Observing the IR Transients of Gamma-Ray Bursts and their Host Galaxies

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Scientific category:	SUPERNOVAE
Instruments:	OPT/CAM, NIR/CAM, NIR/SPEC, MIR/CAM
Days of observation:	36

Abstract

GRBs are the brightest phenomenon in the universe, with isotropic energy releases of $10^{51} - 10^{54}$ ergs emitted over seconds to days. Because they are so rare, one million times less common than supernovae, and therefore relatively distant, our understanding of GRBs and their origins involves the study of their host environments. If GRBs were an end product of massive star formation, they could be signposts to active starforming regions. GRBs can also be unique beacons for the study of the IGM at very high redshift. We propose to follow-up 2-10 keV X-ray GRB identifications, particularly those that are found to be visibly faint or apparently reddened. These may be GRBs at very high redshift or hidden by the Lyman-alpha forest/Gunn-Peterson absorption, reddened GRBs ($A_\mathrm{v} \sim$10-50) in the nuclei of protogalaxies, or hypernovae observed by their scattered light . NGST will be used to image and obtain redshifts of the host galaxies of GRBs. NGST mid-IR imaging will be useful to observe high redshift, dust-enshrouded GRBs in the rest frame NIR. At z>3, NGST must image at > 8 microns to reach the rest K band.

Observing Summary:

Target	RA	Dec	K_{AB}	Configuration/mode	Days
100 GRB CANDIDATES			29. JAB	NIR/CAM R3	5
100 GRB CANDIDATES			29.5 LAB	NIR/CAM R3	5
100 GRB CANDIDATES-M			27.5 MAB	NIR/CAM R3	5
100 GRB CANDIDATES-N			25.5 NAB	MIR/CAM R3	4
100 HIGH-Z GRB HOSTS			28 KAB	NIR/SPEC R100	14
3 HIGH-Z GRBS			26.4 KAB	NIR/SPEC R3000	3
				Grand total days	36

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Scientific Objectives

Gamma-Ray Bursts (GRBs) are the most energetic transient events in the known universe. Although they are quite rare – perhaps 10^6 times rarer than Type II supernovae – their optical and NIR afterglows may provide a unique way of identifying early sites of star formation and probing the interstellar and intergalactic medium at high redshifts, z 2-10. Woods & Loeb (1998, WL) point out that the great volume made accessible by the GRB afterglow in the NIR helps compensate for their rarity. If the progenitors of GRBs are massive stars (hypernovae), their rates should follow the star formation history of the universe. In this so-called "evolutionary" case it is possible to probe the entire volume (z = 0 - 5) of star formation at a K-band sensitivity of $KAB_{max} \sim 19$ versus $KAB_{max} \sim 28$ for SNeII.

Visible counterparts for GRBs can be very bright, $V \sim 19 - 20$. At these brightnesses, the sources themselves can be confirmed and followed using ground-based telescopes. As of this writing, all of the optically identified sources (optical transients) have been found in faint galaxies at cosmological redshifts (Kulkarni et al 1998).Indeed GRB980329 , whose colors are consistent with $z \sim 5$ (Fruchter 1998) does not have a confirmed optical host. Such galaxies are not readily detected from the ground, particularly if they are not engaged in active star formation or are reddened by dust. For GRB980329, Fruchter estimates that the host galaxy would be I ~ 27, R ~ 29, essentially undetectable from the ground but reachable from HST and NGST. The greater senstivity of NGST can readily detect the underlying host galaxies at very high redshifts and will be the only facility capable of confirming GRB NIR candidates in cases where the GRB itself is heavily reddened.

In addition, WL estimate that the number density of long-lived afterglows, with an assumed cutoff age of 1 yr., is 10^{-2} to 1 deg^{-1} yr^{-1} depending on their evolutionary history. While we expect that the discovery of long-lived afterglows will be made as part of dedicated ground-based, wide-field visible band surveys such as the Sloan Digital Sky Survey, NGST would be able to provide stronger constraints by using the results of other NGST deep surveys. In the rest of this proposal we will concentrate on finding the NIR or MIR counterparts soon after the gamma ray burst is detected.

