Dwarf Galaxies: From the Deep Universe to the Present
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Dwarf galaxies as hosts of stellar explosions: gas kinematics and abundances in 3D

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Abstract. The hosts of long Gamma-ray bursts (GRBs) are places of intense star-formation, which, at low redshift, are primarily low-mass dwarf starburst galaxies. Spatially resolved studies of these galaxies are still sparse, even more so at high spectral resolution where we can probe gas kinematics, in- and outflows and differences in abundance between different components. Here we present the first high resolution IFU sample of six low redshift GRB hosts, all dwarf starbursts. All galaxies in our sample show evidence for excess emission or broad emission components, with velocities of 100-200 km s^{-1}. For GRB 030329, outflowing gas had also been observed in absorption in spectra of the GRB afterglow. The high velocity emission is usually blue shifted, connected to the brightest star-forming regions and more metal rich than the narrow component associated with the emission of the general host ISM. This gives strong indications that the excess emission/broad component is indeed associated to a starburst wind as observed in many field star-burst galaxies and a sign for the intense ongoing star-formation in those galaxies.

Keywords. galaxies: dwarf, galaxies: starburst, galaxies: kinematics and dynamics, gamma rays: bursts

1. Gamma-ray bursts and their hosts

Gamma-ray bursts (GRBs) are the most violent stellar explosions in the Universe and outshine their host galaxies for hours to days. Their afterglows can also be used to probe the ISM in the line-of-sight in the host. Long GRBs (T_{90}>2 s) mark the end of a fast-rotating massive star at low metallicity and have been associated to broad-line Ic supernovae (SNe, for a review on GRB-SNe see e.g. Cano *et al.* 2012). Consequently, their host galaxies are mostly metal poor, highly star-forming and have a young stellar population. At z<1, these conditions are primarily found in dwarf galaxies such as dwarf irregulars (dIrr) or blue compact dwarfs (BCDs). We still know very little about the star-formation triggers and gas kinematics in those galaxies. Most do not seem to have experienced a recent mergers nor are they found in groups. Winds and outflows (for a review see Veilleux, Cecil & Bland-Hawthorn 2005) are commonly observed in starbursts such as BCDs and green peas (Amorin *et al.* 2012) in emission. Galactic winds have been extensively studied in absorption both for starbursts and GRB hosts at high redshift, however, such studies are missing at low redshift.

2. Observations and analysis

Our sample is the first 3D study of GRB hosts at high spectral (and spatial) resolution and comprises six GRB hosts at z<0.3 observed with FLAMES/ARGUS: The hosts of

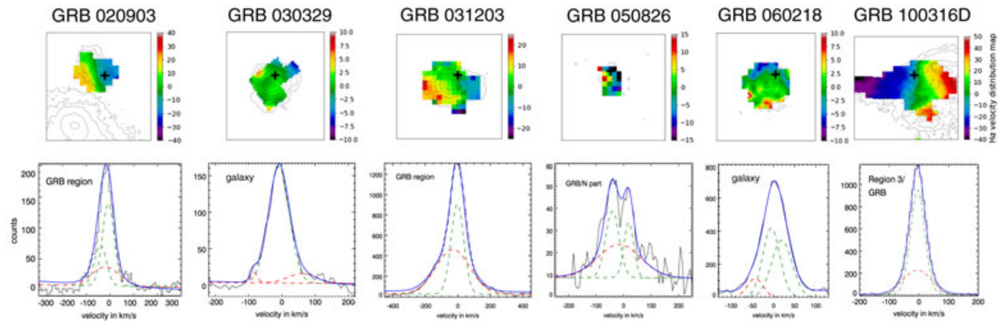

Figure 1. Velocity field from Hα and multi-Gaussian fits to the integrated galaxy spectrum or the spectrum of the GRB site for the six galaxies of our sample.

GRB 020903, GRB 030329, GRB 031203, GRB 050826, GRB 060218 and GRB 100316D. FLAMES/ARGUS has a field-of-view (FOV) of 6.6×4.2 arcsec at 0.3 arcsec sampling and observations were done in one grism with R=8000-13000 for each galaxies, chosen to cover the region from Hα to [SII] at their respective redshifts.

