Continuum spectral energy distribution of GRB, SLSN, SB and AGN host galaxies at intermediate redshifts

M. Contini
School of Physics and Astronomy, Tel Aviv University, Tel Aviv 69978, Israel

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ABSTRACT

Continuum SED models of gamma-ray burst (GRB) and obscured GRB host galaxies at moderately high redshifts are presented and compared with those of superluminous supernovae (SLSN), starburst (SB) and active galactic nuclei (AGN). We consider that continuum radiation (bremsstrahlung) is emitted from the same clouds which emit the line spectrum in each object. Therefore, we have selected from the samples of the GRB host continuum observations those that were previously modelled on the basis of the line spectra, because modelling the continuum SED is less constraining. The bremsstrahlung is generally recognised in the radio and in the UV-X-ray frequency ranges, while dust reradiation peaks in the IR. We have found that GRB980703 host extended clouds have dust-to-gas ratio $d/g = 0.03$, while for GRB980425 $d/g < 0.0001$. To reproduce the continuum SED of most of the GRB, SLSN, SB and AGN in the near-IR-optical range, the contribution of an old star background population is needed. This radiation can be reproduced by a black body (bb) corresponding to temperatures $T_{bb} \sim 3000-8000$ K. The best fit of a few host SEDs includes also the direct contribution of the bb flux from the SB corresponding to $T_s \sim 5 \times 10^4$ K. $d/g$ calculated by modelling the SEDs of obscured GRB hosts roughly increases with $z$ resembling the SFR trend.

Key words: radiation mechanisms; general — shock waves — galaxies: GRB host — SN host — starburst— AGN —galaxies: high redshift

1 INTRODUCTION

Gamma-ray bursts (GRB) are explosions characterized by huge energy release. GRB events generally occur at redshifts higher than local. Their characteristics are analysed by the interpretation of phenomena connected with the explosion (light curves, ejecta, emitted and absorbed spectra, etc) and those relative to the host galaxy, in particular the emitted spectra. The physical conditions and the element abundances of the host galaxies are investigated from all points of view such as star formation, star formation rates (SFR), star chemical nucleosynthesis and their evolution with time (Krühler et al. 2015, Han et al. 2010, Levesque et al. 2010, Savaglio et al. 2009, Contini 2016, 2017a,b etc). In previous works (Contini 2017b and references therein) we have investigated physical conditions and element abundances of some basic elements (H, N, O, S, etc) throughout the hosts comparing model calculations with the line spectra emitted from galaxies hosting long and short period GRB, supernovae (SN) of different types, active galactic nuclei (AGN), starbursts (SB), HII regions. Some peculiarities were revealed e.g. the interplay between oxygen and nitrogen release throughout the hosts at different redshifts.

In this paper we refer to the continuum spectral energy distribution (SED) observed from GRB host galaxies at moderately high redshifts, in particular those from the obscured ones and we compare them with SLSN of different types. The continua are generally investigated using population synthesis models of more host galaxies to create a set of theoretical SEDs (e.g. Sokolov et al. 2001). We will start our study by the analysis of Hunt et al (2014) sample of obscured GRB hosts because they present the continuum data on a large frequency range (from radio to NIR). To reproduce the continuum SED Hunt et al (2014) applied the fitting method introduced by Michalowski et al (2009, 2010) based on 35000 templates in the library of Iglesias-Paramo et al (2007) plus templates of Silva et al (1998). Krühler et al (2011) reported the SEDs of GRB dusty host galaxies. The UV/optical/NIR photometry of the selected GRB hosts were analysed in a standard way using stellar population synthesis techniques to convert luminosities into stellar masses. Perley et al (2016) analyzed the UV-optical-
NIR SEDs of SLSN of different types to estimate host galaxy stellar parameters using a custom SED-fitting code (Perley et al 2013). To compare the GRB SEDs with those of SB and AGN hosts at relatively high redshifts, we will refer to the Ramos Almeida et al (2013) sample presented in the frame of AGN-SB feedback investigation. They adopted the diagnostic SEDs based on different types of galaxies (AGN type 1, type 2, SB, etc., Polletta et al 2007). The diagnostics result from averages on hundreds of objects.

Nevertheless, star formation within galaxies at various redshifts depends also on the interstellar medium (Spaans & Carollo 1997) due to gas and dust heating by the radiation flux and to compression by, e.g., supernovae and stellar winds. During mergers of spiral galaxies at high redshifts (Springel et al 2005) the collision and mixing of galaxy debris trigger nuclear gas inflow, which leads to energetic starbursts and black hole accretion. The gas photoionised and heated by radiation from the SB, by the AGN power-law flux and by collisional process within the galaxies emits the line spectrum as well as the continuum. However, the continuum emitted from the gaseous and dusty clouds within the host galaxy is generally neglected in the modelling of the SED.

In this paper we would like to demonstrate that gas and dust contributions from clouds within the host galaxies have a leading role to explain the observed continuum SEDs on a large frequency range. We focus on the continuum (by free-free and free-bound radiation) emitted from the gas inside the host clouds. The physical conditions and the element relative abundances are revealed by the detailed modelling of the line ratios, while the continuum SED permits to recognize directly the radiation sources dominating in the different frequency ranges as well as the background stellar populations. The interpretation of the line ratios constrains the models, while the modelling of the continuum SED is less straightforward, because the contributions from different radiation sources (e.g. background stars, dust grains at different temperatures, synchrotron radiation, etc) overlap within close frequency ranges; some of them are uncertain and not well disentangled. In this paper we model the observed SED consistently with the line spectra by the code SUMA which has been successfully used to calculate line and continuum spectra from clouds under the coupled effect of shock and photoionization in different cases. Dust reprocessed radiation is consistently calculated by the code. Shocks are significant because most galaxies at high and low redshifts are the product of merging. Therefore, we will adopt for the analysis of the continuum SED of each object the same model as that previously calculated to reproduce the line fluxes emitted from host galaxy. Comparing the calculated continuum with the photometric data observed in the different wavelength domains, (from radio to X-ray, when available) the old star background contribution is expected to emerge. The GRB host samples presented in the following are relatively poor because few objects appear in both line and continuum samples. The SLSN host sample presented by Perley et al (2016) is relatively abundant in number of objects because the observations contain both spectroscopic and photometric data. The same occurs for the Ramos Almeida et al sample. This sample has been chosen because in each galaxy a SB and/or an AGN are disclosed by modelling the line and continuum spectra.

