SPECTROPOLARIMETRY OF 3CR 68.1: A HIGHLY INCLINED QUasar

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ABSTRACT

We present Keck spectropolarimetry of the highly polarized radio-loud quasar 3CR 68.1 (z = 1.228, V = 19). The polarization increases from 5% in the red (4000 Å rest frame) to greater than 10% in the blue (1900 Å rest frame). The broad emission lines are polarized the same as the continuum, which shows that 3CR 68.1 is not a blazar, as it has sometimes been regarded in the past. We also present measurements of the emission lines and a strong, blueshifted, associated absorption line system as well as a detection at the emission-line redshift of Ca II K absorption, presumably from stars in the host galaxy. Neither a blazar nor a partially obscured radio-quiet QSO, 3CR 68.1 belongs to an observationally rare class of highly polarized quasars. Taking into account the other unusual properties of 3CR 68.1, such as its extremely red spectral energy distribution and its extreme lobe dominance, we explain our spectropolarimetric results in terms of unified models. We argue that we have a dusty, highly inclined view of 3CR 68.1, with reddened scattered (polarized) quasar light diluted by even more dust-reddened quasar light reaching us directly from the nucleus.

Subject headings: quasars: individual: 3CR 68.1 — line: profiles — quasars: absorption lines — quasars: emission lines — quasars: general — techniques: polarimetric

1. INTRODUCTION

The quasar 3CR 68.1 (z = 1.228, V = 19) possesses a unique combination of extreme properties. The optical-UV continuum is among the reddest of any known quasar, with F_v ∝ v⁻⁹ in the UV (Boksenberg, 1976; Smith & Spinrad 1980). The quasar 3CR 68.1 is one of the most highly polarized quasars, with a polarization in a broad bandpass from 3000–8000 Å of 7.5% ± 1.3% at 52° ± 5° (Moore & Stockman 1981, 1984). The lobes of 3CR 68.1 mark the quasar as a powerful radio source, but the extremely faint radio core (~1 mJy at 5 GHz; Bridle et al. 1994) makes this object one of the most lobe-dominant quasars. Under unified schemes, it is the most highly inclined 3CR quasar known (e.g., Orr & Browne 1982; Hoekstra, Barthel & Hes 1997). Extreme objects like 3CR 68.1 may provide clues as to how their properties may be related in less extreme active galactic nuclei (AGNs).

The quasar 3CR 68.1 has been classified as a blazar because of its high polarization and red color (e.g., Ledden & Odell 1985), but we thought that this was unlikely because the degree of polarization and position angle did not change between measurements made 6 months apart (Moore & Stockman 1981, 1984) and the optical continuum level is not violently variable (Smith & Spinrad 1980). Also, it does not have the core-dominant radio structure that is always characteristic of radio-selected blazars. In fact, in the revised 3C sample (Laing, Riley, & Longair 1983; Hoekstra et al. 1997), it is the most lobe-dominant quasar with the largest projected lobe separation, which is large even among radio galaxies, suggesting a radio axis close to the sky plane.

Most highly polarized QSOs (HPQs) can be classified as radio-quiet (including many BAL QSOs) or radio-loud blazars. The polarization mechanism in radio-quiet QSOs is scattering (e.g., BAL QSOs: Wills et al. 1997; IRAS non-BAL QSOs: Wills et al. 1997; Wills et al. 1992). The broad emission lines and continuum show similar degrees of polarization, but the narrow emission lines are unpolarized (Goodrich & Miller 1988). Apparently OI 287 is a normal...
SPECTROPOLARIMETRY OF 3CR 68.1

