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SOLAR RESPONSE OF THE BATSE INSTRUMENT ON THE GAMMA-RAY OBSERVATORY

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Abstract: The Burst and Transient Source Experiment (BATSE) on board the Gamma-ray Observatory (GRO) aims at comprehensive observations of time profiles, spectra, and locations of high-energy transient sources. The mysterious cosmic γ-ray bursts provided the main motivation for the observations, but BATSE will make excellent observations of many classes of sources, and in particular solar flares. This paper analyzes the solar response of BATSE, as inferred from its design parameters, for two purposes: the optimization of the solar observations themselves, and the characterization of the solar effects on ordinary non-solar observations.

1. Introduction

The Gamma-Ray Observatory, the second of NASA's "Great Observatories" after the Hubble Space Telescope, contains four major instruments for γ-ray astronomy. Each of these is much more capable than predecessors in its category. The delay of the GRO launching caused by the Challenger accident has moved its observation period squarely into the maximum phase of solar flare activity: the presently-scheduled launch date of March, 1990, is approximately a year before the expected peak of flare activity. Understanding the solar response of these instruments is therefore important not only scientifically but also from the point of view of non-solar observations, since the sun frequently becomes an extremely bright "nuisance" source of hard radiations under these conditions.

These notes describe the BATSE experiment in particular, beginning with a heliocentric view of its design, followed by comments on the detector responses to model solar input spectra, and concluding with an assessment of the operating modes of the instrument electronics. For the solar community and for the GRO experimenters, it would be desirable for the other GRO instruments to be subject to solar analyses of this type in preparation for launch.

2. BATSE: Description from a Solar Point of View

2.1 Detectors

The BATSE instrument consists of eight pairs of detectors, each pair oriented along the outward normal to one face of a regular octahedron. This approximates an isotropic coverage of the sky and also allows approximate determination of the origin on the sky of a given high-energy transient via detector response ratios. The main detector of each pair is a NaI(Tl) scintillation counter (50.8 cm diameter $\times$ 1.27 cm thick); the primary purpose of this detector is to provide high counting rates for time-profile measurements and burst locations. These large-area detectors have rather poor energy resolution, about 30% (FWHM) at 100 keV. The second detector of each pair is also a NaI(Tl) detector (12.7 cm diameter $\times$ 7.62 cm thick), but optimized for γ-ray and hard X-ray spectroscopy in a wide energy band (ranging from 7 keV to $>$ 50 MeV, and with energy resolution of 7% (FWHM) at 662 keV.

Both types of detector offer significant capabilities for solar observation. Of course the source-location capability is of little interest, since the precision will probably not be good enough to contribute to physical interpretations of solar sources. However the large area ($\sim$ 5730 cm^2) and fast electronics (up to 200,000 cps without spectral distortion) make the large-area detectors attractive for the detection of weak bursts or of fine time structure in strong bursts. The great sensitivity of the large-area detectors places their dynamic range of effective response in a domain unaccustomed to attention by solar physicists. This is both a strength and a weakness for solar observations, since there is a tendency in flare research to study preferentially the most dramatic and spectacular "big flare" events.

The spectroscopy detectors are probably of more intrinsic interest for solar physicists, offering a new and powerful look at the rich physics mostly defined now by the γ-ray observations of the Solar Maximum Mission (1980—present). These observations (e.g. Chupp, 1984) showed powerful acceleration of energetic (few MeV) ions to occur commonly in flares, rather than in a rare sub-class of "proton flares." Given the ubiquity of this particle acceleration, the γ-ray emission lines – chiefly prompt inelastic-scattering lines – have many diagnostic uses, not least of which is the energetics of solar flares, which appears to be dominated by the acceleration of energetic particles.

2.2 Electronics

The BATSE digital electronics unit possesses a great deal of flexibility in its operating modes, in order to maximize the return of information about the different high-energy sources in the face of on-board memory and telemetry limitations. The design of this electronics and its software has many implications for the utility of the solar data that will be returned by the BATSE instrument. Many performance features can also be altered during the mission with new software, if desirable.

