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# DETECTION OF A Ly$\alpha$ EMISSION-LINE COMPANION TO THE $z = 4.69$ QUASAR BR 1202−0725[1]

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## ABSTRACT

We report the detection of a nearby emission-line companion to the $z = 4.695$ quasar BR 1202−0725. Deep narrowband exposures on this field from the University of Hawaii 2.2 m telescope show a Ly$\alpha$ flux of $1.5 \times 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$. High-resolution imaging in the F814W filter band with the *Hubble Space Telescope* Wide Field Planetary Camera (WFPC2) shows continuum structure near the emission position, at 2".6 northwest of the quasar, corresponding to a projected separation of $\sim 7.5\ h^{-1}$ kpc for $q_0 = 0.5$, where $h \equiv H_0/100$ km s$^{-1}$ Mpc$^{-1}$. We discuss possible explanations for the combined line and color properties. The ionization is most likely produced by the quasar, but, if due to underlying star formation, would require a star formation rate of $\sim 7\ h^{-2}\ M_\odot$ yr$^{-1}$.

*Subject headings:* cosmology: observations — early universe — intergalactic medium — quasars: emission lines — quasars: individual (BR 1202−0725)

## 1. INTRODUCTION

The known high-$z$ quasars are extremely luminous objects, capable of lighting up any gas or dust in their vicinity out to several hundred kiloparsecs by direct ionization, and by scattering in Ly$\alpha$ and continuum light. At redshifts $z \sim 4$, when the age of the universe was $\sim$1 Gyr, the available time is comparable to the dynamical timescales of galactic halos, and any infalling gas within a quasar host galaxy should be illuminated by the central source (Rees 1988). A number of Ly$\alpha$ searches around high-redshift quasars have succeeded in identifying Ly$\alpha$ emitters at the redshift of the quasar and within a small angular separation from the quasar (e.g., Djorgovski et al. 1985; Hu et al. 1991). The simplest explanation for the Ly$\alpha$-emitting gas seen around these systems is that it is due to ionization of the gas in nearby, possibly interacting, galaxies or gas clouds by the quasar (Hu & Cowie 1987; Hu et al. 1991). Even very small column densities of gas or dust (e.g., as little as $10^{18}$ cm$^{-2}$ in neutral hydrogen) can result in significant scattering or reprocessing.

In the present Letter, we describe the discovery of a very high redshift emission companion to the $z = 4.695$ quasar BR 1202−0725, designated here as BR 1202−0725e, which is detected in deep narrowband images centered on the quasar's Ly$\alpha$ emission, at a position $\sim$2".3 northwest of the quasar. At $z = 4.69$, 1" corresponds to 3.0 $h^{-1}$ kpc for $q_0 = 0.5$ (or 5.2 $h^{-1}$ kpc for $q_0 = 0.1$), so 2".3 corresponds to a projected separation of 6.9 $h^{-1}$ (12.0 $h^{-1}$) kpc. The object is also seen in a *Hubble Space Telescope* (*HST*) *I*-band continuum exposure (F814W), with a centroid slightly offset from the emission, and has been studied in several colors by D'Odorico et al. (1995), who argued based on the optical colors, with additional evidence from near-IR magnitude measurements by Djorgovski (1995), that this object is at $z > 4$, but identify it with the $z = 4.38$ damped Ly$\alpha$ system discovered by Storrie-Lombardi et al. (1995) rather than with the quasar itself. The present data suggest that the continuum object is at the redshift of the quasar rather than at the redshift of the foreground-damped Ly$\alpha$ system.

## 2. DATA

The QSO BR 1202−0725 was discovered in the Automatic Plate Measuring Facility (APM) *BRI* survey for $z > 4$ QSOs (Irwin, McMahon, & Hazard 1991). As part of a program to search for high-$z$ objects in the fields of $z > 4$ quasars, we have obtained a number of exposures through a narrowband filter centered on the quasar's redshifted Ly$\alpha$ emission (central wavelength 6925 Å, 80 Å bandpass) and through *B*, *I*, *K* multicolor imaging with a Tektronix 2048$^2$ camera at optical wavelengths and the NICMOS3 (256$^2$) and QUIRC (1024$^2$) cameras at near-infrared wavelengths.[3] The optical data were taken as a series of sky noise–limited integrations, each with an exposure time of 30 minutes (in the case of the narrowband exposures), with an offset step of 10" between successive frames, and a median sky flat was generated from the on-field exposures for each night, while the IR data followed standard deep-IR imaging procedures (e.g., Cowie et al. 1994). The optical data were taken on the University of Hawaii (UH) 2.2 m telescope on the nights of (UT) 1994 March 5–7, 1994 April 7–8, and 1995 March 29–30, while the IR data were taken on

