Fermilab FERMILAB-Pub-01/338-A November 2001

Draft version November 2, 2001
Preprint typeset using LaTeX style emulateapj v. 25/04/01

SDSS J124602.54+011318.8: A HIGHLY LUMINOUS OPTICAL TRANSIENT AT $Z = 0.385$[1]

Daniel E. Vanden Berk[2], Brian C. Lee[2], Brian C. Wilhite[3], John F. Beacom[2], Donald Q. Lamb[3], James Annis[2], Kevork Abazajian[2], Timothy A. McKay[4], Richard G. Kron[2,3], Stephen Kent[2,3], Kevin Hurley[5], Robert Kehoe[4,6], Jim Wren[7], Arne A. Henden[8,9], Donald G. York[3,10], Donald P. Schneider[11], Jennifer Adelman[2], Jon Brinkmann[12], Robert J. Brunner[13], István Csabai[14,15], Michael Harvanek[12], Greg S. Hennessy[9], Željko Ivezić[16], Atsuko N. Kleinman[12], Scot J. Kleinman[12], Jurek Krzesinski[12,17], Daniel C. Long[12], Eric H. Neilsen[14], Peter R. Newman[12], Stephanie A. Snedden[12], Chris Stoughton[2], Douglas L. Tucker[2], Brian Yanny[2]

Draft version November 2, 2001

ABSTRACT

We report the discovery of a highly luminous optical transient (OT), SDSS J124602.54+011318.8, associated with a galaxy at a redshift of 0.385. Although other explanations cannot be ruled out, the observational evidence suggests that the OT may be a GRB afterglow. Three sets of images and two sets of spectra were obtained as part of the normal operations of the Sloan Digital Sky Survey (SDSS). In the first two image sets, observed two nights apart, the object appears as a point source at $r^* \approx 17$. The third image set, observed about 410 days later, shows an extended source which was more than 2.5 magnitudes fainter. The spectra were observed about 400 and 670 days after the first two image sets, and both show an apparently normal galaxy at a redshift of 0.385. Associating the OT with the galaxy, the absolute magnitude was $M_{r^*} = -23.8$, which is over 4 magnitudes brighter than the most luminous supernova ever measured. The spectral energy distributions of the galaxy-subtracted OT derived from the first two image sets are well-fit by single power-laws with indices of $\beta_\nu = -0.92$ and -1.29 respectively, similar to most GRB afterglows. Based upon the luminosity of the OT, non-detections in contemporaneous ROTSE-I images, and the change in spectral slope, the OT, if an afterglow, was likely discovered early during a "plateau" or slowly-fading phase. The discovery of a GRB afterglow at this stage of the SDSS is consistent with expectations, but only if the optical emission is much less strongly beamed than the gamma-rays.

Subject headings: gamma-rays: bursts – galaxies: active – stars: variables: other

1. INTRODUCTION

All gamma-ray burst (GRB) afterglows discovered to date have been found by follow-up optical or radio imaging of satellite gamma-ray detection localizations. The optical follow-up observations have helped to identify GRB host galaxies, and to determine redshifts, spectral-energy distributions (SED), and decay rates for the optical counterparts. The GRB afterglows observed so far typically exhibit a power-law SED of about $f_\nu \propto \nu^{-1}$, and a luminosity time decay which is also usually well-fit by one or two power-laws with indices of -1.1 to -2.4. The lack of detections of optical GRB afterglows in supernova searches and other variable object surveys has placed constraints on the relative gamma-ray to optical beaming angles, and hence on the GRB rate and energy output (Rhoads 1997).

The Sloan Digital Sky Survey (York et al. 2000, SDSS) was not designed to search for GRB afterglows, or any other transient objects. The explicit use of the camera for such follow-up can only occur under rare favorable conditions (e.g., Lee et al. 2001). However, many classes of highly variable or transient objects have photometric colors which separate them from the locus of main sequence

[1] Based on observations obtained with the Sloan Digital Sky Survey, which is owned and operated by the Astrophysical Research Consortium.