The GRO telemetry is packetized, with an individual instrument such as BATSE creating and labeling its own packet types for entry into the telemetry. One BATSE packet contains 455 16-bit words, and a new packet is transmitted every 2.048 seconds. Each packet contains some routine scientific data independent of the current observational mode, plus the specialized data corresponding to that particular mode; these routine data generally consist of integral counting rates with relatively low spectral and temporal resolution. For solar purposes, of course, such routine data will mainly be useful as a means of defining the statistics of burst occurrence under well-determined conditions, and as basic synoptic support data for simultaneous observations carried out by other observatories. Each different observing mode produces a different packet type, optimized for one or another specialized observation. Section 4 below discusses some of the mode structure as relevant to the purposes of solar observing.

2.3 Routine Data

The routine science data in each packet contains the following items of interest:

- Discriminator rates for each of the eight large-area detectors at time resolution of 1.024 sec:

Channel 1	25 keV <	E	< 50 keV (adjustable)
Channel 2	50 keV <	E	<100 keV
Channel 3	100 keV <	E	<300 keV
Channel 4		E	>300 keV

- Discriminator rates for each of the eight spectroscopy detectors, at a time resolution of 2.048 sec:

Channel 1	E > 7 keV
Channel 2	E > 14 keV (adjustable)
Channel 3	E > 25 MeV
Channel 4	E > 50 MeV

- Continuous data from each of the eight large-area detectors, at 16-channel energy resolution and 2.048-second time resolution. The sixteen channels are narrow at low energies and broad at high energies, adequately resolving the detector resolution below 100 keV.

The spectroscopy detectors cover large spectral ranges, and to optimize their coverages the plan is to have different units operating at different gain settings. Four will run at the nominal gain setting described in the User's Manual and shown above; two will run at reduced (0.4×) gain; and two at expanded (4×) gain. For the spectroscopy detectors, channel 1 is also adjustable in the sense that it is always a factor of two lower than channel 2.

These routine data may not appear to hold very much interest for solar physics, given the long history of simple photometric hard X-ray and γ-ray observations (e.g. Dennis, 1986), but in fact their continuity and large dynamic range should make them useful in statistical studies. Note that some of the eight detectors will be shadowed from solar radiation by the body of the spacecraft and other instruments; this suggests that we can observe more intense flares with those detectors facing away from the Sun, for which the bulk of the spacecraft will reduce the powerful low-energy radiation. The projected area of the large-area detectors is $\sim$5730 cm^2, far exceeding that of any previous solar experiment, so that BATSE will make significant observations of "microflares" (Lin et al., 1981).

The spectroscopy detectors exceed in total photopeak efficiency the γ-ray spectrometer experiment on board the **Solar Maximum Mission** (e.g. Chupp, 1984), so that routine data may also be interesting from the statistical point of view and for "microflare" observations. Unfortunately, the BATSE routine data do *not* give much emphasis to the spectroscopy detectors, which were added to BATSE relatively late in the program.

3. Detector Responses to Solar Input

Solar fluxes of γ-rays, hard X-rays, and especially soft X-rays can be enormous by comparison with the fluxes from cosmic sources (e.g. Seyfert galaxies). Furthermore these solar fluxes are extremely time-variable, leading to the classical problem of solar high-energy photometry in obtaining sufficient dynamic range. The solar high-energy spectrum is relatively well understood, however, with some uncertainty in detail regarding the "superhot" spectrum in the 20–40 keV range, so that the BATSE detector response should be amenable to numerical modeling. We have developed a model of the spectroscopy detector and its entrance-window geometry, as shown in Figure 1, suitable for Monte Carlo calculations of response. These calculations need to be made in enough generality so that the dynamic range can be understood precisely; then we will be able to optimize trigger and data modes for either solar or non-solar observational objectives. One should note that complete generality in these calculations will require including the Earth and the spacecraft mass-distribution model as well as the simple detector model.

