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GAMMA-RAY BURST JETS: COMPOSITION AND CONFIGURATION

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Long Gamma-ray bursts (GRBs) are believed to be originated from relativistic jets launched during the core collapses of some massive stars. The two core questions in the contemporary GRB science are the physical composition and the geometric configuration of the jets. Here I review the recent theoretical progress in both directions, and discuss how *Swift* may address both questions in the near future.

Keywords: Gamma-ray bursts; jets; magnetic field

1. Introduction

Evidence suggests that GRBs are originated from relativistic jets. Among other problems (e.g. Ref.1 for a review), there are two core questions in the contemporary GRB science concerning the nature of the jets.

(1) What is the physical composition of the jets? A GRB jet in principle include two fundamental energy components, i.e. a baryonic component and a Poynting flux component. The former is stored in the form of the kinetic energy of the baryons, while the latter stems from the strong magnetic fields attached to the central engine. A generic GRB flow could be parameterized with the σ-parameter, the ratio between the Poynting flux and the kinetic flux. The leading GRB scenario is hydrodynamical, with magnetic fields being neglected dynamically. This is essentially the $\sigma \rightarrow 0$ limit (e.g. Refs.2, 1 for reviews). Alternatively, Poynting flux dominated GRB models have been also discussed, which represent the $\sigma \rightarrow \infty$ limit (e.g. Ref.3 and references therein). In reality, the GRB ejecta may be magnetized to some degree with an arbitrary-σ value. Within the baryonic energy component, the jet composition further includes the conventional proton (or ion) component, and a free neutron component (e.g. Ref.4 and references therein). One can denote the ratio between the neutron and the proton components as χ. Diagnosing the unknown σ and χ parameters is of great interests to understand the nature of the jets.

(2) What is the geometric configuration of the jets? The simplest jet model invokes a conical jet with uniform energy distribution inside the cone and a sharp cutoff outside. For the sake of unification of GRBs and related phenomena such as X-ray flashes (XRFs), there are arguments that jets may have a more complicated

angular distribution of the jet energy, with the jet "structure" being a function of the angle from the jet axis, such as Gaussian, power-law, or other function forms[5,6]. Whether GRB jets are structured and what is the most likely jet structure are questions of great interests in the GRB community.

2. Jet Composition

Most of the current afterglow observations take place hours after the burst triggers. At this stage, the observed afterglow emission comes from the shocked circumburst medium, so that essentially all the initial information of the jet is lost. In order to diagnose the the jet composition, well-monitored early afterglow data are needed, since the early afterglow emission (especially in the optical band) is believed to include not only the forward shock emission component, but also the emission contributions from the reverse shock region and possibly a neutron decay product trail. The reverse shock propagates into the jet ejecta, and the emission property depends on the magnetization of the jet.

In order to diagnose jet magnetization with afterglow data, recently we have developed a reverse shock emission theory for GRB jets with an arbitrary magnetization parameter, σ (Ref. 7, cf. Ref.8). We find the following interesting conclusions. (1) As σ increases from 0 to ~ 1, the flux contrast between the reverse shock emission component and the forward shock emission component increases. The main reason is that the magnetic field in the reverse shock region, which is originated from compression of the upstream magnetic field, becomes progressively stronger than that in the forward shock region, a phenomenon already revealed from the analysis of the early afterglow data of GRB 990123 and GRB 021211[9]. (2) As σ keeps increasing above 1, the emission levels for both the reverse and the forward shock components drop, although the contrast between the two component essentially remain the same. (3) In the high-σ regime, the reverse shock peak is broadened, mainly due to the separation of the shock crossing radius and the deceleration radius of the jet. Such a plateau feature of the reverse shock emission may be used to interpret the early afterglow data of GRB 021004 and GRB 030428. All these characteristics could be used as an important diagnostic tool for pinning down the σ parameter of the jet flow. The theory is also applied to the internal shock phase, with magnetic dissipation processes taken into account. The results suggest that a moderately magnetized internal shock model is competitive to interpret the GRB prompt emission data[10].

In order to diagnose the neutron component in the jet, recently we[11] performed a careful study for the early afterglow lightcurves with an arbitrary χ parameter. Two types of the circumburst medium, i.e. the constant ISM model and the stellar wind model, are discussed. The emission from both the neutron decay product trail and the ion-shell shocks are calculated. The predicted early afterglow lightcurves show rich bumpy signatures for the ISM case and an extended plateau for the wind case[11]. Such predicted signatures can be used to diagnose or constrain the neutron component with the current and future data.

3. Jet Configuration

There are two ways to diagnose the jet configuration of GRB jets. One is through modeling individual burst lightcurves to see whether or not the observations are consistent with the theoretical predictions of a particular type of structured jet. The afterglow lightcurves for structured jets have been extensively modeled. No firm conclusion is however drawn with this approach. The second way is to perform a global test of the jet configuration using the statistical properties of many bursts. This has been carried out recently for a quasi-universal Gaussian type structured jet model[12,13]. This model is found to be generally consistent with a broad spectrum of both the prompt emission and the afterglow data for both GRBs and XRFs. None of the other models have passed the global test with all the available data. It looks to us that the quasi-universal Gaussian model at least gives a first-order representation of the reality.

4. What can *Swift* do?

Swift, a dedicated GRB mission to be launched in early November 2004, is highly expected to solve the two problems discussed above. The uniqueness of the mission includes that it can record early afterglows of many bursts (about 100-150 per year) during the mission, and that it will provide a uniform large data base for both prompt emission and afterglow. The first function is the key to diagnose the physical composition of the jet, and the second function is essential to globally constrain the possible jet configuration. A new epoch of the GRB study is soon coming, and it is optimistic that the two core questions concerning the nature of GRB jets will be solved in the near future.

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