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[3] The IR observations cited here are taken using the $K'$ filter, which has a central wavelength of 2.1 $\mu$m, in order to suppress the thermal component of background. We will refer to $K$ and $K'$ interchangeably here; the detailed photometric conversion is given in Wainscoat & Cowie (1992).

1994 April 16–18 (NICMOS3) and on 1995 March 18–20 (QUIRC) using the UH 2.2 m. The total exposure times were 8 hr in Ly$\alpha$, 4.2 hr in $B$, 5.25 hr in $I$, 1.5 hr in $I'$ (8340/895), and 17 hr in $K'$. The broadband data were calibrated using Landolt standards (Landolt 1992) and stars drawn from both the United Kingdom Infrared Telescope (UKIRT) faint standards (Casali & Hawarden 1992) and Elias standards (Elias et al. 1982) in observations both before and after the target exposures. The narrowband exposures were calibrated using Feige 34 and BD +33°2642. In addition, a relative calibration check with Landolt standard-calibrated continuum exposures taken in an 895 Å line-free band centered at 8340 Å was also used to verify estimates of the Ly$\alpha$ and continuum flux.

A series of *HST* exposures were obtained on 1995 July 25–26 using the Wide Field Planetary Camera (WFPC2) and the F814W filter. The F814W filter has an effective central wavelength of ~7900 Å and an effective width of ~1450 Å, sampling the spectral range 1260–1514 Å in the rest frame of the QSO (a region free of strong lines such as Ly$\alpha$ and C IV). *HST* exposures were taken as a sequence of eight exposures, with the two initial exposures each being 1000 s long and the subsequent six exposures each 1200 s in duration, over four primary orbits for a total of 9200 s. Object magnitudes on the *HST* F814W data were obtained using the PHOTFLAM-calibrated fluxes over a 2″ diameter aperture and converted to a Kron-Cousins $I$-band magnitude following Cowie, Hu, & Songaila (1995).

The Ly$\alpha$ image of the quasar shows a substantial extension to the northwest of the quasar and centered at a radial separation of 2″.3. In Figure 1 (Plate L6) (*left panel*), we show a sharpened version of this image, which was deconvolved using maximum entropy from typical FWHM of ~0″.9 on individual exposures to a FWHM of 0″.6, with the point-spread function taken from the star that can be seen in the upper northwest corner of the image. The *HST* $I$-band image shows a linear galaxy, extended toward the quasar, also lying at this position, though on the westward side of the Ly$\alpha$ emission (Fig. 1, *right panel*). This slight displacement (~0″.6 in the east-west direction) appears to be real. The continuum object agrees in position with the object detected by D'Odorico et al. (1995) using the ESO New Technology Telescope (NTT). Subtracting the continuum, we find a Ly$\alpha$ flux of $1.5 \times 10^{-16}$ ergs cm$^2$ s$^{-1}$ for the companion and an $I$ (Kron-Cousins) = 24.2 ± 0.1 for the associated continuum object. The emission is comparable to the measured fluxes found for other quasar Ly$\alpha$ companions (e.g., Djorgovski et al. 1987; Hu et al. 1991), which are typically a few times $10^{-16}$ ergs cm$^2$ s$^{-1}$, and the continuum magnitude is in good agreement with D'Odorico et al. (1995), who find ($B$, $V$, $R$, $I$) = (>27.3, 26.5, 24.3, 24.1). Our $K'$-band observations shown in Figure 2 (Plate L7) also show an extension to the northwest of the quasar. (There are hints in both the *HST* and the $K'$ data of further emission extending in a line to larger radii.) Measuring in a 1″ diameter aperture centered on the $I$-band object, we find $K = 23.4 \pm 0.3$ when the underlying quasar contribution is subtracted, while Lu et al. (1996) quote a $K$ magnitude of 23 ± 1 based on Djorgovski's (1995) observations. D'Odorico et al. (1995) point out that the sharp break in the optical implies that the object is at high redshift ($z > 4$), consistent with its identification as a quasar companion. The combined spectral energy distribution (SED) is illustrated in Figure 3, where it is compared with the spectrum of the quasar itself, showing that the photometry on the companion is consistent

