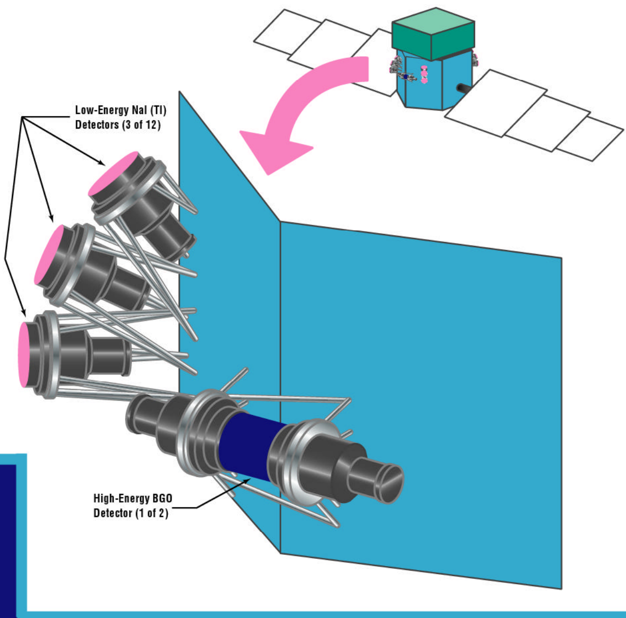

GLAST Burst Monitor

A Proposal to NASA for a Burst Monitor (GBM) for the GLAST Mission

Volume I.
Science Investigation and Technical Description

Version 2
March 20, 2000

Submitted by
Space Science Department
Science Directorate
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Note—No substantial content modifications were made to this 2nd version. Minor typographical changes were made as needed.

Executive Summary

We propose to provide a Burst Monitor for the Gamma-Ray Large Area Space Telescope (GLAST) that will, in conjunction with the Large Area Telescope (LAT), produce ground-breaking spectral observations of gamma-ray bursts (GRB's). The unique capabilities we propose may lead to breakthroughs in our understanding of the central engines and emission mechanisms of gamma-ray bursts, which remain one of the most exciting and baffling areas of astronomical research today. The importance of studying bursts with GLAST has been recognized by the GLAST Science Working Group, which has specifically called for a burst monitor as a secondary instrument.

The purposes of this monitor, as spelled out in the GLAST science requirements document, are: 1) To provide lower energy context measurements of the light curve and spectrum of bursts and, 2) to provide positions for bursts over a wide field of view (FOV) to a few degrees of accuracy that will allow repointing of the main instrument. The spectral requirement is crucial, since bursts emit most of their energy below the GLAST threshold.

Our scientific investigation follows directly from the GLAST science requirements. We propose to study the gamma-ray emission mechanisms of bursts by examining the relation between the high-energy and low-energy components of the gamma radiation. This study will require time resolved spectroscopy over a wide energy range. Since the prompt gamma radiation provides information closest to the central engine, this study may provide a breakthrough in our understanding of burst progenitors. As a service to the main instrument, we will also provide approximate burst locations over a wide FOV, which may be used to repoint the spacecraft and to improve the sensitivity of the LAT for detection of bursts within its FOV. We will produce a catalog of triggered bursts containing similar information as in the Burst and Transient Source Experiment (BATSE) catalog, such as location, duration, flux, and fluence, as well as spectral properties. We will also perform a search for untriggered bursts.

Due to severe constraints on resources for any GLAST secondary instrument, we have narrowed our focus to those specific goals that will augment the science return from the GLAST main instrument. These goals require that the Burst Monitor have a broad spectral range and a wide FOV. Specifically, we do not intend to duplicate the goals of the High Energy Transient Explorer (HETE) and SWIFT, which will, in the GLAST timeframe, have identified numerous burst counterparts through precise burst locations. The GLAST main instrument itself will also add to this fund of knowledge by locating a significant number of bursts to ~10 arcmin accuracy. Consequently, we have concluded that providing precise burst locations with the Burst Monitor is not cost effective in meeting the GLAST objectives. Instead, we provide a capability that is unique to GLAST, broad-band time-resolved spectroscopy from about 5 keV up to the highest energies accessible to the LAT.

To achieve these goals, our Burst Monitor incorporates sodium iodide (NaI) scintillation detectors to cover the energy range from 5 keV to 1 MeV, and bismuth germanate (BGO) scintillation detectors to cover the energy range from 150 keV to 30 MeV, providing good overlap with the main telescope. Thus the GLAST observatory, with our Burst Monitor as a secondary instrument, will provide time-resolved burst spectra covering an unprecedented 6 decades of energy (~5 keV to >5 GeV) with no gaps. Figure 1 shows a simulation of the count rates expected from a strong burst for the LAT, BGO, and NaI detectors. This figure demonstrates the synergy of the three types of detectors, enabling us to determine burst spectra over such a large energy range with high accuracy.

We generate burst locations in three steps of increasing accuracy, using the relative count rates in differently oriented thin detectors, a technique proven BATSE. Our instrument has 12 thin NaI detectors oriented to provide good angular coverage. For purposes of repointing the spacecraft to observe delayed emission locations to 15˚ of accuracy will be computed on board in real time. Note that the requirement to provide locations for repointing, as clearly stated in the Announcement

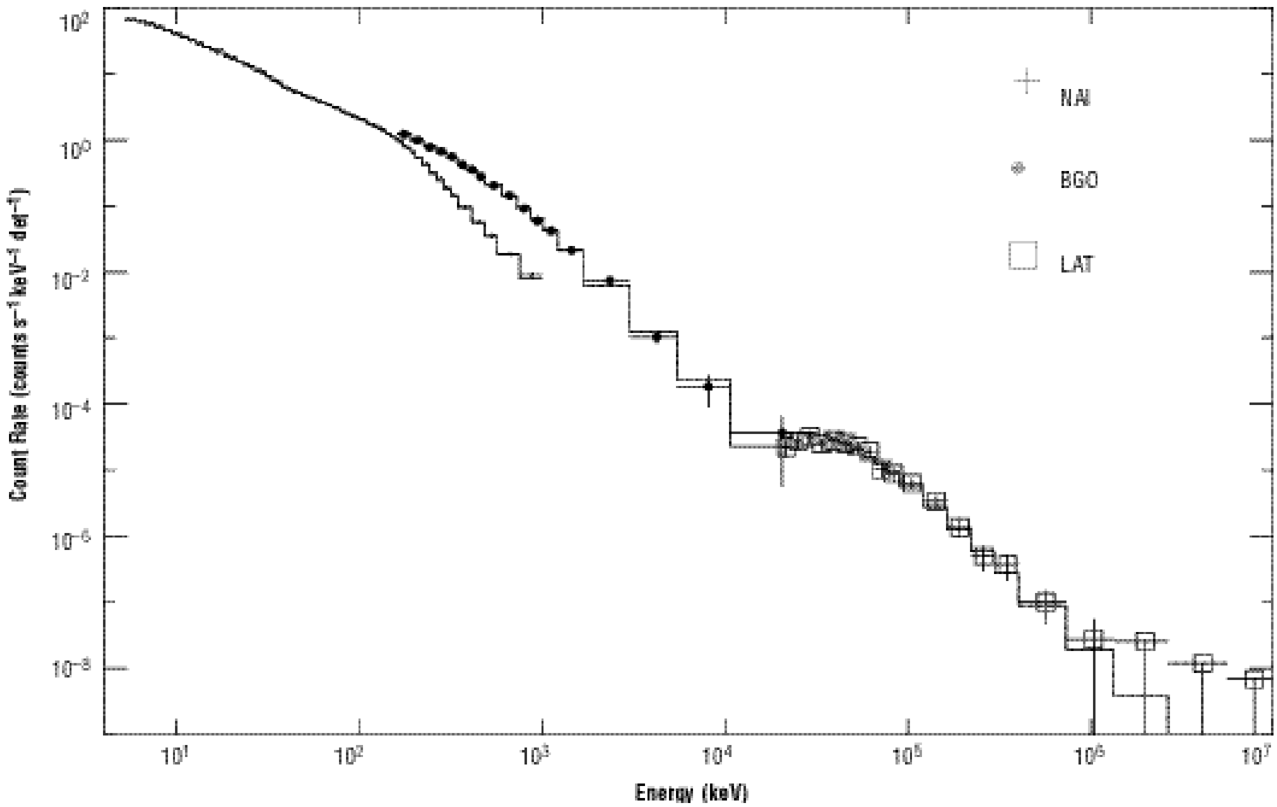


Figure 1.—Simulated GBM and LAT Gamma-Ray Burst Spectrum.
The simulation is for a burst like GRB 940217. The simulated count rate data (points) and the best-fit count rate models (histograms) are shown for a GBM NaI and a GBM BGO detector, and for a baseline LAT.

of Opportunity (AO), cannot be satisfied by an instrument with a FOV smaller than the LAT, which is expected to be 2 to 3 sr. Our Burst Monitor has an effective FOV of over 8 sr, significantly exceeding the requirements. For purposes of coordinated ground observations, we immediately transmit sufficient data to compute more accurate locations automatically on the ground within a few seconds of a burst, as is currently done by the Gamma-ray Coordinates Network (GCN) (Barthelmy, et al. 1997). The best and final locations, with systematic error less than 2˚, are produced manually within a day or two of the burst.

Our hardware interface with the spacecraft is simple and flexible. We have 12 NaI detectors and 2 BGO detectors placed within the area between the LAT footprint and the shroud envelope on two sides of the spacecraft so as not to interfere with the LAT FOV or the solar array. The detectors can be mounted in banks or individually; only the orientation of the NaI detectors is important.

A data processing unit (DPU) digitizes and formats the detector outputs. The DPU uses field programmable gate arrays (FPGA's), under software control, to accumulate spectra with adjustable time and energy resolution, and a central processing unit (CPU) for instrument control functions and for computing real-time burst locations.

Our science team has extensive experience in the field of gamma-ray astronomy, burst observations, and detector development. The team members at Marshall Space Flight Center (MSFC) and the University of Alabama in Huntsville (UAH) have extensive experience with BATSE, which the NaI detectors and the burst detection and location techniques are modeled. Team members from the Max Planck Institute for Extraterrestrial Physics

(MPE) produced BGO detectors for the Integral mission and developed the Compton Telescope (COMPTEL) instrument on the Compton Gamma-Ray Observatory (CGRO).

An important aspect of our proposal is the major hardware contribution by MPE, allowing us to meet the stringent cost cap. All of the detectors and the low-voltage and high-voltage power supplies will be provided by MPE at no cost to NASA. MSFC will provide the DPU, software development, management oversight, engineering support, and testing.

Ground operations are simple and undemanding. Commanding will consist only of occasional instrument adjustments. Spectra, time histories, and refined locations will be generated for all triggered bursts. All data products are delivered to the Science Operations Center (SOC) within 6 weeks of receipt, and a web-based burst catalog is updated at least weekly.

Educational and societal opportunities

Gamma-ray bursts, the most powerful explosions in the universe, have great appeal to the public and therefore provide an excellent tool for public outreach. We will collaborate with the LAT team to produce an exciting and informative integrated EPO program on gamma-ray bursts.

Management Plan

The Burst Monitor will be managed by MSFC using NPG 1720.5A. An experienced program manager, Mr. Steven Elrod, has been assigned. Overall responsibility for the program rests with the PI, Dr. Charles Meegan. The effort at MPE will be directed by Giselher Lichti as Co-PI. The Burst Monitor is a small program with straightforward interfaces between MSFC and MPE, and between the instrument and the spacecraft.

Cost Plan

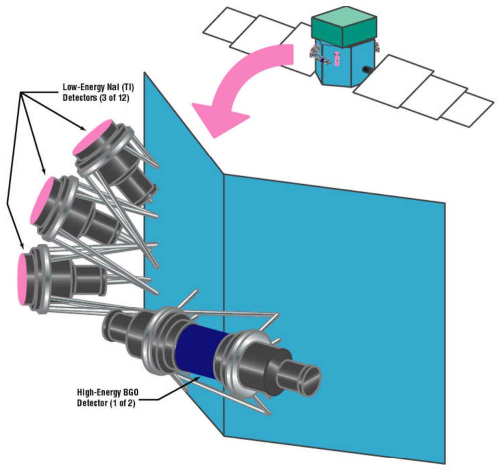
A major hardware contribution from MPE allows us to meet the stringent cost cap for secondary instruments. We have adopted a design-to-cost approach to control costs in the development phase. We have a viable descope option in reducing the number of NaI detectors.

In summary, our Burst Monitor is ideally suited to the purposes of GLAST for the following reasons:

- Our instrument will greatly enhance the scientific capabilities of the mission for GRB's.
- We meet the nominal sensitivity performance with a 5σ detection threshold of 0.35 photons cm^{-2} s^{-1} and an on-board trigger threshold of <0.57 photons cm^{-2} s^{-1}.
- In combination with the LAT, we provide unprecedented spectral coverage—over 6 decades of energy with no gaps.
- We provide burst locations in real time using proven techniques.
- We obtain burst locations over at least 8 sr, well above the requirement.
- MPE will provide a large hardware contribution, significantly reducing costs.
- All technology is proven and low risk.
- Our team members have extensive relevant experience.
- There will be no intrusion on the FOV of the main instrument.
- Mounting requirements are simple and allow flexibility in placement.

GLAST Burst Monitor

Fact Sheet



Science Objective:

Discovering the sources of gamma-ray bursts is an important objective of NASA's Office Space Science and is prominently featured in the list of GLAST Scientific Objectives. The scientific objective of the Burst Monitor is to augment the GLAST LAT scientific return of GRB's by extending the energy range of burst spectra down to ~5 keV, and provide real time burst locations over a wide FOV with sufficient accuracy to repoint the GLAST spacecraft. With the Burst Monitor included as a secondary instrument on GLAST, spectra of many bursts will cover an unprecedented 6 decades of energy with no gaps. Time resolved spectroscopy over such a large energy range will be crucial in advancing our understanding of the mechanisms by which gamma-rays are generated in GRB's. Determining real time locations for bursts can significantly increase the number of bursts detected by GLAST in two ways: 1) If the burst is outside the LAT FOV, the spacecraft can be reoriented, allowing observation of delayed high-energy emission and, 2) if the burst is within the LAT FOV, but weak, the location provided by the Burst Monitor may be used to enhance the statistical significance in the LAT.

Data Provided:

The Burst Monitor will provide the data necessary to satisfy the scientific objectives of time resolved spectroscopy and burst locations. The following data will be provided:

- Spectra in 128 channels every 8 s in each of 14 detectors,
- Spectra in 4 channels every 0.256 s in each of 14 detectors,
- For bursts, a total of one million time-tagged events,
- Real-time on-board estimates of burst locations and spectra,
- Rapid telemetry to allow automated ground calculations of burst locations,
- Flight software parameters (trigger thresholds, digital HV settings, etc.),
- Housekeeping data (voltages, currents, temperatures, etc.).

Contributed Resources:

Most of the Burst Monitor hardware will be provided at no cost to NASA. MPE will provide all of the detectors, the HVPS, and the low voltage power supply (LVPS).

Heritage and Experience:

The GLAST Burst Monitor benefits significantly from our experience with BATSE. The detector technology, on-board data system, on-board algorithms, data products and data analysis algorithms are very similar in these two experiments. We have experience in the development of BGO detectors on Integral.

Key Technical Characteristics:

Sensitivity (untriggered bursts, 5σ):	~0.35 photons cm^{-2} s^{-1}
Burst Trigger Threshold:	<0.57 photons cm^{-2} s^{-1}
Effective FOV (as defined in AO):	8.6 steradians
Angular resolution	
Systematic On-board	<~15°
Systematic Automated On-ground	<~3°
Systematic Final On-ground	<~1.5°
Statisical (10 photons cm^{-2} s^{-1} burst	<~1.5°
Mass:	54.5 kg with 20% contingency on unknown items
Power:	7.8 W
Telemetry rate:	4 kbps (nonburst mode), 9 kbps (burst mode)

GLAST Burst Monitor

Fact Sheet

Science Team:

The Burst Monitor science team has extensive experience in astrophysical applications of scintillation detectors, in the design and implementation of space-qualified instrumentation, in the analysis and interpretation of gamma-ray data, and in observational and theoretical studies of gamma-ray bursts.

Team members are:

Principal Investigator:
Dr. Charles Meegan, MSFC
Co-Principal Investigator:
Dr. Giselher Lichti, MPE
Co-Investigators:
Dr. Michael Briggs, UAH
Dr. Roland Diehl, MPE
Dr. Gerald Fishman, MSFC
Dr. Robert Georgii, MPE
Dr. Andreas von Kienlin, MPE
Dr. Marc Kippen, UAH
Dr. Robert Mallozzi, UAH
Dr. William Paciesas, UAH
Dr. Robert Preece, UAH
Dr. Prof. Volker Schönfelder, MPE

Science Payload:

The Burst Monitor includes 12 NaI scintillation detectors and 2 BGO scintillation detectors. The NaI detectors are 1.27 cm thick by 12.7 cm diameter, directly coupled to a 12.7 cm diameter photomultiplier tube (PMT). The purpose of the NaI detectors is to provide a burst trigger, to obtain burst spectra from ~5 keV to ~1 MeV, and to provide rates for computing the location. Each BGO detector is 12.7 cm in diameter, 12.7 cm thick, and is viewed by two PMT's for improved resolution and redundancy. The purpose of the BGO detectors is to provide spectral information from ~150 keV to ~30 MeV, thereby providing complete spectral coverage that overlaps both the NaI detectors and the LAT.

Management:

GBM is a collaboration among scientists at Marshall Space Flight Center (MSFC), the University of Alabama, Huntsville (UAH), and the Max Planck Institute for Extraterrestrial Physics (MPE) in Garching, Germany. The PI and Project Manager are at MSFC. A co-PI at MPE directs the effort of the team members there. The experiment will be managed as a small project according to guidelines in NPG 7120.5A.

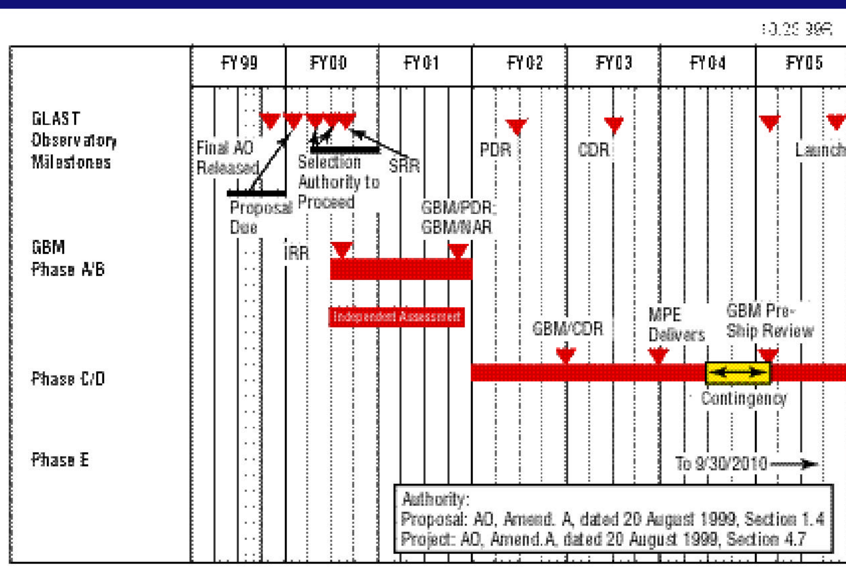
Cost:

The large hardware contribution from MPE allows the Burst Monitor to remain under the stringent cost cap for secondary instruments. Costs are provided in the table:

	Cost through phase D	Cost through phase E
NASA	$4,975,200	$6,064,900
MPE/DRL Contribution	$3,865,191	$4,134,950
Total	$8,840,391	$10,199,850

Schedule:

Since no new technology must be developed for GBM, the schedule is easily accommodated to the Observatory schedule. Generous schedule contingency is available before shipping to the spacecraft contractor.



1.0 Science Goals and Objectives

1.1 Introduction

1.1.1 Importance of Gamma-Ray Bursts

Cosmic GRB's are intense flashes of gamma rays that last from milliseconds to hundreds of seconds and have a great diversity of temporal morphologies. They come at random times, from random directions, briefly dominating the sky and then fading without a trace in the gamma-ray energy band. The origin of these bursts is one of astronomy's greatest mysteries. With the discovery that they arise from sources at cosmological distances, GRB's are known to be the most powerful explosions in the universe, each releasing the equivalent energy of several solar masses, as gamma rays, during their brief lifetime. Since the universe is transparent to gamma radiation, sources of this type could potentially be very distant, and thus very old, possibly describing conditions in the early universe. Currently, popular models for burst progenitors include merging binary neutron stars, accretion-induced collapse of a single compact object to a black hole, or magnetically powered supernovae (called 'hypernovae').

One of the main missions of NASA's Space Science Strategic Enterprise is to advance and communicate scientific knowledge and understanding of the mysteries of universe. The GRB puzzle is one of a few challenges to astronomers that has also caught the public's interest. This interest presents an opportunity for effective education and public outreach, an integral part of NASA's research and missions.

1.1.2 Gamma-Ray Burst Observations

1.1.2.1 Establishing the Distance Scale

GRB's were discovered serendipitously and were quickly determined to be cosmic sources of extremely energetic radiation, unrelated to our local solar neighborhood. The discovery of GRB's came late in the 1960's, with the launch of several defense-related satellites with gamma-ray detection capability, part of a program called Vela that monitored Russian compliance with the recently signed nuclear test ban treaty in space. At that time, theoretical work suggested that gamma rays should be observable from supernovae. An archival search of the collected data turned up no correlation between outbursts of gamma rays and observed supernovae; however, bursts of gamma rays, occurring at random times, were observed. Analysis to determine timing differences between detections, from several separate satellites in Earth orbit, quickly ruled out the Sun as the source. Thus, a new cosmic phenomenon was discovered. With time, the baseline between observing satellites was extended to planetary distances, around Venus and several missions to Mars, by the Pioneer Venus Orbiter (PVO) and the Russian Venera probes. This first interplanetary network (IPN) was able to firmly push back the closest distance to the newly named gamma-ray bursts to well beyond the solar neighborhood by determining the maximum allowed curvature, assuming a spherical wavefront, impinging on all spacecraft. More importantly, by triangulation, the IPN was able to narrow the possible locations for the elusive sources of GRB's to small, arcmin square error boxes on the sky. When examined, sometimes years after the fact, no special type of astrophysical object was revealed as common to all locations.

The lack of an observable counterpart was vexing for several reasons. Of most importance was the intrinsic efficiency of gamma radiation emitted by strongly magnetized galactic neutron stars, which emerged as a popular model. This model made several testable predictions. Although the detected bursts appeared isotropic and homogenous, the proposed source population of neutron stars should map out the galactic disk on the sky. Following the development of very sensitive instruments, it was expected that the newly detected dim bursts would be anisotropic, indicating an absence of sources beyond the galactic plane.

This set the stage for BATSE on board CGRO. BATSE's principal scientific goals were the localization of large numbers of events on the sky and increased sensitivity, by roughly a factor of 10, over any existing detector. Localization was done with a set of eight matched detectors, pointed in eight

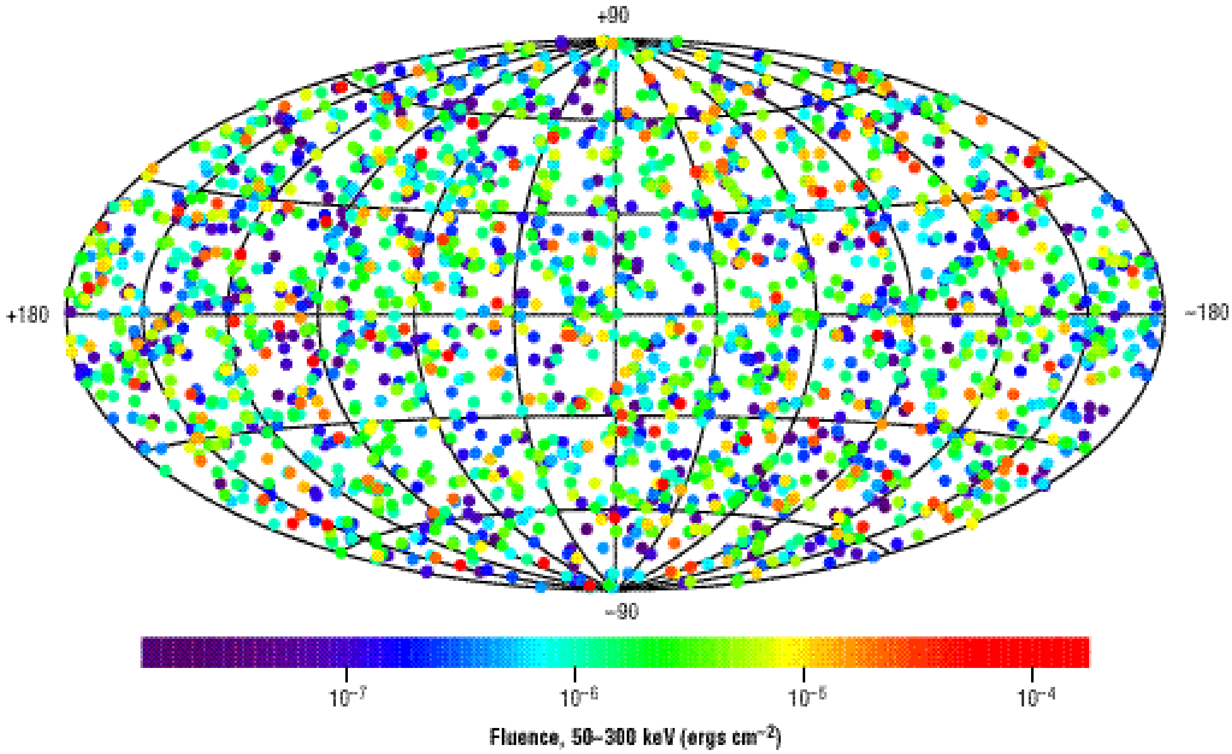


Figure 2.—Locations and fluences of 2,013 GRB's observed with BATSE over 8.5 years. The locations are consistent with isotropy. In the context of a local galactic model, this can be explained only if faint sources (violet and blue) dominate the intensity distribution. Instead, there is a relative deficiency of faint sources, implying that GRB's are simultaneously isotropic and inhomogenous. The local distance scale is excluded and a cosmological distance scale is indicated.

different directions, as defined by a regular octahedron. Each detector was constructed as a flat plate of scintillating material to maximize differences in response with different angles between the source and the detectors. In addition, the detectors were large in area to maximize their sensitivity to the weakest events. CGRO, launched in April 1991, introduced an entirely new era in GRB observations. After the first year of observations, two things were very clear: 1) GRB's were isotropic on the sky, independent of their brightness, in stark contrast with expectation, and 2) their relative numbers decreased with intensity in a way that indicated inhomogeneity, as was expected (see figure 2). Both observations, taken together, did not correspond with known populations of galactic sources of any kind, strongly suggesting that the sources should be associated with distant galaxies, and that GRB's were truly cosmological objects with tremendous intrinsic brightness. Despite several challenges, these observations are even more firmly established today, after 8 1/2 years of in-orbit operations by BATSE.

1.1.2.2 Temporal Properties of Bursts

In general, bursts consist of one or more episodes of emission, each of which may be smooth or irregular, joined or distinct, all of differing intensities. That is to say, no two burst light curves are alike. Several examples of bursts, observed by BATSE, can be seen in figure 3. The time history of GRB 910522, in figure 3 begins with a small pulse followed by over 100 s of inactivity, before resuming with a complex series of pulses that includes the peak of emission. If the later complex were to have been blocked from view by the Earth, the first pulse would be quite acceptable as a separate, complete burst. Smooth, single-pulse bursts, such as GRB 990206 in figure 3, may seem to be an easily-identifiable separate class until each is examined closely, revealing differences in duration, intensity, and residual fluctuations. Only the total duration has

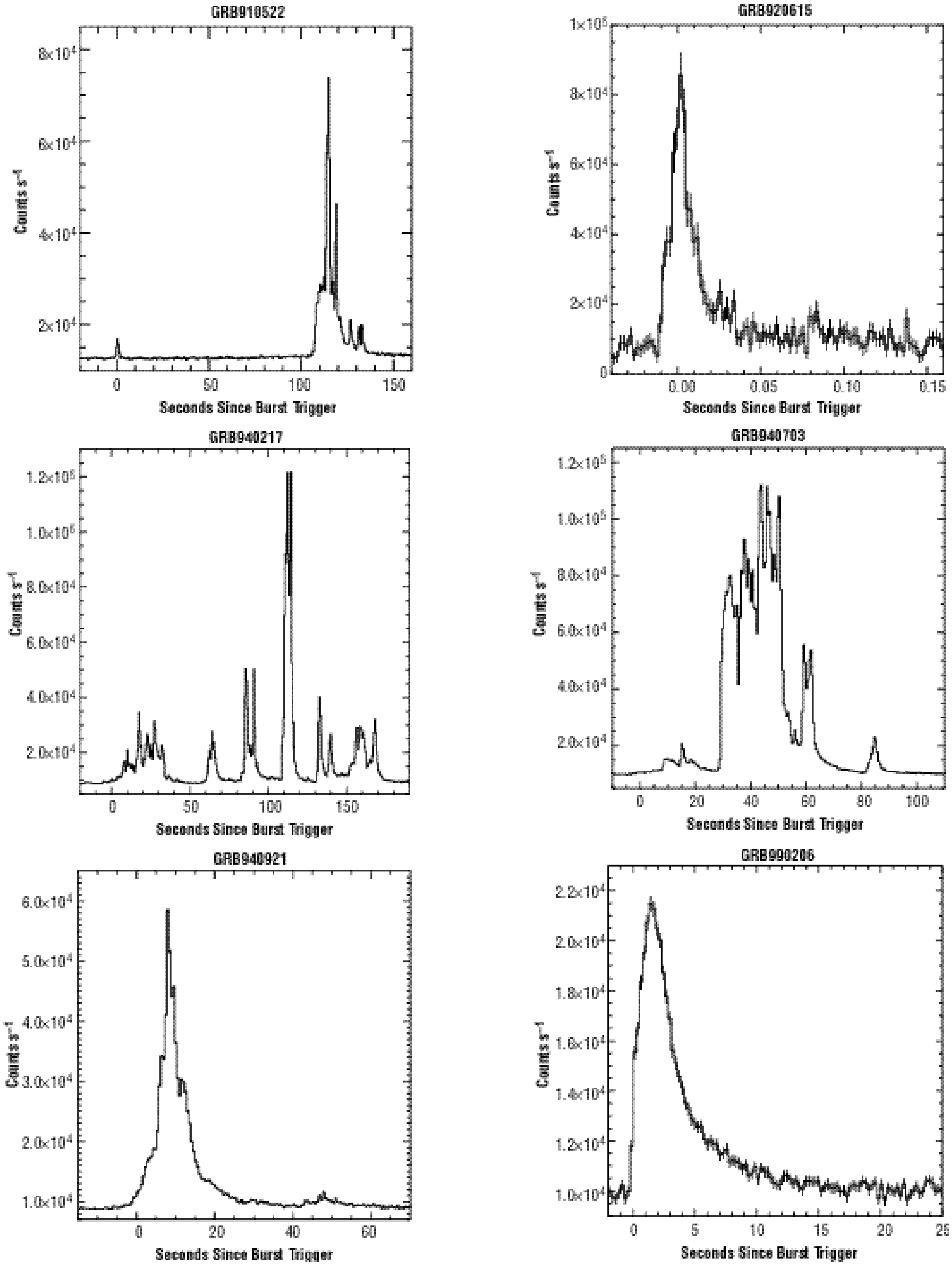


Figure 3.—Time histories of six GRB’s. The morphologies are very diverse.

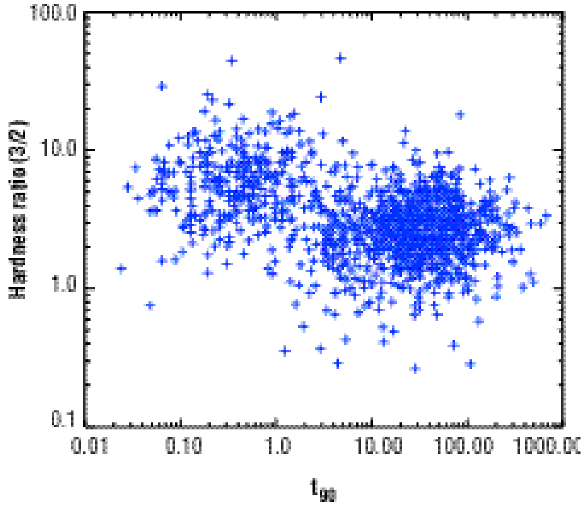


Figure 4.—Hardness-ratio and duration characteristics of GRB's. When GRB's are plotted against hardness ratio and duration, two classes become evident: short/hard and long/soft. No other distinguishing characteristics of the classes have been identified.

been found to be useful in classifying bursts (Kouveliotou, et al. 1993). As can be seen in figure 4, when burst duration is plotted against a measure of the burst hardness (the ratio of BATSE energy channels 3 and 2), the whole population separates into two distinct classes, short/hard and long/soft. It should be emphasized that the two classes are not different in any other observable behavior, such as their spatial or intensity distributions, which might be a clue to what underlying physical cause distinguishes them.

While some attempts have been made to deconvolve bursts into individual pulses, as yet no method has been found that is totally model-independent (Norris, et al. 1996). Other time-domain techniques have been applied, with mixed results. Band (1997) has done cross-correlation of burst time histories between several broad energy bands, demonstrating that pulses at lower energies lag in time behind the same pulse at higher energies. The width of pulses generally diminishes with increasing energy, as can be seen dramatically in figure 5. Not only do the pulses narrow at higher energies, implying spectral evolution during pulses, the spectral hardness differs greatly from pulse to pulse, showing further strong spectral evolution. While the pulses between 45 and 50 s are present in all three energy bands, the pulse at 15 s is radically softer, being weak in the 21 to 62 keV band and absent above 330 keV.

Besides the general property of duration, bursts are characterized by several other quantities, presented in the BATSE burst catalog series. Some of these quantities, such as peak flux and fluence, are based upon a nominal energy band, so the GLAST Burst Monitor (GBM) should have good sensitivity over the same energy range of 50–300 keV as used for the BATSE catalog. Of more interest to theoretical work is the extension of these quantities to bolometric measures, including energy bands below and above the nominal 50–300 keV band to include essentially all the burst energy. This would require continuous energy coverage from a few keV up to that of the LAT.

1.1.2.3 Spectral Properties of Bursts

As soon as bursts were discovered, their energy characteristics were analyzed by the best available methods. With small detectors, the results were spotty at best, deriving a rough temperature estimate of typically several hundred keV. With better instrumentation, it was soon realized that burst spectra generally had a high-energy, non-thermal power law component. Recent analyses contributed to the growing consensus that most, if not all, burst spectra could be fit with a single four-parameter functional form, determined empirically. The canonical spectral form consists of two power law segments joined smoothly at a characteristic break energy (E_{break}). A representative broadband GRB spectrum is shown in figure 6, using the CGRO observations of GRB 990123 (Briggs, et al. 1999a). Both panels show the deconvolved spectrum over three decades in energy. The top panel shows the spectrum in photon flux units, while the bottom panel shows the the spectrum in υF_υ units. The υF_υ spectrum is E^2 times the photon flux spectrum; a flat spectrum in υF_υ units has equal energy per decade. The advantage of the υF_υ presentation is that it depicts the energetics: in the case of GRB 990123 it shows that the bulk of the energy is emitted between a few hundred keV and a few MeV.

