More than Skin Deep

UT's nuclear physicists use powerful calculations to help determine the size of the atomic nucleus

November 2, 2015

The atomic nucleus is a bit like a celebrity in the world of physics. Since Ernest Rutherford discovered it in 1911 and plucked it from obscurity, it's enjoyed fame for roles in medicine, energy, and explaining the fundamental laws of nature. And like any public figure, it also has a few secrets. UT physicists and their colleagues, however, are getting closer to unveiling them. The results of those investigations appeared in **"Neutron and weak-charge distributions of the ^{48}Ca," nucleus (http://www.nature.com/nphys/journal/vaop/ncurrent/pdf/nphys3529.pdf)** published online in *Nature Physics*.

While it's well-known that the nucleus is made up of protons and neutrons and takes up very little space in an atom, pinpointing its actual size is considerable more complex. A key to getting that information is determining the neutron distribution, a critical piece of information because it constrains the size of the nucleus and in turn impacts properties of neutron-rich systems from the very small (short-lived isotopes) to the macroscopically large (neutron stars). Finding where the neutrons lie in a nucleus determines the limits of the nuclear landscape, and as such has inspired experiments all over the world.

While protons' electric charge make it easier to accurately measure their distribution, the distribution of the neutral neutron is much more problematic to assess. Much of what scientists know about proton and neutron distributions has been gleaned from density functional theory (DFT), which describes a system in terms of proton and neutron densities and currents, rather than the nucleons themselves. Yet DFT provides what the authors of the *Nature Physics* paper call "a coarse-grained description of nuclei across the nuclear chart."

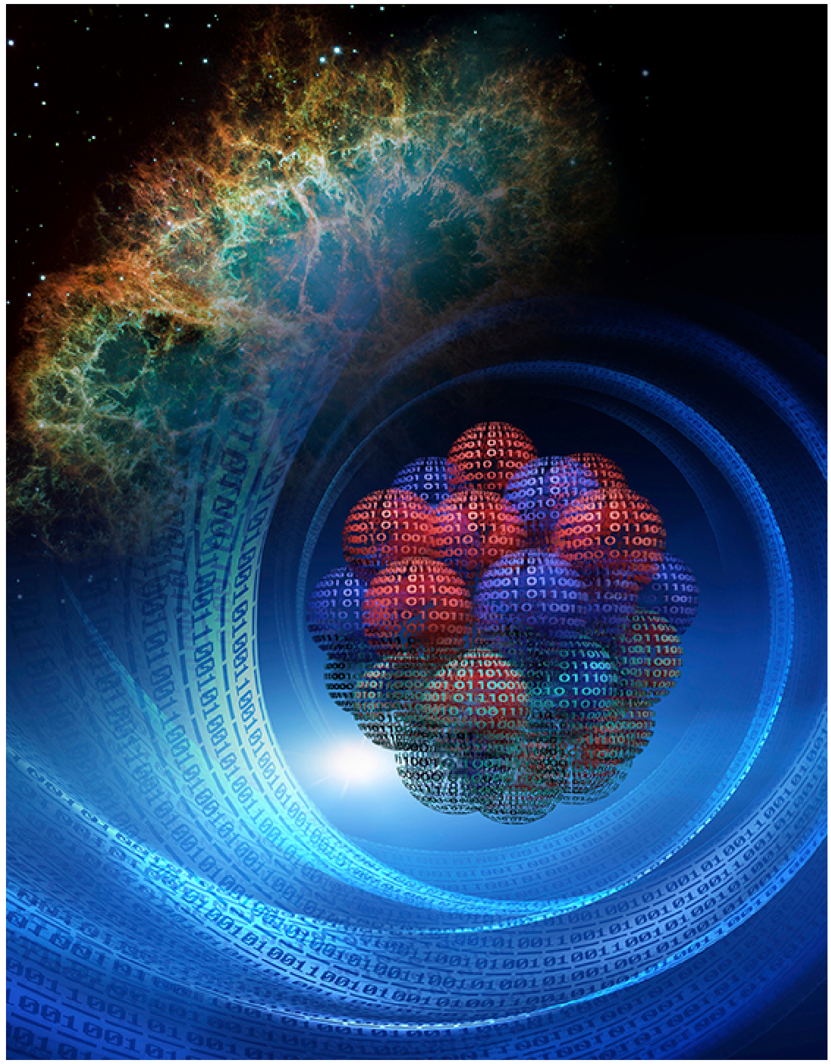

Image credit: Oak Ridge National Laboratory, U.S. Dept. of Energy; conceptual art by LeJean Hardin and Andy Sproles.

