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Sub-arcsecond imaging and spectroscopy of the radio-loud highly polarized quasar PKS 1610–771*

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Abstract. We report on imaging and spectroscopic observations of the radio-loud, highly polarized quasar PKS 1610–771 (z = 1.71). Our long-slit spectroscopy of the companion 4.55″ NW of the quasar confirms the stellar nature of this object, so ruling out the previously suspected gravitationally lensed nature of this system.

PKS 1610–771 looks fuzzy on our sub-arcsecond R and I images and appears located in a rich environment of faint galaxies. Possible magnification, without image splitting of the quasar itself, by some of these maybe foreground galaxies cannot be excluded. The continuum fuzz (made of the closest two objects, viz. A and D) is elongated in a direction orthogonal to the E vector of the optical polarization, as in high-redshift radio-galaxies. The spectrum of PKS 1610–771 appears strongly curved, in a convex way, with a maximum of intensity at $\sim$ 7,600 Å (2,800 Å rest frame), possibly indicating a strong ultraviolet absorption by dust.

Key words: quasars: general; PKS 1610–771

1. Introduction

In the late eighties, optical imaging surveys for gravitationally lensed quasars have used sample of known QSOs selected on the basis of apparently large absolute luminosities and high redshifts (Turner et al. 1984, Meylan et al. 1990, Swings et al. 1990, Surdej et al. 1992). Combining all radio and optical surveys, the number of multiple-image quasars due to gravitational lensing amounts to about twenty more or less convincing cases (Keeton and Kochanek 1996).

In the framework of the ESO key-program on gravitational lensing (Surdej et al. 1989), a large sample of highly luminous quasars has been observed between 1989 and 1992. One of the gravitationally lensed quasar candidates found is the radio-loud quasar PKS 1610–771, at z = 1.710 from Hunstead & Murdoch (1980), for which preliminary poor-seeing imaging has been obtained in August 1991 by Meylan & Djorgovski using the ESO 3.5-m New Technology Telescope (NTT). In spite of these non-optimal seeing conditions, the object appeared double.

In April and May 1995, we have been able to obtain, under much better seeing conditions, new NTT R and I images of the field of PKS 1610–771, as well as long-slit low-resolution spectra of both the quasar and its companion. These observations are presented and discussed here, together with polarimetric measurements by Impey & Tapia (1988).

2. Imaging

2.1. Observations and reductions

The observations took place during the two nights of April 17-18 and May 16-17, 1995, using the NTT in remote control observing mode, from the ESO Headquarters in Garching, Germany. The telescope was used with EMMI, the ESO-Multi-Mode-Instrument. The detector was the ESO CCD #36, a Tektroniks 2048$\times$2048, with a pixel size of 24μm corresponding to 0.268″ on the plane of the sky. The photometric conditions were good during the two observing runs, although a few cirri present during the observations with the I filter prevented flux calibration of these frames.

Two images were obtained with the R filter during the night of April 17-18, 1995. The final co-added frame has a total exposure time of 1,200 seconds, with a seeing of 0.85″, giving a limiting magnitude of 23.5 in R (2-σ_{sky} in at least 3 pixels).

The two images in the I filter were obtained during the night of May 16-17, 1995. The final co-added frame has a total exposure time of 1,200 seconds, with a seeing of 0.95″.

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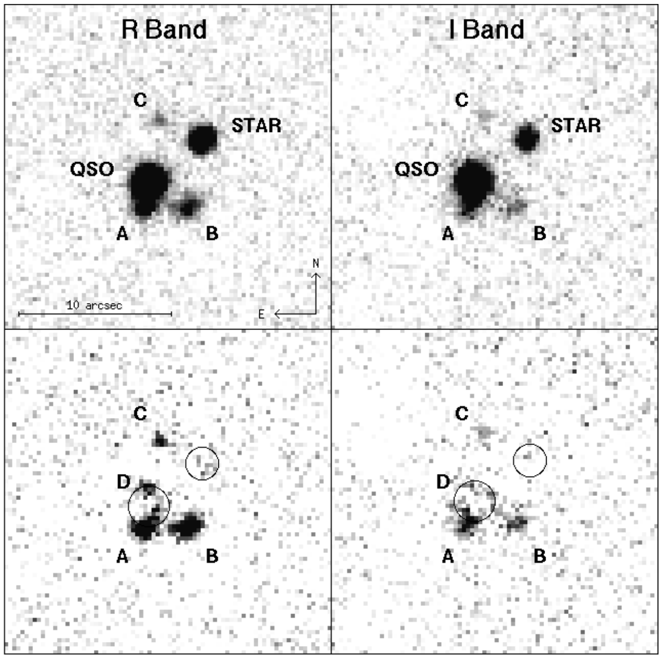

