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LIMITS ON REPORTED TRANSIENT EMISSION EVENTS NEAR 0.5 MeV FROM THE CRAB AND 1E 1740.7 – 2942

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ABSTRACT

The SIGMA coded-mask telescope aboard the *Granat* observatory has reported transient emission near 0.5 MeV lasting for about 1 day from three Galactic objects: the Crab, black hole candidate Nova Muscae 1991, and, on two occasions, black hole candidate 1E 1740.7−2942 (1E) near the Galactic center. Two of these events (the Crab and one from 1E) have occurred since the launch of the *Compton Gamma Ray Observatory* (*CGRO*). Jung et al. searched for the 1E transient of 1992 using the Oriented Scintillation Spectrometer Experiment on *CGRO* but did not confirm the result. We use the Burst and Transient Source Experiment (BATSE) on *CGRO* to search for both this event and the Crab transient. We find a 3 σ upper limit of 1.7×10^{-3} photons s^{-1} cm^{-2} compared to the reported flux of $(5.1 \pm 1.7) \times 10^{-3}$ photons s^{-1} cm^{-2} for the Crab transient, and a 3 σ upper limit of 1.8×10^{-3} photons s^{-1} cm^{-2} versus $(4.28^{+2.7}_{-1.5}) \times 10^{-3}$ photons s^{-1} cm^{-2} reported for the 1E event. Therefore, we do not confirm the two 1 day SIGMA transients for which BATSE data are available.

Subject headings: Galaxy: center — gamma rays: observations — ISM: individual (Crab Nebula) — stars: individual (Nova Muscae 1991, 1E 1740.7−2942) — X-rays: bursts

1. INTRODUCTION

Bright, transient emission features near 0.5 MeV have been reported from a number of Galactic sources and are summarized in Table 1. All but one are from the SIGMA hard X-ray imager on the *Granat* spacecraft (Gilfanov et al. 1994; Cordier et al. 1993; Bouchet et al. 1991; Sunyaev et al. 1991; Churazov et al. 1993; Goldwurm et al. 1992; Sunyaev et al. 1992; Goldwurm et al. 1993). The remaining event was observed with the Medium Energy Detectors on *HEAO 1* for ~2 weeks and appeared ~12° below the Galactic plane near the Galactic center (Briggs et al. 1995).

These features are all near the positron annihilation energy of 511 keV, with variations in energy and width. Most occur over a time of ~1 day. They appear in sources considered black hole candidates (1E 1740.7−2942, hereafter "1E," and Nova Muscae 1991) but also in a pulsar (the Crab) and the *HEAO 1* source, which has no firm counterpart identification owing to a localization uncertainty of several degrees.

The Nova Muscae and 1990 1E transients have stimulated a great deal of theoretical work. They were first interpreted as the annihilation, in a black hole accretion disk, of positrons created in a thermal pair plasma during an episode of high accretion (Hua & Lingenfelter 1993). Other current models involve jets, since radio jets have been observed in 1E (Mirabel et al. 1992). Models in which positrons annihilate in the jet have been proposed by Misra & Melia (1993) and by Maciołek-Niedźwiecki & Zdziarski (1994). The model of Skibo, Dermer, & Ramaty (1994) requires no positrons; they demonstrated that any sufficiently hard gamma-ray continuum could be Compton scattered into an ~0.5 MeV feature if the original photons were beamed in a jet parallel to the bulk motion of slightly relativistic scattering electrons. Ramaty et al. (1992) suggested that positrons escaping the 1E system in the jets could annihilate in a nearby molecular cloud, causing a long-term variability in the narrow 511 keV line from the Galactic center region; Chen, Gehrels, & Leventhal (1994) used the brightness of the radio jets and their penetration into the interstellar medium to argue that from 80%–98% of the positive charges in the jets are probably positrons rather than protons.

Two of the ~1 day transients in Table 1 occurred since the launch of the *Compton Gamma Ray Observatory* (*CGRO*). One of the *CGRO* instruments, the Oriented Scintillation Spectrometer Experiment (OSSE), has already been used to look for the 1992 transient of 1E, with a negative result (Jung et al. 1995): a 3 σ upper limit of 1.0×10^{-3} photons s^{-1} cm^{-2} for a feature with the parameters given by Cordier et al. (1993).

