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# VARIABILITY OF THE BL LACERTAE OBJECTS PKS 2155−304 AND OJ 287 IN THE FAR-ULTRAVIOLET

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## ABSTRACT

All the ultraviolet spectra of the two bright BL Lacertae objects PKS 2155−304 and OJ 287 taken with the *International Ultraviolet Explorer* in the period 1978–1984 are examined. For each spectrum the best-fitting power law is determined and a correlation between spectral slope and intensity is searched for. The correlation, if present, is weak. This is discussed in terms of models of the continuum emission of active galactic nuclei.

*Subject headings:* BL Lacertae objects — ultraviolet: spectra

## I. INTRODUCTION

During the period 1978–1984 the two bright BL Lacertae objects OJ 287 and PKS 2155−304 were extensively studied with the *International Ultraviolet Explorer* (*IUE*). The data represent an essentially homogeneous set which enables us to study the variability of the sources in the spectral range 1200–3200 Å. They were retrieved from *IUE* archives, except for those directly obtained by us. Part of them have already been published (for PKS 2155−304 see Maraschi *et al.* 1980; Urry *et al.* 1982; Maraschi *et al.* 1983*a*, Urry 1984; for OJ 287 see Worrall *et al.* 1982; Maraschi *et al.* 1983*b*; Bregman *et al.* 1984).

Both sources are typical members of the BL Lacertae class, with flat radio spectra, large optical variability, high and variable optical polarization, and significant X-ray emission. Lines are virtually absent in both objects. For PKS 2155−304, the redshift, $z = 0.117$, was obtained from the study of the surrounding nebulosity (Bowyer *et al.* 1984), while for OJ 287, the suggested value, $z = 0.306$, is based on the measurement of a single emission line on one occasion (Miller, French, and Hawley 1978).

OJ 287 is remarkable for the occurrence of large optical flares with durations of months, several of which have been found in archival plates (Visvanathan and Elliot 1973). One of them occurred at the beginning of 1983 ($\Delta m \approx 2$), and some *IUE* spectra discussed here refer to this epoch. The magnitude of the object in quiescence is $m_v \approx 15$–16.

Archival plates of PKS 2155−304 (Griffiths *et al.* 1979) reveal that the optical magnitude varied between $m_v = 12.4$ and $m_v = 14$, with flares of duration similar to that of OJ 287 but less conspicuous.

The procedure for analysis of the *IUE* spectra is described in § II. The time variability is discussed in § III. Comparison with optical data is given in § IV, and a brief discussion of the results is presented in § V.

## II. ULTRAVIOLET FLUXES AND SPECTRAL SHAPES

The journals of all *IUE* observations of OJ 287 and PKS 2155−304 are reported in Tables 1 and 2, respectively. All images were obtained with the large aperture (10″ × 20″ oval) of the spectrograph in the low-resolution ($\Delta\lambda \approx 6$ Å) mode, either with the short-wavelength primary (SWP) camera, which covers the wavelength range from 1200 Å to 2000 Å or with the long-wavelength primary (LWP) and long-wavelength redundant (LWR) cameras, which operate between 2000 Å and 3200 Å. The *IUE* Standard Image Processing System (SIPS) reduced spectra, with the calibration curve by Bohlin and Holm (1981) and Cassatella and Harris (1983), were used in the analysis.

Continuum fluxes were derived averaging the spectrum over 50 Å intervals, avoiding hot spots and reseau marks. The standard deviation of the mean in each interval is assumed to represent the associated uncertainty. For well-exposed spectra this uncertainty is smaller than the photometric accuracy of the *IUE*; however, it seems reasonable to adopt this error for the purpose of determining the spectral slope of each individual spectrum, and to consider the photometric accuracy as a wavelength-independent uncertainty when comparing absolute fluxes at different epochs.

The OJ 287 data were corrected for interstellar reddening, adopting the extinction curve given by Seaton (1979) with $A_v = 0.1$ as derived from the Galactic reddening estimate of Burstein and Heiles (1982). For PKS 2155−304 the reddening estimate of Burstein and Heiles (1982) is consistent with zero.

All the available data in the 1200–2000 Å (SWP) and in the 2000–3200 Å (LWR or LWP) intervals were separately best-fitted with a power law, $F_\nu = k\nu^{-\alpha}$, adopting statistical errors as discussed above. The parameters $k$ and $\alpha$ and their uncertainties were obtained by minimizing $\chi^2$, with a confidence limit of 90% following the criteria discussed by Avni (1976). Uncertainties in the calibration curves and nonlinearity in the response of the cameras may introduce systematic errors on the derived slope which are not taken into account here. Exposures in the two wavelength ranges, taken within ∼1 day, were combined and the best-fitting single power law was derived. A sample of observed combined spectra (averaged over 50 Å intervals) is shown in Figures 1 and 2 for PKS 2155−304 and OJ 287, respectively. The use of combined spectra, extending from 1200 to 3200 Å, substantially reduces the uncertainty on the derived spectral index. On the other hand, this procedure may be subject to errors due to intraday variability. In one case (images SWP 13479 and LWR 10138 of OJ 287) a substantial mismatch is apparent (see Fig. 2), and therefore no fit of the combined spectrum was attempted. In all other cases the combined fits gave acceptable results. The spectral indices in the

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TABLE 1[a]

