Highlights of Spanish Astrophysics VII, Proceedings of the X Scientific Meeting of the Spanish Astronomical Society held on July 9 - 13, 2012, in Valencia, Spain. J. C. Guirado, L. M. Lara, V. Quilis, and J. Gorgas (eds.)

The distribution of equivalent widths in GRB spectra

J. Gorosabel[1,7,8], A. de Ugarte Postigo[1,2], J.P.U. Fynbo[2], L. Christensen[2], C.C. Thöne[1], B. Milvang-Jensen[2], S. Schulze[3], P. Jakobsson[3], K. Wiersema[3], R. Sánchez-Ramírez[1], G. Leloudas[2,5], T. Zafar[6], D. Malesani[2], and J. Hjorth[2]

[1] Instituto de Astrofísica de Andalucía (IAA-CSIC), Glorieta de la Astronomía s/n, E-18008, Granada, Spain
[2] Dark Cosmology Centre, Niels Bohr Institute, Juliane Maries Vej 30, Copenhagen Ø, D-2100, Denmark
[3] Centre for Astrophysics and Cosmology, Science Institute, University of Iceland, Dunhagi 5, IS-107 Reykjavik, Iceland
[4] University of Leicester, University Road, Leicester LE1 7RH, UK
[5] The Oskar Klein Centre, Department of Physics, Stockholm University, 106 91 Stockholm, Sweden
[6] Laboratoire d'Astrophysique de Marseille - LAM, Université Aix-Marseille & CNRS, UMR7326, 38 rue F. Joliot-Curie, 13388 Marseille Cedex 13, France
[7] Unidad Asociada Grupo Ciencia Planetarias UPV/EHU-IAA/CSIC, Departamento de Física Aplicada I, E.T.S. Ingeniería, Universidad del País Vasco UPV/EHU, Alameda de Urquijo s/n, E-48013 Bilbao, Spain
[8] Ikerbasque, Basque Foundation for Science, Alameda de Urquijo 36-5, E-48008 Bilbao, Spain

Abstract

Our study is based on 69 low-resolution gamma-ray burst (GRB) afterglow spectra, mostly acquired with the VLT. We describe the distribution of rest-frame equivalent widths (EWs), providing the means to compare individual spectra to the sample and identify its peculiarities. We introduce a *line strength parameter* (LSP) that allows us to quantify the strength of the absorption features in a GRB spectrum as compared to the sample by a single number. We find correlations between the LSP and the extinction of the GRB and the host galaxies absolute magnitudes. However, we see no significant evolution of the LSP with the redshift. Another interesting finding is the fact that spectral features in GRB spectra are, on average, 2.5 times stronger than those seen in QSO intervening damped Lyman-α (DLA) systems. We also note the larger excess in the EW of C IV$\lambda\lambda$1549 relative to QSO DLAs, which could be related to an excess of Wolf-Rayet stars in the environments of GRBs.

1 Introduction

The extreme brightness of γ-ray burst (GRB) afterglows and their simple spectral shape make them ideal beacons to study the interstellar medium of their host galaxies through absorption line spectroscopy at almost any redshift. In fact, GRB afterglows shine, during the first hours, as the most luminous objects that can be detected in the Universe [7, 8]. For this work is essential to note that optical spectra of GRB afterglows are instrinsically clean (usually single power-laws), making them ideal beacons to probe the material in the line of sight of GRBs.

