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ScienceDirect
Advances in Space Research 38 (2006) 1329–1332
Advances in Space Research
(a COSPAR publication)
www.elsevier.com/locate/asr

The E_p distribution of long-duration γ-ray bursts observed by the PHEBUS experiment

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Received 29 July 2004; received in revised form 16 September 2004; accepted 7 November 2004

Abstract

We present a distribution in E_p, the break energy of γ-ray burst (GRB) spectra, obtained from a spectral analysis of 91 long-duration, high fluence, GRBs recorded by the PHEBUS experiment. From spectral fits above 0.1 MeV of 279 time slices during these 91 GRB events, the centroid of the E_p distribution is found to be ∼0.41 MeV while the full width at half maximum (FWHM) is ∼0.60 MeV. These values are significantly higher than those derived from BATSE data (viz. ∼0.25 and ∼0.30 MeV, respectively). Nevertheless, we confirm that the E_p distribution is narrow with an upper-energy limit at about 2 MeV.

Keywords: γ-Rays; Bursts – γ-rays; Observations

1. Introduction

Most γ-ray burst spectra are satisfactorily described by the well-known Band expression which consists of two power laws smoothly joined by an exponential cutoff. This analytical form has 4 free-parameters: A, the amplitude, α and β, the low- and high-energy power-law spectral indices, respectively, and E_p, the break energy. Since it is common that $\alpha > -2$ and $\beta < -2$, E_p generally represents the peak energy of the νF_ν spectrum. From a time-resolved spectral analysis of 156 high-fluence BATSE events, Preece et al. (2000) (hereafter P2000) reported a distribution in E_p centered around ∼0.25 MeV with a FWHM of ∼0.30 MeV. The narrowness of the E_p distribution is striking and challenges current GRB emission-models (Zhang and Mészáros, 2002).

Although PHEBUS and BATSE results somewhat differ, this paper provides an independent confirmation of the narrowness of the E_p distribution. Originally our primary purpose was the investigation of only the upper-energy limit of the distribution, since we believed that PHEBUS' 0.1 MeV lower limit would bias the measurement of the bulk of E_p values. However, as we observed the centroid of the E_p distribution to be at significantly greater energies than that obtained by P2000 (i.e., 0.25 MeV), we go further in this work and report preliminary results on the entire distribution of E_p. A more detailed analysis of the other spectral parameters will be presented in a future paper.

2. The PHEBUS experiment

The PHEBUS experiment was in operation onboard the Granat satellite. Designed for the spectrometry of GRBs above ∼0.1 MeV, PHEBUS consisted of six detector modules arranged on the spacecraft structure for a ∼4π coverage of the sky. Each module includes a

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doi:10.1016/j.asr.2004.11.010

cylindrical crystal of BGO, 7.8 cm in diameter and 12.0 cm in height, surrounded by a plastic anticoincidence shield to reject particles and improve the detector sensitivity above ~2 MeV. Owing to the high stopping-power of BGO (density 7.13 g/cm^3), the PHEBUS detectors had a total efficiency of 0.78 throughout the nominal 0.075–100 MeV energy range. Moreover, since the detectors' responses were dominated by full-energy peak interactions below 5.1 MeV, PHEBUS data provides an excellent capability for the study of the spectral characteristics of GRBs in the MeV region. More details about the PHEBUS experiment are given in Barat et al. (2000).

3. Data analysis

Between December 1989 and September 1994, the period during which Granat was 3-axis stabilized, PHEBUS detected 175 GRBs with a duty cycle of approximately 30%. To separate long-duration events from short, we have used the emission time τ_{90} (Mitrofanov et al., 1999) instead of the usual T_{90} measure. The τ_{90} criterion is more stable than T_{90} for measuring the durations of bursts which have poor signal-to-noise (S/N) ratios. Adopting a boundary value of τ_{90} = 1.2 s, roughly corresponding to T_{90} = 2.0 s, yields 128 PHEBUS long-duration events (i.e., 73%).

