THE AFTERGLOWS, REDSHIFTS, AND PROPERTIES OF Swift GAMMA-RAY BURSTS

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ABSTRACT

We present optical, near-IR, and radio follow up of sixteen Swift bursts, including our discovery of nine afterglows and a redshift determination for three. These observations, supplemented by data from the literature, provide an afterglow recovery rate of 60% in the optical/near-IR, much higher than in previous missions (BeppoSAX, HETE-2, INTEGRAL, and IPN). The optical/near-IR afterglows of Swift events are on average 1.7 mag fainter at t = 12 hr than those of previous missions. The X-ray afterglows are similarly fainter compared to those of pre-Swift bursts. In the radio the limiting factor is the VLA threshold and the detection rate for Swift bursts is similar to that for past missions. The redshift distribution of pre-Swift bursts peaked at z ∼ 1, whereas the five Swift bursts with measured redshifts are distributed evenly between 1.3 and 3.2. From these results we conclude that (i) the pre-Swift distributions were biased in favor of bright events and low redshift events, (ii) the higher sensitivity and accurate positions of Swift result in a better representation of the true burst redshift and brightness distributions (which are higher and dimmer, respectively), and (iii) as many as 1/3 of the bursts can be optically dark, as a result of a high redshift and/or dust extinction. We remark that the apparent lack of low redshift, low luminosity Swift bursts, and the lower event rate compared to pre-launch estimates (90 vs. 150 per year), are the result of a threshold that is similar to that of BATSE. In view of these inferences, afterglow observers may find it advisable to make significant changes in follow up strategies of Swift events. The faintness of the afterglows means that large telescopes should be employed as soon as the burst is localized. Sensitive observations in Riz and near-IR bands will be needed to discriminate between a typical z ∼ 2 burst with modest extinction and a high redshift event. Radio observations will be profitable for a small fraction (∼ 10%) of events. Finally, we suggest that a search for bright host galaxies in untriggered BAT localizations may increase the chance of finding nearby low luminosity GRBs.

Subject headings: gamma-rays:bursts

1. INTRODUCTION

The Swift satellite (Gehrels et al. 2004) has now been operational for over four months. So far, about two dozen bursts have been rapidly localized to better than 109 accuracy thanks to the on-board X-ray telescope (XRT). Such precise and rapid positions are critical for deep ground-based follow up, in particular for the determination of redshifts and whether a burst is optically “dark” (due to extinction within the host galaxy or attenuation by Lyman scattering from intergalactic hydrogen).

For past missions (BeppoSAX, HETE-2/WXM, INTEGRAL, IPN) while ∼ 90% of the afterglows were detected in the X-rays (Piro 2001; Berger et al. 2003; De Pasquale et al. 2003), the fraction with optical and radio afterglow (essential for arcsecond localization) was only 30% (e.g., Fynbo et al. 2001; Lazzati et al. 2002; Berger et al. 2002; Frail et al. 2003). Bursts localized by the Soft X-ray Camera (SXC; Vanderspek et al. 1999) on-board HETE-2, on the other hand, had a recovery rate in the optical of about 85% and in the radio of about 55% (Lamb et al. 2004; Berger et al. 2005a). This has been attributed to the relatively accurate and rapid positions provided by the SXC, and has placed the tightest limit on the fraction of dark bursts.

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The current *Swift* sample of well localized bursts is now of sufficient size to provide a meaningful comparison to past missions, and to start to draw statistical inferences about the GRB population. Of particular interest is whether the increased sensitivity of *Swift* results in a sizable fraction of low redshift, low luminosity GRBs, or an increase in the detection rate of GRBs at higher redshifts. A related question is whether the recovery rate of optical/near-IR afterglows is close to unity.

Here we present our comprehensive optical/near-IR and radio follow-up observations of *Swift* bursts. Of the 21 *Swift* GRBs with XRT positions and ground-based follow up we observed a total of sixteen in the optical/near-IR and thirteen in the radio. We discovered nine of the twelve optical/near-IR afterglows to date, radio afterglows for three bursts, and determined redshifts of three *Swift* bursts and one SXC burst. We show that the optical/near-IR detection rate for *Swift* bursts is indeed higher than in past missions, but that the afterglows are significantly fainter, and their redshifts tend to be higher. Deep limits suggest that as many as 1/3 of the *Swift* bursts can be optically dark. These conclusions have major ramifications for future follow up efforts, which we discuss towards the end of the paper.

