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Spectral analysis of GRB with the gamma–ray burst monitor on–board BeppoSAX

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Abstract. Despite the difficulties due to the location of the experiment at the center of the scientific payload, efforts have been made to determine BeppoSAX Gamma–Ray Burst Monitor detectors response functions by means of extensive on–ground calibrations, Monte Carlo simulations and in–flight testing. Satisfactory results have been obtained particularly for the two detectors co–aligned with the two Wide Field Cameras (WFC, 1.5 − 26 keV) on–board the same satellite, allowing nearly unprecedented broad band (1.5 − 700 keV) spectral analysis of events detected by both experiments.

Key words: gamma–rays: bursts — methods: data analysis

1. The BeppoSAX gamma–ray burst monitor

The scientific payload of the Italian–Dutch X–ray astronomy satellite BeppoSAX (Boella et al. 1997) includes a Gamma–Ray Burst Monitor, GRBM (Costa et al. 1998), whose detecting units are the four CsI(Na) scintillators that act primarily as anticoincidence Lateral Shields (LS) for the PDS experiment main detectors (Frontera et al. 1997). Due to their large geometrical area of 1136 cm^2 each, the LS were also equipped with electronics dedicated to Gamma–Ray Bursts (GRB) detection. The scientific data available from each GRBM detector consist of: 1 s ratemeters continuously stored in the "GRBM" and "AC" energy bands, corresponding, with the actual thresholds settings, to 40 − 700 and > 100 keV respectively; 240 channels PHA spectra accumulated in the GRBM energy band over a time interval of 128 s; high resolution (down to 0.5 ms) time profiles stored and transmitted when the GRB trigger condition (Costa et al. 1998) is satisfied.

2. Instrument calibration and response functions

The GRBM is located at the center of the BeppoSAX payload and thus its response as a function of incoming photons energy and direction is very complex. In order to derive it, in addition to the standard calibrations at experiment level, a campaign of on–ground calibrations when the payload was integrated in the satellite (about 8 months before launch) has been performed (Amati et al. 1997; Costa et al. 1998). Moreover, a very detailed model of the entire satellite has been developed using the Los Alamos MCNP Monte Carlo code (Rapisarda et al. 1997). Both calibrations and model show that LS1 and LS3, the two detectors which are co–aligned with the WFCs (Jager et al. 1997), have rather clean and uniform field of views. Particular efforts have been made to reconstruct the response functions of these units, in order to be able to perform broad band (WFC+GRBM, 1.5 − 700 keV) spectral analysis of GRB detected by both experiments. The effective area in the GRBM and AC bands as a function of energy and photon direction was described with an analytical model partly based on physical and geometrical considerations and partly empirical (Amati et al. 1997). This allowed the construction of a two–channels (40 − 100 and 100 − 700 keV) response matrix that can be used to derive flux and spectral evolution from the 1 s ratemeters in the two bands under the assumption of a simple input model (e.g. power–law, thermal bremsstrahlung). The response matrices for the 240 channels PHA spectra have been built on the basis of the calibration spectra by modeling the relevant components typical of gamma–ray spectra of radioactive sources (photo-peak, escape peak, Compton continuum, back–scattering peak) (Amati et al. 1997). Preliminary results of the Monte Carlo simulations have been used to better determine detector efficiency above 200 keV and to estimate the effects of the environment on calibration measurements.