SPECTRAL PARAMETERS AND OBSERVED FLUXES OF PKS 2155−304

| Date | Image | Spectral Index $\alpha$ ($F_\nu \propto \nu^{-\alpha}$) | Combined Index $\alpha_{comb}$ ($F_\nu \propto \nu^{-\alpha}$) | Flux at 1500 Å (mJy) | Flux at 2500 Å (mJy) |
|---|---|---|---|---|---|
| 1979 May 15 ........ | SWP 5238 | 0.68 ± 0.02 | 0.76 ± 0.01 | 8.67 ± 0.13 | ... |
| 1979 May 15 ........ | LWR 4522 | 0.82 ± 0.07 | 0.71 ± 0.02 | ... | 13.18 ± 0.22 |
| 1979 May 15 ........ | SWP 5239 | 0.87 ± 0.05 | | 8.93 ± 0.13 | ... |
| 1979 Aug 19 ........ | LWR 5397 | 1.15 ± 0.07 | 0.87 ± 0.02 | ... | 12.06 ± 0.21 |
| 1979 Aug 19 ........ | SWP 6221 | 0.82 ± 0.05 | | 8.05 ± 0.13 | ... |
| 1979 Aug 19 ........ | LWR 5398 | 0.94 ± 0.07 | 0.84 ± 0.02 | ... | 12.48 ± 0.20 |
| 1979 Aug 19 ........ | SWP 6222 | 0.76 ± 0.04 | | 8.52 ± 0.12 | ... |
| 1979 Oct 13 ......... | LWR 5828 | 0.75 ± 0.04 | 0.86 ± 0.02 | ... | 13.45 ± 0.23 |
| 1979 Oct 13 ......... | SWP 6856 | 0.82 ± 0.05 | | 8.90 ± 0.13 | ... |
| 1979 Oct 13 ......... | LWR 5829 | 0.54 ± 0.07 | 0.86 ± 0.02 | ... | 14.60 ± 0.25 |
| 1979 Oct 13 ......... | SWP 6857 | 0.78 ± 0.05 | | 9.21 ± 0.14 | ... |
| 1979 Oct 14 ......... | SWP 6867 | 0.82 ± 0.05 | 0.85 ± 0.02 | 8.50 ± 0.13 | ... |
| 1979 Oct 14 ......... | LWR 5839 | 0.79 ± 0.07 | 0.87 ± 0.02 | ... | 12.46 ± 0.20 |
| 1979 Oct 14 ......... | SWP 6868 | 0.86 ± 0.05 | | 8.00 ± 0.13 | ... |
| 1979 Nov 2 ......... | LWR 6009 | 1.09 ± 0.07 | 0.68 ± 0.02 | ... | 11.17 ± 0.18 |
| 1979 Nov 2 ......... | SWP 7070 | 0.63 ± 0.02 | 0.68 ± 0.02 | 8.55 ± 0.12 | ... |
| 1979 Nov 2 ......... | LWR 6010 | 0.77 ± 0.07 | | ... | 11.44 ± 0.18 |
| 1979 Nov 13 ........ | SWP 7139 | 0.76 ± 0.11 | 0.80 ± 0.02 | 6.00 ± 0.09 | ... |
| 1979 Nov 13 ........ | LWR 6135 | 0.86 ± 0.07 | | ... | 8.69 ± 0.14 |
| 1979 Nov 14 ........ | SWP 7140 | 0.68 ± 0.05 | 0.80 ± 0.02 | 6.21 ± 0.09 | ... |
| 1979 Nov 14 ........ | LWR 6136 | 0.71 ± 0.07 | | ... | 9.52 ± 0.16 |
| 1980 May 21 ........ | LWR 7813 | 0.96 ± 0.07 | 0.86 ± 0.02 | ... | 10.31 ± 0.16 |
| 1980 May 21 ........ | SWP 9066 | 0.73 ± 0.05 | | 6.76 ± 0.09 | ... |
| 1980 Dec 11 ......... | SWP 10799 | 0.67 ± 0.05 | 0.75 ± 0.02 | 11.03 ± 0.16 | ... |
| 1980 Dec 11 ......... | LWR 9476 | 0.87 ± 0.07 | | ... | 14.64 ± 0.24 |
| 1981 Jun 9 .......... | LWR 10815 | 0.90 ± 0.08 | | ... | 11.23 ± 0.18 |
| 1982 Oct 29 ......... | SWP 18421 | 0.69 ± 0.05 | | 4.55 ± 0.07 | ... |
| 1983 Oct 31 ......... | SWP 21418 | 0.81 ± 0.05 | 1.05 ± 0.02 | 5.83 ± 0.10 | ... |
| 1983 Oct 31 ......... | LWP 2189 | 0.84 ± 0.21 | | ... | 9.09 ± 0.10 |
| 1983 Nov 29 ........ | SWP 21637 | 0.72 ± 0.03 | 1.00 ± 0.02 | 6.97 ± 0.06 | ... |
| 1983 Nov 29 ........ | LWP 2330 | 0.91 ± 0.12 | | ... | 11.62 ± 0.12 |
| 1984 Apr 28 ......... | SWP 22873 | 0.67 ± 0.25 | 1.18 ± 0.06 | 6.19 ± 0.33 | ... |
| 1984 Apr 29 ......... | LWP 3246 | 0.94 ± 0.25 | | ... | 11.17 ± 0.46 |
| 1984 Apr 30 ......... | SWP 22882 | 1.03 ± 0.13 | 1.13 ± 0.05 | 5.88 ± 0.20 | ... |
| 1984 Apr 30 ......... | LWP 3247 | 0.40 ± 0.31 | | ... | 11.46 ± 0.52 |
| 1984 Apr 30 ......... | SWP 22883 | 1.01 ± 0.37 | | 5.85 ± | ... |
| 1984 Apr 30 ......... | SWP 22884 | 0.71 ± 0.18 | 1.18 ± 0.07 | 5.20 ± 0.33 | ... |
| 1984 Apr 30 ......... | LWP 3248 | 1.01 ± 0.38 | | ... | 9.8 ± 0.62 |
| 1984 Apr 30 ......... | SWP 22885 | 0.50 ± 0.21 | 0.94 ± 0.08 | 7.83 ± 0.35 | ... |
| 1984 Apr 30 ......... | LWP 3249 | 0.50 ± 0.38 | | ... | 11.27 ± 0.69 |
| 1984 Apr 30 ......... | SWP 22887 | 0.39 ± 0.23 | | 7.78 ± 0.43 | ... |
| 1984 May 1 ......... | SWP 22889 | 0.97 ± 0.09 | 1.07 ± 0.03 | 6.77 ± 0.14 | ... |
| 1984 May 1 ......... | LWP 3252 | 0.81 ± 0.18 | | ... | 10.00 ± 0.31 |
| 1984 Nov 6 ......... | SWP 24406 | 0.60 ± 0.05 | 0.88 ± 0.02 | 9.86 ± 0.06 | ... |
| 1984 Nov 6 ......... | LWP 4738 | 0.94 ± 0.06 | | ... | 15.01 ± 0.15 |
| 1984 Nov 7 ......... | SWP 24410 | 0.63 ± 0.05 | 0.93 ± 0.02 | 10.91 ± 0.08 | ... |
| 1984 Nov 7 ......... | LWP 4746 | 0.76 ± 0.10 | | ... | 17.08 ± 0.20 |
| 1984 Nov 11 ........ | SWP 24445 | 0.59 ± 0.05 | 0.94 ± 0.02 | 9.71 ± 0.08 | ... |
| 1984 Nov 11 ........ | LWP 4782 | 0.90 ± 0.08 | | ... | 14.86 ± 0.19 |
| 1984 Nov 11 ........ | LWP 4783 | 0.70 ± 0.13 | | ... | 14.46 ± 0.30 |

[a] Purely statistical errors are reported.

short ($\alpha_s$) and long ($\alpha_l$) wavelength ranges and that of the combined full-range spectra ($\alpha_{comb}$) are given in Tables 1 and 2 for the two sources, respectively, together with the average undereddened fluxes at 1500 and 2500 Å. Also plotted as a function of time in Figures 3 and 4 are $\alpha_{comb}$ and $F_{1500}$.