On 1996 December 10 (UT), we observed 3CR 68.1 with the Low Resolution Imaging Spectrometer (Oke et al. 1995) in spectropolarimetry mode (Goodrich, Cohen, & Putney 1995; Cohen et al. 1997) on the 10 m Keck II telescope. The 300 line mm$^{-1}$ grating blazed at 5000 Å with a 1" slit (at 226°, approximately the parallactic angle) gave an effective resolution $\leq$10 Å (FWHM of comparison lamp lines); the dispersion was 2.5 Å pixel$^{-1}$. The seeing just prior to the observation was 1.1". The observation was broken into four 15 minute exposures, one for each wave plate position (0°, 45°, 22.5°, and 67.5°). We observed a bright star through UV22°.5, 67°.5). The seeing 226°, approximately the parallactic angle) gave an effective resolution $\leq$10 Å (FWHM of comparison lamp lines); the dispersion was 2.5 Å pixel$^{-1}$. The seeing just prior to the observation was 1.1". The observation was broken into four 15 minute exposures, one for each wave plate position (0°, 45°, 22.5°, and 67.5°). We observed a bright star through UV and IR polaroid filters to measure and calibrate the wavelength-dependent polarization position angle changes imparted by the instrument optics. The polarization measurement efficiency was essentially 1.0 at all wavelengths. We observed the flux standard Feige 110 (at the parallactic angle, seeing 1.3°) both in direct light and with an OG 570 filter. No order-blocking filter was used for the 3CR 68.1 observation because of its weak blue flux and the decreased second-order efficiency of the grating. Then we observed the polarized standard star HD 245310 (at the parallactic angle; Schmidt, Elston, & Lupie 1992) in all four wave plate positions in order to determine the zero point of the polarization position angle.

We reduced our data to one-dimensional spectra using standard techniques within the IRAF NOAO package. The root mean square uncertainties in the dispersion solution were 0.2 Å, and we used sky lines to ensure that our zero point was accurate to 0.1 Å. Wavelengths are air wavelengths. We followed standard procedures (Miller, Robin-son, & Goodrich 1988; Cohen et al. 1997) for calculating Stokes parameters and uncertainties. We used the measurements of Massey et al. (1988) and Massey & Gronwall (1990) for flux calibration. The Galactic absorption in the direction of 3CR 68.1 is small, $A_V = 0.15$ (Burstein & Heiles 1982). We give observed quantities below, but where noted, we have corrected our data for the Galactic extinction using the curve of Cardelli, Clayton, & Mathis (1989).

### 3. RESULTS

Figure 1 shows our main results, including the total flux density spectrum ($F_\nu$), the percentage polarization ($P$), the electric vector polarization position angle ($\theta$), and the polarized flux density ($P/100 \times F_\nu$). Except for the total flux spectrum, the data are binned (100 Å in the continuum but more finely around the emission lines, as described below). The bins were first formed using the one-dimensional raw count spectrum from each wave plate position; the error bars assume Poisson noise from the object and background sky counts, plus the CCD read noise. These binned data then determine the binned linear Stokes parameters, including $P$ and $\theta$, with errors propagated through the polarization calculation.

![Figure 1: Spectropolarimetric results for 3CR 68.1.](image-url)
3.1. Polarimetry

The continuum polarization increases toward shorter wavelengths, from \( \approx 5\% \) at the red end of our spectrum to greater than 10% at the blue end. Within the uncertainties, \( \theta \) is constant across the entire range, with an average of \( \approx 53.3 \pm 0.2 \). The high polarization and position angle are consistent with the broadband results of Moore & Stockman (1984), which suggests that the polarization has not varied over more than a decade.

The open squares in Figure 1 designate finer bins coincident with some of the more prominent spectral features (observed wavelength range of the bins): C \([\text{III}] \lambda 1909\) (4140–4220 and 4260–4360 Å for the broad wings, 4220–4260 Å for the narrower core), [Ne \( IV \)] \( \lambda 2424 \) (5385–5415 Å), Mg \( II \) \( \lambda 2800 \) (6040–6170 and 6270–6440 Å for the broad wings, 6170–6200 and 6240–6270 Å for the narrower core emission, and 6200–6240 Å for the absorption doublet), [O \( II \)] \( \lambda 3727 \) (8290–8325 Å), and [Ne \( III \)] \( \lambda 3869 \) (8605–8635 Å). The Mg \( II \) and C \([\text{III}] \) lines appear polarized at similar levels and position angles as the continuum. The strong forbidden lines [O \( II \)] \( \lambda 3727 \) and [Ne \( III \)] \( \lambda 3869 \) appear unpolarized in the polarized-flux spectrum, although the uncertainties are too large to be sure.

