GRB 070125: The First Long-Duration Gamma-ray Burst in a Halo Environment

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Abstract. We present the discovery and high signal-to-noise spectroscopic observations of the optical afterglow of the long-duration gamma-ray burst GRB 070125. Unlike all previously observed long-duration afterglows in the redshift range $0.5 \lesssim z \lesssim 2.0$, we find no strong (rest-frame equivalent width $W_{\mathrm{r}} \gtrsim 1.0$ Å) absorption features in the wavelength range 4000-10000 Å. The sole significant feature is a weak doublet that we identify as Mg II $\lambda\lambda$ 2796 ($W_{\mathrm{r}} = 0.18 \pm 0.02$ Å), 2803 ($W_{\mathrm{r}} = 0.08 \pm 0.01$ Å) at $z = 1.5477 \pm 0.0001$. The low observed Mg II and inferred H I column densities are typically observed in galactic halos, far away from the bulk of massive star formation. Deep ground-based imaging reveals no host directly underneath the afterglow to a limit of $R > 25.4$ mag. Either of the two nearest blue galaxies could host GRB 070125; the large offset ($d \geq 27$ kpc) would naturally explain the low column densities. To remain consistent with the large local (i.e. parsec scale) circum-burst density inferred from broadband afterglow observations, we speculate GRB 070125 may have occurred far away from the disk of its host in a compact star-forming cluster. Such distant stellar clusters, typically formed by dynamical galaxy interactions, have been observed in the nearby universe, and should be more prevalent at $z > 1$ where galaxy mergers occur more frequently.

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INTRODUCTION

The connection between long-duration ($\Delta t \gtrsim 2$ s) gamma-ray bursts (GRBs) and hydrogen-stripped, core-collapse supernovae (i.e. Type Ib/c SNe) is now well-established (see e.g. [1]). Bright GRB afterglows are therefore ideally suited to probe the dense gas in the very regions where stars are being formed. Consequently, absorption spectra of GRB systems are characterized by large metal equivalent widths and extremely high neutral hydrogen column densities, typically falling at log N(H I) > 20.3 (the so-called damped Lyα systems, or DLAs; [2]).

Here we present observations of a long-duration event, GRB 070125, that does not fit neatly into this paradigm. A complete discussion of our findings can found in [3].

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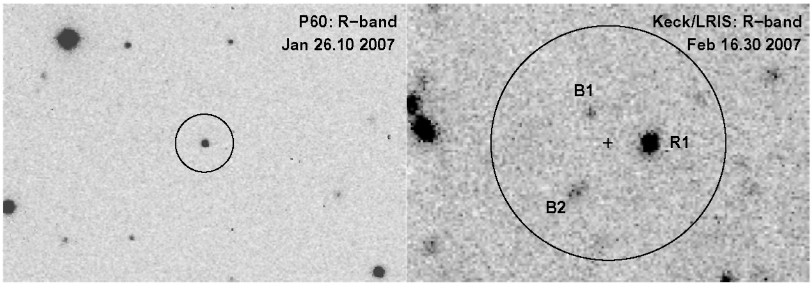

FIGURE 1. Optical imaging of the field of GRB 070125. *Left*: P60 R-band discovery image of the afterglow of GRB 070125. The afterglow is centered inside a circle of radius $10''$. *Right*: Late-time Keck/LRIS R-band image of the field. The location of the afterglow is marked with a cross. The black circle again has a radius of $10''$.

OBSERVATIONS AND DATA REDUCTION

GRB 070125 was discovered by the Inter-Planetary Network at 07:20:45 UT on 2007 January 25 [4]. The burst was notable both for its brightness ($F_\gamma = 1.75^{+0.18}_{-0.15} \times 10^{-4}\,\mathrm{erg\,cm^{-2}}$; [5]) and its long duration ($\Delta t \gtrsim 200\,\mathrm{s}$; [4, 5]).

We began observing the field of GRB 070125 with the automated Palomar 60-inch telescope [6] at 02:18:59 UT on 2007 January 26 ($\Delta t = 19.0$ hours). Inside the burst error circle, we found a bright, stationary source ($R = 18.59 \pm 0.03$) not present in the Sloan Digital Sky Survey images of this field that we identified as the optical afterglow of GRB 070125 (Fig. 1).

We undertook spectroscopic observations of GRB 070125 with the Gemini Multi-Object Spectrograph (GMOS) mounted on the 8-m Gemini North Telescope beginning on the night of 2007 January 26. Details of our observations can be found in [3].

Deep, late-time imaging to search for the host galaxy of GRB 070125 was taken with the Low-Resolution Imaging Spectrometer (LRIS) mounted on the 10-m Keck I telescope. We obtained 4×300 s images at a mean epoch of 7:12:06.6 UT on 2007 February 16. The resulting R-band image is shown in Figure 1 (right panel).

RESULTS

In our combined GMOS spectrum from the night of 2007 January 26, we identify the sole significant feature as the Mg II $\lambda\lambda$ 2796,2803 absorption doublet at $z = 1.5477 \pm 0.0001$. Besides the observed wavelength ratio, the observed equivalent width ratio (Mg II λ 2796 / Mg II λ 2803) is consistent with the value of 2:1 predicted for weak, unsaturated absorption from this transition. Furthermore, this Mg II doublet is the strongest absorption feature observed in *all* GRB hosts identified in the redshift range $0.5 \lesssim z \lesssim 2.0$, and is common in intervening systems of both QSOs [7] and GRBs [8].

