Trimer and Tetramer Bound States in Heteronuclear Systems

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in collaboration with
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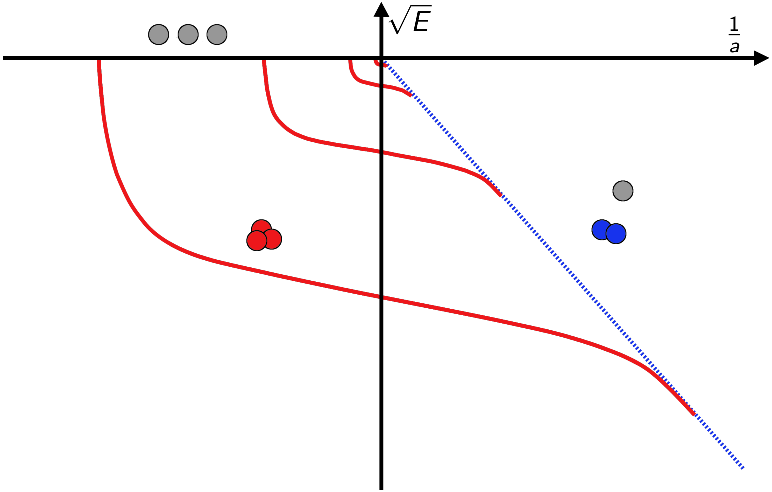
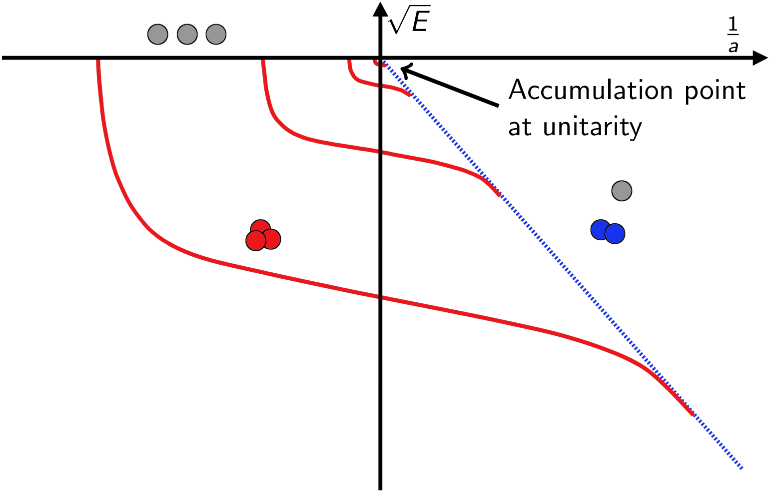
Outline

