Three-body recombination at vanishing scattering lengths

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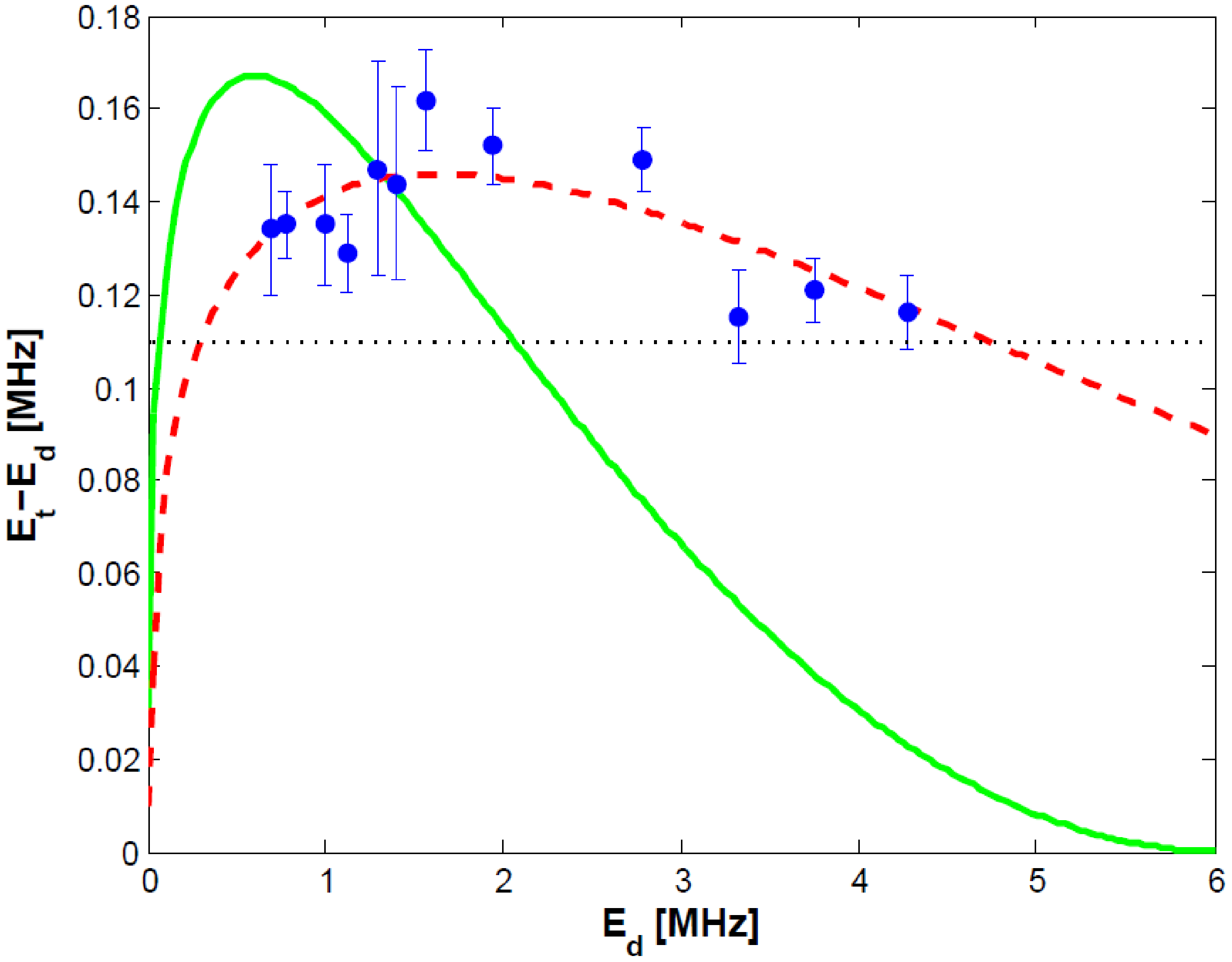
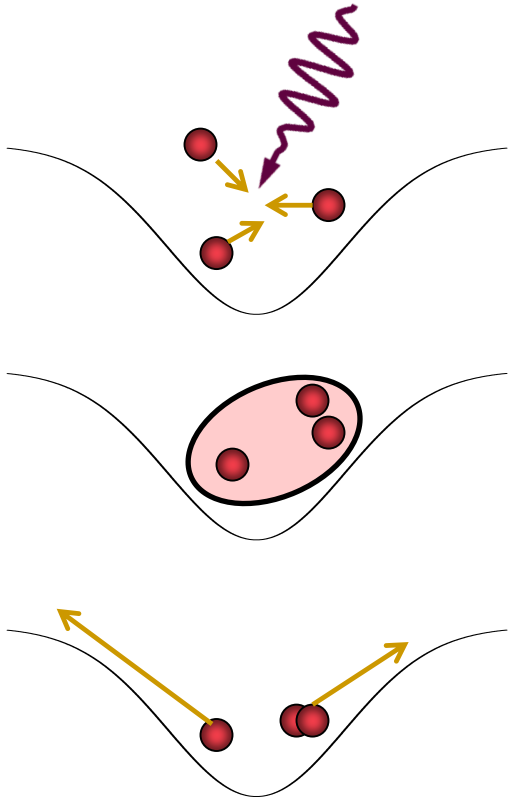
RF association of Efimov trimers



