Spectral Analysis of GRBs Measured by RHESSI

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Summary.

The Ge spectrometer of the RHESSI satellite is sensitive to Gamma Ray Bursts (GRBs) from about 40 keV up to 17 MeV, thus ideally complementing the Swift/BAT instrument whose sensitivity decreases above 150 keV. We present preliminary results of spectral fits of RHESSI GRB data. After describing our method, the RHESSI results are discussed and compared with Swift and Konus.

PACS 95.55.Ka – X- and $\gamma$-ray telescopes and instrumentation.
PACS 95.55.Qf – Photometric, polarimetric, and spectroscopic instrumentation.
PACS 98.70.Rz – $\gamma$-ray sources; $\gamma$-ray bursts.
PACS 01.30.Cc – Conference proceedings.

1. – Introduction

The energy spectra of Gamma Ray Bursts (GRBs) are an important element for a complete understanding of the GRB phenomenon. Most GRB spectra peak at some energy $E_{\text{peak}}$ in a $\frac{dN}{dE} \propto E^2$ representation. For GRBs with a measured redshift, the distance can be estimated, and, combined with the observed fluence, the total isotropic energy $E_{\text{iso}}$ can be determined. In several publications, Amati et al. (1) and e.g. 2 and references therein) show that $E_{\text{iso}}$ and $E_{\text{peak}}$ are strongly correlated. Correcting $E_{\text{iso}}$ for beaming, to derive the intrinsic energy $E_{\gamma}$, Ghirlanda et al. (3, 4) find a strong $E_{\text{peak}}$-$E_{\gamma}$ correlation. It has been argued that both relations might be an artefact of selection effects (5, 6). However, it has been shown by Ghirlanda et al. (7) that BATSE GRBs with known redshift are consistent with the $E_{\text{peak}}$-$E_{\text{iso}}$ correlation.

A larger sample of GRBs may hold the key to understanding spectral-energy correlations in general. Since Swift’s launch, the number of GRBs with measured redshift has increased rapidly. However, the Swift BAT energy sensitivity – steeply declining above about 150 keV – does not allow the determination of the peak energy for many GRBs. In order to fully determine peak energy and fluence, information from other spacecraft with better sensitivity at higher energies is needed.
2. – Instrument

The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI, [8]) is a NASA small explorer mission and was designed to study solar flares in hard X-rays and γ-rays. It was launched in 2002 into a low Earth orbit (580 kilometer altitude, 38 degree inclination). RHESSI consists of two main parts: the imaging telescope and the spectrometer behind it. The RHESSI spectrometer ([9]) consists of 9 germanium detectors, each 7.1 cm in diameter and 8.5 cm high. They are segmented into a thin front (≈ 1.5 cm) and a thick rear segment (≈ 7 cm). Each detected photon is time- and energy-tagged from 3 keV to 2.8 MeV (front) or 20 keV to 17 MeV (rear). The energy resolution is ≈ 3 keV at 1 MeV, and the time resolution is 1 µs. RHESSI always points towards the Sun and rotates about its axis at 15 rpm.

Since the shielding of the rear segments is minimal, photons with more than about 25 keV can enter from the side. Above about 50 – 80 keV, photons from any direction can be detected. Thus, for GRBs, RHESSI views 65% of the sky, the rest being occulted by the Earth. The effective area for GRB detection depends on the incident photon energy and the angle between the GRB direction and the RHESSI axis (‘polar angle’). Over a wide range of energies and polar angles, the effective area is around 150 cm$^2$. The sensitivity drops rapidly at energies below ≈ 50 keV. RHESSI observes 1–2 GRBs per week.

3. – Method

The response of RHESSI to γ-rays is simulated using GEANT3, the simulation software for high energy physics experiments by CERN. Knowing the burst direction, we simulate γ-rays with the corresponding polar angle and a simple power law spectrum, i.e. $(dN/dE)_{\text{sim}} \propto E^{-\alpha}$ with typically $\alpha = 2$. Rotation angles are generated with uniform distribution, i.e. the response function is spin averaged. The output of the simulation is an event list containing the deposited energy as well as the initial photon energy.

The observed GRB spectrum – in the form of a histogram – is compared with a spectrum accumulated from the simulated event list. In order to generate an arbitrary spectral shape, we apply a weighting factor to each simulated event in the list. These factors would all be 1, if the GRB spectrum had the same form as the simulated one. In general, the weighting factors are a function of the initial energy and the parameters of the spectral shape.

