

# BATSE SPECTROSCOPY ANALYSIS SYSTEM

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## ABSTRACT

The BATSE Spectroscopy Analysis System (BSAS) is the software system which is the primary tool for analysis of spectral data from BATSE. As such, Guest Investigators and the community as a whole need to know its basic properties and capabilities. This paper describes the characteristics of the BATSE spectroscopy detectors and the BSAS.

## INTRODUCTION

One of the primary goals of the BATSE is to obtain high quality spectra of gamma-ray bursts. The data returned from the Gamma Ray Observatory satellite will require considerable processing. In addition, a substantial bookkeeping system is needed to obtain ready access to the data. The BSAS is designed to handle the processing, analysis, and cataloging of the data. The BSAS was developed at the Goddard Space Flight Center and is now also in use at Marshall Space Flight Center and the University of California at San Diego.

## BATSE SPECTROSCOPY DETECTORS

The eight detector modules of BATSE are positioned around the GRO spacecraft to provide a complete view of the entire sky including the Earth. The orientation of each module with respect to the satellite is the same as for the faces of a regular octahedron. This means that a burst from any region on the sky will directly illuminate four different detector modules. One of these four modules will be facing most directly at the burst and hence will have the highest count rate. During a burst, the on-board electronics chooses the four most brilliantly illuminated detectors (based on count rates) so that only data from these four detectors is transmitted to the ground. Frequently, the four chosen detectors will include one that is actually pointing away from the burst, but is nevertheless illuminated by the gamma rays reflected from the Earth's atmosphere.

Two types of detectors coexist inside each module; the Large Area Detectors (LADs) with high sensitivity and good time resolution, and the Spectroscopy Detectors (SDs) with good spectral resolution and a wide energy range. This paper will concentrate on the SDs due to their superior characteristics for spectral analysis.

The SDs each consist of a NaI(Tl) scintillator which has a round front face (127 cm<sup>2</sup> area) and is 7.6 cm thick. The energy range depends on the gain, with a range from roughly 60 keV to 11 MeV for high resolution channels at 1X gain. Some of the detectors have been operated at 0.4X gain, so that discriminator channels carry information for energies above 110 MeV. Currently, four detectors are being operated at 7X gain so as to get useful information as low as roughly 10 keV for the detection of cyclotron lines. The energy resolution is illustrated in Figure 1. The sensitivity for the detection of narrow lines is given by Figure 9 of Fishman et al. (1984).

The BATSE data can be sent to ground in a variety of data types or formats. These are summarized in Table 1. For spectral analysis, only three data types are used. The first is SHERB, which contains binned histograms (i.e., counts as a function of channel for some small time interval) for burst data. This data comes with a time resolution of 0.128 seconds or more depending on the brightness of the burst and on the detector. This data stream lasts typically for