### III. TIME VARIABILITY

In the considered time span (∼6 years) the maximum observed variation in the UV flux is a factor of 8 for OJ 287 and a factor of 2.5 for PKS 2155−304 (see Figs. 3 and 4). The difference in the amplitudes of the UV variability in the two objects seems to mirror the diversity of their historical optical light curves (Visvanathan and Elliot 1973; Griffiths *et al.* 1979). For both objects, the recorded UV variations are smaller than the maximum recorded optical ones, which may be due to the limited time coverage of the UV observations.

Fluctuations on time scales of hours and days are clearly present. Defining the variability time scale as $\tau = (\bar{F}/\Delta F)\Delta t$, where $\Delta F = F_{max} - F_{min}$ and $\Delta t$ is the time over which the variation occurred, we find values of $\tau$ as short as 1 day for OJ 287, and ∼2 days for PKS 2155−304, corresponding respectively to light-travel distances of $2.5 \times 10^{15}$ and $\sim 5 \times 10^{15}$ cm.

It appears from Tables 1 and 2 and Figures 3 and 4 that spectral variability, though small, is present in the ultraviolet range. The maximum variation of the spectral index derived

TABLE 2[a]

SPECTRAL PARAMETERS AND OBSERVED FLUXES OF OJ 287

| Date | Image | Spectral Index $\alpha$ ($F_\nu \propto \nu^{-\alpha}$) | Combined Index $\alpha_{comb}$ ($F_\nu \propto \nu^{-\alpha}$) | Flux at 1500 Å (mJy) | Flux at 2500 Å (mJy) |
|---|---|---|---|---|---|
| 1978 May 30 ........ | LWR 1582 | 1.53 ± 0.20 | | ... | 1.59 ± 0.66 |
| 1978 Jun 9 .......... | SWP 1749 | 1.85 ± 0.18 | 1.66 ± 0.04 | 0.61 ± 0.04 | ... |
| 1978 Jun 8 .......... | LWR 1637 | 1.08 ± 0.16 | | ... | 1.53 ± 0.06 |
| 1978 Nov 4 .......... | SWP 3218 | 1.35 ± 0.09 | 1.54 ± 0.03 | 1.15 ± 0.05 | ... |
| 1978 Nov 3 .......... | LWR 2815 | 1.66 ± 0.14 | | ... | 2.25 ± 0.05 |
| 1978 Nov 6 .......... | LWR 2842 | 1.47 ± 0.16 | | ... | 2.74 ± 0.05 |
| 1980 Mar 16 ........ | SWP 8260 | 1.73 ± 0.23 | 1.77 ± 0.06 | 0.66 ± 0.04 | ... |
| 1980 Mar 16 ........ | LWR 7191 | 1.50 ± 0.50 | | ... | 1.90 ± 0.25 |
| 1980 Oct 22 ......... | SWP 10453 | 1.50 ± 0.18 | 1.45 ± 0.05 | 0.49 ± 0.03 | ... |
| 1980 Oct 23 ......... | LWR 9134 | 1.22 ± 0.27 | | ... | 1.14 ± 0.08 |
| 1980 Dec 15 ......... | SWP 10817 | 1.31 ± 0.16 | 1.61 ± 0.05 | 0.35 ± 0.06 | ... |
| 1980 Dec 17 ......... | LWR 9519 | 1.53 ± 0.24 | | ... | 0.83 ± 0.03 |
| 1981 Mar 13 ........ | SWP 13479 | 1.15 ± 0.08 | | 1.17 ± 0.03 | ... |
| 1981 Mar 14 ........ | LWR 10138 | 1.54 ± 0.11 | | ... | 1.37 ± 0.04 |
| 1981 Dec 24 ......... | SWP 15875 | 1.65 ± 0.12 | 1.31 ± 0.03 | 0.82 ± 0.04 | ... |
| 1981 Dec 25 ......... | LWR 12219 | 1.63 ± 0.12 | | ... | 1.55 ± 0.03 |
| 1982 Dec 20 ......... | LWR 14859 | 2.20 ± 0.10 | | ... | 2.22 ± 0.08 |
| 1982 Dec 21 ......... | LWR 14866 | 1.52 ± 0.14 | | ... | 1.81 ± 0.05 |
| 1982 Dec 22 ......... | LWR 14867 | 1.10 ± 0.25 | | ... | 2.11 ± 0.13 |
| 1983 Jan 16 ......... | SWP 19007 | 1.58 ± 0.07 | | 2.68 ± 0.06 | ... |
| 1983 Feb 12 ......... | LWR 15269 | 1.21 ± 0.14 | | ... | 3.99 ± 0.10 |
| 1983 Feb 15 ......... | SWP 19259 | 1.64 ± 0.10 | 1.56 ± 0.03 | 1.47 ± 0.06 | ... |
| 1983 Feb 15 ......... | LWR 15290 | 1.57 ± 0.11 | | ... | 3.38 ± 0.10 |
| 1983 Mar 10 ........ | LWR 15458 | 1.39 ± 0.10 | | ... | 3.67 ± 0.08 |
| 1983 Mar 10 ........ | LWR 15459 | 1.64 ± 0.12 | | ... | 3.40 ± 0.08 |
| 1983 Mar 11 ........ | LWR 15466 | 1.37 ± 0.10 | | ... | 4.33 ± 0.13 |
| 1983 Mar 11 ........ | LWR 15467 | 1.36 ± 0.12 | | ... | 4.92 ± 0.13 |
| 1983 Mar 11 ........ | LWR 15468 | 1.59 ± 0.12 | | ... | 5.04 ± 0.21 |
| 1983 Mar 27 ........ | SWP 19558 | 1.67 ± 0.08 | | 2.83 ± 0.06 | ... |
| 1983 Apr 15 ......... | SWP 19733 | 0.97 ± 0.20 | 1.23 ± 0.08 | 2.23 ± 0.13 | ... |
| 1983 Apr 15 ......... | LWR 15740 | 1.16 ± 0.40 | | ... | 4.30 ± 0.40 |
| 1983 May 11 ........ | SWP 19959 | 1.43 ± 0.09 | 1.30 ± 0.05 | 1.80 ± 0.04 | ... |
| 1983 May 11 ........ | LWR 15906 | 1.30 ± 0.18 | | ... | 3.57 ± 0.10 |
| 1983 Oct 9 .......... | SWP 21262 | 1.31 ± 0.09 | 1.54 ± 0.03 | 1.22 ± 0.02 | ... |
| 1983 Oct 10 ......... | LWP 2023 | 1.53 ± 0.15 | | ... | 2.44 ± 0.05 |
| 1983 Dec 7 .......... | SWP 21717 | 1.87 ± 0.16 | | 0.89 ± 0.03 | ... |

