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Flux Measurements Using the BATSE Spectroscopic Detectors

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Introduction

Among the Compton Gamma-Ray Observatory instruments, the BATSE Spectroscopic Detectors (SD) have the distinction of being able to detect photons of energies less than about 20 keV. This is an interesting energy range for the examination of low mass X-ray binaries (LMXBs). In fact, Sco X-1, the prototype LMXB, is easily seen even in the raw BATSE spectroscopic data. The all-sky coverage afforded by these detectors offers a unique opportunity to monitor this source over time periods never before possible.

The aim of this investigation was to test a number of ways in which both continuous and discrete flux measurements can be obtained using the BATSE spectroscopic datasets. A instrumental description of a SD can be found in the Compton Workshop of April 1989 (p 2-39), this report will deal only with methods which can be used to analyze its datasets. Many of items discussed below, particularly in regard to the earth occultation technique, have been developed, refined, and applied by the BATSE team to the reduction of BATSE LAD data. Code written as part of this project utilizes portions of that work. The following discussion will first address issues related to the reduction of SD datasets using the earth occultation technique. It will then discuss methods for the recovery of the flux history of strong sources while they are above the earth's limb. The report will conclude with recommended reduction procedures.

SD Fluxes Measured Using the Earth Occultation Technique

The earth occultation technique utilizes two source flux measurements per orbit: one obtained shortly after the source rises above the earth's limb and one shortly before the source sets behind the earth's limb. These fluxes are subtracted from background values taken near these times but when the source is behind the earth's limb. Since the background changes in a continuous fashion, a detailed background model is not needed to obtain source flux measurements using this method. This is the strongest positive attribute of the earth occultation method. The actual details of how the source and background fluxes are measured depend upon such things as the source strength, the presence of other sources, and the time over which the measurement takes place. These are discussed below.

Item 1): The source strength

The main complicating factor here occurs when the source is strong and exhibits random, short period, variations. Such sources are not common in SD datasets. In fact, only one celestial source, Sco X-1, has been observed to show this type of activity. In this case the slope of the least squares line on either side of the occultation step is normally quite different. If the same slope is assumed an inaccurate estimate of the step size can result.

In addition, if the source variability timescale is less than but comparable to the interval being fit, then the least squares slope and intercept can be influenced by activity somewhat removed in time from the step. This will also result in a difference in the source strength, depending on the integration time.

Item 2): Least squares based estimates of the background flux

The background flux reflects an approximate sinusoidal pattern governed by the amount of earth blockage as seen by the detector. Over time intervals exceeding a few hundred seconds the background flux can change in a nonlinear fashion. Incorporating a quadratic term into the background model to account for this departure can produce a better fit. An undesirable effect of this is that as one includes times further and further from the step, flux changes which occur close to the step have less and less of an impact on the model. This makes the estimate of the background flux located at the step suspect. A second problem is that as a wider time interval is included, other rising and setting sources may effect the background fit in undesirable ways.

Item 3): Using background fluxes measured close to the step

This might appear to solve the problem raised above. Unfortunately it also has problems. Generally the background level is not constant with time. One must therefore somehow correct the computed background flux to the value it would have had at the time when the (step + background) flux is measured. If the time interval over which the background is measured is short, the resultant flux level will be sensitive to noise fluctations since it will be based on relatively few points.

Item 4): Dealing with very noisy data

The data collected using a gain setting of 8X is normally quite noisy compared to that at 4X. To lessen the impact of noise, two types of filters can be employed. The first removes large cosmic ray spikes from the data. This can be accomplished by passing the data through a filter which removes datapoints which deviate from prior points by a user defined number of standard deviations. A second filter which removes high frequency noise (such as Butterworth filter) can then be applied. This procedure was tested with BATSE SD data an appears to work quite well. The selection of filter parameters involves a subjective decision but reasonable variations in their values only change the step sizes by small amounts i.e. 1-2 cnts/sec.

SD Light Curves Obtained During a Single Orbit

In many cases it is desirable to obtain the entire light curve of a source while it is above the earth's limb. To do this one must have a model which accounts for the background during this entire time period. Two models have been developed and tested which, at least to first order, allow this to be done. The first fits the background to a second order polynomial in terms of the cosine of the earth angle. The second model attempts to remove the background by subtracting a nearby orbit which not only includes background but the primary and/or other sources. This latter model assumes that the secondary sources have an identical level of activity in the reference and program orbit. These two models are more fully described below.