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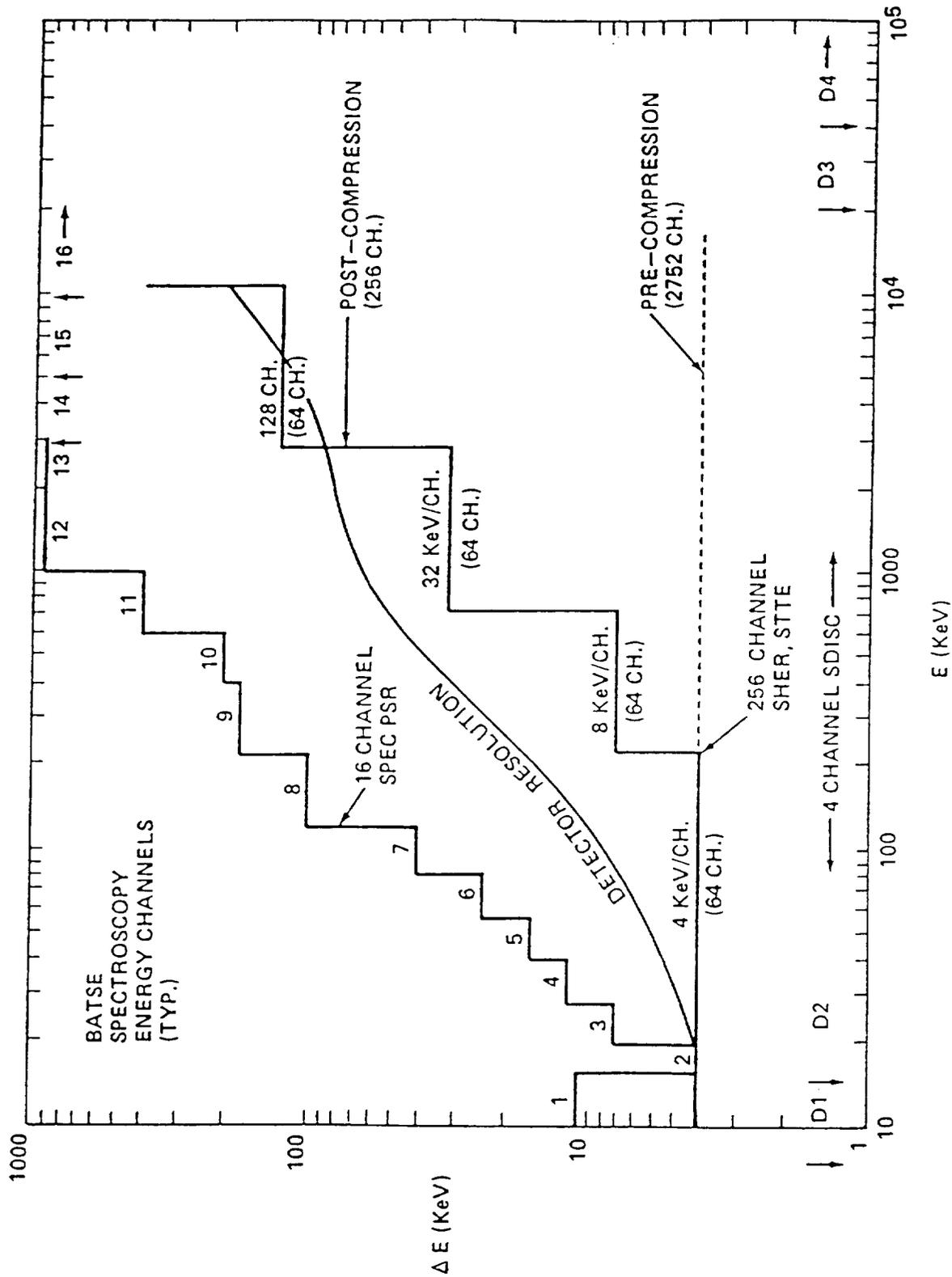


Figure 1. Energy resolution for the BATSE spectroscopy detectors.

TABLE 1. BATSE DATA TYPES

Mnemonic	Packet ID	# in Seq.	Detector	# of Channels	Mode	Burst Data?	Time Resolution
HER	20	8	LAD	128	binned	no	100-500 sec
HERB	32	128	LAD	128	binned	yes	N x 64 ms
MER	50-5F	32	LAD	16	binned <sup>†</sup>	yes	10-50 ms
CONT	*	*	LAD	16	binned	all	2.048 sec
TTE	33,34	128	LAD	4	time tag	yes	2 $\mu$ s
TTS	41-44	128	LAD	4	spill time <sup>†</sup>	yes	typically $\approx 30 \mu$ s
DISCSC	30	1	LAD	4	binned <sup>†</sup>	yes	64 ms
DISCLA	*	*	LAD	4	binned	all	1.024 sec
PREB	31	8	LAD	4	binned	yes	64 ms
SHER	21	16	SD	256	binned	no	200-1000 sec
SHERB	60-62	128	SD	256	binned	yes	Nx64 ms, N $\geq$ 2
STTE	71-74	128	SD	256	time tag	yes	128 $\mu$ s
DISCSP	*	*	SD	4	binned	all	2.048 sec
PSR16A	10	4	LAD <sup>¥</sup>	16	pulsar	no	64 phase bins
PSR16B	11	4	SD <sup>¥</sup>	16	pulsar	no	64 phase bins
PSRSELA	12	1	LAD <sup>¥</sup>	4	pulsar	no	64 phase bins
PSRSELB	13	1	SD <sup>¥</sup>	4	pulsar	no	64 phase bins
PSRSUMA	14	1	LAD <sup>¥</sup>	4	pulsar	no	64 phase bins
PSRSUMB	15	1	SD <sup>¥</sup>	4	pulsar	no	64 phase bins
PSRFULA	16	8	LAD <sup>¥</sup>	16	pulsar	no	64 phase bins
PSRFULB	17	8	SD <sup>¥</sup>	16	pulsar	no	64 phase bins
DUMP	00	1	-	-	-	-	-

\*This data is contained in all packets.

