*Astronomy & Astrophysics* manuscript no. aa
June 2, 2012


# An early detection of the optical transient of the GRB 080413A ⋆

Martin Jelínek[1], Sergei Guziy[1], Guðlaugur Jóhannesson[2], Rubén Sánchez Ramírez[1], Javier Gorosabel[1], Alberto J. Castro-Tirado[1], Antonio de Ugarte Postigo[1], Michael Prouza[3], Petr Kubánek[3], Stanislav Vítek[4], Petr Páta[4], Pablo G. Pérez-Gonzalez[5], René Hudec[6], Benito A. de la Morena[7], J.A.Adame[7], J.A.Diaz-Andreu[7], Paul Tristram[8], Akihiko Fukui[9], and Lola Sabau-Graziatti[10]

[1] Instituto de Astrofísica de Andalucía (IAA-CSIC), Apartado de Correos, 3.004, E-18.008 Granada, Spain.
[2] Science Institute, University of Iceland, Dunhaga 5, IS-105 Reykjavik, Iceland
[3] Fyzikální ústav AV ČR, Na Slovance 2, CZ-182 21 Praha 8, Czech Republic
[4] České vysoké učení technické, Fakulta elektrotechnická, Technická 2, 166 28 Praha
[5] Universidad Complutense de Madrid, Avda. de Séneca 2, 28040 Madrid, Spain
[6] Astronomický ústav AV ČR, Fričova 298, CZ-251 65 Ondřejov, Czech Republic
[7] CEDEA INTA, El Arenosillo, Ctra de San Juan del Puerto a Matalascañas km 33, Huelva, Spain
[8] University of Canterbury, Private Bag 4800 Christchurch 8140, New Zealand
[9] Solar-Terrestrial Environment Laboratory, Nagoya University, Nagoya, 464-8601, Japan
[10] Instituto Nacional de Técnica Aeroespacial (INTA), Carretera de Ajalvir, km 4, 28850 Torrejón de Ardoz (Madrid), Spain

Received / Accepted

**ABSTRACT**

We present results of our early follow-up of the bright optical afterglow of the GRB 080413A with the 30 cm telescope BOOTES-1B, together with the later photometry and spectroscopy by various larger telescopes. We found a bright, slowly decaying optical afterglow with magnitude 13.3, fading slowly with a temporal power law decay index of $\alpha_1 = (0.30 \pm 0.16)$. This early decay gradually steepened at ∼ 16 min after the GRB trigger steepened to a fireball-model-typical slope of $\alpha_2 = (1.33 \pm 0.05)$. We fit the afterglow lightcurve as a forward shock afterglow with an energy injection, expanding in the stellar wind density profile. The NOT observation reveal a positionally coincident, bright host galaxy with $r' = 22.8 \pm 0.1$.

**Key words.** Gamma-rays: bursts

## 1. Introduction

After the establishment of the GRB Coordinates Network (GCN) (Barthelmy et al., 1995) in 1995, the technical advances have enabled a fast and reliable dissemination of satellite gamma-ray burst (GRB) data to ground-based observers. Subsequently, wide use of the sophisticated robotic follow-up systems has led to the first insight into the very early phases (less than 5 minutes after trigger) of the optical transients (OTs) accompanying some GRBs. However, despite the extended efforts, optical data at the very early stages are still sparse, so the whole picture remains unclear.

In this letter we present the observation of a bright optical transient associated with GRB 080413A observed by the robotic telescope BOOTES-1B.

## 2. Observations

A bright long-soft GRB 080413A was detected by *Swift* (Gehrels et al., 2004) satellite on friday April 13, 2008, at 2:54:19.3 UT (Marshall et al., 2008). It showed a triple-peak structure with $T_{90}=46 \pm 1$ s with maximum peak flux $48.9 \pm 1.6\,\mathrm{ph\,cm^{-2}s^{-1}}$. Coordinates computed by *Swift* were available within 14 s and immediately distributed by GCN.

