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ABSOLUTE SPECTROPHOTOMETRY OF QUASARS; TON 469 (3C 232) AND 3C 249.1

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RESUMEN

Se dan valores de las intensidades absolutas y anchos equivalentes para varias líneas no reportadas con anterioridad. Para TON 469, encontramos una razón de Mg II $\lambda\lambda$2934/2798 que es mayor (por un factor de alrededor de 2) que la encontrada por Grandi y Phillips (1978) y se discuten la posibilidad e implicaciones de que este cociente varíe con el tiempo. También se discuten los mecanismos de excitación de la línea de Mg II λ2934. Para 3C 249.1, hemos identificado las siguientes líneas nuevas: [Ne V] λ3346, [Ne V] λ3426 y He I λ3889. Se hacen comentarios sobre la distribución de energía en el contínuo de cada objeto, luego de comparar con observaciones previas. En ambos casos se confirman observaciones previas de variabilidad en el contínuo óptico.

ABSTRACT

Absolute intensities and equivalent widths for several lines not reported before are given for these two quasars. For TON 469, we find a ratio Mg II $\lambda\lambda$2934/2798 which is higher (by a factor of about 2) than that found by Grandi and Phillips (1978) and we discuss the possibility and implications of its variation with time. We also discuss the excitation mechanism of Mg II λ2934. For 3C 249.1, we have identified the following new lines: [Ne V] λ3346, [Ne V] λ3426 and He I λ3889. Some commentaries are made on the continuum energy distribution of each object, after comparing with previous observations. In both cases optical continuum variability is confirmed.

Key words: QUASARS – EMISSION LINES – CONTINUUM ENERGY DISTRIBUTION

I. INTRODUCTION

The observed continua of quasars arise from a combination of various emission mechanisms, both thermal and non-thermal. There seems to be a clear correlation at radio and infrared frequencies with the strength of the X-ray emission (Cruz-González 1985), suggesting that the mechanisms that power the emission at different frequencies must be related. However, in some regions of the spectrum one mechanism dominates over the others, and in other regions several mechanism can contribute.

There are of course, observed continuum properties common to all quasars, one of these has been claimed to be the "blue bump". Nevertheless, as we shall see in what follows when studied closely we see that there are differences from one object to the other.

Although physical conditions, emission mechanisms and the underlying power source are, very likely common, in each object we may be looking at different dominant processes: radiation from accretion disks (and within this frame, different modes of accretion, see e.g., Begelman 1985), relativistic jets, stellar atmospheres, dilute ionized plasma, dust, and so on.

Recently absolute spectrophotometric studies of large samples of quasars have been undertaken by several authors (see e.g., Bechtold *et al.* 1984; Oke, Shields, and Korykansky 1984). Many important general (statistical) conclusions can be drawn from these studies about the nature of quasars.

Detailed studies of the line and continuum spectra of each object, however, reveal even more crudely the complexity of the problem we face in trying to understand the nature of these, until now, mysterious objects. In what follows, we shall analyze in some detail the spectrophotometric properties of quasars TON 469 (3C 232) and 3C 249.1 and compare our results with previous observations of these objects.

II. OBSERVATIONS

The observations were carried out in March 1982 with the 2.1-m telescope of the Observatorio Astronómico Nacional at San Pedro Mártir, B.C., using a low dispersion Boller & Chivens spectrograph coupled with the Optical Multichannel Analyzer (OMA) described by Firmani and Ruiz (1981).

The spectra were taken with a 400 line/mm grating giving a resolution of about 5.5 A per channel in the second order (3800-5500 A). A wide entrance slit (3.5 X 16.5 arcsec) was used for the spectra and a second slit of the same dimensions located 7 arcsec East was used alternatively for sky subtraction. Spectrophotometric standards from Stone (1977) were observed on the same nights for calibration.

All the values for line intensities are observed values. To link the emission line intensities to the continuum, the observed equivalent widths are given.

