IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10153-x

A flash in the dark: UVES/VLT high-resolution spectroscopy of GRB afterglows(*)

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(ricevuto il 23 Maggio 2005; pubblicato online il 20 Ottobre 2005)

Summary. — We present the first high-resolution observations of the optical afterglow of a gamma-ray burst. The spectra show that the matter of the host galaxy in the circumburst region is complex, with many components contributing to each system. Also the presence of low- and high-ionisation lines allows rather strong constraints on the gas ionisation parameters of the various components to be derived. These can be interpreted as density fluctuations on top of a regular R^{-2} wind density profile.

PACS `98.70.Rz` – γ-ray sources; γ-ray bursts.
PACS `01.30.Cc` – Conference proceedings.

(*) Paper presented at the "4th Workshop on Gamma-Ray Burst in the Afterglow Era", Rome, October 18-22, 2004.

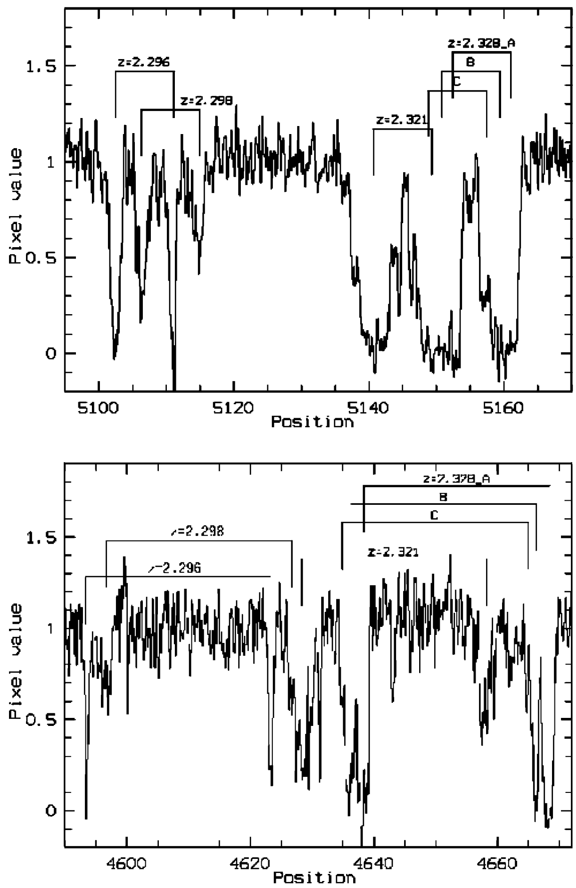

Fig. 1. – The most prominent absorption systems in the afterglow of GRB021004, CIV (top) and SiIV (bottom). Each doublet was observed at 6 redshifts.

1. – A flash in the dark?

For a few hours after their onset, Gamma Ray Bursts (GRBs) are the brightest beacons in the far Universe, offering a superb opportunity to investigate both GRB physics and high redshift galaxies. There is a need for higher resolution spectroscopy for many reasons: i) lines can be separated; ii) the metal column densities can be measured through a fit to the line profile; iii) fainter lines can be measured; iv) information on the gas dynamics in the GRB host galaxies can be derived.

One of the aims of this program is to prepare the groundwork and develop techniques for the advent of the GRB-dedicated Swift mission.

2. – GRB 021004—Observations and data reduction

GRB 021004 was detected on Oct 4 12:06:13.57 UT. UVES observations on VLT commenced 13.52 hours after the trigger. High-resolution ($R = 20000$–45000, corresponding to 14 km s^{-1} at 4200Å and 16 km s^{-1} at 9000Å) spectra of the optical afterglow were obtained.

TABLE I. – *GRB021004 ion column densities.*

System	Velocity ([a])	SiIV	CIV	AlII	AlIII	FeII	MgII
$z = 2.328\_A$	0	15.30 ± 0.35	> 15.5	13.55 ± 0.14	13.54 ± 0.06	13.34 ± 0.10	13.82 ± 0.15
$z = 2.328\_B$	-139	14.27 ± 0.10	> 14.63	12.23 ± 0.15	<12.3	12.53 ± 0.15	12.93 ± 0.41
$z = 2.328\_C$	-224	13.24 ± 0.11	14.40 ± 0.07	< 11.8	<12.3	< 12.1	< 12.6
$z = 2.321$	-632	14.11 ± 0.05	15.04 ± 0.03	< 11.8	< 12.3	< 12.1	< 12.6
$z = 2.298$	-2729	13.43 ± 0.21	14.16 ± 0.13	< 11.8	< 12.3	12.68 ± 0.13	13.22 ± 0.07
$z = 2.296$	-2913	13.79 ± 0.16	14.72 ± 0.25	< 11.8	< 12.3	< 12.2	12.68 ± 0.13

(a) km/s.

