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THE OPTICAL AND NEAR-INFRARED POLARIZATION PROPERTIES OF THE OVV QUASAR 3C 345

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ABSTRACT

We present the results of an extensive optical and near-infrared polarimetric and photometric monitoring program of the highly polarized quasar 3C 345. Several optical polarization properties of this quasar are unique among the class of active, highly polarized extragalactic objects. From early 1983 to mid–1984, the polarization showed a strong correlation with brightness. Strong wavelength-dependent fractional linear polarization was observed at optical wavelengths throughout our monitoring program. The dependence was always in the same sense: higher fractional polarization toward longer optical wavelengths. Mild wavelength dependence was sometimes observed in the optical polarization position angle (less than 5° rotation over the entire optical spectral range). The polarization was 35% in 1983 February, when the quasar was near its peak brightness during an outburst. The fractional polarization then fell to less than 10% and the polarization angle rotated smoothly from 15° to 70°–90° as the object dimmed during 1983.

The wavelength dependence of the fractional polarization can be explained by dilution of the polarized light by unpolarized thermal emission. However, Balmer recombination, Fe II emission, and the observed emission lines of 3C 345 are not strong enough to account for the wavelength-dependent polarization. We propose that the wavelength dependence is caused by optically thick thermal emission, possibly from an accretion disk, and have modeled the thermal component with a blackbody. The temperature of the thermal component is not well constrained because of the relatively few wavelengths sampled by our observations. Reasonable fits to the data can be found for blackbody components between 13,000 and 20,000 K. A hotter thermal component cannot be ruled out, and observations at wavelengths shorter than 2260 Å (rest frame) are needed to better constrain the temperature of the thermal component.

Near-infrared observations also show wavelength dependence. However, polarized emission at these wavelengths would not be affected significantly by the thermal emission causing the optical wavelength dependence. The infrared wavelength-dependent polarization may arise from the presence of a second polarized synchrotron component, especially since the polarization angle exhibits much stronger wavelength dependence than at optical wavelengths.

Subject headings: photometry — polarization — quasars — radiation mechanisms

I. INTRODUCTION

The optically violent variable (OVV) quasar 3C 345 ($z = 0.595$; Burbidge 1965) is one of the few objects of its type well studied over a broad wavelength range. 3C 345 exhibits all of the classic properties of the class of highly polarized extragalactic objects (Angel and Stockman 1980; Moore and Stockman 1981). Optically, it shows large-amplitude variability in brightness on a time scale of weeks to a few months and a steep continuum. Large changes in both degree of linear polarization (P) and polarization angle (θ) can be observed in a few weeks, and the optical polarization can be high ($P > 30\%$).

Dent (1965) found 3C 345 to be a radio variable. The nearly simultaneous, multifrequency spectra of Bregman *et al.* (1986) show a characteristic flat radio continuum that becomes steep at wavelengths shorter than ~ 1 mm. These multifrequency spectra also show a spectral index (α, where $S_\nu \propto \nu^\alpha$) that steepens from -1.1 to -1.4 from submillimeter to near-infrared

3C 345 has been studied extensively using VLBI techniques and was one of the first objects in which superluminal motion of radio VLBI components was detected (Kellermann 1978, and references therein). The VLBI "jet" is at a position angle of about $-80°$, with the superluminal components moving away from the core at an apparent speed of $\sim 800c/H_0$ (Cohen and Unwin 1984). There may be a connection between the optical polarization and the VLBI structure since Kinman (1977) pointed out that the yearly averages of the optical

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polarization position angle were typically between 80° and 110° in 1967 and from 1970 through 1974.

Some optical properties common to the low-polarization quasars (Moore and Stockman 1984; Stockman, Moore, and Angel 1984) are seen in the spectrum of 3C 345. The spectrum has an emission feature at 2000–4000 Å (rest frame) that does not vary in intrinsic brightness even though the continuum level is highly variable (Netzer *et al.* 1979; Oke, Shields, and Korycansky 1984). Most of the flux in this spectral feature (hereafter referred to as the "3000 Å bump") is believed to be Balmer recombination and Fe II emission (Grandi 1981; Wills, Netzer, and Wills 1985). Bregman *et al.* (1986) have found that the 3000 Å bump lies upon a broad "blue bump" (1000–4000 Å in the object's rest frame). This emission feature is quite similar to the broad UV excess seen in low-polarization quasars but is much less pronounced because of the large contribution made by nonthermal light to the observed spectrum. Malkan and Sargent (1982) and Malkan (1983) have modeled the UV excess of low-polarization QSOs in terms of optically thick thermal emission from an accretion disk. They find that blackbody components with temperatures of 20–30,000 K fit the broad UV excess observed in these objects very well. Blue bumps have also been found in the spectra of two other highly polarized quasars; PKS 0736+017 and PKS 1510−089 (Malkan and Moore 1985).

Emission lines common to the low-polarization QSOs are seen in the optical and UV spectra of 3C 345 (Mg II and Hβ being the strongest lines falling within the optical bandpass). Bregman *et al.* (1986) find that the observed line ratios are very similar to those observed for low-polarization QSOs, and no evidence has been found for variability in the line strengths.

Wavelength-dependent polarization in 3C 345 at optical and near-infrared (0.44–2.2 μm) wavelengths was first detected by Knacke, Capps, and Johns (1979). They observed that the fractional linear polarization increases with wavelength. Other observers, notably Visvanathan (1973) and Bailey, Hough, and Axon (1983), did not detect this wavelength dependence in the fractional polarization. More recently, Sitko, Schmidt, and Stein (1985) observed wavelength-dependent polarization (in the same sense as that observed by Knacke *et al.*) during most of their optical monitoring of 3C 345. Strong wavelength dependence in the polarization position angle was not seen by any of these observers.

In this paper we present the results of our extensive polarimetric and photometric monitoring program of 3C 345 at optical and near-infrared wavelengths. This was part of a 2 yr observing program designed to study the optical-IR polarization behavior of OVV quasars and BL Lacertae objects. 3C 345 exhibits polarization properties as yet unique to highly polarized extragalactic objects. These properties are discussed in detail in § III. Possible mechanisms responsible for the observed wavelength-dependent polarization are discussed in § IV, and a model is developed to explain the polarization properties of 3C 345 in terms of the blue bump detected by Bregman *et al.* (1986). We summarize our results and conclusions in § V. Section II briefly describes the instruments and techniques used in this monitoring program.

II. OBSERVATIONS

Optical (*UBVRI*) photometric and polarimetric observations 3C 345 were made from 1983 February to 1984 June with the UCSD/University of Minnesota 1.5 m telescope on Mount Lemmon, Arizona, at intervals of ~1–3 months. Nightly observations of 3C 345 were made during each observing session (sessions were ~1 week long) to monitor any daily variations in the source. All measurements were made within a 1–2 hr period, much shorter than the observed variability time scale. Polarimetry and photometry were done using the "two-holer" polarimeter (Sitko, Schmidt, and Stein 1985).

The *UBVRI* photometric system of the two-holer matches that of Bessell (1976) very closely. Differential photometry of 3C 345 was accomplished using the *UBVRI* field comparison stars of Smith *et al.* (1985). All Photometric measurements were made with a 16″ aperture. Uncertainties in the photometry were determined by the photon statistics, and the uncertainties in the magnitudes of the comparison stars. Usually the latter dominated. No correction for interstellar extinction was needed for 3C 345 ($A_v < 0.02$ mag; Heiles 1975; Burstein and Heiles 1978). We converted the apparent magnitudes to flux densities (1 mJy = 10^{-26} ergs s^{-1} cm^{-2} Hz^{-1}) using the zero-point calibrations of O'Dell *et al.* (1978) for the *UBV* spectral bands and Bessell (1979) for the *R* and *I* bands.

The two-holer uses a continuously rotating half-wave plate to modulate the incident linear polarization. A Wollaston prism directs orthogonally polarized components to two RCA C31034 photomultiplier tubes. The amplitude of the sine-wave modulation of the flux is proportional to the degree of polarization, and the phase of the modulation gives the uncalibrated position angle of the polarization. Standard polarized stars are observed during each observing session to calibrate the position angle (Krzemiński and Serkowski 1976; Mathewson and Ford 1970). The instrumental polarization of the two-holer is very low ($\ll$0.1%), and no correction for this has been made to the data. Instrumental efficiency ranged from 0.98 at *R* band to 0.91 at *B*, and was measured by inserting a completely polarizing prism in the light path. Typically we used a 4″ aperture for the polarimetry and integrated on the source for 10–20 minutes. Sky polarization was determined by "chopping" the secondary mirror off of the source every 1–2 minutes during the observation. An LSI-1103 computer handled the data taking and first-round reduction (sky subtraction). Uncertainties were determined purely by photon statistics. The observed degree of polarization was corrected for a statistical bias caused by the fact that polarization is a positive, definite quantity and does not have a normal error distribution (Wardle and Kronberg 1974). This correction was usually quite small because $\sigma(P)/P$ was small for most observations of 3C 345.

