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The UV spectrum of the BL Lac object PKS 0521 – 36

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Summary. Ultraviolet observations (1200–3000 Å) with the *IUE* satellite of the BL Lac object PKS 0521 – 36 are presented. The only emission line which appears clearly in the spectrum is Lyα, which is asymmetric with a component displaced ~ 3000 km s^{-1} to the red. The intensity of the line and the upper limits on other lines are compared with the model calculations on QSOs and Seyfert nuclei by Kwan & Krolik. The continuous energy distribution is discussed, combining non-simultaneous observations from the ultraviolet to the infrared. The spectral range of the non-thermal source from far IR to far UV can be described by a single power law of index – 1.5.

1 Introduction

PKS 0521 – 36 is a BL Lac object lying at the centre of an E galaxy whose redshift $z = 0.055$ has been measured from both emission and absorption lines. The optical and radio properties have been discussed by Danziger *et al.* (1979) who, in particular, noted the presence of an optical jet. New optical and radio data will be presented in a forthcoming paper (Danziger *et al.* 1983, in preparation).

During the 1976 optical observations it was apparent that weak optical emission lines were present superimposed on a stellar and non-thermal continuum. Assuming that the stellar component contributed by the underlying galaxy is ≃ 20 per cent of the total observed emission at ~ λ5900, the spectral index $\alpha\,(F_\nu \propto \nu^\alpha)$ of the non-thermal continuum was deduced to be approximately – 1. Variability of the continuum (Eggen 1970) may have been responsible for the apparent changes in the visibility of the emission lines measured by Searle & Bolton (1968).

On spectra taken in 1981 August by Danziger *et al.* (1983, in preparation) and 1981 February by Ulrich (1981) remarkable changes were noted namely the appearance of broad

Hα and Hβ emission. The inferred slope of the non-thermal continuum was consistent with that given by Danziger *et al.* (1979). The presence of low density ionized gas distributed at large distances from the nucleus has been noted by Fosbury (1982) and Danziger *et al.* (1983, in preparation).

The X-ray emission from PKS 0521 − 36 has been measured by Schwartz & Ku (1982) with the *Einstein* satellite, yielding an intrinsic luminosity of 0.7×10^{44} erg s^{-1}.

Further studies of this object have continued over a period of years using a variety of observational techniques. The ultraviolet observations reported here, extend our knowledge of the non-thermal continuum and are relevant to a discussion of the physical conditions in the gas.

2 Observations

PKS 0521 − 36 was observed in the low resolution mode (Δλ = 6 Å) with the *International Ultraviolet Explorer* satellite (*IUE*) during 1980 March (in the range 1200–2000 Å) and during 1980 September (in the range 1900–3200 Å). The source was put in the large aperture (10 × 20 arcsec slot) of the spectrometer by means of the blind offset technique. The journal of observations is given in Table 1. Conversion to absolute flux from the standard line by line extracted spectrum has been made at the European Southern Observatory by means of the calibration curve provided by Bohlin *et al.* (1980).

We have combined the short and long wavelength spectra in Fig. 1. In the overlapping region near 2000 Å the flux levels of the two observations are well matched, although there may have been variations between the two epochs. The continuum, over the range 1300–

Table 1. Journal of observations.

Exp. No.	Duration	Date	Julian date
SWP 8169	300 min	1980 March 5	2 444 303.5
LWR 8913	110 min	1980 Sept. 29	2 444 511.5

