Gamma Ray Bursts in the Swift and GLAST Era

Truong Le and Charles D. Dermer

Code 7653, Space Science Division, Naval Research Laboratory
Washington, DC 20375, USA

Abstract. We summarize our model for long-duration gamma ray bursts (GRBs) that fits the redshift (z) distributions measured with Swift and missions before Swift, and the pre-Swift GRB jet opening-angle distribution inferred from achromatic breaks in the optical light curves. We find that the comoving rate density of GRB sources exhibits positive evolution to $z \gtrsim 3$ – 5, whereas the star formation rate inferred from measurements of the blue and UV luminosity density peaks at $z \sim 1 - 3$. The mean intrinsic beaming factor of GRBs is found to be $\approx 34 - 42$, and we predict that the mean GRB optical jet opening half-angle measured with Swift is $\approx 10^\circ$. We estimate the number of GRBs per year that GLAST is expected to observe based on ratios of BATSE and EGRET GRB fluences.

Keywords: gamma-rays: bursts — cosmology
PACS: 98.62.Nx, 98.70.Rz

INTRODUCTION

With the launch of the *Swift* satellite [1], rapid follow-up studies of GRBs triggered by the Burst Alert Telescope (BAT) on *Swift* became possible. A fainter and more distant population of GRBs than found with the pre-*Swift* satellites CGRO-BATSE, BeppoSAX, INTEGRAL, and HETE-2 is detected [2]. The mean redshift of 41 pre-*Swift* GRBs that also have measured optical afterglow beaming breaks [3] is $\langle z \rangle = 1.5$, while 16 GRBs discovered by *Swift* have $\langle z \rangle = 2.72$ [4]. The null hypothesis that the redshift distributions of *Swift* and pre-*Swift* GRBs are the same is rejected in several statistical tests at the $\gtrsim 97\%$ confidence level [5].

In recent work [6], we considered whether the differences between the pre-*Swift* and *Swift* redshift distributions can be explained with a physical model for GRBs that takes into account the different flux thresholds of GRB detectors, where we assume the detector threshold for *Swift* and pre-*Swift* GRBs to be $\sim 10^{-8}$ and $\sim 10^{-7}$ ergs cm^{-2} s^{-1}, respectively [6], corresponding to the minimum peak fluxes of GRBs with redshifts measured by Swift and missions before Swift. We summarize [6] and make an independent estimate of the number of GRBs that GLAST should detect.

RESULTS

We parameterize the distribution of GRB jet opening angles with a function of the form $dN/d\mu_j \propto (1-\mu_j)^s$, where $\arccos(\mu_j)$ is the jet half-angle, and find best fit values for the γ-ray energy release $\mathscr{E}_\gamma$ for different functional forms of the comoving rate density of GRBs (see Fig. 1, left panel). We simplify the analysis with a flat GRB νF_ν spectrum, and assume that the properties of GRBs do not change with time. Adopting the uniform jet model where the energy per solid angle is roughly constant throughout the GRB jet, and taking a mean intrinsic duration of 10 seconds, we obtain best-fit values with a corrected emitted γ-ray energy $\mathscr{E}_\gamma = 4 \times 10^{51}$ ergs, jet opening angles in the range 0.05 – 0.7 radians, and with $s \approx -1.25$.

Our analysis shows that good fits to the pre-*Swift* and *Swift* redshift and opening angle data require a GRB rate history that rises faster than the star formation rate (SFR2,3,4) at high redshifts (SFR5 and SFR6; see Fig. 1, left panel). The results of our fitting indicate that GRB activity was greater in the past and is not simply proportional to the bulk of the star formation as traced by the blue and UV luminosity density of the universe. Furthermore, our model predicts the mean intrinsic beaming factor of GRB jetted outflows contributing to the optical breaks to be in the range from $\approx 34 - 42$. The analysis also indicates that the average jet opening half-angle of GRBs detected with Swift is $\langle \theta_j \rangle \approx 10^\circ$, compared to the pre-*Swift* average of 7° [6]. Thus we expect to detect more faint low-redshift, large opening angle GRBs that pre-*Swift* satellites could not detect (see also [8]).

We also estimate the number of GRBs per year GLAST will observe using the fluence ratios of BATSE ($\simeq 20$ keV – 2 MeV) and EGRET (100 MeV – 5 GeV) for the 5 BATSE bursts also detected in the EGRET spark chamber [9].