[a] Purely statistical errors are reported.

from combined spectra is $(\Delta\alpha)_{comb} = 0.6 \pm 0.04$ for OJ 287 and $(\Delta\alpha)_{comb} = 0.3 \pm 0.02$ for PKS 2155−304.

Possible correlations between spectral shape and flux density were investigated by means of a linear regression fit of the type $\log F = a\alpha + b$. Errors in both $\log F$ and $\alpha$ are taken into account following Bevington (1969). The adopted error in the flux is here the statistical error combined with a fixed photometric error of 8%. The spectral index of combined spectra was considered, since the associated uncertainty is smaller than that of individual spectra. The correlations of $F_{1500}$ and $F_{2500}$ with $\alpha_{comb}$ were examined. The results are summarized in Table 3, where we report the correlation coefficient $r$, the number $N$ of data points, and the associated *a priori* chance probability. An indication of spectral correlation, in the sense that higher fluxes correspond to harder spectra, is present in both objects for the short-wavelength flux at the 97% and 90% confidence levels for PKS 2155−304 and OJ 287, respectively (see Figs. 5 and 6).

Figures 3 and 4 seem to suggest that the correlation may be stronger on shorter time scales. We have therefore examined the correlation of the flux variation $\Delta F$ between successive observations and the corresponding variation of the combined spectral index $\Delta\alpha_{comb}$ (see Table 3). The result is significant for PKS 2155−304 both for $\Delta F_{1500}$ and for $\Delta F_{2500}$, while for OJ 287 a negative result is found.

TABLE 3

INTENSITY–SPECTRAL INDEX CORRELATION[a]

| Correlations Examined | PKS 2155−304 $r$ | PKS 2155−304 $N$ | PKS 2155−304 $P(r, N)$ | OJ 287 $r$ | OJ 287 $N$ | OJ 287 $P(r, N)$ |
|---|---|---|---|---|---|---|
| $\alpha_{comb}$, $\log F_{1500}$ ............ | −0.44 | 24 | ~0.03 | −0.55 | 10 | 0.1 |
| $\alpha_{comb}$, $\log F_{2500}$ ............ | −0.08 | 24 | >0.5 | −0.38 | 10 | ~0.30 |
| $\Delta\alpha_{comb}$, $\Delta F_{1500}$ ............ | −0.80 | 22 | <0.001 | −0.35 | 9 | ~0.30 |
| $\Delta\alpha_{comb}$, $\Delta F_{2500}$ ............ | −0.67 | 21 | <0.001 | −0.08 | 9 | >0.50 |

[a] In cols. (2)–(7), $r$ is the correlation coefficient, $N$ is the number of data points, and $P(r, N)$ is the corresponding chance probability.

## IV. COMPARISON WITH OPTICAL DATA

It is of interest to compare the intensity–spectral shape behavior found in the ultraviolet with that in the optical band. For PKS 2155−304 extensive *UBV* photometry in the years 1979–1982 was published by Miller and McAlister (1983). The *V* light curve, complemented with observations obtained by us in 1983 and 1984, is compared with the 1500 Å light curve in Figure 7. No obvious correlation (or anticorrelation) is present. However, the observations of Miller and McAlister show that the colors are redder when the object is brighter, i.e., a behavior is observed that is in contrast to that suggested by

