CAPABILITIES OF THE GRO/BATSE FOR MONITORING OF DISCRETE SOURCES

W. S. Paciesas
Department of Physics, University of Alabama in Huntsville
Huntsville AL 35899
USA

R. B. Wilson, G. J. Fishman, and C. A. Meegan
Space Science Laboratory, NASA Marshall Space Flight Center
Huntsville AL 35812
USA

ABSTRACT

Although the Burst and Transient Source Experiment (BATSE) to be flown on the Gamma Ray Observatory has as its primary objective the detection of gamma ray bursts, its uncollimated design will enable it to serve a unique function as an all-sky monitor for bright hard x-ray and low-energy gamma ray sources. Pulsating sources may be detected by conventional techniques such as summed-epoch and Fourier analyses. The BATSE will, in addition, be able to use earth occultation in an unprecedented way to monitor sufficiently bright sources as often as several times per day over ~85% of the sky. We present estimates of the expected BATSE sensitivity using both of these techniques.

I. INTRODUCTION

Various details of the design and expected performance of the BATSE have been presented in previous papers [1-3]. Although the prime scientific objective of this instrument is to detect and characterize gamma ray bursts, the observation of other types of sources constitutes an important secondary objective. The ability to act as a near-all-sky monitor for persistent and longer-lived transient sources (by using earth occultation) and for long-period pulsating sources (by the standard techniques such as epoch-folding, Fourier analysis, etc.) is inherent in the instrument as designed for its prime objective. The capability to detect short-period pulsars has been incorporated by adding electronics hardware and software which performs on-board epoch-folding. We report here the results of calculations of the estimated BATSE sensitivity for observations using the epoch-folding and earth-occultation techniques. These results apply only to the BATSE large area detectors. Similar analyses of data from the spectroscopy detectors may significantly improve the sensitivity in specific cases where a wider energy range and/or finer energy resolution are of interest.

II. DETECTOR EFFICIENCY AND BACKGROUND ESTIMATES

The accuracy of the calculated sensitivity depends upon the reliability of the estimates of a detector's efficiency and its expected background properties. Estimates of the efficiency of a BATSE large area detector which we used for this calculation have been derived analytically and are presented in an accompanying paper at this conference [3]. The expected background in orbit is the sum of three principal components: the diffuse gamma ray sky background, the earth's atmospheric gamma ray albedo, and the interactions of charged particles in the detector and surrounding material. We have calculated the first component by convolving the diffuse background spectrum with the estimated detector efficiency. The sum of the second and third components was taken to be equal to the background of the detectors in MSFC's balloon-borne instrument [4], which can be considered design prototypes of the BATSE large area detectors.

III. SENSITIVITY USING THE OCCULTATION TECHNIQUE

Approximately 85% of the sky is occulted at some time during each GRO orbit; the orbital precession of 7° per day ensures that any point in the sky may be monitored at least once every two months with the occultation technique. A sufficiently long-lived source will produce one or more steps in the overall detector count rate corresponding to immersion into and/or emersion from occultation by the earth. This is of interest not only for monitoring the variability of persistent sources and long-lived transients, but also for detecting transients on timescales of a few minutes to a few days which are too long-lived and/or too weak to trigger the on-board burst detection system. Although a few such events have been observed previously [e. g., ref. 5], very little is known of their nature.

The time of occurrence of the occultation steps provides information on the location of a transient. The accuracy of the source location will depend somewhat on its intensity and its elevation above the orbit plane; preliminary estimates indicate that an accuracy of ~0.5° should be typical.

Because of the wide field of view of the BATSE detectors, the variation in background due to the difference in surface brightness between earth and sky will occur on a much longer timescale than the occultation steps (which last about 8 s for a source in the plane of the orbit). It is assumed that other systematic background variations will also be negligible on the occultation timescale, and that improvement of sensitivity by summation of the occultation steps over many orbits will be feasible.

The sensitivity estimates were derived by assuming that the source intensity at each step may be determined by taking the difference of two 60 s integrations, one while the source was unocculted and the other while it was occulted. Table I shows the estimated sensitivity (relative to the intensity of the Crab nebula) at 99.9% confidence for several different energy ranges. The improvement obtained by multi-orbit summation is evident. The practical upper limit to the number of orbits which may be combined is presently unknown.

Table I. BATSE Occultation Sensitivity

Energy Range (keV)	99.9% confidence sensitivity (Crab units) 1 orbit (90 min.)	16 orbits (1 day)	224 orbits (2 weeks)
20-50	0.1	0.03	0.007
50-100	0.2	0.04	0.01
20-100	0.07	0.02	0.005
100-500	0.3	0.08	0.02

The most sensitive sky survey performed thus far at these energies used the UCSD/MIT A-4 instrument on HEAO-1 [6]. This instrument scanned the entire sky once every six months using fan-shaped fields of view, so that a given source was typically observable for several weeks at a time at six month intervals. In Table II we list the number of sources in the A-4 catalog which would be detected by BATSE in the 40-80 keV energy band for various timescales. It is interesting to note that the limiting sensitivity of the A-4 survey in this range is approximately the same as the BATSE sensitivity for a two-week orbit sum. Thus, the BATSE will be able to monitor all 40-80 keV sources in the A-4 catalog with two-week time resolution.

