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Contents
UVES - VLT High Resolution Spectroscopy of GRB Afterglows

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Abstract. We present early time, high resolution spectroscopy of three GRB afterglows: GRB050730, GRB050922C and GRB060418. These data give us precious information on the kinematics, ionization and metallicity of the interstellar matter of GRB host galaxies up to a redshift $z \sim 4$, and of intervening absorbers along the line of sight.

In particular, we find that the GRB surrounding medium is complex, featuring a clumpy environment in which gas is distributed in regions of space with different distances from the GRB explosion site. The absorption spectra show that elements are present both with high and low ionization states, and even forbidden, fine structure levels are commonly observed. These features allow us to evaluate the physical parameters of the absorbing gas. In details, the density of the gas regions lie in the range $n = 10^6 \div 10^8$ cm$^{-3}$, and the temperatures are of the order of $T = 10^3 \div 10^4$ K.

The metallicity of the GRB host galaxies is computed using the hydrogen absorption features. We find undersolar abundances for our GRBs, namely, $Z_{\odot} \sim 10^{-3} \div 10^{-2}$. However, $Z_{\odot}$ can be underestimated since the H column presents large uncertainties and dust depletion has not been taken into account. The latter effect can be taken into account using as metallicity indicators Zn and Cr, which tend to remain in the gas phase. We find metallicities higher than the previous values and in agreement with other measurements for GRB host galaxies.

Finally, the observed [C/Fe] ratio for GRB050730 ($z \sim 4$) agrees with values expected for a galaxy younger than a Gyr undergoing bursts of star-formation. In addition, the [C/Fe] ratio evaluated component by component can give informations on the relative distances of the components from the GRB explosion site, since Fe dust is more efficiently destroyed than graphite; inversely, if the distance of the shells from the centre were known, we could obtain a powerful tool to investigate the dust depletion in GRB host galaxies.

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INTRODUCTION

Gamma Ray Bursts (GRBs) are one of the great wonders of Universe. They combine several of the hottest topics of 21st century astrophysics. On one side they are privileged laboratories for fundamental physics, including relativistic physics, acceleration processes and radiation mechanisms. On the other side, being GRB associated to the death of massive stars, they can be used as a cosmological tool to investigate star-formation and metal enrichment at the epochs of galaxy birth, formation and growth.

Both purposes can be achieved studying the UV absorption lines of the GRB afterglow spectra. In fact, early time spectroscopy of GRB afterglows can give us precious information on the kinematics, ionization and composition of the gas surrounding the
GRB to put constrains on the GRB progenitor models.

In addition, we can characterize the physical and chemical status of the matter along the line of sight using the GRB as a background beacon for spectroscopy of UV lines. up to a redshift $z \sim 4$. Absorption line spectroscopy is certainly a powerful tool. Spectroscopy of GRBs can be used to study both the galaxy Inter-Stellar-Matter (ISM) and the Inter-Galactic-Matter (IGM) along the line of sight.

High resolution spectroscopy is important for many reasons: 1) absorption lines can be separated into several components belonging to the same system; 2) the metal column densities can be measured through a fit to the line profile for each component; 3) faint lines can be observed.

We focus here on the study of the local, GRB surrounding medium and on the analysis of the absorption lines produced by the gas in the host galaxy throughout observations of three GRBs: GRB050730, GRB050922C and GRB060418.

**OBSERVATIONS**

The GRB050730 afterglow was observed 4.0 hours after the trigger. We find seven main absorption systems at $z=3.968, 3.564, 2.2536, 2.2526, 2.2618, 1.7729$ and $1.7723$

The GRB050922C afterglow was observed 3.5 hours after the trigger. We find four main absorption systems at $z=2.199, 2.077, 2.008$ and $1.9985$.

The GRB060418 afterglow was observed 10 minutes after the trigger. We find four main absorption systems at $z=1.489, 1.106, 0.655$ and $0.602$.

The high resolution spectrum of GRB050730, GRB050922C and GRB060418 are shown in Fig.1. The resolution of all spectra is $R \approx 40,000$ (7.5 km/s in the observer frame). Data sets were reduced using UVES pipeline for MIDAS. All afterglows are clearly detected in the range 3300 - 10000 Å.

**ANALYSIS**

For each absorption system several lines spread over the entire spectral range covered by UVES observations were fitted. The strongest absorption lines are observed in the host galaxy systems. Several components are identified (Fig. 6). The lines were analysed using the line fitting program FITLYMAN, part of the MIDAS data reduction software package. FITLYMAN allows for the simultaneous fitting of multiple absorption systems.

Both high and low ionization lines are detected, but the ratio of their column densities is different for each component. This means that the circumburst gas features have several ionization states (Fig. 5). As observed in previous high resolution spectroscopy of GRB020813 and GRB021004 the circumburst environment showed evidence of a clumpy environment, consisting of multiple shells 1.
FIGURE 1. The spectra of GRB050730, GRB050922C, GRB060418 observed with UVES@VLT.

FINE STRUCTURE LINES

Fine structure lines for CII, OI, FeII and SiII have been identified in all the GRBs. Such lines convey information on the temperature and electron density of the absorbing
medium, provided that they are excited by collisional processes ([2]).

