THE ULTRAVIOLET EXCESS OF QUASARS III.

The Highly Polarized Quasars PKS 0736+017 and PKS 1510-089

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ABSTRACT

We analyze ultraviolet/optical/infrared spectrophotometry of the highly-polarized quasars (HPQ's) 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.

I. INTRODUCTION

Earlier studies of the continuum emission from quasars focussed considerable attention on the optically violently variable, highly polarized quasars(HPQ's), most of which were selected by their strong, flat radio spectra. HPQ's 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, HPQ's 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 HPQ's (Moore and Stockman 1984). Recently Impey and Malkan (1985) have found that even 3C 273, an apparently "normal", low polarization, small-amplitude variable quasar, actually has a highly polarized, violently variable continuum component. It is extremely weak, and even at the peak of an outburst it only produces ~10% of the visual continuum.

Evidently, the ratio of "normal quasar light" to highly polarized continuum can vary continuously from one quasar to another. The HPQ's are simply the extreme end of the distribution, where the polarized blazar component dominates. This hypothesis implies that HPQ's 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 due to the strong dilution from the highly polarized component.

The continuum shape of normal quasars and active galactic nuclei does not vary much from object to object (Malkan 1984). They all have an "ultraviolet excess" or "bump" which is much too strong to be explained by Balmer continuum and Fe II line emission alone (Malkan and Sargent 1982, Paper I; and Malkan and Filippenko 1983). This "normal" continuum differs most significantly from a highly-polarized BL Lac continuum at ultraviolet wavelengths. For example, the average flux ratios $f\nu_{4220}/f\nu_{1770}$ and $f\nu_{4220}/f\nu_{1450}$ are 1.55 and 1.8, respectively, for normal, unreddened active nuclei, whereas they are both roughly two and a half times larger in BL Lac objects. Thus a search for residual "normal" quasar light in the spectrum of an HPQ is most profitably conducted in the ultraviolet.

For this search, we selected two of the brightest HPQ's for our multi-wavelength 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 rises at the shortest optical wavelengths. In addition to their blue colors, these quasars often have relatively low optical polarizations compared to most HPQ's. Thus, they may not be representative of the HPQ class as a whole, but are well-suited to our search for UV excesses. Observational obstacles prevented us from obtaining detailed new polarimetric data to measure the wavelength-dependence of polarization. Thus the new data presented and analyzed in this study are spectrophotometric. We showed in Paper I and Paper II (Malkan 1983) that these data alone can yield substantial information about the continuum, *if* they span the widest possible wavelength range, at least from the infrared to the ultraviolet.

The only previous International Ultraviolet Explorer (IUE) measurements of HPQ's 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.

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 to 17, and variations of several tenths of a magnitude have been seen on timescales as short as a few days (Pica et al. 1980, Wisniewski 1985). 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). Thus, it is difficult to obtain truly simultaneous spectrophotometry over the wide wavelength range needed for a detailed study of the continuum.

We have attempted to overcome this problem by repeating 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. We were also aided by Wieslaw 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 multi-wavelength spectra of these quasars are essentially the same as they would have been if all the data had been obtained simultaneously. This approach eliminates the need to arbitrarily scale any of the fluxes. Table 1 give the dates of all observations, with references. PKS 1510-089 was observed with both cameras of the I. U. E. by Glassgold et al., and we obtained the reduced spectra from the National Spaces Sciences Data Center. We obtained the LWR (1900 - 3200A) spectrum of the 0736+017 with I. U. E. on 31 December 1983, and have combined it with SWP (1200 -2000A) spectra obtained by Wampler and Kunth et al. two years earlier, also supplied by NSSDC.

Although the long and short-wavelength ultraviolet spectra were obtained at different times, they do overlap for a hundred Angstroms around 1900A. In all cases the ultraviolet spectra at different epochs agree well with each other. Either we were fortunate to have caught these HPQ's in the same state each time or they are intrinsically less variable in the ultraviolet.