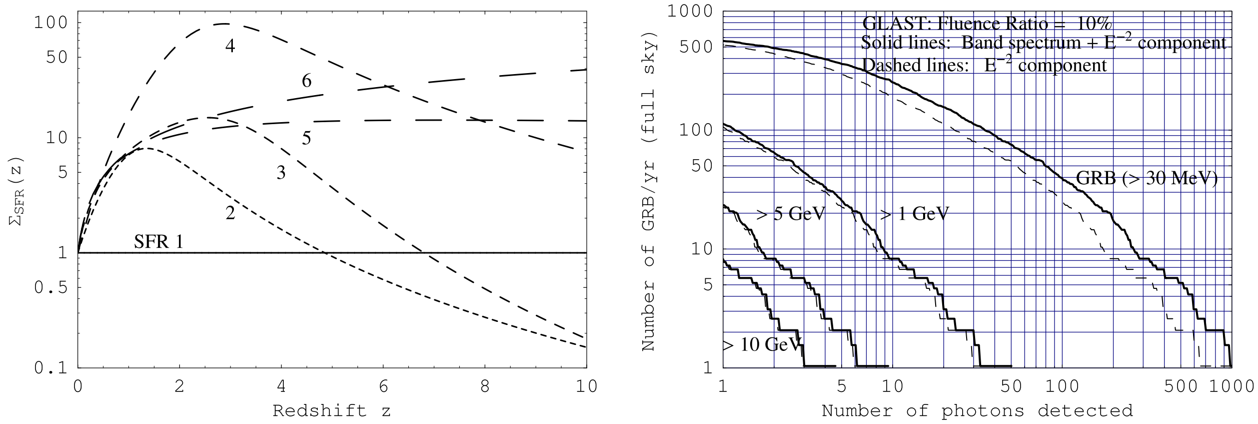

FIGURE 1. *Left panel:* star formation rate (SFR) functions used in our GRB study. The solid line (SFR1) is a constant comoving density; SFR2 and SFR4 are low and high ranges for the SFR; SFR3 is a recent fit [7] to the data; SFR5 and SFR6 are GRB rate histories that give a good fit to the *Swift* and pre-*Swift* redshift distribution and the pre-Swift opening angle distribution [6]. *Right panel:* Estimate of the number of GRBs per year GLAST will observe, based on measured EGRET/BATSE fluence ratios.

We find that the average BATSE/EGRET fluence ratio is $\approx 5\%$, though with large scatter and not taking into account Earth occultation (e.g., for GRB 940217) [11], deadtime effects [9], and anomalous GRBs like GRB 941017 [10]. Our estimate uses the BATSE 4B fluence distribution, a Band function with Band $\beta = -2.5$ added to a > 30 MeV spectral component with a -2 photon index in the EGRET/GLAST range [12], and power-law approximations for the EGRET and GLAST effective areas [13].

Fig.1, right panel, gives the resulting estimate of the number of GRBs GLAST should observe per year full-sky for a fluence ratio of 10%, for different integral photon numbers and energies. We find that there will be ≈ 350 (≈ 25) GRBs/yr full-sky from which the GLAST LAT would detect ≥ 5 photons with energy $E > 30$ MeV (> 1 GeV), and ≈ 25 (≈ 8) GRBs/yr full-sky with ≥ 1 photon with $E > 5$ GeV (> 10 GeV). A similar conclusion [14], obtained by extrapolating BATSE results fitted with the Band function to LAT energies, gives an estimate of 50-70 GRBs/yr with > 5 photons with $E > 30$ MeV. Our analysis also shows that GRBs give very little ($\lesssim 1\%$) contribution to the diffuse extragalactic γ-ray background.

ACKNOWLEDGMENTS

T. L. is funded through NASA *GLAST* Science Investigation No. DPR-S-1563-Y. The work of C. D. D. is supported by the Office of Naval Research. We thank Nicola Omodei and Brenda Dingus for discussions, and Brenda Dingus for pointing out how deadtime effects could be important for EGRET.

REFERENCES

1. Gehrels, N. *et al.* 2004, *Astrophysical J.,* 611, 1005
2. Berger, E. *et al.* 2005, *Astrophysical J.,* 634, 501
3. Friedman, A. S., & Bloom, J. S. 2005, *Astrophysical J.,* 627, 1
4. Jakobsson, P. *et al.* 2006, *Astron. & Astrophys.*, 447, 897
5. Bagoly, Z. *et al.* 2006, *Astron. & Astrophys.*, 453, 797
6. Le, T., & Dermer, C. D. 2006, *Astrophysical J.,* in press (astro-ph/0610043)
7. Hopkins, A. M., & Beacom, J. F. 2006, *Astrophysical J.,* 651, 142
8. Perna, R., Sari, R., & Frail, D. 2003, *Astrophysical J.,* 594, 379
9. Dingus, B. L. 1995, *Astrophys. Space Sci.* 231, 187
10. González, M. M. *et al.* 2003, *Nature*, 424, 749
11. Dermer, C. D. 2005, in *Atmospheric Cherenkov Detectors VII*, astro-ph/0512164
12. Dingus, B. L., Catelli, J. R., & Schneid, E. J. 1998, *AIP Conference Series*, 428, 349
13. Dermer, C. D., & Dingus, B. L. 2004, *New Astronomy Review*, 48, 537
14. Omodei, N., for the GLAST/LAT GRB Science Group 2006, astro-ph/0603762