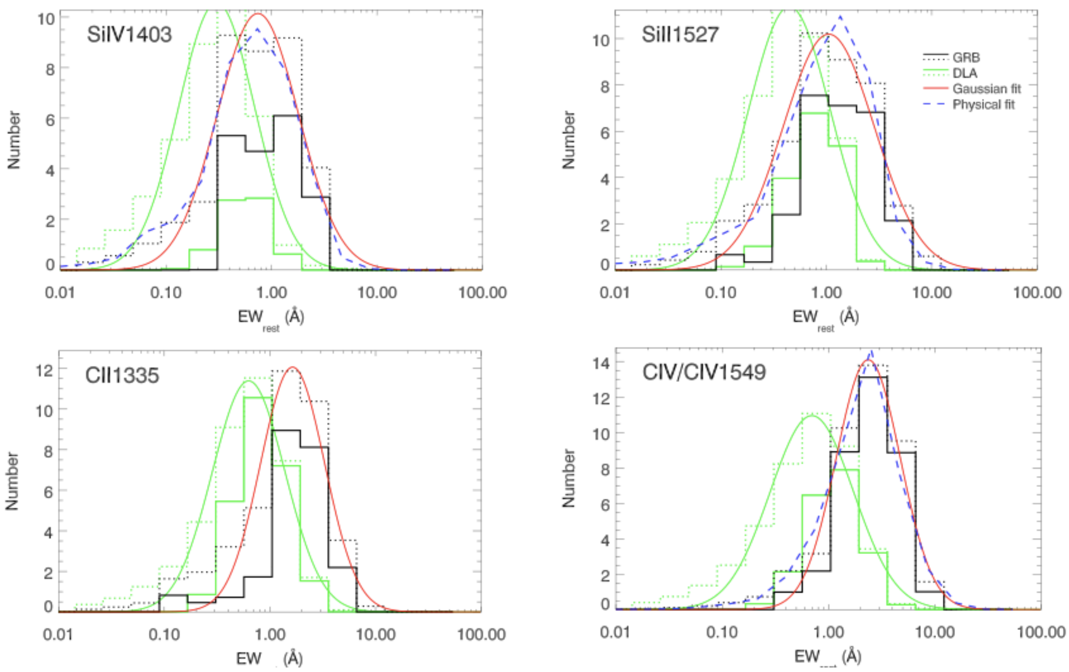

Figure 1: The figure shows for four spectral features the histogram of rest-frame $< EWs >$ for our GRBs and for QSOs. The thick lines of the histograms indicate only detections, for GRBs (black) and QSOs (green). Dotted lines also consider upper limits. The red curve represents the best fit of the complete histogram with a lognormal distribution. The blue curve is the result of a physical fit (more details on the physical fit can be found in [11]). As seen, in all cases GRBs show larger EWs than QSOs.

2 The spectroscopic data set base of our study

The base of our GRB afterglow spectral sample comes from the compilation done by [4]. We have added to the sample 8 new spectra acquired by VLT(+FORS2). The final sample is composed by 69 low resolution spectra. The sample covers five years of observations from 2005 to 2009. The total amount of observing time is over 100 hours, all of it acquired with target of opportunity (ToO) status. The redshifts of the GRBs range from 0.12 [2, 3] to 6.70 [5, 10].

The lines selected from our spectra sample correspond to those lines present in the composite spectrum of [1] with equivalent widths larger EW> 0.5 Å. This selection criterion yielded 22 spectral features. Our sample provides, on average, 36 spectra per spectral feature, so we can use for the first time a statistical approach with an unprecedented sample size. The detection rate of spectral features at the mentioned 22 wavelengths ranged from 30% to 87%, with an average success rate of 52%.

3 Results

3.1 Comparison to the line of sight of quasars (QSOs)

We have compared the strength of the absorption features detected in the line of sight of QSOs to the ones detected in the lines of sight of GRBs. This comparison is based on the the original QSO-DLA sample from [9] that uses the Sloan Digital Sky Survey Data Release 7 (SDSS-DR7) database of QSO spectra. These authors automatically searched for DLA lines, refining their Lyα fits whenever metal lines are detected redward of the Lyα forest. We have selected all systems from their list with $\log(N_{\rm HI}/{\rm cm}^{-2}) > 20$ and redshifts in the range $2.2 < z < 3.2$, located at least 5000 km s^{-1} from a background QSO with $R < 21$. To simplify the analysis we have limited the comparison to the following spectral features: *C II*λ1335, *Si IV*λ1403, *Si II*λ1527, *C IV*λ1549, *Al II*λ1671 and *Al III*λ1855.

Figure 1 shows the rest-frame EW distributions of QSOs and GRBs for four spectral features (*C II*λ1335, *Si IV*λ1403, *Si II*λ1527, *C IV*λ1549). As seen the line of sight of GRBs show systematically larger EWs than in QSOs. On average the features detected in the intervening systems of GRBs are 2.5±0.6 times stronger than in QSO. Is interesting to note that in the case of *C IV*λ1549 the EWs of lines in GRBs are 3.4 times larger. One might speculate if this excess could be explainable by a massive production of Wolf-Rayet stars in the environments of GRBs. Future statistical studies might clarify if this excess still holds when larger GRB samples are used.

3.2 The Line Strength Parameter (LSP): correlations with physical properties

In order to study the line strengths of the different bursts, independently of the wavelength range covered, we define the *line strength parameter* (LSP hereafter) as:

$$LSP = \frac{1}{N} \sum_{i=1}^{N} \frac{\log EW_i - \langle \log EW \rangle_i}{\sigma_{\log\ EW,\, i}}, \qquad (1)$$

where EW_i is the rest-frame equivalent width for each of the individual detected lines in the spectrum, $\langle \log EW \rangle_i$ the central equivalent, $\sigma_{\log\ EW,i}$ is the standard deviation and N the total number of lines used to calculate the LSP.

