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THE X-SHOOTER GTO SAMPLE OF GRB AFTERGLOW AND HOST GALAXY SPECTRA

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ABSTRACT

Later

Keywords: Gamma-ray burst: individual: GRB 120815A — galaxies: high-redshift — ISM: molecules — dust, extinction

1. INTRODUCTION

2. OBSERVATIONS

Table 1
The full sample of afterglows or hosts observed in the program. We here list the burst names and details of the spectroscopic observations. The exposure times and slit widths are given in the order UVB/VIS/NIR. The column Δt shows the time after trigger when the spectroscopic observation was started. $\mathrm{Mag_{acq}}$ gives the approximate magnitude (typically in the *R*-band) of the afterglow in the acquisition image.

GRB	Exptime (ks)	Slit width (arcsec)	Airmass	Seeing (arcsec)	Δt (hr)	$\mathrm{Mag_{acq}}$	Redshift	Ref
GRB090313[1]	6.9/6.9/6.9	1.0/0.9/0.9	1.2–1.4	1.0	45	21.6	3.3736	(1)
GRB090530[1]	4.8/4.8/4.8	1.0/1.2/1.2	1.6–2.2	1.5	20	22	1.266	(2)
GRB090809[1]	7.2/7.2/7.2	1.0/0.9/0.9	1.2–1.1	0.9	10.2	21	2.737	(2,3)
GRB090926[1]	7.2/7.2/7.2	1.0/0.9/0.9	1.4–1.5	0.9	22	17.9	2.1062	(4)
GRB091018	2.4/2.4/2.4	1.0/0.9/0.9	2.1–1.8	0.8	3.5	19.1	0.9710	(5)
GRB091127	6.0/6.0/6.0	1.0/0.9/0.9	1.1–1.2	1.0	101	21.2	0.490	(6)
GRB100205A	10.8/10.8/10.8	1.0/0.9/0.9	1.9–1.8	1.0	71	–	–	(2)
GRB100219A	4.8/4.8/4.8	1.0/0.9/0.9	1.3–1.1	0.7	12.5	23	4.667	(7)
GRB100316B	2.4/2.4/2.4	1.0/0.9/0.9	2.0–2.4	0.7	0.7	18.2	1.18	(2)
GRB100316D-1[2]	7.2/7.2/7.2	1.0/0.9/0.9	1.2–1.5	1.0	12	–	0.059	(8)
GRB100316D-2	2.4/2.4/2.4	1.0/0.9/0.9	1.2–1.2	1.0	58	–	0.059	(8)
GRB100316D-3	2.4/2.4/2.4	1.0/0.9/0.9	1.2–1.2	0.8	192	–	0.059	(8)
GRB100418A-1	4.8/4.8/4.8	1.0/0.9/0.9	1.6–1.3	0.7	8.4	18.1	0.6235	(9)
GRB100418A-2	4.8/4.8/4.8	1.0/0.9/0.9	1.2–1.3	0.6	34	–	0.6235	(9)
GRB100418A-3	4.8/4.8/4.8	1.0/0.9/0.9	1.2–1.4	0.7	58	–	0.6235	(9)
GRB100424A[3]	4.8/4.8/4.8	1.0/0.9/0.9	1.1–1.2	0.8	–	–	2.465	(2)
GRB100425A	2.4/2.4/2.4	1.0/0.9/0.9	1.5–1.3	0.7	4.0	20.6	1.755	(2,3)
GRB100621A	2.4/2.4/2.4	1.0/0.9/0.9	1.3–1.4	1.0	7.1	–	0.542	(2)
GRB100625A[3]	4.8/4.8/4.8	1.0/0.9/0.9	1.1–1.0	0.8	13	–	0.452	(2)
GRB100724A[4]	4.2/4.2/4.2	1.0/0.9/0.9	1.5–2.3	0.7	0.2	–	1.288	(2)
GRB100728B[5]	7.2/7.2/7.2	1.0/0.9/0.9	1.5–1.1	0.5	22	23	2.106	(2)
GRB100814A-1[4]	0.9/0.9/0.9	1.0/0.9/0.9	1.9–1.7	0.5	0.8	19	1.44	(2)
GRB100814A-2	4.8/4.8/4.8	1.0/0.9/0.9	1.5–1.2	0.6	1.4	19	1.44	(2)

[†] Based on observations collected at the European Southern Observatory, Paranal, Chile, Program ID: 084.A-0260, 085.A-009, 086.A-0073, 087.A-0055.