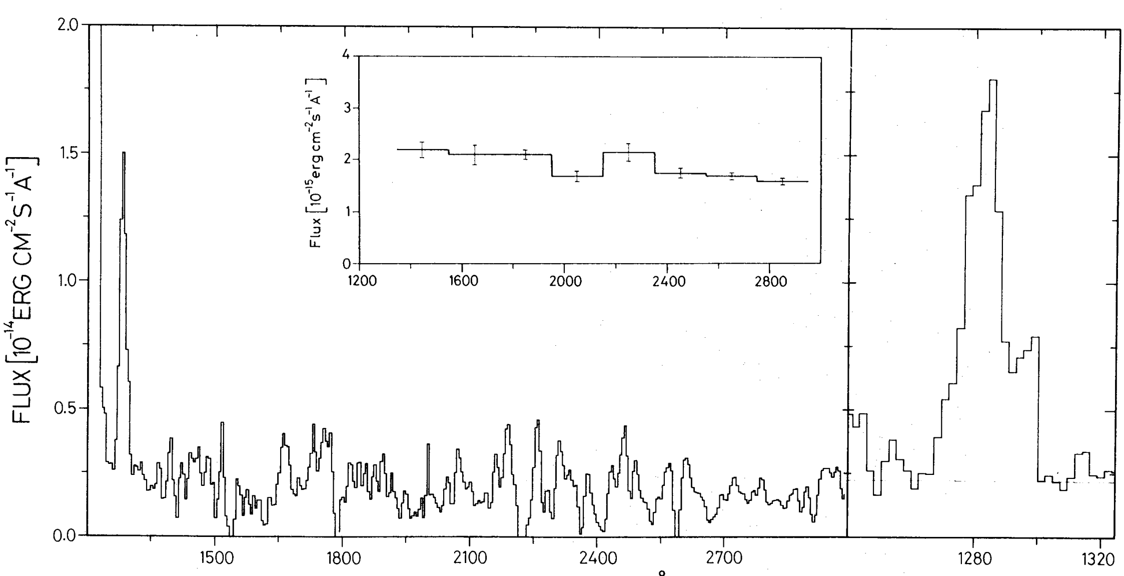

Figure 1. In the lower left is a plot of the complete flux calibrated UV spectrum of PKS 0521 − 36. The lower right shows the region around Lyman α on an expanded scale revealing the structure alluded to in the text. The upper inset shows the flux calibrated ultraviolet continuum binned in 200 Å intervals to improve the signal-to-noise with the mean level for 200 Å shown by the solid line. Estimated random errors are shown by vertical lines.

3000 Å, is well represented by a power law $F_\lambda = 8.3 \times 10^{-14} \lambda^{-0.5} \pm 0.8$ erg s^{-1} cm^{-2} Å^{-1} ($F_\nu = 1.4 \times 10^{-7} \nu^{-1.5} \pm 0.8$ W m^{-2} Hz^{-1}): see the inset of Fig. 1 which represents the combined spectrum rebinned in 200 Å intervals. The absence of any noticeable 2200 Å dip is consistent with a very small amount of interstellar reddening, as is derived from both the cosec law ($E_{(B-V)} \simeq 0.03$; Sandage 1973) and the hydrogen column density in the direction of the object (Heiles & Cleary 1979) which, assuming the mean gas-to-dust ratio (e.g. Savage and Mathis 1979), gives $E(B-V) \simeq 0.08$. Therefore, no correction for reddening has been applied to the observations. A negligible reddening correction is also suggested by the Balmer decrement in the broad-line component observed and discussed by Danziger *et al.* (1983, in preparation).

Only one emission line is clearly apparent with a wavelength of λ1283 Å, corresponding to the redshifted Lyman α emission from the source. Its profile is clearly asymmetric (see Fig. 1) and a feature peaked at λ1294 (λ1226 rest wavelength) affects the red wing. The full width zero intensity of Lyα is > 32 Å (or > 8000 km s^{-1}) while the equivalent width of Lyα is $\simeq$ 110 Å and the observed flux F(Lyα) $\simeq 2.4 \times 10^{-13}$ erg cm^{-2} s^{-1}.

The S/N ratio is not sufficient to detect any other spectral features of intensity $\leqslant 0.18$ times the Lyα intensity.

3 Discussion

The asymmetry of Lyman α and the second peak displaced by 3000 km s^{-1} redward correspond to a similar structure in Hβ observed by Danziger *et al.* (1983). This asymmetry and resolved secondary component are not uncommon in quasar and Seyfert 1 spectra. See, for example, Osterbrock & Shuder (1982). A model of clouds of gas expanding from the centre where one observes preferentially the heated surfaces of those on the far side of the nucleus receding from us, has been proposed by Lawrence (1982) for quasars and Seyfert 1 galaxies and may equally well apply here.

