Hubble Space Telescope Imaging of the Field of GRB970508

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Abstract. We report on Hubble Space Telescope (HST) observations of the optical transient (OT) discovered in the error box of GRB970508. The object was imaged on 1997 June 2 with the Space Telescope Imaging Spectrograph (STIS) and Near-Infrared Camera and Multi-Object Spectrometer (NICMOS). The observations reveal a point-like source with R = 23.1 ± 0.2 and H = 20.6 ± 0.3, in agreement with the power-law temporal decay seen in previous ground-based monitoring. Unlike the case of GRB970228, no nebulosity is detected surrounding the OT of GRB 970508, although Mg I absorption and [O II] emission seen in Keck spectra at a redshift of z = 0.835 suggest the presence of a dense, star-forming medium. The HST observations set very conservative upper limits of R ∼ 24.5 and H ∼ 22.2 on the brightness of any underlying extended source. If this subtends a substantial fraction of an arcsecond, then the R band limit is ∼25.5. Subsequent photometry suggests a flattening of the light curve at later epochs. Assuming the OT decline follows a pure power-law and ascribing the flattening to the presence of an underlying component of constant flux, we find that this must have R = 25.4, consistent with the upper limits determined by HST. At z = 0.8, this would correspond to an absolute magnitude in the U band of ∼ −18, similar to that of the Large Magellanic Cloud (LMC). We propose a scenario in which the host galaxy of the GRB is of Magellanic type, possibly being a “satellite” of one of the bright galaxies located at few arcseconds from the OT.
INTRODUCTION

Optical and infrared imaging of GRB fields has been pursued for several years with the aim of studying the environments of the gamma-ray events, and of localizing and characterizing their host sources. However, till recently, due to the insufficient angular precision in the knowledge of GRB positions, the results have been inconclusive, as reviewed by Band and Hartman [1].

The high positional accuracy attained by the BeppoSAX Wide Field Cameras has allowed the pointing of optical telescopes at the error circles of GRB970228 and 970508, and the discovery of optical transients (OT) associated with them [2,3]. For the former GRB, HST has resolved an extended source surrounding the point-like OT [4], whose shape, colors and constant brightness led to the identification with a galaxy of irregular morphology.

R band photometry of the OT of GRB970508 [9–11,7,12–18,6,19,20] shows that, following a first increase, the flux started subsiding ∼2 days after the GRB (see Figure 1). This decay can be modeled, till the epoch of the HST observation, with a power-law temporal dependence of index $-1.17 \pm 0.04$.

Spectroscopy at the Keck II telescope [5] reveals absorption systems at $z = 0.767$ and 0.835 superposed on the continuum as well as [O II] line emission at $z = 0.835$ [6]. These features, besides proving unambiguously the extragalactic location of the OT, suggest a line of sight through a dense interstellar medium; however, the only potential host galaxy detected from ground-based imaging is a faint blue object lying 5′′.2 away from the OT [7].

The HST observations presented here were designed to search for a host galaxy and to obtain late-time photometry of the OT of GRB970508. A detailed description of the data and results has been given in Pian et al. [8], to which we refer for a complete presentation.

OBSERVATIONS, DATA ANALYSIS AND RESULTS

Four 1250-second exposures were obtained of the GRB970508 field using the STIS CCD in Clear Filter mode during 1997 June 2.52-2.66 (UT). They have been dithered to allow removal of hot pixels and to obtain the highest possible resolution. The images were bias subtracted, flat-fielded, corrected for dark current and calibrated by the newly created STIS pipeline. The final “drizzled” [21] image is available in the Web (URL http://www.stsci.edu/~fruchter/GRB/data_970508).

Four exposures of 514 seconds each were also made with the NICMOS Camera 2 on 1997 June 2.67-2.74 (UT) and dithered using the NICMOS spiral dither pattern. The F160W filter (close to the standard near-infrared H band) was used. The OT point-like source is easily visible in all of the data sets.

The photometric calibration of the images was done using the synthetic photometry package SYNPHT in IRAF/STSDAS. For STIS, given the broad-band
response of the instrument, a power-law spectral shape with index $\alpha \nu \simeq 1$ was assumed, based on Keck spectrophotometry and on the photometric colors. This yields for the OT $V = 23.45 \pm 0.15$ (1\sigma) and $R = 23.10 \pm 0.15$. For NICMOS, our calibration gives an OT magnitude of $H = 20.6 \pm 0.3$. The faint galaxies located at North-East (G1, adopting the convention of Djorgovski et al. [7]) and North-West of the OT (hereafter G2) are found to have apparent magnitudes $R = 24.8 \pm 0.2$, $H = 22.8 \pm 0.1$ (G1), and $R = 25.5 \pm 0.2$, $H = 21.9 \pm 0.1$ (G2), respectively.

