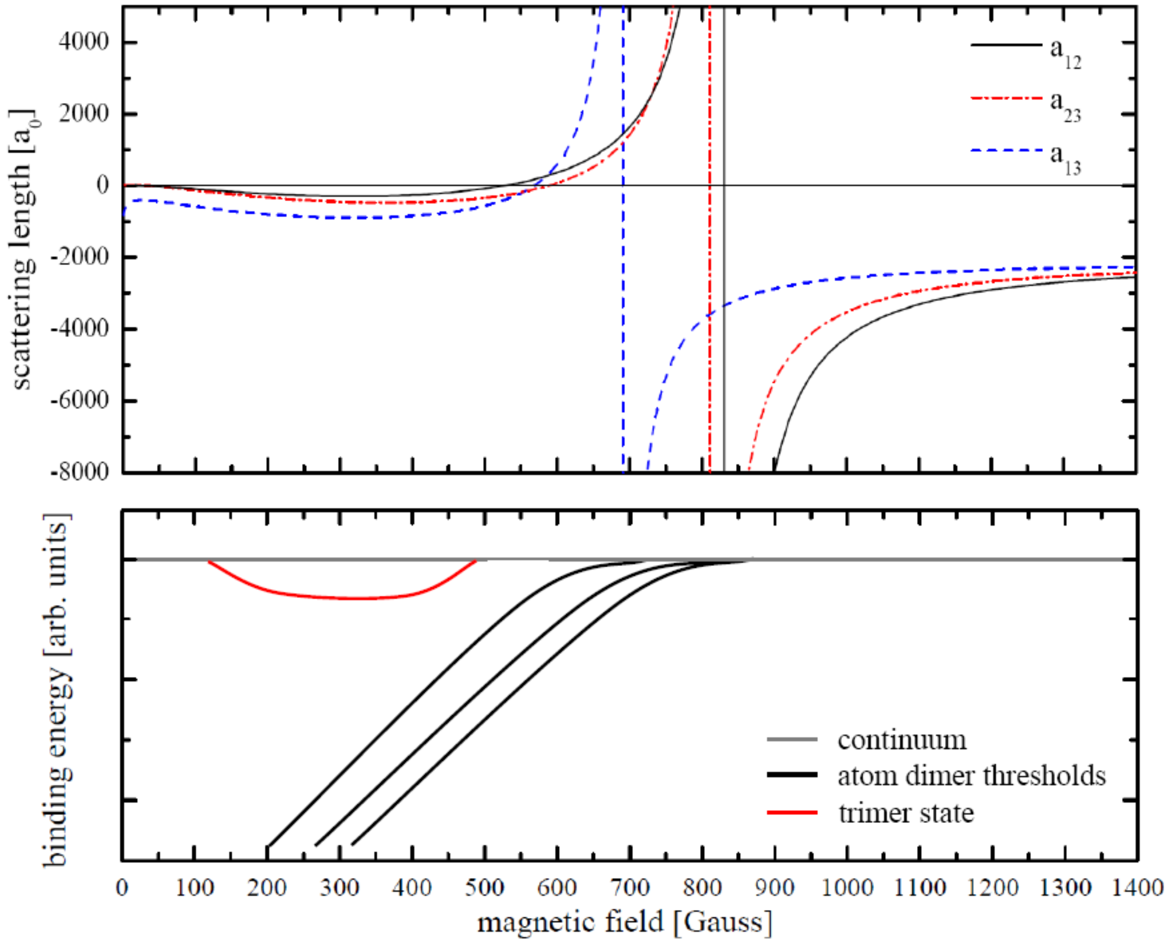
The properties of the most weakly bound dimers vary strongly between 127 G and 500 G

→ Try scaling η_* with the binding energy E_B:

$$\eta_*(E_B) = A\frac{1}{E_B}$$



Our model works well!