The continuum has been fitted by eye, this being one of the main sources of error in the measurement of emission line intensities. The other sources of error (related to the first) are the estimation of the width of the broad wings, and the degree of blending due to nearby lines. The errors presented in Tables 1 and 3 are estimated on the basis of extreme combinations of these three sources of errors.

III. EMISSION LINE SPECTRA

a) *TON 469 (3C 232) – 0955 + 32*

Table 1 shows the intensities and equivalent widths measured for this object; the spectrum is shown in Figure 1. Grandi and Phillips (1978) published a high S/N spectrum of this quasar, but they give only relative fluxes, whereas we have absolute flux values.

A list of comparative measurements by different authors for the Mg II line are given in Table 2. This table gives indication of possible variability for the Mg II λ2800 emission line. This indication should be regarded with care, though, since the continuum fitting is particularly difficult in this region.

The values for the Mg II intensity and equivalent width given by Oke *et al*. (1984), are measured relative

TABLE 1

OBSERVED INTENSITIES AND EQUIVALENT WIDTHS FOR TON 469

Line	λ_{rest} (A)	I_{obs} (x 10^{-14}) (erg cm^{-2} s^{-1})	W_{obs} (A)
Mg II	2798	23 ± 5.0	148 ± 26
Mg II	2932	13 ± 3.0	119 ± 15
[O II]	3727	5 ± 0.1	70 ± 1

a. For this object z = 0.529 (Baldwin 1977*a*).

TABLE 2

INTENSITIES AND EQUIVALENT WIDTHS OF Mg II λ2800 IN TON 469

I_{obs} (x 10^{-14}) (erg cm^{-2} s^{-1})	W_{obs} (A)	I/W	References[a]
...	97	...	1
...	109	...	2
22	131	0.17	3
7	72	0.10	4
17.2	82	0.20	5
23 ± 5	148 ± 26	0.16	6

a. 1) Baldwin 1977*b*; 2) Phillips 1978; 3) Neugebauer *et al.* 1979; 4) Grandi 1981; 5) Oke *et al.* 1984; 6) this work.

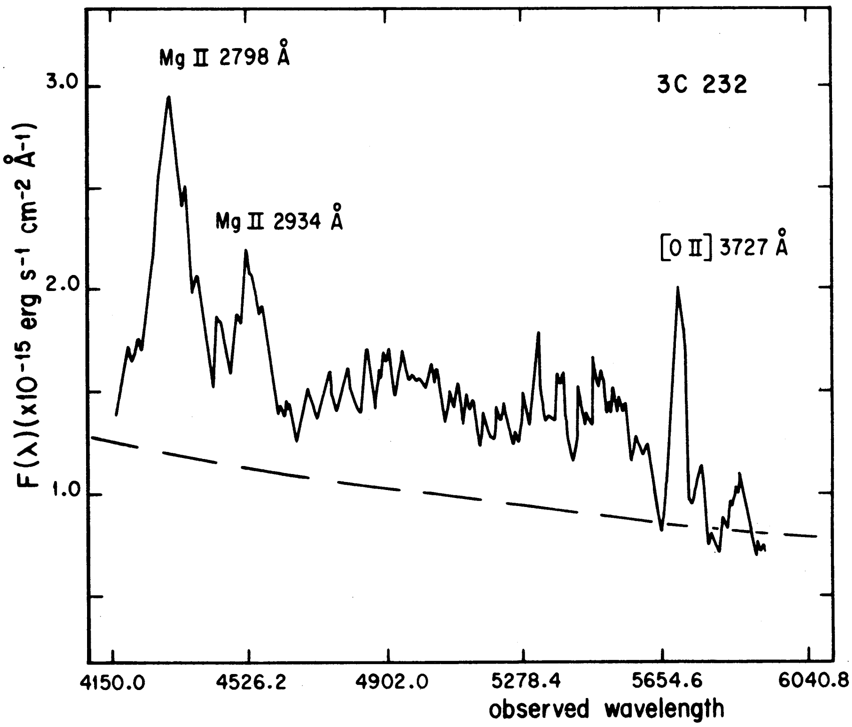

Fig. 1. Observed spectrum of TON 469 (3C 232)

to a "pseudo-continuum" estimated by them in order to avoid the Fe II emission contamination (see e.g., Joly 1981; Netzer and Wills 1983). We have made no attempt to correct for this effect, since the problem of the composition and extension of the "blue bump" is not yet a settled question, and the amount of hydrogen emission (thin or thick) and/or Fe II emission (assuming that one or both of these emissions are indeed the main contribution to the bump), cannot be as yet quantitatively distinguished. However, the minimum values (within the error bars) of our measurements, are comparable to their values (the continuum fit is similar), and we can see from Table 2 that the suggestion of variability persists.

