

Spectral energy distributions of submm/radio bright gamma-ray burst host galaxies

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Abstract.

We present optical to radio spectral energy distribution fitting of the host galaxies of four long gamma-ray bursts: 980703, 000210, 000418 and 010222, which were detected at submillimetre and/or radio wavelengths. We find that only very young starburst galaxy models are consistent with the data having both blue optical colors and a pronounced submm emission. For each host we are able to construct a model consistent with the short- and long-wavelength parts of the spectra. We find galaxy ages ranging from 0.09 to 2.0 Gyrs and star formation rates ranging from 138 to 380 $M_{\odot} \text{ yr}^{-1}$.

Keywords: galaxies: GRB hosts — galaxies: starburst — galaxies: high redshift — gamma rays: bursts — individual: GRB 980703, 000210, 000418, 010222

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INTRODUCTION

Observations of gamma-ray burst (GRB) host galaxies have attracted a lot of interest since the first interpretation of a constant extended source at a GRB position as the host galaxy [1, 2]. A detailed description of the GRB environment can provide important constraints on GRB physics [see 3, for a review] and can be used for statistical studies of starburst galaxies.

The host galaxies of the long GRBs 000210, 000418 and 010222 are somewhat special because they are the only hosts, among ~ 30 targeted by SCUBA [4], showing submillimetre emission. The hosts of GRBs 980703 and 000418 were also firmly detected at radio wavelengths [5, 6, 7] whereas those of GRBs 000210 and 010222 were only weakly detected [7]. The host of GRB 010222 was also detected at millimetre wavelengths [8]. Both submillimetre and radio detections may indicate high star formation rates (SFRs), of the order of several hundreds solar masses per year ($M_{\odot} \text{ yr}^{-1}$), if the whole emission is powered by a starburst, namely by dust at submillimetre and by supernova remnants at radio wavelengths. Moreover, a spectral energy distribution (SED) fitting applied only to optical/near-infrared data agreed reasonably with starburst templates [9, 10, 11]. This picture is consistent with the hypernova GRB model [12, 13].

However, the starburst scenario of GRB hosts is more complicated because, unlike red, dusty, sturbursting submillimetre galaxies [14], GRB hosts have been found to exhibit blue optical colors [9, 10, 15, 16]. The submillimetre/radio fluxes were also underestimated by any SED template fitted to the optical data.

Mid-infrared *Spitzer* observations of the hosts of GRBs 980703 and 010222 could not bridge the optical and submillimetre data and provide an explanation of the unusual

TABLE 1. Ages and total SFRs of GRB host galaxies. All four are young starbursts.

GRB host	z	Age* (Gyr)	SFR ($M_{\odot} \text{ yr}^{-1}$)			References	
			This work [†]	Infrared	Submm		Radio
980703	0.97	2.0	179 ± 29	$<24^{\ddagger} < 226^{\S}$	<380	180 ± 25	[23], [17], [18], [7]
000210	0.85	0.3	138 ± 17		560 ± 165	90 ± 45	[24], [7]
000418	1.12	0.14	380 ± 46		690 ± 195	330 ± 75	[25], [7]
010222	1.48	0.09	366 ± 84	$<130^{\ddagger}$	610 ± 100	300 ± 115	[26], [17], [7]
Arp 220 [¶]	0.02	13.0	580				[27], [20]

* Defined as the time since the beginning of the galaxy evolution.

[†] Errors are statistical at 1σ level calculated assuming that the template fits to the data.

[‡] Based only on $24\mu\text{m}$ [17]

[§] All photometric datapoints taken into account [18]

[¶] The Arp 220 parameters given for the comparison.

SED behaviour and a clue on dust properties because only the former was detected in the bluest $4.5\mu\text{m}$ *Spitzer* passband [17, 18].

In this contribution we attempt to find reasonable full SED fits for those four GRB host galaxies and constrain their ages and SFRs. This approach seems to be a promising tool to constrain the dust properties and the obscured star formation rates as shown, for example, by Priddey et al. [19]. We use a cosmological model characterized by $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_{\Lambda} = 0.7$ and $\Omega_M = 0.3$.

SED MODELLING

In order to model the SEDs of GRB hosts we used the GRASIL¹ software described by Silva et al. [20]. It is a numerical code that calculates the spectrum of a galaxy by means of a radiative transfer method, applied to photons produced by a stellar population, and reprocessed by dust. The importance of this model is the fact that it is self-consistent in that it fulfills the principle of energy conservation between the energy absorbed by dust in the UV/optical wavelengths and the energy re-emitted in the infrared.