Harris, Share, & Leising (1994a, b) searched with null results for transients from 1E and the Crab in data from the *Solar Maximum Mission* Gamma-Ray Spectrometer (*SMM*/GRS). This mission ended before SIGMA began taking data, but it had exposure to both these sources from 1981–1988. The average 3 σ upper limit for an event like the SIGMA Crab transient was 2.92×10^{-3} photons s^{-1} cm^{-2}, and for a transient like the 1990 and 1992 1E events it was 4.84×10^{-3} photons s^{-1} cm^{-2}.

We undertook to test SIGMA's observations using another instrument, the Burst and Transient Source Experiment (BATSE) on *CGRO*.

2. OBSERVATIONS

BATSE (Fishman et al. 1989) consists of two types of detec-

TABLE 1

REPORTED BRIGHT ~0.5 MeV TRANSIENTS

Source	Date	Duration[a]	Flux ($\mathrm{ph\ s^{-1}\ cm^{-2}}$)	Line Center (keV)	Line FWHM (keV)	Reference[b]
1E 1740.7−2942	1990 Oct 13–14	~1 day	$(6.2 \pm 1.6) \times 10^{-3}$	385^{+30}_{-25}	110^{+60}_{-40}	1
	1991 Oct 1-19	~18 days	$(3.4 \pm 1.1) \times 10^{-3}$	380 ± 70	340^{+160}_{-90}	1
	1992 Sep 19–20	1.16 days	$(4.28^{+2.70}_{-1.50}) \times 10^{-3}$	350^{+110}_{-40}	170^{+210}_{-65}	2
Crab	1992 Mar 10–11	0.95 day	$(5.1 \pm 1.7) \times 10^{-3}$	536^{+11}_{-14}	44^{+41}_{-44}	1
Nova Muscae 1991	1991 Jan 20–21	13 hr	$(6.3 \pm 1.5) \times 10^{-3}$	476 ± 15	58 ± 34	3
Unidentified	Late 1977	~15 days	$(6.0 \pm 1.0) \times 10^{-3}$	457 ± 16	213 ± 37	4

[a] Duration of the observation; in each case the event may have lasted longer. See the references for the true duration constraints.

[b] (1) Gilfanov et al. 1994; (2) Cordier et al. 1993; (3) Sunyaev et al. 1992; (4) Briggs et al. 1995.

tors, both uncollimated crystals of NaI: the Large Area Detectors (LADs) and the Spectroscopy Detectors (SDs), which have a much smaller area but a greater energy range and better resolution. There are eight of each, one facing outward from each corner of the spacecraft, so that any point in the sky is observed by two to four of each kind of detector during every ~90 minute orbit.

We do not use Earth occultation imaging, which has been very successful with BATSE data (Harmon et al. 1993; Zhang et al. 1993). That technique uses broad energy bins: 16 channels cover the entire energy range of the LADs. Instead, we produce background-subtracted spectra in fine energy bins which contain the entire half-sky of the source of interest. If a transient as bright as those in Table 1 is present, it will be detectable in the background-subtracted spectrum. The large BATSE detectors have enough sensitivity to see the transients of Table 1 easily considering only statistical errors; our critical task is to reduce the systematic errors in the background subtraction to less than 1% of the background.

Background subtraction is accomplished by a method similar to that used by Harris et al. (1994a, b) to search for similar transients in data from *SMM*/GRS. Background spectra are taken 15 orbits (~1 day) before and after the source spectrum; therefore, the result is a *differential* spectrum (comparing the "source" day with the days before and after it) of half the sky. We choose background spectra this way because many of the parameters which control the background (Earth angle to the detector axis, time since last transit of the South Atlantic Anomaly [SAA], geomagnetic cutoff, etc.) come roughly back in phase after a day.

Although the background spectrum is usually a very good approximation to the source spectrum, there are small variations from day to day. For the LADs, we use a series of three minor background corrections based on three parameters: the count rate in the LAD above 1 MeV, the ratio between the count rate in the plastic Charged-Particle Detector (CPD) associated with each LAD and the >1 MeV LAD rate, and a measure of the activation attributable to the last SAA transit. For each parameter, over a year of data have been combined to determine the average differential spectrum associated with a given difference in the parameter. We call these spectra "templates," and a small amount of each of the three templates is added to the background spectrum. We stress that we are not *fitting* the spectrum with the templates; how much of each template is added depends only on the relative values of the three parameters in source and background.

