ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

JANUARY 1993, PAGE 341

Astron. Astrophys. Suppl. Ser. **97**, 341-344 (1993)

Search for Gamma-Ray Transients Using the SMM Spectrometer

G.H. Share[1], M.J. Harris[2], M.D. Leising[3] and D.C. Messina[4]

[1] Code 7652, Naval Research Laboratory, Washington, DC, 20375 U.S.A.
[2] Universities Space Research Association, Code 7652, NRL, Washington, DC, 20375 U.S.A.
[3] Dept. of Phys.& Astr., Clemson University, Clemson, SC, 29634 U.S.A.
[4] SFA, Inc., 1401 McCormick Dr.,Landover, MD, 20785 U.S.A.

Received June 3; accepted June 10, 1992

Abstract. — Data from the SMM Gamma-Ray Spectrometer (GRS) have been searched for $\geq$ 300 keV transients lasting from seconds to months during its near ten-year life. Spectra have been obtained from 215 solar flares and 177 gamma-ray bursts. Although lines are common in flares, no narrow or moderately broadened lines were observed in any of the bursts. The rate of bursts is consistent with a constant over the mission but is weakly correlated with solar activity ($\sim$ 95% confidence level). No evidence was found for bursts of 511 keV line emission, unaccompanied by a strong continuum, at levels $\geq 5 \times 10^{-2}$ γ cm^{-2}s^{-1} for bursts lasting $\leq$ 16 s. No evidence was found for broad features near 1 MeV from Cyg X-1, the Galactic Center, or the Crab in 12-day integrations at levels $\geq 6 \times 10^{-3}$ γ cm^{-2}s^{-1}. No evidence was found for transient celestial narrow-line emission from 300 keV to 7 MeV on min-to-hrs long time scales from 1984 to 1989.

Key words: gamma-rays: bursts, transients, lines, celestial.

1. Introduction.

The γ-ray sky has shown itself to be highly variable on time scales from fractions of a second to months. Several hundred flares emitting radiation $\geq$100 keV are produced by the sun over its 11-year cycle. Bursts of still unknown origin occur with a frequency of a few hundred per year and appear to be isotropically distributed over the sky. Supernovae and novae produce hard continua and line emissions, such as observed from SN1987A and Nova Muscae 1991. Binary sources, such as Cygnus X-1, are strikingly variable on several time scales. AGN exhibit significant changes in intensity on time scales of a day or shorter. Transient lines of uncertain origin have also been reported in the vicinity of 400 - 500 keV from sources such as the Galactic Center, the Crab Pulsar, and in γ-ray bursts.

In this paper, we summarize observations of transient radiation made by the Gamma Ray Spectrometer (GRS) on NASA's Solar Maximum Mission (SMM) satellite; the experiment was in operation from 1980 to 1989 and provided an excellent database for observation of such transients, as well as extended Galactic emissions. Spectral measurements of $\sim$190 flares have been made and indicate that more than 50% exhibit evidence of nuclear-line emission. On the other hand, no evidence has been found for lines in any of the 177 γ-ray bursts observed during the mission. The GRS was fortunately still in operation when SN 1987A occurred and resulted in the discovery and monitoring of at least four γ-ray lines from decay of ^{56}Co (Leising & Share 1990). Only upper limits have been obtained for the ^{56}Co lines from Type I SN 1986G (Matz & Share 1990) and for the ^{7}Be and ^{22}Na lines from recent nearby novae (Leising *et al.* 1988; Harris *et al.* 1991). The spectrometer also measured what appears to be the diffuse Galactic spectrum from 0.3 to 8.5 MeV, revealing narrow lines at 0.511 and 1.809 MeV (from positron annihilation and ^{26}Al), and a positronium continuum below 0.5 MeV, superimposed on a power-law continuum (Harris *et al.* 1990). No evidence was found for any significant variation in the intensity of the measured 511 keV line (3σ limit 8×10^{-4} γ $cm^{-2}s^{-1}$), when comparing times when the reported Galactic Center annihilation source was in high and low states (Share *et al.* 1990).

In Section 2 we summarize recent work on γ-ray bursts including a systematic search for line features and study of the rate of bursts detected over the $\sim$ 10-yr mission. In Section 3 we discuss a search for short 511 keV line transients utilizing the same techniques used to discover bursts in the data. In Section 4 we summarize results obtained to date on searches for broad line emission near 1 MeV similar to the episode observed from Cygnus X-1 by the germanium spectrometer on HEAO- 3. In Section 5

we discuss a search for narrow-line transients of the type observed during a balloon observation in 1974.