The full width at zero intensity (FWZI) of Ly$\alpha \sim 8000$ km s^{-1} is possibly less than that measured for Hβ by Danziger *et al.* (1983, in preparation) who suggest a value > 12 000 km s^{-1}. This quantity is so difficult to determine observationally that one cannot put great weight on this difference. The full width half maximum (FWHM) for Lyα is 2300 km s^{-1} (corrected for the instrumental resolution) and for Hβ 4530 km s^{-1}. Because the second velocity component is stronger in Hβ than in Lyα, this width of Hβ includes this second component, but for Lyα it is not included. Given the relatively poor S/N ratio in the spectrum, it is impossible to convincingly deconvolve the Lyα emission feature into a unique set of multiple components, which might reveal what proportions of narrow and broad line features contribute to the observed line. However, the narrower width of Lyα could be explained by a much higher Lyα/Hβ ratio for the narrow component than for the broad one, when the contribution of the narrow component to the total Lyα intensity is significant as observed in some broad line radio galaxies.

Our measurements of the UV spectrum of PKS 0521 – 36 fit well the linear relationship between Lyα luminosity and the UV continuum luminosity shown by Osmer (1977) and Wu *et al.* (1979) to apply to quasars and Seyfert 1 nuclei, if extended fainter to cover a total range in luminosity of 4 orders of magnitude. In other words, the equivalent width of Lyα in PKS 0521 – 36 is similar to that observed in the higher luminosity quasars and Seyfert 1 nuclei.

Since the models of Kwan & Krolik (1981) describe with some success the emission line spectra of quasars and Seyfert 1 nuclei, it is possibly instructive to examine whether the spectrum of PKS 0521 – 36 can be also understood. Our measured value of Lyα/Hβ ratio $\simeq$ 11 is in close agreement with the predicted value ~ 10. In view of even a small uncertainty in reddening causing a significant uncertainty in the Lyα/Hβ ratio, and the fact that PKS 0521 − 36 is a much lower luminosity object than the quasars discussed by Kwan & Krolik (1981), this good agreement should not be overinterpreted. However, the model also gives a shallow Balmer decrement in agreement with the observations of Danziger *et al.* (1983, in preparation). This model requires only a small contribution of collisional population of the relevant levels in neutral hydrogen and shows that the C IV (λ 1550)/Lyα ratio decreases as the parameter Γ_i ($\propto L/N_0R^2$ = continuum flux/mass density) decreases. Extrapolation in Γ_i from their model suggests that C IV/Lyα could be as low as 0.02 and therefore C IV would be below the limit of detection in our data. We estimate that an upper limit to the equivalent width of C IV in our spectra is 20 Å. This provides a deviant point on the relationship between equivalent width of C IV and the continuum flux observed by Baldwin (1977) and Wu *et al.* (1979).

This observed value of the ratio Lyα/C IV > 5 suggests some other possibilities for understanding how the physical conditions in PKS 0521 − 36 might differ from those in more luminous objects. For example, the observed ratio is more typical of narrow-line galaxies (Bergeron, Maccacaro & Perola 1981) than of Seyfert 1 nuclei (Oke & Goodrich 1981). The presence in the broad-line region of structures of only moderate opacity (suggested by the Lyα/Hβ ratio) and a smaller flux of ionizing C^{++} photons (suggested by the steep UV slope of the non-thermal spectrum), might be responsible for this result. Also it will be seen in the following discussion that there is no sign whatsoever of the presence of an optically thick gas emitting thermal blackbody radiation at a temperature of $2–5 \times 10^4$ K, as is evident in NGC 4151 and 3C 273. At present the evidence is not incontrovertible that the broad-line region has formed in the past two years, rather than simply being masked by the non-thermal source at maximum luminosity. However, if it has, a plausible postulate might require that when a broad-line region is first formed, it is less opaque than the long established ones existing in Seyfert 1 nuclei and quasars.

