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Measurements at CERN help to re-evaluate the element of life

January 14 2005

Results from experiments at CERN and the Jyväskylä Accelerator Laboratory in Finland, reported in *Nature* today, cast new light on the primary reaction that creates carbon in stars. All the carbon in the Universe, including that needed for carbon-based life forms such as ourselves, has been made in the hearts of stars through what is known as the "triple alpha reaction". The new findings modify the rate at which the reaction occurs and have broad implications for astrophysics, from the formation of the first stars to the creation of the heaviest elements in supernovae.

"The connection between the subatomic world and the cosmos is fascinating. The example of carbon is an old problem with contributions from many heroes in the field. It is a pleasure to be able to answer some of the questions they have left for us. It is the technological development in the intervening years, for example at ISOLDE, that has made this possible," says from Hans Fynbo of the University of Aarhus, lead author of the paper.

The big bang created mainly only hydrogen (mass 1) and helium (mass 4), because there are no long lived atomic nuclei with mass 5 and 8 to make the bridge to heavier elements such as carbon (mass 12). But in the hearts of stars the formation of carbon is possible through the triple-alpha reaction, where three helium nuclei (alpha particles) fuse to make to make a nucleus of carbon-12.

Rather than recreate the scorching conditions inside stars, the team from

CERN and eight other European universities and institutes watched the reaction unfold in reverse, as nuclei of carbon-12 broke into three alpha particles. To do this, they created boron-12 and nitrogen-12, which are short-lived isotopes of the elements that flank carbon in the Periodic Table. The boron-12 was produced at CERN's ISOLDE facility, while the nitrogen-12 was created at the IGISOL facility at the Jyväskylä Accelerator Laboratory at the University of Jyväskylä. These unstable nuclei soon transformed into carbon-12, through beta decay, in which a proton changes into a neutron or vice versa; the carbon-12 then broke into three alpha particles.

The ISOL method – isotope separation on line - originally pioneered and developed mainly at CERN played an important role in these experiments. "While ISOLDE at CERN could make the boron-12, IGISOL in Jyväskylä was needed to produce the nitrogen-12. This facility in Finland was specifically developed to complement ISOLDE's performance through its ability to produce very short-lived radioisotopes of chemically reactive elements such as nitrogen," said Juha Äysto, head of the group responsible for the experiment at the University of Jyväskylä.

By measuring precisely the timing and energies of alpha particles shooting from the samples, the researchers were able to infer the energy states of the carbon nuclei just before decay. With this information in hand, they were able to determine the rate for the triple alpha process over a wide range of temperatures, from 0.01 – 10 billion K.

For the conditions in most stars, the researchers' calculated rates for the triple alpha process agree with previous calculations. But their findings suggest the triple alpha rate at the relatively low temperatures of the Universe's first stars (around 0.05 billion K), which began without carbon, was much faster. This in turn implies that the amount of carbon that could catalyze hydrogen burning in the first stars was produced twice as fast as previously thought.

At high temperatures, above 1 billion K, the new results indicate that the triple alpha process would work significantly slower than previous estimates, modifying the process of element production - nucleosynthesis – in supernovae. These explosions of old massive stars are a major source of the heaviest elements, those more massive than iron, through interactions in the surrounding shock wave. The new results suggest a reduction in the amount of nickel-56 produced with subsequent effects for heavier elements.

This work was carried by a team from CERN and eight other European universities and institutes.

Publication: Nature, Vol 433, Issue 7022, pp 136-139

Source: CERN