The burst was also detected by *Suzaku* Wide-band All-sky Monitor (WAM) (Enoto et al., 2008), allowing for a joint spectral fit of *Swift*/BAT and *Suzaku*/WAM data (Ohno et al., 2008).

At optical wavelengths, a bright, rapidly decaying object was found, and its presence was reported by various teams (Rykoff & Rujopakarn (2008), Beardmore et al. (2008), Klotz et al. (2008)) soon after the discovery.

Two independent groups – Thoene et al. (2008) from the VLT and Cucchiara et al. (2008) from Gemini-South – reported Spectroscopic observation with large telescopes, fixing the GRB redshift at $z = 2.433$.

*Swift* itself observed the GRB position with its optical (UVOT) and an X-ray (XRT) telescopes Evans et al. (2008).

## 3. Follow-up

BOOTES-1B (Jelínek et al. (2010), Castro-Tirado (2011)) did receive the notice at 02:54:33.7 UT, 14.4 s after the trigger and immediately started the slew. The first exposure started at 02:55:20.0, 60.7 s after the GRB. About hundred thirty images with different exposure times were taken during the folowing hour before the GRB become undetectable. The weather conditions during the observation were fine, with the Moon about 7° below horizon at the time of trigger. The GRB location was about 11° (airmass=5.2) above horizon, rising slowly to about

*Send offprint requests to*: Martin Jelínek, e-mail: `mates@iaa.es`

⋆ Based on observations of robotic telescope BOOTES-1B, operated in the Spanish-Czech colaboration at Centro de Experimentacion de El Arenosillo, Huelva, Spain. This work made use of data supplied by the UK Swift Science Data Centre at the University of Leicester.

18° during the first hour after the GRB. Table 1 displays the log of our observations (see also Fig 1), where the magnitude errors do not include systematic error of the USNO-B1.0 R1 magnitude, which should be <0.1 mag.

The celestial coordinates of the optical counterpart of the GRB 080413A, determined from our best resolution 2.5m NOT images are

$$\alpha = 19^{\mathrm{h}}09^{\mathrm{m}}11\overset{\mathrm{s}}{.}76 \quad \delta = -27°40'40\overset{''}{.}6 \quad \pm 0\overset{''}{.}3 \quad (\mathrm{J2000}),$$

about 0.6°E from $\tau$ Sgr. The error amounts to a 1-$\sigma$ uncertainty including systematic errors.

## 4. Data acquisition and reduction

After the reception of the alert, BOOTES-1B automatically obtained a set of 60× 6 s, 48× 20 s and 90× 60 s unfiltered exposures. These exposures were automatically dark-frame and flat-field corrected. To obtain a good signal-to-noise ratio, some of the exposures were combined.

Following the detection by BOOTES, the 2.54 m Nordic Optical Telescope was triggered. Although the weather at La Palma was not perfect (thick cirrus passing), several exposures with a good detection of the OT were obtained. The first 300 s was errorneously obtained in a narrow-band NII filter. Then a 300 s R-band image was obtained. Further, a series of unfiltered

