The galaxies in the field of the nearby GRB 980425/SN 1998bw

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Received/accepted

Abstract. We present spectroscopic observations of ESO 184–G82, the host galaxy of GRB 980425/SN 1998bw, and six galaxies in its field. A host redshift of $z = 0.0087 \pm 0.0006$ is derived, consistent with that measured by Tinney et al. (1998). Redshifts are obtained for the six surrounding galaxies observed. Three of these galaxies lie within 11 Mpc of each other, confirming the suggestion that some of these galaxies form a group. However, all of the field galaxies observed lie at significantly greater distances than ESO 184–G82 and are therefore not associated with it. The host galaxy of GRB 980425/SN 1998bw thus appears to be an isolated dwarf galaxy and interactions with other galaxies do not seem to be responsible for its star formation.

Key words. galaxies: ESO 184–G82 – gamma rays: bursts – supernovae: individual: SN 1998bw

1. Introduction

Gamma-Ray Burst GRB 980425 was detected by BeppoSAX (Soffitta et al. 1998) and with the Burst and Transient Source Experiment (BATSE, Kippen 1998). It is most notable for its co-incidence in both space and time with SN 1998bw (Galama et al. 1998), a very energetic Type Ic supernova (Galama et al. 1998). Therefore this detection provided the first convincing evidence for the link between long-duration GRBs and SNe, one which has subsequently been confirmed by the direct detection of SN 2003dh associated with GRB 030329 (Hjorth et al. 2003; Stanek et al. 2003). This case lent particular weight to the proposed GRB 980425/SN 1998bw connection due to the spectral similarity observed between SN 1998bw and SN 2003dh. Additional spectroscopic and photometric studies strongly support the GRB–SN connection (Della Valle 2005; Matheson 2005; Fynbo et al. 2004). Examples include the unambiguous association of SN 2003bw with GRB 031203 (Malesani et al. 2004; Thomsen et al. 2004) and evidence for extra light at later times in a large proportion of GRB afterglows (Zeh et al. 2004).

Assuming this association to be true, GRB 980425 was a sub-luminous GRB, emitting an equivalent isotropic γ-ray energy of $\sim 8 \times 10^{57}$ erg (Galama et al. 1998), less luminous than typical GRBs by a factor of $10^6$. It occurred in a spiral arm of ESO 184–G82, at a redshift of $0.0085 \pm 0.0002$ (Tinney et al. 1998). This makes GRB 980425 by far the closest GRB detected to date, the next closest being GRB 031203 at a redshift of $z = 0.1055$ (Prochaska et al. 2004). Given such relative proximity, GRB 980425 provides a rare and excellent opportunity for further study of the host’s galaxy field.

Hubble Space Telescope (HST) imaging of ESO 184–G82, as undertaken by Fynbo et al. (2004), indicates that the host has a high specific star-formation rate. This has recently been confirmed by Sollerman et al. (2005). Attention is drawn to the local environment of ESO 184–G82, showing a number of galaxies lying in apparent close proximity to the GRB host (see Fig. 1). ESO 184–G82 has been considered to be a member of this group of galaxies including ESO 184–G80 and ESO 184–G81 (Holmberg et al. 1977). If these galaxies lie at distances comparable to that of ESO 184–G82, the star-formation rate of the host galaxy, and hence the probability of a GRB event, may have been enhanced by interaction with these galaxies.

In this paper we present optical spectroscopy of ESO 184–G82 and six field galaxies in its vicinity. The paper is organised as follows: Observations and data reduction procedures are described in Sect. 2. Section 3 presents the results of our investigation into the host’s environs and Sect. 4 discusses the conclusions and implications of our results.

