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INTERMEDIATE-RESOLUTION SPECTROPOLARIMETRY OF 3C 273

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ABSTRACT

Spectropolarimetric observations of the quasar 3C 273 over the range 3200–8000 Å show wavelength-dependent polarization in the continuum, while the lines had no detectable polarization. The total polarization at the red end spectrum was near 2.5%, the highest ever measured for 3C 273. No wavelength dependence of the polarized flux is observed in most of the spectrum, while the position angle remains close to 130°. All these characteristics support a multiple synchrotron source model.

Subject headings: galaxies: nuclei — polarization — quasars: individual 3C 273

1. INTRODUCTION

The origin of the polarization in AGNs is not well understood. Many objects show some polarization, with both polarization degree and angle usually varying.

While the existence and behavior of the polarization of the continuum is well established, this is not the case for the emission lines. Some work has been published on both Seyfert galaxies (e.g., McLean et al. 1983; Miller & Antonucci 1983; Antonucci & Miller 1985; Goodrich 1989a, b) and quasars (Goodrich & Miller 1988), showing that the lines are usually polarized, although they do not always share the continuum polarization. Electron scattering mechanisms have been proposed to explain these observations. The difficulty of dealing with spectropolarimetric measurements, due to the lack of appropriate instruments, has limited such observations, although they are of great importance to understand the origin of physical processes in AGNs.

We present new spectropolarimetric observations with a resolution of ≈9Å that show the complex behavior of the polarization in 3C 273. We believe that these are the first ever spectropolarimetric observations of the quasar 3C 273. Observations made with the *Hubble Space Telescope* by Allen & Smith (1992) are not published yet and further information is not available to us. 3C 273 has $z = 0.158$ and a typical degree of polarization of $p \approx 0.5\%$. One advantage of observing this object is that extensive *UBVRI* photopolarimetry has already been published (e.g., Valtaoja et al. 1991 and references therein), which covers almost the entire range of our spectra. Both frequency-dependent polarization and position angle have been detected in this object at different times.

2. OBSERVATIONS AND REDUCTIONS

The observations were obtained on 1991 June 11–12 using the 4.2 m William Herschel Telescope (WHT) sited in the Observatorio del Roque de Los Muchachos (ORM) on the island of La Palma (Spain), equipped with the Faint Object Spectrograph (FOS). The FOS camera is a fixed-format low-dispersion spectrograph with a blue-sensitive GEC (EEV) P803 coated chip. This system has a focal ratio of f/1.4. The dispersion at the detector is 400 Å mm^{-1} in the first order (4800–9800 Å), and 200 Å mm^{-1} in the second order (3450–4800 Å). These characteristics make FOS an ideal instrument for obtaining spectropolarimetry of quasars as faint as $V = 17$ with acceptable exposure times.

For linear spectropolarimetry, a calcite plate is attached to FOS. The optics are the same as for the ISIS spectrograph and have been explained elsewhere (Rutten & Dhillon 1992). To compute the Stokes parameters, four exposures of the object are needed. See Rutten & Dhillon (1992) for further details of observation and reduction procedures. The standard exposure time was 5 minutes using a three-hole mask, each with an aperture of 1."4 on the sky, in order to get simultaneous detection of both object and sky, without superposition between the ordinary and extraordinary rays from different parts of the slit. This aperture was large enough to capture almost all the light from the quasar, given the seeing of 0."7–1."0 during the night.

Observations of standard polarized and unpolarized stars were obtained for instrumental calibration. We used HD 154445 (HR 6353) and HD 204827 (BD +58°2272) from Hsu & Breger (1982) list of high-polarization standard stars and HD 172310 (SAO 86267) from the zero polarization standards list of the Nordic Optical Telescope at the ORM. The white dwarf star HZ 44 was used for flux calibration along with the Carlsberg Automatic Meridian Circle (CAMC) measurement of extinction in V. A standard atmospheric model (King 1985) is used to calculate the extinction at other wavelengths. Sky subtraction was performed only on the first order spectra. Unfortunately, the CCD chip has a lower response near the borders (sky background), than in the middle. This effect, combined with the darkness of the sky at wavelengths shorter than 5000 Å, yields a second-order sky spectrum (blue) with insufficient counts to perform a good sky subtraction. However, it is safe to say that, on a dark, moonless night, the effect of the sky on the polarization are negligible and the flux is minimally affected, if at all. The data were reduced to a one-dimensional spectrum using the FOS package on a VAX 8350 computer, and the resulting spectra were handled using the commercial package MATLAB on a PC.