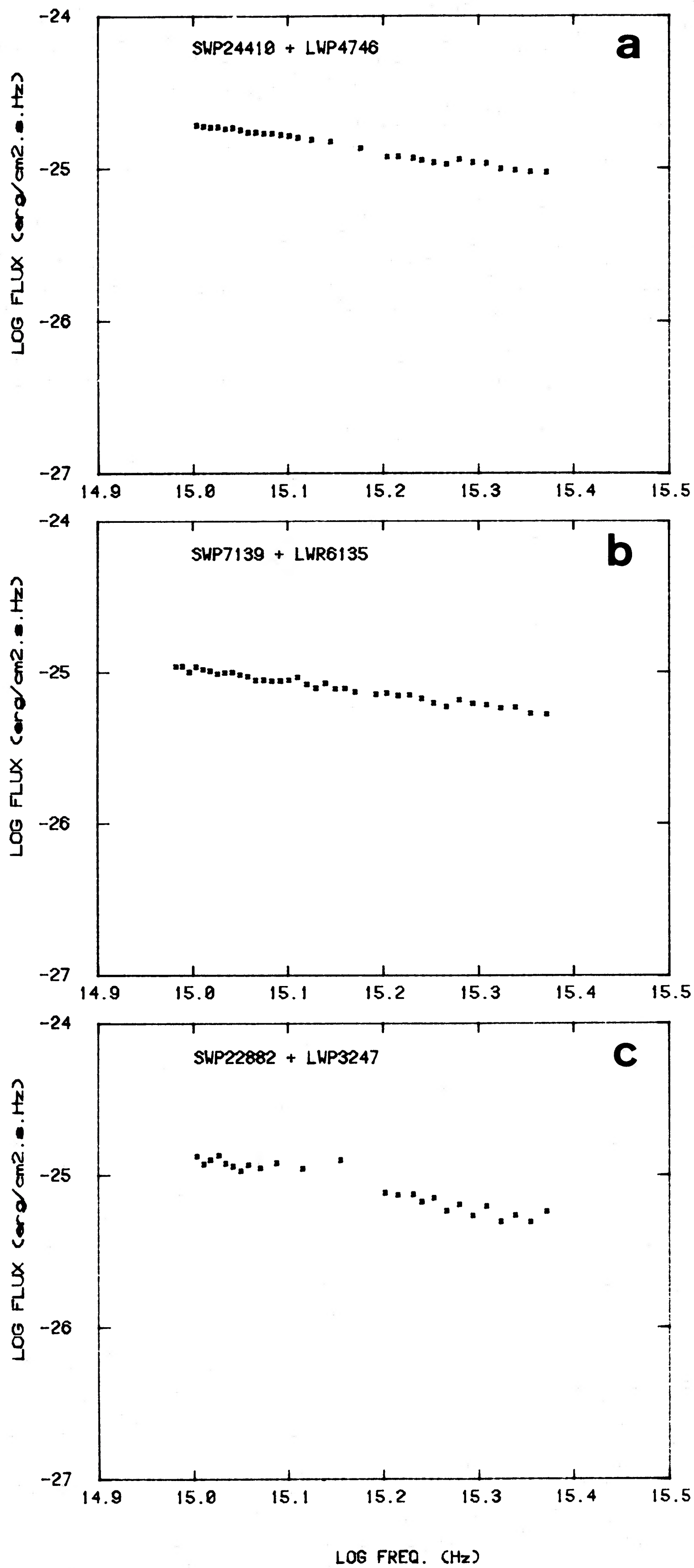


FIG. 1.—The observed ultraviolet continuum (averaged over 50 Å intervals) of PKS 2155−304 is shown for three cases: (*a*) the maximum and (*b*) the minimum intensity recorded and (*c*) the worst case of mismatching between short- and long-wavelength spectra which still gives an acceptable fit. See Table 1 for dates of observations and parameters of the obtained fits.

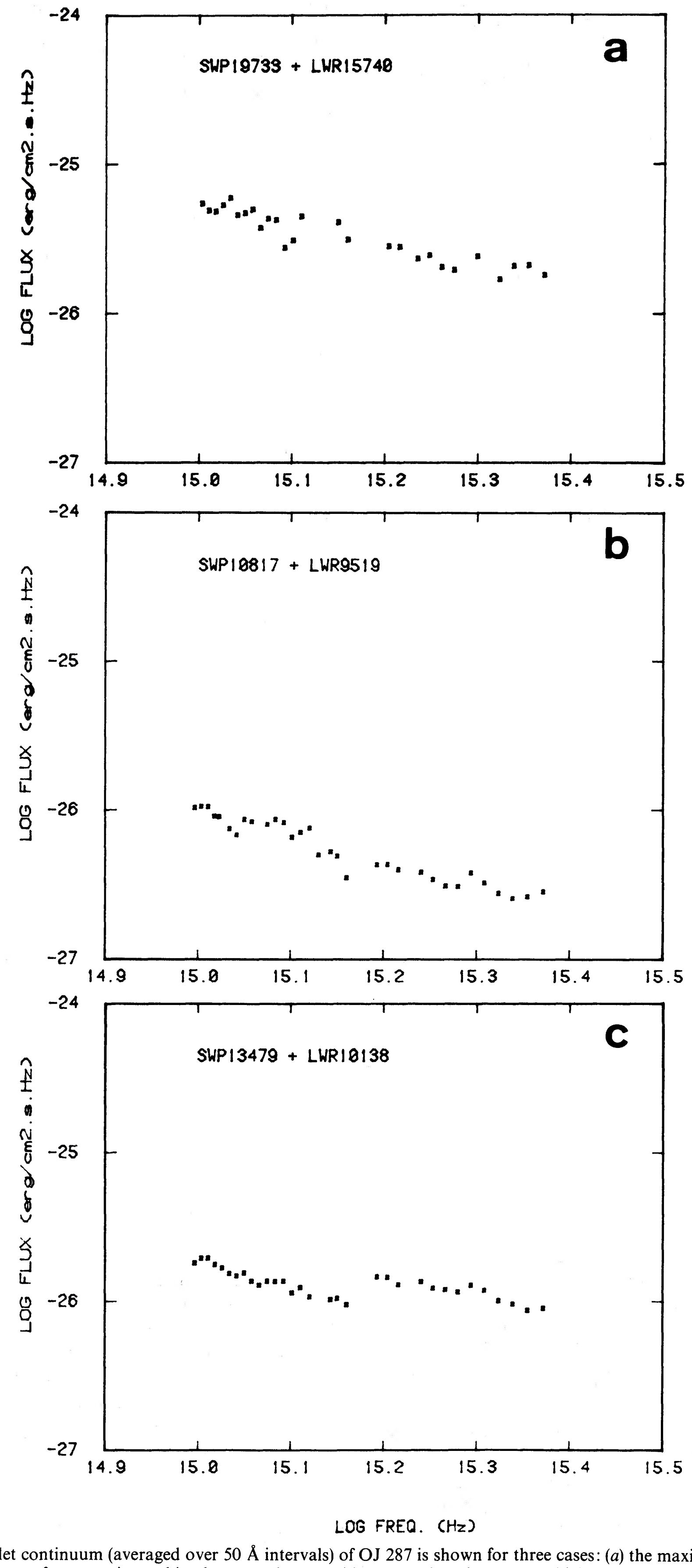


FIG. 2.—The observed ultraviolet continuum (averaged over 50 Å intervals) of OJ 287 is shown for three cases: (*a*) the maximum and (*b*) the minimum intensity recorded and (*c*) the one and only case of severe mismatching between short- and long-wavelength spectra, which prevents any fitting attempt. See Table 2 for dates of observations and parameters of the obtained fits.