The goal of the NGST GRB program is to confirm the NIR counterparts of GRBs and study the sites of their formation to redshifts greater than $z \sim 5$ The high sensitivity of NGST could be used to take detailed spectra of bright afterglows and could easily detect time-dependent absorption lines (due to the effect of the afterglow radiation on the ambient gas; Perna & Loeb 1997) and serendipitous spectral features. Should a significant percentage of GRBs occur at high redshifts with only moderate reddening, we will be able to use them as probes of the interstellar and intergalactic medium.

NGST Uniqueness/Relationship to Other Facilities

Although many GRBs have been detected in the X-rays, only a handful have been detected at visible wavelengths. Paczynski (1998) has suggested that many, if not most GRBs, occur in dusty, star formation regions. Indeed GRB 980326 has been identified with a very red source, KAB ~ 22.8, in a reddened galaxy, RAB-KAB ~ 3 (Larkin et al 1998). While it is probably

not meaningful to speak of an average reddening for a star formation region at cosmological epochs, we do know that the cores of giant molecular cloud complexes and the UltraLuminous Infrared Galaxies (ULIGS) are extremely obscured at visible wavelengths (A_v= 10-1000, Lutz et al 1998). Recalling that the observed visible light afterglows may correspond to NUV wavelengths in the rest frame, we can see that the afterglows from GRBs within these dense cores or large complexes of giant molecular clouds would be undetectable even with HST. A more optimum waveband would correspond to the rest K bands, where the reddening is reduced by approximately a factor of 10. For redshifts at z > 2, the corresponding apparent wavelengths are $> 6 \mu$m. For GRB models with high mass progenitors, WL finds the flux near maximum light to be essentially identical in this wavelength range or $LAB \sim AB_{6\mu m} \sim 17.5$ for $z \sim 2$. GRB afterglows would be detected in the M and$N$ bands in star forming complexes with $A_v \sim 50 - 100$. Groundbased observations of GRBs or SNe in the infrared will be very difficult due to the higher background and the complex morphology of the underlying host galaxies.

The rare unreddened GRB at high redshift, z > 8, will have rest Lyman α Appearing in the NIR, where strong OH emission or atmospheric absorption will make the detection difficult and ambiguous from the ground. NGST will be able to detect and clearly separate relatively bright, stellar I and J-band dropouts from faint foreground stars and galaxies. Indeed, it may be possible to detect the high redshift GRB on the first visit due to its unusual colors, and thereby facilitate moderate resolution NIR spectroscopy near the peak of the afterglow.

An intriquing possibility is that NGST will detect a significant number of "off-axis" hypernovae, whose optical and infrared afterglows are intermediate in brightness between a SNe II and a GRB afterglow and is due to light scattering outside a doppler-enhanced light cone. The statistics of these objects and their decline rates may provide crucial clues about the underlying GRB mechanism. At cosmological distances, where they would be most common, "off-axis" GRBs will be difficult to confirm from groundbased observatories.

We anticipate that many optical and K-band counterparts of GRB sources will be found prior to NGST operations and the nature of GRB progenitors may be preliminarily determined. (Indeed, Chary et al. (1998) report the detection of GRB 970508, z > 0.835, in the K band or the objects rest $I - J$ bands.) However, the use of GRBs to detect star formation at high redshift or obscured star formation and the potential of using GRBs to study the early IGM will remain a task uniquely that of NGST.

