THE ASTROPHYSICAL JOURNAL, 252:447–454, 1982 January 15

A HIGH REDSHIFT BL LACERTAE OBJECT: PKS 0215+015[1]

C. MARTIN GASKELL
Lick Observatory, Board of Studies in Astronomy and Astrophysics, University of California, Santa Cruz
Received 1980 September 10; accepted 1981 July 27

ABSTRACT

Spectrophotometry and polarimetry of PKS 0215+015 show it to have all the commonly accepted defining properties of a BL Lac object. Over the past 30 years PKS 0215+015 has varied by over 4 mag. It has been observed to show variable polarization of up to 37%. Although PKS 0215+015 has so far shown no emission lines, it has three definite absorption line systems with redshifts of 1.3449, 1.5494, and 1.6494. PKS 0215+015 is shown to be similar to previously known lower redshift BL Lac objects. A curve of growth analysis of the $z=1.3449$ system shows it to have similar column densities and a similar velocity dispersion to the halo of our Galaxy. A new value of the oscillator strength of Fe II λ1608 is proposed. The possible nature of the other two absorption line systems is discussed. Some objections are raised to the idea of BL Lac objects having their optical continua boosted by relativistic beaming of the continua toward us.

Subject headings: BL Lacertae objects — polarization — quasars

I. INTRODUCTION

PKS 0215+015 was observed in the program of spectrophotometry of a complete sample of flat radio spectrum QSOs (Baldwin *et al.* 1978, 1980; Wampler 1980) which was undertaken to establish luminosity criteria. In an attempt to overcome possible selection effects which might influence the C IV equivalent width continuum luminosity correlation, the quasars were chosen so that the only basis for identification had been coincidence of radio and optical positions. PKS 0215+015 was one of the objects taken from the complete sample used by Masson and Wall (1977) and Wills and Lynds (1978, sample 6) in $\langle V/V(\max)\rangle$ tests. The latter authors reported PKS 0215+015 as having a featureless spectrum. The possibility remained, however, that it was a normal QSO with very weak and broad lines, and so high quality Image Dissector Scanner (IDS) spectra of it were obtained at Lick Observatory to search for these.[2] No emission lines have yet been found, but PKS 0215+015 nonetheless proves to be a very interesting object in its own right.

[1] *Lick Observatory Bulletin*, No. 897.

[2] To emphasize the importance of this, it should be pointed out by way of example that the high redshift quasar PKS 0528−250 was originally suggested by Jauncey *et al.* (1978) to be a high redshift BL Lac object, but Lick Observatory data (Smith, Jura, and Margon 1979) showed that it did have emission lines, and this QSO does in fact fall on the bright end of the C IV luminosity relation.

II. OBSERVATIONS

a) *Optical Variability History*

PKS 0215+015 was first identified from the Parkes 2700 MHz survey (Wall, Shimmins, and Merkelijn 1971) by Bolton and Wall (1969) on the basis of optical variability. At the time of the sky survey (1954 November), its V magnitude was estimated by Wills and Lynds (1978) to have been 18.33. PKS 0215+015 had faded below the plate limit of the two-color 48 inch (1.2 m) Schmidt plates taken in late 1968 by Bolton and Wall and was thus that time fainter than about 19.5 mag (V). It was just detectable on Lick astrograph plates taken in 1948 September and 1971 October ($B\sim19$ on both occasions). In 1977 November, from IDS observations (made under very poor conditions) PKS 0215+015 had a V magnitude of ~16.0; and a photometric IDS observation on 1978 November 15 yielded $V=15.7$. It can thus be concluded that PKS 0215+015 has varied at least 3 and possibly 4 mag over the past 30 years.

b) *Radio Observations*

A literature search has revealed 15 independent flux density measurements made at eight frequencies by a wide range of instruments over a period of ~12 years: Fitch, Dixon, and Krand (1969); Wall, Shimmins, and Merkelijn (1971); Wall (1972); Shimmins and Bolton (1972); Bentley *et al.* (1976); Condon and Jauncey (1974); McEwan, Browne, and Crowther (1975); Wills

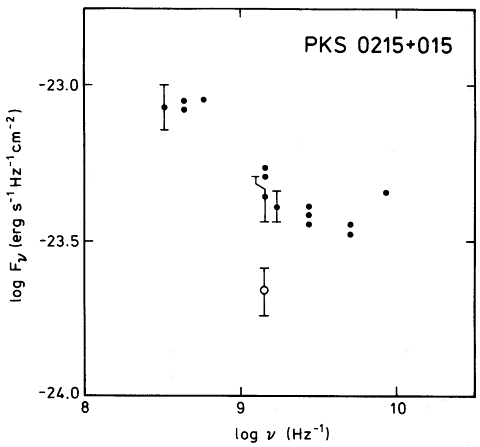

FIG. 1.—Collected radio observations of PKS 0215−015 from the references listed in the text. The open circle shows the VLBI measurement of the core (Briggs and Wolfe 1981). For clarity, error bars are only shown where uncertainties in fluxes are significantly greater than 15%.

