THE ASTROPHYSICAL JOURNAL, 326:L39–L44, 1988 March 15

EVIDENCE FOR ACCRETION DISKS IN HIGHLY POLARIZED QUASARS

PAUL S. SMITH, RICHARD ELSTON, GRAHAM BERRIMAN, AND RICHARD G. ALLEN
Steward Observatory, University of Arizona

AND

THOMAS J. BALONEK
Department of Physics and Astronomy, Colgate University
Received 1987 October 22; accepted 1987 December 14

ABSTRACT

We present *UBVRI* polarimetry and photometry of 11 highly polarized quasars (HPQs). Three of these HPQs (0420−014, 1156+295, and 3C 454.3) clearly show decreasing linear polarization toward shorter wavelengths. We model the observed optical continua of these HPQs as a combination of polarized synchrotron emission, unpolarized emission from the broad-line region, and an unpolarized flat spectral component that may be optically thick thermal emission from an accretion disk. Marginal evidence for such a thermal component is also seen in the data for 1510−089 and 2345−167. Rough upper limits for the brightness of a thermal component can be placed on five other HPQs. We find a range in luminosity of at least a factor of 10 for the HPQ thermal components. The near-ultraviolet luminosities of the HPQ thermal components derived from our models fall near the average luminosity of the quasars in the PG survey. Only the presence of a bright synchrotron component seems to distinguish some HPQs from low-polarization, optically selected QSOs at optical and near-UV wavelengths.

Subject headings: photometry — polarization — quasars — radiation mechanisms

I. INTRODUCTION

Evidence for a broad near-ultraviolet "bump" in the continuum emission of the highly polarized quasar (HPQ) 3C 345 has recently been found by two independent observational techniques. Bregman *et al.* (1986) detected a broad UV excess through simultaneous multifrequency observations spanning X-ray to radio frequencies. Smith *et al.* (1986, hereafter Paper I) found that an unpolarized emission component with a fairly flat optical to near-UV spectrum can explain the decrease in the degree of linear polarization (P) observed in 3C 345 from near-infrared to optical wavelengths. This component corresponds closely to the continuum bump found by Bregman *et al.* Both groups of investigators suggest that the optical to near-UV continuum of this QSO is a combination of synchrotron emission and optically thick thermal emission from an accretion disk.

Do other HPQs show evidence for thermal components like that of 3C 345? Spectrophotometry by Malkan and Moore (1986) find evidence for such a component in two other HPQs, PKS 0736+017 and PKS 1510−089. In this *Letter* we report the results of our search for thermal components in 11 HPQs through *UBVRI* polarimetry and photometry. Our sample of HPQs was drawn primarily from the list of Moore and Stockman (1981). We find evidence for thermal emission components in three HPQs: PKS 0420−014, B2 1156+295, and 3C 454.3, with marginal evidence in another two, PKS 1510−089 and PKS 2345−167.

II. OBSERVATIONS

Most of the polarimetry and photometry of the HPQs reported here was done using the Steward Observatory 2.3 m telescope and the "Two-Holer" polarimeter/photometer (Sitko, Schmidt, and Stein 1985). A few of the observations were made using the same instrument on the UCSD/University of Minnesota 1.5 m telescope on Mount Lemmon, AZ. The procedures outlined in Smith (1986) (see also Smith *et al.* 1987) were used to reduce the photometry and polarimetry. We present the observations in Table 1.

Differential photometry of 1156+295 and 3C 446 using the field comparison stars given by Smith *et al.* (1985) determined the broad-band optical spectra of these two quasars. Differential photometry of the other quasars was accomplished using field stars chosen at random. These stars were calibrated using the Two-Holer and the Mount Lemmon 1.5 m (1986 December) and Steward 1 m (1987 June) telescopes. We made power-law fits to the continua of the HPQs and their spectral indices ($\alpha = d \log S_\nu / d \log \nu$) are given in Table 2.

