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Sensitivity tests on the rates of the excited states of positron decays during the rapid proton capture process of the one-zone X-ray burst model

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Abstract

In this paper, we investigate the sensitivities of positron decays on a one-zone model of type-I X-ray bursts. Most existing studies have multiplied or divided entire beta decay rates (electron captures and beta decay rates) by 10. Instead of using the standard Fuller & Fowler (FFNU) rates, we used the most recently developed weak library rates [1], which include rates from Langanke et al.'s table (the LMP table) (2000) [2], Langanke et al.'s table (the LMSH table) (2003) [3], and Oda et al.'s table (1994) [4] (all shell model rates). We then compared these table rates with the old FFNU rates [5] to study differences within the final abundances. Both positron decays and electron capture rates were included in the tables. We also used *pn*-QRPA rates [6,7] to study the differences within the final abundances. Many of the positron rates from the nuclei's ground states and initial excited energy states along the rapid proton capture (*rp*) process have been measured in existing studies. However, because temperature affects the rates of excited states, these studies should have also acknowledged the half-lives of the nuclei's excited states. Thus, instead of multiplying or dividing entire rates by 10, we studied how the half-lives of sensitive nuclei in excited states affected the abundances by dividing the half-lives of the ground states by 10, which allowed us to set the half-lives of the excited states. Interestingly, we found that the peak of the final abundance shifted when we modified the rates from the excited states of the ^{105}Sn positron decay rates. Furthermore, the abundance of ^{80}Zr also changed due to usage of *pn*-QRPA rates instead of weak library rates (the shell model rates).

Keywords: Nuclear astrophysics; Beta decays; X-ray bursts; *rp*-Process

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1. Introduction

X-ray bursts are frequently observed in the cosmos [8–11] and are caused by thermonuclear reactions on the surface of accreting neutron stars. X-ray bursts form when hydrogen and helium accretes on the surface of a neutron star, resulting in a continuous X-ray emission due to changes in gravitational energy. Although the energy of X-ray bursts (6 MeV) is insignificant compared to continuous X-ray emissions that are caused by changes to gravitational force (200 MeV), these brief releases of nuclear energy are substantial enough for the observation of X-ray emissions to take place [8,9].

X-ray bursts can last from seconds to minutes at a time [8]. They can reoccur for periods that last from hours to days. Their luminosity ranges from 10^{36} to 10^{38} ergs^{-1}, their rising time lasts from 2 to 10 seconds long, and their decay time can range from 10 seconds to several minutes in duration. X-ray bursts begin when helium burns and are powered by the resulting triple-α reaction. They then continue through the αp-process and the rapid proton capture (rp) process. At the dripline, the (γ, p) process slows the (p, γ) process and the positron decays [12–17]. The peak temperatures of an X-ray burst can range from 1 to 2 GK. The rp-process can end in the SnSbTe cycle, which can then result in (γ, α) reactions on α unbound proton-rich Te isotopes [14].

Several studies, such as Woosley et al.'s (2004) [18] and Parikh et al.'s (2008) [19], have investigated the sensitivities of the of X-ray bursts' beta decay rates (positron decay and electron captures). While Woosley et al. examined varied groups of beta decay rates and studied their effects on X-ray bursts, Parikh et al. used post-processing code to investigate the effects of different beta decay rates on X-ray bursts. These studies have helped to improve estimates of stellar weak interaction rates by encouraging new nuclear physics experiments and theoretical rate estimates.

Previous studies have concentrated on changing the beta decay rate as a whole. In addition, recent studies have experimentally measured the half-lives of the ground states of nuclei within X-ray bursts. Stellar weak rates have primarily been calculated using theories (FFNU rates, for example). Thus, in this paper, we perform sensitivity tests on the half-lives of the excited states of waiting point nuclei's positron rates and the most significantly affected nuclei.

In X-ray burst models, nuclear reactions are particularly vital to the waiting point nuclei, as they control the rates of the X-ray bursts. The rates of X-ray bursts depend heavily on the waiting point nuclei. Waiting point nuclei became well-known decades ago [13]. These waiting points include ^{64}Ge, ^{68}Se, ^{72}Kr, ^{76}Sr, ^{80}Zr, ^{84}Mo, ^{88}Ru, ^{92}Pd, and ^{96}Cd. While the energies of some of the waiting points' first excited states were unknown a short time ago, the half-lives of ground states' positron decays, in addition to the excited energies of the first excited states of waiting point nuclei and other nuclei within the rp-process, have recently been measured due to advancements in new rare-isotopes facilities [20]. Regardless, the half-lives of the first excited states' positron decays remain unknown.

Research by Sarriguren [21] and other theoretical studies [6,7,22–24] have applied various changes to the rates of waiting point nuclei. In Sarriguren's paper, Kr and Sr isotopes were used to calculate positron decay with a deformed QRPA approach that was based on the mean fields that had been generated from consistent Skyrme Hartree–Fock calculations. A two-state mixing model was then used to mix the intrinsic configurations into physical states. Sarriguren's paper used a rough estimate for the mixing. Coefficients that had been extracted phenomenologically from Coulomb-excitation experiments were also used. The paper reproduced the same half-lives from the Coulomb-excitation experiments, as well.

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