(1979); and Briggs and Wolfe (1981). These observations are summarized in Figure 1. The good agreement of the various flux measurements exclude variations of more than 20% at frequencies below 5 GHz.

The shape of the radio spectrum is complex, suggesting several components. There would appear to be a low frequency cutoff at 500 MHz and a strong centimeter excess. Interferometric observations by Bentley *et al.* (1976) give a largest angular size in right ascension of <0″.1 at 1666 MHz and observations by Wills (1979) give an upper limit to the overall angular size of 0″.6 at 8 GHz. From VLBI observations made in the summer of 1979 with a 20 milli-arcsec fringe spacing at 1400 MHz, Briggs and Wolfe (1981) got 0.22±0.04 Jy of correlated flux density compared with their single dish measurement of 0.52±0.08 Jy at 1400 MHz. The strong centimeter excess in Figure 1 can then be understood as being due to the VLBI core. This would leave the halo component with spectral index α of about 0.6 ($F_\nu \propto \nu^{-\alpha}$) and a low frequency cutoff at around 500 MHz. More observations at high frequencies are desirable.

c) *Spectrophotometric Observations*

An IDS spectrum was obtained in 1977 November with 17 Å (FWHM) resolution covering 3200 to 7000 Å. It showed that the optical region was devoid of any emission lines. There were, however, a number of strong absorption lines. Subsequently the entire spectrum from 3200 to 7100 Å was observed at 9 Å (FWHM) resolution. The sum of these observations is shown in Figure 2. Additional observations were made in 1978 November of selected regions of the spectrum at 4 Å resolution. Much of the observing was done under poor conditions, with light clouds and very poor seeing, but probably the overall continuum shape was unaffected. Spectra taken with a narrow slit were scaled to spectra taken with a photometric (8″) aperture.

d) *The Optical Continuum*

The spectrum from 3200 to 7100 Å seems to be well represented by a single power law of the form $F \propto \nu^{-\alpha}$. The slight irregularities in the spectrum shown in Figure 2 are the results of known difficulties with the flux calibration procedure and from adding up separate scans. The spectral index α was determined to be 2.11 in 1977 November and 1.76 in 1978 September. The difference is probably not significant.

e) *Polarimetry*

PKS 0215+015 was observed on the 1978 September 28 with the Nordsieck polarimetric system (Nordsieck 1974) used in conjunction with the IDS on the Shane 3 m telescope. Unfortunately, the device was suffering from misalignment of the fixed quartz wave retarders and polarizers which made determination of the position angle of the polarization impossible with the available reduction techniques and made determination of the linear polarization somewhat uncertain. According to Nordsieck (1974), the amplitudes of the wavelength dependent fringes, which are the basis of this device, have errors which are second order in the misalignment angle, and to attempt to correct for this we also observed a star of known interstellar polarization. While the errors in our measurements were rather large, it is certain that PKS 0215+015 was very strongly polarized. This polarization amplitude appeared to be about 25%

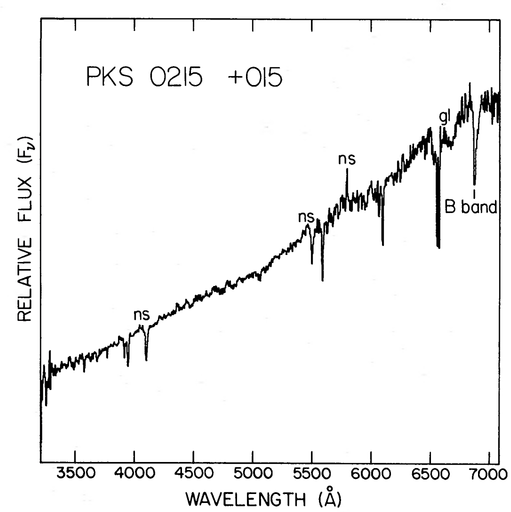

FIG. 2.—Summed IDS observations at 9 Å resolution of PKS 0215+015

(±5%) on that night. J. S. Miller and G. D. Schmidt (1980, private communication) found a wavelength independent polarization of 30% on 1979 September 25 and 37% the following night.

