AN INDIRECT STUDY OF THE ASTROPHYSICAL ^{34}Ar(α,p)^{37}K REACTION AND IT'S IMPACT ON TYPE-1 X-RAY BURST LIGHT CURVES

Abstract

by

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Shortly after their discovery in 1976, x-ray bursts were determined to be thermonuclear runaways occurring on the surface of neutron stars in binary systems with H/He rich low-mass companion stars. During these explosive events the sudden release of nuclear energy heats up the atmosphere, causing its luminosity to rapidly increase by more than an order of magnitude within a few seconds. Over the past three decades, thousands of bursts from almost a hundred systems have been observed, revealing a rich diversity of bursting characteristics. One of the more interesting characteristics observed is the double-peak structure in the luminosity curve seen in a handful of x-ray burst events. Through modeling and simulations of these exotic events, it was found that this double-peaked structure can arise in systems where a thermonuclear runaway is triggered within pure He layer below a mixed H/He layer. In this scenario, the rapid consumption of the pure He layer is seen to be the source of the first peak, while the second peak occurs due to the burning of the mixed H/He layer with the αp-process and the rp-process. Current x-ray burst sensitivity studies have revealed that certain (α,p) reactions along the αp-process have a direct influence on the early rise-time structure of x-ray burst light curves originating from mixed H/He burning. More notably, results from the sensitivity study of Fisker *et al.*, showed the importance of ^{34}Ar as one possible waiting point

in the rp-process given its relatively long β-decay half-life and low Q-value for the ^{34}Ar(p,γ) reaction. The ^{34}Ar(α,p)^{37}K reaction within the αp-process may act as a bypass for this waiting point, depending on its strength. Fisker *et al.* showed that by varying the strength of the ^{34}Ar(α,p)^{37}K reaction, which was based on HF prediction, a possible double peaked light curve would emerge in particular simulation for lower reaction strength values. This suggest that nuclear impedance by a possible waiting point in ^{34}Ar could contribute to the dipping structure observed in double peak light curves.

It has been augured that a HF predicted rate is most likely not valid for the ^{34}Ar(α,p)^{37}K reaction based on level density considerations in the compound nucleus ^{38}Ca. Given proximity of ^{38}Ca to the N = Z = 20 shell closure and it's low α-threshold, the number of levels available to participate at the relative bombarding energies may not be high enough to satisfy the statistical approach of a HF model. Instead this reaction may possibly proceed via a handful of strong α-cluster resonances located within the relevant energy window, and because of this, any HF prediction would grossly mis-predict the ^{34}Ar(α,p)^{37}K reaction rate.

The predictive power of current x-ray burst models depends critically on the accuracy of the many reaction rates involved. Therefore, to use these models to explore other parameters relevant to the double-peak bursting behavior, such as accretion rates and metallicties, this large uncertainty in the ^{34}Ar(α,p)^{37}K reaction rate must be significantly reduced.

With this in mind, the ^{34}Ar(α,p)^{37}K reaction was indirectly studied using the ^{40}Ca(p,t)^{38}Ca to study possible (α,p) resonances in the compound nucleus ^{38}Ca. This experiment was performed at iThemba LABS using 100 MeV, dispersion matched proton beam and the K=600 spectrograph. Given the information collected on the triton reaction products in the focal plane detectors of the K=600 spectrograph, excitation energies of levels populated in the recoil nucleus ^{38}Ca were determined with uncertainties within 10 keV. From this experiment, 45 states were identified in ^{38}Ca, of which 33 states above the α-threshold, that could act as possible (α,p), were identified.

With precise energy information on possible resonances taken from this work, along with model based assumptions to fill in the remaining unknown resonances parameters, a Monte Carlo calculation was performed based on narrow resonance formalism to generate distributions of the ^{34}Ar(α,p)^{37}K reaction rate over a range of astrophysical temperatures relevant to XRB's. From these rate distributions, the ^{34}Ar(α,p)^{37}K reaction rate was found to be significantly lower than the corresponding HF predicted rate used in X-ray burst models. This lower (α,p) rate implies that ^{34}Ar is most likely a waiting point nuclei and a possibly impedance source that will contribute to the structure of the dip and second observed peak.

Additionally, to investigate the effects of a lower ^{34}Ar(α,p)^{37}K reaction rate on x-ray burst light curves, simulations were performed using the single-zone self-consistent model, ONEZONE. These initial studies with ONEZONE show that this lower ^{34}Ar(α,p)^{37}K rate delays the peak of the burst by roughly half a second, but further studies with more sophisticated models need to be done before any thing conclusive can be reached.