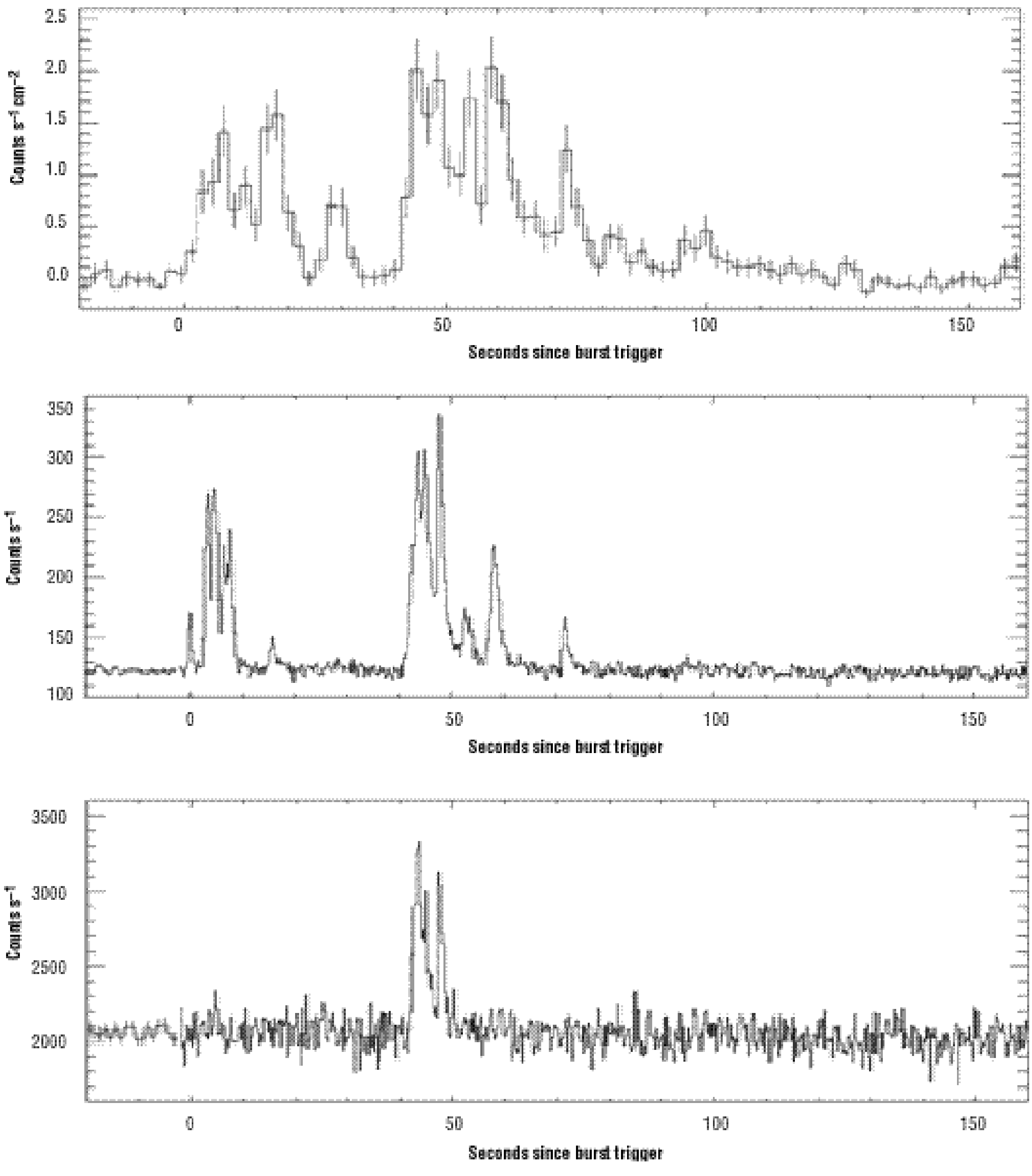


Figure 5.—Time history of GRB 990510 in 3 energy ranges.
The light curves are for 5.2 to 8.5 keV (top) as observed with the Wide Field Camera on BeppoSAX, and for 21 to 62 keV (middle) and >330 keV (bottom) as observed with BATSE Large Area Detectors. This illustrates how dramatically time profiles can differ over the energy range to be observed with the GBM.

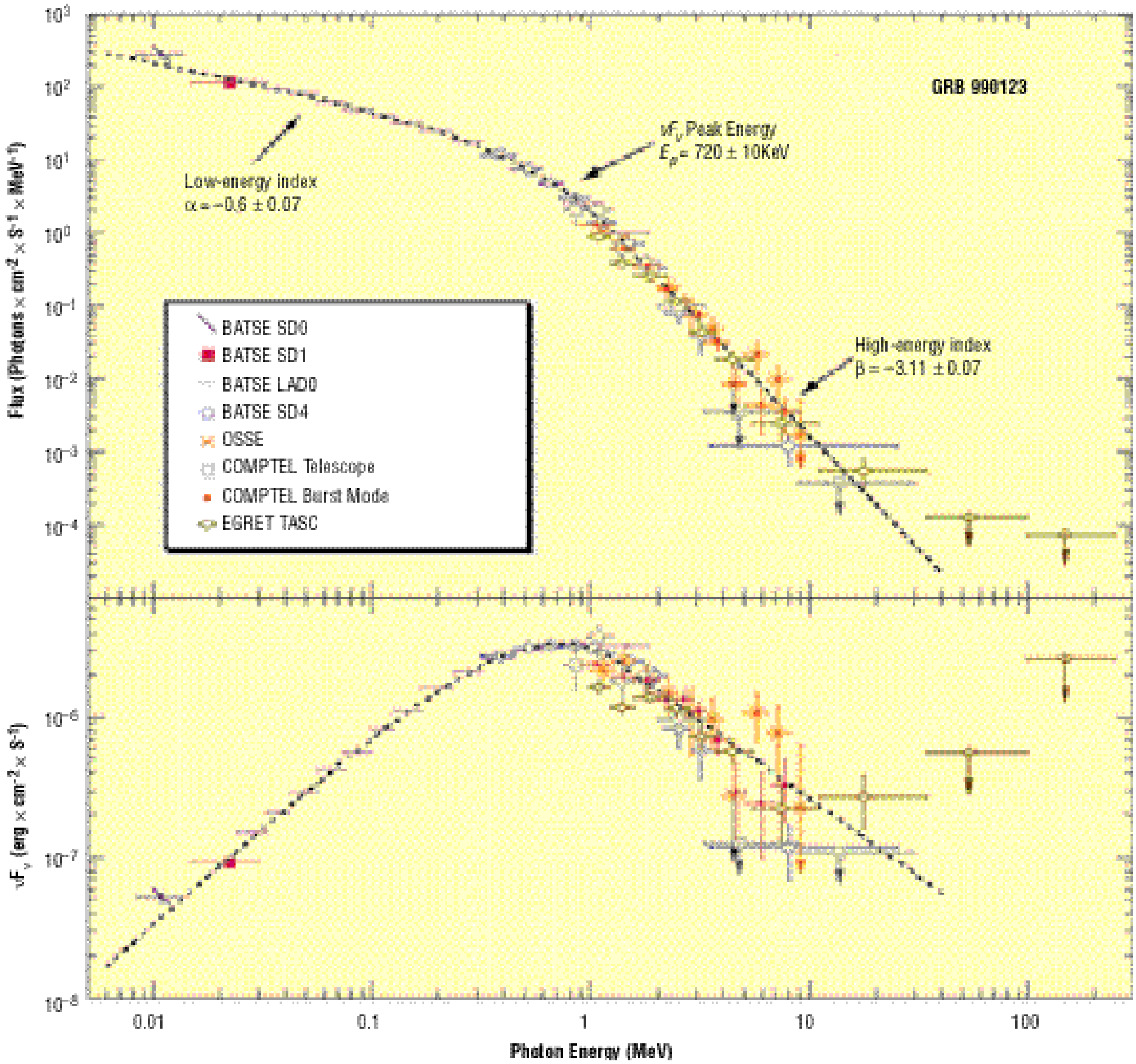


Figure 6.—Spectrum of GRB 990123.
The spectrum is for a 32 s interval for which data from all four CGRO instruments is available. Overall, the spectrum is well fit with a model in which a low-energy power-law smoothly transitions to a high-energy power-law. The lowest-energy point provides evidence of an x-ray excess. The υF_υ plot shows that the few hundred keV to few MeV band dominates the energetics of this event and that the peak energy of emission is about E_{break} = 700 keV.

This simple spectral shape is in sharp contrast with the extremely varied temporal behavior of bursts, which remains unclassified, except for the duration bimodality. The temporal behavior of the spectrum of GRB 990123 is shown in figure 7. The top panels show light curves in six energy bands; the narrowing of pulses with increasing energy is apparent. The bottom panels show the evolution of the spectral parameters E_{break} and α. The overall trend is for both parameters to decrease, coexisting with the pattern of E_{break} increasing for each pulse. The combination of a hard-to-soft trend and a hardness-intensity correlation is typical of GRB's (Ford, et al. 1995). In the case of GRB 990123, E_{break} reaches the unusually high value of 1,470 ± 110 keV at the peak of the most intense pulse.

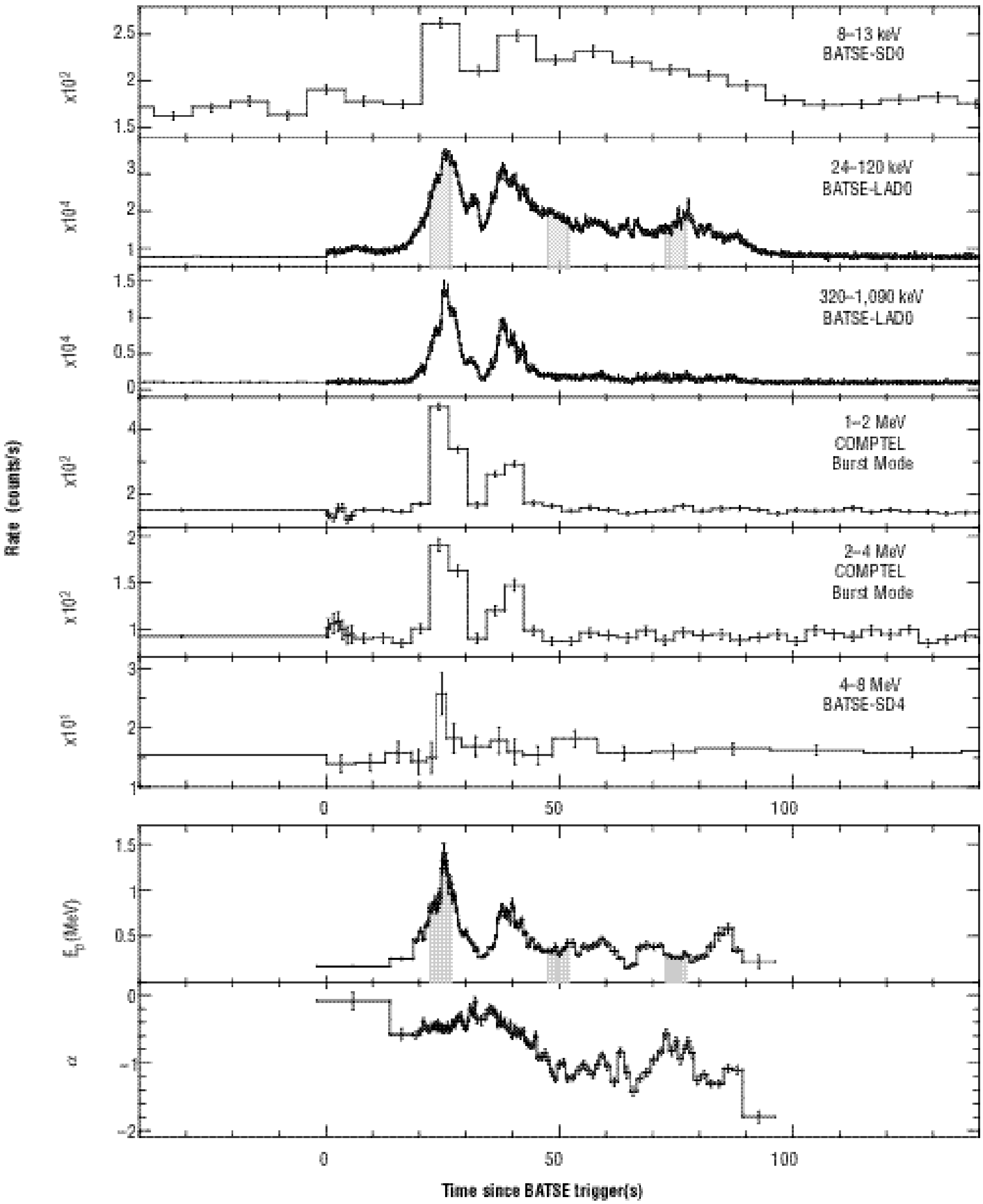


Figure 7.—Time history of GRB 990123.
Light curves in six selected energy ranges observed with the CGRO instruments and the evolution of two spectral parameters, the break energy E_{break} and the low-energy power-law slope α. E_{break} varies over the range ~200 keV to ~1400 keV.

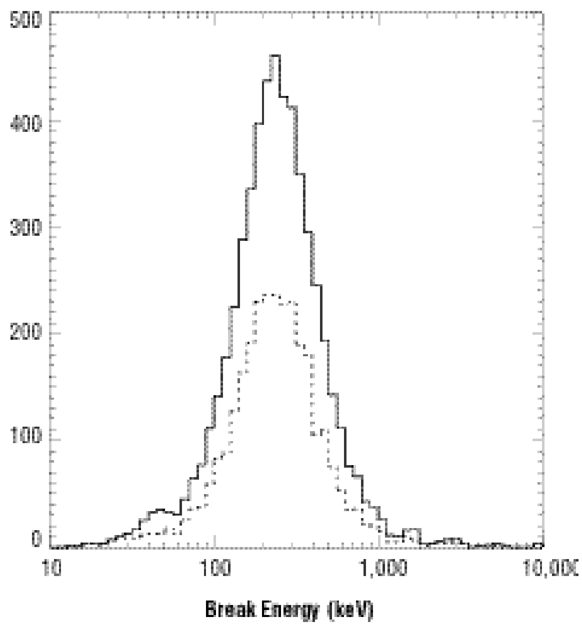


Figure 8.—Distribution of E_{break}.
The histogram shows the values measured for 5,000 spectra from 156 GRB's observed with BATSE. The distribution is an important constraint on the range of Lorentz factors of GRB blastwaves because any intrinsic characteristic energy is Doppler shifted.

Interestingly, E_{break}, the single spectral parameter that can theoretically indicate relative Doppler motion between the observer and the source, is characterized by a log-normal distribution of surprisingly narrow width, peaking at 250 keV (fig. 8). Likely causes of relative motion include cosmological redshift and bulk Lorentz motion of emitting particles, as required by blast-wave models. Mallozzi, et al. (1995) have presented evidence for the cosmological redshift, in that the average value for the E_{break} distribution lies at progressively lower energies for bursts with lower peak intensities.

The two remaining spectral form parameters, the low-energy (α) and high-energy (β) power-law indices, are broadly distributed around –1 and –2, respectively (Preece, et al. 1999) (fig. 9). While not sensitive to relative motion, there is considerable science in each of these as well. The width of the α distribution severely constrains the applicability of at least one popular burst emission model, based upon synchrotron emission from shocked electrons (Tavani, 1996, and Rees and Meszaros, 1992). The fact that the α distribution peaks at –1, rather than at –2/3 constrains the more popular blast wave model as well (Cen, 1999). Further tests of the blast wave model are quite sensitive to the relationship between the two power-law indices (Preece, et al. 1999), requiring an accurate determination of β, which is

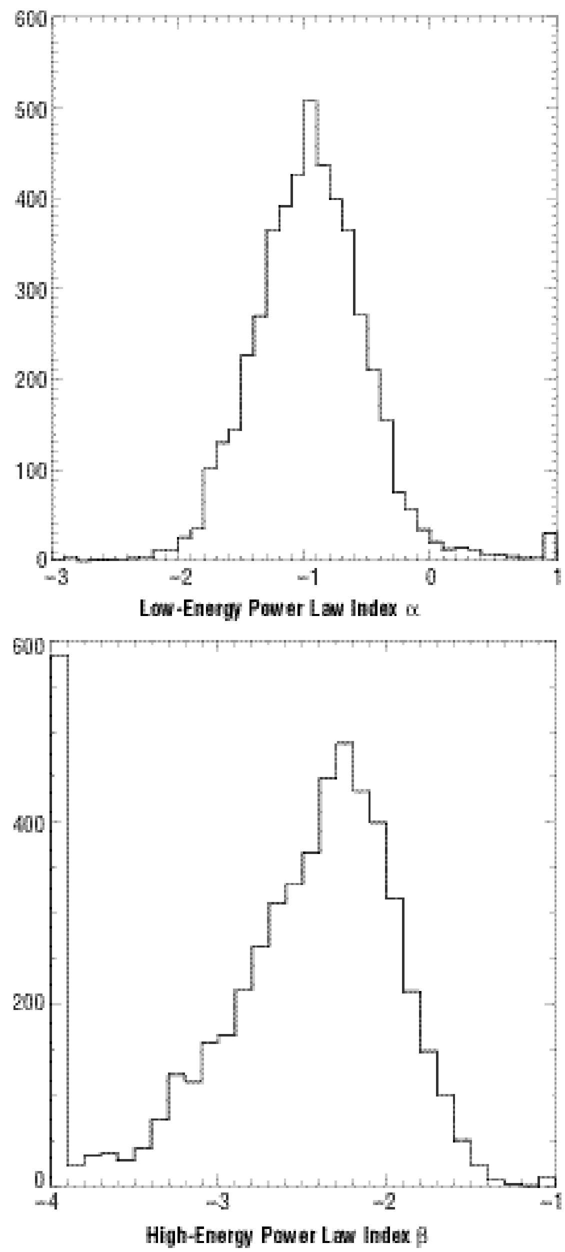


Figure 9.—Distributions of the low-energy spectral index α and the high-energy index β. Low values of α pose difficulties for synchrotron models, while values of β above –2 are unphysical unless a break occurs at higher energy.

the most difficult to do with the current instrumentation. While the LAT will measure β, only a broadband burst monitor will be able to connect this observation with the other two spectral parameters.

Those spectra with $\beta > -2$ are especially interesting, in that the power per unit decade increases with increasing energy, implying an unphysical infinite energy output. Where there were enough counts to be statistically significant, the high-energy power law component has been observed to extend through the bandpasses of all the CGRO instruments, including EGRET (e.g. fig. 6). It is currently unknown at what typical energies this component cuts off, yet arguments based on estimates of the efficiency for hard photon production, or the energization of the particles that emit such photons, clearly predict some limiting energy for burst emission that the LAT should be able to determine. It is essential to know how this cut off, should it be observed, behaves in relation to the evolution of other spectral parameters, so that a unified picture of the emission can be assembled.

This picture should extend into the hard x-ray band, where a hint of extra spectral structure has been observed in 15 percent of all bursts. Figure 6 also shows an example of this, where the photon rate at the lowest energy point is significantly different than the model rate. Here again, the correlation between the high and low regimes of energy should be determined, with the LAT determining the presence or absence of high-energy photons and the GBM covering the lowest energies at a better resolution and sensitivity than is possible with BATSE.

1.1.2.4 Discovery of Burst Afterglow and Counterparts

Although bursts' output typically peak in the 50–300 keV energy range, localization using gamma-ray data simply cannot produce the accuracy required for telescope-based observations of the source. In the end, it took roughly 30 years from the discovery of GRB's to determine the distance to a sufficient number of candidate GRB counterparts, emitting at other wavelengths, for the cosmological distance scale for bursts to be proven and for counterparts to be discovered. The first observation of counterparts came quite late in the process, requiring pointed x-ray observations by Dutch–Italian instruments on board the BeppoSAX orbiting x-ray observatory, launched in April 1996. Several bursts were observed to fade in the x-ray band accessible to the Wide Field Camera (WFC) on BeppoSAX at long enough time scales for the extremely sensitive Narrow Field Instruments (NFI) to be pointed at the source. Finally, a fading point source was found by optical telescopes with a location consistent with that provided by the SAX instruments. Imaged much later by very powerful telescopes, such as Keck and Hubble, these first source identifications emerged as distant galaxies, after the point source had faded away. It should be noted that the time scales for fading in GRB afterglow are not the same as the light curves established for typical type II supernovae, so any association between these two would involve unusual examples of both. In several cases, the underlying galaxies were bright enough for optical line emission spectroscopy, which gave a typical red shift for burst host galaxies of $z=1$.

The fading remnants of bursts, when they are observed, cool rapidly with the peak in emission passing through x-ray, optical, and down to radio wavelengths. This behavior is reminiscent of an adiabatically cooling shocked fireball, which is the standard picture for the observed afterglows of bursts. Shocked acceleration of electrons is also consistent with the detection of very high-energy photons at times much later than the beginning of the event, as the time scale for accelerating electrons grows increasingly longer with energy. The detection of very high-energy photons emitted by these electrons, is one of the science goals of the LAT. However, there should be a context into which these higher-energy observations are placed. Interestingly, SAX has been unable to find an afterglow to any burst from the short duration class, thus no counterparts for these bursts has been discovered. EGRET also was unable to investigate the short class bursts, with a dead time per photon that is longer than many of the bursts' durations, even though they are harder, on the average, than the longer class. Since the high-energy behavior that the LAT will explore for these events is completely unknown, the GBM is required for their proper classification in the classical burst energy regime of 50–300 keV.

1.1.3 Existing and Near-Future Capabilities

Given the difficult questions that still surround GRB's, such as gamma-ray production and energetics, it is important to look to the present and planned missions that have burst detection capabilities for answers. Currently, BATSE is very healthy and can last for a considerable number of years, given the present orbit of CGRO. BATSE will continue to help progress burst research by making context observations coincident with other instruments, such as the WFC on BeppoSAX, and it may well create the longest duration dataset of general burst properties when it passes the more than 14-year operational lifetime of the pioneer Venus orbiter (PVO), sometime after the launch of GLAST. EGRET's burst operations are severely constrained, due to its nearly exhausted supply of gas. BeppoSAX can continue to observe bursts in the WFC and track afterglow in the NFI well past its design lifetime; however, the spacecraft has had a number of setbacks due to failures of the stabilizing gyros, and is now operating on only one. Also, the ability of BeppoSAX alone, to detect bursts in the traditional gamma-ray band, is limited by the characteristics of the active shielding surrounding the x-ray detectors—the data are limited to either poor time resolution or poor energy resolution. Other instruments, such as the Burst Monitor on Ulysses and a similar instrument on WIND, although very small, are serving the important role of maintaining the IPN.

To complement the currently operating suite of detectors in orbit, several new missions have been planned for various GRB studies. Each of these has a particular emphasis; however, the focus of all will be on counterpart identification. It is hoped that after several years of operation, several hundred GRB hosts will have been identified and their distances measured. First, the High-Energy Transient Explorer (HETE-II), a broadband instrument primarily intended to investigate the hard x-ray portion of the burst spectrum, 2–400 keV, with good resolution, will be launched in early 2000. In addition, the soft x-ray camera will provide onboard localization to 10 arcmin accuracy for approximately 25 bursts a year. HETE-II has the capability to transmit the location quickly to the ground, for independent observations by other instruments and observatories, and will be operational for up to 2 years. Following HETE-II, SWIFT will provide rapid localization of hundreds of GRB's to within 2.5 arcsec and broadband spectroscopy (10–150 keV in the Burst Alert Telescope) of the afterglow of bursts. The spacecraft will slew to point co-aligned x-ray and ultraviolet (UV) telescopes at the source location in roughly 50 s. Neither HETE-II nor SWIFT will accomplish broadband gamma-ray spectroscopy of bursts, since neither will be able to observe the high-energy power law portion of the typical burst continuum or even the energy range where the break occurs in many bursts. Without a Burst Monitor on the GLAST spacecraft, there will be no U.S. mission after BATSE that will fill the gap above 400 keV up to 10 MeV, the lower threshold of the LAT, yet this is the energy range that makes bursts uniquely gamma-ray events.

1.1.4 Needs Unmet by Currently Planned Missions

Although current and planned hard x-ray imaging missions will measure the x-ray continuum for large numbers of GRB's, they will not perform broadband gamma-ray spectroscopy of bursts, nor is it clear that they will be operational in the GLAST time frame. It will be important to combine the exciting discoveries that will come from future planned missions with what is already known from previous burst studies. The energy of the spectral break, E_{break}, is the only fitted continuum parameter that scales with the relative motion between the source and the observer, which must be the product of the cosmological red shift of the host and the bulk motion of a relativistically expanding fireball. Moreover, E_{break} is the spectral component that has traditionally been used to characterize a burst's hardness. The limited high-energy coverage of many of the next generation missions will prevent them from determining this important spectral parameter. Thus, they may not be able to place their observations of very well localized bursts in context of the known hardness distribution, and will be limited in their ability to explore hardness correlations with other burst properties.

If a second spectral component at lower energies is discovered, as indications of an x-ray excess seem to imply, its characteristic energy, along with that of the spectral break observed at higher energies, should be investigated to determine their correlation. This is especially important for distinguishing between several theoretical models that provide a mechanism for the observed x-ray excesses—the measurement of the break energy will be essential in order to do correlative studies. Occasionally, the spectral break energy is high enough that it is poorly constrained by the BATSE data. A detector covering the 2–20 MeV range will be able to determine the correct value. Even for cases where E_{break} is well constrained, β may not be, unless there exists the capability to observe in a broad energy band, above roughly 1 MeV.

Questions left unanswered by EGRET can finally be investigated by the LAT, with the GBM making the important connection with known burst behavior at lower energies. The whole question of actual energy-resolved burst time history at EGRET energies that has been left open is: What changes can be observed in the temporal behavior of bursts as the observed energy band increases? For example, it is known that pulses in bursts tend toward a narrowing in time at higher energies, as well as a shift in the peak of pulse emission toward the beginning as shown in figure 7 (Fenimore, et al. 1995). With a very low deadtime for the LAT, compared with EGRET, burst pulses can be examined with good count statistics at much higher energies than was possible with EGRET to see if the trend continues. Of course, this will not be possible without simultaneous observation at lower energies by a dedicated Burst Monitor. Long term behavior at the highest energies is also in doubt. With EGRET observing a burst lasting longer than 90 minutes where no coincident delayed photons were detected by BATSE, the issue of persistent emission at high energies has been left open. Again, simultaneous lower energy context observations will determine the independence or interdependence of higher-energy bands. In some theories, involving shock acceleration of electrons, the expectation is that the highest energy electrons will be those that have been accelerated the longest. If so, many bursts may have very little flux of high energies at the onset, and the high-energy flux will gradually build over time.

In the case where burst progenitors may be highly magnetized neutron stars undergoing collision or accretion-induced collapse into a black hole, the magnetic field plays an important role in the higher-energy emission. Baring and Harding (1997) have shown that the spectrum above ~50 MeV should have a break from photon-photon pair production. Detection of such a feature requires knowledge of the continuum spectrum at all energies, especially for a broad region just below the onset of the feature, to establish a baseline spectral index for extrapolation.

1.2 Large Area Telescope Burst Observations

The primary mission of the GLAST LAT, with respect to bursts, is exploration. The only instrument that it can be compared with is the EGRET on board CGRO, as this was the first high-energy instrument that could observe bursts as they were occurring and with locations determined well enough that the high-energy events could be classified as coming from the GRB. The results from EGRET were limited by dead time of about 100 ms per event, which is as long as entire pulses in some bursts. With better sensitivity than EGRET and a much wider FOV, the LAT will probe the relatively unknown aspects of GRB's above 100 MeV, where the effects of high-energy particle acceleration, relativistic beaming, and intergalactic attenuation are most clearly observed. The LAT will detect far more GRB's than was possible with EGRET, perhaps as many as 200 per year, with an effective area over six times greater, a response that does not fall rapidly above 500 MeV and a FOV that is more than four times larger. The GLAST LAT will also provide high-quality spectral and temporal measurements, and will be able to localize many GRB sources with a high precision. Roughly 100 bursts per year can be localized to better than 10 arcmin and a few per year to better than 1 arcmin (Bonnell et al. 1997). Within several minutes of burst onset, the LAT may be able to relay burst locations to ground- and space-based observatories to search for afterglow emission.

The spectral observations from EGRET just scratch the surface of what may be a diverse phenomenon. With 45 photons greater than 30 MeV from four bursts, the average spectral index obtained, 1.95 ± 0.25, is consistent with the average of high-energy spectral indices obtained with BATSE, 2.2, for a much larger number of bursts in the sample (156), and a correspondingly larger number of spectra fitted (5,500). This high-energy portion of the continuum can be determined with the extended energy range of the GLAST LAT, and a distribution of spectral indices can be built up, to be compared with the BATSE result and to increase the precision of the GBM spectral fits. The temporal behavior of the high-energy continuum can be determined quite well by the GLAST LAT for comparison with lower energies. For some of the spectra fitted to data from BATSE events, the spectral indices were smaller than 2, indicating that the peak energy of the power distribution per unit decade has not been reached in the BATSE energy band, less than 2 MeV. In addition, the EGRET result is similarly low; at some energy there must be a roll-off in the high-energy spectrum, where the power output of the burst peaks. The energy of this break will help to determine characteristics of the source emission process and if it is due to absorption of the extragalactic background light, it may be an independent measurement of a large source redshift. The presence of high-energy photons in bursts is a very important indication of the energetics of the emitters. In general, the higher the energies that are observed, the higher the bulk Lorentz factors must be at the source in order to avoid runaway pair-production cascades that are inconsistent with the observed spectra. In at least one EGRET event (GRB 940217) high-energy emission continued for 5,000 s after the end of the event, as determined by BATSE. The single photon, detected at roughly 18 GeV, resulted in an extremely accurate burst location, and the extended emission contained a considerable fraction of the total fluence of the burst. In addition, it provided an upper limit to the distance at which the burst source may lie of z less than 2, owing to the opacity due to pair production on the infrared background of photons with energies exceding 10 GeV. Observations of this kind can be done for very long periods of time with GLAST, with its large FOV.

1.3 Observations Needed to Support the Large Area Telescope

There are important limitations to the effectiveness of the main GLAST instrument as a burst detector in its current configuration. First, high-energy measurements alone do not reveal how individual bursts fit into the full population. This problem is most evident in terms of GRB energy spectra, where the most characteristic spectral feature, E_{break}, occurs around a few hundred keV (Band, et al. 1993), well below the currently envisioned GLAST main instrument threshold. The spectrum above E_{break} is typically a power law with no indication of a break (Dingus, et al. 1997; Catelli, et al. 1997), yet the power-law index, in many cases, appears to be flatter than –2 (Preece, et al. 1999) which, for physical reasons, cannot continue to indefinitely high energies without steepening. The high-energy break may, in a few cases, be measured by the LAT alone, but in many cases will be properly constrained only by jointly fitting wide-band spectra. For some subset of the bursts, this may be possible with instruments on other satellites, but optimum coordination is obtained by including a Burst Monitor on GLAST that has appropriate sensitivity in the energy range from x rays to near the LAT threshold. An accurate comparison of the spectral index β measured in the GBM energy range with the measurement in the LAT energy range is essential to distinguish between intrinsic spectral breaks and those caused by intergalactic attenuation of the higher-energy photons.

A further concern is that, without an instrument that covers the conventional GRB energy range, the LAT observations cannot be placed in the context of the whole GRB population. The database of GRB observations, produced by BATSE, will remain definitive for the foreseeable future. It will be scientifically wasteful if the properties of GRB's, as measured by the GLAST LAT, cannot be associated with the BATSE bursts. This is optimally done with an instrument that covers the same energy range as BATSE, especially if it has similar trigger characteristics.

An interesting related question is whether there exists a significant population of hard spectrum bursts that has been missed or poorly sampled by BATSE. Although several authors (Lloyd, et al. 1999 and Piran, et al. 1996) have claimed evidence for such a population, other studies have not confirmed this (Harris, et al. 1997 and Brainerd, et al. 1999). The GLAST LAT can definitively settle this question, but only if sufficient simultaneous coverage is available in the BATSE energy range.

A further significant concern for the GLAST LAT, as a burst detector, is the technical problems associated with triggering. Although the LAT can trigger on the total event rate, without knowledge of their sky location, this is not optimal. The wide FOV of the LAT implies a background rate that cannot be neglected for burst triggering, and the best trigger sensitivity will be obtained by binning the events according to their sky location. This can easily be done during ground data processing, but is a significant constraint for onboard triggering. A Burst Monitor with sufficient sensitivity can provide onboard triggers with a corresponding savings in complexity of onboard LAT data processing, and hence a savings in cost.

1.4 Burst Monitor Requirements

1.4.1 Lower-Energy Context Measurements

The GBM is designed to provide near full-sky burst observations, in an energy band that overlaps both that of the LAT and the hard x-ray regime, unifying them for the first time. It provides an important context in which the highest energy observations of GRB's, by the LAT, can be placed. Much of the burst science from GLAST will be entirely new, as the expected number of bursts per year will be many times the total number of events observed by EGRET over its entire mission to date. Some of the expected results cannot be determined without simultaneous observation at wavelengths below the lower threshold of 10 MeV for the LAT, such as the narrowing of pulses and the shift of their peak in time toward the beginning. The discovery of high-energy spectral breaks or rollovers, in the LAT energy range, for bursts with too much high-energy power (spectral index >–2) rests on the ability to determine the spectral index with good accuracy. This may only be possible with an instrument that has good spectral coverage below that of the LAT without large energy gaps. Determining which spectral hardness class an individual burst belongs to can only be possible with an instrument that covers the crucial energy range, 100–400 keV, that bounds most of the fitted spectral breaks, as shown by BATSE data. Indeed, it has been shown, by an analysis of Solar Maximum Mission (SMM) data, that there is no large class of high-break energy bursts extending beyond the tail of the BATSE distribution, so energy coverage below approximately 500 keV is as crucial to determining the spectral break as higher coverage is to determining the high-energy spectral index. In addition, the energy range 20–2,000 keV contains much of the energy output of typical bursts, and it is in this range that burst fluxes and fluences are traditionally calculated. Burst Monitor observations are needed to determine the near-bolometric peak fluxes and fluences in conjunction with the LAT and to allow comparison with the general population of events.

1.4.2 Provide Localization for Bursts Over a Wide Field of View

For roughly 100 bursts a year, the LAT will obtain burst locations better than 10 arcmin. There is no need for a narrow-field detector to independently produce good burst locations. Rather, what is required is a wide-field monitor that can localize bursts to a few degrees to permit repointing of the spacecraft for optimal observations by the LAT. The best design for a Burst Monitor will observe the half of the sky surrounding the pointing direction of the LAT.

1.4.3 Enhance Sensitivity of Main Instrument

Finally, there will be many bursts for which the LAT will register only a few high-energy photons. The lower-energy Burst Monitor will detect these and can provide a source location that is accurate to several degrees. This location can be used to search the LAT data for coincident photons from the source, greatly enhancing the sensitivity over having no monitor at all. The reason for this is that the angular resolving power of the LAT is so great, over the portion of the sky it observes, that there will be a tremendous number of possible angular resolution elements to search through at all times for possible triggers. In the absence of any context instrument, it may be feasible to search for these coincident photons only in data archived on the ground, greatly reducing the number of possible good source locations from the LAT. In addition, the constellation of other spacecraft, operating concurrently with GLAST, that could possibly provide timely GRB source localization is completely unknown.

1.5 Science Investigation Plan

Our primary science investigation will be elucidating the relation between keV/MeV and GeV burst emission by time resolved spectroscopy using data from the Burst Monitor and the LAT. We will perform simultaneous spectral fits to the data of one or more Burst Monitor NaI detectors, a Burst Monitor BGO detector, and the LAT. We will determine whether a single spectral model, such as the Band GRB function (Band, et al. 1993), can simultaneously explain the keV–GeV data. We will relate the behavior in the classical GRB band, such as the value of E_{peak}, to the GeV observations of the LAT. We will correlate the evolution of the keV–MeV spectrum to LAT observations. The two basic products will be spectra for subintervals of the burst and light curves for energy bands. For the purpose of time-resolved wide-band spectroscopy we propose nonexclusive access to GRB data from bursts that trigger the Burst Monitor. We will produce a spectral catalog of time-resolved model fit parameters, plus fit residuals. Example analyses, simulated results and expected performance are detailed in section 2.5.1.

We propose two other main science projects: 1) Generation of GRB locations and, 2) publication of GRB catalogs. These have been chosen for their importance and because development of the algorithms and procedures requires the experience and knowledge of the instrument team.

As a service, we will produce prompt GRB locations which will allow repointing of the spacecraft to initiate LAT observations, aid in detecting GRB's in the LAT data, and make possible prompt ground-based observation and possibly observation by other spacecraft. The locations will help identify GRB events in the LAT data. Locations will be generated using the same technique used for the BATSE instrument, by comparing rates of several NaI detectors. A simplified algorithm will be implemented in the flight software to produce near real-time locations, to facilitate space and ground-based follow-up observations. A more sophisticated algorithm will be implemented in ground software to calculate more accurate locations. Further implementation details and expected accuracy are given in section 2.5.2.

We will produce a catalog of bursts that will include parameters such as fluence, peak flux, and duration. These parameters will be defined as closely as possible to those in the BATSE catalog so that bursts, observed by GLAST, can be related to the large sample of the BATSE catalogs. Scientists in Huntsville, using their experience of producing the BATSE catalogs, will implement most of the procedures and software for producing values for the catalog. To extend the detection threshold as low as possible, scientists at MPE will develop an untriggered burst search. This search will detect fainter events by using more sophisticated algorithms than will be implemented in the flight software. The ground-based burst search will incorporate a higher order or more physical background, which can be fit to a longer time period. Data from more than two NaI detectors and from the BGO detectors can be used to "trigger," and flux increases can be searched for on many timescales, etc. Techniques like these have been successful in finding untriggered bursts in the BATSE data stream (Kommers, et al. 1997, and Stern, et al. 1999). The extended detection threshold will yield additional events to search for in the LAT data (several scientists have proposed a very hard burst class which might be faint in the few hundred keV band), extend the fluence and flux range of detected bursts, and increase the catalog size for burst population studies.