3. RESULTS

The spectral index, given by

$$F_\nu \propto \nu^{-\alpha}$$

changes from 0.38 to −0.26 from the red to the blue spectral region. In the first-order spectrum, the Hγ, Hβ, Fe II–[O III] λ5007, He I λ5876 and Hα are detected. Fe II blends are important in the whole spectrum, particularly between 4000 and 5300 Å. Their presence is associated with a large optical depth (Netzer 1990). A bump, at 7100 Å, is also clear. In the second-order spectrum, Hδ is seen, as well as Fe II–[Ne III] λ3869 and Fe II blend on 3950 Å. Unfortunately, the Hα line of 3C 273 is superposed on the O_2 atmospheric absorption band at 7600–7700 Å. This makes its flux calibration less reliable than other spectral features, although it does not affect the polarization measurements.

Figure 1 also shows the polarized flux spectrum, degree of polarization (p) and polarization position angle (Θ) of 3C 273, allowing an easy comparison of the polarization features with the spectrum. The observed p is rather high for this source. Valtaoja et al. (1991) report *UBVRI* photopolarimetric observations of 3C 273 for a period of 15 months in 1989–1990 showing that the average p was below 1%. In our spectra, the p slightly exceeds 2.5% in the region that corresponds to filter I; this is the highest value observed in 3C 273, along with a similar value from Courvoisier et al. (1988).

To obtain a dispersion in p less than 0.15%, the original signal has been resampled to a signal-to-noise ratio of 700. A well defined increase is seen in p between 3600 and 7600 Å. This is a similar result to that of Impey, Malkan, & Tapia (1989), who found that when the polarization is greater, p increases toward longer wavelengths. Nevertheless, at least four features seem to deviate from the general trend. The most noticeable is a deep minimum in the position of the Hα line. There appears to be a maximum at 6090 Å that may correspond to the [Fe VII] λ6087 line; its statistical significance is 90%. The Fe II blend of lines at 5190 Å may, in contrast, show a lower polarization than the continuum. A further feature is seen at the Hβ line, where a deep minimum, possibly also affecting the Fe II–[O III] λ5007 region, is seen.

McLean et al. (1983) found that the region between Hβ and He II λ4686 in M77 had a lower p. In 3C 273 this feature extends till 3600 Å (Fig. 1*c*). The overall form of the polarized spectrum resembles that of an inverted flux spectrum.

Figure 1*d* shows Θ resampled with the same wavelength resolution as p. Nevertheless, as Θ is a more complicated function of the Stokes parameters than p, the errors range from 2° at 3600 Å to 0°.5 in the 6850–8000 Å region, decreasing steadily with the wavelength except by a second peak of $\sigma = 4°$ that coincides with Hα. Θ appears to be steady at ≈130° over the whole spectrum, as observed by Impey et al. (1989), and around ≈ 130°, but some apparent wavelength dependence (≈10°) is observed between the blue end of the spectrum and 5500 Å. From 5500 Å to the red end, the variations in Θ have an amplitude of around 5°.

The polarized flux spectrum (P), Figure 1*b*, has an error given by the product of the flux and the error in p (0.0015%), ranging from 10^{-16} in the blue end to 1.5×10^{-17} ergs cm^{-2} s^{-1} Å^{-1} in the red end. Although Figure 1*b* shows a dependence relative to the wavelength, when considering the errors