<sup>†</sup>This data is summed over all triggered detectors.

<sup>¥</sup>Typically, memory A will be used for the LAD and memory B for the SD.

100 seconds after the trigger. The second burst data type is STTE, which contains a record of the channel and time (to within a 0.000128 second time bin) of every photon until the memory is filled up. This data type typically contains several seconds of pre-trigger data and 20 seconds of post-trigger data. SHERB data is partially redundant with the STTE data, where the STTE data should be used for the best time resolution. The SHER data type is for binned histograms of background data. The primary use of SHER data is to allow for the interpolation of the background spectrum at the time of the burst. The typical time resolution is five minutes. The total number of counts in the background spectra varies with the position of the satellite, with typical variations by a factor of two over one orbit (the counts are somewhat higher just after GRO passes through the South Atlantic Anomaly).

The calibration of the detector response matrix was achieved by detailed Monte Carlo calculations utilizing the precise geometry of the detector and spacecraft and confirmed with extensive ground-based testing of each module. The channel-to-energy conversion is based on ground-based testing, however there are currently some fine-tuning of the calibration in progress.

## **BSAS PROGRAMS**

The BSAS embodies the traditional spectral deconvolution techniques as described in Loredo and Epstein (1989). That is, the deconvolution program (MODFIT) varies a set of model spectral parameters such that when the predicted spectrum is folded through the detector response matrix the predicted count spectrum is the best match to the observed spectrum in a chi-square sense. The output photon spectrum is then the predicted photon spectrum scaled by the ratio of the observed to predicted count spectra. The uncertainties in parameter values are found by searching through parameter space for the boundaries of the region for which the chi-square value is within some value of the minimum chi-square, as in Lampton, Margon, and Bowyer (1976). The minimization of chi-square is made with the CURFIT algorithm of Bevington (1969).

BSAS also contains a model-independent deconvolution technique (Schaefer 1988). Additional model-independent deconvolution techniques (including the Backus-Gilbert method of Loredo and Epstein) will be added sometime soon.

In support of these deconvolution programs, BSAS contains many programs which extract the histograms, plot the spectra, plot the time histories, search for lines, derive the detector response matrix, list the output, and so on. A list of these programs and a brief description of each is:

<b>BCOUNT</b>	-	Extracts count spectra for background data
<b>BTIMES</b>	-	Calculate times, rise times, and durations from light curves
<b>CONF</b>	-	Produce error bars for the fit parameters found by MODFIT
<b>COUNT</b>	-	Extract count spectra and background subtract
<b>EXTMRG</b>	-	Extract and merge data between the Inst.PDB and the User PDB
<b>FLUENC</b>	-	Calculates fluence from a spectrum
<b>LSRCH</b>	-	Search for spectral lines in a spectrum
<b>MAXKEV</b>	-	Find highest energy with significant flux in a spectrum
<b>MATRIX</b>	-	Calculate detector response matrix
<b>MODFIT</b>	-	Produce best fit parameters for specified models
<b>PDBEDT</b>	-	Modify or delete data stored in the PDB
<b>PDBGEN</b>	-	Create entry in the PDB and run initial analysis
<b>PDBLST</b>	-	List selected data from the PDB
<b>PHOTON</b>	-	Produce the photon spectrum using the results from MODFIT
<b>PRBACK</b>	-	Store background data from daily data set, and update catalog
<b>PRBRST</b>	-	Store burst data from daily data set, and update catalog
<b>PRNTAR</b>	-	Prints analysis results generated by PDBGEN
<b>QFIT</b>	-	Produce a model fit to a QPHOTN spectrum
<b>QPHOTN</b>	-	Produce a model-independent photon spectrum
<b>RDCMAT</b>	-	Utility to read coefficient matrices (for DRM generation) to file