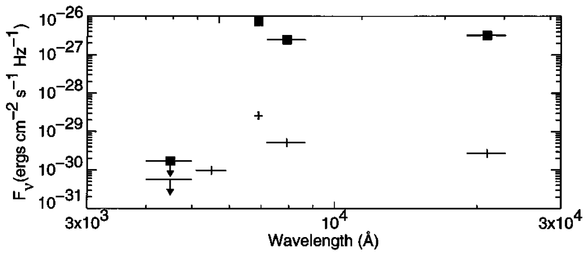


FIG. 3.—SED of the quasar (*filled squares*) and its Ly$\alpha$ companion (*horizontal bars*) as measured at $B$, $I$, and $K'$, and in the 6925 Å narrowband filter. The observed wavelength from 3000 Å to 3 $\mu$m is shown plotted logarithmically; corresponding rest-frame wavelengths (from 527 to 5268 Å) are indicated by the tick marks along the top axis. The width of each bar reflects the filter bandpass. The $B$, $I$, and $K$ photometry for the quasar is taken from Egami (1995), and these imaging data sets have been combined with the narrowband imaging data for the measurements shown here. The $I$ data for the Ly$\alpha$ companion are taken from the 2.6 hr *HST* WFPC2 exposure, and the Ly$\alpha$ narrowband and $K$ images have been sharpened with maximum entropy techniques as shown in Figs. 1 and 2 to allow separation from, and subtraction of, the underlying quasar light in these bands. We have supplemented these measurements for the companion with the upper limit on $B$ and the $V$ magnitude given by D'Odorico et al. (1995); their $R$ band is heavily contaminated by emission and is not used here. One sigma error bars are shown.

with its lying at the quasar redshift. The association of the continuum object with the quasar Ly$\alpha$ strongly suggests that it is *not* associated with the damped Ly$\alpha$ system at $z = 4.38$, as D'Odorico et al. (1995) and Lu et al. (1996) have recently suggested. A second galaxy lying about 3″.5 to the southwest of the quasar with a slightly fainter $I$ magnitude (24.5) may represent an alternative candidate, since we do not see any strong Ly$\alpha$ emission at the quasar redshift associated with this object.

The present results indicate that some caution must be applied to identifying objects in close proximity to high-redshift quasars with foreground absorption systems. Steidel, Sargent, & Dickinson (1991) and Aragón-Salamanca (1995) have serendipitously discovered Ly$\alpha$-emitting companions to $z \sim 3$ QSOs, when attempting to identify foreground absorbers. At high redshift, the difference in distance modulus between the background QSO and an intervening absorber is much less than for a typical case at low redshift, so that any faint object lying in the vicinity of a QSO may be as likely to be associated with the QSO as with the absorption-line system.

The discovery of a Ly$\alpha$ companion near BR 1202−0725 indicates that it is fruitful to search for such objects at optical wavelengths. More precise information on the nature of this object will require spectroscopic data at IR and optical wavelengths, which will also provide physical diagnostics on the emission system, to distinguish between active galactic nucleus–like or quasar-excitation mechanisms and to supply additional information on the nature of this system.

## 3. CONCLUSIONS

Since the rest frame $B$ magnitude is roughly coincident with the observed $K$ magnitude, we may directly obtain the rest frame absolute $B$ magnitude ($M_B$) as

$$M_B = m_K - dm + 4.1, \quad (1)$$

where $dm$ is the distance modulus, and the last term is the $K$-correction. For $q_0 = 0.5$ and $H_0 = 50$ km s$^{-1}$ Mpc$^{-1}$, we find $M_B = -20.5$, or only about 1/3 of the local $L_*$ (Loveday et al. 1992), so the galaxy is roughly comparable to an $L_*$ galaxy. As

