A search for gamma-ray flares from black-hole candidates on time scales of ~ 1.5 hours

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Abstract. Strong short-lived flares from black-hole candidates have been detected in the hard X-ray regime and possibly also at γ-ray energies. Here we present a search for short-lived flares in the 0.75–30 MeV COMPTEL data. No flares are found during the 5 viewing periods considered, with typical upper limits of a few times the Crab flux.

INTRODUCTION

Galactic black-hole candidates (BHCs), which are binaries suspected to harbour a black hole, have been extensively studied during the last years. Most noticably, several X-ray transients have been the subject of correlated multi-wavelength campaigns, which yielded a wealth of observational data. At γ-ray energies, however, the amount of data gathered so far is limited. Although there is not much doubt that accretion onto a compact object is the main source of energy in BHCs, the detailed physics of such configurations are not yet completely clear. One of the basic uncertainties that still remains is whether or not the ions and electrons in the accretion flow near the compact object decouple to form a two-temperature plasma. If so, non-thermal processes such as π^0-decay and nuclear de-excitations may produce an appreciable γ-ray flux. The γ-ray domain is therefore important for assessing the possible existence of such two-temperature plasmas.

Gamma-ray flares from BHCs have been reported on several occasions in the past. Ling et al. (1987) observed a large ~ 1 MeV flare from Cyg X-1

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VP	Start-end	l_Z	b_Z	Target BHCs
20.0	8658–8672	39.7	0.8	GRS 1915+105
36.5	8846-8854	168.2	-9.5	GRO J0422+32
318.0	9384-9391	68.5	-0.4	GRS 1915+105
336.5	9568-9573	340.4	2.9	GRO J1655-40
522.5	10248-10259	65.8	2.7	Cyg X-1

TABLE 1. The viewing periods (VPs) used in this analysis. Of these, VP 36.5, 336.5 and 522.5 were TOOs resulting from hard X-ray outbursts of GRO J0422+32, GRO J1655-40 and Cyg X-1 respectively. The other VPs were included to obtain results for GRS 1915+105 (BATSE detected hard X-ray flaring during TJDs 8748-8762 [Paciesas et al. 1996]). *Column 1*: the CGRO VP number; *column 2*: the start and end day [TJD $\equiv$ JD$-$2440000.5]; *columns 3 and 4*: the Galactic longitude and latitude of the pointing direction; *column 5*: the main BHCs searched for in the field-of-view.

with a total flux of 1.6×10^{-2} photons cm^{-2} s^{-1}. Long-term observations with SMM have shown that MeV flares of this strength cannot be a frequent phenomenon (Harris et al. 1993). More recently, Boggs et al. (1996) reported on measurements with the balloon-borne HIREGS of a strong 1-10 MeV flare from GRO J1655-40, one of the Galactic superluminal BHCs. A search for MeV flares on time scales of two days in ~ 5 years of COMPTEL data did not reveal more evidence for occurrences of flares from GRO J1655-40 (van Dijk et al. 1997). The flare observed with HIREGS, however, lasted much shorter than two days ($\lesssim 1$ hour; S. Boggs, private communication). In addition, BATSE has seen strong 20–100 keV flares from GRS 1915+105, the other Galactic superluminal source, on time scales of only 15 minutes (Paciesas et al. 1996). This prompted us to search for short-lived gamma-ray flares from black-hole candidates in the COMPTEL data, the results of which are presented here.

OBSERVATIONS AND ANALYSIS

The CGRO viewing periods used are listed in Table 1. The observations were divided into segments of ~ 1.55 hours, the duration of 1 orbit of the CGRO satellite. Due to excluded time periods such as SAA passages and incomplete real-time telemetry coverage, the actual lengths of the segments varied from $\sim 1.5 \times 10^3$ to 5.2×10^3 seconds (left plot in Fig. 1). The number of events in each orbit is further influenced by event selections that effectively remove the Earth from the field-of-view (right plot in Fig. 1; see Section 2.3.3 in van Dijk 1996). For each of the time intervals separately, the exposure, geometry and event matrices were generated (Schönfelder et al. 1993). Instead of the standard energy selections, we used the 0.75–1.25, 1.25–3.0, 3.0–8.0 and 8.0–30.0 MeV energy ranges which yield a more balanced distribution of events