4. BATSE Observing Modes

4.1. General Overview

The BATSE electronics provide a powerful variety of different observing modes, to be used for different properties of bursts; pulsar observations are also possible via on-board phasing of data. These observational modes fill the remainder of each of the data packets (after housekeeping and routine science data have been accommodated) at 128 16-bit words per packet. The choice of packet type and the readout schedule of packets depends upon what observations are desired. Table 1 (From Table 2.3-2 of the User's Manual) lists some of the individual packet types.

The on-board burst memories offer still more flexibility in BATSE data transmission. For burst observations a burst-recognition trigger logic allows a portion of memory to be filled according to the requirements of the observing mode and its parameters. Because the sun is bursty, the triggered data will be most important for solar purposes,[1] and we must pay proper attention to the trigger criteria. One should note that the solar flare trigger in BATSE consists of a set of restrictions on a set of data that have already satisfied the basic burst trigger. This implies that obtaining solar burst observations will require the generation of burst-memory-overwrite criteria and/or shortened "solar" burst-memory readout modes; otherwise the primary burst trigger criteria are likely to be defined in such a way as to minimize the number of solar triggers – given that GRO will fly during solar maximum!

Table 1. BATSE Data Types

Mnemonic	Number in Sequence	Description
PSRx		Pulsar modes, not applicable
HER	8	Large-area detector
SHER	16	Spectroscopy HER
DHER	24	Both detector sets HER
DISC	1	Selected detector rates
PREB	8	Preburst buffer readout
HERB	128	Large-area HER burst
TTE	128	Time-tagged event data
TTS	128	Time-to-spill
MER	32	Medium resolution data
SHERB	128	HERB for spectroscopy
STTE	128	TTE for spectroscopy

The three sections of Table 1 contain pulsar packets (PSRx), high-energy-resolution packets (xHER), and burst packets. The priority scheduling of packet transmission can be chosen by program, typically to have packets with burst data (up to about five minutes' worth) interleaved with packets of other types. The burst memory can be read out in one GRO orbit (about 96 minutes period). The time binning and energy resolution of the data differ from packet type to type. Further description of individual types follows:

[1]BATSE also generates a solar trigger to alert the other experiments on board GRO.

- HER data for the large-area detectors consist of 128-channel spectra for each detector, one per packet. Spectroscopy detectors (SHER) have 256-channel resolution and therefore need 16 packets. DHER packets have both types of detector. If nothing else were being transmitted, therefore, DHER packets would provide high resolution at 24×2.048 sec = 49 sec time resolution. Either SHER or DHER would provide excellent solar γ-ray observations, albeit with rather coarse time resolution, if these packet types dominated the telemetry allocation.

- DISC data follow the large-area detector rates in the four most brightly illuminated detectors that trigger the burst mode, in four energy channels at 64 msec resolution. For solar purposes, DISC packets can provide high-time-resolution data for intercomparison with radio or other observations.

- Time-tagged event data (TTE for large-area, STTE for spectroscopy detectors) consist of memory data in four channels for large-area, or 16 bits per photon for spectroscopy. For the spectroscopy detectors the energy resolution is 128 channels; for both types of detector the (short-term) time resolution is 2 μsec. These data are stored in memories with capacities of 32,000 words for large-area, and 64,000 words for spectroscopy. Nominally the burst trigger will happen as time-tagged events are being stored in a ring-buffer arrangement in these memory boards, so that some of the first quarter of the memory will have pre-burst data; the remaining 3/4 will follow the trigger time and proceed until the capacity is used up. There is flexibility in the choice of detectors from which to store events.

- Time-to-spill data (TTS) applies to large-area data only, and is a mechanism for obtaining high time resolution in four-channel spectra by measuring the time intervals needed to obtain a specified number of counts.

- Medium-energy-resolution (MER) data are 16-channel spectra from the large-area detectors selected at a burst trigger.

- High-resolution burst data from spectroscopy detectors are in SHERB packets, a sequence of 128 giving 64 spectra from one of three memory units as filled by the four brightest detectors at burst trigger. Spectra are accumulated in multiples of 64 msec, determined by an on-board program, with the possibility of increasing the integration time as the burst proceeds.

