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Laboratoire national canadien pour la recherche en physique nucléaire et en physique des particules

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Calcium Built From Scratch, Much Smaller Than Expected

TRIUMF theorists contribute to discovery resulting from massive computation on America's largest supercomputer

(Vancouver, BC) – An international team of theoretical physicists has succeeded for the first time in calculating important properties of the Calcium-48 nucleus from basic principles. The massive computation using America's largest supercomputer, Titan, revealed that the "neutron skin" of the nucleus is considerably smaller than previously thought. The collaboration, including TRIUMF scientist Dr. Sonia Bacca and University of British Columbia Ph.D. student Mirko Miorelli, made a variety of predictions that are current targets of precision measurements. These calculations also have implications for the size of neutron stars, astronomical objects a billion, billion times larger than the calcium nucleus. This groundbreaking work was published in the prestigious journal *Nature Physics*.

The central challenge of modern nuclear physics is to calculate the structure of atomic nuclei starting from the basic ingredients, protons and neutrons, and the fundamental forces between them. The task is far from trivial for nuclei as large as Calcium-48, which has 28 neutrons and 20 protons all interacting in a very complicated quantum-mechanical many-body problem. Employing state-of-the-art nuclear force models coupled with sophisticated computer algorithms, the collaboration ran their nuclear structure codes for 15,000,000 cpu*hours on the largest supercomputer in the U.S. to essentially build this nucleus from scratch.

Calcium-48 is a good candidate for experimental studies since it is a long-lived isotope that is rather "neutron rich" for a nucleus of its mass. Its neutron distribution determines the actual size of the nucleus since it extends beyond the proton distribution. While the latter is well known from electron scattering experiments, the distribution of the neutrons, which have no electric charge, is difficult to measure and only indirect experimental techniques exist. So a theoretical calculation is insightful in 'measuring' the size of the Calcium-48 nucleus, which the team found to be much smaller than previously thought.

The collaboration also made predictions for the nucleus' electric dipole polarizability, a quantity that involves nuclear excitations and correlates to the nucleus size. Bacca and Miorelli's contributions were key to the successful computation of this quantity, which is currently targeted by precision experiments with proton scattering in Japan. Bacca pointed out that "when a nucleus is excited, it can disintegrate into many pieces. Only very recently have we managed to account properly for disintegration effects with as many as 48 protons and neutrons involved. Our contribution was integral to developing the necessary theoretical tools underpinning the results for this quantity."

To gain confidence in their predictions, the team checked their calculations of dipole polarizabilities for lighter isotopes such as Helium-4, Oxygen-16, and Calcium-40 against experimental measurements. "We took the data calculated from the powerful Titan supercomputer and post-processed it on our local TRIUMF theory cluster to obtain electric dipole polarizabilities, giving us further insights into the size of the Calcium-48 nucleus," said Miorelli.

A Darmstadt-Osaka collaboration already has measured the dipole polarizability of Calcium-48 and is analyzing the results, while scientists at Jefferson Lab in Newport News, VA are preparing a measurement of its neutron radius. These experimental results could validate this newly published *Nature Physics* work and refine future theoretical models.

Beyond advancing our understanding of nuclear structure, the collaboration's work is relevant to nuclear astrophysics as well. For example, their work can help constrain the size of neutron stars. In addition, since the size of neutron-rich nuclei affects a wide range of systems, the results of this team's efforts using a long-lived isotope are relevant to investigations of short-lived synthetic ones, such as those currently being probed at rare isotope facilities like TRIUMF.

Beyond the Canadian members, the collaboration involved scientists at Oak Ridge National Laboratory (U.S.), the University of Tennessee (U.S.), Michigan State University (U.S.), Chalmers University of Technology (Sweden), Hebrew University (Israel), Technical University Darmstadt (Germany), University of Oslo (Norway), and University of Trento (Italy).

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For More Information

The Nature Physics paper is entitled, "Neutron and weak-charge distributions of the ^{48}Ca nucleus." Further details can be found in this news release from Oak Ridge National Laboratory.

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About TRIUMF

TRIUMF is Canada's national laboratory for particle and nuclear physics. Together with its partner AAPS, Inc., TRIUMF also seeks to commercialize its technologies for the benefit of all Canadians. Located on the south campus of the University of British Columbia, TRIUMF receives operating support from the Government of Canada through a contribution agreement via National Research Council Canada; the Government of British Columbia provides capital for new buildings. TRIUMF is owned and operated as a joint venture by a consortium of the following Canadian universities: University of Alberta, University of British Columbia, University of Calgary, Carleton University, University of Guelph, University of Manitoba, McGill University, McMaster University, Université de Montréal, University of Northern British Columbia, Queen's University, University of Regina, Saint Mary's University, Simon Fraser University, University of Toronto, University of Victoria, Western University, University of Winnipeg, and York University. Visit us at www.triumf.ca and tweet us @TRIUMFLab.

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