2. Observations and Data Reduction

Spectroscopic observations were undertaken of the host and six galaxies in its field, as marked in Fig. 1. The field galaxies include ESO 184–G80, ESO 184–G81 and four previously unclassified galaxies, labelled A to D with increasing angular distance from the host.
The field galaxies were observed using the Danish 1.54 m telescope at La Silla, Chile. The Danish Faint Object Spectrograph and Camera (DFOSC) was mounted on the telescope with grism #7 for all observations, resulting in a spectral range of 3800–6800 Å. The slit width was varied between 2.5′′ and 2.0′′ giving a spectral resolution of ∼10 Å and ∼8 Å, respectively, measured from the typical FWHM of an arc spectrum emission line. In most cases, the slit was aligned so as to include two of the sample galaxies. The detector used was a 2k × 2k Loral CCD with a gain of 1.3 e− ADU−1, read-out noise of 7.5 e− and pixel scale of 0.40′′ pixel−1. The DFOSC field of view (FOV) is 13.7′ × 13.7′. In order to measure the redshift of the host galaxy we used the VLT spectra obtained on June 13 1999 by Sollerman et al. (2000). These observations were carried out using the FORS1 instrument. Grism 300V was used, giving a wavelength range of 3600–9000 Å. The width of the slit was 1′′ giving a spectral resolution of ∼7 Å. The gain and read-out noise of the CCD were set to 0.34 e− ADU−1 and 5.75 e−, respectively. These data are also available in the ESO archive.

Zero-exposure bias frames and flat-field exposures were taken on each observing night. Spectral images of He-Ne arc lines were obtained immediately before and subsequent to the object exposures under identical observing conditions for the Danish 1.54 m observations. For the stable VLT lines were obtained immediately before and subsequent to the object exposures. The object spectra were then extracted to 1-D images of pixel number against ADU pixel−1. A variance-weighted extraction was chosen to remove random cosmic ray events. In order to wavelength calibrate the pixel scale, calibration spectra were extracted from the arc lamp images and a dispersion scale determined from the known wavelengths of a number of Hg-He-Ar/He-Ne emission lines. Dispersion scales were assigned to object spectra by taking an average of those arc spectra solutions from the calibration exposures nearest in time to the object exposures. The typical rms of the dispersion fit ranged from 0.01 Å to 0.1 Å. The accuracy of the wavelength calibration was verified by identifying the wavelengths of prominent sky lines for each night. The observed deviations are consistent with the above rms scatter. No systematic variations in the wavelength scale from night to night were observed. A flux calibration was performed for the host galaxy using the observed flux of the spectrophotometric standard LTT 7379.

3. Analysis

The redshift of each galaxy was determined using two methods (see Table 2). An initial determination of the redshift was made using the IRAF task rividlines. This requires the identification of a prominent spectral feature to which a gaussian function is fit. Based on the central wavelength of this line and an input list of known spectral lines, other features at a consistent redshift are identified. A weighted average redshift value and corresponding error based on the gaussian fit is output.

An alternative measurement of each redshift was obtained using the Fourier cross-correlation method as described by Tonry & Davis (1979) using the IRAF task fxcor. In this analysis, each galaxy spectrum was cross-correlated with template spectra obtained from Kinney et al. (1996). These spectra are characterised by high S/N ratios and are de-redshifted to the rest frame. Template spectra for bulge, elliptical, S0, Sa, Sb (absorption-line dominated) and Sc (emission-line dominated) galaxy morphologies were used. Fxcor determines the wavelength shift of the object spectrum at the point of maximum correlation and computes a redshift value. The task outputs redshift errors based on the height of the correlation peak and noise statistics.

Combined spectra for each galaxy observed are shown in Fig. 3. Table 2 gives the heliocentric redshifts determined in each case using the fxcor and rividlines methods discussed above. Through the use of a number of templates for correlation with the absorption spectra, a mean value for the redshift was determined for a given galaxy spectrum, weighted by the square inverse of the fxcor error. The fxcor errors from each

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1 Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatories (NOAO).
Table 1. Log of observations.