Bibliography

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■ Observing Strategy

Given the small statistics of detected and undetected visible counterparts, we cannot accurately state the number of GRBs that should be detected in visible ground-based followups, but a 50% detection rate is reasonable. We will assume ~ 300 GRBs yr^{-1} are detected and located to a few arcminutes by a specialized space observatory(s). These will have gamma ray fluxes near or fainter than the cosmological knee in the number counts. Within a few days, ground-based telescopes would be able to identify or place an upper limit on any optical transient. During the HST epoch, we expect that bright visible sources will be followed from the ground and HST. During the NGST epoch, we expect that 30will be within the mutual Gamma Ray Burst locator and NGST viewing zones. This provides ample headroom for additional constraints such as established, time-critical observations or thermal slew constraints. We would propose to observe 20 in the first year and, depending on the results of that initial followup survey, about 30 per year for another 3 years for a total of over 100 GRB afterglows. Within a 1-2 arcminute search region, the typical NGST observation would be three visits that include 4 1000s integrations in $J, L, M,$ and N bands (assuming onboard cosmic ray rejection or splits). The visits would be spaced about 4 days after the GRB detection(visit 1), 8 days after the GRB (visit 2) and 20 days after the GRB (visit 3). The declining GRBs at z $\sim$ 2 will be detected after the second visit, z $\sim$ 2, and the third visit will be adjusted accordingly to include high resolution NIR spectroscopy to detect intrinsic ISM absorption features. GRBs at much higher redshifts will be detected after the third visit. Depending on their colors and the brightness of the host galaxy, they would be observed in a fourth visit to obtain the redshift of the host galaxy using low resolution spectroscopy. I-band or J-band dropouts would be the most exciting discoveries since they might correspond to GRBs at very high redshift. Using high resolution ($R \sim$ 3000) spectroscopy, it should be possible to probe the ionization state of the high redshift IGM with unprecedented sensitivity. Note that in these cases, the response time does not need to be rapid since the apparent decay time would be measured in weeks for these high redshift sources. We estimate that only a small fraction of the sources, say 3%, would be I-band or J-band dropouts and require long spectroscopic followups (10^5 s).

Estimated Resources: We calculate the following fluxes assuming high mass stellar progenitors for GRBs (WL's eta= 10). Here we give examples of obscurred GRBs for which ground-based observations would be essentially incapable of detecting reddened sources at redshifts z = 2 or higher. In the giant molecular cloud case, within 8 days – a typical decay time – the sources will be below the sensitivity limit of ground- based telescopes in the K band. The same might be true for ULIGs ($A_{\rm v} > 50$) at redshifts greater than z > 0.4. Even in the many cases with low obscuration, we emphasize the unique ability of NGST to determine the colors and morphology of the faint, underlying galactic host.

Obscurred Target Fluxes (8 days after burst):

GRB at z $\sim$ 2, with $A_{\rm v} \sim 10$ (a molecular cloud, which may be ionized by the high surface brightness of the GRB flux):

$J \sim$ 35, $Lsim$ 24, $M \sim$ 20.5, $N \sim$ 19.

GRB at z $\sim$ 2, with $A_{\rm v} \sim 50$ (Arp 220 type ULIG):

$J \sim$ infinite, $L \sim$ 42, $M \sim$ 26.6, $N \sim$ 20.2.

Very high redshift, unreddened GRB (GRB at z $\sim$ 10, with $A_{\rm v} \sim$ (no metals. clear view):

$J \sim$ 22.1, $L \sim$ 21.4, $M \sim$ 20.9, $N \sim$ 20.4.

Sensitivities (10 sigma)

J, L bands (1000s @) = 3-6 nJy = 30.2-29.5 AB

M band (1000s @) = 30 nJy = 27.7 AB

N Band (1000s @) = 200 nJy = 25.6 AB

J band (100000s. R= 3000 spectroscopy) = 100 nJy = 26.4

The entire 4-year observing program would require the following NGST resources.

100 Sources x 3 visits x 4000 s (4 band observations) + 20overhead= 18 days 100 sources x 1 visit x 10000s (NIR spectroscopy for redshift) +20overhead = 14 days

3 Sources at high redshift x 100,000s spectroscopy = 4 days

Special Requirements

We will require $\sim$ two day Target of Opportunity turnaround on the first observations of the GRB candidates (see above). We will then need to schedule about two return visits spaced 8 days and 20 days after the first visit. The exact offset coordinates will not be needed for these visits but will be required for spectroscopy on the third or fourth visit.

Maximum time until replanned science followup: 8 days

Maximum time from TOO until observations: 2 days

Minimum % sky for TOO: 25%

Precursor/Supporting Observations

We will require an operating X-ray or Gamma-Ray burst detector and locator capable of locating a GRB within a 1 arcmin radius (90 % confidence level). We expect that ground-based observatories will locate bright GRBs and broadcast their observation with 48 hrs. The first NGST visits will occur within 48hrs after the ground-based detection or upper limit for an optical transient.