BATSE Sky Exposure

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Abstract. Angular sky exposure is presented for a number of published BATSE gamma-ray burst catalogs. A new algorithm was required due to telemetry gaps resulting from onboard tape recorder failures; the new algorithm improves the 1B Catalog exposure calculation. The most influential effects limiting BATSE’s exposure are (1) deadtime due to triggering, (2) sky blockage by the Earth, and (3) trigger disabling when the spacecraft is in the SAA and over other specific Earth locations. Exposure has improved during the CGRO mission as a result of decreased Solar flares and magnetospheric particle events.

INTRODUCTION

Analyses of the angular and intensity distributions of gamma-ray bursts require knowledge of instrumental sensitivities and biases (e.g. [4,3,7,1]). It is important to have available not just a catalog of gamma-ray bursts detected by an experiment, but a summary describing the sensitivity of the experiment to detecting gamma-ray bursts. The sensitivity is generally subdivided into two components: angular exposure (describing the angular instrumental sensitivity), and trigger efficiency (describing the flux-dependent instrumental sensitivity). Angular exposure is described here; the algorithm to be used for calculating trigger efficiency is described elsewhere [9].

The angular exposure was initially calculated for the BATSE 1B Catalog [2], but was not updated because onboard flight recorder failures produced telemetry gaps in the data. A statistical approach was needed rather than the previous procedure of direct extraction of the exposure information. The 1B analysis helped in designing this approach, however, as a number of important considerations were identified:
### TABLE 1. BATSE catalog start and end times.

| Catalog       | start time (tjd) | stop time (tjd) |
|---------------|------------------|-----------------|
| 1B catalog    | 8358             | 8686            |
| 2B-1B catalog | 8686             | 9055            |
| 3B-2B catalog | 9055             | 9614            |
| 4B-3B catalog | 9614             | 10324           |
| 3B catalog    | 8358             | 9614            |
| 4B catalog    | 8358             | 10324           |

- Zeroth order exposure is due to experimental livetime (burst detection is impossible if high voltage is off or if onboard triggers are disabled).
- The first order exposure effect is sky blockage by the Earth, which introduces a quadrupole moment in the coverage such that bursts are less-easily detected in the equatorial plane.
- Second order exposure effects are a dipole moment and quadrupole moments altered by the SAA and trigger disable boxes.

Small right ascension-dependent exposure components result from CGRO’s 52-day precession period, but these components have been found to be small for BATSE catalogs since these span more than one precession cycle. Other higher-order effects have also been omitted because they are small.

### ANALYSIS

Calculation of the angular exposure proceeds as follows:

- A CGRO orbital model is used to step the satellite through 30-second positional increments during the BATSE catalog in question. Inclusive dates of specific BATSE catalogs are given in Table 1.
- At the beginning of each day (labeled by tjd, or Truncated Julian Date), parameters relating to BATSE operations are checked and loaded. These parameters include trigger disable boxes, number of triggers occurring, and mean trigger durations. At each time step, the satellite is either found to be in the SAA or trigger disable box (in which case it is unable to trigger) or outside of these. The amount of livetime (time spent outside trigger disable boxes) is thus strongly dependent on satellite latitude.

- The Earth and its atmosphere block a substantial portion of the sky from BATSE at any given time; averaged over many orbits this produces a declination dependence. The Earth center declination and satellite altitude are used to calculate Earth blockage, which is then used to obtain the declination-dependent livetime.
TABLE 2. Mean trigger durations during the BATSE operation time.

| start time (tjd) | stop time (tjd) | mean trigger duration (sec) |
|------------------|----------------|-----------------------------|
| 8358             | 8973           | 5631                        |
| 8973             | 8995           | 2747                        |
| 8995             | 9078           | 2177                        |
| 9078             | 9320           | 1927                        |
| 9320             | 9495           | 3905                        |
| 9495             | 9614           | 4854                        |
| 9614             | 9922           | 5180                        |
| 9922             | 10092          | 5131                        |
| 10092            | 10095          | 1721                        |
| 10095            | 10122          | 2700                        |
| 10122            | 10182          | 4109                        |
| 10182            | 10465          | 4741                        |
| 10465            | 10505          | 4245                        |
| 10505            | 10617          | 5231                        |

• The deadtime due to trigger enabling (originally 90 minutes per trigger, irrespective of the actual event duration) has been made much more complicated by the failure of the onboard flight recorders. Telemetry gaps resulting from these failures have required a number of flight software revisions, and trigger durations have been recalculated whenever these have been made, and/or when trigger criteria have changed. The mean trigger duration is composed of a weighted average of long and short readouts, with longer readouts being returned when bright triggers occur. The mean trigger durations are shown in Table 2.