2. AFTERGLOW DISCOVERY AND REDSHIFTS

Follow-up observations by our group were made using an armada of telescopes at the following facilities: Las Campanas Observatory (LCO), Magellan, Palomar Observatory, Keck, Siding Spring Observatory (SSO), and the Very Large Array (VLA\(^{15}\)). Afterglow discovery and follow up of GRBs 041223, 050117a, 050124, and 050126 were detailed in Berger et al. (2005a). In Table 1 we provide photometry and radio flux measurements for subsequent events, augmented by relevant data from the literature.

All optical/near-IR observations were reduced in the standard manner using IRAF routines. Astrometry was performed relative to the USNO-B catalog, and the afterglow identifications were made by comparison to the Digitized Sky Survey (DSS) or through detection of a fading behavior. The VLA radio observations were undertaken in the standard continuum mode, and the data were reduced and analyzed using the Astronomical Image Processing System.

We used the LDSS3 and IMACS spectrographs on the Magellan 6.5-m telescopes to obtain absorption spectra for the *Swift* GRBs 050315 (Figure 1) and 050318 (Figure 2), and the HETE-2 SXC burst GRB 050408 (Figure 3). We also used ESI on the Keck-II telescope to obtain a redshift for the host galaxy of GRB 050126 (Berger et al. 2005a). In all cases, we used standard IRAF routines to bias-subtract and flat-field the data, while rectification and sky subtraction were performed using the method and software described in Kelson (2003). Air-to-vacuum and heliocentric corrections were applied to the wavelength calibration. The redshifts determined from these spectra are listed in Table 1, along with two other redshifts available from the literature. A detailed analysis of the absorption spectra will be provided in a separate paper (Berger et al. in prep.)

Finally, we list in Table 1 the X-ray fluxes and \(\gamma\)-ray peak photon fluxes and fluences when available from the literature. For GRBs 050401, 050406, 050416a, and 050421 we undertook our own analysis of the XRT data (from the *Swift* archive\(^{16}\)). We cleaned the data using the standard settings in *xrtpipeline*, and extracted photons in the 0.5–7 keV band. This optimizes detection signal-to-noise for the average afterglow, which has a photon spectral index of about \(-2\). For the photon counting mode we used an extraction radius of 20 pixels (90% encircled energy) for the source, and an annulus outside of this, starting at a radius of 30 pixels, for background extraction. The data were fit with a power law plus absorption. Finally, we used the measured photon spectral index to extrapolate the flux to the 2–10 keV band for comparison with bursts from other missions. The conversion from count rate to flux is \(1 \text{ cps} = 2 \times 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1} (2–10 \text{ keV})\).

3. THE PROPERTIES OF SWIFT BURSTS

In this section we summarize the properties of the sample of 21 *Swift* bursts that have XRT positions and ground-based optical/near-IR follow up (Table 1; as of the end of April 2005). We compare the *Swift* sample with two previous samples: (i) HETE-2 SXC bursts with positional accuracy better than 2′ (“SXC”), and (ii) bursts localized by other past missions (BeppoSAX, HETE-2 XWM, IPN, and INTEGRAL; “BWI”). The former sample (14 objects) enjoys superior localizations, while the latter sample (96 objects) has moderate localizations (\(\sim 3–30′\)).

The overall detection fraction of X-ray afterglows for *Swift* bursts is 21/22 (one burst detected in \(\gamma\)-rays has no XRT detection). This is essentially the same as the detection fraction for past missions of about 90%. The recovery fraction of optical/near-IR afterglows for the *Swift* sample, 12/21 \(\approx 60\%\), is significantly higher than the 30% recovery fraction of the BWI sample, but is slightly worse than the 85% fraction for the SXC bursts.