Fig. 1. Upper panels: NTT R and I band images of PKS 1610–771 obtained, in both filter, with a total exposure time of 1,200 seconds. The seeing (FWHM) is 0.85″ in R and 0.95″ in I. Lower panels: same images as above, but a PSF has been subtracted from the quasar and its companion. The two circles in both PSF-subtracted images show the position of the quasar and the star.

Figure 1 displays part of the images in the two R and I bands (upper panels), as well as the result of the subtraction of a double two-dimensional PSF profile (lower panels). The profiles of both the quasar and the star were fitted simultaneously in order to take into account relative light contamination of one object by the other. The PSF subtraction was carried out using the high-performance codes written by Remy (1996) to detect gravitational deflectors. In order to optimize the quality of the subtraction, the numerical PSF was calculated by using four different stars, all of them as bright as the quasar and as close to the quasar as possible in order to minimize any possible PSF variations across the field. The final PSF is a weighted average of the individual PSFs obtained from these stars. The PSF subtractions are carried out on the individual 600 seconds exposures in order to avoid any PSF changes due to the alignment procedure of the frames. The individual residuals are then added and are displayed in Fig. 1.

2.2. Results

In Fig. 1, the quasar PKS 1610–771 appears fuzzy and clearly separated from the object located at 4.55″ to the NW and suspected to be a second, lensed, image of the quasar. The latter has definitely a stellar-like profile and does not leave any significant residual after the PSF subtraction. The follow-up spectroscopic observations (see §3 below) confirm its stellar nature and rule out the possibility that PKS 1610–771 is a multiple image gravitationally lensed quasar.

Table 1. Relative positions of the five objects around PKS 1610–771 along with their R magnitudes (see text).

Object	Δx (″)	Δy (″)	$m_{\rm R}(1)$	$m_{\rm R}(2)$
Quasar	0	0	18.2 ± 0.2	...
Star	$+3.5 \pm 0.1$	$+2.9 \pm 0.1$	19.6 ± 0.2	...
A	-0.2 ± 0.2	-1.7 ± 0.2	...	21.3 ± 0.3
B	$+2.6 \pm 0.2$	-1.6 ± 0.2	21.0 ± 0.3	21.3 ± 0.3
C	$+0.7 \pm 0.2$	$+4.1 \pm 0.2$	23.0 ± 0.5	22.5 ± 0.5
D	-0.1 ± 0.2	$+1.0 \pm 0.2$	...	23.0 ± 0.5

Three resolved, galaxy-like, objects (noted A, B, and C) surround the quasar position on the plane of the sky. An additional faint object (noted D) appears only after the PSF subtraction; it is detected in the two individual R frames and their sum, as shown in Fig. 1. Although with a worse seeing, significant residuals are also seen on the I frames at the position where D is detected on the R frames. This faint D feature is unlikely to be an artifact due to bad PSF subtraction, since no significant residual can be seen after the subtraction of the PSF profile from the nearby star. Other applications of our PSF subtraction method show it to be reliable and free of any artifacts (Magain et al. 1992, Remy et al. 1993).

