Lifetime-analysis of three-body resonance states

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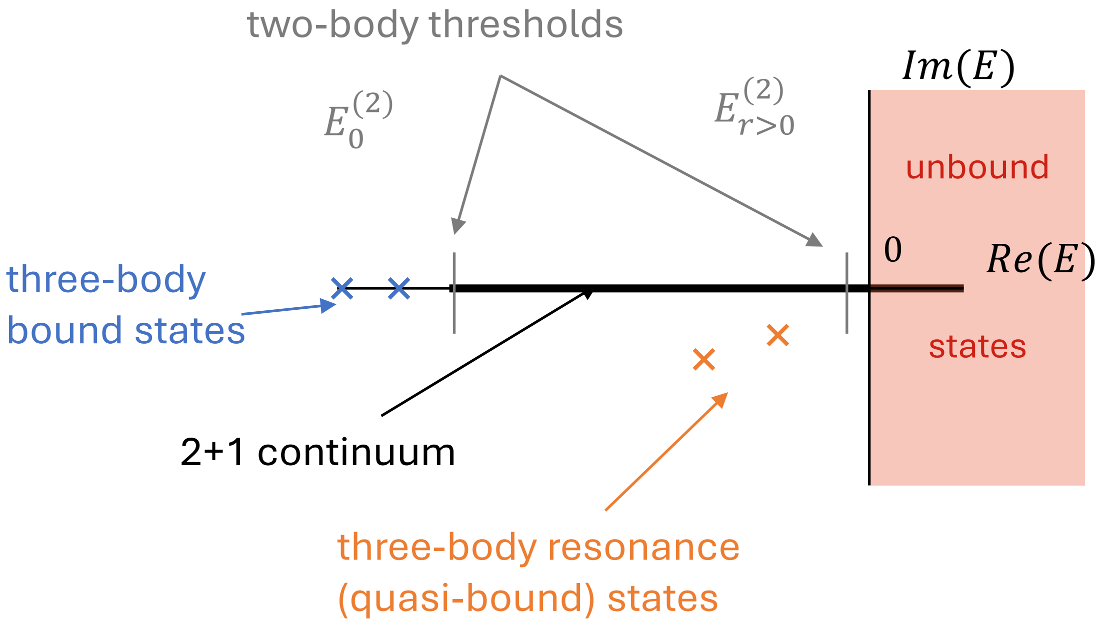
What is a resonance state?



complex energy

$$E = E_R - \frac{i}{2}\Gamma$$

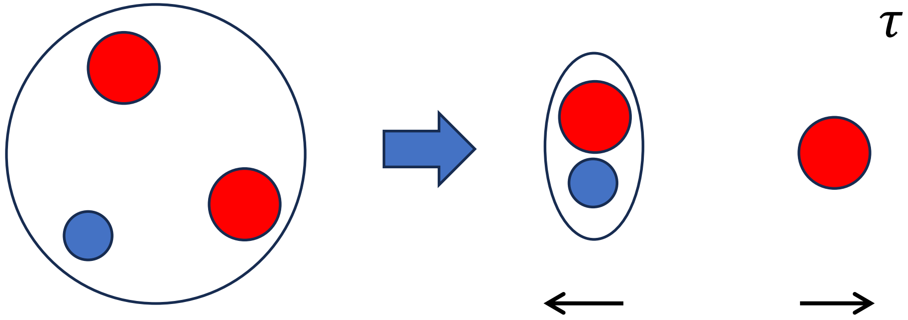
Survival probability

$$P(t) = |\langle\psi|e^{-i\hat{H}t/\hbar}|\psi\rangle|^2 = e^{-\Gamma t/\hbar}$$

Gadella, *Found Phys* **45**, 177 (2015)

Lifetime

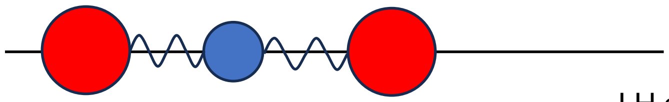
$$\tau = \frac{\hbar}{\Gamma} = \frac{-\hbar}{2\,Im(E)}$$