To reproduce the Krühler et al (2011) observed SEDs we select the objects which appear in the Krühler et al (2015) sample of line spectra that were analysed in detail by Contini (2016). For the Hunt et al (2014) SEDs we use the models calculated by Contini (2016, 2017a) for the Han et al (2010), Sollerman et al (2005), Krühler et al (2015), Levesque et al (2010), Graham & Fruchter (2013) and Michalowski et al. (2014) line spectra. In Sect. 2 we briefly describe the calculation process. In Sect. 3 the results of modelling Hunt et al, Krühler et al and Sokolov et al observed continuum SEDs are discussed and compared with those obtained for the Perley et al SLSN host galaxy sample and for the SB-AGN survey presented by Ramos Almeida et al. Concluding remarks follow in Sect. 4.

2 ABOUT THE CALCULATION CODE

We use composite models which account consistently for photoionization and shocks. The code SUMA is adopted. The main input parameters are those which are used for the calculations of the line and continuum fluxes. They account for photoionization and heating by primary and secondary radiation and collisional process due to shocks. The input parameters such as the shock velocity $V_s$, the atomic preshock density $n_0$ and the preshock magnetic field $B_0$ (for all models $B_0=10^{-5}$Gauss is adopted) define the hydrodynamical field. They are used in the calculations of the Rankine-Hugoniot equations at the shock front and downstream and are combined in the compression equation which is resolved throughout each slab of the gas in order to obtain the density profile downstream. Primary radiation for SB in the GRB host galaxies is approximated by a black-body (bb). The input parameters are the effective temperature $T_\alpha$ and the ionization parameter $U$. For an AGN, the primary radiation is the power-law radiation flux from the active centre $F$ in number of photons cm$^{-2}$ s$^{-1}$ eV$^{-1}$ at the Lyman limit and spectral indices $\alpha_U=-1.5$ and $\alpha_X=-0.7$. The primary radiation source does not depend on the host physical condition but it affects the surrounding gas. This region is not considered as a unique cloud, but as a sequence of slabs with different thickness calculated automatically following the temperature gradient. The secondary diffuse radiation is emitted from the slabs of gas heated by the radiation flux reaching the gas and by the shock. Primary and secondary radiation are calculated by radiation transfer.

In our model the line and continuum emitting region throughout the galaxy covers an ensemble of fragmented clouds. The geometrical thickness of the clouds is an input parameter of the code $(D)$ which is calculated consistently with the physical conditions and element abundances of the emitting gas. The fractional abundances of the ions are calculated resolving the ionization equations for each element (H, He, C, N, O, Ne, Mg, Si, S, Ar, Cl, Fe) in each ionization level. Then, the calculated line ratios, integrated throughout the cloud thickness, are compared with the observed ones. The calculation process is repeated changing the input parameters until the observed data are reproduced by the model results, within 10 percent for the strongest line ratios and within 50 percent for the weakest ones.

However, some parameters regarding the continuum SED, such as the dust-to-gas ratio $d/g$ and the dust grain...
radius \( a_{gr} \) are not directly constrained by fitting the line ratios. Dust grains are heated by the primary radiation and by mutual collision with atoms. The intensity of dust reprocessed radiation in the IR depends on \( d/g \) and \( a_{gr} \). In this work we use \( d/g=10^{-14} \) by number for all the models which corresponds to \( 4.1 \times 10^{-4} \) by mass for silicates (Draine & Lee 1994). The distribution of the grain size along the cloud starting from an initial radius is automatically derived by \textsc{summa}, which calculates sputtering of the grains in the different zones downstream of the shock. The sputtering rate depends on the gas temperature, which is \( \propto V_s^2 \) in the immediate post-shock region. In the high-velocity case \( (V_s \gtrsim 500 \text{ km s}^{-1}) \) the sputtering rate is so high that the grains with \( a_{gr} \lesssim 0.1 \mu m \) are rapidly destroyed downstream. So, only grains with large radius \( (a_{gr} \gtrsim 0.1 \mu m) \) will survive. On the other hand, the grains survive downstream of low-velocity shocks \( (<200 \text{km s}^{-1}) \). Graphite grains are more sputtered than silicate grains for \( T=10^6 \text{ K} \) (Draine & Salpeter 1979). Small grains (e.g. PAH) survive in the extended galactic regions on scales of hundred parsecs and lead to the characteristic features that appear in the SED. In conclusion, cold dust or cirrus emission results from heating by the interstellar radiation field, warm dust is associated with star formation regions and hot dust appears around AGN (Helou 1986) and in high velocity shock regimes. Therefore, we will consider relatively large grains, e.g. silicate grains with an initial radius of \( 0.1 - 1.0 \mu m \).

In the radio range the power-law spectrum of synchrotron radiation created by the Fermi mechanism at the shock front is seen in most galaxies. It is calculated by \textsc{summa} adopting a spectral index of -0.75 (Bell 1977).

\section{3 ANALYSIS OF THE SED}

The models constrained by the fit of the line spectra give a hint about the relative importance of the different ionization and heating mechanisms which are recognised throughout the continuum SED in each of the objects. In particular:

1) The black body radiation corresponding directly to the temperature dominating in the starburst is seldom observed in the UV, because absorption is very strong in this frequency range due to strong line formation.

2) The shock effect throughout the SED can be recognized from the maximum frequency and intensity of the dust reprocessed radiation peak in the infrared and of the bremsstrahlung at high frequencies (see Contini, Viegas & Prieto 2004, Contini & Viegas 2000).

3) The gas ionized by the SB (or AGN) radiation flux emits bremsstrahlung from radio to X-ray. The black body emission from the background old star population with \( T_{sb}\sim 3000-8000 \text{ K} \) generally emerges over the bremsstrahlung throughout the SED in the near-IR (NIR) - optical range.

4) In the radio range synchrotron radiation created by the Fermi mechanism is recognized by its spectral index. Thermal bremsstrahlung in the radio range has a steeper trend which becomes even steeper by self-absorption at low \( \nu \) (Sect. 3.5). In the far-IR only comparison with the observation data indicates the source of the continuum radiation flux, because thermal bremsstrahlung, synchrotron radio and cold dust reradiation may be blended.