Figure 1 shows that submm and radio emissions of the GRB hosts discussed here are underestimated even for a template corresponding to the nearby ultraluminous infrared galaxy (ULIRG) Arp 220 [20], which is also too red in the optical compared to GRB hosts. This indicates the need for new empirical SED models, which are presented here.

We performed SED modelling investigating a wide range of GRASIL parameters (see Michałowski [21] for a description) We scaled the SED templates to the datapoints and chose those which resulted in acceptably small χ^2 . Then we calculated the total SFRs using the infrared luminosity, integrating between 8 and 1000 μm (rest frame), and applying Kennicutt [22]: $\text{SFR}(M_{\odot} \text{ yr}^{-1}) = 4.5 \cdot 10^{-44} L_{8-1000}(\text{erg s}^{-1})$.

¹ <http://web.pd.astro.it/granato/grasil/grasil.html>

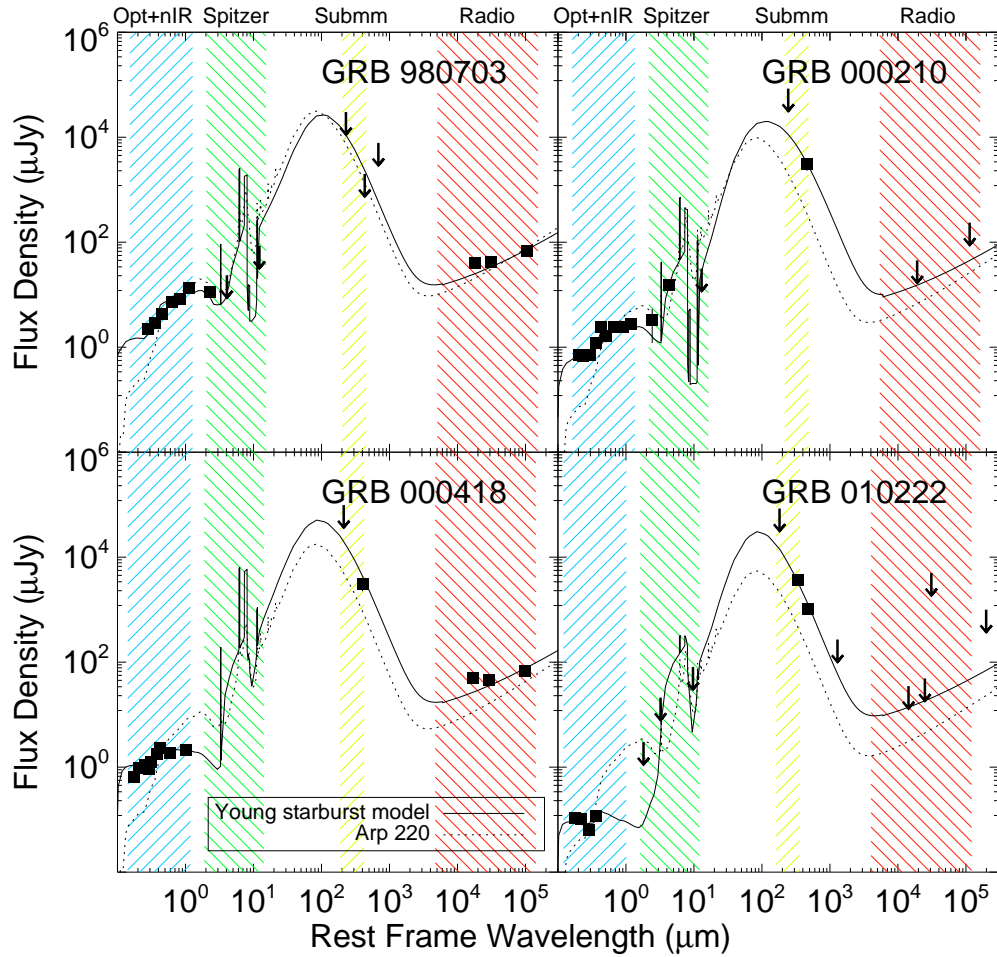


FIGURE 1. SEDs of GRB hosts. Solid lines: the young starburst galaxy models calculated using GRASIL and consistent with the data. Dotted lines: Arp 220 model [from 20]. Squares: detections with errors, in most cases, smaller than the size of the symbols. Arrows: 3σ upper limits (values marked at the base). Hashed columns mark the wavelengths corresponding to optical/near infrared filters, mid-infrared Spitzer filters, SCUBA submillimetre bands and the radio domain. Data are from: optical/near-infrared: Gorosabel et al. [9, 10], Vreeswijk et al. [15], Galama et al. [16], Sokolov et al. [28]; mid-infrared: Le Floc’h et al. [17], Castro Cerón et al. [18]; submillimetre: our reduction of archival SCUBA data, Tanvir et al. [4]; radio: Berger et al. [6, 7], Frail et al. [8], Sagar et al. [29]

RESULTS AND DISCUSSION

For each host we were able to construct an SED that fitted the data reasonably well. The corresponding ages of the galaxies and the SFRs are presented in Table 1 and fits are shown in Figure 1.

All the galaxies discussed are young (ages less than 2 Gyrs). Here, the age of a galaxy was defined as the time since the beginning of its evolution, when the stellar population starts to build up. The bigger the difference between optical and submillimetre fluxes, the lower the needed age was. This is because a younger galaxy has more stars still embedded in molecular clouds, so optical light is weaker and dust emission stronger.

The construction of the SEDs assuming low ages for the galaxies was therefore the way to take into account both significant submillimetre/radio emission and the blue optical colors of GRB hosts. In young galaxies there are, on one hand, lots of young, hot, blue stars, because they have not finished their lives yet. Hence the total optical spectrum of the galaxy is blue. On the other hand, the majority of the stars still resides in dense molecular clouds, so a significant part of the energy is absorbed and re-emitted. This increases the dust emission. GRBs reside in molecular clouds and it was found that gas column densities derived from *X*-ray afterglows in a sample of 8 GRBs (including GRB 980703, discussed here) were in the range corresponding to the column densities of giant molecular clouds in the Milky Way [30]. A similar conclusion for high-redshift GRBs was recently drawn by Jakobsson et al. [31] by means of modelling Ly α absorption features.

