THE PROMPT, HIGH-RESOLUTION SPECTROSCOPIC VIEW OF THE “NAKED-EYE” GRB080319B*

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ABSTRACT

GRB080319B reached fifth optical magnitude during the burst prompt emission. Thanks to the Very Large Telescope (VLT)/Ultraviolet and Visual Echelle Spectrograph (UVES) rapid response mode, we observed its afterglow just 8m:30s after the gamma-ray burst (GRB) onset when the magnitude was \( R \sim 12 \). This allowed us to obtain the best signal-to-noise (S/N), high-resolution spectrum of a GRB afterglow ever (S/N per resolution element \( \sim 50 \)). The spectrum is rich of absorption features belonging to the main system at \( z = 0.937 \), divided in at least six components spanning a total velocity range of 100 km s\(^{-1}\). The VLT/UVES observations caught the absorbing gas in a highly excited state, producing the strongest Fe \( \Pi \) fine structure lines ever observed in a GRB. A few hours later, the optical depth of these lines was reduced by a factor of \( 4-20 \), and the optical/UV flux by a factor of \( \sim 60 \). This proves that the excitation of the observed fine structure lines is due to “pumping” by the GRB UV photons. A comparison of the observed ratio between the number of photons absorbed by the excited state and those in the Fe \( \Pi \) ground state suggests that the six absorbers are \( \sim 2-6 \) kpc from the GRB site, with component I \( \sim 3 \) times closer to the GRB site than components III–VI. Component I is characterized also by the lack of Mg I absorption, unlike all other components. This may be both due to a closer distance and a lower density, suggesting a structured interstellar matter in this galaxy complex.

Key words: gamma rays: bursts

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1. INTRODUCTION

For a few hours after their onset, gamma-ray burst (GRB) afterglows are the brightest beacons in the far universe, providing an alternative and complementary tool to study the properties of high redshift galaxies (see Savaglio 2006; Prochaska et al. 2007). In a small fraction of the cases, extremely bright optical transient emission is associated with the GRB event, offering a superb opportunity to investigate high-z galaxies through high-resolution spectroscopy of the optical transient. The study of the rich absorption spectra can yield unique information on the gas in the GRB environment and the physical, chemical, and dynamical state and geometry of the interstellar matter (ISM) of intervening galaxies, including the GRB host galaxy. In particular, the absorption coming from the circumburst environment can be dissected into single components, allowing a precise investigation of the dynamical, physical, and chemical status of the absorbing gas (see Fiore et al. 2005 for GRB020813 and GRB021004; Prochaska et al. 2006 for GRB050730 and GRB051111; and D’Elia et al. 2007 for GRB050730). In addition, the contribution to the absorption coming from the circum-burst environment can be separated from that of regions of the host galaxies far away and less affected from the GRB afterglow, as in the case of GRB 050922C (Piranomonte et al. 2008). The detection of fine structure and other excited levels of the atom 0 \( \Pi \) is characterized also by the lack of Mg I absorption, unlike all other components. This may be both due to a closer distance and a lower density, suggesting a structured interstellar matter in this galaxy complex.

* Based on observations collected at the European Southern Observatory (ESO) with the VLT/Kueyen telescope, Paranal, Chile, in the framework of program 080.A-0398.
Table 1
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| Observation | UT Observation | Time From Burst (s) | Exp. (s) | S/N Range | Dichroics | Arms | R mag |
|-------------|----------------|--------------------|----------|-----------|-----------|------|-------|
| RRM 1       | 2008 Mar 19, 06:21:26 | 517               | 600      | 30–50     | 2         | Blue + Red | 12–13 |
| RRM 2       | 2008 Mar 19, 08:06:42 | 6833              | 1800     | 7–12      | 1 + 2     | Blue + Red | 16–17 |
| ToO         | 2008 Mar 19, 09:07:22 | 10482             | 1200     | 5–8       | 1 + 2     | Blue + Red | 16–17 |

Figure 1. UVES spectra of GRB080319B around the Fe II λ2374 (left panel) and Fe II λ2396* (right panel) transitions. The solid lines refer to the first-epoch spectrum (8m:30s after the Swift trigger), the dashed lines refer to the second-epoch spectrum (1.9 hr after the GRB event), and the dotted lines to the third-epoch spectrum (2.9 hr after the GRB event).

