Time-Resolved Spectroscopy of RHESSI GRBs

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Abstract. Time-resolved spectroscopy may help to determine the still unknown emission mechanism which produces prompt gamma-ray burst spectra. Prompt spectra evolve significantly over timescales much shorter than the total burst duration. It has been proposed that this evolution is due to the presence of thermal components which are masked in time-integrated fits. We perform systematic spectral fitting of time-resolved spectra for bright GRBs observed by RHESSI. We compare the effectiveness of phenomenological and quasi-thermal models over RHESSI's broad energy band (30 keV–17 MeV). The simplest quasi-thermal model, a black body plus a power law, is disfavored relative to the Band function. Quasi-thermal models with more realistic nonthermal components will be required to successfully reproduce the RHESSI data.

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TIME-RESOLVED SPECTRAL FITS

The Ramaty High Energy Solar Spectroscopic Imager (RHESSI) observes the Sun at gamma-ray energies using nine coaxial germanium detectors. The RHESSI spectrometer is unshielded and is therefore sensitive to astrophysical sources like GRBs over a broad energy band (30 keV–17 MeV) with excellent energy (1–5 keV) and time resolution (1 binary μs). RHESSI's broad field of view ($\sim 2\pi$ sr) and moderate effective area ($\sim$150 cm^2) allow it to observe about 80 bursts per year.

For this study, we selected bursts of high signal-to-noise in order to adequately constrain the fit parameters in time-resolved spectral fits. Starting from a sample of bursts from the RHESSI catalog[1] with a minimum (time-integrated) signal-to-noise ratio of 15, we used a modified version of the Bayesian Blocks algorithm [1] to segment each burst into subintervals with background-subtracted signal-to-noise greater than 45 in the 60 keV–3 MeV band. We conducted spectral fitting on those bursts with at least three such subintervals. This selection yielded 9 bursts with a total of 88 subintervals: GRBs 020715 (3 subintervals), 021008A (15), 021206 (31), 030329A (12), 030519B (7), 031027 (4), 031111 (3), 040228 (10), and 040810 (3). Because we did not use data from RHESSI detectors showing signs of radiation damage, these bursts are primarily from early in the RHESSI mission.

We determined RHESSI's spectral response to off-axis sources using the Monte Carlo package MGEANT [2]. RHESSI's response varies with off-axis angle, so we created responses every 15 degrees. For each response, we simulated monoenergetic photons in 192 logarithmic energy bins ranging from 30 keV–30 MeV. Since RHESSI's per-detector response also varies during the spacecraft's four-second spin period, we binned the annular response in six azimuthal bins and weighted these bins by the total burst lightcurve to create the final response. We fit a polynomial background (allowing for possible modulation with the RHESSI spin period) and extracted the burst data in SSW-IDL. Spectral fitting was conducted with ISIS v1.4.9 [3].

[1] `http://grb.web.psi.ch/`

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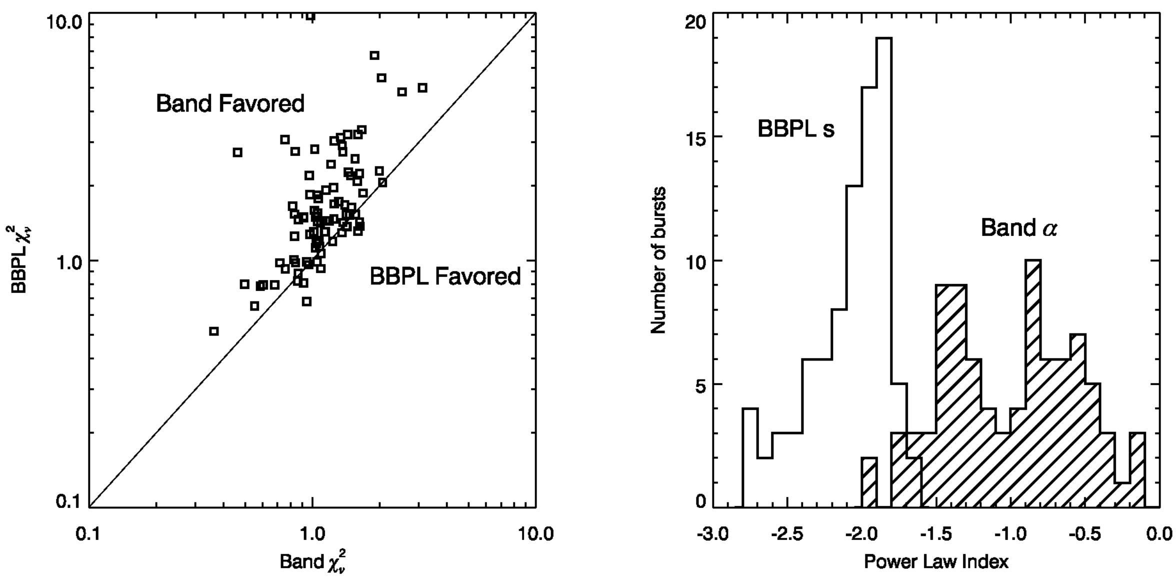

