The optical/near-IR spectral energy distribution of the GRB 000210 host galaxy

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Abstract.

We report on UBVRIZJsHKs-band photometry of the dark GRB 000210 host galaxy. Fitting a grid of spectral templates to its Spectral Energy Distribution (SED), we derived a photometric redshift ($z = 0.842^{+0.054}_{-0.042}$) which is in excellent agreement with the spectroscopic one ($z = 0.8463 \pm 0.0002$; Piro et al. 2002). The best fit to the SED is obtained with a blue starburst template with an age of $0.181^{+0.027}_{-0.026}$ Gyr. We discuss the implications of the inferred low value of $A_V$ and the age of the dominant stellar population for the non detection of the GRB 000210 optical afterglow.

1. Introduction

GRB 000210 is currently one of the few systems that allow a detailed study of a galaxy which hosted a dark GRB. The burst exhibited the highest $\gamma$-ray peak flux among the GRBs localized during the entire SAX operation (Piro et al. 2002). However, no optical afterglow (OA) was detected in spite of a deep search carried out $\sim 16$ hrs after the gamma-ray event (Gorosabel et al. 2000a). X-ray observations performed with the Chandra X-ray telescope 21 hrs after the GRB localised the X-ray afterglow of the burst to an accuracy of $0'06$ (Piro et al. 2002). The optical search revealed an extended constant source coincident with the X-ray afterglow which was proposed as the GRB host galaxy (Gorosabel et al. 2000b). Based on the detection of a single host galaxy spectral line, interpreted as [O II] $\lambda 3727$ Å, Piro et al. (2002) proposed a redshift of $z = 0.8463 \pm 0.0002$. Recently Berger et al. (2002) and Barnard et al. (2003) have reported $\sim 2.5 \sigma$ detections of sub-mm emission towards the position of the GRB 000210 host, suggesting a Star Formation Rate (SFR) of several hundred $M_\odot$ yr$^{-1}$. 

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By fitting SED templates to the near-IR/optical photometric points we can estimate the SFR, the extinction ($A_V$) and the dominant stellar population age. The inferred stellar age can help us to distinguish between the two families of GRB progenitors; the hypernovae (stellar age < $10^8$ yr) and the binary compact mergers (stellar age > $10^8$ yr). The SED also provides information on the extinction law and the metallicity. Furthermore, the SED fitting provides the photometric redshift of the host. The comparison of the derived photometric redshift with the spectroscopic one allows us to eliminate incorrect SED fits and to check the consistency of our method. In the present paper we present the most intensive multi-colour host galaxy imaging performed to date and the results obtained when SED templates are fitted to the photometric points.

2. Method: constructing SED templates

A number of optical/near-IR resources (VLT, NTT, 1.54-m Danish and 3.6-m ESO telescopes) have been used in order to compose a well-sampled SED, from the U to the Ks band. The fits of the SEDs have been carried out using Hyperz\(^1\) (Bolzonella et al. 2000). Eight synthetic spectral types were used representing Starburst galaxies (Stb), Ellipticals (E), Lenticulars (S0), Spirals (Sa, Sb, Sc and Sd) and Irregular galaxies (Im). The time evolution of the SFR for all galaxy types is represented by an exponential model, i.e. $\text{SFR} \propto \exp(-t/\tau)$, ranging $\tau$ from 0 (Stb) to 30 Gyr (Sd). The SFR of Im galaxies are represented by a constant SFR ($\tau \rightarrow \infty$).

| IMF   | $\chi^2$/dof | Photometric redshift               | Template | Age (Gyr) | $A_V$ | $M_B$  |
|-------|--------------|-----------------------------------|----------|-----------|-------|--------|
| Sa55  | 1.096        | $0.842^{+0.064}_{-0.042}0.198$   | Stb      | 0.181     | 0.00  | -20.16 |
| MiSc79| 1.046        | $0.836^{+0.087}_{-0.053}0.140$   | Stb      | 0.181     | 0.00  | -20.16 |
| Sc86  | 0.903        | $0.757^{+0.067}_{-0.044}0.219$   | S0       | 1.015     | 0.00  | -19.90 |