Predissociation

Motivation

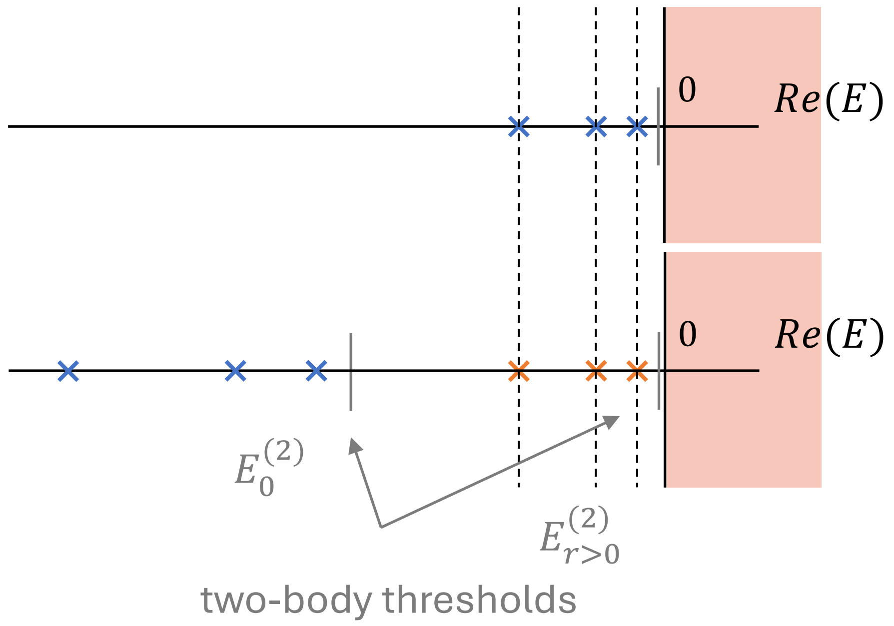
1D



LH et al., *JPB* **55**, 015301 (2022)

Realizable in cold-atom experiments

Energy spectrum:

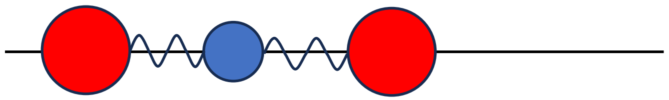


$Re(E)$ of resonance states converges smoothly to values for bound states

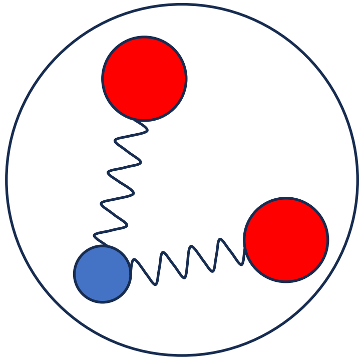
➢ Why are resonance states so stable in this 1D system?

System & Method

1D



3D



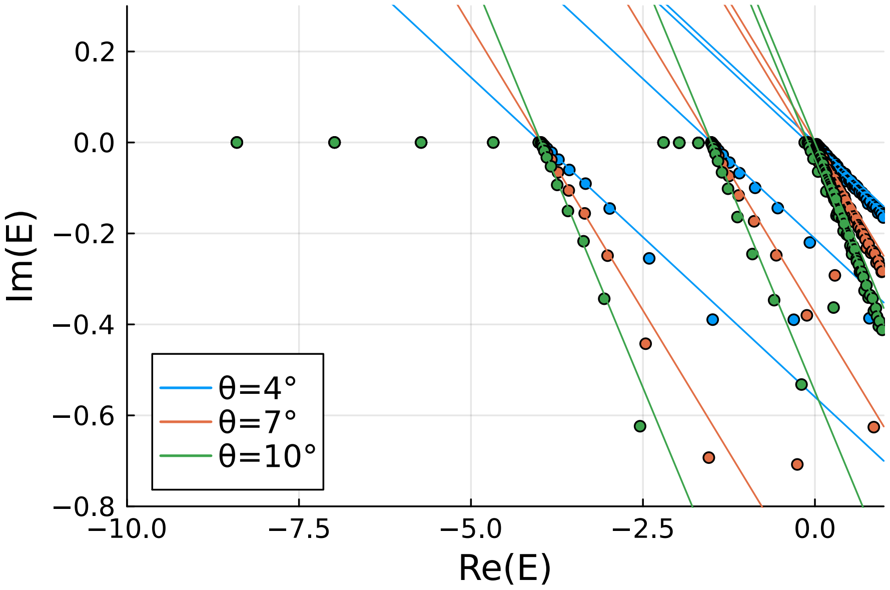
Gaussian interaction $V(r) = v_0 e^{-\left(r/r_0\right)^2}$ Deltuva et al., *PRC* **102**, 064001 (2020)