Table 1 gives the R magnitudes of the objects in the field, as well as their positions relative to the quasar. Flux calibration was done using the star LTT 7987 (Landolt 1992) observed at an airmass of 1.1, while PKS 1610–771 was at a mean airmass of 1.55. The magnitudes and positions were obtained using "S-Extractor", an aperture photometry program which computes the magnitudes through elliptical isophotes fitted to the objects (Bertin & Arnouts 1996; Bertin 1996). Two R magnitudes are given: $m_R(1)$ magnitudes are measured on the summed R frame while the $m_R(2)$ magnitudes are derived from the PSF subtracted frame. The magnitudes $m_R(2)$ are more accurate for the fuzzy objects, since they do not suffer from light contamination by the point-like bright objects.

Although we cannot calibrate the I-band image in flux, it is possible to derive the relative brightness of the quasar and the nearby star, and to compare it with the relative brightness found in the R band. We find $m_I(star) - m_I(quasar)$ = 1.95, whereas $m_R(star) - m_R(quasar)$ = 1.40, showing that the quasar is much redder than the star (as can, in fact, be seen from the spectra shown in Fig. 2). We cannot, however, rule out possible photometric variations of the quasar relative to the star, between April and May.

3. Spectroscopy

The spectra were obtained during the same nights, using the long-slit spectroscopic capability of EMMI. The grism #1 (see EMMI User Manual) provides low-resolution spectra with a spectral resolution of 5.8 Å pix^{-1} and a scale of 0.268″ per pixel in the spatial direction.

3.1. The April 17-18, 1995 spectra

The first aim of these observations being to investigate the potential lensed nature of PKS 1610–771, we acquired low resolution spectra of the quasar and its stellar-like companion. The 1″-wide slit had a position angle $\theta = 320°$ in order to obtain simultaneous spectra of the two point-like objects.

Two 1,200-second exposures and two 1,800-second exposures were taken, under good seeing conditions ($\sim 0.8''$) at airmass 1.5. A two-dimensional wavelength calibration was applied using He+Ar emission-line spectra. The standard star LTT 7987 was observed at an airmass of 1.1 and used to calibrate the observations in flux (Stone & Baldwin 1983, Baldwin & Stone 1984, Landolt 1992). Both the cosmic-ray removal and the sky subtraction were performed on the 2-D individual frames, before extracting and averaging the final 1-D spectra, which were subsequently corrected from atmospheric extinction.

3.1.1. Results

The spectra of the two objects are displayed in Fig. 2. In the upper panel is the quasar spectrum showing a very steep blue continuum, as observed by Hunstead & Murdoch (1980). Longwards of $\sim$ 7,600 Å (2,800 Å rest frame), the quasar spectrum decreases in intensity, creating an unusual convex shape. We identify the usual MgII $\lambda 2,795$, CIII] $\lambda 1,909$, and CIV $\lambda 1,549$ emission lines, which yield the redshift estimates given in Table 2, in good agreement with previous results by Hunstead & Murdoch (1980).

In the lower panel, the spectrum of the stellar-like companion is typical of a late-type star with $T_{eff} \sim 4,500° K$, ruling out the hypothesis of gravitational splitting. However, we can not exclude gravitational magnification of the quasar's luminosity by the nearby (angle-wise) fuzzy objects.

3.2. The May 16-17, 1995 spectra

We re-observed PKS 1610–771, in May 1995, this time with a 1.5″-wide slit positioned along the parallactic direction in order to avoid any possible bias caused by atmospheric dispersion.

We also observed several standard stars at different airmasses, some close to the airmass of the quasar, in order to have good corrections for atmospheric absorptions. The flux calibration was done using the standard star EG 274 (Stone & Baldwin 1983, Baldwin & Stone 1984, Landolt 1992) observed close to the quasar's airmass.

The observation and data reduction procedures were similar to those followed for the April 1995 data. The spectrum of PKS 1610–771 is a stack of four 1,800 second exposures (showing all the same convex shape after flux calibration) and obtained with seeing values between 1″ and 1.2″.

The quasar spectrum is shown in Fig. 3 along with the spectrum of the standard star LTT 9491. Both are flux calibrated using the standard star EG 274. The flux reference data for EG 274, used to establish the response curve of the instrument, is better sampled and extends over the spectral range 4,000 - 12,000 Å. The comparison between the reference and the observed spectral energy distributions of LTT 9491 illustrates a good accuracy of our flux calibration procedure.

