Herschel/PACS Observations of the Host Galaxy of GRB 031203 *

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Accepted Received; in original form

ABSTRACT

We present Herschel/PACS observations of the nearby (z = 0.1055) dwarf galaxy that has hosted the long gamma ray burst (LGRB) 031203. Using the PACS data we have been able to place constraints on the dust temperature, dust mass, total infrared luminosity and infrared-derived star-formation rate (SFR) for this object. We find that the GRB host galaxy (GRBH) 031203 has a total infrared luminosity of 3 × 10^{10} L⊙ placing it in the regime of the IR-luminous galaxy population. Its dust temperature and specific SFR are comparable to that of many high-redshift (z = 0.3–2.5) infrared (IR)-detected GRB hosts (T_{dust} > 40 K; \mathcal{SFR} > 10^{-12} M⊙ yr^{-1}), however its dust-to-stellar mass ratio is lower than what is commonly seen in IR-luminous galaxies. Our results suggest that GRBH 031203 is undergoing a strong starburst episode and its dust properties are different to those of local dwarf galaxies within the same metallicity and stellar mass range. Furthermore, our measurements place it in a distinct class to the well studied nearby host of GRB 980425 (z = 0.0085), confirming the notion that GRB host galaxies can span a large range in properties even at similar cosmological epochs, making LGRBs an ideal tool in selecting samples of star-forming galaxies up to high redshift.

1 INTRODUCTION

The currently favoured scenario for the origin of long gamma-ray bursts (LGRBs) is that they result from the collapse of massive, metal-poor stars and as a result LGRBs are thought to mark the sites of cosmic star-formation (e.g. Christensen et al. 2004; Tanvir et al. 2004). In comparison to the typical flux limited galaxy surveys, LGRBs are considered more unbiased identifiers of star-forming galaxies because their occurrence and detection is independent of many galaxy properties, such as extinction (e.g. Ramirez-Ruiz et al. 2002; Watson et al. 2011). As a result, the follow up of LGRB hosts plays a key role in determining the cosmic star-formation history and at high redshift (z > 5) it has important implications for our understanding of the epoch of re-ionisation (e.g. Robertson & Ellis 2012).

Targeted observations of LGRB host galaxies have shown them to be young, spanning a large range of properties (e.g. Krühler et al. 2011; Perley et al. 2013), however, the role of dust in the star formation history, chemical enrichment and evolution of these sources is still largely unclear. Determining host galaxy properties, such as dust extinction, using the LGRB afterglows (e.g. Schady et al. 2007; Starling et al. 2007) target only line-of-sight conditions and hence may only be typical of the local environment around the GRB event rather than the host itself, particularly since there is evidence that measurements over small scales are not necessarily representative of global galaxy attributes (e.g. Padoan et al. 2006). Furthermore, as the abundance of dust in star-forming galaxies implies that they radiate a large fraction of their energy in the infrared (IR), star-formation rates (SFRs) derived from optical observations cannot account for deeply dust-embedded star-forming regions and have to rely on uncertain extinction corrections. Examining the infrared part of the spectral energy distribution (SED) is thus essential in order to determine the total energy budget and global SFR, as well as dust properties such as temperature, mass and extinction. Indeed, estimating the gas-to-dust mass ratio, a key ingredient in constraining the chemical evolution of galaxies, is not feasible without infrared observations. Ultimately, determining the role of dust in young environments, such as those found in LGRB host galaxies, is crucial for our understanding of primordial galaxy formation in the early Universe.

