Chin. J. Astron. Astrophys. Vol. 6 (2006), **Suppl. 1**, 357–360
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Swift Gamma-Ray Burst Explorer: The First Results

John A. Nousek *

Dept. of Astronomy & Astrophysics, Penn State University, University Park, PA 16827, USA

Abstract The Swift GRB Explorer mission is designed to discover ∼100 new gamma-ray bursts each year, and immediately (within tens of seconds) to 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 gamma ray bursts (reaching more sensitive limits than BATSE); uniform X-ray/UV/optical monitoring of afterglows (with a dedicated weatherless observatory with broad multi-wavelength imaging capability); and rapid followup by other observatories (utilizing a continuous ground link with burst alerts and data posted immediately to the GCN).

Key words: space vehicles – gamma rays: bursts – gamma rays: observations

1 INTRODUCTION

Despite impressive advances over the roughly three decades since gamma ray bursts (GRBs) were first discovered (Klebesadel et al. 1973), study of bursts remains highly dependent on the limitations 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 electro-magnetic 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 & Mésarós 1997).

In late 1997, a team of scientists from Goddard Space Flight Center, led by Neil Gehrels and Nick White, joined forces with a team from Penn State, led by John Nousek and David Burrows. This collaboration, joined by major partners at the University of Leicester, the Mullard Space Sciences Laboratory (UK); and the Astronomical Observatory of Brera and the Italian Space Agency (ASI), proposed and won funding from NASA, PPARC and ASI to develop, build, launch and operate the Swift Gamma Ray Burst Explorer mission.

The key concept behind Swift is to use a dedicated observatory which combines the ability 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 sets the following goals:

1. What causes GRBs?
2. What physics can be learned about Black Hole formation and ultra-relativistic outflows?
3. What is the nature of subclasses of GRBs?
4. What can GRBs tell us about the early Universe?

After five years of concentrated effort, Swift was deployed by a near perfect Delta II rocket launch from the Kennedy Space Flight Center on 20 November 2004. The spacecraft and instruments were carefully

* E-mail: nousek@astro.psu.edu

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 fuller description of the Swift mission can be found in Gehrels et al. (2004).

As of 13 May 2005, the Swift discoveries/performance achievements include: discovery of more than 39 new GRBs by the Swift BAT instrument (with a typical error region of less than $2'$ radius); discovery of more than 24 X-ray afterglows by the Swift XRT instrument (with a typical error region of less than $3''$ radius); and observation of 22 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 GRB 050408, discovered by HETE-II).

Highlights from individual targets include the hard X-ray light curve of SGR 1806–20, the discovery of the first accurate X-ray position of a short GRB (GRB 050509B), the discovery of a delayed giant X-ray flare (GRB 050502B), the lack of prompt, bright UV/optical emission from most afterglows, and accurate positions of two absorbed INTEGRAL transient sources (submitted as Targets of Opportunity).

The next section reviews these highlights of the Swift mission up to 13 May 2005.

2 SWIFT HIGHLIGHTS

2.1 UV/Optical & X-ray Observations of SN 2005am

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 SN 2005am is a prime example.

Brown et al. (2005) provide ultraviolet and optical light curves for SN 2005am, starting four days prior to maximum light, and extending to 69 days after peak. (Swift also offers simultaneous X-ray observations, but in this case no X-ray emission was detected.) In addition, when the target is bright enough, Swift can carry out low-resolution grism UV/optical measurements. These data for SN 2005am are the best sampled in time, and cover the widest range of any type Ia supernova follow-up to date.

2.2 Giant Flare from SGR 1806–20

On 17 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 able to easily detect more than a billion gamma-rays detected after they traversed the structure of the spacecraft.

Palmer et al. (2005) present the Swift data on this dramatic event. Although the emitting system is located many kiloparsecs 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 brighter than the two previous flares seen in 1998 from SGR 1900+14 and in 1979 from SGR 0526–66.

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 time and energy profile to a short GRB. Had such an event been located farther away, it would have been detectable out to 40 Mpc, but the fainter emission which persisted after the giant flare would not be detected at such distances.

2.3 BAT Detected GRBs

The Burst Alert Telescope (BAT) on Swift has detected 39 GRBs since it was turned on in December, 2004, to 13 May, 2005. Thus in 21 weeks of operation, the BAT has discovered GRBs at a rate of about 97 bursts per year. This value is quite close to the rate of 100 bursts estimated prior to launch.