2. Gamma-ray bursts.

A total of 177 events $\geq$300 keV were detected during the SMM mission which have been categorized as γ-ray bursts (Share *et al.* 1992). A V/V_{max} study of 132 of these events found by a computer search algorithm revealed that the spatial distribution of burst sources is inconsistent with uniformity at the 4σ level (Matz *et al.* 1992), consistent with the more recent results from the BATSE experiment on the Compton Observatory (Meegan *et al.* 1992). We recently completed a systematic search for narrow or moderately broadened lines $\geq$300 keV in time-integrated spectra of bursts (Messina & Share 1992). The search was performed by fitting spectra with Gaussian lines centered at each energy channel and fixed at either the intrumental resolution (e.g. 45 keV FWHM @ 0.6 MeV) or twice the instrumental resolution. We found that broader Gaussians were difficult to separate from our simple definition of the continuum shape and made searching for such broad lines inclusive. No evidence was found for narrow or moderately broadened lines in any of the bursts.

The spatial non-uniformity of bursts coupled with their apparent isotropy on the sky (Meegan *et al.* 1992) suggests that the sources are either relatively close (e.g. perhaps heliospheric) or very distant (e.g. cosmological). If the sources are in the solar neighborhood and their activity related to the 11-year solar activity cycle, one might expect to see the rate of bursts to be cyclic as well. The long-term SMM data base, together with the uniform and stable computer search routine used to identify the 132 events used in our V/V_{max} study, permit us to assess the constancy of the burst rate from 1980 to 1989. We divided this observing period into 12 intervals of 283 days and determined the number of bursts per interval, after correcting for livetime and using Poisson statistics to estimate the errors. Assuming the rates to be constant yields an acceptable fit ($\chi^2 = 13.3$ for 11 degrees of freedom). The background rate in the 0.3 to 0.8 MeV range changed by a maximum of 30% from the beginning to the end of the mission when the satellite dropped below the radiation belts before re-entering the atmosphere. This change did not significantly affect the rate of detection of bursts.

Alternatively, one can ask whether the burst rate is correlated with solar activity. We used the number of 'M'- or 'X'-class flares categorized by the GOES satellites as a monitor of solar activity. Plotted in Figure 1 is the livetime corrected number of SMM/GRS bursts plotted against the total number of GOES 'M' and 'X' flares observed in the twelve 283-day intervals. The solid line shows a linear fit to the data; this fit provides modest improvement over the constant burst rate hypothesis ($\chi^2 = 10.5$ for 10 degrees of freedom). The slope of the line is significant at the $1.6\,\sigma$ level; roughly 5% of randomly-distributed data would give a greater or equal value. Although this possible correlation with solar activity is interesting, it is not mandated by the data.

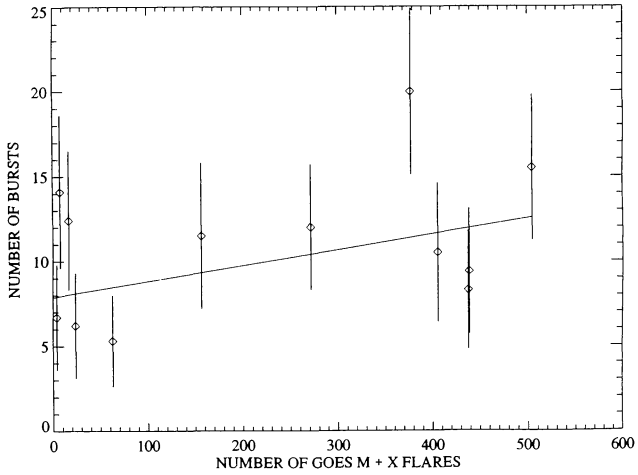

FIGURE 1. Rate of bursts plotted against rate of GOES 'M' + 'X' class flares observed in 283-day intervals over the lifetime of SMM

3. Search for 511 keV 'bursts'.

The same computer algorithm used to search for cosmic bursts in the 0.3 to 0.8 MeV range was applied throughout the mission to search for short term transient events in other energy windows. One of these is a window covering the 511 keV annihilation line. This search revealed about 1000 annihilation events due to positrons emitted by Soviet nuclear-reactor powered satellites (Share *et al.* 1989). In striking contrast to this large number of events, not a single 511 keV transient event was found (aside from solar-flare emission) when no reactors were in operation. Taking into account the aperture of the detector, we estimate that the experiment had a total sky-exposure of $\sim 10^8$ sr-s during these times without reactors or flares. The sensitivity to bursts depends upon the background rate at 511 keV. We estimate that a sensitivity of $\sim 5 \times 10^{-2}\ \gamma\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ for bursts of duration $\leq$ 16.4 s was typical for this search. Bursts with durations up to about 3 minutes would have also been found with similar peak intensities.