| Telescope/Grism         | Object        | Date         | Exposure Time (s) | Seeing (′′) |
|-------------------------|---------------|--------------|-------------------|-------------|
| VLT/300V                | ESO184–G82   | 13-06-1999   | 4x1800            | 1.8         |
| D 1.54m/#7              | ESO 184–G80  | 24-08-2000   | 3×1200, 1×1050    | 1.2         |
|                         | ESO 184–G81  | 30-08-2000   | 6×1200            | 1.4         |
|                         |               | 27-08-2000   | 5×1200            | 1.6         |
|                         | Galaxy A     | 28-08-2000   | 7×1200            | 1.6         |
|                         |               | 01-09-2000   | 4×1200            | 1.4         |
|                         | Galaxy B     | 26-08-2000   | 2×1200, 1×1118    | 1.0         |
|                         | Galaxy C     | 29-08-2000   | 6×1200            | 1.0         |
|                         | Galaxy D     | 02-09-2000   | 5×1200            | 1.4         |
|                         | Galaxy C     | 02-09-2000   | 5×1200            | 1.4         |
|                         | Galaxy C     | 30-08-2000   | 6×1200            | 1.2         |
|                         | Galaxy D     | 28-08-2000   | 7×1200            | 1.6         |
|                         | Galaxy D     | 01-09-2000   | 4×1200            | 1.4         |

Table 2. Heliocentric-corrected redshifts for galaxies in the field of GRB 980425 as marked in Fig.1.

| Galaxy       | Redshift (fxcor) | Redshift (ridelines) |
|--------------|------------------|----------------------|
| ESO 184–G82 | 0.00985 ± 0.0003 | 0.00987 ± 0.00004    |
| ESO 184–G80 | 0.0470 ± 0.0007  | 0.0470 ± 0.0002      |
| ESO 184–G81 | 0.0448 ± 0.0007  | 0.0452 ± 0.0001      |
| Galaxy A    | 0.0447 ± 0.0007  | 0.0448 ± 0.0003      |
| Galaxy B    | 0.0314 ± 0.0003  | 0.0317 ± 0.00002     |
| Galaxy C    | undetermined     | 0.0609 ± 0.0001      |
| Galaxy D    | 0.0605 ± 0.0006  | 0.0604 ± 0.0002      |

ESO 184–G81, ESO 184–G80 and Galaxy A are most likely located in a small group, but are not near to the host galaxy.

4. Are GRB hosts in underdense regions?

In an extensive HST imaging study of 42 GRB host galaxies, a large proportion of those observed (~30–60%) show evidence for interaction (Wainwright et al. 2005). Analysis of the environments of four GRB hosts identify several galaxies at a similar redshift in all cases (Fynbo et al. 2002, Jakobsson et al. 2005). GRB 980613 also occurred in a host galaxy which appears to be part of a complex, interacting system (Hjorth et al. 2002) as is the host of GRB 001007 (Castro Cerón et al. 2002). However, it is not known if any of these fields are overdense.

Whether GRBs preferentially occur in galaxy-dense regions remains uncertain, but the evidence seems to hint that they do not. Photometric redshifts have been determined for galaxies in the field of GRB 000210 showing that there is no obvious grouping of galaxies around the host (Gorosabel et al. 2003). In a study of the cross-correlation between GRB host galaxies and the surrounding galaxy environments, Bornancini et al. 2004 found tentative evidence that GRB host galaxies are more likely to be located in low density galaxy environments. It has been suggested that objects found in lower-density galaxy regions may also tend to be sub-luminous (Le Floc’h et al. 2003), consistent with ESO 184–G82 in particular and GRB host characteristics in general. The GRB 030329 host at z=0.1685 (Greiner et al. 2003) may be a counter-example, having at least one field galaxy at z ~0.171 and hence being consistent with a potential clustering (Gorosabel et al. 2005).

We can now conclude that ESO 184–G82, generally regarded as being part of a galaxy group, appears in fact to be isolated and that interaction with nearby galaxies can be eliminated as a source of its high specific star-formation rate. Interestingly, in a recent study, Sollerman et al. (2005) find that the host galaxy properties are consistent with a constant star-formation rate over a few Gyrs. Therefore, it seems that the present state of the galaxy is not that of a starburst and hence...
that the current star-formation activity does not necessarily require an external trigger.

Acknowledgements
The Dark Cosmology Centre is supported by the DNRF. The authors acknowledge benefits from collaboration within the EC FP5 Research Training Network "Gamma-Ray Bursts - An Enigma and a Tool". This research is partially supported by the Spanish Ministry of Science and Education through programmes ESP2002-04124-C03-01 and AYA2004-01515.

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