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Spectroscopy of the extended emission associated with two high-z quasars*

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Abstract. We present spectra taken with the Low Resolution Imaging Spectrograph on the Keck 10m telescope of spatially-resolved structures ('fuzz') around the high-redshift radio-loud quasars PKS 0445+097 (z=2.108) and PKS 2338+042 (z=2.589). For PKS 0445+097 we oriented the slit such that it passed through the quasar nucleus and through an object identified on an HST exposure 1.8" to the southeast of the nucleus. We find that this object has strong [OII]λ3727 emission and weaker emission due to [NeV]λ3426 and [NeIII]λ3869, at a redshift of z=0.8384. This redshift is very close (Δv=200 km s^{-1}) to that of a MgII absorption line identified in the spectrum of PKS 0445+097. The line ratios and narrowness of the lines indicate that this galaxy probably has a Seyfert 2 nucleus. Moreover, we find that there is faint extended HeIIλ1640 and CIII]λ1909 from the quasar host galaxy. Both of the lines are broad (FWHM$_{HeII}$=1000 $\pm$ 200 km s^{-1} and FWHM=2200 $\pm$ 600 kms^{-1}). The limits on the fluxes, the large line widths, and the line ratio HeII/CIII] are similar to that observed for high redshift radio galaxies.

From the spectrum of PKS 2338+042, we find extended Lyα emission on scales about 10" which is strongly one sided (on the side of the stronger, closer to the nucleus, more distorted radio lobe). The extended Lyα line is broad with widths of over 1000 km s^{-1}. The extended emission shows no evidence for a strong velocity shear. We also find weak extended CIV and HeII emission which has similar characteristics (line widths, line fluxes, and line ratios) to that of high redshift radio galaxies. In addition, we serendipitously discovered what appears to be a Lyα emitting galaxy about 29" to the southeast of the quasar at z=2.665. The single line identified in the spectrum has a measure equivalent width of 2100Å and a full width at half maximum of 2150 km s^{-1}. The high equivalent width and large velocity width of the putative Lyα line suggest that this galaxy must be a high redshift AGN, although we note that the upper limits on the CIV and HeII line ratios are mildly inconsistent with this galaxy harboring an AGN. An approximate calculation shows the quasar nucleus is not exciting the Lyα emission from this galaxy.

Key words: quasars: individual: PKS 0445+097 – quasars: individual: PKS 2338+042 – galaxies: evolution – radio continuum: galaxies

1. Introduction

Luminous active galactic nuclei (AGN) are very much a high-redshift phenomenon – their co-moving space density has fallen by about a factor of 1000 between the epochs z≈2.5 and the present (e.g., Hartwick & Schade 1990; Boyle 1993). Many current cosmogonical scenarios suggest that the era of major star-formation within galaxy spheroids (the "epoch of galaxy formation") took place at about the same time as this dramatic peak in the co-moving space densities of quasars (e.g., Rees 1988). If this is indeed the case, then by gaining insight into the processes which govern the creation, evolution, and "mass extinction" of AGN, we can perhaps achieve a deeper understanding of the mechanisms that control the evolution of galaxies in general.

Recently, there has been a breakthrough in our understanding of the environments of radio-loud quasars at z≈2. Ground-based data and more recently obtained high-quality HST imaging data have revealed many fascinating properties of the host galaxies of high redshift quasars. It has been found that quasar fuzz has strong nebular emission, super-galactic size scales (tens of kpc) of the line and continuum emission, continuum spectral energy distribution similar to those of present-day Magellanic Irregulars or very late type spiral galaxies (but on average, redder than the nuclei of the associated AGN), K magnitudes that fall along the band defined by the radio galaxies in the IR Hubble diagram (K magnitude versus redshift), and rest-frame optical/UV luminosities about ten times

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* Based on observations taken at the W. M. Keck Observatory

more luminous than the most luminous galaxies in the present-day universe (Heckman et al. 1991a; Heckman et al. 1991b; Lehnert et al. 1992; Lehnert et al. 1997a). Moreover, the ground-based data revealed very asymmetric emission line and continuum morphologies for the fuzz, and a weak tendency for quasars to exhibit an "alignment effect" like radio galaxies (Heckman et al. 1991a). Recent HST images now suggest that these asymmetric morphologies are due to interactions with nearby companions, optical synchrotron emission, scattering of light from the AGN, or to galaxies responsible for intervening absorption systems along the line of sight to the quasar. They also imply that quasars exhibit a radio-UV/optical alignment similar to radio galaxies (Lehnert et al. 1997b). In general, the companion object or intervening absorber (which contributes a substantial amount of the extended luminosity) does not lie along the radio axis (Lehnert et al. 1992; Lehnert et al. 1997a) and tend to weaken the "alignment" generally seen in the quasar population.

To further our understanding of the properties of the high redshift quasar population, we obtained spectra of two high (z$\geq$2) redshift quasars using the Keck 10m to obtain optical (rest frame UV) spectra of a sample of high redshift radio loud quasar that are known to have extended Lyα and continuum emitting "fuzz" around quasars selected from Heckman et al. 1991a. Generally, obtaining spectra of the host galaxies of high redshift quasars will allow us to attack a number of specific issues concerning the nature and properties of these objects. Specifically, with data like the ones presented here, we would like to be able to address the issues of: What is the process that is responsible for the ionization of the extended emission line gas? Is the gas photoionization by massive stars whose formation may have been induced by the passage of the radio emitting plasma, shocks due to the kinetic energy released by the AGN, photoionization by the AGN, or something else? What is the nature of the extended continuum emission? Is the extended continuum scattered quasar light or due to the stellar population of the host galaxy? What are the kinematic properties of the extended emission line gas? Is the gas likely to be infalling? Might we be seeing the formation of galaxy disks (some of the nebulae are quite elongated)? Is the gas interacting dynamically with the radio emitting plasma? Can we find evidence for rotation which might suggest a more relaxed dynamical state, or find large scale velocity shears that might implicate galaxy mergers as important in fueling the "quasar epoch"? What is the relationship (if any) between the $z_{abs} \approx z_{em}$ absorption line systems and the extended emission line gas?