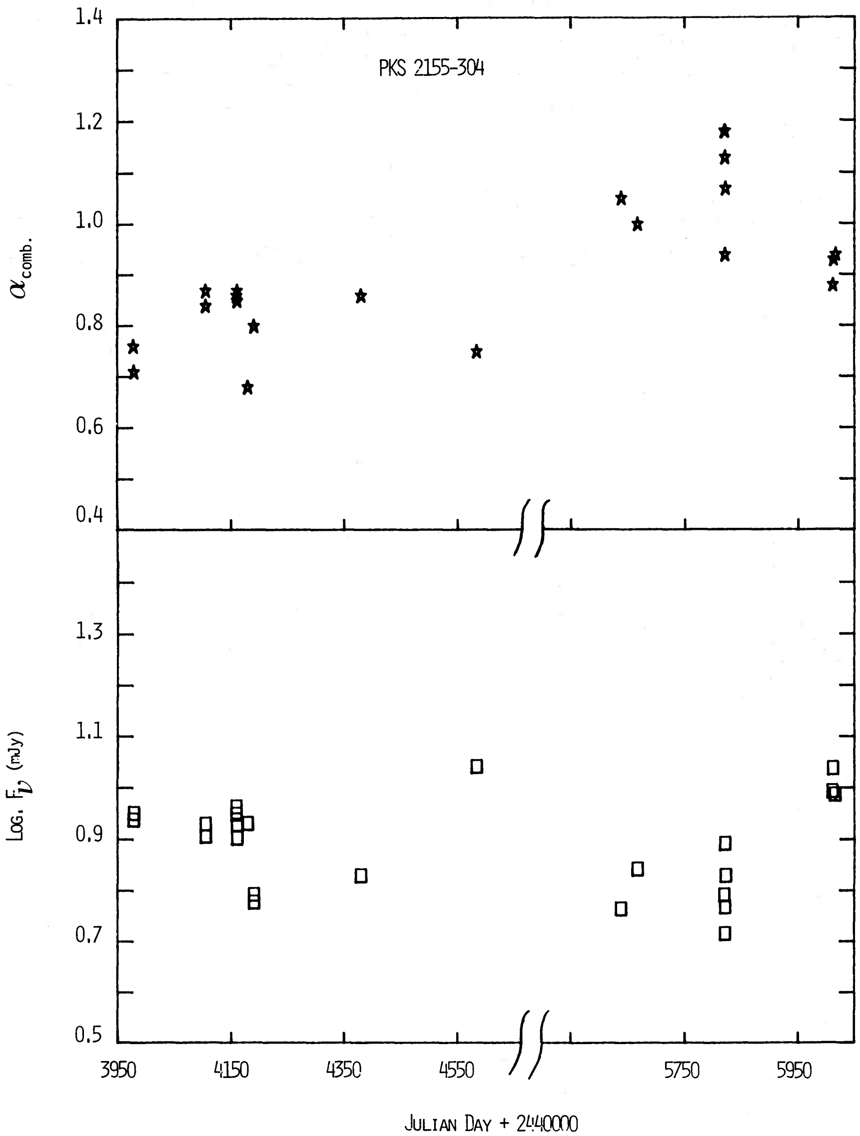


FIG. 3.—Combined (1200–3200 Å) spectral index (*upper panel*) and 1500 Å continuum flux (*lower panel*) vs. time for PKS 2155 − 304

the observations at UV frequencies. It appears that the flux variations are less pronounced in $U$ than in $V$, so that, combining optical and UV results, the overall spectrum appears to pivot around a wavelength of ∼3000 Å.

It seems relevant to mention that two quasi-simultaneous optical and ultraviolet spectra taken in low-ultraviolet states (1979 November 13; 1983 October 31; see Maraschi *et al.* 1983*b*; Tanzi *et al.* 1984) both exhibit a change of slope $\Delta\alpha \approx 0.3$–0.4 between the two ranges, i.e., around 3000 Å. The fact that the spectral break occurs at the same critical wavelength $\lambda_c = 3000$ Å at which the spectral index–intensity correlation reverses its sign or at least disappears may not be coincidental.

In the case of OJ 287, *UBVRI* photometry by Moles, Garcia-Pelayo, and Masegosa (1984), which covers the 1983 flare, shows a correlation of the $U$ and $B$ fluxes with the overall optical index in the sense that harder spectra correspond to higher states (i.e., the same as possibly present in the far-UV). The correlation weakens in $V$ and $R$ and may change sign in $I$. This behavior seems similar to that of PKS 2155 − 304, but with a critical wavelength $\lambda_c$ shifted to ∼7000 Å. The observations of OJ 287 of Worrall *et al.* (1982), which refer to a low state of the source (1980 October), indicate that the UV power-law spectrum extends to the optical spectral range, while at ∼1 $\mu$m the spectrum tends to flatten. Therefore, also for OJ 287 the position of the break in the energy spectrum may be related to the spectral dynamics, in analogy with the case of PKS 2155 − 304. On the other hand, in the 1983 high state of OJ 287, evidence of a change in spectral shape around 3000 Å was found (Maraschi *et al.* 1983*a*; Moles, Garcia-Pelayo, and Masegosa 1984), which weakens the inference above. It is of course possible that the critical wavelength changes with the occurrence of large outbursts, but the data are insufficient for discussion of this possibility.

## V. DISCUSSION AND CONCLUSION

The above analysis shows that there are both intensity and spectral changes in the UV emission of OJ 287 and PKS 2155 − 304. Harder spectra tend to correspond to higher intensity at shorter wavelengths, especially on short time