To constrain these parameters we need to estimate the fine structure column densities for two different ions and compare them. For GRB050730, two out of five components show fine structure lines (Fig. 3). Reliable values for temperature and electron density are $T \approx 10^3 \text{ K}$ and $n > 10^4 \text{ cm}^{-3}$ (second component; the components are numbered according to decreasing $z$) and $n \sim 10 \div 100 \text{ cm}^{-3}$ (third component). The other components do not show fine structure features: this is an indication that they refer to a clumpy environment.
Metallicity in GRBs can be measured comparing the column densities of heavy elements to that obtained for hydrogen by fitting the Ly-$\alpha$, $\beta$ and $\gamma$ profiles. Both for GRB050730 and GRB050922C, we find metallicities between $10^{-3}$ and $10^{-2}$ with respect to the solar values.

Since metals tend to form dust, that then does not contribute to the absorption lines, this result is affected by some uncertainties. In GRB060418 we identify CrII and ZnII lines (Fig. 4). Such elements tend to stay in the gas state, minimizing the uncertainty when estimating the metallicity. No H features are present in this GRB spectrum, so we derive the $N_H$ column from the X-ray data, leading to: $Z(\text{Cr}) = -1.8 \pm 0.3$ and $Z(\text{Zn}) = -1.3 \pm 0.2$, a bit higher than for the other two GRBs, but still below the solar values.

Even if Cr and Zn features are not observed in the spectra, a correlation linking FeII and ZnII abundances can be used [4]:

$$\log N_{\text{ZnII}} = (1.47 \pm 0.11) \log N_{\text{FeII}} + (-9.4 \pm 1.7).$$

For GRB050730 we find $Z(\text{Zn}) = -1.5 \pm 0.4$, while for GRB050922c we obtain $Z(\text{Zn}) = -0.2 \pm 0.2$. We show in Fig. 5 how the GRBs analyzed in this paper place in the plot from [4]. Such a plot shows that GRB host galaxies (filled circles) have a higher metallicity than galaxies lying along the line of sight of quasar (open squares). Since the light coming from the quasars tends to preferentially probe the halos of the intervening galaxies for a cross section effect, while the GRB afterglows probe the innermost regions of the hosts. Fig. 5 shows that GRB050730 has a value of $Z$ in agreement with the redshift-metallicity relation, while that of GRB060418 lies beyond the correlation. This
FIGURE 5. The metallicity redshift relation for galaxies lying along the line of sight of quasars (open squares), for GRB host galaxies (filled circles) and for GRB050730, GRB050922C and GRB060418 (filled triangles). The metallicity for GRB hosts has been computed using the Zn spectral features when present, or the FeII/Zn correlation otherwise. The plot is taken from from [4].

could be due to the fact that in the latter case the H column has been computed from the X-ray data, since no optical features were available in the spectrum.

THE [C/FE] RATIO

We can also calculate the ratio [C/Fe], representative of the enrichment of the $\alpha$ elements relative to iron. For GRB050730 we measure a mean [C/Fe]=0.08±0.24, consistent with the value predicted by the models of [5] for a galaxy younger than 1 Gyr subject to a burst of star-formation. In such a case [5] also predict a low [Fe/H] value, close to what we find. Again, we warn that mean abundance estimates may be affected by large systematic uncertainties.

A safer approach is to estimate the [C/Fe] of each component of the main absorption system. For GRB050730, we observe FeII columns only on component 2 and 3 (the same in which fine structure lines are present). We find that [C/Fe] of component 2 is
FIGURE 6. The CIV and FeII absorption features in GRB050730. Note that the CII is roughly constant in component 2 and 3, while the FeII is almost absent in component 3.

-0.15±0.13 while that of component 3 is +0.53±0.23. More specifically, while the total carbon column density of component 2 and 3 are similar, the total column density of iron of component 3 is about four times less than that of component 2 (see Fig. 6). A similar conclusion applies to silicon. The total silicon column density of component 3 is also about 10 times less than that of component 2. Interestingly, [6] found that silicates tend to be destroyed more efficiently than graphite if a dusty medium is exposed to the intense
GRB radiation field. This would leave more iron free in the gas phase in clouds closer to the GRB site than in farther clouds, possibly indicating that component 2 is closer to the GRB site than component 3.

CONCLUSIONS

The absorption spectra of GRB afterglows are extremely complex, featuring several systems at different redshifts. Both high and low ionization lines are observed in the circum-burst environment, but their relative abundances vary from component to component, indicating a clumpy environment consisting of multiple shells. Fine structure lines give information on the temperature and electron density of the absorbing medium, provided that they are excited by collisional effects. Different components have different densities, suggesting a variable density profile. Reliable values for temperature are $T \approx 10^3 \text{ K}$, while density varies from component to component. For GRB050730 we find $n > 10^4 \text{ cm}^{-3}$ in component 2 and $n \sim 10^{-3} \div 100 \text{ cm}^{-3}$ in component 3, respectively. Metallicity can be derived from the metal column densities relative to that of Hydrogen. Values between $10^{-3}$ and $10^{-2}$ with respect to solar are found. However, since metals tend to form dust, that then does not contribute to the absorption lines, this result is affected by some uncertainties. Cr and Zn are the best indicators, since they do not form dust. Even if these indicators are not observed in the spectra, we can compute the column of ZnII using a correlation law that links such a ion with the FeII. Metallicity values above $10^{-2}$ with respect to the solar ones have been found with this method. Finally, the [C/Fe] ratio can give us informations about the galaxy evolution. For GRB050730, whose redshift is $z = 3.967$, we find a value in agreement with that expected for a galaxy younger than 1 Gyr subject to a burst of star-formation. Again, dust depletion may still play an important role. The [C/Fe] ratio evaluated component by component in GRB050730 shows that FeII is less abundant in component 3 than in component 2. This indicates that the gas in the latter is closer to the GRB than that in the former, since iron dust is more efficiently destroyed than graphite.

More details can be found in [3].

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