4. Search for sources of transient MeV mission.

Broad and variable emission features near 1 MeV have been reported from observations made by the HEAO-3 Ge spectrometer experiment. Similar features, peaking near 1 MeV and having a width of $\sim$ 1.2 MeV, were reported in emissions coming from both the Cyg X-1 and Galactic Center regions (Ling *et al.* 1987; Riegler *et al.* 1985). A new component consisting of enhanced emission above about 1 MeV was observed by HEAO-3 during the Spring of 1980 originating in the vicinity of the Crab (Ling and

Dermer, 1991). Because of the GRS' large aperture and long lifetime, it was likely to have detected similar episodes of transient emission. We therefore initiated a study to search for such features in the data. An initial study set limits of $\sim 7 \times 10^{-3}$ γ cm^{-2}s^{-1} for the peaked emission near 1 MeV in 48-day integrations from sources observed during the 10-year mission. In this study, long-term instrumental background was significantly reduced by subtracting earth-viewing spectra from sky-viewing spectra. Residual instrumental features, arising from β -decays of isotopes such as ^{128}I and varying exposure to the atmospheric γ-radiation, resembled the reported *celestial* emissions and limited the sensitivity of this search.

We have continued this investigation by using data taken a year earlier, under similar orbital conditions, as a monitor of the background in order to further reduce the systematic variations. Background subtractions were performed on a minute-by-minute basis and the resulting spectra were summed to 12-day accumulations. In this analysis, specific celestial source locations were identified for study by subtraction of earth-occulted data from data accumulated with the source above the horizon. This analysis was therefore only sensitive to changes in the emission from selected sources and not to their steady radiation. The residual 12-day spectra derived from this analysis largely could be fitted by the measured shape of the atmospheric spectrum or the difference of two such spectra. Superposed on top of these spectra were the shapes of the reported *celestial* features. The intensities of these features for different sources were obtained and found to have systematic variations that were mostly removed by monitoring the local charged-particle background.

We find no evidence for any MeV transient emission (relative to the year before) from the regions around the Galactic Center, Cyg X-1, and the Crab Nebula from 1981 until 1989. Characteristic 3σ limits (includes estimates of systematic effects) for 12-day integrations during the ~3-month transits of the sources through the GRS' aperture are 6×10^{-3} γ cm^{-2}s^{-1} for the broad line near 1 MeV. This is about 3 times lower than the flux in the feature observed from Cyg X-3 by HEAO-3 in 1979. Furthermore, we can set limits on any transient excess emission in the range from 0.6 to 7 MeV from any source during its 3-month transit of typically $\sim$ 15% of the DC Crab emission (Jung 1989) for sources near the ecliptic plane. The excess MeV emission reported by HEAO-3 from the vicinity of the Crab in the Spring of 1980 was about 4 times the DC emission. At this time, the source would have been about 90° off-axis to the SMM GRS. The GRS limit of $\sim$ 50% of the DC Crab flux from this region based on comparison with data from 1981 appears to be in conflict with the HEAO-3 observation.

5. Search for gamma-ray line transients.

During a balloon flight in 1974, a high-resolution Ge spectrometer (Jacobson *et al.* 1978) observed "a flare-like event lasting about twenty minutes, during which four intense gamma-ray lines were measured at 0.41, 1.79, 2.22, and 5.95 MeV". The transient occurred with the detector pointed near RA 7 hr and Declination 20°. The lines had fluxes ranging from $(7 - 15) \times 10^{-3}$ γ cm^{-2}s^{-1} for a source location on the instrument's axis and were measurably broader than the resolution of the spectrometer. The lines were apparently not accompanied by a strong continuum. The authors concluded that the source of the lines was probably extraterrestrial.

We have utilized the SMM spectrometer's database to search specifically for such transient line emission. The analysis is still in progress, but preliminary results are available from a search carried out during 1984 to 1989 over a total observation period of 4×10^7 s. Only data taken more than 10^4 s from the last transit of the South Atlantic Anomaly are included for study. Spectra during times of known transients such as flares, bursts, etc. are excluded from the study.