In Figure 4 we plot the \(R\)-band magnitudes for the three samples, normalized to \(t = 12\) hr. We extrapolate (or interpolate) to the fiducial time (and for near-IR afterglows to the fiducial band) using the measured temporal and spectral slopes or by conservatively assuming\(^{17}\) \(F_x \propto t^{-0.9} \nu^{-0.6}\). As can be seen from Figure 4, the *Swift* afterglows, with a mean \(\langle R \rangle = 21.5\) mag, are fainter relative to the SXC and BWI samples by about 1.7 magnitudes. In fact, while 40% of all afterglows from past missions had \(R < 19\) mag at \(t = 12\) hr, not a single *Swift* burst falls in that bright category.

We carry out a similar exercise for the X-ray afterglow emission (Figure 5). The X-ray fluxes at \(t = 12\) hr are estimated using the measured decay indices (when available), or the mean value based on all bursts, \(\langle \alpha_X \rangle = -1.3\); for *XRT* fluxes measured in the first hour we use a more conservative \(\alpha_X = -1\). As with the optical/near-IR afterglows, the X-ray afterglows of *Swift* bursts are fainter relative to those of the other two samples by about a factor of five.

Our comprehensive radio follow up of thirteen *Swift* bursts led to the detection of only three (GRBs 050315, GRB 050401, GRB 050416a; Figure 6). This is comparable to the 30% recovery fraction of the BWI sample, but is lower than the 55% recovery of the SXC sample.

\(^{15}\)The VLA is operated by the National Radio Astronomy Observatory, a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

\(^{16}\)http://heasarc.gsfc.nasa.gov/docs/swift/archive/

\(^{17}\)The choice of spectral and temporal indices is appropriate for the case of spherical geometry, a constant density circumburst environment, an electron power law index \(p = 2.2\), and a synchrotron cooling frequency \(\nu_c > \nu_R\). This provides the most conservative decay rate: for a Wind medium the dependence is \(t^{-1.4}\), for \(\nu_c < \nu_R\) it is \(t^{-1.15}\), and for the case of a collimated explosion it is \(t^{-p} \sim t^{-2.2}\).
The redshift distribution of Swift bursts differs from that of the BWI sample, which peaks at $z \sim 0.8$ (Figure 7). In fact, the flat distribution of Swift bursts is similar to that of the SXC sample. It is interesting to note that the redshifts of the (admittedly small) Swift sample are all beyond 1.25, while the median redshift for pre-Swift bursts is 1.05.

To summarize, Swift bursts, relative to both the BWI and SXC samples, have fainter X-ray and optical afterglows. Swift and the BWI sample have a similar and low (30%) recovery fraction for radio afterglows. We explain these findings as follows. The BWI sample with its moderate localization precision favored brighter afterglows, which in turn favored lower redshift events. The Swift/XRT positions, combined with a greater trigger sensitivity (Figure 8), allow us to increase the detection fraction and hence to find fainter and higher redshift events. The low rate of radio recovery is primarily a result of the VLA sensitivity (which is lower relative to the optical/near-IR bands). The accurate and faster positions available from Swift do not help to increase the radio detection fraction. In fact, the fainter afterglows of Swift bursts may in the long run result in a lower recovery fraction in the radio (Figure 6).

The statistics of the SXC sample, however, are puzzling. The high afterglow detection fraction for SXC bursts, and their flat redshift distribution (unlike the the BWI sample), can be attributed to better localizations. However, with a higher recovery rate we would expect the SXC afterglows to be fainter than those of the BWI sample, while they are in fact just as bright. Similarly, the recovery fraction of radio afterglows, which is set by the VLA threshold, is expected to be comparable to that of the BWI and Swift samples; it is instead significantly higher.

There are two possible explanations. Either the SXC sample is suffering severely from Poisson statistics (though this is unlikely), or the sample is biased to brighter afterglows. We speculate that soft X-ray contribution from the very early afterglow, or excess soft X-ray emission in the prompt phase (e.g., Vanderspeck et al. 2004) may enhance detection by the SXC, and possibly give rise to a sample with brighter afterglows. It appears that the SXC sample may not serve as a proxy for the true distribution of afterglow properties, including the fraction of dark bursts.