f) *Emission Lines*

No emission lines have been found in the spectra of PKS 0215+015. Because of the presence of C IV absorption at redshifts of 1.5494 and 1.6494 (see below), one would definitely expect that the usually strong C IV emission line (which has been seen in all quasars of high enough redshift) would be visible. If the emission line redshift were greater than 1.67 and less than 4.8, Lyman α would fall in the observed range. On the basis of observed irregularities in the continuum of PKS 0215+015, an absolute upper limit for the equivalent width of a very broad flat peaked line with a FWHM of 20,000 km s^{-1} (about the maximum seen in known QSOs) is about 8 Å (rest frame). Because the observed irregularities are believed to be due to uncertainties in the flux calibration procedure, a more reasonable upper limit on the equivalent width of the emission lines should perhaps be only 4 Å.

g) *Absorption Lines*

Absorption lines were found by using the following procedure: large scale plots of the spectrum were made, and the wavelengths of possible absorption lines were noted. Separate lists of possible lines were made for independent sets of the data. Table 1 lists all lines which occurred in more than one such set of data. The first column lists the observed wavelengths [λ(obs)] in angstroms. The heliocentric correction has been neglected. For consistency, vacuum wavelengths have been used for *all* lines in this paper. Refractive indices for air have been taken from Edlèn (1953). The second column gives the identification of the ion causing each line, and the third column gives the rest wavelength [λ_0(rest)] of that line. Lines which were *not* used for redshift determination are marked with an asterisk. The residual difference $\Delta\lambda$, in angstroms, of each observed wavelength from the expected wavelength is given in the fourth column. The fifth column gives the rest frame equivalent width (W_0) of each line. For unresolved lines the combined equivalent width is given. Observed wavelengths are estimated from repeated measurements on separate scans to be good to better than an angstrom. The uncertainties in the quoted redshifts are due to noise in the individual lines, the limit in the accuracy of the wavelength calibration (usually several tenths of an angstrom), and a small residual uncertainty in the corrections to the starting wavelengths made from the night sky lines. The latter uncertainty is believed to be not more than 0.5 Å here.

Most of the absorption lines were found to be members of the $z = 1.34490$ (±0.00013) system (called system 1 here). Two strong features at about 3948 and 4102

TABLE 1

DEFINITE ABSORPTION LINES OBSERVED IN PKS 0215+015

λ(Observed)[a]	ID	λ_0(Rest)[a]	$\Delta\lambda$(Observed)	W_0
System 1: $z = 1.34490 \pm 0.00013$				
3579.9...........	Si II	1526.71	−0.08	0.79
3632.4*	C IV	1549.06bl	−0.09	0.48
3772.9...........	Fe II	1608.46	+1.22	0.33
3917.5...........	Al II	1670.79	−0.33	0.49
5497.1...........	Fe II	2344.21	+0.16	1.36
5552.8*	Fe II	2367.58?[b]	+1.06	0.26
5566.2*	Fe II	2374.45	−1.65	0.20
5588.1...........	Fe II	2382.76	+0.77	2.49
6064.8...........	Fe II	2586.65	−0.63	0.69
6096.0...........	Fe II	2600.17	−1.14	1.23
6556.4...........	Mg II	2796.35	−0.76	1.92
6573.0...........	Mg II	2803.53	−1.00	1.29
System 2: $z = 1.54945 \pm 0.0002$				
3947.3...........	C IV	1548.19	...	1.57bl
3953.0...........	C IV	1550.76	...	
System 3: $z = 1.649 \pm 0.0002$				
4102.1...........	C IV	1548.19	...	1.68bl
4108.0...........	C IV	1550.76	...	

[a]Vacuum wavelengths.
[b]This identification is unlikely, and the line might not be real.

Å could not be identified in system 1. They were noticeably broader than the instrumental profile in the 9 Å resolution scans. Spectra were therefore taken of the 4000 Å region at 4 Å resolution. On these scans the features were partially resolved, with the correct separations and with the appropriate equivalent width ratios, to be C IV 1548.20–1550.77 doublets. These two features are shown in Figure 3. It is concluded then that the 3948 and 4102 Å features are due to two further absorption line systems (called systems 2 and 3 here), with redshifts of 1.5494 ($\pm$0.0003) and 1.6494 ($\pm$0.0003). It should be noted that the possible redshifts given in Gaskell (1978) are wrong. Neither system 2 nor system 3 contains any other identifiable lines. To the red of the C IV doublets, an upper limit to the strength of possible features is about 0.15 Å rest frame equivalent width. In particular, the stronger Fe II lines are lacking. The spectra do not go far enough to the red to detect possible Mg II absorption. To the blue of the C IV doublets, the signal-to-noise ratio in the data is poorer, and consequently stronger lines might be undetected.

