Feshbach resonances in a hybrid atom-ion system

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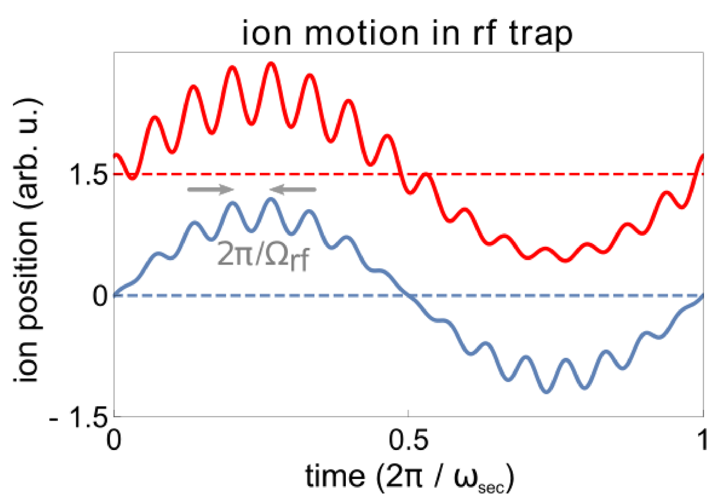
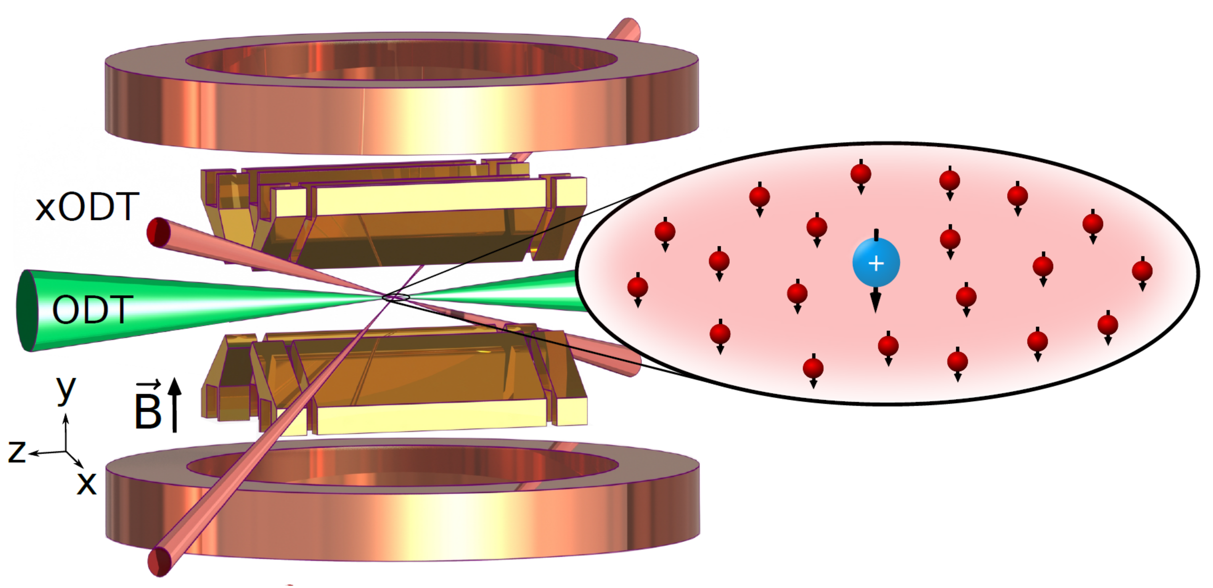
Motivation

The interplay of ultracold atoms and ions has recently gained interest in the atomic community [1]. In order to control the atom-ion interaction, it is necessary to prepare the mixture at ultracold temperatures. So far these interactions have been limited by the intrinsic micromotion heating effects of a conventional Paul trap [2]. We lowered this limit by choosing a proper atom-to-ion mass ratio to minimize the radio-frequency (rf) heating.

