Summer 6-1-2002

LOTIS, Super-LOTIS, Sloan Digital Sky Survey, and Tautenburg Observations of GRB 010921

H. S. Park
Lawrence Livermore National Laboratory

G. G. Williams
Steward Observatory, University of Arizona

Dieter H. Hartmann
Department of Physics and Astronomy, Clemson University, hdieter@clemson.edu

D. Q. Lamb
Department of Astronomy and Astrophysics, University of Chicago & Enrico Fermi Institute, University of Chicago

B. C. Lee
Experimental Astrophysics Group, Fermi National Accelerator Laboratory

See next page for additional authors

Authors
H. S. Park, G. G. Williams, Dieter H. Hartmann, D. Q. Lamb, B. C. Lee, D. L. Tucker, S. Klose, B. Stecklum, A. Henden, and J. Adelman

The Astrophysical Journal, 571:L131–L135, 2002 June 1

LOTIS, SUPER-LOTIS, SLOAN DIGITAL SKY SURVEY, AND TAUTENBURG OBSERVATIONS OF GRB 010921

H. S. Park,[1] G. G. Williams,[2] D. H. Hartmann,[3] D. Q. Lamb,[4,5] B. C. Lee,[6] D. L. Tucker,[6] S. Klose,[7] B. Stecklum,[7] A. Henden,[8] J. Adelman,[6] S. D. Barthelmy,[9] J. W. Briggs,[10] J. Brinkmann,[11] B. Chen,[12,13] T. Cline,[9] I. Csabai,[12,14] N. Gehrels,[9] M. Harvanek,[11] G. S. Hennessy,[15] K. Hurley,[16] Željko Ivezić,[17] S. Kent,[6] S. J. Kleinman,[11] J. Krzesinski,[11,18] K. Lindsay,[3] D. Long,[11] R. Nemiroff,[19] E. H. Neilsen,[6] A. Nitta,[11] H. J. Newberg,[20] P. R. Newman,[11] D. Perez,[19] W. Periera,[19] D. P. Schneider,[21] S. A. Snedden,[11] C. Stoughton,[6] D. E. Vanden Berk,[6] D. York,[4,5] and K. Ziock[1]

Received 2002 January 1; accepted 2002 April 19; published 2002 May 9

ABSTRACT

We present multi-instrument optical observations of the *High Energy Transient Explorer* (*HETE-2*) and Interplanetary Network error box of GRB 010921. This event was the first gamma-ray burst (GRB) partly localized by *HETE-2* that has resulted in the detection of an optical afterglow. In this Letter, we report the earliest known observations of the GRB 010921 field, taken with the 0.11 m Livermore Optical Transient Imaging System (LOTIS) telescope, and the earliest known detection of the GRB 010921 optical afterglow, using the 0.5 m Sloan Digital Sky Survey Photometric Telescope (SDSS PT). Observations with the LOTIS telescope began during a routine sky patrol 52 minutes after the burst. Observations were made with the SDSS PT, the 0.6 m Super-LOTIS telescope, and the 1.34 m Tautenburg Schmidt telescope 21.3, 21.8, and 37.5 hr, respectively, after the GRB. In addition, the host galaxy was observed with the US Naval Observatory Flagstaff Station 1.0 m telescope 56 days after the burst. We find that at later times ($t > 1$ day after the burst), the optical afterglow exhibited a power-law decline with a slope of $\alpha = 1.75 \pm 0.28$. However, our earliest observations show that this power-law decline cannot have extended to early times ($t < 0.035$ days).

Subject heading: gamma rays: bursts

1. INTRODUCTION

The *High Energy Transient Explorer* (*HETE-2*)[22] is currently the only gamma-ray burst (GRB) detector capable of localizing and disseminating GRB coordinates in near real time. Low-energy emission during and shortly after a GRB ($t \lesssim 1$ hr) potentially holds the key to understanding the central engine of GRBs and could provide clues to their progenitors (Mészáros 2001).