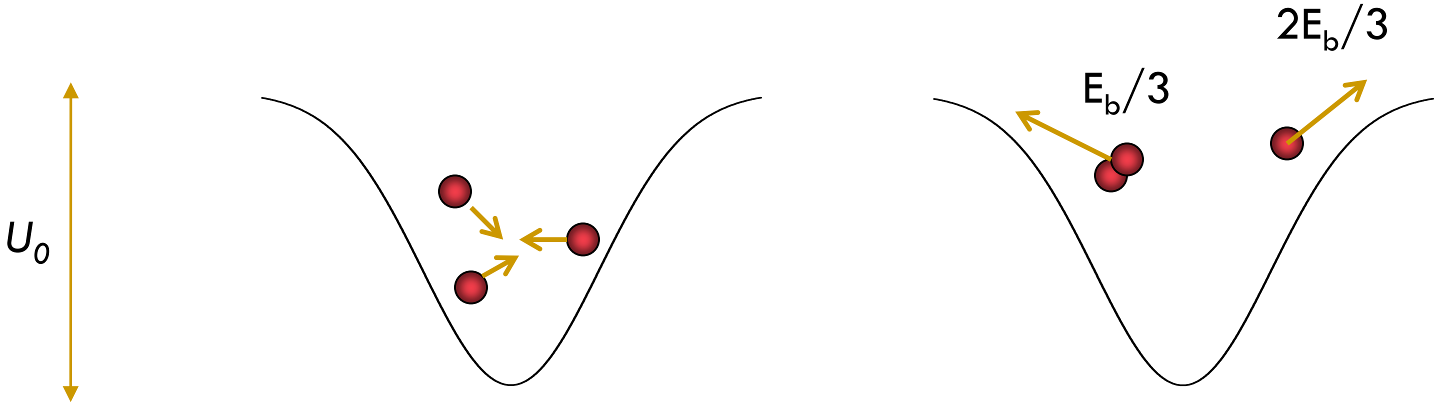


Talk on Wednesday by Mario Gattobigio.

O. Machtey, Z. Shotan, N. Gross, and L. Khaykovich, PRL **108**, 210406 (2012).

Three-body recombination

Three body inelastic collisions result in a weakly (or deeply) bound molecule.



Release of the binding energy causes loss of atoms from a ***finite depth trap*** which probes 3-body physics.

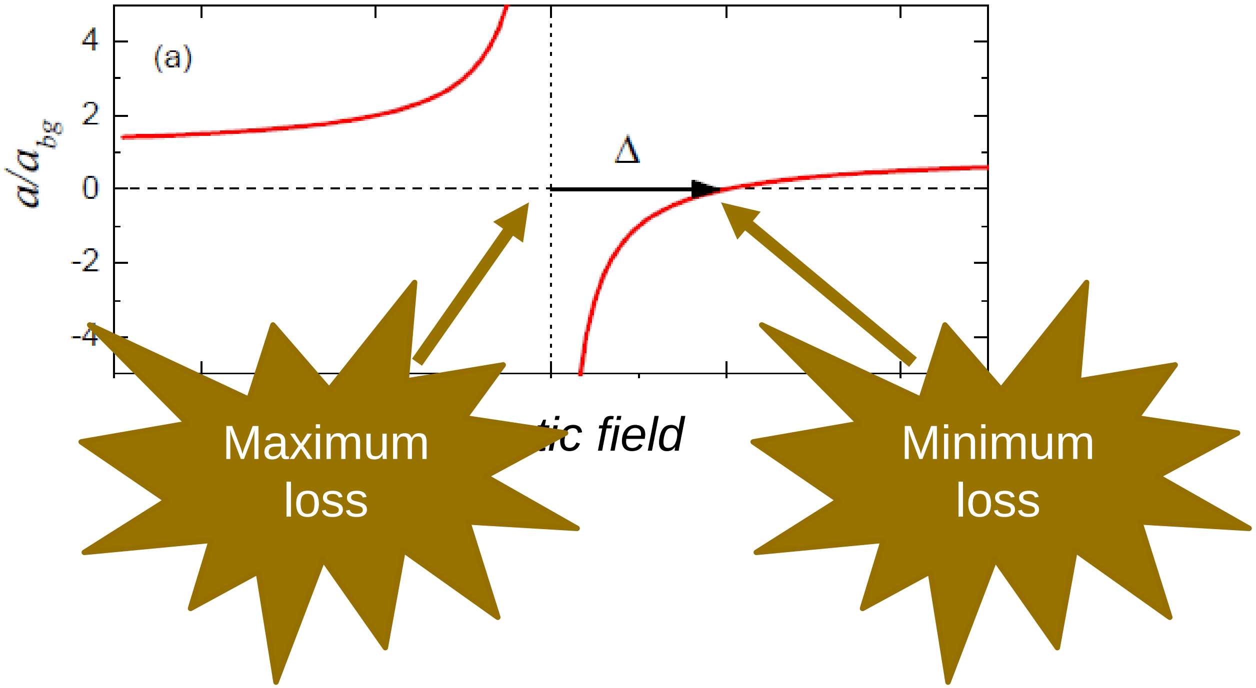
Loss rate from a trap:

$$\dot{N} = -3K_3\left\langle n^2 \right\rangle N$$

K_3 – 3-body loss rate coefficient [cm^6/sec]

Take-home message

Feshbach resonance in a bosonic system.



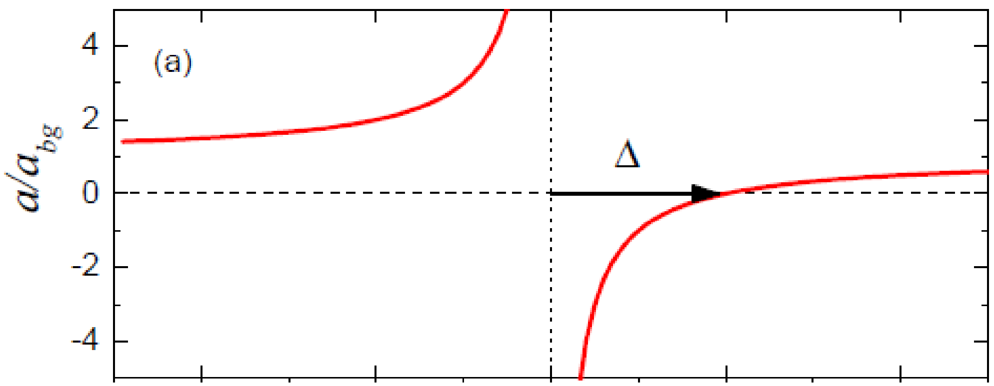
Maximum loss

Minimum loss

Misconception!

Take-home message

Feshbach resonance in a bosonic system.