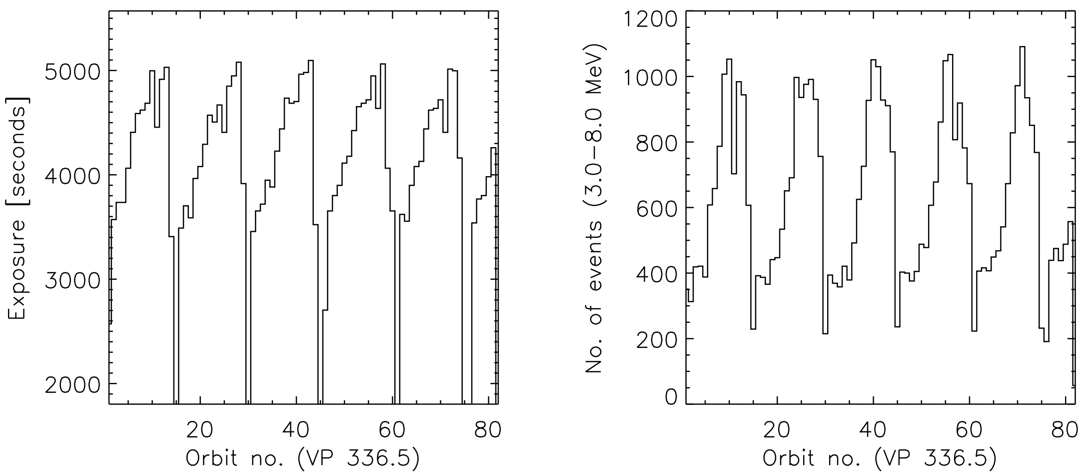

FIGURE 1. The exposure (left) and the number of 3–8 MeV events (right) for each orbit of the CGRO satellite during VP 336.5.

over energy. The analysis is based on the maximum likelihood ratio (MLR) method, which yields for each location within the search region an MLR value and a flux with error (de Boer et al. 1992). The square root of the MLR value is the detection significance for a source at that location. Here we typically used a circle of radius 20° as search region.

THE BACKGROUND MODEL

An often used data-space model for the instrumental-background radiation used in the analysis of COMPTEL data is obtained by applying a smoothing to the observed events in the 3-dimensional data space. Since COMPTEL data are usually dominated by instrumental background, this technique works quite well. Here, however, the total number of events in data space due to instrumental background is typically only a few hundred up to a few thousand and can be as low as ~ 50. Not only the sparseness of the data space but also the large relative contribution from any sources that might be detected were suspected to cause problems for this background model. We tested the applicability of the smoothing-based background model to sparse data spaces by adding simulated sources to the data spaces for the orbits in VP 336.5 and analysing them with the MLR method. In addition, we also tested a simple background model based on the geometry function, for which the scalings of the third data-space dimension (the scattering angle $\bar{\varphi}$) are taken from the observed event distributions. We conclude that the simple geometry-based background model works better for sparse data spaces than the usual smoothing-based background model. This can be inferred from Fig. 2, which shows the flux losses for both background models as a function of energy range

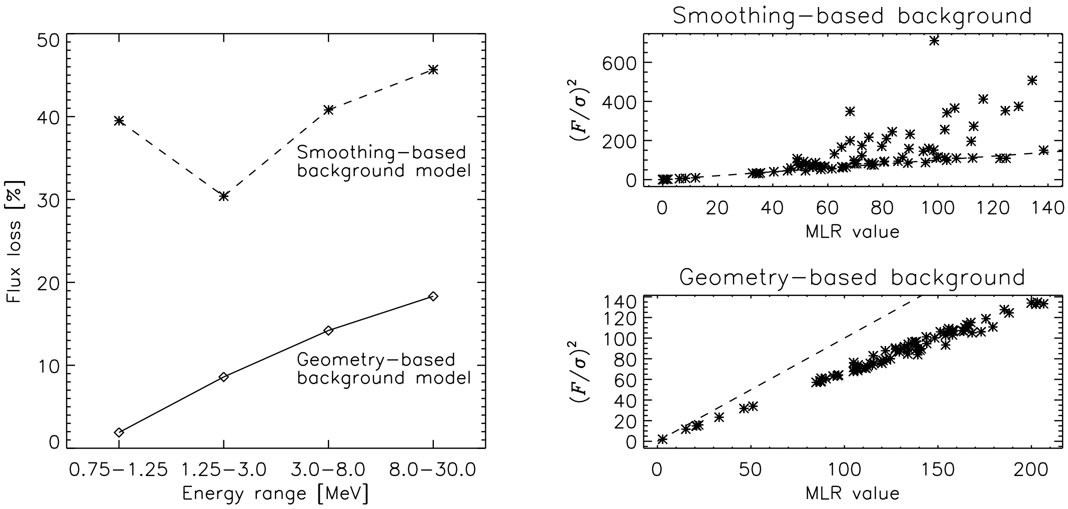

FIGURE 2. Results from the analysis of the data spaces for VP 336.5 with simulated sources added. *Left*: the average loss of source flux for each background model. *Right*: $(F/\sigma)^2$ for the 3–8 MeV energy range, where F is the flux and σ the error on the flux, versus the MLR value. In a proper MLR analysis (i.e., with an independent background model), these should be the same to first approximation (dashed lines).