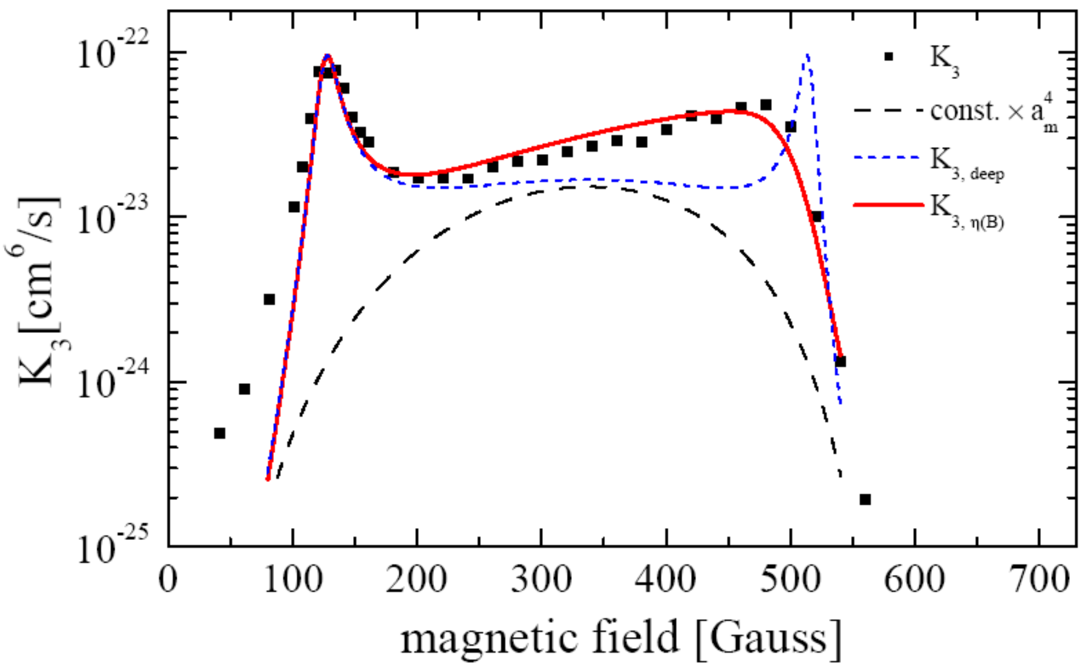
$$K_3 = C(a_m, a_*, \eta_*)\,\frac{\hbar\, a_m^4}{m}$$

η_* is proportional to $1/E_B$

Fitted values:

