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THE HIGH-LUMINOSITY BL LACERTAE OBJECT PKS 0823−22[1]

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ABSTRACT

Simultaneous infrared, optical, and UV observations of the BL Lacertae object PKS 0823−22 are presented. The identification of the observed absorption doublet at λλ5341, 5355 with Mg II λλ2796, 2803 gives an absorption redshift $z_{abs} = 0.910$. At this redshift, the object is one of the most luminous of its class with $M_V \lesssim -29.4$. The spectral flux distribution of the source and the properties of intervening absorbing matter are discussed. Analogies with other sources suggest that the object may be gravitationally lensed.

Subject headings: BL Lacertae objects — galaxies: individual (PKS 0823−22) — galaxies: redshifts — gravitational lenses

I. INTRODUCTION

The optical counterpart of the flat radio source PKS 0823−22 was identified by Condon, Hicks, and Jauncey (1977) as a starlike object of $m_p \sim 17.5$. Optical spectroscopy obtained by Wright *et al.* (1979) and Wilkes *et al.* (1983) showed a continuous spectrum without spectral features of line-to-continuum ratio in excess of 0.15. These observations suggested a BL Lac classification of the object. Variability (Adam 1985; Beskin *et al.* 1981; Impey and Tapia 1988) of up to ∼1.5 mag in the V band and optical polarization of 4%–10% (Beskin *et al.* 1981; Impey and Tapia 1988), confirmed the BL Lac nature of the object. The near-IR colors (Allen, Ward, and Hyland 1982) are typical of the class. In the far-IR, it was detected by *IRAS* at 60 μm while only upper limits are given at 12, 25, and 100 μm (Impey and Neugebauer 1988). Radio fluxes at 2700 MHz and 5 GHz have been reported by Condon, Hicks, and Jauncey (1977) and by Bolton, Shimmins, and Wall (1975). Monitoring of the source at 1410 MHz has been recently reported by Giacani and Colomb (1988), showing that the flux density increased continuously from 1985 December to 1986 December, with a slight decrease in 1987 January. No measurements in the X-ray band are reported.

In the course of a multifrequency monitoring program of BL Lac objects (see, e.g., Tanzi *et al.* 1989), aimed at studying the energy distribution in the UV to near-IR range, we found the object in a bright state ($V = 15.7$) in 1988 January. This prompted low-(FWHM = 15 Å) and medium-(FWHM = 4 Å) resolution spectrophotometry of the source in the visible, together with simultaneous low-dispersion *IUE* observations and near-infrared photometry.

The energy distribution derived from simultaneous optical and near-IR observations is discussed, together with the results obtained from medium-resolution spectroscopy. The analysis of absorption features detected in medium-resolution spectra allows the derivation of an absorption redshift for the source and a study of the properties of intervening matter.

Preliminary reports on the redshift are given in Tanzi *et al.* (1988) and Falomo, Tanzi, and Treves (1989).

[1] Based on observations collected at the European Southern Observatory, La Silla, Chile.

II. OBSERVATIONS

The observations were made on 1988 January 7–14 at the European Southern Observatory (ESO) both in the visible and in the near-infrared spectral regions. A journal of the observations is given in Table 1.

Optical spectrophotometry was obtained with the Boller and Chivens spectrograph attached at the 1.5 m ESO telescope, at dispersions of 115–225 Å mm^{-1} using a CCD detector (RCA with 1024 × 300 pixels). Slit widths of 8″ and 4″ were used for, respectively, the low- and medium-resolution spectroscopy. The seeing, derived from Gaussian interpolation across dispersion of pointlike source spectra, was in the range 1″.5–2″.5. Standard reduction techniques were applied for flat-field correction, sky subtraction, and absolute flux calibration. An optimal extraction was adopted for the spectra of January 13 and 14 in order to improve the signal-to-noise ratio favoring the detection of possible emission/absorption features. Double exposures of each spectrum were taken in order to reduce the contamination produced by cosmic-ray events. The photometric accuracy, as derived from several observations of standard stars from the list of Stone (1977), is better than 10%.

In the infrared, we obtained broad-band J, H, K, and L photometry with the InSb detector attached at the ESO–MPI 2.2 m telescope on 1988 January 7 and 8, simultaneous with the optical observations. Magnitudes and statistical 1 σ errors are given in Table 1. Conversion to flux density was performed using the zero magnitude fluxes given in Falomo *et al.* (1988).

The object was also observed on 1988 January 7 in the UV with the Short Wavelength Primary camera aboard the *International Ultraviolet Explorer* (*IUE*). The target was centered in the large aperture (10″ × 20″ oval) by using the blind offset procedure with coordinates $\alpha(1950) = 08^h23^m50^s.07 \pm 0^s.04$ and $\delta(1950) = -22°20'35''.0 \pm 0''.8$ as measured on a blue copy of the POSS. No signal was detected in the 300 minute exposure.