The *HETE-2* detection of GRB 010921 together with data from the Interplanetary Network (IPN) provided the localization that resulted in the detection of an optical afterglow. Although the afterglow was relatively bright, early observations of the error box failed to reveal any candidate afterglows because of source confusion with its bright host galaxy ($R \sim 21.7$; Price et al. 2001). Spectroscopy of the host galaxy performed with the Palomar 200 inch telescope 4 weeks after the burst indicates a redshift of $z = 0.450 \pm 0.005$ (Djorgovski et al. 2001).

2. OBSERVATIONS

2.1. *GRB Observations by HETE-2 and IPN*

On 2001 September 21 at 05:15:50.56 UT (September 21.21934 UT), the French Gamma Telescope instrument detected a bright GRB (Trigger 1761). GRB 010921 had a duration of ∼12 s in the 8–85 keV band, a peak flux of $F_p > 3 \times 10^{-7}$ ergs cm^{-2} s^{-1}, and a fluence of $S \sim 1 \times 10^{-6}$ ergs cm^{-2} (Ricker et

[1] Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550.
[2] Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721.
[3] Department of Physics and Astronomy, Clemson University, 118 Kinard Laboratory, Clemson, SC 29634-0978.
[4] Department of Astronomy and Astrophysics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637.
[5] Enrico Fermi Institute, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637.
[6] Experimental Astrophysics Group, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510.
[7] Thüringer Landessternwarte Tautenburg, Karl-Schwarzschild-Observaorium, Sternwarte 5, 07778 Tautenburg, Germany.
[8] Universities Space Research Association/US Naval Observatory, Flagstaff Station, P.O. Box 1149, Flagstaff, AZ 86002-1149.
[9] NASA Goddard Space Flight Center, Greenbelt, MD 20771.
[10] Yerkes Observatory, University of Chicago, 373 West Geneva Street, Williams Bay, WI 53191.
[11] Apache Point Observatory, P.O. Box 59, Sunspot, NM 88349-0059.
[12] Department of Physics and Astronomy, Johns Hopkins University, 3701 San Martin Drive, Baltimore, MD 21218.
[13] *XMM* Science Operation Center, European Space Agency–Vilspa, Villafranca del Castillo, Apartado 50727-28080 Madrid, Spain.
[14] Department of Physics of Complex Systems, Eötvös University, Pázmány Péter Sétány 1, H-1518 Budapest, Hungary.
[15] US Naval Observatory, 3450 Massachusetts Avenue, NW, Washington, DC 20392-5420.
[16] Space Sciences Laboratory, University of California at Berkeley, 601 Campbell Hall, Berkeley, CA 94720.
[17] Princeton University Observatory, Peyton Hall, Princeton, NJ 08544-1001.
[18] Mount Suhora Observatory, Cracow Pedagogical University, ul. Podchorazych 2, 30-084 Cracow, Poland.
[19] Department of Physics, Michigan Technological University, 1400 Townsend Drive, Houghton, MI 49931.
[20] Department of Physics, Rensselaer Polytechnic Institute, SC1C25, Troy, NY 12180.
[21] Department of Astronomy and Astrophysics, Pennsylvania State University, 525 Davey Laboratory, University Park, PA 16802.
[22] See http://space.mit.edu/HETE.

al. 2001). For a spatially flat FRW cosmology ($\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 65$ km s^{-1} Mpc^{-1}), the measured redshift implies an equivalent isotropic energy release of 6×10^{50} ergs. We compare this energy with the standard energy reservoir, $E_0 \sim 5 \times 10^{50}$ ergs, suggested by Frail et al. (2001) in the 20–2000 keV range by multiplying by the flux ratio $F_{20\text{–}2000\,\mathrm{keV}}/F_{8\text{–}20\,\mathrm{keV}}$ of 3–10, estimated utilizing average values of $\alpha = -1$, $\beta = -2.2$, and $E_{\mathrm{peak}} = 220$ keV for the Band function (Preece et al. 2000). Thus, the inferred energy of (3–10) $\times 6 \times 10^{50}$ ergs is consistent with a standard gamma-ray jet with modest opening angle (Ricker et al. 2001, 2002; Price et al. 2002b).

