Absorption spectroscopy of GRB160410A: The first complete study of the ISM of a short GRB

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Abstract

Short gamma-ray bursts (GRBs) are the electromagnetic signature produced by the coalescence of two compact objects such as neutron stars. These kind of systems release large amounts of energy in gravitational waves as they coalesce into a single compact object. We present our results of the study of the short GRB 160410A, one of the farthest short GRBs ever detected, at a redshift of z = 1.717. The afterglow emission was observed by the X-shooter spectrograph on VLT at Paranal Observatory starting just ~ 8 min after the GRB.. The fast response to the alert, together with the resolution of X-shooter allowed us to record one of the best, and only, spectra of a short GRB afterglow, and perform the first chemical study of the circumburst medium of a short GRB. We find several low-ionization absorption lines common to long GRBs but the typically strong high-ionization lines are almost absent. The host environment has a large hydrogen column density, compatible with the definition of a Damped Lyman-α Absorption (DLA) region, and our study shows no evidence for dust depletion. We measure a very low metallicity, with [Fe/H] = -2.9 ± 0.3, and a low ionization. Late observations obtained with OSIRIS at the 10.4 m GTC failed to detect an underlying host galaxy down to a limit of r > 27 mag. We also perform an analysis of the light curve and find that it is best described by a double-broken power-law, with the spectral energy distribution showing no evidence for extinction. GRB 160410A has one of the brightest afterglows associated with a short GRB and is one of the hardest short GRBs ever detected.

Burst detection

GRB 160410A was detected by the Burst Alert Telescope (BAT) on-board the *Neil Gehrels Swift Observatory* (Gehrels et al. 2004) on the 10th of April, 2016 at 05:09:48 UT, localised at RA: 10^{h} 02^{m} 44.37^{s}, DEC: +03^{o} 28' 42.7" (GCN 19271, 19275). The burst shows a T_{90} = 8.2 s, way longer than the typical 2 s division (Kouveliotou et al. 1993), however, the ratio between the fluence in the 50 - 100 and 25 - 50 keV bands shows a very hard burst (> 2.0). Recent works classify GRB 160410A as a short burst based in a lower T_{90} = 1.58 s in the observer frame using the Konus/*Wind* detection (Minaev & Pozanenko 2020) and interpreting it as a short GRB with extended emission (Dichiara et al 2021).