As in Paper I, we define a quantity $P(\nu) = d \log P / d \log \nu$ and consider an object to have significant wavelength dependence in P if $P(\nu)$ is greater or less than zero by more than 2 σ (σ is the formal uncertainty in the slope of the linear regression line fitted to the measurements of P). Of the 11 QSOs observed, seven exhibited significant wavelength dependence in P. The optical polarization of 0420−014, 1156+295 (Fig. 1), 1510−089, 3C 454.3 (Fig. 2), and 2345−167 increased with wavelength, whereas that of 0716+332 and 3C 216 decreased. A similar criterion was applied to the optical polarization position angle [θ; $\theta(\nu) \equiv d\theta / d \log \nu$] and significant wavelength dependence in θ was observed in 0420−014 (1986 November 9 and 27), 3C 216, 1156+295 (1987 June 24), and 2345−167.

III. THERMAL COMPONENT MODELS OF HIGHLY POLARIZED QUASARS

This section models the continuum emission of the HPQs exhibiting wavelength-dependent P in the sense of increasing polarization with increasing wavelength. We interpret this type of wavelength dependence as being caused by the presence of a thermal emission component that dilutes the polarized flux supplied by a steep-spectrum, power-law synchrotron component. We assume that the emission from thermal gas is

1988ApJ...326L..39S

TABLE 1

OPTICAL PHOTOMETRY AND POLARIMETRY OF HIGHLY POLARIZED QUASARS

Object	UT Date	Filter	m	σ	S_ν (mJy[a])	σ	P (%)	σ	θ (°)	σ
0336−019	86.11.26[b]	U	17.38	(0.08)	0.25	(0.02)	···		···	
z=0.852		B	17.92	(0.04)	0.33	(0.01)	10.00	(0.80)	161.0	(2.3)
A_V=0.19		V	17.53	(0.03)	0.42	(0.01)	8.61	(0.53)	158.4	(1.8)
		R	17.13	(0.03)	0.50	(0.01)	10.43	(0.63)	158.9	(1.7)
		I	16.43	(0.04)	0.76	(0.03)	9.92	(0.61)	161.8	(1.8)
0420−014	86.11.09[c]	U	16.91	(0.07)	0.39	(0.03)	···		···	
z=0.915		B	17.50	(0.05)	0.50	(0.02)	17.01	(0.84)	179.0	(1.4)
A_V=0.21		V	17.00	(0.05)	0.70	(0.03)	16.11	(0.74)	0.9	(1.3)
		R	16.63	(0.05)	0.81	(0.03)	···		···	
		I	···		···		18.93	(0.78)	3.0	(1.2)
	86.11.27	U	16.18	(0.05)	0.76	(0.04)	13.17	(0.77)	50.1	(1.7)
		B	16.51	(0.02)	1.25	(0.02)	13.90	(0.55)	46.2	(1.1)
		V	15.89	(0.02)	1.95	(0.04)	13.97	(0.41)	44.1	(0.8)
		R	15.43	(0.02)	2.44	(0.05)	15.71	(0.37)	43.7	(0.7)
		I	14.90	(0.02)	3.15	(0.06)	15.56	(0.44)	42.2	(0.8)
	86.12.20[c]	B	···		···		9.51	(0.98)	48.5	(2.9)
		V	···		···		9.17	(0.50)	46.0	(1.6)
		R	···		···		11.19	(1.11)	46.2	(2.8)
		I	···		···		13.80	(0.71)	43.7	(1.5)
	86.12.23[c]	U	16.97	(0.11)	0.37	(0.04)	···		···	
		B	17.45	(0.09)	0.53	(0.04)	4.67	(1.19)	111.4	(7.1)
		V	16.94	(0.08)	0.74	(0.06)	5.33	(1.11)	113.9	(5.9)
		R	16.30	(0.06)	1.09	(0.06)	2.99	(0.67)	109.5	(6.2)
		I	···		···		2.23	(0.97)	112.8	(11.5)
0716+332	86.11.27	U	17.37	(0.06)	0.24	(0.01)	···		···	
A_V=0.17		B	17.66	(0.03)	0.41	(0.01)	7.43	(0.56)	52.3	(2.2)
		V	17.05	(0.02)	0.64	(0.01)	7.39	(0.51)	54.0	(2.0)
		R	16.52	(0.02)	0.87	(0.02)	6.50	(0.52)	53.7	(2.3)
		I	15.80	(0.03)	1.35	(0.04)	5.98	(0.53)	56.8	(2.5)
3C 216	86.11.28	U	18.17	(0.07)	0.10	(0.01)	···		···	
z=0.670		B	18.60	(0.04)	0.15	(0.01)	5.46	(1.16)	18.5	(5.9)
A_V=0.04		V	18.10	(0.03)	0.22	(0.01)	3.31	(0.91)	0.0	(7.5)
		R	17.55	(0.03)	0.30	(0.01)	2.22	(0.92)	174.2	(10.5)
		I	17.00	(0.04)	0.41	(0.02)	< 2.1		···	
1156+295	86.11.28[d]	U	17.39	(0.13)	0.19	(0.02)	7.89	(2.42)	31.2	(8.2)
z=0.729		B	17.71	(0.05)	0.32	(0.02)	4.84	(0.72)	26.0	(4.2)
A_V=0.00		V	···		···		7.65	(0.65)	31.4	(2.5)
		R	16.98	(0.05)	0.50	(0.02)	8.78	(0.57)	36.2	(1.9)
		I	16.22	(0.08)	0.83	(0.06)	8.19	(1.03)	32.2	(3.4)
	87.06.24[e]	U	17.24	(0.13)	0.21	(0.03)	4.29	(1.32)	28.5	(8.5)
		B	17.73	(0.06)	0.32	(0.02)	···		···	
		V	17.37	(0.05)	0.41	(0.02)	···		···	
		R	17.03	(0.05)	0.48	(0.02)	7.86	(0.49)	0.6	(1.8)
		I	16.40	(0.09)	0.70	(0.06)	8.33	(1.19)	2.8	(4.1)
1510−089	86.06.12[c]	U	16.15	(0.04)	0.89	(0.04)	2.63	(1.74)	80.5	(16.8)
z=0.361		B	16.87	(0.04)	1.00	(0.04)	5.17	(0.90)	83.3	(5.5)
A_V=0.30		V	16.59	(0.04)	1.12	(0.05)	···		···	
		R	16.16	(0.04)	1.34	(0.05)	7.96	(1.01)	80.9	(3.7)
		I	15.84	(0.06)	1.40	(0.08)	···		···	
	87.03.15[c]	U	···		···		14.45	(2.25)	91.4	(4.4)
		B	···		···		10.13	(1.80)	92.9	(5.0)
		V	···		···		12.62	(1.09)	85.7	(2.5)
		R	···		···		11.92	(1.06)	86.1	(2.5)
		I	···		···		11.75	(0.86)	87.2	(2.1)
	87.06.23	B	···		···		1.93	(0.55)	14.3	(7.8)
		R	···		···		2.13	(0.37)	11.7	(4.9)
		I	···		···		3.55	(0.61)	12.8	(4.9)