We need multiple templates because variations in the >1 MeV flux, variations in the CPD rate, and variations in the flux in the energy range of interest (250–650 keV) are not perfectly correlated: for instance, the >1 MeV flux is the better predictor of the flux in the 511 keV background line itself, while the CPD rate is the better predictor of the continuum around 300 keV. The template based on SAA transits addresses a special background component which only occurs on a few orbits per day. Our combination of templates naturally allows each parameter to dominate the correction during the times and at the energies where it tends to correlate best with the data. In addition, use of three corrections minimizes the possible influence of real transient source flux >1 MeV on the result (see below).

For the SDs, we use only two templates: one based on the upper level discriminator (ULD) rate, which is dominated by cosmic rays, and one based on the same SAA activation parameter used for the LADs. Because the SDs are smaller, it is easier to bring the residual systematic error close to the level of statistical errors in a day's data.

These background subtraction techniques will be discussed in more detail in an upcoming paper (see the discussion in § 4).

3. RESULTS

Figure 1 (*top*) shows the background-subtracted count spectrum from the summed LADs over the same time interval as the SIGMA 1E transient of 1992. The smooth curves are the Gaussian from Table 1 folded through the LAD response, and the upper and lower (1 σ) flux limits are from the same table. Figure 1 (*bottom*) shows the corresponding result for the SIGMA Crab transient, and Figure 2 shows both days in the SDs. The continua from these sources should not appear in these differential spectra, since they were not observed by SIGMA to vary during the high-energy flaring.

We measure the flux in the line by fitting the spectrum from each detector with a multiple of that detector's response to the SIGMA Gaussian. We then combine the LAD and SD results for each event, weighting each detector by the inverse square of the error in the fit. For one detector, the SD error is on average about 1.3 times the LAD error for a Crab-like transient and 2.5 times the LAD error for a 1E-like transient. The thin LADs lose efficiency much more quickly in going from 350 keV (the 1E center energy) to 536 keV (the Crab center energy), so the statistical errors in photon flux increase more dramatically.

Using all the detectors available, we find fluxes of $(0.02 \pm 0.20) \times 10^{-3}$ photons $\mathrm{s^{-1}\ cm^{-2}}$ for the 1E transient and $(0.18 \pm 0.15) \times 10^{-3}$ photons $\mathrm{s^{-1}\ cm^{-2}}$ for the Crab transient. The 3 σ upper limits using only statistical errors are then 0.62×10^{-3} photons $\mathrm{s^{-1}\ cm^{-2}}$ for 1E and 0.63×10^{-3} photons $\mathrm{s^{-1}\ cm^{-2}}$ for the Crab.

There are residual systematic uncertainties in the background subtraction which can be larger than the statistical