The most often used spectral shape is the Band function ([10]), which is a smooth combination of a cut off power law at lower energies $(dN \propto E^{\alpha} \exp(-E/E_0) dE)$ and a decaying simple power law at higher energies $(dN \propto E^\beta dE)$. If $\beta < -2$ and $\alpha > -2$ then $E_{\text{peak}} = E_0(2 + \alpha)$.

4. – Examples of fitted GRB spectra and ongoing work

The spectral fits of GRB 050525A [11] and GRB 050717 [12] are shown in fig. 1 and the RHESSI fit parameters are summarized and compared with the Swift and Konus fit parameters in table I. For energies above the Swift/BAT energy range, the RHESSI results for the spectral parameters (typically $\beta$ and $E_{\text{peak}}$) are well determined and better constrained than the Konus values. In the lower energy range, the RHESSI spectral parameters still agree within errors with the Konus and Swift/BAT results.
The spectral fit of another GRB, namely GRB 021206, is presented in fig. 2. This GRB is famous for its debated polarization ([16], [17], [18], [19]).

The huge number of excess events observed in the rear detectors below 300 keV is due to GRB photons that were backscattered from the atmosphere. The geometrical constellation of the GRB, RHESSI, and Earth was such that the GRB photons came from the front direction, where the effective area is relatively small, whereas the Earth was behind RHESSI so that the backscattered photons could easily reach the rear segments. In order to simulate this effect, we have constructed an atmospheric scattering model. The first preliminary results show qualitative agreement with the observed spectrum.

5. – Summary, Conclusion and Outlook

Even though RHESSI was designed to observe solar flares, it is also a capable GRB detector with an energy range from about 40 – 80 keV (depending on the direction of

| Instrument      | Ref. | $\alpha$   | $E_{\text{peak}}$ (keV) | $\beta$ | $f$ (erg/cm$^2$)       |
|-----------------|------|------------|--------------------------|--------|------------------------|
| RHESSI          |      | $0.8^{+1.8}_{-3.0}$ | $75^{+14}_{-10}$ | $-2.62^{+0.15}_{-0.24}$ | $(1.43^{+0.17}_{-0.12})\cdot10^{-5}$ (1) |
| Swift/BAT       | [13] | $-0.99^{+0.11}_{-0.12}$ | $78.8^{+3.9}_{-3.1}$ | $-\infty$ | $(2.01 \pm 0.05)\cdot10^{-5}$ (1) |
| Konus           | [14] | $-1.10 \pm 0.05$ | $84.1 \pm 1.7$ | $-\infty$ | – |
| RHESSI          |      | $-1.14^{+0.18}_{-0.15}$ | $1550^{+519}_{-370}$ | $-\infty$ | $(1.25 \pm 0.07)\cdot10^{-5}$ (1) |
| Swift/BAT       | [15] | $-1.0$ to $-1.5$ (3) | $\infty$ | $-\infty$ | $(1.40 \pm 0.03)\cdot10^{-5}$ (1) |
| Konus           | [15] | $-1.19 \pm 0.12$ | $2101^{+1934}_{-830}$ | $-\infty$ | $(6.5^{+0.9}_{-2.2})\cdot10^{-5}$ (2) |

The RHESSI errors and the errors of Refs. [13] and [15] are given with 90% C.L. (1) 15-350 keV (2) 20-6000 keV (3) time dependent values (softening)
Fig. 2. – Spectrum of GRB 021206. The front spectrum (left) and the rear spectrum (right) were fitted independently with agreeing results. The fit ranges are indicated by the vertical dashed lines. The weighted means of the spectral parameters are $(1\sigma$ errors): $\alpha = -0.65 \pm 0.04$, $E_{\text{peak}} = 705 \pm 14$ keV, and $\beta = -3.19 \pm 0.06$. The excess events observed in the rear segments (right plot) are due to GRB photons backscattered from the atmosphere.

the GRB) up to 17 MeV. With its wide field of view and its excellent energy resolution, RHESSI is a useful high-energy complement to Swift/BAT for measuring GRB spectra. About one fourth of the Swift GRBs are also detected by RHESSI. We have developed tools for spectral analysis. Our spectral parameters agree within uncertainties with those obtained from other instruments. The RHESSI errors on the high energy parameters tend to be smaller compared with other instruments. First GCN messages with spectral parameters by RHESSI were published ([20], [21], [22]).

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