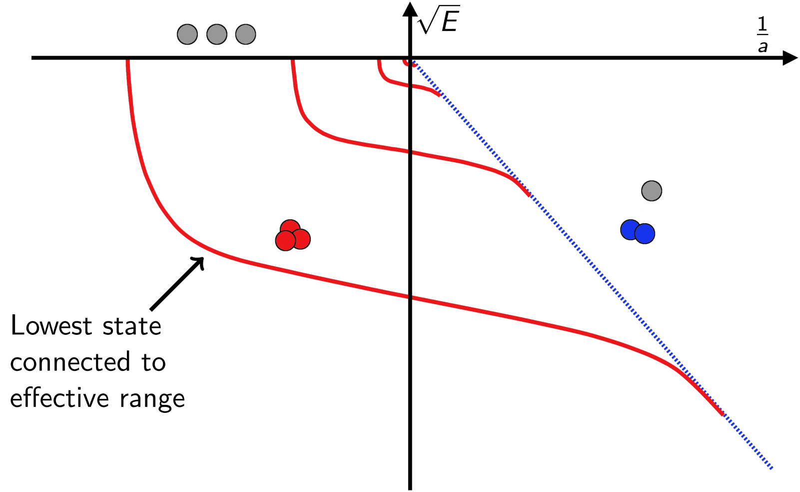
Efimov Effect



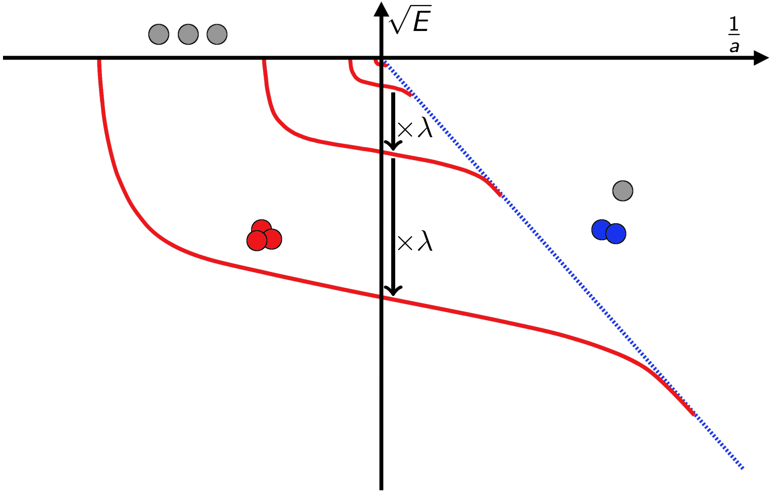
Efimov Effect



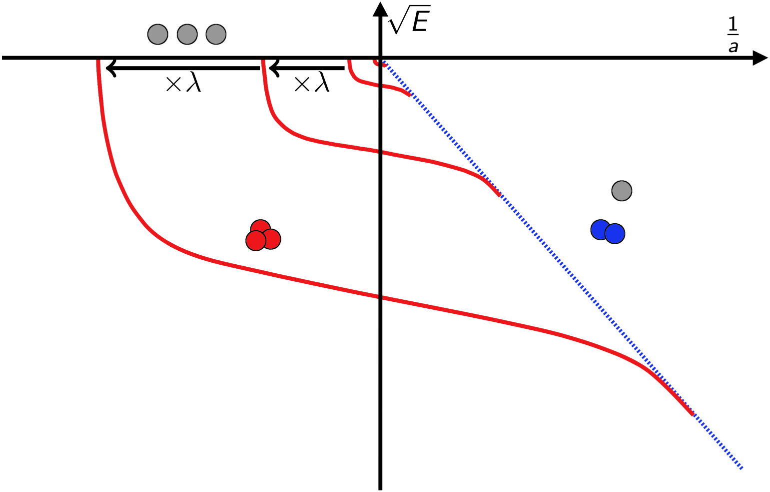
Efimov Effect



Efimov Effect

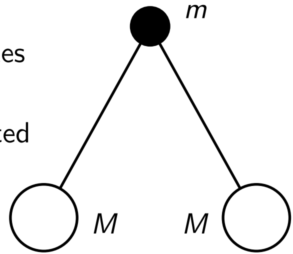


Efimov Effect



Efimov Effect for Mixtures

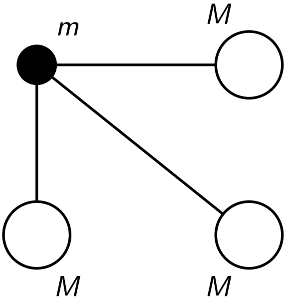
- Similar effect appears for fermion-boson and boson-boson mixtures
- The factor between consecutive energies of states **depends on the mass ratio**
- If there is only one fermion, spin can be neglected
- We neglected interaction between atoms of the same type



- In **heavy-heavy-light** mixtures, the ratio between consecutive energies of states is smaller than for identical bosons
  $\rightarrow$ **easier to observe** experimentally