The burst was also detected in the Wide-field X-ray Monitor (WXM) *X*-detector but was outside the field of view (FOV) of the WXM *Y*-detector. Because the GRB was not well localized in the *Y*-direction, a location was not distributed with the real-time trigger. Approximately 5 hr after the GRB, ground analysis gave a long narrow error box ($\sim$10° $\times$ $\sim$20′) centered at $\alpha, \delta = 23^{\mathrm{h}}2^{\mathrm{m}}14\overset{\mathrm{s}}{.}6$, 44°16′4″.8 (J2000.0; Ricker et al. 2001). *Ulysses* and *BeppoSAX* also detected GRB 010921. These detections resulted ($\sim$15 hr after the burst) in an IPN annulus centered at $\alpha, \delta = 15^{\mathrm{h}}29^{\mathrm{m}}11\overset{\mathrm{s}}{.}8$, 67°36′18″.0 (J2000.0), with radius of 60°.003 ± 0°.156 (3 σ; Hurley et al. 2001). The combined *HETE-2*/IPN data resulted in an error box with area $\sim$310 arcmin^2 with corners at $\alpha_1, \delta_1 = 22^{\mathrm{h}}54^{\mathrm{m}}21\overset{\mathrm{s}}{.}87$, 40°36′25″.84, $\alpha_2, \delta_2 = 22^{\mathrm{h}}54^{\mathrm{m}}52\overset{\mathrm{s}}{.}09$, 40°54′33″.20, $\alpha_3, \delta_3 = 22^{\mathrm{h}}56^{\mathrm{m}}7\overset{\mathrm{s}}{.}16$, 40°45′22″.04, and $\alpha_4, \delta_4 = 22^{\mathrm{h}}56^{\mathrm{m}}37\overset{\mathrm{s}}{.}60$, 41°3′29″.06 (J2000.0).

2.2. *LOTIS Observations*

Although coordinates were not distributed with the real-time *HETE-2* trigger, the f/1.8, 0.11 m Livermore Optical Transient Imaging System (LOTIS) telescope (Park et al. 1998) observed the position of the error box during routine sky patrol on September 21 UT at 21.255 and 21.417 UT, only 52 minutes and 4.75 hr after the GRB. LOTIS consists of four lens/camera systems directed toward a common 8°.8 × 8°.8 FOV. Two of the LOTIS cameras are equipped with clear filters, one with a Cousins *R* filter and one with the Johnson *V* filter. During sky patrol observations, LOTIS obtained 50 s exposures at each position on the sky.

2.3. *SDSS PT Observations*

GRB 010921 was also observed with the Sloan Digital Sky Survey (SDSS; York et al. 2000) Photometric Telescope (PT), located at Apache Point Observatory (Sunspot, New Mexico). The PT is an f/8.8, 0.5 m telescope equipped with $u^*g^*r^*i^*z^*$ filters. The SDSS is designed to be on the $u'g'r'i'z'$ photometric system described in Fukugita et al. (1996), which is an AB$_\nu$ system where flat spectrum objects ($F_\nu \propto \nu^0$) have zero colors. The current photometric calibration of the PT may differ from this system by at most a few percent (Stoughton et al. 2002), and we therefore denote the PT photometric magnitudes by $u^*g^*r^*i^*z^*$. The single SITe 2048 × 2048 CCD camera has a 41′.5 × 41′.5 FOV. On September 22 UT beginning at 22.108 UT (21.33 hr after the GRB), 200 s exposures were taken in each of the $u^*g^*r^*i^*z^*$ filters, and on September 23 UT, beginning at 23.224 UT, 200 and 400 s exposures were taken in each of the same filters (Lamb et al. 2001). Observations on both nights covered the entire GRB 010921 error box.