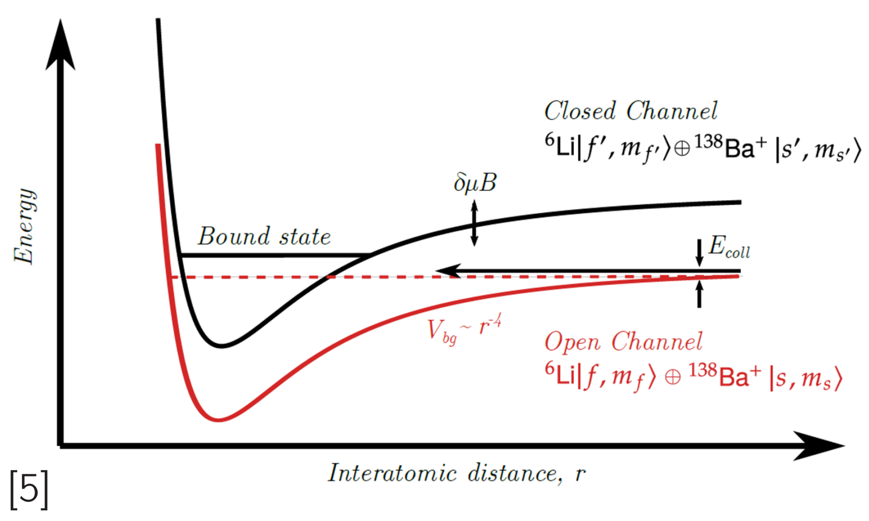


In this poster, we report on the first observation of Feshbach resonances between an individual ion and ultracold atoms – using the beneficial mixture of $^{138}Ba^{+}$ and ^{6}Li [3].



Feshbach resonances

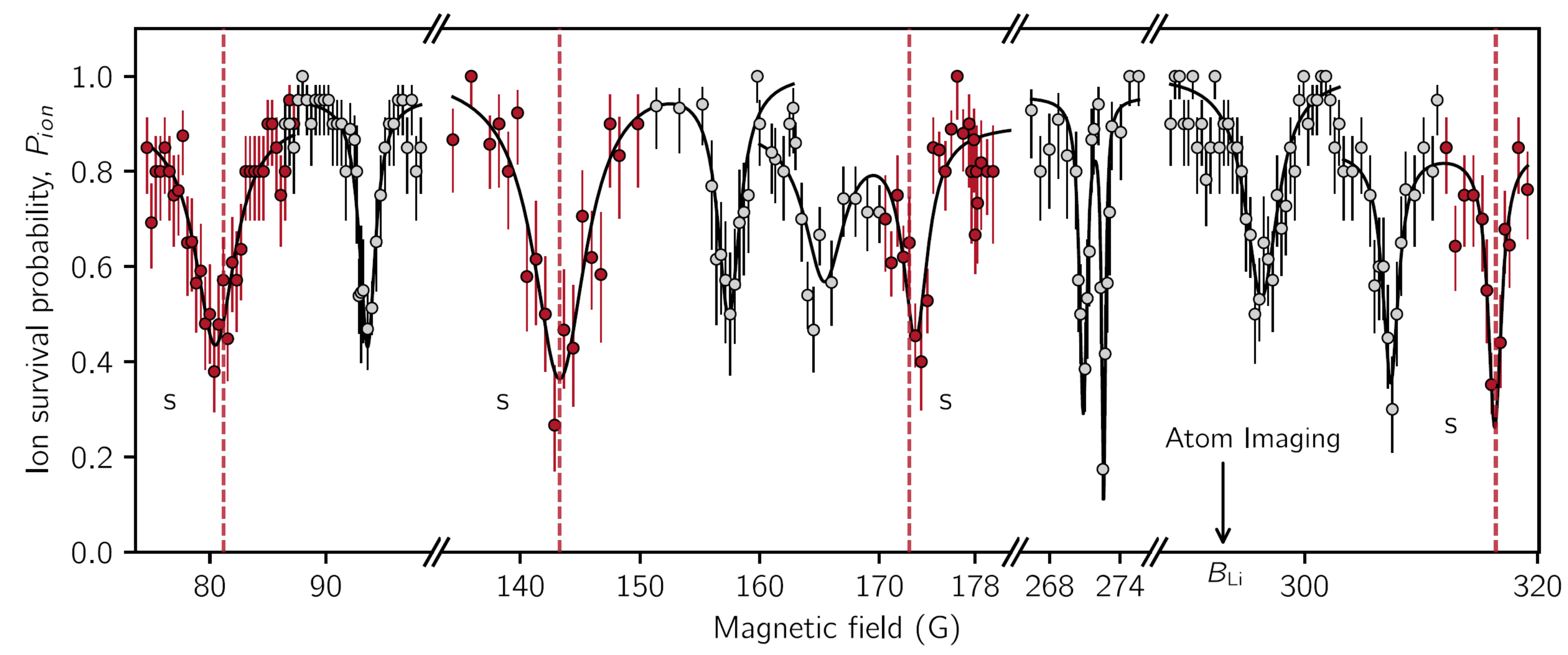
Feshbach resonances are a powerful tool that allows coherent control over the scattering cross section by means of an external magnetic field [4].



