THE ASTROPHYSICAL JOURNAL, 300:216–223, 1986 January 1

THE ULTRAVIOLET EXCESS OF QUASARS. III. THE HIGHLY POLARIZED QUASARS PKS 0736+017 AND PKS 1510−089

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Received 1985 March 11; accepted 1985 July 1

ABSTRACT

We analyze ultraviolet, optical, and infrared spectrophotometry of the highly polarized quasars (HPQs) PKS 0736+017 and PKS 1510−089. A "blazar" continuum component like that in BL Lac objects (e.g., with violent variability, high polarization, and a steep power-law shape) contributes about half the visual light of 1510−089, and at least three-quarters of that in 0736+017. The remaining light has the same spectrum as normal (low-polarization) quasars, including an "ultraviolet excess" or "blue bump," which is easily detected in the *IUE* spectra of 1510−089, and weakly detected in 0736+017. The line fluxes do vary, but not as much as the continuum. The ratios of the broad emission lines and the Balmer continuum are normal in both quasars.

Subject headings: quasars — radiation mechanisms — spectrophotometry

I. INTRODUCTION

Earlier studies of the continuum emission from quasars focused considerable attention on the optically violently variable, highly polarized quasars (HPQs), most of which were selected by their strong, flat radio spectra. HPQs share the violent variability and high polarization of the BL Lac objects, and also have relatively steep optical continua, which either resemble power laws, or sometimes curve down at higher frequencies (Moore and Stockman 1981). Like BL Lac objects, HPQs have compact, flat-spectrum radio sources. This suggests that the same steep, violently variable, highly polarized "blazar" continuum, which dominates the optical light of BL Lac objects, is also seen in HPQs (Moore and Stockman 1984). Recently Impey and Malkan (1986) have found that even 3C 273, an apparently "normal," low polarization, small-amplitude variable quasar, has a highly polarized, violently variable continuum component. It is extremely weak, and even at the peak of an outburst it only produces $\sim 10\%$ of the visual continuum.

Evidently the blazar continuum in quasars is mixed in with "normal" low-polarization quasar (LPQ) light, in proportions which vary from one quasar to another. The BL Lac objects would be at the extreme end of the distribution, where the polarized blazar continuum totally dominates over the low-polarization continuum and line emission, and the HPQs would be intermediate cases. This hypothesis implies that HPQs should also have a weak underlying continuum component that is the same as that of normal quasars, but it would be very difficult to detect because of the strong dilution from the highly polarized component.

The continuum in normal LPQs has a markedly different shape from that of HPQs. Although it, too, resembles a power law at red and infrared wavelengths, the normal quasar continuum always flattens in the blue and ultraviolet. This distinctive "ultraviolet excess" or "blue bump," which is much too strong to be explained by Balmer continuum and Fe II line emission alone, has been identified as optically thick thermal emission (Malkan and Sargent 1982; hereafter Paper I). Its relative strength and shape does not vary much among LPQs and Seyfert 1 galactic nuclei (Malkan 1984*a*), but it has not been found in any previous spectrophotometry of BL Lac objects and HPQs. In this paper we search for this residual normal quasar light in the spectra of HPQs.

Given the different spectral shapes, our search is most profitably conducted in the ultraviolet, especially in the wavelength range accessible to *IUE*. For example, the average ratio of fluxes at rest wavelengths of 4220 and 1450 Å is $f\nu_{4220}/f\nu_{1450} = 1.8$, for normal unreddened active nuclei, whereas it is ~ 2.5 times larger in BL Lac objects. The only previous published ultraviolet measurements of HPQs were obtained when the objects were bright or flaring. The infrared/optical/ultraviolet spectra of 1156+295 (Glassgold *et al.* 1983; Wills *et al.* 1983) and 3C 345 and 3C 446 (Bregman *et al.* 1984) are indistinguishable from those of BL Lac objects. They resemble smooth steep power laws (with slopes steeper than −1.0), with some downward curvature at high frequencies. None shows any evidence of the "ultraviolet excess" seen in normal quasars.

For this search, we selected two of the brightest HPQs for our multiwavelength continuum study. PKS 0736+017 ($Z_{em} = 0.191$) and PKS 1510−089 ($Z_{em} = 0.361$) were singled out by Moore and Stockman (1981) as having possible excesses at the shortest optical wavelengths. In addition to their blue colors, these quasars often have relatively low optical polarizations compared to most HPQs. Thus, they may not be representative of the HPQ class as a whole, but are the most promising for our search for UV excesses. Observational obstacles prevented us from obtaining detailed new polarimetric data to measure the wavelength dependence of polarization. However, we did obtain new spectrophotometric data for these HPQs, both at visible wavelengths, and with the *IUE*. In addition, we obtained previously unpublished *IUE* spectra of both objects. We showed in Paper I and Paper II (Malkan 1983) that these