Table II. BATSE Sensitivity to HEAO A-4 Catalog Sources

40-80 keV (99.9% confidence)

Time Resolution	BATSE sensitivity (Crab units)	Number of HEAO A-4 sources
1 orbit (90 minutes)	0.1	5
16 orbits (1 day)	0.03	17
224 orbits (2 weeks)	0.009	46

IV. SENSITIVITY TO PULSATING SOURCES

Pulsating sources fall into two categories in the BATSE data, according to their pulse period. The first type have periods longer than ~10 s, so that the continuous readout of rates with 1.024 s or 2.048 s resolution may be used to search for both known and unknown periodicities. All-sky coverage is implicit, except during earth occultation. The second type, with shorter periods (down to a few ms), requires on-board folding and thus is possible only for known periodicities. The hardware limits on-board folding to two periods at a time, one using data from selected large area detectors and the other from selected spectroscopy detectors.

It has been assumed for the purpose of estimating sensitivity that pulsating sources will be detected by using the conventional epoch-folding technique. In addition to its dependence upon predicted detector efficiency and background, the time required to observe pulsations of a particular statistical significance using this method is dependent upon the shape of the pulse light curve. Table III shows the estimated sensitivity (99.9% confidence) relative to the pulsed flux of the Crab pulsar (assumed to be 0.027 ph/cm^2-s in the 30-100 keV range) for several values of the integration time and for three cases of pulse light curve: a sine-wave, the hard x-ray light curve of the Crab pulsar, and a rectangular pulse with 10% duty cycle.

Table III. BATSE Pulsar Sensitivity (30-100 keV)

	99.9% confidence pulsed sensitivity (Crab pulsar units)		
Integration length	Sine shape	Crab shape	Rectangular shape
1 orbit (90 minutes)	0.2	0.1	0.04
16 orbits (1 day)	0.04	0.02	0.01
224 orbits (2 weeks)	0.01	0.007	0.003

V. SUMMARY

Sensitivities attainable with the BATSE in observing non-burst sources have been estimated using assumptions appropriate to searches for known or suspected sources and presented in this paper. Except in the case of short-period pulsars (where on-board folding requires a priori knowledge of the approximate pulse period), it will also be possible to examine the BATSE data for previously unsuspected sources. In this latter case, efficient search procedures will most likely make use of other techniques such as Fourier analysis which have not been explicitly considered in our sensitivity estimates. Therefore, these estimates should be treated with some caution in applying them to generalized searches.

Finally, we show in Table IV the time required for BATSE to achieve 99.9% confidence measurements of typical high energy sources using the occultation technique and, where applicable, epoch-folding. It is clear that the successful application of these and similar techniques to the BATSE data will provide unprecedented and valuable sensitivity for near all-sky monitoring of low energy gamma ray sources.

Table IV. BATSE Sensitivity (30-100 keV) -- Selected Sources

Source name	Pulse Period (s)	Time required (99.9% conf. detection) Total emission (occultation)	Pulsed component (summed epoch)
A0535+26 (max.)	104	single step	single pulse
Centaurus A	N/A	single step	N/A
Crab pulsar	.033	single step *	1 minute
Vela X-1	283	single step	single pulse
Hercules X-1	1.24	6 hours	20 minutes
NGC 4151	N/A	1/2 day	N/A
3C273	N/A	2 days	N/A
A0535+26 (min.)	104	3 days	2 hours
MKN 509	N/A	2 weeks	N/A

* nebula plus pulsar

REFERENCES

1. G. J. Fishman et al., in Gamma-Ray Transients and Related Astrophysical Phenomena, AIP Conf. Proc. No. 77, pp. 443-451 (1982).

2. G. J. Fishman et al., in High Energy Transients in Astrophysics, AIP Conf. Proc. No. 115, pp. 651-664 (1984).

3. G. J. Fishman et al., paper OG9.2-14, these proceedings.

4. R. B. Wilson et al., in Gamma-Ray Transients and Related Astrophysical Phenomena, AIP Conf. Proc. No. 77, pp. 67-78 (1982).

5. Carol Armbruster and Kent S. Wood, in High Energy Transients in Astrophysics, AIP Conf. Proc. No. 115, pp. 73-76 (1984).

6. A. M. Levine et al., Astrophys. J. Suppl., 54, 581 (1984).