[2] Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510
[3] The University of Chicago, Department of Astronomy and Astrophysics, 5640 S. Ellis Ave., Chicago, IL 60637
[4] University of Michigan, Department of Physics, 500 East University, Ann Arbor, MI 48109
[5] University of California at Berkeley, Space Science Laboratory, Grizzly Peak and Centennial Drive, Berkeley, CA 94720
[6] Michigan State University, Department of Physics and Astronomy, East Lansing, Michigan 48824
[7] Los Alamos National Laboratory, PO Box 1663, Los Alamos, NM 87545
[8] Universities Space Research Association
[9] U.S. Naval Observatory, 3450 Massachusetts Ave., NW, Washington, DC 20392-5420
[10] The University of Chicago, Enrico Fermi Institute, 5640 S. Ellis Ave., Chicago, IL 60637
[11] Department of Astronomy and Astrophysics, The Pennsylvania State University, University Park, PA 16802
[12] Apache Point Observatory, P.O. Box 59, Sunspot, NM 88349-0059
[13] Department of Astronomy, California Institute of Technology, Pasadena, CA 91125
[14] Department of Physics and Astronomy, The Johns Hopkins University, 3701 San Martin Drive, Baltimore, MD 21218
[15] Department of Physics of Complex Systems, Eötvös University, Pázmány Péter sétány 1
[16] Princeton University Observatory, Princeton, NJ 08544
[17] Mt. Suhora Observatory, Cracow Pedagogical University, ul. Podchorazych 2, 30-084 Cracow, Poland

stars in the SDSS color space. Therefore such objects may, in principle, be targeted for spectroscopic follow-up in the SDSS (c.f. Vanden Berk et al. 2001b; Stoughton et al. 2001; Rhoads 2001; Krisciunas, Margon, & Szkody 1998). We show here that at least one object with properties similar to known GRB afterglows has been detected in the SDSS imaging survey, with follow-up observations in the spectroscopic survey. If the object is indeed a GRB afterglow, then it is the first to be found entirely with optical methods.

2. OBSERVATIONS AND SELECTION TECHNIQUES

The SDSS is a project to image 10^4 deg^2 of sky centered roughly on the Northern Galactic Pole, in five broad photometric bands (u, g, r, i, z), to a depth of $r \sim 23$, and to obtain spectra for 10^6 galaxies and 10^5 quasars selected from the imaging survey. The observations are made with a dedicated 2.5 m telescope (Siegmund et al. 2001) equipped with a large mosaic CCD camera (Gunn, et al. 1998) and a pair of fiber-fed spectrographs (Uomoto et al. 2001). Technical details of the survey data acquisition system and reduction are given by York et al. (2000) and Stoughton et al. (2001).

Images are taken nearly simultaneously through 5 filters, *ugriz*, reduced with the SDSS photometric reduction pipeline PHOTO (Lupton et al. 2001), and calibrated in the preliminary SDSS photometric system, $u^*g^*r^*i^*z^*$, which may differ by at most a few percent from that described by Fukugita et al. (1996) (c.f. Stoughton et al. 2001). Three sets of images each containing the coordinates of the optical transient were taken on 1999 March 20, 1999 March 22, and 2000 May 5, denoted by run numbers 745, 756, and 1462 respectively. The magnitudes and coordinates on each of the three nights are given in Table 1. A finder chart and comparison images from each night are shown in Figure 1. The profiles of the object on the first two nights are consistent with the point spread function (PSF) of the images. The object has an r band half-light radius of $0\farcs79$ in the third image set, and is extended relative to the PSF, indicative of a galaxy. The relative astrometric accuracy across runs is $0\farcs07$ in both RA and DEC, and all three coordinates are consistent within this uncertainty.

The OT was selected for spectroscopic follow-up as a quasar candidate based upon color criteria and a FIRST radio source optical match, from the imaging data in run 756. Several types of transient or otherwise variable objects – including cataclysmic variables, supernovae, and GRB afterglows – may be selected by the quasar algorithms, since they occupy some of the same volume of color space in the SDSS filter system as quasars (Vanden Berk et al. 2001b; Rhoads 2001; Krisciunas, Margon, & Szkody 1998). The OT was targeted on the SDSS spectroscopic plate number 291, and spectra were obtained on 2000 April 26 and 2001 January 19. The spectra were reduced and calibrated using the SDSS spectroscopic pipeline (Frieman et al. 2001). The coadded spectrum is shown in Figure 2, and reveals a galaxy at a redshift of $z = 0.385$.

The OT was discovered as part of a program to find supernovae and other highly variable objects in the SDSS dataset, details of which are given by Vanden Berk et al. (2001b). Briefly, the flux-calibrated spectra are convolved with the SDSS g, r, and i filter transmission curves (the u and z bands are not fully covered by the spectra), including 1.2 airmasses of extinction and the CCD response function, to generate synthetic spectroscopic magnitudes. Spectroscopic targets which are significantly fainter in the spectra compared to the images are flagged as variable object candidates. Each candidate's spectrum and corresponding image are examined in order to identify the object type. The optical transient faded by ≈ 2.5 magnitudes in all three bands, and the normal galaxy spectrum made it a candidate supernova or GRB afterglow. The spectroscopic magnitudes are given in Table 1.