TABLE 1

Log of Observations

Date	Telescope	Wavelength	Spectral Resolution	Aperture	Source
		0736+017			
1972[a]	Lick 3.0 m	3200–8200 Å	7 Å	2″ × 4″	Baldwin 1975
1976 Nov	Lick 3.0 m	3200–5300 Å	7 Å	2″ × 4″	Grandi 1981
1979 Apr, Nov[a]	AAT	1.2–2.2 μm	0.1 μm	10″ circular	Hyland and Allen 1982
1981 Dec 16, 21[a]	*IUE*	1200–2000 Å	6 Å	10″ × 15″ oval	Wampler; Kunth *et al.*[b]
1982	Lick 3.0 m	3200–7000 Å	7 Å	2″ × 4″	BKM 1982
1983 Apr 9	Palomar 1.5 m	3500–6900 Å	9 Å	8″ × 16″	This paper
1983 Dec 31[a]	*IUE*	1900–3300 Å	7 Å	10″ × 15″ oval	This paper
1984 Jan 27	Steward 2.3 m	3300–6500 Å	8 Å	5″ circular	This paper
1984 Apr 21	Steward 2.3 m	3300–6500 Å	8 Å	5″ circular	This paper
1984 Oct 13	Steward 2.3 m	3300–6500 Å	9 Å	8″ circular	This paper
1985 Feb 14, 15	Steward 2.3 m	3600–6700 Å	9 Å	8″ circular	This paper
1977 Mar–1984 Mar[a]	Steward 1.5 m	3500–8000 Å	1500 Å	12″.7 circular	Wisniewski 1985
		1510−089			
1976 Jun	Lick 3.0 m	3200–7000 Å	7 Å	2″ × 4″	BKM 1982
1977 Feb	Palomar 5.0 m	3200–10000 Å	40/80 Å	10″ circular	Neugebauer *et al.* 1979
1977 May[a]	Palomar 5.0 m	1.2–2.2 μm	0.1 μm	10″ circular	Neugebauer *et al.* 1979
1979 Mar[a]	AAT	1.2–2.2 μm	0.1 μm	10″ circular	Hyland and Allen 1982
1981 Jun 6[a]	*IUE*	1900–3200 Å	7 Å	10″ × 15″ oval	Glassgold *et al.*[b]
1983 Jan 21[a]	*IUE*	1200–2000 Å	6 Å	10″ × 15″ oval	Glassgold *et al.*[b]
1983 Apr 7[a]	Palomar 1.5 m	3500–6900 Å	9 Å	8″ × 16″	This paper
1984 Apr 21	Steward 2.3 m	3300–6500 Å	8 Å	5″ circular	This paper
1985 Feb 14	Steward 2.3 m	3600–6700 Å	9 Å	8″ circular	This paper
1982 Feb–1984 May	Steward 1.5 m	3500–8000 Å	1500 Å	12″.7 circular	Wisniewski 1985

[a] These spectra were used in the multiwavelength continuum fitting described in the text. They are also plotted in the figures.
[b] These reduced *IUE* spectra were obtained from the National Space Sciences Data Center.

data alone can yield substantial information about the continuum, if they span a wide wavelength range, at least from the infrared to the ultraviolet.

II. OBSERVATIONS

Like other highly polarized quasars, 0736+017 and 1510−089 are optically violently variable. The magnitudes of both objects usually range from $V = 16$–17, and variations of several tenths of a magnitude have been seen on time scales as short as a few days (Pica *et al.* 1980; Wisniewski 1985).[1] Thus, it is highly desirable to obtain truly simultaneous spectrophotometry all on the same night over the wide wavelength range needed for a detailed study of the continuum. However, such spectrophotometry would require simultaneous scheduling of several heavily subscribed instruments, which is nearly impossible in practice. One way to merge nonsimultaneous observations is to scale arbitrarily the spectra to agree in their overlapping wavelength regions. This technique implicitly assumes that the spectral shape is constant throughout brightness variations. Our objective, to search for continuum components which might differ in spectral shapes and variability, is inconsistent with this assumption.

Our solution to the problem of nonsimultaneous spectra has been to repeat the observations of each quasar several times over the last few years. These observations allowed us to piece together infrared/optical/ultraviolet spectra which, although not completely simultaneous, are continuous at the overlaps between each spectral section without any scaling. We were also aided by Wisniewski's (1985) unpublished *UBVRI* monitoring of both quasars over the last several years, which he generously made available to us. Thus, we believe that our adopted multiwavelength spectra of these quasars are essentially the same as they would have been if all the data had been obtained simultaneously. Table 1 gives the dates of all observations, with references.

[1] In 1948, 1510−089 showed a remarkable outburst, reaching a photographic magnitude of 12, but there is no indication that it has been nearly so bright in the last several decades (Liller and Liller 1975).

PKS 1510−089 was observed with both cameras of the *IUE* by Glassgold *et al.* (unpublished), and we obtained the reduced spectra from the National Space Sciences Data Center. We obtained the LWR (1900–3200 Å) spectrum of 0736+017 with *IUE* on 1983 December 31, and have combined it with the SWP (1200–2000 Å) spectra obtained by Wampler (unpublished) and Kunth *et al.* (unpublished) 2 yr earlier, also supplied by NSSDC. The ultraviolet fluxes, corrected to zero redshift, are given in Table 2.

TABLE 2

Ultraviolet Fluxes Corrected for Redshift

$\log \nu_0$	0736+017	1510−089
15.506	...	0.15
15.426	0.08	0.18
15.352	0.12	0.28
15.320	...	0.28
15.310	0.15	0.24
15.229	0.16	0.18
15.169	0.23	0.27
15.142	0.29	0.33
15.122	0.32	0.26
15.095	0.33	0.30
15.084	0.34	0.32

Note.—Fluxes in millijanskys.

Although the long- and short-wavelength ultraviolet spectra were obtained at different times, they do overlap for 100 Å around 2000 Å. The noisiest point is usually at the shortest wavelength in the LWR camera, near an observed wavelength of 2000 Å. Nonetheless, within the uncertainties, all the ultraviolet spectra from different cameras and epochs agree well with each other. Either we were fortunate to have caught these HPQs in the same state each time, or they are intrinsically less variable in the ultraviolet than in the visible.

