Monitoring of active galactic nuclei*,**,

V. The Seyfert 1 galaxy Markarian 279

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Abstract. We report on the Lovers of Active Galaxies’ (LAG) monitoring of the Seyfert 1 galaxy Markarian 279 from January to June 1990. The source, which was in a very bright state, gradually weakened after the first month of monitoring: the Hα and Hβ flux decreased by 20% and 35% respectively, and the continuum under Hα by 30%. The luminosity-weighted radius of the broad line region (BLR), as derived from the cross-correlation function, is of the order of 10 light days. This result is very uncertain because the features in the light curves are very shallow, but it is unlikely that the radius of the BLR is more than 1 light month.

The profile variations of Hα confirm that the prevailing motions are not radial. The data of the present campaign and those obtained in previous years, when the source was in a much weaker state, show that the red asymmetry of the Balmer lines correlates positively with the broad line flux. This new effect is briefly discussed.

Key words: Galaxies: individual: Markarian 279 – Galaxies: Seyfert – Line: profiles

1. Introduction

The continuum and emission line variability of broad-line active galactic nuclei (AGN) is a phenomenon which has been known for several decades (Andrillat & Souffrin 1968; see also Peterson (1988) for a review of early results). The typical time scales are of the order of a week or less. Line and continuum monitoring has been extensively used in recent years as one of the very few tools available to probe the innermost region (≪ 1 pc) of AGN, specifically the spatially unresolved broad line region (BLR). The assumption is made that the ionizing continuum source is point-like with respect to the BLR, and that therefore the broad line gas reacts with light travel-time delay to the variations of the continuum. Simultaneous monitoring of the continuum and broad emission lines can thus provide information on the structure, size and kinematics of the BLR, through the technique of reverberation mapping (Blandford & McKee 1982). Because of the large amount of telescope time required to monitor AGN variability, at present only a few objects have been studied with adequate time resolution and coverage. The most recent results are reviewed by Peterson (1993). Detailed information on the velocity field of the BLR is still not available, but data presented by Clavel et al. (1990), Koratkar & Gaskell (1991) and Stirpe & de Bruyn (1991) indicate that dominant radial motions can be ruled out.
One of the programmes carried out by the Lovers of Active Galaxies (LAG) collaboration consisted in the frequent high-quality monitoring of a sample of 8 broad-line AGN, spanning a wide range of intrinsic luminosities. The main purposes of the programme consisted of increasing the sample of well-monitored AGN both in number and luminosity range, and adding high spectral resolution to frequent sampling. The observations took place from early January to early June 1990. In this paper we present the data obtained for one of these sources, the Seyfert 1 galaxy Markarian 279, and the immediate conclusions which they imply. For a review of the previous variability of Markarian 279, see Stirpe (1991) and references therein. Jackson et al. (1992), Wanders et al. (1993), Salamanca et al. (1993) and Dietrich et al. (1993a) discuss results from other targets of the LAG campaign.

2. Observations and reduction

The observations of Markarian 279 during the LAG campaign were conducted with the double spectrograph ISIS at the 4.2m William Herschel Telescope (WHT), and with the Intermediate Dispersion Spectrograph (IDS) at the 2.5m Isaac Newton Telescope (INT). CCDs were attached to both spectrographs. Tables 1 and 2 list the observations for Hα and Hβ respectively. For each observation, a letter (A–D) indicates the instrumental configuration used, following the definitions in Table 3. A wavelength interval of \( \sim 800 \, \text{Å} \) covering Hα was observed at all epochs except the last. When enough time was available a similar interval covering Hβ was also observed. A slit width of 1′′.5 was used throughout the campaign. The slit was oriented in the NS direction.

Standard procedures were followed to reduce the spectra, using the Starlink software package Figaro (Fuller 1989). The mean bias level was measured on the overscan section of each CCD frame, and a corresponding constant was subtracted from the entire frame. The pixel-to-pixel sensitivity variations were then corrected for by dividing each frame by a tungsten lamp flat-field (normally taken at the beginning or end of the same night) which had previously been normalized in the wavelength direction. Synthetic sky frames were obtained by fitting a 3rd order polynomial to each row (i.e. in the spatial direction) of a 2-D spectrum, discarding from the fit all pixels corresponding to bad columns, cosmic ray events, and target spectrum. Each fitted sky frame was subtracted from its corresponding spectrum frame.
Cu/Ar and Cu/Ne lamps were used for the wavelength calibration of the Hβ and Hα regions respectively. Depending on the resolution and number of useful lines in the arc frame (always more than 10, and occasionally exceeding 20), 2nd to 5th order polynomial fits were used, which yielded residuals lower than 0.4 Å at the lowest resolution and lower than 0.1 Å at the highest resolution.

