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Nucleosynthesis of rare heavy elements in supernova explosions

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The origin of the p-nuclei among heavy elements has been discussed for long years. Analyzing the solar system abundances, we have found the empirical scaling laws concerning the p- and s-nuclei with the same atomic number. The abundance ratio of s- and p- nuclei is almost constant with a wide range of the atomic number. In addition, the ratio of two p-nuclei with the same atomic number is also constant. They are an evidence that twenty-seven p-nuclei are dominantly synthesized by the p-process in SNe. We have calculated the ratios by a Type II SN model and the results have reproduced these scalings. The other eight p-nuclei may be synthesized by different processes such as the ν -process. We have proposed two novel concepts of universality of the p- process and a new nuclear cosmochronometer of the p-process, which are based on the scalings. We also report the experimental study using thermal neutrons provided by nuclear reactors for the ^{187}Re - ^{187}Os cosmochronometer of the r-process. Co-authors: Toshiyuki Shizuma, Nobuyuki Iwamoto, Satoshi Chibam, Tuneo Nakagawa, Nobuo Shinohara, Toshitaka Kajino, National Astronomical Observatory; Hideyuki Umeda, Ken'ichi Nomoto, University of Tokyo.