There are only two other lines that appear in more than one set of data. One possible feature occurs at 3493.9 Å with an equivalent width of 0.96 Å, and the other is at 6527.9 Å with an observed equivalent width of 1.2 Å. This is just to the blue of the Mg II absorption lines of system 1. At this wavelength, the instrumental response is poor, and the feature might not be real.

In the high resolution data there appears to be possible absorption around 3930 Å between the C IV doublet of system 2 and the Al II 1617 Å line of system 1 (see Fig. 3). This could possibly be the Ca II K line (3933 Å) at zero redshift, but a zero redshift H line is not seen. It was also noted that the data shown in Figure 3 do not resolve the system 2 C IV doublet as well as one might expect. (The Al II line in that figure represents the instrumental resolution quite well.) It is possible therefore that the C IV doublets could be quite broad or have multiple components.

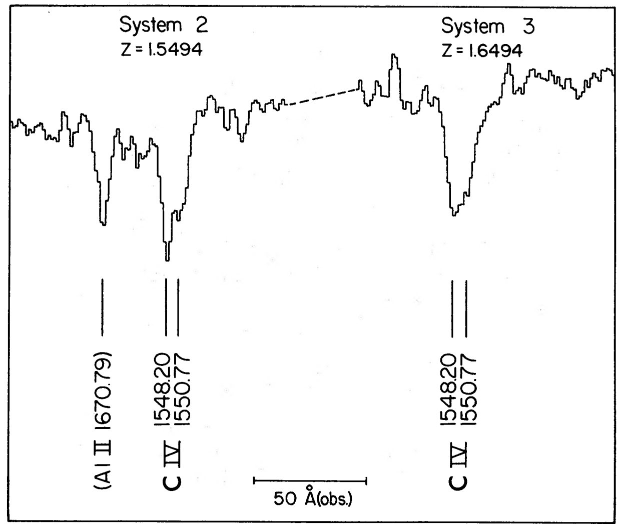

FIG. 3.—The C IV doublets of systems 2 and 3 at 4 Å resolution. The Al II line in brackets belongs to system 1.

h) *Curve of Growth Analysis for the $z = 1.3449$ System*

A proper study of the column densities and velocity structure of absorption line clouds needs information on the profiles of the lines. In the absence of data of adequate resolution and signal-to-noise ratio, a simple curve of growth analysis can still be performed, but the results need to be treated with caution (see Boksenberg, Carswell, and Sargent 1979).

A grid of theoretical curves of growth was used to estimate an effective Doppler parameter $b = 2^{1/2}\sigma$ (Stroemgren 1948) from the Fe II and Mg II lines of the $z_{(\text{abs})} = 1.3449$ system. The lines of both ions lie unambiguously on the linear (Doppler) part of the curve of growth and yield $b = 100$ $\left(^{+100}_{-40}\right)$ km s^{-1}. Because the lines lie close to the linear part of the curve of growth, b is poorly determined, but there is also the compensating advantage that the derived relative abundances are insensitive to the value of b. The value of b derived from curve of growth analyses can be regarded as either a measure of the internal velocity dispersion in a single cloud or of the dispersion in relative velocities of a number of clouds, each of lower internal velocity dispersion (see discussion in Stroemgren 1948).

Figure 4 shows the fit of the observed low ionization lines to a theoretical curve of growth with $b = 100$ km s^{-1}. The oscillator strengths adopted are given in

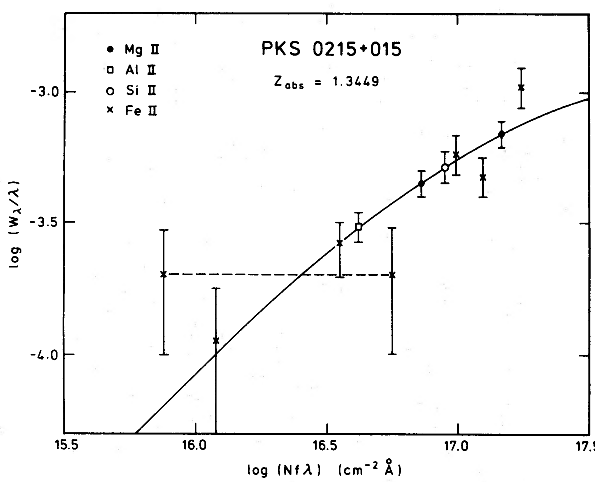

FIG. 4.—Curve of growth for low-ionization ions in the $z =$ 1.3449 system. The theoretical curve for a single cloud with Doppler parameter $b = 100$ km s^{-1} is shown. Fe II λ1608 is shown twice, with the left and right crosses (joined by the dashed line) corresponding to the oscillator strengths of Kurucz (1974) and Morton (1978), respectively.