2.4. *Super-LOTIS Observations*

The center of the IPN error box for GRB 010921 was added to the Super-LOTIS sky patrol table, and observations of the location began shortly after nightfall on September 22.128 UT. Super-LOTIS is an f/3.5, 0.6 m Boller & Chivens telescope located at Kitt Peak (near Tucson, Arizona). Its focal plane array is a Loral 2048 × 2048 CCD camera covering a 51′ × 51′ FOV. The system is fully automated and capable of responding to a real-time GRB trigger within $\sim$30 s. A total of 20 50 s exposures were obtained during the first epoch. Super-LOTIS reobserved the field on September 22 and 23 UT beginning at 22.267, 23.128, and 23.269 UT. Each of these (no filter) observations also consisted of 20 50 s exposures.

2.5. *Tautenburg Observations*

On September 22.781, the Tautenburg Schmidt telescope began observations of the error box in the I_{C} band. This telescope, located at Tautenburg, Germany, is an f/2, 1.34 m aperture telescope equipped with a SITe 2048 × 2048 CCD as the focal plane array. Its FOV is 36′ × 36′. Thirty-eight 120 s exposures were acquired. The same field was reobserved on October 25 with eight 120 s exposures.

2.6. *USNOFS Host Galaxy Observations*

On November 17 UT (56 days after the burst), the US Naval Observatory Flagstaff Station (USNOFS) 1.0 m telescope at Flagstaff, Arizona, observed the GRB 010921 area to determine the brightness of the host galaxy in the R_{C} and I_{C} bands. The USNOFS 1.0 m is an f/7.3 telescope equipped with *UBVRI* filters; its focal plane array is a SITe/Tektronix 2048 × 2048 CCD with a 23′ × 23′ FOV. For these observations, eight 600 s exposures per filter were acquired and co-added.

3. RESULTS

Early observations of the error box of GRB 010921 with large-aperture telescopes found no evidence of an optical afterglow to the limit of the Digital Palomar Observatory Sky Survey plates, $R \sim 20.5$ (Fox et al. 2001; Henden et al. 2001b). However, follow-up observations by Price et al. (2001) resulted in the report of a fading source. The coordinates of this candidate afterglow are $\alpha, \delta = 22^{\mathrm{h}}55^{\mathrm{m}}59\overset{\mathrm{s}}{.}929$, +40°55′52″.83 (J2000.0).

Following the reported detection of an afterglow candidate, we searched our images at its estimated position. In the LOTIS clear and *V*-band images taken 52 minutes after the burst, we found no optical transient (OT) brighter than $m_{\mathrm{clear}} > 15.4 \pm 0.15$ and $V > 15.9 \pm 0.15$. The shutter for the *R*-band camera failed to open. In the second epoch of LOTIS clear and *V*-band images taken on September 21.417 UT (4.75 hr after the burst), we found no OT to the same limiting magnitude. This instrument undersamples the point-spread function (PSF), with most of the flux from a source falling within 2 × 2 pixels. We define object intensity to be the sum over 2 × 2 pixels above the sky background. The statistical error for individual pixels is determined from a larger background area (11 × 11) where we calculate the sky level and the standard deviations of pixel intensities. The systematic error is determined by fitting many reference stars and calculating residuals between the catalog and the calibrated magnitude values. The limits reported here represent the 3 σ level, calculated by propagating individual pixel and sky background errors.

