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Is GRB 050904 at z=6.3 absorbed by dust?

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Abstract. Dust is an important tracer of chemical enrichment in primeval galaxies and it has also important implications for their evolution. So far, at $z > 6$, close to the reionization epoch, the presence of dust has only been firmly established in quasar host galaxies, which are rare objects associated with enormous star formation rates. The only non-quasar host galaxy, with modest star formation rate, for which dust extinction has been tentatively detected at these early cosmic epochs, is the host of gamma ray burst GRB050904 at $z = 6.3$. However, the claim of dust extinction for this GRB has been debated in the past. We suggest that the discrepant results occur primarily because most of previous studies have not simultaneously investigated the X-ray to near-IR spectral energy distribution of this GRB. The difficulty with this burst is that the X-ray afterglow is dominated by strong flares at early times and is poorly monitored at late times. In addition, the Z band photometry, which is the most sensitive to dust extinction, has been found to be affected by strong systematics. In this paper we carefully re-analyze the Swift/XRT afterglow observations of this GRB, using extensive past studies of X-ray flare properties when computing the X-ray afterglow flux level and exploiting the recent reanalysis of the optical (UV rest frame) data of the same GRB. We extract the X-ray to optical/near-IR afterglow SED for the three epochs where the best spectral coverage is available: 0.47, 1.25, and 3.4 days after the trigger. A spectral power-law model has been fitted to the extracted SEDs. We discuss that no spectral breaks or chromatic temporal breaks are expected in the epochs of interest. To fit any UV rest-frame dust absorption, we tested the Small Magellanic Cloud (SMC) extinction curve, the mean extinction curve (MEC) found for a sample of QSO at $z > 4$ and its corresponding attenuation curve, the starburst attenuation curve, and the extinction curve consistent with a supernova dust origin (SN-type). The SMC extinction curve and the SN-type one provide good fit to the data at all epochs, with an average amount of dust absorption at $\lambda_{rest} = 3000$ Å of $A_{3000} = 0.25 \pm 0.07$ mag. These results indicate that the primeval galaxy at $z = 6.3$ hosting this GRB has already enriched its ISM with dust.

Key words. dust, extinction – γ-ray burst:individual: GRB 050904

1. Introduction

The presence of dust at high redshifts (z>6) is fundamental both for the formation and evolution of the stellar populations in early galaxies, as well as for their observability. High dust masses at z>6 have been detected in the host galaxy of some powerful quasars, through detection of intense mm/submm (far-IR rest

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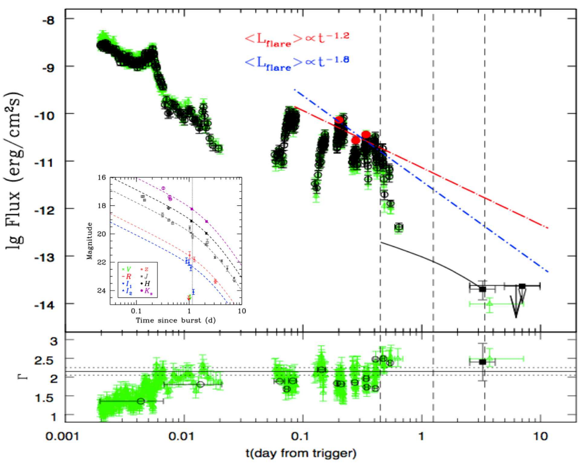

Fig. 1. GRB 050904 X-ray afterglow unabsorbed flux as obtained from "xrtgrblc" task (open black circle) and from the "burst analyzer" tool by Evans et al. (2010) (green triangles). The black solid square at about 3.254 days after the burst trigger is the flux estimated with the stacking method discussed in the text and used in the temporal analysis. The solid line is the best-fit smoothed broken power-law model from the optical data from Tagliaferri et al. (2005) (see inserted panel). The dashed vertical lines indicate the three epochs at which the largest spectral optical coverage is available from the literature, namely T+0.47, T+1.25, and T+3.4 days. The blue dot-short-dashed and red dot-long-dashed lines indicate the expected average flare intensity evolution with time, for two different decay rates predicted for late time flares. The bottom panel shows the X-ray photon index as a function of time obtained by both the "xrtgrblc" task (black circle) and the "burst analyzer" tool (green triangles), as well as the estimate obtained with the stacking method at about 3.4 days after the burst (black squares). Horizontal dashed line indicates the expected value at the epochs of our interest where $\nu_c < \nu_X$, for a synchrotron emission from an electron population with energy spectral index of $p \sim 2.1 - 2.5$, that is $\Gamma_X^{exp} = 2.15 \pm 0.10$.

