GAMMA-RAY BURST SPECTROSCOPY CAPABILITIES OF THE BATSE/GRO EXPERIMENT

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ABSTRACT

A scintillation spectrometer is included in each of the eight BATSE/GRO detector modules, resulting in all-sky coverage for gamma-ray bursts. The scientific motivation, design and capabilities of these spectrometers for performing spectral observations over a wide range of gamma-ray energies and burst intensities are described.

1. Introduction. In the past five years it has become clear on both observational [1,2] and theoretical [3] grounds that the spectra of gamma-ray bursts are rich sources of information which is crucial to determining the nature of the burst phenomenon. The observations have revealed various spectral components, most of which must arise in separate regions. A long-lived component in the x-ray band may be the afterglow of the cooling burst plasma [4]. A gamma-ray component from tens to hundreds of keV, the classical burst emission, has an exponential form [5,6] and appears to be due to some thermal process with a temperature of ~10^9 K. Above ~500 keV a high energy gamma-ray component often extends to at least 6 MeV with an approximate power law form [7] and has been observed up to 30 MeV in one case [8]. In the 25-70 keV band unresolved absorption lines have been observed in ~30 percent of the bursts and a few emission lines have also been observed [5,6,9]. These have been interpreted as due to cyclotron processes in terragauss fields, i.e. near a neutron star. At ~400 keV, broad, marginally resolved emission lines with ~200 keV width have been observed in ~5 percent of the bursts [5,6] and are interpreted as red-shifted pair annihilation radiation. All these lines' narrow widths require a cool, $T<2x10^8$K, region for their formaton. A narrow, ~40 keV wide, emission line observed in one burst at ~740 keV is consistent with a redshifted gamma-ray from the first excited state of ^{56}Fe [10] and implies a temperature of ~ $2x10^9$K. All of the components vary on time scales

shorter than the observations' integration times, which range from 0.25 sec to 5 seconds. In general, correlations among the components' variations have not been established. However, the annihilation line appears to be correlated with intensity on a 0.25 sec time scale in one well observed burst [11].

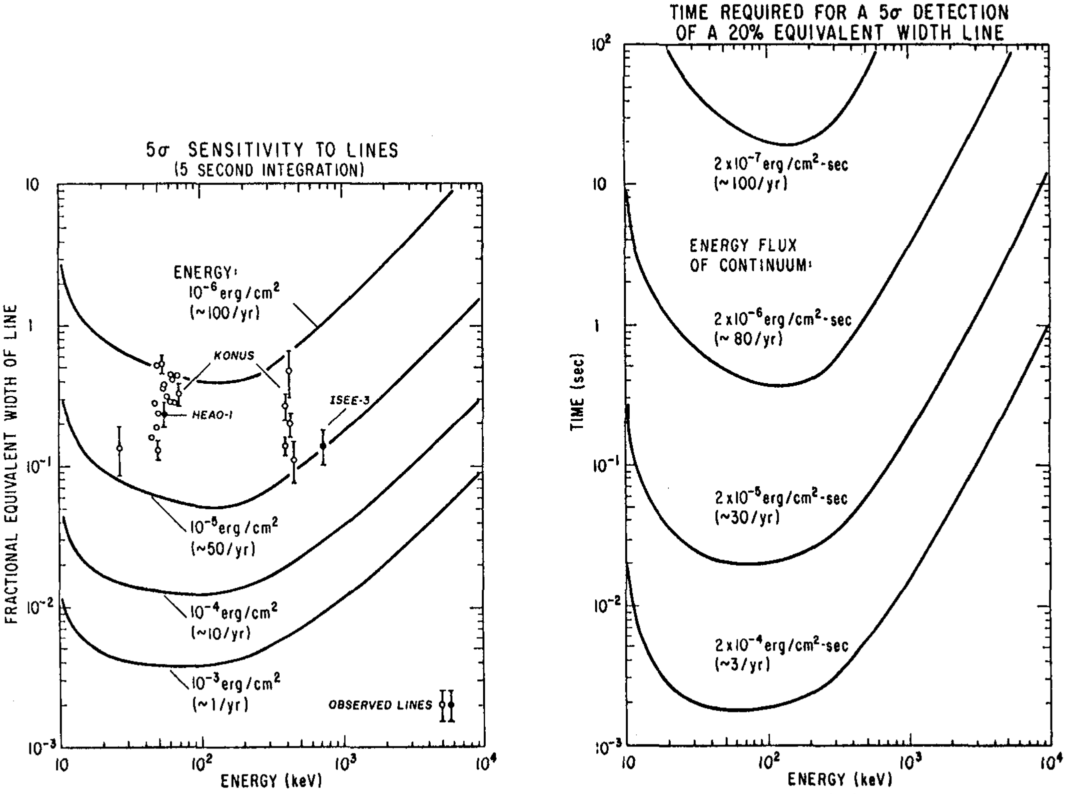
It is apparent that each region has its particular spectral signature which, in principle, can be independently followed with time-resolved spectroscopy over a broad energy band during a burst. Such observations would result in a new level of understanding of the evolution of the physical conditions of the various emission regions, their causal relationships, and their relationships to the underlying energy source of the burst. This is the primary motivation for the BATSE Spectroscopy Detectors, which are the subject of this paper. The very short cooling time scales near a neutron star, $<10^{-6}$ sec, imply that the spectral components are expected vary on the same time scale as the intensity. Thus sensitive spectral observations are required on short time scales, typically 0.1-1 sec, often as short as 10 msec and in one case, 5 March 1979, <0.2 msec.