[5]

- In absence of a resonance, the scattering behavior is given by the background potential (open channel) and the background scattering length a_{bg}.
- Using external magnetic fields, we can tune a higher-lying bound state (within the closed channel) into resonance with the zero-energy threshold. The admixing of the molecular state allows to arbitrarily set the scattering length a – creating both attractive and repulsive interactions.

Enhancement of three-body recombination



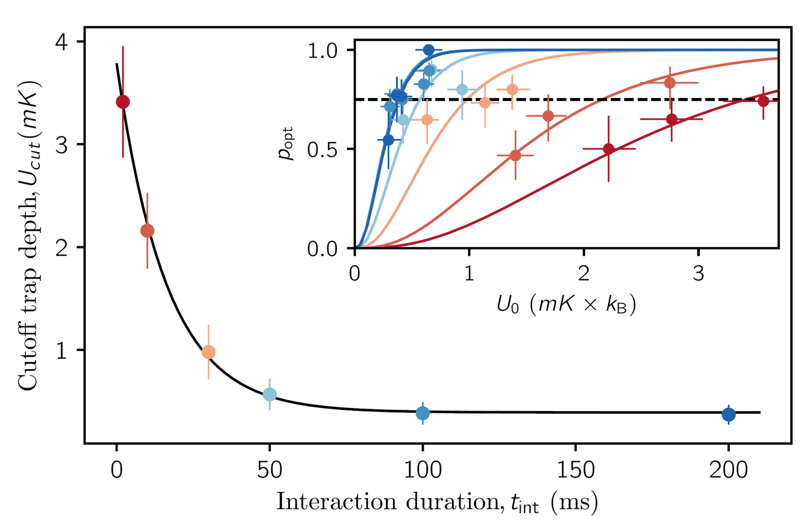
We assign four s-wave resonances (red vertical lines) by fitting the singlet and triplet scattering lengths a. The assignment relies on strong spin-orbit coupling (SOC).

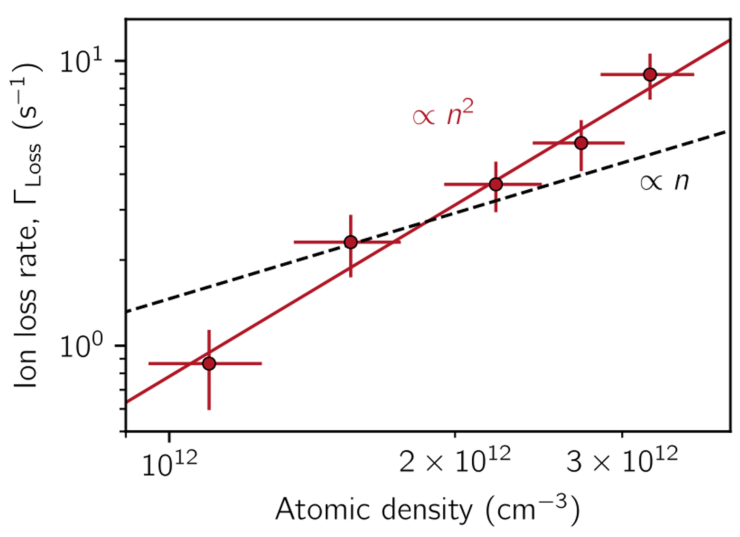
$$a_S = 0.236 \cdot R_4 \qquad a_T = -0.053 \cdot R_4 \qquad RMSD = 0.44\ \mathrm{G}$$