TABLE 2

ADOPTED OSCILLATOR STRENGTHS DIFFERING FROM MORTON AND SMITH 1973

Ion	Line	f	Reference(s)
Si II	1526.71	0.23	1
Fe II ...	1608.5	0.03–0.22	2, 3
	2344.2	0.263	4
	2367.6	0.001	4
	2374.4	0.051	4
	2382.8	0.460	4
	2586.6	0.087	4
	2600.2	0.303	4

REFERENCES.—(1) Shull, Snow, and York 1981. (2) Kurucz 1974. (3) Morton 1978. (4) Nussbaumer and Storey 1980.

Table 2. In many cases, these differ significantly from values used in previous curve of growth analyses. For Fe II λ1608, neither detailed theoretical calculations nor laboratory measurements are available, and Figure 4 suggests that neither the semispherical oscillator strength of Kurucz (1974) nor the observational one of Morton (1978) are correct. Since Fe II λ1608 lies on the linear part of the curve of growth, one can estimate f(Fe II λ1608) $=0.08 \pm 0.03$. Derived column densities for the ions observed are given in Table 3. For comparison, column densities are also given for the $z=2.7685$ absorption system in quasar PKS 2126−158 (Young *et al.* 1979) and for the halo of our Galaxy toward HD 36402 (Savage and Jeske 1981). The effective Doppler parameter for absorption towards HD 36402 has been estimated from the velocities of its multiple components.

Briggs and Wolfe (1981) searched for 21 cm absorption and got a 3 σ upper limit to the 21 cm optical depth $\tau_{21}=0.038$. PKS 0215+015 thus differs from AO 0235+164 which has strong 21 cm absorption in its $z=0.524$ absorption line system (caused by several low velocity dispersion high column density components). This corresponds to an H I column density

$$N(\text{H I}) = 1.8 \times 10^{18} \sqrt{2\pi}\, T_s \tau_{21} \sigma\ (\text{cm}^{-2}),$$

where T_s is the spin temperature and σ is the velocity dispersion. If we adopt an approximate spin temperature of 100 K (typical of values observed in our Galaxy; see review by Dalgarno and McCray 1972) and take the velocity dispersion of 70 km s^{-1} derived from the curve of growth analysis as an upper limit to σ, then we get an upper limit of N(H I) $< 1.2 \times 10^{21}$ cm^{-2}. 21 cm absorption is relatively rare (Wolfe 1979), and the upper limit for PKS 0215+015 is consistent with the derived column densities for other ions (assuming solar abundances).

III. DISCUSSION

a) The Distance and Luminosity in Comparison with Other BL Lac Objects

Miller (1978) gives the following list of what he regards as the defining optical characteristics of bona fide BL Lac objects:

1. A starlike object (often surrounded by nebulosity);
2. Large ($m > 1.5$) light variations (which are sometimes very rapid);
3. High polarization with rapid changes in both angle and amount; and
4. A weakness or undetectability of emission features in the optical spectrum.

PKS 0215+015 appears to have all of these characteristics and is, by these criteria, a BL Lac object. Except for its high redshift, there seems to be no reason for thinking of PKS 0215+015 as different from the BL Lac objects observed by Miller, French, and Hawley (1978), all of which have much lower redshifts (mostly less than 0.1). For at least seven of these BL Lac objects, underlying galaxies have been detected, so there is no doubt that they at least are at cosmological distances.

The high ionization absorption lines in PKS 0215+015, in addition to being interesting in themselves, permit an estimate of possible emission line redshifts. The absorption lines are not distinguished in any way from those of normal quasars. The catalog of QSOs with well

TABLE 3

COLUMN DENSITIES

Ion	PKS 0215+015 $z=1.3449$, $b=100$ km s^{-1} (cm^{-2})	Milky Way Halo[a] (HD 36402) $b=85$ km s^{-1} (cm^{-2})	PKS 2126−158[b] $z=2.7685$, $b=70$ km s^{-1} (cm^{-2})
C IV	9×10^{13}	1×10^{14}	5×10^{14}
Mg II ...	9×10^{13}	3×10^{14}	...
Al II	1.3×10^{13}	1.5×10^{13}	1.7×10^{13}
Si II	2.5×10^{14}	3.5×10^{14}	1.8×10^{14}
Fe II	1.6×10^{14}	2.5×10^{14}	2×10^{14}

[a]Data from Savage and Jeske 1981.