We have proposed three investigations of GRB's. Much of the language of the AO is oriented toward investigations based on a fixed number of discrete source observations. Our instrument is more suitable for continuing investigations of transient GRB's, so we are proposing key project multiyear efforts. These investigations have been chosen because of their importance and because they require the detailed knowledge of the instrument possessed by the instrument team. While the development of the catalog and location projects will be essentially completed during the first year of phase E, these projects clearly should be continued for the duration of the mission. The scope and difficulty of the time-resolved spectroscopy project make it best suited to a multiyear effort. We do not intend for these projects to impede other researchers and plan full cooperation with the GLAST guest investigator (GI) program. Both the Huntsville and MPE teams have good track records in supporting the CGRO GI program. We do not need exclusive access to the data.

1.6 Other Science Capabilities

Data from the Burst Monitor will permit other important scientific investigations which will likely be conducted by other scientists through the GI program. The extensive nature of the GBM data includes: 1) Continuous good temporal resolution data background time (BTIME), 2) high spectral resolution data background spectroscopy (BSPEC), and 3) trigger data at full temporal and spectral resolution of the detectors time triggered event (TTE). This GBM data will allow GI's to propose and conduct investigations that we haven't conceived, extending the science return of the mission.

GI analyses of GRB data acquired by the GBM and LAT will likely include temporal analyses such as cross-correlating profiles in different energy ranges, and temporal and spectral averaging of weaker events to boost the signal-to-noise ratio. The prompt locations will enable ground based searches for emission in other wavelengths during the burst phase of GRB's, as was successfully accomplished for GRB 990123 using a BATSE GCN location with $\sigma=13^\circ$ (Akerloff, et al. 1999). The locations may also be used by other spacecraft, to search for prompt emission and counterparts in other wavelengths (x-ray, ultraviolet, optical, infrared, etc.).

As demonstrated by the BATSE experiment on the CGRO, numerous scientific investigations other than gamma-ray bursts can be undertaken with all-sky hard x-ray and gamma-ray detectors such as those of the GBM. Sources that are strong and variable, relative to the background, are easily distinguished as distant point sources. In particular, numerous solar flare investigations have made use of BATSE data because of its high efficiency for hard x-rays and near-continuous coverage. Studies have included fast timing of hard x-ray flares and correlations with solar impulsive microwave emission.

As with GRB's, the location, intensity and spectral characteristics can be determined for short, intense flares from soft gamma repeaters (SGR's) and galactic black hole systems. Pulsars are observed by folding their periodic signals. Many additional sources can be observed by the Earth occultation method, which was pioneered by BATSE. This method has proven to be extremely valuable for continuously monitoring over 70 known objects and discovering about a dozen new, bright (>100 mCrab) sources. While the smaller detector area of the GBM detectors will limit the GBM sensitivity to ~0.5 Crab for short-term flares or one-day occultation flux determinations, many investigations of sources at this level can be made over the GLAST mission.

Due to the limitation of data analysis resources in phase E, we do not propose to perform any of the above data analysis under the GLAST GBM funding profile. All data will be properly archived in low-level form and documented for analysis by others. They can also be utilized in near real time, deposited into a repository, and/or given to approved outside investigators as specified by NASA Headquarters or the GLAST Project Office.

2.0 Science Implementation

2.1 Instrument Overview

The primary scientific goals of the Burst Monitor are to measure the spectrum of GRB's below energies accessible to the LAT and to provide rapid approximate burst locations over a wide FOV. We have selected a complement of detectors and a data

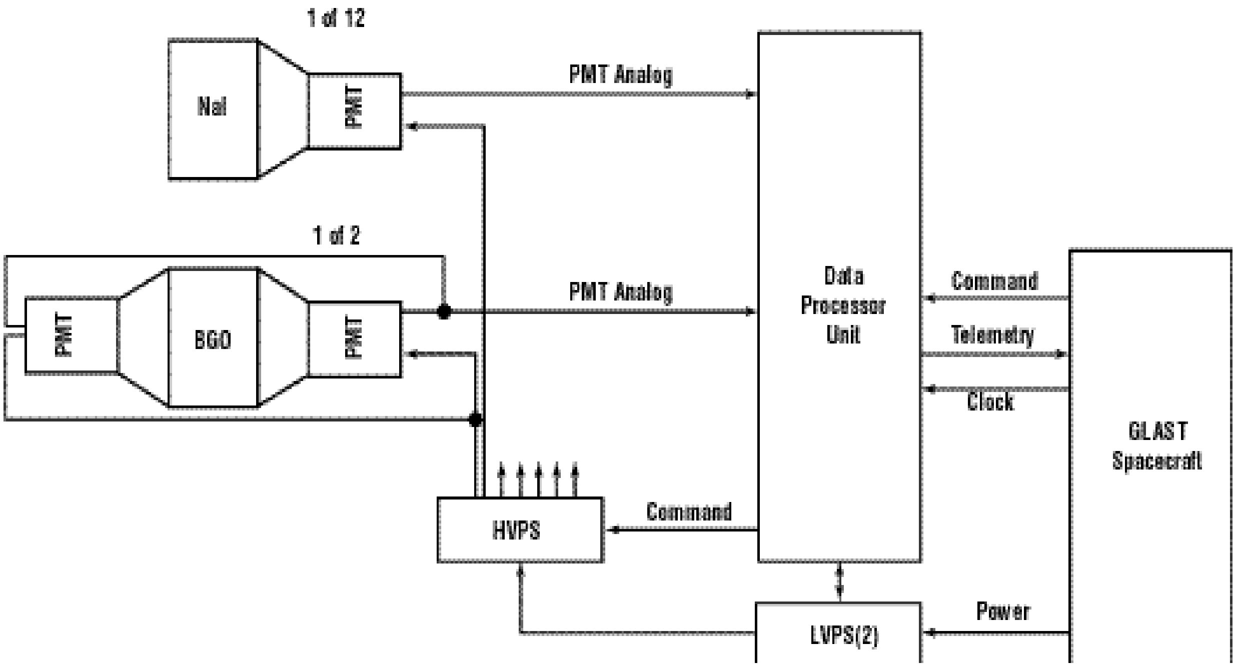


Figure 10.—Top level Block Diagram.

system that meet or exceed these requirements, yet are simple and low risk.

A top level block diagram of the Burst Monitor is shown in figure 10. There are 12 NaI scintillation detectors and 2 BGO scintillation detectors. The NaI detectors are 12.7-cm diameter by 1.27-cm thick, directly coupled to a PMT. These detectors are oriented to provide good sky coverage and perform two functions: 1) Provide spectral coverage from about 5 keV–1 MeV, and 2) determine burst locations using relative rates, similar to BATSE (Pendleton, et al. 1999). NaI is an ideal scintillation material for this energy range combining low cost, high efficiency, and adequate spectral resolution. The BGO detectors are 12.7-cm diameter by 12.7-cm thick. To provide better light collection, as well as redundancy, the BGO crystals are directly coupled to two PMT’s, on opposite sides, whose outputs are summed. The two BGO detectors are roughly omnidirectional and are positioned on opposite sides of the LAT providing full-sky coverage. They provide spectral coverage from 150 keV–30 MeV. The high density of BGO provides good sensitivity over this difficult energy range. The HV of each PMT is separately controlled. In the baseline design, a single high-voltage power supply (HVPS) box provides 16 separate outputs, which

Table 1.—A traceability matrix showing the GLAST Burst Monitor design characteristics as derived from the scientific goals and constraints.

Goal or Constraint	**Burst Monitor**
Low-energy spectral measurements	Spectroscopic observations from ~5 keV to ~30 MeV
Field of view: >~3 steradians	8.6 steradians
Burst threshold: ~0.5 photons cm^{-2} s^{-1}	0.35 photons cm^{-2} s^{-1} for 5 σ 0.57 photons cm^{-2} s^{-1} trigger threshold
Mass: 50 kg	54.5 kg, with 20% contingency
Power: 50 W.	17.8 W. without contingency
Telemetry: 10 kbps	4 kbps normally, 9 kbps during bursts

are routed to the individual detectors. Each detector incorporates shaping circuitry and preamplification of the PMT anode signal.

The type, number, and size of the detectors were chosen to satisfy the scientific objectives:

- The two detector types cover the entire energy range from 5 keV–30 MeV, with good overlap between the NaI and BGO energy ranges, and between the BGO and LAT energy ranges.
- The small physical size of all detectors allows flexibility in placement.
- The detector diameter is the same as the PMT to allow direct coupling, which results in good light collection, energy resolution, and sensitivity down to low-energy with minimal complexity and risk.
- The thickness of the NaI detectors is optimum for the energy range where bursts typically emit the most energy and provides approximately a cosine angular response, which is important for determining locations.
- The number of NaI detectors provides a combination of good sky coverage, greatly exceeding the nominal FOV in the AO, and good sensitivity, closely matching the nominal threshold.
- The thickness of the BGO detectors and their placement provide approximately uniform response over the entire sky, despite blockage by the LAT.

A schematic diagram of the mounting of the detectors to the spacecraft is shown in figure 11. The detectors will not block any part of the LAT FOV nor interfere with the solar panels. They easily fit between the LAT and the shroud envelope on two sides of the spacecraft. Figures 12 and 13 show top and side views. The mounting arrangement is quite flexible and will be explored with the spacecraft contractor during phase B. With our approach, FOV can be traded for sensitivity simply by changing the orientation of the NaI detectors. For example, if it is decided not to incorporate the capability for real-time repointing of the spacecraft, we could match our FOV to the LAT and improve our sensitivity by positioning the NaI normals closer to the spacecraft +*Z* axis.

Table 2.—Comparison of GBM and BATSE.

	BATSE	**GBM**
	Large Area Detectors	*Low-Energy Detectors*
Material	NaI	NaI
Number	8	12
Area	2,025 cm^2	126 cm^2
Thickness	1.27 cm	1.27 cm
Energy range	25 keV to 1.8 MeV	5 keV to 1 MeV
.	*Spectroscopy Detectors*	*High-Energy Detectors*
Material	NaI	BGO
Number	8	2
Area	126 cm^2	126 cm^2
Thickness	7.62 cm	12.7 cm
Energy Range	30 keV to 10 MeV	150 keV to 30 MeV
Total Mass	850 kg	~50 kg
Trigger Threshold	~0.2 photons $cm^{-2}s^{-1}$	<0.57 photons $cm^{-2}s^{-1}$
Telemetry Rate	3.55 kbps	4 to 9 kbps

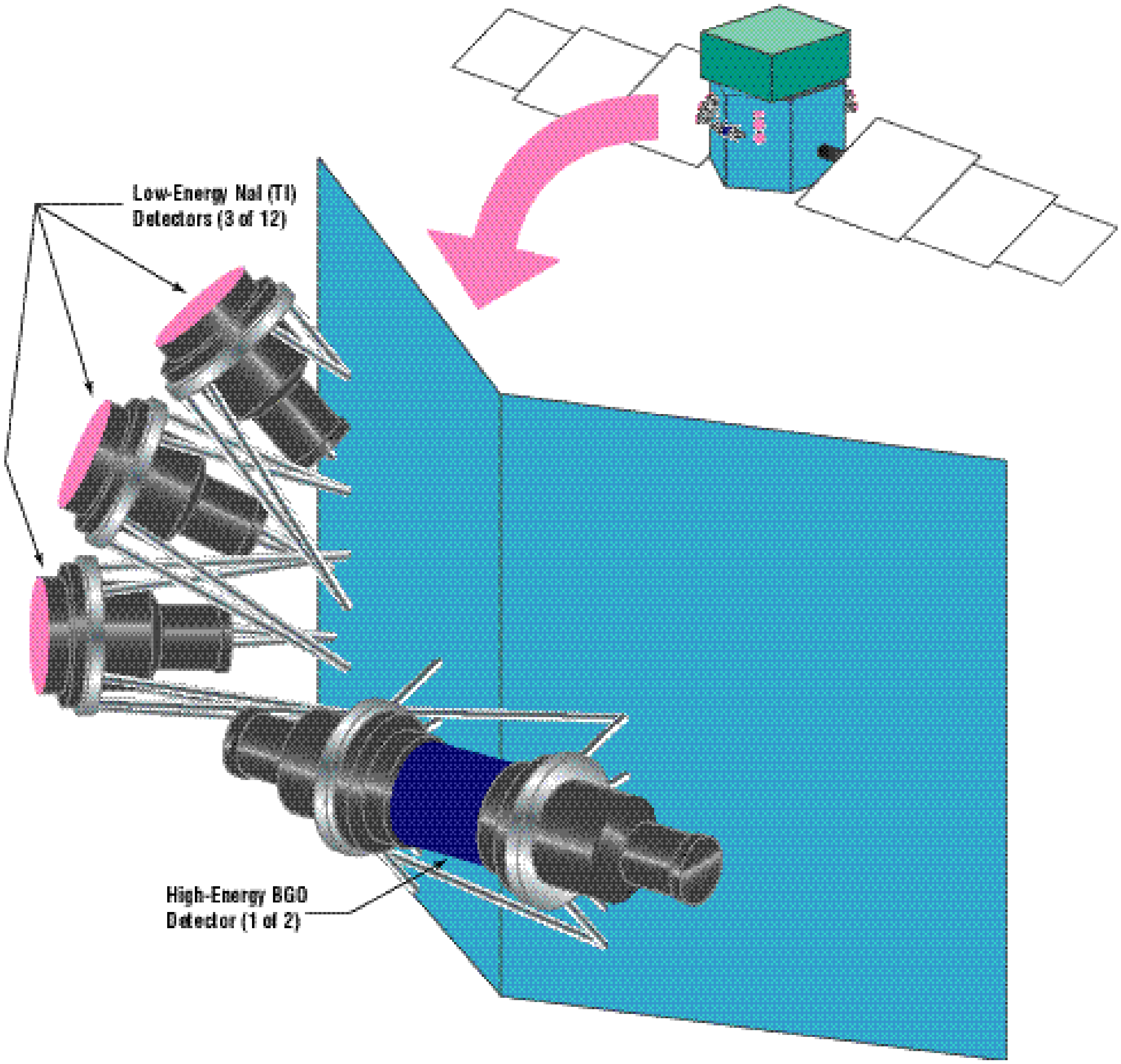


Figure 11.—Detector placement concept. Detector placement is flexible and will be coordinated with the spacecraft contractor.

The GBM instrumentation is similar to that of BATSE on CGRO, since observation of gamma-ray bursts is the objective of both instruments. There are significant differences, however, due primarily to: 1) The GBM emphasis on spectral measurements to complement the LAT, 2) the blockage of the GBM FOV by the LAT, and 3) the mass and cost constraints on the GBM. BATSE used eight large area detectors (LAD's) and eight smaller spectroscopy detectors, analogous to the NaI and BGO detectors on GBM. A comparison of the two instruments is provided in table 2. Key improvements compared to BATSE for the spectroscopy goals are lower energy coverage obtained by using a beryllium window on the NaI detectors, better high-energy coverage by including BGO detectors, and better temporal resolution of spectra via a TTE datatype with sufficient memory to record very bright GRB's. The larger number of NaI detectors viewing a smaller FOV will reduce the systematic errors for burst locations and allow an improved triggering algorithm.

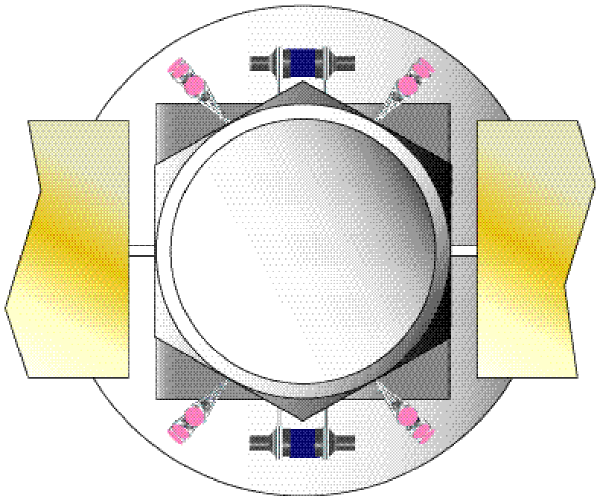


Figure 12.—Detector placement concept, top view.

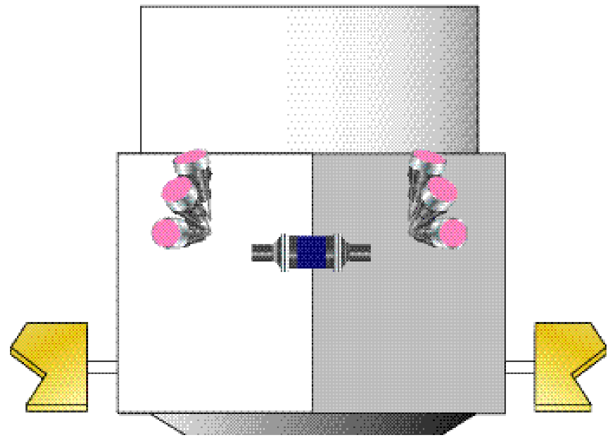


Figure 13.—Detector placement concept, side view.

2.2 Data Formats

To achieve all of our scientific goals, the burst monitor will have four datatypes, two continuously produced datatypes and two datatypes produced in response to a trigger. The continuous datatypes BSPEC and BTIME provide good temporal and spectral resolution at all times, while the trigger datatype TTE provides 5 μs data for triggers and the trigger datatype TRIGDATA reports location and spectral estimates determined on board along with rates to allow the determination of improved locations on the ground in near real time.

The goal of the trigger datatype TTE is to provide the maximal information about a trigger, with 5-μs time resolution and 128 channel spectral resolution. The limitations of TTE data will only be those inherent in the counting statistics and energy resolution of the detectors. The TTE data will optimize our ability to correlate GBM data with LAT data. For example, the trend of pulse width with energy suggests that GRB pulses might be very narrow at GeV energies, an idea which has not been tested with EGRET because of EGRET's long dead time per event and low counting statistics. The TTE datatype will allow binning of the GBM data according to time boundaries determined from pulses observed in the LAT data. In normal operation, TTE data will be accumulated for the BGO and the two NaI detectors with the best view of the source. For very bright bursts or when the TTE memory still contains events from a previous burst, data will be accumulated from only one NaI detector. Approximately 50 s of pretrigger data will be provided in TTE to enable analysis of any precursor emission.

The TTE temporal resolution of 5 μs is chosen to match the expected maximum deadtime per count and to match the probable performance of the LAT, for which table 1 of the NRA specifies a requirement of 10 μs and a goal of 2 μs. The spectral resolution of 128 channels was selected to oversample the data; the 5 to 1,000 keV NaI data are spanned by ~30 resolution elements, while the 150 keV to 30 MeV BGO data are spanned by ~85 resolution elements. A large oversampling factor is unnecessary for the BGO data because of the limited number of counts at the higher energies.

We base the estimates of the memory requirements for TTE on the bright burst, GRB 940217, which had the largest number of counts of the bursts simulated for section 2.5.1. A similar burst observed with the GBM would produce 650,000 counts in the NaI detector and 210,000 counts in the BGO detector with the best view of the source. Hence TTE memory to contain 1 million events will suffice to accumulate the data from one NaI and one BGO detector. For fainter events, to improve statistics, data will be accumulated from two NaI detectors. The temporal resolution of 5 μs and the spectral resolution of 128 channels will require 24 bits per event, so the memory requirement is three megabytes.

The other datatype produced in response to a trigger, TRIGDATA, will contain several record types. One record type will report location and spectral estimates determined on board. This information can be used by the spacecraft or LAT computer to repoint the spacecraft, and for rapid ground-based observations. If the mission chooses to support a special real-time telemetry mode in response to triggers, the other record type will contain selected detector rates to enable more accurate near real-time computation of locations on the ground, using a more capable computer than the GBM DPU.

The two background data types are designed for the goals of providing background data for burst analysis, providing data for nontriggered events and for extremely long GRB's, >500 s, and to permit detection of bright sources via Earth occultation. The BSPEC data type accumulates 128 channels of data from each detector with 8 s resolution, while the BTIME data type provides 0.256 s resolution in four energy channels. One or two of the BTIME energy channels will correspond to the trigger energy band so that trigger sensitivity can be precisely calculated on the ground.

Together, the two background datatypes (BSPEC and BTIME) require 3,600 bits per s. Using 5,000 bits per s of telemetry, the entire TTE memory will be read out in 1 hr 20 min. At the expected trigger rate of 0.5 day^{-1}, collisions between events will be rare. Three methods will be used to save some TTE memory for a second trigger: 1) TTE accumulation will end at ~500 s so that background data from weak events will not consume the entire memory, 2) for very bright bursts or if some of the memory is occupied by a previous trigger, data will be accumulated from one instead of the usual two NaI detectors, and 3) as readout occurs, portions of the memory will become available for another trigger. The telemetry usage of the Burst Monitor will therefore range from about 4 kbits per s to about 9 kbits per s, depending on whether triggered data are being downloaded.

2.3 Flight System Hardware

2.3.1 Detectors

To cover the energy range from 5 KeV to 30 MeV two scintillator materials are chosen: Sodium iodide for the low energies, 5 KeV to 1 MeV, and bismuth germanate for the high energies, 150 KeV to 30 MeV.

Bismuth Germanate Detectors

BGO scintillation detector crystals are selected to provide high efficiency and adequate resolution for the higher-energy range of the GBM. This type of detector is being designed and fabricated by the MPE team members for the thick shield sections of the SPI instrument on the INTEGRAL spacecraft. The BGO crystals will be manufactured by Crismatec Corp. in France. For the GBM application, the BGO detectors will have a uniform light collection geometry and large photocathode area, resulting in superior resolution. While the light output of BGO is ~20 percent of that of NaI (Tl), the high density and high average atomic number of this material makes it preferable for detectors at higher energies.

Two identical detectors, mounted on opposite sides of the spacecraft, each have a single cylindrical BGO crystal that is 12.7-cm diameter by 12.7-cm high. The energy resolution will be ~14 percent at 661 keV and ~4 percent at 10 MeV. Resolution as a function of energy, is shown in figure 14. They are sufficiently thick for photons up to 40 MeV, as shown in the response curve in figure 15. Because of their large volume, there is significant photopeak efficiency, up to the energy range of the GLAST main instrument.

Table 3.—BGO detector characteristics.

Number of detectors	2
Thickness	12.7 cm
Diameter	12.7 cm
Energy range	150 keV to 30 MeV
Resolution at 100 keV	35% FWHM
Resolution at 662 keV	14% FWHM
Resolution at 10 MeV	4% FWHM
Resolution at 20 MeV	3% FWHM

Each of these BGO crystals are optically coupled through a fused silica window to two 12.7-cm diameter PMT’s, attached on both ends of the cylinder. This design allows a homogenous light collection over the detector volume and also provides redundancy should one of the PMT’s fail or degrade. The BGO detector would still be operational, but with lower resolution and gain if this occurs. The two detectors will be mounted on opposite sides of the spacecraft, providing nearly a 4π steradian FOV. The sensitivity of the detectors, in the directions through the PMT’s, will be somewhat diminished at energies below ~400 keV. Table 3 provides the basic characteristics of each BGO detector. Figure 16 shows the angular response; note that the BGO crystal orientation is such that 90° corresponds to the crystal axis of symmetry.

Sodium Iodide Detectors

Twelve identical NaI scintillation detectors will be used to determine GRB locations, as described in section 2.5.2. The spectral range for these detectors will be 5 keV to 1 MeV. These are conventional detectors with a diameter of 12.7 cm and a thickness of 1.27 cm. The thickness and the large diameter-to-thickness ratio results in a response function similar to the LAD’s on the BATSE instrument. The angular response of the NaI detectors, as a function of energy, is shown in figure 16. This design simplifies the GRB location methodology, using proven software for this application.

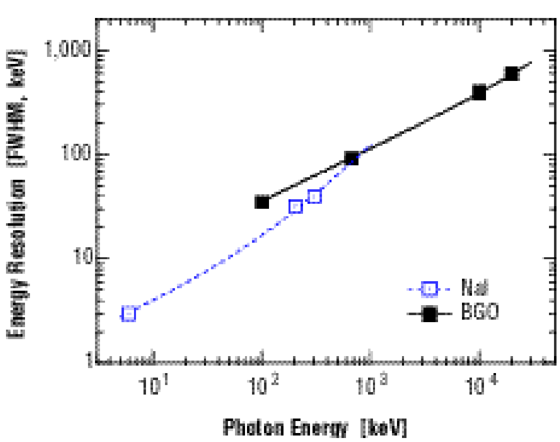


Figure 14.—**Energy Resolution of the GBM NaI and BGO detectors**.

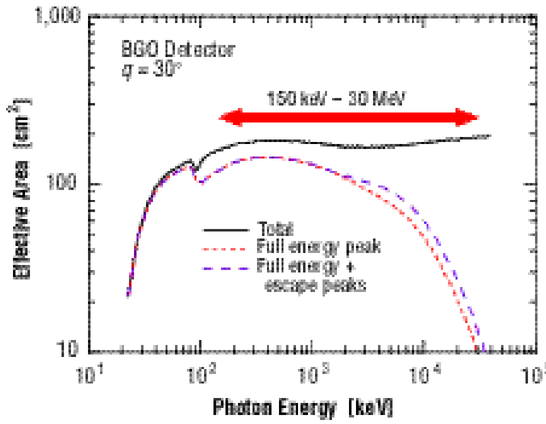


Figure 15.—Response of a GBM BGO detector. The total curve is for detecting a count of any energy from an incident photon, while the full energy peak is the response for capturing the entire energy of the photon. The double arrow shows the energy range of the BGO channels.

Each crystal will be viewed by a single 12.7-cm PMT, providing excellent light collection and having a homogeneous response over the whole crystal. The detector module will be evacuated and hermetically sealed using standard practices, used on other scintillation detectors, designed for flight. The detector entrance window will be made from 0.25-mm thick beryllium, electron-beam welded to an aluminum housing. This approach was successfully used for the BATSE spectroscopy detectors. There will be a thin, low-*z*, highly reflective material just behind the entrance window, in contact with the crystal, to provide good optical reflectivity and

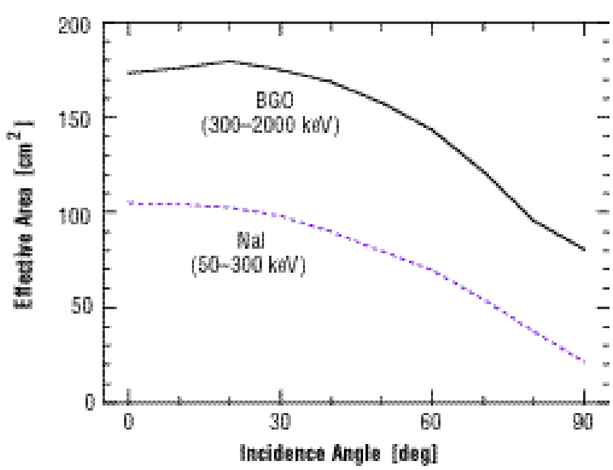


Figure 16.—Effective area of the GBM detectors as a function of angle of incidence.

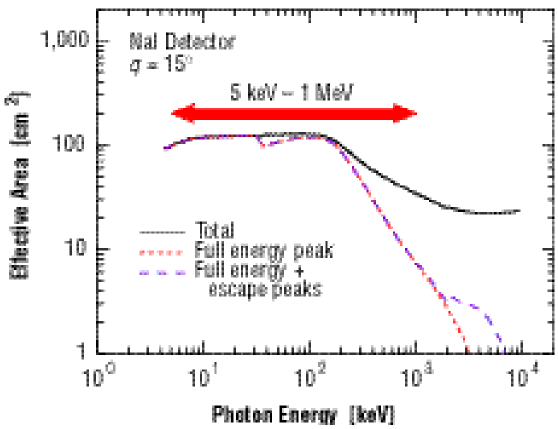


Figure 17.—Response of a GBM NaI detector. The total curve is for detecting a count of any energy from an incident photon, while the full energy peak is the response for capturing the entire energy of the photon. The double arrow shows the energy range of the NaI channels.

ensure adequate sensitivity down to 5 keV. The PMT will view the crystal through a fused silica optical window. The energy response of the NaI detectors is given in figure 17. This calculation does not take into account absorption by a thin thermal blanket, which will be designed somewhat in conjuction with the spacecraft insulation. It is assumed that this can be done without significantly degrading the low-energy performance of the NaI detectors. Table 4 summarizes the characteristics of the NaI detectors.

Photomultiplier Design

Both types of detectors will use the same PMT housing design and preamplifier, with slight variations in the bleeder strings and preamps, to accommodate larger pulses from cosmic rays expected in the BGO detectors. The NaI detectors will likely operate at higher voltages to achieve a greater gain than the BGO detectors.

Table 4.—NaI detector characteristics.

Number of detectors	12
Thickness	1.27 cm
Diameter	12.7 cm
Energy range	5 keV to 1 MeV
Resolution at 6 keV	50% FWHM
Resolution at 200 keV	16% FWHM
Resolution at 300 keV	13% FWHM

There are at least two qualified vendors for 12.7-cm diameter (5-inch) PMT's for the Burst Monitor: Electron Tubes Ltd. and Hamamatsu Corp.
The selection of the vendor for the PMT's, the photocathode type and dynode structure will be made during the phase B studies.

Mechanical and Thermal Interfaces

The detectors will be mechanically mounted onto the spacecraft with struts or brackets to provide the required viewing orientation. Details of the mounting design must await the selection of the GLAST main instrument and spacecraft. It is expected that the thermal requirements of the detectors can be passively met using the same multilayer insulation (MLI) blankets that cover the spacecraft structure. The covering of the entrance window of the NaI detectors may need to have fewer layers of MLI, to allow adequate x-ray transmission for the NaI detectors. It is assumed that both the thermal blanket design and the mounting design will be provided by the spacecraft contractor, in consultation with the GBM team.

Calibration

Preflight calibration of the GBM will be accomplished using a combination of Monte Carlo simulations and calibrations. The GEANT simulation package (Brun, et al. 1993) will form the basis for simulation of the photon interactions in the detectors, including secondary leptons and nuclear excitations. Hadronic event responses (i.e., background) will also be simulated with GEANT linked to FLUKA (Aarnio, et al. 1990). A detailed geometrical and chemical model of the detector units forms the basis for these simulations, supplemented by a coarse model of the GLAST main instrument and spacecraft.

Simulation codes can be uncertain in absolute magnitude on the order of 30 percent, and the mass model may be in error. Therefore calibration measurements at specific energies and incidence angles constitute the second base for the detector responses of the Burst Monitor. These measurements will be performed at MPE prior to delivery of the detectors to MSFC. Gamma-ray sources are available as calibrated radioactivity standards, ±5 percent in intensity, in the energy range up to 4.4 MeV photon

Table 5.—Gamma-ray sources for BGO calibration measurements.

Source	Energy	Angles
^{241}Am	59.5 keV	0°, 60°, 135°
^{57}Co	122 keV	0°
^{137}Cs	662 keV	0°
^{54}Mn	835 keV	0°
^{22}Na	1,275 keV, 511 keV	0°, 60°, 135°
^{88}Y	1,840 keV	0°
^{24}Na	2,754 keV	0°
$^{241}Am/^{9}Be$	4,430 keV	0°, 60°, 135°
$^{19}F(p,a)^{16}O$	6,100 keV	0
$^{3}He(p,n)^{4}He$	19,800 keV	0

energy. To calibrate the BGO detectors at higher energies, up to 20 MeV, we will use nuclear gamma rays from reactions triggered by a proton beam at a Van de Graaf accelerator. We have previously performed such accelerator calibrations for the COMPTEL instrument aboard the CGRO and the calibrations of the SPI instrument aboard the ESA INTEGRAL Observatory will be completed by the end of 2000. Very detailed calibrations will be performed in energy space, due to the required precision of the differential response, for accurate spectral deconvolution. Additionally, at several energies, the directional change of the response will be calibrated. Source alignment, with respect to the detectors, through theodolite precalibrated setups will be sufficient. Calibration data will be recorded coincidentally with a standard 3-in. NaI detector, for which simulation codes have been extensively compared and checked. Analysis will use the tools also used for detector design and for science data analysis.

Tables 5 and 6 list the calibration energies and angles for the BGO and NaI detectors, respectively.

2.3.2 Power Supplies

The low-voltage power supply (LVPS) provides power to the DPU and to the preamplifiers on each PMT. There will be two LVPS', cross-strapped for redundancy. There will be an HVPS for each PMT of the GBM, all housed in a single box. The HVPS will be under the control of the DPU. Power supply designs will be conventional, space-qualified designs, derived from other flight programs such as ROSAT and INTEGRAL, both of which were MPE projects.

2.3.3 Data Processing Unit

2.3.3.1 Introduction

The Burst Monitor instrument consists of 14 independent, remotely located detector modules. Each module provides analog pulse height signals at a high rate. Rather than process the signals at each detector, the centrally located DPU collects, processes and packages data from all the individual detectors. The main functions of the DPU are to digitize the analog pulse height signals, accumulate time resolved, pulse height spectra with variable temporal resolution, tag the spectra with time and detector information, package the data for telemetry, and use the data to realize a burst trigger, and compute burst locations. The other important DPU functions are to control the operation of the instrument, including power supply settings, and to accumulate adjunct housekeeping and instrument status data (temperatures, voltages, currents, etc.) for inclusion in the telemetry. The DPU acts as the sole electrical interface between the Burst Monitor instrument and the GLAST spacecraft computer. It is also the electrical interface for instrument integration and instrument level testing.

2.3.3.2 Requirements

The DPU requirements are summarized in table 7. The origin of the requirements is explained in section 2.2. The most important demands on the DPU design are imposed by the expected data rates, in particular the nominal background rate, the maximum rate during GRB events, and the cumula-

Table 6.—Gamma-ray sources for NaI calibration measurements.

Source	Energy	Angles
^{55}Fe	5.9 keV	0°, 45°, 80°
^{109}Cd	22, 88 keV	0°, 45°, 80°
^{241}Am	59.5 keV	0°
^{22}Na	511, 1,275 keV	0°, 45°, 80°
^{137}Cs	662 keV	0°
^{54}Mn	835 keV	0°
^{88}Y	1,840 keV	0°

Table 7. —Data processing unit requirements.

Inputs	14 detector/PMT analog signals, 0–5 V Housekeeping sensors (analog/digital) 14 power supply voltage and current Temp. sensors for each electronics board, each electronics box and each detector Digital commands from spacecraft (S/C) interface Clock Sync. from S/C	
Detector Inputs	Count Rates	0.2 kcps per det, nominal 100 kcps per det, peak; for ~100 sec; 1/wk
	ADC resolution	12 bits
	Dead time	< 5 µs
	Dynamic range	200:1
	Time-tagging	5 µs resolution
FPGA's	Functions	Data routing and buffering; spectral accumulation; time tagging of events—all controllable via CPU
	Type	TBD, ~10 MHz
CPU	Functions	Data transfer & formatting; control of FPGA and detector power supplies; burst trigger; burst location determination
	Type	TBD, 5-10 MHz
	Memory	4 MB data, 1 MB program
Serial Command Interface	Functions	Transmit digital commands from CPU to detector power supplies
Spacecraft Interface	Functions	Commands, data and power; ~9 kbps data rate
Other Hardware	UTC clock	Synchronized with S/C UTC clock
	Telemetry buffer	~4 MB
	Survival heaters	typical for space hardware
Physical	Size	TBD
	Weight	< 3 kg
	Power consumption	< 5 w

tive counts for a GRB. These data rates and the instrument dead time requirements determine the appropriate processing speed, memory buffer depth, and processing architecture. The other major DPU requirement is the need for rapid computation of burst locations using data from all detectors.

2.3.3.3 Hardware Design

The block diagram shown in figure 18 provides a conceptual view of the baseline DPU design. There are two different board types: the data receiver electronics board (DRE) and the processing electronics board (PRE). The general redundancy strategy for the DPU is that each board has one main unit and one unpowered redundant spare. If the main unit fails, it can be deactivated and the redundant unit activated via spacecraft command.