4.2 Solar Possibilities

Many of the data types listed above have some possible utility for solar observations, although it is clear that some would be preferred over others. Probably the most important direct solar scientific contributions from BATSE (i.e., not considering for the moment the important supporting role that BATSE high-energy monitoring will perform) will come from the spectroscopy detectors, which will add greatly to our knowledge of γ-ray lines and continuum. To obtain high time resolution in these observations, burst data storage in memory mode will be necessary. This means SHERB or STTE data types.

The choice of observing mode and its parameters will be subject to a great deal of pressure as the BATSE experimenters optimize the primary science programs of the experiment. It is likely that the great flexibility of the BATSE data system will allow a considerable amount of experimentation before optimal modes can be found. Because solar flares will occur so frequently during the GRO mission, they may in fact provide a good basis for program optimization.

5. Conclusions and Recommendations

- The BATSE investigators should carry out a thorough modeling effort to understand the detector responses to solar inputs.
- There should be solar participation in discussions of spacecraft mass distribution and simulated response, including atmospheric albedo effects.
- It may be appropriate to recommend a minimal use of the instrument flexibility at the beginning of the GRO observations – several months of data under the same observing conditions would be conducive to good statistics.
- We should consider the possibility of using the solar trigger to enable a BATSE mode selection for solar data. Could this be done in a low-priority configuration, so that a stored solar burst could be overwritten?

- There should be a solar working group, possibly with help from guest investigators, to assess the data starting at time of launch. This group should form earlier than launch, if possible, so that it can get sufficiently along on the learning curve to be useful.

- The possibility of solar "campaigns" over restricted time periods (e.g. VLA availability) for coordinated observations should be explored.

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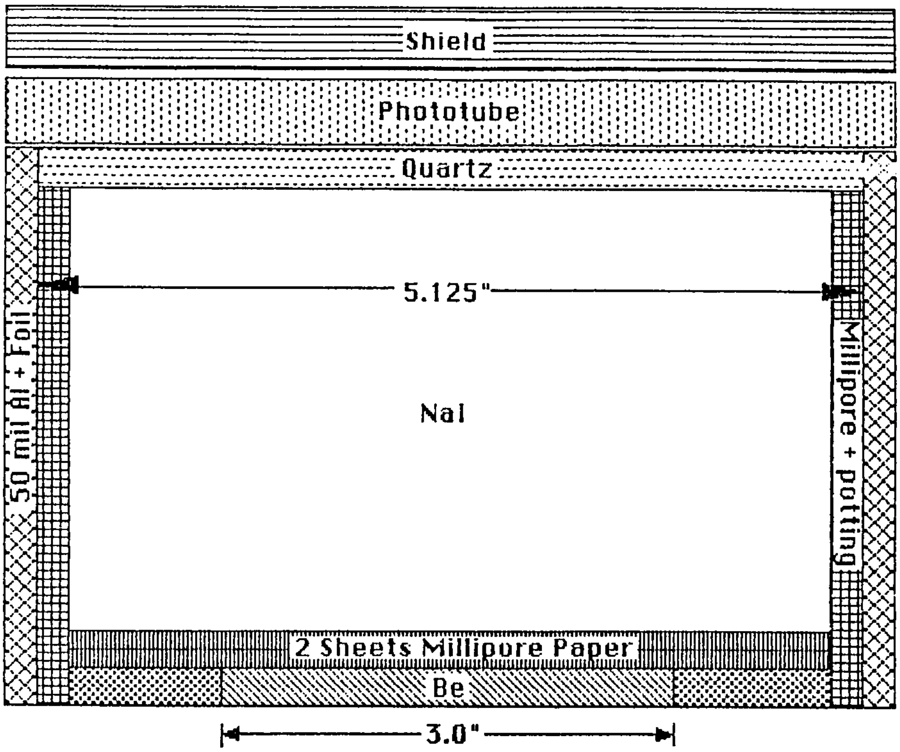

Figure 1. Model for Monte Carlo simulation of the BATSE spectroscopy detector, showing some of the materials and geometry. Flux may be incident from any direction, since the BATSE experiment contains eight of these modules oriented in the directions normal to the faces of a regular octahedron. The nominal view direction is downwards on this sketch.