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IN ROSAT AND PRELIMINARY SEARCH RESULTS

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# The Expected Rates of X-ray Flashes from GRBs in ROSAT and Preliminary Search Results

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**Abstract.** The recent long (up to days) and relatively bright soft X-ray afterglows from GRBs detected by BeppoSAX raise the possibility of detecting similar events in the ROSAT database. We perform detailed calculations on the expected number of ROSAT events based on the extended halo scenario. We use the realistic ROSAT capabilities and the actual exposure time on bright nearby galaxies. We find that the expected number of x-ray events is quite low,  $\sim 1$ , and depends on the peak x-ray luminosity. Thus a nondetection of such events from nearby galaxies (within 12 Mpc) can *not* rule out most of the viable halo models. We also present the preliminary search results from the ROSAT PSPC database.

## INTRODUCTION

The possibility that Gamma-ray Bursts (GRBs) might come from objects in our galactic halo has provoked several studies on the feasibility of detecting bursts from M31 (e.g., [1]; [2]; [3]) and other nearby galaxies within a couple of Mpc (e.g., [4]). In particular, detecting events in the x-ray band (anywhere between 1- 20 keV) is regarded as more promising due to the high sensitivity typically offered by focusing x-ray instruments. The expected rate of GRBs, however, is critically dependent on several aspects: (1) Various halo model parameters. (2) The distribution of the x to gamma-ray fluence ( $S_x/S_\gamma$ ) or flux ( $F_x/F_\gamma$ ) ratios in GRBs. This will determine the sampling distances of the x-ray instruments. (3) Detailed specifications of various instruments, such as how bursts are detected, field-of-view (FOV), angular and temporal resolution, imaging or non-imaging, etc.

Prior to BeppoSAX discoveries, it was generally assumed that the duration of the x-ray emissions is only slightly longer than their gamma-ray phase (e.g., the GINGA bursts). This resulted in the proposal [1] of searching 30-50 sec x-ray flashes from ROSAT's observations of M31. It was found that at least two weeks' observing time is needed to seriously constrain halo models.

The recent discovery of long ( $\sim$  days) and bright x-ray afterglows has opened up new windows on GRB studies. The long x-ray afterglow, albeit decaying, has led

us to reevaluate the best method to catch such events. Meanwhile, ROSAT has accumulated a sizable database on nearby galaxies over the years. We therefore carried out a search for x-ray flashes with durations between hundreds and one thousand second from ROSAT PSPC observations on nearby bright galaxies, as well as over the full sky (cf. Sun et al., this proceeding).

## OPTIMAL INTEGRATION TIME FOR ROSAT AND DATA SELECTION

Even though ROSAT has demonstrated the unprecedented sensitivity in the soft x-ray band, it is not really devised for transient event studies (or source variability study in general). This is mainly due to its low earth orbit which causes frequent earth blockage of targets typically once per orbit. In addition, it has a roughly 402 sec wobbling period, which requires careful evaluations of any short time variability ( $< 400$  sec).

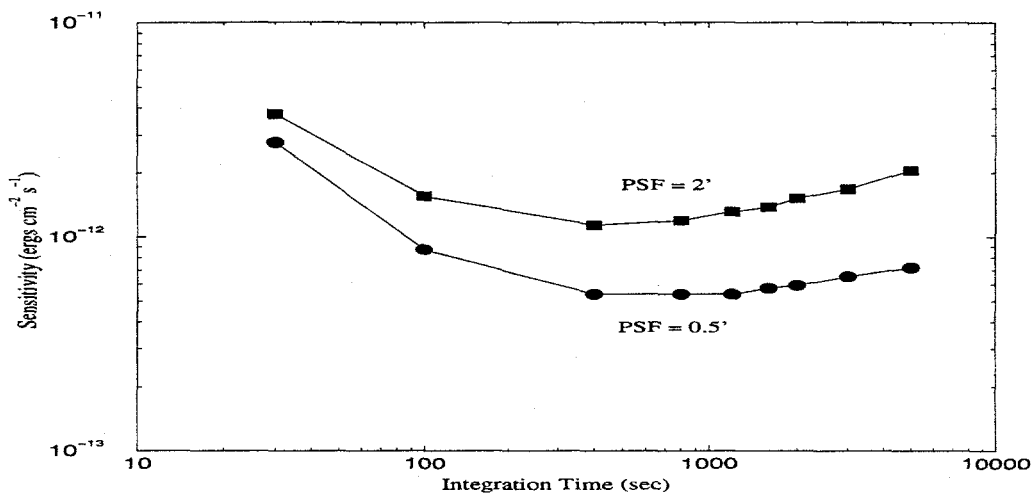
In order to determine the optimal integration time for searching x-ray flashes that are possibly associated with GRBs from nearby galaxies, we adopt the following assumptions of the x-ray behavior: (1) The x-ray lightcurve has a plateau of  $t_0 = 100$  sec with a constant luminosity  $L_0$ ; and (2) After  $t_0$ , the luminosity decays as  $1/t^{1.4}$ . To determine the sensitivity of ROSAT on these transient events, we perform simulations using different source fluxes in a constant background. We adopt a mean background count rate of  $3.1 \times 10^{-4}$  cts/s, roughly corresponding to the low background level in the hard band (0.5-2 keV) of ROSAT. Figure 1 shows the ROSAT sensitivity  $F_{lim}$  as a function of the integration time, where  $F_{lim}$  is the flux level during the *plateau* phase.