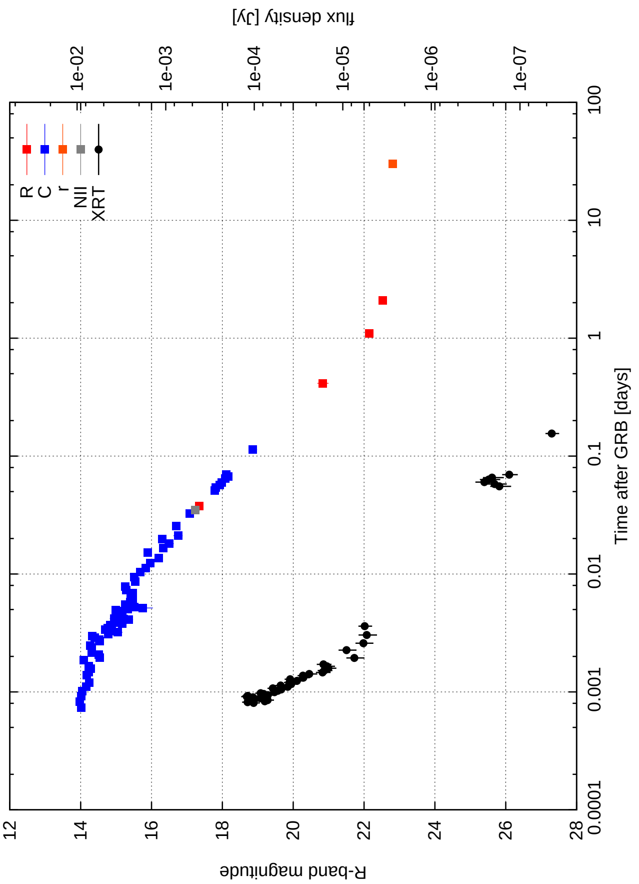


**Fig. 1.** The optical and X-ray lightcurve of the afterglow of GRB 080413A. The lightcurve is fitted as a hyperbolic transition between two power-law decays (Bouguermanns function) - the plateau phase and forward shock.

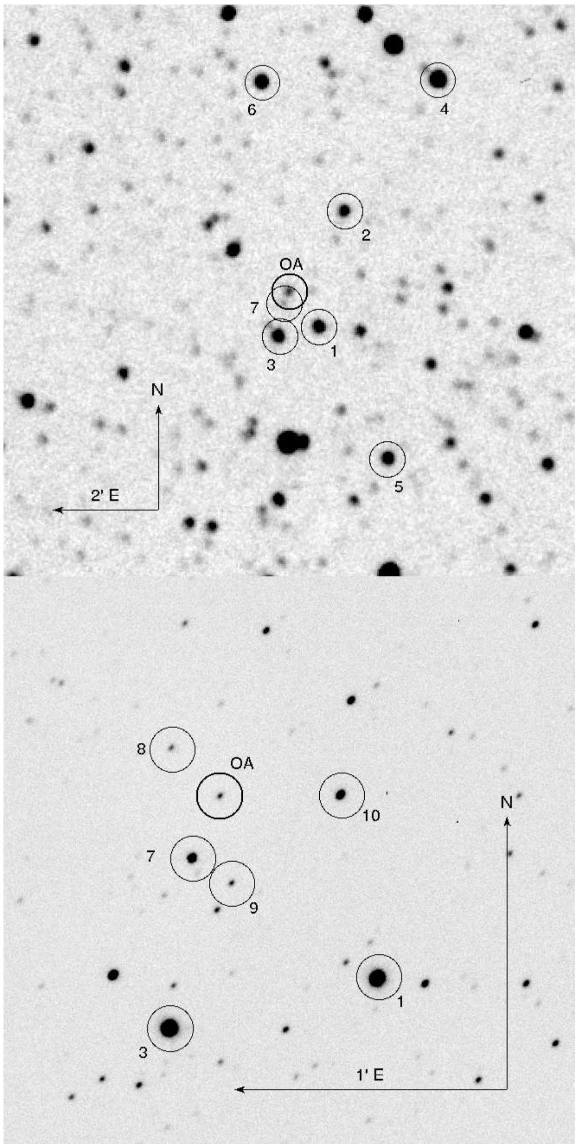


**Fig. 2.** The neighborhood of the optical afterglow of GRB080413A taken by BOOTES-1B 60.7s after the GRB (up) and NOT 1 day after (down). The comparison stars (cf. Table 2) are marked at the latter image.

spectroscopical acquisition images was taken, but but the worsening weather did not allow for a good spectra to be taken. By the end of the night, another series of unfiltered images was obtained. NOT kept observing the position for two following nights. The optical afterglow was further observed by the 0.6 m B&C telecope at Mt. John, New Zeland. One month after the GRB, the position was reimaged and photometrically calibrated with the 2.54 m Isaac Newton Telescope in the r' band.

