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Triple-alpha and deexcitation reactions of the Hoyle state of 12C and heavy element synthesis in Hypernova

The origin of extremely abundant p-isotopes 92,94Mo and 96,98Ru has been a long-standing unsolved question in astrophysics since B2FH [1]. We have recently proposed that these p-isotopes are abundantly produced by the neutrino-proton process in Hypernovae/Collapsars which are the energetic branch of core-collapse supernovae (CCSNe) [2]. In the ordinary CCSNe, triple-alpha reaction populates the Hoyle state of 12C (0+,7.65 MeV) to proceed heavy element production. However, it was claimed [3] that the hadronic reactions of deexciting Hoyle state, h + (triple-alpha ⟺ 12C*Hoyle)* ⟶ *h' + 12Cgr, destroy the ideal condition for the heavy element synthesis because the deexcitation accelerates the triple-alpha reaction strongly and leads to a decrease of available protons and neutrons used for the synthesis of heavier nuclei. To assess this claim, we have studied the nucleosynthesis in both CCSNe and HNe. We firstly find that the neutron-induced deexcitation effect is negligibly small because almost all neutrons have already been exhausted before the neutrino-proton process operates on the seed nuclei 56Ni-60Zn-64Ge [4]. This fact was proved using recently measured small neutron-induced deexcitation rate of the Hoyle state [5]. Secondly, we find that the proton-induced deexcitation effect even enhances the final 92,94Mo and 96,98Ru abundances in HNe because of stronger p + anti-e-neutrino ⟶ n + e+ than n + e-neutrino ⟶ p + e+ due to the temperature hierarchy of HN neutrinos, i.e. T(anti-e-neutrino) > T(e-neutrino). We extensively study the Galactic chemical evolution and confirm that the HN νp-process dominates the production of abundant p-isotopes 92,94Mo and 96,98Ru over the entire history of cosmic evolution [4]. It is highly desirable to study the details of a few/many-body reactions of hadron-induced deexcitation of the Hoyle-state, i.e. h+(triple-alpha⟺12C*Hoyle)*⟶h' +12Cgr.

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