We obtained several low-resolution optical spectra of both quasars covering 3500–7000 Å on photometric nights in 1983 and 1984 at the Palomar 1.5 m and Steward 2.3 m reflectors. Accurate absolute fluxes were measured with large apertures on the Palomar SIT spectrograph and on the Steward Reticon spectograph. By averaging over bins of 100 or more angstroms, we always achieved a signal-to-noise ratio of at least 10 and usually 20, as with the *IUE* spectra. Thus, the typical measuring uncertainties of data points are $\sim 5\%$, and are comparable to the systematic errors which may exist in the calibrations. Each figure shows a bar of ± 0.05 dex, somewhat larger than the error of the worst data points. Our new optical continuum fluxes, corrected to zero redshift, are listed in Table 3.

Our optical observations span the full range of magnitude variations that 0736+017 has been observed to undergo in the last few decades. The spectra of 1984 April 22 and October 14 (which is slightly bluer) both represent the quasar near its maximum, while the 1976 November 21 (Grandi 1981), 1983 April 10 (this paper), and 1980 (Blumenthal, Keel, and Miller 1982; hereafter BKM) spectra were obtained near minimum light. Even between these extremes, the shape of the spectrum did not seem to vary much—in other words, the percentage variability at 3500 Å is of almost the same magnitude as that in the far-red: 1 σ is 0.2 mag at *U*, *B*, *V*, *R*, and *I* (Wisniewski 1985).

We chose the 1972 optical spectrum of 0736+017 by Baldwin (1975) for our multiwavelength analysis because it gives the best match to the ultraviolet observations. It is almost identical (within ~ 0.1 mag) to the *average UBVRI* fluxes determined by Wisniewski (1985) in 10 epochs spanning the last 7 yr.

We have one additional reason to believe that our optical and ultraviolet spectra are well matched. The *IUE* SWP spectra, which are essentially identical, were obtained on 1981 December 17 and 21. One week later, Wisniewski (1985) obtained *UBVRI* photometry of 0736+017 which agrees very well (to within ~ 0.1 mag at all wavelengths) with Baldwin's spectrophotometry obtained at Lick Observatory in 1972 (Baldwin 1975). Assuming that 0736+017 did not change significantly in the few days between the SWP spectra and Wisniewski's photometry, then the SWP spectra should match well with Baldwin's 1972 spectrophotometry. Our LWR spectrum, obtained on 1983 December 31, agreed well with both the SWP and Baldwin spectra. On the basis of these agreements, we believe that our adopted spectrum is indeed a good representation of 0736+017 in late December 1981.

Our 1984 April 21 spectrum of 1510−089 is quite similar to that obtained by Neugebauer *et al.* (1979) in 1977 February. The quasar was fainter than average, and considerably fainter than when Oke, Neugebauer, and Becklin (1970) measured it in 1967 near maximum. In fact, it was almost as faint as it was on 1983 July 16, when it reached an historical minimum brightness (Malkan 1984*b*). In the following analysis, we use the 1984

TABLE 3

Optical Continuum Fluxes Corrected for Redshift[a]

	0736+017				1510−089		
$\log \nu_0$	1985 Feb 14, 15	1984 Apr 21	1984 Jan 27	1983 Apr 9	1985 Feb 14	1984 Apr 21	1983 Apr 7
15.017..........	...	0.76	...	0.39	0.43	0.38	0.48
15.001..........	...	0.85	...	0.38	0.43	0.38	0.44
14.988..........	...	0.82	0.67	0.37	0.42	0.37	0.45
14.976..........	0.78	0.88	0.69	0.42	0.48	0.43	0.47
14.962..........	0.81	0.90	0.71	0.44	0.50	0.46	0.49
14.951..........	0.80	0.93	0.71	0.45	0.49	0.47	0.50
14.942..........	0.84	0.99	0.75	0.46	0.50	0.48	0.50
14.933..........	0.86	1.01	0.75	0.47	0.50	0.48	0.51
14.924..........	0.84	1.01	0.73	0.46	0.49	0.46	0.50
14.913..........	...	1.03	0.75	0.48	0.50	0.48	0.47
14.895..........	0.84	1.05	0.76	0.48	0.49	0.48	0.48
14.873..........	0.81	1.02	0.73	0.48	0.48	0.44	0.48
14.851..........	0.81	1.04	0.76	0.50	0.51	0.46	0.48
14.828..........	0.89	1.10	0.86	0.57	0.53	0.52	0.57
14.807..........	0.92	1.20	0.90	0.58	...	0.45	0.66
14.790..........	...	...	...	...	0.55	0.49	...
14.772..........	0.98	...	1.01	0.76	...	...	0.73
14.758..........	...	...	...	0.87	...	0.52	...
14.744..........	1.07	1.28	...	0.95	...	0.46	...
14.730..........	1.08	1.42	...	1.05	...	0.56	...
14.713..........	1.08	...	...	1.15	...	0.52	...
14.690..........	...	...	...	...	...	0.58	0.96
14.673..........	...	...	...	...	...	0.65	...
14.653..........	...	...	...	...	...	0.84	...
14.636..........	...	...	...	...	...	0.79	...
14.610..........	...	...	...	...	...	0.99	...
14.600..........	...	...	...	...	...	0.77	...
14.588..........	...	...	...	...	...	1.04	...

[a] In millijanskys ($= 10^{-26}$ ergs s^{-1} cm^{-2} Hz^{-1}).