FIGURE 1. Fit results of the BBPL model and the Band function. The left plot compares the reduced chi-squared values of the Band and BBPL fits for each burst subinterval. (The two models have identical degrees of freedom.) The Band function is generally preferred. The left plot shows the distribution of the low energy power-law indices for the two models. The distribution of α for the Band function is consistent with the BATSE result [6], while the index of the power law s in the BBPL is shifted relative to [7].

TESTING QUASI-THERMAL SPECTRAL MODELS

Time-resolved spectroscopy of bright BATSE bursts has indicated that most bursts may be well fit by a quasi-thermal black body plus power-law model (BBPL) [4]. In this physically-motivated model, thermal emission from the GRB photosphere provides the peak of the νF_ν prompt emission spectrum. A simple power-law is sufficient to represent the nonthermal emission above and below the peak in the BATSE band. The spectral model is accordingly $N_E = A\frac{E^2}{\exp E/kT - 1} + BE^s$. We fit the BBPL model to the RHESSI data to test its effectiveness over a broader gamma-ray band. We also fit the spectra with three empirical models: a simple power-law, a power-law with an exponential cutoff, and a Band function [5].

The BBPL model is effective in fitting the RHESSI data, and its parameters are generally well-constrained. The νF_ν peak of the thermal component of the BBPL model (3.9 kT) is consistent with the E_{peak} parameter of the Band and cutoff power-law functions. Moreover, the black body contributes a major fraction of the total flux, generally 20–60 percent for these fits.

However, the BBPL model is statistically disfavored relative to the Band function. We have not attempted to determine the best-fit model from our fit sample. Since the Band function and the BBPL have identical degrees of freedom, though, it is possible to compare their chi-squared values directly. In Figure 1, we show the reduced chi-squared values of both models for each subinterval shown in this work. In the majority of cases, the Band function is significantly preferred.

Moreover, the nonthermal power-law index s of the BBPL model appears softer than reported in previous works [7]. While the authors of [7] show a histogram of s peaking at -1.5, our fits have s values peaking near -1.9 (Figure 1). This shift may be due to the relatively small number of bursts (9) considered in this sample. However, since GRB spectra fall off at higher energies, a softer power-law index is expected when fitting a single power law to data extending to higher energies. The best-fit index is therefore band-dependent. One of the strengths of the BBPL model is that its nonthermal component typically is softer than the "line of death" of $-2/3$ predicted for optically thin synchrotron emission. However, this argument appears to be weakened by the sensitivity of the fit power-law index to the range of the data above the peak energy. It is not clear that the fit value of s provides useful insight into the nonthermal emission physics, as its value may be an artifact of the fit band.

The sample mean and variance of the low energy index α of the Band function fits to these data are consistent with the distribution of α reported for time-resolved fits of bright BATSE bursts [6]. We attribute the apparent bimodality of our α distribution to the small number of bursts in this sample.

While the BBPL model is generally statistically disfavored in fits to the prompt emission over the full RHESSI energy band, more sophisticated quasi-thermal models may be more successful. The representation of the nonthermal emission by a simple power-law is an approximation, and thus it is not expected to be effective over a broad band [8, 4, 9]. Previous extrapolation of BATSE BBPL fits to X-ray data from the *Beppo*SAX WFC proved ineffective [10]. Analysis of this dataset with quasi-thermal models utilizing more realistic nonthermal components will be presented in a future work (Bellm et al. 2009, in preparation).

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