1\[^1\]http://webast.ast.obs-mip.fr/hyperz/
Once the population of stars is generated following the time evolution given by the assigned SFR, the mass of the newly formed population is distributed in stars following an assumed Initial Mass Function (IMF). Three IMFs have been considered: Miller & Scalo (1979), Salpeter (1955), and Scalo (1986). These IMFs will be abbreviated hereafter as MiSc79, Sa55 and Sc86, respectively.

Several extinction laws have been tested for the SED fitting, yielding all of them very similar results. Thus hereafter the extinction law given by Calzetti et al. (2000) for starburst galaxies will be adopted. A more detailed description on the impact of the assumed extinction laws and IMFs can be found at Gorosabel et al. (2003).

3. Results and conclusions

The inferred photometric redshifts are (independently of the extinction law and IMF assumed) consistent, within the 99% percentile error range, with the spectroscopic redshift (see Table 1). However, within the 68% percentile (≈ 1σ) error range, only the Sa55 and MiSc79 IMFs are consistent, Sc86 is not. Thus, we conclude that the fit based on the Sc86 IMF (third row of Table 1) provides the least likely fit solution. As shown in the first two rows of the table, the resolution of our template grid is not able to make a distinction between most of the properties (Age, \(A_V\), \(M_B\)) derived for the Sa55 and MiSc79 IMFs.

Hence, the SED of the host galaxy is consistent with a blue starburst template with an age of \(\sim 0.181\) Gyr and a very low extinction (\(A_V \sim 0\), see Fig. 1). Based on the restframe UV flux (Kennicutt 1998) a star formation rate of \(2.1 \pm 0.2 M_\odot\) yr\(^{-1}\) is estimated. The absolute restframe B-band magnitude of the host is \(M_B = -20.16\), which corresponds to \(L = 0.5 \pm 0.2L^*\), depending on the assumed value of \(M_B^*\) (Lilly et al. 1995; Schechter 1976). Therefore, we conclude that the GRB 000210 host is very likely a subluminous galaxy.

The low value of the extinction obtained in the SED fit (\(A_V \sim 0\)) makes it difficult to explain the optical darkness of GRB 000210 in terms of the global host galaxy dust extinction. If dust extinction is the reason of the lack of optical afterglow emission, then the circumburst region has to be very compact and localised around the progenitor. This clumpy and fragmented ISM may help to explain the apparent discrepancy between our SFR estimate (derived from the galaxy UV flux, \(2.1 \pm 0.2 M_\odot\) yr\(^{-1}\)) and the one recently reported based on the sub-millimeter range (Several hundred \(M_\odot\) yr\(^{-1}\), Berger et al. 2002).

Both the collapsar and the binary merging models show severe limitations to explain the visible stellar age and the line of sight H I column density (derived from the afterglow X-ray spectrum) respectively. A solution to this problem would be the existence of a younger population of stars (several Myr of age) hidden by the clumpy ISM. Such population (which would include the GRB progenitor) would not have a detectable impact on the host galaxy SED probed by our observations.
Figure 1. **Left:** The figure shows the UBVRIZJsHKs-band photometric points of the GRB 000210 host galaxy. The solid curve represents the best fitted SED ($\chi^2$/dof = 1.096), corresponding to a starburst synthetic template at a redshift of $z = 0.842$. The derived value of the starburst age corresponds to 0.181 Gyr. The fit is consistent with a very low host galaxy global extinction. **Right:** The plot displays the evolution of the fitted SED $\chi^2$/dof as a function of the photometric redshift. The dotted vertical line indicates the spectroscopic redshift proposed by Piro et al. (2002). As shown the minimum of $\chi^2$/dof (at $z = 0.842$) is consistent with the spectroscopic redshift.

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