Several low-resolution spectra covering 3500-7000A were obtained on photometric nights in 1983 and 1984 at the Palomar 1.5m and Steward 2.3m reflectors. Accurate absolute fluxes were measured with large apertures on the Palomar SIT spectrograph and on the Steward reticon spectrograph. As with the I.U.E. spectra, by averaging over bins of a hundred or more Angstroms, we always achieved a signal/noise ratio of at least 10 and usually 20. Thus, the typical measuring uncertainties of data points are about 5%, and are comparable to the systematic errors which may exist in the calibrations. Each figure shows a bar of $\pm$ 0.05 dex, somewhat larger than the error of the worst data points.

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 22 April and 14 October 1984 (which is slightly bluer) both represent the quasar at its brightest, while the 21 November 1976 (Grandi 1981) 10 April 1983 (this paper), and 1980 (Blumenthal, Miller and Keel, 1982) 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 3500A is of almost the same magnitude as that in the far-red: one sigma is 0.2 magnitudes at U, B, V, R and I (Wisniewski, private communication). The optical spectrum we selected (Baldwin 1975) as the best match to the ultraviolet observations is almost identical (within ~ 0.1 mag.) to the average UBVRI fluxes determined by W. Wisniewski (1985) in ten epochs spanning the last seven years.

We have one additional reason to believe that our optical and ultraviolet spectra are well-matched. The SWP spectra, which are essentially the same, were obtained on the 17th and the 22nd of December 1981. One week later, Wieslaw Wisniewski (1985) obtained UBVRI photometry of 0736+017 which agrees very well (to within ~ 0.1 mag. at all wavelengths) with Baldwin's spectrophotometry. And since we adopted Baldwin's spectrum in our analysis, it should at least match the SWP points. The continuity of the LWR spectrum indicates that our adopted spectrum is indeed a good representation of 0736+017 in late December 1981.

Our 7 April 1984 spectrum of 1510-089 is quite similar to that obtained by Neugebauer et al. (1979). The quasar was fainter than average, and considerably fainter than when Oke et al. (1970) measured it in 1967 near maximum. In fact, it was almost as faint as it was on 16 July 1983, when it reached an historical minimum brightness (Malkan 1984). In the following analysis, we use the 7 April 1984 spectrum, since it gives the best match to the I.U.E. spectra. The original 200" multichannel spectra from Neugebauer et al. (1979) are also used to fill in the 0.7--1.05um fluxes. The percentage variability of 1510-089 is slightly smaller, with a one-sigma 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 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 two days, with its fainter fluxes the same as those Neugebauer et al. (1979) observed in May 1977. The 2.2 μm flux measured at Palomar in June 1967 (Oke, Nueugebauer, and Becklin, 1970) was 0.6 mag. brighter. For 0736+017 we use the average of the Hyland and Allen measurements of April and November 1979.

In Table 2, we give emission line equivalent widths and, where available, fluxes. The forbidden lines (e.g. [OII] 3727A, [OIII] 5007A) 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 2800 and $H\beta$ 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} = $0^m.01$ and $0^m.12$ respectively (Burstein and Heiles 1982). A small amount of internal reddening (E_{B-V} = $0^m.02$) is included in the analysis of 1510-089, since it decreases the residuals of the continuum fits slightly.

Direct imaging by Wyckoff et al. (1983) shows that PKS 0736+017 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 to be detectable in deep photographs of Wyckoff et al. 1981 and Hutchings et al. 1984.

The fitted spectra included the Balmer emission lines and continuum, 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 3700A, where blended Balmer emission produces a strong pseudo-continuum.

(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 is even visible 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 5000A.

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 ± 2,000 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 HPQ's. The total power-law/blackbody ratio at λ_0 = 5500A is 6.6, nearly twice as strong as in the average normal quasar. 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 roughly one-to-one at 5500A.