Efimov Effect for Mixtures II

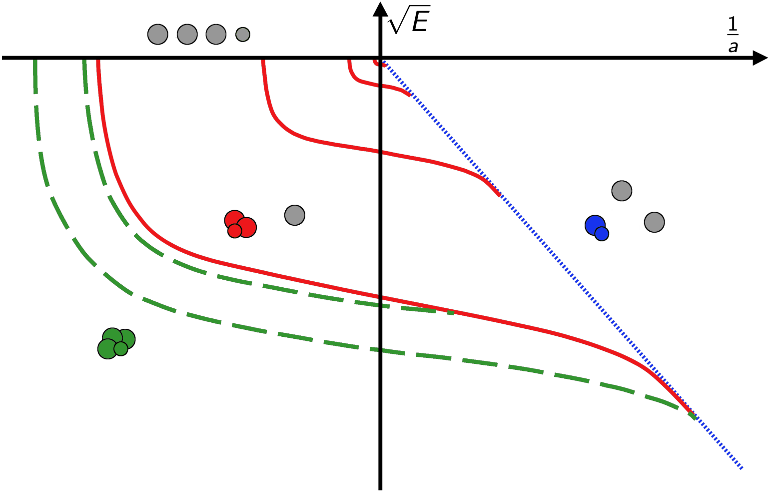
- Four-body states exist as well



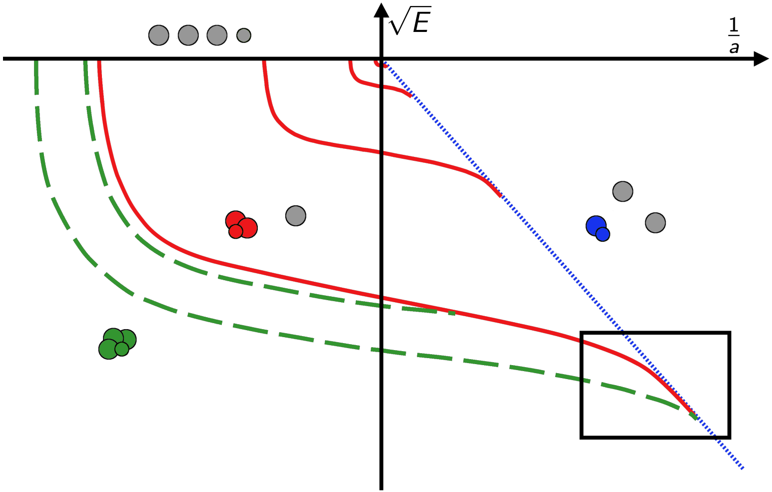
- As with identical bosons, there is typically a ground and an excited state at unitarity

Blume, Yan *Phys. Rev. Lett.* 113 (2014),213201

Efimov Effect in the Heteronuclear Four-Body System



Efimov Effect in the Heteronuclear Four-Body System



Gaussian Expansion Method

Implementation by Hiyama, Kino, Kamimura *PPNP* 51 (2003),223

- Rayleigh-Ritz Variational Method
- Base functions are selected via geometric progression between a minimum and a maximum range
- Number of parameters used:

System	Parameters
Dimer	3
Trimer	18
Tetramer	45

- Parameter space increases rapidly
- Used a mixture of systematic scanning of parameter subspaces and random sampling within relatively broad boundaries to find optimized base functions

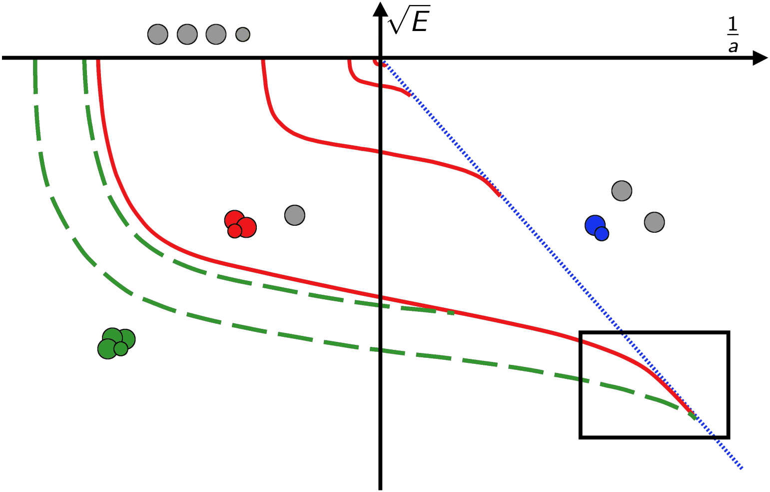
Interaction

- Use **effective** potentials for good performance, stable behaviour and easy parameter choice
- Combination of **attractive** 2-body and **repulsive** 3-body potential