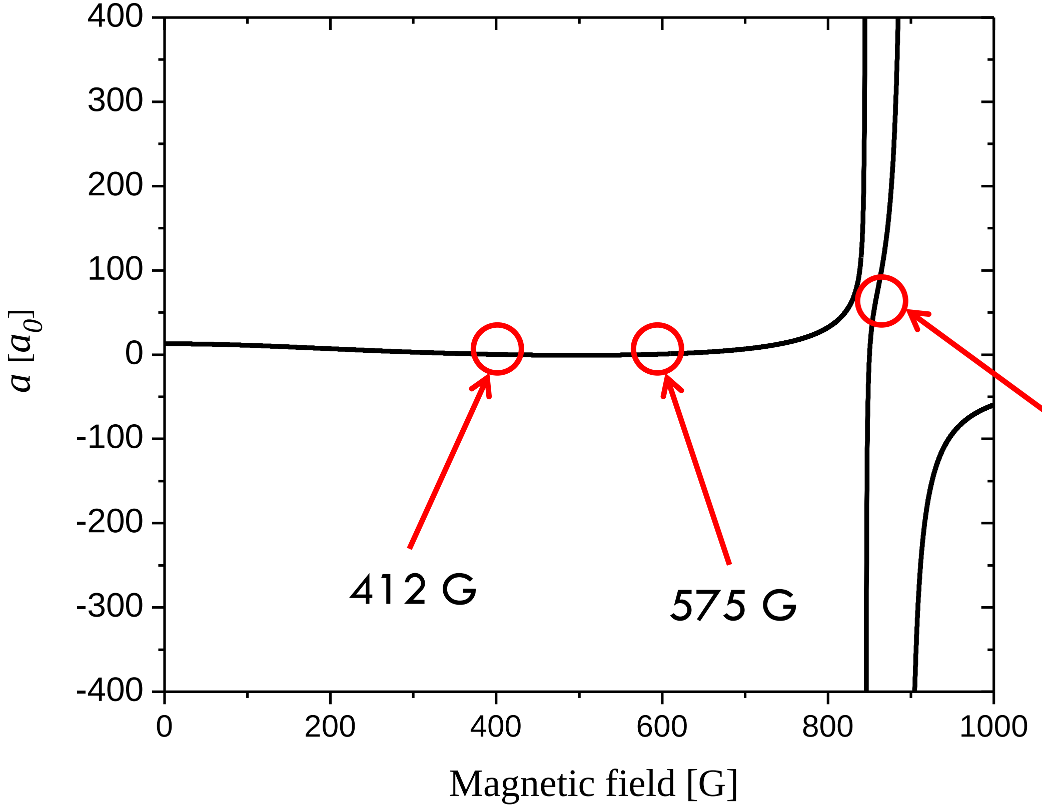


Magnetic field

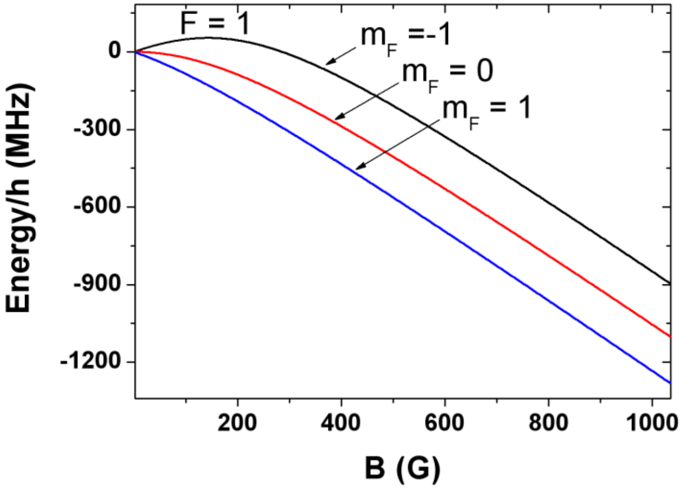
Zero-crossing does not necessarily correspond to a minimum in a three-body recombination rate.

Motivation

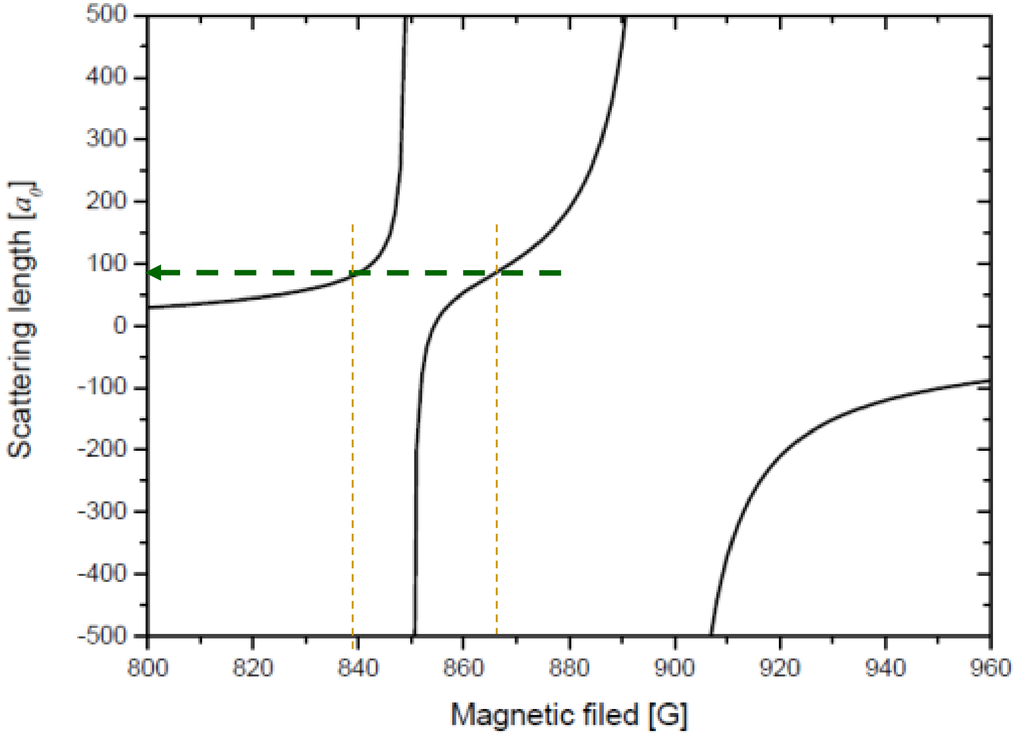
Feshbach resonance $m_F = 0$ state.