BOOTES-1B (Jelínek et al., 2010) is a 30 cm rapid-response telescope driven by RTS2 (Kubánek et al., 2004) located at Centro de Experimentacion de El Arenosillo near Huelva, in Spain. It uses an unfiltered EMCCD Andor iXon 887 as a detector. With a plate scale of 2″/*pixel* it has a field of view of ∼ 16′ × 16′.

The raw images were dark-frame subtracted using a median of several dark-frame exposures. Given the significant dark current of the camera, the darks were treated separately for each exposure time. The flat-field correction was then applied using

**Table 1.** Optical unfiltered photometric observations of the optical afterglow of the GRB 080413A.

| UT Date of mid exp. | $T - T_0[s]$ | $T_{\mathrm{exp}}[s]$ | filter | mag | $\delta$ mag | tel. |
|---|---|---|---|---|---|---|
| 2008 Apr 13.121793 | 63.7 | 6 | C | 14.02 | 0.09 | B-1 |
| 2008 Apr 13.121886 | 71.7 | 6 | C | 13.98 | 0.05 | B-1 |
| 2008 Apr 13.121977 | 79.6 | 6 | C | 14.02 | 0.06 | B-1 |
| | | ...some data removed... | | | | |
| 2008 Apr 13.133412 | 1067.6 | 4×20 | C | 15.96 | 0.07 | B-1 |
| 2008 Apr 13.134764 | 1184.4 | 5×20 | C | 16.20 | 0.10 | B-1 |
| 2008 Apr 13.136250 | 1312.8 | 5×20 | C | 15.89 | 0.07 | B-1 |
| 2008 Apr 13.137690 | 1437.2 | 5×20 | C | 16.33 | 0.11 | B-1 |
| 2008 Apr 13.139134 | 1561.9 | 5×20 | C | 16.50 | 0.13 | B-1 |
| 2008 Apr 13.140774 | 1703.6 | 5×20 | C | 16.30 | 0.09 | B-1 |
| 2008 Apr 13.142179 | 1825.0 | 5×20 | C | 16.75 | 0.13 | B-1 |
| 2008 Apr 13.146529 | 2200.9 | 10×60 | C | 16.70 | 0.07 | B-1 |
| 2008 Apr 13.153694 | 2819.9 | 10×60 | C | 17.08 | 0.10 | B-1 |
| 2008 Apr 13.155857 | 3006.8 | 180 | NII | 17.24 | 0.13 | NOT |
| 2008 Apr 13.158959 | 3274.8 | 180 | R | 17.34 | 0.02 | NOT |
| 2008 Apr 13.172279 | 4425.7 | 90 | C | 17.78 | 0.01 | NOT |
| 2008 Apr 13.174941 | 4655.7 | 90 | C | 17.81 | 0.01 | NOT |
| 2008 Apr 13.177962 | 4916.7 | 40 | C | 17.93 | 0.01 | NOT |
| 2008 Apr 13.180533 | 5138.8 | 40 | C | 17.98 | 0.03 | NOT |
| 2008 Apr 13.185452 | 5563.8 | 40 | C | 18.08 | 0.02 | NOT |
| 2008 Apr 13.188367 | 5815.7 | 40 | C | 18.17 | 0.03 | NOT |
| 2008 Apr 13.190763 | 6022.7 | 40 | C | 18.11 | 0.04 | NOT |
| 2008 Apr 13.234727 | 9821.2 | 2x300 | C | 18.86 | 0.12 | NOT |
| 2008 Apr 13.535831 | 35835 | 0 | R | 20.84 | 0.16 | B&C |
| 2008 Apr 14.221936 | 95116 | 5×200 | R | 22.14 | 0.05 | NOT |
| 2008 Apr 15.218093 | 181184 | 5×300 | R | 22.52 | 0.07 | NOT |
| 2008 May 13.121056 | 2592000 | 5×600 | r′ | 22.81 | 0.10 | INT |
| 2011 Aug 29.916324 | $1.06\times10^{8}$ | 13×1200 | U | 23.2 | 0.2 | NOT |