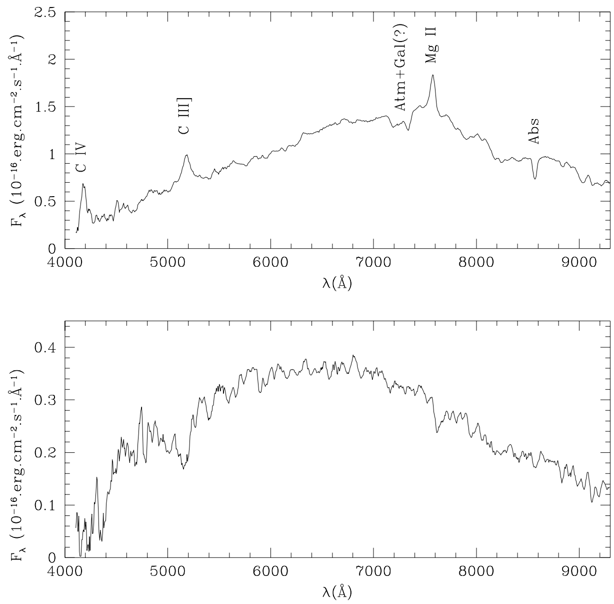

Fig. 2. April 1995 spectra of PKS 1610–771 (top) and of the nearby stellar-like bright object (bottom). The latter appears to be a late-type star . Note the general convex shape of the quasar continuum, and the steep slope bluewards of $\sim$ 7,600 Å

3.2.1. Results

These May 1995 spectra of PKS 1610–771 confirm the unusual convex spectral shape of the continuum observed in April 1995. Since the final reduced spectrum is better flux calibrated than the April one - but it has a lower signal-to-noise ratio - we measured the shape of the spectrum on the May data. Note that there are obvious differences in the shape of the continuum between April and May but that atmospheric refraction could have affected the April spectra, because of the slit orientation. Assuming a power-law dependence of the flux density with $F_\nu \propto \nu^{-\alpha}$, we measure $\alpha_b \simeq 4.5$ from λ 4,200 Å to λ 7,600 Å, which is even steeper than the value 3.8 reported by Hunstead & Murdoch (1980), and $\alpha_r \simeq -1.0$ from λ 7,600 Å to λ 9,300 Å.

An unidentified absorption feature seen in the April 1995 spectra is detected at 8,552 Å (and not present in the standard star, although at the same airmass as the quasar). Some additional absorptions are possibly present between 7,200 and 7,400 Å, on the blue side of the MgII emission line (see Figs. 2 and 3). These absorptions, blended with the atmospheric absorption bands (also present in the standard stars observed at the same airmass as the quasar), are never fully corrected after flux calibration, although the much stronger A- and B-bands are perfectly removed. This suggests that these absorptions are actually present in the quasar spectrum. Note that all the atmospheric absorption bands are perfectly corrected in the standard star LTT 9491 (Fig. 3).

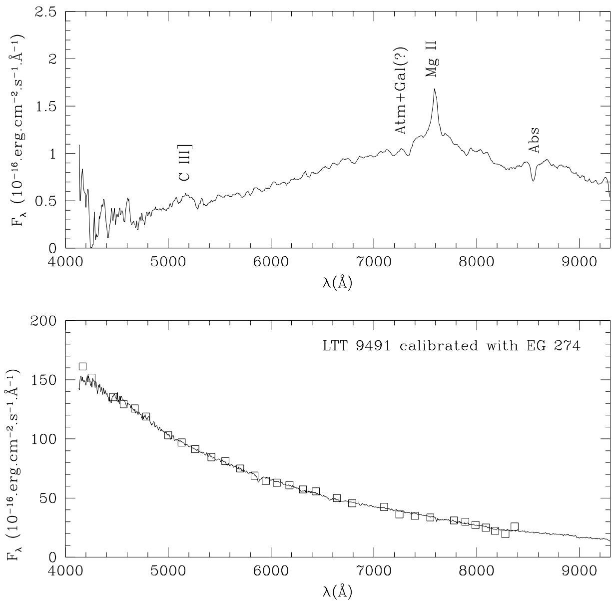

Fig. 3. The May 1995 spectra of PKS 1610–771 (top) and of the standard star LTT 9491 (bottom), both flux calibrated using the standard star EG 274. The tabulated values of the absolute flux of LTT 9491 are plotted with open squares. The perfect agreement between the reference and observed spectral energy distributions of LTT 9491 show that the unusual convex shape of the spectrum of PKS 1610–771 is intrinsic to the quasar rather than an artifact due to data reduction.