Infrared (*JHK*) polarimetric and photometric observations of 3C 345 were made on 10 nights during this observing program using the KPNO 2.1 m telescope with a continuously rotating wire grid infrared polarizer and the "Blue Toad" InSb detector. These observations were made simultaneously (within 1 hr) with the optical measurements. All infrared observations were made with an 18″ aperture. The secondary mirror was chopped at ~5 Hz (triggered by the rotating polarizer) in the north-south direction to subtract the sky signal. Polarimetric data were reduced in a fashion similar to the optical polarimetry. Instrumental polarization, however, is not negligible (1.0% at *H*; 0.6% at *K*) for this instrument/telescope combination and was measured by observing unpolarized stars given by Serkowski (1975). The instrumental efficiency is 0.93 and 0.96 at *H* and *K* bands, respectively (Probst and Joyce 1984). Bright infrared polarization standards were observed to calibrate the polarization position angle (Serkowski 1975;

TABLE 1

OPTICAL AND NEAR-INFRARED PHOTOMETRY AND POLARIMETRY OF 3C 345

UT Date	Fil	mag	(σ)	S_ν(mJy)	(σ)	P(%)	(σ)	θ (°)	(σ)
83.02.18	U	...		...		27.2	(1.5)	14.3	(1.7)
	B	...		...		29.0	(1.2)	15.7	(1.3)
	V	...		...		32.5	(0.6)	15.4	(0.5)
	R	...		...		34.7	(1.3)	16.3	(1.1)
	I	...		...		36.2	(1.0)	16.0	(0.8)
83.02.19	U	14.84	(0.10)	2.0	(0.2)	27.7	(1.1)	17.9	(1.2)
	B	15.26	(0.05)	3.1	(0.1)	29.8	(0.7)	17.3	(0.8)
	V	14.81	(0.05)	4.3	(0.2)	33.1	(0.5)	16.1	(0.5)
	R	14.37	(0.03)	5.5	(0.2)	34.2	(0.6)	16.7	(0.5)
	I	13.84	(0.06)	7.4	(0.4)	35.9	(0.7)	16.0	(0.6)
83.02.20	U	14.67	(0.10)	2.3	(0.2)	30.4	(2.8)	20.7	(2.8)
	B	15.29	(0.05)	3.0	(0.1)	28.8	(0.7)	17.6	(0.8)
	V	14.90	(0.05)	4.0	(0.2)	32.4	(0.6)	16.7	(0.6)
	R	14.44	(0.03)	5.2	(0.1)	33.5	(0.5)	17.1	(0.5)
	I	13.86	(0.06)	7.3	(0.4)	35.2	(0.7)	16.7	(0.6)
83.02.21	U	...		...		26.6	(1.4)	20.8	(1.6)
	B	...		...		27.6	(1.2)	18.7	(1.4)
	V	...		...		31.0	(0.7)	16.8	(0.7)
	R	...		...		35.3	(0.9)	16.6	(0.8)
	I	...		...		34.0	(1.1)	16.5	(0.9)
83.02.22	U	...		...		27.2	(1.2)	20.8	(1.4)
	B	...		...		28.7	(0.6)	18.7	(0.7)
	V	...		...		32.1	(0.6)	18.6	(0.5)
	R	...		...		32.7	(0.5)	17.4	(0.4)
	I	...		...		34.2	(0.6)	17.6	(0.6)
83.03.28	U	15.62	(0.13)	0.9	(0.1)	20.2	(1.8)	34.3	(2.6)
	B	16.17	(0.11)	1.3	(0.1)	21.8	(1.2)	38.4	(1.8)
	V	15.51	(0.07)	2.3	(0.2)	22.6	(1.0)	31.1	(1.3)
	R	14.98	(0.05)	3.1	(0.1)	25.3	(0.8)	36.3	(1.0)
	I	14.48	(0.07)	4.1	(0.3)	23.5	(0.9)	31.9	(1.2)
83.03.29	U	...		...		21.5	(1.7)	31.7	(2.4)
	B	...		...		22.9	(1.1)	33.2	(1.5)
	V	...		...		24.5	(0.9)	33.2	(1.1)
	R	...		...		25.1	(0.8)	32.1	(0.9)
	I	...		...		26.8	(0.9)	32.3	(1.0)
83.03.30	U	...		...		21.3	(1.9)	29.0	(2.7)
	B	...		...		18.5	(0.8)	32.6	(1.3)
	V	...		...		22.9	(0.9)	32.7	(1.1)
	R	...		...		25.5	(0.9)	29.4	(1.0)
	I	...		...		23.0	(0.9)	32.8	(1.1)
83.05.20	U	...		...		15.6	(3.7)	27.7	(7.0)
	B	...		...		17.8	(0.9)	30.4	(1.5)
	V	...		...		21.0	(1.1)	35.4	(1.5)
	R	...		...		21.9	(0.9)	33.9	(1.2)
	I	...		...		25.7	(0.8)	35.2	(1.0)
83.05.21	U	15.41	(0.10)	1.1	(0.1)	19.2	(3.8)	40.8	(5.8)
	B	15.84	(0.06)	1.8	(0.1)	14.3	(1.1)	39.4	(2.4)
	V	15.47	(0.06)	2.4	(0.1)	19.7	(1.2)	35.7	(1.8)
	R	15.08	(0.04)	2.9	(0.1)	21.4	(1.0)	34.9	(1.3)
	I	14.66	(0.07)	3.5	(0.2)	24.5	(1.2)	32.5	(1.5)
83.05.22	U	15.65	(0.15)	0.9	(0.1)	12.6	(1.4)	43.4	(3.4)
	B	16.27	(0.12)	1.2	(0.1)	17.0	(0.8)	36.1	(1.5)
	V	15.84	(0.09)	1.7	(0.1)	20.0	(0.8)	32.9	(1.2)
	R	15.24	(0.06)	2.5	(0.1)	21.6	(0.7)	34.8	(1.0)
	I	14.50	(0.07)	4.0	(0.3)	24.1	(0.8)	32.1	(1.0)
83.05.24	U	...		...		13.8	(3.1)	38.5	(6.6)
	B	15.50	(0.25)	2.5	(0.6)	15.6	(1.9)	35.6	(3.8)
	V	15.45	(0.13)	2.4	(0.3)	17.6	(1.6)	37.6	(2.7)
	R	15.11	(0.09)	2.8	(0.2)	21.2	(1.4)	36.6	(1.9)
	I	14.53	(0.13)	3.9	(0.5)	20.7	(1.4)	36.1	(2.1)
83.05.25	U	15.42	(0.31)	1.1	(0.3)	...		...	
	B	15.89	(0.20)	1.7	(0.3)	10.9	(2.4)	36.6	(6.9)
	V	15.41	(0.13)	2.5	(0.3)	...		...	
	R	15.32	(0.13)	2.3	(0.3)	21.4	(1.7)	35.3	(2.3)
	I	14.53	(0.11)	3.9	(0.4)	...		...	
83.06.28	U	15.45	(0.12)	1.1	(0.1)	...		...	
	B	16.32	(0.11)	1.2	(0.1)	4.9	(1.7)	76.4	(10.5)
	V	15.85	(0.08)	1.7	(0.1)	8.8	(1.8)	85.3	(5.9)
	R	15.43	(0.06)	2.1	(0.1)	8.4	(1.4)	75.9	(4.8)
	I	15.03	(0.08)	2.5	(0.2)	9.1	(1.4)	73.5	(4.5)
	J	13.82	(0.10)	4.9	(0.4)	...		...	
	H	12.81	(0.10)	8.2	(0.8)	9.8	(1.2)	73.8	(3.5)
	K	11.83	(0.10)	12.4	(1.1)	8.5	(1.4)	69.8	(4.8)
83.06.30	U	15.78	(0.14)	0.8	(0.1)	...		...	
	B	16.32	(0.11)	1.2	(0.1)	6.0	(1.8)	78.3	(9.1)
	V	16.21	(0.11)	1.2	(0.1)	9.5	(1.3)	79.6	(4.2)
	R	15.71	(0.08)	1.6	(0.1)	8.2	(1.6)	80.9	(5.5)
	I	15.62	(0.15)	1.4	(0.2)	8.6	(1.4)	84.5	(4.8)
	J	13.83	(0.10)	4.8	(0.4)	...		...	
	H	12.96	(0.10)	7.1	(0.7)	...		...	
	K	12.03	(0.10)	10.3	(0.9)	5.3	(1.2)	65.8	(6.5)
83.07.01	R	...		...		10.0	(1.7)	81.6	(4.9)
83.07.02	K	...		...		7.8	(2.2)	65.5	(8.1)
83.07.04	U	15.63	(0.10)	0.9	(0.1)	...		...	
	B	16.22	(0.06)	1.3	(0.1)	7.6	(1.4)	82.6	(5.9)
	V	15.92	(0.06)	1.6	(0.1)	8.6	(1.0)	77.8	(3.6)
	R	15.49	(0.05)	2.0	(0.1)	10.4	(0.9)	81.4	(2.7)
	I	14.94	(0.07)	2.7	(0.2)	10.7	(1.1)	91.3	(3.2)