**Table 2.** Secondary calibration standard stars

| Star | mag | Star | mag |
|---|---|---|---|
| 1 | 13.043±0.03 | 6 | 0.xx±0.0x |
| 2 | 13.211±0.03 | 7 | 1.xx±0.0x |
| 3 | 12.866±0.03 | 8 | 1.xx±0.0x |
| 4 | 13.xx±0.0x | 9 | 1.xx±0.0x |
| 5 | 13.xx±0.0x | 10 | 1.xx±0.0x |

the median of 40 normalized 1s exposures obtained while mosaicing through the twilight sky. The psf-fitting photometry was done using the `daophot` routines in IRAF.[1]

Photometric calibration was done by establishing secondary standards in the vicinity of the optical afterglow (see Table 2). Two stars were calibrated in SDSS-r’ band using the AB magnitudes obtained from SDSS DR7 web page. NOT and B&C images were calibrated against these standards, as well. BOOTES-1B unfiltered images needed brighter calibration stars. These were obtained from unfiltered, cloud-affected NOT images. (In any other images these stars were overexposed.)

The ignorance of a difference between r′ and R band filters is expected to cause a constant offset in the measured brightness of the afterglow. However, the size of this offset seems to be small enough and we decided to ignore it.

All images were astrometrically calibrated using the `past` program in the context of JIBARO (de Ugarte Postigo et al., 2005), using all sources with more than 10-$\sigma$ significance from the image compared to USNO-B1.0 (Monet et al., 1998) positions and *R1* magnitudes. `Past` employs a sigma-clipped third-degree polynomial surface fit.

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under co-operative agreement with the National Science Foundation.

## 5. Discussion

### 5.1. The Host Galaxy

By the second day after the GRB detection, the optical lightcurve starts to flatten, and a more careful analysis unveils slight positional offset of the source detected at later times. Careful analysis of the best resolution images reveals its extended nature, making it a candidate to a host galaxy.

The measured brightness of this object is $r' = 22.81 \pm 0.10$ and $U = 23.2 \pm 0.2$. Using two images taken by NOT (one from the first night, and the second 30 days later), we measured the positional offset between the afterlow and the supposed host galaxy as 0.94±0.02".

Applying the chance probabilities of Bloom et al. (2002) that a galaxy not associated with the GRB ($\sigma_{gx}$ ~0.5 %) and of (cite star density study) that any object would be found ($\sigma_{sx}$ ~1.0 %), implies a likelihood of $\sigma$ ~99.0 % that the object is a galaxy related to the GRB. We therefore consider this object the putative host galaxy.

Using (Kobulnicky, 2010) we estimate a distance modulus $D_m = 46.5 \pm 0.2$ for the GRB redshift ($z = 2.433$, $H_0 = 71 \pm 7$, $\Omega_M = 0.27$, $\Omega_\Lambda = 0.73$). For a roughly estimated host galaxy spectral slope of $\alpha = -1.0 \sim -3.0$ we derive a k-correction of $\sim 1.8 \pm 0.6$. Further, the (local) Galactic extinction is $A_r = 0.435$ Schlegel et al. (1998). The redshift of $z$=2.433 thus implies an absolute magnitude -22.3±0.6 for such a host, a brightness corresponding to a large elliptical galaxy, with a projected distance GRB-host 6.9 kpc.

While a large portion of GRB host galaxies are blue sub-luminous star forming objects (Savaglio et.al., 2008), it is not impossible for a large galaxy to be found, especially in case of dark GRBs (Rossi et.al., 2012).

### 5.2. Spectroscopy of the host galaxy

We used Gran Telescopio Canarias equipped with Osiris to obtain a spectra of the host galaxy (see Fig.5.1). The spectra shows a flat continuum without prominent spectral features except a single spectral line which we identify as the Lyman-$\alpha$ line at the redshift of 2.433.