Figs. 1-6 show the calculated SEDs which best fit the data. In all the diagrams two curves appear for each model. The continuum calculated by the models (which reproduce also the observed line ratios) in the radio-X-ray range refers to free-free and free-bound radiation (hereafter addressed to as bremsstrahlung). In the IR range dust reprocessed radiation dominates. The bremsstrahlung at \( \nu<10^{13} \text{ Hz} \) has a similar slope in all the diagrams. In fact, the bremsstrahlung continuum, emitted by free electrons accelerated in Coulomb collisions with positive ions (mostly \( \text{H}^+ \), \( \text{He}^+ \) and \( \text{He}^{++} \)) in nebulae of charge Z has an emission coefficient (Osterbrock 1974):

\[ J_{\nu} \propto N_e N_z Z^2 (\pi \hbar \nu / 3 k T)^{1/2} e^{- (\hbar \nu / k T)} \]

The photoionization radiation flux can heat the gas to \( T \sim 2-4 \times 10^4 \text{ K} \), while the gas is heated collisionally by the shock to a maximum of \( T=1.5 \times 10^7 \text{ (} V_s / 100 \text{ km s}^{-1} \text{)}^2 \text{ K} \), where \( V_s \) is the shock velocity. The cooling rate downstream depends on \( N_e N_z \) (\( N_z \) is the proton density). The trend of the bremsstrahlung as function of \( \nu \) depends from the interplay between \( T \) and \( \nu \). High temperatures of the emitting gas determine the maximum bremsstrahlung at high \( \nu \). At \( T \sim 1-4 \times 10^5 \text{ K} \) the exponential term is significant at frequencies between \( 10^{14} \) and \( 10^{15} \text{ Hz} \). The temperatures are calculated by thermal balancing between the heating rates which depend on the photoionizing flux and the cooling rates by free-free, free-bound and line emission. Therefore, the radiation effect is seen mainly in this frequency range. In the radio range, the exponent in eq (1) tends to 0 and the continuum is \( \propto \nu^{-1/2} \) (see Figs 1-6). So the SEDs in all the diagrams (Figs. 1-6) of all galaxy types have similar trends at relatively low frequencies and the dust reprocessed radiation bump in the IR is clearly recognizable.

\subsection{3.1 The Hunt et al (2014) GRB host sample.}

**Herschel observations**

Hunt et al. (2014) claim that dark GRBs which are characterised by the very faint observed optical afterglow relative...
to the extrapolation from the X-ray, can be found in massive, star forming galaxies with red colour, high extinction and large SFR. Observations with Herschel (by the Photodetector Array Camera & Spectrometer) up to redshift $\sim 3$ have detected 7 out of 17 GRB. Combining the IR data with optical, near IR and radio data from the literature, Hunt et al have successfully modelled by GRASIL the SEDs on 6 orders of magnitude. Hunt et al found that GRB host galaxies are medium-seized with relatively high specific SFRs. Hunt et al concluded that the fraction of observed dark hosts suggests that they are more likely to be detected at IR/submm wavelength than their optically bright counterparts.

We compare the models calculated for the Hunt et al GRB host sample in Fig. 1 on a large frequency range be-
cause the data cover the radio-UV domain. The errorbars are absent for sake of clarity. The errors are relatively small (<10 percent) but could confuse the dataset trends. In Table 1 we report the objects selected from the Hunt et al. (2014) sample that were already analysed by modelling the line ratios (Contini 2016) emitted from the host galaxies presented in different samples (described in the bottom of Table 1) and the model results. (Model results are represented by the code input parameter set which leads to the best fit of the data). For GRB980425, GRB980703 and GRB080207, $a_{gr}$ = 1. $\mu m$ has been adopted, for the other objects of the Hunt et al. sample, $a_{gr}$ = 0.1 $\mu m$. Dust reradiation is calculated by the models adopting $(d/g)_0$ = 0.0004 by mass for all the hosts. In Fig. 1 we present the best fit of calculated to observed SEDs. The data are observed at Earth while bremsstrahlung and dust reprocessed radiation are calculated at the emitting nebulae. Therefore an adjusting factor $\eta_d$ is adopted to shift the calculated flux. $\eta_d$ depends on the galaxy distance to Earth and on the distance $r$ of the emitting cloud from the central radiation source in the host galaxy (Table 2). We calculate $r$ by $(\nu F_\nu)_c$ = $4 \pi d^2 F_\nu$, $4 \pi r^2$, where $(\nu F_\nu)_c$ (in erg cm$^{-2}$ s$^{-1}$) is the flux observed at Earth and $(\nu F_\nu)_c$ is the bremsstrahlung calculated at the nebula. Considering that dust and gas coexist in the same cloud, to fit the observation data in the IR we can enhance or reduce the reradiation bump by multiplying $(d/g)_0$ by a factor $f_{d/g}$. We obtain $d/g = f_{d/g} \times (d/g)_0$ (Table 2). The average $d/g$ in the Milky Way is 0.007 (Dwek & Chercnereff 2011). If dust and gas coexist in the nebula at the same radius, $d/g$ ranges between 8.2 $\times$ 10$^{-5}$ and 0.032. Adopting a patchy distribution of dust ($f < 1$) the results can change towards higher $d/g$. In Table 2, the galaxy distances to Earth are given in column 2 followed by $r$ in column 3, $d/g$, in terms of $(d/g)_0 = 0.0004$ in column 4, $\eta_d$ and $\eta_n$ in columns 5 and 6, respectively. Table 2 shows that $\eta_d > \eta_n$ for GRB980425 and GRB0511022. For a few GRB hosts (GRB980425, GRB080207 and GRB070306) the contribution of the old star population is shown throughout the SED. In column 7 the temperatures corresponding to the background old stars are given.

In particular, GRB980703 shows a very high $T_s$ (3.4 $\times$ 10$^5$K) similar to that of stars close to outburst, high $U$ and extended clouds with a relatively low preshock density. The high $T_s$ is similar to those found in GRB990712 and GRB020903 (Contini 2016) which are also included in the sample of Han et al. for hosts containing W-R stars. $d/g$ is very high, reaching $d/g$ = 0.03. We have found that the dusty clouds are relatively far from the high temperature radiation source. Dust grains could evaporate at temperatures reaching $> 1000$ K. They are also partly sputtered throughout shocks with $V_s$ = 190 km s$^{-1}$. In this case we suggest that dust grains are created in the outskirt of the host galaxy.