TABLE 1—*Continued*

Object	UT Date	Filter	m	σ	S_ν (mJy[a])	σ	P (%)	σ	θ (°)	σ
1958−179	87.06.23	U	...		...		14.73	(0.60)	113.6	(1.2)
z=0.650		R	...		...		14.47	(0.20)	112.7	(0.4)
		I	...		...		14.53	(0.26)	113.4	(0.5)
2201+171	87.06.23	B	...		...		6.12	(1.00)	61.1	(4.6)
z=1.075		R	...		...		7.48	(0.66)	70.7	(2.5)
		I	...		...		6.96	(0.90)	58.1	(3.6)
3C 446	86.11.27	U	16.74	(0.05)	0.47	(0.02)	...		...	
z=1.404		B	17.35	(0.03)	0.59	(0.02)	8.47	(0.66)	144.5	(2.3)
A_V=0.23		V	16.87	(0.04)	0.80	(0.03)	7.77	(0.62)	148.3	(2.3)
		R	16.40	(0.07)	1.01	(0.07)	7.87	(0.51)	144.0	(1.9)
		I	16.00	(0.18)	1.16	(0.19)	8.02	(0.68)	145.6	(2.4)
	87.06.23	B	...		...		11.83	(1.20)	110.7	(2.9)
		R	...		...		10.24	(0.71)	107.3	(2.0)
3C 454.3	86.12.23[c]	U	16.16	(0.13)	0.72	(0.09)	1.84	(1.02)	77.3	(14.1)
z=0.859		B	16.59	(0.05)	1.10	(0.05)	2.18	(0.75)	77.7	(9.5)
A_V=0.16		V	16.16	(0.04)	1.45	(0.05)	3.10	(0.52)	86.5	(4.8)
		R	15.74	(0.04)	1.76	(0.07)	3.07	(0.69)	85.5	(6.3)
		I	15.27	(0.06)	2.18	(0.12)	4.88	(0.69)	83.5	(4.0)
	87.06.23	B	...		...		2.62	(0.41)	120.6	(4.4)
		V	...		...		3.25	(0.31)	118.5	(2.7)
		R	...		...		3.96	(0.56)	118.9	(4.0)
		I	...		...		5.28	(0.40)	119.5	(2.2)
	87.06.24	U	16.52	(0.13)	0.52	(0.06)	2.37	(1.09)	118.6	(11.4)
		B	16.90	(0.04)	0.82	(0.03)	2.32	(0.45)	120.7	(5.4)
		V	16.55	(0.03)	1.01	(0.03)	2.87	(0.49)	121.1	(4.7)
		R	16.02	(0.03)	1.36	(0.04)	3.48	(0.35)	115.9	(2.9)
		I	15.41	(0.04)	1.92	(0.07)	5.11	(0.42)	124.2	(2.4)
2345−167	86.11.28	U	18.17	(0.12)	0.10	(0.01)	...		...	
z=0.576		B	18.71	(0.06)	0.13	(0.01)	4.78	(1.53)	139.8	(8.5)
A_V=0.03		V	18.41	(0.06)	0.16	(0.01)	...		...	
		R	...		...		11.81	(4.29)	161.6	(9.4)
		I	...		...		11.90	(2.29)	167.1	(5.4)