3.2. Emission-Line Spectrum

Table 1 gives parameters for the emission lines in the total flux spectrum of 3CR 68.1. The uncertainties are based on choosing extreme, but still reasonable, high and low continua, thus representing the range in probable values.

In both C \([\text{III}] \lambda 1909\) and Mg \( II \) \( \lambda 2800 \), there are clear inflections that suggest “narrow” and “broad” components. In addition to total line measurements, we fitted Gaussians to these separate components (making a simple linear interpolation across the absorption in the Mg \( II \) profile—certainly an underestimate for the associated Mg \( II \) absorber). Again, uncertainties represent the range in measurements for reasonable continuum choices.

We derive \( z_{\text{em}} = 1.228 \), which is in agreement with that from the broad lines, by averaging values for several narrow lines. This is the same value as obtained by Smith & Spinrad (1980).

3.3. Absorption-Line Spectrum

Table 2 gives measurements of the wavelengths and equivalent widths for absorption lines in the total flux spectrum of 3CR 68.1. We identify a number of low-ionization associated absorption lines at \( z_{\text{abs}} = 1.2258 \) and a Ca \( II \) K feature at \( z_{\text{abs}} = 1.2287 \) (Ca \( II \) H is coincident with the [Ne \( III \)] \( \lambda 3967 \) line). The measurements of the Mg \( II \) absorption are more uncertain than suggested by the table because of the narrow Mg \( II \) emission component. The absorption lines are labeled in the upper panel of Figure 1.

Our results differ from those of Aldcroft, Bechtold, & Elvis (1994) in several respects. Their spectrum is of higher resolution (350 km s\(^{-1}\)) but has a lower signal-to-noise ratio. We find a lower blueshift for the Mg \( II \) doublet (\( \approx 300 \) km s\(^{-1}\) instead of 2000 km s\(^{-1}\)), which seems robust in light of our low uncertainties and good agreement among lines, both in emission and absorption (the Fe \( II \) absorbers, which are too weak for Aldcroft et al. to have found, have redshifts that match that of Mg \( II \) and Mg I). The absolute agreement in wavelength between our results and Aldcroft et al. is good (about 100 km s\(^{-1}\)). The cause of the blueshift difference is our adopted \( z_{\text{em}} \); we use \( z_{\text{em}} = 1.228 \), while Aldcroft et al.
use the less accurate z_{em} = 1.240. We do not see the inter- 
vening Mg II absorber at z = 0.7750 that they report. We do 
not separate the absorption feature at 7093.5 Å into a 
doublet, even though our resolution should be sufficient to 

slope the doublet, even though our resolution should be sufficient to 

slope the feature in the elliptical galaxy template of Kinney et al. (1996) would suggest that at 3900 Å rest frame, one-quarter (1996) of the total flux in 3CR 68.1 is contributed by the host galaxy (see also § 4).