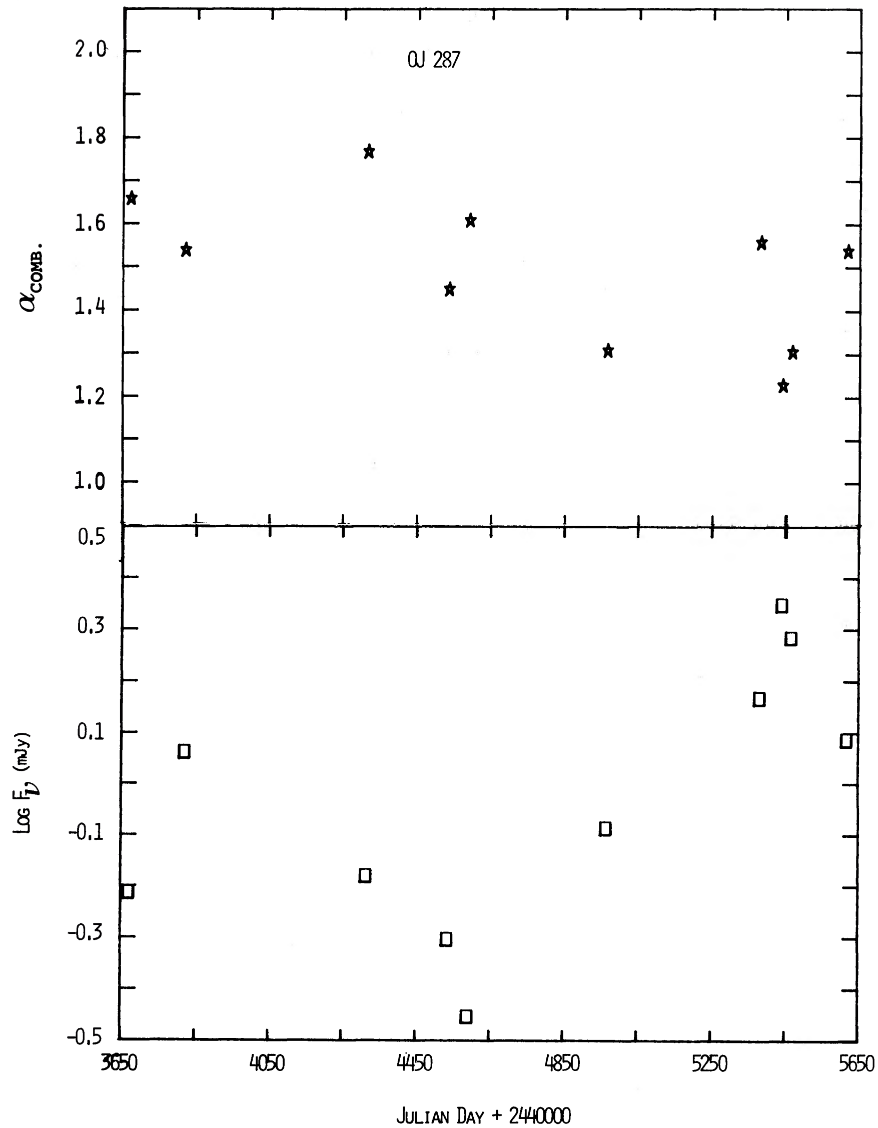


FIG. 4.—Combined (1200–3200 Å) spectral index (*upper panel*) and 1500 Å continuum flux (*lower panel*) vs. time for OJ 287

scales. The correlation between spectral index and intensity measured at longer wavelengths (2500 Å) is weaker, if present at all. A weak correlation between spectral index and intensity was found also for Mrk 421, the only other BL Lacertae object for which extensive UV observations exist (Ulrich *et al.* 1984). In the latter case the 2500 Å flux was considered.

In Seyfert galaxies much larger spectral changes ($\Delta\alpha \sim 2$) have been found in the ultraviolet, with a strong correlation with intensity, harder spectra corresponding to higher intensities (see Perola *et al.* 1982 for NGC 4151; Barr, Willis, and Wilson 1983 for NGC 3783; Ulrich and Boisson 1983 for NGC 3516 and NGC 5548; Clavel 1984 for NGC 4593). The difference between the two classes of objects may be ascribed to the presence of a thermal component in the spectra of Seyfert galaxies and quasars which is absent in BL Lacertae objects (e.g., Maraschi, Tanzi, and Treves 1984). The larger hardening observed in Seyfert galaxies corresponding to the source brightening could be due either to the spectral variation of the thermal component or to a large variation of the intensity (but not of the shape) of the nonthermal component, important in the short-wavelength range, superposed on a quasi-stationary thermal component, which dominates at 3000 Å (e.g., Wamsteker *et al.* 1984).

The UV emission of BL Lacertae objects is probably due to synchrotron radiation, as can be argued from the strong polarization observed in the optical band and envisaged by present models (e.g., Urry and Mushotzky 1982 and Ghisellini, Maraschi, and Treves 1985 for the case of PKS 2155−304, and Worrall *et al.* 1982 for OJ 287). Evaluation of the lifetime for synchrotron radiation of the emitting particles indicates the need for an acceleration mechanism active in the emission region (e.g., Maraschi *et al.* 1980; Ulrich *et al.* 1984). The weak dependence on intensity of the UV slope implies that the electron acceleration mechanism should yield the same power-law spectrum, practically irrespective of luminosity. This self-regulation may be less efficient at higher frequencies where the radiative losses are stronger, as indicated by the appearance of some slope-intensity correlation above a "break" frequency. This kind of inference is in qualitative agreement with models considering acceleration through strong shocks and radiatively

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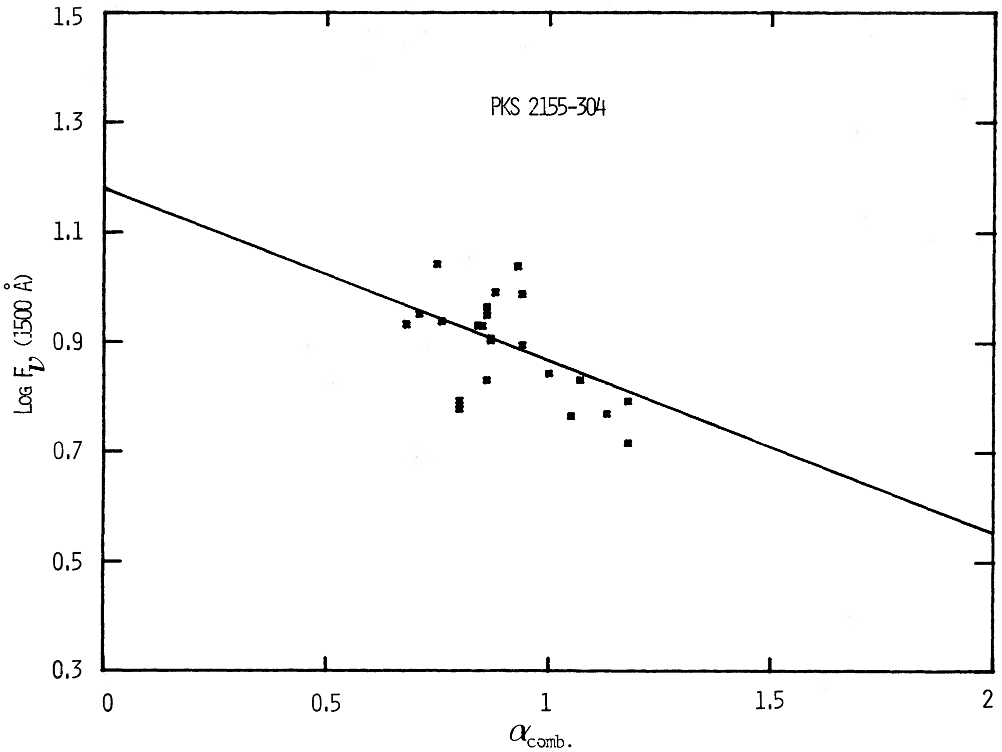