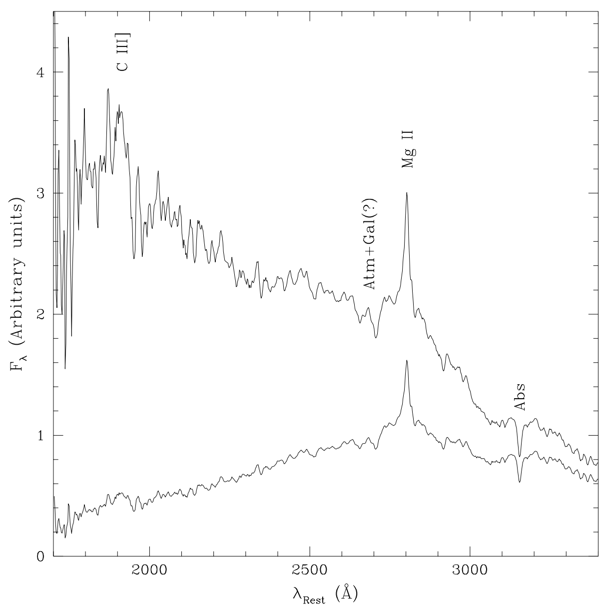

Fig. 4. The May 1995 spectrum of PKS 1610–771 (bottom) in the rest wavelength frame, and a plausible de-reddened version.

Table 2. Emission-line measurements and estimated redshift values from the spectra of PKS 1610–771

Line	April 1995		May 1995	
	λ_{obs}(Å)	z_{em}	λ_{obs}(Å)	z_{em}
CIV λ1549	4184	1.701	...	...
CIII] λ1909	5185	1.716	5163	1.705
MgII λ2795	7573	1.706	7595	1.714

4. Discussion

PKS 1610–771 was already recognized by Hunstead & Murdoch (1980) as a flat-spectrum radio-source with a steep optical continuum. Observed with the VLBI by Preston et al. (1989), PKS 1610–771 appeared slightly elongated (PA = 35 °) at the milliarcsecond scale. Its high optical linear polarization (p = 3.8 ± 0.7 %; θ = 78 ± 5 °) led Impey & Tapia (1988, 1990) to classify this object as a blazar, although there is no evidence for polarimetric variability.

While a few blazars display a curved continuum (see Falomo et al. 1994), none of them appears as steep as the one of PKS 1610–771. Baker & Hunstead (1995) give composite spectra of quasars with various values of R, the core-to-lobe radio flux density ratio. The composite spectrum which corresponds to the R ratio of PKS 1610–771, viz. $R \sim 0.3$ (Impey & Tapia 1990), shows a strong ultraviolet-optical bump. Although the blue end of the bump is well defined (Baker & Hunstead 1995), it is not seen in our spectra of PKS 1610–771, in which the slope of the short-wavelength continuum (blueward 6,000 Å) is constant and much steeper than in the composite spectrum.