2. Instrumentation. An overall description of the BATSE experiment is presented in an accompanying paper [12]. Each of the eight BATSE modules contains a 12.70 cm x 5.62 cm NaI(Tl) Spectroscopy Detector, which has an energy resolution of 7 percent at 662 keV and a Be window that extends its energy range down to 7 keV. (The effective area versus energy is shown in the accompanying paper.) The set of detectors has all-sky coverage and burst data are taken taken from the four detectors which most directly view a burst, resulting in an average sensitive detector area of ~ 500 cm^2. 14 keV to 10 MeV energy losses are analyzed into 2752 linear channels and then data compressed into 256 channels, preserving the detectors'energy resolution. An average event conversion cycle requires ~ $6 \mu s$, allowing a throughput of ~ 2×10^5/sec-det, which corresponds to a burst flux of ~ 2×10^{-4}erg/cm^2-sec. Discriminators at 7 keV, 20 MeV and 40 MeV provide data in the 7-14 keV, 10-20 MeV, 20-40 MeV and > 40 MeV bands. Linear operation at high counting rates is assured by 1) high current PMT bleeder strings which are zener diode regulated and 2) a gated baseline restorer in the analog electronics. It is planned to calibrate the nonlinear light output of the NaI(Tl) scintillators below 100 keV with the monochromatic x-ray beam at the Stanford Synchrotron Radiation Laboratory. Additional calibrations up to ~ 10 MeV will use radioactive sources and neutron capture gamma-rays.

The data are simultaneously stored in memories in two modes which are enabled by the BATSE burst trigger and preserve the detector IDs. In the HER (high energy resolution) mode, 192 spectra, including discriminator counts, are stored with a time resolution based on a time-to-spill algorithm that allows integrations as short as 64 msec at times of high rates and provides up to ~ 100 seconds of coverage with an average integration time of ~ 1 sec. Higher time resolution, for a subset of a burst's gamma-rays, is provided by the TTE (time-tagged events) mode, which stores 65,536 pulse heights, each time tagged to 128 μs precision. These data will provide a statistically significant spectrum measurement for each ~ 200 counts during source limited observations, e.g. each msec at a burst flux of ~ 5×10^{-5}erg/cm^2-sec. Part of the TTE memory acts as a pre-trigger buffer and will capture the leading edge of a burst that preceeds the the burst trigger.

3. <u>Background and Sensitivity</u>. Since the detectors are unshielded, their background is dominated by gamma-rays of cosmic, spacecraft and atmospheric origin. Lines at 511 keV and several other energies due to detector radioactivity will not significantly affect the sensitivity and the 511 keV line will be used for energy calibration. The background rate above 20 keV will be ~ 2000 sec^{-1}. A burst with <E> = 100 keV and a flux of $2x10^{-6}erg/cm^2$-sec would produce the same rate.

In order to estimate sensitivity, we assume a 5 second burst with the spectrum, dN/dE = 1/E exp(-E/250 keV) plus an extension above 300 keV as an E^{-2} power law. Line strengths are expressed in units of fractional equivalent width, i.e. the usual equivalent width (keV) divided by the line centroid energy (keV). Figure 1a shows the sensitivity to unresolved lines. Data from various line observations [5,9,10] are plotted. These all have large equivalent widths and much weaker lines could be detected in the more intense bursts. The time required to detect a typical, 20 percent width line is shown in Figure 1b. During the most intense flux periods it



(a) (b)

Figure 1. (a) - Sensitivity to spectral lines. (b) - Integration times required for line detection. The observations will be background limited at fluences (fluxes) below $10^{-5}erg/cm^2$ ($2x10^{-6}erg/cm^2$-sec). The anticipated observed frequency of bursts above the indicated strength is given in parenthesis.

will be possible to obtain cyclotron and annihilation line measurements with few msec time resolution, while at low fluxes, i.e. ~ 10^{-6}erg/cm^2-sec, ~ 1 sec time resolution will be possible. The search for nuclear lines in the ~ 1-10 MeV region will require longer integration times, from ~ 0.01 to 1 sec in the more intense bursts. Assuming 6 logarithmic energy channels per decade, 5σ measurements of the continuum spectrum would require half of the time indicated in Figure 1b.

4. Conclusion. The BATSE Spectroscopy Detectors have a powerful combination of energy band, sensitivity, and energy and time resolution, which represents a one to two orders of magnitude improvement over previous instruments. We can anticipate an equally large increase in our knowledge of gamma-ray bursts late in the decade when these detectors' observations become available.

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