4. DISCUSSION AND RAMIFICATIONS

Swift has been in orbit for six months and has localized 32 bursts as of the end of April 2005. In this paper we presented the results of our ground-based optical/near-IR and radio follow up programs of the 21 bursts with accurate positions from the XRT, including the determination of three redshifts.

There is high expectation amongst astronomers that Swift, over the remaining 30 months of its prime phase, will help address several major questions: Are Swift bursts representative of the overall GRB population? How do GRBs evolve with redshift? Is there a large population of nearby events like GRBs 980425 and 031203? Separately, many astronomers are poised to exploit the brilliance of the afterglows to investigate the star-formation history of the Universe, probe the intergalactic medium in the early Universe, and investigate the build up of elements in the disks of galaxies. For these astronomers the following questions are of prime importance: What is the fraction of dark bursts, and how many of these lie at high redshift ($z > 6$)? Will the afterglows be bright enough to undertake high resolution optical/near-IR spectroscopy? What is the annual Swift rate of such interesting bursts? We believe that our investigation of the current sample has started to address some aspects of the above questions.

To start with, the observed Swift rate is about 80–90 bursts per year. This is less than the 150 bursts per year estimated from pre-launch simulations, which assumed a threshold of five times better than that of BATSE (Fenimore et al. 2004). The smaller rate is consistent with the fact that the fluences and peak count rates of the observed Swift events are in fact similar to those that triggered BATSE, as are the resulting threshold and the logN/logS distribution (Figure 8).

Next, there is at the present no indication of a large sample of nearby ($z \lesssim 0.2$) low luminosity events. As noted earlier, the lowest measured redshift is $z \approx 1.29$. More importantly, there is no evidence of bright galaxies in the XRT error circles. The lack of low redshift objects is not surprising given that Swift’s threshold is similar to that of BATSE. In the BATSE sample, even when including the faint, non-triggered bursts, the limit on a contribution from a spatially homogeneous, local population is about 7% (90% confidence; Kommers et al. 2000).

In addition, the Swift afterglows are fainter and their redshifts are higher. The rapid response of a variety of telescopes to Swift events, and their accurate positions, means that the Swift sample has the least bias (relative to the previous samples). We therefore conclude that (i) the true GRB population peaks at a higher redshift than indicated by pre-Swift bursts, $z \gtrsim 2$, and (ii) the typical optical and X-ray afterglows are faint: at $t = 12$ hr, $R \sim 21.5$ mag and $F_X \sim 3 \times 10^{-13}$ erg cm$^{-2}$ s$^{-1}$, respectively.

A number of ramifications follow from the above discussion. First, the fainter afterglows mean that it is critical that moderate (and large) telescopes be pressed into service to identify optical/near-IR afterglows; the expected signal level (at $t = 15$ min) of $R \sim 17.7$ mag, $J \sim 16.6$ mag, and $K \sim 15.2$ mag is difficult to achieve on small robotic telescopes. In addition, the combination of higher redshifts and fainter afterglows strongly favor longer wavelength observations ($RIz$ bands versus $UBV$); indeed, a simple way to improve the current low detection fraction by the UVOT (5/16) is to observe in only the V band (unless the afterglow is noted to be bright). Finally, near-IR observations are essential to distinguish dusty events from high redshift events.

So far we have tacitly assumed that Swift events are representative of the true sample, and the afterglow and redshift distributions are simply due to a lower threshold and better localizations than BeppoSAX and HETE-2. However, a possible bias arises from the softer band of the BAT (15–150 keV) compared to the BeppoSAX GRBM (40–700 keV) and HETE-2 FREGATE (6–1000 keV) instruments. Amati et al. (2002) and Sakamoto et al. (2004) show that there is a correlation between the peak energy of the prompt emission spectrum, $E_{\text{peak}}$, and the fluence (or peak flux). This is an approximate relation but it appears to be obeyed in the mean. This means that the BAT is well suited for finding “X-ray rich GRBs”, which will therefore result in selection of bursts with a lower fluence and peak flux. This is potentially a significant bias in the Swift sample. Conversely, the softer triggering band of the BAT means that the detection of short-hard bursts will be diminished. This may explain why Swift has localized only a single short-hard burst out of the sample of 32 bursts.

