Supernova Neutrino Nucleosynthesis of Radioactive ^{92}Nb and the Timescale for Solar System Formation

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An unstable isotope ^{92}Nb decays to the daughter nucleus ^{92}Zr by β decay with a half-life of 3.47×10^7 years. ^{92}Nb does not exist in the present solar system. However, [1] found evidence of its existence in early solar-system material in primitive meteorites. ^{92}Nb has the potential to be used as a nuclear chronometer to measure the time from the last nucleosynthesis event. However, the astrophysical origin of ^{92}Nb has remained an unsolved problem. Figure 1 shows a partial nuclear chart and typical nucleosynthesis reaction flows for isotopes with nuclear masses around A = 92. ^{92}Nb can only be synthesized by direct nuclear reactions such as the (γ, n) reaction on ^{93}Nb.

We have proposed that direct neutrino reactions in core collapse SNe (ν process) can naturally produce the observed abundance of ^{92}Nb [2]. One of the key inputs for ν-process nucleosynthesis is a set of neutrino-induced nuclear reaction cross sections. We calculate neutrino-induced reaction rates using the quasiparticle random phase approximation (QRPA) with neutron-proton pairing as well as neutron-neutron, and proton-proton pairing correlations. We have calculated ν-process production rates using the core-collapse SN model. We use a 15 solar mass progenitor model with an explosion kinetic energy of 10^{51} erg. We take average energies of kT = 3.2, 4.0, 6.0 MeV for the electron neutrino, anti-electron neutrino, and the other neutrinos (ν_μ and ν_τ), respectively. Figure 2 shows the calculated abundances.

We consider a scenario in which a significant contribution to the observed ^{92}Nb is produced by the single injection of material from a nearby SN before the solar system formation or at early stages of solar system formation (SSF). The material ejected from the last SN will be diluted and then mixed with the collapsing protosolar cloud. We conclude that the observed ratio can be reproduced by mixing of 2×10^{-3} $M_\odot$ of the SN ejecta with the 1 $M_\odot$ proto-solar material.

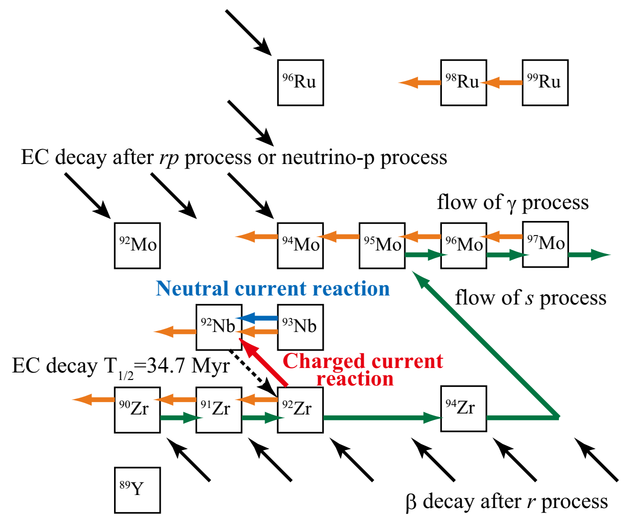

Figure 1: Partial nuclear chart around ^{92}Nb and the relevant nucleosynthesis flows. Most isotopes are produced by the s-process and/or beta-decay after the freeze out of the r-process. Note that ^{92}Nb can not be synthesized by either process.

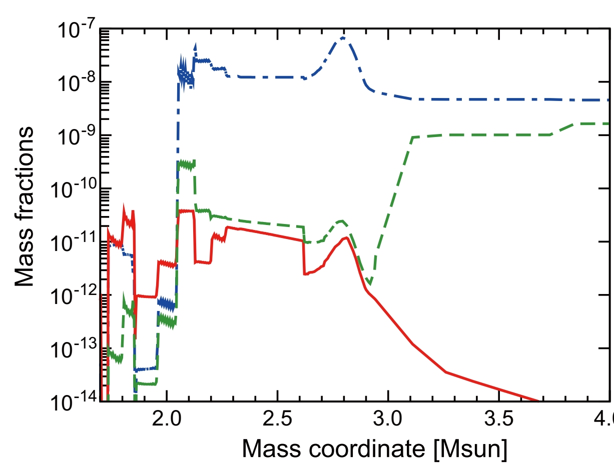

Figure 2: Calculated abundances as a function of interior mass from the supernova ν-process for a 15 solar mass progenitor star with solar metallicity, and an explosion kinetic energy of 10^{51} erg. The solid-line (red) and dashed-line (green) denote the abundances of ^{92}Nb and ^{93}Nb, respectively. The dot-dashed (blue) line indicates the ^{92}Zr abundance.

References

[1] Hayakawa, T., et al.: 2013, *ApJ*, **779**, L9.
[2] Harpper, C. L. Jr.: 1996, *ApJ*, **466**, 437.