THE HISTORY OF BATSE

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Abstract. The BATSE experiment on the Compton Gamma-ray Observatory was the first large detector system designed for the study of gamma-ray bursts. The eight large-area detectors allowed full-sky coverage and were optimized to operate in the primary energy region of emission of most GRBs. BATSE provided detailed observations of the temporal and spectral characteristics of several thousand GRBs, and it was the first experiment to provide rapid notifications of the coarse location of many them. It also provided strong evidence for the cosmological distances to GRBs through the observation of the sky distribution and intensity distribution of numerous GRBs. The large number of GRBs observed with the high- sensitivity BATSE detectors continues to provide a database of GRB spectral and temporal properties in the primary energy range of GRB emission that will likely not be exceeded for at least another decade. The origin and development of the BATSE experiment, some highlights from the mission and its continuing legacy are described in this paper.

1 How BATSE began

Soon after the announcement of the discovery of GRBs by the Los Alamos Group with the Vela satellites (Klebesadel *et al.* 1973) it was realized that balloon flight observations of them were possible by means of sufficiently large area, sensitive detectors. An extrapolation of a $-3/2$ power law intensity distribution of them, expected for a homogeneous, three-dimensional distribution of GRB sources to lower intensities would yield a GRB rate of several dozen per day over the full sky. Thus, a balloon-borne detector system with an effective area of ~ 1 m² had a good chance of observing ~ 10 GRBs during a balloon flight of reasonable duration.

Using the cosmic ray research facilities and personnel kindly made available by T. Parnell at the NASA-Marshall Space Flight Center (MSFC), I decided to begin a modest balloon flight program aimed at observing GRBs that were considerably

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weaker than those observed by the Vela spacecraft and by other small, space-borne detectors. Large-area crystal scintillation detectors were fabricated using cheap, scrap pieces of thallium-activated sodium iodide scintillator crystals, NaI(Tl), immersed in clear mineral oil (Fishman 1974; Fishman & Austin 1976), as seen in Figure 1. These hermetically-sealed detectors had a crystal thickness of ~ 2 cm, with a high detection efficiency for gamma radiation up to a few hundred keV. Two balloon flights with a total duration of 28 hours were carried out in 1975 and 1977 from Palestine, Texas using an array of these detectors on a balloon payload similar to that shown in Figure 2. These observations resulted in an observed GRB rate that was well below that expected for a homogeneous, nearby distribution of GRBs (Fishman *et al.* 1978).

Fig. 1. *Left:* a single large area detector tray made from NaI(Tl) scintillation crystal pieces. *Right:* a group of seven NaI(Tl) detector trays developed for balloon flight observations of GRBs. Notice the variation in the amount of hydration (yellow color) of the crystals in the different trays. This hydration was largely reversible by pumping the interior of the trays for long periods and removing the moisture.

2 The BATSE proposal

NASA Headquarters issued an Announcement of Opportunity (AO) in 1977, soliciting proposals for instruments for a large Gamma-Ray Observatory (GRO), originally scheduled for launch in 1985. This spacecraft was intended to be the second of the four “Great Observatories in Space” that NASA planned to launch with the Space Shuttle in the 1980s (Hubble was the first of the series; Chandra was the third; Spitzer was the fourth). Initially, our balloon group in Huntsville had not planned to submit a proposal, but at the suggestion of Tom Cline and with the encouragement of Tom Parnell, a proposal was submitted with myself (G. Fishman) as the Principal Investigator (P.I.). Chip Meegan and Tom Parnell were Co-Investigators.

The objectives of the experiment were to observe the coarse sky distribution and the intensity distribution of GRBs, along with the spectral and high-time-resolution properties of a large number of them. In addition, this experiment

Fig. 2. A balloon flight array of scintillation detectors comprised of a number of individual detectors, pointed in different directions.

would provide a “trigger signal” to the other GRO instruments, so that their wide-field, secondary detectors could also respond to GRBs detected by our instrument. This was a key element of our proposal; it was to be a “service” to the other, larger experiments that had GRB observations as a secondary objective of their proposals. These experiments were not optimized for GRB observations and they did not have full-sky coverage. This strategy was suggested by Tom Cline.

