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Occultation Analysis of BATSE Data-

Operational Aspects

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Abstract

The BATSE large area detectors are being used to monitor hard x-ray/gamma ray sources on a daily basis for evidence of transient behavior. Flux measurements are performed using a simple earth occultation technique. Daily searches are also performed to detect occultation steps of sources which are not being routinely monitored. Topics concerning the operational aspects of the occultation measurements are presented. Preliminary spectral results are also presented for several of the brighter sources.

I. Introduction

The Burst and Transient Source Experiment (BATSE) on the Compton Gamma Ray Observatory (CGRO) includes, as a part of its daily "quick-look" science analysis, hard x-ray/gamma-ray (20-2000 keV) source monitoring using the earth occultation technique. About 30 known source locations are checked for discontinuities in the detector background at times corresponding to the source rise or set at the earth's limb. This effort also includes searching for occultation steps of previously unknown sources or known sources which are not being monitored. The technique has already been used to detect transient behavior in two sources, GX339-4 and 4U1700-37, which have been monitored daily since the early part of the mission. No new sources have been found.

II. Procedure

The general method of earth occultation to measure gamma ray sources is especially suited to the near full-sky coverage of the BATSE detectors. Coupled with a hopefully long mission lifetime, the technique should eventually be a powerful observational tool for x-ray/gamma-ray source studies. Rigorous use of this technique and its ultimate sensitivity, however, will require a good understanding of the BATSE detector backgrounds in low

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earth orbit. The process of characterizing the gamma ray background in the BATSE detectors is underway (see T. Skelton, *et al.*, these proceedings, where a model for the background is being assembled for use in measuring discrete source fluxes).

The current measuring technique uses a modified step function (background + step) to fit one to two minutes of background on each side of an occultation step feature. The short sampling interval allows the background variation to be treated as approximately linear. The current software uses only the medium energy resolution continuous data (2.048 sec time resolution, 16 energy channels) from the large area detectors (LADs). These eight detectors are gain-matched and employ automatic gain control so that data from different detectors pointing toward a given source can be combined for better statistics. A flux measurement is recorded daily in a history file, which represents the summed result of all available occultation steps for a single day. The sensitivity for a +-1 minute sample for combined data around 32 occultations is approximately 10% of the Crab nebula flux, being somewhat better when other sources are not interfering (i.e., another source along the earth's limb is occulted within the sampling period) with the source of interest.

The large area detector (LAD) data are also searched daily for step features from sources not routinely monitored by the previously described software. The procedure is to use a three-part test, again assuming a linear background, first checking for smoothness by comparison to a straight line, then application of the step model over the sampling interval, followed by a chi-square test on the step fit. This method yields the best time, step size, and brightest detector over the specified interval. Experience with this method has shown that the method is adequate for detecting step features reliably at about 25-40% of the Crab nebula flux in unfolded data. The primary drawback has been the presence of many non-statistical features, such as Vela X-1 pulses or short timescale flickering of Cyg X-1, which frequently produce variations in the background comparable in size to Crab occultation steps. While large background variations due to bursts, solar flares and other events are flagged each day and ignored in the search algorithm, it is still necessary to plot step significances in histogram or scatter plot form, and to examine the search results for recurrent steps in each orbit. Very large occultation steps have been observed from some sources, such as 4U1700-37 and Sco X-1. Occasional outbursts from these can exceed the Crab flux at low energies and vary greatly in intensity on the timescale of one orbit. The standard energy range for the search routine is 20-100 keV.

III. Preliminary Results of Flux Measurements

In this section, we present count spectra for several of the brighter sources, and the flux history for the QPO GX339-4. A count spectrum for the Crab nebula is presented in another contribution (R. B. Wilson, *et al.*, these proceedings), as well as a partial list of the sources which are being monitored. To date, about ten sources consistently exhibit significant fluxes summed over a one day period, with spectral shapes consistent with previous measurements. Complete confirmation of detection will require more thorough analysis of the count spectra convolved through the large area detector response matrices, and time series analyses to search for known periodicities. As yet, only power law fits have been performed to the count spectra.

In Fig. 1, we show sample spectra for Centaurus A, Cygnus X-1, 4U1700-37, and Scorpius X-1 obtained by the BATSE occultation analysis technique. Each spectrum has been time-averaged over a single pointing interval for the CGRO spacecraft to avoid systematic shifts due to the detector response; variability of the source flux has been ignored. The spectral indices obtained from a single power law folded through the LAD response and fit to the count spectra in Fig. 1 are given below:

Power Law Fits (see Fig. 1)

Cen A	(20-2000 keV)	-1.9 +-0.1
Cyg X-1	(20-2000 keV)	-1.9+-0.01
4U1700-37	(20- 230 keV)	-3.3 +-0.1
Sco X-1	(20- 100 keV)	-4.9 +-0.2

These spectral indices are consistent with earlier measurements of these sources over the given energy range [1-6].