We used the spectral data to estimate the star formation rate of the galaxy, using the prescriptions of Dijkstra & Westra (2010). For the measured intensity of Ly-$\alpha$ line

$$L_{\mathrm{Ly}\alpha} = 1.8 \times 10^{-17} \mathrm{erg\,s^{-1} m^{-2}}$$

we obtain a lower limit (because of the limited Ly-$\alpha$ escape fraction cf. Atek et. al. (2008))

$$\mathrm{SFR}_{\mathrm{Ly}\alpha} > 0.5 M_{\odot} \mathrm{yr}^{-1}.$$

For the estimation based on the ultraviolet continuum flux. (we used the flux estimation in the middle of the region suggested by Kennicutt (1998))

$$L_{\mathrm{UV,1900\AA}} = 1.3 \times 10^{-29} \mathrm{erg\,s^{-1} m^{-2} Hz^{-1}}$$

we get the

$$\mathrm{SFR}_{\mathrm{UV,1900\AA}} = 1.7 M_{\odot} yr^{-1}.$$

### 5.3. First look at the lightcurve

The optical lightcurve has a rather simple layout – there seems to be a plateau, with a smooth transition to a steeper decay. This decay seems to be common with the slope observed in X-rays. During the transition, there is an indication of steps, suggesting weak reenergization of the ejecta.

The X-ray afterglow lightcurve, as mentioned by Marshall et al. (2008) has two phases: an early steep decay, which is supposedly associated with an internal shock emission of the gamma-ray burst itself, and a later, rather more shallow lightcurve of the afterglow emission.

Marshall et al. (2008) also mentions a detection of an X-ray flare at T0+5000s. We examined the data obtained by the 2.5 m Nordic Optical Telescope, by coincidence taken at the same time interval for a possible optical counterpart of such a flare without positive detection. The optical emission follows a smooth power law with no sign of a bump.

### 5.4. Through lightcurve modelling

The optical lightcurve data recorded by BOOTES show, apart of the general transition between two decay phases, two less prominent bumps. We show that they can be modeled as energy injections, following Jóhanesson et al. (2006). Our optical afterglow data is fitted simultaneously together with the X-ray data from *Swift*/XRT. The model only reproduces the afterglow, so the optical points affected by the host galaxy (from the second night on), as well as the flarig-phase X-ray data (i.e. until 176 s) are not used. While modelling, we assumed ???. The fit was performed in both ISM and Wind density profiles, and for different numbers of Injections. The best fit was reached with an initial shock followed by 2 refreshed shocks in the stellar wind profile. Parameters of this best fit are shown in Table 3.

Note that we did not use any color information - all the optical data used were unfiltered. The model, however, repeats well the observed multicolor behaviour measured by (Cobb , 2008).

**Table 3.** The 2-injection, wind profile model parameters. The injection energies $E_1$ and $E_2$ are in units of $E_0$, the initial energy. Other model parameters are: the half opening angle $\theta_0$, the electron density index $p$, the fraction of internal energy stored in electrons after acceleration $\epsilon_i$, the fraction of internal energy stored in the form of magnetic field $\epsilon_B$ and the wind parameter $A_*$.

| Parameter | Value |
|---|---|
| $E_0$ | $0.8 \times 10^{50}$ erg |
| $E_1$ (1.6 min) | 0.5 $E_0$ |
| $E_2$ (8.3 min) | 0.9 $E_0$ |
| $\theta_0$ | 1° |
| $p$ | 1.92 |
| $\epsilon_i$ | 0.002 |
| $\epsilon_B$ | 0.02 |
| $A_*$ | 0.4 |

## 6. Conclusions

An early GRB optical lightcurve observed with an initially shallower (plateau) and a later steeper ($\alpha$ 1.33±0.05) decay. Fits with two energy injections. Profile seems to be a stellar wind. No optical emission related to the X-ray flare detected. In contrast to the majority (cite a general GRB host study), the GRB 080413A seems to have happened in the outskirts of a large spiral or an elliptical galaxy. With a brightness of $r' = 22.8 \pm 0.1$ this object could be suitable for spectroscopy.