[a] One millijansky = 10^{-26} ergs cm^{-2} s^{-1} Hz^{-1}. S_ν has been corrected for galactic interstellar extinction.
[b] Photometry was done on 1986 November 27.
[c] Observations made using the UCSD/University of Minnesota 1.5 m telescope.
[d] Polarimetry is averaged over two nights (1986 Nov 27 and 28).
[e] Polarimetry is averaged over two nights (1987 Jun 23 and 24).

unpolarized and that the polarization of the synchrotron component is independent of wavelength. No reddening intrinsic to the HPQs was considered in the model.

In Paper I it was found that emission from the broad-line region (BLR) alone could not account for the strength of the wavelength dependence observed in 3C 345. We constructed models of the BLR based primarily on the photoionization models of Wills, Netzer, and Wills (1985, hereafter WNW) to ascertain if the BLR alone can explain the wavelength dependence shown by the HPQs in this study. Our major concern is the "3000 Å bump" which is comprised of an Fe II emission-line forest, H I lines, and Balmer continuum emission. Several HPQs have this spectral feature (e.g., 0420−014 and 3C 454.3 [Wills *et al.* 1980]; 1510−089 [Malkan and Moore 1986]).

We averaged the model parameters given in Table 1 of WNW for the seven quasars not corrected for internal reddening to make a reasonable guess for the relative strengths of emission sources in the BLR. The Fe II emission was treated as in Paper I except that we normalized the lines to the integrated fluxes given by the "average" WNW model. This yields a total Fe II flux of 9.6 that of Hβ. The fluxes of the Balmer series lines and Balmer continuum ($\sim$7 Hβ) are also taken from the WNW model. Paschen-continuum, two-photon, and free-free emission were added to the model using the strengths from Paper I.

Our approximation of the BLR emission is normalized to the flux of the Mg II λ2798 doublet assuming Mg II/H$\beta \approx 1$. The rest frame Mg II line fluxes for the HPQs that exhibit increasing P with increasing wavelength were measured using either the Steward 2.3 m in 1986 December or the MMT in 1987 May and are given in Table 2.

The HPQs 0420−014, 1156+295, and 3C 454.3 show significant wavelength dependence in P after the BLR contribution is taken into account. Subtraction of the BLR component of 1510−089 increases $P(\nu)$ from -1.25 ± 0.55 to -0.87. Given our 2 σ criterion for $P(\nu)$, we can not rule out the possi-