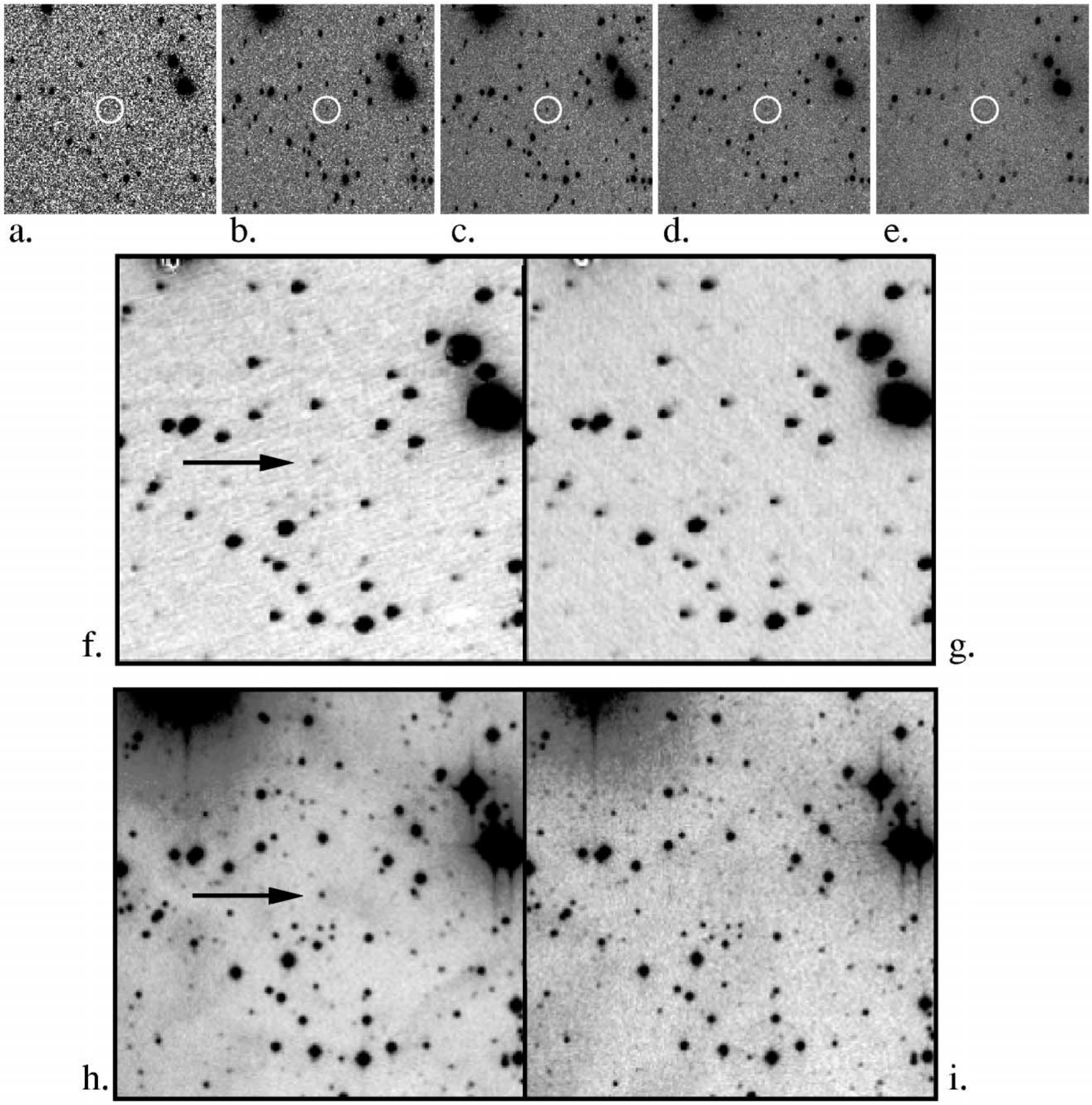

FIG. 1.—*Top panels*: SDSS PT images of the afterglow of GRB 010921 in (*from a to e*) u^*, g^*, r^*, i^*, and z^*, taken on September 22.108 UT. *Middle panels*: Super-LOTIS co-added images in unfiltered light taken on (*f*) September 22.128 UT and (*g*) 22.267 UT. *Bottom panels*: Tautenburg images in *I* taken on (*h*) September 22 UT and (*i*) October 25 UT. In all images, north is toward the top, and east is to the left. The FOV is $4' \times 4'$. The location of the optical afterglow is indicated by circles in the SDSS PT images, and by arrows in the Super-LOTIS and Tautenburg images.