TABLE 1—*Continued*

UT Date	Fil	mag (σ)	S_ν(mJy) (σ)	P(%) (σ)	θ (°) (σ)
83.09.14	J	13.73 (0.10)	5.3 (0.5)	...	...
	H	12.79 (0.10)	8.4 (0.8)	...	...
	K	11.77 (0.10)	13.1 (1.2)	9.4 (1.8)	77.2 (5.4)
84.01.15	B	...	...	4.8 (0.8)	89.4 (5.1)
	V	...	...	12.4 (0.9)	87.1 (2.3)
	R	...	...	13.5 (1.3)	89.2 (2.8)
	I	...	...	14.1 (1.3)	89.5 (2.7)
84.01.16	U	15.95 (0.11)	0.7 (0.1)	...	...
	B	16.75 (0.08)	0.8 (0.1)	5.3 (2.7)	97.6 (14.1)
	V	16.46 (0.07)	0.9 (0.1)	9.0 (1.2)	85.1 (3.9)
	R	16.15 (0.06)	1.1 (0.1)	13.1 (1.3)	84.9 (2.8)
	I	15.49 (0.09)	1.6 (0.1)	10.7 (2.6)	93.1 (7.1)
84.01.18	K	...	...	16.5 (4.7)	71.0 (8.2)
84.01.22	B	...	...	3.4 (2.4)	79.0 (17.9)
	R	...	...	11.6 (1.3)	87.1 (3.4)
84.01.24	U	...	...	3.3 (2.0)	118.2 (15.6)
	B	...	...	8.0 (1.1)	87.4 (4.2)
	R	...	...	9.5 (0.8)	88.5 (2.5)
	I	...	...	14.1 (1.1)	90.5 (2.4)
84.01.25	U	15.53 (0.10)	1.0 (0.1)	...	...
	B	16.19 (0.06)	1.3 (0.1)	...	...
	V	16.04 (0.06)	1.4 (0.1)	...	...
	R	15.73 (0.05)	1.6 (0.1)	...	...
	I	15.27 (0.08)	2.0 (0.2)	...	...
84.03.20	B	...	...	8.7 (1.6)	85.0 (5.8)
	V	...	...	7.8 (1.6)	78.1 (6.0)
	R	...	...	8.2 (1.3)	78.4 (4.6)
	I	...	...	11.0 (1.4)	80.0 (3.7)
84.03.22	U	15.90 (0.13)	0.7 (0.1)	...	...
	B	16.51 (0.10)	1.0 (0.1)	...	...
	V	16.22 (0.09)	1.2 (0.1)	...	...
	R	15.97 (0.08)	1.3 (0.1)	11.9 (1.4)	72.7 (3.4)
	I	15.67 (0.11)	1.4 (0.1)	10.9 (2.0)	78.6 (5.5)
84.03.24	U	15.97 (0.11)	0.7 (0.1)	...	...
	B	16.44 (0.07)	1.0 (0.1)	9.1 (0.8)	66.9 (2.9)
	V	16.22 (0.07)	1.2 (0.1)	10.9 (0.8)	71.7 (2.1)
	R	15.85 (0.05)	1.4 (0.1)	...	...
	I	15.43 (0.08)	1.7 (0.1)	14.2 (1.0)	70.1 (2.2)
84.03.25	V	...	...	11.9 (0.7)	69.8 (1.9)
	I	...	...	13.0 (0.8)	67.9 (1.8)
84.03.26	B	...	...	6.4 (1.0)	67.8 (4.8)
	R	...	...	12.3 (0.7)	69.6 (1.7)
84.03.28	U	...	...	10.6 (3.5)	71.1 (9.6)
	V	...	...	12.4 (1.4)	70.4 (3.3)
	I	...	...	15.6 (1.9)	72.9 (3.5)
84.06.03	B	...	...	5.2 (0.7)	69.2 (4.0)
	V	...	...	6.8 (0.6)	78.0 (2.8)
	R	...	...	7.4 (0.8)	76.8 (3.2)
	I	...	...	10.1 (0.9)	79.1 (2.5)
84.06.04	U	15.87 (0.10)	0.8 (0.1)	...	...
	B	16.28 (0.06)	1.2 (0.1)	...	...
	V	16.04 (0.06)	1.4 (0.1)	7.2 (0.6)	69.1 (2.7)
	R	15.62 (0.04)	1.7 (0.1)	...	...
	I	14.97 (0.06)	2.6 (0.1)	9.7 (0.7)	74.4 (2.3)
84.06.07	U	...	...	5.9 (1.2)	76.6 (6.2)
	B	...	...	6.7 (0.6)	77.5 (2.8)
	V	...	...	6.4 (0.9)	70.7 (4.2)
	R	...	...	9.0 (0.6)	74.0 (1.9)
	I	...	...	9.2 (0.7)	79.6 (2.4)
	K	12.29 (0.10)	8.1 (0.8)	12.0 (2.3)	80.0 (5.4)
84.06.08	U	15.56 (0.10)	1.0 (0.1)	...	...
	B	16.09 (0.06)	1.4 (0.1)	...	...
	V	15.91 (0.06)	1.6 (0.1)	...	...
	R	15.53 (0.04)	1.9 (0.1)	...	...
	I	15.02 (0.07)	2.5 (0.2)	...	...
84.06.10	U	15.75 (0.10)	0.8 (0.1)	...	...
	B	16.25 (0.06)	1.2 (0.1)	2.1 (0.9)	92.2 (12.0)
	V	15.94 (0.06)	1.5 (0.1)	3.6 (0.8)	75.3 (6.5)
	R	15.54 (0.04)	1.9 (0.1)	6.2 (0.6)	84.3 (3.0)
	I	14.92 (0.06)	2.7 (0.2)	6.8 (0.8)	78.1 (3.6)
	K	12.20 (0.10)	8.8 (0.8)	8.6 (2.3)	97.0 (7.8)
84.06.11	R	...	...	7.9 (0.8)	83.0 (3.0)
	K	12.23 (0.10)	8.6 (0.8)	14.8 (1.8)	88.4 (3.5)
84.06.12	R	...	...	7.5 (0.8)	72.9 (3.3)
	K	12.22 (0.10)	8.7 (0.8)	12.7 (3.0)	75.0 (6.7)
84.06.13	R	...	...	7.8 (1.0)	73.9 (3.6)
84.06.14	U	15.76 (0.18)	0.8 (0.1)	...	...
	B	16.20 (0.13)	1.3 (0.2)	...	...
	V	16.01 (0.10)	1.4 (0.1)	6.7 (2.1)	46.7 (8.9)
	R	15.62 (0.07)	1.7 (0.1)	...	...
	I	14.99 (0.08)	2.6 (0.2)	7.4 (1.4)	68.1 (5.4)
	K	12.21 (0.10)	8.8 (0.8)	14.4 (4.9)	72.1 (9.7)

Wilking *et al.* 1980). Polarimetry was not attempted at *J* band because of the faintness of the source.

Rough *JHK* photometry (estimated uncertainty of ~0.1 mag) was done with the IR polarimeter on a few nights. We calibrated the photometry and measured the atmospheric extinction by observing bright KPNO infrared standard stars from a list compiled by R. Joyce. We used the zero-point calibration of Koornneef (1983) to convert our *JHK* magnitudes to flux densities.