Atomic density dependent ion losses

To study the number of particles involved in the loss process of the ion, we probe the dependence of the optical trapping probability P_{ion} on the interaction time t_{int} for five different atomic densities n. For each time evolution, we fit an exponential decay $e^{-t_{int}\Gamma_{Loss}}$, with Γ_{Loss} being the $1/e$ ion loss rate. We model the data by $\Gamma_{Loss}(n) = k_2 n + k_3 n^2$, with k_2 and k_3 representing the two-body and three-body loss rate coefficients. We derive that the ion losses in the vicinity of a Feshbach resonance are given by three-body recombination (TBR), since k_2 remains consistent with zero:

$$k_3 = 7.8^{+3.9}_{-2.5} \times 10^{-25}\ \mathrm{cm^6/s}$$





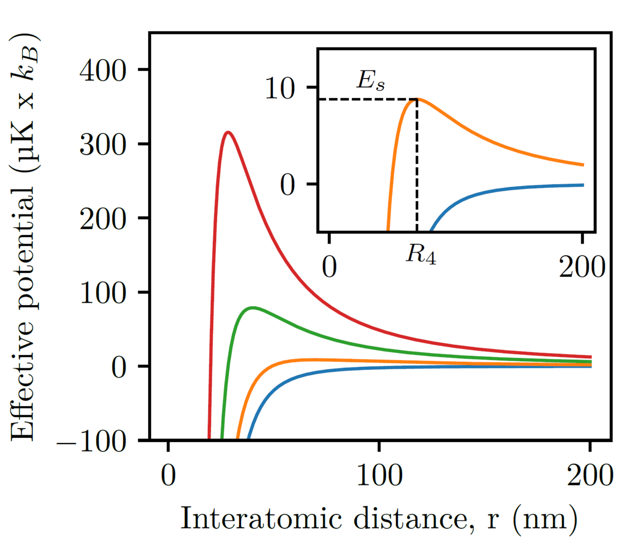
Sympathetic cooling - Reaching the few-partial wave regime

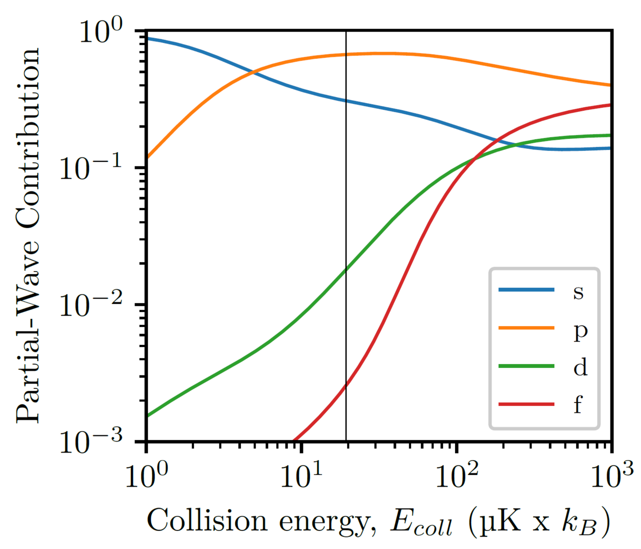
E_{Li}	$\sim 3/2 \cdot 1.3(2)\ \mu\mathrm{K} \cdot k_B$
E_{Ba^+}	$\sim 3/2 \cdot 120(20)\ \mu\mathrm{K} \cdot k_B$
E_{iMM}, E_{eMM}	$\sim 120(20)\ \mu\mathrm{K} \cdot k_B$
E_{coll}	$\sim 19.4(23)\ \mu\mathrm{K} \cdot k_B$

In order to observe quantum effects - such as Feshbach resonances - we need to reach ultracold temperatures on the order of a few μK. We achieve this by collisional or sympathetic cooling.