The DRE board is responsible for receiving the analog detector data and converting it into useable digital form. There are two identical analog data processors, operating in parallel to accommodate the required data rate. These consist of analog circuitry to perform peak-hold and pulse shaping tasks on the input PMT pulse heights from the 14 detectors. The conditioned pulse height signals

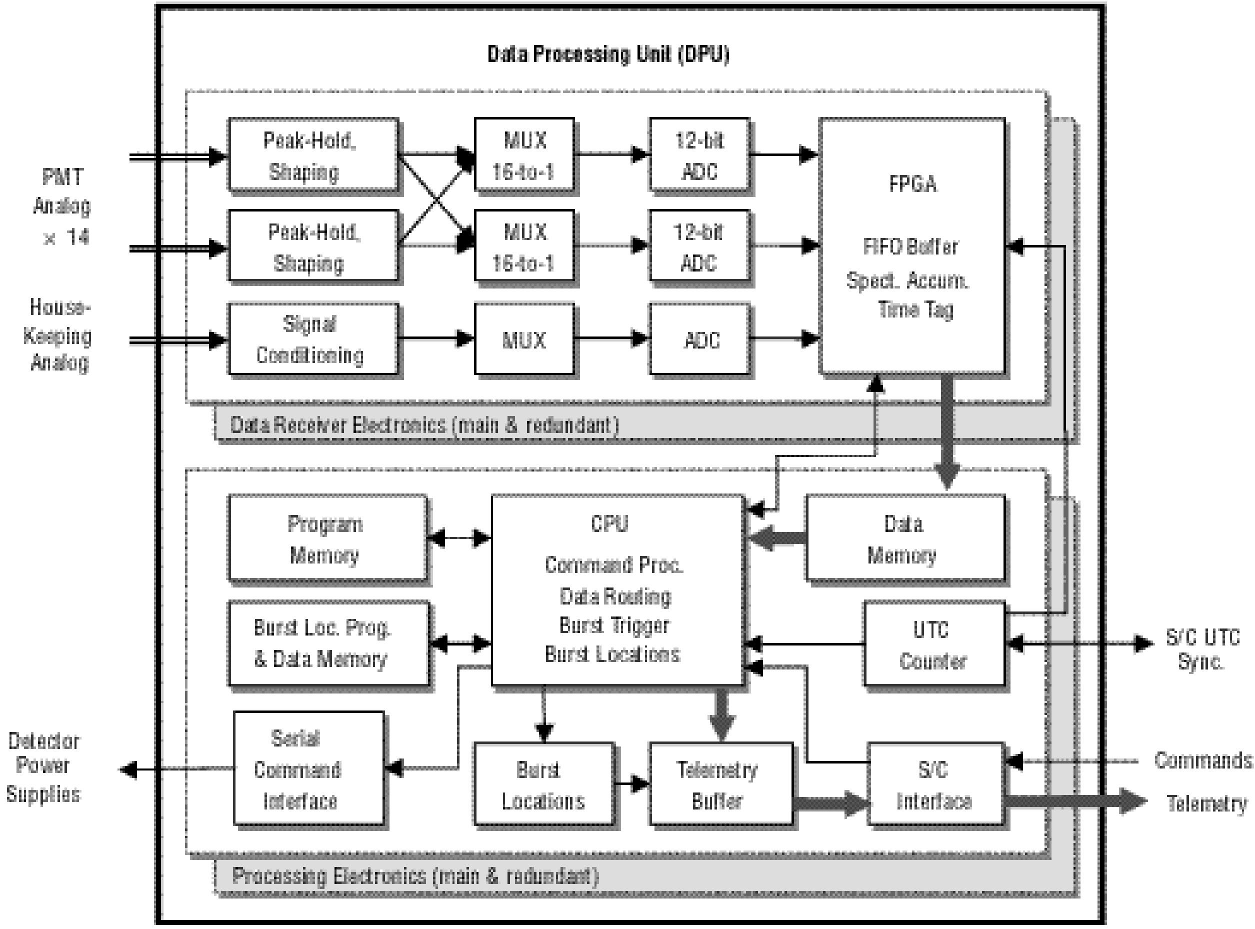


Figure 18.—Conceptual view of the baseline DPU design.

are then multiplexed into 12-bit ADC. This represents a significant oversampling of the detector energy resolution to allow for flexible, programmable data binning. The digital signals are processed by an FPGA. This unit performs the tasks of event buffering, spectral accumulation, time tagging, and detector addressing under control of the CPU on the PRE board. In addition to the main detector data path, the DRE also digitizes and routes adjunct housekeeping data from temperature, voltage, current, and scalar rate sensors dispersed throughout the Burst Monitor instrument. These data are multiplexed, digitized, and fed into the telemetry stream at a low rate through the FPGA.

The main functions of the PRE board are to act as a central control unit, route the data to appropriate telemetry buffers, and enable onboard burst triggering and burst localization. The main data bus, for both detector and housekeeping data, flows from the FPGA on the DRE board into a data storage buffer on the PRE board. The CPU then sorts, packages, and passes the data to a telemetry buffer before they are sent to the spacecraft data bus through the DPU spacecraft interface. As the data are accumulated, the CPU passes selected detector rates to the burst trigger program. In the event of a trigger, commands are automatically issued to the DRE FPGA that switch from background to burst accumulation mode. Concurrently, selected detector rate data are passed to the burst localization program. When this process is complete, a priority burst location trigger alert message is inserted into the telemetry buffer, where it is passed to the spacecraft. The LAT and ground telemetry will have access to the burst trigger location messages via the spacecraft CPU.

The PRE board contains a coordinated universal time (UTC) counter that is synchronized with the spacecraft clock to facilitate time tagging of burst triggers and location alert messages. The PRE clock signal is also routed to the DRE board to allow fast time tagging of individual events and spectra. The PRE board also includes serial command interface electronics that allow control of the detector power supplies, and therefore detector gain. The serial commands can originate via an automatic gain control (AGC) program run by the CPU, or by direct command from the spacecraft command interface. The AGC program operates by monitoring the peak channel of the 511 keV background line and adjusting detector HV accordingly. The serial command interface is also used to deactivate detector HV during passage through the South Atlantic Anomaly (SAA) via commands from the spacecraft controller.

2.3.3.4 Software
The DPU, FPGA, and CPU require several software elements to complete the tasks described above. These are described in detail in section 2.4.

2.3.3.5 Resource Estimates
Resource estimates for the DPU are shown in table 7.

2.3.3.6 Heritage
Our DPU may be provided as a modification of the Compact Environmental Anomaly Sensor (CEASE) manufactured by Amptek, Inc., Bedford, MA. This package has been selected for several Department of Defense (DoD) missions.

2.4 Flight Software

The GBM flight software will reside in the DPU and perform the following functions:

- Receive commands, act on real time and stored commands
- Receive and package housekeeping data for telemetry
- Control transfer of background data accumulated by FPGA’s to a spacecraft solid state recorder for latter telemetry
- Provide burst trigger
- Control accumulation of TTE trigger data provided by FPGA
- Transfer TTE data to a spacecraft solid state recorder for latter telemetry
- Provide AGC of the detectors using 511 keV background line
- Buffer data to be used as background for triggering and location calculation
- Produce classification of triggers and estimation of spectrum
- Calculate and output location of trigger
- Produce and output TRIGDATA data for ground-based location calculation.

In normal operation, the flight software will supervise the accumulation of BTIME and BSPEC background data types, and buffer these data for transfer to the spacecraft solid state memory. The last 200 s of background data will be kept by the flight software to serve as a background reference in determining triggers and burst locations. The flight software will convert sensor signals (thermistors) and hardware status signals (voltage levels) into housekeeping data. It will receive commands and either act upon them or store them for later use. Commanded functions include HV power on/off and levels, parameterized changes in the trigger, classification, and burst location algorithms, and selection of energy channel ranges for BTIME data.

An important function of the flight software is triggering in response to a flux increase. The BATSE approach is to require a 5.5 σ increase in two detectors. With more detectors and detector types than BATSE, a different algorithm might achieve better sensitivity while maintaining a negligible false trigger rate. Triggers will normally activate the TTE accumulation and production of TRIGDATA data for real-time telemetry. Flight software tracks the availability of TTE memory as it is filled by burst accumulation and emptied, by transferal of the data, to the spacecraft solid state recorder. The flight software will classify the cause of the trigger, so events that are probably not GRB’s might be processed differently, and the spacecraft might not be repointed. Triggers caused by particle events can be identified by detector rates inconsistent with a point location at infinity, while solar flares can be identified by their location. A spectrum will be estimated as a possible input in deciding whether to repoint the spacecraft. The flight software will calculate a rough location within several seconds. For long bursts, revised locations with reduced statistical errors will be calculated as the burst progresses. Special TRIGDATA data will be transferred to the spacecraft for immediate telemetry to enable more accurate locations to be calculated on the ground in near real time.

Triggering and onboard location algorithms will be made easier by maintaining constant energy boundaries of the channels via gain control. Gain control will be performed by monitoring the 511 keV background line in each detector and adjusting the PMT HV's or amplifier gains. BATSE experience shows gain variations to occur with 12- and 24-hr periods, depending on spacecraft altitude, in response to temperature variations and SAA particle dose. Because of good magnetic shielding, gain variations on orbital timescales are very low. Sufficient counts in the 511 keV line for accurate gain determination will accumulate once or twice per 90 min orbit.

The DPU vendor will provide some basic software necessary for hardware testing. This will include reading the FPGA's, controlling the TTE memory, accepting commands, outputting data, and outputting HVPS control commands. We will try to reduce duplication of software by making use of vendor generated software where this is expeditious.

We incorporate the capability to revise the flight software by command, a feature that was used to great advantage on BATSE on several occasions. For example, the BATSE data stream was altered to compensate for the failure of the flight tape reorders early in the CGRO mission. The GRM will also provide memory dumps and memory check sums to enable detection and correction of single event upsets, also as is done on BATSE.

Development of the flight software comprises the following tasks:

- Study tradeoffs and algorithm for calculating locations on board
- Product specification—requirements and design
- Management plan
- Assurance and test procedures
- Software coding
- Assurance and test reports
- Software maintenance document (incorporating version description)
- Software Users Guide

During phase B we will study the best division of tasks between hardware and software. We will study how to implement the onboard location algorithm, assessing tradeoffs between location accuracy, time to calculate locations, and CPU speed and memory requirements. A strategy for optimal use of the TTE memory will be defined. These decisions and the requirements to perform the tasks listed above will be incorporated into a Product Specification. Responding to these requirements, the software design will be described in the Product Specification, proceeding from a concept, to an architectural specification, to a detailed design. Using the Product Specification, a Management Plan and a document of Assurance and Test Procedures will be produced. The Management Plan will break into the software design, coding, testing, and documentation stages, document the cost and schedule of these stages, and describe methods of monitoring progress and responding to difficulties. The Assurance and Test Procedures document will describe how the software will be tested for correct functioning and satisfaction of the requirements. The Assurance and Test Procedures will be used at stages of software coding, software acceptance testing, and during integration. Results of these tests will be reported in the Assurance and Test Reports.

Two principal documents, of continuing use, will be produced. The User's Guide will instruct operations staff and scientists on operation of the software, commands, and capabilities. The User's Guide will also contain descriptions of the data and data formats that will be used in the development of the operations and analysis software. The Maintenance Manual will describe implementation details, modification aids, and how to adapt the code. It will assist programmers or scientists in implementing improvements or identifying and solving errors.

These plans and documents will be produced accordance with the NASA Software Docum tion Standard.

2.5 System Performance

2.5.1 Time-Resolved Spectroscopy Performance

2.5.1.1 Simulation and Analysis Approach

As a demonstration of the performance of the GLAST mission with the GLAST Burst Mon we have created simulated spectra for the GE and BGO detectors, and for a conception of a baseline LAT. These simulated spectra are ba upon realistic models of the detectors and the backgrounds and incorporate Poisson fluctua The simulated spectra are based upon GRB s observed with instruments on the CGRO.

For modeling the response to gamma-ray bur representative direction was selected, 30˚ fro GLAST instrument axis and 30˚ azimuth. Th places the hypothetical source at 30˚ from the of both the LAT and a GBM BGO detector, a from the axis of the best-illuminated NaI dete and 29.0˚ from the axis of the second best-ill nated NaI detector.

The detector response models (DRM's) were duced by Monte Carlo simulations of electro netic cascades using a modified version of G (Brun, et al. 1993). This program propagates tons and electrons down to 1 keV and incorporates a model of Compton scattering more accurate than the Klein-Nishina cross-section. The mass model used in GEANT included the scintillation crystals, the detector housing, and the photomultipliers and their housings (see section 2.3.1). All of this material was illuminated with Monte Carlo photons so that the response includes scattering of photons from nearby materials into the scintillators. The energy range of the simulated photons exceeded the energy range that will be recorded by the GBM (i.e., 5 keV to 1 MeV for the NaI, 150 keV to 30 MeV for the BGO) to incorporate into the response photons outside the GBM channel range that produce events in the GBM channel range via resolution broadening (fig. 14) and partial energy

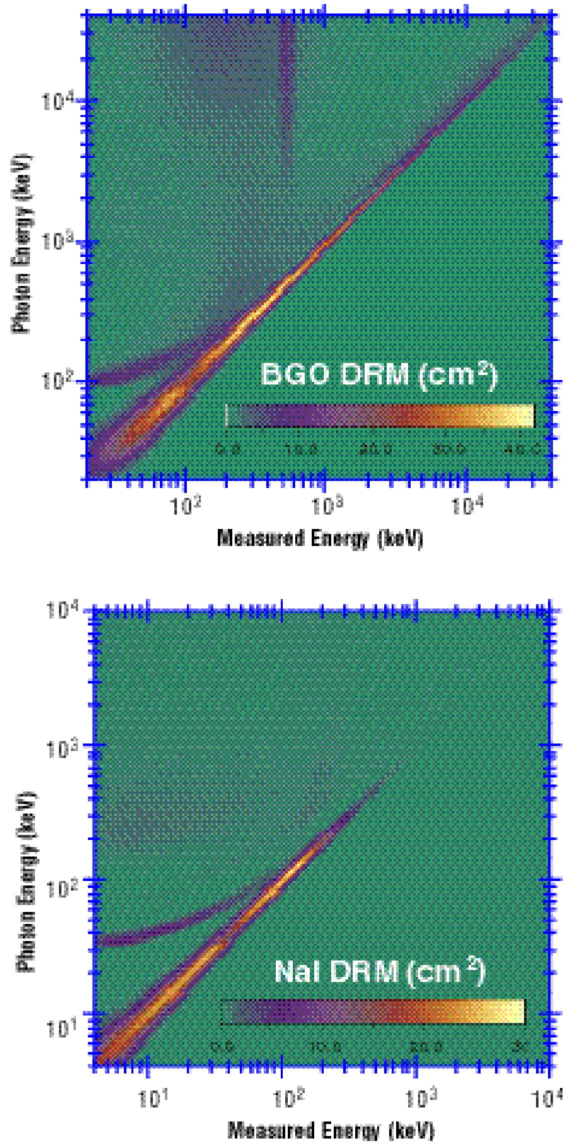


Figure 19.—Detector response as modeled with GEANT. The response as equivalent area is plotted vs the energies of the incident photons (y-axis) and the energies of the detected counts (x-axis). The prominent diagonal band is the full-energy or photopeak response. The "wing" extending to the lower left from the photopeak response is due to the escape of fluorescent x-rays. The blue region in the upper left of the BGO diagram is the response to gamma rays scattered into the detector from nearby material.

deposition. The energy range of input photons was spanned by 128 pseudo-logarithmic bins. For each bin, photons were simulated until 100,000 counts

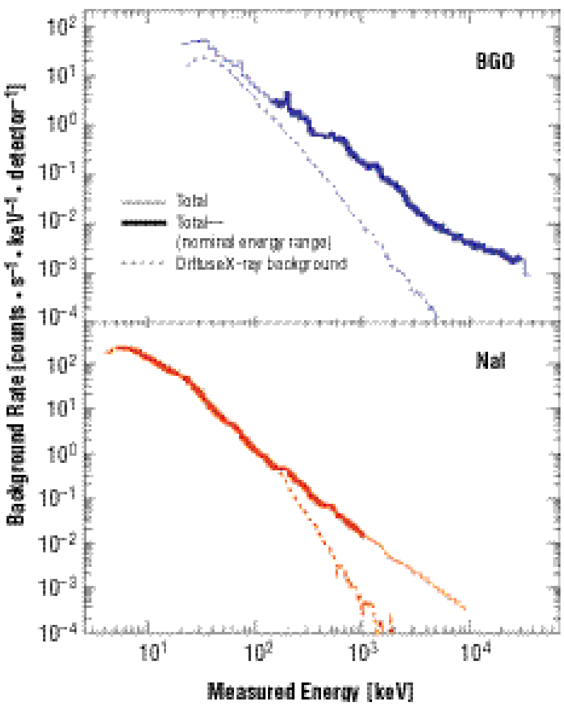


Figure 20—Background rates in the GBM BGO and NaI detectors. The estimates of the total rate and of the contribution of the diffuse x-ray are shown separately. The energy ranges of the channels are depicted in bold.

were detected. The response models are depicted in figures 15, 16, 17, and 19.

Two terms contribute most of the background rates in both NaI and BGO detectors: at lower energies the background from the diffuse sky flux dominates (Gehrels 1992), while at higher energies induced radioactivity dominates. Induced radioactivity is produced primarily by primary cosmic rays and high-energy (>100 MeV) proton irradiation in passes through the SAA. Lower-energy protons lose energy by ionization before they can produce significant spallation.

The background rate in the GBM NaI detectors was estimated by scaling the background rate of a BATSE LAD and correcting for the differing transparencies of the housings to the diffuse sky flux. The GBM NaI detectors have a full-width beryllium window, while the NaI of the BATSE LADs is covered by an aluminum window and a plastic scintillator with aluminum covers. We therefore calculated the diffuse sky flux contribution to the background of the BATSE LADs, subtracted it from the observed background, scaled the resulting background rates to the smaller size of the GBM NaI detectors, and then added the diffuse sky flux background rate calculated for the GBM detectors. The background estimate is on firm foundations because: 1) We have relied on actual space measurements in a NaI detector of similar aspect ratio, view-angle characteristics and in a similiar orbit, 2) since the BATSE LAD's and GBM NaI detectors have the same thickness, the same factor simultaneously scales for area and volume dependent background effects, and 3) the diffuse sky flux is well known. The contributions of the diffuse sky flux to the background rates were modeled with GEANT, using an isotropic flux rather than the plane waves used for the DRM's. A simple model of the spacecraft was used to block photons from a portion of the sky. The resulting background model and the diffuse sky flux contribution are shown figure 20.

The background in the GBM BGO detectors was estimated by scaling the background rates of BATSE Spectroscopy Detectors. Two Spectroscopy detectors operating at different gains were used to span the energy range of the BGO detectors. Since the purpose of the BGO detectors is higher energy coverage, and because the induced radioactivity dominates at these energies, the scaling was based upon the detector mass. In the energy band where the diffuse sky flux background dominates, this procedure estimates a background rate somewhat above our estimate of the diffuse sky background component (figure 20).

This procedure produces a good background estimate because both detectors are uncollimated with similar dimensions and similar view-angle characteristics. It is also known that for high-*Z* materials irradiated by high-energy protons, the intensity, decay and spectral characteristics of the resulting internal radiation, to first order, are dependent only upon the total mass of the material and not upon the particular target nuclei. This results from the large number of radioactive isotopes produced and the average nuclear characteristics of the spallation products (Fishman, 1977, and Barbier, 1969). This assumes that the major fraction of the mass on the detector is contained in the high-Z elements. This is true for both NaI and BGO; thus we have assumed similar induced radioactivity per unit mass for both types of detectors.

The LAT is included in our modeling to show the performance of the entire mission. Because we do not know the performance of the LAT that will be selected, we have modeled our conception of a baseline LAT that meets the baseline requirements given in table 1 of the NRA. Because of the sparsity of the specifications in table 1, we fleshed out a conception of the baseline LAT using our judgment of the general performance characteristics of any instrument in this energy range. For example, the NRA specifies the effective area as 8,000 cm^2, while any instrument will have a decreased effective area near its threshold. At 30˚ off-axis, our assumed effective area is 5,000 cm^2 at 1 GeV, 3,400 cm^2 at 100 MeV, and, just above the 20 MeV threshold, 520 cm^2 at 25 MeV.

Because the LAT will measure the direction of incident photons, there is no need to simulate the response to the isotropic sky flux. Assuming the GRB to be at high galactic latitude, we simply multiply the extragalactic diffuse-sky flux measured with EGRET (Sreekumar, et al. 1998) by the detector response matrix. In a simple model of source detection, we only use counts within the 68-percent radius of the point spread function. Correspondingly, the background is evaluated for this area and the effective area is reduced.

For each detector a simulated dataset consists of two spectra, a background spectrum and a source-plus-background spectrum. For the GBM detectors, a background-only spectrum is made by adding Poisson fluctuations corresponding to a 500 s observation of the background count-rate model. Real observations will have background variations. With BATSE, we model the variations with low-order polynomials. The BATSE experience is that statistical fluctuations dominate and these are well-represented by Poisson fluctuations on a constant background rate. For the LAT analysis a more sophisticated background model will be necessary to describe the temporal and directional variations. We assume that this model will produce background uncertainties corresponding to the Poisson fluctuations of a 10,000-s background observation.

The photon model used for these simulations is the standard Band “GRB” function (Band, et al. 1993), which is one representation of a four-parameter model in which two power laws are smoothly joined (section 1.1.2.3). The source count rate model is created by applying the detector response model to the assumed photon model. The total model for the source interval is the sum of the source count rate model and the background count rate model. Poisson fluctuations in the counts are simulated based upon a livetime slightly below the duration of the the real GRB spectrum that is being modeled.

The simulated data are fit using the standard forward-folding procedure: a parameterized photon flux model is assumed, the photon model is multiplied by the detector response matrix, and the resulting count model is compared to the detected counts using a statistic. For the comparison statistic, in order to correctly treat the small number of counts in the LAT channels and the high-energy BGO channels, we use maximum likelihood with the Poisson probability distribution. Similar results are obtained when χ^2 with model variances is used. The fits to the data of several detectors are true joint fits, with count models for each detector generated from a single photon flux model. The fitting software is directly applicable to real GLAST data.

2.5.1.2 Spectral Performance

GRB 940217 is used as an example because its spectral parameters are comparatively well determined from observations by BATSE, COMPTEL and EGRET. EGRET observed an 18-GeV photon 90 minutes after detectable emission had ceased in the BATSE data (Hurley, et al. 1994). Since it was well observed with COMPTEL and EGRET, it is necessarily a bright event, with a 50- to 300-keV fluence placing it in the brightest 0.5 percent observed by BATSE (fig. 21). The time history is complex, with a series of pulse complexes spread over 180 s (fig. 3).

Our simulation is based upon the time-integrated spectrum because that is the spectrum for which

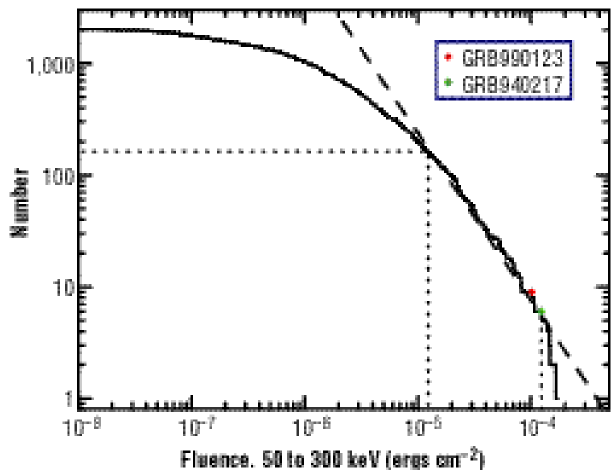


Figure 21.—The fluence distribution of GRB's. The fluences of GRB 940217 and GRB 990123 are shown in the context of all GRB fluences measured with BATSE over 8.5 years. The dashed line is a power-law of slope –3/2 indicating the fluence trend of bright bursts. The dotted lines show that more than 160 bursts have fluence values greater than one-tenth the fluence of GRB 940217. Correcting for the BATSE bursts for which data gaps prevent fluence determinations, ~24 bursts with fluences greater than one-tenth the fluence of GRB 940217 are observed yearly.

COMPTEL and EGRET spectral results have been reported. Analysis of the EGRET TASC data gives a high-energy power-law index of -2.5 ± 0.08 (Hurley, et al. 1994), while COMPTEL telescope data indicate an index of -2.6 ± 0.11 (Winkler, et al. 1995). We have obtained the four spectral parameters of the Band GRB function by fitting the data of three BATSE spectroscopy detectors, which together span the energy range 20 keV to 28 MeV, for a 188 s interval which includes essentially all of the burst flux. The COMPTEL and EGRET response is better at high energies, so we imposed the requirement that $\beta = -2.6$, obtaining from the fit the parameter values $A = 0.0181$ photons s^{-1} cm^{-2} keV^{-1}, E_{break} = 760 keV and $\alpha = -1.26$.

Because this is a very bright burst, the GBM would operate in memory conserving mode and accumulate TTE data from only the best-illuminated NaI detector. Our simulated spectrum (fig. 22) is therefore for one NaI detector viewing the source at 14.9˚ off-axis, and one BGO detector and the baseline LAT both viewing the source at 30˚ off-axis. In the NaI detector the burst is detected at high-statistical significance in each of numerous channels; the BGO detector sees the source in all bins including the 10 to 30 MeV bin, bridging the difficult few MeV region to the threshold of the baseline LAT, which detects the burst to about 1 GeV. The GLAST mission with the GBM would detect a burst like GRB 940217 over 5.3 decades of energy.

The shape parameters obtained from the fit are E_{break} =746 ± 12, $\alpha = -1.261 \pm 0.003$ and $\beta = -2.68 \pm 0.01$. Comparing to the values assumed for the simulation (listed above), the values for E_{break} and α are in excellent agreement, deviating by 1.1 and 0.3 σ respectively. The disagreement between the assumed and fit value for β is small in absolute units (0.08) but large in σ-units (7.1).

We now show that good results are obtained when we analyze a burst with the same spectral shape as GRB 940217, but 10 times dimmer. We do not use an actual dimmer burst as an example, because good COMPTEL and EGRET results on the spectra of such bursts are lacking. Because the cumulative fluence distribution follows a –3/2 power law down to at least 10^{-5} ergs cm^{-2} (fig. 21), bursts like the dimmed example will occur 32 times more frequently. Even though the –3/2 power law can no longer be understood as indicating which bursts originate in Euclidean space where cosmological effects are negligible, it is still an observational fact that fluence distribution of bright bursts is well described by a –3/2 power law.

We show in Figure 23 a simulation of GRB 940217, dimmed by X10 ($A = 0.00181$ photons s^{-1} cm^{-2} keV^{-1}) but otherwise using the Band GRB function parameter values given above. Because this is a dimmer burst, GBM would accumulate TTE data from two NaI detectors and we use simulated data from four detectors. Because of the decreased number of counts, the error bars on the parameters are larger: E_{break} = 1034 ± 146, $\alpha = -1.32 \pm 0.02$ and $\beta = -2.78 \pm 0.06$, deviating by 1.9 σ, 3.0 σ and 3.0 σ from the values assumed for the simulation. The quoted error bars are for single parameters of interest; the agree-

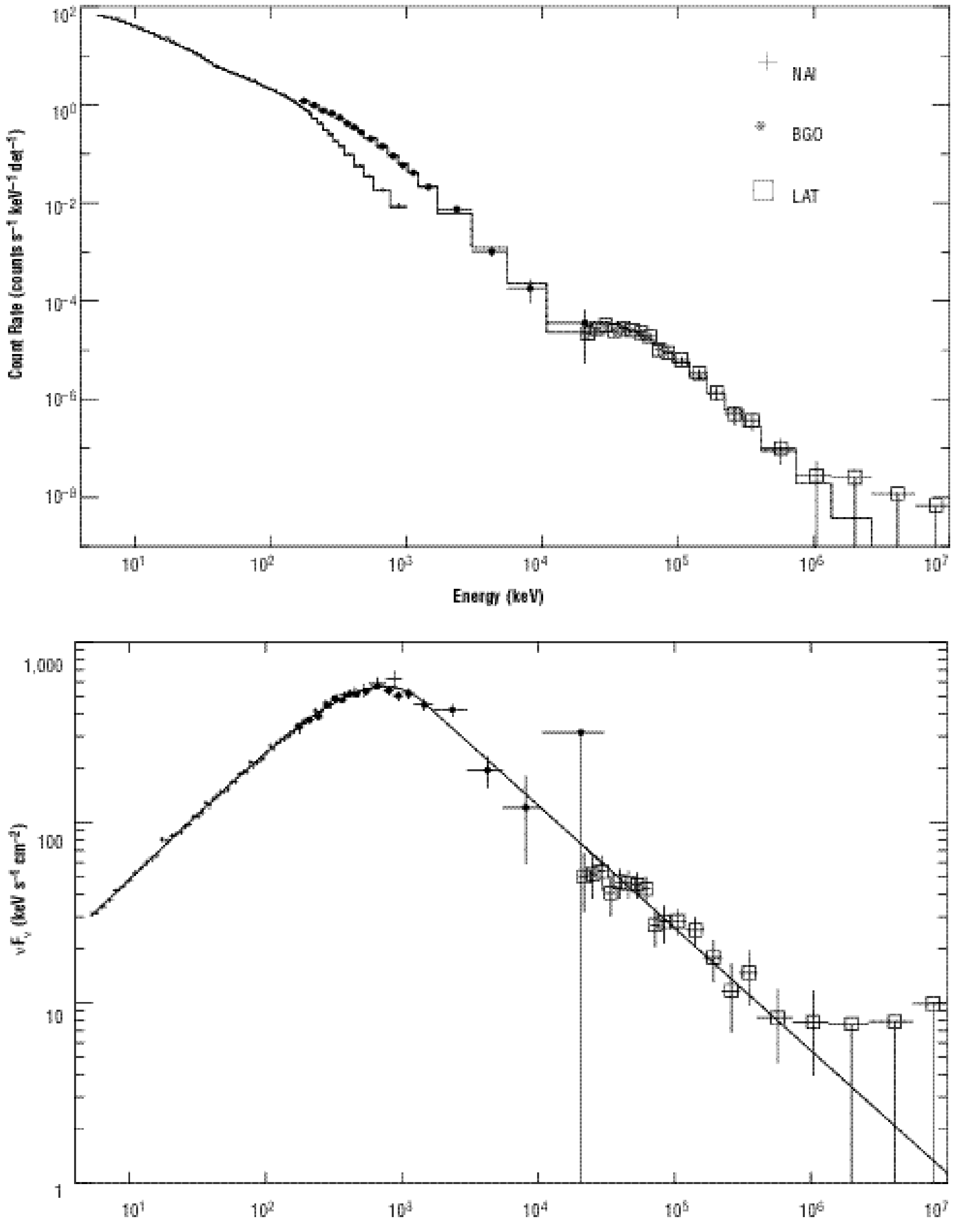
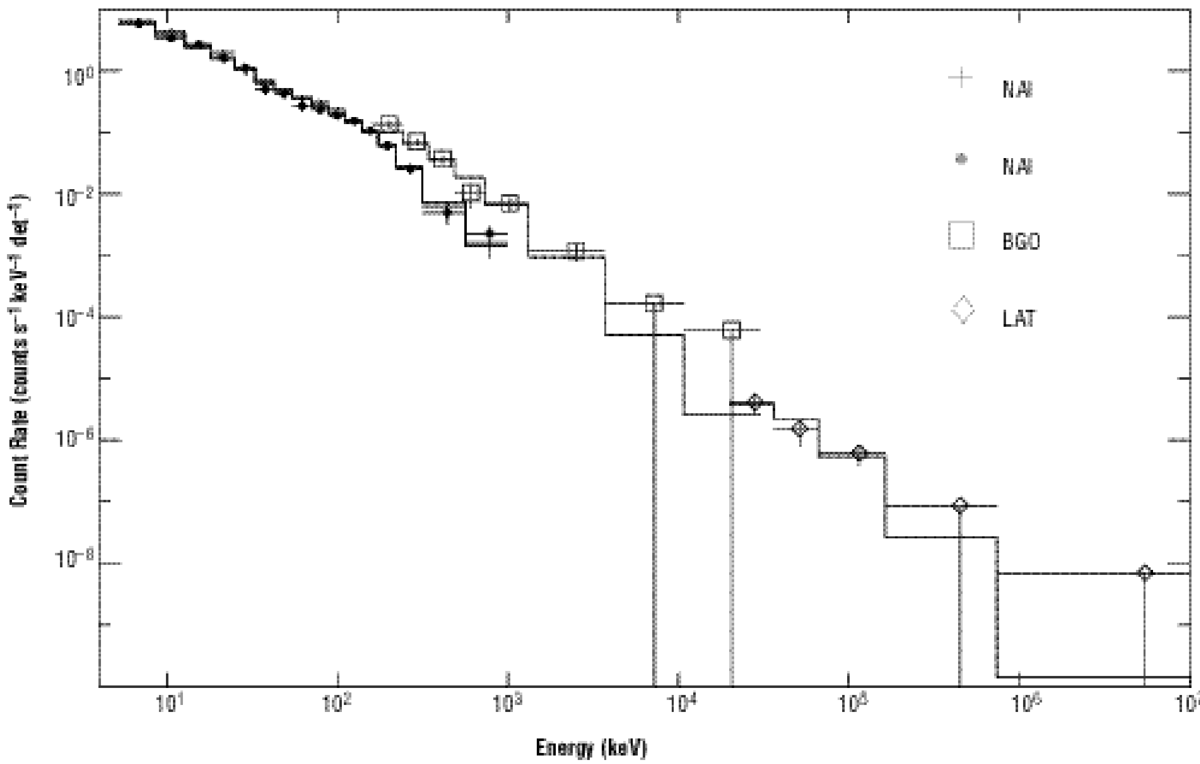


Figure 22.—Simulated spectra of GRB 940217.
The top box shows the best-fit count rate models (histograms) compared to the simulated count rate data (points), while the bottom box shows the deconvolved spectra. The channels have been rebinned into broader bins for display purposes—the fit is made to the data at full resolution. Points within 1σ of zero are plotted as 2σ upper limits.



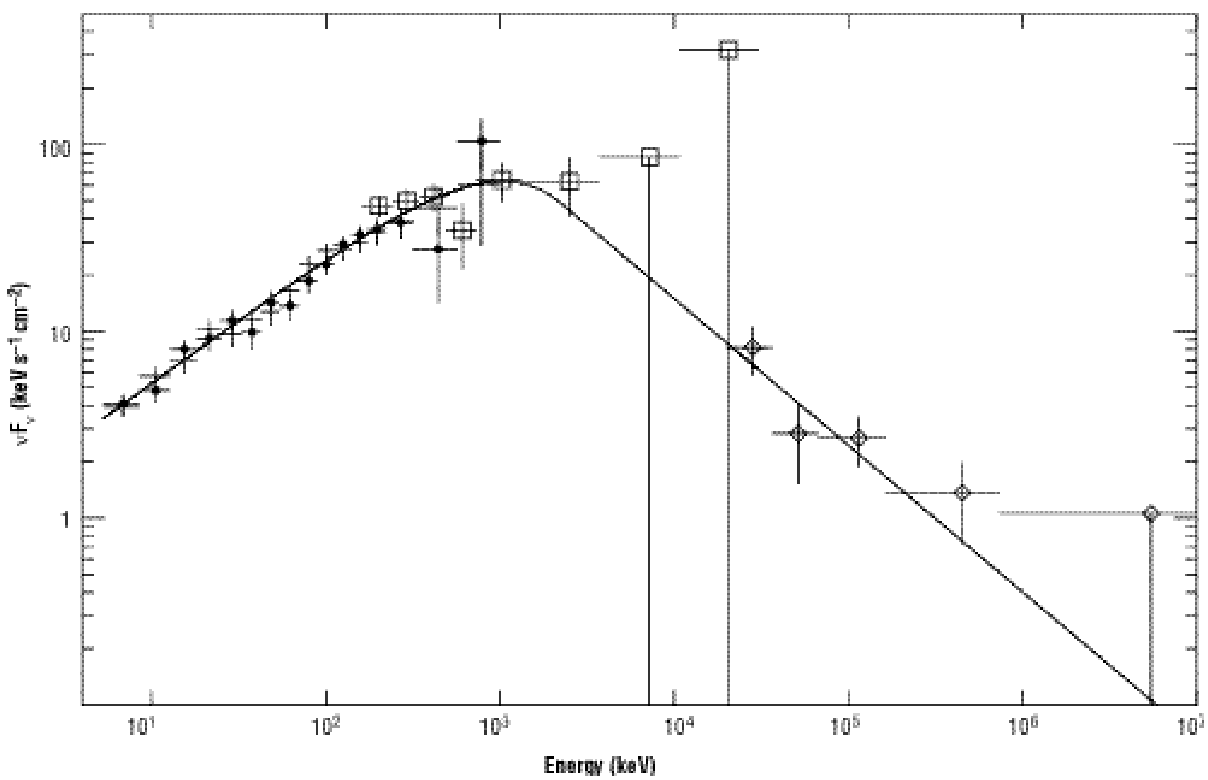


Figure 23.—Simulated spectra for a dimmed version of GRB 940217.
The spectral shape is that of GRB 940217, but the intensity has been reduced 10-fold.

ment is better when the parameter cross-correlations are considered.