The data are shown in Table 1. The UT date (year month day) is followed by the broad-band filter, apparent magnitude (m), flux density (S_ν) in millijanskys, fractional polarization (P) in percent, and the position angle on the sky of the polarized electric vector (θ) in degrees. The 1 σ formal statistical error for each measurement, which includes the photon statistics and uncertainties in the absolute calibration, follows each m, S_ν, P, and θ value in parentheses.

III. RESULTS

We have graphically summarized all of our *R* band (0.64 μm) observations of 3C 345 from 1983 February to 1984 June in Figure 1. During 1983, 3C 345 was declining from an outburst that appeared to begin in early 1982 and peaked in late 1982 (Bregman *et al.* 1986). This outburst was of comparable intensity to the 1971 outburst (Pollock *et al.* 1979). The optical polarization increased as the object brightened (Sitko, Schmidt, and Stein 1985). In 1983 February, the polarization reached the highest level yet reported for 3C 345 ($P \approx 35\%$). During the ensuing 5 months, the source dimmed considerably (1.5 mag), bringing it near its historical photometric minimum of $B \approx 17$. During this period the optical polarization decreased to ~10%, and θ rotated from 15° to 70°–90°.

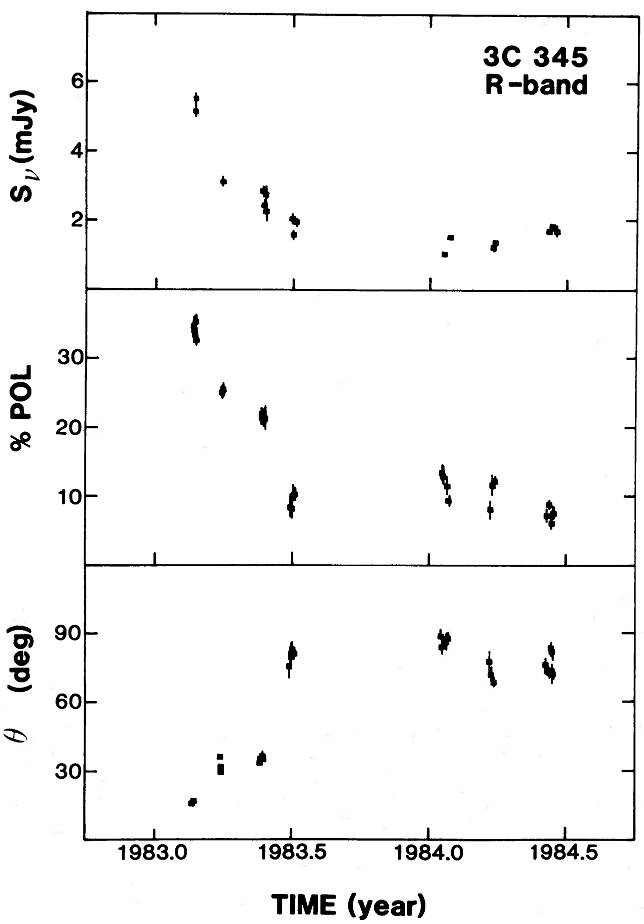

FIG. 1.—Photometric and polarimetric variations of 3C 345 at *R* (0.64 μm) from 1983 February to 1984 June. Each group of observations span no more than 11 days.

The variability time scale for both flux and polarization seems to be on the order of weeks since significant variations (>2 σ) were rarely observed in any 1 week observing session. Our 1983 February–June data and the data from 1983 March and June of Sitko *et al.* (1985) show that the decay of the outburst (both in flux density and polarization) was quite smooth. 3C 345 seems to have stayed fairly constant in brightness and polarization from 1983 July to 1984 June. Although there is a large gap in our optical coverage from 1983 July to 1984 January, the data of the Rosemary Hill Observatory in Bregman *et al.* (1986) show no major fluctuations in optical brightness during the last half of 1983.

The correlation between flux density, P, and θ is quite remarkable during and after the outburst, and has never before been observed to this degree in any other quasar or BL Lacertae object. We have plotted our *R* band measurements of P and θ against flux density in Figure 2. This strong correlation is further substantiated by the data of Sitko *et al.* (1985). Our combined data sets cover nearly the entire outburst, showing that the observed correlation persisted for at least 2 yr.

From 1983 July to 1984 June, θ was close to the VLBI jet position angle of −80° reported by Cohen and Unwin (1984) and the preferred optical θ pointed out by Kinman (1977). This implies that the projection on the sky of the magnetic field, in the optical to near-infrared emission region, was roughly perpendicular to the VLBI jet axis after the 1982–1983 outburst. The changes in the VLBI structure of 3C 345 are complex, and the nonradial motion of one component (C_4) is explained as a result of a curved relativistic jet (Biretta *et al.* 1983). With such complicated behavior, detailed optical polarimetric and VLBI monitoring over a much longer time scale is necessary before anything definitive can be said about possible relationships between VLBI components and the optical emission of the quasar (see Kinman 1977; Sitko *et al.* 1985).

The optical spectral index (α_{opt}; determined from a least-squares fit to the optical flux densities) generally flattened from about −1.6 to −1.2 as 3C 345 dimmed. The quantity α_{opt} averaged −1.3 during our monitoring period. The time evolution of α_{opt} is shown in Figure 3*a*. The data points represent the weighted average over an observing session, and the "error" bars give the 1 σ scatter about the mean α_{opt} during a particular observing session.

No infrared measurements were made during the outburst, but several observations simultaneous with the optical measurements were made in 1983 June and 1984 June. We found the near-infrared (1.2–2.2 μm) spectral index (α_{IR}) to be -1.48 ± 0.16 in 1983 June. This is consistent with $\alpha_{IR} = -1.4$ found by Gear *et al.* (1985) in 1983 early February, and by Bregman *et al.* (1986) in all of their multifrequency spectra. The continuum is significantly steeper at near-infrared wavelengths than at optical wavelengths ($\alpha_{opt} = -1.16 \pm 0.08$) in 1983 June, and is a result of the presence of the broad "blue bump" detected by Bregman *et al.* Figure 4 shows S_ν, P, and θ plotted against log ν for 1983 June and three other representative observing sessions. Because of the lack of significant variability

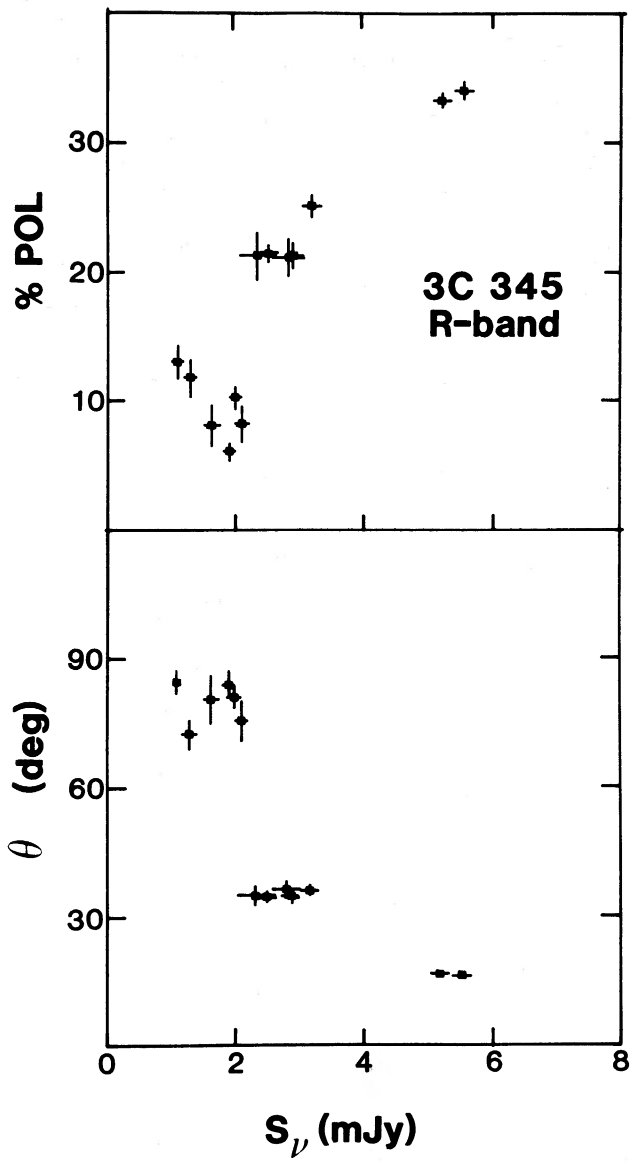

FIG. 2.—Fractional polarization and polarization position angle at 0.64 μm as a function of flux density. Each symbol represents a night between 1983 February and 1984 June when both polarization and flux density were measured.

on a time scale of 1 week, we averaged the flux density and polarization for each bandpass over each observing session to give the higher signal-to-noise ratio plots in Figure 4. The 1984 June data show the K flux density falling slightly below the extrapolation of the best-fit power law to the optical flux densities. The spectral index between K and I was -1.16 ± 0.08, while $\alpha_{\rm opt} = -1.27 \pm 0.06$ during 1984 June.