Based on SEDs fitted to optical data, Gorosabel et al. [9, 10] and Christensen et al. [11] derived the ages of the starbursts in the hosts of GRBs 980703, 000210, 000418. Our estimates are at most a factor of two larger. Given that we calculated the time from the beginning of the galaxy evolution, not the beginning of the starburst, our values agree with those derived by these authors. Sokolov et al. [28] derived ages of both old stellar populations and starbursts. Our estimation for GRB 980703 agrees with the age of the old component, which is conceptually closer to our definition of the galaxy age.

Table 1 also presents the SFRs derived from the SED fits. They are all high, of the order of several hundreds solar masses per year. Statistical 1σ errors, calculated assuming that the model represents the data, are also given in Table 1. On top of that, one should add the 30% uncertainty of the relation between infrared luminosities and SFRs [22].

In Table 1 our SFR estimations are compared with those derived using three other SFR indicators: mid-infrared, submillimetre and radio emission. Our results are consistent with radio-derived SFRs [7]. This is because the calibration of SFR to radio flux requires choosing only two parameters [a normalization factor and a spectral index, see 32], which are relatively well constrained. Our values also agree with the upper limits derived by Castro Cerón et al. [18] using the template of Arp 220. This approach appears to be more self-consistent and reliable than analysing only $24\mu\text{m}$ datapoints, which is strongly dependent on the unknown shape of the infrared part of SED. For example, this method applied by Le Floch et al. [17] gave upper limits inconsistent with our results. Finally, Berger et al. [7] obtained higher SFRs based on submm alone.

The mid-infrared ($5\mu\text{m} < \lambda < 40\mu\text{m}$) shape of the SEDs was not constrained due to a lack of targeted observations or detections. Hence, all SEDs shown on Figure 1 have

different mid-infrared behaviour depending on type, mixture and sizes of dust grains used. Any data in this region would be useful to learn more about the dust properties in these galaxies.

This work provides strong evidence that some GRB hosts are young starbursts. We have proposed an explanation why they have both blue optical colors and significant sub-millimetre emission unlike red, dusty submillimetre galaxies [14]. The SED approach is self-consistent and makes use of all the data available. The research presented here will be continued to build up a larger galaxy sample analysed in this way. Other properties of the host galaxies, the robustness of the technique and a more accurate treatment of the errors are discussed in Michałowski et al. [33, 34].

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