Since trigger efficiency is difficult to calculate during burst overwrites, all overwriting bursts must be excluded from analysis when using the sky exposure calculated here in conjunction with the BATSE burst catalogs.

• The resulting trigger livetime per tjd \( l \) can be calculated statistically from the trigger rate \( t \) (triggers per tjd), and is

\[
l = \left( \frac{d}{86400} \right)^t
\]

where \( d \) is the mean trigger duration (in seconds).

• The overall exposure is the fraction of time that a given location on the sky can be observed, given the trigger deadtime, the Earth blockage, and the orbital trigger disabling.
TABLE 3. Mean exposure, exposure dipole moments, and exposure quadrupole moments for BATSE catalogs and subcatalogs.

| Catalog | mean exposure | $\langle \sin \delta \rangle$ | $\langle \cos \theta \rangle$ | $\langle \sin^2 \delta - 1/3 \rangle$ | $\langle \sin^2 b - 1/3 \rangle$ |
|---------|---------------|-------------------------------|-------------------------------|----------------------------------|-------------------------------|
| 1B      | 0.425         | 0.017                         | -0.008                        | 0.025                            | -0.004                        |
| 2B-1B   | 0.478         | 0.018                         | -0.009                        | 0.024                            | -0.004                        |
| 3B-2B   | 0.507         | 0.019                         | -0.009                        | 0.024                            | -0.004                        |
| 4B-3B   | 0.489         | 0.018                         | -0.009                        | 0.024                            | -0.004                        |
| 3B      | 0.477         | 0.018                         | -0.009                        | 0.024                            | -0.004                        |
| 4B      | 0.481         | 0.018                         | -0.009                        | 0.024                            | -0.004                        |

RESULTS

BATSE’s angular exposure is shown in Figure 1 for the published BATSE burst catalogs and subcatalogs. Statistical properties of the exposure are summarized in Table 3.

There are a number of differences between published 1B results [2] and the 1B results presented here. These results affect many subsequently-published BATSE exposure estimates which were based on the 1B exposure. The most significant differences are as follows:

- The original 1B calculation considered livetime to include only times when the trigger threshold was $5\sigma$ in energy channels 2 + 3. This left as deadtime intervals when the trigger threshold was $5\sigma$ and $10\sigma$. By including these other triggering times in the new calculation, the overall 1B exposure (0.425) is greater than was previously estimated (0.355).

FIGURE 1. Sky exposure as a function of declination for various BATSE burst catalogs.
• The original 1B calculation sampled the sky only on 5 minute intervals. By not interpolating the spacecraft position, the angular size of the SAA box was overestimated, producing a larger dipole moment ($\langle \sin \delta \rangle = 0.026$ and $\langle \cos \theta \rangle = -0.013$) and more pronounced quadrupole moments ($\langle \sin^2 \delta - 1/3 \rangle = 0.026$ and $\langle \sin^2 b - 1/3 \rangle = -0.005$) than those found via the new algorithm.

We have compared the results of the new algorithm over one 52-day precession cycle to that calculated from the untriggered burst search [6]. The untriggered burst search uses different triggering criteria, no trigger disable boxes, and a lower detection threshold than BATSE’s onboard triggers. Although the general exposure properties identified by the new BATSE exposure algorithm and the untriggered burst search are in agreement, there are significant (but easily understood) differences between them:

• The overall angular exposure found from the untriggered burst search is larger than that found using the onboard BATSE triggers because the lack of trigger disable boxes produces more livetime.

• The untriggered burst search has significantly larger dipole and quadrupole moments than those found using the onboard BATSE triggers, which again results from the lack of trigger disable boxes. There have been significantly more particle events detected while the spacecraft was over the southern hemisphere [5], so that an experiment such as the untriggered burst search is more sensitive than the triggered BATSE experiment towards southern hemisphere observations.

Estimated uncertainties in the exposure fractions are less than 4%. Possible sources of systematic error in the moments are currently under study, but are expected to be less than 0.003 for the Galactic moments.

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