In Figure 2, we show the fits to the continuum when we model its ultraviolet excess as light from an accretion disk around a non-rotating (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. The best-fit black hole mass is 6×10^7 $M_\odot$; the two solid lines show models with hole masses of 5 and 7×10^7 $M_\odot$, either of which also fits the data satisfactorily. The best-fit accretion rate corresponds to a luminosity 40% ± 20% that of Eddington 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 to 3. In this case the accretion rate would be about 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 colors of 1510-089 are slightly redder than those of normal quasars: $f\nu_{4220}/f\nu_{1770} = 2.1$ and $f\nu_{4220}/f\nu_{1460} = 1.9$. However, the de-reddened intrinsic colors of 0736 + 017 are 2.7 for both ratios, closer to the average values for BL Lac objects. Its infrared/optical/ultraviolet continuum is almost adequately fitted simply by a power-law plus recombination and FeII line emission (the flatter fit in Figure 3). However, this fit would require a power-law slope of $\alpha = -0.8$, significantly flatter than the -1.1 index usually seen in the far-red (λ_o = 0.6 - 1.8 μm) in other quasars. The pure power-law fit is rather poor in the far-ultraviolet, where it fails to predict the steep fall-off in flux observed at rest wavelengths shorter than 2000A. Such a flat slope is also clearly 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 α = -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 made for 1510-089 (that the "normal" quasar light has a power-law to blackbody ratio less than 4), we infer that less than a quarter of the continuum of 0736+017 is normal quasar light. More than three-quarters of the λ_o = 5500A continuum must belong to the highly polarized, variable, "BL Lac" component.

(c) Emission Lines

The optical and ultraviolet broad emission-line ratios, listed in Table 2, 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 HPQ's 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, 1983). For optically thin Balmer continuum emission at Te = 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 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 HPQ's are illuminated by the underlying "normal" quasar spectrum.

The X-ray luminosities of both quasars were measured by Ku et al. (1980). Comparing the X-ray fluxes to the infrared fluxes (which may actually be somewhat low), (the logarithmic slope from 2 μm to 2 KeV gives α_{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, 1984a). As suggested in Paper I, we see that the violently variable/polarized component in HPQ's 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 HPQ's 0736 + 017 and 1510 − 089 have mixtures of "blazar" (highly polarized, violently variable) light and "normal" quasar light. The blazar component, which produces about half of the visual light in 1510 − 089, and three-quarters 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 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, and lower polarization. It may also be nonthermal, like the blazar continuum, but these 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 diluted 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 ~~(as in the case of PKS 0736 + 017)~~ 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 realtivistic 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 isotopic) 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 anistropic.

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. The two times 0736 + 017 was seen to be highly polarized (4.3% on 10/27/78, and 5.6% on 11/26/78), it was indeed unusually bright (visual magnitude estimated at 15.5 - 16.0). However, even when bright, it sometimes shows a lower polarization. No brightness/polarization correlation is evident in 1510-089 (Moore 1981).

At least one wavelength-dependence measurement of 0736+017 by Moore and Stockman (1981) did show the expected increase in polarization with wavelength. In November 1978, the blue polarization was 4.97 ± 0.27% (θ = 28° ± 1°), while the red polarization was 6.12 ± 0.20% (θ = 31° ± 1°). A marginal effect was seen in October 1978, when the blue polarization was 0.86 ± 0.42% (θ = 63° ± 14°), while the red polarization was 1.17 ± 0.39% (θ = 28° ± 9°).

Recent UBVRI photometry of the low-polarization (P ~ 0.5%) quasar PKS 2128-123 also supports our two-component analysis. 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 Δm = 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 (σ ~ 0.3 mag), presumably becuase 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.

Thus our results establish for the first time that a "normal" quasar continuum is present in these HPQ's, 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 (1985), demonstrates that HPQ's represent one extreme in the relative strength of blazar to "normal" continuum. The presence of a "normal" continuum in HPQ's is an important test of 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.