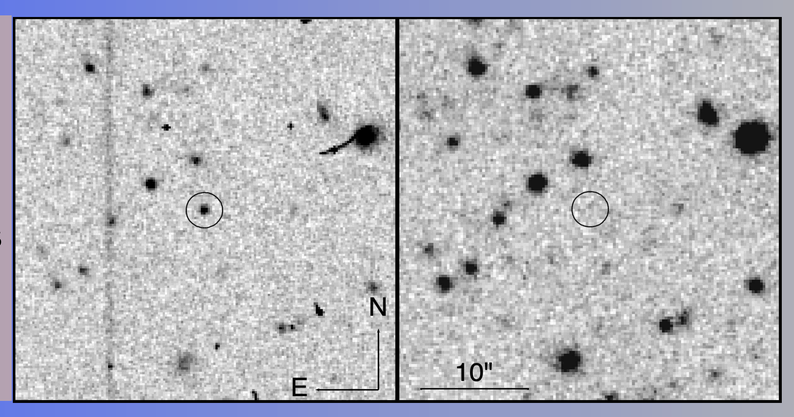


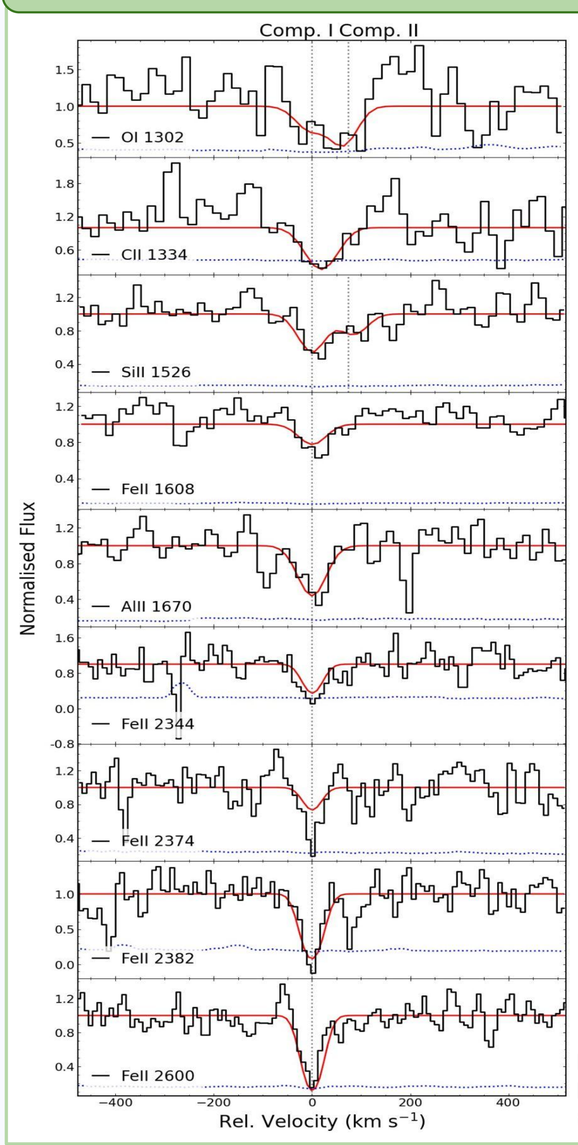
Figure 1. (Left) Finding chart as observed by NOT/ALFOSC. The circles mark the position of the afterglow of GRB 160410A. (Right) Observations with GTC/OSIRIS in *r*-band ~45 days after the burst do not show an underlying galaxy at GRB afterglow location.

Observations

Spectroscopy - GRB 160410A was observed ~ 8 minutes after the BAT alert with the X-shooter spectrograph covering the spectral range between 3000 and 24800 Å. The spectral resolution varies from 54 km s^{-1} to 28 km s^{-1} depending on the spectral region.

Photometry - The afterglow emission was observed with the *Swift*/UVOT (*uvw1*, *u*, *b*, *v* and *white* bands), GROND (*g*', *r*', *i*', *z*', J, H, K) and TAROT, VLT/X-shooter and NOT/ALFOSC in the *r*' band, covering a time span from 28 s after the BAT alert to 1.7 days. Late-time observations were performed with GTC/OSIRIS and *Spitzer*/IRAC to search for an underlying host galaxy.

Results



Absorption lines

- The spectrum of GRB 160410A shows several absorptions of Fe II with a total column density of 13.875 ± 0.061 cm^{-2}.
- We detect none of the typical high-ionization lines found in long GRB environments (neither Si IV nor CIV).
- The column density observed for Ly-α is compatible with DLA system.

Host galaxy environment

- The absorption features are very weak as compared to the lines of sight of long GRBs. We derive a LSP = -1.57 ± 0.87 following de Ugarte Postigo et al. (2012).
- We measure no dust depletion, since $[Zn/Fe]_{exp}$ = 0.0 ± 0.25 following the de Cia et al. (2016) method.
- We find no evidences for an underlying galaxy to a very deep limit, > 27 mag with OSIRIS/GTC in the *r*'-band and m_{ch1}> 24 mag with *Spitzer*/IRAC (both in AB system).
- Following Perley et al. (2016a,b), we derive an upper limit for the stellar mass of the host galaxy of $m \lesssim 1.14 \times 10^{9}\ M_{\odot}$.
- The afterglow light-curve is fitted by a double-broken power-law with no-extinction.
- GRB 160410A is the second brightest short GRB afterglow ever detected at the very early times but remains under-luminous compared to long GRBs afterglows.