III. RESULTS

a) Energy Distribution

No significant variability was observed both in the optical and in the infrared, between the observations of January 7 and 8; therefore, the average data are reported in Figure 1 together with the red spectrum data (see Table 1) obtained on January 12 in poor photometric conditions, scaled to match the January 7 and 8 observations in the overlapping spectral range.

TABLE 1

JOURNAL OF OBSERVATIONS

Date (UT)	Instrument	Range	Notes[a]
1988 Jan 7.3	ESO 1.5 m, B&C[b], CCD	4100–7400 Å	$V = 15.7 \pm 0.1$; $\alpha = 1.71 \pm 0.03$
	ESO-MPI 2.2 m, InSb phot	J, H, K, L	$K = 11.97 \pm 0.02$ $\alpha = 0.90 \pm 0.11$
1988 Jan 7.5	*IUE*, SWP	1200–1900 Å	Exposure = 300 minutes; no signal detected
1988 Jan 8.3	ESO 1.5 m, B&C[b], CCD	4100–7400 Å	$V = 15{,}7 \pm 0.1$; $\alpha = 1.68 \pm 0.02$
	ESO-MPI 2.2 m, InSb photometry	J, H, K, L	$K = 11.96 \pm 0.04$; $\alpha = 0.98 \pm 0.08$
1988 Jan 12.3......	ESO 1.5 m, B&C[b] CCD	6100–9200 Å	Poor photometry
1988 Jan 13.3......	ESO 1.5 m, B&C[b], CCD	5100–6800 Å	FWHM = 4 Å
1988 Jan 14.3......	ESO 1.5 m, B&C[b], CCD	6900–8600 Å	FWHM = 4 Å

[a] Spectral index α is defined as $F_\nu \propto \nu^{-\alpha}$ (quoted errors are 90% confidence level).
[b] Boller and Chivens spectrograph.

A marked steepening of the observed continuum ($\Delta\alpha = 0.75$) is apparent between IR and optical frequencies, which reduces substantially when appropriate correction for interstellar reddening is applied. The extinction suffered by the source ($l = 244°$, $b = 9°$) is in fact high; amounting to $A_V = 0.55$ to 0.65 as deduced from the hydrogen column densities N_H (Stark *et al.* 1989) along directions close to the source and assuming $N_H/E_{B-V} = 5.8 \times 10^{21}$ (Bohlin, Savage, and Drake 1978).

Figure 1 shows the energy distribution dereddened for $A_V = 0.6$ using the interstellar extinction curve of Savage and Mathis (1979) in the optical and its extension to IR by Whittet (1988).

A single power-law fit ($F_\nu \propto \nu^{-\alpha}$) of the dereddened data in the range 8×10^{13} to 8×10^{14} Hz, yields $\alpha = 0.99 \pm 0.02$ ($\chi^2_\nu = 1.0$).

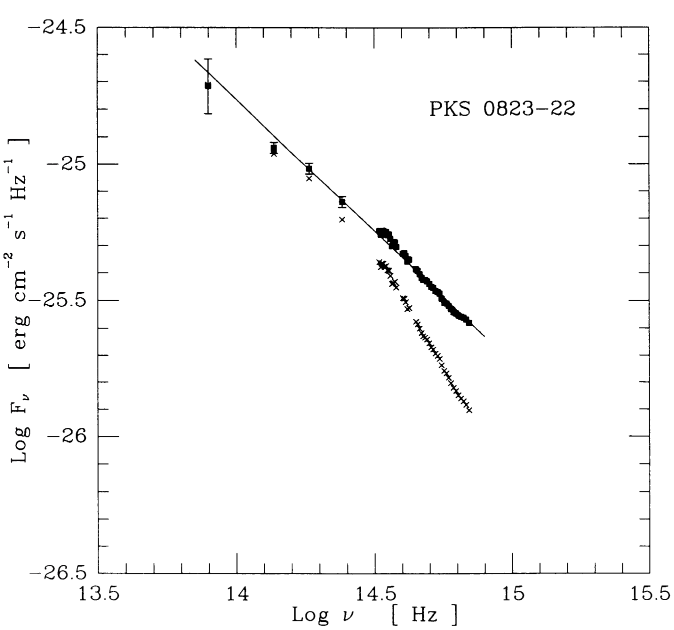

FIG. 1.—Spectral flux distribution of PKS 0823−22 obtained on 1988 January 7–12. *Crosses:* observed data; *filled squares:* dereddened ($A_V = 0.6$) data; *solid line*: fit of dereddened data (see text).