2. Observations and reduction

The spectra were taken on September 1, 1995 (UT) using the Keck 10m telescope in combination with the Low Resolution Imaging Spectrometer (LRIS; Oke et al. 1995) with a TEK 2048^2 CCD. The night was cloudy and we were only able to observe for a few of hours at the end of the night when the clouds thinned sufficiently to warrant observing. We used LRIS in two configurations. For the observations of PKS 2338+042, we used with the 600 l m^{-1} grating (blazed at 5000Å). The resulting spectrum covered the spectral range 3860 – 6430Å and had a resolution of about 4.5Å (as measured using the night sky lines). This range was sufficiently large to include the Lyα, CIVλ1549, and HeIIλ1640 emission lines. The final spectrum of PKS 2338+042 is a result of averaging three separate exposures of 1800 seconds duration. The slit for these observations was oriented along PA=135° and was selected to be along the most extended position angle of the Lyα emission as revealed in the images of Heckman et al. 1991a and approximately along the position angle of the most extended radio emission. For the observation of PKS 0445+097, we used the 300 l m^{-1} grating (blazed at 7500Å). The resulting spectrum covered the spectral range 3980 – 9040Å and had a resolution of 11Å FWHM (as measured using the night sky lines). The spectral range was sufficient to include CIVλ1549, HeIIλ1640, CIII]λ1909, and MgIIλ2798. We were only able to obtain one 1800 second exposure of PKS 0445+097 due to increasing cloudiness. The slit was oriented along PA=110° which was chosen such that the slit would pass through the nucleus and the blob of continuum emission seen in the HST images of PKS 0445+097 in Lehnert et al. 1997a. Both quasars were observed through a 1" wide slit. The scale of the CCD is 0.22" pixel^{-1}. The seeing during the observations was about 1".

The spectra were reduced in the standard way using IRAF. The data were bias subtracted using the values of the overscan region, flat-fielded using several exposures of the internal lamp taken immediately after the observations, and flux-calibrated (to remove the response only since the night was not spectroscopic) using observations of Hz4. The spectra were wavelength calibrated using exposures of the Ne, Hg, and Kr lamps. The parameters of the lines (center, width, and flux) were then estimated by fitting a Gaussian profile using the IRAF task SPLOT. The Lyα emission in the longslit spectrum of PKS 338+042 was obviously spatially extended. We measured the properties of the extended emission in sums of 4 CCD rows which is about 0.9" in projection on the sky. Since the seeing was $\leq$1", these extractions provide independent information. Error estimates were provided by SPLOT assuming that the noise in each pixel was just the root mean square of the noise in the surrounding continuum (see the help for SPLOT). The uncertainties in the fit estimated this way probably slightly under-estimates the true uncertainty of the fit. Generally, for the analysis of the extended line emission, we excluded spatial regions of the spectrum that had strong contamination due to line emission from the nucleus. Thus none of our results rely on the rather difficult and uncertain method of subtracting off a template nuclear spectrum in order to reveal the narrow extended emission line component.

Since the night was not photometric, we have compared our emission line fluxes with those obtained through ground-based narrow-band imaging from Heckman et al. 1991a. We find that our measured Lyα for PKS 2338+042 is about a factor of 4 lower than measured during photometric conditions by Heckman et al. 1991a. Along similar lines of reasoning, we have used the HST F555W (similar to "V") image of PKS 0445+097 to estimate the how much of the flux we may have missed due to the cloudy weather. We find little difference (within about 20%) between the flux estimated from the HST image and that of the Keck spectrum of PKS 0445+097 (the clouds were patchy).

3. Results

3.1. The longslit spectrum of PKS 0445+097

We oriented the slit along a position angle such that the spectrum would obtain the redshift of the nearby (in projection) companion located approximately 1.8" from the quasar nucleus seen in the HST image of Lehnert et al. 1997a. Using the nuclear HeIIλ1640 and CIII]λ1909 emission lines, we estimate the redshift of the quasar to be 2.1083 ± 0.001. The other strong lines in the spectrum, namely, CIVλ1549 and MgIIλ2800, had profiles that were severely affected by absorption lines. Inspecting the extended emission of the quasar reveals that this nearby object to the southeast of PKS 0445+097 is an intervening absorber galaxy (Fig. 1). The extracted spectrum reveals three identifiable lines with central wavelengths of: 6298.9Å, 6853.1Å, and 7110.6Å. We note however that the line at 6298.9Åis very close in wavelength to the telluric [OI]λ 6300 line. Although the sky subtraction appears to be good, it is possible that this line is influenced by inadequacies in the night sky subtraction. The lines are detected at the 5σ, 30σ, and 8σ level respectively. We identify these lines as [NeV]λ3426, [OII]λ3727, and [NeIII]λ3869 which implies a redshift of $z=0.8384 \pm 0.0002$ (where the uncertainty in this determination includes the random error from each individual line). The lines are not resolved at the low resolution of the spectrum. From the nuclear spectrum of PKS 0445+097, we identify a single absorption line at 5147.1 $\pm$ 1Å, which we identify (as Barthel et al. 1990 did also) as MgIIλ2800 absorption at $z=0.8396 \pm 0.0004$. Barthel et al. 1990, who had a higher spectral resolution than the data presented here, measured z=0.8392 for this absorption line system, which is within the 1σ uncertainty of our measurement. Calculating the velocity difference between the absorption line system and the emission line of the galaxy, we find a velocity offset of 200 ± 80 km s^{-1}. Moreover, the relative fluxes in the lines give the following ratios relative to [OII]: $f_{[NeV]}/f_{[OII]} \approx 0.2 \pm 0.2$ and $f_{[NeIII]}/f_{[OII]} \approx 0.3 \pm 0.1$.