(left plot) and the behaviour of the MLR values for different source strengths for the 3–8 MeV energy range (right plot; other energy ranges yield similar results). For the geometry-based background model, the flux losses are less and the MLR values do not scatter as much, although they do require to be calibrated.

RESULTS

The data for each CGRO orbit for the observations listed in Table 1 were analysed using a search region of 20° around the pointing direction. This way, we obtained N_i MLR maps and flux maps for each observation, with N_i the number of CGRO orbits during VP i. At the location of the black-hole candidates (Table 1), none of the detection significances were larger than $\sim 3\sigma$ (in the absence of trials, an MLR value of 9 formally indicates a 3σ detection for a known source). In Fig. 3, we show a typical example of the MLR values and fluxes obtained. For the other locations in the sky regions searched, the maximum MLR values correspond to detection significances of $\sim 3.8\sigma$. Given the large number of trials (# energy ranges $\times$ # orbits $\times$ # locations $\times$ # VPs) these are consistent with being statistical fluctuations.
Using least-squares fits to the N_i fluxes obtained for each location, we searched for time variability in the fluxes during the observations. No significant time variability was found. In cases when the small probability indicated a possible time variable signal, further analysis revealed that these small probabilities

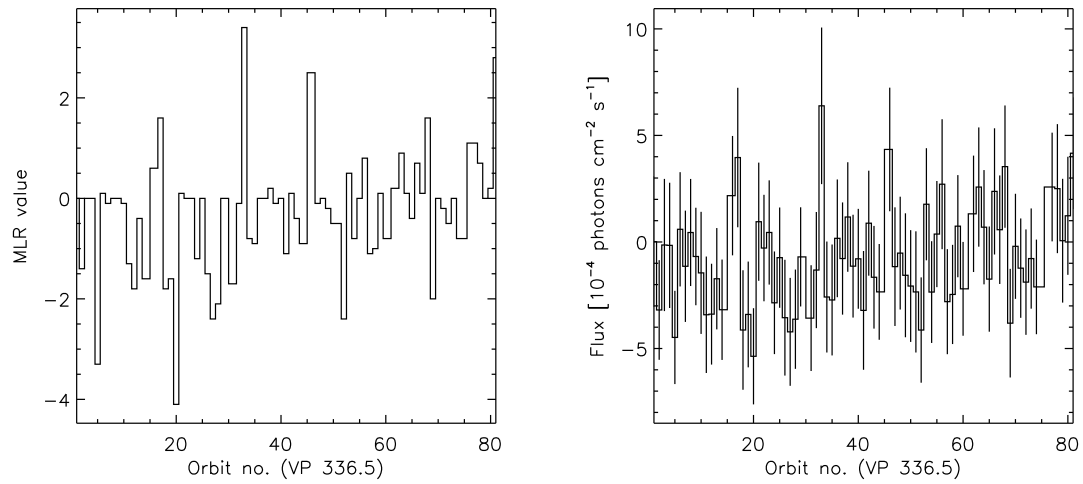

FIGURE 3. The MLR values (left) and fluxes (right) obtained at the location of GRO J1655-40 as a function of CGRO orbit number during VP 336.5.

were driven by significant negative fluxes. These could usually be explained by an incorrect instrumental-background model due to limited statistics.

Given the number of trials performed, we conclude that we did not detect any significant flaring emission in the COMPTEL data considered here. Typical upper limits during the CGRO orbits in these observations, in units of the Crab flux, are 10, 4, 4 and 8 in the 0.75–1.25, 1.25–3.0, 3.0–8.0 and 8.0–30.0 MeV energy ranges. Between 1 MeV and 10 MeV, these upper limits are below the fluxes reported for the flare from GRO J1655-40 observed with HIREGS in January 1995 and indicate that such strong short-time-scale flaring cannot be a phenomenon occurring frequently.

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