To date, out of the GRB host galaxies targeted in the infrared with Spitzer/MIPS and JCMT/SCUBA, only a small fraction have been detected (e.g. Tanvir et al. 2004; Le Floc’h et al. 2006; Michałowski et al. 2008) and more recently with Herschel (Michałowski et al. 2013; Hunt et al. 2014). Here we present Herschel (Pilbratt et al. 2010)/PACS (Poglitsch et al. 2010) observations of the host galaxy of GRB 031203 (hereafter referred to as GRBH 031203). GRBH 031203 is a metal poor compact dwarf at z = 0.1055 (Prochaska et al. 2004, Margutti et al. 2007; Levesque et al. 2010; Han et al. 2010), one of the 4 local (z ≤ 0.1) galaxies that have hosted a GRB event. Our aim is to place constraints on the dust properties and IR SED of this galaxy, which has not been possible to date due to lack of far-IR observations. This letter is laid out as follows: Section 2 outlines the data used, section 3 presents the data analysis and section 4 discusses the results.
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Figure 1. WISE and PACS images of GRBH 031203 (RA 08:02:30.18; DEC -39:51:03.52). North is up and East is left. Each cut-out is 1 arcmin by 1 arcmin. The red circle denotes the position of the galaxy and has a radius of 6 arcseconds.

2 DATA

2.1 Herschel Data

We acquired Herschel/PACS 70, 100 and 160 µm data as part of the OT2 GO proposal cycle in 2013 (P.I. Symeonidis). Reduction of the PACS images was performed with the Herschel Interactive Processing Environment (HIPE) version 10.3.0.

From the PANIC J-band image in Gal-Yam et al. (2004) we see that GRBH 031203 is a compact source (∼2′). On the position of the host galaxy (see Fig 1) we perform aperture photometry with the aperture photometry tool (APF). We use an aperture radius of 12′ and the prescribed aperture correction of 0.794 to determine the 70 µm flux density. For the 100 µm flux density, the same aperture size and an aperture correction of 0.766 is used, whereas for the 160 µm flux density an aperture size of 22′ and an aperture correction of 0.810 is used. To calculate photometric uncertainties and upper limits we use the method outlined in the PACS documents (Muller et al. 2011 and Balogh et al. 2011). We check the validity of this method by calculating the standard deviation of the distribution of flux densities measured in 20 same-sized apertures placed on empty parts of the map near the source. We find that deviations to be the consistent with both methods. The PACS photometry is displayed in Table 1.

2.2 Multiwavelength data

We take optical photometry from Margutti et al. (2007) at λ <800 nm, from Cobb et al. (2004) and Prochaska et al. (2004) at λ <3 µm. We also use the IRAC and MIPS 24 µm photometry from Watson et al. (2011). Watson et al. (2011) report that this source was also observed in the MIPS SED mode, which provides low resolution spectroscopy between 52 to 100 µm, however it was not detected and has an upper limit of 40 mJy. Our estimated flux density at 70 µm is consistent with this value. Finally, we also retrieve near and mid-IR data from the Wide-field Infrared Survey Explorer survey (WISE: Wright et al. 2010) using the newly updated ALLWISE Source Catalogue. Table 1 shows the WISE photometry for GRBH 031203.

3 SED MEASUREMENTS

We fit the photometry of GRBH 031203, with a simple SED model, which combines the grey-body function (GBF) for the far-IR and a power-law (PL) for the mid-IR at a critical frequency ν∗ (see also Blain et al. 2003; Younger et al. 2009) as follows:

\[ F_ν \propto \begin{cases} \frac{hν(\beta+β)}{ν_α} & \text{if } ν < ν∗ \\ \nu^α & \text{if } ν > ν∗ \end{cases} \]

where \( F_ν \) is the flux density, \( h \) is the Planck constant, \( c \) is the speed of light in a vacuum, \( k \) is the Boltzmann constant, \( T_{\text{dust}} \) is the temperature of the grey-body function and \( β \) is the emissivity — we adopt \( β=1.5 \), consistent with studies of the far-IR emissivity of large grains (Desert, Boulanger & Puget 1990). At the critical frequency \( ν∗ \) the slopes of the two functions are equal and hence \( α=\frac{d\log GBF}{d\log ν} \). We perform \( \chi^2 \) fitting to the dust component of the galaxy SED, i.e. from 4 µm onwards, in order to obtain the normalisation, \( T_{\text{dust}} \) and \( α \). The 0.68 lower and upper confidence limits for our computed parameters resulting from the fits (e.g. temperature, total infrared luminosity etc.) are calculated according to the prescribed \( \chi^2 \) confidence intervals for one interesting parameter, namely \( \chi^2_{\text{min}} + 1 \), where \( \chi^2_{\text{min}} \) is the minimum \( \chi^2 \). Fig. 2 shows the SED fit to the photometry.