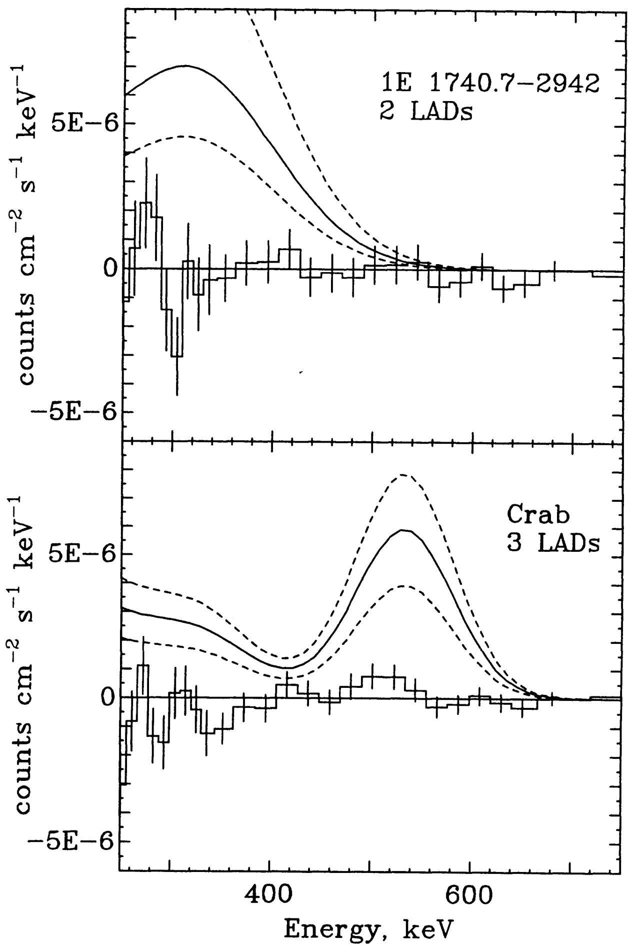

FIG. 1.—BATSE LAD differential count spectra. *Top*: 1E, 1992 September 19–20. *Bottom*: Crab, 1992 March 10–11. The curves are the SIGMA best-fit Gaussian with ±1 σ flux errors, folded through the LAD response.

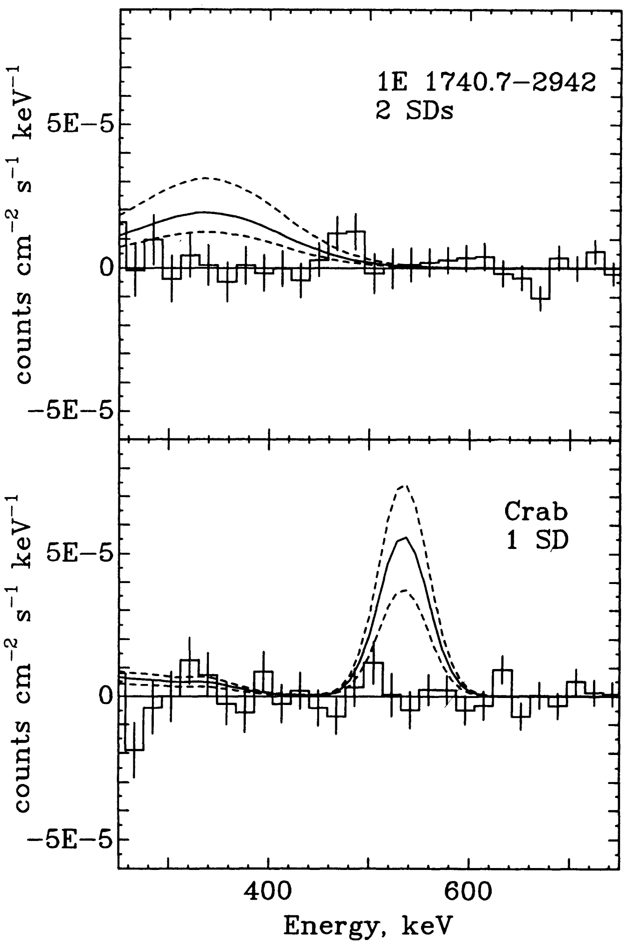

FIG. 2.—BATSE SD differential count spectra. *Top*: 1E, 1992 September 19–20. *Bottom*: Crab, 1992 March 10–11. The curves are the SIGMA best-fit Gaussian with ±1 σ flux errors, folded through the SD response.

errors. In Figure 3 we show daily flux values like those above for many days around the transients. The rms scatter is the total empirical error, systematic plus statistical. It is 0.58×10^{-3} photons s^{-1} cm^{-2} for a 1E-like transient and 0.49×10^{-3} photons s^{-1} cm^{-2} for a Crab-like transient. With these errors, the 3 σ upper limits are 1.8×10^{-3} photons s^{-1} cm^{-2} for 1E and 1.7×10^{-3} photons s^{-1} cm^{-2} for the Crab.

Because the LAD background corrections make use of the flux above 1 MeV, there is a legitimate concern that a real transient might be reduced in our result if it extended beyond this energy. To estimate the maximum possible extent of this effect, we needed an upper limit to the >1 MeV source flux. There is no evidence for emission above about 700 keV in the events listed in Table 1, but SIGMA's sensitivity dropped off rapidly in this range. Since we do not use the MeV photon rate to correct the SDs, we used them to determine the maximum possible source flux from 1.0 to 1.7 MeV (the top of the LAD range).

We ran Monte Carlo simulations of the SD response to high-energy components with a variety of spectral shapes. For each spectral shape, we found the maximum flux allowed at the 1% confidence level by the SD data on the day of each event. We then simulated the LAD response to this high-energy component and artificially added the resulting simulated count spectrum to the real LAD data along with the simulated count spectrum for the SIGMA transient. We ran our usual analysis on the modified data set, comparing the flux derived with only the transient added with the flux derived when both the transient and high-energy component were added.