The principal design philosophy for the BATSE detectors was to maximize the collecting area and monitor the entire sky for GRBs, while providing a rough location for them. A high time resolution, versatile (re-programmable) data system with multiple data types was also important, as it was recognized from the Konus catalogs of the St. Petersburg group (and other space-borne observations) that GRBs had extremely diverse and chaotic time profiles. Background reduction and good energy resolution were of less importance for the instrument.

3 Developing GRO and launch into orbit

Originally, five instruments were selected to be on the GRO spacecraft. An early, conceptual design of the configuration of these five instruments on the spacecraft is shown in Figure 3. In 1980, it was determined that one of these five instruments had to be removed. This difficult decision arose from a combination of limitations of GRO to accommodate the required mass and volume, and also for cost considerations. A review panel was convened to provide input to NASA Headquarters, which made the final decision of which of the five instruments would be removed. In 1981, it was determined that the Gamma-ray Spectrometer Experiment (GRSE)

would not be part of the GRO spacecraft. BATSE was the smallest, lightest, had the lowest data rate, and was the least expensive of the instruments that were selected for GRO in 1978. It was primarily considered as a “monitor”, rather than an “experiment”.

Fig. 3. An early conceptual design of the GRO spacecraft. At the time this drawing was made, it was not yet decided whether there would be six or eight BATSE detector modules on the spacecraft. Also at this time, there were five instruments. The GRSE high-resolution gamma-ray spectrometer instrument was removed from the spacecraft, as described in the text. That instrument had similar scientific objectives as the SPI instrument on the *Integral* spacecraft. The original name for the OSSE instrument was the acronym “GROSS”.

Balloon flights of prototypes of the BATSE detectors and associated instrumentation were carried out in 1980 and 1982. These flights used arrays of more expensive, single-crystal detectors with a much higher light output than those shown in Figure 1. This resulted in better measurements of the rate of weak GRBs than the initial balloon flight measurements (Meegan *et al.* 1985). An example of a BATSE Large Area Detector (LAD) crystal, sealed with its fused silica optical window is shown in Figure 4.

After the elimination of the GRSE instrument from GRO, it was recognized that the spacecraft would not have the capability for wide-field, high-spectral resolution observations of GRBs. At that time, spectral lines from GRBs were reportedly observed by several groups; these were deemed to be high scientific priority capability for the GRO mission. These reported lines were believed to arise from positron annihilation, cyclotron line production, and/or redshifted nuclear excitation lines in the gravitational field of Galactic neutron stars, at that time

Fig. 4. The scintillation detector element of a Large Area Detector (LAD) for BATSE. The design and dimensions are similar to those manufactured for medical diagnostic purposes in devices known as Anger cameras. It consists of a circular, hermetically-sealed disc of NaI(Tl), optically-coupled to a thick, fused silica optical window. The crystal had a thickness of 1.27 cm and a surface area of 2025 cm². Details of the design, development and testing of the BATSE flight system are contained in the comprehensive publication by Horack (1991).

presumed to be the source of GRBs. An appeal was made to NASA Headquarters by a group of GRB theorists to include a capability for these observations by an instrument on GRO. After a study of the impact to the mission, NASA agreed to include this capability. In response, the BATSE team (with additional investigators from UCSD and GSFC) submitted a proposal to include an additional detector in each of the eight BATSE modules, smaller than the LAD, but thicker and with better energy resolution. It would cover a broader energy range (both higher and lower) than the LAD. These detectors were termed the Spectroscopy Detectors (SDs). This proposal was accepted by NASA Headquarters.