Analysis of the SDSS PT images obtained on September 22 UT reveals the optical afterglow at $g^* = 20.8 \pm 0.6$ (2.3 σ above the sky background), $r^* = 19.5 \pm 0.3$ (5.2 σ above sky), and $i^* = 18.8 \pm 0.7$ (3.3 σ above sky) and gives 3 σ upper limits of $u^* > 20.5$ and $z^* > 15.0$. Analysis of the SDSS PT images obtained on September 23 UT reveals the optical afterglow at $g^* = 22.4 \pm 1.0$ (1.2 σ above sky) and $r^* = 21.5 \pm 1.0$ (1.5 σ above sky), with 3 σ upper limits of $u^* > 19.5$, $i^* > 18.5$, and $z^* > 18.0$. Because of clouds and astigmatism, the SDSS PT PSF is not easy to characterize, and aperture magnitudes were used. The local sky level was sampled in a 51 pixel square box, and aperture magnitudes (counts above the local median sky level) were measured in square apertures of 9, 11, 13, and 15 pixels; the reported magnitude is the median of these apertures. The statistical errors were estimated based on the local sky level and fluctuations. We compared these against both fluctuations in magnitudes across the various apertures and the errors for stars of similar magnitudes as determined by the automated pipeline reductions of the repeatedly observed field. Systematic errors were estimated from the known systematic shifts between SDSS PT and SDSS 2.5 m survey data and from measures of the position of the stellar locus in color space (Stoughton et al. 2002). Figures 1*a*–1*e* show the SDSS PT images in $u^*g^*r^*i^*z^*$ obtained on September 22 UT of the GRB 010921 afterglow area (marked by a circle).

We searched for the OT in the Super-LOTIS data by co-

TABLE 1
Observations of GRB 010921

Date (UT)	ΔT (days)	Telescope	Filter	Exposure Time (s)	Magnitude	R Equivalent Magnitude
Sep 21.219	0.000	*HETE-2*	GRB 010921	...	...	...
Sep 21.255	0.036	LOTIS	Clear	1 × 50	>15.5 ± 0.15	>15.3
Sep 21.255	0.036	LOTIS	*V*	1 × 50	>15.9 ± 0.15	>15.4
Sep 21.417	0.198	LOTIS	Clear	1 × 50	>15.5 ± 0.15	>15.3
Sep 21.255	0.198	LOTIS	*V*	1 × 50	>15.9 ± 0.15	>15.4
Sep 22.108	0.889	SDSS PT	*u**	500	>20.5 ± 0.5	>19.82
Sep 22.112	0.893	SDSS PT	*g**	200	20.8 ± 0.6	19.85
Sep 22.115	0.896	SDSS PT	*r**	200	19.5 ± 0.3	19.44
Sep 22.118	0.899	SDSS PT	*i**	200	18.8 ± 0.7	19.49
Sep 22.121	0.902	SDSS PT	*z**	200	>15.0 ± 0.5	>15.39
Sep 22.128	0.909	Super-LOTIS	Clear	20 × 50	19.4 ± 0.2	19.24
Sep 22.267	1.048	Super-LOTIS	Clear	20 × 50	19.9 ± 0.2	19.54
Sep 22.781	1.562	Tautenburg	I_C	38 × 120	19.32 ± 0.08	20.05
Sep 23.128	1.909	Super-LOTIS	Clear	20 × 50	>21.1 ± 0.3	>20.94
Sep 23.244	2.025	SDSS PT	*u**	500	>19.5 ± 0.5	>18.82
Sep 23.249	2.030	SDSS PT	*g**	400	22.4 ± 1.0	21.45
Sep 23.255	2.036	SDSS PT	*r**	400	21.5 ± 1.0	21.44
Sep 23.260	2.041	SDSS PT	*i**	400	>18.5 ± 0.5	>19.19
Sep 23.266	2.047	SDSS PT	*z**	400	>18.0 ± 0.5	>19.18
Sep 23.269	2.050	Super-LOTIS	Clear	20 × 50	>21.2 ± 0.3	>20.94
Oct 25.770	34.551	Tautenburg	I_C	8 × 120	20.94 ± 0.26	21.67
Nov 17.7	56.700	USNOFS	R_C	8 × 600	21.93 ± 0.09	21.93
Nov 17.7	56.700	USNOFS	I_C	8 × 600	21.05 ± 0.08	21.78