b) Mg II *Absorption Doublet*

An absorption feature at $\sim$5350 Å is clearly discernible on the low-dispersion spectra of January 7 and 8. This feature is resolved into two narrow absorption lines in the spectrum obtained at higher dispersion on January 13 (see Fig. 2): $\lambda_1 = 5341.5 \pm 1.0$ Å and $\lambda_2 = 5355.4 \pm 10$ Å. Identification with the Mg II doublet ($\lambda_1^{\rm vac} = 2796.35$ and $\lambda_2^{\rm vac} = 2803.5$) yields, respectively, $z_1 = 0.9102 \pm 0.0003$ and $z_2 = 0.9103 \pm 0.0003$, from which an absorption redshift of $z_{\rm abs} = 0.9103 \pm 0.0005$ is derived.

We measured the equivalent widths of the two lines assuming a linear continuum fitting the mean flux measured in two 100 Å bands at each side of the doublet and centered, respectively, at 5275 and 5425 Å. We obtain $W_1 = 2.2 \pm 0.2$ Å and $W_2 = 1.3 \pm 0.2$ Å. The quoted errors derive from the assumption of different continua as obtained by allowing for a $\pm 1\ \sigma$ variation of the flux measured in the two reference bands. The equivalent widths in the rest frame are: $W_1^{\rm rest} = 1.15 \pm 0.1$ Å, and $W_2^{\rm rest} = 0.68 \pm 0.1$ Å, and the doublet ratio (DR) W_1/W_2 is 1.7.

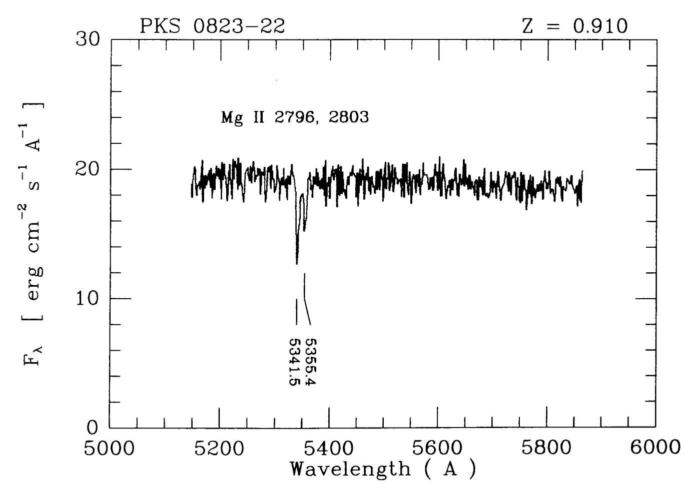

FIG. 2.—Portion of the medium resolution spectrum of PKS 0823−22 showing the absorption doublet identified with Mg II 2800 Å.

IV. DISCUSSION

The IR to optical energy distribution is well represented by a single power law ($\alpha \simeq 1.0$) when appropriate correction for reddening is applied. The case of PKS 0823−22 represents a good example of a fictitious spectral break in the IR to optical range if reddening is not accounted for. This effect is present in a large fraction of BL Lac objects, as reported by Tanzi *et al.* (1989) for a homogeneous set of simultaneous IR and optical observations of BL Lac objects.

We note also that the optical-IR power law $\alpha \sim 1$ appears to extend in the far-infrared up to 60 μm; the extrapolation of this power law being within 2 σ error of the 60 μm flux value. If this power law extends also at UV frequencies, the dereddened flux at $\nu = 2 \times 10^{15}$ Hz should be $I_\nu = 8.9 \times 10^{-27}$ ergs cm^{-2} s^{-1} Hz^{-1} and should produce a well detectable signal (27×10^{-16} ergs cm^2 s^{-1} Å^{-1} at 1500 Å) when observed by *IUE* at low dispersion. However, no signal was detected in the 300 minute exposure with the SWP camera, indicating either that a steepening ($\Delta\alpha \gtrsim 0.7$) of the energy distribution occurs between optical and UV frequencies or that an extinction well in excess of the adopted value has to be invoked.

With respect to the scant photometric data reported in the literature, our observations suggest that we observed the object during a bright state. As for the spectral index variability, we note that the spectrum reported by Wilkes *et al.* (1983), when the object was 1 mag fainter ($V = 16.6$), is fitted by a power law with $\alpha = 2.1 \pm 0.1$ (derived from the nondereddened published spectrum), while we find $\alpha = 1.7 \pm 0.02$ at $V = 15.7$. This behavior is similar to that observed in PKS 0048−09 (Falomo *et al.* 1988), suggesting that during bright states in both cases, the spectrum becomes harder with increasing intensity.