The worst case was when the hypothetical high-energy component began abruptly at 1 MeV and followed a power law with index -2 above that energy. In this case, the flux derived for the 1E transient was 13% too low, and the flux for the Crab transient was 17% too low. Components with a higher or lower index and components which contained some flux between the transient Gaussian and 1 MeV had even less of an effect. For comparison, eliminating the >1 MeV flux entirely as a template parameter resulted in a decrease in sensitivity of about a factor of 2 owing to increased systematic errors. We conclude that the SDs provided an adequate monitor for >1 MeV source flux, allowing us to use the LAD count spectrum >1 MeV to correct the LAD background.

In addition, we were concerned that if each event lasted longer than the reported SIGMA observation interval, transient flux might appear in some background spectra. Therefore, we redid the analysis on the assumption that the transients are 3 days long and found essentially no change in the null results: $(-0.28 \pm 0.43) \times 10^{-3}$ photons s^{-1} cm^{-2} for the 1E transient and $(-0.03 \pm 0.30) \times 10^{-3}$ photons s^{-1} cm^{-2} for the Crab transient (errors are rms empirical errors from a

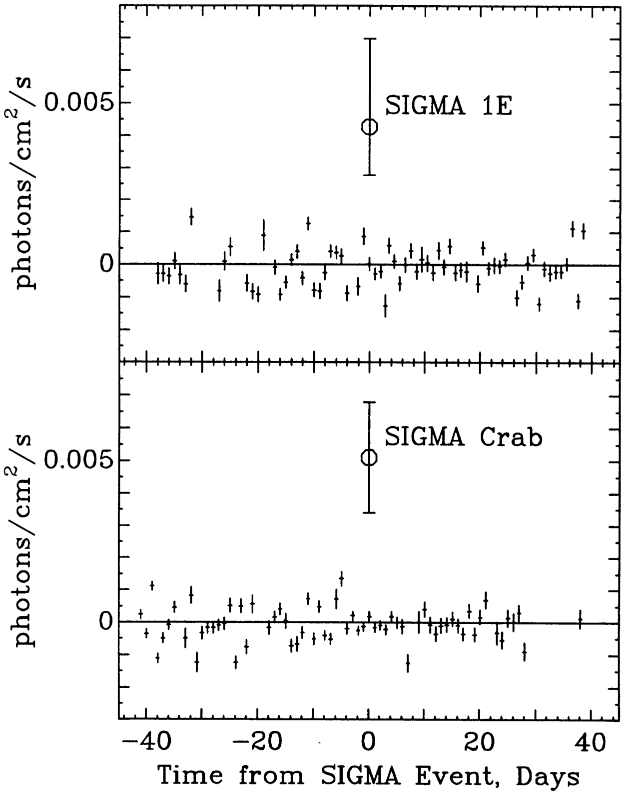

FIG. 3.—Daily fluxes fit to the SIGMA Gaussian parameters (combined LAD and SD results), shown with the SIGMA data point. *Top*: 1E transient. *Bottom*: Crab transient.

number of similar 3 day periods). This is particularly significant for 1E, since SIGMA saw no flux above 200 keV 1 day before and 2 days after the reported transient, making 3 days the upper limit to its duration.

4. DISCUSSION

In summary, we offer no explanation of the discrepancy between the BATSE and SIGMA results other than the limited statistical significance of the SIGMA data. The two brightest SIGMA 1 day transients (1E in 1990 October and Nova Muscae in 1991 January) had better statistics but occurred before the launch of *CGRO*.

We cannot use either the background selection algorithm for 1 day intervals or the algorithm for 3 day intervals to search for the 18 day 1E transient of 1991 (Churazov et al. 1993). Since *CGRO* repoints roughly every 2 weeks or less, a different algorithm is needed to look for events as long as or longer than a spacecraft repointing. The appropriate technique is under development but does not yet have the sensitivity to see a dim, broad feature such as this (see Table 1).

Since BATSE is an all-sky detector, we can search any point source for transient features at approximately this sensitivity. In a paper now in preparation, we monitor 1E for more than 2 years, look at X-ray novae similar to Nova Muscae 1991, and finally complete a scan of the entire sky for 1 day transients at several energies near 0.5 MeV and several energy widths.

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