3. RESULTS

We have generated spectral energy distributions (SEDs) for the OT in its bright phase by transforming the reddening-corrected (Schlegel, Finkbeiner, & Davis 1998) and galaxy-subtracted magnitudes into flux density values according to the AB_ν system as described by Fukugita et al. (1996). The SEDs of the OT light in runs 745 and 756 are shown in Figure 3. Both SEDs are well-fit by power laws of the form $f_\nu = (\nu/\nu_0)^{\beta_\nu}$, with index values $\beta_\nu = -0.92 \pm 0.01$ (run 745) and -1.29 ± 0.04 (run 756). Both values fall well within the typical range for GRB afterglows ($-2.3 \lesssim \beta_\nu \lesssim -0.7$). If the OT is at the same redshift as the galaxy, $z = 0.385$, and using a flat Λ-dominated cosmology ($\Omega_m = 0.3, \Omega_\Lambda = 0.7, H_0 = 100$ km s^{-1} Mpc^{-1}) the absolute magnitudes of the OT on 1999 March 20 and 22 were $M_{r^*} = -23.81$ and $M_{r^*} = -23.87$ respectively. This is about 5 magnitudes brighter than Type Ia supernovae at maximum (c.f. Vaughan, Branch, Miller, & Perlmutter 1995), and as much as 4 magnitudes brighter than the most luminous supernova ever discovered (SN 1997cy, Germany et al. (2000)). The luminosity and SED rule out the identification of the OT as any known type of supernova.

Before discussing the implications of the GRB afterglow hypothesis, we consider other potential identifications. The OT is unlikely to be within the solar system as Earth reflex motion would cause an offset of greater than $0\farcs3$ (3σ detection) between the g and r image positions for objects out to the Kuiper Belt (Ivezić et al. 2000). The only known types of variable stars that cannot be excluded based upon insufficient variability amplitude or non-matching colors and SEDs are some types of cataclysmic variables. We have examined 22 cataclysmic variables with SDSS photometry (Szkody et al. 2001; Krisciunas, Margon, & Szkody 1998) and find only 2 or 3 which are reasonably consistent with power-law SEDs. The remarkably close coincidence with a galaxy would have to be explained as a random alignment (for example, the probability of a random coordinate falling within $0.5''$ of a galaxy brighter than $r^* = 20.0$ is $\approx 10^{-4}$ (Yasuda et al. 2001)). There is also no evidence for the spectral signature of any type of Galactic variable star, nor any evidence for past variability in archival images (see below). Based upon these arguments, it is unlikely that the OT can be identified with any type of Galactic object.

Aside from GRB afterglows, the only known types of variable objects luminous enough to identify with the OT are quasars and other active galactic nuclei (AGN). The SEDs of AGN can often be approximated by power laws with indices $\beta_\nu \sim -0.5$, and radio emission such as that associated with the galaxy can indicate AGN activity. The radio flux is high for a "normal" galaxy (Magliocchetti et al. 2000), and would indicate a star formation rate of at least several thousand $M_\odot$ per year (Berger, Kulkarni, & Frail 2001). The absence of a far-infrared detection in the IRAS catalogs (Beichman et al. 1988) also implies AGN activity rather than star formation as the source of radio emission (Condon 1992). Therefore the galaxy probably harbors an AGN which is obscured, perhaps entirely, at optical wavelengths. However, the defining optical characteristics of an AGN – a non-stellar spectrum with strong broad emission lines – are not seen in the galaxy spectrum. The galaxy is also undetected in the ROSAT All Sky Survey (Voges et al. 1999), which nearly precludes the identification of the galaxy as a blazar – a class of AGN which have been observed to vary by several magnitudes on timescales of months to years (e.g. Schramm et al. 1994; Webb et al. 1988). In addition, there is no evidence for past variability based upon images extracted from the Digitized Sky Survey[18] of photographic plates observed in 1956, 1979, 1990, and 1991. The coordinates set the location of the OT at 0.5 ± 0.5kpc from the galaxy center, in line with known GRB afterglows (Bloom, Kulkarni, & Djorgovski 2000). We argue, therefore, that although the galaxy may harbor an obscured AGN, the OT was not the result of normal AGN activity.