GRB080319B was imaged by the “Pi of the Sky” apparatus located at Las Campanas Observatory before, during, and after the GRB event (Cwiok et al. 2008). The field was also targeted by the robotic telescope REM just 43 s after the BAT trigger (Covino et al. 2008a, 2008b). The TORTORA wide-field optical camera (12 cm diameter, 20 × 25 deg field of view (FOV), TV-CCD, unfiltered) mounted on REM also imaged the field before, during, and after the GRB event with good temporal resolution (Karpov et al. 2008). These observations show that the GRB reached the magnitudes $V = 5.3$ about 20 s and $H = 4.2$ about 50 s after the trigger. This makes GRB080319B the brightest GRB ever recorded at optical wavelengths (Bloom et al. 2009; Racusin et al. 2008).

The optical afterglow of GRB080319B was observed at high resolution with the Very Large Telescope (VLT)/Ultraviolet and Visual Echelle Spectrograph (UVES) starting just 8m:30s after the BAT trigger, thanks to the VLT rapid response mode (RRM), when its magnitude was $R \approx 12–13$. This afforded a S/N of 30–50 per resolution element. Two more UVES observations followed, the first one again in RRM mode, activated in the framework of program 080.D-0526 and starting 1.9 hr after the GRB event, and the second a ToO, starting 2.9 hr after the GRB, see Table 1.

Data reduction was carried out by using the UVES pipeline (Ballester et al. 2000). The final useful spectra extend from ~3800 Å to ~9500 Å. The resolution element, set to 2 pixels, ranges then from 4 km s$^{-1}$ at 4500 Å to 1.9 km s$^{-1}$ at 9000 Å. The noise spectrum, used to determine the errors on the best-fit line parameters, was calculated from the real-background-subtracted spectra using line-free regions. This takes into account both statistical and systematic errors in the pipeline processing and background subtraction.

3. UVES SPECTROSCOPY OF EXCITED LINES

The three UVES observations were analyzed in the MIDAS environment using the fitlyman procedure (Fontana & Ballester 1995). The highest $z$ system present in these spectra is at $z = 0.937$, as also reported by Vreeswijk et al. (2008). This system presents absorption features from the ground states of Mg I, Mg II, Fe II, and several Fe II fine structure lines (Fe II hereafter). The most striking feature in the UVES spectra is the variation of the opacity of the fine structure lines between the first and the second UVES observations. Figure 1 shows the
Fe II $\lambda$2374 and Fe II$^*$ $\lambda$2396 absorption features in the three epochs. We see strong variations of both lines. While the strength of the Fe II $\lambda$2374 absorption increases from the first to the third epoch, strong Fe II$^*$ $\lambda$2396 absorption is present only in the first spectrum and nearly disappears in the second and third spectra. The huge variations of Fe II fine structure lines imply that “pumping” by the GRB UV photons is the main mechanism for populating the excited states (Silva & Viegas 2002; Prochaska et al. 2006; Vreeswijk et al. 2007).

UVES spectra of bright GRB afterglows have always revealed a complex structure of the absorption system associated with the GRB host galaxy, reflecting the clumpy nature of the ISM (see, e.g., D’Elia et al. 2007). This is confirmed by the UVES spectra of GRB080319B. A detailed line fitting was performed using a Voigt profile with three parameters: the line wavelength, the column density, and the Doppler parameter $b$. Several absorption features were fitted simultaneously by keeping the redshift and $b$ value of each component fixed at their common values (best-fit $b$ values in the 3–10 range). The Fe II$^*$ $\lambda$2396 absorption lines are not saturated, and can be used to guide the identification of different components. Statistically acceptable fits to the first-epoch UVES spectrum are obtained by using six components. These span a range of $\sim$100 km s$^{-1}$ in velocity space. Figure 2 shows the best-fitting model to the Mg i $\lambda$2026, Fe II $\lambda$2382, and Fe II$^*$ $\lambda$2396 lines. The lower S/N spectra from the second and third epochs were then fitted by fixing the $z$ and $b$ parameters of each component at their respective best-fit values found for the first epoch, highest S/N spectrum.

Table 2 gives the Mg i and Fe II and column densities of each of the six components in the three epochs. Components are labeled from I to VI for decreasing wavelengths (and decreasing redshift, or positive velocity shift with respect to a zero point, placed at $z = 0.9371$). Fe II is represented by the ground, first excited (4$F$) and second excited (4$D$) levels. Fine structures of each level are marked with asterisks; the ground state shows four fine structure levels, the excited ones just the first level. The second column indicates which transitions have been used to evaluate the ionization of each ionic species. Strong Mg i absorption is present for all components, but reliable column densities cannot be derived for this ion because the lines are strongly saturated. The column density uncertainties are given at the 1σ confidence level, while upper limits are at a 90% confidence level (i.e., 1.6σ). The column densities derived from the second-epoch spectrum are always consistent with those derived from the third-epoch spectrum, to within their relatively large errors. Thus, in order to improve the S/N, we also added together the second- and third-epoch spectra and repeated the fits.