GRB980425 was investigated in detail by Michalowski et al. (2014) who presented data for both the entire GRB host and for the W-R star formation region located at 800 pc from the GRB position. In a previous modelling of the spectra in the different regions of GRB980425 (Contini 2017a) we have found similar physical conditions throughout the host, in particular next to the SN and the GRB regions. GRB980425 is associated with SN 1998bw (Galama et al. 1998) which hosts the closest GRB. By modelling the SEDs Michalowski et al. found a low dust content in the GRB host. Moreover, the W-R region contribution is relatively high in the far-IR-radio range. They claim that the presence of dust is connected with star formation. The modelling of GRB980425 SED by the physical parameters (see Table 1) constrained by the detailed modelling of the line ratios is shown in Fig. 1 top left diagram. We added in this diagram the data from Poonam & Frail (2012) in the radio range which are attributed to the afterglow because they are well fitted by the thermal bremsstrahlung calculated by the model which accounts for photoionization and shocks. On the other hand, the data in the radio range provided by Michalowski et al. show a lower flux and a different slope, which could suggest synchrotron radiation by the Fermi mechanism at the shock front. For these reasons we leave in the diagram all the observation data throughout the frequency range. The bb flux from background star radiation corresponding to 6000 K and another bb flux at 100 K are used to reproduce the whole SED. The 100 K black body could be easily explained by dust grains heated throughout the host. Our modelling shows that reradiation by dust calculated consistently with gas should be very low, because constrained by the data in the far-IR.

The modelling of the flux from the whole galaxy shows some ambiguities. First, the fit of the afterglow radio data by the model referring to the host is rather suspicious. Second, the suppression of dust reradiation calculated from the emitting clouds. Therefore we now model the SED presented by Michalowski et al. for the W-R star formation region (Fig. 1 top right). The data from this region contribute to the SED by a low percent which increases sensibly in the radio range. We thus believe that the radiation source is identified with W-R stars rather than with other sources in the extended GRB region. The composite model reproduces the data in the radio, in the far-IR corresponding to both dust reradiation and thermal bremsstrahlung. The bb radiation from 6000K stars and from 100K dust contribute to the SED also in the W-R region. Then, we can remove the bremsstrahlung from the GRB extended region and confirm that the Poonam & Frail (2012) observed radio data come from the afterglow. Concluding, from the extended host region we see the bb flux at 100K and 6000K, while from the W-R region we see the thermal bremsstrahlung from the clouds heated and photoionized by the SB at an effective temperature of 6.5 $\times$ 10$^4$ K, and some percent of the bb fluxes at 100K and 6000K. It seems that the bb flux at 100K, too low to represent background stars, derives from matter spread all over the host galaxy.

GRB070306 appears in the Hunt et al. sample and in the Krühler et al. (2011) one. The line ratios were modelled on the basis of Krühler et al. (2015) data for both, but the continuum observations come from different sources. The results are the same, but Hunt et al. survey covers also some data in the IR. Therefore this GRB SED is reported in both Figs. 1 and 3.

In Fig. 2 we report together the calculated continuum SEDs for the objects presented in Fig. 1 because they cover the radio-IR-optical and UV frequency range. Fig. 2 shows that the bremsstrahlung, dust reradiation and radio emission domains are well recognizable and indicate that at relatively high frequencies the shock velocity leads to X-ray emission. The background old stars are mostly at temperatures of $\sim$ 6000 K. The dust reradiation bump does not invade the radio emission range at $\nu \leq 10^{10}$ Hz.
3.2 Continuum SEDs for selected objects from the Krühler et al (2011) GRB host sample

The observations were initiated by GROND and in the case of non-detections in individual filters they were continued by EFOSC/SOFI at the NTT (4m class) and FORS2/HAWKI at the VLT (8m class). The UV/optical/NIR photometry of the selected GRB hosts were analysed in a standard way using stellar population synthesis techniques to convert luminosities into stellar masses. We selected the objects that were modelled on the basis of the line spectra presented by Krühler et al (2015). The models are described in Table 3 (see Contini 2016, table 6).

In Fig. 3 the observed data from the GRB host (Krühler 2011) correspond to the 10^{14} < v < 10^{15} Hz frequency domain, therefore they do not contain any contribution from dust. The modelling of the SEDs for the selected GRB hosts does not constrain the dust-to-gas ratios, but the line ratios were reddening corrected indicating that dust could be present.

In GRB070306 optical-near IR data are well fitted by the bremsstrahlung calculated by the model presented in Table 3 which is characterized by a relatively high $T_\ast$ ($7\times10^4 K$). In this host galaxy as well as in GRB080605 and GRB090926B the contribution of the bb flux from background stars with $T\sim 6000 K$ is evident. GRB080605 continuum SED is well reproduced by the bremsstrahlung from the clouds. Elasdottir et al (2009) claim that the dust-to-gas ratio for GRB070802 host is significantly lower than that of other GRB hosts. There are no data available to confirm it. The bremsstrahlung calculated by the model fitting the line spectrum of GRB100621A (described in Table 3) reproduces only a few data at <3×10^{14} Hz of the SED. The data reported by Krühler et al cover a large frequency range (see Krühler et al 2011, fig. 8). To reproduce the entire observation trend the bb fluxes referring to 6000K and 5×10^4 K are added in the diagram. The bb flux at $T=6000 K$ from the background star population is common also to the other sample galaxies. The bb flux at $T=5\times10^4 K$ which fits the continuum data at the highest observed frequencies can be considered as the direct flux (not reprocessed by the gasous clouds) from the photoionizing source. Actually, a SB temperature $T_\ast=5\times10^4 K$ was found phenomenologically by modelling the line ratios (Contini 2016, Table 6).

Factors $\eta_g$ calculated adopting a filling factor $f_f=1$ for each object appear in Table 4. They are the same for gas and dust for the Krühler (2011) sample hosts, considering that dust and gas coexist. However, there are no data in the IR to constrain $d/g$.