The data were analyzed with standard tools in IRAF and IDL. Line maps were made summing the flux over the width of the emission line and subtracting the galaxy continuum. 3D kinematics were determined by fitting a single Gaussian to Hα in each spaxel as first approximation. We also extract integrated spectra of different regions to enhance the S/N and fit multiple Gaussian components to Hα. For the galaxy with the highest S/N, the host of GRB 100316D, we are able to make a 2D map of the two main emission components of Hα.

3. Results

3.1. *Velocity fields*

Our galaxies are all low-mass dwarfs with stellar masses between log M*= 7.4 and 8.9 $M_\odot$. Only two galaxies from our sample (see Fig. 1) show evidence for a regular rotating disk, namely GRB 031203 and GRB 100316D. The two smallest hosts, GRB 030329 and GRB 060281, are dispersion dominated, which is not surprising considering their small sizes of less than 2 kpc. For the remaining two hosts (GRB 020903 and GRB 050826), the combination of two narrow emission components with varying strength across the galaxy mimics a velocity field, which, however is not real (see Sect. 3.2).

Interestingly, none of the GRB locations are on top of the spaxel with the brightest Hα emission. Given the association between long GRBs and very massive stars we would expect to find them in the center of large star-forming regions as it is usually the case for Galactic star-forming regions. The physical distances of the GRB from the location with the highest Hα emission are between ∼0.6 and 3 kpc. This implies either that the location of massive SF is not always in the center of large SF regions, that GRB progenitors could be runaway stars, or that GRB progenitors can also originate in smaller SF regions with e.g. a top-heavy IMF.

3.2. *Broad emission components*

All hosts show a weak broad component in Hα or excess emission in the wings of the main, narrow Hα emission (see Fig. 1). GRB 020903 and GRB 050826 show a double narrow component possibly associated to different major star-forming regions in the host. For the host of GRB 020903, the two components can be associated with the larger SF region to the N-E of the galaxy while the second component is associated to the SF

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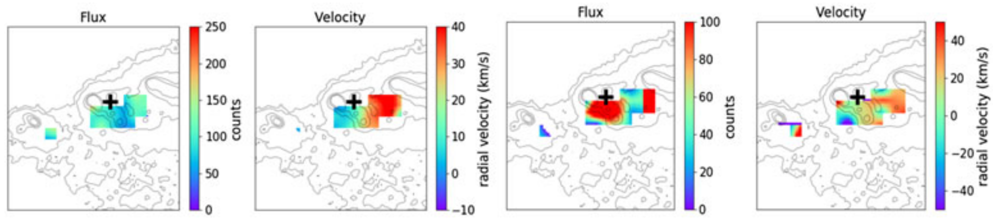

Figure 2. Left panels: Flux and velocity of the narrow component in the host of GRB 100316D. Right panels: Same for the broad component which is concentrated towards the region with the highest SFR and has a more irregular velocity field

region at the GRB site. In general, the main, narrow components have a FWHM of 40-60 $\mathrm{km\,s^{-1}}$, the broad components reach from 130 to 260 $\mathrm{km\,s^{-1}}$.

For GRB 100316D we were able to make 2D maps of the broad and narrow component see Fig. 2). While the narrow component follows the general velocity field of the galaxy, the broad component does not and is in fact strongest in the brightest SFR in the FOV, next to the GRB site. In all the sample, the broad components are concentrated in the brightest SF regions of the host. For the two highest S/N datasets (GRB 031203 and GRB 100316D) there are also indications for a presence of a broad component in the weaker emission lines such as [NII], [SII], already noted by Guseva *et al.* (2011) in X-shooter spectra of the host of GRB 031203. This allows us to measure independent metallicities for the broad and narrow components in these two hosts and find that while the overall metallicity (also at the GRB site) is low, the broad component is more metal rich by 0.2 – 0.4 dex.

3.3. *Absorption and emission kinematics*

Two of our GRB hosts also show absorption lines from the ISM in spectra from observations of the GRB afterglow: GRB 030329 and GRB 060218, which, coincidentally, are the two smallest hosts in our sample and, in fact, in the entire GRB host sample. In both cases, the excess emission in the red and blue wings are not symmetrical and cannot be fit with a single component, which could be related to the small size of the galaxy. For the host of GRB 030329 we fit two extra components in the wings at $\sim\pm$ 80 $\mathrm{km\,s^{-1}}$ while for the host of GRB 060218 (Wiersema *et al.* 2007) found a double component in emission while our spectra show an additional small component in the blue wing.