Mg i is detected for all components but I. The Mg i column density of the five detected components is consistent with a constant value (within each component) at all epochs. Conversely, we see strong variations in time of both Fe II excited and ground state lines for all six components. The Fe II fine structures line of the lower redshift components underwent the strongest variations, as most of these lines are not detected in the second- and third-epoch spectra. The Fe II first fine structure line of the highest redshift component I varies less, and it is still detected in the second- and third-epoch spectra. Figure 3 compares the column density of the Fe II$^*$ $\lambda$2396 line of the six components in the first epoch spectrum to that measured 2–3 hr later. The column density of component I dropped by a factor of $\sim$4, while that of component III dropped by a factor of $\sim$20 (Table 3). On the other hand, the column density of ground state Fe II increased by a factor of 1.3–2 for all the six components (Table 3). The de-excitation of the excited levels into ground-state levels, as time passes and the UV radiation field diminishes, is certainly contributing to this increase. For all components, the increase in the column density of the Fe II resonant line is consistent with the decrease of the excited lines within 1σ. This is a first indication that the absorbing medium must be relatively distant, since photoionization of the medium by the burst photons, predicted to be important in the vicinity of the source (Perna & Loeb 1998; Perna & Lazzati 2002) appears to be negligible here.

4. DISTANCE OF THE ABSORBERS FROM THE GRB

A constraint on the distance of the absorbing gas to the GRB can be obtained using the ratio between the number of photons absorbed by the first fine structure level of Fe II and its corresponding ground state. This ratio in the prompt spectrum of GRB080319B is 0.6 for components I and II, 0.3 and 0.4 for components III–VI. Note that the value for components I and II is close to the maximum theoretical value of 0.8. As a comparison, the same ratio in the prompt spectrum of GRB060418 was 0.09 (Vreeswijk et al. 2007). Calculations of population ratios (Silva & Viegas 2002; see also Prochaska et al. 2006) show that the observed ratios are obtained for a UV flux of $\sim 3 \times 10^9$–$10^7$ $G_0$ for the six components, where $G_0 = 1.6 \times 10^{-3}$ erg cm$^{-2}$ s$^{-1}$. This implies distances from the GRB to the six absorbers $R = [L_{UV}/(4\pi G_0 \times (3 \times 10^5–10^7))]^{1/2} \approx 18$–34 kpc (having assumed $L_{UV} = 6.7 \times 10^{50}$ erg s$^{-1}$, obtained integrating the light curve by Racusin et al. 2008b).

However, these population ratios are calculated assuming a steady-state ionizing flux, an approximation which is not an appropriate description for a GRB afterglow. To obtain a more
Table 2

| Species | Trans. | Obs. | I (64 km s\(^{-1}\)) | II (47 km s\(^{-1}\)) | III (20 km s\(^{-1}\)) | IV (0 km s\(^{-1}\)) | V (−20 km s\(^{-1}\)) | VI (−32 km s\(^{-1}\)) |
|---------|--------|------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
| Mg \(\text{t}\) | 2820 | 1 | < 11.80 | 12.14 ± 0.10 | 13.00 ± 0.02 | 13.18 ± 0.01 | 11.83 ± 0.17 | 12.38 ± 0.05 |
| Fe \(\text{t}\) | ≤2852 | 2 | < 11.2 | 12.09 ± 0.03 | 13.06 ± 0.08 | 12.94 ± 0.12 | 11.77 ± 0.06 | 12.02 ± 0.05 |
| Fe \(\text{t}\) | ≤2853 | 3 | < 11.6 | 12.05 ± 0.04 | 13.39 ± 0.11 | 12.87 ± 0.10 | 11.81 ± 0.07 | 12.05 ± 0.07 |
| Fe \(\text{t}\) | ≤2854 | 2+3 | < 11.0 | 12.08 ± 0.02 | 13.85 ± 0.06 | 12.95 ± 0.07 | 11.80 ± 0.05 | 12.07 ± 0.05 |
| Fe \(\text{t}\) | ≤2855 | 2+3 | < 11.0 | 12.08 ± 0.02 | 13.85 ± 0.06 | 12.95 ± 0.07 | 11.80 ± 0.05 | 12.07 ± 0.05 |
| Fe \(\text{t}\) | ≤2856 | 3 | < 11.0 | 12.08 ± 0.02 | 13.85 ± 0.06 | 12.95 ± 0.07 | 11.80 ± 0.05 | 12.07 ± 0.05 |

Note. All values are in logarithmic cm\(^{-2}\).