Fixed $E'_{2B} = {E_{2B}}/{E_{char}} = -0.1$ $E_{char} = \frac{\hbar^2}{2\,\mu_{hl} r_0^2}$ $(a \simeq 3\, r_0)$ → close to unitarity

$Im(E)$ via complex scaling method (CSM)

1D vs 3D

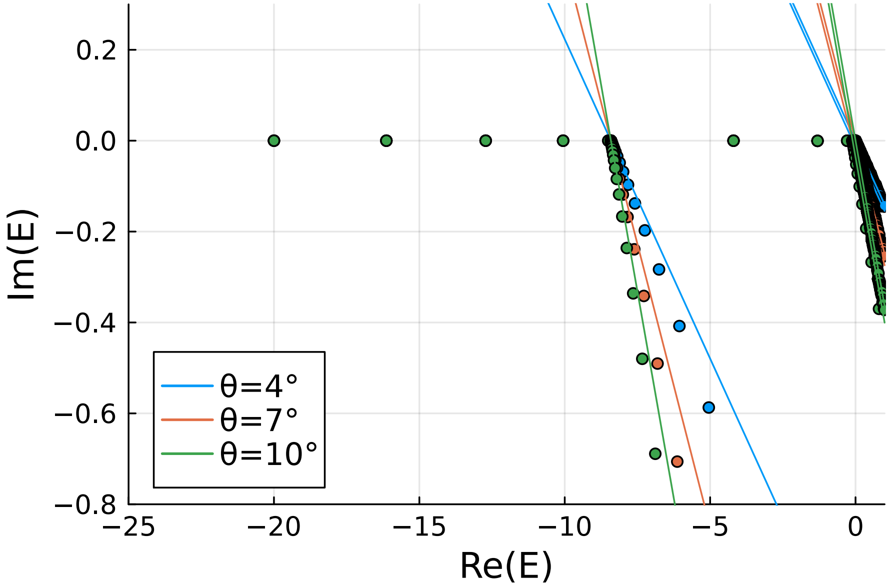
1D



1D: all parity waves

$$\frac{M}{m} = \frac{87(Rb)}{7(Li)}$$

3D



3D: only s-wave

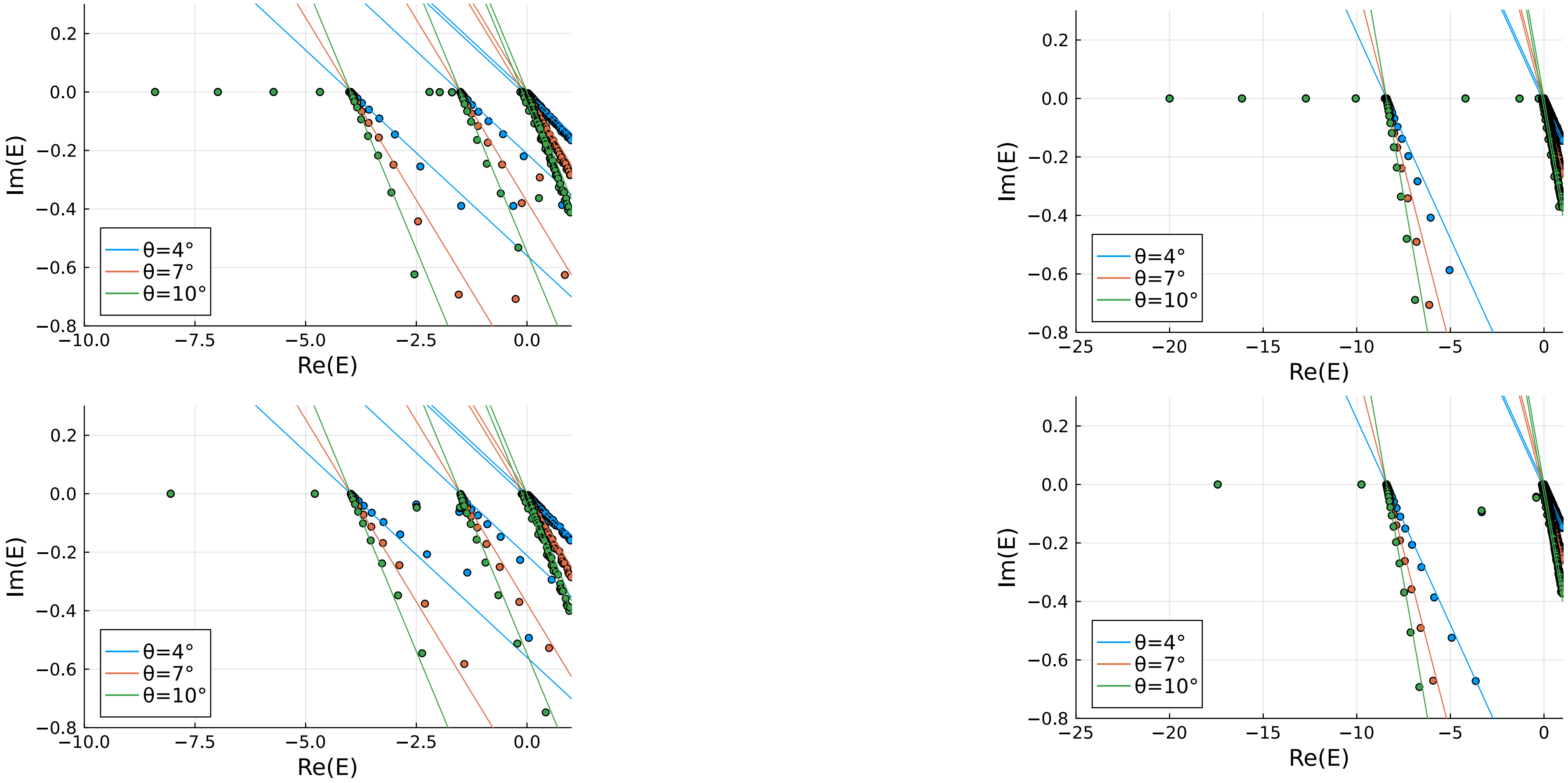
$$Im(E) \simeq 0 \pm 10^{-5}$$

Reducing the mass ratio

1D 3D

$$\frac{M}{m} = \frac{87}{7}$$

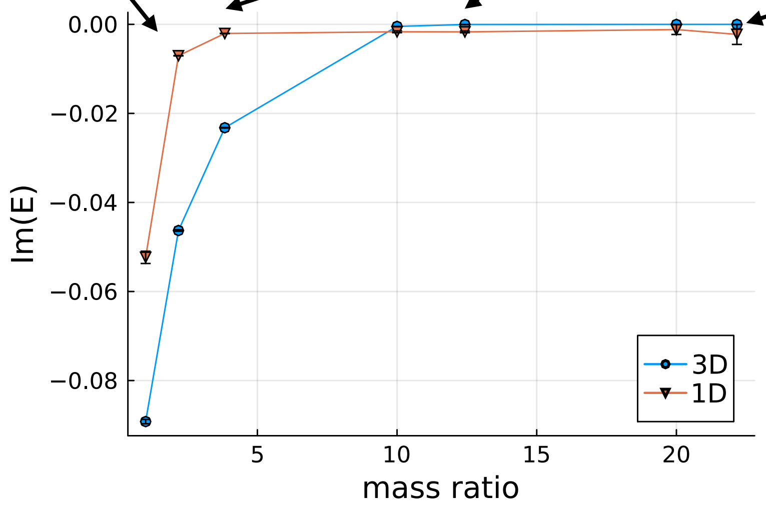
$$\frac{M}{m} = 1$$



➢ larger mass ratio has decreased $Im(E)$ for both 1D & 3D