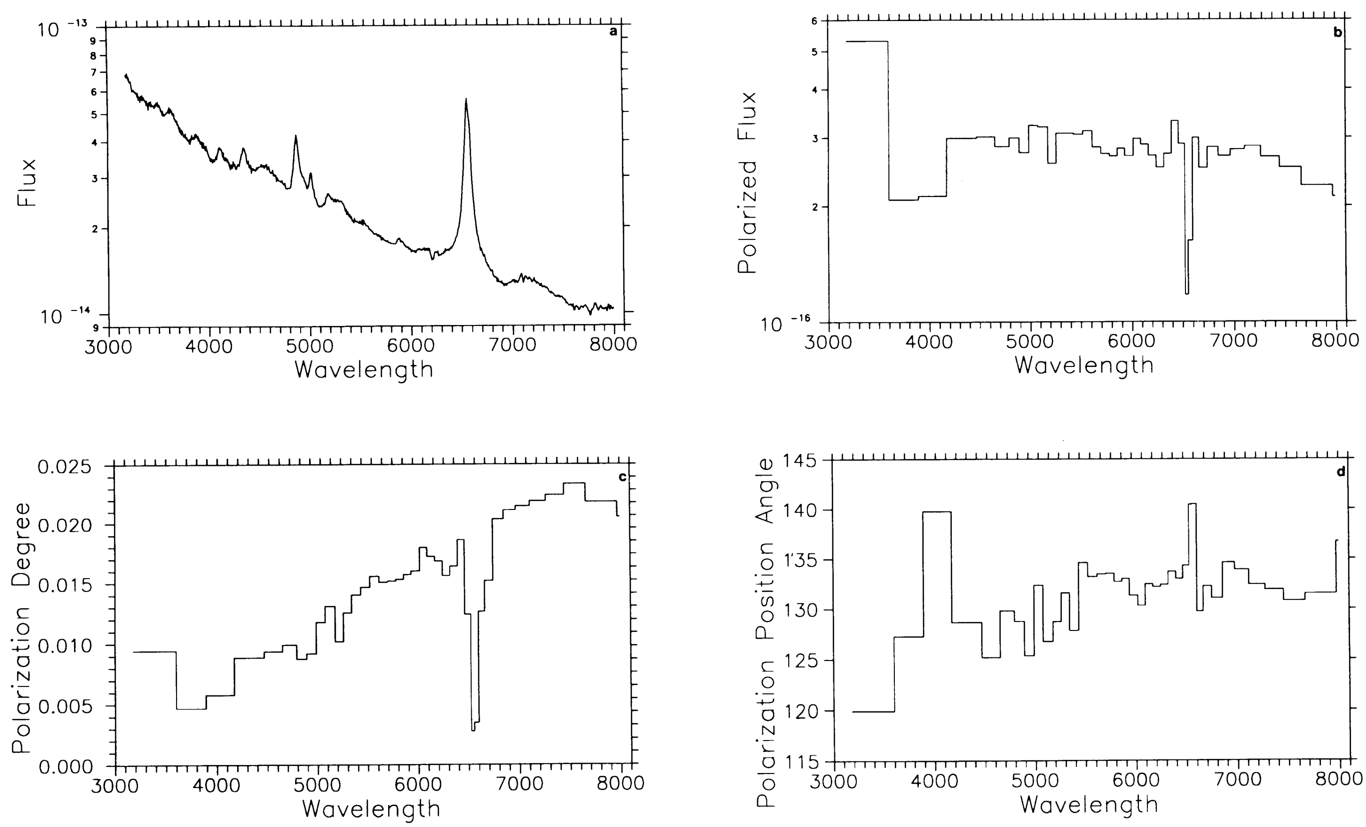

FIG. 1.—Comparison of the flux calibrated spectrum of 3C 273 with its polarization. While the total flux spectrum shows some strong emission lines (*a*), the polarized flux spectrum fails to show them (*b*). The polarization degree diminishes on the emission lines, as a consequence of being unpolarized (*c*). The polarization position angle remains close to 130°, but some apparent wavelength dependence is observed (*d*).

in P, only the larger variations have statistical significance. So, we do not have enough evidence of wavelength variations in P except at both extremes of the spectrum and possibly in the H_2 line, but the uncertainty in the line flux, due to the atmospheric O_2 absorption band noted above, might be responsible for this variation. Thus, the observations are compatible with the lines being completely unpolarized.

4. DISCUSSION

The known variable polarization of 3C 273 (e.g., Courvoisier et al. 1988; Impey et al. 1989; Valtaoja et al. 1991), rules out dust transmission and electron or dust scattering as the cause of its polarization properties. Synchrotron emission by a single source can explain the difference in polarization between the continuum and the lines, but it also produces a wavelength-independent polarization, which is not the case for the observed p. The effect of galactic dilution would be the opposite to the observed p dependence, which would decrease toward the infrared region. Nevertheless, the presence of a blackbody component, peaking in the ultraviolet region, would dilute the synchrotron component (e.g., Malkan & Sargent 1982; Malkan 1983) and may account for the observed decrease of p in the blue, as well as the blue bump observed in this object. Impey et al. (1989) propose a two-component model: a miniblazar that produces a 10% of the optical flux and a typical low-polarization quasar component totaling 90% of the optical flux, which peaks in the ultraviolet.

Synchrotron emission by a multiple source could also explain the wavelength dependence of p, e.g., the model proposed by Valtaoja et al. (1991), based on optical and radio polarimetric observations of 3C 273, which avoids any wavelength dependence of Θ in the optical region. Finally, a combination of both models (i.e., multiple synchrotron source and dilution by radiation of the blue bump) cannot be excluded.

5. CONCLUSIONS

We have presented spectropolarimetric observations of the quasar 3C 273 that show a high p for this source compared to the normal observed level, and a strong wavelength dependence of p. The Θ remains constant near 130° along the spectrum, despite the suggested preferred value of $\approx 60°$ reported by Valtaoja et al. (1991) for most of their 1989–1990 observing campaign. The polarization mechanism does not affect the emission lines, which remain unpolarized, indicating that they are formed in a different region to the continuum. Nevertheless, at the resolution of our observations, our data is compatible with the polarized flux remaining constant along the whole spectrum. If this is the case, and assuming that the BLR is optically thick (Netzer 1990), then either the observed continuum is produced between the BLR and the observer, or the continuum and the emission lines that we observe come from two separate, but not resolved, regions. The combination of a single-synchrotron, blazar-like source and dilution due to the radiation of the blue bump, as well as a multiple source model, may explain the spectral and polarization features and the variability reported elsewhere.

The effect of the unpolarized emission lines affects broad-band photopolarimetry. In particular, the bright Hα line and, to a lesser degree, the Hβ Fe II–[O III] λ5007 notch could mislead measurements in the R and V filters.

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