The feature redward from the Mg II λλ2796, 2802 resonance doublet, has been identified as Mg II doublet λλ2929, 2936 ($3p^2P^0 - 4s^2S$) by Grandi and Phillips (1978). These authors suggested a fluorescence mechanism for the excitation of this line, with two possibilities: the first one, is Lβ flourescence of $5p^2P^0$ and subsequent cascades through ^2S, $^2P^0$ and ^2D terms. The second possibility is N V λλ1238.8, 1242.8 flourescense of $4p^2P^0$. Several observational predictions made by Grandi and Phillips (1978) have not been confirmed for the case of Lβ flourescence; in particular, the presence of Mg II ($3p^2P^0 - 5s^2S$) λ1752 and ($3p^2P^0 - 4d^2D$) λ1737. Unfortunately the lines, if present, would be blended with N III] λ1750. In the *UV* spectrum of this quasar published in Dultzin-Hacyan, Salas, and Daltabuit (1982) there is a line identified as N III] λ1750, but its intensity is a factor of 6 less than the intensity found for Mg II λ2798 in this work (Table 1). Lβ fluorescence should also be indicated by the presence of OI ($2p^4\ ^3P - 3s^3S^0$) λ1302, but this line is not present (see Figure 3 and Table 7 in Dultzin-Hacyan *et al.* 1982) in the *UV* spectrum.

Excitation of Mg II λ2934 by NV fluorescence does not suffer from several of the problems affecting Lβ fluorescence. The calculated ratio of Mg II λλ2934/(2798 + 2796) (see Table 2 in Grandi and Phillips 1978) is 0.50. Our observed ratio (Table 1) is 0.56 ± 20, the value by Grandi and Phillips (1978) for the observed ratio is 0.28 (no error bars are given). Thus, the ratio seems to have increased by about a factor of 2. If this ratio is varying with time, simultaneous UV and optical observations are needed in order to establish whether the mechanism of N V fluorescence is responsible for the excitation of Mg II λ2934. If this is the case, we would expect the variability of Mg II λ2934 (or the ratio 2934/2798) to be correlated with variability of N V λ1240.

Two possibilities can be contemplated: the first is that the intensity of N V is correlated (positively) with that of Mg II λ2934. This would mean that if the volume times the density square of the region where the N V line originates increases, the intensity of N V λ1240 and Mg II λ2934 raise together because as N V raises, there is an increase of resonance photons which can be absorbed by Mg II to radiate the fluorescence line. The second possibility is that the sum of I(1240) + I(2934) remains constant but their ratio changes with time. This could be due to mass motions within the region where the Mg II λ2934 line originates, affecting the optical depth in the line and thus the efficiency with which the resonance λ1240 photons are absorbed.

The totally uncorrelated behaviour of the two lines would imply that the exciting mechanism for Mg II λ2934 is not N V λ1240 flourescence.

b) *3C 249.1 – 1100 + 772*

The spectrum is shown in Figure 2 and Table 3 shows the intensities and equivalent widths. The first spectra of this quasar were obtained by Schmidt (1966), Ford and