^{7}Li lower hyperfine level.



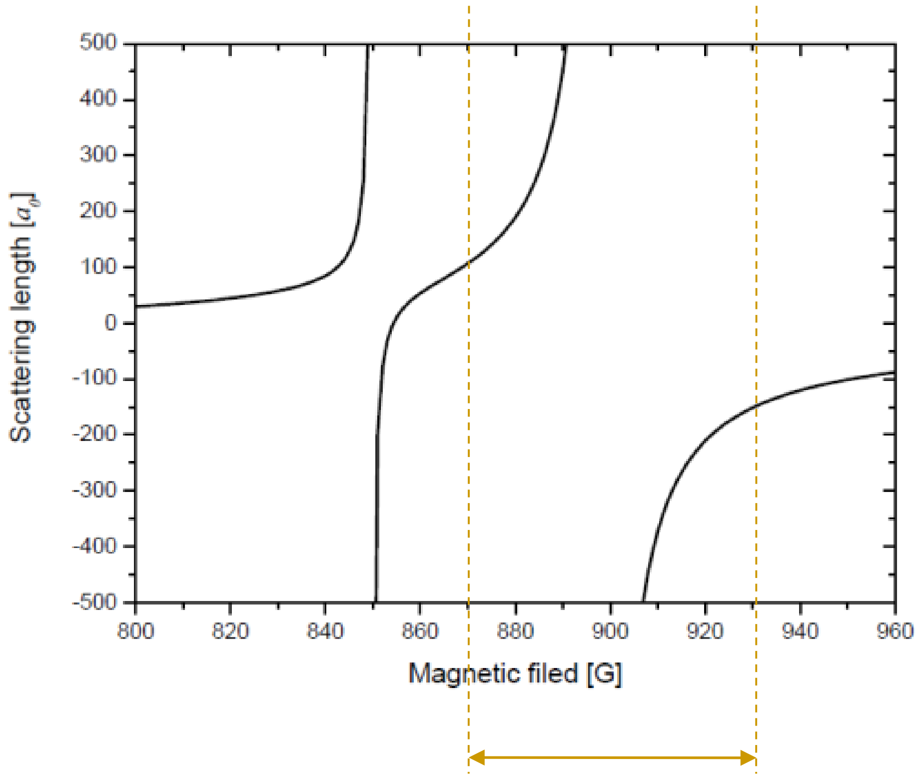
Motivation



Same scattering length – different three-body recombination rates.

Motivation

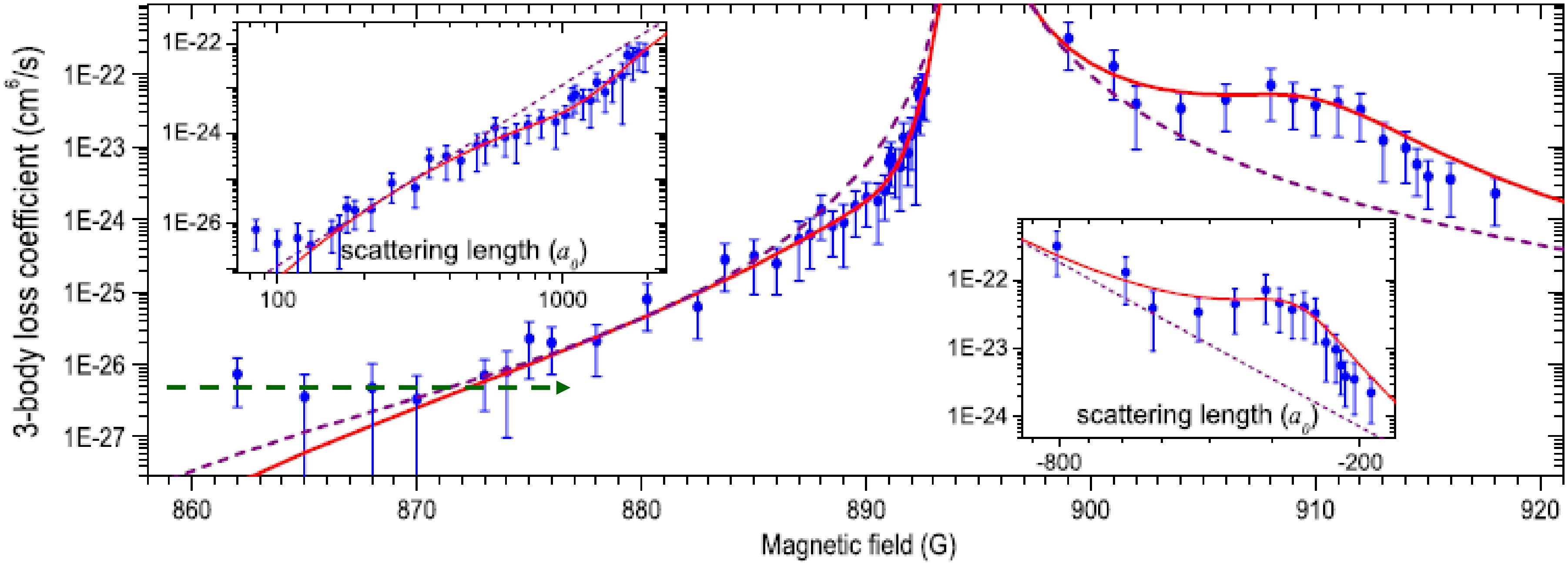
Universal region.



$$K_3 \propto a^4$$

Motivation

Saturation of the three-body recombination rate.