The rest-frame equivalent widths ($W_\mathrm{r} = 0.18 \pm 0.02, 0.08 \pm 0.01$ Å) correspond to an Mg II column density of log N(Mg II) $= 12.61 \pm 0.05$ in the optically thin (i.e. unsat-

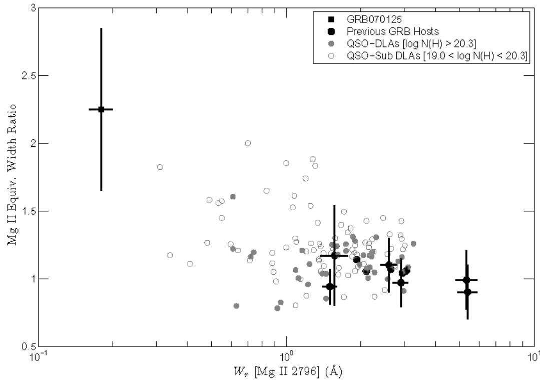

FIGURE 2. Mg II absorption in GRB host galaxies. Here we plot a compilation of all the equivalent width measurements of the Mg II λ 2796 absorption feature in GRB hosts. On the y-axis, we plot the observed ratio between the Mg II λ 2796 and Mg II λ 2803 lines. Ratios deviating from 2 indicate the lines have become saturated and the corresponding optically thin densities should be treated as lower limits. Shown in gray are analogous measurements for QSO-DLAs ((log N(H I) > 20.3; filled circles) and QSO-Sub DLAs (19.0 < log N(H I) < 20.3; empty circles) [13].

urated limit). This serves as a strict upper limit on the Mg II column density present in the GRB host; although this absorption may be from an intervening system, the lack of Lyα absorption limits the GRB host redshift to $z < 2.3$ and guarantees the Mg II $\lambda\lambda$ 2796,2803 transition falls within the observed bandpass.

We compare the observed rest-frame Mg II equivalent widths for GRB 070125 to all previous GRB hosts in Figure 2, as well QSO-DLAs (log N(H I) > 20.3) and QSO-Sub DLAs ($19.0 <$ log N(H I) < 20.3). Clearly GRB 070125 is an outlier. The factor of 10–15 discrepancy between the equivalent width measurements of GRB 070125 and previous GRBs likely underestimates the true difference in column density because all previous GRB Mg II detections were highly saturated.

We can infer the neutral hydrogen column density for the host of GRB 070125 using a variety of methods. Previous GRB hosts range in metallicity from $-2.0 \lesssim$ [M/H] $\lesssim -0.5$ [9, 10], predicting an H I column density of $18.0 \lesssim$ log N(H I) $\lesssim 19.5$ (using solar abundances from [11]). By comparing with QSOs in Figure 2, we find it likely that log N(H I) < 19.0. Such densities are usually associated with galaxy halos, and stand in contrast with the sample of previously observed GRB hosts [12].

Our late-time imaging of GRB 070125 (Fig. 1) reveals no host directly underlying the afterglow to limits of $R > 25.4$ mag (Vega), $g' > 26.1$ mag (AB). At large offsets, three candidate host galaxies lie within $10''$ of the afterglow location: $R1$, $B1$, and $B2$ (Fig. 1, right panel). $R1$ is a large red ($g' - R \approx 2.4$ mag) early-type galaxy in the foreground at $z = 0.897$. The other two objects, $B1$ at $3.2''$ distance, and $B2$ at a distance of $5.5''$, are both blue ($g' - R \approx 0$ mag) and compact, more typical of long-duration GRB hosts. Unfortunately neither galaxy fell on the slit in any of our spectra.

DISCUSSION

Finally, we speculate on the origin of GRB 070125. Despite the recent discovery of two nearby, long-duration GRBs lacking associated SN emission [14, 15, 16, 17], we believe GRB 070125 had a massive star progenitor. In a separate work, Chandra et al. (*ApJ* submitted) have shown that the collimation-corrected energy release ($E_\gamma \approx 10^{52}$ erg) and *local* (i.e. parsec scale) density ($n \approx 30\,\mathrm{cm}^{-2}$) are inconsistent with a degenerate binary merger origin. While this may seem inconsistent with the low Mg II column density derived from absorption spectroscopy, we instead consider the two observations the strongest evidence to date that afterglow studies and absorption spectroscopy probe *distinct regions*: the parsec-scale circum-burst medium for the afterglow versus the more distant (≥ 100 pc) ISM for absorption spectroscopy [18].

For the closest putative host from our LRIS imaging, the observed offset of $3.2''$ corresponds to a projected distance of ≈ 27 kpc at $z = 1.5477$. A massive star would need an extremely large peculiar velocity to leave its hosts disk: $\sim 10^4$ km s^{-1} for a 20 Myr lifetime. It is much more probable that the progenitor was formed *in situ*.

Such a scenario has precedent in the local universe, where young, massive, compact star clusters have been found at large distances in tidal tails of interacting galaxies (e.g. "Antenna" system, "Tadpole" galaxy). Broadband surveys of nearby galaxies indicate a significant fraction ($\lesssim 1\%$) of the current star formation in the local universe takes place in these extreme environments. With our current understanding of hierarchical galaxy formation, such interactions should only increase in frequency as a function of look-back time. In retrospect, it is not entirely surprising that, of the ~ 50 long-duration GRBs with absorption spectra, we should discover such an event.

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