TABLE 2

THERMAL EMISSION COMPONENTS IN HIGHLY POLARIZED QUASARS

Object	F_{Mg}[a]	α	α_{syn}	P_0 (%)	S_{syn}[b]	S_{th}[b]	S_{Bc}[b]	L_{BLR}[c]	L_{th}[c]	B[d]
0420−014	0.3	−1.7	−1.9	16.9	2.33	0.36	0.02	0.5	3.7	18.6
1156+295	0.4	−1.4	−2.2	11.1	0.27	0.14	0.02	0.3	0.8	19.2
1510−089	0.7	−0.6	−1.8	15.3	0.30	0.60	0.07	0.2	0.6	17.8
3C 345[e]	1.9	−1.6	−1.9	37.8	3.10	0.53	0.11	0.9	1.8	17.7
3C 454.3	1.4	−1.5	−2.7	6.2	0.66	0.53	0.09	2.0	4.6	18.1
0336−019		−1.3				< 0.15			< 1.3	> 19.5
1958−179		−1.5				< 0.29			< 1.2	> 18.4
2201+171		−1.5				< 0.31			< 4.8	> 18.6
3C 446		−1.3				< 0.14			< 4.5	> 19.9
2345−167		−1.1				< 0.17			< 0.5	> 18.9

[a] Rest frame flux of Mg II (λ2798) in units of 10^{-13} ergs cm^{-2} s^{-1}.
[b] Rest frame flux density in mJy at 2500 Å.
[c] Rest frame luminosity in units of 10^{45} ergs s^{-1} in the 2000–2500 Å band assuming isotropic emission ($H_0 = 75$ km s^{-1} Mpc^{-1}; $q_0 = 0$).
[d] Approximate B magnitude in the observer's frame of the optically thick thermal component.
[e] The values listed for α, P_0, and S_{syn} for 3C 345 are for the 1983 February data of Paper I. During 1984 June $\alpha = -1.3$, $P_0 = 10.8\%$, and $S_{syn} = 0.7$ mJy.

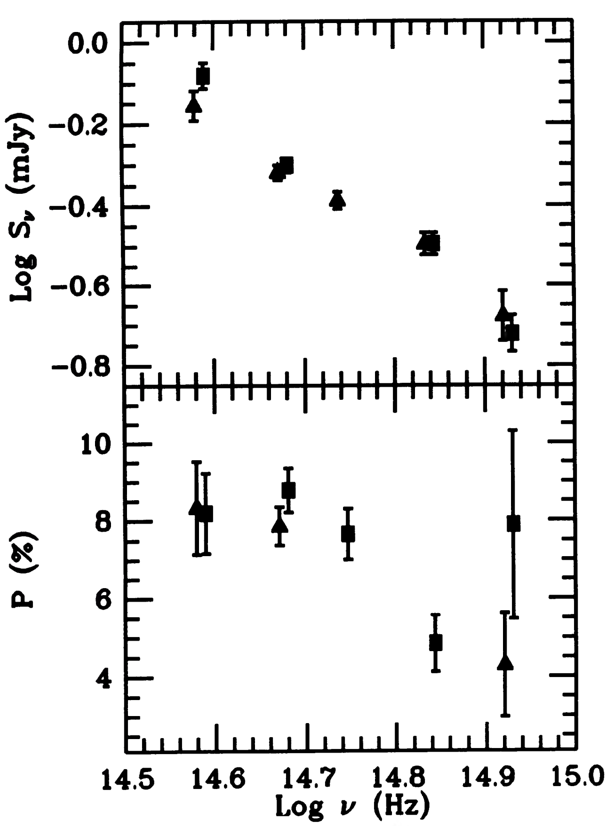

FIG. 1.—Observations of 1156+295 during 1986 November (*squares*) and 1987 June (*triangles*). Because no significant difference in brightness or polarization were observed, we averaged the data for the modeling (§ III).