N. Gross, Z. Shotan, S.J.J.M.F. Kokkelmans and L. Khaykovich, PRL **103**, 163202 (2009).

TWO-BODY PHYSICS

Scattering phase shift at zero-crossing

Effective range expansion of the scattering phase shift:

$$k\cot\left(\delta(k)\right)=-\frac{1}{a(B)}+\frac{1}{2}R_e(B)k^2$$

Inconvenient when $a\rightarrow 0$

Inverted expression:

$$-\frac{\tan\left(\delta(k)\right)}{k}=a+\frac{1}{2}(R_e a^2)k^2$$

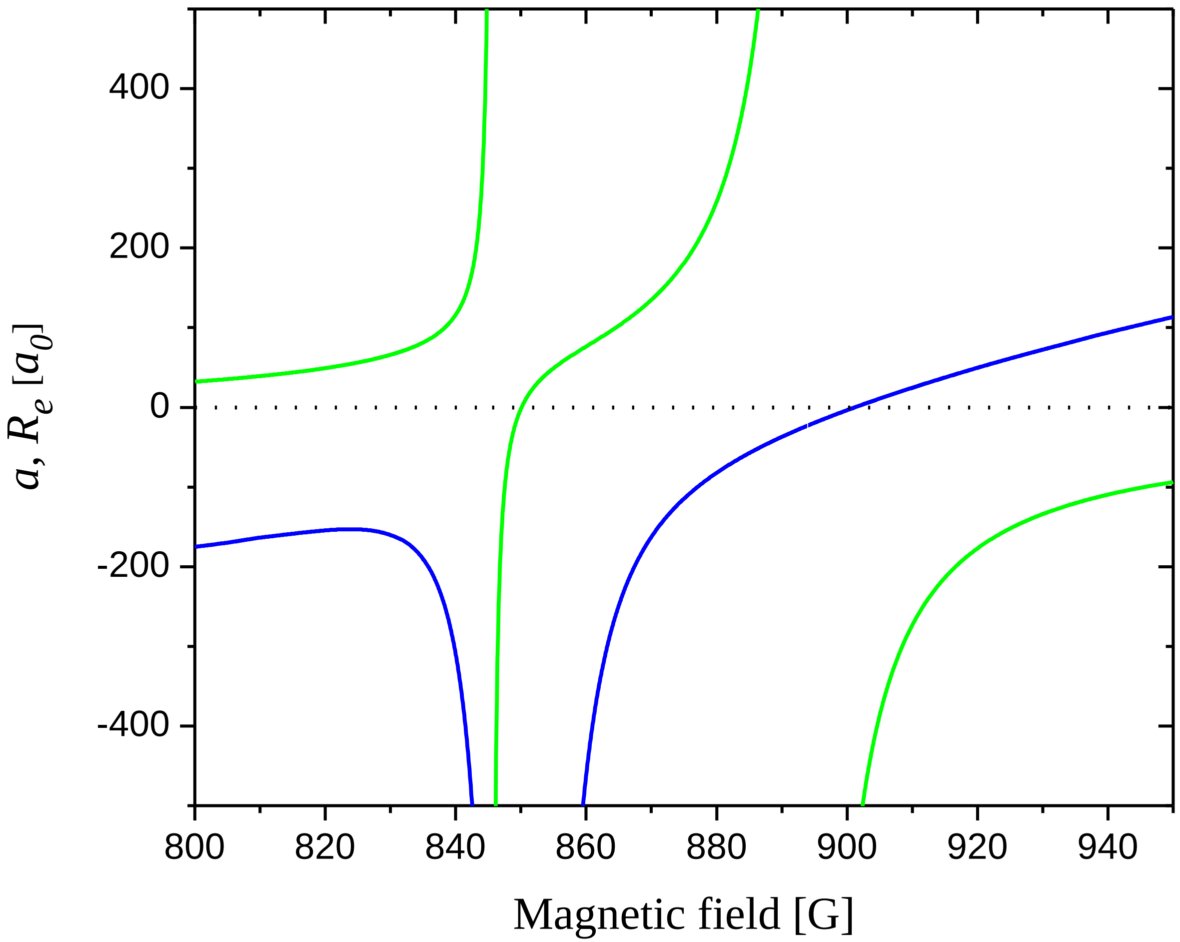
Well defined when $a\rightarrow 0$

Effective volume: $V_e=-R_e a^2/2$

See also: C. L. Blackley, P. S. Julienne and J. M. Hutson, PRA **89**, 042701 (2014).

