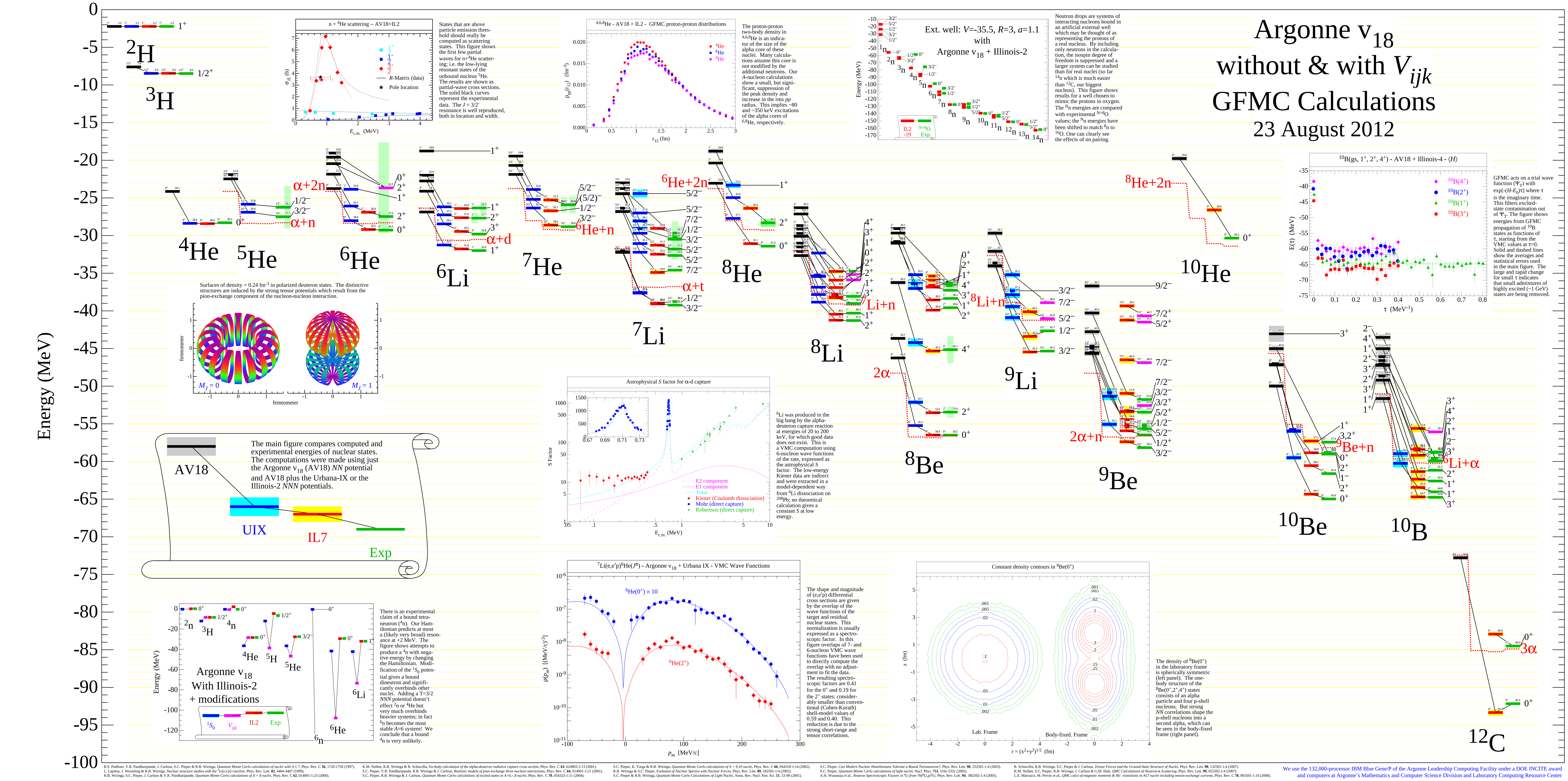


We use the 132,000-processor IBM Blue Gene/P of the Argonne Leadership Computing Facility under a DOE INCITE award and computers at Argonne's Mathematics and Computer Science Division and Laboratory Computing Resource Center

