# *Ab-initio* no-core shell-model study for lighter nuclei

Praveen C. Srivastava*
*Department of Physics, Indian Institute of Technology Roorkee, Roorkee-247667, INDIA*

The aim of modern nuclear theory is to develop novel techniques. Progress has been made in the development of different modern many-body *ab initio* approaches, one of them being the no-core shell model (NCSM) [1]. *Ab initio* methods are more fundamental compared to the nuclear shell model.

In NCSM, all nucleons are treated as active, which means there is no assumption of an inert core, unlike in the standard shell model. Atomic nucleus is described as a system of nonrelativistic nucleons which interact by realistic $NN$ or $NN + 3N$ interactions. In our work, we have considered only realistic $NN$ interactions between the nucleons. The Hamiltonian for the A nucleon system is given by

$$H_A = T_{rel} + V = \frac{1}{A}\sum_{i<j}^{A}\frac{(\vec{p}_i - \vec{p}_j)^2}{2m} + \sum_{i<j}^{A} V_{ij}^{NN},$$

where $T_{rel}$ is the relative kinetic energy, $m$ is the mass of nucleon, and $V_{ij}^{NN}$ is the realistic $NN$ interaction that contains both nuclear and electromagnetic (Coulomb) parts. In the NCSM, translational invariance as well as angular momentum and parity of the nuclear system are conserved. The many-body wave function is cast into an expansion over a complete set of antisymmetric $A$-nucleon harmonic oscillator (HO) basis states containing up to $N_{max}$ which is HO excitations above the lowest possible configuration. We use a truncated HO basis while the realistic $NN$ interactions act in the full space.

To solve the Schrödinger equation of A nucleons system, the full Hilbert space is split into two parts which are finite model space (P) that contains all HO basis states up to $N_{max}$ and the remaining model space Q (= 1 - P). Thus, final NCSM calculations are performed in the P model space. To derive effective Hamiltonian, two renormalization procedures are implemented that are the Okubo-Lee-Suzuki (OLS) scheme and the Similarity Renormalization Group (SRG).

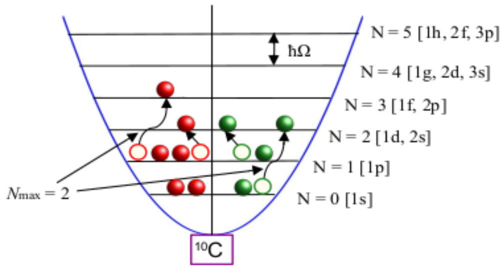


FIG. 1: Illustration of $N_{max} = 2$ configurations in HO basis for $^{10}$C.

There are two parameters: $N_{max}$ and $\hbar\Omega$, that control the computational requirement and convergence of results. In Fig. 1, the configuration corresponding to $N_{max} = 2$ HO basis is shown. Large $N_{max}$ calculations are necessary to obtain converged results while dealing with hard-core potentials. But, large $N_{max}$ calculations are computationally challenging and to avoid such huge computational resources Okubu-Lee-Suzuki (OLS) transformation is used.

We have initiated project based on NCSM study of nuclei in the lower mass region. The results of B, C, N, O, F, and Ne chain were reported in Refs. [2, 3, 4, 5, 6, 7]. The dimension corresponding to C and B chains are shown in Fig. 2. In particular, we have applied the inside nonlocal outside Yukawa (INOY), charge-dependent Bonn 2000 (CDB2K), the chiral next-to-next-next-to-leading order (N3LO), and optimized next-to-next-to-leading order ($N2LO_{opt}$) interactions to study energy spectra, electromagnetic

*praveen.srivastava@ph.iitr.ac.in

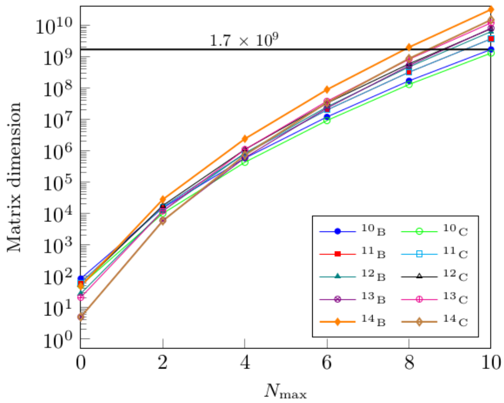


FIG. 2: Dimension of the Hamiltonian matrices for $^{10-14}$B and $^{10-14}$C isotopes corresponding to different $N_{max}$ is shown. The horizontal line indicates the limit of computational facility.