Feshbach resonances and zero-crossing

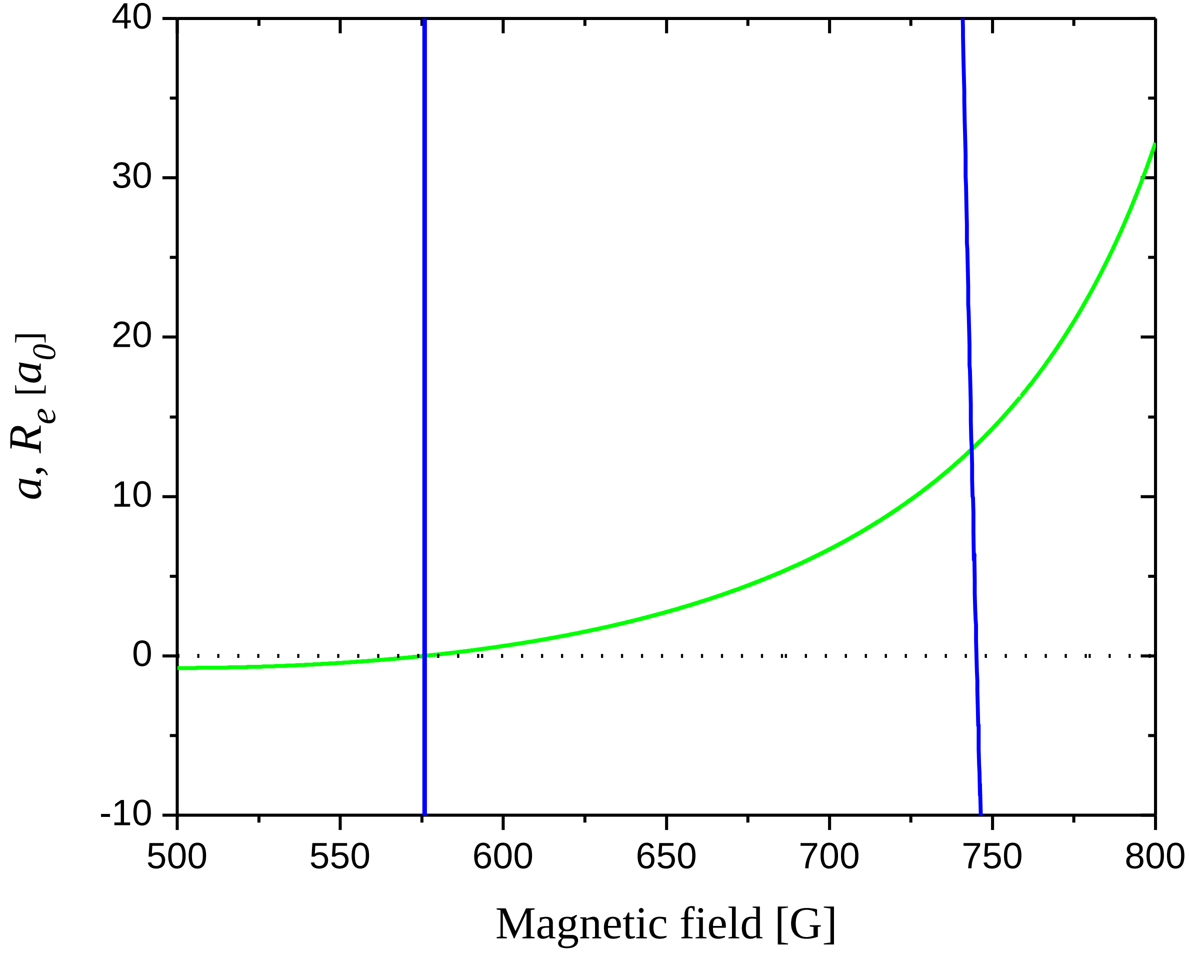
Scattering length and the effective range:



N. Gross, Z. Shotan, S.J.J.M.F. Kokkelmans and L. Khaykovich, PRL **103**, 163202 (2009).

Low field zero-crossing

Scattering length and the effective range:



Two-body physics near zero-crossing

Energy dependent two-body collisional cross-section:

$$\sigma(k)=\frac{8\pi}{k^2}\sin^2(\delta(k))=\frac{8\pi\left(V_e k^2-a\right)^2}{1+\left(V_e k^2-a\right)^2 k^2}$$

Condition for vanishing collisional cross-section:

$$\sigma(k)=0 \quad \Rightarrow \quad a=V_e k^2 \quad \Rightarrow \quad a=-\frac{2}{R_e k^2}$$

- The zero-crossing position is well defined now by precise characterization of Feshbach resonances:

  N. Gross, Z. Shotan, O. Machtey, S. Kokkelmans and L. Khaykovich, C.R. Physique **12**, 4 (2011).

  P. S. Julienne and J. M. Hutson, arXiv:1404.2623 (Data from Heidelberg, ENS, Rice and Bar Ilan).

- Experimental approach to test the temperature dependence of the cross-section – evaporation cooling around zero-crossing.

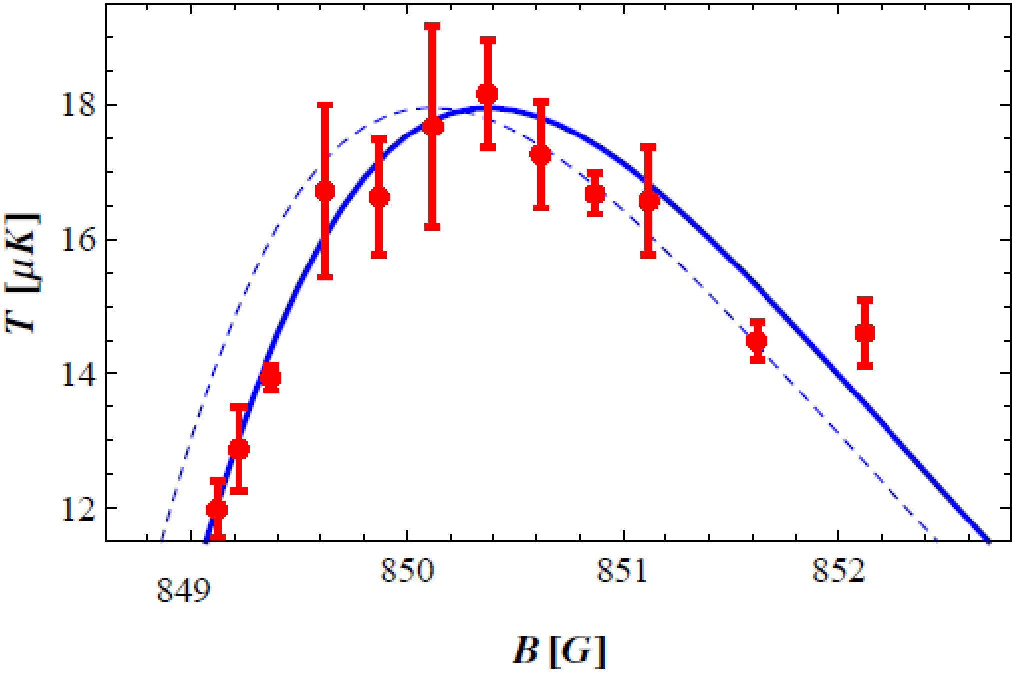
  S. Jochim et. al. , Phys. Rev. Lett. **89** 273202 (2002).

  K. O'Hara et. al. , Phys. Rev. A **66** 041401(R) (2002).

Zero-crossing of ^{6}Li resonance.

