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The Use of Weighting in Periodicity Searches in All-Sky Monitor Data: Applications to the GLAST LAT

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Abstract. The light curves produced by all-sky monitors, such as the Rossi X-ray Timing Explorer All-Sky Monitor and the Swift Burst Alert Telescope (BAT), generally have non-uniform error bars. In searching for periodic modulation in this type of data using power spectra it can be important to use appropriate weighting of data points to achieve the best sensitivity. It was recently demonstrated that for Swift BAT data a simple weighting scheme can actually sometimes reduce the sensitivity of the power spectrum depending on source brightness. Instead, a modified weighting scheme, based on the Cochran semi-weighted mean, gives improved results independent of source brightness. We investigate the benefits of weighting power spectra in period searches using simulated GLAST LAT observations of γ-ray binaries.

Keywords: gamma-rays: observations, X-rays: binaries, methods: data analysis
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INTRODUCTION

The light curves produced by many types of all-sky monitor do not have uniform errors. For example, the pointing direction of the Burst Alert Telescope (BAT) on Swift is determined by observations using the narrow-field instruments also onboard Swift which are primarily used to study gamma-ray bursts and their afterglows. BAT observations of X-ray sources are thus generally obtained in an unpredictable fashion. The All-Sky Monitor (ASM) on board RXTE also suffers from similar problems. Even though the RXTE ASM is controlled to make observations of the sky as complete as possible, there is still considerable non-uniformity. The quality of observations of any particular point on the sky will depend on the observation duration and the location of that point in a detector field of view if there is non-uniform response across the FOV.

WEIGHTED AND SEMI-WEIGHTED POWER SPECTRA

Scargle (1989) proposed that the effect of unequally weighted data points in a power spectrum can be found by considering two points that coincide and treating this as a single point of double weight. A "natural" approach to combining data points of different error bar size is to use the weighted mean. This approach can be considered as calculating the power spectrum of y_i/σ_i^2. Although this procedure is very effective for faint sources, if the scatter in data values is large compared to the error bar sizes weighting by error bars can be inappropriate. This is because the concept of combining "coincident" points must be treated carefully. In a power spectrum it is not just points at the same time, but points at the same phase, which are combined. If there is a strong signal then, at all frequencies except the modulation frequency, we will be combining points with discrepant values and hence the weighted mean will not be valid.

A refinement is to treat source variability as an additional "error"[2], i.e. calculate the power spectrum of $\frac{y_i}{((f\sigma_i)^2+V_S)}$ where f is a correction to nominal error bar size and V_S is the estimated variance due to source variability. This procedure is related to the semi-weighted mean, [4, 5] and hence may be termed "semi-weighting"[3]. Semi-weighting works well for sources across a wide range of brightness, providing that the correction factor f is applied, and gives improvements for Swift BAT[2], RXTE ASM and CGRO BATSE light curves (Fig. 1).

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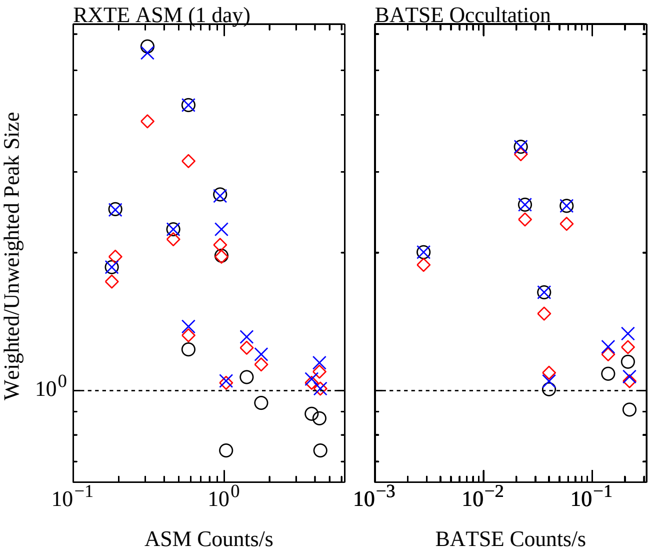

FIGURE 1. Comparison of power spectrum weighting techniques for power spectra of RXTE ASM (left) and BATSE Occultation (right) light curves. The y-axes show the ratio of peak heights in weighted power spectra compared to the heights in unweighted power spectra. Black circles show simple weighting, blue crosses semi-weighting, and red diamonds semi-weighting without error bar correction applied. Points below the horizontal dashed line indicate that weighting was worse than not weighting.

ANALYSIS OF SIMULATED GLAST LAT LIGHT CURVES

The GLAST LAT[8] is also a large field of view detector, and it will provide a sensitive survey of the γ-ray sky. It is expected that GLAST will predominantly operate in a sky survey mode which will give much more uniform sky coverage than with the RXTE ASM or Swift BAT. However, precession of GLAST's orbit will affect the exposure of each point on the sky. In order for weighting to improve period searches two conditions must be met: the signal amplitude should not be very much larger than typical error bar size, and the sizes of the errors on data points in light curves must have considerable variation. If these conditions are not met then, although weighting may still be used, it will not have a significant benefit. To investigate whether weighting will be beneficial for GLAST we used simulated light curves of γ-ray binaries that have been presented elsewhere[6] with 1 day or 90 minute binning. For light curves accumulated in 1 day bins, sky coverage was sufficiently uniform that weighting gave no improvement.

The 90 minute time bins were not synchronized to GLAST's orbital period which produced large changes in exposure from bin to bin. For these bins the number of photons was low and we calculated asymmetric error bars based on Pearson's χ^2[7]. We investigated several symmetrization schemes to convert error bars to a single weighting factor[1]. It was found that weighting gave very strong benefits for period detection. Of the symmetrization methods investigated, the use of just the larger (upper) error bar on data points gave the strongest gain in signal detection. However, no conversion method gave results that could be used in semi-weighting as the predicted source variability variance values were not well defined.

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