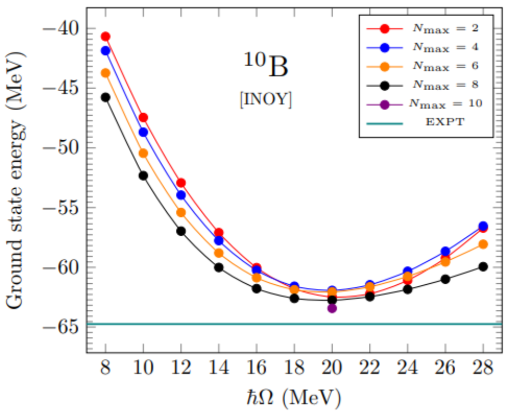


FIG. 3: Ground state energy of $^{10}$B as a function of HO frequency for different $N_{max}$.

properties, and point-proton radii. The experimental ground state spin $3^+$ of $^{10}$B has been reproduced using the INOY $NN$ interaction. Typically, the $3N$ interaction is required to correctly reproduce the aforementioned state. In Fig. 3 we have shown g.s. energy of $^{10}$B corresponding to different $N_{max}$.

With increasing mass numbers, the dimension of the Hamiltonian matrix increases in the NCSM method, which becomes computationally challenging. Thus we have applied no-core shell-model with core approach to study upper *sd* shell nuclei [8, 9, 10]. All these results will be presented during meeting.

## Acknowledgments

We acknowledge financial support from SERB (India), CRG/2019/000556.

## References

[1] B. R. Barrett, P. Navrátil and J. P. Vary, Ab initio no core shell model, Prog. Part. Nucl. Phys. **69**, 131 (2013).

[2] P. Choudhary, P. C. Srivastava and P. Navrátil, Ab initio no-core shell model study of $^{10-14}$B isotopes with realistic $NN$ interactions, Phys. Rev. C 102, 044309 (2020).

[3] P. Choudhary, P. C. Srivastava, M. Gennari and P. Navrátil, Ab initio no-core shell-model description of $^{10-14}$C isotopes, Phys. Rev. C **107**, 014309 (2023).

[4] P. Choudhary and P. C. Srivastava, Ab initio no-core shell model study of neutron-rich $^{18,19,20}$C isotopes, Nucl. Phys. A **1029**, 122565 (2023).

[5] A. Saxena and P. C. Srivastava, *Ab initio* no-core shell model study of neutron-rich nitrogen isotopes, Prog. Theor. Exp. Phys. **2019**, 073D02 (2019).

[6] A. Saxena and P. C. Srivastava, *Ab initio* no-core shell model study of $^{18-23}$O and $^{18-24}$F isotopes, J. Phys. G: Nucl. Part. Phys. **47**, 055113 (2020).

[7] C. Sarma and P. C. Srivastava, *Ab initio* no-core shell-model study of $^{18-24}$Ne isotopes, J. Phys. G: Nucl. Part. Phys. **50**, 045105 (2023).

[8] S. Sahoo, P. C. Srivastava, T. Suzuki, Study of structure and radii for $^{20-31}$Na isotopes using microscopic interactions Nucl. Phys. A **1032**, 122618 (2023).

[9] P. Choudhary and P. C. Srivastava, Nuclear structure properties of Si and P isotopes with the microscopic effective interactions, Nucl. Phys. A **1033**, 122629 (2023).

[10] P. Choudhary and P. C. Srivastava, Study of S, Cl and Ar isotopes with $N \geq Z$ using microscopic effective sd-shell interactions Eur. Phys. J. A **59**, 97 (2023).