GRB 980329: Determining Density Without a Redshift

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Abstract. We fit models to the late-time broadband dataset of gamma-ray burst (GRB) 980329. Despite being limited by sparse early optical data and no redshift measurement, we determine some parameters of the afterglow and its host robustly. The fireball expanded into a relatively dense medium with $n \sim 200\ cm^{-3}$. The host is far bluer than the afterglow, and is not compatible with high $z \sim 5$.

INTRODUCTION

GRB 980329 was one of the earliest and brightest bursts detected by the BeppoSAX satellite. After fruitless optical searches, its afterglow was initially identified in the radio [1], which then led to the discovery of its faint R-band and relatively bright near-IR afterglow [2, 3, 4]. With evidence of a high column density nH in the X-ray [5], the very red nature of this burst's afterglow and the "dropout" of the R band flux has been postulated to be due to intrinsic host absorption by both Taylor[1] and Palazzi[2]. However, there is no direct redshift determination for this burst, despite observational efforts; Fruchter[6] proposed that the "dropout" could be due to absorption by the intergalactic medium's Lyman-alpha (Lyα) forest if the burst is at a redshift $z \geq 5$.

THE GRB REDSHIFT

The R band "dropout" and R-I=2 OT colour could be due to extinction in the host, or to Lyα flux suppression at $z \sim 5$. The latter would extinct the host flux similarly.

A good host spectrum was taken, but no lines were detected, leaving the redshift undetermined. However, the host is well detected at both R and I, (see Fig. 1) with a much bluer colour than the OT, rejecting Lyα as a significant effect on the R band and thus restricting $z \leq 4$.

AFTERGLOW MODELLING

We fit late-time optical and radio points along with the early, published data to a broadband model of the afterglow emission (explained in some detail in Harrison [7]) and host galaxy. We assume several different fixed redshifts (z=1, 2, 3) in the modelling and find some robust physical parameters of the afterglow and its host. Results are presented in Table 1.

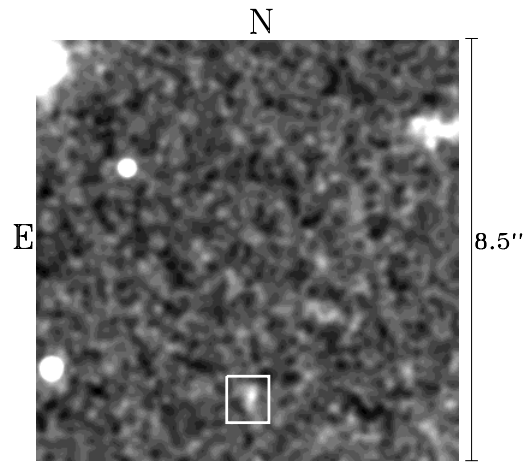

FIGURE 1. The host is well detected, indicated by the box in this HST longpass filter exposure. It is also well detected in late Keck eposures and has a colour $(R-I)_{host} = 0.2 \pm 0.3 << (R-I)_{OT} \sim 2$. Image courtesy of Joshua Bloom, Caltech.

CIRCUMBURST MEDIUM

The broadband model fits to a relatively high density, $n \gtrsim 200\ cm^{-3}$ (typical of a diffuse cloud), independent of the redshift assumed. The uncertainty in n by changing z is comparable to the modelling accuracy.

The density is chiefly determined by the high self-absorption frequency ν_a, below which the spectrum $\propto \nu_a^2$. As can be seen in Figure 2 and 3, ν_a is certainly above 8.5 GHz at early times and comes out in the model near 100 GHz.

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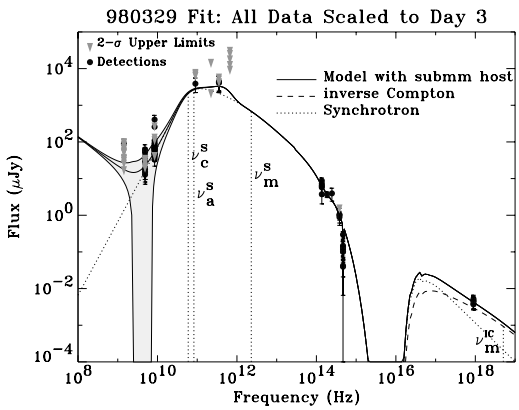

FIGURE 2. The model fit for z=2 with all the data used scaled to the common time of day 3. The model fit includes the model uncertainty introduced by interstellar scintillation, shown in pale grey. The host is included in the model in the radio and submm, but the optical data have the host component removed for clarity. The optical data are dereddened for Galactic effects and the model includes extinction in the host frame.