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Table I

Log of Observations

Date	Telescope	Wavelength	Spectral Resolution	Aperture	Source
		0736 + 017			
72[2]	Lick 3.0m	3200-8200A	7A	2x4"	Baldwin 1975
Nov 76	Lick 3.0m	3200-5300A	7A	2x4"	Grandi 1981
Apr, Nov 79[2]	AAT	1.2 — 2.2um	0.1um	----	Hyland and Allen 1982
16, 21 Dec 81[2]	IUE	1200-2000A	6A	10x15" Oval	Wampler, Kunth et al.[1]
82	Lick 3.0m	3200-7000A	7A	2x4"	BKM
9 Apr 83	Palomar 1.5m	3500-6900A	9A	8x16"	This Paper
31 Dec 83[2]	IUE	1900-3300A	7A	10x15" Oval	This Paper
27 Jan 84	Steward 2.3m	3300-6500A	8A	5" Circular	This Paper
21 Apr 84	Steward 2.3m	3300-6500A	8A	5" Circular	This Paper
13 Oct 84	Steward 2.3m	3300-6500A	9A	8" Circular	This Paper
14, 15 Feb 85	Steward 2.3m	3600-6700A	9A	8" Circular	This Paper
Mar 77-Mar 84[2]	Steward 1.5m	3500-8000A	1500A	12"7 Circular	Wisniewski 1985
		1510-089			
Jun 76	Lick 3.0m	3200-7000A	7A	2x4"	BKM 1982
Feb 77	Palomar 5.0m	3200-10,000A	40/80A	10" Circular	Neugebauer et al. 1979
May 77[2]	Palomar 5.0m	1.2 — 2.2um	0.1um	10" Circular	Neugebauer et al. 1979
Mar 79[2]	AAT	1.2 — 2.2um	0.1um		Hyland and Allen 1982
6 Jun 81[2]	IUE	1900-3200A	7A	10x15" Oval	Glassgold et al.[1]
21 Jan 83[2]	IUE	1200-2000A	6A	10x15" Oval	Glassfold et al.[1]
7 Apr 83[2]	Palomar 1.5m	3500-6900A	9A	8x16"	This Paper
21 Apr 84	Steward 2.3m	3300-6500A	8A	5" Circular	This Paper
14 Feb 85	Steward 2.3m	3600-6700A	9A	8" Circular	This Paper
Feb 82-May 84	Steward 1.5m	3500-8000A	1500A	12"7 Circular	Wisniewski 1985

1 These reduced IUE spectra were obtained from the National Space Sciences Data Center.

2 These spectra were used in the multi-wavelength continuum fitting described in the text. They are also plotted in the Figures.

Table 2

Emission Line Fluxes (in 10^{-14} erg sec^{-1} cm^{-2})

and

Equivalent Widths [1] (in Å)

Spectrum	Lyα	CIV	MgII	Hγ	Hβ	Hα
			<u>0736 + 017</u>			
12/81	15	8				
/72			12 51	2.8 23	7.0 63	30 310
11/76	---	---	67	39	91	374
/77				18	45	250
1/84				2.1 17	5.8 52	
4/84				2.7 14	7.6 45	
10/84				3.0 18	7.7 55	
2/85				2.5 18	6.2 54	
			<u>1510-089</u>			
6/76			55	38	78	
/77					--- 115	
2/77			6.5 57	--- ---	5.3 110	18 530
1/83		8 31				
4/84			9 66	4.5 66	7.0 115	
2/85			7.2 47			

1 corrected to zero-redshift

Table 3

Ultraviolet Fluxes (in mJy)

Corrected for Redshift

log ν_o	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

Table 4

Optical Continuum Fluxes

Corrected for Redshift

(in mJy = 10^{-26} erg sec^{-1} cm^{-2} Hz^{-1})

log ν_o	0736 + 017				1510 − 089		
	14,15 Feb 85	21 Apr 84	27 Jan. −	9 Apr. 84	14 Feb 85	7 Apr. 84	7 Apr 83
15.017	—	0.76	—	0.39	0.43	0.36	0.48
15.001	—	0.65	—	0.38	0.43	0.38	0.44
14.986	—	0.82	0.67	0.37	0.42	0.37	0.45
14.976	0.78	0.88	0.60	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	0.49	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	—

Table 5

Model-Fitting Results

QSO	Balmer Continuum[a]	Power-Law		Blackbody		Accretion Disk	
	$H\alpha$	α	$f\nu_o$[b]	$f\nu_o$	Temp (K)	$M_{bh}(M_\odot)$	$\dot{M}(M_\odot/yr)$
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 10,000K.

b All fluxes refer to rest frequency of log ν_o = 14.74, and are given in mJy (10^{-26} erg cm^{-2}s^{-1} Hz^{-1}), reddening-corrected.