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Table 1 — *Continued*

GRB	Exptime (ks)	Slit width (arcsec)	Airmass	Seeing (arcsec)	Δt (hr)	$\mathrm{Mag}_{\mathrm{acq}}$	Redshift	Ref
GRB100814A-3	4.8/4.8/4.8	1.0/0.9/0.9	1.2–1.0	0.6	99	20	1.44	(2)
GRB100816A[6]	4.8/4.8/4.8	1.0/0.9/0.9	1.8–1.6	0.8	3.7	–	0.806	(2)
GRB100901A	2.4/2.4/2.4	1.0/0.9/0.9	1.5–1.5	1.8	66	–	1.408	(10)
GRB101219A	7.2/7.2/7.2	1.0/0.9/0.9	1.1–1.7	2.0	3.7	–	0.718	(2)
GRB101219B-1	4.8/4.8/4.8	1.0/0.9/0.9	1.6–2.6	1.3	11.6	20	0.5519	(11)
GRB101219B-2	7.2/7.2/7.2	1.0/0.9/0.9	1.2–2.0	0.8	394	22.7	0.5519	(11)
GRB101219B-3	7.2/7.2/7.2	1.0/0.9/0.9	1.4–2.1	0.9	886	–	0.5519	(11)
GRB110128A	7.2/7.2/7.2	1.0/0.9/0.9	2.0–1.6	0.9	5.5	22.5	2.339	(2)
GRB110407A	9.6/9.6/9.6	1.0/0.9/0.9	1.4–1.3	2.0	12.4	23	–	(2)
GRB110709B[1], 3	7.2/7.2/7.2	1.0/0.9/0.9	1.6–1.1	1.0	–	–	–	(2)
GRB110715A	0.6/0.6/0.6	1.0/0.9/0.9	1.1–1.1	1.7	12.3	18.5	0.82	(2)
GRBGRB110808A	2.4/2.4/2.4	1.0/0.9/0.9	1.2–1.1	1.1	3.0	21.2	1.3488	(2)
GRB110818A	4.8/4.8/4.8	1.0/0.9/0.9	1.3–1.3	1.0	6.2	22.3	3.36	(2)
GRB111005A[3]	1.2/1.2/1.2	1.0/0.9/0.9	1.3–1.3	0.7	–	–	0.013?	(2)
GRB111008A-1	8.8/8.8/8.4	1.0/0.9/0.9	1.1–1.0	1.2	8.5	21?	4.9898	(12)
GRB111008A-2	8.0/8.0/7.2	1.0/0.9/0.9	1.3–1.0	1.0	20.1	22?	4.9898	(12)
GRB111107A	4.8/4.8/4.8	1.0/0.9/0.9	1.8–1.5	0.7	5.3	21.5	2.893	(2)
GRB111117A[6]	4.8/4.8/4.8	1.0/0.9/0.9	1.5–1.4	0.6	38	–	1.3?	(2)
GRB111123A-1	6.2/6.6/6.6	1.0/0.9/0.9	1.6–1.1	1.0	12.2	>24	3.1516	(2)
GRB111123A-2[3]	2.4/2.4/2.4	1.0/0.9/0.9	1.0–1.0	0.5	–	–	3.1516	(2)
GRB111129A	3.6/3.6/3.6	1.0/0.9/0.9	1.6–2.1	1.7			–	(2)
GRB111209A-1	4.8/4.8/4.8	1.0/0.9/0.9	1.1–1.2	0.8	17.7	20.1	0.677	(13)
GRB111209A-2	9.6/9.6/9.6	1.0/0.9/0.9	1.2–2.0	0.8	497	23	0.677	(13)
GRB111211A[1]	2.4/2.4/2.4	1.0/0.9/0.9	1.4–1.6	0.6	31	19.5	0.478	(2)
GRB111228A	2.4/2.4/2.4	1.0/0.9/0.9	1.4–1.4	0.9	15.9	20.1	0.716	(2)
GRB120118B[3]	3.6/3.6/3.6	1.0/0.9/0.9	1.1–1.0	1.0	–	–	2.943	(2)
GRB120119A-1	2.4/2.4/2.4	1.0/0.9/0.9	1.1–1.1	0.6	1.4	17	1.728	(2)
GRB120119A-2	1.2/1.2/1.2	1.0/0.9/0.9	1.8–1.9	0.6	4.5	20	1.728	(2)
GRB120119A-3[3]	4.8/4.8/4.8	1.0/0.9/0.6JH	1.0–1.1	1.1	–	–	1.728	(2)
GRB120211							2.346	(2)
GRB120224A	2.4/2.4/2.4	1.0/0.9/0.9	1.7–2.1	1.4	19.8	22.3	–	(2)
