NUCLEOSYNTHESIS FROM LGRB-TYPE ACCRETION DISKS

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Abstract. We investigate the vertical structure and element distribution of neutrino-dominated accretion flows around black holes in spherical coordinates with reasonable nuclear statistical equilibrium. According to our calculations, heavy nuclei tend to be produced in a thin region near the disk surface. In this thin region, we find that ^{56}Ni is dominant in the flow with low accretion rate (*e.g.*, $0.05 M_{\odot} \text{ s}^{-1}$). The solutions indicate that ^{56}Ni comes from the central engine, whose decay may drive the bumps in the light curve of core-collapse supernova.

1 Introduction

The popular model of the central engine in gamma-ray bursts (GRBs) is named neutrino-dominated accretion flows (NDAFs, see, *e.g.*, Gu *et al.* 2006, Liu *et al.* 2007, 2008, 2010a, 2012a, 2013; Sun *et al.* 2012). The NDAF involves a hyperaccreting spinning stellar black hole with mass accretion rates in the range of $0.01 \sim 10 M_{\odot} \text{ s}^{-1}$. The extreme state is a hotbed to produce heavy nuclei, and the central region of GRBs is an ideal location to supply an extremely hot and dense state. Actually, nucleosynthesis should also be involved in the NDAFs model. The purpose of this paper is to investigate the element distribution in the vertical direction of NDAFs for long GRBs (LGRBs) with detailed neutrino physics and precise nuclear statistical equilibrium (Seitenzahl *et al.* 2008). The detailed equations is in Liu *et al.* (2013).

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Fig. 1. Variations of the mass fraction of the main elements with θ at $r = 10r_g$ and $100r_g$ for $\dot{M} = 0.05 M_{\odot} \text{ s}^{-1}$.

2 The distribution of heavy nuclei

Figure 1 shows the variations of the mass fraction (also approximately equals the number density) of free neutron and proton, and the other major nuclei with opening angle of the disk θ at $r = 10r_g$ and $100r_g$ for $\dot{M} = 0.05 M_{\odot} \text{ s}^{-1}$ corresponding to (a) and (b). ^{56}Ni dominates at the disk surface, and the other heavy nuclei also appear in these cases. The solutions show that the proportion of the nuclear matter increases with radius for a certain accretion rate. The mass fraction of ^{56}Ni near the surface increases with radius. In the middle region, ^4He is dominant for any accretion rate. The free neutrons and protons are dominant near the equatorial plane of the disk in the hot and dense state. Most of the free protons are transformed into the free neutrons due to the Urca process, which causes the dominant free neutrons and the decrease of electron fraction.

3 Discussion

When a massive star collapses to a black hole, a powerful supernova occurs. The newborn hyperaccreting black hole may power a GRB. Conjecturally, the optical light curve bumps of the supernovae accompanied with LGRBs is driven by the decay of ^{56}Ni in the outflows coming from the central engine. We have described self-consistently how to produce ^{56}Ni and other elements in the central region of LGRBs with the NDAF model. Only for the low accretion rate corresponding to the central engine of LGRBs, ^{56}Ni dominates near the disk surface. More daringly, if the outflow occurs from the disk surface, which consists of ^{56}Ni and the other heavy nuclei, the bumps in supernova light curve can be naturally generated due to ^{56}Ni decay in the outflow from NDAFs. Actually, Liu *et al.* (2012a) revisited the vertical structure of NDAFs and showed that the possible outflow may appear in the outer region of the disk according to the calculations of the vertical distribution of the Bernoulli parameter. We also noticed that the basic equations of NDAF are similar to that of slim disk. The high-speed outflow may be generated near the disk surface in the two-dimensional simulations of supercritical disk (*e.g.*,

Fig. 2. Schematic picture of a Nickel factory in the collapsar.

Ohsuga & Mineshige 2011). All these suggest that an outflow near the disk surface may appear in NDAF model. Nickel existing in the outflows from the surface of NDAF with the low mass accretion rate may be the most important source of LGRB ^{56}Ni production (see Fig. 2).

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