TABLE 4

EMISSION-LINE FLUXES AND EQUIVALENT WIDTHS[a]

Date of Spectrum[b]	Lyα	C IV	Mg II	Hγ	Hβ	Hα
0736+017						
1981 Dec	15/70	8/40	...	...	...	...
1972 Dec	...	...	12/51	2.8/23	7.0/63	30/310
1976 Nov	...	...	/67	/39	/91	/374
1977 Nov	...	...	...	/18	/45	/250
1984 Jan	...	...	...	2.1/17	5.8/52	...
1984 Apr	...	...	...	2.7/14	7.6/45	...
1984 Oct	...	...	...	3.0/18	7.7/55	...
1985 Feb	...	...	...	2.5/18	6.2/54	...
1510−089						
1976 Jun	...	...	/55	/38	/78	...
1977 Jan	...	...	...	...	/115	...
1977 Feb	...	...	6.5/57	...	5.3/110	18/530
1983 Jan	...	8/31	...	...	...	...
1984 Apr	...	...	9/66	4.5/66	7.0/115	...
1985 Feb	...	...	7.2/47	...	...	...

[a] Emission-line fluxes in 10^{-14} ergs s^{-1} cm^{-2}; equivalent widths in angstroms and are corrected to zero redshift.
[b] Refer to Table 1 for reference.

April 21 spectrum, since it gives the best match to the *IUE* spectra. The original 200″ multichannel spectra from Neugebauer *et al.* (1979) are also used to fill in the 0.7–1.05 μm fluxes. The percentage variability of 1510−089 is slightly smaller, with a 1 σ magnitude of 0.15 mag, again with no wavelength dependence.

Unfortunately, the only available infrared photometry was not obtained in the same years as the ultraviolet spectra. Hyland and Allen (1982) observed both quasars at 1.2–2.2 μm on two occasions each, and found that both had varied. 1510−089 changed by 0.3 mag in 2 days, with its fainter fluxes the same as those Neugebauer *et al.* (1979) observed in 1977 May. The 2.2 μm flux measured at Palomar in 1967 June (Oke, Neugebauer, and Becklin 1970) was 0.6 mag brighter. For 0736+017 we use the average of the Hyland and Allen measurements of 1979 April and November.

In Table 4, we give emission-line equivalent widths and, where available, fluxes. The forbidden lines (e.g., [O II] λ3727, [O III] λ5007) were too weak to measure. Although the Balmer line fluxes do not appear to be constant, they certainly do not vary as strongly as the continuum. Thus the equivalent widths tend to drop with increasing continuum flux, in both quasars. When they change, it is by a roughly wavelength-independent factor (e.g., the equivalent widths of Mg II λ2800 and Hβ drop by the same factor). This observation, along with the absence of strong systematic spectral changes, confirms our view that the variability is primarily due to a component with a roughly power-law shape, with about the same slope as the overall spectrum, and that this variable component is a major contributor (at least 50%) to the light observed at 0.35–0.85 μm.

III. ANALYSIS

We analyze the continuous spectra, plotted in Figures 1–3, following the procedures of Papers I and II. First, we make corrections for the effects of reddening and contamination from the starlight of the underlying galaxy.

The H I column densities in the directions to 1510−089 ($l = 353°$, $b = -38°$) and 0736+017 ($l = 218°$, $b = +11°$) imply Milky Way reddenings of $E_{B-V} = 0.01$ and 0.12 mag respectively (Burstein and Heiles 1982). A small amount of internal reddening ($E_{B-V} = 0.02$ mag) is included in the analysis of 1510–089, since it decreases the residuals of the continuum fits slightly.

Direct imaging by Wyckoff, Wehinger, and Gehren (1983) shows that PKS 0736+017 ($Z_{em} = 0.191$) lies in a faint host galaxy, with a total diameter and red magnitude of 20″ and 19.9 mag. Our fits include a 0.07 mJy starlight contribution to the observed visual flux, a very minor correction. The galaxy which is presumed to harbor PKS 1510−089 is almost too distant ($Z_{em} = 0.361$) to be detectable in deep photographs of Wyckoff, Wehinger, and Gehren (1981) and Hutchings *et al.* (1984), and no starlight contribution was included in the fits.

The fitted spectra include the Balmer emission lines and continuum (see Table 5), and an extensive tabulation of Fe II emission lines. Their relative strengths were calculated by Netzer and Wills (1983), who kindly provided a printout of the results of their "standard model."

Since the Balmer continuum is always stronger than the predictions of case B recombination, our fits (which assume case B ratios for the Balmer lines) fall below the observations between 3900 and 3700 Å, where blended Balmer emission produces a strong pseudo-continuum. The data, as expected, do not show such a sharp Balmer jump as do our models with case B emission-line ratios. The continuum components which are varied to fit the data are the same as in Papers I and II: a power law and, if required, an optically thick thermal component. Thus there are up to three free parameters: the slope of the power law, the effective temperature (or peak frequency) of the thermal component, and the ratio of power law to thermal fluxes. We note that although our continuum fits include the effects of starlight, reddening, Fe II line emission, and hydrogen line and continuum emission, they are not free parameters. They are fixed by other observations.