In addition to the flux associated with the intervening absorber, we also see extended flux that is apparently associated with the quasar. Because the southeastern side of the quasar is "contaminated" with the emission from the intervening absorber, we have extracted a spectrum whose center is about 2.3" from the brightest quasar emission and is a sum of about 7 CCD rows ($\approx$1.5"). We display the extracted spectrum of the fuzz on the northwest side of the nucleus in Fig. 2. The two obvious lines are HeIIλ1640 and CIII]λ1909. Due to falling sensitivity of the chip, the bad weather conditions and for the case of the MgII line, the strong night sky emission, we were unable to obtain high signal-to-noise information about the possibility of extended CIVλ1549 and MgIIλ2800. We find that the HeIIλ1640 line is relatively narrow (FWHM=1000 $\pm$ 200 km s^{-1}) and that the profile of the CIII]λ1909 line is much broader (FWHM=2200 $\pm$ 600 km s^{-1}). For the quasar nucleus, we find that the lines broader still, FWHM(HeIIλ1640)=2400 km s^{-1} and FWHM(CIII]λ1909)=5500 km s^{-1}. The width of the extended HeII and CIII] lines is comparable to the width of extended Lyα measured by Heckman et al. 1991b who measured about 1500 km s^{-1} for the full width at half maximum. The central wavelengths of the extended HeII and CIII] imply a redshift of 2.1087 and 2.1058 respectively, in fair agreement with the redshift estimated from the nuclear emission lines. Moreover, we find that the ratio of HeIIλ1640/CIII]λ1909$\approx$0.55. For comparison, a rough estimate of the ratio for the quasar nucleus is HeIIλ1640/CIII]λ1909$\approx$0.13. Estimating the signal to noise near the location of the undetected CIVλ1549, we find that the 3σ upper limit to the strength of CIVλ1549 gives CIVλ1549/CIII]λ1909$<$0.2.

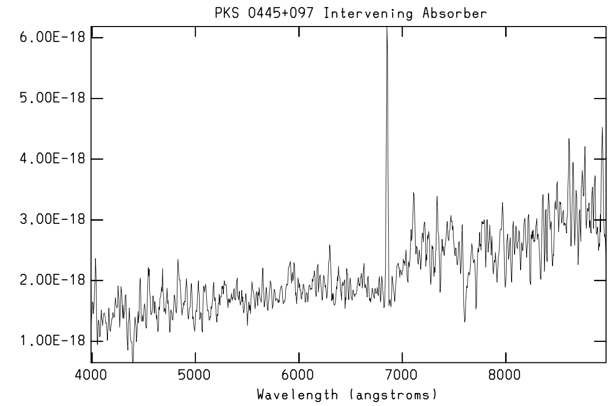

Fig. 1. The spectrum of the intervening absorber 1.77" from the nucleus of PKS 0445+097. This spectrum is a result of extracting a region centered 1.6 arc seconds from the nucleus and over a region 1 arc second in diameter. We have identified three lines in this spectrum, [NeV]λ3426 at 6298.9Å, [OII]λ3727 at 6853.1Å, and [NeIII]λ3869 at 7110.6Åwhich imply a redshift of 0.8384 ± 0.0002. The identification and strength of the [NeV]λ3426 line might be influenced by the strong telluric line of [OI] at 6300Å.

3.2. The longslit spectrum of PKS 2338+042

The longslit spectrum of PKS 2338+042 reveals extended Lyα emission. As described previously, we extracted the spatially-resolved Lyα emission in 0.9" wide bins. In Fig.3, we show a portion of the longslit spectrum specifically selected to show the region around Lyα. As can be seen, the emission along PA=135° is strongly one-sided and with the most intense, most extended emission being on the side with the radio jet and most intense, most distorted radio emission (see Barthel et al. 1988 and Lehnert et al. 1997a). In Fig. 4, we show a spectrum of the sum of the extended emission from the southeastern and northwestern sides of the nucleus along the slit of PKS 2338+042. In Fig. 5, we show the velocity structure of the Lyα emission. We see that the velocity offsets of the extended Lyα emission relative to the nucleus of PKS 2338+042 are relatively small.

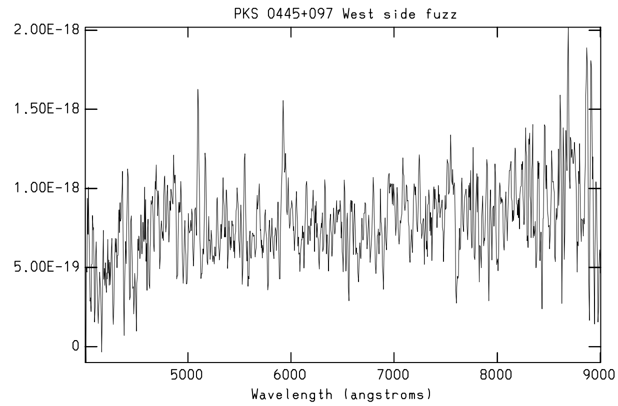

Fig. 2. The spectrum of the extended emission from the quasar PKS 0445+097. The spectrum was extracted from a region that spans from 1.4 arc seconds to 2.9 arc seconds from the nucleus of PKS 0445+097 and was specifically chosen to avoid the broad line emission from the nucleus.