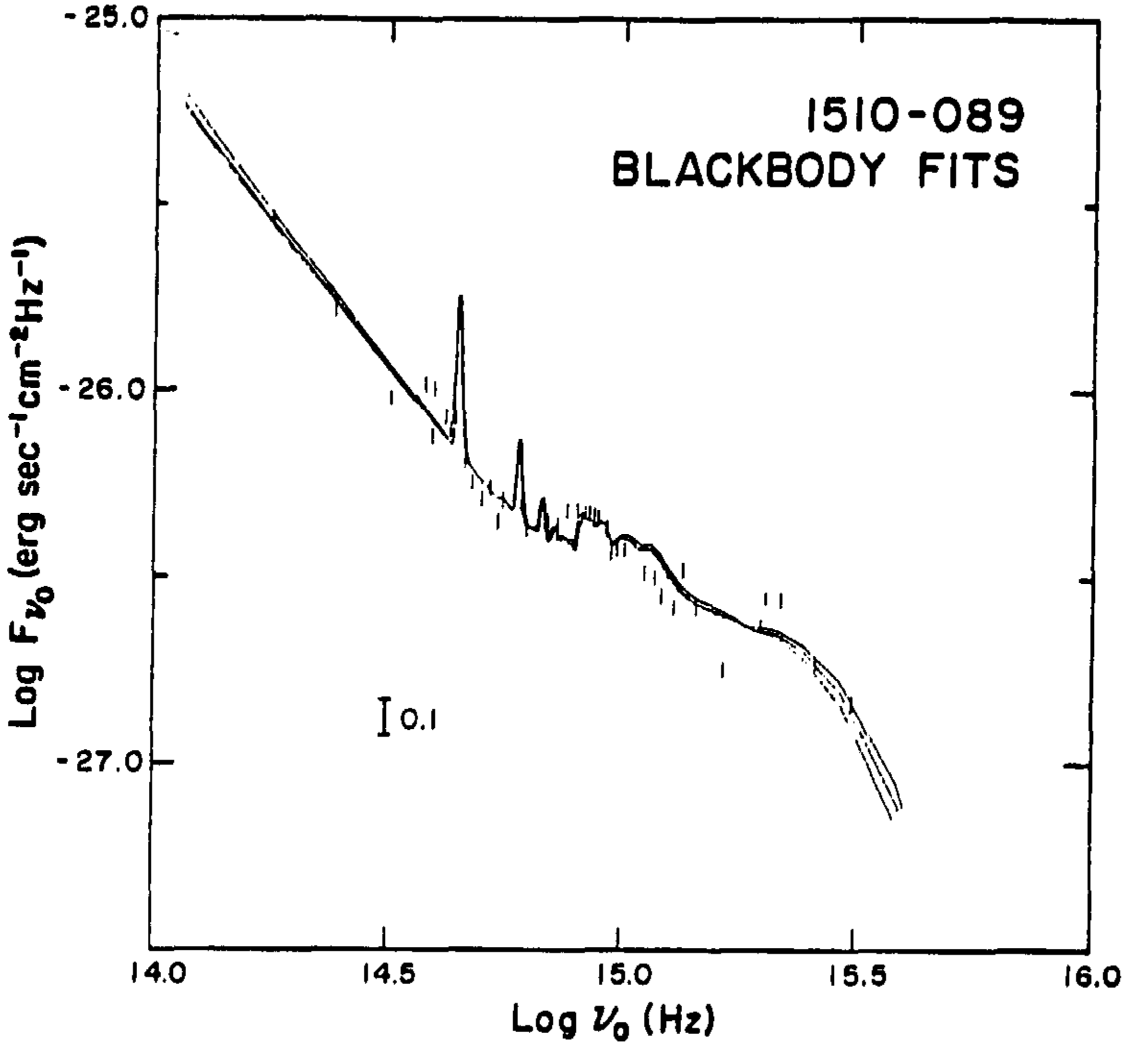
c The ultraviolet excess in 0736 + 017 is too weak to allow accurate estimation of disk parameters.