These bursts include a short burst (seen on 2 May, 2005), but that burst could not be imaged by the XRT or UVOT, because the burst was too close to the Sun. Thus we have demonstrated that the Swift BAT is capable of detecting short bursts, but measurement of an afterglow candidate by Swift required waiting for a more favorably placed GRB.

Swift successfully detected a short burst on 9 May, GRB 050509a. This burst was rapidly imaged by the XRT, and a rapidly fading X-ray counterpart was found. The counterpart was found in the neighborhood of an early type galaxy at a redshift of 0.226. It is intriguing to speculate that the burst occurred in a stellar system associated with this galaxy. If so, there is a near total lack of recent star formation in this galaxy, suggesting that the short GRBs result from system different than the hypernova model used to explain long GRBs.

Spectral analysis of the BAT bursts show them to be consistent with the population of GRBs seen by the Comption 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.

2.4 XRT Detected GRBs

The X-Ray Telescope (XRT) has rapidly imaged the location determined by the BAT trigger for new GRBs, very quickly following the BAT discoveries. In the first 25 cases, every BAT GRB detection resulted in detection of an X-ray counterpart for the BAT source. In one case the XRT observations started while the BAT was still detecting hard X-ray prompt emission from the GRB.

In 12 of the 25 cases, Swift started observations in less than 300 seconds after the burst. When XRT arrives this quickly it is very common (9 of 12) 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. Seven of the XRT afterglows have redshift determinations.

In addition to the BAT detected GRBs, Swift can also observe GRBs discovered by other satellites. Swift has discovered X-ray afterglow emission in one case each of the HETE-II and INTEGRAL satellites. The case of HETE-II is particularly impressive, as Swift was able to respond to the ground control commands and start observations of the GRB 050408 within 40 minutes of the GRB.

2.5 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 25 GRBs measured by the UVOT, only five showed emission detected by the UVOT. The UVOT has generated upper limits for the emission at these early times which are stronger than previously reported for burst 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. (2006).

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 GRB 050318 (Still et al. 2006) and GRB 050319 (Mason et al. 2006).

2.6 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).

These extremely prompt observations have given rise to a new phenomenology. In roughly 3/4 of the cases, the GRBs can be characterized by a three-part light curve. First comes an extremely rapid decay of a very bright source. At these early times the decay can be fit by a power law in the range of 2.5 or greater. After a few minutes the decay rate flattens, and we can fit it with a power 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. (2005) consider two of the early Swift XRT afterglows and describe the XRT lightcurves in reference to this multi-part light curve.

Swift also detects strong X-ray increases in afterglows at early times. In one case (GRB 050502b) 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 mult-part behavior mentioned above. Burrows et al. (2005) discusses the flaring behavior seen in GRB 050502b and GRB 050408.

3 CONCLUSIONS

The Swift observatory is performing excellent science 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. As of 13 May 2005, it has discovered 39 GRBs. The positional agreement to the XRT and ground-based detections suggests that the typical on-board positional accuracy for GRBs is roughly 65 arc seconds, exceeding the pre-launch predictions.

The UVOT (UV/Optical Telescope) has demonstrated excellent UV and optical performance, especially in the UV regime. As of 13 May 2005, it had observed 25 prompt GRB locations, and detected five of these.

The XRT (X-Ray Telescope) has also demonstrated excellent X-ray sensitivity and rapid responsiveness. As of 13 May 2005, it had also observed 25 afterglows (with 12 observations starting in less than five minutes after the GRB was detected). The average accuracy for the XRT positions confirmed with XMM or ground-based optical detection was $2.6''$. 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 light curve 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.

Acknowledgements This work was supported by NASA Contact NAS5-00136.

References

Briggs, M. S., 1996, ApJ, 459, 40
Brown, P. J., et al. 2005, ApJ, 635, 1192
Burrows, D. N., et al. 2005, Sci., 309, 1833
Costa, E., et al. 1997, Nature, 387, 783
Frail, D., et al. 1997, Nature, 389, 261
Gehrels, N., et al. 2004, ApJ, 661, 1005
Klebesadel, R., W., Strong, I. B., & Olson, R. A., 1973, ApJ, 182, L85
Mason, K., et al. 2006, ApJ, 639, 311
Palmer, D., et al. 2005, Nature, 434, 1107
Roming, P., et al. 2006, ApJ, submitted
Still, M., et al. 2006, ApJ, 639, 315
Tagliaferri, G., et al. 2005, Nature, 434, 985
van Paradijs, J., et al. 1997, Nature, 386, 686
Wijers, R. A. M., Rees, M. J., & M´eszar´os 1997, MNRAS, 288, L51