We are unable to distinguish between the HPQ power-law component of normal quasar light and blazar continuum, which is also presumed to be described by a power law. Thus

TABLE 5

MODEL-FITTING RESULTS

QSO	BLAMER CONTINUUM[a] Hα	POWER LAW α	POWER LAW $f\nu_0$[b]	BLACKBODY $f\nu_0$[b]	BLACKBODY T (K)	ACCRETION DISK $M_{bh}(M_\odot)$	ACCRETION DISK $\dot{M}(M_\odot\ yr^{-1})$
0736+017	2.3	−1.0	0.90	0.05	26,000	...[c]	...[c]
1510−089	1.9	−1.7	0.46	0.07	33,000	6×10^7	1.0

[a] Balmer continuum was assumed optically thin, at 10,000 K.
[b] All fluxes refer to rest frequency of $\log \nu_0 = 14.74$, and are given in millijanskys, (10^{-26} ergs cm^{-2} s^{-1} Hz^{-1}), reddening corrected.
[c] The ultraviolet excess in 0736+017 is too weak to allow accurate estimation of disk parameters.

our fitted power law refers to the sum of these two power laws, but, as we discuss below, the HPQ component predominates.

a) 1510−089

The infrared/optical/ultraviolet continuum, shown in Figures 1 and 2, can certainly not be fitted by a single power law, even in combination with strong Balmer continuum and blended line emission. The spectrum is similar to those of normal quasars: it has strong upward curvature which becomes evident between Hβ and the near-infrared. At these longer wavelengths, the emission-line and Balmer continuum components are negligible. Thus, 1510−089 has a strong "ultraviolet excess," or "blue bump," which begins to contribute noticeably to the continuum below 5000 Å.

In normal quasars, this bump is broader than a single-temperature blackbody (as shown in Paper II, and more dramatically for B201 in Paper IV). Nonetheless, we first fitted the blue bump in 1510−089 as a single Planck function because it is a fair approximation over the observed wavelength range, and can be compared with the blackbody fits in Paper I. The best fit, and two which closely bracket it, are shown as the solid lines in Figure 1. The best-fit blackbody temperature is 33,000 K, and the other lines show the effect of changing it by ± 2000 K. This temperature is at the high end of the range of 21,000–34,000 K found in Papers I and II.

The fitted power-law slope, -1.7, is markedly steeper than those of normal quasars, but is typical of BL Lac objects and other HPQs. The total power-law/blackbody ratio at $\lambda_0 =$ 5500 Å is 6.6, nearly twice as strong as in the average normal quasar (Papers I and II). The normal quasar continuum probably also has a red component resembling a power law with slope -1.1 (Paper I). However, at long wavelengths, the steeper, blazar power law dominates the spectrum. Thus, the continuum properties of 1510−089 can be interpreted as a combination of BL Lac continuum (with high polarization, violent variability, and a steep power-law slope which extends out to millimeter wavelengths) and normal quasar light. In the faint state we observed it in, the ratio of these two components was ~ 1 at 5500 Å.

In Figure 2, we show the fits to the continuum when we model its ultraviolet excess as light from an accretion disk around a nonrotating (Schwarzschild) black hole (as in Paper II). As before, we assumed the disk was in a steady state, optically thick, geometrically thin, and viewed face-on. In this case the thermal component is still entirely specified by only two free parameters, the black hole mass and the accretion rate. The best-fit hole mass is $6 \times 10^7\ M_\odot$; the two solid lines show models with hole masses of 5 and $7 \times 10^7\ M_\odot$, either of which also fits the data satisfactorily. The best-fit accretion rate corresponds to a luminosity 40% $\pm$ 20% that of the Eddington

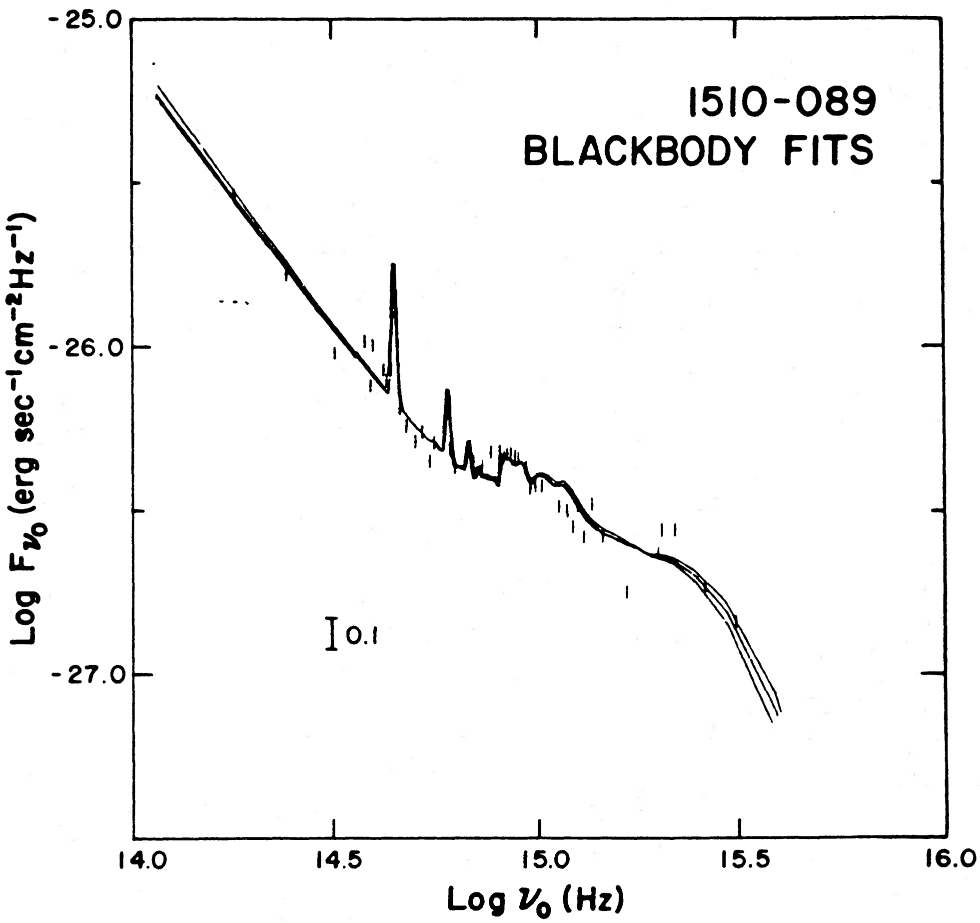

FIG. 1.—Fits to the infrared/optical/ultraviolet spectrum of 1510−089, with a power law, blackbody, Balmer and Fe II emission lines, and Balmer continuum. The three curves are for blackbody temperatures of 31,000, 33,000, and 35,000 K. The bar which shows 0.1 dex in flux is larger than the errors of the worst data points. The curve with the hottest blackbody temperature has the most flux in the far-ultraviolet.