Data sets were reduced using the UVES pipeline for MIDAS. The most prominent absorption systems are the CIV and SiIV absorption systems. For each multiplet six corresponding redshift systems were identified, z = 2.296, 2.298, 2.321, 2.328A, 2.328B and 2.328C (see fig. 1).

The lines were analysed using the line fitting program FITLYMAN, which is part of the MIDAS data reduction software package. FITLYMAN allows for the simultaneous fitting of multiple absorption/emission systems. Along with the CIV and SiV systems observed, we also identified AlII, AlIII, FeII and MgII systems.

For each absorption system several lines spread over the entire spectral range covered by the UVES observations were fitted, using the same number of components for each line, and the same redshift and b value for each component. The column densities which were derived are listed in table I.

The detection of both high and low ionisation lines allowed us to obtain constraints on the ionisation status of the circumburst medium, by comparing ion column density ratios with the predictions of the photoionisation code CLOUDY.

3. – Line ratios

Figure 2 shows the logarithmic ratio between the CIV, FeII, AlII and MgII column densities and that of SiIV, for the six absorption systems as a function of the velocity shift with respect to the redshift of the host galaxy. No clear trend of line ratios with velocity is observed.

We compared these line ratios to the predictions obtained by simulating a gas cloud illuminated by an ionising continuum. This was done using CLOUDY. We studied gas densities between 1 cm^{-3} and 10^8 cm^{-3}. The ionising continuum is assumed to be a power law, $F(E) = E^{-\Gamma}$ photons cm^{-2}s^{-1}, with a high-energy cut-off fixed at 10^{21} Hz. The low-energy cut-off was varied from 10^{10}Hz to 10^{14} Hz. Several sets of simulations, computed assuming a constant density profile and plane parallel geometry, were produced with Γ in the range 1–2.

4. – Ionisation parameter constraints

The results obtained with CLOUDY yield an ionisation parameter constrained in a relatively small range, $10^{-1.7} < U < 10^{-1}$. In a single explosion U scales with the square of the outflow velocity; however in a wind environment U is a constant [6, 4].

The relatively small variations in the measured U, which do not show any clear trend with velocity, can therefore be interpreted as density fluctuations on top of a regular R^{-2} wind density profile.

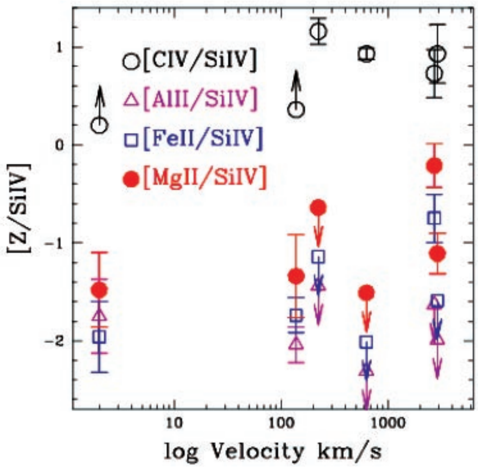

Fig. 2. – Ion ratios for [MgII/SiIV], [FeII/SiIV], [AlII/SiIV] and [CIV/SiIV] against the logarithm of the velocity shift with respect to the host galaxy.

The GRB 021004 absorption systems span 3000 km/s. It seems unlikely that velocities this high are as a result of radiative acceleration by the prompt GRB emission since low ionisation ions such as FeII and MgII are present. The radiative acceleration is dominated by the GRB and early afterglow radiation; the two main contributions to which are photoionisation

$$V_{\mathrm{ion}} \sim (h v_{\mathrm{ion}}/m_{\mathrm{p}})^{1/2} \sim 50 \quad \mathrm{km} \quad \mathrm{s}^{-1}\,, \tag{1}$$

and, once the gas is fully ionized, inverse Compton interactions:

$$V_{\mathrm{IC}} \sim 0.6 R_{18}^{-2} \quad \mathrm{km} \quad \mathrm{s}^{-1}\,. \tag{2}$$

However the minimum distance ahead of the firball the absorption features could be is $R \sim 10^{18}$ cm [2, 1], and therefore the observed velocities are not possible through radiative acceleration.

A possible explanation for the observed absorption characteristics is a high-velocity wind from a progenitor WR star [3, 6, 4]. WR winds are known to be clumped and velocities up to ~ 4000 km s^{-1} have been detected from P-Cygni profiles [5]. This would account for the observed density fluctuations and high velocity of the material.

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