All spectra were corrected for atmospheric extinction using the coefficients provided by the Royal Greenwich Observatory for La Palma. The flux calibration was achieved with the stars HD 84937 and BD +26°2606, using the fluxes tabulated by Oke & Gunn (1983). A correction for the B-band of O2 was obtained by interpolating the continuum of the same stars, and used to divide the band out of the Hα spectra of Markarian 279. The spectra of Markarian 279 were then extracted by summing a number of spectrum columns corresponding to the same spatial interval (6′′.5) on all frames. Finally, the wavelength scale was corrected for the redshift of Markarian 279 (z = 0.0303): unless otherwise stated, all wavelengths mentioned hereafter are in the rest system of Markarian 279.

Tables 1 and 2 also list the spatial full width at half maximum (FWHM) of the unresolved portion of each spectrum. This quantity was obtained from each frame as follows. A 2-D section of the frame containing only continuum (underlying galaxy + non-stellar component) and one containing also the broad emission line were collapsed in the wavelength direction. The spatial profiles thus obtained present extended wings formed by the resolved underlying galaxy. The continuum profile was scaled so that its extended wings had the same flux as those of the continuum + broad line profile, and the former was then subtracted from the latter. The positive residual obtained was assumed to be emitted entirely by the unresolved BLR. The cores of the residual profiles could be well fitted by Gaussians: the FWHM of the fits are listed in Tables 1 and 2. These values provide an indication of the seeing for each observation.

3. Derivation of light curves

The spectra were corrected for differences in flux scale (caused by differences in seeing and transparency) by applying the internal calibration discussed in Stirpe & de Bruyn (1991), based on the assumption that the narrow lines do not vary. The lines used as calibrators were the strongest of each wavelength region, i.e. [O III] λ4959 and λ5007 for Hβ, and the narrow Hα and [N II] λ6584 for Hα. The spectra obtained on 31 January (JD2447923) were used as reference for the scaling. The fluxes of the [O III] λ5007, narrow Hα, and [N II] λ6584
lines in these spectra are $(14.3 \pm 0.8) \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$, $(6.2 \pm 0.9) \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$, and $(6.2 \pm 0.9) \times 10^{-14}$ erg s$^{-1}$ cm$^{-2}$ respectively. The uncertainties were estimated from the rms of the same measurements made on all spectra obtained on photometric nights with good seeing ($\leq 1\,\prime\prime.5$).

The internal calibration method consists in scaling a spectrum with respect to the reference spectrum, and adjusting the scaling factor until the narrow line residuals in their difference are minimized. The residuals were minimized automatically with the algorithm described by van Groningen & Wanders (1992). This procedure is more objective and accurate than visual inspection, and led to uncertainties in the relative calibration of typically $\leq 3\%$ for H$\alpha$ and $\sim 2\%$ in H$\beta$. The uncertainties were estimated by perturbing the internal calibration of each spectrum until clear narrow line residuals appeared in the difference between it and the reference spectrum. The narrow line region (NLR) of Markarian 279 is compact and unresolved, and therefore the internal calibration is not affected by narrow line slit losses as, for instance, NGC 3516 (Wanders et al. 1993). Figures 1 and 2 show the scaled H$\alpha$ and H$\beta$ spectra.

A power-law continuum was fitted to all H$\alpha$ spectra to intervals of 40 Å centred at 6140 Å and 6820 Å. For the spectra obtained on 16 February (JD2447939) and 17 March (JD2447968), whose wavelength ranges are slightly shifted bluewards, the second interval was centred at 6800 Å and 6780 Å respectively, and for the latter it was narrowed to 10 Å. After the continuum subtraction, the broad component of H$\alpha$ was isolated by subtracting the narrow H$\alpha$ component, and the forbidden lines [O i] $\lambda$6300 and $\lambda$6364, [S ii] $\lambda$6717 and $\lambda$6731, and [N ii] $\lambda$6548 and $\lambda$6584. The [O iii] $\lambda$5007 profile was used as a template for the narrow H$\alpha$, and high signal-to-noise templates for the other forbidden lines were obtained from the average of all H$\alpha$ spectra. To isolate [N ii] $\lambda$6584 in the average spectrum, a smooth broad H$\beta$ template was subtracted from H$\alpha$ after the subtraction of the narrow Balmer components, in order to eliminate the first order structure underlying the [N ii] lines. The [N ii] template thus obtained was used also for [N ii] $\lambda$6548, with the appropriate intensity scaling. Figure 3 shows the H$\alpha$ spectrum of 31 January before and after deblending. The broad line components resulting from this cleaning process were integrated between 6400 Å and 6750 Å to obtain the light curve of H$\alpha$.

