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Direct measurement of the 12C+12C fusion reaction at astrophysical energies

Only a handful of the most energetic reactions involving the most abundant elements are driving the evolution and chemical structure of massive stars. Among these, the fusion of two carbon nuclei is a key process during the late stages of the evolution such stars, in explosive nucleosynthesis in Type 1a supernovae and superbursts in x-ray binary systems [1]. The precise measurement of the ultra-low oscillating carbon fusion cross sections is extremely challenging so that the quantification of this critical reaction still lacks the necessary accuracy to constrain astrophysical models. Current data from direct measurements span from above the Coulomb barrier to the region of astrophysics interest, but with large uncertainty towards low relative energies so that extrapolations into the Gamow window can differ by orders of magnitude.
The STELar LAboratory (STELLA) experiment has been developed to increase the accuracy of direct carbon fusion reaction measurements, as compared to conventional experiments, by using the coincident detection of the evaporation residues characteristic gamma rays and the emitted charged light particles, which drastically suppresses the backgrounds [2]. STELLA furthermore combines nano seconds timing with this approach for unambigious exit channel identification with timing gates of tens of nanoseconds. The setup employs thin large self-supporting rotating carbon targets and is designed for reliable and stable fusion measurements during weeks of bombardment with beam of an intensity of up to ten μA.
We will present recent $^{12}C+^{12}C$ measurements with STELLA, right in the astrophysics region of interest of 25 $M_\odot$ stars. These data complement an earlier experiment at the lowest-energy direct measurement carried out so far [3], where partly only limits could be established, and largely improves the understanding of the fusion excitation function. The results will be discussed on terms of molecular resonances in the $^{24}Mg(^{12}C-^{12}C)$ compound nucleus as well as hindrance of the fusion process at the lowest energies.
The impact of the STELLA results on the chemical structure and evolution scenarios of massive stars will be discussed, based on novel hydrodynamics calculations using the GENEC code.

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[3] G. Fruet, S. Courtin et al., Advances in the Direct Study of Carbon Burning in Massive Stars, Phys. Rev. Lett. 124,192701 (2020).

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