3. In–flight data analysis and calibration

The GRBM is performing very well since the satellite launch. The background level along the orbit, outside the region near the South Atlantic Geomagnetic Anomaly (SAGA), remains very stable, with an average variation of ∼10%. Because of background stability and source

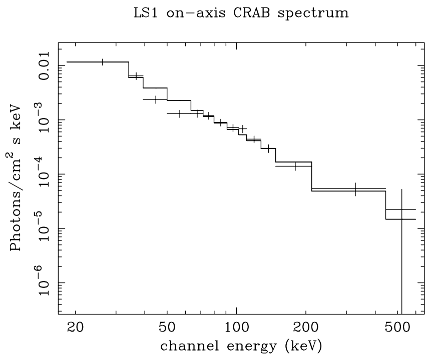

Fig. 1. LS1 on–axis CRAB nebula spectrum (during this measurement the GRBM low energy threshold was set to ~ 20 keV)

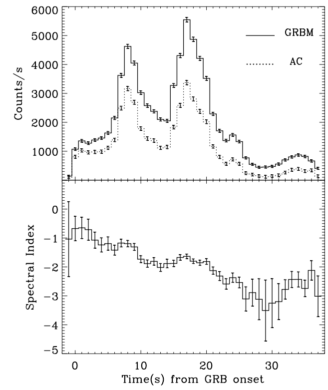

Fig. 2. GRB 970111 1s spectral evolution measured with LS3

intensity, background subtraction for GRB data analysis is in general not critical, except for very weak events, events occurring close to the crossing of the SAGA and, for spectral evolution analysis, during the very beginning and tails of some events. For the ratemeters data, the background during the event is estimated by interpolating the data in ~250 s before and after the event with a polynomial, the order of which is chosen basing on the background variation level. In the case of the 240–channels spectra, polynomials are used to interpolate the background trend in different energy ranges using 3 packets (each one covering 128 s) before and after the packet(s) containing the event spectrum. After background subtraction and proper grouping, GRBM data are analyzed using the response matrices described in previous section, which have also been converted to FITS format to be used with standard spectral analysis software packages like XSPEC. The systematics due to uncertainties in the knowledge of the response functions are on average of the order of 10%. They are mainly due to the uncertainty on calibration sources fluxes and to the statistical errors on calibrations data. The systematic error term is added in quadrature to that on the data before performing the fits.

The goodness of the response matrices has been verified in flight with Crab Nebula flux and spectrum measurements performed exploiting source occultation by the Earth. The Crab flux and spectrum derived from both the 2-channels ratemeters and the 240–channels spectra are consistent with values found by other experiments in the hard X–rays and soft gamma–rays, i.e. a photon index of ~2.2 and a 100 keV flux density of ~ 60 10^{-5} photons cm^{-2} s^{-1} keV^{-1}, with reduced χ^2 values of ~1.3 for ~ 13 d.o.f. In particular, by fixing the photon index at the commonly adopted X–rays value of 2.1, we obtain a normalization of 9.64 ± 0.49 photons cm^{-2} s^{-1} keV^{-1}, fully consistent with the standard value of 9.7. The 240–channels spectra fits have been performed ignoring the energy channels from ~40 to ~70 keV. Indeed, as can be seen from Fig. 1, the calibration–based response matrix is performing very well in the whole detector energy band except for this energy range, in which the detector response is not well described, with a discrepancy between expected and measured counts/channel of ~40%. This is observed also in LS3 and the reason is under investigation by means of Monte Carlo simulations. Up to now, the $40 - 70$ keV region has been ignored when fitting the 240–channels spectra. The efficiency in the lower ($40 - 100$ keV) energy channel of the 2–channels response matrices has been corrected to account for this effect.

In addition to Crab Nebula measurements, cross–checks with BATSE results on a sample of 33 GRBs detected by both experiments and arriving from directions between $\pm 30°$ with respect to LS1 and LS3 axis have been performed, showing that the fluences and peak fluxes in the range $50 - 300$ keV agree within 10%.

4. Scientific results

GRBM spectral analysis was performed on several GRB events. In Fig. 2 we report, as an example, the spectral evolution of GRB970111 obtained using the LS3 2–channels response matrix. Broad band ($1.5 - 700$ keV) spectral evolution and average spectral study have been performed by jointly fitting WFC and GRBM data. We mention here the interesting results obtained for GRB 960720 (Piro et al. 1997), GRB 970228 (Frontera et al. 1998), and the comparative analysis reported in Frontera et al. (1999).

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