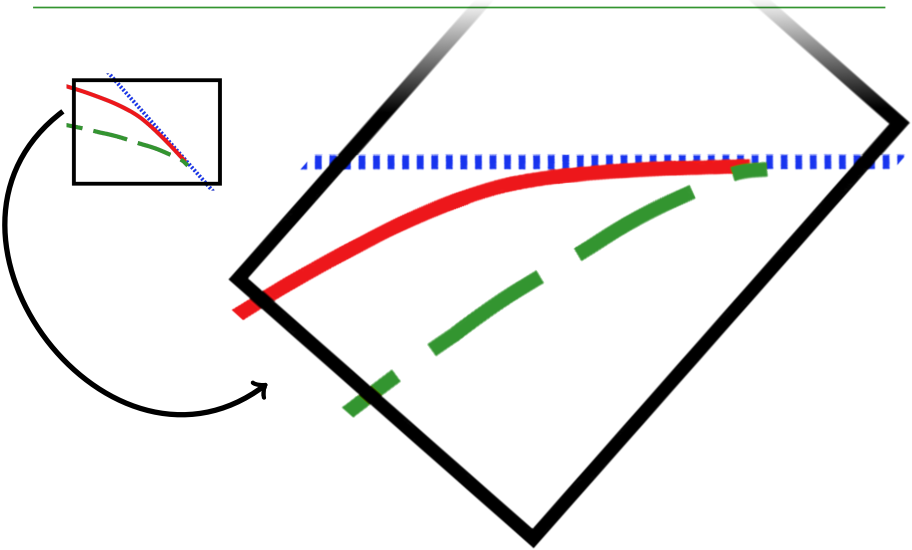
$$V_{iN} = \mathbf{V_0} \exp\left(-\frac{r_{iN}^2}{2r_0^2}\right), \qquad W_{ijN} = \mathbf{W_0} \exp\left(-\frac{r_{ij}^2 + r_{jN}^2 + r_{iN}^2}{16r_0^2}\right)$$

- $N-1$ atoms of mass M, Nth atom of mass m
- Natural energy scale of the problem: $E_s = \frac{1}{2r_0^2}\frac{m+M}{Mm}$
- Approximation valid, if binding Energies $|E| \ll E_s$

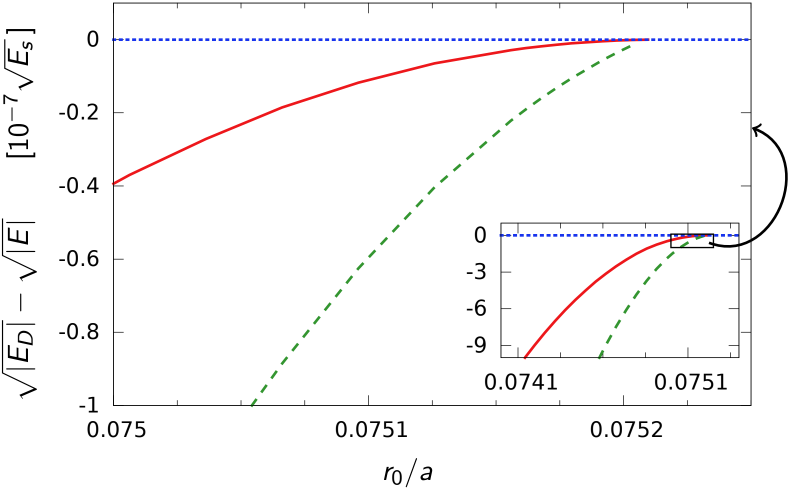
Efimov Plot for Heteronuclear Four-body System