The broad H$\beta$ profiles were obtained as follows. A broad H$\alpha$ template was used to subtract the multiplet 42 Fe ii lines ($\lambda$4924 and $\lambda$5018) and He ii $\lambda$4686 from the spectra. The [O iii] template was used to deblend H$\beta$ from its own narrow component and from
[O III] λ4959 and λ5007. Finally, a power-law continuum was fitted to and subtracted from the results. The Hβ spectrum obtained on 31 January is shown in Fig. 4, before and after the deblending. The deblending of Hβ is inevitably a subjective procedure, because of the contamination of its wings by the Fe II and He II lines. The highest uncertainty affects the placing of the continuum. In order to derive a realistic error bar for the broad Hβ fluxes, the deblending, continuum subtraction, and flux measurements were repeated with “extreme” continua (i.e. continua considered to represent upper or lower limits to the true ones): the relative uncertainty of the fluxes thus obtained is ~ 5%. This does not include systematic uncertainties caused by the choice of the continuum-fitting method. The Hβ fluxes were obtained by integrating the deblended spectra between 4760 Å and 4960 Å.

The data-set formed by the Hα spectra is more complete than that formed by the Hβ spectra. Therefore the non-stellar continuum light curve had to be derived from the former. The continuum at Hα was represented by the values of the power-law fits at the rest wavelength of Hα. These were corrected for seeing effects as described in the Appendix. The use of such a red continuum has a drawback: it is likely in fact that the amplitude of the variations is much smaller in the red continuum with respect to the ionizing continuum, or even with respect to the optical blue continuum, given that Seyfert variability tends to be stronger at higher frequencies (e.g. Peterson et al. 1991). Furthermore, the stellar continuum under Hα causes additional dilution of the variations. On the other hand, there is no evidence that the optical continuum is delayed with respect to the UV by more than 2 days in NGC 5548, a Seyfert 1 of intrinsic luminosity comparable to that of Markarian 279 (Peterson et al. 1991), and from one of the best studied cases up to now (Fairall 9, Clavel et al. 1989) it appears that the delay effects observed in the IR continuum with respect to the optical and UV continua do not extend to the red part of the optical spectrum. We therefore assume that the light curve of the red continuum is simply a lower amplitude representation of those of the UV and blue continuum.

The measured and corrected continuum fluxes (F_{6563} and F_{6563}^{corr} respectively) and the integrated broad Hα and Hβ fluxes are listed in Tables 4 and 5, and the light curves are shown in Fig. 5. The intervals between consecutive observations of the Hα region range from 1 to 18 days, with an average value of 6.1 days.
4. Continuum and line flux variations

When the monitoring started in January 1990, Markarian 279 was in a much brighter state than in previous years: the broad Hα component in the LAG spectra is about twice as strong when compared with the data obtained in 1987 by Stirpe & de Bruyn (1991) and in 1988 by Stirpe & de Bruyn (in preparation) and Maoz et al. (1990). Its intensity is comparable to that observed before the low state (e.g. Stirpe, 1990).

After a short quiescent period at the beginning of the campaign, the broad Hα flux increased by 10%, and after about 20 days decreased again by the same amount, and continued to decrease slowly until the end of the monitoring season. A shallow secondary maximum is visible around JD2447995. There is no isolated maximum in the continuum light curve corresponding to that visible in the Hα curve between JD2447921 and JD2447940: lack of observations and scaling uncertainties may have hidden a driving feature in the continuum curve corresponding to the Hα maximum. The peak-to-peak variation of Hα during the entire campaign did not exceed 20%. The continuum underwent a higher amplitude decrease (∼30%), and only very shallow deviations from the generally negative slope of the light curve are visible. Notice that the apparently correlated short time scale, low amplitude variations in the two light curves are most probably due to scaling uncertainties, both curves being derived from the same spectra. The Hβ light curve confirms the decreasing trend, with an amplitude of 35% (higher than that of the Hα variations, as is usually observed in varying Seyfert 1 nuclei). This light curve is too sparsely sampled to add significant information to the Hα data. The HeⅡλ4686 and FeⅡ lines also decreased during the campaign.

CCD images of Markarian 279 were obtained for the duration of the LAG campaign at the 1m Jacobus Kapteyn Telescope (JKT). The nuclear fluxes obtained from the images are not accurate enough to confirm or add information to the spectroscopic results, but are consistent with them within the uncertainties. The fluxes decreased by ≤50% and ≤40% in the B and V bands respectively, between mid-January (JD2447910) and late May (JD2448040). The variability in the R and I bands was ≤20%.

Figure 6 shows the cross correlation function (CCF) of the Hα vs. continuum light curves, and the autocorrelation function (ACF) of the continuum light curve, calculated with the Gaskell & Peterson (1987) method, but without artificially extending the light curves with a constant value before and after the campaign (in other words, for each lag only the overlapping branches of the light curves were cross correlated). The fluxes
obtained on JD2447975, which have the highest scaling uncertainties because of the low signal-to-noise ratio in the corresponding spectrum, were eliminated from both light curves before computing the two functions. The sampling window ACF (see Gaskell & Peterson 1987), also shown in Fig. 6, has FWHM $\leq 6$ days, implying that the variations on longer time scales are resolved.