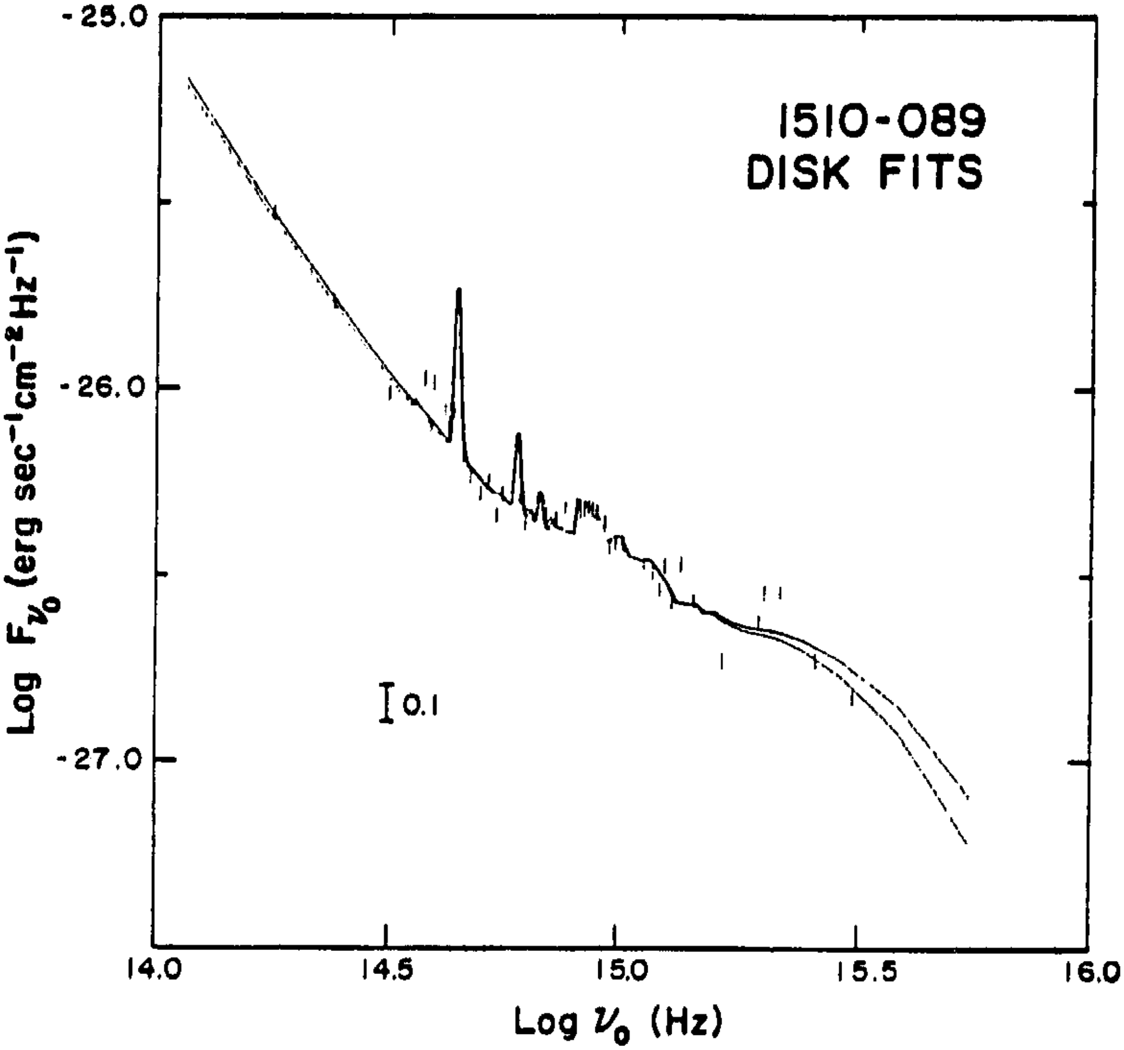
FIGURE CAPTIONS

Figure 1. Fits to the infrared/optical/ultraviolet spectrum of 1510-089, with a power-law, blackbody, and contributions from Balmer and Fe II emission lines, and Balmer continua. The three curves are for blackbody temperatures of 31,000, 33,000, and 35,000K. 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.

