Black hole accretion disks as site for the νp-process

L. T. Kizivat[1] and G. Martinez-Pinedo[1]
[1]GSI, Darmstadt, Germany

Important questions like the definite astrophysical sites of the r- and p-process still remain unanswered. The puzzle concerning the origin of the light p-nuclides might have been solved recently with the discovery of the νp-process [1, 2]. The νp-process operates via antineutrino capture reactions on free protons in proton-rich environments with high neutrino and antineutrino fluxes such as the early ejected matter in core-collapse supernovae. Recent studies indicate that quite similar physical conditions also occur in the windlike outflows from the accretion disk surrounding a black hole in the collapsar model of gamma-ray bursts.

Once the ejected matter reaches cooler regions, i.e. with increasing distance from the neutron star surface or accretion disk, the nucleons assemble in nuclei and, without further neutrino reactions, the proton-rich matter freezes out with a significant production of $N = Z$ nuclei like ^{56}Ni and ^{64}Ge and some free protons left. However, antineutrino captures on these protons via

$$\bar{\nu}_e + p \rightarrow e^+ + n \qquad (1)$$

ensure a significant presence of free neutrons which can be captured on the $N = Z$ nuclei via (n,p) and (n, γ) reactions allowing for matter flow beyond ^{56}Ni and ^{64}Ge.

Our study is based on profiles from a windlike outflow model of refs. [3, 4] that are coupled to an extensive nuclear network. The disks studied in this work are all based on the model of Neutrino-Dominated-Accretion-Flows, "NDAF's" [5]. We have studied the nucleosynthesis in the accretion disk outflows varying different parameter values: the accretion rate $\dot{M}$, the acceleration parameter β, which determines the acceleration of the ejected matter, the radius R_0 at which the matter is ejected from the disk, and the entropy S of the ejecta [6].

Here we will discuss the influence of the velocity of the outflows, i.e. the acceleration parameter β, on the νp-process nucleosynthesis. Both models A and B assume the same physical conditions except for the outflow velocity. Model A has a relatively slow outflow velocity which corresponds to conditions for which one expects the outflows to be proton-rich as neutrino producing reactions occur with significant rates. A sequence of (n, p) and (p, γ) reactions allows for synthesis of elements upto the mass range $A \sim 80$–100 for the conditions of model A, as can be seen in Fig. 1, top. As a comparison we also show the abundance distribution obtained with the same nucleosynthesis network, however, switching off the neutrino and, importantly, antineutrino capture reactions once the freeze-out value of the electron fraction is reached. Strikingly the matter flow stops at the alpha seed nuclei with long halflives as in this scenario no free neutrons are available to carry the matter flow to larger mass numbers as it is guaranteed in the νp-process. Model B is expected to show only a rather weak νp-process as it has a relatively high outflow velocity. This is indeed borne out by our nucleosynthesis calculation, as can be seen in Fig. 1, bottom.

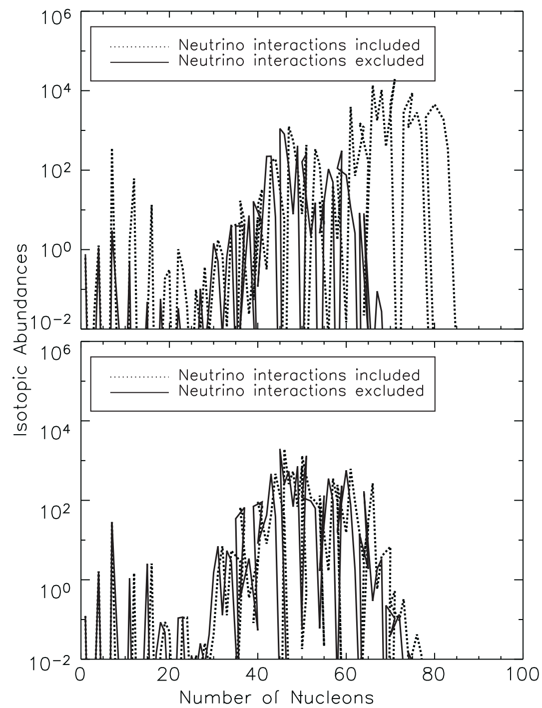

Figure 1: Final isotopic abundances normalized to solar abundances. On top the results for model A, at bottom the results for model B.

References

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