Evaporation cooling near zero-crossing

Evaporation during: 500 ms
Initial temperature: 31 μK



Zero-crossing is at 850.1G
Maximum is at 850.4G

→

Two-body collisions show energy dependence.

Z. Shotan, O. Machtey, S. Kokkelmans and L. Khaykovich, arXiv:1404:3575.

Three-body physics near zero-crossing

Universal limit: $$K_3 = 3C(a)\frac{\hbar}{m}a^4$$

Formal definition: $$K_3 = 3C_{\max}\frac{\hbar}{m}L_m^4$$

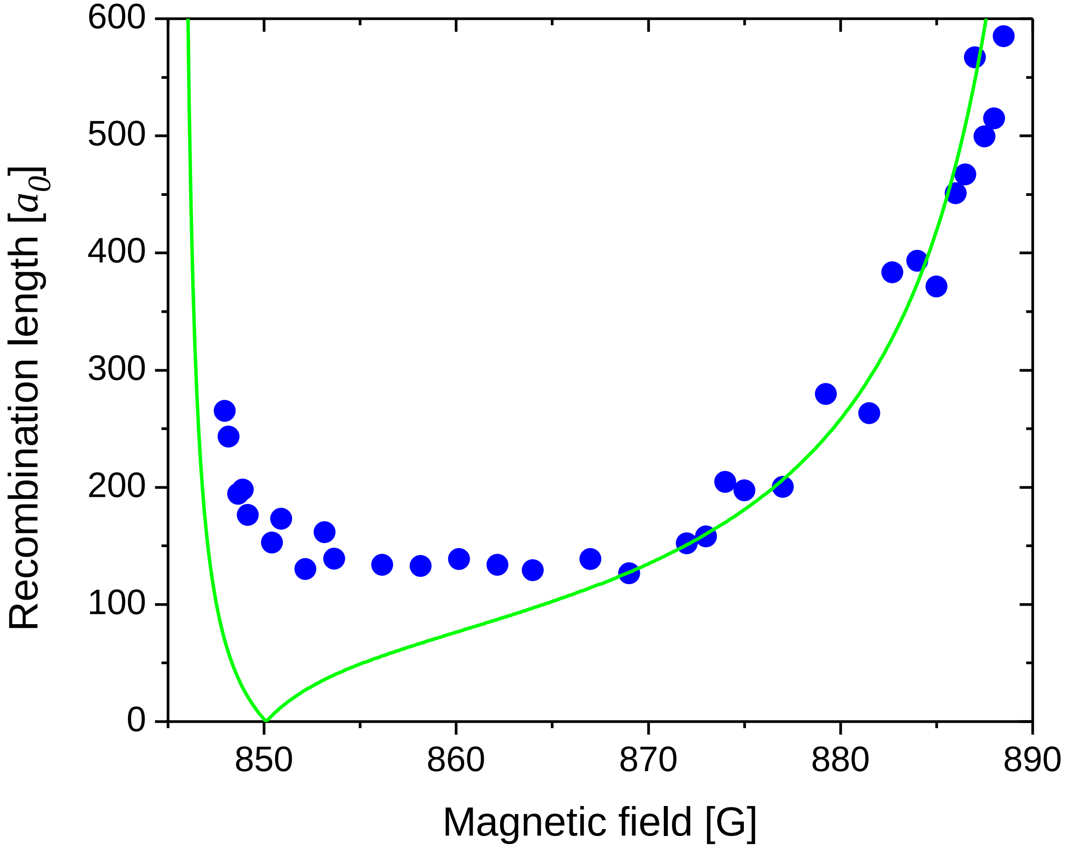
Recombination length: $$L_m = \left(\frac{mK_3}{3C_{\max}\hbar}\right)^{1/4}$$

B. D. Ezry, C. H. Greene and J. P. Burke Jr., Phys. Rev. Lett. **83** 1751 (1999).

We measure K_3 and represent the results as L_m.

Three-body physics near zero-crossing

Three-body recombination length:



Effective recombination length

Recombination length:

$$L_m = \left(\frac{mK_3}{3C_{\max}\hbar} \right)^{1/4}$$

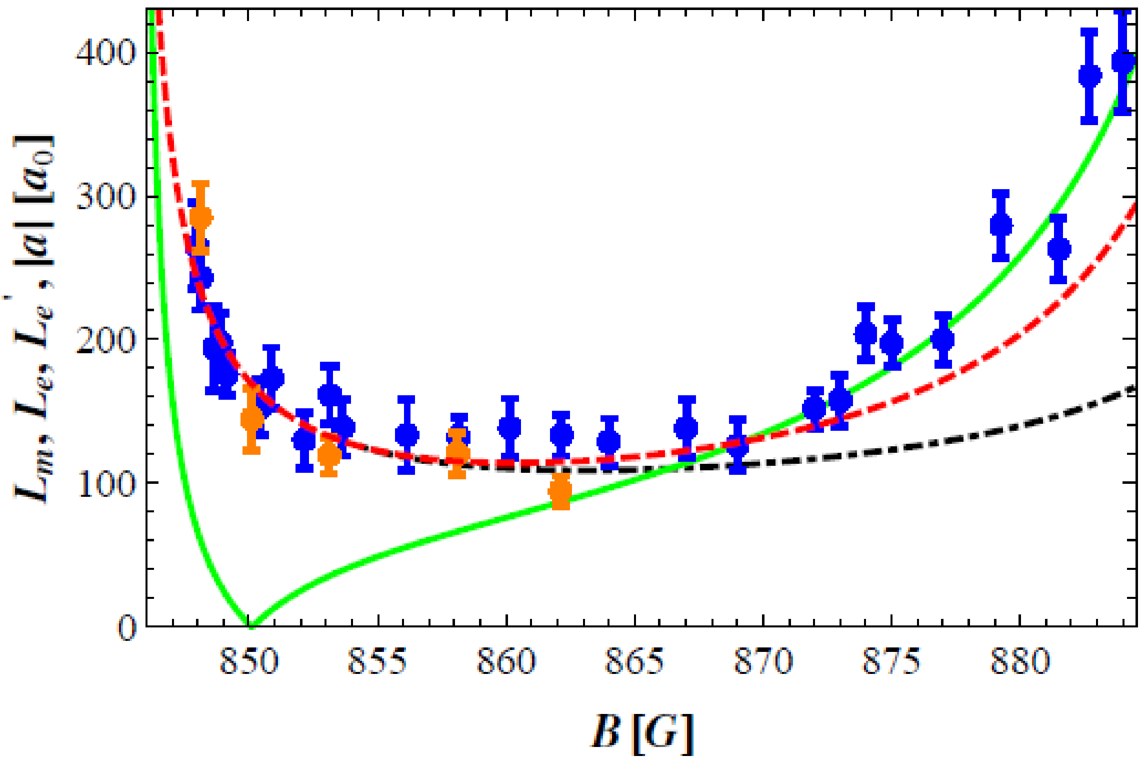
From the effective range expansion the leading term is proportional to the effective volume.

