The *Swift* Gamma-Ray Burst Mission: First Results

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ABSTRACT

The Swift mission is designed to discover 100 new gamma-ray bursts (GRBs) each year, and immediately (within tens of seconds) start simultaneous X-ray, optical and ultraviolet observations of the GRB afterglow. Since its launch on 20 November 2004, it has already collected an impressive database of bursts (reaching more sensitive limits than BATSE); uniform X-ray/UV/optical monitoring of afterglows; and rapid follow up by other observatories (utilizing a continuous ground link with burst alerts and data posted immediately to the GCN).

1. INTRODUCTION

Despite impressive advances over the roughly three decades since GRBs were first discovered (Klebesadel et al. 1973), study of bursts remains highly dependent on the capabilities of the observatories which carried out the measurements. The era of the Compton Gamma Ray Observatory (CGRO) led to the discovery of 2609 bursts in just 8.5 years. Analysis of these data led to the conclusion that GRBs are isotropic on the sky and occur at a frequency of roughly one per day (Briggs 1996).

The *BeppoSAX* mission made the critical discovery of X-ray afterglows (Costa et al. 1997). With the accompanying discoveries by ground-based telescopes of optical (van Paradijs et al. 1997) and radio (Frail et al. 1997) afterglows, GRBs could start to be studied within the astrophysical context of identifiable objects in a range of wavelength regimes. Successful prediction of the light curves of these afterglows across the electromagnetic spectrum has given confidence that GRBs are the signal from extremely powerful explosions at cosmological distances, which have been produced by extremely relativistic expansion (Wijers, Rees & Mesaros 1997).

The Swift mission selected by NASA in 1999 combines the sensitivity to discover new GRBs with the ability to point high sensitivity X-ray and optical telescopes at the location of the new GRB as soon as possible. From this capability Swift has the goal to answer the following questions:

1. What causes GRBs?

2. What physics can be learned about black hole formation and ultra-relativistic out- flows?

3. What is the nature of subclasses of GRBs?

4. What can GRBs tell us about the early Universe?

After five years of development Swift was launched form Kennedy Space Center on 20 November 2004. The spacecraft and instruments were carefully brought into operational status over an eight-week period, followed by a period of calibration and operation verification, which ended with the start of normal operations on 5 April 2004. A complete description of the Swift mission can be found in Gehrels et al. (2004).

As of 28 September 2005, the Swift achievements include: discovery of 77 new GRBs by the Swift BAT instrument (with a typical error region of less than 2 arcmin radius); discovery of 60 X-ray afterglows by the Swift XRT instrument (with a typical error region of less than 3 arcsec radius); and observations of 14 afterglows by the Swift UVOT instrument. More than half of the afterglow observations start within two minutes of the BAT GRB trigger (with a record of only 54 seconds!); and afterglow observations have been made of non-Swift discovered bursts within hours (with a record of 40 minutes for the GRB050408, discovered by HETE-II).

2. SWIFT HIGHLIGHTS

2.1 BAT Detected GRBs

The Burst Alert Telescope (BAT) on Swift has detected 77 GRBs since it was turned on in December 2004 to 28 September 2005. Thus in 285 days of operation, the BAT has discovered GRBs at a rate of about 98 bursts per year. This value is quite close to the rate of 100 bursts estimated prior to launch. These bursts include short bursts and x-ray flashes.

Spectral analysis of the BAT bursts show them to be consistent with the population of GRBs seen by the Compton Gamma-Ray Observatory BATSE experiment, both in the ratio of the fluxes in the 25-50 keV and 50-100 keV energy bands, and in the comparison of flux ratios to T90 values.

2.2 XRT Detected GRBs

The X-Ray Telescope (XRT) has rapidly imaged the location determined by the BAT trigger for new GRBs. In the first 60 cases, all but 3 of the BAT GRB triggers resulted in detection of an X-ray counterpart for the BAT source. In 2 cases the XRT observations started while the BAT was still detecting hard X-ray prompt emission from the GRB.