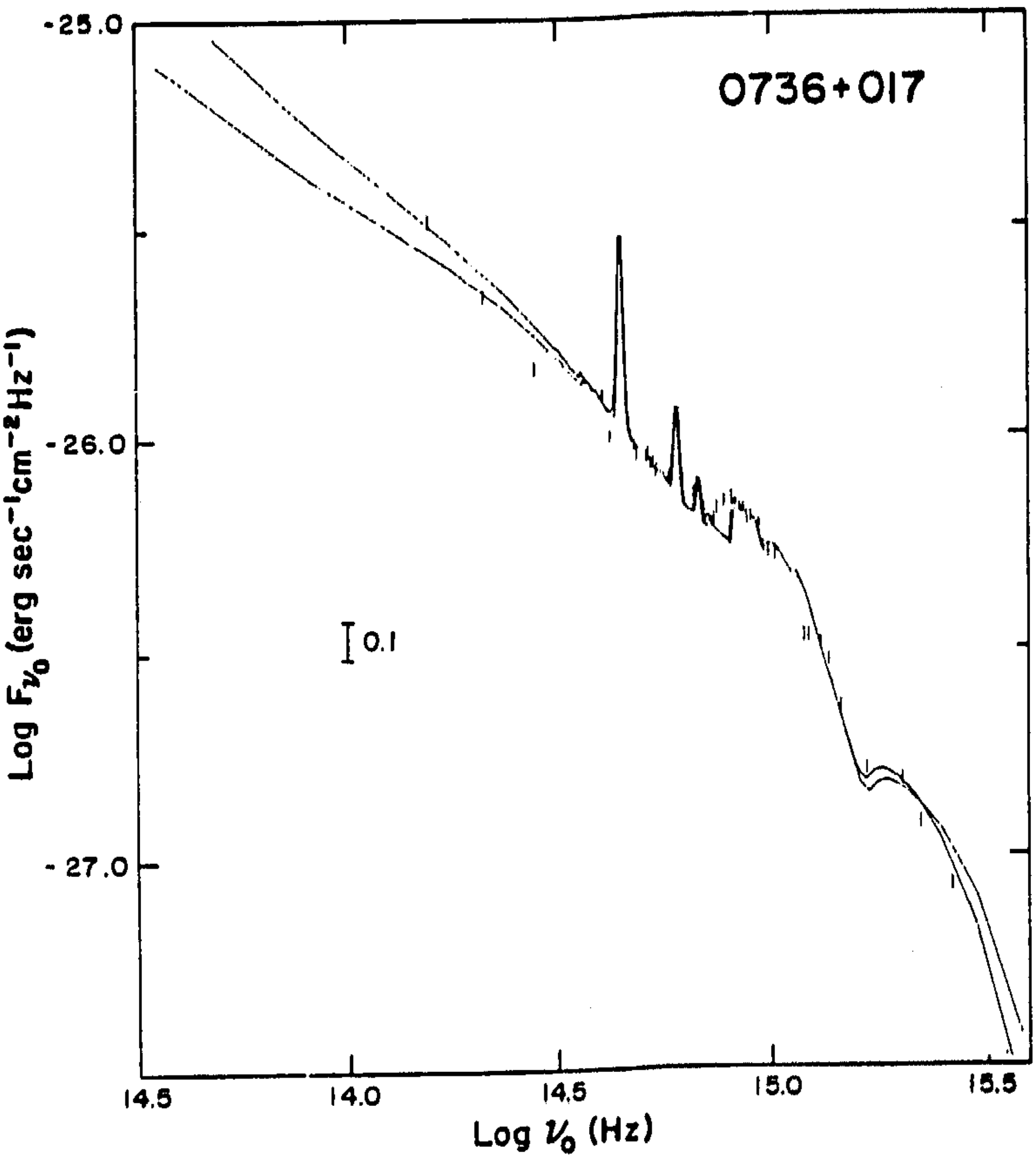
Figure 2. Fits to the same multi-wavelength data as shown in Figure 1. Here the blackbody component was replaced by the spectrum emitted from an optically-thick, geometrically thin, face-on accretion disk. The two curves, which fit the data better than the blackbody fits in Figure 1, are for Schwarzschild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

Figure 3. Fits to the multi-wavelength 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.


1510-089
BLACKBODY FITS
-25.0
-26.0
-27.0
Log F_{ν_0} (erg sec^{-1}cm^{-2}Hz^{-1})
0.1
14.0
14.5
15.0
15.5
16.0
Log ν_0 (Hz)



1510-089
DISK FITS
Log F_{ν_0} (erg sec^{-1}cm^{-2}Hz^{-1})
-25.0
-26.0
-27.0
0.1
14.0
14.5
15.0
15.5
16.0
Log ν_0 (Hz)


0736+017
Log F_{ν_0} (erg sec^{-1}cm^{-2}Hz^{-1})
-25.0
-26.0
- 27.0
0.1
14.5
14.0
14.5
15.0
15.5
Log ν_0 (Hz)

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