GRB120311A	2.4/2.4/2.4	1.0/0.9/0.9	1.6–1.4	0.6	3.7	21.6	–	(2)
GRB120327A-1	2.4/2.4/2.4	1.0/0.9/0.9	1.6–1.4	0.5	2.1	18.8	2.815	(14)
GRB120327A-2	4.2/4.2/4.2	1.0/0.9/0.9	1.0–1.1	1.0	29	22.5	2.815	(14)
GRB120404A	9.6/9.6/9.6	1.0/0.9/0.9JH	1.7–1.3	1.3	15.7	21.3	2.876	(2)
GRB120422A-1	4.8/4.8/4.8	1.0/0.9/0.9	1.3–1.3	0.6	17.2	22.0	0.283	(15)
GRB120422A-2	4.8/4.8/4.8	1.0/0.9/0.9	1.3–1.4	0.9	113	–	0.283	(15)
GRB120422A-3	4.8/4.8/4.8	1.0/0.9/0.9	1.4–1.7	1.0	210	–	0.283	(15)
GRB120422A-4	4.8/4.8/4.8	1.0/0.9/0.9JH	1.3–1.4	0.6	449	–	0.283	(15)
GRB120422A-5	4.8/4.8/4.8	1.0/0.9/0.9JH	1.3–1.6	0.8	593	–	0.283	(15)
GRB120422A-6	4.8/4.8/4.8	1.0/0.9/0.9JH	1.7–2.4	2.5	882	–	0.283	(15)
GRB120422A-7	4.8/4.8/4.8	1.0/0.9/0.9JH	1.5–1.9	1.3	906	–	0.283	(15)
GRB120712A	4.8/4.8/4.8	1.0/0.9/0.9	1.5–2.5	1.3	10.4	21.5	4.175	(2)
GRB120714B	4.8/4.8/4.8	1.0/0.9/0.9JH	1.5–1.2	1.2	7.8	22.1	0.398	(2)
GRB120716A[1]	3.6/3.6/3.6	1.0/0.9/0.9JH	1.8–2.6	1.0	62	20.9	2.486	(2)
GRB120722A[2]	4.8/4.8/4.8	1.0/0.9/0.9	1.3–1.3	1.1	10.3	23.6	0.959	(2)
GRB120805A[2]	3.6/3.6/3.6	1.0/0.9/0.9JH	1.3–1.7	0.9	218	–	2.8?	(2)
GRB120815A	2.4/2.4/2.4	1.0/0.9/0.9	1.3–1.4	0.6	1.7	20	2.358	(16)
GRB120909A	1.2/1.2/1.2	1.0/0.9/0.9	1.6–1.6	1.4	1.7	21	3.929	(2)
GRB120923A	9.6/9.6/9.6	1.0/0.9/0.9JH	1.2–1.4	1.0	18.5	–	$\gtrsim 8$	(2)
GRB121024A	2.4/2.4/2.4	1.0/0.9/0.9	1.2–1.1	0.6	1.8	20	2.300	(17)
GRB121027A	8.4/8.4/8.4	1.0/0.9/0.9	1.3–1.3	0.9	69	21.1	1.773	(2)
GRB121201A	4.8/4.8/4.8	1.0/0.9/0.9JH	1.1–1.1	0.9	12.9	23	3.385	(2)
GRB121229A	4.8/4.8/4.8	1.0/0.9/0.9JH	1.4–1.2	1.4	2.0	21.5	2.707	(2)
GRB130131B[3]	7.2/7.2/7.2	1.0/0.9/0.9JH	1.3–1.6	0.8	–	–	2.539	(2)
GRB130408A	1.2/1.2/1.2	1.0/0.9/0.9	1.0–1.0	1.0	1.9	20	3.758	(2)
GRB130418A	1.2/1.2/1.2	1.0/0.9/0.9	1.4–1.3	1.3	4.6	18.5	1.218	(2)
GRB130427A	1.2/1.2/1.2	1.0/0.9/0.9JH	1.8–1.8	0.8	16.5	19	0.340	(18)
GRB130427B	1.2/1.2/1.2	1.0/0.9/0.9JH	1.2–1.0	0.8	20.3	22.7	2.78	(2)
GRB130603B[6]	2.4/2.4/2.4	1.0/0.9/0.9	1.4–1.4	1.1	8.2	21.5	0.356	(19)
GRB130606A	4.2/4.2/4.2	1.0/0.9/0.9JH	1.7–1.9	1.1	7.1	19	5.91	(20)
GRB130612A	1.2/1.2/1.2	1.0/0.9/0.9	1.3–1.3	1.4	1.1	21.5	2.006	(2)
GRB130615A	1.2/1.2/1.2	1.0/0.9/0.9	2.1–2.2	1.0	0.8	21	3?	(2)
GRB130701A	1.2/1.2/1.2	1.0/0.9/0.9JH	2.0–2.0	1.6	5.5	19.9	1.155	(2)
Friis et al. (2015)								