Table 3

|       | I      | II     | III    | IV     | V      | VI     |
|-------|--------|--------|--------|--------|--------|--------|
| Fe \(\text{t}\) | −0.35 ± 0.05 | −0.13 ± 0.12 | −0.35 ± 0.10 | −0.21 ± 0.12 | −0.24 ± 0.14 | −0.07 ± 0.19 |
| Fe \(\text{t}\) | 0.62 ± 0.13 | 0.75 ± 0.14 | 1.24 ± 0.14 | > 1.36 | > 0.40 | > 0.30 |

Note. Ratios are expressed in logarithmic cm\(^{-2}\).

A reliable result, we built up a time-dependent photoexcitation code to compute the column densities of the excited states as a function of the absorbing gas distance from the GRB, in a similar way to that of Vreeswijk et al. (2007). The basic equation to be solved is the balance equation

\[
\frac{dN_u}{dt} = N_l B_{lu} F_u(\tau_0) - N_u [A_{ul} + B_{ul} F_u(\tau_0)],
\]

which describes the transition between two atomic levels. It gives the increment in the upper level population \(N_u\) as a function of the lower level \(N_l\), the flux \(F_u(\tau_0)\) experienced by the absorber, and the Einstein coefficients \(A\) and \(B\). In more detail, \(A_{ul}\) represents the spontaneous decay from the upper to the lower state, \(B_{ul} = A_{ul} \lambda^3 / 2hc\) the stimulated emission, and \(B_{lu} = B_{ul} g_u / g_l\) the absorption. Here, \(\lambda\) is the transition wavelength and \(g\) is the degeneracy of the levels. \(F_u(\tau_0)\) is the monochromatic flux at the transition frequency:

\[
F_u(\tau_0) = F_u(0) e^{-\tau} + S_u (1 - e^{-\tau}),
\]

corrected by the optical depth at the line center \(\tau_0 = 1.497 \times 10^{-2} N \lambda f / b\) (cgs units); \(b\) is the Doppler factor of the transition and \(f\) is its oscillator strength, which is related to the
GRB080319B in the slopes in the time interval between 20 and 104 s from the GRB. be described by a broken power law with at least four different (III, respectively). Late time points represent the observations 2 and 3 added together. For clarity reasons, components have been slightly shifted with each other. Note that the highest redshift component I varies less than the lower redshift components III and IV (the dashed and dotted lines are for components I and III, respectively).

Einstein coefficient \( A \) by

\[
f = \frac{m_e c A_{al} g_a A^2}{8 \pi^2 q_e^2 g_l}.
\]  

The source function of the radiative transfer in Equation (2) is defined as (Lequeux 2005)

\[
S_\nu = \frac{N_{\nu}(v) A_{al}}{N_{\nu}(v) B_{lu} - N_{\nu}(v) B_{al}}.
\]

Finally, the uncorrected flux experienced by the absorber is

\[
F_\nu(0) = \frac{F_{br} (t/t_{br})^{-\alpha_{br}} (\lambda/5439\,\text{Å})^{-\beta_{br}} (d_{L,\text{GRB}}/d)^2}{1 + z},
\]

(in cgs units) with \( z \) the GRB redshift used to compute its luminosity distance \( d_{L,\text{GRB}} \) and \( d \) the distance of the absorber from the GRB. The normalization constant \( F_{br} \) and the temporal and spectral indices, \( \alpha_{br} \) and \( \beta_{br} \), have been taken from the paper by Racusin et al. (2008b). The optical light curve of GRB080319B in the V band (5439 Å) is not monotonic, but can be described by a broken power law with at least four different slopes in the time interval between 20 and 10⁴ s from the GRB. For each break time \( t_{br} \), we took the corresponding normalization constant \( F_{br} \) and the temporal and spectral indices, \( \alpha_{br} \) and \( \beta_{br} \), given in Racusin et al. (2008b).