Figure 2. Voigt profile fit (red) to the absorption features in the GRB 160410A spectrum. The black line corresponds to the normalized spectrum in velocity space. The dotted blue line is the error spectrum The vertical dotted lines indicate the velocity components for each line.

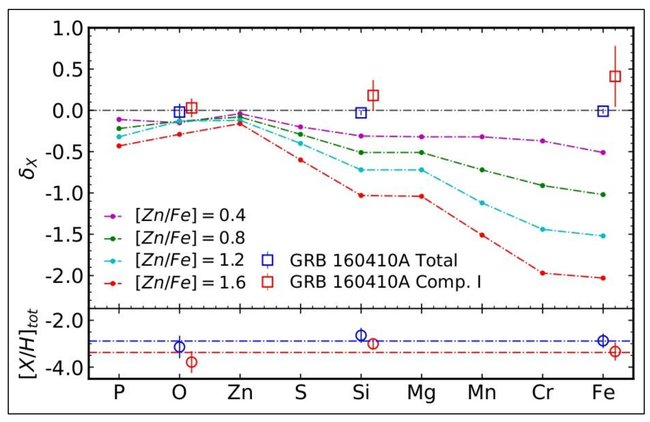


Figure 3. Dust-depletion pattern for the host of GRB 160410A. Red squares are the depletion-corrected values obtained for a single velocity component, blue squares are the depletion considering the total column density. As comparison, we plot the sequences derived by de Cia et al (2016). In the lower panel we show the corresponding metallicities and the mean value with horizontal lines.

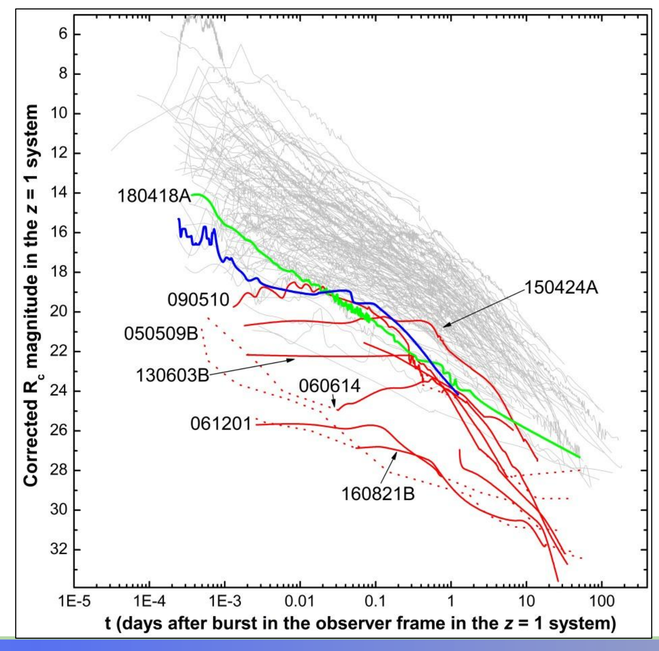


Figure 4. The afterglow of GRB 160410A (thick blue line) in the context of a large sample of GRB afterglows (Kann et al. 2021). Thin grey lines are afterglows of long GRBs. Thicker red lines are a selection of afterglows of other short GRBs. The afterglow of GRB 160410A is one of the brightest short GRBs at early times but subluminous compared to long GRBs.

Conclusions

1. This is the first chemical study of the host environment of a short GRB and one of the few cases in which a spectroscopic absorption redshift has been obtained for a short GRB.
2. The Lyman-α absorption is indicative of a DLA system, being the first case in which this kind of system has been studied with a short burst.
3. The chemical study shows an extremely low metallicity and a very weakly ionized environment, far from what is typically found for long GRBs.
4. The dust depletion in the circumburst area of the burst is zero and the fit of the afterglow photometry shows no extinction along the line-of-sight.
5. The non detection of an underlying host galaxy together with the lack of extinction, the low metallicity and the large Ly-α column density, imply a very faint host galaxy with properties similar to those found in dwarf galaxies.

Acknowledgements

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