If the galaxy contains an AGN, an intriguing possibility for the OT is that of a tidally disrupted star near a supermassive black hole (Rees 1988), which may cause a bright relatively short-lived flare. However, estimates of the spectral signature of such events predict either thermal emission from the accretion disk at $\sim 10^5$K (Ulmer 1999), which would be too blue to match the OT, or reprocessing of the radiation by tidal debris at $\sim 10^4$K lasting at least several years (Loeb & Ulmer 1997), which also would not match the observed properties of the OT. In addition, any flare associated with an obscured AGN would still have to overcome the optical obscuration. While we find the evidence for an AGN less consistent than for a GRB afterglow, we cannot completely rule out the possibility that the OT is some kind of extreme AGN. Further observations such as higher signal-to-noise ratio spectra, high resolution radio mapping, and especially long-term optical monitoring (AGN activity may reoccur while an afterglow will not) would place further constraints on either the afterglow or AGN hypothesis.

If the OT is a GRB afterglow, then the properties of its presumed host galaxy are of interest. The absolute magnitude of the galaxy (in run 1462) at $z = 0.385$ is $M_{r^*} = -21.4$ – slightly brighter than an L_* galaxy in the SDSS photometric system (Blanton et al. 2001), and near the median value for GRB host galaxies (Djorgovski et al. 2001). Based upon the possible detection of narrow [O II]λ5007 and Hα emission lines, we estimate the star formation rate to be $SFR \approx 1 \mathrm{M}_\odot\ \mathrm{yr}^{-1}$, (Kennicutt 1998), which is well within the range observed for GRB hosts (Djorgovski et al. 2001). The galaxy is coincident with a radio source detected in the FIRST survey (Becker, White, & Helfand 1995) with integrated flux $S = 79.4$ mJy at 1.4 GHz, and the PMN survey (Griffith, Wright, Burke, & Ekers 1995) with $S = 51$ mJy at 4.9 GHz. We argued above that the radio flux is most likely due to an AGN which is heavily obscured at optical wavelengths. The star formation rate is therefore probably better measured by the emission line flux (which could yield a lower limit due to extinction). Except for the high radio flux, the intrinsic galaxy properties are quite similar to those of GRB afterglow hosts discovered to date.

4. DISCUSSION

We reserve a detailed discussion of the theoretical implications of the OT and GRB hypothesis for a separate paper (Lamb et al. 2001). Here we consider some of the observational consequences. In two nights the spectral slope of the OT changed from -0.92 to -1.29, which is about a 7σ difference. The two slopes and the difference in the slopes do not change significantly when the u band magnitudes, which are the most uncertain, are excluded. The OT faded only modestly, if at all, at the longest wavelengths observed (i.e., in the z band). The modest decline rate can be explained by either a late phase ($t \gg 10$ d) of a power-law flux time decay, or by an early "plateau" or slowly declining phase before the onset of a power-law decay, similar to that of GRB 970508 (Galama et al. 1998; Pedersen et al. 1998) and GRB 000301C (Masetti et al. 2000). ROTSE-I archival images (Kehoe et al. 2001) from 50, 30, 10, and 4 days before and 1, 2, and 3 days after run 745 reveal no source to a limiting magnitude of $r^* \sim 16.0$ (~ 15.0 for 8, 17, and 50 days later), casting doubt on the late phase scenario. The absolute magnitude of the OT is near the average value reached by fading afterglows in only a few days (Šimon, Hudec, Pizzichini, & Masetti 2001). Additionally, a comparable change in spectral slope was observed for the afterglow of GRB 970508 during an early "plateau" phase (Galama et al. 1998). Thus, the OT was likely imaged in the SDSS initially during an early slowly varying stage. Based upon the standard ultrarelativistic external shock model of GRB afterglows, we estimate that the first image may have been taken at about 0.2d after the GRB (Lamb et al. 2001).