adding 20 images obtained during each epoch, two epochs per night. In the first co-added image, taken on September 22 UT beginning at 22.128 UT, we detect the afterglow at $m_{clear} = 19.4 \pm 0.2$ at 15 σ above noise level. The same analysis applied to the second-epoch data (September 22.267 UT) detects the afterglow at $m_{clear} = 19.9 \pm 0.2$ at 12 σ above the noise level. We applied DAOPHOT PSF fitting photometry to determine brightness values and associated error levels. Figures 1*f* and 1*g* show co-added images with the afterglow indicated by an arrow. We also searched the data set obtained on September 23 UT and find no afterglow to the 3 σ noise limit of $m_{clear} = 21.1 \pm 0.3$. This 3 σ limit is determined after estimating the errors over the aperture used for reference stars.

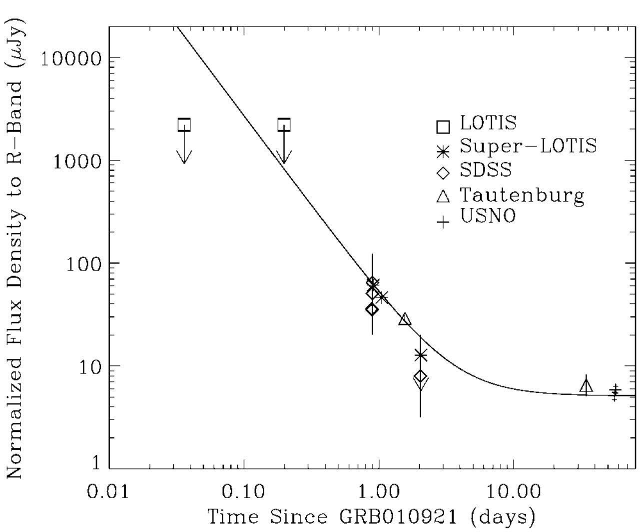

Fig. 2.—Normalized flux density in the *R*-band light curve of the afterglow of GRB 010921, as constrained by the upper limits from the LOTIS telescope, and the measurements from the SDSS PT, the Super-LOTIS, the Tautenburg Schmidt, and the USNOFS telescopes. The fluxes in the different filters have been transformed to the *R* band assuming a power-law spectrum of index $\beta = -2.3$ (Price et al. 2001).

The Tautenburg data taken on September 22 UT and October 25 UT were co-added to search for the afterglow of GRB 010921. Figure 1*h* shows the location of the detected afterglow (*arrow*). Calibrating the afterglow against secondary standards (Henden et al. 2001a), the brightness is estimated as $I_C = 19.32 \pm 0.08$. The host galaxy is detected at the 5 σ level in the second-epoch image (October 25 UT at 25.770) at $I_C = 20.94 \pm 0.26$ (Fig. 1*i*). The errors are calculated by IRAF DAOPHOT, used to analyze these images.

The USNOFS deep-imaging data were analyzed to measure the brightness of the host galaxy, which was clearly visible in the co-added image 56 days after the burst. We determine its brightness to be $R_C = 21.93 \pm 0.09$ and $I_C = 21.05 \pm 0.08$.

4. IMPLICATIONS AND CONCLUSIONS

Table 1 summarizes the magnitudes and upper limits in the various filters from all the above observations. We transformed fluxes measured in various filters to the *R* filter by normalizing a $\beta = -2.3$ power-law spectrum (Price et al. 2001, 2002a). The calculated values are listed in the last column of Table 1. Figure 2 shows the resulting light curve, together with a fit using a power-law decay plus a constant host galaxy flux, $F = F_0(t - t_0)^{-\alpha} + F_{host}$. We obtain a best-fit decay index of $\alpha = 1.75 \pm 0.28$ for a host galaxy magnitude of $R = 21.93$ (from the USNO measurements 56 days after the burst). This is a typical value for an optical afterglow prior to the jet break, which was predicted to take place ~130 days after the GRB based on the observed energetics (Djorgovski et al. 2001) and was observed at ~35 days with the *Hubble Space Telescope* (Price et al. 2002b).