2.5.1.3 Time-Resolved Spectroscopy Performance

Our second example burst is GRB 990123, the only burst for which prompt optical emission has been detected (Akerlof, et al. 1999). The wide-band spectrum observed with all four instruments on the CGRO is shown in figure 6. High-energy flux was detected in a low-gain BATSE Spectroscopy Detector, COMPTEL and the EGRET TASC (the EGRET spark chamber was not operating). In the gamma-ray band, the burst is notable for its high fluence (figure 21) and the high value of E_{break} reached for the peak of one pulse, 1470 ± 110 keV (figure 7). At the observed redshift of $z \geq 1.61$, the gamma-ray emission, if isotropic, is at least 1.6×10^{54} erg (Briggs, et al. 1999a).

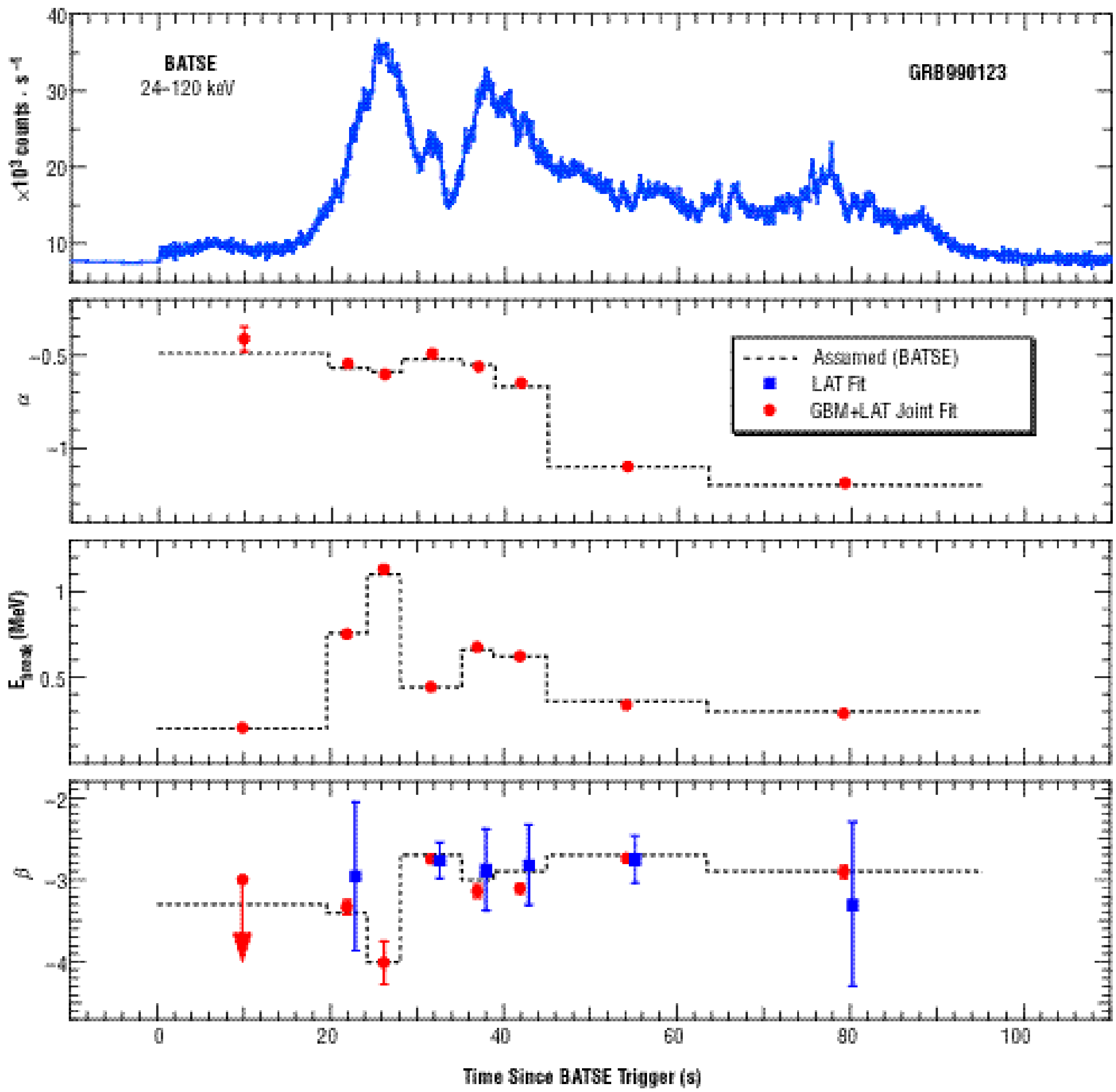


Figure 24.—Simulated spectral parameter time history of GRB 990123.
The top panel shows the light curve of GRB 990123 observed with BATSE. The dashed histograms in the remaining panels show the parameter values obtained by fitting BATSE data. Simulations of GBM and LAT data were made assuming the BATSE parameter values. The values from joint fits to GBM and LAT data are shown in red, while the LAT-only measurements of β are shown in blue.

Our goal is to use this burst as an example of GBM performance for time-resolved spectroscopy. Because of the coarse time resolution of the data from COMPTEL and EGRET, and due to the differing phasing of the accumulation intervals, the published spectrum (figure 6) is for a 32-s interval encompassing most of the burst flux. We therefore use data from two BATSE Spectroscopy Detectors to determine the spectrum for 8 intervals. The two Spectroscopy Detectors together cover the energy range 26 keV to 25 MeV with a flux detection to at least the 4 to 8 MeV band (figure 7). The time-resolved values obtained for β using the BATSE data cluster about the time-integrated value of ~–3 found by the four Compton instruments (Briggs, et al. 1999a table 1). The first row of each trio of rows in table 8 shows the Band GRB function parameter values obtained from this BATSE data.

Parameter values from the fits to the BATSE data are assumed for the purpose of simulating GLAST GBM and LAT spectra and therefore become the "true" parameter values to which the simulated results can be compared. Results from fitting the simulated GLAST spectra have both actual noise from the BATSE observation and simulated noise from the GLAST simulations. The eight spectra have a wide range of realistic GRB spectral shapes and demonstrate the performance of the GBM and LAT combination for time-resolved spectroscopy. The parameter values obtained by fitting one GBM NaI detector, one GBM BGO detector, and the baseline LAT are listed on the second row of each trio of rows in table 8 and are depicted with red symbols in figure 24. The agreement between the assumed values (dashed histogram) used to create the simulations and the best-fit GBM/LAT values is excellent with only one or two exceptions for β. The final row of each trio lists the values of the high-energy spectral index obtained from fitting only the LAT data (blue points in the bottom panel of figure 24). The LAT-only values are also in excellent agreement with the "true" values; however, the errors are much larger. In two intervals

Table 8.—Time resolved spectroscopy performance.

	Start time(s)	End Time(s)	A	E_{break} (keV)	Alpha	Beta
BATSE	0.090	19.648	0.015	200	–0.49	–3.3
GBM+LAT				203±9.3	0.410±0.067	<3.2
LAT						Not detected
BATSE	19.648	24.256	0.049	760	–0.57	–3.4
GBM+LAT				750±16	–0.548±0.016	–3.33±0.09
LAT						–2.96±0.91
BATSE	24.256	28.096	0.081	1100	–0.59	–4.0
GBM+LAT				1130±16	–0.603±0.009	–4.01±0.26
LAT						Not detected
BATSE	28.096	35.136	0.056	440	–0.52	–2.7
GBM+LAT				442±9.4	–0.494±0.019	–2.75±0.04
LAT						–2.77±0.22
BATSE	35.136	38.848	0.074	660	–0.55	–3.0
GBM+LAT				675±13	–0.560±0.014	–3.14±0.08
LAT						–2.88±0.5
BATSE	38.848	44.928	0.06	620	–0.67	–2.9
GBM+LAT				621±12	–0.649±0.012	–3.11±0.06
LAT						–2.82±0.49
BATSE	44.928	63.488	0.031	360	–1.1	–2.7
GBM+LAT				338±10	–1.10±0.010	–2.74±0.04
LAT						–2.75±0.29
BATSE	63.488	95.168	0.021	300	–1.2	–2.9
GBM+LAT				289±9	–1.19±0.010	–2.91±0.07
LAT						–3.3±1.0

there no significant flux detection in the LAT and therefore no constraint on the spectral index.

The combination of the GBM and LAT clearly provides a much fuller picture of the spectral shape and evolution of the burst than can be obtained with the LAT alone. The six measurements of the spectral index obtained from the simulated data of the baseline LAT are all consistent with their mean of 2.80 ± 0.15, so in this example the baseline LAT is unable to detect spectral evolution. We hope that the selected LAT will be more sensitive than the baseline; nevertheless any LAT by itself will be unable to measure the crucial parameters E_{break} and α.

Burst data from both the GBM and the LAT will consist of TTE, so the data from a burst could be analyzed for whichever time intervals seem appropriate, e.g., based upon pulse structure seen with the LAT. The error bars obtained for this example are small enough that in an actual analysis, finer binning would probably be selected.

2.5.2 Burst Detection

Capabilities for detecting and locating bursts are determined by size, number and orientations of the NaI detectors, and the degree to which the LAT blocks their FOV. Our calculations are based on several assumptions and approximations, described below.

Burst Detection Technique

Our baseline triggering scheme is similar to BATSE. We require two detectors to be above a threshold specified in standard deviations above background. The energy interval used is 50 keV to 300 keV, and the time interval used for sensitivity calculations is 1.024 s, although other trigger time intervals may also be employed, as is done with BATSE. The baseline threshold will be 4.5 σ above background, rather than the value of 5.5 normally used for BATSE. This reduction is possible because of the lower sensitivity of the Burst Monitor, which precludes triggering on fluctuations from Cygnus X–1. The accidental trigger rate, based on Poisson distributed statistical fluctuations in the background rate at a threshold of 4.5 σ, is about 0.05 per year.

Background

The background in the NaI detectors is readily scaled from BATSE, since the orbit will be similar and the detectors are the same thickness. The average rate will be 156 counts/s, with orbital variations of about a factor of 3.

Detector Orientations

In our baseline configuration, the detectors are oriented in four banks of three units. The zenith angles of the detectors in each bank are 30°, 60°, and 90°. Each bank is oriented at a different azimuth, equally spaced by 90°. Only the NaI detectors are considered in these calculations.

LAT Blockage

We model the LAT blockage using the conservative assumption that it blocks all azimuthal angles, in spacecraft coordinates, beyond 90° of the azimuth of the detector normal. This is equivalent to modeling the LAT as an infinitely long cylinder. There is no blockage of detectors at 90° zenith angle and the amount of blockage approaches half of a detector’s FOV as the zenith angle approaches zero.

Detector Response

Based on BATSE experience, we approximate the detector response between 50 and 300 keV as a single conversion factor of 0.8 counts/photon. With this value, the simplified calculation of trigger efficiency employed here reproduces the BATSE efficiency quite well. For these calculations, the angular response is considered to be a cosine function.

The baseline system has full-sky coverage for sufficiently strong bursts, although the sensitivity drops rapidly at zenith angles above ~120°. Figure 25 shows the projected area, in units of one detector (126.7 cm^2), of the second most brightly illuminated detector as a function of zenith angle for several azimuthal angles. This plot provides an indication of the trigger sensitivity, since triggering requires two detectors above threshold. Figure 26 shows a similar plot for the sum of the detectors illuminated by the burst. This plot provides an indication of the quality of spectra produced by summing detector outputs. Averaged over the whole sky, the average projected area is 340 cm^2, equivalent to 2.685

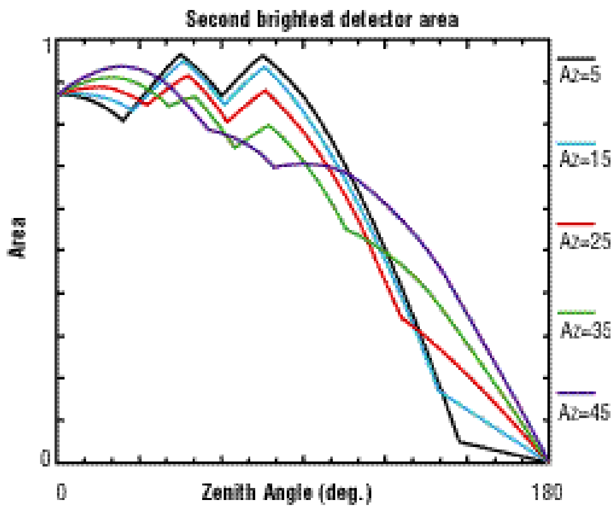


Figure 25.—The projected area of the second best-illuminated detector. In a trigger scheme which requires a significant signal in two detectors, the second detector is the critical one.

detectors. The effective FOV, defined in the GLAST AO as the sensitivity integrated over solid angle divided by the peak sensitivity, is 8.6 steradians. Locations can be computed for sufficiently strong bursts that illuminate three or more detectors, which is the case over a solid angle of 11.5 steradians.

The burst trigger sensitivity is shown in figure 27. The fraction of the sky over which a burst is detectable is plotted against the peak flux, where peak flux is defined as integrated over 1 s and between 50 and 300 keV. The absolute threshold is 0.57 photons/cm^2–s, although lower flux bursts will be detected at times when the background is lower than the average. The flux at which the system is 50 percent efficient is 0.74 photons/cm^2–s, at this flux level bursts can be detected over 2π steradians. This is a conservative calculation of the threshold, since it assumes the BATSE trigger algorithm, which demands two NaI detectors individually above threshold. For the larger number of detectors used here, this scheme is clearly not optimum. Lower thresholds can be achieved by summing the rates of closely pointing detectors and including the omnidirectional BGO detectors. For example, a burst with a peak flux of only 0.35 photons/cm^2–s will yield a 5 excess above background in the 1-s summed rate of the four upward facing detectors. Alternative trigger schemes will be investigated in phase B. Independent of the GBM triggering, bursts identified by the LAT can be analyzed using the 0.256-s resolution BTIME data at fluxes well below the trigger threshold.

Based on the Burst Monitor sensitivity and the burst intensity distribution determined by BATSE, we find that the Burst Monitor will trigger on about 150 bursts per year. This rate calculation assumes SAA dead time and Earth blockage similar to BATSE and random pointing directions. The rate

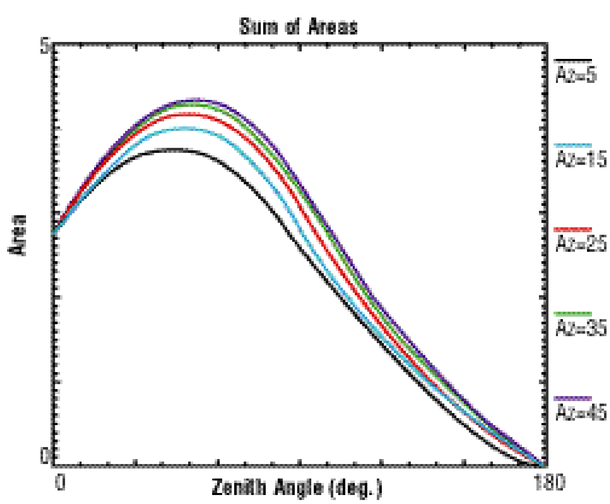


Figure 26.—The projected area of the detectors illuminated by the burst.

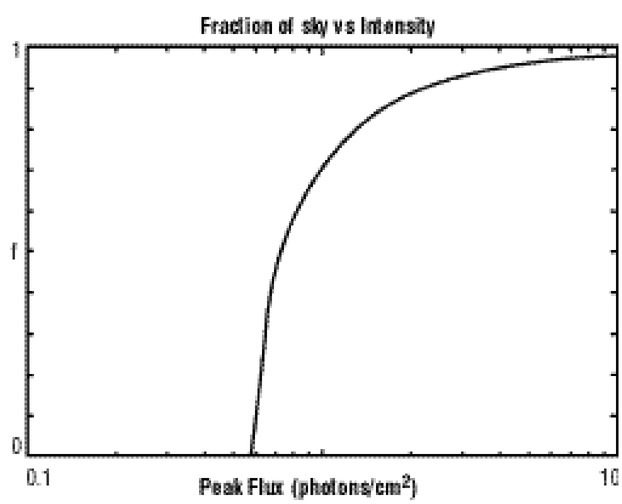


Figure 27.—Trigger sensitivity for bursts. The curve shows the fraction of the sky over which bursts of a particular peak flux will trigger the GBM.

will be up to 50 percent higher if the GLAST +*Z* axis is preferentially zenith pointing, as currently planned. Based on the GLAST Science Requirements, the LAT will trigger on 50 to 100 bursts per year. Although this estimate is sensitive to the poorly known distribution of spectral indices above 1 MeV, the GBM will probably have a more sensitive burst trigger than the LAT for all but very hard bursts.

2.5.3 Burst Locations

Locating GRB's by comparing rates in detectors that are facing in differing directions was pioneered by the Russian Konus experiments (Mazets, et al. 1981). The method has been very successfully implemented in the BATSE instrument. Our experience with locating GRB's using BATSE will guide us in locating GRB's with the GBM.

For the GBM, we plan a three-stage refinement of locations of GRB's: On board, ground automated, and ground manual. Each serves a different purpose and represents a different trade between accuracy and speed.

The onboard location is used to repoint the spacecraft to allow the LAT to detect delayed high-energy emission. The location must be computed in a short time—short compared to the time necessary to repoint. Several seconds is clearly adequate. Accuracy of about 20˚ is sufficient to ensure that the source is within the large LAT FOV. Simple algorithms are easily capable of meeting these requirements. BATSE is, in fact, currently providing onboard locations to OSSE that are this good. Our baseline algorithm for GBM neglects atmospheric and spacecraft scattering. Computing much better locations on board requires more memory and a faster CPU, increasing the costs significantly with little scientific return.

The ground automated location is computed in near real time on the ground and is used to provide coordinates for rapid follow-up by ground-based instruments. The model for this capability is the GCN system currently in use on the CGRO. When a burst triggers the GBM, the data needed to compute accurate locations (TRIGDATA) are immediately transmitted to the MOC. The burst location is computed automatically at the mission operations center (MOC), using a program provided by the GBM team, and sent electronically to any interested observers.

The ground manual location is determined with human intervention after the data are received at the instrument operations center (IOC). These locations are used for the burst catalog and to optimize the LAT sensitivity to the burst. The model for this capability is the current production of burst locations, by the BATSE team, within a day or two of the occurrence of a burst. The operator optimally selects the source and background intervals, resulting in the best available burst location.

Statistical fluctuations in counts received by each detector result in location solutions differing from the true location. The effect of Poisson fluctuations on GBM location accuracy can be accurately simulated by computing how much the rates change with azimuth and zenith angles, compared to statistical fluctuations. The average angular uncertainty is 9° for a 1 s burst with flux of 1 photon / cm^2 s, a flux value which is less than a factor of two above the trigger threshold. Figure 28 shows a color-coded map of the angular resolution as a function of zenith

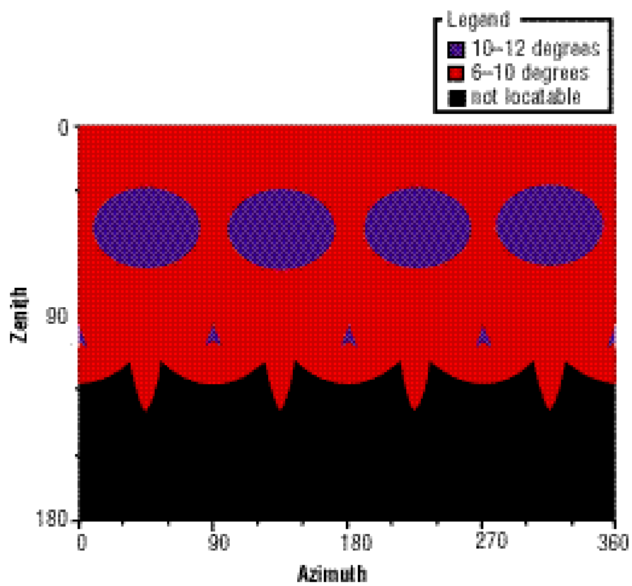


Figure 28.—Map of statistical errors in location of a 1-s burst with peak flux of 1 photon cm^{-2} s^{-1}.

and azimuth angles. At 10 photons/cm^2–s, the statistical error is 1.5°.

Because statistical location errors arise from fluctuations in the detected counts, all three stages of locating GRB's will have similar statistical errors when all of the burst data have been received. For long GRB's, a succession of onboard and ground-automated locations will be produced, with decreasing statistical errors as more counts are received. The ground manual locations will have optimum statistical errors because of careful human selection of background and source time intervals.

In addition to statistical errors, the location process is also subject to systematic errors. These are more difficult to estimate a priori. Our BATSE experience is valuable, allowing us to estimate the systematic errors of each GBM location method by comparison to the systematic errors obtained in a similar approach to locating GRB's with BATSE. The methods and development of the BATSE location algorithm LOCBURST are described by Pendleton et al. (1999). The initial primitive version of LOCBURST guides us in estimating the accuracy on the onboard locations. The initial LOCBURST algorithm, which is the first stage of the current program, inverts the rates of the three detectors with the highest rates to obtain the location. No complex fitting procedure is used, spectral effects are implemented using tables indexed by hardness ratio, and atmospheric scattering is ignored. The simplicity of this approach makes it feasible to implement on board at reasonable cost. This approach obtains systematic errors below 6˚ for 50 percent of the locations and below 12˚ for 80 percent of the locations (Pendleton, et al. 1999). Combining the 12° systematic error which 80 percent of the locations will meet with the 9° statistical error for a burst with an intensity 1.8 times the trigger threshold, a total error of 15° is obtained, easily meeting the accuracy requirement for repointing the LAT.

The error distribution of locations produced with the current version of LOCBURST, as used to produce the 4Br catalog (Paciesas, et al. 1999) has been derived (Briggs, et al. 1999b) by comparing a subset of BATSE locations with the more accurate locations determined with the IPN. The IPN uses arrival time information, at widely separated spacecraft, to triangulate the location. With two spacecraft, a narrow annulus of typical width, 10 arcmin, is obtained. With three or more spacecraft, the intersecting annuli give a small error box (Hurley, et al. 1999). When intersecting annuli give a small error box, one has a direct measurement of the error in the BATSE location. In more common cases, where only single annuli is available, the separations between the BATSE locations and the annuli can be used to constrain the distribution of BATSE total location errors. This comparison of BATSE and IPN locations has produced a two-term model for BATSE location errors. Most of the probability is in a core term with a small systematic error, while a small fraction of the probability is in a tail term with a larger systematic error. We have also found that the systematic error values depend on the spectral resolution of the BATSE data used to determine the location.

Locations based upon the BATSE 16-channel data type (CONT) have 82 percent of the probability in a core with σ=1.67° and 18 percent of the probability in a tail with σ=5.4°. We believe that the dominate causes of the systematic error are the circular error box approximation, the approximation of the spectrum as a power law, "edge" cases in which the burst is located 90° from the axis of a detector, and imperfections in the response model. Cases in which the location is at 90° to some detectors cause the location to be well determined perpendicular to those detectors, but poorly determined parallel to them, i.e., highly elliptical error boxes. Additionally, in these cases, the location becomes highly dependent on the power-law index, which controls the importance of scattering from the Earth's atmosphere.

The GBM design and ground location algorithms will improve on all of these systematic error causes. The most important improvement is the increased number of detectors: 12 NaI detectors viewing ~3π steradians instead of 8 detectors viewing 4π. Over most of the FOV there will be enough detectors with a non-edge view of the burst to constrain the location in all directions, thereby producing nearly circular error boxes, e.g., bursts over 6.3 steradians are within 70˚ of the axis of four or more detectors. With BATSE, bursts occasionally presented localization problems when only two detectors showed significant flux. The BATSE response model is deficient because the computing power of 1990 required the detector response to be averaged over azimuth and because the spacecraft mass model is too crude. Current computing power will allow a full mapping of the detector response and we expect that an accurate mass model will be developed for GLAST, which is a simpler spacecraft than CGRO. We will also use more accurate spectral models than the power law currently used by the BATSE algorithm.

The ground-automated locations will be based upon the rates provided in the TRIGDATA datatype, which will probably have the same resolution as the BTIME data, i.e., 4 energy channels and 0.256-s temporal resolution. This automated algorithm will probably use a power-law spectrum or a small library of more complex spectra, and will report circular error regions. This is quite similar to BATSE locations based upon 4-channel data, which currently have a systematic error distribution with 82 percent of the probability in a core of 2.7° and 18 percent of the probability in a tail of 5.4° (Briggs, et al. 1999b). We estimate that the ground automated algorithm will have a systematic error between 2° and 3°, which will enable ground-based observations by specialized telescopes with wide FOV, as was done with ROTSE to detect the prompt emission of 990123 in response to a BATSE automated location (Akerlof, et al. 1999).

The ground manual algorithm will have additional improvements, such as using 128 channel TTE data to obtain a more accurate spectral model, better selection of the source interval and modeling of the background, and generation of elliptical error boxes. The detector response model will fully include response variations over direction and energy, and differing responses of the detectors because of their positions on the instrument. This represents an improvement over the BATSE analysis of 16-channel data, which has a systematic error distribution with 82 percent of the probability in a core of 1.67° and 18 percent in a tail of 5.4°. We expect a modest reduction in the width of the core and a substantial reduction in the fraction of the probability in a wide tail, resulting in a typical systematic error of about 1.5° or less.

2.5.4 False Trigger Rejection

If the capability is implemented to slew the spacecraft in response to a Burst Monitor trigger, it will be important to avoid false triggers arising from solar flares, electron precipitation events, etc. Much of the information required for trigger identification is generated by the burst location algorithm. Electron precipitation in the vicinity of the spacecraft is characterized by approximately equal rates in oppositely facing detectors and very poor fits to a point source model. Location and high fluxes below 25 keV efficiently identify solar flares. Electron precipitation events, at a distance from the spacecraft, are somewhat more difficult to identify in real time. They usually appear as long, slowly rising humps in the background, near the latitude extremes of the orbit, peaking at slightly different times in different facing detectors, with computed locations near the horizon. The Burst Monitor will therefore provide a slew trigger only if the rate data indicate a high probability that the trigger is in fact a GRB.

Spacecraft slews that are initiated by false triggers could seriously impair the scientific return of GLAST. Fortunately, our team has extensive experience from BATSE in recognizing these false triggers, and the Burst Monitor detectors and trigger scheme are similar to those of BATSE. We can therefore provide assurance that false burst triggers will be not be a problem for GLAST.

2.6 Spacecraft Interface

2.6.1 Mechanical

An important feature of the mechanical design of the GBM is a high degree of flexibility in positioning the components. This is crucial since the physical characteristics of the main instrument and the spacecraft are not yet specified. This flexibility is achieved by using relatively small detectors, but increasing their number to achieve sensitivity and redundancy, even with the main instrument significantly reducing any one detector’s FOV. We assume the conservative case that all Burst Monitor components must be out of the LAT FOV, and only on the two sides not occupied by the solar panels. Even

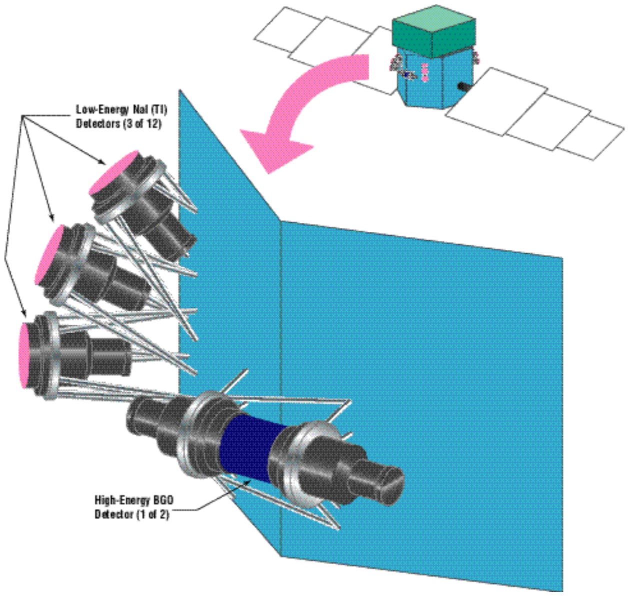


Figure 29.—Detector placement concept. Detector placement is flexible and will be coordinated with the spacecraft contractor.

Table 10.—Power.

Component	Power/Unit	Total Power
BGO detector	0.6	1.2
NaI	0.3	3.6
DPU	4	4
LVPS Losses	4	4
HVPS Losses	5	5

with these constraints, the Burst Monitor components are easily accommodated.

Figure 29 (same as 11) shows one possibility for mounting the detectors. Two BGO detectors are positioned on each side of the LAT, providing full sky coverage. The NaI detectors are mounted in four banks of three, with each bank at a different azimuth, and at different zenith angles. Each detector, of course, is blocked by the LAT over a large fraction of the sky. It is important to note that almost any mounting arrangement is satisfactory as long as the following conditions are met: 1) Two BGO detectors must be on opposite sides of the LAT, 2) all detectors are unobstructed in the +Z direction, and 3) the NaI detector normals must sample a wide range of azimuth and elevation angles. If the Burst Monitor is descoped to a smaller number of NaI detectors, their viewing angles will become somewhat more constrained to assure adequate sky coverage.

Table 9 provides a summary of the mass and size of the various components. The total mass is estimated at 54.5 kg with 20 percent contingency on all items except the crystal mass. Most of the mass is in the detector assemblies, and is known quite accurately, based on measurements of BATSE flight PMT assemblies. The electronic boxes are small and present no mounting problems. Mounting structure, to be provided by the spacecraft contractor, is not included.

Table 9.—Mass and size.

Component	Mass (kg)	Size (cm)	Number	Total Mass (kg)
BGO crystal	11.47	12.5 cm dia. × 12.5 cm	2	22.94
BGO housing	0.28	2 mm thick	2	0.56
NaI Crystal	0.59	12.5 cm dia. × 1.25 cm	12	7.08
NaI Housing	0.028	2 mm thick	12	0.34
PMT (inc. housing)	0.5	12.5 cm dia.	16	8.0
DPU	1.0	10 cm × 10 cm × 10 cm	1	1.0
HVPS	1.5	TBD	1	1.5
LVPS	1.5	TBD	2	3
Cables	6	n/a	n/a	6
Contingency	20% on all items except crystals			4.1
Total				54.5

2.6.2 Electrical

The electrical interface presents no complications. The Burst Monitor requires unregulated power, clock, command, and telemetry lines. Communication with the LAT, if desired, can be achieved through the spacecraft using data in the telemetry packet, or by a direct interface to the LAT. The power requirements are summarized in table 10. The total power is 17.8 watts, without contingency.

The required telemetry rate is normally 4 kbps, increasing to 9 kbs during bursts, as was described in more detail in section 2.2.

2.6.3 Thermal

The spacecraft will provide thermal control and insulation. The MSFC Engineering Directorate will use thermal radiation analyzer system (TRASYS) and system improved differencing analyzer (SINDA) computer models to support the GRBM thermal and thermal/vacuum testing. Preliminary analysis shows the following thermal requirements.

Detectors

0 to 20 °C operational, –10 to 30 °C storage, stable 1 °C over one orbit. The stability requirement is derived from the need for short term gain stability. The AGC can maintain stability over longer times.

Electronic Boxes

0 to 50 °C operational, –30 to 90 °C storage.

2.7 Ground System and Operations

2.7.1 Requirements and Operations Concept

The ground system for the GBM is a hardware and software system that accepts instrument data from the GLAST MOC and produces scientific data sets. The system also monitors instrument performance and safety.

The GBM IOC receives data from the instrument via the MOC, and converts it into standard low-level data products for distribution to the GLAST SOC. The system data flow for GBM is shown in figure 30.

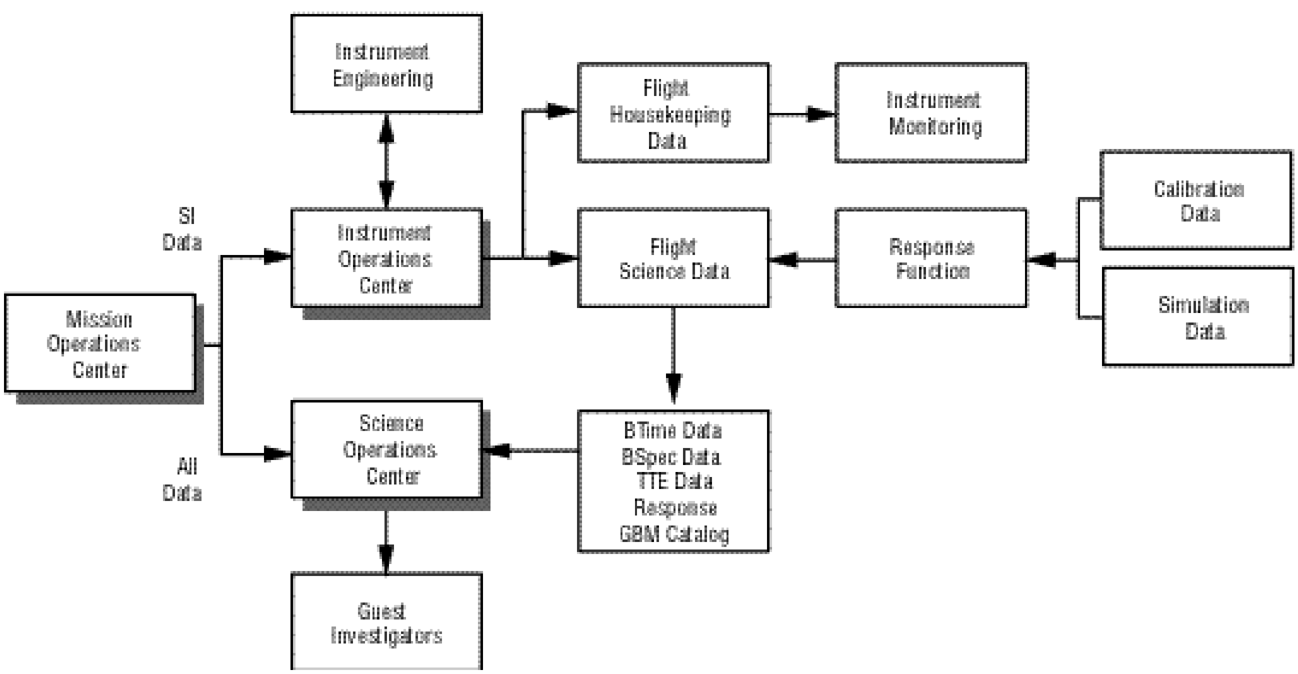


Figure 30.—System Data Flow for the GLAST Burst Monitor.

Table 11.—Responsibilities of the GBM IOC.

Responsibilities of the GBM IOC
Nominal instrument operations and monitoring
Instrument calibration
Production and maintenance of operations software
Production of data analysis software
Production of low-level standard data products useable by the community
Verification of flight data
Processing of data to support the IPI team's investigations
Support of the MOC and Guest Observer Facility

The IOC is responsible for monitoring the instrument and generating instrument commands. To avoid duplication and reduce costs for this secondary GLAST instrument, we plan to have tasks completed by the GLAST SOC whenever reasonable. Specific responsibilities of the Burst Monitor IOC are listed in table 11.

The GBM operations concept utilizes an approach that minimizes the costs and risks of computer hardware and software development. The same instrument ground support equipment (IGSE) and software developed and employed for instrument integration and testing (I&T) is also used for on-orbit nominal operations tasks such as instrument monitoring, state of health verification, and commanding. By using the same IGSE hardware and software during instrument I&T and normal flight operations, development costs are lower, and risk is minimized. Software development for instrument monitoring and for data reduction and analysis is based on the prior flight data operations experience of the BATSE and COMPTEL instrument teams on the CGRO. Software developed for analysis of BATSE GRB data serves as the basis for the GBM data analysis software.

2.7.2 Instrument Ground Support Equipment

The GBM ground system provides instrument monitoring and commanding, data reduction and processing, and data distribution. The ground system consists of three components: Calibration hardware and software (see section 2.3.1), ground support equipment, and operations equipment. Calibration hardware accepts raw analog detector output for input into the calibration software that is used to generate the detector response function. The required hardware is available as standard commercial, off-the-shelf products. Ground support equipment, consisting of a PC or workstation and associated peripherals and software, is used during I&T to accept output from the instrument DPU or spacecraft simulator. Ground support software provides data verification and analyses of detector performance. During nominal flight operations, the IGSE is connected to the MOC network, and receives daily operations data. The housekeeping and instrument status data are extracted and formatted, for visual verification of instrument performance by operations personnel. The science data are forwarded to the operations equipment for reduction, analysis, and distribution. Operations equipment consists of several PC's or workstations and associated peripherals and software that receive and display data from the IGSE.

