Similarity Renormalization Groups (SRG) for nuclear forces

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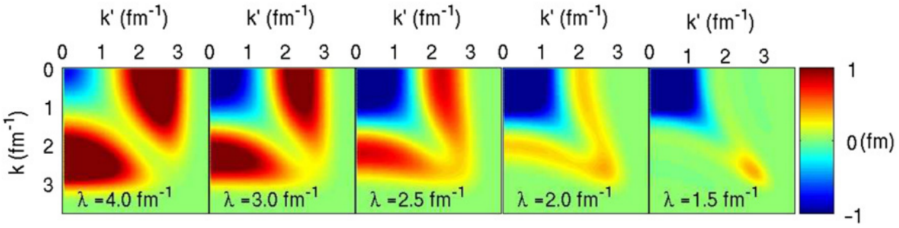

Introduction

The talk on Similarity Renormalization Groups (SRG) as a part of the seminar on nuclear structure and nuclear astrophysics is outlined here. It will begin with a short introduction to the basics of Effective Field Theory (EFT) before motivating the use of Renormalization Group (RG) methods. The principles of SRG are explained and a basic flow equation is derived. Problematic issues such as the inclusion of 3-body forces and higher are mentioned. The presentation ends after showing an application of SRG in No Core Shell Model (NCSM) calculations.

Renormalization groups in low-energy nuclear physics

The theory of low-energy nuclear physics describes scattering processes and the structure and behavior of nuclei. The nucleon potentials serve as the input to all calculations and therefore play a crucial role. Unfortunately, phenomenological potentials directly derived from experiments show a high coupling between low and high momenta and a strong repulsive core. Renormalization Groups are of great use as they can transform potentials to be more perturbative.

This greatly suits the EFT approach which relies on a separation of energy scales. Since low energies are equivalent to a low resolution (deBroglie wavelengths), short-ranged details are not resolved and can therefore be changed without distorting the observables of interest.

Similarity Renormalization Groups

Basis transformations by insertion of a $\mathbb{1}$ are commonly used in quantum mechanics:

$$E = \langle\Psi|H|\Psi\rangle = \langle\Psi|\underbrace{U^\dagger U}_{\mathbb{1}} HU^\dagger U|\Psi\rangle$$
$$= \langle\widetilde{\Psi}|\widetilde{H}|\widetilde{\Psi}\rangle$$

With a good choice of U, an effect as schemed at the top of this page can be achieved - the reduction of off-diagonal matrix elements in favor of on-diagonal elements. The importance of this is easily understood when the large matrix sizes that are common in numerical calculations are accounted for.

In SRG, flow equations determine a steady evolution of the potential. For a simple case, it is shown that the following relation holds:

$$\frac{\mathrm{d}V_\lambda}{\mathrm{d}\lambda}(k,k') \approx -(\epsilon_k - \epsilon_{k'})^2 V_\lambda(k,k')$$

A drawback of an exorbitant evolvement is that many-body forces increase which are difficult to handle.

Application of SRG in NCSM calculations

The NCSM is a method to perform ab-initio calculations for light nuclei (A $\leq$ 24) in an harmonic oscillator basis. The total excitation energy and the maximum amount of energy levels (shells) are varied to find convergence. Since NCSM relies on large scale matrix diagonalizations, it can be a well-suited application for SRG.