Equation (1) must be simultaneously solved for many transitions, connecting in principle all the levels of a given atom or ion (Fe ii in our case). We included in our computation a total of 38 levels, the 16 lowest levels plus 22 higher excited states. The atomic data for the transitions among these levels have been taken from Quinet et al. (1996; for transitions between the low-energy states) and the National Institute of Standards and Technology (NIST) database for other transitions (at the Web site http://physics.nist.gov/PhysRefData/ASD/index.html). In order to verify that the number of included transitions was large enough, we ran our code with the input parameters used by Vreeswijk et al. (2007) for GRB060418, and we found column densities fully consistent with their results.

We stress that collisional processes and/or direct infrared (IR) pumping alone cannot be responsible for the variability we observe. If the first mechanism is at work, i.e., if the variability is produced by a decreasing temperature, we should observe a reduction of all the column densities of the excited states. Table 2 shows that fine structure levels dramatically decrease, but the first excited level (Fe ii 4F) stays almost constant in all components. On the other hand, in case of pure IR pumping (assuming that the dominant UV pumping process is for some reason inhibited), the fine structure levels of the ground state should be more populated than those for higher excited levels, which again is not observed. For more details on the competition between such mechanisms, see again Vreeswijk et al. (2007).

We ran our code using the total Fe ii column densities and Doppler factors observed for components I and III (\( N = 1.16 \times 10^{14} \) and \( 1.88 \times 10^{14} \) cm\(^{-2}\), \( b = 5 \) and 10 km s\(^{-1}\), respectively). The distance from the absorber was set as a free parameter in order to obtain the best agreement between the data and the photoexcitation code. In Figure 4, we show the results from our code. The dotted, solid, and dashed lines represent the predictions for ground, fine structure, and other excited levels, respectively. The short (long) dashed lines are for Fe ii 4F and 4F* (4D and 4D*) levels. The data are reported as follows. The open circles represent the ground-state levels, the closed circle represents the fine structures of the ground state of Fe ii, the open squares represent Fe ii 4F and 4F*, and the open triangles represent Fe ii 4D and 4D*. The data represent the first and second+third observation, and have been slightly shifted to each other for clarity reasons. Figure 4 shows that the time evolution of the Fe ii column densities of component I is best reproduced by a model with an absorber located at 2 kpc from the GRB (left-hand plot), while the behavior of component III is well fitted with an absorber at 6 kpc from the GRB (right-hand plot). The closer the gas to the GRB, the longer the excited levels tend to be populated with respect to the ground state. The “anomalous” behavior of the Fe ii 4F level is due to its high spontaneous decay rate toward the ground state, which is \( \sim 3 \) hr.

In order for our results to be self-consistent, we need to make sure that, at the smallest distance of 2 kpc as derived for component I, Fe ii is not photoionized away by the strong UV radiation of the burst. To this purpose, we performed a series of runs of the photoionization code by Perna & Lazzati (2002), which accounts for the radiative transfer of the radiation. We first simulated a medium in thermal equilibrium at a temperature of \( \sim 10^5 \) K, and let the radiation from the burst, modeled as in Equation (5), propagate through it. For a range of densities between \( 10^{-1} \) and \( 10^3 \) cm\(^{-3}\), we followed the concentration of Fe ii and Mg i absorbers at a distance of 2 kpc, while the radiation from the burst impinges on them. For densities \( \sim 10^3 \) cm\(^{-3}\), the burst appears not to alter the initial concentration of Fe ii and Mg i. As the density decreases down to about \( 10^{-2} \) cm\(^{-3}\), the concentration of Fe ii still remains unaltered, but Mg i begins to be photoionized significantly. This different behavior is due to the fact that Fe ii is screened by hydrogen, because its photoionization threshold is just above that of H. For even lower densities, Fe ii begins to get photoionized away. For a density of \( 10^{-3} \) cm\(^{-3}\), the concentration of Fe ii decreases by about 15% during the burst. These calculations show that...
there is a wide range of medium densities for which an Fe \text{ii} absorber at a distance of 2 kpc is not photoionized away by the radiation from the burst, while, on the other hand, Mg \text{i} is substantially destroyed. Interestingly, component I is the only one for which Mg \text{i} is below the detection limit. A constraint to the distance of the absorbing gas can be set in this scenario. In order not to have a substantial photoionization of the Fe \text{ii} to the distance of the absorbing gas can be set in this scenario.

