Session 3: Diagnostics of High Gravity Objects with X- and Gamma Rays

3-4. Gamma-Ray Bursts

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GAMMA-RAY BURST OBSERVATIONS WITH BATSE

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1. Introduction

Gamma-ray bursts (GRBs) will be recorded as one of the outstanding new phenomena discovered in astronomy this century. About once per day, a burst of gamma rays appears from a random direction on the sky. Often, the burst outshines all other sources of gamma-rays in the sky, combined. This paper reviews some of the key observed phenomenon of bursts in the hard x-ray/gamma-ray region, as observed with the BATSE experiment [4] on the Compton Gamma Ray Observatory. The observed time profiles, spectral properties and durations of gamma-ray bursts cover a wide range. Recent breakthroughs in the observation of gamma-ray burst counterparts and afterglows in other wavelength regions have marked the beginning of a new era in gamma-ray burst research. Those observations are described in following papers in these proceedings.

BATSE has been in operation since its launch by the Space Shuttle Atlantis in April 1991 and it is planned to continue operation at least until the year 2005. A comprehensive gamma-ray burst catalog from the BATSE experiment is available from the CGRO Science Support Center at the NASA/Goddard Space Flight Center. The field of gamma-ray bursts has undergone a dramatic change since BATSE. This has resulted primarily from more sensitive observations of the gamma-ray burst intensity and sky distributions [8]. Prior to these observations, the source of gamma-ray bursts were considered by most workers in the field to be relatively nearby neutron stars in the Galactic plane [6]. They are now generally considered to come from sources at cosmological distances.

K. Koyama et al. (eds.), The Hot Universe, 159-162.

2. Temporal and Spectral Characteristics

The most striking feature of the time profiles of gamma-ray bursts is the diversity of their time structures and the wide range of their durations. Coupled with this diversity is the difficulty of placing gamma-ray bursts into well-defined types, based on their time profiles. Many bursts have multiple characteristics and many other bursts are too weak to classify. Some burst profiles are chaotic and spiky with large fluctuations on all time scales, while others show rather simple structures with few peaks. No periodic structures have been seen from gamma-ray bursts. There is, however, one general characteristic. At higher energies, the overall burst durations are shorter and sub-pulses within a burst tend to have shorter rise-times and fall-times (sharper spikes). Most bursts also show an asymmetry, with the leading edges being of shorter duration than the trailing edges. There are many bursts which have similar shaped sub-pulses within the burst. The durations of gamma-ray bursts range from about 30ms to over 1000s. However, the duration of a gamma-ray burst, like the burst morphology, is difficult to quantify since it is dependent upon the sensitivity and the time resolution of the experiment.

Almost all of the power from gamma-ray bursts is emitted above 50 keV. Typical spectra from Compton Observatory experiments covering a wide energy range are shown by Tavani (1996) [11]. Most spectra are well fit by a relatively simple analytical expression which has become known as the Band expression [1]. A search for line features (either absorption or emission features) with the detectors of BATSE-Compton Observatory has thus far been unable to confirm the earlier reports of spectral line features from gamma-ray bursts.

3. Intensity and Sky Distributions, Dilation and Redshift

The spatial distribution of the sources of gamma-ray bursts is derived from the observed intensity and sky distributions. The angular (sky) distribution provides two of the dimensions of the spatial distribution, while the intensity distribution is a convolution of the unknown luminosity function and the radial distribution. Even though the luminosity function is unknown, the intensity distribution can still provide constraints on the allowable spatial distributions of gamma-ray burst sources. The BATSE data show a significant deviation of the observed intensity distribution from that expected for a homogeneous, Euclidean distribution.

Since the launch of the Compton Observatory, burst locations have become available for a large sample of weak bursts. BATSE determines directions to burst sources by comparing the count rates of individual detectors, whose response varies approximately as the cosine of the angle from the detector normal. The systematic error of these locations is presently about 1.5°, as determined by comparison with burst locations known via interplanetary timing. The statistical error varies according to the burst intensity; it is around 13° near the BATSE threshold. The BATSE sky distribution, as shown in Figure 1 indicate that this distribution is consistent with isotropy and that this isotropy extends to the weakest bursts [3].