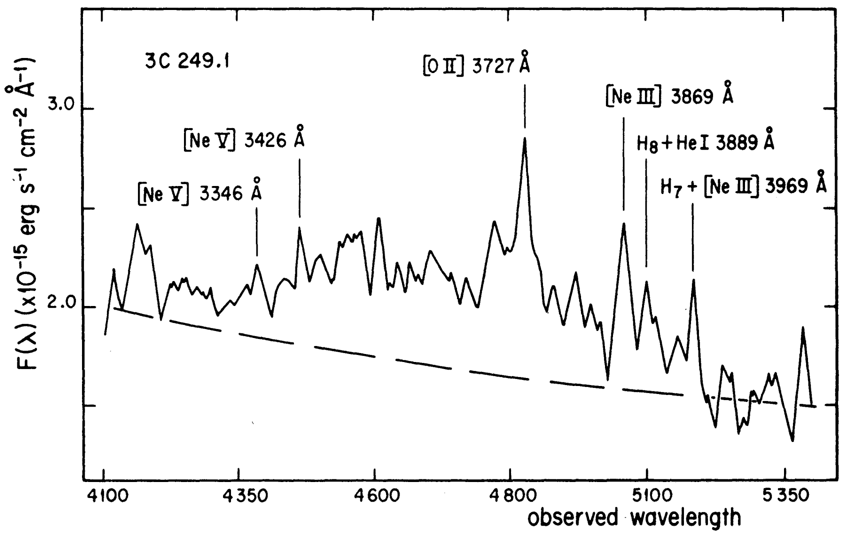

Fig. 2. Observed spectrum of 3C 249.1.

TABLE 3

OBSERVED INTENSITIES AND EQUIVALENT WIDTHS FOR 3C 249.1

Line	λ^{a}_{rest} (A)	I_{obs} ($\times 10^{-14}$) (erg cm^{-2} s^{-1})	W_{obs} (A)
[Ne V]	3346	0.9 ± 0.20	5 ± 1.0
[Ne V]	3426	1.1 ± 0.20	6 ± 1.0
[O II]	3727	2.7 ± 0.90	16 ± 5.0
[Ne III]	3869	2.2 ± 0.30	13 ± 2.0
He I + H_8	3889	1.8 ± 0.40	12 ± 2.0
[Ne III] + H_7	3967	1.2 ± 0.08	8 ± 0.5

a. For this object z = 0.311 (Schmidt 1966)

Rubin (1966) and Wampler (1968). Schmidt (1966) identified Mg II λ2798, Hβ, [O III] λλ4959, 5007 and suspected the presence of [Ne V] λ3426 and [O II] λ3727. Ford and Rubin were able to identify [O II] λ3727, [Ne III] λ3869, Hδ, Hγ, Hβ and [O II] λλ4959, 5007. Wampler measured fluxes for Mg II, hydrogen (Hα to Hδ), [O II], [O III], He I λ5876 and He II λ4686. More recently, Richstone and Oke (1977) discovered a nebulosity surrounding 3C 249.1 and were able to measure separately the nucleus and nebulosity contributions to the following lines: Mg II λ2987, [O II] λ3727, Hβ, [O III] λλ4959, 5007, He I λ5876 and Hα using a ∿ 7″ diameter aperture and an annulus with inner and outer diameters of ∿ 4″ and 10″ respectively. The only measurement that we can compare is that of [O II] λ3727, our value for the intensity of this line, corresponds to the sum of nucleus plus annulus intensities measured by Richstone and Oke (this is not surprising given the size of our slit).

Richstone and Oke used also a narrow slit (0.9 X 60 arcsec East-West) to measure the lines: [O II] λ3727 and [Ne III] λλ3869, 3968. They notice that the observed fluxes they obtain this way are lower by a factor of the order of 5, due to the narrow slit used.

We have identified and measured the following new lines: [Ne V] λ3346, [Ne V] λ3426 and He I 3889 (which is contaminated with H_8). 3C 249.1 is very similar to 3C 49 by its redshift and also by the nebula surrounding it (Wampler *et al.* 1975). The nebula is also similar to that found near 4C 37.43 (Stockton 1976). The presence of strong [O II] and [O III] lines and the absence of strong Hβ line are common features. Weak [Ne III] lines are also present in 3C 48 and 4C 37.43. The [Ne V] lines reported in this paper for 3C 249.1 are also present in 3C 48 and 4C 37.43.