Each of the major components of the GBM ground system are tested prior to verification of the full ground system. After test readiness of the components is validated, the ground system is activated for end-to-end testing of data flow and component compatibility, using the IGSE in its instrument integration mode, accepting data from the instrument DPU or spacecraft simulator.

Continuity of the ground system software tools is the central feature of our operations software development approach. This is a low risk, cost-efficient approach. The same institution that has the responsibility for using the IGSE for instrument operations is responsible for its development from the earliest phase of the project. IGSE software development begins with integration with the DPU or spacecraft simulator. Software development continues through the instrument I&T phases and the integrated spacecraft test phase. During those phases, the operator tools, for commanding state of health and configuration verifications, are refined based on the accumulated experience gained while meeting the requirements of instrument testing and calibration.

The same IGSE operator tools are used for integrated mission system development, including end-to-end testing. Prior to and during this phase, the tools to support network communications, planning, stored commanding, anomaly response, and mission system administration are developed and verified.

The GBM instrument simulator (the instrument engineering model) is maintained and operated at the IOC. It is used for testing operational software updates and DPU performance prior to uplink to the flight instrument. It is also available for hardware and software anomaly investigations.

2.7.3 Nominal Instrument Operations

The IOC has the responsibility for nominal operation of the GBM instrument. Table 12 lists the top level ground support software tasks and summarizes the functions of each module. Software modules to support these functions are fully developed, tested and validated prior to launch. The ground support hardware is a PC or workstation connected to the GLAST MOC network.

Most instrument commanding is automated and accomplished via preplanned or stored commands. The use of the real time commanding capabilities is expected to be rare after initial on-orbit instrument activation, checkout, and tuning. All instrument commands and flight software updates, with certain exceptions for anomaly response, are processed through the Burst Monitor IGSE at the IOC, and transferred to the MOC for transmission to the spacecraft. Exceptions include instrument power on/off and related safe hold commands. These and other related spacecraft safety commands are prepared and uplinked by the MOC using predefined procedures.

Command data verification is accomplished by pre-uplink screening of commands through a configuration controlled database. All flight software updates are verified prior to uplink using the instrument simulator. Instrument status, state of health, and functional verifications are accomplished using the IOC IGSE data reduction tools. These tasks are automated and the output is reviewed routinely by the instrument operators. Anomalous conditions are the subject of alerts to the appropriate personnel, further study of the IGSE data, and appropriate response and reporting.

2.7.4 Instrument Ground Calibration

Calibrations with sources and Monte Carlo simulations will establish the baseline detector preformance before launch, as described in section 2.3.1. On orbit, the detector gains are maintained

Table 12.—Instrument operations software tasks.

Task	Function Summary
Network Communications	Use established common network protocols for two-way communications with the MOC; security monitoring; problem alerts
State of Health Verification	Housekeeping monitors; instrument parameter diagnostics; limit alarms and other alerts
Commanding	Command database; real-time commands; stored commands; command verification
Administrative	Administrative messages; operations activity records; anomaly records
Anomaly Response	Automated alerts; responses for predefined telemetry anomalies
Data Transfer	FTP transfer of raw data from the MOC
Detector Status	Format and display housekeeping data of detector operational parameters (temperature, voltage, etc)
Reduction and Analysis	Data reduction and analysis; delivery to SOC
Archiving	Archive raw instrument data

using the AGC technique described in section 2.4. Ground software verifies the AGC operation and detector resolution by maintaining an archive of position and width of the 511 keV annihilation line, which will be readily visible in both the NaI and BGO detectors. Additional lines in the detector spectra allow verification of the channel to energy nonlinearity.

2.7.5 Instrument Monitoring

Instrument status monitoring is an automated feature of the IGSE software. Details of the instrument's commanded status are periodically telemetered to ground and compared by the IGSE with the expected parameter values. Alarms and automated operator alerts are generated when selected differences between the expected and the telemetered status are registered. These records are logged for subsequent operator analysis and anomaly reporting.

Operations personnel generate daily summary reports, charts, and graphs of instrument status and performance for visual inspection. Data validation is accomplished through generation of daily orbit plots and trigger event data for visual inspection for anomalies.

2.7.6 Operations Software

Daily operations with IGSE at the IOC include processing of instrument housekeeping data and limited processing of scientific data, for quick-look instrument functional verification, record keeping, and timely response to anomalies, with the goal of minimizing loss of observing time.

Operations software reads raw instrument data received from the MOC and extracts housekeeping and science data. Science data are reduced and formatted into flexible image transport system (FITS) format, in preparation for delivery to the SOC. The software creates sets of daily standard plots of both housekeeping and science data. Standard plots include housekeeping instrument parameters (temperatures, voltages, etc.), orbital plots of full-day detector rates (BTIME and BSPEC data types) for inspection and analysis, and detailed plots of GBM trigger data.

2.7.7 Data Analysis Software

Analysis of event light curves and count spectra is performed using software based on mature data display and spectral fitting software, developed for use in the analysis of GRB data obtained with BATSE. Time-resolved spectroscopy is performed using the program WINGSPAN, developed by the BATSE science team, for multi-detector time-resolved spectral analysis. This robust, forward folding, spectral fitting package contains the capability for simultaneous spectral fits to data from multiple detectors. This capability is required for support of the GBM IPI team's science investigations (see section 1.5). Some of the functions implemented in this software, such as data and response readers, will require modification for the GBM datasets.

An event location algorithm will be developed for on-ground processing of trigger event locations on the sky. The premise for computing the location of a given event observed with the GBM is based on the relative counting rates, due to the differing projected area in those detectors that observe the event. This technique has been successfully used to compute locations of gamma-ray events observed with the eight detector module BATSE system. Additional details are provided in section 2.5.3.

The GBM triggered event data are formatted into the binary platform-independent FITS data format. The data analysis software is based on this data format. Raw science instrument data and FITS data files are archived to digital video disk (DVD). DVD is a cost effective, high volume, permanent storage medium, similar to a compact disk (CD), but with a much larger storage capacity see section 2.7.10.

2.7.8 Data Products

Science data reduction is performed at the Burst Monitor IOC in Huntsville, AL. These tasks prepare flight data for delivery to the SOC, and process data for analysis by the IPI team in accordance with the proposed science investigations. Reduced science data are transferred to the SOC in the portable binary FITS format. After a 30–60 day in-orbit checkout, all data products are delivered to the SOC in useable form within 6 weeks of data receipt, with the exception of the published GBM Burst Catalog,

Table 13.—Delivery data products.

Product	Content Summary
Background Data (BTIME, BSPEC)	Count spectra in continuous coverage mode; data delivered to the SOC as files in FITS format containing continuous coverage background spectra; each file contains a 24-hr daily dataset
Burst Data (TrigData, TTE)	Count spectra at high time and energy resolution for triggered events in FITS format; also ±2,000 s of BTIME and BSPEC background spectra
BTIME Display	Software to read Burst Data event files and display lightcurves as a function of energy
BSPEC Display	Software to read Burst Data event files and display time integrated count spectra
Skymap	Angular distribution of triggered GRB's
Calibration and Response	Combine calibration and simulation data to generate instrument response function for all triggered events; response functions are formatted into FITS files, and a software response reader is provided
Event Catalog	Catalog containing parameters of interest for all GBM-triggered events, including parameters such as location, duration, and intensity
FITS Tools	Data readers for all GBM FITS files
GBM User's Manual	User's manual for data products; software documentation
GBM Instrument Status	Documentation of instrument configuration; operations summary log

which will normally be released at the end of every 2 years of observation. All data will also be continuously available via the World Wide Web, with new data added weekly. During the first 12 months of observations, the instrument may not be completely calibrated, and thus any data made available will be subject to later revision. Table 13 lists the data products delivered to the SOC.

After the first 12 months, the GLAST observing program will be based on a guest observer program (GOP). Data gathered for a selected investigation will be verified by the guest observer (GO). After a 3-month verification phase, the data are delivered to the SOC.

The FITS format, selected for delivery data products, is a data format designed to provide a means for convenient exchange of astronomical data between installations whose standard internal formats and hardware differ. The FITS standard is the format adopted by the astronomical community for data interchange and archival storage. The FITS support office, at NASA's Goddard Space Flight Center (GSFC), is responsible for documenting the FITS standard defined by NASA's Science Office of Standards and Technology, participating in its evolution, and advising NASA astrophysics missions on how to present their data in FITS format. Although this format allows for transparent data access from all popular computer platforms, users must develop or obtain separate software to read and display the data from the FITS file. The IOC provides software optimized for GLAST datasets. Investigators can also use software from other available packages such as FTOOLS and XSPEC for GBM data analysis. FITS readers for GBM datasets are provided as part of the standard delivered data products.

2.7.9 Verification of Flight Data

Flight data are verified by daily operations personnel and Instrument Principal Investigator (IPI) science team members. Initial verification is performed via daily summary charts and graphs of instrument performance and safety parameters, as well as raw data that are produced by operations personnel as part of GBM daily operations. These reports and data plots are examined for indications of anomalies.

Analysis of GBM data by the IPI science team provides secondary data verification. As data are reduced and analyzed by the IPI science team, errors and corrections are propagated to the IOC daily operations team, for modification of procedures that format data for delivery to the SOC.

2.7.10 Hardware Requirements

Calibration and validation equipment consists of a commercial system interface to the analog output of the GBM detectors. Spectra are accumulated and analyzed for detector performance verification. The GBM IGSE consists of one PC or workstation and associated peripherals, with interface software to the DPU or spacecraft simulator, and the operations equipment. Operations equipment consists of two to three PC's or workstations, for daily processing of raw science data (approximately 100 Mb/day), and associated peripherals, such as disk storage, backup, printers, etc.

Expected data rates, including specifications for the maximum rate and size of events, represent important design requirements imposed on the DPU by instrument simulations. These data rates and instrument dead time requirements determine the appropriate data buffer size and processing architecture. The nominal GLAST context instrument data rate of 10 kbs=40 Gb/yr results in a raw data storage capacity of 200 Gb for a projected 5-year mission. Raw data are archived to nonvolatile storage medium DVD. Currently available single sided, single layer DVD disks have a capacity of 4.7 Gb. Double sided, dual layer DVD, not yet available, have a capacity of 17 Gb. Twelve 17-Gb disks will hold the projected 5-year GBM dataset. This storage estimate is conservative, since the data rate for the GBM is 4 kbps nominal, and 9 kbps in trigger mode.

2.7.11 Staffing Plans

The IOC staffing plan is severely constrained by the Phase E funding profile. Consequently, we will predominantly use low-cost UAH student support for routine operation tasks. Table 14 presents the full-time equivalent (FTE) manpower for operations during each of the 5 years of the nominal mission. Covered tasks include data receipt, instrument health and safety, archiving, mission operations, and command generation and transmission. Scientific analysis is not included.

Table 14.—Phase E staffing profile.

Year of Mission	1	2	3	4	5
Scientist	1.7	1.4	1.0	0.5	0.5
Student	2.3	2.0	1.7	1.3	1.3

2.8 Science Team Roles and Responsibilities

The science team selected for the GBM has extensive experience with scintillation detector systems, spacecraft instrument development and analysis of gamma-ray data. The team consists of scientists who designed, built, and operate BATSE and COMPTEL on CGRO and who are currently developing SPI on INTEGRAL. The extensive experience and outstanding track record of these team members assures success of the GBM. Additional details of the investigator's qualifications are presented in the resumes (Appendix A).

Table 15 presents a list of the co-investigators, with a summary of their responsibilities on the Burst Monitor, and previous relevant experience.

2.9 Descope Options

The primary descope option for the Burst Monitor is a reduction in the number of NaI detectors. Table 16 summarizes the loss of scientific capability as the number of detectors is reduced. The relative sensitivity in the table is the approximate area, in units of one detector, for a burst near the zenith. In each descoped case, we have oriented the detectors to try to obtain burst locations over as wide a FOV as possible. The locations require observation by a minimum of three detectors. The burst trigger requires observation by at least two detectors. The minimum science mission is reached when there are only two NaI detectors, at which point the science goal of burst locations is abandoned. The minimum mission does retain the most important goal of the Burst Monitor, which is time resolved broadband spectral response for GRB's. Burst triggers remain possible, although the sensitivity is significantly degraded. All descope options include two BGO detectors.

Reduction in the number of NaI detectors reduces risks to all constrained resources: Cost, schedule,

Table 15.—GMB Science Team

Name & Institution	Responsibility	Experience
Dr. Charles Meegan, PI NASA/MSFC	Scientific requirements and oversight, NASA point of contact	Performance of balloon flights; BATSE: instrument development, flight software, data analysis, operations, Burst Team leader; HST Asst. Project. Scientist; ASTRO-2 Mission Scientist
Dr. Giselher Lichti, Co-PI MPE	Leadership of MPE effort	Performance of balloon flights; COS-B: leader of Fast-Routine Facility at ESOC; COMPTEL: project manager of MPG's hardware development; INTEGRAL: local project manager
Dr. Michael Briggs UAH	Flight software, Mission Operations Director	BATSE: spectral analysis, line search, burst isotropy & location accuracy, Spectroscopy Detector hardware development
Dr. Roland Diehl MPE	Software and data analysis at MPE	COMPTEL: Chairman of Data Reduction Group; Instrument Calibration and Data Analysis Method development; COMPTEL/OSSE/SMM Spectral Analysis INTEGRAL/SPI: Chairman of Data Analysis Group
Dr. Gerald Fishman NASA/MSFC	Detector performance specifications	Performance of balloon flights; Gamma-Ray Astronomy Team Leader at MSFC; Spacelab NRM PI; BATSE: PI, instrument development
Dr. Robert Georgii MPE	Detector design and mass modeling	INTEGRAL/SPI: BGO-Shield design and test; SPI simulations, calibration, software development; ACS performance tests; COMPTEL data analysis
Dr. Andreas von Kienlin MPE	Detector electronics, detector performance test, calibration	INTEGRAL/SPI: ACS electronics, ACS performance tests, ACS burst detection system, SPI calibration; Development of Low Temperature Detectors
Dr. Marc Kippen UAH	Simulations, detector response matrices, DPU specifications, I&T procedures	BATSE: Rapid Burst Response Team Leader, data analysis, simulations; COMPTEL data analysis
Dr. Robert Mallozzi UAH	Operations Software; Ops and DA hardware, Education and Public Outreach	BATSE: software development, data analysis, Web site development, simulations
Dr. William Paciesas UAH	Interface with LAT team	Performance of balloon flights; BATSE instrument development, BATSE Spectroscopy Team leader
Dr. Robert Preece UAH	Data Analysis requirements and software	BATSE: software development, spectral analysis and interpretation; theory of gamma-ray emission mechanisms
Dr. Prof. Volker Schoenfelder MPE	MPE coordination with DLR and MSFC	PI of Compton Telescope Balloon Program at MPE; PI of COMPTEL aboard CGRO; Co-PI of spectrometer INTEGRAL (SPI)

mass, volume, power, and telemetry. Since these detectors are provided by MPE at no cost, the NASA cost is reduced primarily by transferring some tasks from MSFC to MPE holding fixed the MPE costs. Two specific descope cases are considered below.

Descope to Eight NaI Detectors.

With a reduction in the number of NaI detectors from 12 to 8, the Burst Monitor sensitivity and FOV are degraded, but the scientific return is still good and the scientific goals are not severely compromised. With this option, MPE would assume re-

Table 16.—Scientific performance for several descope options.

NaI Detectors	Burst Locations FOV (steradians)	Burst Trigger FOV (steradians)	Effective FOV (steradians)	Relative Sensitivity
12	11.55	12.57	8.61	2.8
8	8.98	11.47	6.71	2.1
6	8.24	10.59	5.16	0.9
2	0	0	*	0.5

* We define the effective FOV in terms of the trigger sensitivity, which for two detectors on opposite sides of the LAT is 0 sr. If defined as projected area, the effective FOV for two detectors is ~2π sr.

sponsibility for the cable harness, which would probably not exceed the cost savings of procuring four fewer detectors. MSFC would realize cost savings of $102.5k for this descope, occurring at any time before Critical Design Review (CDR). The total mass reduces to approximately 46 kg.

Descope to Two NaI Detectors.

This option is a descope to the performance floor. In this case, MPE would accept responsibility for the cable harness and for performing the instrument I&T, including thermal vacuum tests. MPE would realize offsetting cost savings in the detector and HVPS procurements, and in the reduced preflight calibration effort. MSFC would retain responsibility for test requirements, plans, and procedures. There would be additional costs for work on these documents, as a result of transferring implementation responsibilities to MPE. Significant cost savings are realized, not only in the manpower and materials for I&T, but also in the DPU and the flight and ground software efforts, since burst locations are not calculated. Cost savings are presented in table 17 and are calculated for two cases: descope at PDR and descope at CDR. All I&T and harness construction costs (items 1–4) are incurred after CDR and are therefore the same for both cases. I&T performance savings (item 2) are based on one FTE contractor cost. Savings for items 1, 3, and 4 are taken from the cost breakdown in table B–4, Volume 2. DPU descope savings (item 5) represents only the reduced parts, therefore it is a conservative lower limit, and is valid for descoping at any time before the request for proposal (RFP) for the DPU. Software savings (items 6–7) are based on UAH research scientist manpower costs and reflect the requirements and design effort that occur prior to PDR and CDR. The descoped flight software effort is conservatively estimated at 80 percent of the fully scoped effort and the descoped data analysis software effort is conservatively estimated at 80 percent of the fully scoped effort. The additional documentation cost represents one FTE of civil service manpower for descope, occurring after CDR.

Table 17.—NASA cost savings for descope to performance floor.

Effort	Saving ($k) (PDR/CDR)
1. Cable harness construction	102.5/102.5
2. I&T performance	90/90
3. I&T hardware	35/35
4. Thermal-Vac test, inc. fixtures	32/32
5. DPU descope	16/16
6. Flight Software Reductions	51/26
7. Data Analysis Software Reductions	52/26
8. Added Documentation	0/–25
TOTAL	378.5/302.5

If the descope to the performance floor occurs early enough, we will increase the thickness of the NaI detectors to regain some of the lost sensitivity. Since burst locations will not be determined in the full descope case, a more isotropic response for these detectors is desirable.

The total cost savings to NASA is $378.5k, for a descope to the performance floor at PDR, and $302.5k if descope occurs at CDR. The mass reduces to approximately 30–40 kg, depending on the revised thickness of the NaI detectors.

3.0 Technical Approach

3.1 Overview

The Burst Monitor project will produce an instrument with excellent scientific performance and low risk, using flight proven hardware with simple interfaces. Most of the hardware will be procured through competitive bid or supplied by MPE at no cost to NASA. No technology development is required. All technology needed to produce this instrument is similar to the BATSE experiment which the developers of this proposal designed, produced, and still operate. A schedule for instrument development is provided in the fact sheet. End items to be provided are:

- Flight GRBM instrument
- Electrical and mechanical ground support Equipment for use in integration and operations.
- IOC and equipment
- Flight software and documentation
- Instrument ground operations command, control, housekeeping software and documentation
- Data analysis and archiving software and documentation

3.2 Fabrication/Procurement Plans

3.2.1 Sodium Iodide and Bismuth Germanate Detectors

MPE provides these detectors at no cost to NASA. The vendor of the BGO will be Cristmatec. Performance requirements will be developed by the science team and design specifications will be developed by the MPE project team during phase B. MPE procures flight qualified detectors by contract administered through Deutsches Zentrum fuer Luft- und Raumfahr (DLR). MPE retains technical direction over the production. Flight qualified detector assemblies include PMT's, high-voltage bleeder strings, and preamplifiers.

3.2.2 Power Supplies.

MPE provides both HV and LV power supplies at no cost to NASA. These power supplies are similiar to ones that have been previously designed and flown by MPE.

3.2.4 Data Processing Unit.

MSFC will procure the DPU by competitive bid. The MPE/U.S. science team is working with the Engineering Directorate at MSFC to develop performance specifications. At least one vendor, Amptek Incorporated, can provide a flight qualified unit, at the price used for our cost estimates, by making modifications to their CEASE radiation monitor system. The MSFC engineering team provides technical, cost, and schedule oversight for this procurement.

3.2.5 Cables

The MSFC project works with the GSFC project office, the spacecraft contractor, and the main instrument provider to establish interface control documents (ICD's) for the Burst Monitor with the spacecraft and the main instrument. After detector placement and mounting has been determined, the spacecraft contractor specifies flight cable routing. Flight cables are to be fabricated at MSFC. We have produced cable harnesses for flight equipment including the lightning imaging sensor, optical transient detector, and the solar x-ray imager.

3.2.6 Software

Software development on the GBM project employs many of the same people as used for BATSE. BATSE software for data acquisition, flight command and control, and data analysis is still in use. Algorithms for data acquisition and processing for onboard tasks and for data analysis and archiving are used for GBM. The current software provides prototypes for development of GBM software using modern software applications and computers. A formal development process is used for software development with milestones indicated on the schedule (figure 3 in the Management Section). In-process technical management uses software status walkthroughs on a weekly basis. The software developer discusses status and approach with the science team to assure that coding reflects requirements.

3.3 Calibration Plan

MPE calibrates the detectors. The calibrations are sufficient to verify computer simulations of the detector response. The calibration plan is developed by MPE in consultation with the science team at MSFC and UAH. All flight detectors will be exposed to radioactive sources to acquire spectra as shown in tables 5 and 6. These spectra will be used to fine tune the detector response matrices obtained by Monte Carlo simulations. UAH co-investigators, who have extensive experience in this area, will perform the simulations. A spare flight DPU card, used for data acquisition from the detectors, is supplied to MPE for use in this calibration. This card is returned to MSFC and is used to compare results of system calibrations using the flight DPU with MPE results. In-flight calibration and validation uses detector response from astronomical sources, as is done for BATSE.

3.4 Assembly, Integration & Test

3.4.1 Overview

The separate hardware components are shipped to MSFC for instrument assembly and test. The detectors, DPU, and power supplies are interconnected using flight cables. The DPU is connected to the spacecraft simulator, which is connected to the electrical ground support equipment (EGSE).

3.4.2 Integration and Test Procedure Generation

The subsystem integration control procedure will be prepared by SD71. All procedures shall be submitted to the responsible organizations for review and signature approval. An integration/test readiness review (ITRR) will be conducted by SD71 prior to starting the GBM I&T. The ITRR chairman will issue minutes of the review and verify that all of the “constraints to test,” identified during the ITRR, are closed prior to starting test operations. The SD71 lead engineer will be the test conductor for GBM I&T control procedures. Generated documentation will include the following:

- Original signature procedures
- “As-run” test procedures
- TDR/DR and TDR log
- Data generated during testing
- Test report

3.4.3 Integration and Test Requirements

GBM subsystem integration activities will be performed in MSFC building 4481, in a class 10k clean room. All clean room operations will be performed in accordance with MSFC–STD–246 “MSFC Design/Operational Criteria of Controlled Environment Areas”. The handling and test operations for any hardware classified as electrostatic discharge (ESD) sensitive will be in accordance with MSFC–RQMT–2918. This ESD designation will be specified on the hardware drawings, packing lists, inspection reports, or paperwork accompanying the hardware. In addition, an ESD sensitive test article will be labeled with a sensitive electronic device symbol. All integration and test operations will be monitored and accepted by the Quality Assurance Office. All nonconformances will be documented on MSFC Form 460 in accordance with MPG 8730.3. The TDR/DR troubleshooting and dispositions shall be in accordance with MSFC–P13.1.

3.4.4 Functional Testing

Functional tests will be performed to verify gamma-ray and housekeeping data from each detector, commands, telemetry, and DPU flight software. Separate hardware components will be shipped to MSFC for instrument assembly and test. Detectors will be mounted on flight-like mounting structures and the DPU and power supplies will be interconnected using flight cables. The DPU will be connected to the spacecraft simulator, which will be connected to the EGSE.

The following tests will be performed:

1. Functional tests to verify gamma-ray and housekeeping data from each detector, commands, telemetry, and DPU flight software.

2. Thermal vacuum test: The GBM will be exposed to 3–4 days of thermal vacuum functional tests in chamber V7, at MSFC’s environmental test facility. The environmental test facility provides facilities and engineering/technical support

for performing environmental testing of space systems and components. The facility was first organized in the early 1960's and has provided support to all major NASA projects developed at MSFC since that time. Chamber V7 is used for Earth orbital and deep space simulations to test performance of space systems and subsystems. The chamber is equipped with a shroud that is liquid nitrogen cooled. Heat lamps are used to simulate the radiance of the Sun or reflected heat from the Earth. The chamber is horizontally oriented with internal dimensions of 8 ft. diameter and 10 ft length. Typical pressures that can be obtained in this chamber are 1×10^{-6} Torr and lower. The system is equipped with two rotary, oil-sealed roughing pumps and two 24-inch cryo pumps. There are six 6-inch ports available on the chamber for connection of instrumentation cabling, power cabling, mechanical feedthroughs, and fluid feedthroughs. A data acquisition system, known as PACRATS, is available for monitoring and recording up to 190 channels of temperature, pressure, and voltage data.

3. Vibration Test: GBM experiments will be qualification and acceptance tested to meet the dynamic environment on one of four Unholtz-Dickie T4000 shakers within the MSFC ED27 vibration laboratory. Each of the tables is configured to run vibration tests from 5 Hz to 2,000 Hz and is capable of 40,000-lb force. All standard vibration tests can be generated—random, sine, sine on random, random on random, classical shock, and rocket separation shock. The vibration control systems handle 16 input channels and more can be made available.

Burst Monitor experiments will be mounted to the shaker table through the use of a flat aluminum interface plate between the shaker and the detectors or CPU's. A total of 16 tests will be run (14 detector tests and 2 CPU tests). Both of the high-energy BGO detectors will receive three axis random vibration tests. Each of the 12 low-energy detectors will receive three axis random vibration tests as well.

4. Pyro Test: Each of the high-energy BGO detectors, low-energy detectors, and the CPU's will receive pyroshock testing to simulate the Delta launch vehicle separation loads in the MSFC pyroshock test laboratory, also located in building 4619. The aluminum interface plate used for vibration testing will also be utilized for pyroshock testing. The shock spectra environment will be duplicated to laboratory best tolerances. There will be a total of 16 pyroshock tests.

Following I&T the GBM hardware will be shipped to the GLAST spacecraft integration contractor.

3.5 Spacecraft Integration

Hardware components will be delivered to the spacecraft contractor, who will be responsible for mounting the Burst Monitor hardware to the spacecraft, using procedures jointly developed by GSFC, MPE, and MSFC in conjunction with the spacecraft and main telescope contractors. Functional tests will be performed after mounting to the spacecraft. MPE, MSFC and UAH will support the spacecraft integration tests.

3.6 Quality Assurance and Safety

The Safety and Mission Assurance (S&MA) Office at MSFC oversees the GBM tasks and supplies safety and mission assurance engineering and inspection according to in-place ISO 9001 certified policies and procedures.

3.7 Parts

Responsibility for parts resides with the Parts and Packaging Group of MSFC's Engineering Directorate. Only flight qualified parts will be used in the Burst Monitor. An electronic electrical electromechanical (EEE) parts plan will be part of the Burst Monitor Quality Assurance approach.

Table 18.—Burst monitor risk mitigation.

Burst Monitor Risk Mitigation Table			
Instrument Risk	**Mitigation**	**Risk Level**	**Responsible Party**
Uncertainty in DPU costs, since requirements are preliminary	Design-to-cost; reduce redundancy requirements; descope number of detectors	6	PI
Schedule recovery from a hardware failure during integration and test.	a. The schedule has slack after integration and test to recover. b. Sufficient spares will be available for quick change out of hardware.	4	Project Manager
U.S.—Germany (MPE) interface: a. Will export control issues be an impediment? b. Are there any problems with MSFC not directly managing the MPE effort?	a. Following NASA export control guidelines b. Team communication, insight into MPE reviews. Previous team experience. c. Control of Interface Control documents with MPE	3	Project Manager
Phase E performance at funding levels specified in AO.	Consider transferring some responsibilities, such as data archiving, to MOC; consider larger role for MPE	7	PI, Co-PI
EMI in relatively long signal and HV cables.	Early analysis; enhanced shielding; decentralize HV	2	MSFC and MPE System Engineers

Risk level is defined from 1 to 10 with 10 being the highest and 1 being the lowest.

3.8 ISO 9001

MSFC is ISO 9001 certified and employs ISO 9001 standards to all flight projects..

3.9 Risks and Risk Mitigation.

The GBM should be considered relatively low risk due to maturity of the technology and in consideration of the similiar experience of developing a similiar instrument (BATSE) by the assigned personnel at MSFC.

The items in table 18 have been identified as possible risk areas.

3.10 Reviews

Section 9.0 in the Management Volume details the Burst Monitor project and program reviews.
The Burst Monitor team will conduct a series of internal design reviews and participate in the NASA mandated formal design reviews. All members of the Burst Monitor development team will participate in these reviews. The formal design reviews will be coordinated with the GSFC project office. MSFC will coordinate and prepare the review package to be submitted to GSFC prior to the scheduled review. The Burst Monitor team will participate in the following reviews:

Quarterly GSFC Reviews (per GLAST schedule)–
Annual Independent Assessment Reviews (IAR):

- System requirements review (SRR)– June 1, 2000
- Preliminary design review (PDR)– August 3, 2001
- Nonadvocate review (NAR)– August 17, 2001
- Critical design review (CDR)– August 15, 2002
- Pre-environmental review (PER)– 1 month prior to start of environmental tests
- Preship review (PSR)– 1 month prior to delivery to spacecraft contractor

4.0 Phase A/B Development Technical Definition Plan

This section details the development of the instrument design prior to the PDR. This includes all scientific and engineering trade studies, calculations, tests and analyses, as well as the preliminary engineering design efforts for the flight instrument.

4.1 Preliminary Design Process

During Phase A/B, the scientific performance trade studies will include, but not be limited to:

- optimum placement of the detectors on the GLAST fight system to meet the scientific objectives
- NaI detector entrance window, seal, and thermal covering selection.
- Detailed calibration plan, preflight and onorbit
- Onboard trigger and location algorithms

Analyses will include the following:

- Detailed detector response simulations
- Modeling the detector background inorbit
- Estimation of dead-time effects for strong GRB's
- Simulations of joint GRB spectral fits for GRB's with the GLAST LAT and other contemporaneous GRB instruments

Engineering trade studies will include:

- PMT circuit design, including pre-amp, for optimum resolution and minimizing deadtime
- Evaluation of alternate mounting designs for the detectors (to be performed jointly with the spacecraft contractor).

Phase A/B efforts related to procurement of major purchased elements:

- Testing and evaluation related to alternative PMT suppliers
- Finalizing the DPU specifications and preparation of an RFP
- Design, procurement and test of science performance test detectors
- Development of specifications for flight detector procurement

Prototype hardware will be developed for all flight components and tested to ensure the design will meet all scientific performance and design requirements. GSE will be designed to the preliminary design level.

The following sections detail these Phase A/B efforts according to institution.

4.1.1 Marshall Space Flight Center Development Phase A/B:

Science Participation in phase A/B:
As the P.I. institution, the P.I. at MSFC will assign responsibilities to Co-I institutions for the phase A/B activities, as outlined in Section 4.1 above, and oversee the development and implementation of all phase A/B activities. If needed, the P.I., in consultation with the GBM P.M.,will direct changes in these responsibilities to meet GLAST GBM resources and schedule.

The MSFC tasks during Phase A/B will also include the development of Safety and Mission Assurance documentation, system engineering documentation, flight software and data processing software development plan and preliminary design, and development of the Burst Monitor DPU draft contract end item (CEI) specification. It is anticipated that no flight hardware will be procured.

Safety and Mission Assurance
The MSFC GBM project team will support S&MA activities in phase A/B with an approach that includes: 1) Strong emphasis on S&MA management, 2) thorough, experienced-based understanding of S&MA principles, NASA and MSFC S&MA policies and requirements, 3) focus on establishing clear goals and expectations for the GBM project S&MA effort, and 4) applying the appropriate use of existing state-of-the-art S&MA tools and techniques or, if deemed necessary and/or advantageous, the judicious development of new tools and techniques.

A draft safety and mission assurance program plan (SMAPP) has been developed for the GBM project to ensure risk management, system safety, quality assurance, reliability, and maintainability analysis. The draft SMAPP will be finalized and submitted for approval within the first 60 days of contract award. The draft SMAPP may be found as Appendix B of the Burst Monitor management plan.

Systems Engineering

Using the Burst Monitor project plan and NPG7120.5A as a guide, a draft ICD will be developed for MPE-provided hardware, the DPU and the Burst Monitor to spacecraft harness, when detailed information becomes available on the spacecraft interface. A memorandum of understanding (MOU) will be developed with MPE that outlines the MSFC data requirements (DR's) that MPE will follow during development of the MPE flight hardware. A draft instrument integration plan and hardware processing flow document, including identification of ground support equipment (GSE) will be developed.

Software

Preliminary requirements will be developed in phase B for flight software, operations software, and science analysis software. For flight software, the focus will be on the burst trigger and location algorithms. Specifically, we will perform trade studies to determine if there is a cost effective and more sensitive alternative to the BATSE technique for triggering. We will also derive a requirement for program and data memory. For the data analysis software, the focus will be on revisions and enhancements to our spectral analysis package WINGSPAN.

We will also work with the LAT team to determine what products are expected from the Burst Monitor, both on board and on the ground.

Data Processing Unit

A preliminary CEI performance specification for the DPU will be produced in phase B. The primary focus will be on memory requirements derived from the flight software study. A cost/risk trade study will be performed to determine the appropriate level of redundancy.

4.1.2 Max-Plank Development Phase A/B:

MPE is a major collaborator in the development of the Burst Monitor. MPE will provide the GBM scintillation detector elements and other flight components, the HVPS, and LVPS to the Burst Monitor Project. MPE provides these detectors at no cost to NASA. The science team will develop performance requirements and design specifications by the MPE project team during phase B.

Flight hardware tasks, undertaken by MPE, can be subdivided into two main parts: development and fabrication of the NaI and BGO detector modules and fabrication of the HV and LV power supplies. Development and fabrication of the power supplies will be performed under contract to MPE. The detector modules will be designed by MPE, together with industry. At MPE a breadboard (BB) model of the detection chain will be built for optimization and study of the electrical design. Fabrication and integration of flight hardware and structural test models (STM's) and the electrical models (EM's) of the detector modules will be performed by industry. BGO and NaI crystals, needed for the flight hardware, will be contracted for separately by MPE. MPE scientific personnel will carry out all detector performance tests and detector calibrations.

Development and fabrication of the detector modules will be accomplished in several phases. The idea is to reach predefined goals and to simplify the organization of the project at the end of each phase. For each phase a major reassessment of the project will be conducted that will allow an effective control of the costs.

The development plan with the different project phases A/B is listed below with a short description of the contents of each phase. The development of the detector modules will be accomplished with the help of several prototype and test modules, as needed for design verification, spacecraft integration fit and form, structural, thermal, electrical, and functional tests.

MPE Development Plan

Phase A—MPE and Contractors

- Preliminary studies by MPE and MSFC/UAH

- Industrial studies of the structure, thermal, and EMC behavior
- Design of voltage divider and preamplifier
- Monte Carlo simulations of detector behavior for optimization of the design, together with UAH/MSFC
- Build a breadboard of the detector chain for systematic investigations of detector behavior

Phase B—Contractors, with MPE Oversight

- Definition of the detector module design
- Coordination of the mechanical interfaces
- Coordination of the electrical interfaces
- Verification of the detection chain (PMT, voltage divider, preamplifier) with the BB
- Assembly, integration, and test—planning, definition of the specifications, test procedures and scientific requirements.

Models of the Detector Modules

Several structural and engineering models will be built to facilitate detector development:

Structure and Thermal Model:

A structure/thermal model of an NaI and a BGO detector module will be manufactured which will be representative of the mass, center of gravity, and moment of inertia of the flight detectors. Thermal and power characteristics will be simulated.

Tests: vibration and thermal vacuum test

Engineering Model:

An engineering model of an NaI and a BGO detector module will be fabricated, which will be representative in structure and electrical design. Only one PMT will be used in the case of the BGO module. Light-Emitting Diodes (LED's) will be used for simulation of high-energy signals.

Tests: functional and thermal vacuum test, and performance test.

4.1.3 University of Alabama in Huntsville (UAH)

As a major co-investigator institution in the GLAST GBM, UAH will participate in most of the analyses and trade studies described above (section 4.1) during the phase A/B effort. An evaluation of test procedures, software, calibration and data analysis software design carry-over from the BATSE/Compton Observatory program will be made by UAH scientific personnel during phase A/B. Scientific support will be provided by UAH in the development of flight hardware specifications, although no flight hardware design work will be performed by UAH.