5-NOV-91 09:37:19

File: 910503\_25454\_S\_6\_OBS\_7.SPC

Stop Time: -243.185234

Disk Directory: USR1:[SCHAEFERBATSE.PDB.SPECTRA]

Start Time: -1859.056578

Data Types: SHER

Detector: 8 ..... 2 - - - - - 4 - - - - - 1 - - - - -

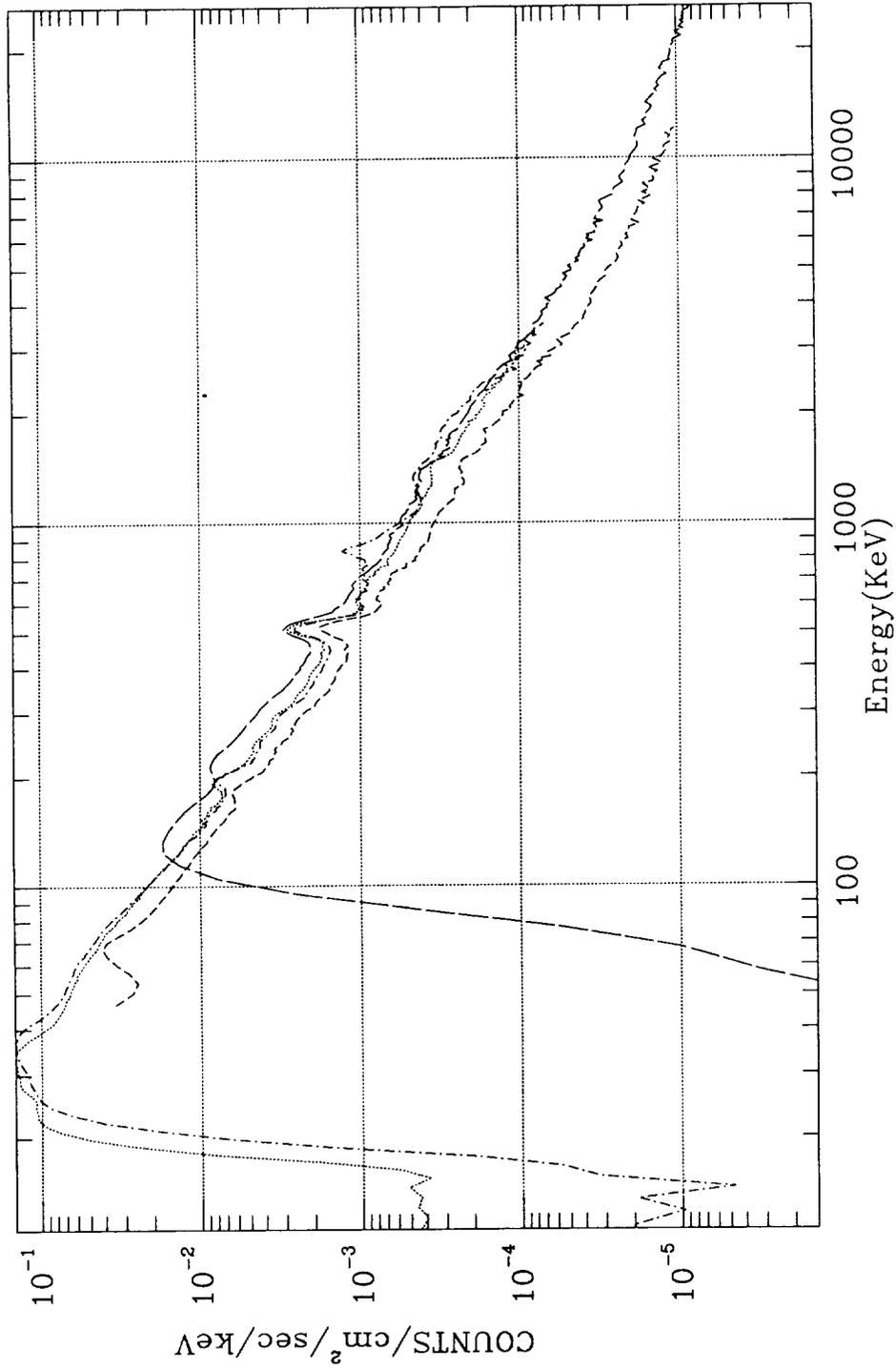


Figure 2. Background count spectra for four spectroscopy detectors.