*Acknowledgements.* MJ would like to thank to the Spanish Ministry of Education and Science for the support via grants AP2003-1407, ESP2002-04124-C03-01, and AYA2004-01515 (+ FEDER funds). GTC program to obtain the host spectrum. CEDEA-INTA for help with the telescope.

## References

Jelínek, M., Castro-Tirado, A.J., de Ugarte Postigo, A. et al., Adv.Ast. 2010, id.432172
Castro-Tirado A.J., Acta Polytechnica 51/2, 2011
Savaglio, S., Glazebrook, K. & Le Borgne, D., ApJ 691, 182, 2008
Rossi, A.; Klose, S., Ferrero P., arXiv:1202.1434, 2012
Atek, H. et.al., A&A 488, 491-509, 2008
Dijkstra, M. & Westra, E., MNRAS 401, 2343, 2010
Kennicutt, Jr., R. C., ARA&A 36, 189, 1998
Gehrels, N., Chincarini, G., Giommi, P. et al., 2004, ApJ 611, 1005
Beardmore, A.P., Burrows, D.N., Evans, P.A. et al., 2008, GCN Circular 7594
Rykoff, E. S. & Rujopakarn, W., 2008, GCN Circular 7593
Klotz, A., Boer, M. & Atteia J.L., 2008, GCN Circular 7595
Thoene, Ch., Malesani, D., Vreeswijk, P.M. et al., 2008, GCN Circular 7602
Evans, P.A., et al. 2008, GCN Circular 7605
Cobb, B. E., 2008, GCN Circular 7609
Cucchiara, A., Fox, D.B., Cenko, S.B. et al., 2008, GCN Circular 7616
Enoto, T., Nakagawa, Y.E., Tamagawa, T. et al., 2008, GCN Circular 7624