### Table 1

| Line Identification | Center$^a$ (Å) | Observed Flux (10^{-16} ergs s^{-1} cm^{-2}) | EW$^b$ (Å) | FWHM$^c$ (km s^{-1}) | Galactic Factor$^d$ (A_v = 0.15) |
|---------------------|----------------|------------------------------------------|------------|---------------------|---------------------------------|
| Total C IV 1909     | 4251.0 ± 0.4   | 7.0 ± 0.8                                 | 19.7 ± 1.8 | 1300 ± 200          | 1.45                            |
| Broad C IV 1909     | 4249 ± 3       | 5.9 ± 0.8                                 | 13 ± 1.8   | 7400 ± 800          | 1.45                            |
| Narrow C IV 1909    | 4251.0 ± 0.4   | 3.0 ± 0.1                                 | 6.7 ± 2.2  | 800 ± 50            | 1.45                            |
| C II 2326           | 5183.5 ± 1.0   | 1.1 ± 0.4                                 | 1.1 ± 0.4  | 1300 ± 400          | 1.44                            |
| [Ne IV] 2425        | 5399.5 ± 0.4   | 1.6 ± 0.1                                 | 1.3 ± 0.1  | 700 ± 50            | 1.39                            |
| Total Mg II 2800    | 6226 ± 2       | 40 ± 8                                    | 28 ± 5     | 4500 ± 500          | 1.30                            |
| Broad Mg II 2800    | 6227 ± 5       | 38 ± 5                                    | 25 ± 2     | 14400 ± 500         | 1.30                            |
| Narrow Mg II 2800   | 6226 ± 2       | 5.5 ± 0.5                                 | 3.1 ± 0.3  | 2000 ± 200          | 1.30                            |
| He I 2830          | 6314.2 ± 0.8   | 1.4 ± 0.5                                 | 0.8 ± 0.3  | 1100 ± 200          | 1.30                            |
| O III 3333         | 6978 ± 2       | 1.2 ± 0.4                                 | 0.7 ± 0.2  | 1400 ± 200          | 1.27                            |
| He II 3230 + (Fe II) | 7139 ± 1.5     | 1.5 ± 0.3                                 | 7.9 ± 1.6  | 1600 ± 200          | 1.27                            |
| [Ne V] 3346         | 7452.6 ± 0.3   | 1.3 ± 0.4                                 | 0.8 ± 0.2  | 700 ± 100           | 1.25                            |
| [Ne V] 3346 + O III 3444 | 8309.0 ± 0.3 | 6.8 ± 0.4                               | 3.5 ± 0.2  | 500 ± 40            | 1.24                            |
| [Ne II] 3869 + H8 + He I 3888 | 8623.3 ± 0.3 | 6.8 ± 1.0                           | 3.5 ± 0.6  | 600 ± 70            | 1.23                            |

$^a$ Air wavelengths.
$^b$ Corrected to rest frame.
$^c$ Corrected for the instrumental resolution of \( \sim 10 \) Å.
$^d$ Flux densities should be multiplied by this factor to correct for Galactic reddening.

### Table 2

| Identification     | Center$^a$ (Å) | \( \lambda_{grep} $ (Å) | \( z_{abs} $ | EW$^b$ (Å) |
|--------------------|----------------|-------------------------|------------|------------|
| Fe II 2382         | 5301.7 ± 0.7   | 2382.0                  | 1.2257(3)  | 1.0 ± 0.3  |
| Fe II 2386         | 5757.3 ± 0.1   | 2585.9                  | 1.2264(1)  | 1.0 ± 0.2  |
| Fe II 2600         | 5785.5 ± 0.1   | 2599.4                  | 1.2257(1)  | 2.0 ± 0.2  |
| Mg II 22796        | 6221.0 ± 0.5   | 2795.5                  | 1.2254(2)  | 6.5 ± 0.2  |
| Mg II 22803        | 6238.3 ± 0.2   | 2802.7                  | 1.2258(1)  | 4.4 ± 0.2  |
| Mg II 22853        | 6348.3 ± 0.6   | 2852.1                  | 1.2258(2)  | 1.1 ± 0.2  |
| He I 31877         | 7093.0 ± 1.0   | 3187.7                  | 1.2251(5)  | 1.5 ± 0.9  |
| Ca II K            | 8767.0 ± 0.5   | 3933.7                  | 1.2287(1)  | 5.0 ± 0.8  |

$^a$ Uncertainties quoted denote the range of acceptable measurements rather than formal \( \sigma \) fitting errors.
$^b$ Air wavelengths.
$^c$ Equivalent widths (EWs) are in the observed frame.

### 4. Discussion

#### 4.1. The Spectral Energy Distribution

The quasar 3CR 68.1 would not be found in an UV- excess survey. Some 10% of quasars in the 3CR sample, 3CR 68.1 being the most extreme, are significantly redder than bright optically selected quasars (Smith & Spinrad 1980). The object 3CR 68.1 has been observed in many wave bands. Figure 3 shows the spectral energy distribution (SED) of 3CR 68.1, from the far IR through the 2 keV X-rays, using measurements from the literature as noted in the caption. For comparison, 3C 110, a normal “blue” lobe-dominated quasar, is also shown.

