Size of proton distribution in exotic carbon isotopes revealed

Carbon is an essential element necessary for life on our planet. The stable abundant isotope of carbon (12C) has an equal number of proton (six) and neutrons (six). There exists however in nature more exotic forms of carbon where the neutrons out number the protons extending all the way to 22C with six protons and sixteen neutrons. The additional neutrons create exotic forms of nuclei, such as neutron halos in 15C, 19C and 22C. These special nuclear forms come as surprises breaking the boundary of conventional knowledge. They remain a challenge to understand from basic principles of the nuclear forces what drives nature to create them.

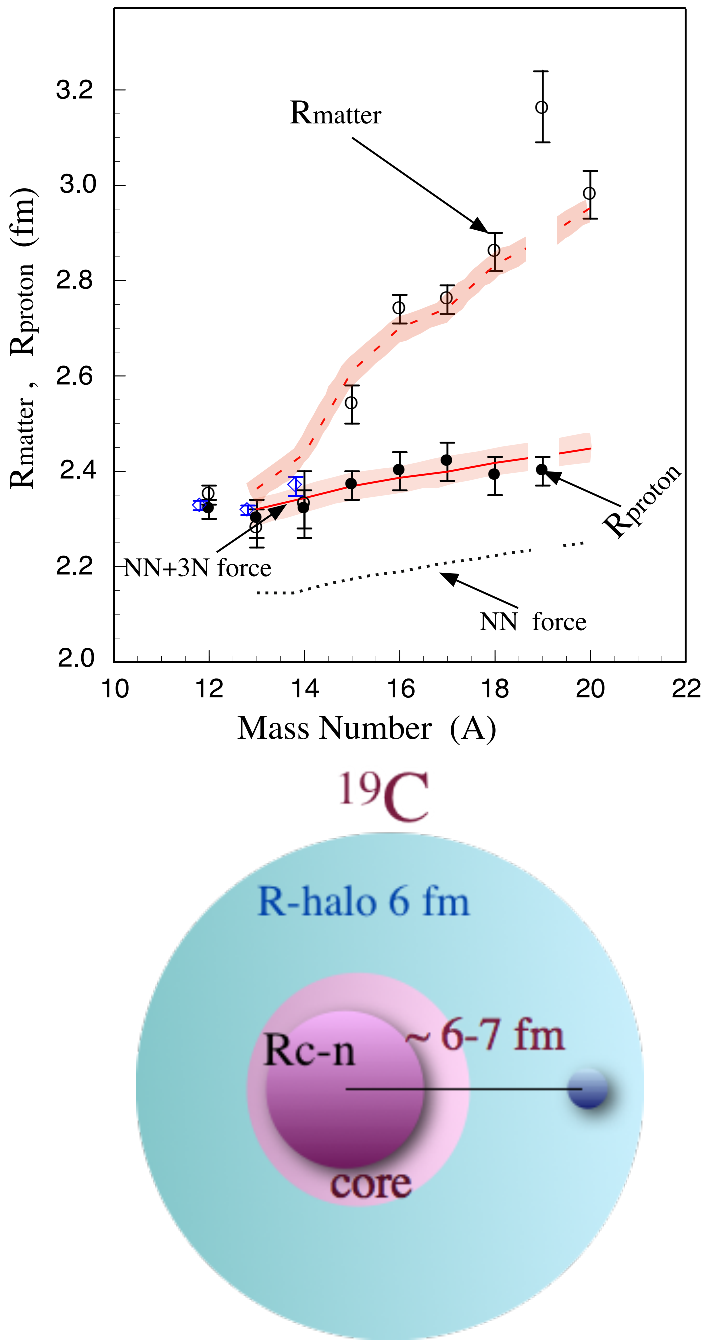
Does the addition of neutrons influence the protons and if so, how ? The answer to this question can also allow for a characterization of the exotic halos. The task to reach this information is challenging since traditional methods to measure the proton distribution radius are inapplicable for these very short-lived isotopes.

Dr. Rituparna Kanungo, Professor of the Astronomy and Physics Department at Saint Mary's University led an international team to measure the radii of carbon isotopes from 12C to 19C using the highest energy rare isotope facility at GSI Helmholtz Center, Darmstadt, Germany. Post doctoral fellow **Dr. Alfredo Estrade** (currently Assistant Professor at Central Michigan University, USA) was also a key player in this endeavor.

The observations show a mild increase in the proton distribution radius due to the neutron halo in 15C. Beyond that a mild increase is seen for 16C and 17C but the proton radii become nearly constant after that although 19C is also a halo nucleus. This shows that in 19C the neutron surface is very thick $\sim$ 1 fm, giving rise to as large a halo as seen for the first discovered halo nucleus 11Li.

Theory colleagues from Japan, USA and Canada joined the team to bring the most advanced theoretical formulation for the radii. Dr. Gaute Hagen, Dr. Gustav Jansen from Oak Ridge National Laboratory (ORNL) and Dr. Petr Navratil from TRIUMF developed the *ab initio* theory for computing the radii of these isotopes using the supercomputers at ORNL computing facility. The measured radii together with the theoretical predictions show the importance of the three-nucleon force.

The results were published in Physical Review Letters on September 2, 2016.
http://journals.aps.org/prl/pdf/10.1103/PhysRevLett.117.102501



Upper Panel : Measured proton and matter radii of carbon isotopes compared to theoretical predictions (red lines + bands of uncertainty and black dotted line). Lower Panel : The halo picture derived for the 19C nucleus from the measured radii.