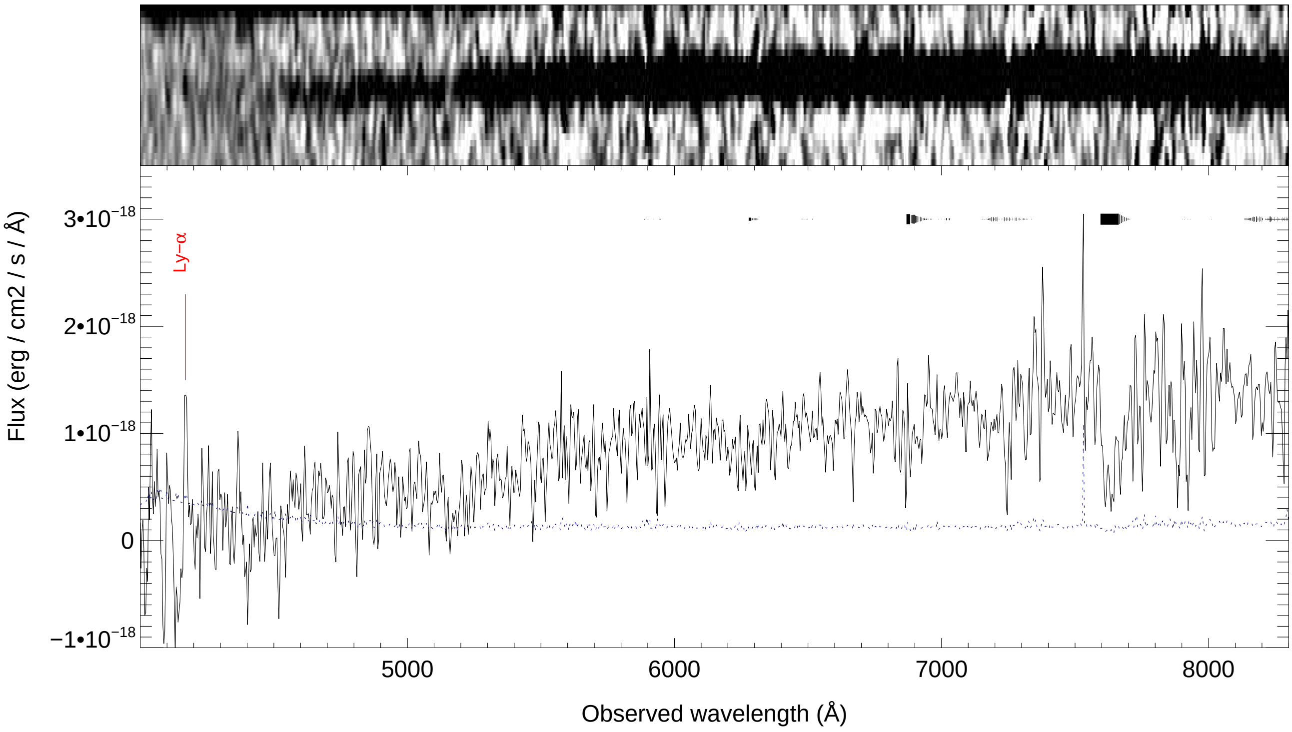


**Fig. 3.** The spectrum of the GRB 080413A host galaxy. Note the Ly-$\alpha$ line on the far ultraviolet (left) side of the spectrum.


Ohno, M., Kokubun, M., Suzuki, M. et al., 2008, GCN Circular 7630

Marshall, F.E., Barthelmy, S.D., Burrows, D.N. et al., 2008, GCN report 129.1

Akerlof, C., Balsano, R., Barthelmy, S., et al. 1999, Nature, 398, 400

Barthelmy, S. D., Butterworth, P., Cline, T. L., et al. 1995, Ap&SS, 231, 235

Björnsson, G., Gudmundsson, E. H., & Jóhannesson, G. 2004, ApJ, 615, L77

Blustin, A., Band, D., Barthelmy, S., et al. 2006, ApJ, 637, 901

Burrows, D. N., Hill, J. E., Nousek, J. A., et al. 2005, Space Science Reviews, 120, 165

Chincarini, G., Moretti, A., Romano, P., et al. 2005, `astro-ph/0506453`, 1

de Ugarte Postigo, A., Jelínek, M., Gorosabel, J., et al. 2005, in Astrofísica Robótica en España, ed. A. Castro-Tirado, B. de la Morena, & J. Torres, Madrid, 35–50

Guidorzi, C., Monfardini, A., Gomboc, A., et al. 2005, ApJ, 630, L121

Kubánek, P., Jelínek, M., Nekola, M., et al. 2004, in AIP Conf. Proc. 727: Gamma-Ray Bursts: 30 Years of Discovery

Lazzati, D., Rossi, E., Covino, S., Ghisellini, G., & Malesani, D. 2002, A&A, 396, L5

Li, W., Filippenko, A. V., Chornock, R., & Jha, S. 2003, ApJ, 586, L9

Monet, D. B. A., Canzian, B., Dahn, C., et al. 1998, VizieR Online Data Catalog, 1252, 0

Piran, T. 1999, Phys. Rep., 314, 575

Rykoff, E., Mangano, V., Yost, S., et al. 2006, ApJ, 638, L5

Sari, R. & Piran, T. 1999, ApJ, 520, 641

Schlegel, D., Finkbeiner, D., & Davis, M. ApJ, 500, 525 (1998)

Jóhanesson, G. et al.(2006), ApJ647, 1238 (2006)

Kobulnicky, Ch.: Online cosmology calculator at `http://faraday.uwyo.edu/ chip/misc/Cosmo2/cosmo.cgi`

Schmidt, B., Wieringa, M., Frail, D. A., & Soderberg, A. 2006, GCN Circular 4546

Shao, L. & Dai, Z. G. 2005, ApJ, 633, 1027

Shen, R., Kumar, P., & Robinson, E. 2005, `astro-ph/0512489`, 1

Terada, Y., Yamaoka, K., Sugita, S., et al. 2006, GCN Circular 4573

Zhang, B., Kobayashi, S., & Mészáros, P. 2003, ApJ, 595, 950