We compute the total IR luminosity (\( L_{\text{IR}} \)) in the 8–1000 µm range, \( T_{\text{dust}} \) (the average dust temperature of the galaxy representing the peak of the SED) and the dust mass (\( M_{\text{dust}} \)) — see Table 2. \( M_{\text{dust}} \) is calculated as follows:

\[ M_{\text{dust}} = \frac{f_{\nu,\text{rest}} D_L^2}{B(ν_{\text{rest}}, T_{\text{dust,rest}})} \kappa_{\text{rest}} \]

where, \( D_L \) is the luminosity distance, \( B(ν_{\text{rest}}, T_{\text{dust,rest}}) \) is the black body function (in units of flux density), \( f_{\nu,\text{rest}} = f_{ν,\text{obs}}(1+z) \), \( \kappa_{\text{rest}} = \kappa_{50\mu m}(\nu_{\text{rest}}/\nu_{50\mu m})^β \) and \( \kappa_{50\mu m} = 0.0431 \text{ m}^2 \text{kg}^{-1} \) taken from Li and Draine (2001). Here, we take \( f_{ν,\text{obs}} \) as the observed flux density at 250 µm computed by using the model SED and \( ν_{\text{rest}} \) is the rest-frame frequency equivalent to 250 µm (observed).

We convert \( L_{\text{IR}} \) to SFR using the prescription of Kennicutt (1998), finding 5.06 ±0.07 M⊙/yr as the SFR of GRBH 031203. This is consistent with SFRs estimated from radio measurements: Stanway et al. (2010) report an SFR of 4.8±1.4 M⊙/yr as the SFR of GRBH 031203. However, SFRs calculated from optical and UV measurements (mainly Hα and [OII] lines and UV continuum) are in disagreement varying from 0.4 to 13 M⊙/yr (Prochaska et al. 2004; Margutti et al. 2007; Savaglio et al. 2009; Svensson et al. 2010; Levesque et al. 2010; Guseva et al. 2011). It is likely that the discrepancies between the optical SFR measurements in literature are mainly due to discrepant extinction corrections. Stanway et al. (2010) also propose that optically-derived SFR measurements for GRBH 031203 are subject to AGN contamination, based on the conclusions of Levesque et al. (2010), however, many authors dispute the pres-
4 THE PROPERTIES OF GRBH 031203

In this section we examine the dust properties of GRBH 031203 and compare to the following sources: (i) the Herschel dwarf galaxy sample (JDGS; Madden et al. 2013, hereafter Ma13 and Rémy-Ruyer et al 2013, hereafter RR13), consisting of 48 dwarf galaxies at z < 0.05 and selected to span the largest range in SFR and metallicity for dwarf galaxies in the local Universe, (ii) GRBH 980425 (Michałowski et al. 2013; hereafter M13), the only other GRB host galaxy in the local Universe observed by Herschel (iii) the 3 SCUBA-detected GRB hosts at z ∼ 1 from Michalowski et al. (2008; hereafter M08) and (iv) the 7 Herschel-detected GRB hosts at 0.3 < z < 2.5 from Hunt et al. (2014; hereafter H14).