FIG. 5.—Continuum flux (1500 Å) vs. spectral index (1200–3200 Å) for PKS 2155 – 304. Continuous line is the result of a linear regression fit (see Table 3).

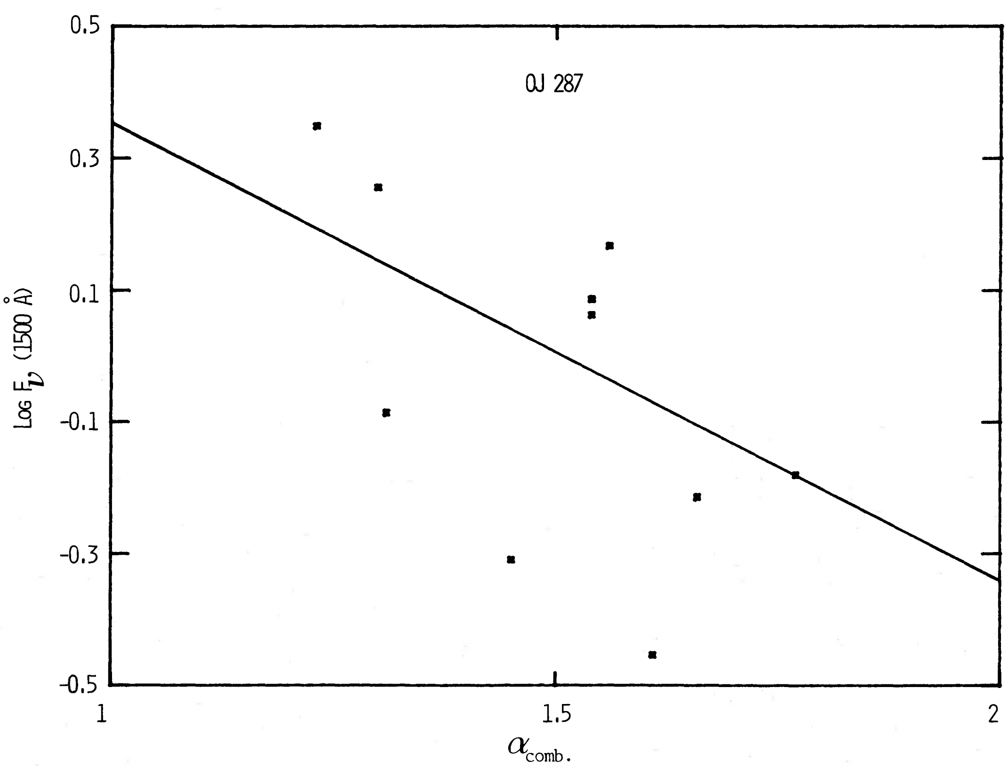


FIG. 6.—Continuum flux (1500 Å) vs. spectral index (1200–3200 Å) for OJ 287. Continuous line is the result of a linear regression fit (see Table 3).

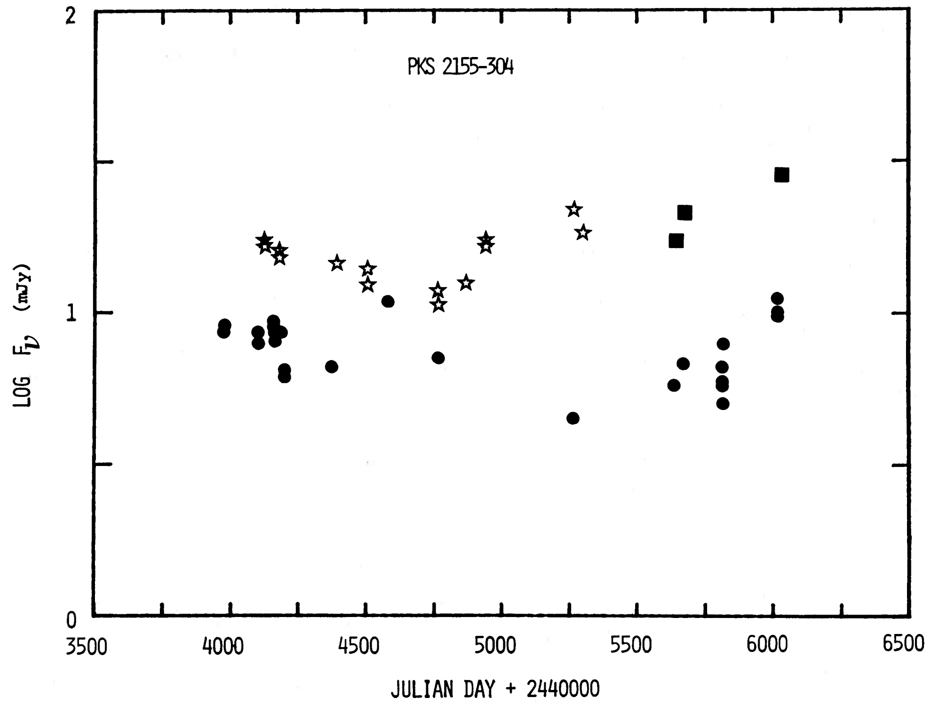


FIG. 7.—Light curves of PKS 2155−304 at 1500 Å (*filled circles*) and in the *V* band (*stars*: data from Miller and McAlister 1983; *filled squares*: measurements obtained by us).

limited acceleration (e.g., Begelman, Blandford, and Rees 1984; Bregman 1985).

Observations of the type discussed here show the need of developing time-dependent models of particle acceleration which are as yet unexplored.

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