<b>RDDRM</b>	-	Utility to read full-resolution DRM to file and screen
<b>RDIBDB</b>	-	Utility to read nearly-raw spectral data in IBDB to file and screen
<b>RDSPEC</b>	-	Utility to read spectrum to file and screen
<b>REDUCE</b>	-	Menus for executing other programs
<b>SETUP</b>	-	Changes terminal and printer type for plotting programs
<b>SPPLOT</b>	-	Plot a spectrum and/or spectral fit on the terminal or printer
<b>THGEN</b>	-	Generate the time history (i.e., the light curve) of a burst
<b>THPLOT</b>	-	Plot the time history (i.e., the light curve) of a burst
<b>VRANGE</b>	-	Sets valid energy range for each burst

At the time of this writing, the programs LSRCH, BCOUNT, and BTIMES are not yet completed.

To give a general feel for the analysis procedure, let us describe the sequence of programs that should be run to obtain a photon spectrum for a new burst: (1) Create the Individual Burst Data Base from the daily dataset residing at Marshall Space Flight Center with PRBRST. (2) Create an entry in the Processed Data Base and perform some initial analysis with PDBGEN. (3) Enter the BSAS menu-driven analysis program with REDUCE. (4) Transfer the new burst entries to a personal Processed Data Base with EXTMRG. (5) Create the detector response matrices with MATRIX. (6) Accumulate background spectra for all four detectors with COUNT, as illustrated in Figure 2. (7) From these spectra, determine the energy range over which there is valid data, then enter these ranges with VRANGE. (8) Generate a time history file for some desired energy range with THGEN. (9) Plot the time history with THPLOT. (10) Accumulate the count spectra for the time interval of interest with COUNT. (11) Interpolate the background spectra to the time of the burst with COUNT. (12) Background subtract the observed count spectrum with COUNT. (13) Fit the background subtracted count spectrum to the spectral model of your choice with MODFIT. (14) Evaluate the error bars for the best fit model parameters with CONF. (15) Create the photon spectrum with PHOTON. (16) Plot the photon spectrum with SPPLOT.

The BSAS runs with menu driven inputs. The menus are created with the programs TAE and INGRES. A typical example of an input menu is shown in Figure 3 for the MODFIT program. A detailed and helpful user's guide is available from the BATSE team.

## INSTALLATION

The BSAS is currently installed at Marshall Space Flight Center, Goddard Space Flight Center, and the University of California at San Diego. Guest Investigators may apply for support at any of these three BATSE institutions. This might imply a period of residence possibly combined with remote use of BATSE computers. A possible alternative would be for the Guest Investigator to port BSAS to their home institution.

The porting of BSAS is not a trivial task. First, the BSAS requires that the computer be a VAX running VMS. Second, it requires that the commercial programs FORTRAN, INGRES, TAE, and MONGO be installed. Third, our experience shows that minor differences in version numbers for these programs can lead to errors that can be difficult to track down. Fourth, the receiving system is likely to have some non-standard conditions that will also lead to errors. Thus, substantial help from an experienced system programmer will ease the problems of installation.

## REFERENCES

- Bevington, P. R. 1969, *Data Reduction and Error Analysis for the Physical Sciences* (New York: McGraw-Hill).
- Fishman, G. J., Meegan, C. A., Parnell, T. A., Wilson, R. B., and Paciesas, W. 1984, in *High Energy Transients in Astrophysics*, ed. S. Woosley, American Institute of Physics Conf. Proc. No. 115 (New York: A. I. P.), p. 651.
- Lampton, M., Margon, B., and Bowyer, S., 1976, *Ap. J.*, 208, 177.
- Loredo, T. J. and Epstein, R. I. 1989, *Ap. J.*, 336, 896.
- Schaefer, B. E. 1988, in *Nuclear Spectroscopy of Astrophysical Sources*, eds N. Gehrels & G. Share, American Institute of Physics Conf. Proc. No. 170 (New York: A. I. P.), p. 505.