Proof-of-principle calculations in the *ab initio* no-core Monte Carlo shell model[†]

T. Abe,[*1] P. Maris,[*2] T. Otsuka,[*3,*1,*4] N. Shimizu,[*5] Y. Utsuno,[*4,*5] and J. P. Vary[*2]

Understanding of nuclear structure from first principles is a major challenge in low-energy nuclear theory. This challenge includes not only the confirmation of existing experimental data but also the predictions where the experimental information has not been available yet. In addition, one hopes to extract a detailed understanding of a variety of complex nuclear phenomena, described by successful nuclear models, from the underlying microscopic descriptions. Under these motivations, a number of *ab initio* investigations have been actively done for more than a decade. This trend in *ab initio* studies has been supported by the rapidly growing computational power of supercomputers and continuing improvements of *ab initio* techniques for nuclear many-body calculations.

Here we report the proof-of-principle calculations in the *ab initio* no-core Monte Carlo shell model (MCSM).[1)] This is the extension of the MCSM with an assumed inert core[2–4)] to the *ab initio* no-core shell model.[3–5)] Ground-state energies are obtained in the basis spaces up to seven harmonic oscillator (HO) major shells ($N_{\rm shell}$ = 7) with several HO energies, $\hbar\omega$, around the optimal $\hbar\omega$ for the convergence of ground-state energies. These energy eigenvalues are extrapolated to obtain estimates of converged ground-state energies in each basis space using energy variances of computed energy eigenvalues. We further extrapolate these energy-variance-extrapolated energies obtained in the finite basis spaces to infinite basis-space results.

Figure 1 shows our results with two nonlocal NN interactions[6,7)] in comparison with the experimental data.[8)] In Fig. 1, the JISP16[6)] and Daejeon16[7)] results are shown by blue and red symbols, respectively, with estimated error bars from our fit to $N_{\rm shell}$ = 4–7 results at their respective optimal $\hbar\omega$ values. From Fig. 1, the JISP16 results yield overbinding at ^{12}C and beyond. An improved picture emerges using Daejeon16 with some overbinding still evident when compared with experiments. There are encouraging trends with the Daejeon16 results compared with the JISP16 results. However, this finding suggests the necessity of further revisions of nonlocal NN interactions for the heavier-mass region beyond the p shell and/or the explicit inclusion of a $3N$ interaction. Note that the no-core MCSM results are in reasonable agreement with the other *ab initio* results with the same interactions where those are available.

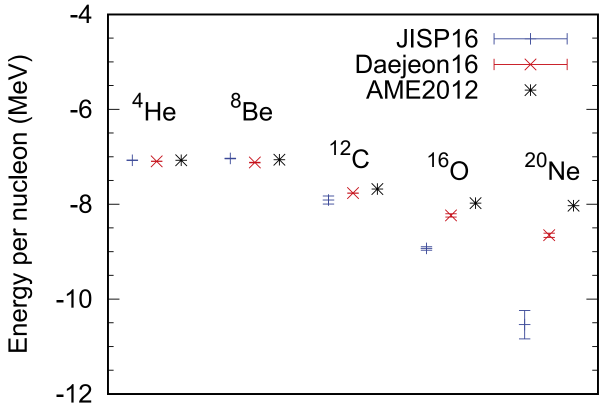

Fig. 1. Comparison of the no-core MCSM results for the energy per nucleon with the JISP16[6)] and Daejeon16[7)] NN interactions to experimental data.[8)] The MCSM results are shown for the basis-space extrapolations using the $N_{\rm shell}$ = 4–7 energy-variance-extrapolated results with the respective optimal $\hbar\omega$ values.

The current study offers a foundation for pathways to investigate nuclear structure from first principles, for instance, α-cluster structure and dineutron correlations of valence neutrons on the p-shell nuclei. Also the sd-shell nuclei and beyond continue to provide rich insights into emergent nuclear phenomena. With improved nuclear interactions and increasingly precise *ab initio* tools for nuclear many-body calculations such as the no-core MCSM, we expect an opportunity to probe these emergent phenomena and, at the same time, to probe the limits of our knowledge of the strong and electroweak interactions.

References
1) T. Abe *et al.*, Phys. Rev. C **104**, 054151 (2021).
2) T. Otsuka *et al.*, Prog. Part. Nucl. Phys. **47**, 319 (2001).
3) N. Shimizu *et al.*, Prog. Theor. Exp. Phys. **2012**, 01A205 (2012).
4) N. Shimizu *et al.*, Phys. Scr. **92**, 063001 (2017).
5) T. Abe *et al.*, Phys. Rev. C **86**, 054301 (2012).
6) A. M. Shirokov *et al.*, Phys. Lett. B **644**, 33 (2007).
7) A. M. Shirokov *et al.*, Phys. Lett. B **761**, 87 (2016).
8) G. Audi *et al.*, Chin. Phys. C **36**, 1603 (2012).

† Condensed from the article in Phys. Rev. C **104**, 054315 (2021)

*1 RIKEN Nishina Center
*2 Department of Physics and Astronomy, Iowa State University
*3 Department of Physics, University of Tokyo
*4 Advanced Science Research Center, Japan Atomic Energy Agency
*5 Center for Nuclear Study, University of Tokyo