frame) dust emission (Bertoldi et al. 2003; Beelen et al. 2006; Wang et al. 2008). It is important to understand whether dust is also present in less extreme galaxies at z>6, as can be the GRB hosts, which are more representative of the primeval galaxy population. Therefore, high-z GRBs provide additional opportunities to study the dust properties at high redshift (e.g. Stratta et al. 2007; Li et al. 2008; Zafar et al. 2010; Perley et al. 2009, 2010). In principle, this kind of studies may provide more stringent constraints on dust extinction curves relative to QSOs, since the intrinsic slope of their continuum can be inferred from the associated X-ray data, which are not affected by dust absorption. Moreover, GRBs have been discovered at redshifts greater than the ones of the most distant quasars (Salvaterra et al. 2009; Tanvir et al. 2009; Cucchiara et al. 2011). GRB 050904 was a very bright burst at z=6.29 for which extensive multi-band afterglow follow-up has been performed (Cummings et al. 2005; Tagliaferri et al. 2005; Haislip et al. 2006; Price et al. 2006; Kawai et al. 2006; Boër et al. 2006). Dust extinction in GRB 050904 has been investigated by several authors, but with discordant results (see Stratta et al. 2011 and reference therein). Given the importance of any confirmation of dust at such high redshifts, in this work we carefully revisit the global SED analysis for this burst. In particular, contrary to the majority of past works based on optical/near-IR data SED fitting alone, we exploit the X-ray afterglow emission of this burst to determine the spectral

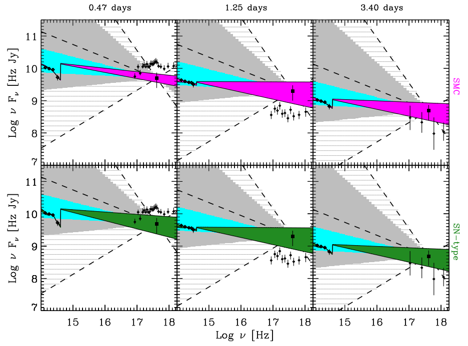

Fig. 2. Optical to X-ray SED at 0.47, 1.25 and 3.4 days after the burst trigger (from left to right) and fitted using the two extinction curves that provide excellent fit at all epochs, that is, the SMC and the SN-type (from top to bottom). Squares show the X-ray flux obtained by our analysis while diamonds are the fluxes by Zafar et al. (2010). The hatched area (delimited by dashed lines) indicates the range of intrinsic power-laws consistent with the $\pm 2\sigma$ uncertainty on β_X. The dashed line in the middle shows the power-law resulting from the best-fit slope to the X-ray data at late epochs ($\beta_X = 1.4$). The gray shaded areas show the range of intrinsic power-laws consistent with the $\pm 1\sigma$ uncertainty on β_X. The cyan shaded areas show the the power-laws expected from synchrotron emission (for an electron spectral index $p \sim 2.1 - 2.5$ and $\nu_c < \nu_{X,opt}$). The colored areas show the optical to X-ray SED best-fit assuming a power-law model with index free to vary within the range $\beta_X \pm 2\sigma$.

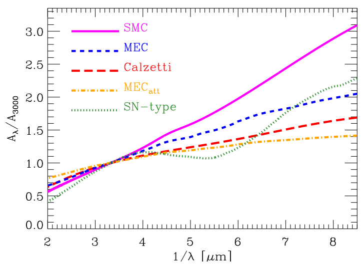

Fig. 3. Extinction and attenuation curves adopted in our analysis, normalized to the extinction value at the rest frame wavelength of $\lambda_{rest} = 3000$ Å.

slope and normalization of the intrinsic, unabsorbed continuum.