### Table 4. Modelling the Krühler et al (2011) SEDs

| GRB    | $d$ (Mpc) | $r$ (kpc) | $\eta_g$ | $T_{bb}$ (1000 K) |
|--------|-----------|-----------|-----------|-----------------|
| 070306 | 11052.3   | 4.93      | -12.7     | 6               |
| 070802 | 20278.3   | 38.19     | -11.45    | -               |
| 080605 | 12384.5   | 13.11     | -11.95    | 6               |
| 080805 | 11088.9   | 5.25      | -12.65    | -               |
| 090926B| 8754.9    | 14.7      | -11.55    | 8               |
| 100621A| 3162.9    | 2.23      | -12.19    | 6               |

### Table 5. Approximated modelling of Sokolov et al (2001) SEDs

| GRB    | $z$     | $\eta_g$ | $T_{bb}$ (1000 K) |
|--------|---------|----------|-----------------|
| 970508 | 0.8349  | -12.70   | -               |
| 980613 | 1.0994  | -12.12   | -               |
| 990123 | 1.6     | -12.70   | 8               |
| 991208 | 0.7063  | -12.50   | 6               |
Figure 3. The continuum SED of selected galaxies from Krührer et al. (2011) sample. Asterisks: data from Punha & Freil (2012); open circles: the data from Krührer et al (2011); solid lines: the result of models (Contini 2016, table 6b) obtained by fitting line ratio observations of Krüler et al (2015); dashed line: bb radiation corresponding to $T \geq 6000$K; dotted line: bb radiation corresponding to $T = 5 \times 10^4$K.

Figure 4. The best fit of GRB hosts from the Sokolov et al (2001) sample. Symbols as in Fig. 3.

glected GRB971214 which is defined by only the V and $R_c$ fluxes. The detailed analysis results of GRB980703 appear in Table 1. Fig. 4 shows that the bremsstrahlung emitted from the clouds within the GRB hosts reproduces satisfactorily the SEDs of GRB970508, GRB980613 and GRB991208 but not the data in the B and $V_c$ bands of GRB990123. For it and perhaps also for GRB991208 the contribution of the bb flux corresponding to $T_{bb} \geq 6000$K is needed.
3.4 Line spectra and continuum SEDs for SLSN host galaxies from the Perley et al (2016) SLSN survey

Perley et al (2016) presented UV - IR photometry and spectroscopy of SLSN hosts discovered by the Palomar Transient Factory (PTF) prior to 2013. They derive the luminosities, star formation rates, stellar masses and gas-phase metallicities by ground-based Imaging (SDSS, Palomar P60 telescope imaging camera, the WIRC on the Palomar 5-m Hale telescope, or the LRIS on the MOSFIRE on the KeckI 10 m telescope) and by ground based HST Observations, Spitzer and WISE observations described in Perley et al (2016, sect. 3). Regarding the spectral analysis, all the lines were corrected for foreground extinction (Schlafly & Finkbeiner 2011). The gas-phase oxygen abundance are calculated using direct methods, e.g. the empirical derivation of Nagao et al (2006). Perley et al (2016) concluded that the host galaxies of SLSN I have different properties from the general star-forming galaxy distribution, in particular, lower masses and metallicities and unusually high specific SFRs.

We focus on the spectra emitted from the gaseous clouds in each galaxy and we calculate the physical conditions and the element abundances by the detailed modelling of the observed line ratios. In Table 6 we present the host galaxies selected for our analysis. They include at least the data (not only upper limits) of Hα , Hβ , [OII]3727+ , [OIII]5007+ , [NII]6548+ and possibly [OIII]4363. In Table 6 we compare calculation results (models mp1-mp19) with Perley et al (2016, table 5) observed line ratios to Hβ . The results of our analysis will be used to constrain the models suitable to represent the emitting gas SEDs for each galaxy. The models are given in Table 7. In Table 7 last column we report the metallicities in terms of O/H determined by Perley et al (2016). Metallicities calculated by detailed modelling (Table 6, column 6) are nearly all solar (O/H=6.6 10 ^{-4}, Grevesse & Sauval 1998) while those evaluated by Perley et al are mostly lower than solar (except PTF 10tpz and 10uhf). Calculated N/H are lower than solar (N/H=10 ^{-4}). In previous papers (Contini 2017a and references therein) we have demonstrated that the detailed modelling of the line ratios leads generally to higher metallicities (in terms of O/H) than those calculated by the strong line methods.

The observed [SII] 6717/6731 line ratios are >1, indicating that the preshock density is < 100 cm^{-3} and shock velocities V_s cannot be > 140 km s^{-1} otherwise compression would enhance the density downstream. Most of the lines are emitted from the gas compressed downstream of the shock front and photoionised by the SB radiation. In fact, the observed line ratios show the characteristic values of radiation dominated spectra e.g. [OIII]5007+ /[OII]3727+ > 1. PTF 10qaI has outstanding V_s =200 km s^{-1} and n_0=200 cm^{-3}. They were adopted to fit the oxygen line ratios. In this case the calculated [SII]6717/6731 line ratios are < 1, while the observed ratio is > 1. We suggest that the gas emitting the [SII] lines is merging with ISM matter or with another galaxy as suggested by Perley et al (2016).

Regarding the continuum SED, to estimate stellar masses M_*, SFR and interstellar extinction A_V, Perley et al (and generally the author community) analyzed the UV-optical-NIR SEDs by a custom SED-fitting code (e.g. Perley et al 2013) using the population synthesis templates (Bruzual & Charlot 2003) summed according to a parametric star formation history (see Perley et al 2016). Indeed, in their fig. 2 they reproduced the observed SEDs with high precision. However, we suggest that the clouds emitting the line spectra should also contribute to the continuum radiation (bremstrahlung). To calculate the continuum SED we adopted the physical parameters and the element abundances which result by the best fit of all the line ratios in each spectrum (Table 7). In Fig. 5 we compare the calculated SED with Perley et al data. The fluxes (in erg cm^{-2} s^{-1}) are given as function of the frequency $\nu$ (in Herz) in a reduced range ($\log \nu$=13.5-15.5) similar to that adopted in Fig. 3 diagrams.

Fig. 5 shows that calculated models mostly fit the data at the lowest $\nu$ (≤ 3 × 10^{14} Hz), while to reproduce the data at higher $\nu$ the flux from the old star population background should be added. This flux is generally approximated by a black body to fit the SED of different galaxy types such as SB and AGN in the 10^{14}-10^{15} Hz range, even for objects at redshift higher than local. Towards lower frequencies our models diverge from the bb flux. More data will confirm the calculated trend. It was shown by Contini & Contini (2007, figs 5 and 6), Contini (2013, fig. 8), etc that the old star population data are nested within the Planck function corresponding to the effective star temperature. The bremsstrahlung from the gas defines the lower bound. To fit the observed SEDs in Fig. 5 sometimes two bb fluxes are needed. The temperatures (T_bb) are reported in Table 7, column 11. In the host galaxies PTF 11hrq and 12dam the bb fluxes corresponding to T=5× 10^{4} K are added to reproduce a few data in the SED at relatively high frequencies. Those temperatures may represent the bb flux from the SB in the host galaxy.