Afterglow spectra in the host of GRB 030329 (Thöne*et al.* 2007) show MgI&II absorption spanning more than 200 $\mathrm{km\,s^{-1}}$, significantly larger than the velocity width of the hot emitting gas, and which the authors already interpreted as evidence for a starburst wind. The host GRB 060218 only shows two components in NaD/CaII absorption at the same velocity as the two emission components (Wiersema *et al.* 2007). Either this host has a weaker wind or this implies a non-spherical distribution of the outflow, which, in fact has been shown by studies of other starburst galaxies (e.g. Chen *et al.* 2010).

4. Discussion: What are the evidences for an outflow?

Taking all the properties listed above, we believe that the broad component detected in all galaxies of our sample might indeed be signatures of an outflow, possibly a galactic wind driven by SN explosions during the ongoing starburst which also lead to the production of the (massive) GRB progenitor:

- The broad component is usually blueshifted compared to the narrow component.
- The velocity field of the broad component does not follow the one of the narrow component but is rather constant across the galaxy.
- The broad component is more metal rich.

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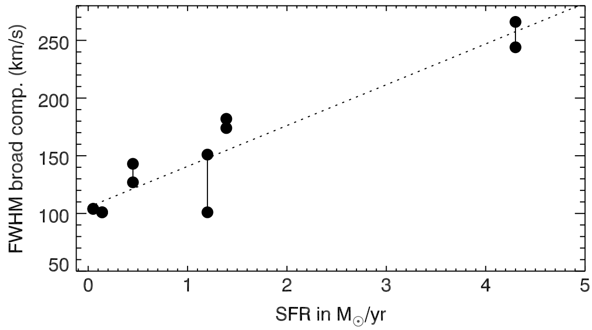

Figure 3. Correlation between the absolute SFR and the FWHM of the broad component for our six galaxies. The dotted line shows a linear fit to the possible correlation.

• We find no indications for shocks in most regions, except a shocked region in the GRB 100316D host (see Izzo *et al.* 2017).

• For two hosts we find outflows from absorption spectra of the GRB afterglow.

A last intriguing hint is that we find a correlation between the FWHM of the broad component and the absolute SFR (see Fig. 3), but no correlation with other properties such as stellar mass or metallicity. The velocity width of the broad increases with the absolute SFR in GRB hosts, making an associating with a star-burst wind very likely. For other starbursts, wind velocity and/or strength of outflows measured via absorption systems have been found to correlate strongly with absolute SFR or SFR density but less with stellar mass or metallicity (Bordoloi *et al.* 2014, Heckman & Borthakur 2015).

While we already know that galactic winds are ubiquitous in starburst galaxies, this is the first time this has been measured in a consistent way for GRB hosts. It also confirms the theory that they are no special galaxies, but simply belong to a class of metal-poor highly star forming dwarf galaxies.

References

Amorín, R., Vílchez, J. M., Hägele, G. F., Firpo, V., Pérez-Montero, E. & Papaderos, P. 2012, *ApJ* (Letters), 754, L22

Bordoloi, R., Lilly, S. J., Hardmeier, E. *et al.*. 2014, *ApJ*, 784, 130

Cano, Z., Wang, S.-Q., Dai, Z.-G. & Wu, X.-F. 2016, *Adv. Astr.*, 2017, 8929054

Chen, Y.-M., Tremonti, C. A., Heckman, T. M., Kauffmann, G., Weiner, B. J., Brinchmann, J. & Wang, J., *The Astronomical Journal*, 2010, 140, 445

Guseva, N. G., Izotov, Y. I., Fricke, K. J. & Henkel, C. 2011, *A&A*, 534, A84

Heckman, T. M. & Borthakur, S. 2016, *ApJ*, 822, 9

Izzo, L., Thöne, C. C., Schulze, S. *et al.* 2017, *MNRAS*, 472, 4480

Thöne, C. C., Greiner, J., Savaglio, S. & Jehin, E. 2007, *ApJ*, 671, 628

Wiersema, K., Savaglio, S., Vreeswijk, P. M. *et al.* 2007, *A&A*, 464, 529

Veilleux, S., Cecil, G. & Bland-Hawthorn, J. 2005, *ARAA*, 37, 239

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