In about half of the cases, Swift started observations in less than 300 seconds after the burst. When XRT arrives this quickly it is very common to see a fast X-ray decline within the first 300 seconds. Measurement of redshift for these burst afterglows is very important. With a redshift it is possible to convert the observed fluxes into luminosities. Fifteen of the Swift GRBs have redshift determinations.

In addition to the BAT detected events, Swift can also observe GRBs discovered by other satellites. Swift has discovered X-ray afterglow emission in 2 cases each for the HETE-II and INTEGRAL satellites. In a particularly impressive case, Swift was able to respond to the ground control commands and start observations of the GRB050408 within 40 minutes of the GRB.

2.3 UVOT Detected GRBs

The Ultra-Violet/Optical Telescope (UVOT) is co-aligned with the XRT and so observes the GRB afterglows just as promptly as the XRT. Despite these prompt observations the UVOT has detected far fewer UV/optical counterparts than the XRT.

Of the first 50 GRBs observed by the UVOT, only 14 had detected emissions. The UVOT has generated important upper limits for these early times, which are lower those for bursts studied by previous missions.

Speculation on the reasons for this reduction include the possibility that the Swift bursts are farther away (higher z) than previous bursts; that a substantial number of GRBs have intrinsic dust extinction which suppresses the optical/UV emission compared to the I and R bands typically reported for earlier afterglows; or the possibility that some afterglows come from high magnetic field regions in the outflow which suppresses the optical and UV emission. These possibilities are discussed in Roming et al. (2005).

Although not every GRB produces UV or optical flux which can be detected by the UVOT, several bursts have produced early time light curves, including GRB050318 (Still et al. 2005) and GRB050319 (Mason et al. 2005).

2.4 XRT Early Light Curve Behavior

Swift has opened up a new regime for GRB afterglow studies. Never before has it been possible to study the X-ray behavior on timescales of minutes after the GRB happens. Swift has frequently started observations within a few minutes of the detection of GRBs by the BAT (with a record of only 52 seconds).

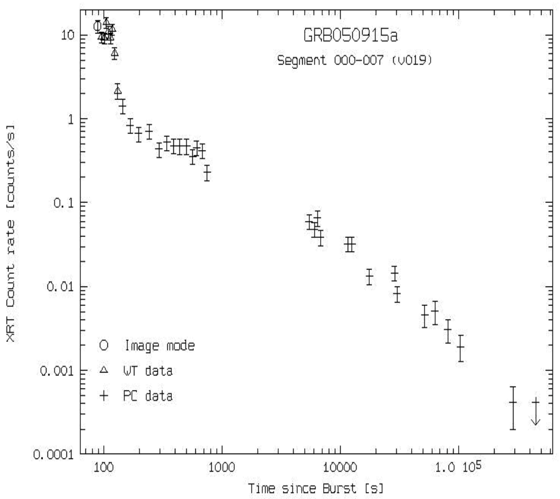
Typical Swift Lightcurve

Fig. 1. Typical afterglow light curve.

These extremely prompt observations have given rise to a new phenomenology. In roughly 50% of the cases, the GRBs can be characterized by a three-part light curve (see Figure 1). First comes an extremely rapid decay of a very bright source. At these early times the decay can be fit by a power law of index in the range of 2.5 or greater. After a few minutes the decay rate flattens, and we can fit it with an index in the range of 1 (plus or minus perhaps 0.5). Finally after a delay ranging from hours to days, the decay rate will steepen again, resulting in a behavior interpreted as the jet break. Tagliaferri et al (20005) and Barthelmy et al. (2005a) each consider two early XRT afterglows. They show that the X-ray emission during the prompt phase (estimated from extrapolation of the BAT spectrum) connects the bright early XRT afterglow (see Figure 2). This suggests that the bright early afterglow is an extension of the prompt phase.

Swift also detects strong X-ray flares in afterglows at early times. In one case (GRB050502b) the X-ray flux increased by a factor of roughly 1000. The dramatic flaring events seem to be superposed on a background which follows the multipart behavior mentioned above. Burrows et al. (2005) discuss the flaring behavior seen in GRB050502b and GRB050408.