References. — (1) de Ugarte Postigo et al. (2010); (2) This work ; (3) Skuladottir (2010); (4) D'Elia et al. (2010); (5) Wiersema et al. (2012); (6) Vergani et al. (2011); Cobb et al. (2010); (7) Thöne et al. (2013); (8) Bufano et al. (2011) ; (9) De Ugarte Postigo et al. (2011) ; (10) Hartoog et al. (2013); (11) Sparre et al. (2011); (12) Sparre et al. (2014); (13) Levan et al. (2014); (14) D'Elia et al. (2014); (15) Schulze et al. (2014); (16) Krühler et al. (2013); (17

[1] Not part of the statistical sample

[2] Spectrum dominated by light from the host galaxy

[3] Spectrum of the host galaxy taken long after the burst

[4] RRM observation

[5] ADC malfunction during observation

3. RESULTS

3.1. *Spectral resolution*

The afterglow spectra described in this paper are obtained in Target-of-Opportunity (override) mode. In most cases there is therefore little possibility to tweak slit widths to the seeing at the time of observations (i.e. to optimise spectral resolution and signal to noise), and almost all our data is therefore taken with a fixed set of slit widths and binning, described above. In a fair number of cases, the seeing full width at half maximum (FWHM) is considerably smaller than the silt width, and the delivered spectral resolution will then be determined by the seeing rather than slit width, as afterglows are point sources (this is evidently not the case for extended sources, e.g for host galaxies). The delivered resolution for slit width dominated spectra post-reduction and extraction can easily be determined from the bright sky emission lines. For afterglow spectra with very high signal to noise, the delivered spectral resolution can at times be determined from the science data themselves. However, in the presence of multiple velocity components in absorption, other forms of line broadening, and a lack of lines at some redshifts, this is difficult to do at poorer signal to noise ratios (the majority of spectra in our sample). A broad starting value for the expect resolution will help fitting of these spectra, and can be important in upper limit determination, and for this reason we construct a aim to construct a crude relation between the seeing and the delivered resolution at our slit width, binning, and reduction pipeline settings. To this end we use observations of telluric standard stars that are taken with identical instrument settings as our afterglow spectra, usually just after the science data, as part of the ESO X-shooter calibration plan. These spectra have been reduced together with the afterglow spectra, using identical pipeline settings with the same version of the pipeline. First we fit a Gaussian function in the spatial direction of the trace of the standard star at 792 nm (i.e. in the VIS arm). After this, we fit a series of 20 telluric absorption lines in the telluric standard star spectra with Gaussians, taking care to select transitions that are not almost-resolved multiples, should be intrinsically unresolved, and are in areas with well defined continuum flux. We pick 34 telluric standard stars spanning a range of DIMM seeing values, with the majority between $0.5-1.5 arcsec$. The resulting distribution of spectral FWHM (km/s) as a function of spatial FWHM at 792 nm is fairly well described by a linear relation $a + b * x$, with x the spatial FWHM in pixels (with 0.15 arc sec per pixel), $a = 21.4 \pm 1.3$ km/s, $b = 1.4 \pm 0.2$. We use this linear relation as a way to