5. DISCUSSION AND CONCLUSIONS

Thanks to the VLT RRM, which allowed the observation of GRB080319B in just 5 minutes (rest frame), we were able to catch the absorbing gas in a highly excited state, producing the strongest Fe \text{ii} fine structure lines ever observed in a GRB (or quasi-stellar object (QSO)) spectrum. The optical depth of these lines was dramatically reduced 2–3 hr later, implying a factor of 4–20 decrease for all six components belonging to the main absorption system. At the same time, the optical/UV flux dropped by a factor of ~60 (Bloom et al. 2009; Racusin et al. 2008b). The variation of the Fe \text{ii} fine structure lines is spectacular, when compared to previous GRB observations. Before GRB080319B, the best case was certainly that of GRB060418 at z = 1.490, observed with UVES on comparably short timescales, Vreeswijk et al. (2007) report for this burst variations of the Fe \text{ii} fine structure lines column densities by a factor of 1.4, in spectra taken 700 s and 7680 s after the GRB onset; in the same time interval the optical/UV flux dropped by a factor of ~20. The variations seen in GRB080319B at similar rest-frame timescales are clearly much more prominent. This is probably due to the extremely intense optical/UV radiation field of GRB080319B.

The optical GRB magnitude reached $V \sim 5.3$ about 40 s after the start of the GRB event. At $z = 0.937$, this magnitude implies a $\sim 912$ Å ionizing luminosity $L = 1.2 \times 10^{51}$ erg s$^{-1}$, assuming a power-law spectrum with frequency spectral index $-1$ and integrating it up to 1 keV. Since the Fe \text{ii} ionization potential is just above the photoionization edge of H, this ion is efficiently screened and it can be photoionized only after H has been photoionized. We can compute the number of ionizing photons by integrating the optical/UV light curve (Bloom et al. 2009, Racusin et al. 2008b). We find $N_\gamma = 8.6 \times 10^{62}$ ph at 912 Å; similar numbers are obtained by extrapolating the XRT X-ray spectrum down to 912 Å assuming no absorption, in addition to the Galactic value along the line of sight (LOS).

We can constrain the distance of the absorbing gas to the GRB using these numbers and the ratio between the number of photons absorbed by the first fine structure level and the Fe \text{ii} ground state. In a steady-state approximation (Silva & Viegas 2002; see also Prochaska et al. 2006), this distance turns out to be $\sim 18$ and $\sim 34$ kpc for components I and III, respectively. Since GRBs are highly variable events, to refine these results, we built up a time-dependent photoexcitation code, to model the expected column densities of the Fe \text{ii} levels as a function of time for an absorber illuminated by a flux such as that of GRB080319B. We obtain smaller values for the distances, namely, $\sim 2$ and $\sim 6$ kpc for components I and III, respectively. This discrepancy can be explained by considering the light curve of GRB080319B. The flux of this GRB drops with a steep power law (decay index $\sim 5$) in the first 100 s (Racusin et al. 2008b). The steady-state approximation assumes a constant flux from the GRB, with this constant being the total fluence radiated up to the moment of the absorption line observation, divided by this time range itself. Thus, this constant is $\sim 10^{2}$ times higher than the real flux experienced by the absorber at the moment of the first UVES observation. In this scenario, the steady-state model will then predict a larger distance in order to account for the higher fluxes at later times.

To assure self-consistency, we need to make sure that, at the smallest distance of 2 kpc as derived for component I, Fe \text{ii} is not photoionized away by the strong UV radiation of the burst. We showed that there is a wide range of medium densities for which an Fe \text{ii} absorber at a distance of 2 kpc is not photoionized away by the radiation from the burst ($10^{5} - 10^{2}$ cm$^{-3}$). On the other hand, at densities below $\sim 1$ cm$^{-3}$, Mg \text{i} is substantially destroyed. Interestingly, component I is the only one for which Mg \text{i} is below the detection limit. In addition, 2 kpc can be considered in this scenario a robust lower limit to the distance of the absorbers for reliable gas densities.
Taken at face value, these distances are rather large for a typical galaxy at \( z \sim 1 \) (e.g., Sargent et al. 2007) and could imply that the 0.937 system is in the outskirts of the GRB host galaxy or in a nearby clump along the LOS. Interestingly, *Hubble Space Telescope* imaging of the field shows diffuse emission elongated south of the afterglow. In particular, two faint clumps of emissions are located at 1.5′′ and 3′′ from the afterglow (Tanvir et al. 2008). At \( z = 0.937 \) these correspond to projected distances of 12 and 24 kpc, and may suggest the presence of a complex structure of clumps around the GRB host galaxy. If this is the case, the absorbers may well belong to one of these clumps.

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