[b]Data from Young *et al.* 1979.

(1981*a*, *b*) of the strong broad UV emission lines relative to the forbidden lines, while strengthening the QSO galaxy cluster hypothesis (by reducing the required cluster velocity dispersion), does at the same time increase the relative number of "ejected" systems at the expense of the "QSO cluster" component. The probability that an absorption line redshift system with a redshift close to the emission line redshift is ejected could be greatly increased.

In the case of PKS 0215+015 the emission line redshift is as yet unknown, but since systems 2 and 3 differ in velocity by 11,500 km s^{-1}, we can be certain that they do not *both* arise in a cluster of galaxies associated with the BL Lac object. Using Figure 1 of Weymann *et al.* (1979) and considering *both* high ionization systems, the probability that system 2 is due to an intervening galaxy is about 70% (the other possibility being that it is ejected), while the probability that system 3 is due to an intervening galaxy is less than 10%. System 3 is equally likely to arise from a cluster of galaxies associated with PKS 0215−015 or to have been ejected.

The probabilities just presented are based on the assumption that the distribution of high ionization absorption line systems associated with BL Lac objects is the same as that given by Weymann *et al.* (1979). More high redshift BL Lac objects showing absorption lines will have to be found before this assumption can be statistically tested. Demonstration of the ejection of gas from BL Lac objects would be very interesting in view of the weakness of the emission lines (Miller, French, and Hawley 1978).

c) *Isotropy of Optical Continuum Radiation in BL Lac and Other Objects*

It has been proposed by Blandford and Rees (1978) that BL Lac objects are active galactic nuclei (AGNs) which we view from such an angle that the emitting region is relativistically approaching us at a small angle to our line of sight. The continuum radiation from the relativistically moving region is thus preferentially beamed towards us. There are certainly many reasons that mildly relativistic motion is probably involved in radio frequency emission from compact extragalactic sources (see reviews by O'Dell 1978, 1979). Such motion also makes it easier to understand cases of rapid polarization variability with little change in total flux. The (relativistic) "beaming" model has been developed by Blandford and Königl (1979), Scheuer and Readhead (1979), and Readhead *et al.* (1978) to explain the VLBI radio morphology of compact extragalactic sources and the relationship between these sources and radio-quiet quasars. In this model BL Lac objects could be the compact nonthermal radio sources which are found in about 10% of elliptical galaxies, viewed with their radio jets pointing straight at us.

There are at least 100 BL Lac objects per cubic Gpc ($H_0 = 75$), and if the Lorentz factor (Γ) for the bulk relativistic motion of the emitting region is about 10, as Blandford and Rees suggest, the number of "misdirected" BL Lac objects must be 200 times greater; i.e., 2×10^4 per cubic Gpc. This is the same as the space density of low luminosity radio galaxies (Colla *et al.* 1975). The typical luminosity in the [O III] lines of a BL Lac object is 8×10^{40} ergs s ($H_0 = 75$) based on the data of Miller, French, and Hawley (1978). This luminosity is greater than the [O III] line luminosity of any of the nearby E galaxies, but quite typical of the fainter radio galaxies reported by Cohen and Osterbrock (1981). There is thus no problem with finding enough misdirected potential BL Lac objects.

Despite the success of the beaming model in explaining the *radio* properties, the author feels that there is no direct evidence that a significant part of the *optical* continuum is beamed towards the observer from any extragalactic source. Miller, French, and Hawley (1978) consider highly polarized, optically violently variable (OVV) objects like 1308+326 and 3C 446 to be indistinguishable from BL Lac objects apart from the former having strong broad emission lines (which low redshift BL Lac objects lack). There are a number of problems that the Rees and Blandford picture must address if it is used to explain the relationship between these OVV quasars and the various classes of the quasar phenomena as Scheuer and Readhead have attempted, although none of these problems arise specifically for BL Lac objects. Space in this paper does not permit more than listing these problems.

1. There are optical spectral differences between different types of AGNs which Doppler boosting of the continuum does not readily explain: the characteristically steeper optical–ultraviolet continuum in BL Lac objects and optically violently variable (OVV) quasars than in normal AGNs; the lack of strong Fe II emission in extended radio source quasars (Miley and Miller 1979); the failure of the C IV equivalent width versus continuum luminosity correlation for radio-quiet quasars (Osmer 1980), and the differences in the widths and profiles of the broad lines between compact and extended radio structure quasars (Miley and Miller 1979).

