Advancing the Microscopic Relativistic Description of Nuclear Excitations: From Second Tamm-Dancoff Approximation to Second Random Phase Approximation

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A detailed understanding of nuclear collective excitations and astrophysical processes necessitates theoretical approaches that surpass the limitations of the Random Phase Approximation (RPA). While RPA has been instrumental in describing small-amplitude oscillations in nuclei, its simplicity, rooted in the 1 particle - 1 hole (1p1h) configuration space, leads to its limitations to account for the fragmentation of nuclear strength, the spreading width, and the neglect of multi-particle correlations crucial for describing higher-order phenomena.

To resolve these limitations, we have developed and applied a fully self-consistent relativistic Second Tamm-Dancoff Approximation (STDA) and Second Random Phase Approximation (SRPA) framework, which incorporates 2 particle - 2 hole (2p2h) configurations. Both methods are grounded in relativistic nuclear energy density functional theory, providing a microscopic foundation for the description of nuclear excitations.

Our work focuses on isoscalar and isovector monopole, quadrupole, and dipole transitions in ^{16}O, ^{40}Ca, and ^{40}Ca. The subtraction method was employed to consistently eliminate double-counting effects and ultraviolet divergence. Using the relativistic contact interaction with DD-PC1 parametrization in the particle-hole channel, we analyzed the excitation spectra and the percentage of sum rule exhaustion.

We explored the impact of the subtraction method by comparing results with and without its application in both SRPA and STDA. Preliminary SRPA results for selected transitions provide a perspective for further analysis of higher-order correlations. These findings emphasize the importance of complex configurations and the subtraction method in achieving a detailed microscopic description of nuclear collective phenomena.