The Neutrino p-Process

Core collapse supernovae (SN II) take place at the end of stellar evolution when massive stars ($m \geq 8$–$10\ M_{\odot}$) end their life. These cataclysmic events are responsible for producing mainly iron and neighboring elements. The production of elements beyond iron has long been attributed to three classical processes: the r and s process (caused by rapid or slow neutron capture) and the p-process (producing heavy neutron-deficient, stable nuclei). While the location, operations, and uniqueness of the r and the p process in astrophysical sites are still subject to debate, the s process acts via neutron captures on Fe produced in previous stellar generations and thus is a *secondary process* depending on the initial heavy element content of the star.

Observations of extremely metal-poor stars provide us with information about the nucleosynthesis processes at the earlierst times in the evolution of the Galaxy. They are therefore a probe of the supernova events of the earliest massive stars. Galactic chemical evolution studies (Travaglio *et al.* 2004) and recent observations of metal-poor stars (Cayrel *et al.* 2004 and François *et al.* 2007) show strong indications for the existence of a primary process (denoted *lighter element primary process, LEPP*) which is independent of the r-process and which operates very early in the Galaxy.

In this project a new nucleosynthesis process has been discovered which is clearly distinct from previous nucleosynthesis processes involving neutrinos. This new nucleosynthesis process occurs in all core collapse supernovae and could explain the existience of Sr and other elements beyond iron in the very early stage of galactic evolution. In addition, the process is a candidate for the postulated lighter element primary process LEPP.

A prerequisite for this process to occur is the presence of proton-rich neutrino-heated matter - as recent supernova simulations with accurate neutrino transport have shown to exhibit. As this proton-rich matter expands and cools nuclei start to form, resulting in a composition dominated mainly by ^{56}Ni, ^{4}He, and protons. Without further inclusion of neutrino and antineutrino reactions, we find the typical composition of a proton- and alpha rich freeze-out (composition dominated by protons, alpha particles, and Fe-group nuclei) and the matter flow stops at ^{64}Ge. The neutrino p-process allows the synthesis of nuclei heavier than A=64 due to the abundant antineutrinos streaming from the hot proto neutron star. The antineutrinos capture predominantly on free protons, causing a residual density of free neutrons of 10^{14} to 10^{15} cm^{-3} for several seconds. These neutrons are readily captured by heavy neutron-deficient nuclei, allowing the matter flow to proceed to nuclei heavier than A=64, thus effectively bridging the beta-decay waiting points by (n,p) reactions. Similar results have been obtained by Pruet *et al.* (2006), studying the nucleosynthesis in the early proton-rich neutrino wind.

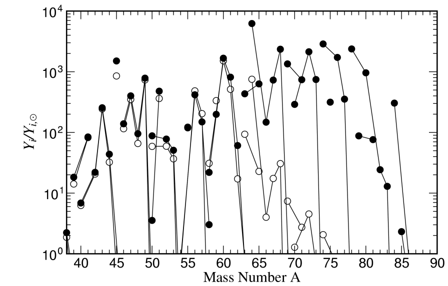

Fig. 1: Isotopic abundances relative to solar abundances. The solid circles represent calculations where (anti)neutrino-absorption reactions are included in the nucleosynthesis while for the open circles neutrino interactions are neglected.

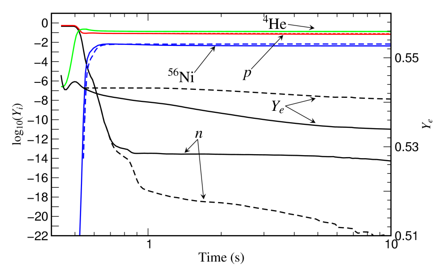

Fig. 2: Evolution of the abundances of neutrons, protons, alpha particles, and ^{56}Ni in a representative nucleosynthesis trajectory resulting. The solid (dashed) lines desplay the nucleosynthesis results which include (omit) neutrino and antineutrino absorption interactions after nuclei are formed. The abscissa measures the time since the onset of the supernova explosion.

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