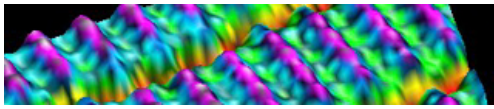

Heavenly Calculations

UTK-ORNL-Oslo Theorists Pin Down the Proton-Halo State in Fluorine-17

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A halo may be difficult to acquire in terms of virtue, but it can also be tough to calculate in terms of physics. Associate Professor Thomas Papenbrock and his colleagues Gaute Hagen from Oak Ridge National Laboratory and Morten Hjorth-Jensen from the University of Oslo have managed to do just that, however, and report their findings in "Ab-initio computation of the ^{17}F proton-halo state and resonances in A = 17 nuclei," published earlier this month in *Physical Review Letters*.

A halo nucleus differs from the more traditional nuclei because it has one or more nucleons (protons or neutrons) that are only weakly bound to the nuclear core. Consequently, they drift far away from it, forming, in effect, a halo. These nuclei are difficult to study because their lives are both short (often lasting only milliseconds) and fragile. Halo nuclei appear at the limits of nuclear existence, very near a placed called the dripline. This is the perilous territory where the number of protons and the number of neutrons are plotted against each other and one too many of either means the nucleus will not hold together. Halo nuclei also come with a large number of degrees of freedom—independent configurations required to explain how a system is built.

Hagen, Hjorth-Jensen and Papenbrock set out to study fluorine-17, a "mirror nucleus" of oxygen-17. Each of these isotopes has an atomic number of 17, but with their protons and neutrons in flipped numbers (fluorine-17 has 9 protons and 8 neutrons, while oxygen-17 has 8 protons and 9 neutrons). Part of what makes these nuclei interesting is that they are neighbors of the most abundant and stable isotope of oxygen: oxygen-16. They determine its proton and neutron energies, which are the basic ingredients of the nuclear shell model—the way protons and neutrons are arranged in a nucleus—and are also key to understanding the shell structure in fluorine and oxygen isotopes. Fluorine-17, in particular, has a "halo" formed by an excited proton orbiting far away from the oxygen-16 core that plays an important role in nucleosynthesis, the stellar processes that generate the elements that surround us.

The UTK-ORNL-Oslo team used sophisticated methods to work with the 17 interacting particles in this isotope to better understand it. This is called a many-body problem, meaning that whenever there are more than two bodies interacting with one another, it is difficult to pin down precise calculations of the system. Starting at the beginning (or *ab initio*, in Latin) the team began with a nuclear Hamiltonian, the operator that describes the energy of a system in terms of its momentum and positional coordinates. They also used the coupled-cluster method — a numerical technique that solves such quantum many-body problems — and ORNL's supercomputer Jaguar to successfully complete first-principle calculations of the proton halo state in Fluorine-17. The calculations contain no adjustable parameters and show a computed binding energy (what holds the nucleus together) that closely reflects experimental data.

The more tools scientists have to calculate the properties of nuclei—how long they live, what holds them together, and how they decay—the more clearly they can investigate the limits of nuclear existence, understand phenomenological models of the nucleus, and predict nuclear properties in applied fields like nuclear medicine or stockpile stewardship.