The search technique differs from the one outlined in Section 4, in that it was specifically designed for finding transients on time scales from 3 min to 14 hr. Background subtraction is accomplished by utilizing data accumulated 15 orbits prior to and following each 3 min observation period, when the atmospheric leakage and instrumental backgrounds are similar. This technique was based on a suggestion by J. Ryan (priv. comm., 1983) and has been used successfully to obtain background-corrected spectra from solar flares. Residual systematics are generally small and permit integration of background-corrected spectra up to several hours.

No significant narrow or moderately broadened line transients were detected in this preliminary study. To test the sensitivity for detecting such transients, we superimposed four Gaussian line features on the data at the energies and with the intensities observed during the 1974 balloon flight. This *event* was easily detected by the search algorithm. The lines were individually detected with statistical significances ranging from 7 to 20 σ for source locations well within the broad aperture of the SMM spectrometer. We conclude that such line transients do not occur more frequently than once a year.

Typical sensitivities (3σ) for finding lines having intrinsic widths narrower than the instrumental resolution achieved during this search were $\sim 3 \times 10^{-3} \times (\frac{t}{20\text{min}})^{-.5}\gamma$ cm^{-2}s^{-1} from 300 keV to 7 MeV. The SIGMA experiment detected a transient line feature near 480 keV during a 13 hr observation of Nova Muscae 1991 (Sunyaev *et al.* 1992a). The line intensity was $\sim 6\times10^{-3}$ γ cm^{-2}s^{-1}, but it may have been broadened. Moderately broadened features from similar transient sources occurring from

1984 to 1989 should have been detected at several standard deviations by the GRS.

6. Future work.

The searches for narrow and broadened line emission described in Sections 4 and 5, above are in the process of being completed. Final results will be available shortly. These studies will be extended to specifically search for broadened lines below 511 keV such as were reported from the variable Galactic Center source 1E1740.7-2942 (Sunyaev *et al.* 1992b) and an unidentified source lying about 13 deg below the Galactic Plane near the Center (Briggs 1991).

Acknowledgements.

We wish to thank R.L. Kinzer and J.E. Grove for their assistance in the search for transient line features in the SMM data. A. Iadicicco assisted in our studies of γ-ray bursts. This work was funded in part by NASA DPR W17,972.

References

Briggs M.S., 1991, Observations of Galactic Positron Annihilation Radiation. Dissertation, Univ. Cal. San Diego

Harris M.J., Share G.H., Leising M.D., Kinzer R.L., Messina D.C., 1990, ApJ 362, 135

Harris M.J., Leising, M.D., Share G.H., 1991, ApJ 381, 439

Jacobson A.S., Ling J.C., Mahoney W.A., Willett J.B., 1978, In: Cline T.L., Ramaty R. (Eds.) Gamma Ray Spectroscopy in Astrophysics., NASA Tech. Mem. 79619, Greenbelt MD, p. 228

Jung G.V., 1989, ApJ 338, 972

Leising M.D., Share G.H., Chupp E.L., Forrest, D.J., Reppin C., 1988, ApJ 326, 717

Leising M.D., Share G.H.,1990, ApJ 357, 638

Ling J.C., Mahoney W.A., Wheaton W.A, Jacobson A.S., 1987, ApJ 321, L117

Ling J.C., Dermer C.D., 1991, In: Durouchoux P., Prantzos, N. (eds.) Gamma-Ray Line Astrophysics. Amer. Inst. Phys., New York, p. 361

Matz S.M., Share G.H., 1990, ApJ 362, 235

Matz S.M., Higdon J.C., Share G.H., *et al.*, 1992, $V/V_{\max}$ Test Applied to SMM Gamma-Ray Bursts. In: Ho C., Fenimore E., Epstein R., (Eds.) Gamma-Ray Bursts Cambridge Univ., Cambridge p. 249

Meegan C.A., Fishman G.J., Wilson R.B., *et al.*, 1992, Nature 355, 143

Messina D.C., Share G.H., 1992. In: Paciesas W., Fishman G., (Eds.), Gamma-Ray Burts, Am. Inst. Phys., New-York, p. 206

Riegler G.R., Ling J.C., Mahoney W.A., *et al.*, 1985, ApJ 294, L13

Share G.H., Kurfess J.D., Marlow K.W., *et al.*, 1989, Science 244, 444

Share G.H., Leising M.D., Messina D.C., Purcell W.R., 1990, ApJ 358, L45

Share G.H., Messina D.C., Iadicicco A., *et al.*, 1992, In: Ho C., Fenimore E., Epstein R, (Eds.) Gamma-Ray Bursts Cambridge Univ., Cambridge p. 249

Sunyaev R.A., *et al.*, 1992a, ApJ (in press)

Sunyaev R.A., *et al.*, 1992b, ApJ (in press)