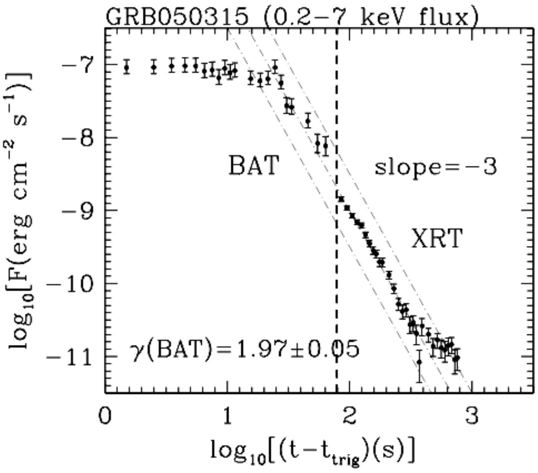

Fig. 2. From Barthelmy et al. (2005a). The BAT spectrum is extrapolated to the 0.2 – 7 keV band. The early XRT lightcurve connects smoothly to the prompt emission.

2.5 Short GRBs

As of late September 2005, the BAT has detected 4 GRBs in the short-hard class. One of them (GRB 050202 had no prompt slew and no counterparts. One (GRB 050813) had a prompt slew and XRT detection, but no identification of a counterpart or host galaxy. It did establish an important lower limit of z>0.7 for a host. From the remaining 2 events we have learned a lot. GRB 050509b (Gehrels et al. 2005) had an X-ray afterglow that gave an error circle with a bright elliptical galaxy (cD galaxy in a cluster) in it (Figure 3) GRB 050724 (Barthelmy et al. 2005b) had an XRT afterglow, plus Chandra, optical and radio detections. The sub-arcsecond positions located it once again in the outer regions of a bright elliptical. The fact that these ellipticals have very low star formation rates argues strongly against a collapsar origin like that for long bursts. Also, the redshifts for the two are in the z = 0.2 to 0.3 range, a factor of ~3 closer than typical long GRBs. The evidence to date is consistent with an origin of short burst in merging binary neutron stars.

2.6 GRB Redshifts

As of late September 2005, redshifts have been determined for 17 Swift GRBs. The average redshift (excluding short GRBs) is z=2.6. This is significantly higher than the pre-Swift average of z=1.2. The sensitivity of the Swift instruments is leading to a sampling of more distance GRBs.

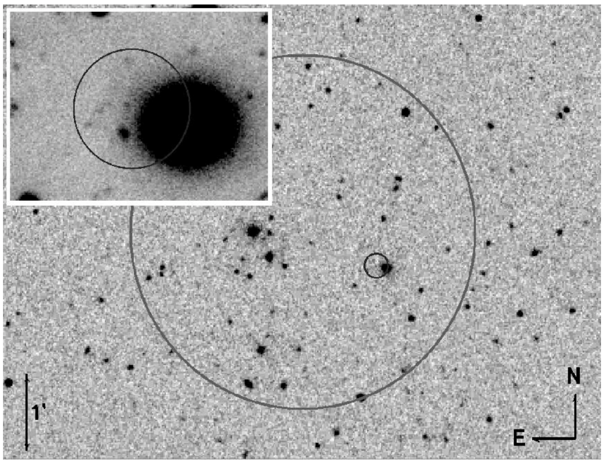

Fig. 3. Localization of short GRB 050509b. Large circle is BAT position; small circle is XRT position. The inset shows a bright elliptical galaxy in the XRT circle.

On September 4, 2005, Swift detected a long, smooth GRB (Cusumane et al. 2005). The redshift was found to be the very large value of z =6.29, one of the highest redshift objects ever seen. The light curve for this GRB is shown in Figure 4.

