Carbon burning towards the zero energy limit: An α-cluster study in imaginary time

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The carbon burning process is a fundamental step of stellar evolution and governs the synthesis of chemical elements important for the formation of life. It has already been investigated from the late 1960's [1]. Since then, its description is the central theme of several studies, both theoretical [2-4] and experimental [5-8]. In this work, we utilize the microscopic hybrid α-cluster (HαC) model and an analytical approach, both in the framework of the Imaginary Time Method (ITM), to study the carbon fusion reaction towards zero energy. The HαC model [9] is a semi-classical dynamical approach to the nuclear N-Body problem, that considers the dynamical evolution of the α-degrees of freedom within A=4n nuclei. The ITM [2] on the other hand, is a procedure based on the Feynman Path Integral method, that simulates the quantum tunneling below the Coulomb barrier (Fig. 1), in a microscopical dynamic model, such as HαC.

We obtain the values of the cross sections, astrophysical factors (Fig. 2) and correlate our results to collective motion. We also include a calculation for the 2^+ carbon fusion and discuss a possible experimental investigation. The results confirm direct experimental and theoretical results close to the barrier, while suggest possible 2^+ mixtures in the indirect experimental data. Our study offers an accurate view of the burning process in the somewhat unexplored low energy region.

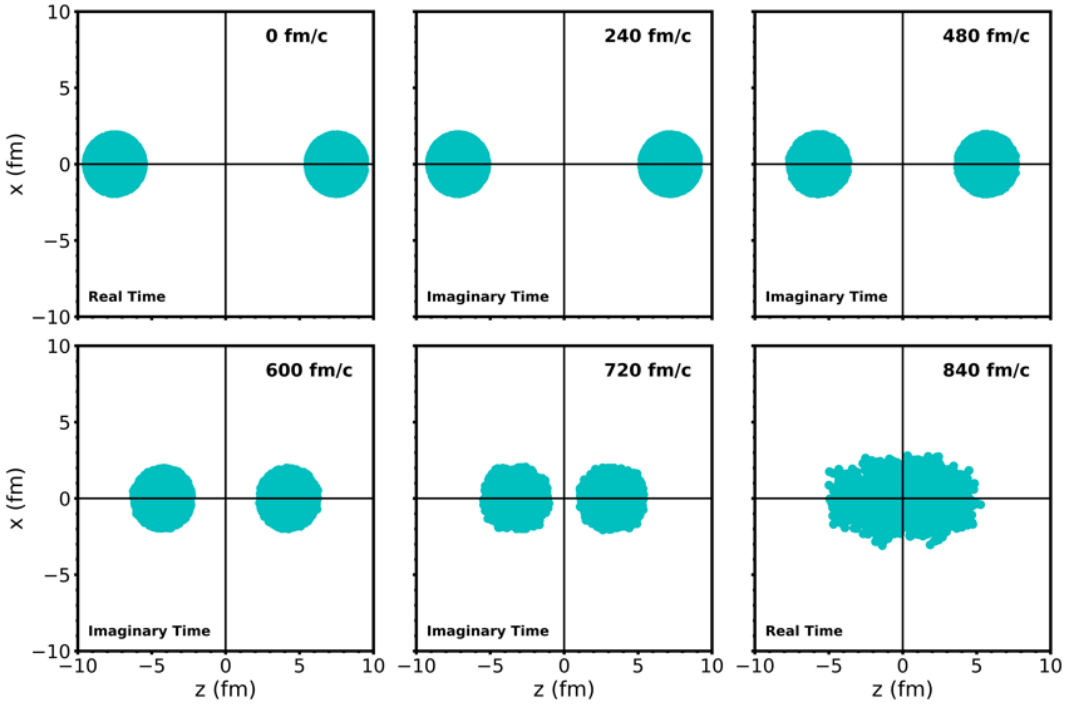

Fig. 1. (Color online) Evolution of the 12C+12C fusion in the xz plane with EC.M. = 3.5 MeV. The cyan points are the densities of the alpha particles from 300 event calculations with the HαC model, while the reaction axis is defined to be the z-axis.