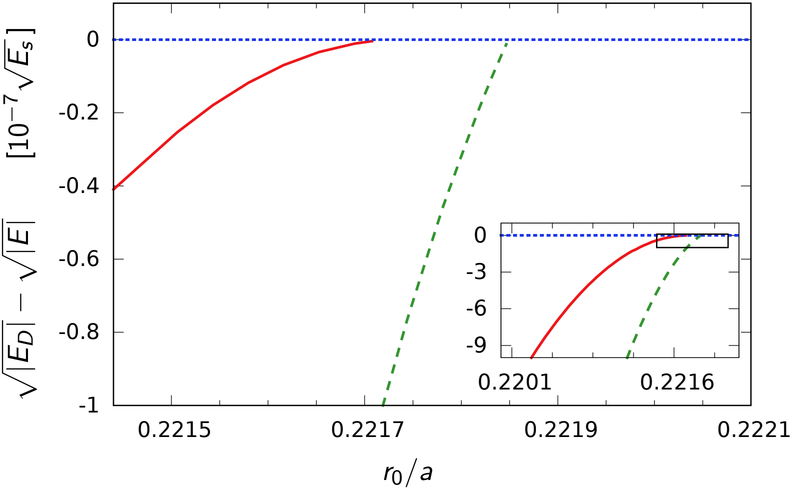
Efimov Plot for Heteronuclear Four-body System