Steep continua are not uncommon in flat-spectrum radio quasars (e.g., Rieke et al. 1979). However, such continua, attributed to an extension of the synchrotron radio emission, extend from the optical to the infrared, contrary to what is observed in the spectrum of PKS 1610–771. Indeed, the continuum slope we measure longwards of MgII, $\alpha_r \simeq -1.0$, is in reasonable agreement with the radio-to-optical slope reported by Impey & Tapia (1990): $\alpha_{ro} \simeq -0.9$, suggesting a net deficiency of flux bluewards of $\lambda_{rest} \sim 2,800$ Å. A most plausible explanation is dust absorption, which apparently occurs frequently in quasars (Webster et al. 1995). Dust may be either internal, in a dusty torus around the nucleus or external, i.e. in the host galaxy, or in intervening galaxies on the line of sight. Figure 4 illustrates a reasonable example of de-reddening using an SMC-like extinction curve (Prévot et al. 1984) with E(B-V)=0.4 and assuming the dust at the redshift of the quasar. The de-reddened spectrum shows a shape compatible with the "usual" shape of quasar continua, e.g. like the quasars observed in the LBQS sample (Morris et al. 1991). FeII emission can also be a present, as observed for example in PG 0043+039 (Turnshek et al. 1994)

The nature of the fuzzy objects (A+D) very near or superposed on PKS 1610–771 is unclear. They could constitute the quasar host galaxy: their size and brightness (cf. Table 1) are comparable to those of the fuzzy objects / host-galaxies found around high redshift radio-loud quasars (Hutchings 1995). We can however not exclude the fact that it is a galaxy located on the line of sight, although no absorption features (in the MgII line for example) due to an intervening object can be unambiguously identified in our spectra, except the possible residual absorptions observed between 7,200 and 7,400 Å. Note however that these features could as well be due to the gap between the two strong FeII emission bands seen in AGNs spectra at $\lambda_{rest} \sim 2,000 - 2,600$ Å and $\lambda_{rest} \sim 2,700 - 3,000$ Å (Wills et al. 1985). Even if we can not ascertain the redshift of the objects around PKS 1610–771, we can give the plausible redshift range of 1-1.7, comparing the magnitudes given in Table 1 with the predicted ones from Guiderdoni and Rocca-Volmerange (1988).

Most interesting is the fact that the A-D fuzzy elongation is detected in the continuum and that its direction (PA $\simeq 173^\circ \pm 5^\circ$) is orthogonal to the E vector of the –integrated– optical polarization ($\theta \simeq 78^\circ \pm 5^\circ$) measured by Impey & Tapia (1988, 1990). This property is an important characteristics of high redshift radio-galaxies (di Serego Alighieri et al. 1993), which, in the context of AGN unification models, are thought to be related to radio-loud quasars, simply being differently oriented relative to the observer. This suggests that the high polarization of PKS 1610–771 could be due to diffusion as in radio-galaxies, rather than to a synchrotron emission as in bona-fide blazars. Note that the VLBI structure of PKS 1610–771 (PA $\simeq 35^o$) is not aligned with the optical polarization, on the contrary to the majority of highly polarized radio-sources (Impey et al. 1991)

5. Conclusions

The present spectroscopic observations lead to the conclusion that the quasar PKS 1610–771 is not gravitationally lensed. However, in addition to its quite unusual spectrum, it appears fuzzy and surrounded by a rich environment of faint galaxies (which could magnify the quasar's luminosity).

The quasar's spectrum shows a break at 7,600 Å (2,800 Å rest frame) and an unusually steep slope blueward 7,600 Å, most likely due to strong reddening by intervening objects on the line of sight and/or by the quasar's host galaxy.

Our sub-arcsecond R and I images of the quasar show fuzzy extensions supporting the possible presence of absorbing objects on the line-of-sight. The orientation of the continuum emission of the fuzz around PKS 1610–771, perpendicular to the optical polarization, suggests that the polarization of the quasar could be due to diffusion, as in radio-galaxies.

PKS 1610–771 therefore appears as an interesting object, possibly intermediate between blazars and radio-galaxies, its core being not completely obscured and hidden, as for example in 3C 265 (Dey & Spinrad 1996), but highly reddened.

Further observations are needed to identify the exact nature and the redshifts of the fuzzy objects around PKS 1610–771, its spectral energy distribution on a wide wavelength range, and more particularly which mechanism is responsible for the observed optical polarization.

Confirming objects A+D as the host galaxy of PKS 1610–771 would provide us with a unique case of highly reddened (but not hidden) QSO in a high redshift (z=1.7) radio galaxy, strongly supporting the AGNs unification schemes.

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