# QUANTUM MONTE CARLO FOR LIGHT NUCLEI


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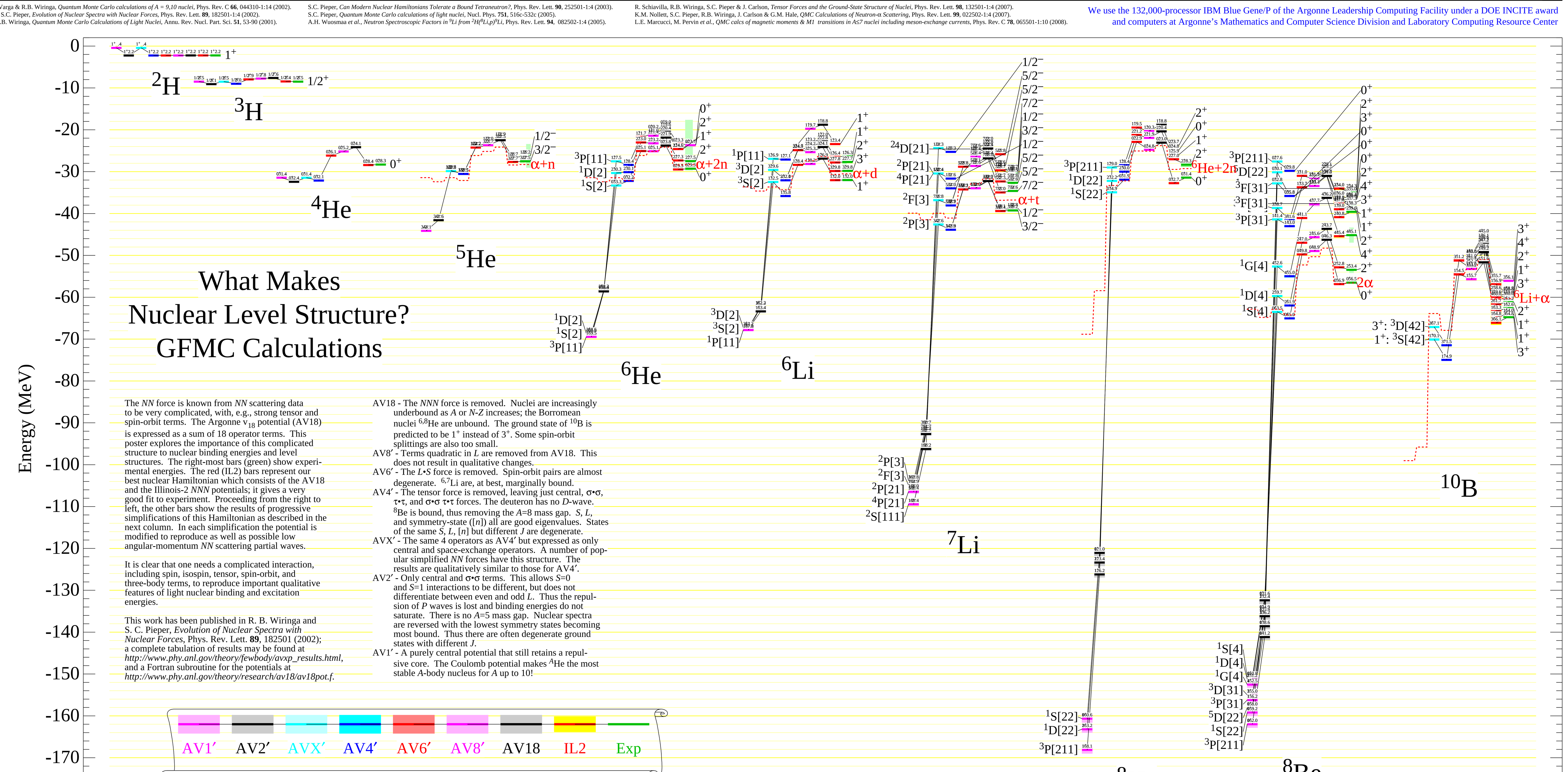


## What Makes Nuclear Level Structure? GFMC Calculations

The *NN* force is known from *NN* scattering data to be very complicated, with, e.g., strong tensor and spin-orbit terms. The Argonne $v_{18}$ potential (AV18) is expressed as a sum of 18 operator terms. This poster explores the importance of this complicated structure to nuclear binding energies and level structures. The right-most bars (green) show experimental energies. The red (IL2) bars represent our best nuclear Hamiltonian which consists of the AV18 and the Illinois-2 *NNN* potentials; it gives a very good fit to experiment. Proceeding from the right to left, the other bars show the results of progressive simplifications of this Hamiltonian as described in the next column. In each simplification the potential is modified to reproduce as well as possible low angular-momentum *NN* scattering partial waves.

It is clear that one needs a complicated interaction, including spin, isospin, tensor, spin-orbit, and three-body terms, to reproduce important qualitative features of light nuclear binding and excitation energies.

This work has been published in R. B. Wiringa and S. C. Pieper, *Evolution of Nuclear Spectra with Nuclear Forces*, Phys. Rev. Lett. **89**, 182501 (2002); a complete tabulation of results may be found at *http://www.phy.anl.gov/theory/fewbody/avxp_results.html*, and a Fortran subroutine for the potentials at *http://www.phy.anl.gov/theory/research/av18/av18pot.f*.

AV18 - The *NNN* force is removed. Nuclei are increasingly underbound as *A* or *N-Z* increases; the Borromean nuclei $^{6,8}$He are unbound. The ground state of $^{10}$B is predicted to be $1^+$ instead of $3^+$. Some spin-orbit splittings are also too small.

AV8′ - Terms quadratic in *L* are removed from AV18. This does not result in qualitative changes.

AV6′ - The $L\cdot S$ force is removed. Spin-orbit pairs are almost degenerate. $^{6,7}$Li are, at best, marginally bound.

AV4′ - The tensor force is removed, leaving just central, $\sigma\cdot\sigma$, $\tau\cdot\tau$, and $\sigma\cdot\sigma\ \tau\cdot\tau$ forces. The deuteron has no *D*-wave. $^8$Be is bound, thus removing the *A*=8 mass gap. *S*, *L*, and symmetry-state ([*n*]) all are good eigenvalues. States of the same *S*, *L*, [*n*] but different *J* are degenerate.

AVX′ - The same 4 operators as AV4′ but expressed as only central and space-exchange operators. A number of popular simplified *NN* forces have this structure. The results are qualitatively similar to those for AV4′.

AV2′ - Only central and $\sigma\cdot\sigma$ terms. This allows *S*=0 and *S*=1 interactions to be different, but does not differentiate between even and odd *L*. Thus the repulsion of *P* waves is lost and binding energies do not saturate. There is no *A*=5 mass gap. Nuclear spectra are reversed with the lowest symmetry states becoming most bound. Thus there are often degenerate ground states with different *J*.

AV1′ - A purely central potential that still retains a repulsive core. The Coulomb potential makes $^A$He the most stable *A*-body nucleus for *A* up to 10!