3.5 The SB-AGN sample by Ramos Almeida et al (2013)

Ramos Almeida et al (2013) examined star formation quenching in AGN galaxies at redshift 0.27<z<1.28 on the basis of AGN activity and star formation delay. To investigate the interactivity between AGN and star formation in galaxies they presented near-IR (NIR) spectroscopic observations of 28 X-ray and mid-infrared selected sources at median redshift $z$~ 0.8 in the Extended Groth Strip : 13 AGN dominated and 15 host-galaxy dominated. New NIR spectra referring to the continuum SEDs of objects at $z$ between ~ 0.4 and ~1.25 were reported. Moreover, they showed the spectra of an AGN subset at 0.28<z<1.28 including Hα and other key optical lines for each of them. The data reported by Ramos Almeida et al in their table 3 and completed by the data presented in their table 4 were observed by the Long-Slit Intermediate Resolution Infrared Spectrograph (LIRIS) at the 4.2m William Herschel Telescope (WHT) from the Deep Extragalactic Evolutionary Probe 2 (DEEP2). SFRs were calculated from the Hα luminosities and the line fluxes were obtained subtracting the continuum SED from each observed spectrum. The interpretation of the SED was done by the diagnostic SEDs of Polletta et al. (2007), that are based on different types of galaxies (AGN type 1, type 2, SB, etc.). The diagnostics result from averages on hundreds of objects.

We have selected 9 out of the 28 galaxies from the
Figure 5. SEDs of the Perley et al (2016) survey. Open circles: the data; solid lines: results obtained by the detailed modelling of the line spectra; dashed lines: bb fluxes referring to temperatures $T_{bb}$. 

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Ramos Almeida et al sample which show enough line ratios for a suitable modelling without any risk of degeneracy (see Contini 2013). The modelling of the observed line ratios from the selected objects adopting the code SUMA by Contini (2013, table 2) is shown in Fig. 6.

Whether the AGN or the SB dominates in each galaxy was investigated by modelling the observed spectra using a power-law and/or a black-body radiation flux, respectively. The models are described in Tables 8 and 9.

The templates adopted by Ramos Almeida et al in their fig. 2 to explain the observed IR data, were obtained combining the observed continuum SEDs of many objects for each of the sample galaxy. They classified the galaxies as starburst dominated, starburst contaminated, Seyfert 1, Seyfert 2 and normal galaxies. In Fig. 6 we show the SEDs on a scale large enough ($\nu$ between $10^7$ and $10^{19}$ Hz) to contain the X-ray data. There is now common agreement that there is mutual triggering between SB and AGN activity in the galaxies. So in Fig. 6 diagrams we have included both kinds of models.

In Table 10 we summarize the results obtained by modelling the SEDs. In column 2 the distances of the galaxies in Mpc are given. The readjusting factors ($\eta_{\text{AGN}}, \eta_{\text{SB}}$) are followed by the distances of the emitting nebula from the galaxy centre ($r_{\text{AGN}}, r_{\text{SB}}$), respectively. The results show that the distance from the radiation source of the clouds photoionised by the AGN flux is larger by a factor at least 2 than that of clouds photoionised by the the SB flux. We suggest that the AGN flux reaches the outskirts of the galaxy while the starburst flux is contained inside smaller regions throughout the ISM. The radii of the emitting clouds from the active centre are similar to those of the AGN narrow line region (NLR). Fig. 6 shows that the datum at 24 $\mu$m is always produced by dust reprocessed radiation. It is the only datum at $\lambda > 10$ $\mu$m constraining the dust reradiation peak. Dust-to-gas ratios by mass $d/I_g = 0.0004$ were adopted in the models. At frequencies referring to wavelengths between $\sim 8$ and 12 $\mu$m the large crater of silicate absorption at $\lambda \sim 10$ $\mu$m and a large absorption by ices and HAC at 6 $\mu$m and 7 $\mu$m respectively (Spoon et al 2002) may affect...
Table 7. Models used to reproduce Perley et al (2016) spectral line ratios and SEDs

| model | $V_\alpha$ | $n_0$ | $D$ | log(N/H)+12 | log(O/H)+12 | log(S/H)+12 | $T_\alpha$ | $U$ | H$\beta$ | $T_{bb}$ | log(O/H)+12 |
|-------|-----------|-------|-----|-------------|-------------|-------------|----------|----|---------|---------|------------|
| mp1   | 120       | 65    | 5.8 | 7.54        | 8.74        | 7.7         | 5.2      | 24 | 3.5     | 6       | 7.98       |
| mp2   | 120       | 65    | 52.5| 7.3         | 8.82        | 7.3         | 6.5      | 8.5 | 74.5    | 5       | 8.21       |
| mp3   | 120       | 55    | 26. | 7.0         | 8.82        | 7.48        | 4.9      | 15  | 8.2     | 6       | 8.09       |
| mp4   | 100       | 63    | 27. | 7.0         | 8.82        | 7.48        | 6.1      | 6.5 | 18.3    | 6       | 7.41       |
| mp5*  | 100       | 260   | 1.  | 7.0         | 8.82        | 7.48        | 5.6      | 20  | 100     | 6       | 8.78       |
| mp6*  | 100       | 60    | 5.  | 7.95        | 8.82        | 7.48        | 3.       | 3   | 8.2     | 5       | 8.30       |
| mp7   | 120       | 55    | 6.  | 7.6         | 8.82        | 7.52        | 5.5      | 3.5 | 6.5     | 8       | 8.30       |
| mp8   | 120       | 55    | 13.5| 7.9        | 8.82        | 7.52        | 5.5      | 1.5 | 9.2     | 3       | 8.87       |
| mp9   | 140       | 65    | 5.8 | 7.48        | 8.73        | 7.7         | 5.2      | 24  | 3.8     | 8       | 8.14       |
| mp10  | 200       | 200   | 0.55| 7.3         | 8.76        | 7.7         | 5.5      | 3.5 | 27.5    | 5       | 8.36       |
| mp11* | 100       | 60    | 500 | 9.          | 8.82        | 7.78        | 1.       | 0.6 | 17.5    | 3.5     | 9.22       |
| mp12* | 120       | 90    | 90. | 9.          | 8.88        | 7.78        | 1.6      | 13. | 3.5     | 9       | 9.0        |
| mp13* | 100       | 80    | 2.  | 8.          | 8.82        | 7.48        | 5.6      | 13  | 6.5     | 8       | 8.38       |
| mp14* | 100       | 70    | 1.6 | 7.84        | 8.82        | 7.52        | 4.       | 12  | 3.8     | 5       | 8.19       |
| mp15* | 100       | 70    | 1.6 | 7.84        | 8.82        | 7.52        | 4        | 22  | 3.5     | 8       | 8.20       |
| mp16* | 100       | 70    | 1.6 | 7.84        | 8.82        | 7.52        | 4.4      | 16  | 3.4     | 6       | 8.15       |
| mp17* | 140       | 65    | 1.2 | 7.48        | 8.82        | 7.7         | 5.2      | 24  | 3.2     | 8       | 7.97       |
| mp18  | 120       | 55    | 10. | 7.6         | 8.82        | 7.52        | 5.5      | 3.5 | 85.     | 6       | 8.64       |
| mp19  | 120       | 63    | 10. | 7.7         | 8.82        | 7.7         | 4.9      | 8.5 | 3.6     | 6       | 8.07       |