estimate the spectral resolution for medium to poor signal to noise afterglow spectra in the VIS arm. To extend this to the UVB and NIR arm, we measured a series of lines in NIR arm spectra of a subset of 19 sources used for the VIS arm above, and find that the resulting distribution is consistent with a simple scaling of the VIS arm relation by the ratio of resolutions of the NIR and VIS arm for unresolved, slit filling, sources as given on the ESO instrument website. The UVB arm contains no suitable absorption lines to use, and we therefore use a scaled value as in the NIR arm. While this simple method is not terribly accurate (for one, the spatial profile of the trace is not a perfect Gaussian), but it gives a sufficiently accurate estimate for the analysis of these poor signal to noise science spectra.

3.2. *Correction for offsets in the wavelength calibration*

X-shooter, being installed at the VLT Cassegrain focusi is prone to flexures during operations. The flexures modify the projection of the slit on the detector with respect to the one obtained in daytime calibration. This require a modification of the wavelength solution in order to process correctly the night-time data. Part of this correction is performed by the pipeline using the frames taken during X-shooter Active Flexure Compensation procedure [22] We corrected the remaining part using as a reference the sky emission lines present in the observed data.

For every afterglow observation we reduced one frame individually in STARE mode without sky subtraction obtaining ~ 100 sky spectra. The sky line list compiled at ESO for the E-ELT study[23] from the work of (Hanuschik, 2003, A&A, 407, 1157) and (Rousselot et al. (2000, A&A, 354, 1134), was used as a reference. From this list, we selected a subset of bright and isolated lines. In the case of the OH doublets, unresolved at X-shooter resolution, we took as line position the average between the blue and red components. To find the offsets of the spectra, we fitted gaussians near the expected positions under IDL using the MPFIT software (Markwardt, 2009, Astronomical Society of the Pacific Conference Series, Vol. 411, ADASS XVII, ed. D.A. Bohlender, D. Durand, & P. Dowler, 251) and we compared the result to the tabulated values. The resulting offsets, which were smaller than 0.1 Å in the UVB and VIS data and smaller than 0.5 Å in the NIR spectra, were applied to the corresponding spectra.

3.3. *Redshifts*

4. DISCUSSION

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APPENDIX

A. NOTES ON INDIVIDUAL OBJECTS

A.1. *GRB090313*

A.2. *GRB120327A (z = 2.813)*

The data presented here also formed the basis of GCN # 13134[24] and is published in D'Elia et al. (2014). The observation consists of two visits, 2.13 hrs and 29.98 hrs after the burst, with an afteglow continuum visible in all arms for both visits. We detect absorption features from Ly-limit, Lyα, C II/C II*, Si II/Si II*, Al I, Fe II and Mg II are detected at a consistent redshift, $z = 2.813$.

A.3. *GRB130408A (z = 3.758)*

The data presented here also formed the basis of GCN # 14365[25]. The spectrum has not otherwise been published previously. The observations consists of two 600sec spectra taken 1.9hr after the burst. We detect absorption features from a wide range of ions. We also detect intervening absorption at $z = 1.255$ and $z = 3.248$.

[24] `http://gcn.gsfc.nasa.gov/gcn3/13134.gcn3`
[25] `http://gcn.gsfc.nasa.gov/gcn3/14365.gcn3`