GLOBAL PROPERTIES OF HIGH-ENERGY EMISSION FROM GAMMA-RAY BURSTS

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Abstract. In three years of observations the Large Area Telescope (LAT) on board the *Fermi* Gamma Ray Space Telescope has observed high-energy γ -ray emission from 35 gamma-ray bursts (GRBs). The first *Fermi*-LAT catalog of GRBs is in preparation within the *Fermi* LAT collaboration and will provide a systematic study of high-energy emission from GRBs. In this paper we present some of the main results, briefly discussing durations, energetics, time-resolved and time integrated LAT spectral analysis. We also discuss characteristics of LAT-detected emission such as its delayed onset and longer duration compared to emission detected by the GBM, and its power-law temporal decay at late times.

1 Introduction

The *Fermi* observatory was placed into orbit on 2008 June 11. It provides unprecedented breadth of energy coverage and sensitivity for advancing knowledge of GRB properties at high energies. It has two instruments: the Gamma-ray Burst Monitor (GBM; Meegan *et al.* 2009), comprised of twelve sodium iodide (NaI) and two bismuth germanate (BGO) detectors sensitive in the 8 keV–1 MeV and 150 keV–40 MeV respectively, and the Large Area Telescope (LAT; Atwood *et al.* 2009), a pair conversion telescope sensitive to γ rays in the energy range from ~ 20 MeV to $\gtrsim 300$ GeV. The wide field of view (~ 2.4 sr at 1 GeV) of the LAT, its continuous observations in scanning mode, its broad energy range, its large effective area (~ 6500 cm² on axis at $\sin > 1$ GeV), its low dead time per event (~ 27 μ s), its efficient background rejection, and its good angular resolution

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(~ 0.8 at 1 GeV) are vastly improved in comparison with those of EGRET. As a result, the LAT provides more GRB detections, higher statistics per detection, and more accurate localizations ($\lesssim 1^\circ$).

2 Properties of Gamma-Ray Burst emission at high energy

We have analyzed 3 years of *Fermi* LAT data using Pass 6 v3 Transient-event class above 100 MeV, significantly detecting 28 GRBs. We have also detected 7 additional GRBs using the “LAT Low Energy” (LLE) event class (Pelassa *et al.* 2010) which increases the effective area between ~ 20 MeV– ~ 1 GeV. While the rate of LAT GRBs is a small fraction of the rate of GRBs detected by the *Fermi*-GBM (Goldstein *et al.* 2012; Paciesas *et al.* 2012), there are unique features that emerge only at high energies. First we compute the onset time (T_{05}) and the duration (T_{90}) of the high-energy emission, and we compare our measurements with the durations reported in the GBM GRB catalog (Paciesas *et al.* 2012). In the left (right) panel of Figure 1 the >100 MeV LAT T_{05} (T_{90}) is compared to the GBM results (in the 50 keV–300 keV energy band).

Fig. 1. *Left:* comparison between the >100 MeV T_{05} as measured using the LAT Transient class events and the 50 keV–300 keV T_{05} as measured by the GBM. *Right:* T_{90} . GBM data from Paciesas *et al.* (2012). Long (short) GRBs with filled blue (empty red) markers. Squares markers highlight the 4 brightest bursts (labeled).

We use the maximum likelihood technique implemented in the *Fermi* LAT ScienceTools to perform the spectral analysis from which we derive the fluences of the LAT GRBs. The left panel of Figure 2 shows the fluence measured by the LAT *versus* the fluence measured by the GBM. The bulk of the LAT GRB population, primarily composed of long GRBs, has a ratio of high- (100 MeV – 10 GeV) to low-energy (10 keV – 1 MeV) fluence $\lesssim 20\%$. It is interesting to note that short LAT-detected bursts (red markers) have a greater ratio of high- to low-energy fluence than the bulk of the long-GRB population (blue markers). In this figure,

Fig. 3. *Left:* the decay of the luminosity L with time measured in the rest frame for all the GRBs with detected extended emission. *Right:* same quantity, but for 3 GRBs with a significant time break detected. Dashed-dotted lines are the best fits of the broken power law model to each GRB, while dashed crosses are the luminosities before the peak times, which have not been used in the fits.

090902B and 090926A) with a significant break detected in the lightcurve (chance probability smaller than 10^{-3}).

3 Discussion

In this study, we have presented some of the results that will be published in a LAT collaboration paper characterizing the high-energy emission of *Fermi*-LAT detected GRBs. Here we briefly discuss few important points.

The origin of the delayed onset of the LAT emission is poorly understood, but a possible interpretation is based on the early afterglow model for the temporally-extended LAT emission (De Pasquale *et al.* 2010; Ghisellini *et al.* 2010; Kumar & Barniol Duran 2009; Razzaque 2010). The bolometric flux from a coasting fireball increases as $\propto t^2$ (Sari 1997) before it decelerates and enters a self-similar phase (Blandford & McKee 1976; Rees & Meszaros 1994). The time required for the flux to increase and be detected by the LAT corresponds to the delay time in this scenario. The flux of LAT-detected emission at late times decays rather smoothly and can generally be fitted with a power law $F_\nu \propto t^{-\alpha_L}$. For three bright bursts (GRBs 090510, 090902B and 090926A), a broken power law fits the LAT data better than a single power law with the initial flux decay steeper than the later one, which is always close to $\alpha_L = 1$. In the context of the external shock, the bolometric flux decays as $\propto t^{-\alpha}$, with $\alpha = 1$ and $\alpha = 10/7$ for an adiabatic and a radiative fireball in a constant density environment (Ghisellini *et al.* 2010; Katz & Piran 1997; Sari 1997), respectively. A simple interpretation of $\alpha_L \approx 1$ flux decay-index for most LAT bursts suggests that the $\gtrsim 100$ MeV emission in

the long-lasting phase is more likely from an adiabatic fireball (De Pasquale *et al.* 2010; Kumar & Barniol Duran 2009; Razzaque 2010) rather than from a radiative fireball, as Ghisellini *et al.* (2010) had suggested. The observed break in the decay rate of the extended emission might be due to a transition from the prompt (internal shocks) to afterglow (external shock) emission.

Spectral analysis of bright bursts shows that the GRBs in which we detect with high significance a break in the lightcurves (GRBs 090510, 090902B and 090926A), also require an additional extra component (Abdo *et al.* 2009a,b; Ackermann *et al.* 2010, 2011; Giuliani *et al.* 2010). In these cases, the high-energy photon index of the Band function (β), is systematically softer (and more variable) than the photon index of the high energy extra component, indicating again a possible dichotomy between the prompt and the early afterglow.

Finally, the fluence of LAT GRBs (see Fig. 2) provides hints of two classes: a hyper-fluient class currently with four members (GRBs 080916C, 090510, 090902B, and 090926A); and a larger class with a lower typical fluence. The bolometric isotropic equivalent energy E_{iso} (see Fig. 2, right panel) is also higher for LAT bursts, suggesting that, in agreement with Cenke *et al.* (2011) and Racusin *et al.* (2011), LAT bursts possibly comprise the most energetic sub-sample of GRBs.

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