(1): km s$^{-1}$; (2): cm$^{-3}$; (3): $10^{46}$ cm$^3$; (4): solar = 8.0; (5): solar = 8.82; (6): solar = 7.48; (7): $10^4$ K; (8): 0.001; (9): $10^{-4}$ erg cm$^{-2}$ s$^{-1}$; (10): $10^3$ K; (11): Perley et al (‘best’); * models adopting outflowing clouds

the SED between the vertical dashed lines in Fig. 6 (top left panel).

For all the sample galaxies, except for G60, G63 and G90, bb radiation calculated by a uniform temperature $T_\alpha$ ($\sim 4 \times 10^4$ K, Table 7) contributes to the modelling of nearly all the data. The old star background temperature ranges between 2000K and 3000 K for all the galaxies except for G90 where both $T_\alpha$ = 1000 K and $T_\alpha$ = 300 K are required to the best fit of the NIR and FIR data, respectively (Table 10). A temperature of 1000 K can be reached near IR range of G90, the contribution of a starburst dominates bremsstrahlung with high $V_\alpha$ and $n_0$ can be recognized summed up with the old star background black body radiation and the reradiation by hot dust. In fact, Ramos Almeida et al classified it as SB contaminated, including three different starburst composite SEDs, one starburst/Seyfert 1 and two starburst/Seyfert 2. The G63 galaxy shows the contribution of an AGN with rather high $V_\alpha$ and $n_0$ and the contribution of a SB. The other galaxies of the sample show a mixed nature of AGN and SB and shocks.

4 CONCLUDING REMARKS

We have modelled the continuum SED for a sample of GRB hosts presented by Krühler et al (2011) at $z=0.543-2.45$, of obscured GRB hosts presented by Hunt et al (2014) at $z=0.0085-2.86$ and of GRB hosts showing high extinction by Sokolov et al (2001) at $z=0.7-1.6$. We have compared them with the sample of SLSN hosts observed by Perley et al (2016) at $z=0.0395-0.477$ and the SB-AGN by Ramos Almeida et al (2013) at $z=0.465-1.148$. Line and continuum fluxes are calculated consistently by the suma code which accounts for both the photoionization from an active source (SB, AGN) and for the shock. We confirm that the continuum (bremsstrahlung) emitted by the same gaseous clouds which emit the line flux contributes to the SED. Therefore, we have selected from the samples the objects that could be modelled on the basis of the line spectra because modelling the SED is less constraining. As was found in previous works the flux from the background stars and reprocessed radiation from dust grains also shape the continuum SED.

The modelling of the continuum shows that the SED of GRB host galaxies in some frequency domains (e.g. the radio) is similar to that of SLSN, SB and AGN even at redshifts higher than local, because it follows the bremsstrahlung trend at relatively low ($\nu < 10^8$ K) temperatures by the shock. In particular, if we disentangle the large bump in the near IR range of G90, the contribution of a starburst dominated bremsstrahlung with high $V_\alpha$ and $n_0$ can be recognized summed up with the old star background black body radiation and the reradiation by hot dust. In fact, Ramos Almeida et al classified it as SB contaminated, including three different starburst composite SEDs, one starburst/Seyfert 1 and two starburst/Seyfert 2. The G63 galaxy shows the contribution of an AGN with rather high $V_\alpha$ and $n_0$ and the contribution of a SB. The other galaxies of the sample show a mixed nature of AGN and SB and shocks.
Figure 6. The best fit of model calculations to the observed Ramos Almeida (2013) SB-AGN continuum SEDs. Black asterisks : the data; black horizontal segments : the X-ray flux; blue solid lines : AGN model for G63b; red dot-dashed lines : SB model for G63b; blue dotted : AGN model for G63r; red dotted lines : SB model for G63r black lines marked with dots : shock dominated high velocity models; green lines : black body radiation from the old star population background; magenta dotted line : black body flux from the SB for G90.

2) In the IR frequency range the SED is dominated by dust reprocessed radiation even for very low $d/g \ (<0.0004)$. Dust reradiation depends on $d/g$ but also on $a_g$ and $V_\phi$. It seldom contributes to the SED at $\nu<10^{10}$ Hz. The highest frequency limit depends on $V_\phi$. We have found that $d/g$ ranges in obscured GRB hosts between $\sim 0.0001$ and 0.032.

3) In the NIR-optical domain the old star population background emerges from the bremsstrahlung. Our modelling shows that its contribution is present in nearly all the continua of SLSN hosts with temperatures of $\sim 6000$-$8000$K, in most of the SB-AGN galaxies with temperatures of $\sim 3000$K, and in the GRB hosts with temperatures of $\sim 4000$-$8000$K. It was shown by previous investigations (e.g. Contini & Contini 2003) that the data are nested within bb radiation bumps. In the present analysis only a few data are available.

4) The direct bb flux corresponding to SB effective temperatures are seen in a few objects, GRB100621A, PTF11hrq and PTF12dam hosts.