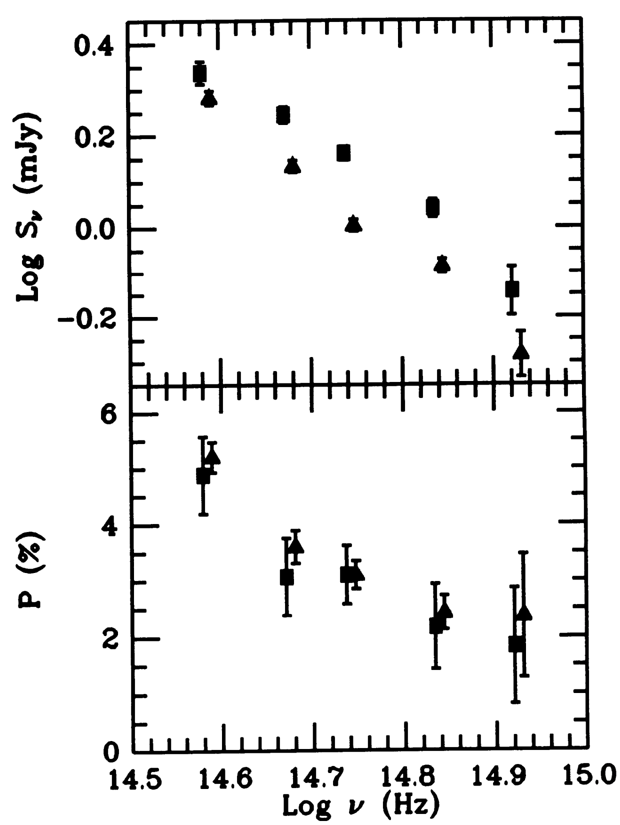

FIG. 2.—Observations of 3C 454.3 on 1986 December 23 (*squares*). The observations of 1987 June 23 and 24 are averaged (*triangles*) and modeled in § III.

bility that the BLR alone causes the wavelength dependence shown by 1510−089.

To explain the wavelength dependence in P that remains after accounting for the unpolarized flux of the BLR we added an unpolarized emission component with a flat optical to near-UV spectrum. If this component is optically thick thermal emission from an accretion disk, the approximation of a flat spectrum is probably a reasonable one given the spectral shape of the accretion disk models of Malkan (1983), the limited wavelength coverage of our observations, and the redshifts of the HPQs. Our model has four free parameters: the spectral index (α_{syn}), intrinsic polarization (P_0), and flux density at 2500 Å of the synchrotron component (S_{syn}), and the flux density at 2500 Å of the thermal component (S_{th}). The best fitting model parameters for the HPQs that exhibit significant wavelength dependence in P are given in Table 2. The strength of the Balmer continuum at $\lambda_0 = 2500$ Å (S_{Bc}) as derived from our BLR model is also given. A model fit for 3C 345 using the data of 1983 February and 1984 June reported in Paper I is also included for comparison.

Our model does not address wavelength dependence in the polarization position angle (wavelength dependence in θ is probably intrinsic to the synchrotron component). The model for 0420−014 is derived from data taken on 1986 November 27 when the object showed a rotation in θ of 8° between U and I. However, the accretion disk model for this object is strengthened by the simultaneous near-infrared and optical observations of Brindle *et al.* (1986). During their measurements 0420−014 was only half as bright as in late 1986 November, yet the P wavelength dependence they observed can be explained with the same thermal component derived from our observations.

Uncertainties in the model parameters can be roughly estimated using the uncertainties in the observed spectral index (α) and $P(\nu)$. For example, the flattest continuum consistent with the photometry and the strongest P wavelength dependence consistent with the polarimetry give an estimate for the upper limit on the brightness of the thermal component. We estimate that the uncertainty in S_{th} is 20%–30%. The data used for the model of 3C 345 is of sufficient quality to give us an uncertainty of about 15% in S_{th}. The estimated uncertainty in α_{syn} ranges from 0.1 for 3C 345 to 0.6 for 1510−089. We have not included a guess of the uncertainty in the contribution of the BLR emission to the rough uncertainty estimates of the models.

For five other objects in this study we are able to place upper limits on the brightness of a possible accretion disk component. These upper limits are listed in Table 2 and are based on the observational uncertainties in α and $P(\nu)$. The upper limits quoted for 1958−179 and 2201+171 are somewhat uncertain because we made a rough estimate of their brightness using the R polarization measurements and assumed that $\alpha = -1.5$. The limits for these two objects will be higher if they were actually brighter or have flatter spectra. We could not place upper limits on possible thermal components for 0716+332 and 3C 216 because P clearly increases toward shorter wavelengths in these two objects.

In addition to the uncertainties in the models mentioned above, the choice of A_v and the assumption that the polarization of the synchrotron component is independent of wavelength, significantly affect the model fits. For example, we are in close agreement with the slope of the power-law component found for 1510−089 by Malkan and Moore (1986), but our thermal component is about twice as bright at 2500 Å. However, most of this discrepancy can be explained by the higher galactic extinction adopted in our model.