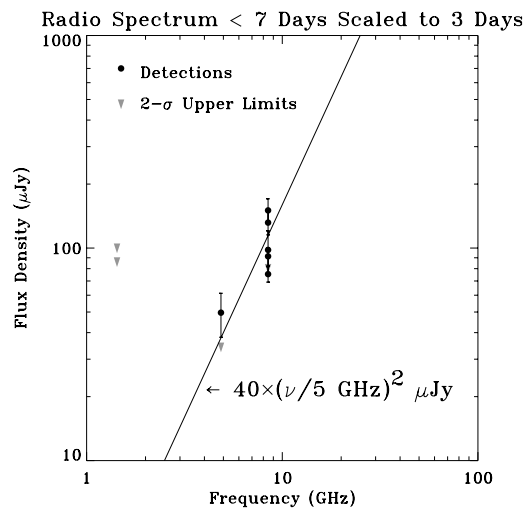

FIGURE 3. The first week's datapoints in the radio, scaled by the fit model to a common time of 3 days are shown, along with a line $\propto \nu^2$ overdrawn. Clearly at least the data below 8.5 GHz scales in this manner and is below the self-absorption frequency ν_a.

TABLE 1. Best-fit parameters from the modelling of GRB 980329

	z=1	z=2	z=3
$E_{\mathrm{iso},t_{\nu_c=\nu_m}}(10^{52}\ erg)^*$	1.5	1.1	3.0
$n(cm^{-3})$	370	250	230
p	2.04	2.11	2.07
ε_e (fraction of E)	1.2	1.5	1.6
ε_B (fraction of E)	0.003	0.002	0.001
θ_{jet} (rad)†	1	1	1
host $A(V)$	1.1	1.1	0.71
host I (μJy)	0.085	0.086	0.086
host H (μJy)	0.20	0.20	0.20
host K (μJy)	0.61	0.63	0.63
host 1.4 GHz (μJy)	19.9	16.4	15.9
host 350 GHz (μJy)	1190	1160	1210
T_{eff}(K)**	4.7	4.5	4.5
χ^2 for 94 data pts	69	65	65
$t_{\mathrm{nonrel.}}$ (days)	25	48	81
$t_{\nu_c=\nu_m}$ (days)‡	4.6	22	24
$P(\alpha_{1.4}^{350})^\S$	0.54	0.52	0.21

* The isotropic-equivalent energy in the fireball at the time fast cooling ends

† Due to model uncertainties, jet angles ≥ 1 rad are treated as isotropic

** Dust temperature T of the host, corrected for redshift, $T_{eff} = T/(1+z)$

‡ Time at which the cooling break becomes larger than the spectral break due to the peak in the input electron distribution and fast cooling ends

§ The probability of the fit's host 350-to-1.4 GHz spectral index at the assumed redshift, based upon the models of Carilli and Yun[8]

From the equation for ν_a in Granot [9], we get for n in cm^{-3}:

$$n \simeq 500(\varepsilon_e \frac{\nu_a}{10GHz}\frac{1+z}{3})^{5/3}(\frac{E}{10^{52}erg}\frac{\varepsilon_B}{0.01})^{-1/3}\frac{K(p)}{K(2.2)} \quad (1)$$

K(p) = $(3p+2)(p-1)^{-8/3}(p-2)^{5/3}/(p+2)$.

A relatively high density is compatible with the high host extinction seen in the GRB afterglow.

HOST EXTINCTION

Figure 4 shows a closeup of the optical spectrum at day 3, dereddened for the effects of the Galaxy, with the late time host flux removed. The I to K spectral slope is approximately -1.6, and the R "dropout" can be seen.

The synchrotron spectral slope is at its steepest $\nu^{-p/2}$; as a value of $p > 3$ isn't compatible with the broadband evolution, the extra steepening is modelled as extinction.

The I to K spectrum calls for a steep extinction law A(λ), much like the SMC. We use the extinction curve parameterization of Reichart[10], with no 2175 bump or far-UV upturn, but a steep linear slope (c2) of $E(\lambda - V)/E(B-V)$ with frequency in μm^{-1} of 3. We find the host contributes a significant extinction A(V)=1.

We cannot explain the extra R dropout of ~ 2 mag below the extinction curve with a standard extinction law. This presumed nonstandard extinction is beyond the scope of this effort.

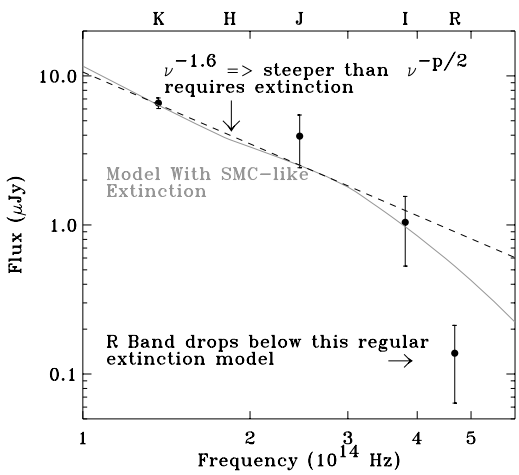

FIGURE 4. Earliest optical and near-IR data scaled by the z=2 fit model to day 3, and host-subtracted. The fit model with its steep extinction curve (see text) is overplotted (solid line). A powerlaw fit from I to K is shown with a dashed line, and the R band drop below both spectral curves is evident.

CONCLUSIONS

We fit models to the late-time broadband dataset of gamma-ray burst (GRB) 980329 for various assumed redshifts.The host is far bluer than the afterglow, and is not compatible with high $z \sim 5$. We determined that the fireball expanded into a relatively dense medium with $n \sim 200\ cm^{-3}$ independent of the redshift.

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