$\eta_*(127\ \text{G}) = 0.17$

$a_* = -292\ a_0$



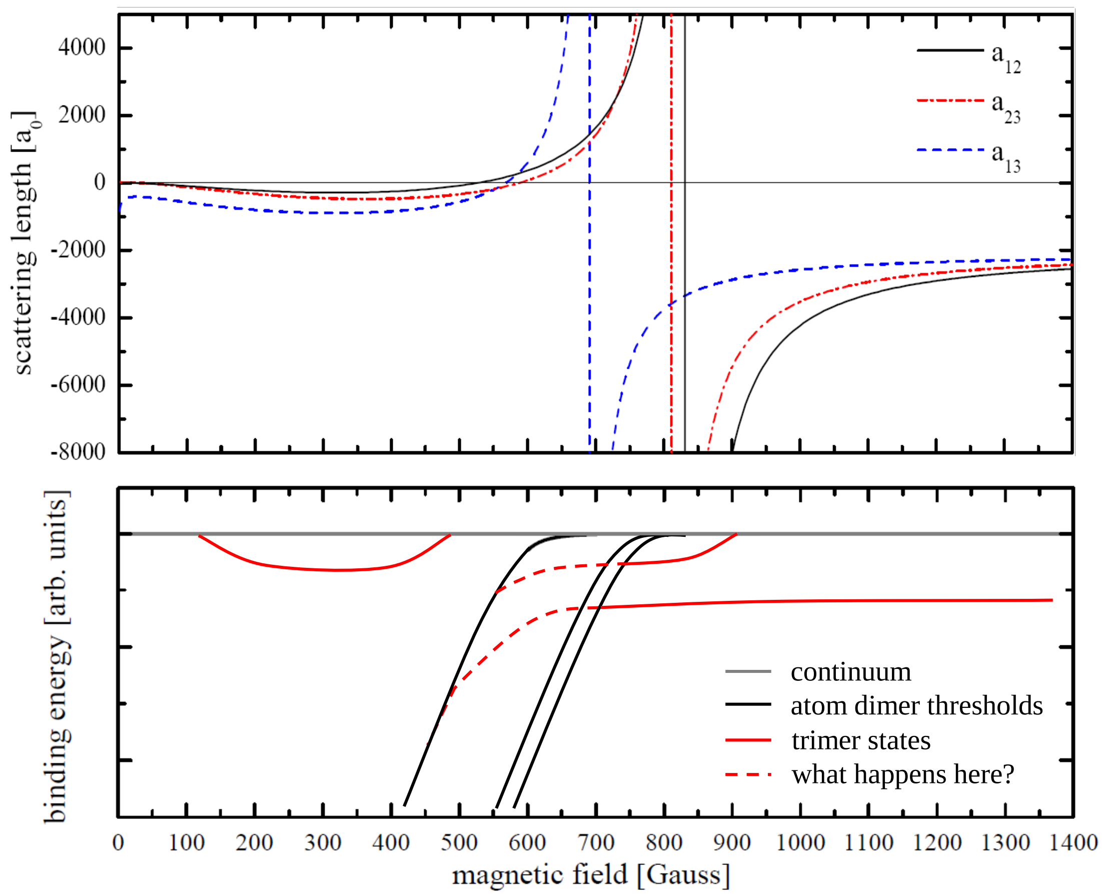
The trimer state is universal, but its lifetime depends on non-universal dimers

High field region

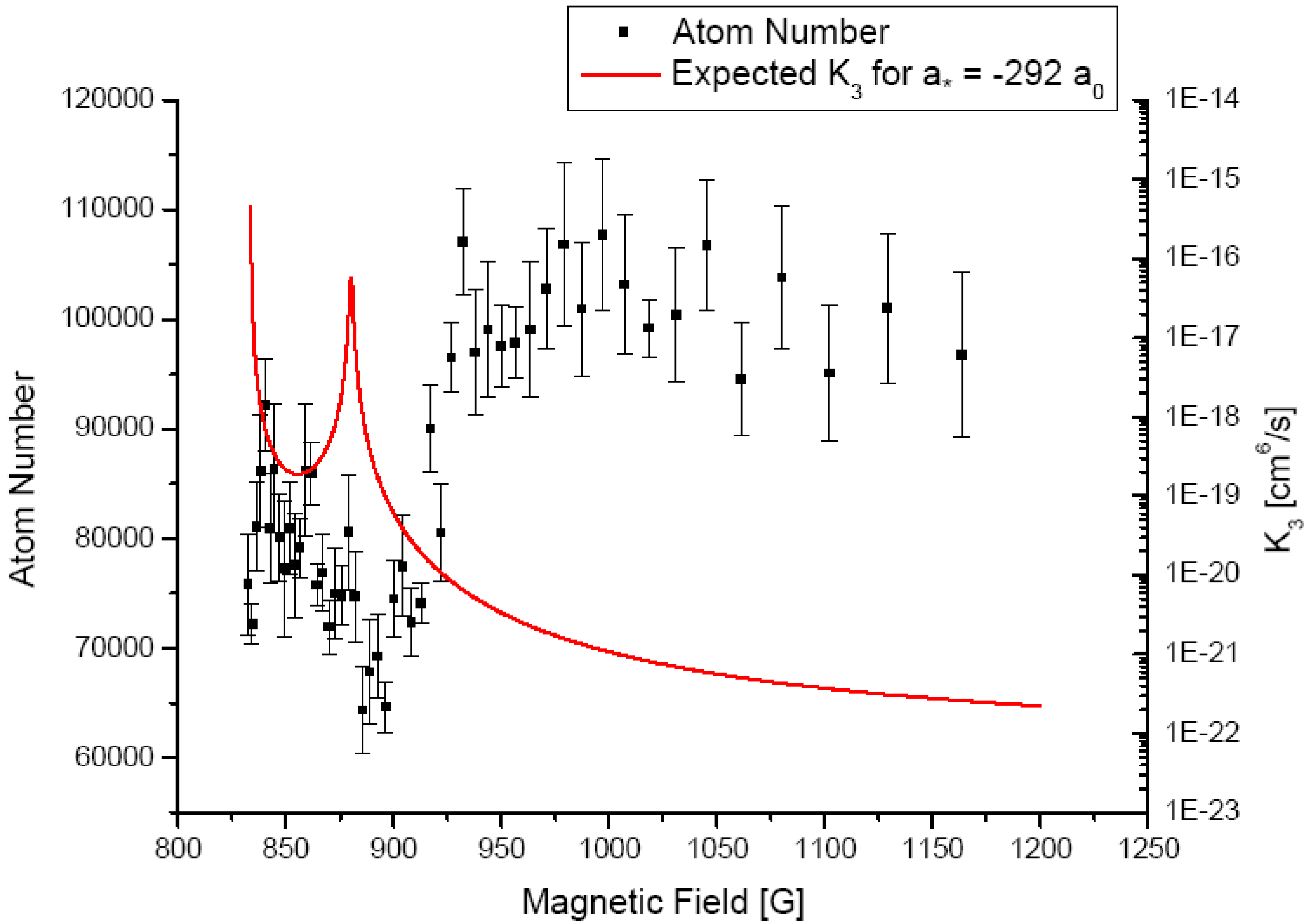
Assume a_* to be insensitive to the magnetic field