It is clear that a search is most sensitive if the integration time is between 400 – 1200 sec. This is quite different from the previous studies where much shorter timescale ( $< 100$  sec) was used. The reason for this longer integration time is due to the newly discovered x-ray tail.

Figure 1 also reveals one of the characteristics of ROSAT. The PSF gets increasingly larger as the off-axis angle increases, resulting in a decreasing sensitivity once the off-axis angle is larger than  $20'$  (the inner region of PSPC). This translates into a quickly decreasing sampling depth for the outer portion of the telescope. Therefore we are only able to use the  $\leq 40'$  region for source detections in our searches.

## EXPECTED RATES FROM NEARBY GALAXIES

We follow the formalism given in Li, Fenimore, & Liang (1996) to calculate the expected number of x-ray flashes using the actual exposure time on all the bright ( $M \leq -19.5$ ) and nearby ( $d \leq 12$  Mpc) galaxies. We excluded all galaxies within 100 kpc. There is  $\sim 1.2$  Msec exposure time in total, with  $\sim 0.43$  Msec for galaxies



**FIGURE 1.** ROSAT sensitivity as a function of integration time for the flash searches. Since the decaying x-ray tail lasts much longer than a day, the best search window is 400–1200 sec. The background starts to dominate for longer timescales. ROSAT sensitivity decreases dramatically as the off-axis angle increases from 0 (PSF= 0.5') to 30' (PSF= 2'). We have used a mean background of  $\sim 3 \times 10^{-4}$  cts  $s^{-1}$  arcmin $^{-2}$  and a conversion factor of  $0.45 \times 10^{11}$  cts  $cm^2$  / ergs is assumed.

above galactic latitude  $30^\circ$  and  $\sim 0.73$  Msec below that (mainly due to M31). Here, we will only consider the delayed turn-on model and assume that the core radius of the GRB halo distribution is  $R_c = 35$  kpc, with a cutoff of 500 kpc and BATSE sampling depth is 200 kpc. We then calculate the expected number of events  $N_{\text{expect}}$  by summing up the product of the expected rate of flashes  $\dot{N}_i$  and the exposure time  $t_{\text{expos } i}$  of each individual galaxy. We also take into account the fact that as the ROSAT “opening angle” increases, the corresponding sampling depths are smaller, hence fewer galaxies could be seen at large off-axis angles.

We plot the expected number of x-ray flashes as a function of peak x-ray (0.5–2 keV) luminosity in Figure 2. We utilize Figure 1 to obtain the sampling depth of ROSAT. The fact that the expected number is higher for higher  $L_0$  is because more galaxies could be observed. The range of x-ray luminosities considered here,  $(1 - 5) \times 10^{39}$  ergs/s, is roughly 1–2% of the peak gamma-ray luminosity,  $\sim 10^{41}$  ergs/s (cf. [5]). We also assume that all GRBs have x-ray tails.

Given all the optimistic assumptions in obtaining Figure 2, the expected number of flashes is still rather low  $\sim 1$ , though a “perfect” ROSAT (i.e., if the same sensitivity across the whole FOV=  $1^\circ$ ) might have been able to provide much more interesting constraints (the dashed curve in Figure 2).