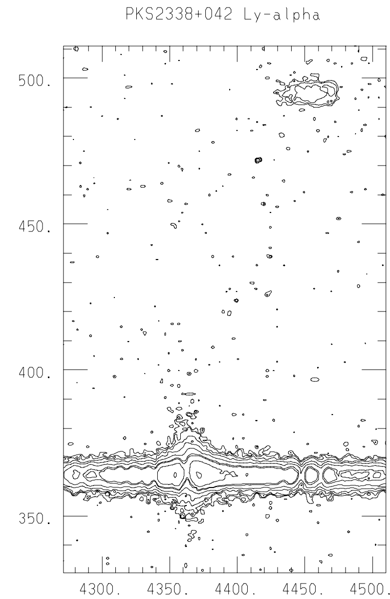

Fig. 3. A section of the full 2-dimensional spectrum of PKS 2338+042 shown to highlight the Lyα emission from both sources. The bottom spectrum is of the quasar, while that at the top shows the putative Lyα emission from the object serendipitously placed along the slit. The x-axis axis is in angstroms and the y-axis is in pixels (0.22" pixel^{-1}). The displayed portion of the long slit spectrum is approximately 240Å $\times$ 40 arc seconds.

We have chosen the wavelength of the absorption (4362.9Å) in the center of the Lyα emission from the quasar as the zero-point for showing the velocity structure. The wavelength of the absorption corresponds to z=2.5888. Unfortunately, it is difficult to determine how the velocity of the Lyα absorption compares with that of the emission since most of the observed lines are strongly affected by associated absorption. Only HeII has a profile that appears to be relatively unaffected by strong associated absorption and is relatively narrow (observed to be about 25Å). The observed wavelength of the nuclear HeII line implies a redshift of 2.5889, in close agreement with that of the associated Lyα absorption. As can be seen the overall flux weighted average velocity of the extended emission line gas (represented by hollow squares in Fig. 4) is small – only being about 100 km s^{-1} to the southeast and about 200 km s^{-1} to the northwest. Although, we should note that some of the offsets are quite large in the very faint, most extended gas. About 6.3" to the southeast we measure a velocity offset of about 900 km s^{-1}.

The extended Lyα emission line is also very broad. Overall the extended Lyα emission has line widths of 1300 km s^{-1} to the southeast and about 1050 km s^{-1} to the northwest. There is some tendency for the line widths to narrow with increasing angular distance from the nucleus. We also note in Fig. 5 the width of the nucleus Lyα absorption (indicated by the point at zero radius). We can see that the absorption width is very narrow (only 500 km s^{-1} FWHM) compared to the width of the extended emission line gas (about 1300 km s^{-1}). However, the measured width of the Lyα absorption is probably best described as a lower limit. In making this measurement, we assumed that the continuum against which the absorption is taking place is accurately represented by the observed peaks in the Lyα emission line profile. Undoubtably, the profile of the Lyα line is still increasing at the point of the highest observed points of the line and thus the true amount of absorption is probably much higher than we have estimated.

The individually extracted spectra that had significant Lyα did not show significant emission from CIVλ1549 or HeIIλ1640. However, in the sum of these spectra we do detect very weak (but significant) CIVλ1549 and HeIIλ1640 emission on each side of the quasar nucleus along the slit. For the spectrum on the southeastern side of the nucleus, the line identified as CIV has a measured ratio of $\approx$0.06 relative to Lyα (the night was not photometric), a central wavelength of 5565.3Å (corresponds to z=2.593), a width of 17.2Å, and is a 7σ detection. For HeII we measure $f_{HeII}/f_{Ly\alpha} \approx 0.03$, a central wavelength of 5880.7Å (which corresponds to z=2.586), a width of 10.7Å, and the line is a $\sim 5\sigma$ detection. For the northwestern side of the nucleus we find that CIV has a measured ratio of $\approx$0.15 relative to Lyα, a central wavelength of 5567.9Å (corresponds to z=2.594), a width of 11.2Å, and is a 7σ detection. We only measure an upper limit to the HeII emission on this side of the nucleus which implies $f_{HeII}/f_{Ly\alpha} < 0.06$.

In addition to seeing extended line emission from PKS 2338+042 we also see another object along the slit with a very strong line. This object lies 29.2" to the southeast of the nucleus of PKS 2338+042 along PA=135°. We show the extracted spectrum in Fig. 6. We find that the one obvious line has a wavelength of 4455.0 $\pm$ 0.4Å, a measured width of 32.0 $\pm$ 0.7Åand a total flux $>$1.3 $\times 10^{-16}$ ergs cm^{-2} s^{-1}. The line is also very broad (FWHM=2150 $\pm$ 50 km s^{-1}) and has a high equivalent width (2100 $\pm$ 100Å). We have also measured the break due the Lyα forest if this line is identified as Lyα. If we quantify the amount of continuum depression due to Lyα absorption lines to