$$E_{coll} = \frac{\mu}{m_{Li}} E_{Li} + \frac{\mu}{m_{Ba^+}} (E_{Ba^+} + E_{iMM} + E_{eMM})$$

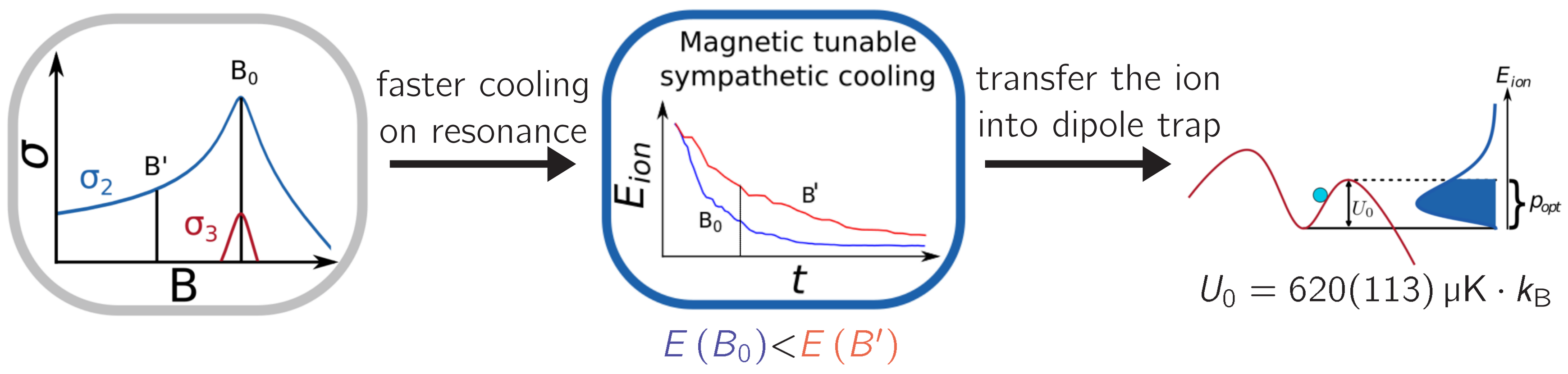
The process of TBR is temperature-dependent. By the width of the Feshbach resonances, we infer our system being dominated by **s-**, **p-** and **d-wave** scattering.

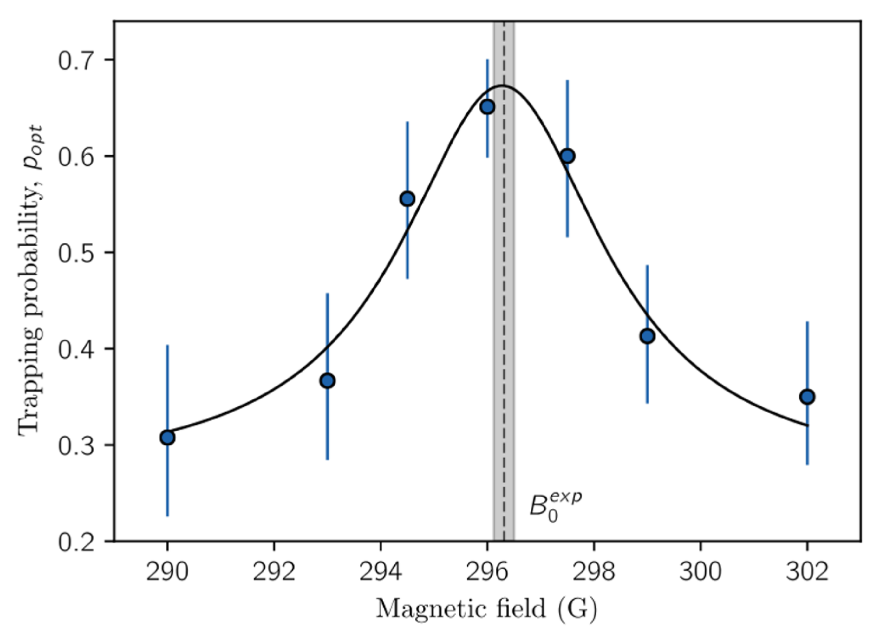




Enhancement of two-body scattering

Aim: Probing the tunable elastic cross section by sympathetic cooling at lower atomic densities leads to suppression of three-body recombination.





