Gamma Ray Bursts in the Swift and GLAST Era

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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.

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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 $\approx 10^{-8}$ and $\approx 10^{-7}$ 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 $\gamma$-ray energy release $\dot{E}_\gamma$ for different functional forms of the comoving rate density of GRBs (see Fig. 1, left panel). We simplify the analysis with a flat GRB $\nu F_\nu$ 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 $\gamma$-ray energy $\dot{E}_\gamma = 4 \times 10^{51}$ 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 $7^\circ$ [6]. Thus we expect to detect more faint low-redshift, large opening angle GRBs that pre-Swift satellites could not detect (see also [6]).

We also estimate the number of GRBs per year GLAST will observe using the fluence ratios of BATSE ($\approx 20$ 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 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. **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 $\approx 350$ ($\approx 25$) GRBs/yr full-sky from which the GLAST LAT would detect $\geq 5$ photons with energy $E > 30$ MeV ($> 1$ GeV), and $\approx 25$ ($\approx 8$) GRBs/yr full-sky with $\geq 1$ 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 ($< \sim 1\%$) contribution to the diffuse extragalactic $\gamma$-ray background.

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