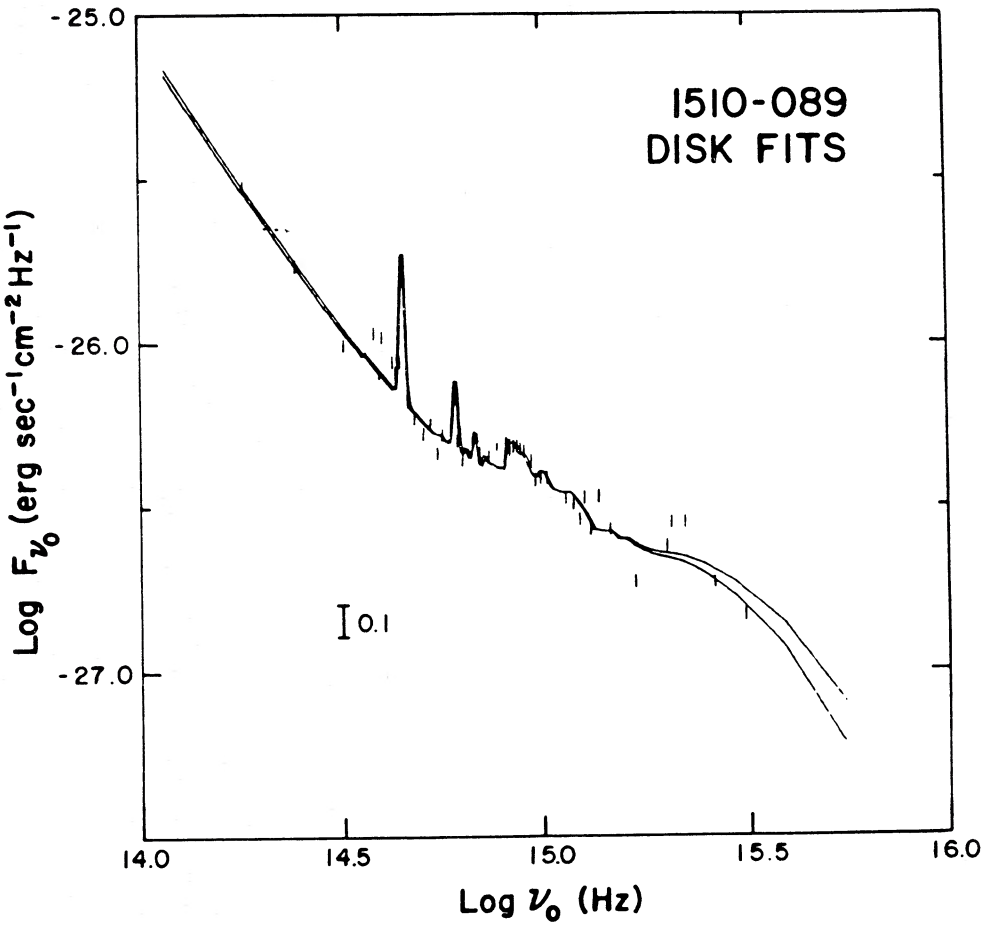

FIG. 2.—Fits to the same multiwavelength data as shown in Fig. 1. Here the blackbody component was replaced by the spectrum emitted from an optically thick, geometrically thin, face-on accretion disk. The two curves, which fit the data better than the blackbody fits in Fig. 1, are for Schwarzschild black hole masses of 5 and $7 \times 10^7 M_{\odot}$. The curve with the stronger far-ultraviolet flux is for the smaller hole mass.

limit. Had we assumed that the hole were rotating rapidly, the inferred mass would nearly triple, while the inferred accretion rate would drop by a factor of 2–3. In this case the accretion rate would be $\sim 30\%$ of critical (Paper II).

b) 0736+017

Even after correction for interstellar reddening, the ultraviolet continuum of 0736+017 is much redder than that of 1510−089. The optical/ultraviolet color of 1510−089 ($f\nu_{4220}/f\nu_{1450} = 1.9$) is slightly redder than that of normal quasars: 1.8. However, the de-reddened intrinsic color of 0736+017 is 2.7, closer to the average value for BL Lac objects. Its 0.2–1.6 μm continuum is almost adequately fitted simply by a power law plus recombination and Fe II line emission (the flatter fit in Fig. 3). However, this fit requires a power-law slope of $\alpha = -0.8$, significantly flatter than the -1.1 index usually seen in the near-infrared ($\lambda_0 = 0.6$–$1.8\ \mu$m) in other quasars. The pure power-law fit is rather poor in the far-ultraviolet, where it fails to predict the steep falloff in flux observed at rest wavelengths shorter than 2000 Å. We have two further reasons to doubt that the continuum can be adequately described by the single, flat power law. Such a flat slope would be inconsistent with both sets of infrared photometry, which give α (1.85–1.0 μm) $= -1.4$, and the average $R-I$ color, which corresponds to α (0.75–0.60 μm) $= -1.2$. This inconsistency is exacerbated when we remember that the infrared measurements shown in Figure 3 are probably a little too faint to match the optical data. Thus, we prefer the fit with $\alpha = -1.0$, which must include a blackbody component, although the latter's presence is not as certain as it is in 1510−089.