In recent years, a better understanding of how protons and neutrons are bound in the nucleus—coupled with ever-increasing computing power such as that offered by Oak Ridge National Laboratory's Titan supercomputer—has translated into tremendous advances in *ab initio* calculations. Latin for "from the beginning," *ab initio* methods solve the nuclear quantum many-body problem numerically without any uncontrolled approximations. Availing themselves of Titan's capabilities, the research team used this approach to study the neutron-rich nucleus Calcium-48 and calculate its properties. Two features distinguished themselves, both having to do with what's called the neutron skin. This "skin" is the difference between the radius of the neutron distribution and the radius of the proton distribution, with the neutrons extending beyond the protons. In contrast to DFT studies, the ab initio calculations indicate the neutron skins are not only independent of the interactions between protons and neutrons (owing to the strong correlation of their radii), but are also significantly smaller than DFT predictions, providing an important insight into the size of the nucleus. The research both expands the frontier for *ab initio* studies from light to medium-mass nuclei and also affords a comparison of these and DFT methods, widening opportunities to bridge the two.

The theoretical predictions will be tested in experiments. A direct measurement of the neutron radius in ^{48}Ca via parity-violating electron scattering is planned at Jefferson Lab. The Darmstadt-Osaka collaboration is currently analyzing their measurement of the electric dipole polarizabilty of ^{48}Ca. This observable is strongly correlated with the neutron radius, and it will be interesting to compare the experimental result to the theoretical prediction.

The study's authors include several with ties to both UT Physics and Oak Ridge National Laboratory: Adjunct Assistant Professor Gaute Hagen, Professor Thomas Papenbrock, and Postdocs Andreas Ekström, Gustav Jansen, and Kyle Wendt. Their co-authors are Witek Nazarewicz (formerly with UT Physics, now with Michigan State); Christian Forssén and B. Carlsson (Chalmers University of Technology, Sweden); Sonia Bacca and Mirko Miorelli (TRIUMF, Canada); Nir Barnea (Hebrew University of Jerusalem); Christian Drischler, Johannes Simonis, Kai Hebeler and Achim Schwenk (Technische Universität Darmstadt, Germany); Morten Hjorth-Jensen (University of Oslo); and Giuseppina Orlandini (University of Trento, Italy).

Hagen and Papenbrock are also part of a Topical Collaboration that recently won funding from the U.S. Department of Energy. Led by Jon Engel at the University of North Carolina at Chapel Hill, the group is seeking to improve our understanding of neutrinoless double beta decay as a means to learn more about the nature of the neutrino and the neutrino mass scale. Papenbrock pointed out that the Nature research gave the team a good benchmark for these studies. The DOE chooses Topical Collaborations for funding to investigate a specific topic in nuclear physics of special interest to the community that's well-aligned with the goals of its Nuclear Physics program.

More Information

- **Oak Ridge National Laboratory Press Release (https://www.ornl.gov/news/calcium-48%E2%80%99s-%E2%80%98neutron-skin%E2%80%99-thinner-previously-thought)**
- ***Nature Physics* paper (http://www.nature.com/nphys/journal/vaop/ncurrent/pdf/nphys3529.pdf)**
- **EurekAlert (http://www.eurekalert.org/pub_releases/2015-11/drnl-cs103015.php)**
- **Oak Ridge National Laboratory's Titan Cray Supercomputer (https://www.olcf.ornl.gov/computing-resources/titan-cray-xk7/)**
- **U.S. Department of Energy Nuclear Physics Program (http://science.energy.gov/np/)**