The R band STIS magnitude lies within the 1\sigma uncertainty of the extrapolation to June 2.5 of the power-law decay fit to earlier data. An R band measurement ($R = 23.4$) taken at Keck after our HST observation (5 June) confirms this trend. However, subsequent photometry suggests a slight flattening of the light curve (see Figure 1). Under the assumption that a power-law correctly reflects the behavior of the OT, the flattening in the temporal descent might be the signature of an underlying component of constant brightness, such as a galaxy. While a fit to the

![FIGURE 1. R band light curve of the OT associated to GRB970508. Photometry is from ground-based telescopes (open circles) and HST-STIS (filled circle). All magnitudes have been converted to Kron-Cousins R. Uncertainties have been rounded up to 0.1 magnitudes when smaller values were reported in the literature, to take into account possible systematic photometric offsets due to instrumental differences. The fit with a power-law plus a constant with $R = 25.4$ is reported (thick solid line) along with the power-law curve of index $-1.24$ (thin solid line) and its 1\sigma uncertainty range (dashed lines).](image-url)
data with a simple power-law yields an index of $-1.14 \pm 0.02$ with a $\chi^2 = 1.6$, a fit with a power-law plus a constant gives a power-law best-fit index of $-1.24 \pm 0.02$, with $\chi^2 = 1.2$. The fitted magnitude of the constant component is $R = 25.4$, with a 90% lower limit of $R = 24.7$.

As visible from Figure 1, at the epoch of the HST observation it would have not been possible to appreciate a deviation of the measured flux from a simple power-law behavior. Consistently, direct inspection and analysis of the HST-STIS image does not reveal any significant residual flux from an extended source underlying the OT either by subtracting the STIS scaled stellar point spread function (PSF) from the image, nor by subtracting a “compact galaxy” PSF, i.e. the convolution of a normal PSF with a Gaussian of intrinsic FWHM = 0.15. This allows us to conclude that any underlying galaxy must be no brighter than $R = 24.5$; if it is an extended object with a scale size greater than a few tenths of an arcsecond, it must be even fainter ($R \sim 25.5$). These limits are consistent with the best fit value derived above.

Similarly, after subtraction of a scaled artificial PSF, the NICMOS image is also consistent with sky noise statistics and we estimate any underlying, extended component must have $H > 22.2$ within 0.4 of the point-like source.

**DISCUSSION**

The detection of Mg I absorption and [O II] emission in the Keck spectra of the OT of GRB970508 implies that the absorbing medium is not highly excited and that active star formation is occurring, respectively. While there are several galaxies with $V > 24.5$ within a few arcseconds of the OT (e.g., G1 and G2), this corresponds to a projected distance of tens of kiloparsecs at $z = 0.8$. It seems unlikely that either the high density or low excitation necessary for the formation of the Mg I line could be maintained this far out in a galactic halo [22]. Therefore, we believe that the absorbing medium responsible for these lines is presently hidden by the light from the OT and is almost certainly the underlying host galaxy.

The apparent magnitude of the constant component derived from the fit to the photometric points, dereddened with $A_R = 0.07$ [7], would correspond, at $z = 0.8$, to an absolute magnitude in the U band of $-17.8$, with a 90% lower limit of $-18.5$, assuming $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, and no $K$-correction. This is consistent with the absolute de-extincted U magnitude of the Large Magellanic Cloud (LMC), $-18$ [23]. If a $K$-correction of half a magnitude is assumed (appropriate for the optical-UV spectrum of the LMC [23]), the absolute magnitude of the putative host galaxy would be $M_U = -17.1$, and the absolute magnitude corresponding to the 90% lower limit would be $-17.8$, still consistent with the luminosity of the LMC, given the uncertainties in the cosmological parameters. Therefore, it is possible that the GRB occurred in a small galaxy of brightness similar to that of the LMC and of comparable size and shape. Strong star formation takes place in Magellanic-like galaxies [24], so that the proposed scenario would be still consistent with the
speculation of Pian et al. [8] about the link of GRBs to star formation.

The OT is located at ~5 arcseconds from the bright galaxies located on the North (G1 and G2). If all three objects are at $z = 0.8$, the GRB host galaxy would be at a few tens of kiloparsecs away from those bright galaxies, and probably be dynamically related to one of them. Indeed, G1 is extremely blue, as reported by Djorgovski et al. [7], and the colors are consistent with a rapidly star-forming galaxy at any reasonable redshift. G2 is somewhat redder, but has the colors of a nearby late-type spiral galaxy whose spectrum has been shifted to $z \sim 0.7 - 0.8$.

In order to confirm or disprove this scenario, further optical and near-infrared imaging of the OT of GRB970508 is necessary, which would extend the sampling of the light curve and possibly directly detect the hiding host galaxy.

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