The theoretical value for the ratio [Ne V] λλ3426/3346 is 2.72. We find a ratio of 1.22, lower by a factor of ∿ 2. The difference may be due to a high contamination of Fe II unresolved blends.

The theoretical value for the ratio [Ne III] λλ3869/3967 is 3.35. We find a value of 1.83, lower by a factor of ∿ 2. This can be due to blending of [Ne III] 3967 with H_7 λ3970. If the contamination is only due to H_7, then to match the theoretical value of [Ne III] 3869/3967, we find $I_{H_7} = 0.55 \pm 0.15 \times 10^{-14}$ erg s^{-1} cm^{-2}.

If we take the value given by Richstone and Oke for He I λ5876 (nucleus plus intrinsic annulus flux), we obtain the ratio He I 5876/3889 $\geq$ 3.1 ± 0.7. This value (which is a lower limit due to contamination of He I λ3889 with H_8), is a factor of ∿ 2 higher than the recombination value (case B): 1.58 (for T = 5000 K, $n_e = 10^4$) or 1.20 (for T = 10 000, $n_e = 10^6$), suggesting that transfer in these lines must be important.

IV. CONTINUUM ENERGY DISTRIBUTION

b) *TON 469 (3C 232)*

From Figure 3 we see that the optical brightness observed by us in 1982, is weaker than that observed by Neugebauer *et al.* (1979). The flux ratio measured at λ = 5500 A corresponds to Δm_v ∿ 0.29 ± 0.18. Grandi and Tifft (1974) –see also references therein– report the optical variability of this quasar with a total amplitude of the variation of 1.2 m.

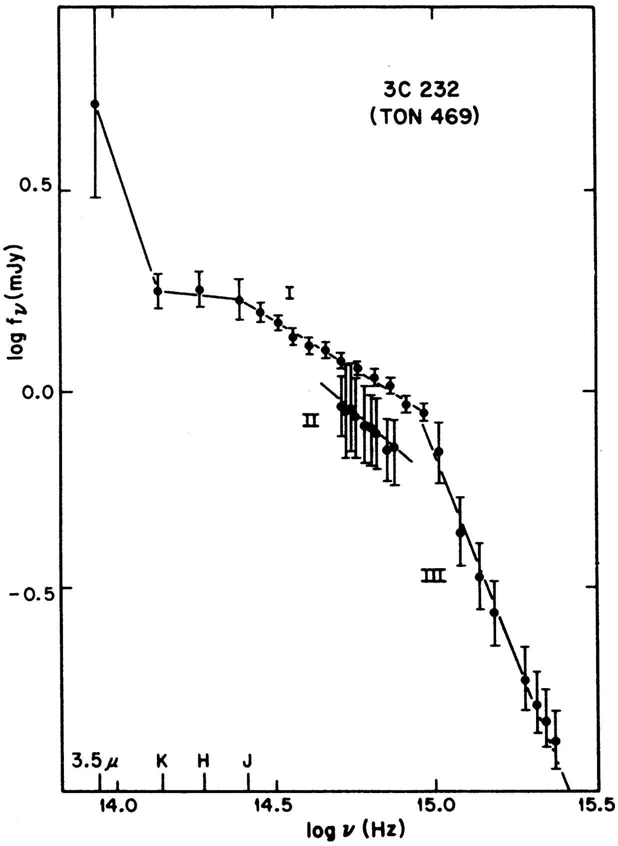

Fig. 3. The continuum energy distribution of TON 469 (3C 232). I. Neugebauer *et al.* (1979); II. This work; III. Dultzin-Hacyan *et al.* (1982).