2.7 Giant Flare from SGR 1806-20

On 27 December 2004 the Solar System was struck by the brightest gamma-ray flux ever observed. Every orbiting gamma-ray observatory responded to the flash, produced by the soft gamma-ray repeater SGR 1806-20. Although Swift was not pointed toward the target, the flux was so high that the BAT detector was swamped by more than a billion gamma-rays passing through the structure of the spacecraft.

Palmer et al. (2005) present the Swift data on this dramatic event. Although the emitting system is located many kilo parsecs from the Earth, the received energy flux was brighter than the full Moon for the 0.2 seconds. This giant flare was more than 100 times more luminous than the two previous flares seen in 1998 from SGR1900+14 and in 1979 from SGR0526-66.

Such an event might be the cause of at least some short GRBs, in that the rapid, extremely bright flash of gamma-rays had a similar duration and energy profile to a short GRB. Had such an event been located in an external galaxy, it would have been detectable out to 40 Mpc.

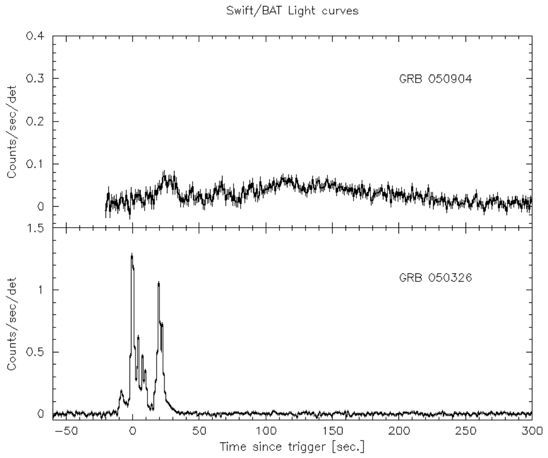

Fig. 4. Lightcurve of high-redshift GRB 050904 compared to a typical GRB. The long smooth nature of the lightcurve is due to cosmologic time dilation as the photons propagated to us from z=6.29.

2.8 UV/Optical & X-ray Observations of SN2005am

Type Ia supernovae are critically important to our understanding of the fundamental fabric of our Universe. They are the most fundamental step in our ability to measure the distances over the range in which cosmological effects become significant. Thus it is a critical astrophysical observation to study relatively nearby supernovae in the ultraviolet, because this is the wavelength regime, which becomes red-shifted into the observing windows of ground-based optical instruments.

Unfortunately nearby UV measurements require space-borne observatories with UV capability. Missions such as the *International Ultraviolet Explorer* (IUE) and the *Hubble Space Telescope* began these studies, but they were limited in the intrinsically slower operational response time than offered by Swift. Thus Swift has been an ideal observatory to start observations of nearby bright supernovae, of which SN2005am is a prime example.

Brown et al. (2005) provide ultraviolet and optical light curves for SN2005am, starting four days prior to maximum light, and extending to 69 days after peak. In addition, when the target was bright enough, Swift was able to carry out low-resolution grism UV/optical measurements. These data for SN2005am are the best sampled in time, and cover the widest range of any type Ia supernova follow-up to date.

3. CONCLUSIONS

The Swift observatory is performing excellent scientific observations at high efficiency and with important progress toward its mission objectives.

The BAT (Burst Alert Telescope) is working flawlessly, and has produced great data. The positional agreement to the XRT and ground-based detections suggests that the typical on-board positional accuracy for GRBs is roughly 65 arcsec, exceeding the pre-launch predictions.

The UVOT (UV/Optical Telescope) has demonstrated excellent UV and optical performance on GRBs and other sources.

The XRT (X-Ray Telescope) has demonstrated excellent X-ray sensitivity and rapid responsiveness. The average accuracy for the XRT positions confirmed with XMM or ground-based optical detection is 2.6 arcsec. XRT is observing afterglows at a level of 100 to 1000 times fainter than Beppo-SAX. This rapid acquisition with sensitive X-ray detection is discovering new lightcurve behaviors.

As Swift observations become more routine we expect to build up a substantial database of early (and late) X-ray and UV/optical light curves, and from these develop insights into GRB formation and GRB environments.

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