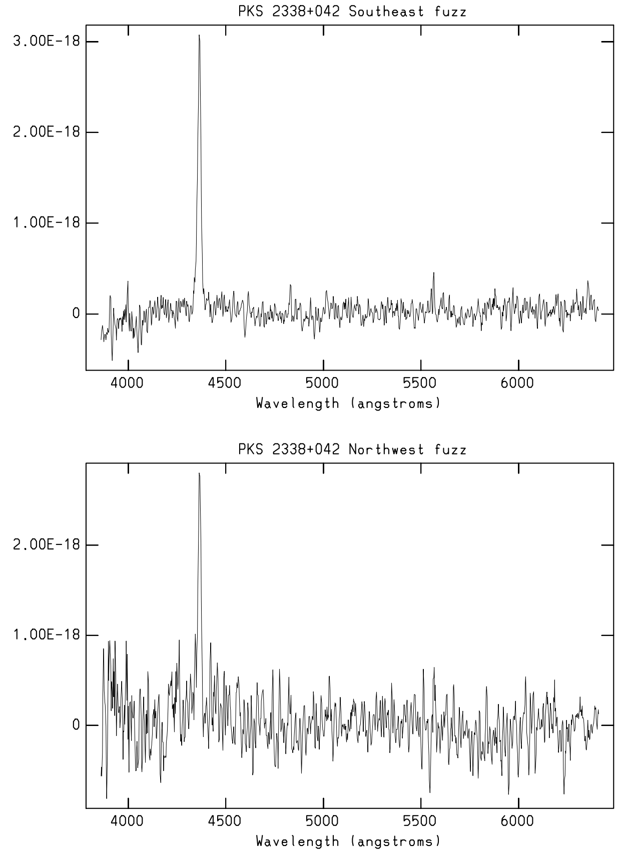

Fig. 4. The top spectrum is that off the extended emission from the quasar PKS 2338+042 on the southeastern side of the nucleus. The bottom spectrum is that extracted from the extended emission on the northwestern side of the nucleus along PA=135°. The two spectra were extracted over a region that was 1.6 arc seconds to 7.5 arc seconds on the southeastern side of the nucleus and 3.2 arc seconds to 6.7 arc seconds on the northwestern side of the nucleus. These regions were specifically chosen to avoid the obvious broad-line emission from the quasar nucleus. On the southeastern side of the nucleus, we identify to weak lines other than Lyα; CIV at 5565.3Å and HeII at 5880.7Å. On the northwestern side of the nucleus, we only identify weak CIV at 5567.9Å.

the blue of the Lyα using the definition of Schneider et al. 1991, namely D_A=1-f_ν(obs)/f_ν(cont), where f_ν(obs) is the observed flux density at blueward of Lyα and f_ν(cont) is the flux density of the extrapolated continuum blueward of Lyα, we find that D_A=0.26 for the unidentified object. This is very similar to that measured for the quasar, D_A=0.19, which is in turn consistent with measurements of quasars at similarly high redshifts (see Schneider et al. 1991).

4. Discussion

4.1. Properties of the extended line emission

The properties of the extended Lyα emission in PKS 2338+042 is typical of the high redshift quasar host observed previously (see e.g., Heckman et al. 1991b). Moreover, the properties of