The possible detection of a GRB afterglow in the first $\approx 1500\ \mathrm{deg}^2$ of the SDSS favors strong gamma-ray beaming relative to the optical emission. We estimate the number of afterglows that should be seen thus far in the SDSS search by integrating the inferred GRB rate in the cosmological volume (Schmidt 2001) in which an afterglow would be detected, to $z \approx 0.5$, which is the rough spectroscopic limit of L_* galaxies by the SDSS. Using the inferred total GRB progenitor event rate of 250 $\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$ at $z = 0$ (Frail et al. 2001), a GRB rate proportional to the star formation rate, and assuming that GRB afterglows remain visible for about one week, the expected number of bursts observed in the 1500 deg^2 is $\sim 5 f_{\mathrm{opt}}$, where f_{opt} is the fraction of the sky illuminated by the optical emission. Frail et al. find that the beaming fraction of the conical fireball producing the GRB is $f_\gamma \approx 500^{-1}$. If the associated optical display is confined to the same jet, i.e. $f_{\mathrm{opt}} = f_\gamma$, then the number of afterglow events expected in this SDSS volume is $\sim 10^{-2}$. Therefore, the observation of this event favors $f_{\mathrm{opt}} \gg f_\gamma$ (and hence disfavors models such as that of Dalal, Griest, & Pruet (2001)). The only relatively close

[18] The Digitized Sky Survey was produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166.

trigger in the current BATSE archive[19] in the months prior to the SDSS imaging is GRB990308, which was identified with an afterglow more than 12 deg away (Schaefer et al. 1999). There is no related IPN trigger, and the nearest Ulysses trigger is an unlocalized event on 1999 March 16. The lack of any clearly associated GRB is not surprising given the implied beaming fraction, and may suggest that the OT is a so-called "orphan afterglow."

5. CONCLUSIONS

We have discovered an unusual transient object associated with a galaxy at redshift of $z = 0.385$. No known type of object is entirely consistent with the observations. The coincidence with an apparently normal galaxy, extreme variability, power-law SED, and high luminosity are suggestive of a GRB afterglow, although other explanations such as a highly unusual AGN are possible. If the object is indeed an afterglow, then the gamma-rays must be strongly beamed relative to the optical emission. Further observations of the galaxy or the discovery of additional transients with similar properties will help to clarify the nature of this unusual object.

The Sloan Digital Sky Survey (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 (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Princeton University, the United States Naval Observatory, and the University of Washington. Apache Point Observatory, site of the SDSS telescopes, is operated by the Astrophysical Research Consortium (ARC). Funding for the project has been provided by the Alfred P. Sloan Foundation, the SDSS member institutions, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Department of Energy, the Japanese Monbukagakusho, and the Max Planck Society. The SDSS Web site is `http://www.sdss.org/`. We acknowledge useful discussions with Jean Quashnock and Daniel Reichart, and thank the ROTSE team for access to their imaging archive. JFB and KA were supported in part by NASA (NAG5-10842).