Then the lowest trimer state remains bound due to the large background scattering length

Loss resonance expected for $a_m \approx -6600\ a_0$ ($B \approx 880$ G)



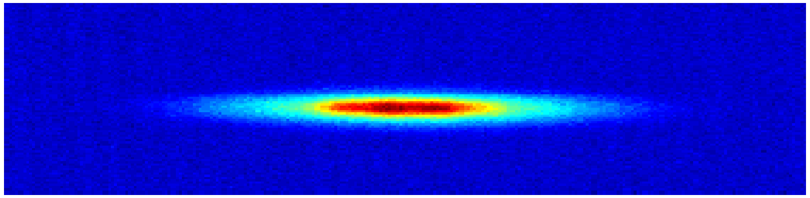
Preliminary results



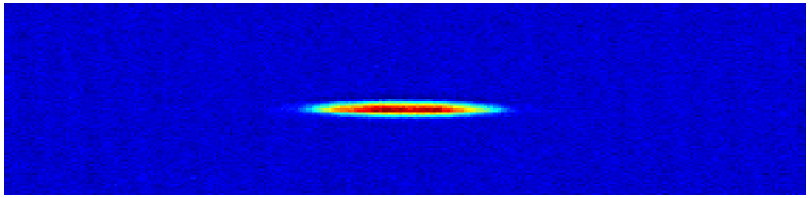
Work in progress

A different starting point: An imbalanced two-component Fermi gas

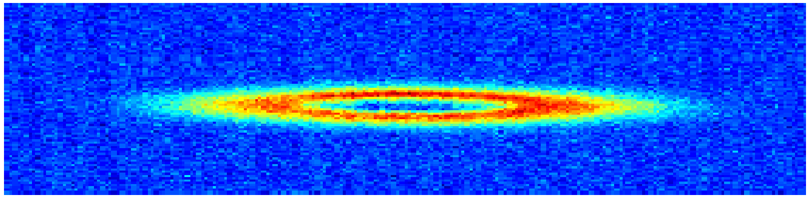
State |1> (atoms + molecules)



State |2> (only molecules)



Difference (free atoms)



Idea: Drive the unbound Atoms to the third state

Conclusion

- We can create stable ultracold three-component Fermi gases of ^{6}Li
- There are universal three-body bound states
- We are working towards a full understanding of the few-body physics…
- … so that we can probe the many-body physics of three-component Fermi gases