Death of Massive Stars: Supernovae and Gamma-Ray Bursts
Proceedings IAU Symposium No. 279, 2012
A.C. Editor, B.D. Editor & C.E. Editor, eds.

doi:10.1017/S1743921312013361

The Accretion-Powered Jet Propagations and Breakout Criteria for GRB Progenitors

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Abstract. We investigate the propagation of accretion-powered jets in various types of progenitor candidates of GRBs. We perform two dimensional axisymmetric simulations of relativistic hydrodynamics taking into account both the envelope collapse and the jet propagation. In our simulations, the accretion rate is estimated by the mass flux going through the inner boundary, and the jet is injected with a constant accretion-to-jet conversion efficiency η. By varying the efficiency η and opening angle θ_{op} for more than 30 models, we find that the jet can make a relativistic breakout from all types of progenitors for GRBs if a simple condition $\eta \gtrsim 10^{-3}(\theta_{op}/20°)^2$ is satisfied, that is consistent with analytical estimates, otherwise no explosion or some failed spherical explosions occur.

Keywords. gamma rays: burst, supernovae: general

1. Overview and Methods

Some populations of Gamma-Ray Bursts (GRBs) are thought to originate from the death of massive stars. It is widely believed that the jet is supposed to be launched due to interaction between black hole and accretion system. After the jet is launched in the vicinity of black hole, the jet head should propagate outward and break out from the stellar surface, otherwise the jet becomes non-relativistic ejecta and fails to create a GRB. Therefore, a relativistic jet breakout is a minimum requirement to produce GRBs. In this study, we investigate the jet break out criteria by simulating the jet propagation (see for more details in Nagakura *et al.* 2011b.)

We perform relativistic two-dimensional hydrodynamics simulations for envelope collapse and jet propagation. The numerical codes employed in this paper are essentially the same as those used in Nagakura *et al.* (2011a). In this study, the jet luminosity is determined by the mass accretion rate, which is a major difference from previous works (Almost every past study assumes a constant jet luminosity). We survey the parameter space of accretion-to-jet conversion efficiency (η) and opening angle of jet (θ_{op}), and discuss how these key quantities affect the jet dynamics. The numerical results are compared with the previous analytical work by Suwa & Ioka (2011).

2. Results

Fig. 1 shows the results of our study and comparison with analytical criteria. The upper left panel shows the Wolf-Rayet progenitor case (16TI model in Woosley & Heger

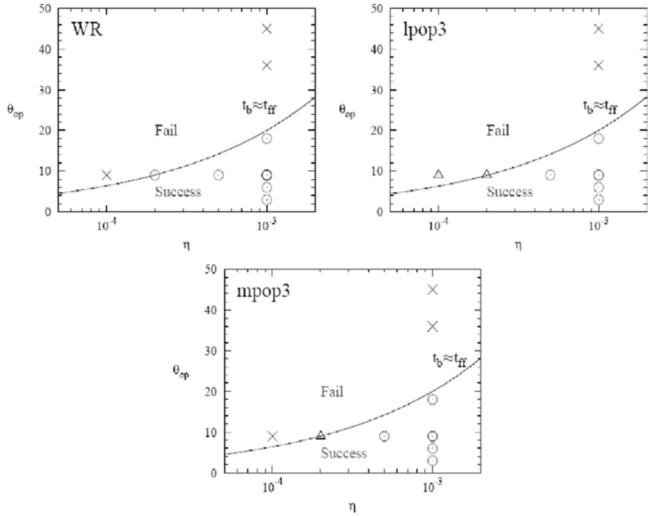

Figure 1. The score sheet of the shock break out. The x-axis denotes the conversion efficiency while the y-axis shows the opening angle.

(2006), hereafter SR model), while the upper right and lower panel show $40M_\odot$, which is the metal free pre-supernova model calculated by Woosley *et al.* (2002) (hereafter lpop3 model) and $1000M_\odot$, which is also the metal free presupernova model calculated by Ohkubo *et al.* (2009) (hereafter mpop3), respectively. The stellar radius for each model is 4×10^{10} cm, 1.5×10^{12} cm and 9×10^{12} cm, respectively. Last two models are investigated with Population III GRBs in mind. The circles correspond to the models which are conducive to GRB formation in our numerical simulations, while the crosses show the failed cases. The triangles correspond to mildly relativistic explosion models. As shown in this figure, if the accretion-to-jet conversion efficiency is high enough and opening angle of jet is small enough, the jet can propagate and break out relativistically even in massive progenitors such as lpop3 and mpop3 models. By comparing with analytical works (solid line in Fig 1), we obtain the simple break out criterion as

$$\eta \gtrsim 10^{-3} \left(\frac{\theta_{op}}{20^\circ}\right)^2. \tag{2.1}$$

In summary, the central engine is not sufficient to produce GRBs by itself, and it should satisfy the condition of Eq. (2.1). It is interesting to note that the jet, whose conversion efficiency satisfies the above condition, succeeds to break out relativistically even if the progenitor has larger radius. It should be noted, however, that the inner part of the progenitor should also be compact in order to keep high mass accretion rate after the formation of the black hole, otherwise the jet luminosity becomes too weak to produce GRBs. Therefore Red Supergiant is not suitable for the production of GRBs.

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https://doi.org/10.1017/S1743921312013361 Published online by Cambridge University Press