Fig. 3 shows the locus of the above samples on the IR-luminosity - dust temperature ($L_{IR} - T_{dust}$) plane; for reference we also plot the 1σ bounds of the $L_{IR} - T_{dust}$ relation from Symeonidis et al. (2013) representative of the z < 2 IR-luminous galaxy population. Note that GRBH 031203 has a warm dust temperature and an IR luminosity in the regime of IR-luminous galaxies.
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Figure 4. Dust temperature as a function of sSFR. GRBH 031203 is denoted by a closed square. The diamonds are the HDGS from Ma13 and RR13 and the cross is GRBH 980425 from M13. The asterisks and open circles are the high redshift IR-detected GRB hosts from M08 and H14 respectively.

Figure 5. The dust-to-stellar mass ratio as a function of specific star-formation rate. GRBH 031203 is denoted by a closed square. The diamonds are the HDGS from Ma13 and RR13 and the cross is GRBH 980425 from M13. The asterisks and open circles are the high redshift IR-detected GRB hosts from M08 and H14 respectively.

Figure 6. The dust-to-stellar mass ratio as a function of metallicity. GRBH 031203 is denoted by a closed square. The diamonds are the HDGS from Ma13 and RR13, the cross is GRBH 980425 from M13.

5 SUMMARY AND CONCLUSIONS

We have reported Herschel/PACS observations of the host galaxy of GRB 031203. Using the PACS data and ancillary IR photometry, we have, for the first time, been able to place constraints on the IR SED shape, total infrared luminosity, IR-derived star-formation rate, dust mass and dust temperature of GRBH 031203. We compared our findings with a representative sample of local dwarf galaxies, high redshift IR-detected GRB hosts and the nearby well studied GRB host 980425, the only other GRB host at z < 0.1 to have Herschel observations.

We found that GRBH 031203 has a warm average dust temperature, a high specific star-formation rate and an IR luminosity placing it in the regime of IR-luminous galaxies. Interestingly, these properties are comparable to those of the high-redshift IR-detected GRB host galaxies and unlike what is seen in local dwarfs. On the other hand its value of $M_d/M_*$ is within the range probed by local dwarf galaxies. GRBH 031203 is overall more active than typical local galaxies within the same metallicity and stellar mass range, consistent with previous reports of higher sSFR amongst GRB hosts compared to other SFGs (e.g. Castro Cerón et al. 2006; Savaglio et al. 2009; Perley et al. 2013). Its large specific star-
formation rate indicates a starburst episode in action, in agreement with other studies of GRBH031203 which conclude that it is a young system undergoing a starburst, the supporting evidence according to Watson et al. (2011) being the values of emission line ratios (e.g. [NeIII]/[NeII]), lack of polycyclic aromatic hydrocarbon (PAH) features and a low value of the 4000˚ A break (D4000 < 1).

Interestingly, GRBH031203 is also in a separate class to the well studied GRBH 980425. Although GRBH 031203 has similar metallicity to GRBH 980425, their T_dust, sSFR and M_d/M_* values are distinctly different. GRBH 031203 is a much more active system, whereas GRBH 980425 seems more quiescent, akin to local dwarfs. This is interesting because it suggests that GRB host galaxies can indeed span a large range in properties, making LGRBs an ideal tool in selecting relatively unbiased samples of star-forming galaxies up to high redshift (z < 10; e.g. Cucchiara et al. 2011).

ACKNOWLEDGMENTS

This paper uses data from Herschel’s photometer PACS, developed by a consortium of institutes led by MPE (Germany) and including UVIE (Austria); KU Leuven, CSL, IMEC (Belgium); CEA, LAM (France); MPIA (Germany); INAF-IFSI/OAA/OAP/OAT, LENS, SISSA (Italy); IAC (Spain) and supported by the funding agencies BMVIT (Austria), ESA-PRODEX (Belgium), CEA/CNES (France), DLR (Germany), ASI/INAF (Italy), and CICYT/MCYT (Spain). RS is supported by a Royal Society Dorothy Hodgkin Fellowship. NS is the recipient of an Australian Research Council Future Fellowship.

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