REFERENCES

Becker, R. H., White, R. L., & Helfand, D. J. 1995, ApJ, 450, 559
Beichman, C. A., neugebauer, G., Habin, H. J., Clegg, P. E., & Chester, T. J., 1988, IRAS Catalogs and Atlases Explanatory Supplement
Berger, E., Kulkarni, S. R., & Frail, D. A. 2001, ApJ, 560, 652
Blanton, M. R. et al. 2001, AJ, 121, 2358
Bloom, J. S., Kulkarni, S. R., & Djorgovski, S. G. 2000, AJ, submitted (astro-ph/0010176)
Condon, J. J. 1992, ARA&A, 30, 575
Dalal, N., Griest, K., & Pruet, J., ApJ, submitted, (astro-ph/0103436)
Djorgovski, S. G. 2001, in Gamma-Ray Bursts in the Afterglow Era: 2nd Workshop, Proc. ESO Astroph. Symp., ed. N. Masetti et al., (Berlin: Springer Verlag), in press, (astro-ph/0107535)
Fillipenko, A. V. 1997, ARA&A, 35, 309
Frail, D. A., et al., 2001, Nature, **??**, **??**, (astro-ph/0102282)
Frieman, J. A., et al. 2001, in preparation
Fukugita, M., Ichikawa, T., Gunn, J. E., Doi, M., Shimasaku, K., & Schneider, D. P. 1996, AJ, 111, 1748
Galama, T. J. et al. 1998, ApJ, 497, L13
Germany, L. M., Reiss, D. J., Sadler, E. M., Schmidt, B. P., & Stubbs, C. W. 2000, ApJ, 533, 320
Griffith, M. R., Wright, A. E., Burke, B. F., & Ekers, R. D. 1995, ApJS, 97, 347
Gunn, J. E., et al. 1998, AJ, 116, 3040
Ivezić, Ž. et al. 2000, AJ, 120, 963
Kehoe, R., et al. 2001, in Supernovae and Gamma-Ray Bursts: The Greatest Explosions since the Big Bang, ed. M. Livio, N. Panagia, & K. Sahu (Cambridge: Cambridge Univ. Press), 47
Kennicutt, R. C. 1998, ARA&A, 36, 189
Krisciunas, K., Margon, B., & Szkody, P. 1998, PASP, 110, 1342
Lamb, D. Q., et al. 2001, in preparation
Lee, B. C., et al. 2001, ApJ, in press (astro-ph/0104201)
Loeb, A. & Ulmer, A. 1997, ApJ, 489, 573
Lupton, R. H., Gunn, J. E., Ivezić, Ž., Knapp, G. R., Kent, S., & Yasuda, N. 2001, Proc. of ADASS X, in press
Magliocchetti, M., Maddox, S. J., Wall, J. V., Benn, C. R., & Cotter, G. 2000, MNRAS, 318, 1047
Masetti, N. et al. 2000, A&A, 359, L23
Pedersen, H. et al. 1998, ApJ, 496, 311
Rees, M. J. 1988, Nature, 333, 523
Rhoads, J. E. 1997, ApJ, 487, L1
Rhoads, J. E. 2001, ApJ, in press, (astro-ph/0008461)
Schaefer, B. E. et al. 1999, ApJ, 524, L103
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Schmidt, M. 2001, ApJ, 552, 36
Schramm, K.-J., Borgeest, U., Kuehl, D., von Linde, J., Linnert, M. D., & Schramm, T. 1994, A&AS, 106, 349
Siegmund, W., et al. 2001, in preparation
Šimon, V., Hudec, R., Pizzichini, G., & Masetti, N. 2001, A&A, 377, 450
Szkody, P., et al. 2001, in preparation
Stoughton, C., et al. 2001, AJ, accepted
Ulmer, A. 1999, ApJ, 514, 180
Uomoto, A., et al. 2001, in preparation
Vanden Berk, D. E., et al. 2001a, AJ, 122, 549
Vanden Berk, D. E., et al. 2001b, in preparation
Vaughan, T. E., Branch, D., Miller, D. L., & Perlmutter, S. 1995, ApJ, 439, 558
Voges, W. et al. 1999, A&A, 349, 389
Webb, J. R., Smith, A. G., Leacock, R. J., Fitzgibbons, G. L., Gombola, P. P., & Shepherd, D. W. 1988, AJ, 95, 374
Yasuda, N. et al. 2001, AJ, 122, 1104
York, D. G. et al. 2000, AJ, 120, 1579