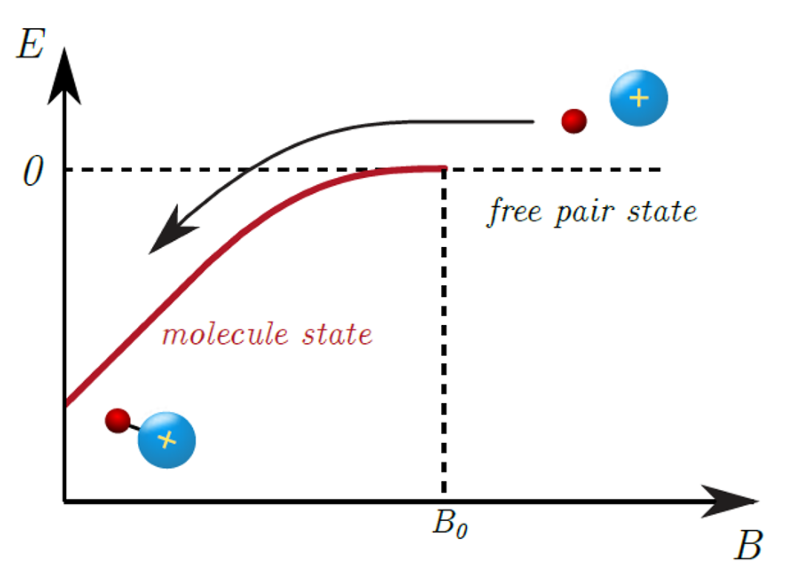
On resonance, we expect lower energies and thus larger optical trapping probabilities:

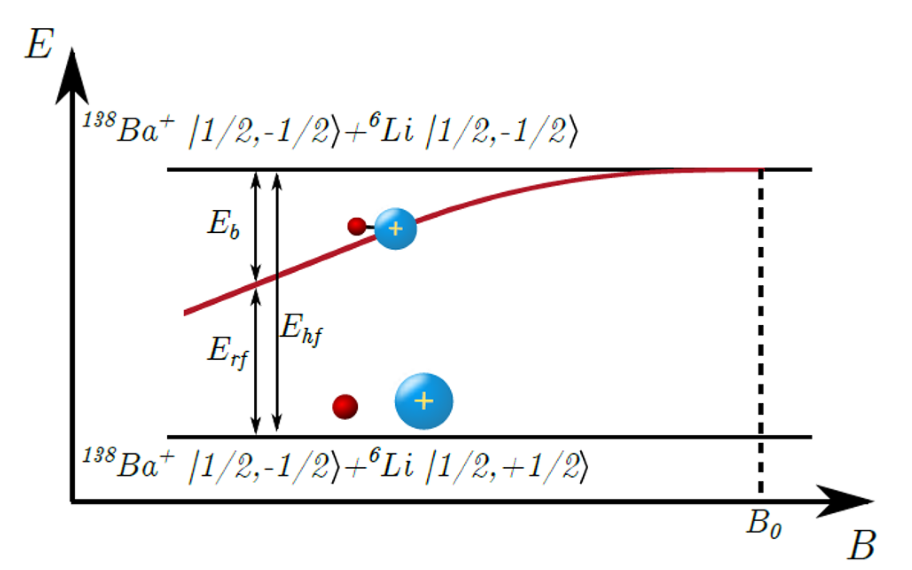
$$p_{opt}(B_0) > p_{opt}(B')$$

We find consistency between the elastic cross section peak (p_{opt} maximum) and the center of the resonances B_0^{exp} derived by ion loss spectroscopy.

Future work

The observation of atom-ion Feshbach resonances allows the potential realization of various novel atom-ion many-body systems, such as ionic polarons or coherent control over weakly-bound molecular ions. The latter can be formed by magneto-association (left) or rf-association (right).





In order to entirely eliminate rf heating, we are working towards atom-ion interaction in a purely optical trap without any residual rf fields [6, 7].

References

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