The UV continuum is so weak that Bregman et al. (1985) argue that the large ratio of low- to high-ionization line intensities is the result of photoionization by a separate soft X-ray component, which gives rise to an extended partially ionized zone in which strong low-ionization lines can be produced. A simpler explanation is that the quasar continuum and line spectrum are highly reddened, and emission-line clouds see a less obscured ionizing continuum than does an observer. The lack of a 2200 Å dust absorption feature is not a strong argument against reddening: no 2200 Å feature is seen in the Small Magellanic Cloud (SMC) reddening “law” (Prevot et al. 1984); even for Galactic dust, the 2200 Å feature can be filled in by scattering in geometries possible for 3CR 68.1 (e.g., Witt, Thronson, & Capuano 1992). A 2200 Å dust feature is also absent in the spectra of BAL QSOs (Sprayberry & Foltz 1992; Hines & Wills 1995). Also, the composition of extragalactic dust may differ from that found in the Milky Way.

Figure 4 compares our total flux spectrum with the photometry of Neugebauer et al. (1979) and Smith & Spinrad (1980). There is good agreement at blue wavelengths and a (≈ 20%) difference at red wavelengths. Given the uncertainties in the flux calibration and our narrow slit, the...
general agreement is satisfactory. It seems probable that 3CR 68.1 has not varied significantly during the last 20 years.

4.2. The Polarization Mechanism

The polarization mechanism in 3CR 68.1 is probably scattering by a nonspherical distribution of either small dust grains or electrons. Other mechanisms can be ruled out:

1. Polarized synchrotron radiation.—This mechanism fails to account for the broad emission lines polarized the same as the continuum.

2. Galactic interstellar polarization.—The interstellar polarization toward two stars close to the line of sight, SAO 55659 and SAO 55667 (less than 1° from 3CR 68.1), is ≤0.4% (D. Wills, private communication).

3. Host galaxy interstellar polarization.—The observed polarization shape and maximum differ significantly from a Serkowski Law, and as we show below, the maximum polarization is significantly greater than $9 \times E(B-V)$, the polarization observed toward aligned dust-redened lines of sight in the Milkey Way.

Scattering by electrons or small dust grains ($2\pi d/\lambda \ll 1$) can result in very high polarization (§ 4.3) that is essentially wavelength independent. Large grains, which polarize light with a stronger wavelength dependence, scatter less efficiently.

We propose that the polarized spectrum arises from scattering of central quasar light and that the rise in polarization to shorter wavelengths results from dilution by a redder spectrum. We further propose that the diluting spectrum is the quasar spectrum seen directly but reddened by dust, with some possible contamination by starlight from the host galaxy. It is likely that interstellar polarization from our galaxy or the host galaxy is small, so we do not include it. Hence the total observed spectrum of 3CR 68.1 can be described as follows:

$$\text{Total}_\lambda = S_{\lambda, \text{as}} + D_{\lambda, \text{ad}} + H_\lambda + \text{NLR},$$

where $S_{\lambda, \text{as}}$ is a scattered QSO spectrum reddened by an extinction $A_B$, $D_{\lambda, \text{ad}}$ is the direct QSO spectrum reddened by an extinction $A_B$, $H_\lambda$ is the host galaxy spectrum, and NLR is the spectrum of the narrow-line region which is unpolarized and is emitted probably from an extended region outside or coincident with the scattering region. The scattered spectrum is equal to the polarized spectrum divided by the polarization, $p_s$, of the scattered light alone.

To illustrate quantitatively the plausibility of our picture and to constrain the fraction of scattered light and reddening toward the central quasar, we have matched composite model spectra to the total light SED of 3CR 68.1. We first adjusted our spectrum to the photometry of Neugebauer et al. (1979). Free parameters are the intrinsic polarization of the scattered light, $p_s$, assumed to be wavelength-independent, and the fraction of host galaxy starlight. The strength of the Ca II K absorption feature suggests that up to one-quarter of the total light at 3900 Å rest frame may be host galaxy starlight. We note that Palomar 5 m image-tube plates show no extensions characteristic of a luminous host galaxy (Longair & Gunn 1975). We use the elliptical galaxy template of Kinney et al. (1996) to represent the starlight contribution. We represent the spectrum of the unreddened central quasar by a mean spectrum of lobe-dominated quasars (based on spectra of the Hubble Space Telescope sample described by Wills et al. 1995). The scattered light spectrum is derived from this mean spectrum by scaling and reddening it using an SMC-type extinction law (Prevot et al. 1984) with $A_V = 0.7$ to match the observed polarized flux density spectrum, then dividing by $p_s$. After subtracting the host galaxy starlight and scattered light from the SED, we are left with a spectrum that we fitted with a reddened central quasar spectrum.