[19] http://gammaray.msfc.nasa.gov/batse/grb/catalog/current/

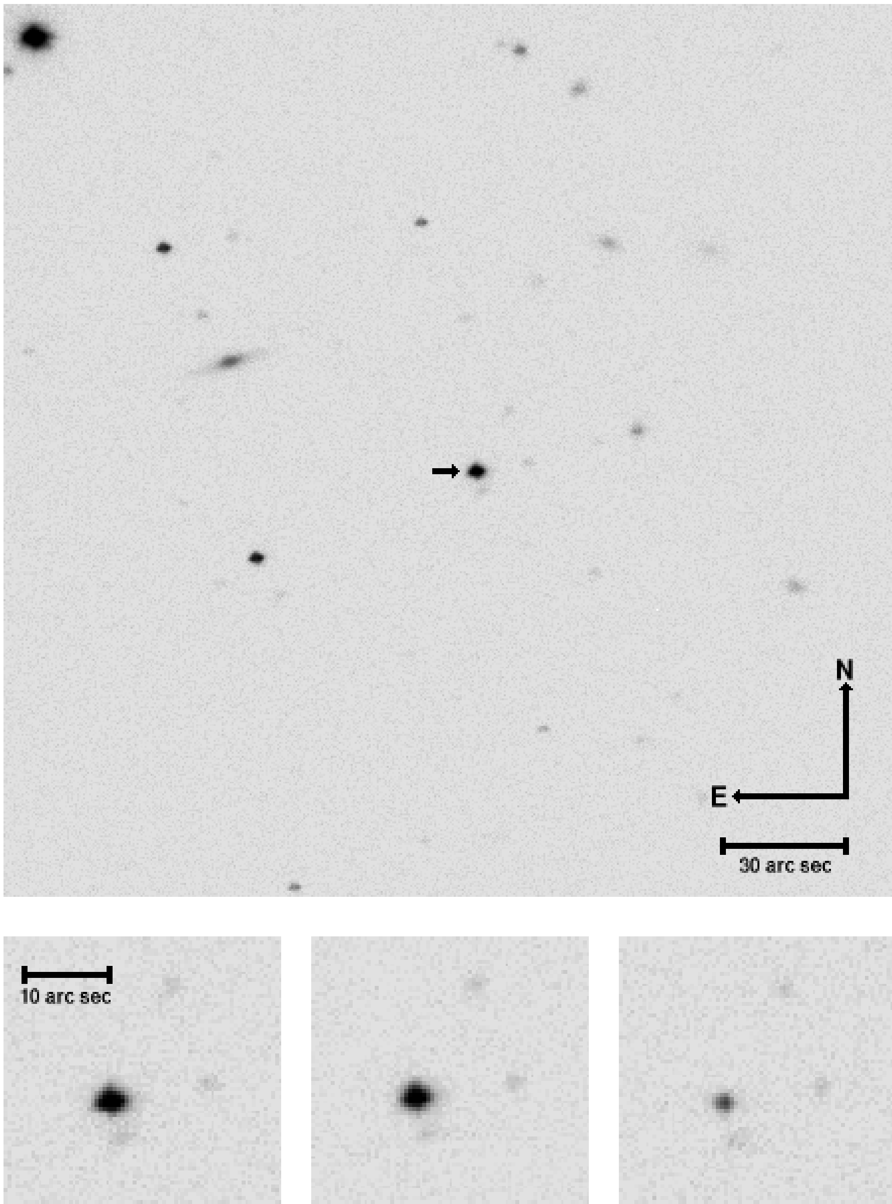

FIG. 1.— Finder chart r band image of a $3' \times 3'$ field containing the optical transient, SDSS J124602.54+011318.8, from run 745. Also shown are three $30'' \times 30''$ r band images from run 745 (1999 March 20), 756 (1999 March 22), and 1462 (2000 May 5) respectively. The first two images match the point spread function, while the third is slightly extended.

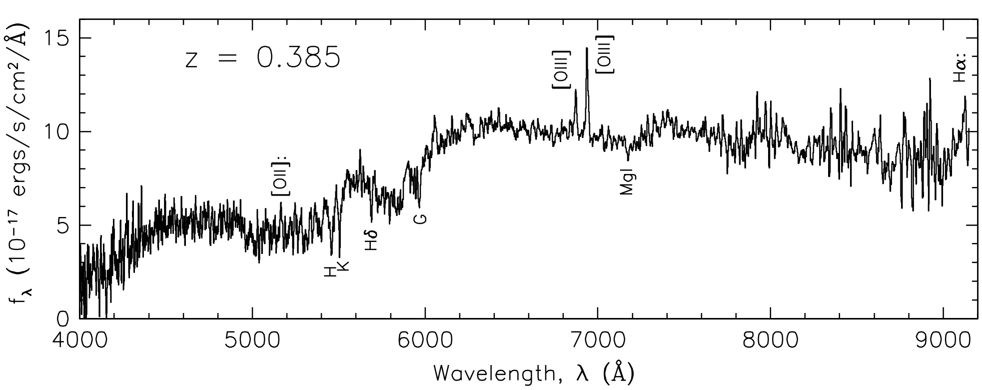

FIG. 2.— Coadded SDSS spectrum of the galaxy at the OT coordinates. The spectrum has been smoothed by 5 bins to improve the signal-to-noise ratio, and truncated below 4000Å to omit the region of highest noise. The smoothed resolution is about 800. Several emission and absorption lines are labeled. The [O II] and H α lines are uncertain.