Model 1: Background Removal Using a Polynomial Earth Angle Fit

For this model to work one must have background data from a substantial portion of an orbit. Lack of TDRSS communication, SAA passages, and the short term decay of radioactive isotopes all combine to make this condition difficult to meet. It is also not intended to track subtle changes in the background. Increasing the order of the polynomial to account for these changes generally results in a poorer overall background fit. A much more detailed, physically based, background model is currently being developed by the BATSE team but is not yet available. A second complicating feature which this model does not address is the presence of multiple sources. In the case of Sco X-1 the galactic center region can rise and set shortly after Sco X-1. Obviously when this situation occurs, results based upon this simple model will be incorrect.

Model 2: Subtraction of an Inactive Nearby Orbit

This technique assumes that orbits exist in which the presence of a source can be treated as a constant additive term to the background. Orbits which appear to meet this condition occur often in the SD datasets of Sco X-1. This type of behavior is associated with Sco X-1 when it is located on its normal branch in a two color x-ray diagram. Even when this source is active, orbits which show a constant level of activity are not uncommon. The equality of step sizes at earth rise and set can be used to help locate orbits of constant activity as can a visual inspection of a flux versus time plot of the data. The subtraction of two orbits which meet these criteria can also be used to reveal subtle, longer term variations that are difficult to see in the unprocessed data. The advantage of this technique is that other sources, which exhibit constant emission over a few orbits, are subtracted out of the signal. The disadvantage of the technique is that slight trends may be introduced into the orbit of interest from the reference orbit. In cases where high precision is needed, the presence of these trends can be determined by differencing the reference orbit to another nearby orbit which meets the above criteria.

Adopted Analysis Techniques

Earth Occultation Method

A compromise between the various issues raised above which appears to work well is to model the background with a linear least squares fit extending 100-150 seconds prior to the step. Longer time periods run the danger of 1) incorporating other sources, 2) violating the linear assumption, and 3) not adequately modeling the region close to the step. For measurement of the source, two different approaches are used. The first measures the average (source + background) flux over a time period of 40-60 seconds immediately after/preceding the step. The 60sec interval yields a slightly smaller step error. The second approach models this region with a linear least squares fit. In both cases the background flux is extrapolated to the time of the step. If the source is relatively inactive, both methods give, to within the step error, identical results. If the source is active, the average value is believed to give a better value of the instantaneous step size. The computer programs written to perform these tasks were tested by running a LAD dataset and then comparing the step sizes with those obtained with the BATSE LAD earth occultation software. The LAD step sizes from both programs were found to be in agreement.

SD datasets collected using gain settings near 8X are very noisy. A significant improvement in the value of a step size can result with the aid of the filtering techniques mentioned earlier. The application of these filters may be a necessary condition in order to obtain meaningful results with a gain setting of 8X. Depending on the source energy distribution and strength some additional higher energy information may be available from channel 2 data when the gain is set at either 4X or 8X. The sensitivity of a SD increases by a factor of about 2.5 from 16 to 40 keV . In the case of Sco X-1 this helps compensate for the fact that the flux emitted by this source drops off steeply above 10 keV.

Orbital Light Curves

At the present time I would recommend the subtraction of a quiescent orbit from a nearby orbit to obtain an orbital light curve. The main assumption inherent in this technique is that occassionally one can find orbits where the source emission is relatively constant. A second but less severe assumption is that the earth modulated x-ray background is also repeatable over at least a few orbits. The former assumption can be tested by viewing the raw orbital data and by comparing the step sizes at earth rise and set for each orbit. If the source is indeed stable during an orbit, its rise and set step sizes should to equal. In the case of Sco X-1 periods of activity are easily distinguishable even in the raw data. The assumption dealing with the repeatable nature of the background was tested by computing its least squares determined slope near a Sco X-1 step during the course of a day. The slope was found to be unchanged over time intervals of approximately 30,000 sec. This implies that the earth modulated x-ray background changes slowly: overtime frames of many hours. A significant advantage that the orbital subtraction model enjoys over that discussed above is that it automatically accounts for other sources that have constant emission over this time period.