Figure 5 presents four model composite spectra. Table 3 summarizes the model parameters, along with those of two intermediate cases. Models A, B, and C include no contribu-

| Model | $p_s$ | Galaxy | Direct $A_V$ | Scattered/Direct |
|-------|-------|--------|-------------|-----------------|
| A     | 80%   | No     | 1.2         | 0.04            |
| B     | 50%   | No     | 1.3         | 0.06            |
| C     | 20%   | No     | 1.6         | 0.13            |
| $A_0$ | 80%   | Yes    | 1.1         | 0.06            |
| $B_0$ | 50%   | Yes    | 1.2         | 0.09            |
| $C_0$ | 20%   | Yes    | 1.5         | 0.17            |
tion from the host galaxy and have $p_s = 80\%$, 50\%, and 20\%. The direct line-of-sight reddening required is $A_V = 1.2$, 1.3, and 1.6, respectively. Models $A_G$, $B_G$, and $C_G$ cover the same range in $p_s$ and include a host galaxy contribution of 25\% of the total flux density at 3900 Å. The deduced line-of-sight reddening is then $A_V = 1.1$, 1.2, and 1.5, respectively. Also tabulated is the ratio of scattered to direct light after correction for reddening. Our comparison in Figure 5 extends over the range in our templates, from rest frame $B$ to $H$; the fits over the range of our Keck data are in good agreement for the continuum, but if the SED from § 4.1 is correct in the near-IR, Figure 5 shows that models without a large elliptical host galaxy contribution are preferred.

Assuming $H_0 = 50\, \text{km s}^{-1}\text{Mpc}^{-1}$ and $q_0 = 0$ and using the observed spectrum and the known Galactic reddening, the absolute rest frame $B$ magnitude for 3CR 68.1 is $M(B) = -26.6$. Under the parameters of model A and dereddening the total light spectrum by $A_V = 1.2$, the intrinsic unreddened $M(B) = -28.2$. This result is not very model dependent. Therefore, 3CR 68.1 is one of the most optically luminous 3CR quasars, more in line with its radio luminosity, which is one of the highest among 3CR quasars. The radio and optical luminosities then follow the trend found by Wills & Brotherton (1995).

4.2.1. Other Red, Scattered Light, Radio-loud Quasars

There are few quasars with unusual combinations of properties similar to that of 3CR 68.1. As mentioned in § 1, the quasar OI 287 (Antonucci, Kinney, & Hurt 1993; Goodrich & Miller 1988; Rudy & Schmidt 1988) has a high, stable optical polarization, a quiescent optical flux, blueshifted associated absorption, and is lobe dominant; OI 287 differs from 3CR 68.1 in that its polarization position angle is parallel to its radio axis. WN J0717 + 4611 (De Breuck et al. 1998) is another highly polarized red quasar, a steep spectrum radio source that is neither a blazar nor radio-quiet QSO; its polarization is perpendicular to the radio jet axis. It has been proposed that these quasars are partially obscured, with red colors as a result of dust extinction and polarization arising from scattering along less obscured lines of sight. 3CR 68.1 and objects such as these constitute a separate class of HPQs distinct from optically violent variables and radio-quiet QSOs. There are other radio-loud type 2 (NLR-dominated) objects known, of quasar-like luminosities, with broad lines and continua seen in scattered light—presumably “buried” quasars, e.g., Cyg A (Ogle et al. 1997), 3C 324 (Cimatti et al. 1996), 3C 265 (Dey & Spinrad 1996), and IRAS 09104 + 4109 (Hines & Wills 1993).