The blackbody component is so weak that its strength is poorly determined. But following the assumption that the "normal" quasar light has a power law to blackbody ratio less than 4 (Papers I and II), we infer that less than one-fourth of the continuum of 0736+017 is normal quasar light. More than three-fourths of the $\lambda_0 = 5500$ Å continuum must belong to the highly polarized, variable, "BL Lac" component.

c) Related Observations

The optical and ultraviolet broad emission-line ratios, listed in Table 4, are indistinguishable from those of normal quasars. The Balmer lines in 0736+017 have unusually small equivalent widths, presumably because of the dilution from the blazar continuum. Equivalent widths measured with respect to the normal quasar light alone are at least as strong in these two HPQs as those of normal quasars.

The intrinsic Balmer continuum/line ratios are the same as those seen in other quasars and Seyfert 1 galaxies (Malkan and Sargent 1982; Malkan 1984*a*). For optically thin Balmer continuum emission at $T_e = 10{,}000$ K, the ratios Bac/Hα and Bac/Hβ are 2.3 and 8.7, respectively, in 0736+017 and 1.9 and 6 in 1510−089. Since these emission-line ratios are normal, we

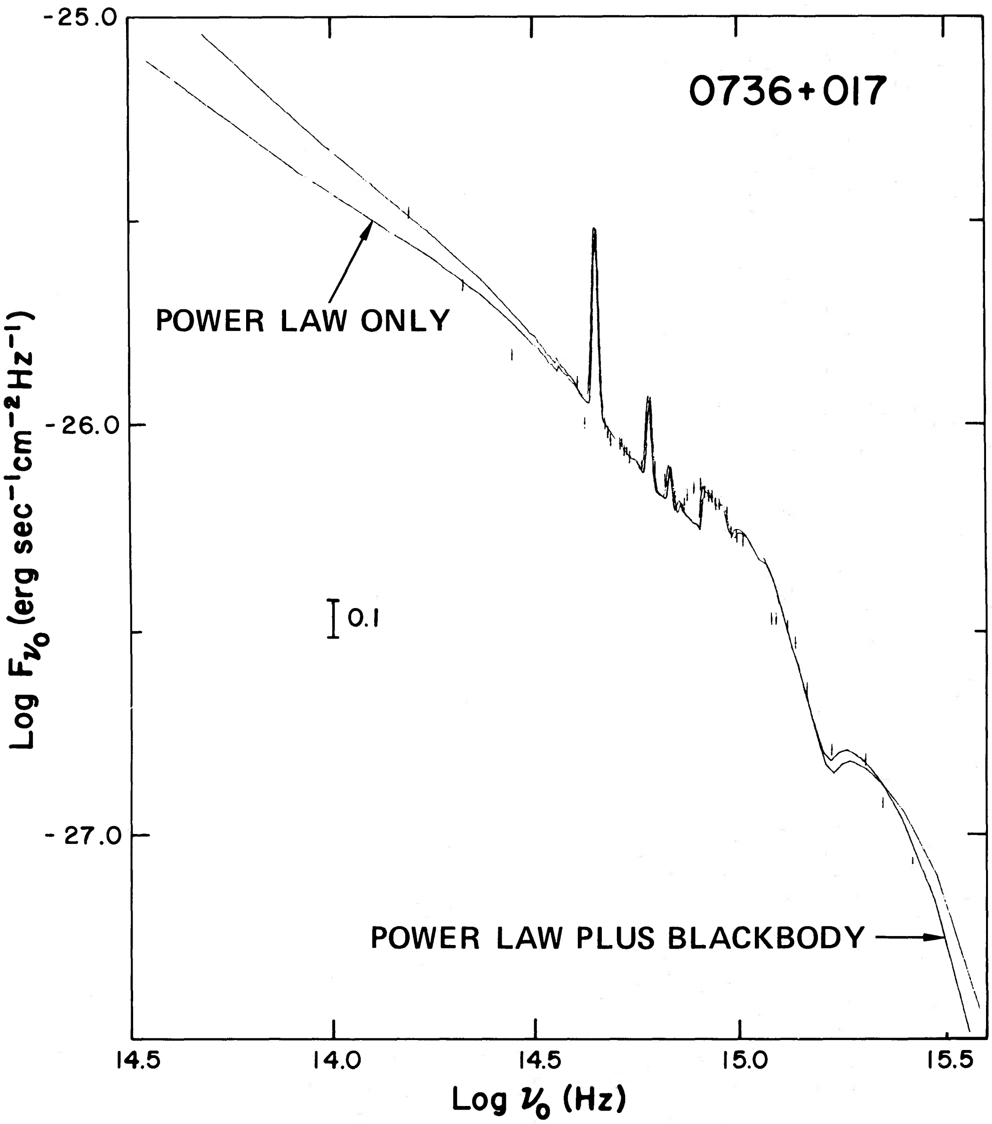

FIG. 3.—Fits to the multiwavelength spectrum of 0736+017. The flatter curve, which is a slightly worse match to the shortest wavelength points, is for a power law of slope −0.8, plus Balmer continuum, and Balmer and Fe II emission lines. The steeper curve has a power-law slope of −1.0 and a weak 26,000 K blackbody component. This blackbody curve has a higher flux in the infrared, and lower flux in the far-ultraviolet, and is crossed twice by the pure power-law curve.

infer that the shape of the unobserved far-ultraviolet ionizing continuum cannot be too abnormal. This strengthens our contention that the broad-line regions in HPQs are illuminated by the underlying "normal" quasar spectrum.