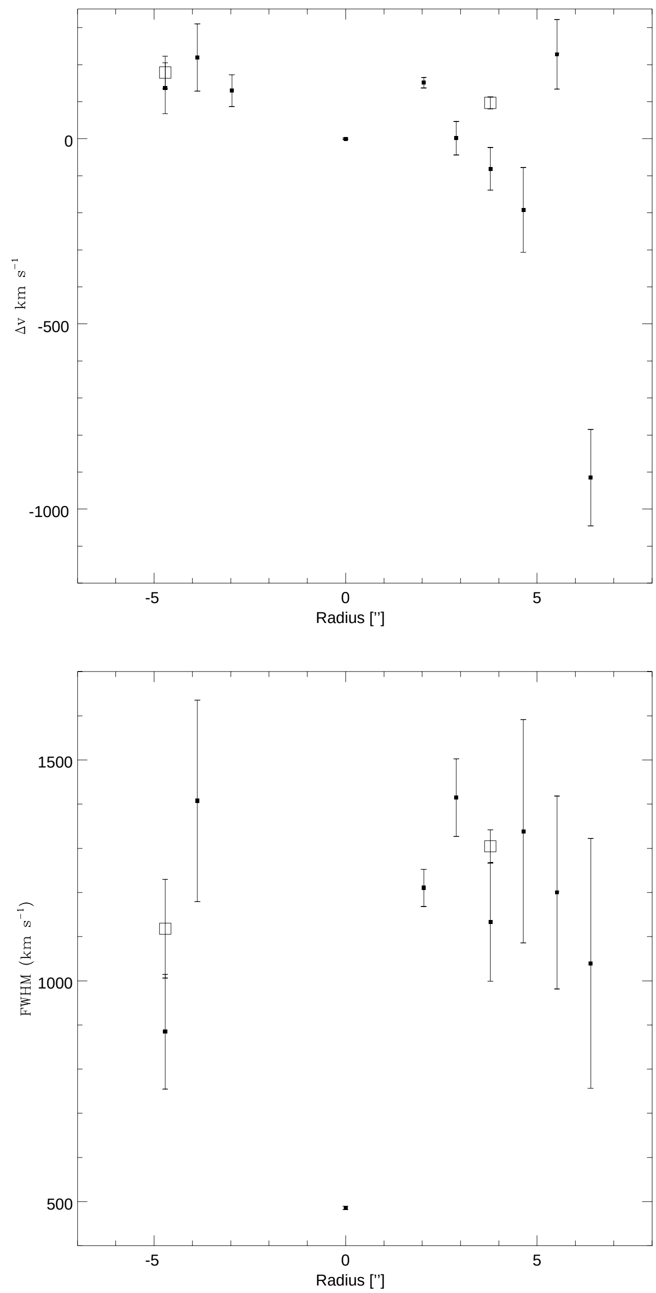

Fig. 5. At the top, the spatially resolved velocity structure of the extended Lyα emission from PKS 2338+042. The zero-point of the velocity scale was chosen to be the redshift of the strong Lyα absorption line seen in the nuclear spectrum of PKS 2338+042. The redshift of the Lyα absorption line is 2.5888, which corresponds quite closely to that of the nucleus HeIIλ1640 line (i.e., 2.5889). The bottom plot shows the spatially resolved line widths of the extended Lyα emission from PKS 2338+042. The hollow squares in both plots represent the integrated measurements on each side of the nucleus as measured on the spectra shown in Fig. 4.

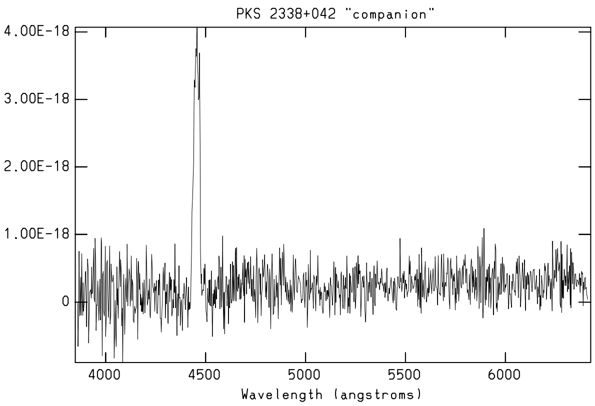

Fig. 6. The spectrum of the "companion" galaxy that was serendipitously placed along the slit.

this emission (flux, luminosity, width, equivalent width) are also very similar to that observed for radio galaxies at similar redshifts (e.g., van Ojik 1995; McCarthy 1993 and references therein). The line ratios (and upper limit) observed however, are not typical of radio galaxies. High redshift radio galaxies typically have CIV and HeII ratios relative to Lyα of $\approx$0.2 and 0.1 respectively. However, the range of these line ratios is relatively large and there are individual cases of radio galaxies which have CIV and HeII to Lyα ratios as low as those observed here (e.g., 1138$-$262 and 4C 41.17, van Ojik et al. 1997; and see Villar-Martin et al. 1997). Therefore, although the line ratios are not typical of radio galaxies, they certainly are consistent with the range of line ratios observed in high redshift radio galaxies.

In the extended emission from PKS 0445+097, we observe two lines which we have identified as HeIIλ1640 and CIII]λ1909. This confirms the possible detection of extended HeII by Heckman et al. 1991b in PKS 0445+097. The extended CIII] is more surprising since that was not detected by Heckman et al. 1991b. Although this is perhaps understandable since this region of the spectrum was near the end of their spectral bandpass where the sensitivity of the CCD was falling sharply. The properties of the extended CIII] are particularly interesting. The width of the line is significantly broader than that of the HeII emission. Extended CIII] emission is often observed in high redshift radio galaxies (McCarthy 1993) and references therein). Typically it is about 50% as strong as HeII as is observed for PKS 0445+097. Moreover, it also appears that on average, the CIII] line is also broader than HeII in the radio galaxies. Since the critical density of CIII] is high ($\sim$10^9 cm^{-3}) and the appropriate conditions for excitation of strong CIII] are not generally seen in extended narrow-line regions (e.g., Osterbrock 1989) and since the ratio of CIII]/HeII is much higher in the broad line emission than in the extended emission, we wonder if the broad extended CIII] is related to scattering of the nuclear light in both PKS 0445+097 and radio galaxies generally. In the sample of van Ojik 1995 there are 20 galaxies that have both HeII and CIII] measurements. Of those 20 radio galaxies, 11 have CIII] broader than HeII and the whole ensemble has a ratio of CIII] to HeII widths of 1.35. The breadth of the CIII] line compared to the HeII line can also be gleaned from the composite high redshift radio galaxy spectrum presented in McCarthy 1993.

We conclude that for these two objects, the properties of their extended line emission are consistent with similar results for high redshift radio galaxies.

The source of the very large velocity dispersions observed in the extended line emission is unknown. If quasars are embedded in cluster-like masses and the geometry is favorable, it is possible that these large line widths are gravitational in origin (e.g., Fall & Rees 1985; Heckman et al. 1991b). However, we consider such an explanation unlikely. A more likely explanation is that the powerful radio jets in these quasars (Lonsdale et al. 1993) is the source of power for generating the large line widths. There are several lines of evidence in support of this hypothesis. First is the anti-correlation between the radio size and velocity dispersion found for high redshift radio galaxies found by van Ojik 1995. Within the context of this finding we note that both PKS 2338+042 and PKS 0445+097 are both compact radio sources (Lonsdale et al. 1993) and we would thus expect them both to have large velocity dispersions in their extended gas as they do. The second is the obvious "jet-cloud interaction" seen in some radio galaxies (van Ojik 1995; Chambers et al. 1990) and in the extended emission in some quasars (Lehnert et al. 1997a). It is interesting to note within this context that Lehnert et al. 1997a find that PKS 2338+042 exhibits a particularly obvious "jet-cloud interaction" at the position where the radio jet has its most severe bend (in projection). Also, the radio lobe nearest to the nucleus and the most distorted, most intense radio emission in PKS 2338+042 (Lonsdale et al. 1993) also lies on the same side of the nucleus as the brightest, most extended Lyα emission. And finally is the observation that radio quiet quasars at z$\approx$2 appear to have much lower extended Lyα luminosities than radio-loud quasars suggesting a relationship between the radio emission and exciting the extended line emission (Lehnert et al. 1997c). These observations all suggest a significant relationship between the radio emission and amount and kinematics of extended line emission.

