

The Similarity Renormalization Group with Spurious Deep Bound States

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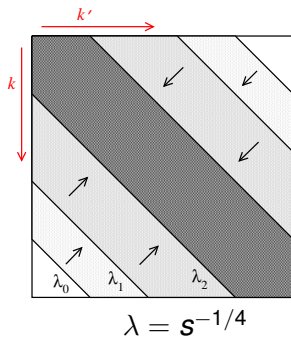
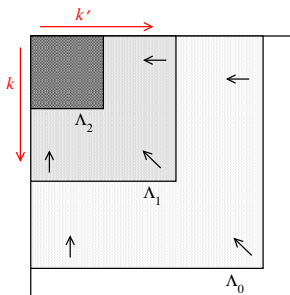


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What Is SRG?

The Similarity Renormalization Group (SRG)

- Taken as a unitary transform
 - $H_s = U_s H_{s=0} U_s^\dagger \Leftrightarrow \frac{d}{ds} H_s = [\eta_s, H_s] = [[G_s, H_s], H_s]$
 - G_s must be hermitian
- Decouples low and high momentum degrees of freedom.



$$\frac{d}{ds} H_S = [[G_S, H_S], H_S]$$

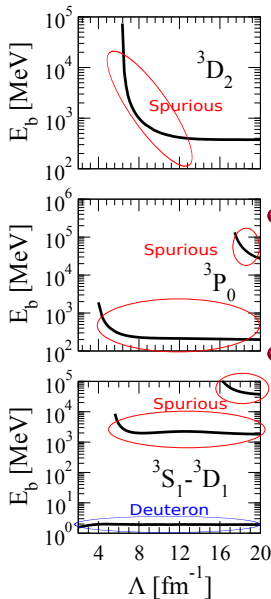
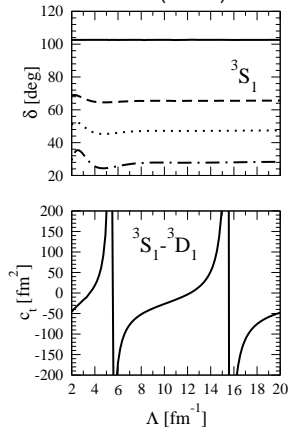
- T_{rel} — Relative kinetic energy:
 - $T_{rel} |k\rangle = \frac{\hbar^2 k^2}{M} |k\rangle$
 - Has been used in most srg nuclear evolutions
 - Decoupling for nuclear potentials (such as N3LO, AV18)
- H_d (Wegner):
 - Diagonal of Hamiltonian: $H_d = T_{rel} + V_{diagonal}$
 - Used in flow equations for condensed matter
 - **Has different decoupling properties than T_{rel} !!**
(Glazek and Perry PRD **78** (2008))
 - Difference only manifests when $\lambda \lesssim \sqrt{M E_{bound}}$
 - No difference for N3LO, AV18

Chiral Effective Field Theory At Leading Order

Testing
renormalization
 $2 \text{ fm}^{-1} < \Lambda < 20 \text{ fm}^{-1}$

Nogga et al.

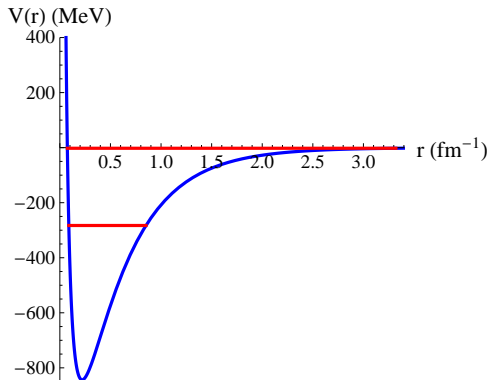
PRC 72 (2005)



● Spurious deep bound states at large Λ

● Want to understand how SRG handles decoupling such states

Toy Model

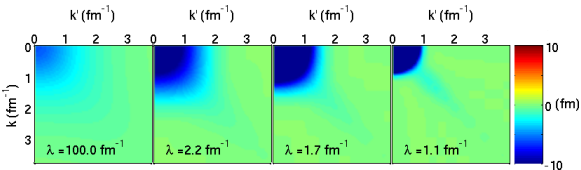


Tweaked Malfliet-Tjon

$$V(r) = A_1 \frac{e^{-M_1 r}}{r} - A_2 \frac{e^{-M_2 r}}{r}$$

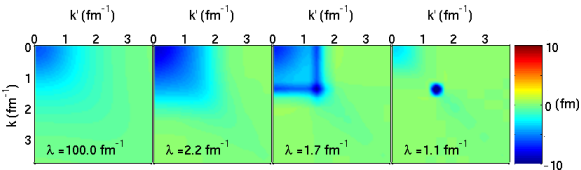
- Increase attraction to add deep bound state
- **2.23 MeV** and **283 MeV**

Model Evolution



$$T_{rel}$$

- Deep state to low mom.
- Truncation will keep spurious state.
- Truncation may remove physical state!!!!