Although the BATSE SDs had considerably better energy resolution than the LADs, their sensitivity was much less than that of the LADs in the energy region from ~ 30 keV to ~ 600 keV. However, at lower and at higher energies, the SDs had greater sensitive area than the LADs for the following reasons: Below 30 keV, the LAD efficiency dropped sharply due to absorbing material in front of the detector and above 600 keV, the LAD efficiency decreased due to the transparency of the relatively thin NaI detector. The final design of the GRO spacecraft, showing the placement of the four main instruments and the eight BATSE detector modules at the corners of the spacecraft is shown in Figure 5. The faces of the BASE LAD detectors are aligned to be parallel to the faces of a regular octahedron; the three axes of this octahedron are parallel to the spacecraft axes.

Fig. 5. The final configuration of the CGRO spacecraft with eight BATSE detector modules at the corners of the spacecraft. Each module had nearly a clear forward field-of-view. Two of the BATSE Modules are circled in red.

The majority of the design, development and testing of the BATSE instrumentation was performed at NASA-MSFC in the timeframe from 1982 to 1988 (Fig. 6). In late 1988, the BATSE flight system was delivered to the facilities of the spacecraft contractor, TRW Inc., in Redondo Beach, California. BATSE underwent two years of integration and testing with the GRO spacecraft. It was then shipped to the Kennedy Space Flight Center (KSC) for integration and testing with the Space Shuttle Atlantis. GRO was launched and deployed into an initial orbit of ~ 450 km in April 1991 (Fig. 7). When it became operational about a month later, it was re-named the Compton Gamma-ray Observatory (CGRO), in honor of Arthur Holly Compton. He was awarded the Nobel Prize in Physics in 1927 for discovering what became known as the Compton scattering of gamma rays. The CGRO spacecraft was re-boostered twice by an on-board propulsion system, following the expected, slow decay of its orbit. It operated extremely well up during its lifetime; it was de-orbited into the Pacific Ocean in June 2000.

4 Primary GRB results from BATSE

Before the end of its first year in orbit, the BATSE-observed isotropic sky distribution, together with the intensity distribution of GRBs, showed with high significance that their origin was unlike that of any known Galactic distribution of objects (Meegan *et al.* 1992). Furthermore, they were not associated with any nearby galaxies, or clusters of galaxies. Over the next few years, as the statistical measurements of these distributions became more accurate, workers in the

Fig. 6. A group of four BATSE detector modules undergoing assembly and testing at the NASA-Marshall Space Flight Center (MSFC) in Huntsville.

Fig. 7. The GRO spacecraft (later re-named the CGRO) during deployment from the payload bay of the Space Shuttle Atlantis in April 1991.

GRB field were abandoning models of GRBs originating from Galactic neutron stars. At that time, these were thought to have been their origin. The most likely explanation was that the GRBs originated from cosmological distances. The final BATSE sky distribution of GRBs after nine years of observations is shown in Figure 8. The definitive recognition of the cosmological distances of GRBs had to

wait for the BeppoSAX observations in 1997 and 1998 which provided precise and rapid GRB locations. Along with this breakthrough came rapid follow-up X-ray and optical observations of GRB afterglows and the redshift measurements of their host galaxies and/or that of intervening matter.

2704 BATSE Gamma-Ray Bursts

Fig. 8. The BATSE sky distribution of GRBs observed over nine years of observation by BATSE-CGRO, plotted in Galactic coordinates. This distribution has not been corrected for sky exposure. The color of each GRB corresponds to the indicated fluence of the burst.

There are generally accepted to be two classes of GRBs, short and long; the usual dividing line between long and short GRBs is ~ 2 s, although there is significant overlap between these classes. Prior to BATSE, it had been suspected that the shorter GRBs had harder spectra than the longer ones. BATSE data showed the definitive separation between the short/hard and the long/soft classes with very good statistics, as shown in Figure 9.

Data from BATSE triggered GRBs are available online (<http://heasarc.gsfc.nasa.gov/>); they are described by Paciesas *et al.* (1999). Limits to gamma-ray lines from GRBs using the BATSE spectroscopy detectors were found to be below those of line fluxes reported previously (Briggs *et al.* 1999). In an effort to find additional (primarily weaker) GRBs that were not part of the standard BATSE GRB catalogs, several investigators compiled catalogs of un-triggered BATSE GRBs, using the so-called “continuous” data stream.