4.2. The intervening absorber galaxy

We have shown that the galaxy 1.77" to the southwest of the quasar nucleus of PKS 0445+097 is at a redshift of 0.8384. This redshift closely corresponds to the redshift of the strongest MgII absorption line seen in the spectrum of PKS 0445+097. At this redshift (with H_0=75 km s^{-1} Mpc^{-1} and q_0=0.0), the separation on the sky of this galaxy from the line of sight of the quasar is about 12.1 kpc. This roughly consistent with the empirical relationship between impact parameter and rest frame MgII equivalent width found by Lanzetta & Bowen 1990 The HST images reveal that this galaxy is a very distorted system. There is a bright compact "nucleus" with a "trail" of material to the southeast which itself has two high surface brightness knots (see Lehnert et al. 1997a). The slit was oriented such that it passed through the brightest of the knots of emission. From the spectrum, we conclude from a comparison with the line ratios and line widths of various types of emission line galaxies (starbursts, radio galaxies, Seyfert 1s and 2s, LINERs) that this galaxy has a Seyfert 2-like spectrum (see Osterbrock 1989).

Of a more speculative nature. Barcons et al. 1995 have used the velocity difference between a galaxy along the line of sight to two quasars and an intervening low redshift Lyα absorption line due to the galaxy along the line of sight to estimate the mass of the galaxy. They assumed that the absorbing material was part of the galaxy rotation curve. In a similar spirit, we wish to estimate what the redshift difference between the galaxy we have identified as giving rise to the MgII absorption line in PKS 0445+097 and that of the absorption line itself implies about the mass of the intervening galaxy. We find that the redshift difference between the absorption line and the galaxy is about 200 km s^{-1}. The distance from the absorbing galaxy from the line of sight to the quasar is about 12 kpc. If we assume that the absorbing cloud is moving about the center of the absorbing galaxy in a circular orbit, implies the mass of the system is 1.2×10^{11} M$_{\odot}$. Since it is unlikely that the absorbing material is in a circular orbit, this estimate is likely to be an upper limit under the assumption that the material is gravitationally bound to the galaxy. Using the absolute (restframe) B magnitude calculated from the HST image by Lehnert et al. 1997a, we find a mass to light ratio of this galaxy in the rest-frame B band to be about 8 (M$_{\odot}$/L$_{\odot}$)$_B$. This mass-to-light ratio is high, but still reasonable for a spiral galaxy. Of course there is no evidence that this material is gravitationally bound. It may well be that in fact this gas is infalling onto the disk or is outflowing due to hydrodynamical processes with the galaxy (perhaps as an AGN or starburst-driven wind; Lehnert & Heckman 1996; Baum et al. 1993; Krolik & Begelman 1986). However, since MgII absorbers appear to be generally associated with "normal" galaxies (see Steidel et al. 1994), it is perhaps unlikely that this halo gas is associated with any spectacular process occurring within this galaxy.

4.3. The nature of the emission line object in the spectrum of PKS 2338+042

With only one detected line in the spectrum of object fortuitously along the slit of our integration on PKS 2338+042 it is difficult to argue definitively as to the nature of this object. There are two likely possible identification of this single line. It is most likely either to be Lyα at z=2.6646 $\pm$ 0.0005 or [OII]λ3727 at z=0.1953 $\pm$ 0.0005. There are several reasons to believe that this line is Lyα emission at z=2.6646.

First the line is very broad with a full width at half maximum of about 2200 km s^{-1}. Lines this broad have been observed for Lyα in high redshift radio galaxies (e.g., van Ojik et al. 1997) and the host galaxies of radio loud quasars (e.g., Heckman et al. 1991b), but never in galaxies with unambiguously identified [OII]λ3727. Second, we find that line has a very high rest-frame equivalent width. The line has a measured equivalent width of about 2100Å. This implies, if the line is Lyα, a rest-frame equivalent width of about 500Å. If the line is [OII] then the line has a rest-frame equivalent width of about 1800Å. Again, rest-frame equivalent width this high have been observed for extended Lyα emission in high-z radio galaxies (e.g., McCarthy 1993), in the hosts of quasars (e.g., Heckman et al. 1991b; this study), and in some high redshift galaxies associated with damped Lyα absorbers (e.g., Macchetto et al. 1993), but is well outside the distribution of [OII] equivalent widths ([OII] equivalent widths $\leq$100Å) measured for low-z star-forming galaxies (e.g., Broadhurst et al. 1988; Colless et al. 1990; Kennicutt 1992). And finally, we measured a "break strength" across the line of this object that is comparable to that of the quasar. If this line were [OII] instead, it is difficult to understand why we see a break at all across the line.