3C 345 showed strong wavelength dependence in its fractional polarization throughout our monitoring program. In general, P was observed to increase toward longer wavelengths. The sense of the wavelength dependence is the same as that observed by Knacke, Capps, and Johns (1979) and Sitko *et al.* (1985). An exception to this trend can be seen in Figure 4*c*, where P is smaller at K than H band (although the degree of polarization at B is less than at V, R, or I). Infrared polarimetry shows P to be greater at 2.2 μm than at optical wavelengths in 1984 January and June. The degree of polarization at I can also occasionally be slightly lower than at R, as seen in our 1983 March data. Sitko *et al.* (1985) observed lower fractional polarization at I relative to R during 1982 May and 1983 March.

Figures 3*b* and 3*c* show the wavelength dependence in the optical spectral region of P [$P(\nu) \equiv d \log P/d \log \nu$] and θ [$\theta(\nu) \equiv d\theta/d \log \nu$] as a function of time. A least-squares fit to the optical polarization data was used to calculate $P(\nu)$ and $\theta(\nu)$ for every night that polarization measurements were made at more than two wavelengths. Each data point represents the average of $P(\nu)$ and $\theta(\nu)$ over an observing session. The error bars have the same significance as in Figure 3*a*. The wavelength dependence of θ is mild, and on many nights the data are consistent with no wavelength dependence over the optical wavelength range.

We do not have many observations in the near-infrared, and their accuracy is rather low (because of the low polarization and faintness of 3C 345 when the IR observations were made), so it is difficult to characterize definitively the wavelength dependence of θ between optical and near-infrared wavelengths. The data suggests that $|\theta(2.2\ \mu\text{m}) - \theta_{\rm opt}| \approx 10°$. While the wavelength baseline is longer here, this is a stronger θ

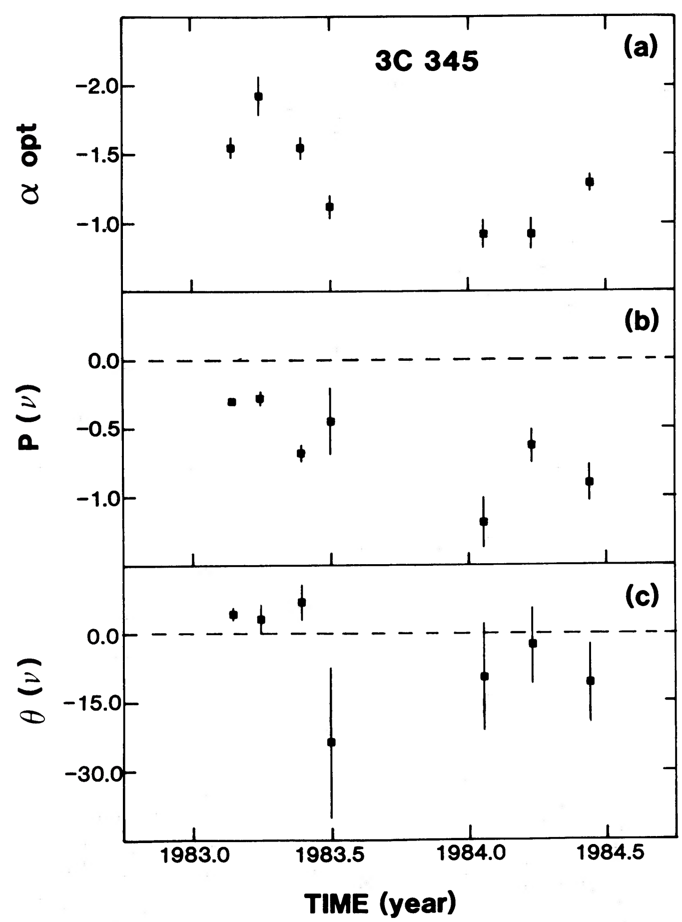

FIG. 3.—Time evolution in the optical bandpasses of (*a*) $\alpha_{\rm opt} \equiv d(\log S_\nu)/d(\log \nu)$, (*b*) $P(\nu) \equiv d(\log P)/d(\log \nu)$, and (*c*) $\theta(\nu) \equiv d\theta/d(\log \nu)$. Each symbol represents the weighted mean of the quantity over an entire observing session. Error bars are the 1 σ deviation about the mean. The quantities $P(\nu)$ and $\theta(\nu)$ were determined only from nights where the polarization was measured in more than two optical filters.

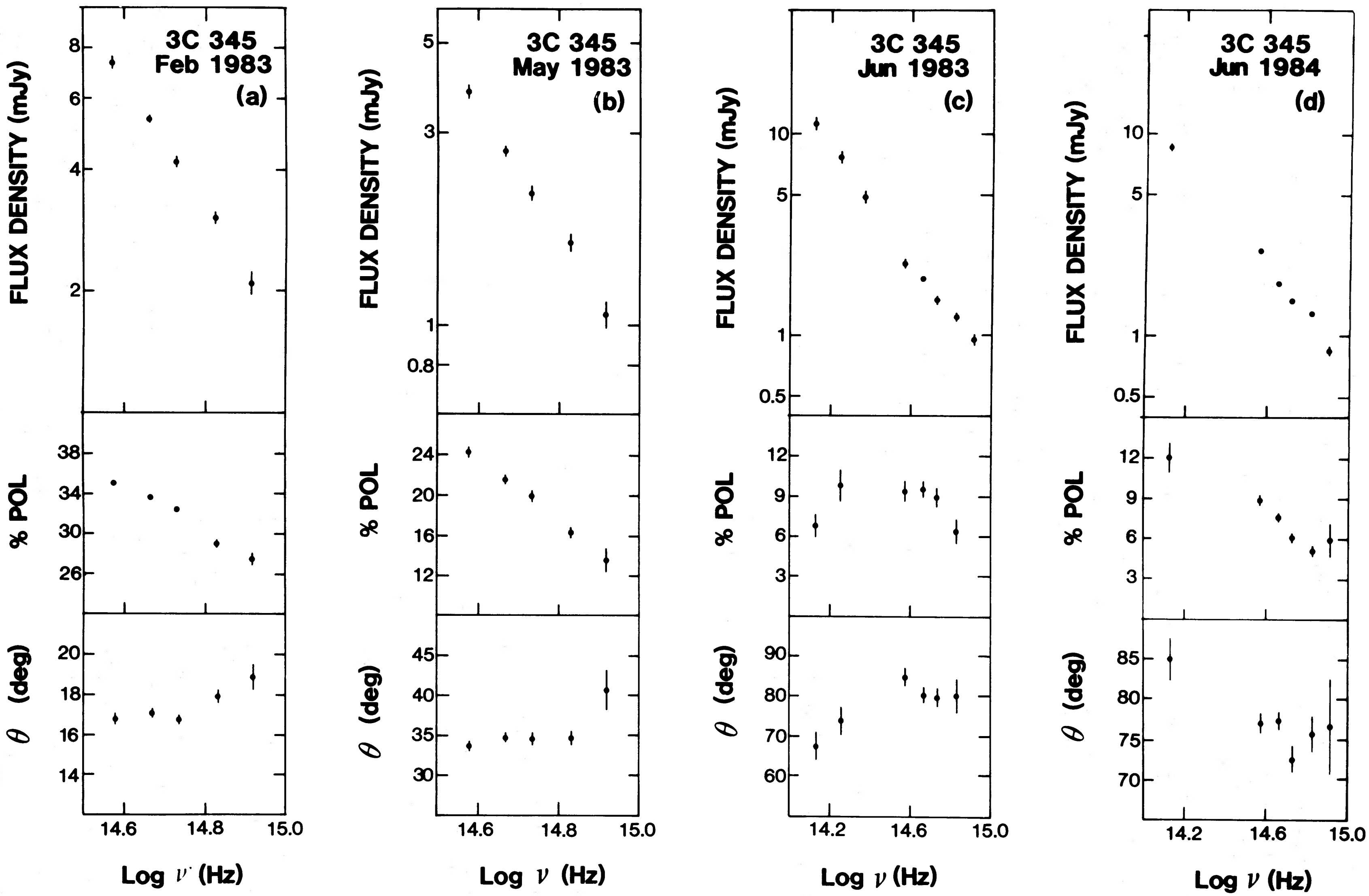

FIG. 4.—Flux density, fractional polarization, and polarization position angle as a function of log frequency. Optical data from 1983 February and May are shown in (*a*) and (*b*), respectively. Optical and near-infrared observations of 1983 June–July and 1984 June are shown in (*c*) and (*d*). Each symbol represents the weighted mean of the quantity over the entire observing session. Error bars have the same significance as in Fig. 3.

wavelength dependence than is typically observed over the optical bandpass alone.