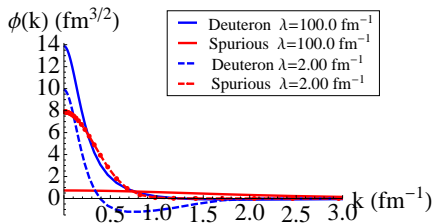
$$H_d$$

- Deep state to high mom.
- May be able to truncate!
- For $\lambda \lesssim \sqrt{ME_{bound}}$ spurious state decouples (Glazek and Perry)

Model Bound State Evolution

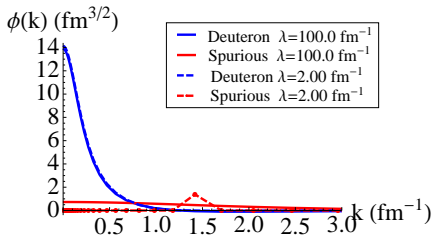
Bound State Wave-Functions

T_{rel}



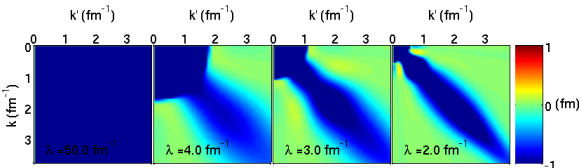
- Both the physical and spurious states are pushed to low momentum
- Their wave functions have a lot of overlap

H_d



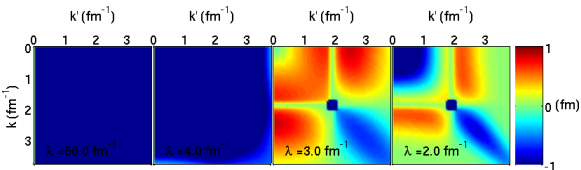
- The physical state is left nearly untouched
- The spurious state is pushed to high momentum
- No overlap

One Pion Exchange + One Counterterm Evolution



$$T_{rel}$$

- Deep state to low mom.
- Truncation will keep spurious state.
- Truncation may remove physical state!!!!

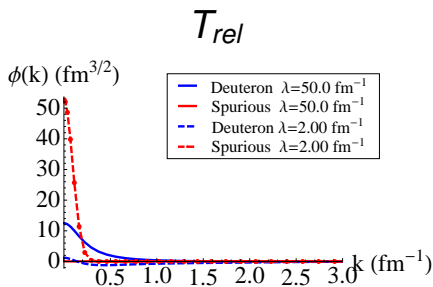


$$H_d$$

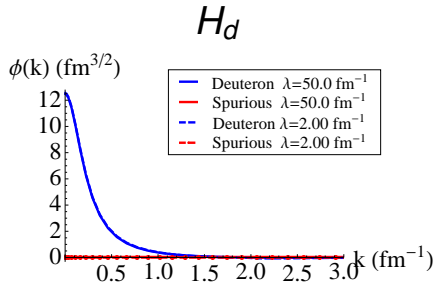
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One Pion Exchange + One Counterterm Bound States

Bound State Wave-Functions

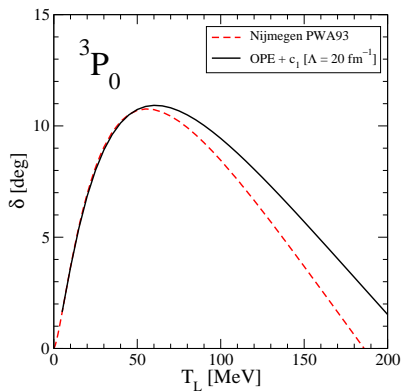


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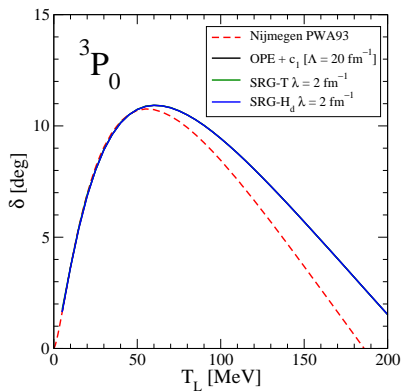
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One Pion Exchange + One Counterterm Phase Shifts



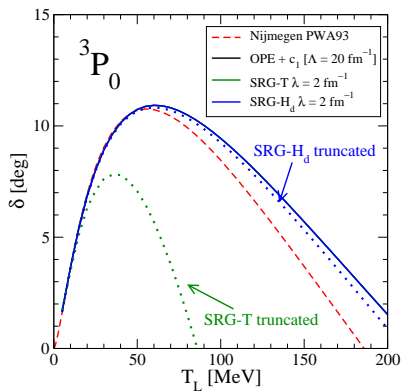
- One Pion Exchange matches Nijmegen for small k

One Pion Exchange + One Counterterm Phase Shifts



- One Pion Exchange matches Nijmegen for small k
- SRG for both T_{rel} and H_d match OPE

One Pion Exchange + One Counterterm Phase Shifts



- One Pion Exchange matches Nijmegen for small k
- SRG for both T_{rel} and H_d match OPE
- Decoupling of evolved Hamiltonian is much better for H_d than T_{rel}

- Summary

- T_{rel} and H_d have different decoupling properties
- Difference is **critical** for EFT with large cutoff
- T_{rel} contaminates the physical bound state
- Truncation with H_d leads to better convergence

- Outlook

- Same behavior in 1D and 3D models
 - Laboratory to explore decoupling effects!
- Further study of renormalization with large EFT Λ
 - Explore effects of different EFT regulators on SRG
 - Explore effects of removing spurious states



Stanisław D. Głazek and Robert J. Perry.

Impact of bound states on similarity renormalization group transformations.

Phys. Rev. D, 78(4):045011, Aug 2008.



A. Nogga, R. G. E. Timmermans, and U. van Kolck.

Renormalization of one-pion exchange and power counting.

Phys. Rev. C, 72(5):054006, Nov 2005.