In Fig. 2 (inset) we present the overall energy distribution of PKS 0521 − 36 from radio to X-ray wavelengths. The radio points plotted are for the compact milliarcsec source at the nucleus of the galaxy. Even so, since it has a diameter of 1.5 pc (Geldzahler *et al.* in preparation), the radio emission is probably coming from a region significantly larger than the broad-line region. The infrared points come from observations at various epochs (Glass 1979; Danziger *et al.* 1983, in preparation) as do the optical (Ulrich 1981; Danziger *et al.* 1983, in preparation) and ultraviolet ones (this paper). The X-ray flux comes from the work of Schwartz & Ku (1982).

Although some caution is in order as the observations are not simultaneous, we note that the far-infrared and far-ultraviolet data, where the contribution from the underlying galaxy should be negligible, are accounted for by a single power law with a slope in the range $-1.5 \rightarrow -1.6$ depending on which set of infrared data is used. The measured X-ray flux lies just above the extrapolation of this power law. The emission appearing in excess over the assumed non-thermal spectrum, between 10^{14} and 10^{15} Hz, is very similar to the stellar component given by Rieke, Lebofsky & Kemp (1982) for the E3 galaxy NGC 1052. In Fig. 2 a decomposition which refers to the infrared data by Danziger *et al.* (1983, in preparation) is shown.

There is reason to believe that the non-thermal source was at or near minimum light during the period of the observations discussed here. Our short and long wavelength UV spectra taken 6 months apart in 1980 match together well. The short wavelength UV observations taken in 1981 December (Danziger *et al.* 1983, in preparation) are very similar to the earlier ones. Optical observations taken in 1981 January (Ulrich 1981), 1981 August