The persistence of the wavelength-dependent fractional polarization of 3C 345 is unparalleled by any other well-monitored, highly polarized extragalactic object. 3C 345 can show periods of apparent wavelength independence (Visvanathan 1973; Bailey, Hough, and Axon 1983); however, strong wavelength dependence in P is very common and is seen over large ranges in brightness, polarization states, and optical spectral indices. Marked wavelength-dependent polarization seems to be much more a temporary phenomenon with BL Lacertae objects such as OI 090.4 (Rieke *et al.* 1977; Puschell *et al.* 1983), PKS 0735+178 (Rieke *et al.* 1977), AO 0235+164 (Impey, Brand, and Tapia 1982), B2 1308+326 (Sitko, Stein, and Schmidt 1984), and OJ 287 (Balonek *et al.* 1984; Holmes *et al.* 1984*b*). All of these objects have shown large rotations of θ with wavelength. 3C 345 is alone among these objects in not showing strong wavelength dependence in θ at optical wavelengths.

3C 345 is also unique among highly polarized and variable objects in that its optical fractional polarization consistently increases toward longer wavelengths. Other observers, notably Holmes *et al.* (1984*a*, *b*), have reported P increasing from the optical to the near-infrared and from 1.2 to 2.2 μm for OJ 287 and a few other objects.

IV. DISCUSSION

The persistent and strong wavelength-dependent polarization observed in 3C 345 must be central to any model developed to explain the behavior of this object. Several simple models for the optical continuum emission from 3C 345 can be rejected on the basis of the postion angle wavelength dependence or the sense of the fractional polarization wavelength dependence. We present arguments against these models in §§ IV*a*–*c*. We then present a model in § IV*d* that explains the observed optical polarization wavelength dependence by letting the nonthermal, polarized emission of the quasar be diluted by optically thick thermal emission from an accretion disk.

a) Synchrotron and Faraday Effects

Synchrotron emission from electrons in regions where the magnetic field is well ordered is generally accepted as the source of polarized light in highly active extragalactic objects. A single, optically thin synchrotron component cannot explain the wavelength-dependent polarization of 3C 345 because such a component has wavelength-independent polarization (Ginzburg and Syrovatskii 1965). Energy losses, or an upper energy cutoff in the electron energy spectrum of an optically thin synchrotron source, can cause P to increase with frequency because of the resulting steepening of the local spectral index with frequency (Nordsieck 1976). This is in the opposite sense to the wavelength dependence observed for 3C 345.

Wavelength-dependent polarization can result from a non-uniform magnetic field within the emission region. Sitko, Stein, and Schmidt (1984) mention this as a possible explanation of the wavelength-dependent polarization they observed in the BL Lacertae object B2 1308+326. Because the P wavelength dependence of 3C 345 is in the opposite sense to that of 1308+326, the magnetic field structure is likely to be quite different for the two objects. For a constant electron density and energy distribution, most of the higher frequency radiation will come from a region in 3C 345 where the magnetic field is stronger, but less well ordered than the region producing the bulk of the lower frequency radiation. If the magnetic field decreases in strength with distance from the central "engine," it must somehow become more ordered with distance. The entire region producing the bulk of the optical continuum must have a magnetic field that is well aligned since θ is largely independent of wavelength.

External Faraday rotation can be ruled out because of the lack of wavelength dependence in θ. Internal Faraday rotation is unlikely because the relative wavelength independence of θ argues for high Faraday depths at optical wavelengths (see Cioffi and Jones 1980). However, since Faraday depth is proportional to λ^2, we should observe a higher degree of depolarization at longer wavelengths (at least with the simple geometries discussed by Cioffi and Jones). In general, it is difficult to see how internal Faraday effects could produce increasing P with wavelength over the entire observed spectral range (0.36–2.2 μm), as seen by Knacke, Capps, and Johns (1979) and in our 1984 January and June data. Large internal Faraday depths would also give rise to such large depolarization that it would be difficult for P to be 35%, as was observed in 1983 February.

b) Contamination of a Polarized Synchrotron Component by the Addition of a Second Polarization Vector

i) *Multiple Synchrotron Components*

The relative wavelength independence of θ also argues against a model consisting of two synchrotron components with differing optical polarizations and spectral indices. Unlikely constraints are needed for this type of two-component model to explain the wavelength dependence of P at optical wavelengths. In order to preserve the wavelength independence of θ, the polarization planes of the two components must track each other fairly closely through the 80° rotation observed during the first half of 1983. The brightness of the two components must also track each other somewhat since $P(\nu)$ seems to stay relatively constant over long periods of time. The problem, presented in this model, is explaining why two components having different spectral indices and fractional polarizations track each other.

If one of the synchrotron components is unpolarized, or nearly so, its spectrum would have to be quite flat at optical wavelengths to explain the strength of $P(\nu)$. This implies that there is a very abrupt spectral cutoff in the near-ultraviolet for this component. Otherwise, the UV continuum of the quasar would be much flatter than observed by Bregman *et al.* (1986).

Sitko, Schmidt, and Stein (1985) model the polarization and flux density variations of 3C 345 during its 1982–1983 outburst by adding a highly polarized component (50%) that is variable both in brightness and θ to a "quiescent" (nonvarying brightness, P, and θ) component. Although this model gives a good representation of the variability of 3C 345, it does not explain why $\theta(\nu)$ is mild while $P(\nu)$ is very pronounced (especially when $P \approx 10\%$ for the quiescent component).

Our infrared observations show a much stronger θ wavelength dependence (see Fig. 4*c* and 4*d*). We could be seeing a second synchrotron component in the infrared with a different plane of polarization from the component dominating at optical wavelengths. This would explain the low polarization observed at 2.2 μm in 1983 June. A possible infrared component could also be responsible for the mild optical wavelength dependence of θ and the lower polarization at 0.79 μm, relative to 0.64 μm, occasionally observed.

ii) *Scattering Mechanisms*

Scattering mechanisms that produce significant polarization are unlikely sources of wavelength-dependent polarization in 3C 345 for the same reasons as those advanced against a second polarized synchrotron component. Scattering from a symmetric distribution of dust would not give rise to θ wavelength dependence. The blue scattered light (now unpolarized), combined with the reddened synchrotron light, would result in the fractional polarization increasing with wavelength. However, the large amount of extinction and reddening needed is not supported by the spectral flux distribution of 3C 345. Harvey, Wilking, and Joy (1982) and Bregman *et al.* (1986) have also found no evidence for emission or absorption by dust in the object's infrared spectrum. See Neugebauer *et al.* (1979) and Puschell *et al.* (1983) for other arguments against these types of contamination of the synchrotron light and against scattering as the sole mechanism for the high degree of polarization seen in OVV quasars and BL Lac objects.

c) *Dilution from Stars, Emission Lines, and the* "3000 Å *Bump*"

The polarization behavior of 3C 345 is consistent with some mechanism that dilutes the polarized flux of the synchrotron component. We have estimated the effect that an extremely bright elliptical galaxy ($M_v = -23.4$) would have on the observed fractional polarization. For this calculation, we have used the standard optical spectrum for an elliptical galaxy determined by Yee and Oke (1978). The spectrum was extended to the infrared and ultraviolet using the observations of elliptical galaxies of Frogel *et al.* (1978) and Oke, Bertola, and Capaccioli (1981).