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18In the host galaxy sample for pre-Swift GRBs, all objects at $z < 0.5$ have $R \lesssim 22$ mag, and a mean of 20.6 mag. Similar hosts should have been detected in most of the afterglow searches of Swift XRT positions (Table 1).
The aggregate effect of Swift’s trigger threshold, energy band, and localization accuracy has resulted in a sample that is dominated by faint optical/near-IR and X-ray afterglows with seemingly higher redshifts than indicated by past missions. The current recovery rate suggests that as many as 1/3 of all Swift bursts may be optically dark. Therefore, while a local population of low energy bursts does not contribute significantly to the sample, the possibility that Swift will uncover a larger population of high redshift bursts than past missions remains open. Follow-up efforts and resources should be focused on this possibility.

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| GRB     | \(\delta_{\text{opt}}\) (hr) | Telescope | Filter | Mag. | \(\delta_{\text{rad}}\) (s) | \(F_{\gamma,\text{rad}}\) (\(\text{erg} \cm^{-2} \text{s}^{-1}\)) | \(F_x\) (\(\text{erg} \cm^{-2}\)) | \(P_x\) (\(\text{cts} \cm^{-2} \text{s}^{-1}\)) | Refs. |
|---------|-------------------------------|-----------|--------|------|-----------------|---------------------------------|-----------------|-----------------|--------|
| 041223  | 14.4                          | LCO40     | r      | 20.81| 1.63 \times 10^4 | 6.5 \times 10^{-12}             | 5.0 \times 10^{-5} | 7.5   | 1.2898 |
| 050117a | 14.6                          | P200/WIRC | K      | > 18.8| 1.54 \times 0.99 | 193                             | 1.8 \times 10^{-8} | 1.7 \times 10^{-5} | 0.9   | 1.2962 |
| 050124  | 24.5                          | Keck/NIRC | K      | 19.66| 4.93 \times 0.150 | 2.54 \times 10^4               | 2.2 \times 10^{-12} | 2.1 \times 10^{-6} | 6.8   | 1.2973 |
| 050126  | 1.920                         | Keck/NIRC | K      | 19.45| 2.09 \times 0.90  | 200                             | 2.5 \times 10^{-11} | 2.0 \times 10^{-6} | 0.4   | 1.2978 |
| 050128  | 11.4                          | Faulkes   | R      | > 20.5| 11.3 \times 0.85  | 873                             | 2.6 \times 10^{-12} | 4.5 \times 10^{-6} | 4.6   | 2.991, 2992, 3001, 3011 |
| 050215b | 9.00                          | P60       | R      | > 20.5| 3.39 \times 0.93   | 5.7 \times 10^3            | few \times 10^{-13} | 4.5 \times 10^{-7} | ...   | 3.032, 3034, 3035, 3053, 3066 |
| 050215b | 9.76                          | UKIRT/UFIT| K      | 20.23| 9.00 \times 0.56   |                     |                 | 5.5   | 3.038, 3041 |
| 050219a | 2.05                          | M1/JO 0.6-m | R      | > 20.5| 5.14 \times 0.96   | 2.3 \times 10^{-13} | 2.3 \times 10^{-5} | 26    | 3.044, 3064 |
