We aim to solve the nuclear quantum many-body problem for large and unstable nuclei including those that are near the neutron drip line using coupled-cluster theory. Within the next five years using peta-scale computing resources we believe an achievable goal will be mass 100 nuclei. The nuclear theory group at ORNL employs Coupled Cluster theory in order to pursue this goal. Such calculations are linked to various experimental programs at HRIBF and other present and future low-energy nuclear facilities.

The first problem involves solving the coupled-cluster equations in the presence of scattering and continuum basis states. This enables a description of very weakly bound nuclei near the drip line. We can also obtain from such calculations life times for unbound nuclei. We recently applied our complex coupled-cluster technique to $^{4\text{-}10}$He nuclei. Figure 1 shows the masses and the widths (inset) in huge basis spaces where the single-particle continuum includes angular momentum 0, 1, and 2 (s,p, and d) orbitals. The many-body dimension of this problem reaches $10^{20}$, more than 11 orders of magnitude larger than the largest Hamiltonian diagonalization calculations performed in nuclear physics today. These results are practically converged with model space and cluster amplitudes. Clearly from the figure, there remains a binding issue which is thought to be due to the three-body force, not present in these calculations.

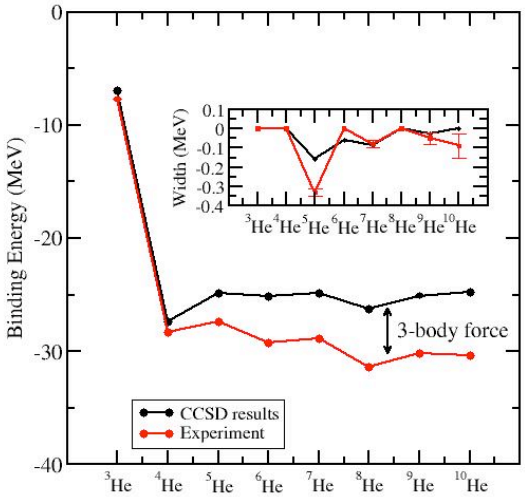


**Figure 0: Complex CCSD energies for He isotopes; inset, widths**

We recently built capability within the coupled-cluster formalism to solve problems that include three-body interactions. We applied our formalism to $^4$He and $^{16}$O. Shown in the figure are the $^4$He results with and without the three-body force and as a function of increasing basis states. Our largest calculations are converging to the known results for this nucleus and Hamiltonian, and we are therefore well on the way to performing such calculations, with reasonable expectation of success, in heavier nuclei.

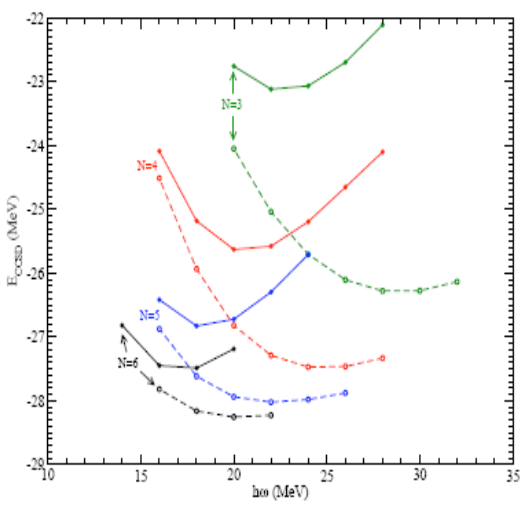


**Figure 0: CCSD with three-body interactions for 4He as a function of increasing model space**

In the future we expect to combine these two applications: performing calculations with continuum basis states and three-body forces. We also plan to perform calculations of excited states and other nuclear properties. Clearly, all of this work requires advanced computational capability afforded through the Office of Science INCITE program.