TABLE 4

SPECTRAL INDEX FOR DIFFERENT WAVELENGTH RANGES FOR TON 469 (3C 232)

	Spectral Index	Wavelength Range[a]	References[b]
α_R	$= -0.57 \pm 0.06$	0.75 – 1.40 GHz	1
α_{IR}	$= -1.10 \pm 0.60$	1.25 – 3.5 μ	2
α_{OPT}	$= -0.70^c$	3550 – 8700 A	3
α_{OPT}	$= -0.75 \pm 0.05$	3000 – 7000 A	4
α_{OPT}	$= -0.48 \pm 0.10$	3350 – 8500 A	1
α_{OPT}	$= -0.35 \pm 0.10$	3050 – 6600 A	5
α_{OPT}	$= -0.70 \pm 0.20$	4100 – 6050 A	6
$\alpha_{OPT(UV)}$	$= -1.12^c$	4250 – 6000 A	7
$\alpha_{UV}{}^d$	$= -1.53 \pm 0.20$	1250 – 3000 A	8
$\alpha_{UB}{}^e$	$= 1.86 \pm 0.20$	1250 – 3000 A	8

a. All rest values that were found in the literature were converted to observed wavelengths.
b. 1) Pauliny-Toth, Wade and Heeschen 1966; 2) Neugebauer *et al.* 1979; 3) Baldwin 1977*b*; 4) Phillips 1978; 5) Oke, Shields and Korykansky 1984; 6) this work; 7) Grandi 1981; 8) Dultzin-Hacyan, Salas and Daltabuit 1982.
c. No errors are given.
d. Corrected for galactic $E_{B-V} = 0.08$ (see ref. 8).
e, Not corrected for galactic reddening.

In Table 4 the infrared spectral index has been computed from 1.25 to 3.5μ (the large error bar is due to the measurement at 3.5μ). It is clear from Figure 3 however, that the infrared spectral index has a break at 2.2μ and steepens towards the red.

The spectrum is flatter in the radio and several explanations have been proposed for this flattening which assume multiple components and/or relativistic jets (see e.g., Blandford and Rees 1978; Konigl 1981).

The flattening of the spectrum in the optical range is also evident. The excess flux over the red power law is referred to as the "3000 A bump". Several interpretations of the nature of this feature have been suggested (e.g., Shields 1978; Collin-Souffrin *et al.* 1979; Richstone and Schmidt 1980; Malkan and Sargent 1982; Puetter *et al.* 1982; Oke *et al.* 1984).

The continuum has a break at $\lambda_{rest} = 1982$ A, and steepens sharply in the ultraviolet. Within the error bars, α_{UV} can be considered an extrapolation of α_{IR} suggesting that the same (nonthermal) mechanism powers the emission at these frequencies.

b) *3C 249.1*

This quasar has also been reported to be variable. Grandi and Tifft (1974) give an amplitude of 0.3^m for the optical variability. Richstone and Oke (1977) report a change in visual magnitude of 0.6^m decreasing from 1974 to 1976. We find a decrease in brightness of $\sim 0.28^m \pm 0.18$ (measured at $\lambda = 5500$ A) with respect to the data of Neugebauer *et al.* (1979). See also Dultzin-Hacyan *et al.* (1982).

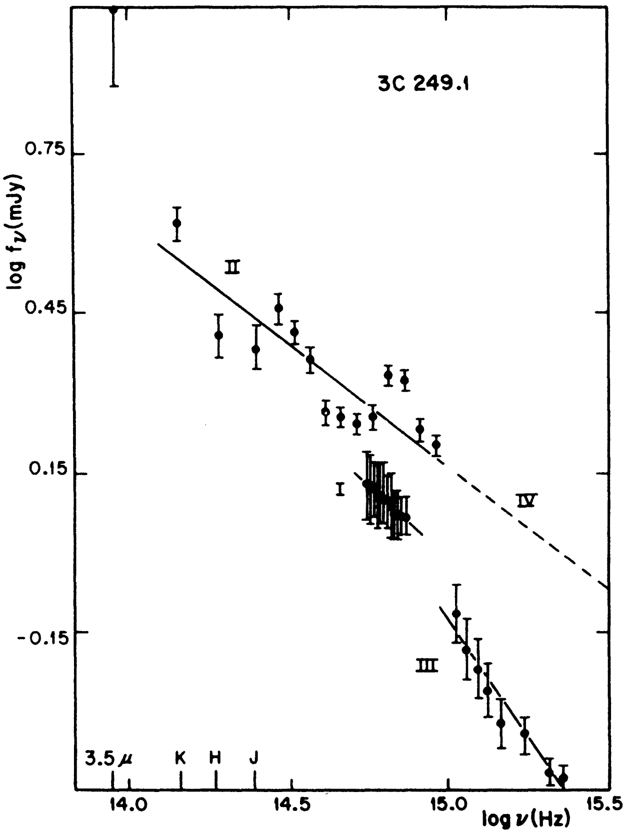

Fig. 4. Continuum energy distribution for 3C 249.1 I. This work; II. Neugebauer *et al.* (1979); III. IV. Dultzin-Hacyan *et al.* (1982).