The transition to the hard state of the QPO source GX339-4[7] was observed in late June through August 1991. The hard state is characterized[7,8] by hard x-ray emission to 200 keV. The soft state, however, has a very different spectrum, emitting 2-10 keV x-rays[9], and is not observable by BATSE. In Fig. 2, the daily average source flux estimated with a single power law fit over the energy range from 20-2000 keV with a fixed index of -2.0 is shown. In late September, GX339-4, which had reached a peak flux of approximately 300 mCrab, had dropped below the one-day sensitivity level. During the period of increasing flux (TJD 8430-8490) a power law fit gave an index of -2.0 and during the peak interval (TJD 8490-8520) softened somewhat to -2.4. The data gaps near 8465 and 8520 are due to the source's elevation with respect to the orbital plane becoming too great for occultations to occur (see discussion below).

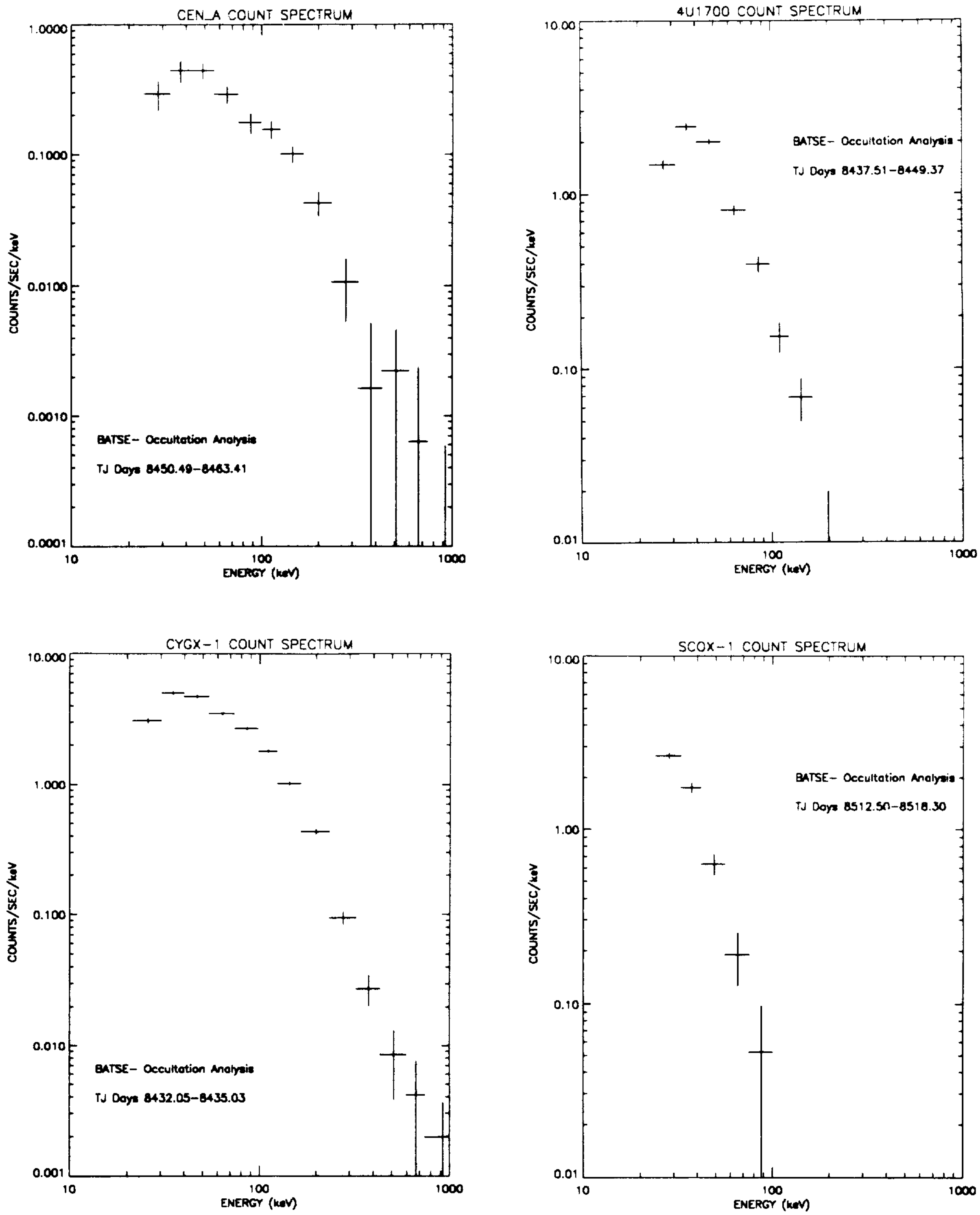

Fig. 1. Sample source spectra obtained with the BATSE occultation analysis averaged over the dates given (Truncated Julian Day=JD-2,440,000.5).