The LSP measures the strength of the absorption features of a spectrum as compared to the average GRB spectrum. A value of zero would mean that the absorption features in the spectrum have the same strength as the average spectrum. Positive values indicate bursts with stronger than average lines, and equal to 1.0 if the deviation is equivalent to 1-σ. In the same way a negative value implies weak lines. We also calculate the standard deviation (of the summation values in Eq. 1) for each of the GRBs that indicates how different is the distribution of line strengths with respect to the average of GRBs. In the case of a spectrum where we only have detection limits, we use the strongest limit given by a single line to calculate a limit value for the LSP. Once the LSP was determined for our sample, we tried to find correlations with different physical properties of the host galaxies.

First, we tried to find whether the LSP was correlated with the intrinsic brightness of the host given by its absolute magnitude. We found that the LSP shows a clear correlation with the galaxy absolute magnitude. Thus we positively gathered that the brightest hosts have the strongest spectral features. This finding was confirmed correlating the LSP with the host galaxy extinction. This correlation will likely mean that the line of sight absorption is related with the host size and not with the GRB environment itself.

Second, a correlation of the LSP with the host galaxy redshift was searched for. We did not find any correlation of the LSP with the redshift, so no obvious evolution of LSP was found.

4 Conclusions

We have used 69 low-resolution optical spectra of GRB afterglows, covering a redshift range of $0.12 < z < 6.7$, to perform a statistical study of the rest-frame equivalent widths of 22 strong absorption features produced by 12 different atomic species.

As compared with a sample of quasar intervening DLA spectra, we find the GRB absorbers to be, on average, 2.5 times stronger and slightly more ionised. The difference of line strength is more significant in the case of the CIV that is 3.4 times stronger in GRBs. This CIV excess could be related to the existence of an excess of Wolf-Rayet stars in the environment of GRBs, consistent with the massive star origin of these explosions [6].

We find correlations between the LSP and the extinction of the GRB, and also with the brightness of the host. However, the LSP is independent of the redshift. However this lack of correlation might well be just the combined effect of the EW errors and the limited size of the GRB sample. Further extensive and fast ToO spectroscopic campaigns done with large aperture telescopes would be necessary to reinforce our results.

Acknowledgments

This research has made use of the GHostS database (www.grbhosts.org), which is partly funded by Spitzer/NASA grant RSA Agreement No. 1287913. The research activity of AdUP, CT, RSR and JG is supported by Spanish research projects AYA2011-24780/ESP, AYA2009-14000-C03-01/ESP, AYA2010-21887-C04-01 and AYA2012-39362-C02-02. JPUF and BMJ acknowledge support from the ERC-StG grant EGGS-278202. SS acknowledges support by a Grant of Excellence from the Icelandic Research Fund. GL is supported by the Swedish Research Council through grant No. 623-2011-7117. AdUP acknowledges support by the European Commission under the Marie Curie Career Integration Grant programme (FP7-PEOPLE-2012-CIG 322307).

References

[1] Christensen, L., Fynbo, J.P.U., Prochaska, J.X., et al. 2011, ApJ 727, 73

[2] Della Valle, M., Chincarini, G., Panagia, N., et al. 2006, Nature 444, 1050

[3] Fynbo, J.P.U., Watson, D., Thöne, C.C., et al. Nature 444, 1047

[4] Fynbo, J.P.U., Jakobsson, P., Prochaska, J.X., et al. 2009, ApJS, 185, 526

[5] Greiner, J., Krüler, T., Fynbo, J.P.U. et al. 2009, ApJ, 693, 1610

[6] Hjorth, J., Sollerman, J., Møller, P., et al. 2003, Nature 423, 847

[7] Kann, D.A., Klose, S., Zhang, B., et al. 2010, ApJ, 720, 1513

[8] Kann, D.A., Klose, S., Zhang, B., et al. 2011, ApJ, 734, 96

[9] Noterdaeme, P., Petitjean, P., Ledoux, C., & Srianand, R. 2009, A&A, 505, 1087

[10] Pérez-Ramírez, D., de Ugarte Postigo, A., Gorosabel, J., et al. 2010, A&A 2010, 510, 105

[11] de Ugarte Postigo, A., Fynbo, J.P.U., Thöne, C.C., et al. 2012, A&A, 548, A11