The redshift of 3C 345 puts the ultraviolet part of its spectrum in the observer's optical bandpasses (V corresponds to a rest frame wavelength of 3500 Å). The contribution of starlight to the total flux would be falling off rapidly in this spectral region and so would not lead to a lessening of P toward shorter wavelengths. The galaxy's spectrum would peak at around 2.2 μm, and a galactic contribution to the total flux would actually lead to an increasing polarization toward shorter wavelengths. However, even an extremely luminous elliptical galaxy will not contribute a significant amount of flux at the distance of the quasar (here we assume $H_0 = 75$ km s^{-1} Mpc^{-1} and $q_0 = +1$). We estimate that such a galaxy would be $\sim$0.01 mJy at V (observer's frame) and $\sim$0.7 mJy at K. The galactic contribution would be only $\sim$10% of the total flux density at K when the quasar is dim (i.e., after 1983 May).

The optical and ultraviolet spectra of 3C 345 show many prominent emission lines and the presence of the "3000 Å bump" common to low-polarization quasars (Wampler 1967; Visvanathan 1973; Netzer *et al.* 1979; Oke *et al.* 1984; Bregman *et al.* 1986). To determine what effect these unpolarized spectral features have on $P(\nu)$, we constructed a synthetic spectrum for 3C 345 using the "standard" QSO spectrum of Grandi (1982). Observed line strengths for Mg II, Hβ, and [O III] were taken from Oke, Shields, and Korcansky (1984) and C III] λ1909 from Bregman *et al.* (1986). We used the ad hoc model of Grandi (1981) to approximate the contribution to the flux by Fe II line emission. The Fe II line strengths are normalized to the UV 2 multiplet (mean rest frame wavelength of 2385 Å) in Grandi's model. The strength of this multiplet was estimated using the observed strength of the 2500 Å blend (Oke *et al.* 1984). All other line strengths and the contributions by Balmer, Paschen, and two-photon emission (all relative to the observed strength of Hβ) were found by following the prescription of Grandi (1982). Free-free emission was also added to the synthetic spectrum using the theoretical intensity of Kwan and Krolik (1981). We took the filter transmission curves given by Bessell (1976) into account in determining the amount of line flux that fell into a particular bandpass. The smaller effect of changes in the response of the RCA C31034 photomultiplier tube over a bandpass was neglected.

A subtraction of our synthetic spectrum from the underlying continuum did not lessen the wavelength-dependent optical polarization significantly. The subtraction amounted to between 0.03 and 0.1 mJy at the effective wavelengths of the filters and translated into small corrections to P in each bandpass (rarely more than 10% of P when 3C 345 was faint). The resulting reduction in the strength of $P(\nu)$ was less than 10%, even when the quasar was faint. Clearly, the 3000 Å bump and emission lines alone are not strong enough to account for the observed $P(\nu)$.

The two-photon emission process is not responsible for the wavelength-dependent polarization. The two-photon flux must be enhanced by at least 500 times its strength in the Kwan and Krolik (1981) model to account for $P(\nu)$. Such a large amount of two-photon emission would considerably flatten the spectrum of 3C 345 from the optical to the ultraviolet, and a large, near-discontinuity would be seen in the continuum level of the UV spectrum (at a slightly longer wavelength than Lyα). The multifrequency spectrum of Bregman *et al.* (1986) show a steep optical-UV continuum, and no discontinuity in the continuum level is seen in their *IUE* spectra.

d) *Dilution from Optically Thick Thermal Emission from an Accretion Disk*

Dilution of the synchrotron component(s) by optically thick thermal emission can account for the decrease in the optical polarization toward higher frequencies observed in 3C 345. Malkan and Sargent (1982) model the large ultraviolet excess observed in low-polarization quasars and Seyfert I galaxies in terms of a blackbody at a temperature between 20,000 and 30,000 K. The suggestion is that the optically thick emission is from an accretion disk. Bregman *et al.* (1986) find a broad blue bump in the spectrum of 3C 345, ranging in wavelength from 1000 to 4000 Å (rest frame). This bump may be quite similar to the UV excess seen in low-polarization QSOs, except that it is hidden better by the synchrotron emission of the object. One way to test this hypothesis is to see how an unpolarized thermal component effects the polarization at optical and ultraviolet wavelengths.

i) *The Model*

We have constructed simple models for each observing session consisting of a single power-law, polarized nonthermal component and a single unpolarized blackbody. The free parameters in the model fits are the intrinsic polarization (P_0), strength, and spectral index (α) of the synchrotron component, and the apparent angular size and temperature (T) of the blackbody. The quantity P_0 is assumed to be wavelength-independent, although it is likely that weaker optical emission from a second synchrotron component is necessary to explain the mild wavelength dependence of θ (see § IV*b*). The flux and polarization data were averaged over an entire observing session since variations in S_ν, P, and θ were minimal on a time scale of 1 week. We subtracted the synthetic spectrum, described in § IV*c*, from the broad-band flux densities and adjusted the fractional polarizations accordingly. The "best fit" (in the usual χ^2 sense) to the data of each observing session was found by using a least-squares search routine.

The best-fitting models for 1983 February and 1984 June are shown in Figures 5*a* and 5*b*, respectively. There is, however, a large range of blackbody and power-law components that can reasonably fit the data because of the few wavelengths observed and the large number of free parameters. For example, reasonable fits to the observations of 1983 February can be found for blackbodies with temperatures between 13,000 and 26,000 K.

Optically thick emission from an accretion disk several light days in diameter would not be expected to vary significantly on time scales less than several months to a few years. We therefore combined all of our observations with those of Sitko, Schmidt, and Stein (1985) to find an "average" blackbody that best describes all of the data. The average blackbody has a peak flux density of ~0.5 mJy at 5100 Å (observer's frame) and an apparent mean angular diameter of ~0.6 μarcsec. We find a temperature of ~16,000 K, which is significantly cooler than

