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Cyclotron Institute

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Nuclear Cauldrons: Studying Star Burning With Radioactive & Neutron Beams

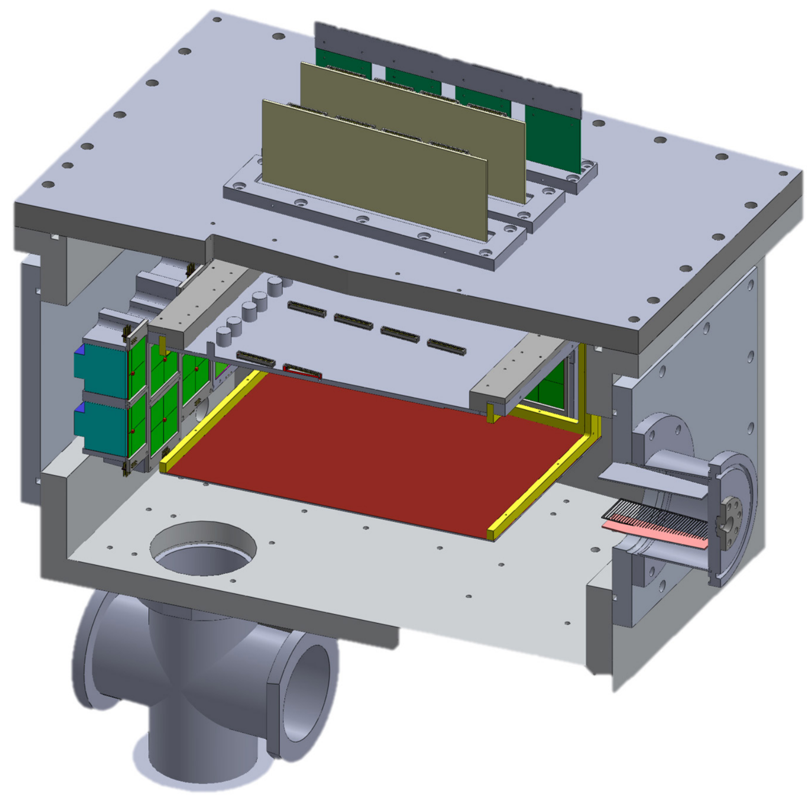
Multi-institution collaboration yields insight into one of universe's most primordial reactions that made all life on Earth possible

THE SCIENCE
Researchers have found a new way of measuring the decay of a special configuration of carbon called the “Hoyle state,” an excited form of carbon-12. Since the 1950s, scientists have theorized that carbon-12 would easily form in this state in stars from three helium-4 nuclei, called alpha particles. This carbon-12 in a Hoyle state would then decay to simple ground-state carbon and, in the process, release energy. One goal of the new experiment was to determine if researchers could reliably see in reverse how the Hoyle state breaks apart into three alpha particles. The researchers then used this method to test the importance of neutron upscattering in the fusing of three alpha-particles to create carbon. Neutron upscattering is where a neutron interacts with a resonance (a vibration) and de-excites it, stealing the resonance’s energy.Scientists have theorized for decades that this process makes stars burn faster than expected.

THE IMPACT
This experiment was the first in the world to use a new type of advanced detector to study the properties of the Hoyle state. The detector has a level of sensitivity that made the previously impossible experiment of measuring the neutron upscattering a reality. The researchers’ analysis of the data from the experiment suggests that upscattering plays a less important role in the formation of carbon in stars than originally thought.

SUMMARY
Measuring reactions that take place within stars is difficult. The necessary high temperatures and densities are impossible to replicate on Earth. Therefore, researchers rely on measuring related reactions that can be performed in the lab. The goal of this project was to understand how the presence of neutrons in stars affects the fusing of three alpha-particles (helium nuclei) together to form the Hoyle state of carbon-12. The neutrons can increase how quickly the three alpha-particles fuse together through neutron upscattering. Measuring this reaction in the lab relies on the time reverse of this reaction—breaking apart carbon with neutrons to form three alpha-particles.

In addition to Texas A&M University, the project included researchers from Ohio University, Washington University in St. Louis, the University of Birmingham, the Université Paris-Saclay, and the Korean Institute for Basic Science. Using a beam of high-energy neutrons at the Edwards Accelerator Laboratory at Ohio University, the researchers fired neutrons into TexAT, a detector developed and built at the Cyclotron Institute at Texas A&M. The researchers then measured the likelihood of the breakup of carbon-12 into three alpha-particles. They found that the propensity of carbon-12 to break apart into three alpha-particles is lower than previously expected from theoretical models. This indicates that the influence of neutron upscattering on the formation of carbon-12 is smaller than originally expected. This result settles a question that has existed for approximately 50 years on the influence neutron up-scattering can have on the way a star burns to create heavier elements.



The Texas Active Target (TexAT) particle detector designed and built by Texas A&M physicists to test whether or not stray neutrons are involved in creating carbon.

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PUBLICATIONS
Bishop, J., et al., "Neutron-upscattering enhancement of the triple-alpha process," Nature Communication 13, 2151 (2022).

Bishop, J. et al., "Almost medium-free measurement of the Hoyle state direct-decay component with a TPC," Physical Review C 102, 4 (2020).

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ABOUT THE CYCLOTRON INSTITUTE: *Dedicated in 1967, the Cyclotron Institute serves as the core of Texas A&M University's accelerator-based nuclear science and technology program. Affiliated faculty members from the Department of Chemistry and the Department of Physics and Astronomy conduct nuclear physics- and chemistry-based research and radiation testing within a broad-based, globally recognized interdisciplinary platform supported by the United States Department of Energy (DOE) in conjunction with the State of Texas and the Welch Foundation. The facility is one of five DOE-designated Centers of Excellence and is home to one of only five K500 or larger superconducting cyclotrons worldwide.*