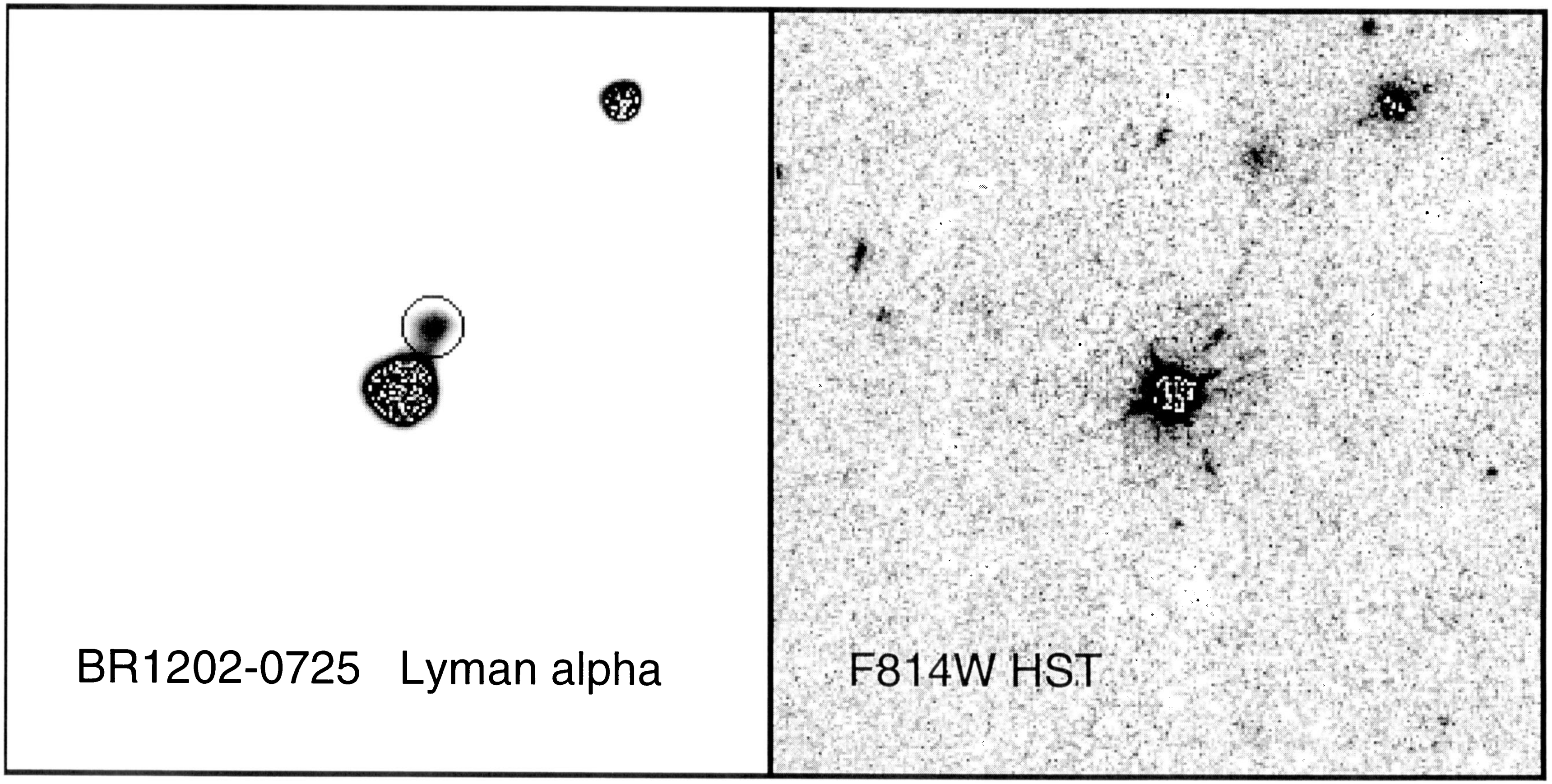


FIG. 1.—The 25″.6 × 25″.6 field surrounding the $z = 4.69$ quasar BR 1202−0725 at coordinate center [$\alpha$(1950): $12^h02^m49^s.19$, $\delta$(1950): −7°25′50″.4; McMahon et al. (1994)] (*left panel*) seen in an 8 hr exposure on the UH 2.2 m telescope through an 80 Å wide, narrowband filter centered on the quasar's redshifted Ly$\alpha$ emission, and in a 2.6 hr *HST* exposure (*right panel*) through the F814W ("wide *I*") continuum band. The narrowband image has been sharpened using maximum entropy methods to highlight the position of the faint companion emission against the bright quasar signal, and this feature