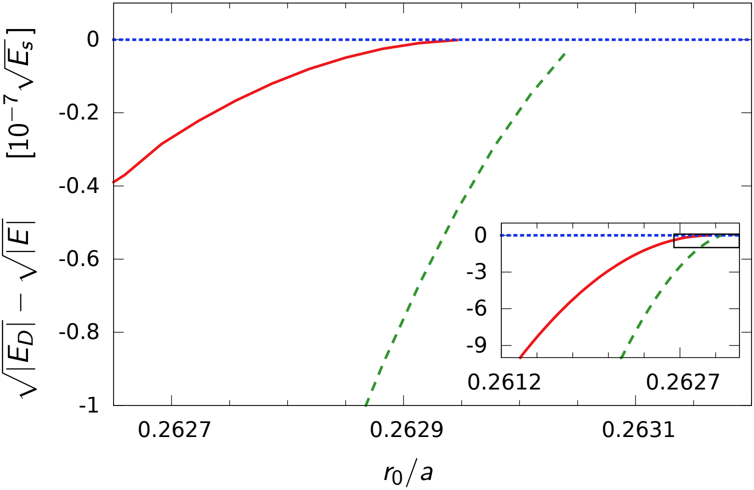
^{7}Li-^{6}Li Mixture



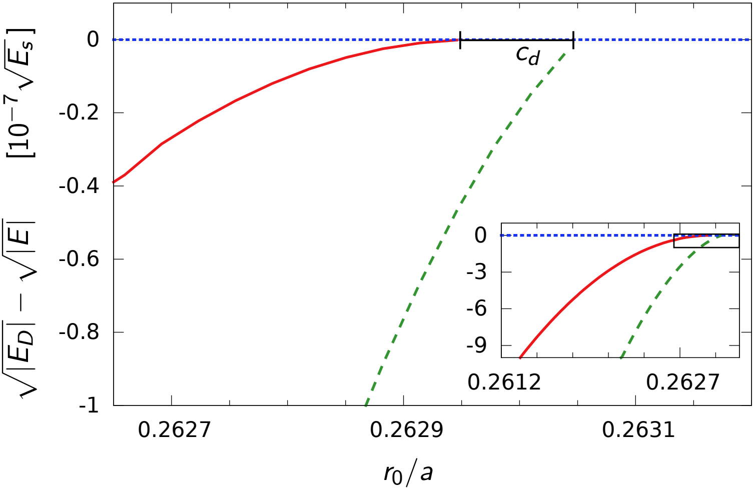
^{87}Rb-^{7}Li Mixture



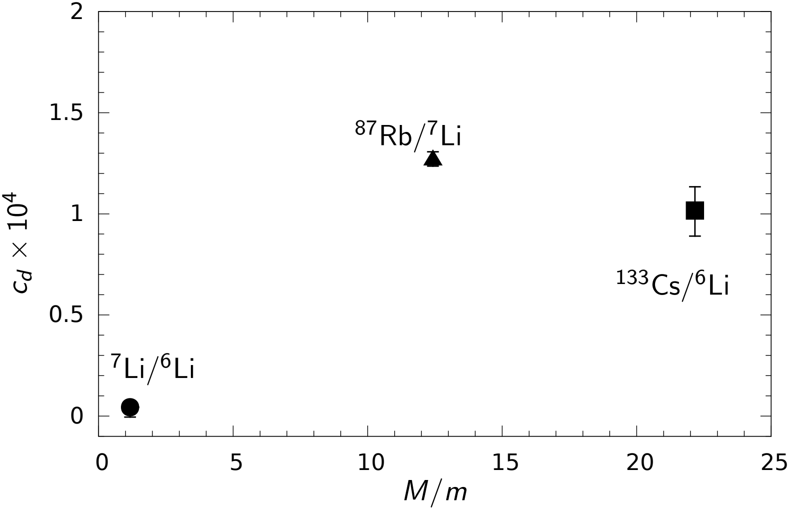
^{133}Cs-^{6}Li Mixture



^{133}Cs-^{6}Li Mixture

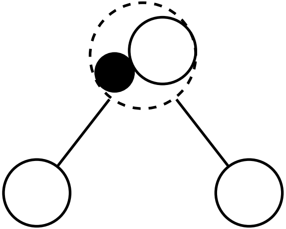


Relative Crossing Point Positions

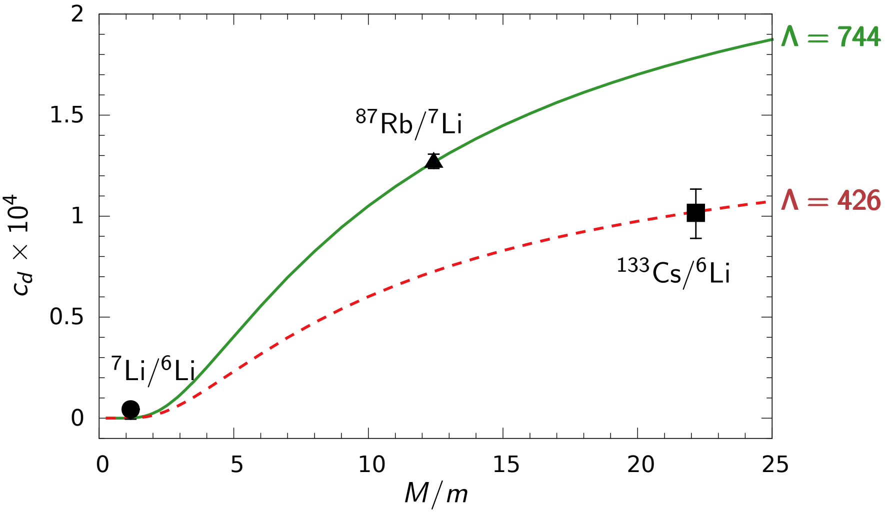


Cross-checking with Effective STM Treatment

- Before vanishing through the dimer threshold, the trimer becomes very weakly bound
- Scattering length can be approximated by inverse binding energy
- Close to threshold, the dimer-atom **scattering length** should be **large** ($a_{Da}/r_0 \approx 10^7$)
- Solve STM-equation for effective 3-body system (dimer-atom-atom)
- Tune 3-body parameter Λ to reproduce results



Relative Crossing Point Positions II



Summary and Outlook

- First investigation into behaviour of heteronuclear trimer and tetramer at dimer threshold
- Trimer and tetramer cross into the dimer at almost the same point
- Results for crossing difference seem inconsistent
  $\rightarrow$ more data points are needed
- Next steps: investigate dependence on potential shape and 3-body potential strength