The dust depletion and extinction of the GRB 020813 afterglow(*)

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Summary. — The Keck optical spectrum of the GRB 020813 afterglow is the best ever obtained for GRBs. Its large spectral range and very high S/N ratio allowed for the first time the detection of a vast variety of absorption lines, associated with the circumburst medium or interstellar medium of the host. The remarkable similarity of the relative abundances of 8 elements with the dust depletion pattern seen in the Galactic ISM suggests the presence of dust. The derived visual dust extinction $A_V = 0.40 \pm 0.06$ contradicts the featureless UV spectrum of the afterglow, very well described by a unreddened power law. The forthcoming Swift era will open exciting opportunities to explain similar phenomena in other GRB afterglows.

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1. – Introduction

The optical afterglow of GRB 020813 ($z = 1.25$) was observed a few hours after the burst with Keck at a reasonable spectral resolution [1] when the burst was still relatively bright. The unprecedented[1] good quality of rest-frame UV spectrum, and the large wavelength range covered, allowed the detection of a tremendous number of absorption lines, including very weak transitions never detected before in GRB spectra.

The GRB rest-frame UV spectrum shows another notable feature: the continuum emission in the interval 7.4×10^{14}–2.1×10^{15} Hz is very well represented by a perfect power law of the form $f_\nu \propto \nu^{-0.918 \pm 0.001}$ [3]. Such a nearly perfect power law is not only a very rare event, but it also strongly suggests (by the standard view of extinction laws) no reddening, or equivalently, little dust along the sight-line.

Here we discuss the dust properties in the interstellar or circumburst medium in front of GRB 020813 by using two different and completely independent means: *i*) studying the relative abundances of several elements with very different refractory properties (*i.e.*,

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(1) Much higher resolution spectra have been obtained for GRB 020813 and GRB 021004 [2], however the information available is somehow limited by the low S/N in large parts of the spectrum.
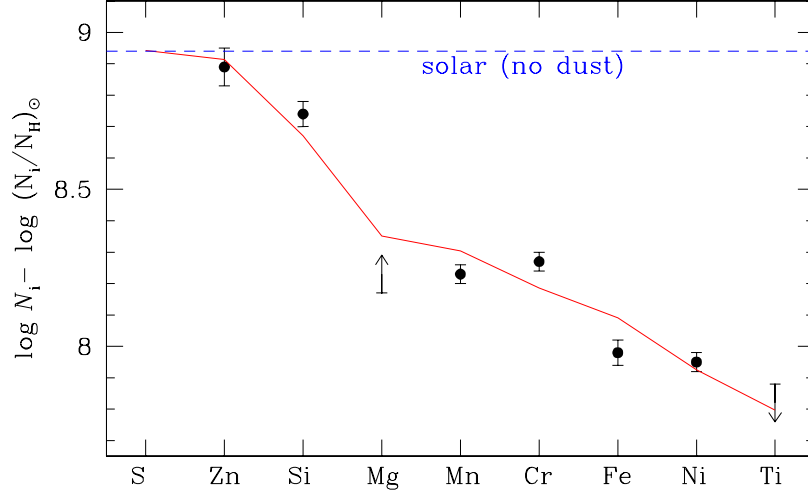
Fig. 1. – Heavy element column densities in GRB 020813. The dashed line shows where points would be in the case of solar relative abundances and no dust. The solid line shows the expected column densities in the case that elements are partly locked in dust grains, as in the gas of the warm disk + halo of the Milky Way. Other depletion patterns in the MW have been considered, with slightly worse fit (higher χ^2).

how easily they are locked in dust grains); ii) trying to reconcile the observed straight UV continuum with the presence of several extinction laws.

