The (α,p)-process in X-Ray Bursts: Reaction rates studied with Radioactive Ion Beams at ATLAS

Type I x-ray bursts (XRBs) occur in binary systems that consist of a neutron star, which is accreting H/He-rich material from a main sequence companion star [1]. As the accreted matter builds up on the surface of the neutron star, high temperatures and densities are reached and a thermonuclear runaway occurs, the result of which is a sharp increase in x-ray emission from the star that lasts for approximately 10 – 100 s. During this thermonuclear explosion, nucleosynthesis of heavier elements is driven toward the proton-drip line by the triple-α reaction, the (α,p)-process, and the rapid proton capture process (*rp*-process) [1].

Along the nucleosynthetic path there exist so-called "waiting-point" nuclei, where the flow stalls at specific nuclei while awaiting β^+-decay. This can affect elemental production in the XRB as well as the energy production, and consequently the luminosity profile that is observed. However, other reactions, such as (α,p)-process reactions, can bypass this β^+-decay. This can have a direct impact on the structure of the luminosity profile and may be responsible for the observed double-peaked structure of some bursts (Figure 1) [2]. Possible waiting points include ^{22}Mg, ^{26}Si, ^{30}S, and ^{34}Ar all of which are unstable. Additionally, some of the reactions involved in the (α,p)-process have been shown to impact final elemental abundances and energy output of XRBs by a recent sensitivity study [3]. Of the several thousand reactions considered in this study, surprisingly few were shown to have a serious impact on the final nuclear abundances (only 28 reactions had a significant effect on XRB nucleosynthesis) and even fewer were found to influence the energy generation of the burst.

Unfortunately, current facilities do not have the capabilities to study many of these important reactions that lie so far from the valley of stability. However, there are a few reactions which, while still requiring radioactive beams, are not so far from stability as to make them experimentally inaccessible. Experiments at the ATLAS facility at Argonne National Laboratory have been undertaken to study two of these (α,p)-process reactions: ^{30}S(α,p)^{33}Cl and ^{34}Ar(α,p)^{37}K. These two reactions were studied in inverse kinematics using the time inverse reactions p(^{33}Cl, ^{30}S)α and p(^{37}K, ^{34}Ar)α.

Radioactive beams of ^{33}Cl and ^{37}K were produced at ATLAS using the "in-flight" technique [4] and bombarded a proton target. The α particles resulting from the reaction were detected in an annular Double-Sided Si Detector (DSSD) and the heavier reaction products (^{30}S and ^{34}Ar) were detected in a Parallel Grid Avalanche Counter (PGAC) and ionization chamber after being separated from the beam by a gas-filled magnetic spectrograph.

The result is that the expected kinematic curve of the α particles from the reaction of interest is detected in the DSSD (Figure 2). Using this method the cross sections of each reaction were measured at three different energies (Figure 3). In continuing these studies the cross sections of other (α,p) reactions will be measured and the reactions discussed above will be further studied at lower, more astrophysically relevant, energies.

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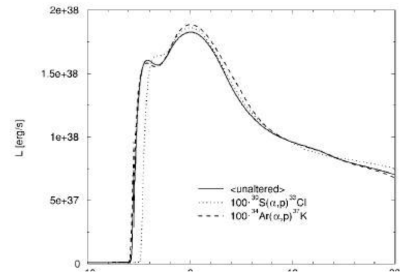

Figure 1: Computed luminosity profiles of double-peaked XRBs as the two reaction rates of interest are varied (dashed and dotted lines) plotted with theoriginal computation (solid line) [2].

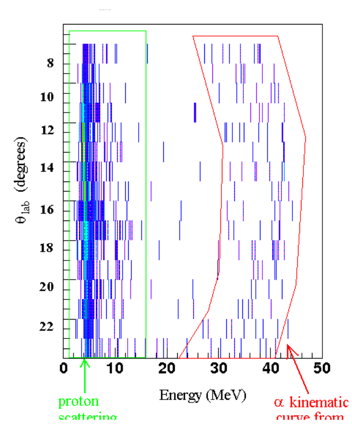

Figure 2: Preliminary results of the particles detected in the DSSD during the ^{33}Cl + p study. The kinematic curve resulting from the α particles is outlined in red.

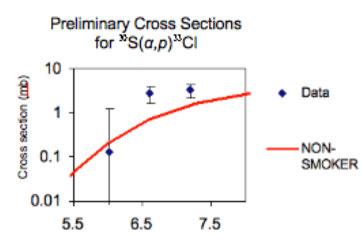

Figure 3: Cross sections measured for the ^{30}S(α,p)^{33}Cl reaction rate at three energy points (blue dots) plotted with the NON-SMOKER calculation [5,6].

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