| 050219b | 1.77                          | LCO40     | I      | > 21.5| 0.20 \times 0.20   |                     |                 | 5.5   | 3.048   |
| 050223  | 4.10                          | PROMPT    | R      | > 21.2| 7.67 \times 10^4   | 4.5 \times 10^{-14}          | 7.4 \times 10^{-7} | 0.8   | 3.055, 3067, 3109 |
| 050306  | 50.5                          | TNG       | R      | 23.30| 8.27 \times 0.84   | ...                             | 1.9 \times 10^{-5} | 2.4   | 3.089, 3092 |
| 050315  | 19.5                          | Mag/LDSS3 | R      | 20.9 | 0.81 \times 0.62   | 300                             | 4.2 \times 10^{-6} | 2.5   | 3.098, 3100, 3101, 3102, 3105 |
| 050318  | 8.15                          | Mag/MACS  | R      | 21.6 | 7.7 \times 10^4    | 3.0 \times 10^{-12}          | 2.1 \times 10^{-6} | 3.8   | 3.112, 3114, 3122, 3134 |
| 050319  | 8.70                          | RTT150    | R      | 21.4 | 0.63 \times 0.14    | 174                             | 8.0 \times 10^{-7} | 1.7   | 3.119, 3127, 3132 |
| 050326  | 6.90                          | MJO 0.6-m | I      | > 20.3| 5.4 \times 0.64   | ...                             | 7.4 \times 10^{-13} | 1.9 \times 10^{-5} | 17    | 3.145, 3151, 3293 |
| 050401  | 9.96                          | SSO40     | R      | 20.3 | 5.69 \times 0.62   | 122 \times 33                | 1.9 \times 10^{-12} | 1.9 \times 10^{-5} | 14    | 3.163, 3164, 3179, 3187 |
| 050406  | 7.80                          | Mag/LDSS3 | R      | 22.0 | 3.8 \times 10^4    | 6.7 \times 10^{-14}          | 9.0 \times 10^{-8} | 3.2   | 3.183, 3184, 3185 |
| 050410  | 4.45                          | ARIES     | R      | > 20.5| 0.21 \times 0.17   | ...                             | 6.9 \times 10^{-7} | 2.0   | 3.219, 3223, 3226 |
| 050412  | 0.22                          | P60       | i      | > 21.5| 8.5 \times 0.85    | ...                             | 3.9 \times 10^{-12} | 2.1 \times 10^{-6} | 0.8   | 3.342, 3251, 3253, 3277 |
| 050416a | 3.50                          | SSO 2.3-m | R      | > 20.4| 3.58 \times 0.55   | 280 \times 55                | 4.3 \times 10^{-12} | 3.8 \times 10^{-7} | 4.8   | 3.266, 3273, 3275, 3318 |
| 050416b | 1.00                          | Mag/MACS  | R      | > 24.0| 3.58 \times 0.55   | ...                             | 2.8 \times 10^{-13} | 3.8 \times 10^{-7} | 4.8   | 3.266, 3273, 3275, 3318 |
| 050421  | 4.62                          | P60       | R      | > 22.0| 0.44 \times 0.17   | 102                             | 3.8 \times 10^{-7} | 1.8 \times 10^{-7} | 0.5   | 3.299, 3301, 3305, 3308 |
| 1.70    | TNG                           |           | K      | > 18.6| 8.5 \times 0.85    | ...                             | 3.8 \times 10^{-7} | 3.3   | 3.330   |
| 9.30    | MAGNUM                        |           | J      | > 20.3| 6.4 \times 0.67    | ...                             | 3.3 \times 10^{-8} | 3.3   | 3.313   |