4.3. Geometry and Unified Schemes

The object 3CR 68.1 is a classic quasar, judging by its luminosity and broad UV emission lines of typical equivalent width. At 178 MHz, it is one of the three most powerful 3CR quasars in the compilation by Laing, Riley, & Longair (1983). The extreme dominance of the powerful lobes in 3CR 68.1, the largest projected lobe separation of any 3CR source, the reddest continuum of any quasar, and the highest scattered-light polarization of any 3CR source immediately suggests a connection with highly inclined
AGNs in unified schemes. It is also of interest for testing unified schemes as it is a member of the only sample with complete optical identifications, selected by an essentially orientation-independent quantity directly related to the power of the central engine—the low-frequency (178 MHz) radio flux density.

Barthel (1989) based the arguments for the unification of radio-loud quasars and FR II radio galaxies on the 3CR sample, suggesting that radio galaxies are quasars at axial inclinations greater than the half-opening angle of a geometrically and optically thick dusty torus, about 45°, so that their quasar nuclei are obscured. A variety of observational techniques have already shown that many 3CR radio galaxies harbor hidden quasar nuclei, and ionization and scattering “cones” have been found along the radio jet direction (e.g., Tran et al. 1998). In principle, the polarization and reddening properties of the 3CR sample could be used to deduce the thickness of the obscuring torus as a function of inclination. Hill, Goodrich, & DePoy (1996) partially perform this exercise by looking for broad lines in the near infrared (where dust reddening is less) for a complete sample of 11 3C radio sources (eight narrow-line radio galaxies, two broad-line radio galaxies, plus 3C 273). They find that the majority of objects have their broad-line regions reddened by $A_V \approx 3.0$ and their narrow-line regions by $A_V \approx 1.5$. We investigate the properties of 3CR 68.1 in light of this unification scheme.

Figure 6 compares the observational results with the results of a simple scattering model (after Brown & McLee 1977; see also Wills et al. 1992) in which we assume a uniformly filled cone of wavelength-independent scatterers and a scattering optical depth of unity appropriate for high polarization efficiency. The geometry of the cone is defined by the inclination $i$ of its axis to the observer’s line of sight and the cosine of its half-opening angle $\theta_c$. The intrinsic polarization of light scattered toward the observer is $p_s$ and $p_d$ Scattered/Direct is the observed ratio of scattered to direct light assuming no obscuration. Grid lines of various $i$’s and $\cos \theta_c$’s are shown. From the position of the models of Table 3 on the grid, the cone half-opening angle is between 26° and 46°, and the inclination $i$ is greater than 41°. For an ideal “virtual” cone with an axis along the radio jets (the central engine axis), the polarization position angle ($E$-vector) is perpendicular to the radio axis, but the observed position angle for 3CR 68.1 is $\approx 60^\circ$ to the radio axis. This discrepancy suggests a partially filled virtual cone or clumpy obscuration within a virtual cone. In this case, the cone determined from Figure 6 will be defined by the scatterers that we “see;” it is tilted in the plane of the sky by 30°, and its opening angle is smaller than the size of the virtual cone.

The smaller inclinations consistent with the polarization of 3CR 68.1 are near the Barthel model dividing value of 45°. The modest reddening toward the center ($A_V \approx 1–1.5$) is also between values for radio galaxies and UV-selected quasars. It may be helpful to realize that the observed continuum is especially steep because the UV is shifted to observed wavelengths, not because the reddening is especially high. The line of sight would be skimming the torus in this case. However, the extreme lobe-dominance and large lobe separation are not consistent with smaller inclinations.

The larger inclinations, corresponding to jets almost in the plane of the sky, are consistent with the radio structure and the polarization results, but in this case we would expect the direct view of the center to be completely blocked by a thick torus. One way out is for the torus to be geometrically thin, a possibility also suggested for the other
scattering-polarized radio-loud quasar, OI 287. This might also tie in with the most luminous AGNs having the thinnest dusty disks (e.g., Antonucci 1993).