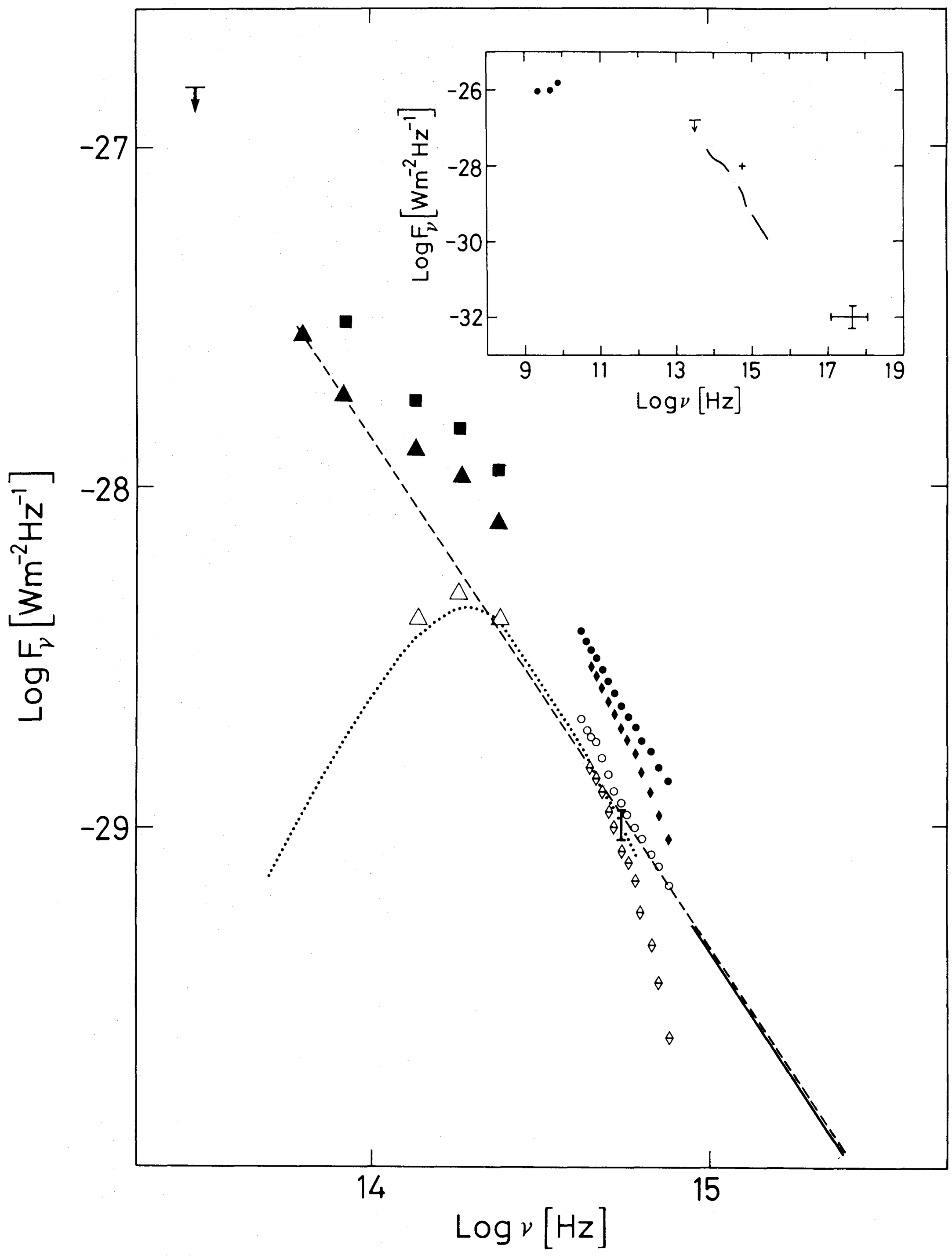

Figure 2. This demonstrates an attempt to decompose the spectrum of PKS 0521 – 36, in the range far-IR to far-UV, into the non-thermal power law and the stellar component of the elliptical galaxy. The following symbols have been used in this figure. IR: ▲ Danziger *et al,* (1983, in preparation), ■ Glass (1979). Visual: ● Ulrich (1981), ♦ Danziger *et al.* (1983, in preparation). UV: This paper. I: Eggen (1970) magnitude at minimum converted to a 4 arcsec aperture following Peterson (1970). .... Dotted line: Rieke *et al.* (1982) stellar component for an E galaxy (NGC 1052) normalized at the Eggen magnitude. ----- Dashed line: a power law $F_\nu \propto \nu^{-1.5}$ fitted through the far-IR and far-UV points. Open symbols: △, ◇, ○ represent the difference between the observations and the adopted power law.
Inset: the electromagnetic spectrum of PKS 0521 – 36. The radio data consists of observations at 13 cm (Broderick *et al.* 1972), 6 cm (Danziger *et al.* 1979) and 3.8 cm (Geldzahler *et al.*, in preparation). The IR and visual points come from Danziger *et al.* (1983, in preparation) and the cross (+) is the Eggen (1970) 20 arcsec aperture measurement at maximum light.

and 1982 January (Danziger *et al.* 1983, in preparation) and IR photometry taken in 1981 November (Danziger *et al.* 1983, in preparation) all show that the non-thermal source is far from maximum. In fact large aperture *UBV* photometry obtained in 1981 August matches very well the Eggen (1970) point at minimum light plotted in Fig. 2. If a stellar component similar to that adopted by Danziger *et al.* (1977) and by Ulrich (1981) is considered, the derived non-thermal component would be flatter in the optical range than that considered above, leading to a more complicated shape of the non-thermal continuum. Assuming that the simpler decomposition is correct, the spectrum of PKS 0521 − 36 is similar to that of I Zw 187 (Bregman *et al.* 1982), in that a single power law can represent the non-thermal component from 6×10^{13} to 2.4×10^{15} Hz. A different behaviour is observed, for instance, in PKS 2155 − 304 (Maraschi *et al.* 1980, 1983, in preparation) where a break is apparent at $\sim 10^{15}$ Hz.

All the available evidence suggests that we have measured the non-thermal source near minimum light which is approximately a factor 3 lower than maximum light. However, simultaneous observations from the ultraviolet to the infrared wavelengths are needed in order to obtain an unambiguous energy distribution of the continuum. It is now particularly important to measure the non-thermal component at more luminous phases simultaneously at all wavelengths. Also, variability and surface photometry studies should improve the estimate of the stellar component.

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