2. Data analysis and results

We extract the simultaneous optical/NIR and X-ray afterglow SED at those epochs where the best spectral coverage is available in the optical/near-IR range (UV rest frame), namely at 0.47, 1.25, and 3.4 days after the trigger. We take optical/near IR data from the literature. In particular, in this work we exploit the recent re-analysis done by Zafar et al. (2010) on Z-band data, which is the most sensitive to dust reddening for this burst. The difficulty with this burst is that the X-ray afterglow at T+0.47 days is dominated by a strong flare activity while at T+1.25 there are no Swift/XRT data (Fig.1). X-ray flares are thought to be a distinct component than the afterglow one, possibly linked to the initial burst production mechanism (e.g. Falcone et al. 2007). Flare intensity decay with time predicted by past, dedicated studies on flare properties (Margutti et al. 2011; Bernardini et al. 2011) strongly suggest that the latest X-ray flux measure of GRB 050904 centered at $T + 3.25$ days (Fig.1), is flare-free (see Stratta et al. 2011 for more details). Therefore to extrapolate the X-ray flux at $T + 1.25$ days and at $T + 0.47$ days, we exploit the X-ray afterglow flare-unbiased flux level at $T + 3.25$ days, corrected for Galactic and extra-galactic absorption. Past, broad band modelings available for GRB 050904 (e.g. Frail et al. 2006; Gou et al. 2007) predict an identical afterglow decay law at X-ray and optical wavelengths since the synchrotron cooling frequency ν_c is expected to be already below the optical range at the time of interest. We therefore normalize the best fit optical light curve model (from Tagliaferri et al. 2005) to the unabsorbed X-ray flux at $T + 3.25$ day and extrapolate the X-ray flux at three epochs. Since no spectral breaks between X-rays and optical wavelengths are expected at these epochs, a spectral power-law model was fitted to each optical to X-ray SED (Fig.2), setting the spectral index at the value measured from the XRT data at $T + 3.25$ days. We investigate any presence of dust extinction in the GRB afterglow by using the SMC extinction curve and the Calzetti attenuation law. We also use the mean extinction curve (MEC) at 4.0<z<6.4 inferred by Gallerani et al. (2010) from the analysis of 33 quasars, and the associated attenuation curve (MEC_{att}). The SN-type extinction curve, proposed by Todini & Ferrara (2001), which reproduces the dust extinction observed in a BAL QSO at z=6.2 (Maiolino et al. 2004; Gallerani et al. 2010) was also tested. All these curves are plotted in Figure 3.

From a simultaneous fit of the rest frame UV to X-ray SED, we find clear evidence of dust absorption at all epochs. The SMC and SN-type extinction curves provide good fits at all epochs, with an average value of dust extinction of $A_{3000} = 0.25 \pm 0.07$ mag at $\lambda_{rest} = 3000$ Å. At $T + 3.4$ days where nearly simultaneous X-ray and optical data are available, thus where X-ray temporal extrapolation weakly depends on the assumed model, the extracted X-ray to optical SED shows clear evidence of dust extinction, with A_{3000} in the range that goes from 0.2 to 0.9 mag, depending on the assumed dust recipe. Our findings indicate that the primeval star-forming galaxy at $z = 6.3$ hosting this GRB has already enriched its ISM with dust. The type of extinction/attenuation curve is not well constrained by the data, although we find that only the SMC and SN-type extinction curves provide good fit to the data at all epochs. We emphasize that our results were obtained from a simultaneous optical to X-ray SED fitting, while most of the previous studies were performed on the optical/near-IR SED alone. Our method strongly benefits of the information from past broad band modeling of this burst and of the X-ray afterglow observations at 3.25 days after the trigger, when we demonstrated that the flare activity has very likely ceased.

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