Expanding the Frontier

Physics students help determine the boundaries of the nuclear chart, with results published in *Nature*

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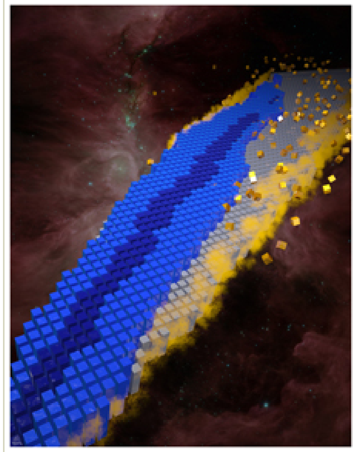

Image courtesy of ORNL

When the U.S. bought the Louisiana Territory from France in 1803, America suddenly doubled its real estate. Two hundred years later, physicists at the University of Tennessee have completed a somewhat similar feat, this time on a subatomic scale. Using sophisticated calculations, they've dramatically widened the frontier of the nuclear landscape, predicting the existence of more than double the number of known nuclei. This expanded vista is exciting, unchartered territory, including the potential for thousands of what physicists call exotic nuclei.

While all nuclei around us reside in what scientists call the valley of stability, the rarer types live short, dramatic lives along the ragged edges of existence, pushing the limits until they no longer can and ultimately disintegrating into the ranks of their stable neighbors. Yet their fame, while fleeting, offers a window for scientists to see where the boundaries begin to unravel in the chart of the nuclides, and UT physics faculty and students have added significantly to that body of knowledge in a new *Nature* paper.

There are 288 nuclei (stable or nearly so) found in nature, comprising 99.9 percent of the world around us. Some 3000 more have been synthesized in laboratories. Creating these new isotopes involves adding nucleons: protons or neutrons. The more protons or neutrons added to a stable nucleus, the farther it moves from the valley of stability and the deeper it edges into the realm of the exotic. This migration, however, doesn't come without peril. Add too many protons or neutrons and there is simply not enough binding energy to hold the nucleus together, so it either emits particles or splits into smaller parts to decay into a more stable state. These limits are known as the proton and neutron driplines because the protons and neutrons drip off the nucleus as it disintegrates. But where are these boundaries? And why do they matter?

In "The Limits of the Nuclear Landscape," Physics Professor Witold Nazarewicz, postdoc Jochen Erler, undergraduates Noah Birge and Alex Perhac, graduate student Erik Olsen, postdoc Markus Kortelainen (currently back in Finland) and the late Mario Stoitsov, a UT research professor, examined these questions. The chart of the nuclides is a work in progress, with new isotopes added every year, including 100 in 2011 alone. To help map the current borders as a benchmark, UT's physicists used the nuclear density functional theory, or DFT. This tool allows scientists to calculate the energy of a nucleus at the quantum mechanical level based on the densities and currents of the neutrons and protons. They worked their way across the chart, selecting nuclei made up of even numbers of protons and neutrons, up to 120 protons and 300 neutrons.

Availing themselves of the Jaguar supercomputer at Oak Ridge National Laboratory, the team used six nuclear energy density functionals — representing complex nuclear interactions — and compared the computational results to existing data. By doing so, they were able to theoretically assess the boundaries of the nuclear landscape. They expect that 6,900 (±500) nuclei exist: more than double the number currently known.

UT's physics students made important contributions to this work. Olsen identified and counted the experimentally-known isotopes, edited figures, and compiled data; Birge and Perhac developed a code to graph data for tables and figures. As Olsen explained, having this kind of research experience is important for undergraduates who want to pursue graduate study and provides a strong foundation for graduate students to build their CVs for postdoctoral or university appointments.

While most of the isotopes they predict may never be seen, their influence will certainly be noticed. All the elements in our world were created during either the Big Bang or the life and explosive death of stars. And the astrophysical processes that generate many heavy elements (e.g., the iron in our blood or the treasures in our jewelry boxes) occur not that far from the driplines. Staking out the landscape also opens up opportunities to design nuclei with specific properties for applications in fields like medicine and energy, which means the nuclear frontier still holds some surprises.

Related Sites

- Read the paper in *Nature*
- Oak Ridge National Laboratory and ORNL Press Release
- From LIVESCIENCE: *How Many Neutrons and Protons Can Get Along? Maybe 7,000*