4.2 Trade Studies

The Burst Monitor design uses flight proven, mature technology. It is therefore anticipated that no major system level trades will be performed in phase A/B until the details of the Burst Monitor to GLAST spacecraft interface is available. At that time system level trades will be performed to determine the optimal location of the Burst Monitor detectors, HV and LV power supplies, and the DPU. Trades also may be performed on the DPU CEI specifications to optimize cost and performance characteristics. A trade study will be performed to determine the appropriate level of redundancy for the DPU.

4.3 Team Interactions

Section 2.8 describes the management approach and responsibilities of each team member. During phase A/B, weekly status telecons will be held to keep team members informed. An action item tracking list will be maintained and used to track open issues.

Quarterly team meetings will be held in conjunction with GLAST project reviews at GSFC. This will optimize limited team resources. The team will interact at major reviews such as PDR, CDR, and FRR.

Effective communication with MPE will be of particular importance because of the distant location of MPE in Germany. Representatives of MPE will be included in Burst Monitor telecons and fax, and e-mail will also be used in maintaining communication. It is anticipated that MPE would be present at the quarterly GSFC reviews and at all major team meetings.

Export control of all information to MPE will be maintained following NASA export control guidelines.

5.0 Education and Public Outreach, Small Disadvantaged Business and New Technology

5.1 Education and Public Outreach

Several characteristics of GRB's make them an excellent topic for education and public outreach. They are now known to be the most powerful explosions in the universe, they can be seen at very large distances and very early times, and their origin remains a mystery. They have and will continue to excite the interest of the science attentive public and will certainly be a major focus of the GLAST education and public outreach (EPO) effort. The Burst Monitor team is committed to a vigorous and productive EPO program for GLAST.

We concur with the approach outlined in the AO, wherein the secondary instrument and interdisciplinary scientist EPO efforts are integrated into a unified GLAST effort led by the LAT team. The contribution of the GBM will be defined during the definition phase. The GBM team expects to provide input to this definition and will provide financial support to the level prescribed in the AO. We have budgeted a total of $50k for the Burst Monitor EPO effort. Since the GBM effort will not be an independent plan, but will support the observatory level plan, we do not provide specific programs or schedules.

The GBM team brings a valuable asset to the GLAST EPO program—the NASA/MSFC Science Communications (SciComm) process, now in its third year of operation at MSFC. The SciComm process, designed and operated by practicing research scientists, gives researchers the opportunity to directly communicate the results and implications of their work to a science-attentive audience and to generate subsequent communication products that improve both peer and nonpeer communication activities. Through direct integration of media relations, education, and technology transfer functions, the SciComm process also provides for the parallel development of other consistent and scientifically accurate communication products, such as press releases. SciComm has been generating three to five headline or feature stories per week for Internet distribution since 1997. The subject matter includes Earth science, microgravity research, and space science. Their web site was the winner of the "1999 People's Choice Webby Award" for best science site on the Internet. Stories on their web site are presented to an audience of over 20,000 individuals per day, and have a significant track record of leveraging additional coverage through popular magazine articles, newspaper articles, television features, and classroom applications.

5.2 Small Disadvantaged Business

MSFC has an impressive record of socioeconomic performance. The trend has been toward increased percentages of Marshall's procurement budget going to targeted business groups. In FY98 a milestone was reached when, for the first time, double digits were achieved for the percentage of procurements with small disadvantaged businesses (SDB). The Center has two general goals of 20 percent small business and 8 percent SDB identified in its implementation plan. Both are currently being exceeded. There are other goals and objectives assigned by NASA headquarters and during the recent Minority Enterprise Development Week, Marshall was recognized for exceeding all of its FY98 goals.

They included:

- Small Business
- 8a Program
- Small Disadvantage Business
- Woman Owned Small Business
- NASA 8 percent SDB
- Small Business Subcontracting
- SDB Subcontracting
- Woman Owned Subcontracting

With the 11 months of FY99 information available, Marshall is meeting its small business goal with 101 percent of goal, 8a with 100 percent, SDB with 100 percent and Woman Owned with 120 percent.

The subcontracting data for FY99 is not yet available; however, MSFC expects to also achieve these objectives.

The GLAST Burst Monitor benefits from these programs which, in many cases, are embedded in the MSFC institutional support contracts. We work with the Small Business Office at MSFC to ensure that any of our requirements for subcontracts that might be generated are considered for SB/SDB set aside.

5.3 New Technology

We employ no new technology in the flight hardware due to the stringent cost cap for secondary instruments and because the scientific requirements are easily met by established, flight proven technology. To perform the time-resolved spectral analysis, that is central to our scientific investigation, we will be adapting and expanding the WINGSPAN program developed for BATSE. This package is already being used extensively by the BATSE team, as well as CGRO GI's, and is an excellent candidate for technology transfer to the high-energy astrophysics community.

WINGSPAN allows interactive spectral fitting in a windowing environment, taking time sequences of count spectra from a single detector, modeled by a response matrix, as the basic data model. This differs, in philosophy, from the well-known XSPEC package, which is commonly used to analyze x-ray spectra one at a time and lacks the ability to easily track temporal behavior of spectral model fit parameters. Like XSPEC, WINGSPAN can perform joint fits to spectra from any instrument that has observed a given event, and is not restricted to only data from BATSE or even just the CGRO instruments. WINGSPAN is written in interactive data language (IDL), published by Research Systems, Inc. and FORTRAN. It relies on computer-portable data products in the FITS format, which has become a standard in the astrophysics community. We are currently extensively revising the program to make it platform independent and to improve its capability for performing a time sequence of simultaneous fits to data from mulitple instruments.

Appendix A

Resumes

Dr. Charles Meegan
Role in GBM: Principal Investigator
Marshall Space Flight Center

Education
B.S. Rensselaer Polytechnic Institute, 1966
Ph.D. University of Maryland, 1973

Role in GBM
As Principal Investigator, Dr. Meegan is responsible for the overall scientific direction of the Burst Monitor project. He supervises the effort of the science team in Huntsville and is the official NASA point of contact.

Experience
Dr. Meegan's main research interests lie in the area of gamma-ray astronomy, with particular emphasis on gamma-ray bursts. He has been actively involved in GRB studies for the past two decades and has played a significant role in major developments in this field. For his doctoral dissertation, Dr. Meegan measured the energy spectrum of cosmic ray electrons. His advisor at the University of Maryland was Dr. James Earl. In 1974, he joined the gamma-ray research team of Dr. Robert Haymes at Rice University as a post-docatoral research associate. There, he participated in balloon flight observations of several gamma-ray sources, including observations of nuclear lines from the Galactic Center.

Dr. Meegan came to Marshall Space Flight Center in 1976, first as an NRC Research Associate. He accepted a civil service position there in 1978. At Marshall, he was involved in several balloon flight campaigns, including a observation of nuclear gamma-ray lines from supernova 1987A.

Dr. Meegan was co-investigator on the original proposal for the Burst and Transient Source Experiment (BATSE). He has been heavily involved in the design, development, testing, on-orbit operations and data analysis for BATSE for the past twenty years. He currently heads the BATSE Burst Team, whose primary responsibility is production of the BATSE burst catalogs.

Dr. Meegan served as assistant project scientist on the Hubble Space Telescope from 1982 to 1984. From 1991 to 1996 he was the mission scientist for Astro2, a Spacelab mission comprising three UV telescopes. Dr.Meegan was chairman of the organizing committee for the 4th Huntsville Symposium on Gamma-Ray Bursts. He has co-authored over 100 refereed journal papers, the vast majority of them on gamma-ray bursts.

Societies
American Astronomical Society (AAS)
AAS High-Energy Astrophysics Division
American Physical Society (APS)
Sigma Xi, The Scientific Research Society
Von Braun Astronomical Society

Honors and Awards
NASA Medal for Outstanding Scientific Achievement, 1993.
NASA Exceptional Achievement Medal, 1995.
Sigma Xi Research Scientist of the Year, Huntsville 1993.
NASA Directors Commendation, 1993

Recent Publications
"Spatial Distribution of Gamma-Ray Bursts Observed by BATSE", 1992, Meegan, C. et al., Nature Vol. 355, p.143.

"Identification of Two Classes of Gamma-Ray Bursts", 1993, Kouveliotou, C. et al., ApJ, Vol. 413, p. L101.

"Detection of Signature Consistent With Cosmological Time Dilation in Gamma-Ray Bursts", 1994, Norris, J. et al., ApJ, Vol. 424, p. 540.

"Discovery of Intense Gamma-Ray Flashes of Atmospheric Origin", 1994, Fishman, G. et al, Science, Vol. 264, p. 1313.

"Do Gamma-Ray Burst Sources Repeat?", 1995, Meegan, C. et al., ApJ, Vol. 446, p. L15.

"Gamma-Ray Bursts", 1995, Fishman, G. & Meegan, C., Annu. Rev. Astron. Astrophys., Vol. 33, p. 415.

"The Third BATSE Gamma-Ray Burst Catalog", 1996, C. Meegan et al., ApJ, Vol. 106, p. 65.

"A New Type of Transient High-Energy Source in the Direction of the Galactic Centre", 1996, Kouveliotou, C. et al., Nature, Vol. 379, p. 799.

"BATSE Observations of the Large-Scale Isotropy of Gamma-Ray Bursts", 1976, Briggs, M. et al., ApJ, Vol. 459, p. 40.

"Transient Optical Emission From the Error Box of the Gamma-Ray Burst of 28 February 1997", 1997, van Paradijs, J. et al., Nature, Vol. 386, p. 686.

"BATSE Observations of Gamma-Ray Burst Spectra. IV. Time Resolved High Energy Spectroscopy", 1998, Preece, R. et al., ApJ, Vol. 496, p. 849.

"The Fourth BATSE Gamma-Ray Burst Catalog (Revised)", 1999, Paciesas, W. S. et al., ApJS, Vol. 122, p. 465.

Dr. Michael S. Briggs
Role in GBM: Co-Investigator

Education
A.B. in Physics, Princeton University, 1982
M.S. in Physics, University of California, San Diego, 1983
Ph.D. in Physics, University of California, San Diego, 1991

Role in GBM:
Primary: Flight software development, Mission Operations Director
Secondary:Detector calibrations, data analysis software

Experience
Dr. Briggs has been involved in high-energy astrophysics since 1978, when he worked for the cosmic ray research group at NASA/GSFC. At the University of California he worked on the design and testing of the BATSE Spectroscopy Detectors. His thesis was an all-sky map in the few hundred keV to few MeV band constructed using archival HEAO A-4 data. Since his graduation from the University of California, he has worked with the gamma-ray group located at NASA/MSFC as a University of Alabama research scientist, focusing mainly on GRB research. He had a major role in the development of the spectral analysis software WINGSPAN and has lead the effort to find spectral lines in BATSE GRB data. In addition to his participation in the spectral research, he has worked on issues related to GRB locations. He was a co-editor of the Third Huntsville Gamma-Ray Burst Symposium and is a coauthor of more than 60 refereed journal articles. His research interests include GRB's, gamma-ray instrumentation, statistical techniques including Bayesian inference, soft-gamma repeaters and x-ray binaries

Societies
American Astronomical Society (AAS)
AAS High-Energy Astrophysics Division

Honors and Awards
First Place in the 37th Annual Science Talent Search for the Westinghouse Science Scholarships and Awards,1978-1982
University of California Regents' Fellowship,1982
Marlar Fellowship,1987-1988
NASA Graduate Student Researcher's Program, 1987-1990
NASA Compton Gamma-Ray Observatory Fellowship, 1991-1994

Recent Publications

M. S. Briggs, D. L. Band, R. M. Kippen, R. D. Preece, C. Kouveliotou, J. van Paradijs, G. H. Share, R. J. Murphy, S. M. Matz, A. Connors, C. Winkler, M. L. McConnell, J. M. Ryan, O. R. Williams, C. A. Young, B. Dingus, J. R. Catelli, & R. A. M. J. Wijers, "Observations of GRB990123 by the Compton Gamma-Ray Observatory ", ApJ, Vol. 524, p. 82 (1999).

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W. S. Paciesas, C. A. Meegan, G. N. Pendleton, M. S. Briggs, C. Kouveliotou, T. M. Koshut, J. P. Lestrade, M. L. McCollough, J. J. Brainerd, J. Hakkila, W. Henze, R. D. Preece, V. Connaughton, R. Marc Kippen, R. S. Mallozzi & G. J. Fishman, "The Fourth BATSE Gamma-Ray Burst Catalog (Revised) ", ApJS, Vol. 122, p. 465 (1999).

G. N. Pendleton, M. S. Briggs, R. M. Kippen, W. S. Paciesas, M. Stollberg, P. Woods, C. A. Meegan, G. J. Fishman, M. L. McCollough & V. Connaughton, "The Structure and Evolution of LOCBURST: The BATSE Burst Location Algorithm ", ApJ, Vol. 512, p. 362 (1999).

T. W. Giblin, J. van Paradijs, C. Kouveliotou, V. Connaughton, R. A. M. J. Wijers, M. S. Briggs, R. D. Preece & G. J. Fishman, "Evidence for an Early High-Energy Afterglow Observed with BATSE from GRB980923 ", ApJL, in press (1999).

M. S. Briggs, "Gamma-Ray Burst Lines", in ASP Conf. Series 190, Gamma-Ray Bursts: The First Three Mintues, ed. J. Poutanen & R. Svensson (1999).

M. S. Briggs, W. S. Paciesas, G. N. Pendleton, C. A. Meegan, G. J. Fishman, J. H. Horack, M. N. Brock, C. Kouveliotou, D. H. Hartmann & J. Hakkila, "BATSE Observations of the Large-Scale Isotropy of Gamma-Ray Bursts ", ApJ, Vol. 459, p. 40 (1996).

Dr. Roland L. Diehl
Role in GBM: Co-Investigator

Education
Diploma in Nuclear Physics, University of Mainz, 1978;
Ph.D. in Physics and Astronomy, with Honors, Tech. University of Munich, 1988;
Habilitation Tech. University of Munich, 1998

Role in GBM:
Calibration of the GBM components. Preparation of data analysis methods and software tools, both for the GBM data and for combined analysis with other burst measurements

Experience
Dr. Diehl's primary research interests have been in gamma-ray astronomy, specifically nuclear astrophysics with gamma-ray lines from radioactivities. He has published several review articles in refereed journals on this subject, and is an internationally recognized expert in this field. He has been the principal scientist in developing the data analysis software system for the COMPTEL gamma-ray telescope aboard the NASA Compton Observatory, and for the ground calibration of this instrument with radioactive sources and accelerator setups. Dr. Diehl coordinates the data analysis preparations for the SPI collaboration of the INTEGRAL gamma-ray mission to be launched in 2001. He chaired the user committee of the Garching Computing Centre of the MaxPlanck Gesellschaft, and co-chaired MPE's division for Computing and Data Analysis, being coordinator of computing facilities of MPE's gamma-ray group. Dr. Diehl has published over 150 papers in refereed journals and conference proceedings, and has presented about 100 talks at international institutes and conferences. Dr. Diehl joined the Max Planck Institut fürextraterrestrische Physik in 1979 as a member of the MPE Compton telescope team headed by Dr. Volker Schönfelder. He is staff scientist in MPE's gamma-ray astronomy group since 1983.

Societies
German Physical Society ‚Deutsche Physikalische Gesellschaft' (DPG)
German Astronomer Society ‚Astronomische Gesellschaft' (AG)
American Astronomical Society (AAS), High-Energy Astrophysics Division

Recent Publications
"1.8 MeV Gamma-Rays from the Vela Region" Diehl, R. *et al:* Astroph. Letters and Communications (1999)

"Gamma-Ray Line Astronomical Measurements and Nucleoynthesis" Diehl, R.: Nuclei in the Cosmos V, eds. N. Prantzos (1999)

"Gamma-Rays Observations and Massive Stars" Diehl, R.: K.A. van der Hucht, G. Koenigsberger & P.R.J. Eenens (eds.), Wolf-Rayet Phenomena in Massive Stars and Starburst Galaxies, Proc. IAUSymp. No. 193 (San Francisco: ASP), p.631(1999)

"Gamma-Ray Line Emission from Radioactivities in Stars and Galaxies" Diehl, R.; Timmes. F.X.: PASP, Vol. 110, 748, pp. 637-659 (1998)

"Ti Gets a Lifetime"[44] Woosley, S.E.; Diehl, R.: Physics World, Vol. 11, pp. 7, 22 (1998)

"Modelling the 1.809 MeV Sky: Tracers of Massive Star Nucleosynthesis" Diehl, R.; et al.: A&AS,Vol. 120,pp. 4, 321 (1996)

"Radioactive ^{26}Al in the Galaxy: Observationsversus Theory" Prantzos, N.; Diehl R.: Phys.Rep.Vol. 267, 1, pp. 1-69 (1996)

"Understanding COMPTEL ^{26}Al 1.8 MeV Map Features" Chen, W.; Gehrels, N.; Diehl, R.: ApJ Vol. 440, pp. L57-L60 (1995)

"The Galaxy in the ^{26}Al Gamma-Ray Line at 1.809 MeV" Diehl, R.; et al.: A&A Vol. 298, pp. 445-460 (1995)

"Imaging Diffuse Emission with COMPTEL" Diehl, R.: Exp. Astr. Vol. 6, pp. 103-108 (1995)

"Response Determinations of COMPTEL from Calibration Measurements, Models,and Simulations" Diehl, R.; et al.: Data Analysis in Astronomy IV, edited by V. diGesu et al.,Plenum Press New York, pp. 201-216, (1992)

Stephen Elrod
Role on GBM: Project Manager

Education
B.S.E. with Honors, University of Alabama, in Huntsville

Awards and Honors
Tau Beta Pi.

Mr. Stephen E. Elrod is a senior systems engineer in the Space Flight Experiments Group, and has continuously served as a U.S. government aerospace engineer and project manager for 23 years. Beginning in 1996, he successfully served as the MSFC project manager and chief systems engineer for the IMAGE/ Wide Imaging Camera (WIC). This instrument is a component of the IMAGE Far Ultraviolet (FUV) instrument package and was developed jointly with the University of California, Berkeley. The WIC development and recent delivery was accomplished on an accelerated schedule that required innovative and streamlined approaches to program management, including tight cost controls, schedule compression and diverse partnerships with academia, technical institutes and foreign governments. Mr. Elrod has also rendered significant support to several other Science Directorate efforts, including the on-going development of the Microgravity Crystal Growth Demonstration, flight component fabrication/testing for the Chandra X-Ray Observatory and MSFC ISO 9001 certification.

In his career, Mr. Elrod has worked in several project offices, including the TOW Missile (U.S. Army MICOM), U.S. Space Station, and the Orbital Maneuvering Vehicle. Additionally, he worked for several years as a supporting systems engineer on the Hubble Space Telescope. Mr. Elrod also serves as a U.S. Naval Reserve Civil Engineer Corps officer (18 yrs. service, CDR/05) and is currently assigned to the office of the Deputy Chief of Naval Operations for Logistics, in Washington, D.C.

Dr. Gerald J. Fishman
Role in GBM: Co-Investigator
NASA/Marshall Space Flight Center

Education

B.S. with Honors in Physics, University of Missouri, 1965
M.S., Space Science, Rice University, 1968
Ph.D., Space Science, Rice University, 1969

Experience

Dr. Fishman's primary research interests have been in gamma-ray astronomy, nuclear astrophysics, and background radiation in space. He has been the principal investigator on a large number of space-borne and balloon-borne gamma-ray astronomy experiments and background monitoring experiments. Dr. Fishman has published over 250 papers in refereed journals and conference proceedings. He has served on a number of NASA Headquarters committees, including the NASA Gamma-Ray Astronomy Program Working Group and the Astrophysics Working Group.

Presently, he is the Principal Investigator of the Burst and Transient Source Experiment (BATSE) on the Compton Gamma-Ray Observatory.

Following graduation from Rice University in 1969 with a Ph.D. in Space Science, he was a senior research scientist for Teledyne Brown Engineering. Dr. Fishman joined NASA/Marshall Space Flight Center in 1975 as an astrophysicist. He spent 1977-78 as a staff scientist in the Astrophysics Division, NASA Headquarters, before returning to MSFC. In 1992 he was named chief of the Gamma-Ray Astronomy Branch. From 1994–1998, he was a senior staff scientist in the Astrophysics Division, serving as the leader of the gamma-ray astronomy team in the Space Science Laboratory of the NASA/MSFC. In 1998, Dr. Fishman was appointed by NASA's Administrator as NASA/MSFC chief scientist for Gamma-Ray Astronomy. This is a senior scientific and technical position, the technical equivalent of a government senior executive service (SES) position.

Societies

American Astronomical Society (AAS)
AAS High-Energy Astrophysics Division
American Physical Society (APS)
APS Astrophysics Division, Executive Committee
American Association for the Advancement of Science
International Astronomical Union
Sigma Xi, The Scientific Research Society

Honors and Awards

O.M. Steward Scholar (Physics) University of Missouri 1963–1965
NASA Medal for Outstanding Scientific Achievement 1982, 1991, and 1992
NRL – Alan Berman Research Publication Award—1992
Sigma Xi Research Scientist of the Year, Huntsville—1993
Distinguished Alumnus Award, Univ. of Missouri—1994
Rossi Prize, High Energy Astrophysics Division, American Astronomical Society—1994
Fellow – American Physical Society—1995

Relevant Publications

Fishman, G.J.; and Hartmann, D.: "Gamma-Ray Bursts," *Scientific American*, Vol. 277, pp. 34–39, July 1997

Galama, T.; Groot, P.J.; van Paradijs, J.; Kouveliotou, C.; Robinson, R.R.; Fishman, G.J.; Meegan, C.A.; et al.: "The Decay of Optical Emission From the Gamma-Ray Burst GRB 970228," *Nature*, Vol.387, pp. 479–481, 1997

Fishman, G.J.; and Meegan, C.A.: "Gamma-Ray Bursts," *Annual Review of Astronomy and Astrophysics*, Vol. 33, pp. 415–458, 1995

Fishman, G.J.: "Gamma-Ray Bursts: An Overview," *Publications of the Astronomical Society of the Pacific*, Vol. 107, pp. 1-7, 1995

Fishman, G.J.: "Observations of Gamma-Ray Bursts," *The Gamma-Ray Sky With Compton GRO and Sigma* (Klewer: Holland), M. Signore et al. (eds), pp. 381–94, 1995

Fishman, G.J.; and Barthelmy, S.: "Gamma-Ray Bursts: Observational Overview, Searches for Counterparts and BACODINE" *Flares and Flashes, proc, IAU colloquium No. 151* (Springer:Berlin), J. Greiner, et al. (eds.), 1995

Fishman, G.J.: "Observed Properties of Gamma-Ray Bursts" *Astronomy and Astrophysics Supplement*, Vol. 138, pp. 395–398, 1998

Pendleton, G.N.; Paciesas, W.S.; Briggs, M.S.; Preece, R.D.; Mallozzi, R.S.; Meegan, C.A.; Horack, J.M.; Fishman, G.J.; Band, D.L.; Matteson, J.L.; Skelton, R.T.; Hakkila, J.; Ford, L.A.; Kouveliotou, C.; Koshut, T.M.: "The Identification of Two Different Spectral Types of Pulses in Gamma-Ray Bursts" *Astrophysical Journal*,Vol. 489, p.175, 1997

van Paradijs, J.; Groot, P.J.; Galama, T.; Douvelioutou, C.; Strom, R.G.; Telting, J.; Rutten, R.G.M.; Fishman, G.J.; Meegan, C.A., Pettini, M.; Tanvir, N.; Bloom, J.; et al.: "Transient Optical Emission From the Error box of the Gamma-Ray Burst of 28 February 1997" *Nature*, April 1997, pp. 686–689, 1997

Dr. Robert H. Georgii
Role in GBM: Co-Investigator

Education

Dipl. Phys. in Physics, Technical University of Munich, 1989; Dr.rer. nat. with magna cum laude in Physics, Technical University of Munich,1994.

Role in GBM

Design of the GBM detector modules and mass modeling.

Experience

Dr. Georgii's primary research interests have been in non-linear dynamics, nuclear physics and gamma-ray astronomy. He joined the MPE in 1995 as an astrophysicist and is a Co-Investigator of the SPI instrument of ESA's INTEGRAL mission. For this mission he is currently working in the detector development.For COMPTEL he is engaged in the data analysis. During his doctoral thesis he spent 3 years at the ILL in Grenoble, France, working on detector development in nuclear physics. He stayed half a year each at ENEA, Frascati, Italy and the University of Oxford, Oxford, England and was participating in detector development in laser and neutronphysics. Dr. Georgii has published about 40 papers in refereed journals and conference proceedings.

Societies

Deutsche Physikalische Gesellschaft (DPG)
European Physical Society (EPS)

Honors and Awards

Fellowship at ENEA within the European Union Human Capital and Mobility (HCM) program.

Recent Publications

Georgii, R.; Diehl, R.; Lichti, G.; Oberlack, U.; Schönfelder, V.; Ködelseder, J.;Rayan, J.: "Upper Limits of ^{26}Al and ^{60}Fe From M82", Proceedings of the 2nd INTEGRAL Workshop, ESA Publication, ESA SP-382 (1997), 51.

Georgii, R.; Diehl, R.; Lichti, G.G.; and Schönfelder, V.: "Can the INTEGRAL-Spectrometer SPI Detect X-Ray Lines From Local Galaxies?", 4th Compton Symposium, AIP Conference Proceedings 410 (1997), 1554.

Georgii, R.; Meißl, M.; Hajdas, W.; Henschel,H.; Gräf, H.-D.; Lichti, G.G.; von Neumann-Cosel, P.; Richter, A.; Schönfelder, V.: "Influence of Radiation Damage on BGO Scintillation Properties", *Nuclear Instruments and Methods* Vol. A413, (1998), pp. 50–58.

Vedrenne, G.; Jean, P.; Kandel, B.; Albernhe, F.; Borrel, V.; Mandrou, P.; Roques, J.P.; von Ballmoos, P.;Durouchoux, P.; Cordier, B.; Diallo, N.; Schönfelder, V.; Lichti, G.G.; Diehl, R.; Varendorff, M.; Strong, A.W.; Georgii,R.; Teegarden, B.J.; Naya, J.; Seifert, H.; Sturner, S.; Matteson, J.; Lin, R.; Slassi, S.; Sanchez, F.; Caraveo, P.; Leleux, P.; Skinner, G.K.; Connell, P.: "The SPI Spectrometer for the INTE-GRAL Mission", *Physica Scripta* T77, (1998), 35–38.

Georgii, R.; Plüschke, S.; Diehl, R.; Collmar, W.; Lichti, G.G.; Schönfelder, V.; Bennett, K.; Bloemen, H.; Knödlseder, J.; McConell, M.; Ryan, J.; "COMPTEL Upper Limits for the ^{56}Co X-rays From SN1998", 5th Compton Symposium, AIP Conference proceedings (1999), inprint.

Dr. R. Marc Kippen
Role in GBM: Co-Investigator

Education

B.S., with Honors in Physics, University of New Hampshire, 1988; M.S., Physics (Thesis: "Monte Carlo Simulation of the COMPTEL Gamma-Ray Telescope"), University of New Hampshire, 1991; Ph.D., Physics (Dissertation: "Locations and Spectra of Cosmic Gamma-Ray Bursts), University of New Hampshire, 1995

Role in GBM:

Simulations for detector optimization, background modeling and detector response; DPU specifications; integration and test oversight; flight and ground-based software design/development; analysis of calibration and flight data.

Experience

Dr. Kippen has over 10 years experience in high-energy astrophysics research, including software & algorithm development; spacecraft operations; analysis and interpretation of astrophysical data from gamma-ray instruments; imaging, spatial and spectral analysis of cosmic gamma-ray bursts; development, operation and maintenance of rapid gamma-ray burst localization systems and counterpart search networks; development and implementation of Monte Carlo detector simulation systems. His primary scientific interests include gamma-ray bursts, nuclear decay emission from astrophysical sources, the origin of cosmic diffuse gamma rays and novel gamma-ray imaging instruments. He has published more than 100 papers in refereed journals and conference proceedings, and has presented about 30 talks at a variety of international institutes, workshops and conferences.

Dr. Kippen has worked as a member of the COMPTEL and BATSE instrument teams, where he participated in the development of analysis and operations software and performed scientific data analysis. Presently, he is a senior research associate at the University of Alabama in Huntsville, where he continues to work on the BATSE instrument team at NASA's Marshall Space Flight Center. Prior positions include research associate at the University of Alabama in Huntsville (1996–1999) and research scientist at the University of New Hampshire (1995–1996).

Societies

American Astronomical Society (AAS)
AAS High-Energy Astrophysics Division
Sigma Xi, The Scientific Research Society
Associate of The Committee on Space Research (COSPAR)

Honors and Awards

Sigma Xi Outstanding Dissertation Award, Durham, NH, 1996

Recent Publications

Kippen, R.M.; et al.: "Simulated Performance of the FiberGLAST Gamma-Ray Telescope Concept." In *Proc. of the 26th International Cosmic Ray Conf.*, ed. D. Kieda, M. Salamon & B. Dingus, Vol. 5, p. 148, 1999.

Briggs, M.S., et al.: "Observations of GRB 990123 by the Compton Gamma-Ray Observatory." *Astrophys. J.* Vol. 524, p. 82, 1999.

Briggs, M.S.; et al.: "The Error Distribution of BATSE GRB Locations." *Astrophys. J. Suppl. Ser.* Vol. 122, p. 503, 1998.

Hurley, K.; et al.: "The *Ulysses* Supplement to the BATSE 4B Catalog of Cosmic Gamma-Ray Bursts." *Astrophys. J. Suppl. Ser.* Vol. 122, p. 497, 1998.

Paciesas, W.S.; et al.: "The Fourth BATSE Gamma-Ray Burst Catalog." *Astrophys. J. Suppl. Ser.* Vol. 122, p. 465, 1999.

Woods, P.M.; et al.: "Discovery of a New Soft Gamma Repeater, SGR 1627–41." *Astrophys. J. Lett.* Vol. 519, p. L139, 1999.

Kippen, R.M.; et al.: "On the Association of Gamma-Ray Bursts With Supernovae." *Astrophys. J. Lett.* Vol. 506, p. L27, 1998.

Galama, T.J.; et al.: "An Unusual Supernova in the Error Box of the Gamma-Ray Burst of 25 April 1998." *Nature* Vol. 395, p. 670. 1998.

Kippen, R.M.; et al.: "Characteristics of Gamma-Ray Bursts at MeV Energies Measured by COMPTEL." *Adv. Space Res.* Vol. 22 (7), p. 1097, 1998.

Pendleton, G.N.; et al.: "The Structure and Evolution of LOCBURST: The BATSE Burst Location Algorithm." *Astrophys. J.* Vol. 512, p. 362, 1998.

Kippen, R.M.; et al.: "The Locations of Gamma-Ray Bursts Measured by COMPTEL." *Astrophys. J.* Vol. 492, p. 246, 1998.

Ryan, J.M.; et al.: "A Balloon-Borne Coded Aperture Telescope for Arc-Minute Resolution at Hard X-Ray Energies." *Adv. Space Res.* Vol. 21 (7), p. 1009, 1998.

Kippen, R.M.; et al.: "The BATSE Rapid Burst Response System." In AIP Conf. Proc. 428, *Gamma-Ray Bursts:Fourth Huntsville Symposium*, eds. C.A. Meegan, R.D. Preece, and T.M. Koshut, (New York: AIP Press), 119, 1998.

Dr. G. Lichti
Role in GBM: Co-Principal Investigator

Education
Diploma in Physics at the Technical University of Munich, 1972,
PhD (Dr. rer. nat.) in Physics at the Technical University of Munich, 1975.

Role in GBM:
Co-PI with main responsibility for the German part of the Burst Monitor.

Experience
Dr. Lichti has worked in the field of gamma-ray astronomy since the early 1970's when he developed, together with Prof. Schönfelder, the first double Compton telescope and participated in several successful balloon campaigns. In August 1975 he went as a member of the Caravan collaboration to the European Space Operations Center in Darmstadt where he was responsible for the scientific operation and surveillance of the European gamma-ray satellite COS-B. In January 1980 he returned to the Max-Planck-Institut für extraterrestrische Physik in Garching and joined the COMPTEL collaboration. As hardware manager he was responsible for the development of the NaI detectors and the anticoincidence subsystem of COMPTEL. After the successful launch of CGRO he was actively involved in the data analysis of the COMPTEL data. In 1994 he joined the SPI team of INTEGRAL and works since then for this project. As local project manager he has to organize and to coordinate the manufacturing of the complete BGO anticoincidence shield by the industry. In parallel he is still involved in the analysis of COMPTEL data.

Societies
Member of the Deutsche Physikalische Gesellschaft (DPG).

Honors and Awards
NASA public service-group achievement award 1992.

Recent Publications

Lichti, G.G.; Balonek, T.; Courvoisier, T.J.-L.; Johnson, N.; McConnell, M.; McNamara, B.; von Montigny, C.; Paciesas, W.; Robson, E.I.; Sadun, A.; Schalinski, C.; Smith, A.G.; Staubert, R.; Steppe, H.; Swanenburg, B.N.; Turner, M.J.L.; Ulrich, M.-H.; and Williams, O.R.: "Simultaneous and Quasi-Simultaneous Observations of the Continuum Emission of the Quasar 3C 273 From Radio to Gamma-Ray Energies", *A&A*, Vol. 298, p. 711, 1995

Lichti, G.G.; Iyudin, A.; Bennett, K.; den Herder, J.W.; Diehl, R.; Morris, D.; Ryan, J.; Schön-felder, V.; Steinle, H.; Strong, A.W.; and Winkler, C.: "COMPTEL Upper Limits on Gamma-Ray Line Emission From Supernova 1993J, *A&A Suppl. Ser.* Vol. 120, p. 353, 1996.

Schönfelder, V.; Bennett, K.; Bloemen, H.; Coll-mar, W.; Diehl, R.; Hermsen, W.; Kuiper, L.; Lichti, G.G.; McConnell, M.; Ryan, J.; Strong, A.; and Winkler, C.: "Highlights from the COMPTEL 1 to 30 MeV Sky Survey", 7th Texas Symposium on Relativistic Astrophysics and Cosmology, Vol. 759 of the Annals of the New York Academy of Sciences, p. 226, September 1995.

Lichti, G.G.; Schönfelder, V.; Diehl, R.; Georgii, R.; Kirchner, T.; Vedrenne, G.; Mandrou, P.; von Ballmoos, P.; Jean, P.; Albernhe, F.; Durouchoux, P.; Cordier, B.; Diallo, N.; Sanchez, F.; Leleux, P.; Caraveo, P.A.; Teegarden, B.; Matteson, J.; Lin, R.; Skinner, G.K.; and Connell, P.: "The Spectrometer SPI of the INTEGRAL Mission", Proc. of the SPIE Conference (Denver), Vol. 2806, pp. 217–233, 1996.

Jean, P.; Gomez-Gomar, J.; Hernanz, M.; Jose, J.; Isern, J.; Vedrenne, G.; Mandrou, P.; Schönfelder, V.; Lichti, G.G.; and Georgii, R.: "Possibility of the Detection of Classical Novae With the Shield of the INTEGRAL-Spectrometer SPI", Proceedings of the 3rd INTEGRAL Workshop (Taormina), 1998.

Weidenspointner, G.; Varendorff, M.; Bennett, K.; Bloemen, H.; Hermsen, W.; S. C. Kappadath, S.C.; Lichti, G.G.; Ryan, J.; and Schönfelder, V.: "The CDG Spectrum From 0.8-30 MeV Measured With COMPTEL Based on a Physical Model of the Instrumental Background", Proceedings of the 3rd INTEGRAL Workshop (Taormina), 1998.

Bloemen, H.; Morris, D.; Knödlseder, J.; Bennett, K.; Diehl, R.; Hermsen, W.; Lichti, G.G.; van der Meulen, R.D.; Oberlack, U.; Ryan, J.; Schönfelder, V.; Strong, A.W.; de Vries, C.; and Winkler, C.: "COMPTEL Orion Results Revisited?", Proceedings of the 3rd INTEGRAL Workshop (Taormina), 1998.

Iyudin, A.F.; Bloemen, H.; Diehl, R.; Hermsen, W.; Knödlseder, J.; Lichti, G.G.; Ryan, J.; Schönfelder, V.; Strong, A.; and Winkler, C.: "COMPTEL Constraints on Nova-Produced ^{22}Na", Proceedings of the 3rd INTEGRAL Workshop (Taormina), 1998.

Lichti, G.G.; Georgii, R.; von Kienlin, A.; Schönfelder, V.; Wunderer, C.; Jung, H.-J.; and Hurley, K.: "The Gamma-Ray Burst-Detection System of the INTEGRAL-Spectrometer SPI", Proceedings of the 5th Compton Symposium, 1999.

Weidenspointner, G.; Varendorff, M.; Bennett, K.; Bloemen, H.; Hermsen, W.; Kappadath, S.C.; Lichti, G.G.; Ryan, J.; and Schönfelder, V.: "The Spectrum of the Cosmic Diffuse Gamma-Ray Background From 0.8-30 MeV Measured With COMPTEL", submitted to A&A , 1999.