Effective recombination length:

$$L_e = V_e^{1/3} = \left(-\frac{R_e a^2}{2} \right)^{1/3}$$

Z. Shotan, O. Machtey, S. Kokkelmans and L. Khaykovich, arXiv:1404:3575.

Three-body physics near zero-crossing



Blue: T=2.5 μK

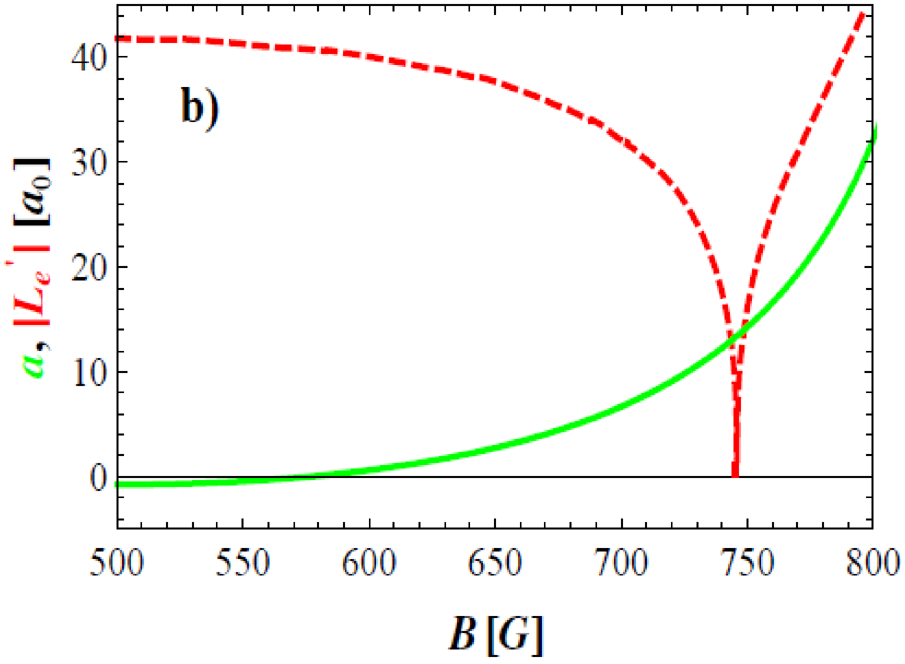
Orange: T=10 μK

If it's not an accidental coincidence!

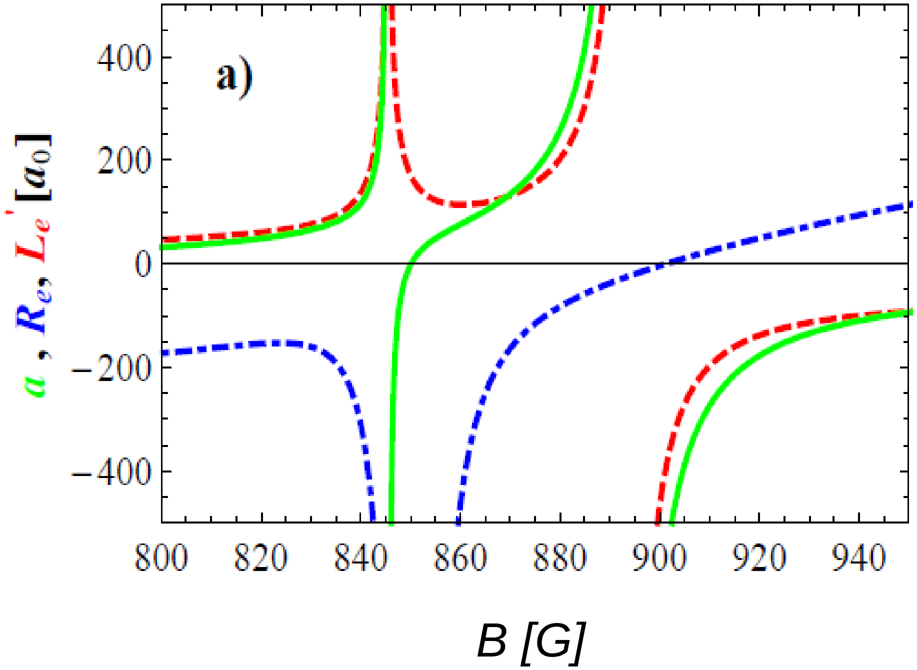
Z. Shotan, O. Machtey, S. Kokkelmans and L. Khaykovich, arXiv:1404:3575.

Three-body physics near zero-crossing

Low field zero-crossing.



Prediction for the recombination length in the resonances' region.



Conclusions

- Zero-crossing does not correspond to the minimum in 3-body recombination rates.
- Three-body recombination rate is different at different zero-crossings.
- We suggest a new lengthscale to describe the 3-body recombination rates based on two-body scattering shift for vanishing scattering length.
- Energy independent 3-body recombination rate.
- We predict a minimum in 3-body recombination in the non-universal regime.

- The question is *how accidental the coincidence is*?

People

Bar-Ilan University, Israel

Zav Shotan, Olga Machtey

Eindhoven University of Technology, The Netherlands

Servaas Kokkelmans