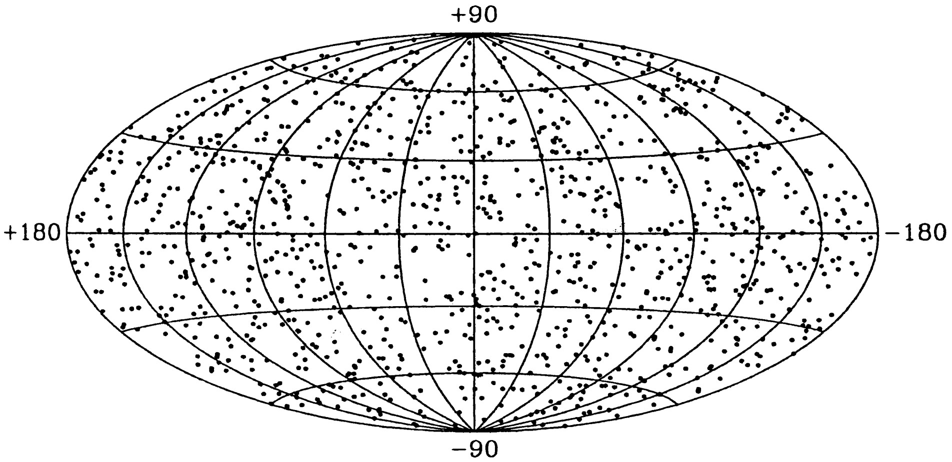

Figure 1. The distribution in galactic coordinates of the 1637 4B bursts.

In accordance with standard cosmology, the more distant bursts are fainter and they are receding faster. Thus they would show a larger time dilation than the nearer, more intense bursts. The entire burst would be "stretched" so that the fainter bursts (and presumably farther) would be, on the average, longer. Individual pulse structures within bursts and the time intervals between these pulse structures would be similarly stretched. Due to the complexity of the gamma-ray burst time structures and the wide range of their durations, any dilation effects can only be tested in a statistical sense. Initial work in these efforts and a positive result was announced by a group at NASA/Goddard Space Flght Center, using BATSE data [10]. An additional indicator of distance can be found in the continua spectra; fainter, more distant bursts would be redshifted, which, in essence, is a time dilation of the wavelength of emission in the observer's frame. Mallozzi et al. [7] show a systematic shift in the energy of the peak power of emission from a large sample of gamma-ray bursts that is consistent with a cosmological redshift.

4. A New Era in Gamma Ray Burst Research

Ever since the initial discovery of gamma-ray bursts, there has been a quest to discover a counterpart to a gamma-ray burst in any other wavelength region before, during, or after the gamma-ray event. These searches have taken many forms, including searches for statistical associations of known objects with bursts with poorly known locations as well as searches of archival plates and other data bases for transient or unusual objects within the error boxes of well-determined burst locations.

BATSE has a quick alert capability which was developed to provide burst locations within several hours, under favorable conditions. A near-real-time burst location system utilizing BATSE data, BACODINE (BAtse COordinates DIstribution NEtwork) [2], is in operation. BACODINE can provide GRB locations to external sites within about 5 s of their detection. When BACODINE is linked to a rapid-slewing optical telescope, there is the possibility of obtaining optical images of burst regions while the burst is in progress. This past year, a rapid burst response system has also been developed to provide more accurate burst locations than BACODINE within about fifteen minutes. The Rossi X-ray Timing Explorer (RXTE) can use this capability to scan a region in search of x-ray afterglow emission.

In 1997, the first x-ray and optical, and radio afterglows from gamma-ray bursts were observed, as described in subsequent papers in these proceedings. Optical observations were used to derive a lower limit for the redshift of the emitter and radio observations were used to derive an angular size. These breakthroughs were made possible by the accurate and precise locations of several gamma-ray bursts observed with BeppoSAX. A new era in gamma-ray burst research has begun.

Note: Some sections of this paper were derived from a review article on gamma-ray bursts [5]. A comprehensive set of references may be found in that paper.

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