is shown encircled by a 2″ diameter aperture. The enclosed emission-line flux is $\sim 1.5 \times 10^{-16}$ ergs cm$^{-2}$ s$^{-1}$—comparable to the Ly$\alpha$ brightness of other close companions to high-redshift quasars (e.g., Djorgovski et al. 1987; Hu et al. 1991). The faint continuum feature seen near the position of the Ly$\alpha$ emission is located 1″.63 west and 2″.08 north of the quasar and has a measured *I* magnitude of 24.2. By contrast, the Ly$\alpha$ emission lies 1″.0 west and 2″.1 north of the quasar. North is up, and east is to the left.

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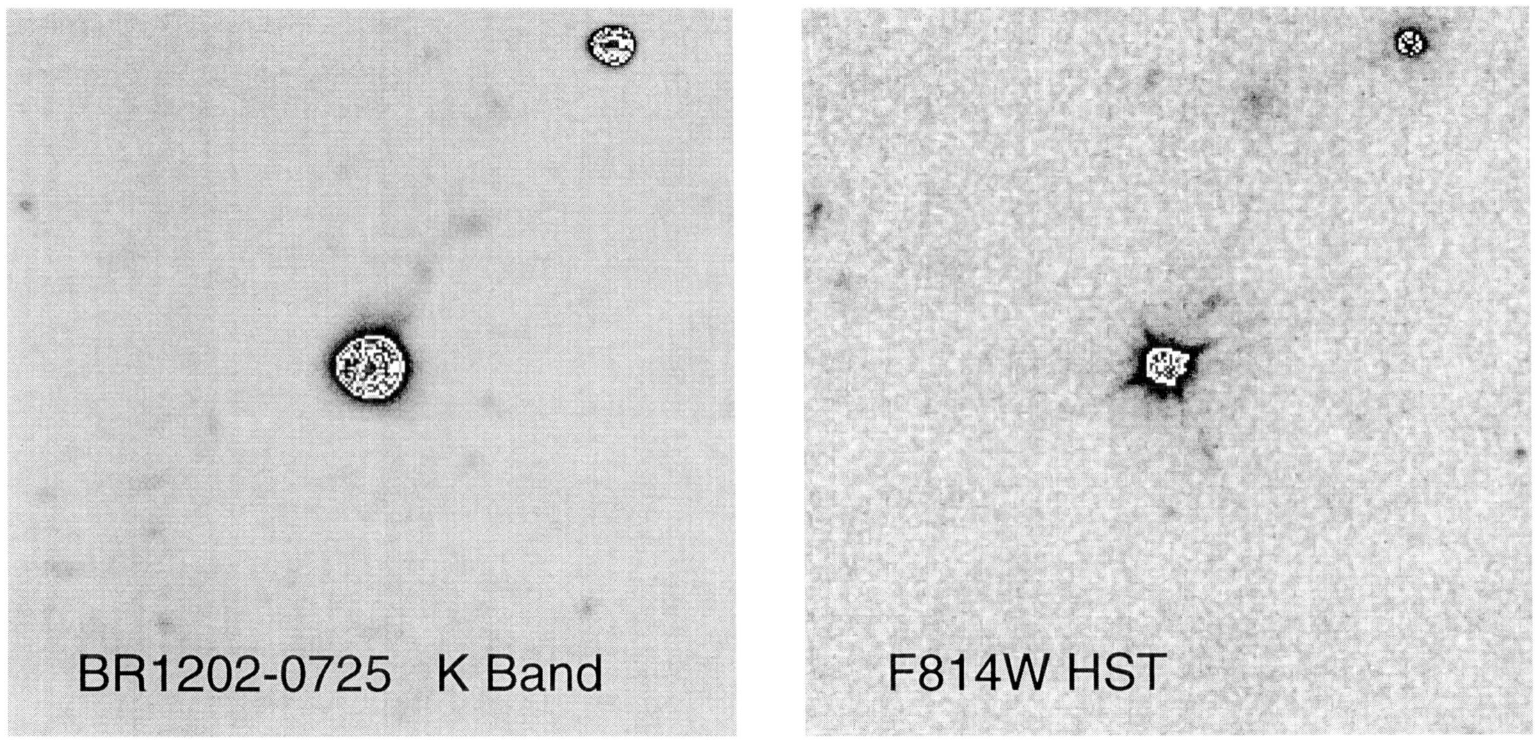