2. From consideration of the relativistic Doppler boosting factor, the beamed continuum cannot contribute significantly to the optical polarization of normal quasars. The fact that highly polarized quasars (which are usually if not always OVV ones) seem to have had similar luminosity functions to radio quasars of normal weak polarization and similar line strengths (Moore and Stockman 1981) does not permit the anisotropic continuum to dominate the isotropic continuum from any viewpoint, which it would have to do to explain the steeper continuum slopes in OVVs and BL Lac objects.

Relatively nonvariable radio-quiet QSOs such as Q 0420−388, which must certainly be close to isotropic radiators, already have luminosities that exceed those of the brightest BL Lac objects. Studies of the emission line variability in Seyferts (Tohline and Osterbrock 1977; de Bruyn 1980) and even in the superluminal radio source 3C 120 (French and Miller 1980) have shown that for variations on a time scale of a few months, it is the central isotropic photoionizing continuum source that is varying.

In conclusion then, there seem to be no compelling reasons yet for having to assume that the *optical* continuum in BL Lac objects is beamed towards us, as in the Blandford and Rees picture. In addition to this picture one should continue developing the idea that BL Lac objects are in fact AGNs in which at optical wavelengths, one gets a direct view of the central energy machine.

The author is most grateful to Dr. E. J. Wampler for the allocation of telescope time for the follow-up observations of PKS 0215+015 which made this study possible, and for his general encouragements during the course of this work. Thanks are also extended to Drs. J. S. Miller and G. D. Schmidt for obtaining further spectrophotometric data. Dr. A. R. Klemola kindly assisted with the inspection of the Lick astrograph plates. Drs. A. M. Wolfe and F. H. Briggs communicated details of their radio observations in advance of publication. The grid of curves of growth was provided by Dr. R. F. Carswell, to whom the author is also grateful for many useful discussions on the subject of absorption lines. The author's understanding of some of the theoretical problems was enhanced by discussions with Claes-Ingvar Bjornsson.