In order to minimize the statistical uncertainties in the determination of E_p, only count spectra from the brightest of these long events have been analyzed. The adopted burst-selection criterion is a S/N ratio greater than 20σ. This value is derived from the total number of counts above 0.1 MeV in background-subtracted, time-averaged spectra accumulated over the τ_{90} period. A total of 91 out of 128 long GRBs satisfy this condition with fluences above 0.1 MeV ranging from $\sim 6 \times 10^{-6}$ to $\sim 2 \times 10^{-3}$ ergs/s. The distribution of peak fluxes for the 91 PHEBUS events is shown in Fig. 1 for a 1-s timescale. The 91 bright events from PHEBUS span approximately two orders of magnitude in peak flux. This is similar to the range covered by the 156 bright BATSE events selected by P2000. Assuming that the most intense events from BATSE and PHEBUS have equivalent peak fluxes above 0.1 MeV, this implies that the two burst sets are drawn from the same population.

From the 91 PHEBUS events, two sets of count spectra, called "A" and "B", have been derived. Sample "A" consists of 91 time-averaged spectra accumulated over the τ_{90} period. In set "A" spectral-accumulation durations range from 3.1 to 67.9 s with a median value of 15.7 s. Since each event is represented by only one spectrum, sample "A" is useful for the study of the variation in E_p between bursts. Sample "B", on the other hand, contains 279 count spectra obtained as follows. For each event, nine count spectra are accumulated over time bins

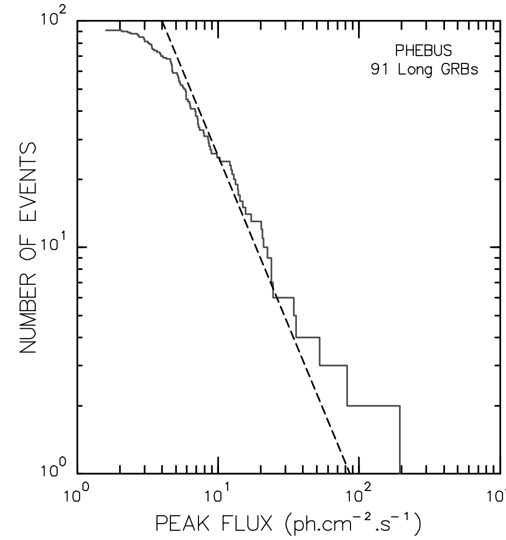

Fig. 1. Peak-flux distribution for the sample of 91 bright events from PHEBUS. The dashed line represents a −3/2 power law. Burst selection effects are visible below 5 photon/cm^2/s. Note that the photon flux is calculated above 0.1 MeV.

corresponding to τ_{10}, τ_{20}–τ_{10}, τ_{30}–τ_{20}... and τ_{90}–τ_{80}. Then, consecutive elementary spectra are combined as necessary in order to meet the >20σ criterion (for example, a burst may give four spectra over τ_{10}, τ_{30}–τ_{10}, τ_{60}–τ_{30}, and τ_{90}–τ_{60}). Consequently, a single burst contributes a variable number of spectra to sample "B", between one (for the weakest events) and nine (for the most intense). Sample "B", therefore, is dominated by spectra which are time resolved, at least to the extent that limited statistics allow, and reflects both how E_p evolves between and within bursts. In set "B" spectral-accumulation durations range from 0.26 to 63.2 s with a median value of 2.7 s.

Since the response of γ–ray detectors is anisotropic, the angle θ between the source direction and detector axes, must be known for a correct spectral analysis. From the 91 PHEBUS events used in this study, only 42 have been localized either by BATSE and/or by the interplanetary network (Hurley et al., 2000). Fortunately, for a given PHEBUS burst, the response of the brightest detector (i.e., the most brightly illuminated) is not very sensitive to the incidence angle. There are two reasons for this weak dependence on θ. First, due to detector-design constraints, the PHEBUS detector effective area peaks at $\theta \approx 90°$ and decreases by roughly 20% between θ = 90° and θ = 45°. Second, the value of θ for the brightest detector is expected to be somewhere between 90° and 45° because the six PHEBUS detectors were aligned along the $\pm X$, $\pm Y$, and $\pm Z$ axes of Granat. Indeed, the distribution in θ for the brightest detectors of *localized* events peaks at 76° with no values of θ below 45° or above 100°. Thus, for a variation of the brightest-detector incidence angle between 90° and 45°, the effective area changes by less than 20% with a consequently