In 1993, a system known as BACODINE (for BATSE COordinates Distribution Network) was implemented at GSFC. This system was made possible due to the deterioration of the CGRO tape recorders during the first year of its mission and the need for real-time data from the spacecraft caused by the resulting lack of on-board data storage. The design and implementation of BACODINE was the work of Scott Barthelmy and colleagues from NASA-GSFC (Barthelmy *et al.* 1995) to take advantage of this unplanned opportunity. It used the near real-time

Fig. 9. Two classes of GRBs, as observed with BATSE: Short-Hard and Long-Soft (Kouveliotou *et al.* 1993). They are seen to have overlapping distributions.

BATSE data to compute a coarse GRB location when an on-board burst trigger occurred. Automated GRB location messages were made available to users for rapid GRB follow-up observations. Even though these locations were usually of the order of several square degrees, they were useful for wide-field optical cameras. Several optical systems were constructed specifically for this purpose. One of these robotic systems was able to observe the optical emission from the intense burst GRB 990123 while the burst was in progress (Akerlof *et al.* 1999). As other spacecraft with GRB capabilities were placed into orbit, their data were also distributed to the GRB community over this same network. The BACODINE system evolved into a more general system, the GRB Coordinates Network (GCN), which distributes data from many spacecraft and ground-based observatories. It is used today by hundreds of observers world-wide and has become an invaluable service for the GRB community.

The large number of GRBs observed with BATSE, afforded by its sensitive area and long duration in orbit, allowed observations of the temporal and spectral properties of GRBs in more detail than those previously. Over a thousand of papers have been published describing the BATSE-observed properties of GRBs and the theoretical implications derived from them. Observations with BATSE afforded an unsurpassed study of many of the fine points of the gamma-ray emission in the energy region where the major fraction of energy is emitted during the prompt phase. The GRBs observed with a single instrument has provided a large, homogeneous dataset of GRBs, without the difficulties associated with cross-calibration between different instruments. This capability will likely not be exceeded for many years. An overview of many more of the GRB and scientific results made possible through BATSE observations, but not covered here, are summarized in a chapter entitled “The BATSE Era”, in a recently-published book (Fishman & Meegan 2012).

References

- Akerlof, C., Balsano, R., Barthelmy, S., *et al.*, 1999, *Nature*, 398, 400
- Barthelmy, S.D., Butterworth, P., Cline, T.L., *et al.*, 1995, *Ap&SS*, 231, 235
- Briggs, M.S., Band, D.L., Preece, R.D., *et al.*, 1999, *ApL*, 39, 237
- Fishman, G.J., & Meegan, C.A., 2012, “The BATSE Era”, Chapter 3, in *Gamma-ray Bursts*, ed. C. Kouveliotou, *et al.* (Cambridge Univ. Press)
- Fishman, G.J., 1974 “Radiation Detectors Using Multiple Scintillation Crystal Pieces”, U.S. Patent #3,835, 325
- Fishman, G.J., & Austin, R.W., 1976, *Nucl. Inst. Meth.*, 140, 193
- Fishman, G.J., Meegan, C.A., Watts, J.W., Jr., & Derrickson, J.H., 1978, *ApJ*, 223, L13
- Horack, J.M., 1991, “Development of the Burst and Transient Source Experiment”, NASA Reference Publication 1268 (Washington: NASA)
- Klebesadel, R.W., Strong, I.B., & Olson, R.A., 1973, *ApJ*, 182, L85
- Kouveliotou, C., Meegan, C.A., Fishman, G.J., Bhat, N.P., *et al.*, 1993, *ApJ*, 413, L101
- Meegan, C.A., Fishman, G.J., & Wilson, R.B., 1985, *ApJ*, 291, 479
- Meegan, C.A., Fishman, G.J., Wilson, R., *et al.*, 1992, *Nature*, 355, 143
- Paciesas, W.S., Meegan, C.A., Pendleton, G.N., *et al.*, 1999, *ApJS*, 122, 465