The physical parameters characteristic of the host galaxies in the different samples are summarized in Table 11. They indicate that the $T_\star$ which are responsible of gas photoionization by black body radiation are roughly lower for SLSN hosts than for the GRB. The systematic presence of two radiation sources at $\sim 1-30 \times 10^4$K and at $3-8 \times 10^3$K in most of the objects leads to think to some sort of connection between them, but comparing the SEDs in Figs. 1-6 diagrams with those of e.g. symbiotic systems (Angeloni et al 2010), a different situation is evident.

Even neglecting the broad line contribution to AGN spectra, the shock velocities reach higher values in the SB-AGN galaxies than in the GRB and SLSN hosts. Freshock densities are definitively higher in the SB-AGN sample by a factor $\leq 10$, increasing the downstream cooling rate and reducing the bremsstrahlung for $\nu>10^{18}$ Hz.

Some objects deserve a special mention. GRB980703 host extended clouds are photoionised by radiation corresponding to a relatively high SB effective temperature ($T_\star = 6.5 \times 10^5$ K). It was found by modelling the continuum SED that this temperature corresponds to the W-R stars and leads to the thermal bremsstrahlung which reproduces the data in the radio range. Dust reradiation in the
Table 8. Physical parameters in AGN dominated models for Ramos Almeida et al (2013)

| model | $V_s$ km s$^{-1}$ | $n_0$ cm$^{-3}$ | $F$ units | $D$ 10$^{16}$ cm | $z$ |
|-------|------------------|-----------------|------------|----------------|---|
| M90   | 700              | 800             | 2          | 0.2            | 1.148 |
| M26   | 200              | 1300            | 2          | 0.00584        | 0.808 |
| M25   | 250              | 1300            | 2          | 0.17           | 0.761 |
| M53   | 350              | 1000            | 0.8        | 0.37           | 0.72  |
| M107  | 100              | 1000            | 0.8        | 1.67           | 0.67  |
| M74   | 280              | 1600            | 2          | 0.073          | 0.551 |
| M60   | 200              | 650             | 2          | 0.18           | 0.484 |
| M63b  | 600              | 500             | 2          | 0.3            | 0.482 |
| M63r  | 200              | 330             | 2          | 0.6            | 0.482 |
| M59   | 260              | 600             | 0.5        | 0.145          | 0.465 |

1 in 10$^{10}$ photons cm$^{-2}$s$^{-1}$eV$^{-1}$ at the Lyman limit

Table 9. Physical parameters in SB dominated models for Ramos Almeida et al (2013)

| model | $V_s$ km s$^{-1}$ | $n_0$ cm$^{-3}$ | $T_*$ K | $U$ | $D$ 10$^{16}$ cm | $z$ |
|-------|------------------|-----------------|---------|----|----------------|---|
| Mz90  | 400              | 300             | 4.3     | 0.76 | 2              | 1.148 |
| Mz26  | 200              | 1300            | 4       | 0.08 | 0.6            | 0.808 |
| Mz25  | 200              | 1300            | 4       | 0.07 | 0.6            | 0.761 |
| Mz53  | 350              | 1000            | 4       | 0.11 | 1              | 0.72  |
| Mz107 | 100              | 1000            | 4       | 0.03 | 1              | 0.67  |
| Mz74  | 280              | 1000            | 4       | 3    | 100            | 0.551 |
| Mz60  | 250              | 750             | 4       | 0.5  | 0.9            | 0.484 |
| Mz63b | 560              | 500             | 4       | 0.5  | 0.6            | 0.482 |
| Mz63r | 250              | 400             | 6       | 0.6  | 8              | 0.482 |
| Mz59  | 280              | 600             | 7       | 12   | 9              | 0.465 |

Table 10. Parameters used to model the Ramos Almeida et al (2013) SEDs

| $d_1$ | $\eta_{AGN}$ | $r_{AGN}^2$ | $\eta_{SB}$ | $r_{SB}^2$ | $T_M$ K |
|-------|--------------|-------------|-------------|------------|--------|
| G25   | 3.04         | -12.        | 3           | -12.5      | 1.7    | 3      |
| G26   | 3.23         | -11.9       | 3           | -12.5      | 1.8    | 3      |
| G53   | 2.88         | -12.1       | 2.6         | -12.7      | 1.29   | 2      |
| G59   | 1.86         | -11.6       | 2.95        | -13.5      | 0.33   | 3      |
| G60   | 1.94         | -11.4       | 3.87        | -12.9      | 0.69   | -      |
| G63b  | 1.93         | -11.1       | 5.44        | -12.1      | 1.7    | -      |
| G63r  | 1.93         | -10.9       | 6.8         | -12.5      | 1.08   | -      |
| G74   | 2.20         | -11.9       | 2.47        | -12.6      | 1.1    | 2      |
| G90   | 4.59         | -13.        | 1.45        | -11.9      | 5.1    | 1      |
| G107  | 2.68         | -11.2       | 6.73        | -11.95     | 2.84   | 2      |

1 in 10$^3$ Mpc ; 2 in kpc ; 3 in 1000 K

Table 11. The physical parameters in the different samples

| object | $V_s$ km s$^{-1}$ | $n_0$ cm$^{-3}$ | $T_*$ K |
|--------|------------------|-----------------|---------|
| Hunt et al | 120-300 | 50-150 | 4-34 |
| Krühler et al | 130-280 | 80-150 | 5-9 |
| Perley et al | SLSN | 100-200 | 55-260 | 1-6.5 |
| Ramos Almeida et al | SB | 100-400 | 50-1300 | 4-7 |
| Ramos Almeida et al | AGN | 100-700 | 330-1600 | - |

Figure 7. Data from Hunt et al (2014) SFR(UV) (asterisks), to the SFR(IR) (cross); SFR data from Krühler et al (2011) (squares); SFR data from Sokolov et al (2001) (hexagons); SFR data from Ramos Almeida et al (2013) (stars) and from Perley et al (2016) (triangles). Calculated $d/g$ in units of $(d/g)_0$ (open circles).

GRB980425 host shows the lowest $d/g$ (<0.0001). We report in Fig. 7 the SFR presented by Hunt et al. (2014), Krühler et al (2011) and Sokolov et al (2011) for GRB hosts, by Perley et al for SLSN hosts and by Ramos Almeida et al for SB-AGN galaxies. For all of them SFR roughly increases with z. Dust-to-gas ratios which result by modelling the observed SEDs of obscured GRB hosts, follow the SFR increasing trend. This suggests that dust grains are destroyed with time towards low z mainly by sputtering downstream of shock fronts throughout the GRB hosts.

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