Joint Institute for Nuclear Astrophysics

Studies of Fusion Reactions in the Systems ^{12}C + $^{10,14,15}C$ and their Relation to X-ray Superbursts

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The study of X-ray binaries has given us valuable information about nuclear reactions occurring on the surface of neutron stars. X-ray bursts, i.e. a sudden increase in X-ray luminosity, occur in binary systems when a neutron star accretes hydrogen and helium material from a companion 'donor' star. Typical X-ray bursts last about 10-100 sec and release about 10^{39} ergs. In addition to standard X-ray bursts a few so-called 'superbursts' have recently been observed. Compared to regular X-ray bursts superbursts last many hours releasing 1000 times more energy with a recurrence time of about a year. These 'superbursts' are powered through nuclear reactions involving the ashes (e.g. carbon) from normal bursts which have moved from the surface deeper into the 'ocean' of the neutron star. In the vicinity of the neutron-star crust the nuclei can fuse via so-called pycno-nuclear reactions. In order to understand the origin of the superbursts a series of publications discussing fusion cross sections of neutron-rich carbon (^{24}C + ^{24}C), oxygen (^{24}O + ^{24}O) and neon (^{40}Ne + ^{40}Ne) nuclei have recently been published. A large fraction of the nuclei included in these calculations are outside the range of our experimental capabilities (e.g. ^{24}C + ^{24}C). In order to test the predictive power of these calculations we have recently measured the total fusion cross sections of ^{12}C + $^{10,12,13,14,15}C$ using a new multi-sampling ionization chamber which can measure a large fraction of an excitation function in one run.

The results of these measurements are shown in Fig. 1 where we have plotted the cross section ratios for fusion in the ^{12}C + $^{10,12,13,14,15}C$ systems normalized to the predictions from a tunneling model using the so-called Sao Paulo potential [1]. Also included are predictions by the TDHF calculations [2] for $^{13,14}C$ + ^{12}C (green curves) and from coupled-channel calculations [3] for the isotopes studied in this experiment (blue lines). The data from this experiment (black circles) are in excellent agreement with the tunneling calculations. They are also in good agreement with the coupled-channel calculations which include couplings to one- and two-phonon excitations as well as mutual quadrupole and octupole excitations in projectile and target. These calculations can also reproduce the structure in the cross sections at ~5.5 MeV for the ^{13}C + ^{12}C system where experimental data exist. Similar structures are also predicted for $^{14,15}C$ + ^{12}C. This peak in the cross section occurs only in the calculations if couplings to two-phonon excitations or two-phonon and one-neutron channels are included. The green curves for $^{13,14}C$ are the results of TDHF calculation from Ref. 3 which over-predict the experimental cross sections.

1 Yakovlev et al., Phys. Rev. C82, 1818 (2010).
2 Umar et al., Phys. Rev. C85, 055802 (2012).
3 Esbensen et al., Phys. Rev. C84, 064613 (2011).

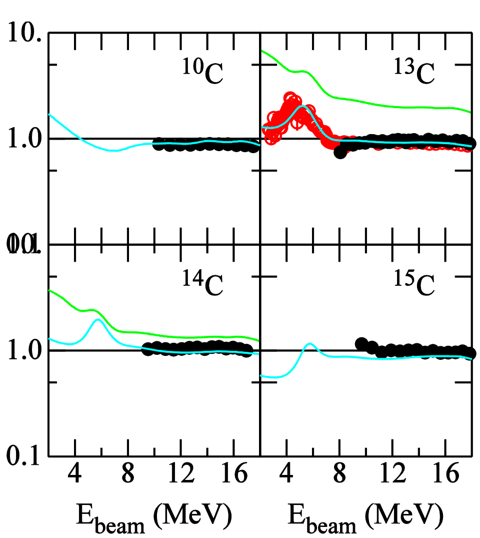

Fig. 1: Ratio of experimental fusion cross sections for the systems ^{12}C + $^{10,13,14,15}C$ compared to theoretical predictions: Tunneling calculations using the Sao Paulo potential[1] (black), TDHF calculations[2] (green) and coupled-channels calculations[3] (blue).

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