Based on observations of BL Lac objects (Smith 1986; Brindle *et al.* 1986, and references therein) and 1156+295 when bright (Smith 1986), we expect that if the synchrotron component exhibits wavelength dependence in P it will be in the sense of increasing P toward shorter wavelengths. This type of wavelength dependence will partially or completely mask the presence of a thermal component and the luminosity of this component will be underestimated. Infrared polarimetry simultaneous with optical observations would provide an estimate of the strength of any wavelength dependence exhibited by the synchrotron component.

IV. DISCUSSION

We have calculated the 2000–2500 Å luminosities of the thermal components (L_{th}) (Table 2) and have also listed our estimated luminosities of the BLR in the same wavelength band for comparison. There is a range in L_{th} of at least a factor of 10 for our sample of HPQs. This range in luminosity is well within the huge luminosity range seen for the QSOs in the Palomar-Green (PG) survey (Neugebauer *et al.* 1987). We calculated a "monochromatic luminosity" ($\nu_0 L_{\nu 0}$) at $\nu_0 = 1.2 \times 10^{15}$ Hz, where $L_{\nu 0} = 4\pi(cz/H_0)^2(1 + z/2)^2 S_{\nu 0}$ and $S_{\nu 0}$ is the rest frame flux density at rest frequency ν_0 ($H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = 0$ are assumed throughout this *Letter*). For the comparison of our HPQs with the PG sample we use the high-frequency power-law fits to the continua of the PG quasars given by Neugebauer *et al.* (1987). The PG quasars have an average log ($\nu_0 L_{\nu 0}$) of 45.5 and a range of 47.9–43.6. We find an average log ($\nu_0 L_{\nu 0}$) of 45.9 for the HPQ thermal components. 3C 454.3 has the most luminous thermal component of the HPQs observed [log ($\nu_0 L_{\nu 0}$) = 46.3], whereas the least luminous upper limit is that of 2345−167 [log ($\nu_0 L_{\nu 0}$) < 45.3].

If our thermal component model is correct, the HPQs that show evidence of a flat spectral component are distinguished from optically selected quasars at optical and near-UV wavelengths only by the amount of synchrotron light that we observe. This explains the higher optical polarization and steeper continua of these HPQs. The question of whether all HPQs have thermal emission components in the luminosity range of the PG quasars is not fully answered by our study. Our observations lack the sensitivity to set upper limits on thermal components having lower luminosities than the faintest PG quasars because such a faint component will not give rise to strong wavelength dependence in P.

If the amount of synchrotron light we receive from an HPQ is highly dependent on the viewing angle of the object (such as in relativistic beaming models), one would expect little correlation between the luminosity of the accretion disk and the luminosity of the quasar at maximum light (when the synchrotron component is dominant). Consistent with a beaming model, our very limited sample of HPQs does not show a correlation between these parameters (Fig. 3*a*). For example, 1156+295 can outshine 0420−014, 3C 345, and 3C 454.3 yet its accretion disk is less luminous. The brightness of the accretion disk components lie close to or below the historical photometric minima of the HPQs (Fig. 3*b*). This suggests that the thermal emission can, at times, be the dominant source of optical and near-UV continuum emission in those HPQs that have photometric minima close to their accretion disk lumin-