Lifetime vs mass ratio

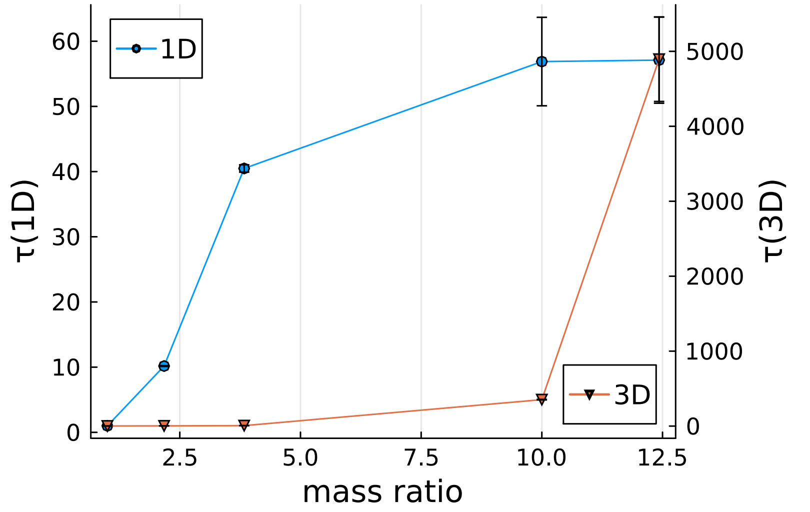
$^{87}Rb - {}^{40}K$ $\quad$ $^{23}Na - {}^{6}Li$ $\quad$ $^{87}Rb - {}^{7}Li$ $\quad$ $^{133}Cs - {}^{6}Li$



Here: „deepest“ resonance state

$$\tau = \frac{\hbar}{\Gamma} = \frac{-\hbar}{2\, Im(E)}$$

Scaled by $\tau(M = m) \simeq \begin{cases} 4\, ns, & 1D \\ 2\, ns, & 3D \end{cases}$



$\tau_{3D}\left({}^{23}/_{6}\right) \simeq 15\, ns$

Experiment: $\tau\left({}^{23}Na - {}^{6}Li\right) \simeq 60\, ns$

Son et al., *Science* **375**, 1006 (2022)

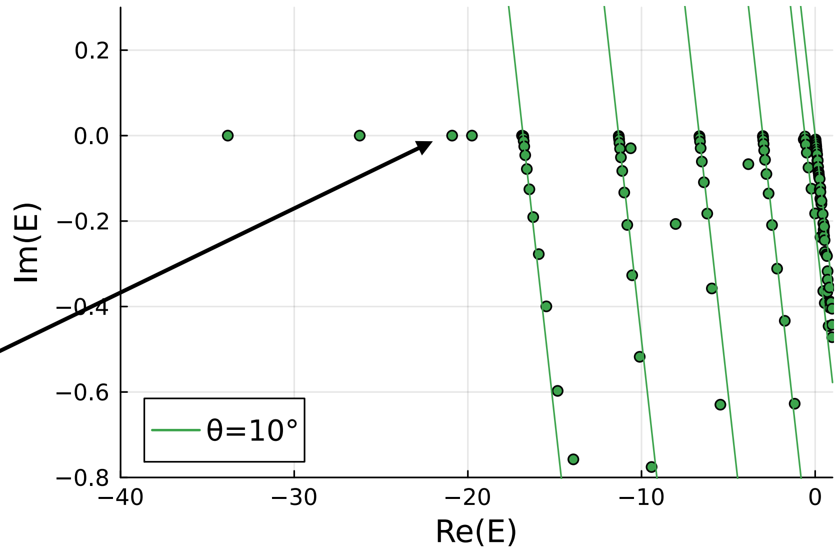
- larger mass ratio has increased lifetime for both 1D & 3D
- Masses effect the continuum via the kinetic energy

Transition 3D to 1D: fixed v_0

Keeping E_{2B} constant is challenging in 3D to 1D transition

→ now: fixed interaction strength $v_0^{1D} = v_0^{3D}$

1D



Former resonance state becomes bound

Summary & Outlook

Summary:

- Larger mass ratio can lead to stabilization of resonance states
- Reasonable agreement with experiment

Outlook:

- Universality (variation of r_0)
- Fermionic system (suppressed near-field probability)
- Analyze higher partial waves