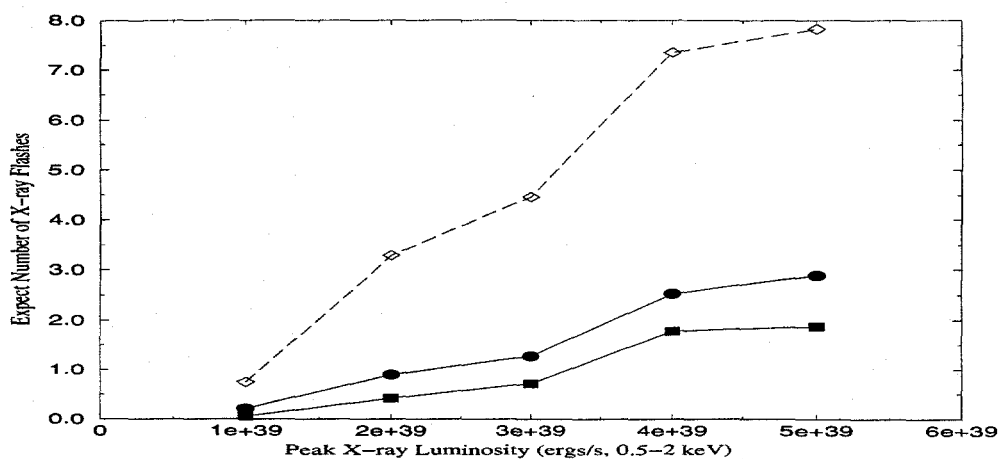
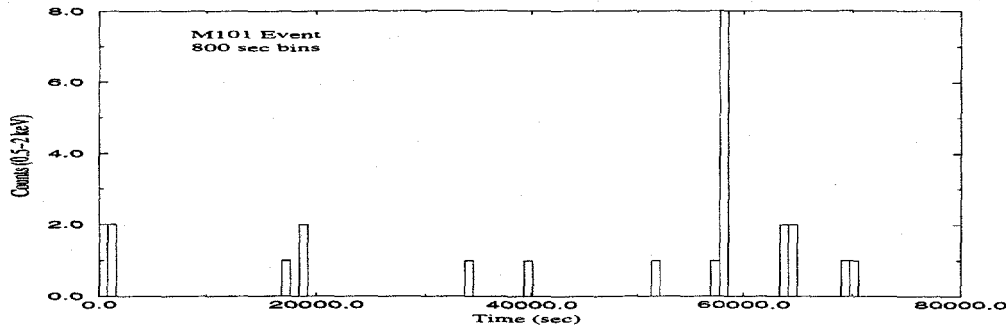


FIGURE 2. The expected number of GRB x-ray flashes from nearby galaxies in ROSAT as a function of the peak x-ray luminosity. The solid dots represent the rate when all bright nearby galaxies are included, whereas solid squares only include high latitude ( $B \geq 30^\circ$ ) galaxies. Open diamonds indicate what one expects if we had a "perfect" ROSAT (i.e., the same sensitivity across the whole FOV).

## PRELIMINARY SEARCH RESULTS

We have carried out extensive searches for x-ray flashes with durations of  $\sim 400 - 1200$  sec from ROSAT PSPC database. The accompanying paper (Sun et al. this proceeding) gives a detailed report on our findings. Here we will concentrate on events from nearby galaxies. We have found 6 events from the directions of *bright* nearby galaxies, with three of them below galactic latitude  $30^\circ$  which we will not discuss here. Among the 3 high latitude sources, two show very weak persistent emissions either before or after the main flash, such behavior leads us to rule them out as GRB candidates. The third event is coming from the direction of M101 ( $\sim 7.4$  Mpc away) and Figure 3 shows the lightcurve of this flash. We now discuss the remaining event in detail.

This flash is located in between of two spiral arms (RA= 140309.6, Dec= +542437, J2000) and is 7.2 kpc away from the center of the galaxy. We do not find any catalogued source at our source location and we do not find any optical counterpart either judging from the images of the Digital Sky Survey. If this flash is indeed from M101, the implied mean luminosity over 800 sec at 7.4 Mpc is  $\sim 1.5 \times 10^{39}$  ergs/s in the hard band (0.5 - 2 keV) and there is no detection in the soft band (0.1 - 0.4 keV). From the ROSAT/PSPC data, we can put upper limits on the pre and post-flash emissions to be lower by a factor of at least 33 and 6, respectively. M101 has also been observed by Einstein IPC and ROSAT HRI and there is no detection in either of them at our source location. In particular, the exposure time from HRI is  $\sim 209$  ks, which translates into an upper limit of



**FIGURE 3.** The lightcurve of the M101 event, binned in 800 sec. The probability of having such a “flash” by random chance is  $\sim 10^{-7}$ . Only upper limits are obtained for both the pre and post-flash emissions and the flux variations are larger than  $\sim 10$ .

$< 2 \times 10^{37}$  ergs/s, a factor of  $\sim 100$  lower than our inferred peak flux during the flash, though the HRI observations is several years later than PSPC.

## CONCLUSIONS

Although the characteristics of the M101 event are generally consistent with what one might expect from the x-rays associated with a GRB, it is certainly premature to claim it is indeed a GRB given the limited information we have on this source. Furthermore, as discussed in Sun et al. (this proceeding), we have detected flash events from both the galaxies and control fields, and the event statistics are not sufficient enough to claim that we see separate classes of events. An equally important aspect is that the expected number of x-ray flashes that are associated with GRBs is small (cf. Figure 2), thus we think our findings on events from nearby galaxies are not conclusive, nor is it likely that any analysis of ROSAT could either prove or disprove any halo models.

The characteristics of other events we found from nearby galaxies and their possible interpretations will be discussed in future publications.

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