We attempt to constrain the early-time power-law decay by extrapolating the best-fit power-law decay model back to the LOTIS upper limit of $R > 15.0$ on September 21.256. Figure 2 shows that the early-time LOTIS upper limits are inconsistent with an unchanging decay index from $t - t_0 = 52$ minutes to $t - t_0 > 20$ hr. We calculate the flux density and its error at $t - t_0 = 52$ minutes from the fit function and find the LOTIS limit 2.2 σ below the predicted value. This mild inconsistency may suggest that the optical emission peaked at a magnitude fainter than the LOTIS limiting magnitude (perhaps similar to the afterglow of GRB 970508) or that the slope changed between the observations, as suggested in the case of GRB 991208 (Castro-Tirado et al. 2001). Complex light-curve shapes at very early times have been observed (e.g., GRB 970508) and can be explained in terms of a distribution of Lorentz factors produced by the central engine (Rees & Mészáros 1998) and the complex evolution of multicomponent shock emission in a relativistic fireball (Kobayashi 2000).

Our early-time observations suggest that afterglow behavior may change quickly within hours after the burst. With rapid localizations, we can probe the transition from the prompt emission phase to the subsequent unfolding of the canonical afterglow phase. GRB 010921 only provided an upper limit 52 minutes after outburst, but *HETE-2* triggers should eventually allow us to obtain simultaneous flux measurements. Robotic telescopes like LOTIS and Super-LOTIS are well suited to finding this early-time emission in response to a near real-time localization of the GRB by *HETE-2*.

Support for LOTIS and Super-LOTIS is provided by NASA (S-03975G and S-57797F) under the auspices of the US Department of Energy by University of California Lawrence Livermore National Laboratory (W-7405-Eng-48). The SDSS is a joint project of The University of Chicago, Fermilab, the Institute for Advanced Study, the Japan Participation Group, The Johns Hopkins University, the Max-Planck-Institute for Astronomy, the Max-Planck-Institute for Astrophysics, New Mexico State University, Princeton University, USNO, and the University of Washington. Apache Point Observatory, site of the SDSS telescopes, is operated by the Astrophysical Research Consortium. Funding has been provided by the Alfred P. Sloan Foundation, the SDSS member institutions, NASA, the NSF, the US Department of Energy, Monbukogabusho, and the Max Planck Society. K. Hurley is grateful for *Ulysses* support (JPL 958059) and for *HETE* support (MIT-SC-R-293291).

REFERENCES

Castro-Tirado, A. J., et al. 2001, A&A, 370, 398
Djorgovski, S. G., et al. 2001, GCN Circ. 1108 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1108.gcn3)
Fox, D. W., et al. 2001, GCN Circ. 1099 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1099.gcn3)
Frail, D. A., et al. 2001, ApJ, 562, L55
Fukugita, M., Ichikawa, T., Gunn, J. E., Doi, M., Shimasaku, K., & Schneider, D. P. 1996, AJ, 111, 1748
Henden, A., et al. 2001a, GCN Circ. 1100 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1100.gcn3)
———. 2001b, GCN Circ. 1101 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1101.gcn3)
Hurley, K., et al. 2001, GCN Circ. 1097 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1097.gcn3)
Kobayashi, S. 2000, ApJ, 545, 807
Lamb, D. Q., et al. 2001, GCN Circ. 1125 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1125.gcn3)
Mészáros, P. 2001, Science, 291, 79
Park, H., et al. 1998, Proc. SPIE, 3355, 658
Preece, R. D., et al. 2000, ApJS, 126, 19
Price, P. A., et al. 2001, GCN Circ. 1107 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1107.gcn3)
———. 2002a, ApJ, 571, L121
———. 2002b, GCN Circ. 1259 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1259.gcn3)
Rees, M. J., & Mészáros, P. 1998, ApJ, 496, L1
Ricker, G., et al. 2001, GCN Circ. 1096 (http://gcn.gsfc.nasa.gov/gcn/gcn3/1096.gcn3)
———. 2002, ApJ, 571, L127
Stoughton, C., et al. 2002, AJ, in press
York, D. G., et al. 2000, AJ, 120, 1579