Dr. Robert S. Mallozzi
Role in GBM: Co-Investigator

Education

B.S., Physics, Pennsylvania State University, 1990;
M.S., Physics, University of Alabama in Huntsville, 1992;
Ph.D., Physics, University of Alabama in Huntsville, 1996.

Role in GBM

As Co-Investigator on the GBM project, Dr. Mallozzi is primarily responsible for instrument operations and data analysis software development and maintenance, including science data analysis tools and instrument monitoring software. He is also involved in instrument simulation studies and calibration, detector response function generation, and public outreach. Science interests include wide band gamma-ray burst spectral studies, and multi-wavelength, multi-instrument gamma-ray burst spectroscopy.

Experience

Dr. Robert Mallozzi is currently a Senior Research Associate at the University of Alabama in Huntsville, working at NASA's Marshall Space Flight Center in the field of high energy astrophysics. His doctoral research involved the study of gamma-ray bursts, which are brief flashes of high energy cosmic radiation that occur randomly on the celestial sphere. His research investigated effects of a cosmological origin of these events. After receiving his doctoral degree, he accepted a research position on the science team of the Burst and Transient Source Experiment (BATSE) to continue studies of gamma-ray bursts. His current research is focused on spectral properties of bursts, and the phenomenon of Terrestrial Gamma Flashes, which are flashes of gamma radiation that were discovered with BATSE to originate from within the atmosphere of Earth. Current work encompasses a broad range of tasks, including advanced scientific data analysis and visualization, numerical modeling and simulation, and three dimensional computer graphics and animation. Although formally trained in the physical sciences, Dr. Mallozzi also has a strong interest in Computer Science, and is currently pursuing an advanced degree in that discipline.

Societies

American Astronomical Society (AAS)

Selected Publications

Preece, R.D.; Briggs, M.S.; Mallozzi, R.S.; Pendleton, G.N.; Paciesas, W.S.; Band, D.L.; "The BATSE Gamma-Ray Burst Spectral Catalog I. High Time Resolution Spectroscopy of Bright Bursts Using High Energy Resolution Data.", *ApJS*, in press 1999.

Preece, R.D.; Briggs, M.S.; Mallozzi, R.S.; Pendleton, G.N.; Paciesas, W.S.; and Band, D.L.: "The Synchrotron Shock Model Confronts a Line of Death in the BATSE Gamma-Ray Burst Data." *ApJ Letters*, Vol. 506, p. L26,1999.

Preece, R.D.; Pendleton, G.N.; Briggs, M.S.; Mallozzi, R.S.; and Paciesas, W.S.: "BATSE Observations of Gamma-Ray Burst Spectra IV. Time-Resolved High-Energy Spectroscopy." *ApJ*, Vol. 497, p. 849, 1998.

Pendleton, G.N.; Paciesas, W.S.; Briggs, M.S.; Preece, R.D.; Mallozzi, R.S.; Meegan, C.A.; Horack, J.M.; Fishman, G.J.; Band, D.L.; Matteson, J.; Skelton, R.T.; Hakkila, J.; Ford, L.; Kouveliotou, C.; and Koshut, T.M.: "The Identification of Two Different Spectral Types of Pulses in Gamma-Ray Bursts." *ApJ*, Vol. 489, p. 175, 1998.

Hakkila, J.; Meegan, C. A.; Horack, J.M.; Pendleton, G.N.; Briggs, M.S.; Mallozzi, R.S.; Koshut, T.M.; Preece, R.D.; and Paciesas, W.S.: "Luminosity Distributions of Cosmological Gamma-Ray Bursts" *ApJ*, Vol. 462, p. 125, 1996.

Mallozzi, R. S.; Paciesas, W. S.; and Pendleton, G. N.: "Effects of Spectral Shape on Cosmological Models of the BATSE Gamma-Ray Burst Intensity Distribution" *ApJ*, Vol. 471, p. 636, 1996.

Meegan, C.A.; Pendleton, G.N.; Briggs, M.S.; Kouveliotou, C.; Koshut, T.M.; Lestrade, J.P.; Paciesas, W.S.; McCollough, M.L.; Brainerd, J.J.; Horack, J.M.; Hakkila, J.; Henze, W.; Preece, R.D.; Mallozzi, R.S.; and Fishman, G.J.: "The Third BATSE Gamma-Ray Burst Catalog" *ApJS*, Vol. 106, p. 65, 1996.

Pendleton, G.N.; Mallozzi, R.S.; Paciesas, W.S.; Briggs, M.S.; Preece, R.D.; Koshut, T.M.; Horack, J. M.; Meegan, C.A.; Fishman, G.J.; Hakkila, J.; and Kouveliotou, C.: "The Intensity Distribution for Gamma-Ray Bursts Observed with BATSE." *ApJ*, Vol. 464, p. 606, 1996.

Mallozzi, R.S.; Paciesas, W.S.; Pendleton, G.N.; Briggs, M.S.; Preece, R.D.; Meegan, C.A.; and Fishman, G.J.: "The _F Peak Energy Distributions of Gamma-Ray Bursts Observed by BATSE." *ApJ*, Vol. 454, p. 597, 1995.

Fishman, G.J.; Bhat, P.N.; Mallozzi, R.S.; Horack, J.M.; Koshut, T.M.; Kouveliotou, C.; Pendleton, G. N.; Meegan, C.A.; Wilson, R.B.; Paciesas, W.S.; Goodman, S.J.; and Christian, H.J.: "Discovery of Intense Gamma-Ray Flashes of Atmospheric Origin." *Science*, Vol. 264, p. 1313, 1994.

Prof. William S. Paciesas
Role in GBM: Co-Investigator

Education
B.S., magna cum laude, Physics, Seton Hall University, 1969; M.S., Physics, University of California, San Diego, 1971; Ph.D., Physics, University of California, San Diego, 1978.

Role in GLAST GBM
Prof. Paciesas is a co-investigator, with primary responsibility for interface with the LAT. He is also the lead UAH representative to the GBM project. His primary science interest in the GBM is time-resolved wide-band spectroscopy of gamma-ray bursts.

Experience
Prof. Paciesas' primary research interests are in observational x-ray and gamma-ray astronomy, including gamma-ray bursts (especially spectroscopy), galactic black hole candidates, low-mass x-ray binaries, and Seyfert galaxies. He has worked on a number of balloon-borne and space-borne telescopes, and he has been the author or co-author of approximately 100 refereed and 275 non-refereed publications. He has been a member of the CGRO User's Committee, the CGRO Data Analysis Operations Working Group, and the CGRO Operations Working Group. He is currently a co-investigator on the CGRO Burst and Transient Source Experiment.

Prof. Paciesas currently holds the position of Research Professor at the University of Alabama in Huntsville. From 1978–1980, he was a NAS/NRC Resident Research Associate at NASA/GSFC, and during 1980–1982 he worked as a Research Associate at the University of Maryland. He has been a research faculty member at UAH since 1982, working primarily on CGRO/BATSE, and is the leader of the UAH gamma-ray astronomy group.

Societies
American Astronomical Society (AAS)
AAS High Energy Astrophysics Division
American Physical Society
American Association for the Advancement of Science
International Astronomical Union
IEEE Nuclear & Plasma Sciences Society

Honors and Awards
Sigma Pi Sigma (physics honor society) 1968
Delta Epsilon Sigma (academic honor society) 1969
NASA Group Achievement Award, Spacelab 2 Nuclear Radiation Monitor 1986
NASA Group Achievement Award, GRO Operations Working Group 1992
NASA Group Achievement Award, BATSE Instrument Team 1992

Selected Recent Publications

Paciesas, W.S.; Meegan, C.A.; Pendleton, G.N.; Briggs, M.S.; Kouveliotou, C.; Koshut, T.M.; Lestrade, J.P.; McCollough, M.L.; Brainerd, J.J.; Hakkila, J.; Henze, W.; Preece, R.D.; Connaughton, V.; Kippen, R.M.; Mallozzi, R.S.; Fishman, G.J.; Richardson, G.A.; and Sahi, M.: "The Fourth BATSE Gamma-Ray Burst Catalog (Revised)" *ApJS*, Vol. 122, p. 465.

Preece, R.D.; Briggs, M.S.; Mallozzi, R.S.; Pendleton, G.N.; Paciesas, W.S.; and Band, D.L.: "The BATSE Gamma-Ray Burst Spectral Catalog I. High Time Resolution Spectroscopy of Bright Bursts using High Energy Resolution Data." *ApJS*, in press, 1999.

Preece, R.D.; Briggs, M.S.; Mallozzi, R.S.; Pendleton, G.N.; Paciesas, W.S.; and Band, D.L.: "The Synchrotron Shock Model Confronts a Line of Death in the BATSE Gamma-Ray Burst Data." *ApJ* Vol. 506, p. L26, 1999.

Mitrofanov, I.G.; Litvak, M.L.; Briggs, M.S.; Paciesas, W.S.; Pendleton, G.N.; Preece, R.D.; and Meegan, C.A.: "Average Emissivity Curve of BATSE Gamma-Ray Bursts With Different Intensities." *ApJ* Vol. 523, p. 610, 1999.

van der Hooft, F.; Kouveliotou, C.; van Paradijs, J.; Paciesas, W.S.; Lewin, W.H.G.; van der Klis, M.; Crary, D.J.; Finger, M.H.; Harmon, B.A.; and Zhang, S.N.: "Hard X-Ray Lags in GRL J1719–24" *ApJ* 519, 332, 1999.

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Preece, R.D.; Pendleton, G.N.; Briggs, M.S.; Mallozzi, R.S.; and Paciesas, W.S.: "BATSE Observations of Gamma-Ray Burst Spectra IV. Time-Resolved High-Energy Spectroscopy" *ApJ*, Vol. 497, p. 849, 1998.

Harmon, B.A.; Deal, K.J.; Paciesas, W.S.; Zhang, S.N.; Robinson, C.R.; Gerard, E.; Rodriguez, L.F.; and Mirabel, I.F.: "Hard X-Ray Signature of Plasma Ejection in the Galactic Jet Source GRS 1915+105" *ApJ* Vol. 477, p. L85, 1997.

Mallozzi, R.S.; Paciesas, W.S.; Pendleton, G.N.; Briggs, M.S.; Preece, R.D.; Meegan, C.A.; Fishman, G.J.; "The nF_n Peak Energy Distributions of Gamma-Ray Bursts Observed by BATSE" *ApJ*, Vol. 454, p. 597, 1995.

Dr. Robert D. Preece
Role in GBM: Co-Investigator

Education

B.A., with Distinction in Mathematics and Physics, University of California, Berkeley, 1982;
M.S., Physics, The Ohio State University, 1985;
Ph.D., Astrophysics, University of Maryland, 1990

Role in GBM: Data Analysis Manager.

Experience

Dr. Robert D. Preece is a senior research associate for the Department of Physics at the University of Alabama in Huntsville (UAH). His primary research interests have been gamma-ray bursts, soft-gamma repeaters and quantum synchrotron emission from astrophysical sources. He is a member of the instrument team for NASA's Burst and Transient Source Experiment (BATSE) on board the Compton Gamma-Ray Observatory, working in the areas of spectral analysis, instrument calibration and astrophysical modeling of gamma-ray emission. He joined the BATSE team while an NRC postdoc at NASA's Marshall Space Flight Center.

With the recent observation of x-ray afterglow in several GRB's, it is crucial to understand the correlation between the x-ray and gamma-ray bands. One of Dr. Preece's recent awarded proposals is to do a time-resolved analysis of the x-ray excess emission (5–20 keV) observed in 15 percent of the GRB's observed by the BATSE spectroscopy detectors. Joint fitting of data between the several space-based instruments that have observed GRB's to date, is feasible with the long-duration mission of CGRO. While any one burst many be seen by a only a few instruments, the whole ensemble has been observed by a large number of detectors, with the CGRO instruments serving as the common thread. With Dr. M. S. Briggs at UAH, he has a long-term (5 year) grant from NASA to accomplish this effort.

Dr. Preece was involved in the planning of the 4th Huntsville GRB Symposium, held on Sept. 15 – 20, 1997, as a member of the Local Organizing Committee; this also included being a co-editor with Drs. Charles Meegan and Thomas Koshut of the Symposium Proceedings. As an aside to this effort, he participated with the CGRO Science Support Center at Goddard Space Flight Center to create the second BATSE data CD-ROM, which was delivered to the gamma-ray burst community at the Symposium.

Societies

American Astronomical Society (AAS)
AAS High-Energy Astrophysics Division

Recent Publications

Preece, R.; Briggs, M.; Mallozzi, R.; Pendleton, G.; Paciesas, W.; and Band, D.: "The BATSE Gamma-Ray Burst Spectral Catalog. I. High-Time Resolution Spectroscopy of Bright Bursts Using High-Energy Resolution Data", *ApJ*, 1999, in press.

Paciesas, W.; Meegan, C.A.; Pendleton, G.; Briggs, M.; Kouveliotou, C.; Koshut, T.; Lestrade, J.P.; McCollough, M.; Brainerd, J.J.; Hakkila, J.; Henze,W.; Preece, R.; et al.: "The Fourth BATSE Gamma-Ray Burst Catalog (Revised)", *ApJS*, 1999, Vol. 122 p. 465.

Briggs, M.S.; Band, D.L.; Kippen, R.M.; Preece, R.D.; Kouveliotou, C.; van Paradijs, J.; Share, G.H.; Murphy, R.J.; Matz, S.M.; Connors, A.; Winkler, C.; McConnell, M.L.; Ryan, J.M.; Williams, O.R.; Young, C.A.; Dingus, B.; Catelli, J.R.; and Wijers, R.A.M.J.: "Observations of GRB 990123 by the Compton Gamma-Ray Observatory", *ApJ*, Vol. 524 p. 82, 1999.

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Giblin, T.W.; van Paradijs, J.; Kouveliotou, C.; Connaughton, V.; Wijers, R.A,M.J.; Briggs, M.S.; Preece, R.D.; and Fishman, G.J.: "Evidence for an Early High-Energy Afterglow Observedwith BATSE from GRB 980923", *ApJ*, Vol. 524 p. L47, 1999.

Mitrofanov, I.G.; Anfimov, D.; Litvak, M.; Briggs, M.S.; Paciesas, W.S.; Pendleton, G.N.; Preece, R.D.; and Meegan, C.A.: "Average Cosmological Invariant Parameters of Cosmic Gamma-Ray Bursts", *ApJ*, Vol. 523 p. 192, 1999.

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Mitrofanov, I.G.; Anfimov, D.; Litvak, M.; Sanin, A.; Saevich, Y.; Briggs, M.S.; Paciesas, W.S.; Pendleton, G.N.; Preece, R.D.; Koshut, T.; Fishman, G.J.; Meegan C.A.; and Lestrade, J.P.: "The Emission Time of Gamma-Ray Bursts", *ApJ*, Vol. 522 p. 1069, 1999.

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Preece, R.; Briggs, M.; Mallozzi, R.; Pendleton, G.; Paciesas W.; and Band, D.: "The Synchrotron Shock Model Confronts a 'Line of Death' in the BATSE Gamma-Ray Burst Data", *ApJ*, Vol. 506 p. L2, 1998.

Dr. V. Schönfelder
Role in GBM: Co-Investigator

Education
Diploma in Physics at University of Kiel, 1966,
PhD in Physics atTechnische Universität München, 1970,
Habilitation inExperimental Physics at Technische Universität München, 1979, apl.
Professor of Physics at Technische Universität München, 1995.

Role in GBM
Co-I with responsibility to coordinate GBM issues between MPE and DLR and between MPE and MSFC.

Experience
Dr. Schönfelder started his carreer in cosmic ray physics (cosmic-ray neutrons) and is working in the field of gamma-ray astronomy since 1971. He is head of the gamma-ray astronomy group at theMax-Planck-Institut für extraterrestrische Physik since 1982. He has been the Principal Investigator of the Compton Telescope Balloon Programs at MPE (from 1971 to 1982), the Principal Investigator of COMPTEL aboard NASA's Compton Gamma-Ray Observatory (from 1979 till now), and one of the two Co-Principal Investigators of the Spectrometer INTEGRAL (SPI) Instrument (since 1995). He has published more than 300 papers in refereed journals and conference proceedings. He has served on a number of committees in Germany, of ESA and of NASA. Since 1995 he is apl. Professor of Physics at the Technische Universität München and as such, teaching courses on "astrophysics" for graduates and undergraduates.

Societies
Deutsche Physikalische Gesellschaft
Astronomische Gesellschaft
International Astronomical Union

Honors and Awards
NASA exceptional scientific achievement Award 1993,
Deutscher Philip Morris Forschungspreis 1997

Recent Publications
Werner Collmar and Volker Schönfelder: "Evidence for Massive Black Holes in the Nuclei of Active Galaxies from Gamma-Ray Observations." Proc. of Heraeus-Seminar, Phys. Soc. Bad Honnef (Aug. 1997), *BlackHoles*: Theory and Observation, submitted to Springer (1998);

Igor V. Moskalenko, Werner Collmar, and VolkerSchönfelder: "A Combined Model for the X-Ray to Gamma-Ray Emisssion of CygX-1." *ApJ*, Vol. 502 pp. 428–436, 1998 July 20;

V. Schönfelder: "Gammastrahlung ausdemKosmos," Physikalische Blätter 54, No. 4,Seite 325–330 (1998);

Iyudin, A.F.; Schönfelder, V.; Bennett, K.; Bloemen, H.; Diehl,R.; Hermsen, W.; Lichti, G.G.; van der Meulen, R.D.; Ryan, J.; and Winkler, C.: "Emission From ^{44}Ti Associated With a Previously Unknown Galactic Supernova.", *Nature*, Vol. 396, pp. 142–144, 12 November 1998.

Aschenbach, B.; Iyudin, A.F.; and Schönfelder, V.: "Constraints of Age, Distance and Progenitor of the Supernova Remnant RXJ0852.0–4622/GRO J0852–4642, *A&A*, submitted March 3, 1999;

Schönfelder, V.: "Prospects for the INTEGRAL Spectrometer SPI.", LiBeB, Cosmic Rays and Related XC and Gamma Rays, ASP Conference Series, eds. R. Ramaty, E. Vangioni-Flam, M. Cassé and K. Olive, Vol. 171, pp. 217–225 (1999);

Schönfelder V.; et al.: "The First COMPTEL Source Catalogue.", *A&A Suppl.*, submitted August 1999.

Dr. Andreas A. von Kienlin
Role in GBM: Co-Investigator

Education
Diploma in Physics, University of Heidelberg, Germany, 1987; Dr. rer. nat.in Nuclear Physics, magna cum laude, GSI Darmstadt and University of Mainz,Germany, 1993

Role in GBM:
Development of the detector module electronics (voltage divider and pre-amplifier electrical design), preparation and execution of detector performance tests and GBM detector calibration.

Experience
Dr. von Kienlin has been primarily working on the development of detectors for astrophysics, nuclear physics and atomic physics applications. During his Ph.D thesis and Postdoc time at the heavy ion facility GSI in Darmstadt and the nuclear physics group at the University of Mainz, he developed a successful new detector type for the energy-sensitive detection of heavy ions. The observed relative energy resolution of the so called low temperature detectors (LTDs) for different heavy ion species (^{20}Ne, ..., ^{209}Bi) at different energies (3 MeV/u, ..., 100 MeV/u) was in the DE/E =10^{-3} range. Compared to conventional detectors, this is an order of magnitude improvement for very heavy ions. In first nuclear physics experiments Dr. von Kienlin has shown the successful use of these new detectors.

During his EC-Fellowship in Genoa Dr. von Kienlin has developed superconducting transition edge sensors (TES) for high resolution x-raydetection and for the application in an neutrino physics experiment (b-decay of ^{187}Re).

Dr. von Kienlin joined the Max-Planck Institute fürextraterrestrische Physik in April 1998 as a member of the INTEGRAL team of the gamma-ray astronomy group.He is working on detector development, detector performance tests and the calibration of the spectrometer SPI. Furthermore he is engaged in the ACS burst detection system.
Dr. von Kienlin has published about 30 papers in refereed journals and conference proceedings and presented about 15 talks at internationali nstitutes and conferences

Societies
German Physical Society " Deutsche Physikalische-Gesellschaft" (DPG)

Honors and Awards
Scholarship of the Studienstiftung des deutschen Volkes – 1984-87

European Community EC-Fellowship at the national Italian nuclearphysics institute INFN in Genoa, Italy – 1996-98

Recent Publications

Lichti, G.G.; Georgii, R.; von Kienlin, A.; Schönfelder, V.; Wunderer, C.; Jung, H.-J.; Hurley, K.: "The Gamma-Ray Burst-Detection system of the INTEGRAL-Spectrometer SPI", 5th Compton Symposium, AIP Conference Proceedings (1999), in print

Jean, P.; Vedrenne, G.; Schönfelder, V.; Albernhe, F.; Borrel, V.; Bouchet, L.; Caraveo, P.; Connall, P.; Cordier, B.; Denis, M.; Cozach, R.; Diehl, R.; Durouchoux, Ph.; Georgii, R.; Juchniewicz, J.; von Kienlin, A.; Knödlseder, J.; Larque, Th.; Lavigne, J.M.; Leleux, P.; Lichti, G.; Lin, R.; Mandrou, P.; Matteson, J.; Paul, Ph.; Roques, J.P.; Sanchez, F.; Schanne, S.; Skinner, G.; Slassi-Sennou, S.; Strong, A.; Sturner, S.; Teegarden, B.; vonBallmoos, P.; Wunderer, *C*.; "The spectrometer SPI of the INTEGRAL Mission", 5th Compton Symposium, AIP Conference Proceedings (1999), in print.

von Kienlin, A.; Galeazzi, M.; Gatti, F.; Vitale, S.; "A Monolithic Superconducting Micro-Calorimeter for X-Ray Detection", *Nucl.Instr. and Meth.* A 412 (1998) 135–139

Meier, H.J.; Egelhof, P.; Henning, W.; Kienlin, A.V.; Kraus, G.; Weinbach, A.; "Low Temperature Bolometers for Experiments with Cooled Heavy Ion Beams From Storage Rings", *Nucl. Phys*. A 626 (1997) 451c

von Kienlin, A.; Galeazzi, M.; Gatti, F.; Meunier, P.; Swift, A.M.; and Vitale, S.: "X-Ray Detection With a Bulk Iridium Transition Edge Calorimeter", Proc. 7th Int. Workshop on Low Temperature Detectors LTD–7, Munich 1997

Egelhof, P.; Beyer, H.F.; McCammon, D.; Feilitzsch, F.V.; von Kienlin, A.; Kluge, H.J.; Liesen, D.; Meier, J.; Moseley, S.H.; Stöhlker, T.; "Applications of Low-Temperature Calorimeters for Precise Lamb Shift Measurements on Hydrogen-like Very Heavy Ions", *Nucl. Instr.And Meth.* A 370 (1996) 263–265

von Kienlin, A.; Azgui, F.; Böhmer, W.; Djotni, K.; Egelhof, P.; Henning,W.; Kraus, G.; Meier, J.; and Shepard, K.W.:"High Resolution Detection of Energetic Heavy Ions With a Calorimetric Low-Temperature Detector", *Nucl. Instr. and Meth.* 370 (1996) 815–818

Appendix B

Letters of Endorsement

UAH
The University of Alabama in Huntsville

Research Administration

Huntsville, Alabama 35899
Phone: (256) 890-6000
Fax: (256) 890-6677

October 27, 1999

Dr. Charles A. Meegan
Mail Code SD50
NASA/MSFC
Marshall Space Flight Center, AL 35812

Subject: UAH Research Proposal No. 2000-027

Reference: AO 99-0SS-03

Dear Dr. Meegan:

The University of Alabama in Huntsville is pleased to submit subject proposal to be included in the Marshall Space Flight Center 's proposal in response to the referenced announcement.

In the event of an award based on this proposal, the University is committed to performing the scope of work as described in the proposal.

If you need technical assistance during the evaluation, please contact Dr. William S. Paciesas, Principal Investigator, at 256-544-7712. For administrative, negotiation, or contractual assistance, you can reach Ms. Mary L. Summerlin, Assistant Research Administrator, at 256-890-6000/233 or summer@email.uah.edu.

Sincerely,

Sue B. Weir

Sue B. Weir
Research Administrator

Sincerely,

William S. Paciesas 10/27/99

William S. Paciesas
Principal Investigator

MAX-PLANCK-INSTITUT FÜR EXTRATERRESTRISCHE PHYSIK

PROF. DR. JOACHIM TRÜMPER
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October 27, 1999

Dr. Charles A. Meegan
NASA/Marshall Space
Flight Center - Code ES62

HUNTSVILLE, AL 35812
USA

Subject: **Letter of endorsement for the GLAST Burst-Monitor Proposal**

Dear Dr. Meegan,

As acting director of the Max-Planck-Institut für extraterrestrische Physik (MPE), I support the proposal for the GLAST Burst Monitor (GBM) on the GLAST spacecraft, which is jointly to be submitted by a collaboration between your group at the Marshall Space-Flight Center (MSFC) and the University of Alabama in Huntsville (UAH) and the gamma-ray group of the Max-Planck-Institut für extraterrestrische Physik (MPE), to the NASA-AO for the GLAST mission. An official application has been submitted by our institute to the Deutsches Zentrum für Luft- und Raumfahrt (DLR) asking for the endorsement of our involvement in this project.

You have kindly invited MPE to participate in such a collaboration because of its important role in gamma-ray astronomy and its excellent experience in developing and manufacturing space-proved scintillation detectors. This experience is based on the successful participation of our institute in NASA's CGRO mission (COMPTEL, EGRET) and in ESA's INTEGRAL project (spectrometer SPI). The work share between your group and MPE will guarantee that this experience is fully exploited: MPE will be responsible for the manufacturing, tests and calibration of all scintillation detectors including the photomultipliers, the voltage dividers and the preamplifiers. Moreover we will manufacture the low-voltage and the high-voltage power supplies. MSFC/UAH will develop and deliver the data-processing unit, the harnesses and will be responsible for the interface to the spacecraft. They will perform the project management and they will be responsible for the mechanical and thermal analysis, the system integration and the system tests.

It is my understanding that the data-analysis is a common effort between your group and our group and that the scientific return is to be equally shared by both groups.

In the event that the proposal is selected by NASA and that the German part of the project is supported by the DLR, the institute will make strong efforts to realize this project.

Sincerely,

J. Trümper

Appendix C

Draft International Agreement

The Gamma-Ray Burst Monitor (GBM) is a NASA secondary instrument on the Gamma-Ray Large Area Space Telescope (GLAST) Mission that is a follow-on to the Compton Gamma Ray Observatory. The primary goal of the mission is to advance our understanding of the origin of the universe through study of astrophysical and solar phenomenology at high energies in the electromagnetic spectrum. The goal will be achieved through the development of advanced instrumentation, that will observe gamma-ray sources over a very broad energy band.

Pursuant to this Interim Agreement, DLR will use reasonable efforts to carry out the following responsibilities:

- Provide overall program management for the GBM Instrument;
- Design and build the detectors, low and high voltage power supplies, and preamplifiers for the detectors;
- Qualify the flight articles for launch and operation in a low-Earth orbit;

Participate in a Co-PI capacity along with the MPE science team members in the science oversight role of the GBM Instrument development and in science operations. Provide the Co-PI as a participant in the Science Working Group at the facility level and in the U.S. PI science team.

Pursuant to this Interim Agreement, NASA will use reasonable efforts to carry out the following responsibilities:

- Design, build, and launch a complete GLAST facility to be integrated to a NASA provided spacecraft and launched with a NASA provided launch vehicle.

Provide instrument integration

- Provide mission operations development and mission operations including preliminary mission design, operations software development, and spacecraft tracking and operations support.
- Provide science support for all mission phases.

Once approved by both Parties, this International Agreement will provide the framework under which MPE will ship the hardware and technical data as detailed above to NASA for use in GBM activities. Detailed arrangements for shipment and receipt of this equipment will be made between the NASA Marshall Space Flight Center (MSFC) and MPE. Once approved by both Parties, this International Agreement will remain in effect until completion of the GLAST Mission

Below are the primary NASA and MPE contacts for this agreement:

NASA:
Dr. Alan Bunner
Code SR
NASA Headquarters
Washington, DC 20546

MSFC:
Mr. Steven Elrod
Spaceflight Experiments Group/SD21
Marshall Space Flight Center, Alabama 35812

MPE:
Dr. Giselher Lichti
Max Planck Institute for Extraterrestrial Physics
Garching, Germany

In order to proceed further both NASA and DLR agree as follows:

1) To endeavor to conclude this government-to-government International Arrangement (MOU) and associated exchange of diplomatic notes as expeditiously as possible, with a goal of completing the same no later than June 30, 2000.

2) The Parties are obligated to transfer only those technical data (including software) and goods necessary to fulfill their respective responsibilities under this agreement, in accordance with the following provisions:

a) The transfer of technical data (excluding software) for the purpose of discharging the parties' responsibilities with regard to interface, integration, and safety shall normally be made without restriction, except as required by national laws and regulations relating to export control or the control of classified data. If proprietary but not export-controlled design, manufacturing, and processing data and associated software is necessary for interface, integration, or safety purposes, the transfer shall be made and the data and associated software shall be appropriately marked.

b) All transfers of proprietary technical data and export-controlled technical data and goods are subject to the following provisions. In the event a party finds it necessary to transfer goods which are subject to export control or technical data which is proprietary or subject to export control, and for which protection is to be maintained, such goods shall be specifically identified and such technical data shall be marked with a notice to indicate that they shall be used and disclosed by the receiving party and its related entities (e.g., contractors and subcontractors) only for the purposes of fulfilling the receiving party's responsibilities under the programs implemented by this agreement, and that the identified goods and marked technical data shall not be disclosed or retransferred to any other entity without the prior written permission of the furnishing party. The receiving party agrees to abide by the terms of the notice, and to protect any such identified goods and marked technical data from unauthorized use and disclosure, and also agrees to obtain these same obligations from its related entities prior to the transfer. Nothing in this article requires the parties to transfer goods or technical data contrary to national laws and regulations relating to export control or control of classified data.

c) All goods, marked proprietary data, and marked or unmarked technical data subject to export control, which is transferred under this agreement, shall be used by the receiving party exclusively for the purposes of the programs implemented by this agreement.

Nothing in this agreement shall be construed as granting or implying any rights to, or interest in, patents or inventions of the Parties or their contractors or subcontractors.

3) All equipment and technical data transferred by the Parties under this interim agreement shall remain the property of the originating Party unless specified otherwise in this interim agreement. The Parties shall seek to arrange free customs clearance and waiver of applicable customs duties and taxes, for equipment and technical data imported into their respective countries under this interim agreement and, if unable to make such arrangements, shall arrange to pay same.

4) Release of public information regarding this program may be made by the appropriate agency for its own portion of the program as desired and, insofar as participation of the other is involved, after suitable consultation.

5) NASA and DLR will each bear the costs of discharging its respective responsibilities as defined in this agreement, including travel and subsistence of its own personnel and transportation of all equipment for which it is responsible.

6) It is confirmed that the Parties will conclude an International Arrangement (MOU) which will provide that activities undertaken pursuant to this Draft International Arrangement (MOU) shall be governed by the Agreement between the Government of the United States of America and the Government of Germany Concerning Cross-Waiver of Liability for Cooperation in the Exploration and Use of Space for Peaceful Purposes (the "Cross-Waiver Agreement"), and shall be subject to the Exchange of Notes between the Governments concerning the Cross-Waiver Agreement and to the arrangements between the Parties regarding subrogated claims of the Government of the United States of America and the Government of Germany.

a) With regard to activities undertaken pursuant to the International Arrangement (MOU), DLR confirms that the <u>appropriate organization</u> will purchase adequate insurance to indemnify and hold harmless NASA, its employees, its related entities (e.g., contractors, subcontractors, investigators or their contractors or subcontractors), and employees of its related entities against claims, including subrogated claims of the German Government, for injury to or death of DLR and MPE employees or employees of its related entities, or for damage to or loss of DLR's own property or that of its related entities, whether such injury, death, damage or loss arises through negligence or otherwise, except in the case of willful misconduct. NASA waives all claims, including the subrogated claims of the United States Government, against DLR, its employees, its related entities (e.g., contractors, subcontractors, investigators or their contractors or subcontractors), and employees of its related entities for any injury to or death of NASA employees or employees of its related entities, or for damage to or loss of NASA property or that of its related entities, whether such injury, death, damage or loss arises through negligence or otherwise, except in the case of willful misconduct.

b) The Parties further agree to use all reasonable efforts to extend this provision as set forth above to their own related entities by requiring them, by contract or otherwise, to waive all claims against the other Party and its related entities against any claim for injury, death, damage or loss arising from activities undertaken pursuant to this agreement.

c) This provision shall not be applicable to:

(1) claims between a Party and its own related entity or between its own related entities;

(2) claims made by a natural person, his/her estate, survivors or subrogees (consistent with paragraph 6.(a) above) for bodily injury, other impairment of health, or death of such natural person;

(3) claims for damage caused by willful misconduct;

(4) intellectual property claims; or

(5) claims for damage based upon a failure of the Parties to extend the provision as set forth above or from a failure of the Parties to ensure that their related entities extend the provision as set forth above;

(6) contract claims between the Parties based on express contractual provisions.

d) Nothing in the above shall be construed to create the basis for a claim or suit where none would otherwise exist.

Appendix D

Reference List

Reference List

Aarnio, P.A.; et al.:1990, *FLUKA User's Guide* CERN TIS-RP-190

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Baring, M.G.; and Harding, S.K.: *ApJ*, 481, L85, 1997

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Appendix E

Acronyms List

Acronym List

ACS	anticoincidence subsystem
ADC	analog to digital converter
AGC	automatic gain control
AO	announcement of opportunity
BATSE	Burst and Transient Source Experiment
BB	breadboard
BGO	bismuth germanate
BSPEC	background spectroscopy
BTIME	background time
CDR	critical design review
CEASE	compact environment anomaly sensor
CEI	contract end item
CGRO	Compton Gamma-Ray Observatory
CPU	central processing unit
CRD	critical design review
DLR	Deutsches Zentrum fuer Luft- und Raumfahr
DoD	Department of Defense
DPU	data processing unit
DR	data requirements
DRE	data receiver electronics
DVD	digital video disk
EEE	electronic, electrical, electromechanical
EGRET	energetic gamma-ray experiment telescope
EGSE	electrical ground support equipment
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EM’s	electrical models
EPO	education and public outreach
ESD	electrostatic discharge
ESOC	European Space Operation Center
FITS	flexible image transport system
FOV	field of view
FPGA’s	field programmable gate arrays
FTE	full time equivalent
GBM	GLAST Burst Monitor
GCN	gamma-ray coordinates network
GEANT	GEometry ANd Tracking Monte Carlo Program
GI	guest investigator
GLAST	gamma-ray large area space telescope
GO	guest observer
GOP	guest observer program
GRB	gamma-ray burst
GSE	ground supply equipment
GSFC	Goddard Space Flight Center
HETE	high energy transient explorer
HV	high voltage
HVPS	high voltage power supply
IAR	independent assessment review

ICD	interface control document
IDL	interactive data language
IGSE	instrument ground support equipment
IOC	instrument operations center
IPI	instrument principal investigator
IPN	Interplanetary Network
IR	infrared
I&T	integration and test
ITTR	integration/test readiness review
LAD’s	large area detectors
LAT	large area telescope
LED’s	light emitting diodes
LVPS	low voltage power supply
MLI	multi layer insulation
MOC	mission operations center
MOU	memorandum of understanding
MPE	Max Planck Institute for Extraterrestrial Physics
MSFC	Marshall Space Flight Center
MUX’s	multiplexer
NaI	Sodium Iodide
NAR	nonadvocate review
NFI	narrow field instruments
OSSE	Oriented Scintillation Spectroscopy Experiment
OWI	organizational work instruction
PDR	preliminary design review
PER	pre-environmental review
PMT’s	photomultiplier tube
PRE	processing electronics
PSR	preship review
PVO	Pioneer Venus Orbiter
RFP	request for proposal
ROTSE	Robotic Optical Transient Search Experiment
S&MA	safety and mission assurance
SAA	South Atlantic anomaly
SBD	small disadvantaged businesses
SGR	soft gamma repeater
SINDA	system improved differencing analyzer
SMAPP	safety and mission assurance program plan
SMM	solar maximum mission
SOC	science operations center
SPI	spectrometer on Integral
SRR	system requirements review
STM’s	structural test models
TDR/DR	test discrepancy record/discrepancy record
TRASYS	thermal radiation analyzer system
TTE	time tagged events
UAH	University of Alabama in Huntsville
UTC	coordinated universal time
UV	ultraviolet
WFC	wide field camera