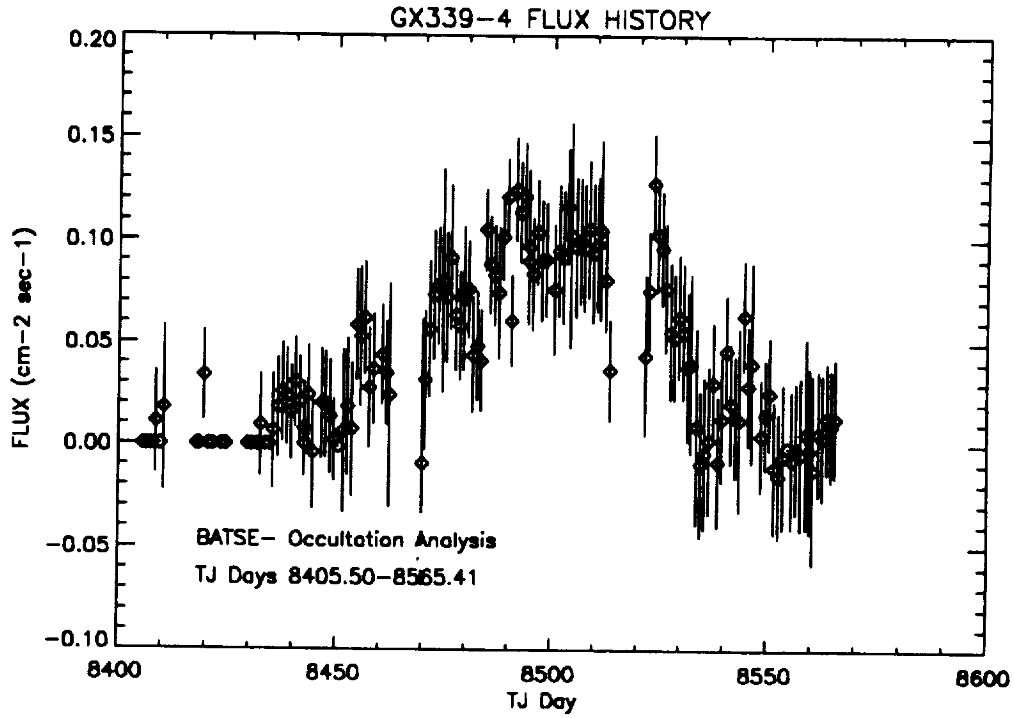

Fig. 2. Flux history for the QPO source GX339-4. TJ (Truncated Julian) Day 8405-8565 corresponds to the period May 29-Nov 2, 1991.

The identification of GX339-4 as a black hole candidate is disputed[8,10], as some quasi-periodic oscillations have been observed in the optical emission region[10].

IV. Improvements to the Occultation System

The BATSE mission operations occultation system has been automated since the early weeks of the mission. Both the source monitoring and the searching programs are now executed by the data operations team. Currently, additional software is being developed to examine processed data products from the occultation system, as well as direct improvements to the operations software.

The predicted times of earth occultation for given source locations are computed using spacecraft position data and an oblate earth+atmosphere model obtained from the Jet Propulsion Laboratory[11]. An occultation is defined to occur when the line-of-sight vector from the spacecraft to the source reaches a specific altitude above the earth's surface. This altitude has been set to 70 km, corresponding to 50% attenuation of 100 keV gamma rays. The predicted times appear to be good to at least +- 5 secs from a statistical analysis of Crab and Cyg X-1 occultation profiles. This is consistent with an error in the spacecraft position of +- 30 km and allowance for statistical effects on the observed occultation profiles. This deviation appears not to significantly affect the measured count rates when averaged over a one day period.

The step model being used to fit LAD data has two parameters for the time and width of the occultation step, which are currently kept fixed at the time predicted for the 70 km occultation altitude and a width of 20 seconds. The effect of the angle of the source with respect to the orbital plane (beta angle) and the energy dependence of the gamma ray attenuation on the duration and time of the occultation, are being investigated. When the beta angle approaches 70°, the spacecraft-source line-of-sight vector is near the geometric limit for occultations to occur, and the step feature is significantly broadened. The data in Fig. 2, for example, show an artificial lowering of the flux estimate near the critical angle. It is planned to adjust the width parameter to allow for the slowly-varying beta angle as the orbit precesses.

A significant concern which will be dealt with explicitly in the enhanced system being developed (see T. Skelton, *et al.*, these proceedings) is the problem of interfering sources. Any source which is undergoing an occultation within the acceptance time interval for the occultation of a source of interest is a potential problem, and requires a model which incorporates multiple source fitting. While the operations system is designed only for the monitoring of transient behavior and generating crude flux estimates, it would be desirable to separate fluxes from a source which is near in the sky to a very bright source. Two instances where this occurs frequently are A0535+26 (about 4° from the Crab) and Cyg X-3 (about 10° from Cyg X-1); where we plan to use a simple two-source model with a linear or quadratic background.

Other improvements to the system will most likely move toward the goals of greater sensitivity and reducing the time required for identification of a transient source. Many factors can affect how well these can be accomplished, which includes optimizing the search routine, dealing with interfering sources, systematic effects due to detector background, and the effect of atmospheric scattering on the flux estimates.

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