Identifying this line as Lyα, we have obtained approximate upper limits for the strength of CIVλ1549 and HeIIλ1640, assuming that both lines have the same width as the punitive Lyα line. This leads to limits in the ratio of $f_{CIV}/f_{Ly\alpha} < 0.06$ and $f_{HeII}/f_{Ly\alpha} < 0.07$. Comparing these upper limits to the line ratios with that of AGN and star-forming regions, we find that these limits are consistent with that expected of a HII region or star-forming galaxy. The upper-limits to the line ratios are inconsistent with the "mean spectrum" for a Seyfert 2 galaxy given in Ferland & Osterbrock 1986. In spite of these rather mundane line ratios compared to active galaxies implied by these upper limits, it is again difficult to understand characteristics of this line within the context of star-formation (see Valls-Gabaud 1993). The observed flux of Lyα implies a total luminosity of $>1h^{-2}\times10^{43}$ ergs s^{-1} (which is likely to actually be about a factor of 4 higher from the analysis given in §2; using H_0=75 km s^{-1} Mpc^{-1} and q_0=0.0). The Lyα luminosity and equivalent width are large compared to low redshift starburst galaxies (see Kinney et al. 1993), but are within the range observed for low-z active galaxies (e.g., Kinney et al. 1990).

We note that several other groups have discovered Lyα emitters near high redshift quasars (e.g., Steidel et al. 1991), radio galaxies, and damped Lyα absorption systems (e.g., Djorgovski et al. 96; Macchetto et al. 1993). Many of the objects so discovered have properties remarkably similar to the object discovered here. One object in particular is strikingly similar to the object discovered here, namely G-Q0000-2619 from Macchetto et al. 1993. These authors have suggested that the line emission is possibly due to star-formation. They estimate star-formation rate of about 20 M$_{\odot}$ yr^{-1}. Since this estimate is highly model dependent and are very sensitive to the amount of extinction within this object (which is unknown), quoting exact numbers for the star-formation rate makes little sense. However, for the purposes of comparison, the Lyα and UV continuum flux observed in the object we have accidentally discovered are comparable with the star-formation rate estimated in Macchetto et al. 1993 for G-Q0000-2619.

The odd characteristics of this possible Lyα emitter makes us wonder if it could be ionized by the radiation from the quasar nucleus. Using our spectrum of the quasar and extrapolating the continuum to estimate the flux at 2500Å in the rest-frame and then using the relations in Elvis et al. 1994 to estimate the number of ionizing photons, we estimate that PKS2338+097 emits about 2×10^{56} ionizing photons s^{-1}. We note that this estimate is very uncertain and could be an order of magnitude higher or lower. Moreover, taking the size of the object to be its total extent in Lyα as measured in the spectrum (about 3"), the distance to be 29" which corresponds to about 260h^{-1} kpc, and that every photon intercepted results in a Lyα photon. The physical distance we assume is a definite lower limit since it assumes that the substantial difference in the measured redshifts (about 6000 km s^{-1}) is not related to the Hubble expansion. These assumptions are perhaps conservative since it is unlikely that the projected distance is the true distance (which will be substantially larger), that the size we observe is the projected size the ionizing photons from the quasar intercept, and since the covering fraction of neutral gas in this object is unlikely to be one. Using our somewhat conservative assumptions, we find that the predicted luminosity of Lyα would be about 2×10^{42} ergs s^{-1}. This is about an order of magnitude less than we observe. The number of ionizing photons may be up to a factor of about 10 larger, but it might also be lower. In spite of the uncertainties, it seems very unlikely that the quasar could provide enough ionizing photons to excite the line emission we see, especially given that it is highly probable that the quasar and emission line object are much more widely separated than we have assumed here.

Given that we have only limited information as to the nature of this object, we consider its exact nature very uncertain. However, the large FWHM and high equivalent width of the line we have identified as Lyα, we consider it likely that this object is a high redshift AGN.

5. Summary and conclusions

We present spectra taken with the Low Resolution Imaging Spectrograph on the Keck 10m telescope of spatially-resolved structures ('fuzz') around the high-redshift radio-loud quasars PKS 0445+097 (z=2.110) and PKS 2338+042 (z=2.594). For PKS 0445+097 we oriented the slit such that it passed through the quasar nucleus and through an object identified on an HST exposure 1.8" to the southeast of the nucleus. We find that this object is at a redshift of 0.8395 and has line ratios suggesting it has a Seyfert 2 nucleus. The redshift of this object is very close (Δv=200 km s^{-1}) to that of a MgII absorption line identified in the spectrum of PKS 0445+097. Moreover, we find that there is faint extended HeIIλ1640 and CIII]λ1909 from the quasar host galaxy. Both of the lines are broad ($FWHM_{HeII}=1000 \pm 200$ km s^{-1} and FWHM=2200 $\pm$ 600 kms^{-1}). The limits on the fluxes, the large widths, and the line ratio HeII/CIII] are similar to what is observed for high redshift radio galaxies.

From the spectrum of PKS 2338+042, we find that Lyα emission is extended up to 10" from the quasar nucleus and is strongly one sided (on the side of the stronger, closer to the nucleus, more distorted radio jet and lobe). The extended Lyα line is broad (FWHM $>$ 1000 km s^{-1}) and the extended emission shows no evidence for a strong velocity shear. We also find weak extended CIV and HeII emission which has similar characteristics (line widths, line fluxes, and line ratios) to that of high redshift radio galaxies. In addition, we serendipitously discovered what appears to be a Lyα emitting galaxy about 29" to the southeast of the quasar at z=2.665. The single line identified in the spectrum has a measure equivalent width of 2100Å and a full width at half maximum of 2150Å. The high equivalent width and large width of the line suggest that this galaxy must be a high redshift AGN, although we note that the upper limits on the CIV and HeII line ratios are mildly inconsistent with this galaxy harboring an AGN. A crude calculation shows the quasar nucleus is not exciting the Lyα emission from this this galaxy.

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