FIG. 2.—Comparison of *K*-band image (*left panel*) of the region near the quasar BR 1202−0725 with the *HST* F814W ("wide *I*," *right panel*) image, showing the extension in continuum light to the northwest in both images. Each field is 22″ × 22″, and the plate scale matches that of Fig. 1. The *K*-band image has been sharpened with maximum entropy using the star in the upper right of the frame in order to highlight the faint structure near the quasar. The composite *K*-band image represents a 17 hr integration at the UH 2.2 m, and the estimated *K* magnitude measured in a 1″ diameter aperture centered on the position of the *HST I*-band continuum source is 23.4 ± 0.4, after subtracting the underlying quasar contribution.

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can be seen from Figure 3, its SED is similar to that of the quasar, but it contains only about 0.1% of the quasar light.

The observed equivalent width of the Ly$\alpha$ is about 450 Å, corresponding to a rest frame value of 80 Å. This would be consistent with excitation by the underlying population (Charlot & Fall 1993), but given the apparently more extended nature of the ionized gas, its slight displacement from the continuum centroid, and its proximity to the much more luminous quasar, it is more probable that the quasar is the primary ionizing source. The ionized gas covers a sufficiently large fraction of the surface surrounding the quasar so that only a very small fraction of the ionizing flux passing through it needs to be absorbed and reradiated to produce the observed Ly$\alpha$ emission (Hu & Cowie 1987). However, Pahre & Djorgovski (1995), who have performed targeted IR narrowband searches around BR 1202−0725 in the [O II] line using the Near Infrared Camera (NIRC) at Keck (with three other fields studied in H$\alpha$ or [O III]), saw no evidence for extended emission near the quasar down to fluxes of $1.60 \times 10^{-17}$ ergs cm$^2$ s$^{-1}$, giving [O II]/H$\alpha \sim 0.1$. This would require there to be very little extinction of the Ly$\alpha$ photons if metallicities were near solar, but it is likely that the metallicities are much lower in these early objects. The proximity of the quasar (separation $\sim 2''$ with typical seeing FWHM $\sim 0\farcs75$ in the Pahre & Djorgovski observations) may also imply that somewhat higher flux limits on [O II] (e.g., by roughly a factor of 2) are appropriate at the position of BR 1202−0725e. If the observed emission were due to photoionization by stars, with little attenuation by dust, then the luminosity in the line of $7 \times 10^{42}\ h^{-2}$ ergs ($q_0 = 0.5$) corresponds to a star formation rate (SFR) of $\sim 7\ h^{-2}\ M_\odot$ yr$^{-1}$, where we use Kennicutt's (1983) relation between H$\alpha$ luminosity and SFR = $L(\mathrm{H}\alpha) \times 8.9 \times 10^{-42}$ ergs s$^{-1}$ $M_\odot$ yr$^{-1}$, and assume Ly$\alpha$/H$\alpha$ = 8.7 for case B recombination (e.g., Brocklehurst 1971).

Close Ly$\alpha$ companions to the high-$z$ quasars are only infrequently seen at these fluxes (about 15% of the cases in Hu et al. 1991, all of which were around radio-loud quasars, where they were detected in roughly a third of the cases, and generally at lower flux levels), and this is also true of the $z > 4$ quasars, where BR 1202−0725 is the only one of five radio-quiet cases where we see such emission. They may represent cases where a neighboring gas cloud or galaxy (as might be the case here) is interacting and merging with the underlying quasar host, producing enough extended gas to form a significant Ly$\alpha$ companion when ionized by the quasar.

Finally, it is notable that BR 1202−0725 has been detected at millimeter wavelengths (McMahon et al. 1994; Isaak et al. 1994). This radiation is consistent with thermal emission from $10^9\ M_\odot$ dust analogous to that detected by *IRAS* in nearby star-forming galaxies, and this would also be consistent with dust originating in an interaction with the quasar.

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