If the absorption redshift originates in intervening material along the line of sight to the object, the knowledge of $z_{\rm abs}$ allows us to derive only a lower limit to the absolute magnitude of the source. From the dereddened magnitude $V = 15.1$ and $z_{\rm abs} = 0.910$, we find $M_V \lesssim -29.4$ ($H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$), corresponding to $L_V \gtrsim 1.8 \times 10^{47}$ erg s^{-1}. Comparing this value with the absolute magnitudes derived for BL Lac objects with known redshift (see, e.g., Veron-Cetty and Veron 1987), one finds that PKS 0823−22 is one of the most luminous objects of its class.

The column density $N(\mathrm{Mg}^+)$ and the velocity dispersion σ of the absorbing gas can be derived from the equivalent width of the Mg II absorption doublet at $z_{\rm abs} = 0.910$ by using the doublet ratio method (see, e.g., Chan and Burbidge 1971; Wolfe and Burbidge 1975).

To calculate W/σ and DR as a function of central optical depth τ_0 (see Fig. 3), we assumed a simple Doppler profile, as justified by the high observed DR that implies small τ_0. Furthermore, because the observed Mg II doublet ratio is higher than the value for pure damping profile (DR $= \sqrt{2}$), unique values for σ and N are derived.

For DR = 1.7, we obtain $\tau_0 = 0.53$ and $W/\sigma = 7.1 \times 10^{-3}$ Å km^{-1} s^{-1} for the weakest component ($\lambda = 2803$ Å). Because

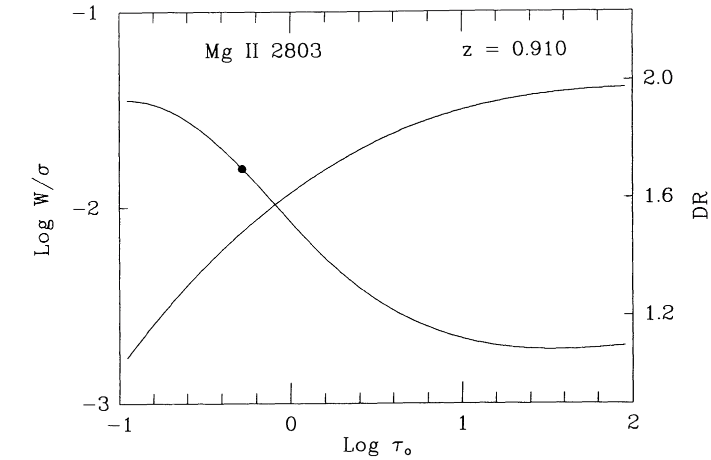

FIG. 3.—Mg II (λ2803) curve of growth and doublet ratio (DR) $\lambda2796/\lambda2803$ curve as a function of central optical depth. A filled circle indicates the observed DR on the doublet ratio curve.

$W^{\rm rest}_{\lambda=2803} = 0.7$ Å, one has $\sigma = 100 \pm 30$ km s^{-1}. Independent of the value of σ, the $N(\mathrm{Mg}^+)$ column density is obtained from

$$\frac{N}{W} = \frac{8\pi\sqrt{\pi}}{\lambda^3}\frac{q_1}{q_k}\frac{1}{A_{k1}}\frac{\sigma}{W}\tau_0 , \tag{1}$$

where q_1, q_k are statistical weights and A_{k1} is the spontaneous transition probability. For the Mg II λ2803 line, equation (1) yields $N(\mathrm{Mg}^+) = 4.2 \times 10^{13}$ cm^{-2} and, assuming solar abundances, we can infer an hydrogen column density $N(\mathrm{H\ I}) \simeq 1 \times 10^{18}$ cm^{-2}.

Although a detailed study of the physical conditions of the gas has to wait for a detailed modeling of the Mg II absorption profiles, the derived column density and velocity dispersion are consistent with the conventional interpretation of the absorption system $z_{\rm abs} = 0.910$ in PKS 0823−22 as originating in the halo of galaxies along the line of sight to the object (see, e.g., Bergeron *et al.* 1988).

A second point we wish to emphasize is that PKS 0823−22, being a BL Lac object with high luminosity and at great distance, could be similar to AO 0235+16, PKS 0537−441, and 0846+51W1, for which gravitational microlensing has been suggested (Stickel, Fried, and Kühr 1988, 1989; Arp *et al.* 1979; Nattale 1986). In the cases of AO 0235+16 and PKS 0537−44, deep CCD images have revealed foreground galaxies very close angularly to the BL Lac object, with diameters of ~50 kpc ($H_0 = 50$, $q_0 = 0$). In the case of 0846+51W1, there is a $V = 22.0$ mag galaxy only 2″.5 far from the BL Lac object (Crampton *et al.* 1989). Deep high-resolution images of the field of PKS 0823−22 are needed to search for a possible foreground galaxy.

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