REFERENCES

Baldwin, J. A., Burke, W. L., Gaskell, C. M., and Wampler, E. J. 1978, *Nature*, **273**, 431.
______. 1980, *Bull. AAS*, **12**, 537.
Bentley, M., Haves, P., Spencer, R. E., and Stannard, D. 1976, *M.N.R.A.S.*, **176**, 275.
Blades, J. C., Murdoch, H. S., and Hunstead, R. W. 1980, *M.N.R.A.S.*, **191**, 61.
Blandford, R. D., and Königl, A. 1979, *Ap. J.*, **232**, 34.
Blandford, R. D., and Rees, M. J. 1978, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: Pittsburgh University Press), p. 328.
Boksenberg, A., and Sargent, W. L. W. 1978, *Ap. J.*, **220**, 42.
Boksenberg, A., Carswell, R. F., and Sargent, W. L. W. 1979, *Ap. J.*, **227**, 370.
Bolton, J. G., and Wall, J. V. 1969, *Ap. Letters*, **3**, 177.
Briggs, F. H., and Wolfe, A. M. 1981, in preparation.
Cohen, R. D., and Osterbrock, D. E. 1981, *Ap. J.*, **243**, 81.
Colla, G., Fanti, C., Fanti, R., Gioia, I., Lari, C., Lequeux, J., Lucas, R., and Ulrich, M.-H. *Astr. Ap.*, **38**, 209.
Condon, J. J., and Jauncey, D. L. 1974, *A.J.*, **79**, 437.
Dalgarno, A., and McCray, R. A. 1972, *Ann. Rev. Astr. Ap.*, **10**, 375.
de Bruyn, A. G. 1980, *Highlights Astr.*, **5**, 631.
Edlèn, B. 1953, *J. Opt. Soc. Am.*, **43**, 339.
Fitch, L. T., Dixon, R. S., and Kraus, J. D. 1969, *A.J.*, **74**, 612.
French, H. B., and Miller, J. S. 1980, *Pub. ASP.*, **92**, 753.
Gaskell, C. M. 1978, *Bull. AAS.*, **10**, 663.
______. 1981*a*, Ph. D. thesis, University of California, Santa Cruz.
______. 1981*b*, *Ap. J.*, submitted.
Jauncey, D. L., Wright, A. E., Peterson, B. A., and Condon, J. J. 1978, *Ap. J.* (*Letters*), **221**, L109.
Kurucz, R. L. 1974, *Smithsonian Ap. Obs. Spec. Rept.*, 360.
Liller, W. 1976, *IAU Circ.*, 2939.
Masson, C. R., and Wall, J. V. 1977, *M.N.R.A.S.*, **180**, 193.
McEwan, N. J., Browne, I. W. A., and Crowther, J. H. 1975, *Mem. R.A.S.*, **80**, 1.
Miley, G. K., and Miller, J. S. 1979, *Ap. J.* (*Letters*), **228**, L55.
Miller, J. S. 1978, *Comments Ap.*, **7**, 175.
Miller, J. S., French, H. B., and Hawley, S. 1978, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: Pittsburgh University Press), p. 176.
Moore, R. L., and Stockman, H. S. 1980, *Ap. J.*, **243**, 60.
Morton, D. C. 1978, *Ap. J.*, **222**, 863.
Morton, D. C., and Smith, W. H. 1973, *Ap. J. Suppl.* **26**, 333.
Nordsieck, K. H. 1974, *Pub. A.S.P.*, **86**, 324.
Nussbaumer, H., and Storey, P. J. 1980, *Astr. Ap.*, **89**, 308.
O'Dell, S. L. 1978, in *Pittsburgh Conference on LB Lac Objects*, ed. A. M. Wolfe (Pittsburgh: Pittsburgh University Press), p. 312.
______. 1979, in *Active Galactic Nuclei*, ed. C. Hazard and S. Mitton (Cambridge: Cambridge University Press), p. 108.
Osmer, P. S. 1980, *Ap. J. Suppl.*, **42**, 523.
Osmer, P. S., and Smith, M. G. 1977, *Ap. J.* (*Letters*), **215**, L47.
Perry, J. J., Burbidge, E. M., and Burbidge, G. R. 1978, *Pub. A.S.P.* **90**, 337.
Peterson, B. M. 1980, *Ap. Letters*, **20**, 119.
Readhead, A. C. S., Cohen, M. H., Pearson, T. J., and Wilkinson, P. N. 1978, *Nature*, **276**, 768.
Savage, B. D., and Jeske, N. A. 1981, *Ap. J.*, **244**, 768.
Scheuer, P. A. G., and Readhead, A. C. S. 1979, *Nature*, **277**, 182.
Shimmins, A. J., and Bolton, J. G. 1972, *Australian J. Phys. Ap. Supplement*, **23**, 1.
Shull, J. M., Snow, T. P., and York, D. G. 1981, *Ap. J.*, **246**, 549.
Smith, H. E., Jura, M., and Margon, B. 1979, *Ap. J.*, **228**, 369.
Stroemgren, B. 1948, *Ap. J.*, **108**, 242.
Tohline, J. E., and Osterbrock, D. E. 1977, *Ap. J.* (*Letters*), **210**, L117.
Wall, J. V. 1972, *Australian J. Phys. Ap. Suppl.*, **24**, 1.
Wall, J. V., Shimmins, A. J., and Merkelijn, J. K. 1971, *Australian J. Phys. Ap. Suppl.*, **19**, 1.
Wampler, E. J. 1980, in *IAU Symposium 92*, *Objects of High Redshifts*, ed. G. Abell and J. Peebles (Dordrecht: Reidel), p. 119.
Weymann, R. J., Carswell, R. F., and Smith, M.G. 1981, *Ann. Rev. Astr. Ap.*, **19**, 41.
Weymann, R. J., Williams, R. E., Beaver, E. A., and Miller, J. S. 1977, *Ap. J.*, **213**, 619.
Weymann, R. J., Williams, R. E., Peterson, B. M., and Turnshek, D. A. 1979, *Ap. J.*, **234**, 33.
Wills, D. 1979, *Ap. J. Suppl.* **39**, 291.
Wills, D., and Lynds, C. R. 1978, *Ap. J. Suppl.*, **36**, 317.
Wolfe, A. M. 1979, in *Active Galactic Nuclei*, ed. C. Hazard and S. Mitton (Cambridge: Cambridge University Press), p. 159.
Wright, E. L., and Kleinmann, D. E. 1978, *Nature*, **275**, 298.
Young, P. J., Sargent, W. L. W., Boksenberg, A., Carswell, R. F., and Whelan, J. A. J., 1979, *Ap. J.*, **229**, 891.

Note added in proof.—The f value of the Fe II λ1608.5 line has recently been calculated ab initio by H. Nussbaumer, M. Pettini, and P. J. Storey (1982, *Astr. Ap.*, in press) to be 0.096, which is in good agreement with the value estimated here.

C. M. Gaskell: Institute of Astronomy, Madingley Road, Cambridge, CB3 OHA, England