Note.—Prompt emission and afterglow properties for all Swift bursts with XRT positions and ground-based follow-up as of the end of April 2005. The columns are (left to right): (i) GRB name, (ii) redshift, (iii) time of optical/near-IR observation, (iv) telescope, (v) filter, (vi) optical/near-IR magnitude, (vii) time of radio observation, (viii) radio flux at 8.46 GHz, (ix) time of X-ray observation, (x) X-ray flux, (xi) \(\gamma\)-ray fluence, (xii) \(\gamma\)-ray peak flux, and (xiii) references.
Absorption spectrum of GRB 050315 taken with the LDSS3 instrument on the Magellan/Clay 6.5-m telescope 11.8 hr after the burst (R = 20.9 mag; Table ref: obs). The spectrum exhibits several absorption features corresponding to Al II ($\lambda$1670), Si II ($\lambda$1808), Al III ($\lambda\lambda$1854,1862), and Mg I ($\lambda$2026) at a redshift, $z = 1.9500 \pm 0.0008$. 

**Figure 1.**
Fig. 2. — Absorption spectrum of GRB 050318 taken with the IMACS instrument on the Magellan/Baade 6.5-m telescope 8.1 hr after the burst ($R = 20.6$ mag; Table reftab:obs). The spectrum exhibits several absorption features corresponding to Fe and Mg lines at redshifts, $z_1 = 1.2037 \pm 0.0004$ and $z_2 = 1.4436 \pm 0.0009$. We identify the higher redshift system with GRB 050318.
Fig. 3.— Absorption spectrum of the HETE-2 SXC burst GRB 050408 taken with the LDSS3 instrument on the Magellan/Clay 6.5-m telescope about 12.9 hr after the burst (R = 22.0 mag). The spectrum exhibits absorption from Fe and Mg, as well as an [OII] λ3727 emission line. The redshift of the burst is $z = 1.2356 \pm 0.0008$. 
Figure 4.— Histograms of optical $R$-band magnitudes (corrected for Galactic extinction) extrapolated to a common time of 12 hours after the burst for the Swift, SXC, and BWI samples. Shaded regions are detections, while thin histograms include all upper limits. The mean $R$ magnitude of the detections in each sample is given as $\langle R \rangle$. The top panel shows the cumulative distributions. The afterglows of Swift bursts are fainter than those of bursts detected in previous missions. This is primarily the result of accurate and rapid localizations, which have allowed us to increase the recovery rate through the detection of fainter objects, and the lower threshold of Swift (Figure 8), which results in detection of fainter bursts. The SXC sample, with a detection rate of $\sim 85\%$ in the optical, contains many bright afterglows, suggesting a bias in favor of bright bursts.
Fig. 5.— Histograms of X-ray fluxes extrapolated to a common time of 12 hours after the burst for the Swift, SXC, and BWI samples. The top panel shows a cumulative distribution. The distribution for pre-Swift bursts is from Berger et al. (2003) and Berger et al. (2005a). The X-ray afterglows of Swift bursts are fainter than those of bursts detected in previous missions. Since the past recovery rate was already about 90%, this suggests that the lower trigger threshold of Swift compared to BeppoSAX and HETE-2 is giving rise to fainter and higher redshift bursts.
Fig. 6.— Detections (circles) and upper limits (triangles) in the radio for Swift bursts. Also shown are the radio light curve of GRB 990123 which was dominated by reverse shock emission, and synthetic light curves of the forward shock emission from a burst with typical parameters \( n_0 = 3 \times 10^{-3} \), \( \epsilon_e = 0.1 \), and \( \epsilon_B = 0.01 \) placed at \( z = 2 \) and with blastwave energies of \( 1 \times 10^{52} \) erg (thick line) and \( 3 \times 10^{51} \) erg (thin line). Clearly, if Swift bursts typically have fainter afterglows (e.g., less energy), as indicated by their optical and X-ray fluxes, the majority may be too faint to detect at the VLA sensitivity.
Fig. 7.— Optical $R$-band magnitudes (corrected for Galactic extinction) extrapolated to a common time of 12 hours after the burst, plotted against redshift. Light gray circles designate BW1 bursts, dark gray circles are SXC bursts, and stars are Swift bursts. The dashed lines designate the median magnitude and redshift for all pre-Swift bursts. The higher redshifts of Swift bursts are the result of deeper and faster searches which uncover fainter afterglows, as well as the lower threshold of Swift.
Swift, 29 bursts  (15−350 keV)

BATSE, 747 bursts  (25−300 keV)

N(>F)



Swift, 29 bursts  (15−350 keV)

HETE−2, 45 bursts  (30−400 keV)

BeppoSAX, 25 bursts  (40−700 keV)

Fluence (erg cm$^{-2}$)

N(>F) yr$^{-1}$

Fig. 8.— Top: logN/logF for Swift bursts with published fluences compared to a sample of BATSE bursts for which a fluence measurement is available in all four channels and the error is smaller than half of the measured value. The BATSE fluence distribution is normalized by the relative number of bursts. The similarity of the distributions and thresholds explain the lack of local, low luminosity bursts in the current Swift sample, as well as the lower event rate compared to pre-launch estimates (90 vs. 150 per year, respectively). Bottom: The same Swift sample but compared to BeppoSAX and HETE-2 bursts (Amati et al. 2002; Sakamoto et al. 2004; Ghirlanda et al. 2005). For HETE-2 we included only GRBs and X-ray rich GRBs. Each sample is normalized by the approximate detection rates per year. Clearly, Swift has a lower threshold and this results primarily in an increase in the number of faint bursts.