The X-ray luminosities of both quasars were measured by Ku, Helfand, and Lucy (1980). The logarithmic continuum slope from 2 μm to 2 keV is $\alpha_{ix} = -1.15$ for 0736+017 and −1.1 for 1510−089. These slopes are only marginally flatter than the average α_{ix} for normal AGN, −1.18 (Malkan 1984*a*). As suggested in Paper I, we see that the violently variable/polarized component in HPQs does not have a very different infrared/X-ray slope from that of normal quasars. At most, for a given infrared flux, the polarized component might produce twice as much X-ray flux as an unpolarized continuum.

IV. CONCLUSIONS

By analyzing the continuum over a wide range of wavelengths (ultraviolet, optical, and infrared), we find that the HPQs 0736+017 and 1510−089 have mixtures of "blazar" (highly polarized, violently variable) light and "normal" quasar light. The blazar component, which produces about one-half of the visual light in 1510−089, and three-fourths of that in 0736+017, is indistinguishable from that of BL Lac objects, and is probably generated by the same physical mechanism. Its spectrum is quite red and is characterized by a power law with slope −1.1 to −2.0.

The "normal" quasar light is probably the same as that of quasars studied in Papers I and II. It can be further divided into two continuum components: a power law with slope -1.1 ± 0.1, and a strong "blue bump" believed to be thermal emission, perhaps from an accretion disk. We emphasize that this "normal" power law is different from the blazar power-law continuum, in having a flatter slope, milder variability (Rieke 1978), and lower polarization (Rudy *et al.* 1982). It may also be nonthermal, like the blazar continuum, but these three differences indicate that the physical origin is not the same in detail. Likewise, the weak optical polarization measured in normal quasars is very different from that of blazars. It rises significantly at shorter wavelengths (Stockman, Moore, and Angel 1984), and is probably not attributable to dilute synchrotron emission.

In contrast, there are several reasons to believe that the blazar component is at least anisotropic, and perhaps relativistically enhanced. It is usually associated with compact, flat-spectrum radio emission and with low-radio frequency variability (Moore and Stockman 1984). In fact, PKS 0736+017 shows strong low frequency variability (McAdam 1976). It is difficult for the standard incoherent synchrotron mechanism to explain the small sizes implied by this variability and the lack of stronger inverse-comptonized X-ray flux without resorting to bulk relativistic motions (Marscher 1980). Most models for the superluminal expansions detected by VLBI also require beamed, relativistic outflow (Unwin *et al.* 1983).

We observe that the line emission (presumed isotropic) does not vary nearly as much as the continuum, in contrast to the lines in normal Seyfert 1 nuclei (e.g., Oke, Readhead, and Sargent 1980; De Bruyn 1980). This further suggests that not all of the optical continuum variation is actually "seen" by the broad-line region, which is expected if the blazar component is anisotropic.

Our two-component analysis of these HPQ spectra predicts that the blazar characteristics should be increasingly important *at longer wavelengths*, and *when the continuum is brighter.* (4.3% on 1978 October 27, and 5.6% on 1978 November 26), it was indeed unusually bright (visual magnitude estimated at 15.5–16.0). However, it sometimes shows a lower polarization even when bright. No brightness/polarization correlation is evident in 1510−089 (Moore 1981).

At least one polarization wavelength-dependence measurement of 0736+017 by Moore and Stockman (1981) did show the expected increase in polarization with wavelength. In 1978 November, the blue polarization was $4.97 \pm 0.27\%$ ($\theta = 28° \pm 1°$), while the red polarization was $6.12 \pm 0.20\%$ ($\theta = 31° \pm 1°$).

Recent *UBVRI* photometry of the low-polarization ($P \approx 0.5\%$) quasar PKS 2128−123 can also be explained by our two-component model for HPQs. This quasar is a flat-spectrum radio source, but is only moderately variable at blue-visual wavelengths (Pica *et al.* 1980). Moles *et al.* (1985) observed large-amplitude (up to $\Delta m = 1.69$ mag) night-to-night variability in the *I* band, where we suspect the light of a blazar component would dominate. At the same time, the variability of shorter wavelengths was much smaller ($\sigma \approx 0.3$ mag), presumably because of the dilution from a normal quasar continuum. Evidently, its ratio of blazar to normal continuum is somewhere between that of 1510−089 and 3C 273.

We have established that a "normal" quasar continuum is present in these HPQs, in addition to their emission lines and highly polarized blazar continuum. This result, combined with the discovery of a weak blazar component in 3C 273 by Impey and Malkan (1986), demonstrates that HPQs represent one extreme in the relative strength of blazar to "normal" continuum. The presence of a "normal" continuum in HPQs is an important test on an anisotropic model for the optical emission of quasars, but does not in itself prove the model. The primary arguments for optical anisotropy remain the statistical connections between optical blazar properties and the anisotropic (beamed) radio properties of quasars.

We are grateful to M. Cohen for sponsoring our *IUE* proposal, and NASA grant NAG 5–337. We thank W. Wisniewski for providing us with his excellent set of photometry, B. Wills and H. Netzer for providing the Fe II line strengths from their standard model, and S. Grandi and W. Keel for supplying plots of some published Lick spectra. We also thank R. Thompson and K. Feggins at the *IUE* RDAF for assistance with the ultraviolet data reduction, the staffs at the *IUE* Observatory and the National Space Science Data Center, and R. Goff, A. Bauer, M. Zeitner for assistance at the 2.3 m telescope. E. Jensen provided valuable comments on an earlier draft, and H. Bluestein typed the manuscript with customary expertise and efficiency.

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