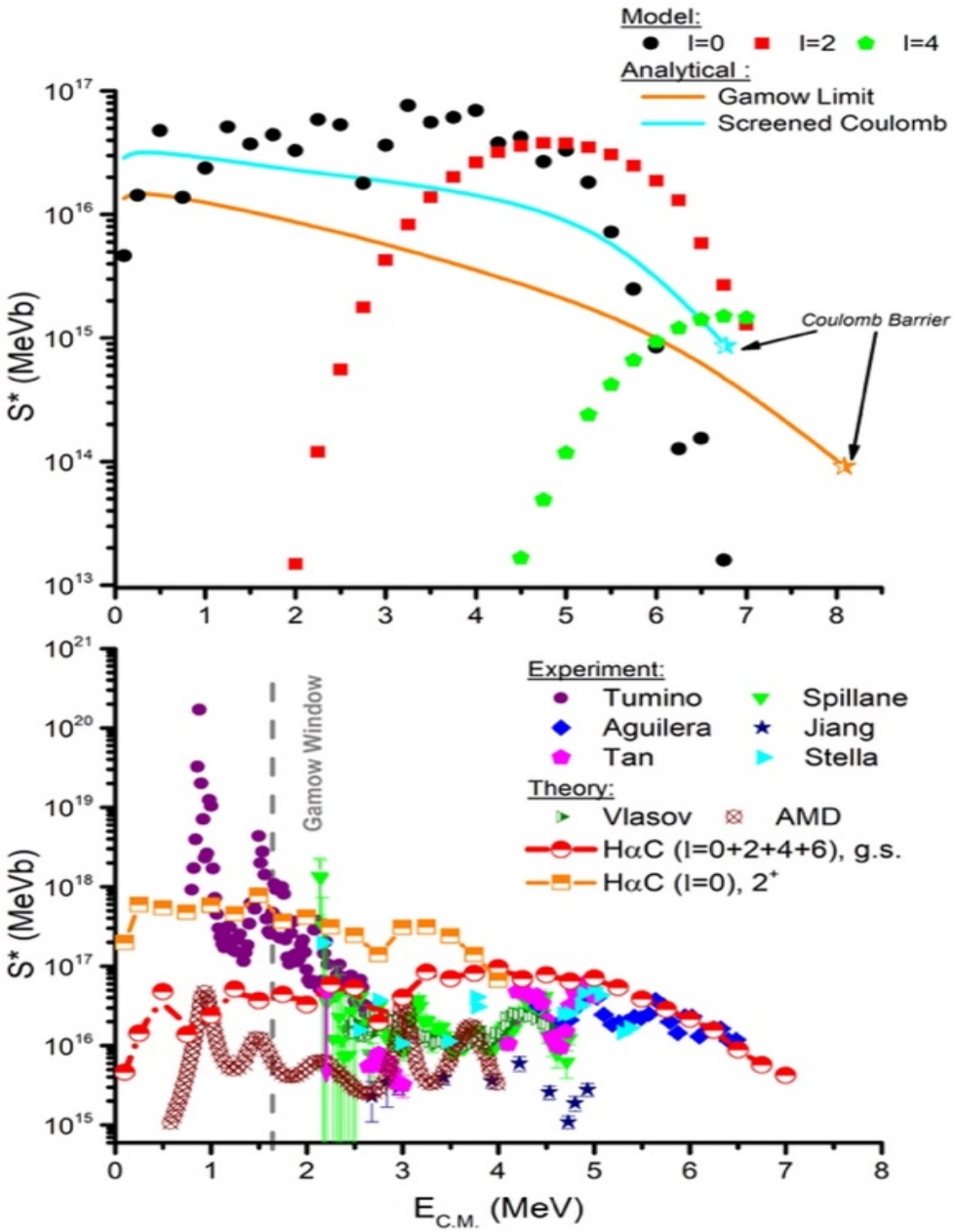

Fig. 2. (Color online) Top Panel: The S∗ factors as a func:on of energy for different l-values (points) obtained via the HαC model and via the analytical approach with free and screened Coulomb (lines), according to the key. BoIom Panel: The S∗ factors as a func:on of energy from several experimental [5-8] and theoretical [2,4] data sets. This work corresponds to the red curve for all l-values (g.s.) and orange curve (4.44 MeV, 2+), as obtained with the HαC model. The pink arrow corresponds to the lowest energy direct measurement and represents an upper limit.

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