2. – Metal abundances and visual extinction

We derived column densities of FeII, SiII, SiII*, ZnII, CrII, NiII, MgI, CI, CaII, CIV, MnII, MgII, AlII, AlIII, and TiII in the GRB 020813 afterglow, using independently line fitting, curve of growth and apparent optical depth analysis [3]. High column densities of low ionization species (e.g., FeII), relative to higher-ionization species (CIV and AlIII), is a good indication that the gas is nearly neutral (the column density of hydrogen is mostly in HI form) and the column density of each element can be approximated by the column density of the ion with ionization potential below 13.6 eV (e.g., Fe $\sim$ FeII). As the Lyman series lines are not in the observed spectral range, we cannot estimate the HI column density. However, we can derive relative metal abundances, compare them with solar values and with relative abundances expected if the various elements are partly locked in the dust grains as in the Milky Way ISM (dust depletion pattern). Figure 1 shows with no ambiguity that relative abundances can be explained if the gas is polluted by dust.

The dust extinction of the GRB afterglow as a function of wavelength depends basically on the dust column density and the grain-size distribution. While there is no obvious way we can determine the latter, the former can be derived by assuming that the element pattern observed in fig. 1 is a dust depletion pattern, with no need to know the metal abundance relative to hydrogen. The main assumption is that the total (dust + gas) element relative abundance in the GRB ISM is as in the solar neighborhood, and what is missing in the gas form is locked into dust grains.

To estimate the visual extinction for GRB 020813, we also assume that the rate of visual extinction per unit column of dust is as in the solar neighborhood [4], or half a
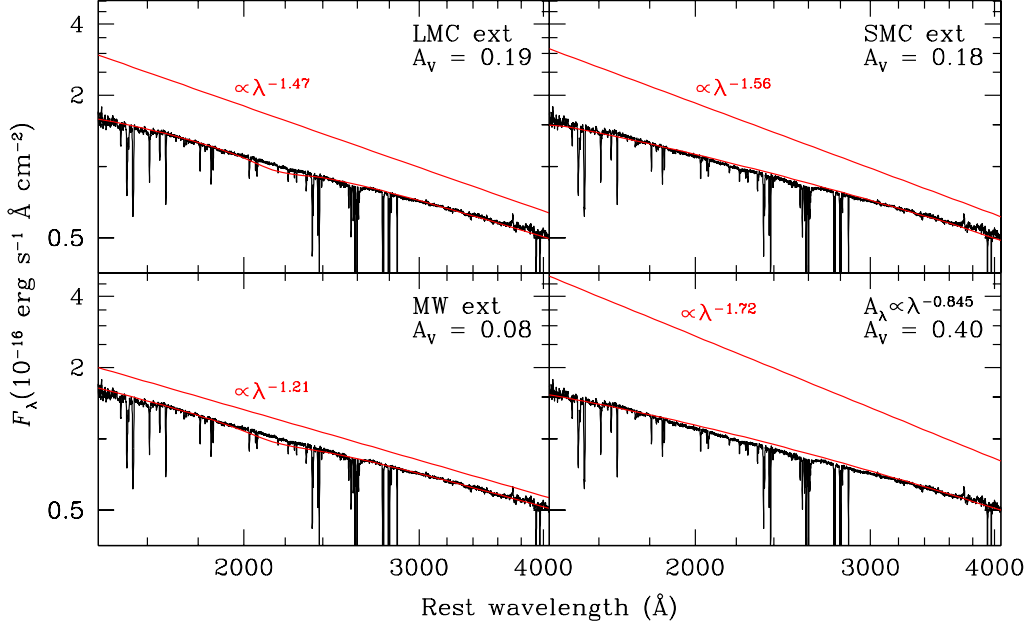
Fig. 2. – GRB 020813 spectrum before and after a dust extinction screen is applied to an intrinsic GRB emission. The MW, LMC, SMC and power law extinctions are used. For the first three, A_V is the maximum value allowed by the observed spectrum. For the power law extinction, $A_V = 0.4$ is assumed, while the power index $\gamma = 0.845$ is the maximum value allowed by the observed GRB spectrum.

magnitude for a total column density of Fe (dust and gas) $N_{\mathrm{FeII}} = 10^{16.5}\,\mathrm{cm}^{-2}$. From fig. 1, we estimated a total Fe column density $N_{\mathrm{FeII}} = 10^{16.46 \pm 0.08}$, and translated into a visual extinction $A_V = 0.40 \pm 0.06$.