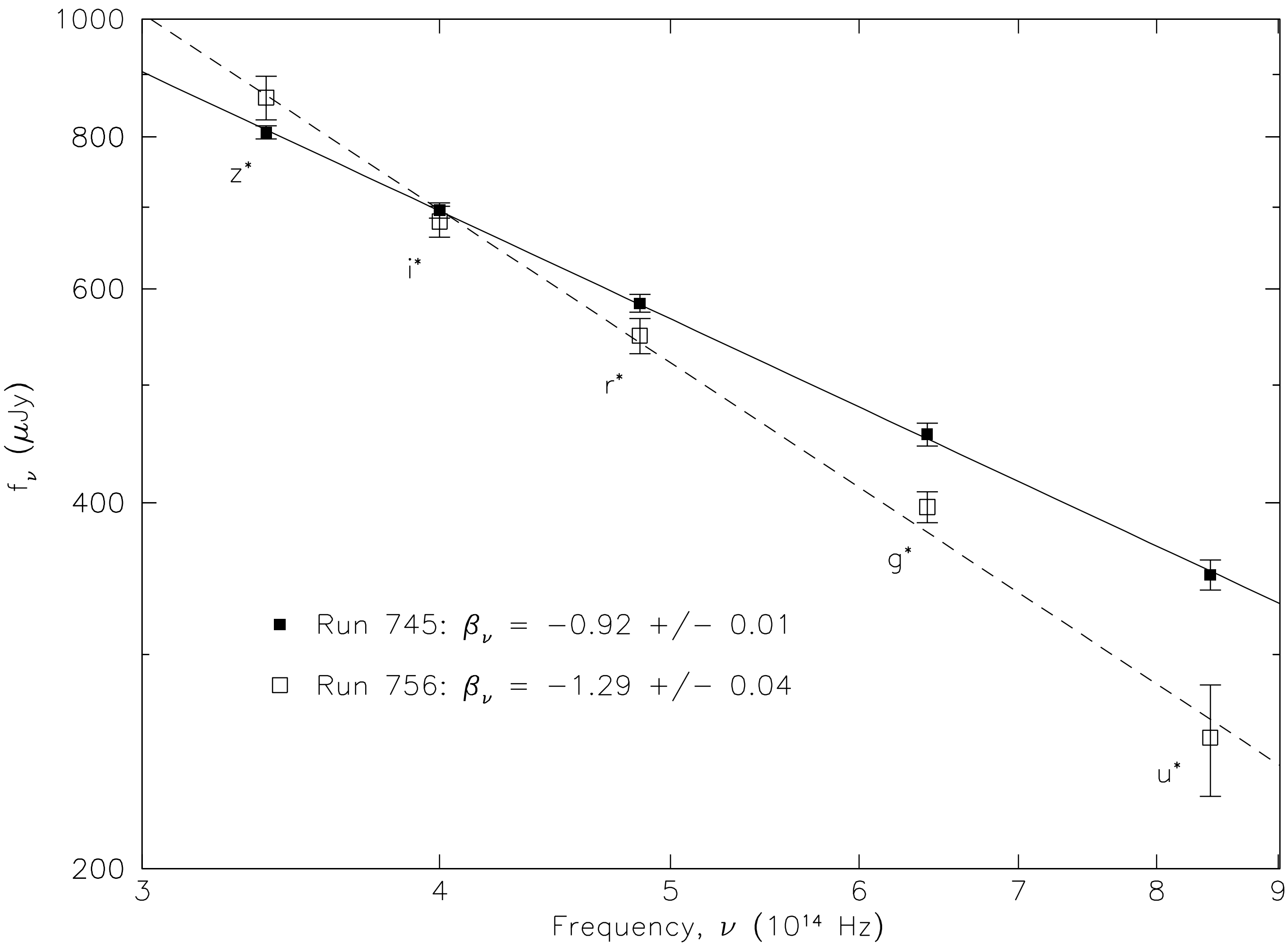

FIG. 3.— Spectral energy distribution of the OT in the observer frame, with the galaxy light removed, and corrected for Galactic reddening, from imaging runs 745 and 756. Power law fits to the SEDs are shown and the indices are given. The errorbars include magnitude uncertainties in both the OT and underlying galaxy.

Table 1

Observations of SDSSp J124602.52+011318.8

Run or Plate	Local Date	MJD	RA Sec. Only	DEC ″ Only	u^*	g^*	r^*	i^*	z^*
					Imaging				
745	1999/03/20	51257.3320	2.539	18.81	17.60 ± 0.01	17.26 ± 0.02	16.92 ± 0.03	16.68 ± 0.02	16.47 ± 0.02
756	1999/03/22	51259.3266	2.539	18.80	17.91 ± 0.03	17.40 ± 0.01	16.98 ± 0.02	16.70 ± 0.01	16.41 ± 0.02
1462	2000/05/05	51669.3173	2.543	18.85	21.11 ± 0.11	20.36 ± 0.03	19.42 ± 0.03	18.88 ± 0.02	18.44 ± 0.04
					Spectroscopy				
291	2000/04/26	51660.26	···	···	···	21.17 ± 0.20	19.76 ± 0.15	19.22 ± 0.18	···
291	2001/01/19	51928.52	···	···	···	20.31 ± 0.37	19.47 ± 0.34	19.08 ± 0.35	···
					Galactic Reddening				
···	···	···	···	···	0.09	0.07	0.05	0.04	0.03