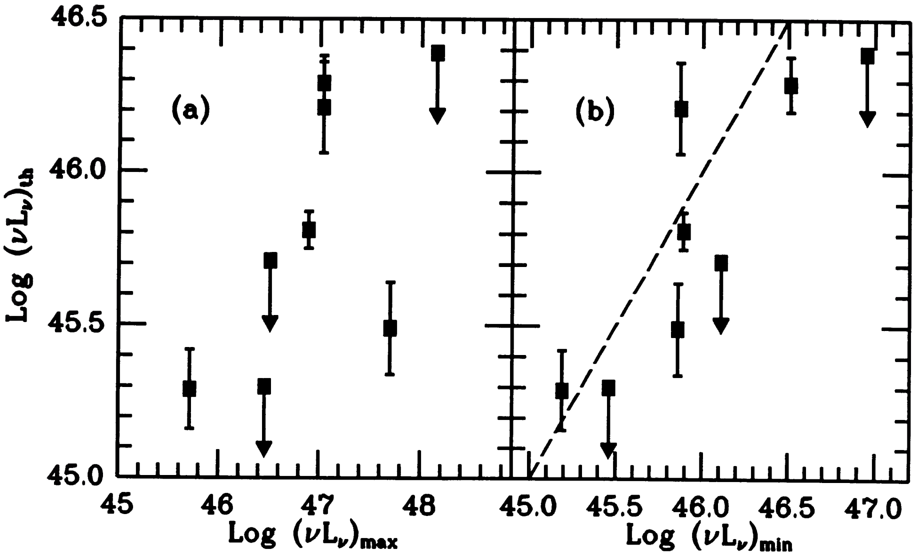

FIG. 3.—Monochromatic luminosity of the accretion disk component at $\nu = 6.8 \times 10^{14}(1 + z)$ Hz (the approximate *B* band of the observer) plotted against the monochromatic luminosity of the HPQs at (*a*) maximum light and (*b*) minimum light. Data from the Rosemary Hill Observatory photographic monitoring program (Pica *et al.* 1980; Webb *et al.* 1987) were used to determine minimum and maximum light at *B*. Error bars represent our estimate of the uncertainty in the brightness of the accretion disk based only on the observational uncertainties in α and $P(\nu)$. The dashed line in (*b*) denotes $(\nu L_\nu)_{th} = (\nu L_\nu)_{min}$ and is *not* a fit to the data.

osities. Our model for these HPQs can be tested when the quasars are faint since they should show low optical polarization and optical spectra substantially flatter than when the synchrotron component is more dominant.

We thank Barbara Jones and Gary Schmidt for letting us use the Two-Holer at the Steward 2.3 m and 1.0 m telescopes. Paul Heckert and Chris O'Dea assisted in the observations of field comparison stars at the UCSD/UM Mount Lemmon telescope. Tex Belschner and Bob Peterson provided necessary support at the Steward 1 m. This research was supported by National Aeronautics and Space Administration contract NAS 5-29293 (P. S. S. and R. G. A.), National Science Foundation and NASA Graduate Fellowships (R. E.), NSF grant 84-08740 (G. B.), and grants from the Colgate University Research Council and the Hewlett Foundation of the Research Corporation (T. J. B.).

REFERENCES

Bregman, J. N., *et al.* 1986, *Ap. J.*, **301**, 708.
Brindle, C., Hough, J. H., Bailey, J. A., Axon, D. J., and Hyland, A. R. 1986, *M.N.R.A.S.*, **221**, 739.
Malkan, M. A. 1983, *Ap. J.*, **268**, 582.
Malkan, M. A., and Moore, R. L. 1986, *Ap. J.*, **300**, 216.
Moore, R. L., and Stockman, H. S. 1981, *Ap. J.*, **243**, 60.
Neugebauer, G., Green, R. F., Matthews, K., Schmidt, M., Soifer, B. T., and Bennett, J. 1987, *Ap. J. Suppl.*, **63**, 615.
Pica, A. J., Pollock, J. T., Smith, A. G., Leacock, R. J., Edwards, P. L., and Scott, R. L. 1980, *A.J.*, **85**, 1442.
Sitko, M. L., Schmidt, G. D., and Stein, W. A. 1985, *Ap. J. Suppl.*, **59**, 323.
Smith, P. S. 1986, Ph.D. thesis, University of New Mexico.
Smith, P. S., Balonek, T. J., Elston, R., and Heckert, P. A. 1987, *Ap. J. Suppl.*, **64**, 459.
Smith, P. S., Balonek, T. J., Heckert, P. A., and Elston, R. 1986, *Ap. J.*, **305**, 484 (Paper I).
Smith, P. S., Balonek, T. J., Heckert, P. A., Elston, R., and Schmidt, G. D. 1985, *A.J.*, **90**, 1184.
Webb, J. R., Smith, A. G., Leacock, R. J., Fitzgibbons, G. L., Gombola, P. P., and Shepherd, D. W. 1987, *A.J.*, submitted.
Wills, B. J., Netzer, H., Uomoto, A. K., and Wills, D. 1980, *Ap. J.*, **237**, 319.
Wills, B. J., Netzer, H., and Wills, D. 1985, *Ap. J.*, **288**, 94 (WNW).

RICHARD G. ALLEN, GRAHAM BERRIMAN, RICHARD ELSTON, and PAUL S. SMITH: Steward Observatory, University of Arizona, Tucson, AZ 85721

THOMAS J. BALONEK: Department of Physics and Astronomy, Colgate University, Hamilton, NY 13346