3. – The dust extinction law

A possible extinction law for the ISM of the GRB has to be shallow enough and/or a weak function of the wavelength in order to make the GRB UV emission consistent with the observed undistorted power law. To constrain the extinction law, we only assumed that the intrinsic GRB emission is itself described by a (unconstrained) power law. We used the MW, LMC, SMC extinctions, and a power law extinction of the form $\propto \lambda^{-\gamma}$. Starting from all possible intrinsic GRB emissions, we constrained A_V for all four different extinctions. Figure 2 shows for MW, LMC and SMC extinctions, the maximum allowed A_V still compatible with the observed GRB spectrum ($2\,\sigma$), together with the associated intrinsic emission. For the MW and LMC extinctions, $A_V < 0.08$ and $A_V < 0.18$, respectively, mainly due to the absence in the observed GRB spectrum of the 2200 Å feature. For the power law extinction, if $A_V = 0.4$, then only extinctions with $\gamma < 0.85$ make the GRB spectrum consistent with the observed one. This last result is summarized in fig. 3, where the allowed regions of A_V (from the depletion pattern analysis) and γ (from the extinction law analysis) are displayed together.
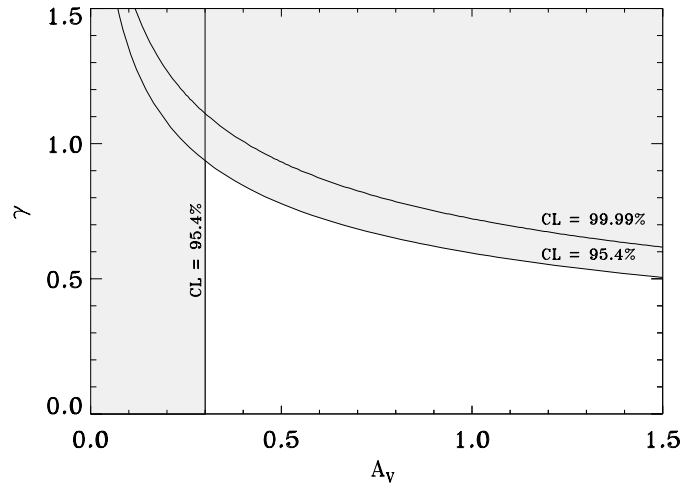
Fig. 3. – The shaded regions indicate the values of visual extinction A_V and of slope of the power law extinction γ not allowed by the analysis of the dust properties in the GRB 020813 afterglow.

4. – Summary

The relative metal abundances of 8 elements are derived with unprecedented accuracy for a GRB afterglow. These are remarkably similar to the metal pattern observed in Galactic ISM clouds, polluted by dust. If dust is indeed responsible of the metal pattern shown in fig. 1, then the visual extinction is $A_V \simeq 0.4$. Such a relatively large extinction is compatible with the observed spectrum (well represented by a power law of the form $f_\nu \propto \nu^{-0.92}$) only assuming a shallow extinction law. If we use the known extinction laws (MW, LMC and SMC) the extincted spectrum is still compatible with the observed spectrum if $A_V < 0.2$. The observed GRB spectral shape and the $A_V > 0.3$ (95% CL) derived from the depletion pattern, can only be explained for a flatter extinction. For instance, if a power law is assumed and $A_V = 0.4$, then the slope has to be shallower than $\gamma \simeq 0.85$.

GRB UV spectra will show their overwhelming potentiality for the understanding of the cosmic chemical enrichment and physical state of the high-z interstellar medium when the Swift satellite will be fully operational. From the low/medium resolution spectra observed so far, it is already very clear that GRBs have a very different (*i.e.*, much stronger absorption) heavy element pattern than other high redshift absorbers [3, 5, 2]. Among many other GRB fundamental parameters, the Swift era will reveal whether the strong absorption is typical of the ISM in high-z star forming galaxies, or it is a peculiarity of the GRB circumburst medium only.

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