In this case, we have once more considered a single α_{IR} from 1.25 to 10μ. But it is evident from Figure 4 and Table 5 (although the 10μ point is not included) that the spectrum steepens considerably to the red of 2.2μ. Whether dust or electron energy losses in a two-component synchrotron model are plausible explanations for this break cannot be answered until far infrared data are available.

The optical part of the spectrum has a large scatter (actually looks "wavy") from the data by Neugebauer *et al.* (1979). We do not find the same bump in the range of coincidence, but our spectrum is rather noisy. From Table 4 we see that within the error bars (which are large for α_{IR}), the spectral index can be considered the same from the radio, through the infrared and optical ranges (α_{OPT} measured in this work) to the ultraviolet, which shows no steepening with respect to the optical part in contrast to the previous case. Thus a single power law could be adopted from the radio to the UV. The value for α_{O-X} is closer to α_{UV} for galactic $E_{B-V} = 0$. This may be (at least in part) because the X-ray measurement is not corrected for galactic reddening. It is well known that quasar spectra steepen shortward of λ1200 A. Bechtold *et al.* (1984) have found a correlation between this

TABLE 5

SPECTRAL INDEX FOR DIFFERENT WAVELENGTH RANGES FOR 3C 249.1

	Spectral Index	Wavelength Range[a]	References[b]
α_R	$= -0.71 \pm 0.05$	0.75 – 1.40 GHz	1
α_{IR}	$= -1.08 \pm 0.41$	1.25 – 10 μ	2
α_{OPT}	$= -0.40 \pm 0.10$	3300 – 8500 A	2
α_{OPT}	$= -0.60 \pm 0.20$	3250 – 5500 A	3
α_{UV^c}	$= -0.46 \pm 0.20$	1250 – 3000 A	4
α_{UV^d}	$= -0.89 \pm 0.20$	1250 – 3000 A	4
α_{OPT-X}	$= -1.22 \pm 0.06$	(3600 – 7000 A) – 1 KeV	5

a. All the rest values that were found in the literature were converted to observed wavelengths.
b. 1) Pauliny-Toth, Wade and Heescher 1966; 2) Neugebauer *et al.* 1979; 3) this work; 4) Dultzin-Hacyan, Salas and Daltabuit 1982; 5) Cruz-González 1985.
c. Corrected for galactic. $E_{B-V} = 0.12$ (see ref. 4).
d. Not corrected for galactic reddening.

steepening and redshift (and interpret it as a result of absorption by intervening material), but this effect should be negligible at the moderate z of this quasar. Intrinsic steepening cannot be ruled out.

V. CONCLUSIONS

1. We find certain indication of variability of the line Mg II λ2798 in TON 469. The ratio Mg II λλ2934/2798 seems also to be variable with time. Simultaneous UV and optical observations are suggested to establish whether the mechanism of N V fluorescence is responsible for the excitation of Mg II λ2934.

2. We have identified the following new lines in the spectrum of 3C 249.1: [Ne V] λ3346, [Ne V] λ3426 and He I λ3889.

3. The evidence for optical flux variability is confirmed in both objects.

4. With only two cases, we have two examples of different continuum energy distributions, in the sense that in TON 469 (3C 232) the optical part shows the typical flattening with respect to the rest of the continuum (specially the UV) whereas for 3C 249.1 the UV (corrected for galactic reddening) is an extrapolation of the optical continuum. For this last object it is possible to fit (although marginally within the error bars) a single power law from the radio to the UV.

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