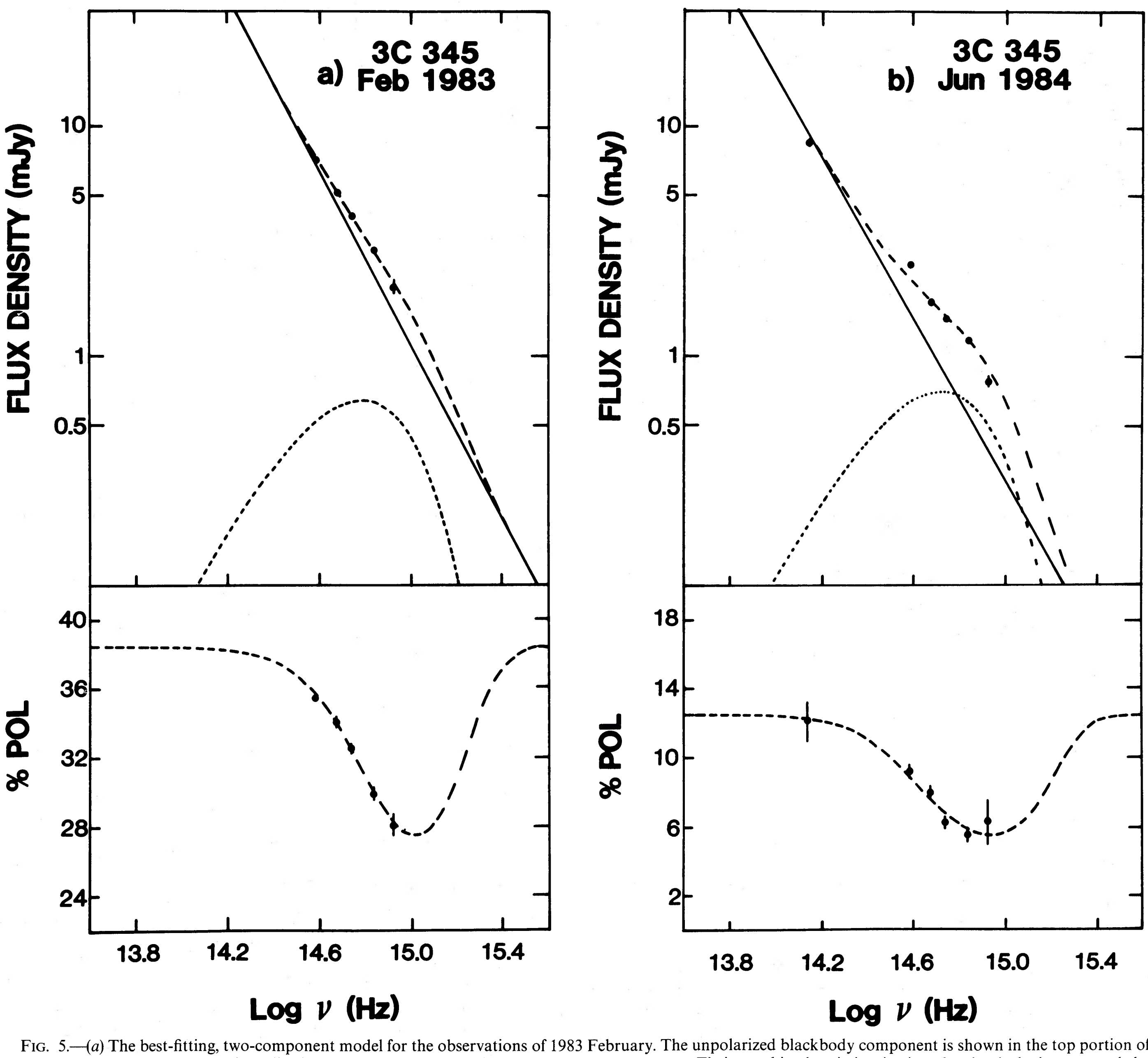

FIG. 5.—(*a*) The best-fitting, two-component model for the observations of 1983 February. The unpolarized blackbody component is shown in the top portion of the figure by the dotted curve. The solid line represents the power-law, synchrotron component. Their combined emission is given by the dashed curve, and the observed flux densities are shown by the filled circles. The spectral index of the polarized synchrotron component (P_0 = 38.5%) is −1.9, and the temperature of the blackbody is $T_{obs}(1 + z)$ = 16,000 K. The fractional polarization as a function of log ν (observer's frame) is represented by the dashed curve in the bottom portion of the figure. Filled circles are the observed fractional polarizations. (*b*) The best-fitting, two-component model for the observations of 1984 June. The figure is essentially the same as Fig. 5*a*, except that T = 14,000 K, α = −1.8, and P_0 = 12.5%.

the models of Malkan and Sargent (1982). However, we emphasize that because no observations were made at wavelengths shorter than 2260 Å (rest frame), the temperature is not well constrained, and a hotter blackbody cannot be ruled out.

Some physical characteristics in the quasar's rest frame of the average blackbody (accretion disk) can be estimated by choosing a cosmological constant ($\Lambda = 0$), deceleration parameter ($q_0 = +1$), and Hubble constant ($H_0 = 75$ km s^{-1} Mpc^{-1}). For a geometrically thin disk, the lower limits of the emitting surface area and the luminosity are $\sim 5 \times 10^{32}$ cm^2 and 5×10^{11} $L_\odot$, respectively.

ii) *Implications of the Model*

A characteristic of our model is that the optical spectral index of the synchrotron component is much steeper than the infrared spectral index measured by Gear *et al.* (1985), Bregman *et al.* (1986), and our own 1983 June and September observations. The spectral indices in our models range from -1.5 to -2.4. Forcing α to -1.4 does not fit the polarization data well. The strength of $P(\nu)$ is largely dependent upon α, and a flatter ($\alpha \geq -1.4$) nonthermal optical spectrum will produce wavelength-dependent polarization that is too weak compared to that actually observed. The spectral index can flatten to -1.4 or greater in the near-infrared, without affecting the fractional polarization because the thermal component does not contribute a significant amount of the total flux at these wavelengths.

Spectral curvature of the synchrotron emission is a common property of active extragalactic objects (O'Dell, Puschell, and Stein 1977; Neugebauer *et al.* 1979; Jones *et al.* 1981; Sitko *et al.* 1983) and is seen in the far-infrared to 1 μm spectra of 3C 345 (Neugebauer *et al.* 1984; Bregman *et al.* 1986). Evidence that the synchrotron spectrum of 3C 345 steepens significantly from the near-infrared through the optical can be seen in Figure 3. The quantity $\alpha_{\rm opt}$ was clearly steeper then -1.4 when the synchrotron emission dominated the spectrum during 1983 February, March, and May. The blue bump, which tends to flatten the optical continuum, is included in the calculation of $\alpha_{\rm opt}$. Bregman *et al.* (1986) also show *IUE* spectra with the ultraviolet continuum having a spectral index of about -2.0. Extrapolation of a steep synchrotron continuum to X-ray wavelengths implies a very large X-ray excess using the 1983 April–May spectrum of Bregman *et al.* Their average X-ray flux density would lie a factor of ~ 100 above the extrapolated synchrotron flux density if $\alpha = -2.0$ from optical to X-ray wavelengths.

One prediction of our two-component model is that wavelength-dependent fractional polarization should always be observed to some degree at optical wavelengths. In fact, measurements of $P(\nu)$ made within a year or so must be explained by essentially the same unpolarized diluting spectrum if an accretion disk model is valid. This is because the variability time scale of the disk is likely to be quite long (1 yr or more), given the large size of the disk. Visvanathan (1973) may not have observed significant wavelength dependence (although his observation on 1968 June 28 shows P dropping from 7.1% at 0.77 μm to 5.1% at 0.63 μm) because 3C 345 was in a low-polarization state ($P \leq 5\%$). This makes observing $P(\nu)$ extremely difficult. Bailey, Hough, and Axon (1983) may not have observed wavelength dependence between optical (0.65 μm) and infrared (1.5 μm) wavelengths because of their red optical bandpass. Weak wavelength-dependent polarization between the red (0.6–1.0 μm) and the near-infrared bandpasses is predicted by our model unless α is extremely steep.

The wavelength-dependent polarization of 3C 345 is fairly well described by the simple two-component model presented above. The viability of this model can be tested by extending the optical and near-infrared simultaneous polarimetric and photometric observations to the ultraviolet. Our model predicts that P should increase in the near-ultraviolet. However, reasonable modifications to the model could keep P depressed, relative to its near-infrared value, far into the UV. The synchrotron spectrum could continue to steepen toward higher frequencies, allowing the thermal component to dominate farther into the UV. The steepening of the spectral index would temper this effect somewhat because of the slightly increased polarization of the synchrotron emission (Nordsieck 1976; Bjornsson and Blumenthal 1982). A much more important modification could be that the emission from an accretion disk may not be approximated very well by a single blackbody. Malkan and Sargent (1982) and Malkan (1983) point out that a more realistic accretion disk model may be one where the thermal emission comes from different regions in the disk, with each region having a different characteristic temperature. Such a model produces significant emission over a much broader spectral region than a single blackbody. Our data do not extend far enough into the UV to see possible thermal components hotter than $\sim 20{,}000$ K.

V. SUMMARY

Detailed multiwavelength, optical, photometric, and polarimetric monitoring of 3C 345, from early 1983 to the middle of 1984, reveals several properties of this OVV quasar not observed in other highly polarized extragalactic objects. The polarization of the optical emission was strongly correlated with brightness during this period. When 3C 345 was close to its peak brightness during the intense 1982–1983 outburst, the fractional polarization was at the highest recorded level for this quasar (35%). The optical polarization dropped to less than 10%, and θ rotated from 15° to between 70° and 90° as the object dimmed. Strong wavelength-dependent fractional polarization was also observed throughout this period. The degree of optical linear polarization increased with wavelength. Wavelength dependence in the optical polarization position angle was very mild.

The polarization wavelength dependence is consistent with dilution of the synchrotron light by unpolarized emission from thermal gas. We have successfully modeled the wavelength dependence with a two-component model consisting of a single blackbody and a power-law, synchrotron component that has a steep optical spectrum ($\alpha < -1.4$). This model also describes well the flattening of the optical spectral index as 3C 345 dimmed during the first half of 1983. The blackbody component is consistent with the blue bump found by Bregman *et al.* (1986) and may be optically thick emission from an accretion disk. A temperature between 13,000 and 20,000 K for the blackbody is indicated by our model. However, the model is not sensitive to hotter thermal components because our observations do not extend to short enough wavelengths. Extending the simultaneous polarimetry and photometry into the ultraviolet will better constrain the strength and spectral shape of the thermal component.

The near-infrared fractional polarization was observed to be greater than the optical in 1984 January and June. There was also a 10° difference between infrared and optical polarization position angles. During 1983 late June and early July, the near-infrared polarization decreased with wavelength and strong wavelength dependence in the polarization angle was observed. The blue bump does not significantly affect the polarization at infrared wavelengths and would not cause wavelength-dependent θ. We interpret the wavelength-dependent polarization observed at near-infrared wavelengths as evidence for a second synchrotron component with different polarization characteristics than the component dominating at shorter wavelengths.

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