The strong, blueshifted, Mg II absorption in 3CR 68.1, identified by Aldcroft et al. (1993, 1994) and confirmed here, is sufficiently deep that the absorbing gas must lie at least in the direct path and perhaps also in the scattered light path. In unified schemes, lobe-dominant, high-inclination quasars are more likely to show absorption along the line of sight (for 3C quasars: Wills et al. 1995; see also Aldcroft et al. 1993). The quasar 3CR 68.1 follows this trend.

Several modifications of the simple Unified Model for radio galaxies and quasars, involving the effects of absorption toward the central source, the radio core, the scatterers, and the NLR, are suggested in the case of 3CR 68.1. (1) Even for highly inclined AGNs like the radio galaxies, the radio core dominance is among the smallest (log $R = -3.2$). In the lower inclination case, a possibility is that the reddened line of sight combined with the very weak radio core is the result of radio free-free absorption by dusty, ionized gas. This could be tested by determining the shape of the radio spectrum and also by searching for X-ray absorption edges of O vii and O viii (as for IRAS 13349+2438: Beichman et al. 1986; Brandt et al. 1997; see also Leighly et al. 1997; Grupe et al. 1997). (2) The polarization position angle is not perpendicular to the radio jets as discussed above, which suggests a partially filled or partially obscured cone, and (3) the narrow-line (NLR) equivalent widths are similar to those in our mean unreddened quasar spectrum and also similar to the composite lobe-dominated quasar spectrum of Baker & Hunstead (1995) formed from the Molonglo sample. If 3CR 68.1 were reddened by the amounts implied by our modeling, then the continuum is suppressed by 20–30 times. If the low-ionization NLR extends well beyond the dusty torus, the NLR should suffer much less redening and the EW(NLR) should be enhanced by 20–30 times. The reddening of the NLR in the Hill et al. radio galaxies, the reddened scattered spectrum of 3CR 68.1, and a partially obscured cone all suggest significant suppression.

We reach a limit to this simple interpretation if there is significant forward-scattered, less polarized light; in this case, the obscuration we derive from the steepening of the UV-optical spectrum would be an underestimate. But then the geometry of the simple unified scheme breaks down. In this regard, 3CR 68.1 makes an especially interesting and important comparison with the (only) other scattered-light, luminous radio-loud quasar, OI 287. In OI 287, the scattered light is thought to be scattered by electrons in the outer regions of a geometrically thin, dusty disk that obscures the center completely at UV-optical wavelengths. This explains its polarization parallel to the radio jets. The quasar 3CR 68.1 also shows polarization that is not exactly perpendicular to the radio jets; a polarized component as in OI 287 provides an alternative explanation to a partially filled or partially obscured scattering cone.

Overall, 3CR 68.1 fits well into the unified scheme, although it falls short of being a textbook example in several potentially interesting respects. These “shortcomings” may in the future provide opportunities to probe intrinsic obscuring structures common to all quasars.

5. SUMMARY

We have presented optical spectropolarimetry of 3CR 68.1, a quasar with an unusual combination of extreme optical, radio, and polarization properties. The polarization increases from $\approx 5\%$ at $\lambda_{\text{rest}} = 4000$ Å to greater than 10% at $\lambda_{\text{rest}} = 2000$ Å, with a nearly constant position angle of $\approx 53\%$. Broad emission lines are polarized the same as the continuum. We have measured parameters of the emission lines and absorption lines in the total light spectrum.

We have argued that scattering by dust or electrons is the polarization mechanism and that we see the quasar along two reddened lines of sight. We have modeled this situation and compared our models with published photometry. The implied reddenings are modest, $A_V = 0.7$ for the scattered line of sight and $A_V = 1.1$ to 1.6 for the direct line of sight, depending on the intrinsic polarization of the scattered light and the possible contribution of light from an elliptical host galaxy implied by Ca II K absorption.

We have interpreted the geometry in terms of unified models such that 3CR 68.1 is observed at a line of sight skimming the edge of an obscuring torus. While this interpretation appears correct and explains the main properties 3CR 68.1 very well, a few interesting issues remain in the details of the geometry and in the placement and nature of both the scattering and absorbing material.

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