The ACF is not only unusually broad (it crosses the zero line at $\pm 52$ days, and declines very slowly from its maximum), but is also broader than the CCF. This would imply that H$\alpha$ varied on shorter time scales than the continuum, which is inconsistent with a simple reverberation scenario, or that the transfer function of H$\alpha$ becomes negative at short lags (Sparke 1993, Goad et al. 1993). Yet another possibility is that the continuum variations are undersampled: this is however unlikely, given that the sampling window ACF is much narrower than the continuum ACF. The discrete cross correlation function (DCF), calculated as described by Edelson & Krolik (1988) with the modifications described in Reichert et al. (1993), is also plotted in Fig. 6, and is consistent with the CCF. Pairs of points obtained from the same spectra were not used in the calculation of the DCF, to eliminate the effect of correlated calibration errors at zero lag.

The peak value of the CCF is at a lag of 6 days, and the DCF reaches its maximum in the bin centred on the same lag. Pérez et al. (1992a) have cautioned against using the peak value of the CCF as an indication of the size of the BLR, particularly when the time baseline does not cover several years. In this case the width of the ACF, the presence of correlated errors at zero lag, and the short duration of the campaign all weigh on the estimates provided by the CCF. Furthermore, the result is strongly influenced by the first three epochs, in which the continuum appears to be at the highest level of the campaign while the line still has to reach its maximum. If these epochs are not included when calculating the CCF, the resulting lag is zero. It is therefore likely that the peak value of the CCF is only a poor indication of the inner radius of the BLR, even beyond the formal error of 4.5 days (Gaskell & Peterson 1987). Some indication on the uncertainty of the peak value can be obtained by using the method described by Maoz & Netzer (1989) which consists in sampling the interpolated light curves many times with the same amount of observations in different patterns, adding random noise comparable to the uncertainties of the measurements, and obtaining the resulting cross correlation peak distribution (CCPD). In our case 90% of the values in the CCPD are between $-1$ and $+22$ days, and 50% between
3 and 15 days. This confirms the high uncertainty; however, there is no evidence that the lag is longer than about 1 month.

The centroid of the CCF is at 10.2 days: this can be interpreted as an estimate of the luminosity-weighted radius of the BLR (Robinson & Pérez 1990, Koratkar & Gaskell 1991), but again caution must be used and this number should be considered only as a rough estimate (Pérez et al. 1992a).

5. Line profile variations

The broad line profiles of Markarian 279 underwent some variation during the LAG campaign: during the first half of the campaign the red side of Hα was clearly more convex than in the second half (Fig. 1). Figure 7, which shows the difference spectra between high and low state spectra of both Hα and Hβ, together with the high state broad profiles, demonstrates how the red side of the lines varied more strongly than the blue side. The peaks of the lines in the difference spectra are shifted to ∼ 1000 km s⁻¹. This behaviour does not generalize to the entire observational history of Markarian 279, as Peterson et al. (1982) reported stronger variations of the blue side of Hβ between March and May 1981.

The profile changes observed during the LAG campaign are closely related to the luminosity of the line: this is evident from Fig. 8, which shows the fraction of broad Hα flux on the red side of the rest wavelength, plotted against the total line flux. The plot also includes measurements from spectra taken at the INT in previous years, with the same instrumental configurations used for the LAG data (most of the spectra used are published in Stirpe 1990, 1991 and Stirpe & de Bruyn 1991). All the spectra were internally calibrated to a common scale, and the broad components were isolated in a consistent manner. There is obviously a correlation between the two quantities plotted in Fig. 8, in the sense that the line is more red-asymmetric when it is stronger. The ordinate in Fig. 8 is only a rough indicator of the shape of the line; however, a comparison between pairs of spectra corresponding to points which are close in the diagram but separated by several weeks or months in time (e.g. JD2447894 and JD2447968, JD2447897 and JD2447995, JD2447911 and JD2447944) shows that the shapes are identical within the noise.

Because the Hα spectra were internally calibrated by minimizing the residuals of narrow lines which are superimposed on the broad Hα component, there is a possibility that the shape of the broad line at a given epoch influences the internal calibration, causing a spurious correlation in the asymmetry vs. line flux diagram. This, however, is ruled out
by the wide range of broad Hα fluxes: between July 1987 and February 1990 the line doubled in intensity, and the uncertainty introduced by the internal calibration is much lower than the total range covered by the variability. Further confirmation of the effect comes from Fig. 9, which shows the same diagram as Fig. 8 derived for Hβ. Within the LAG data-set no correlation is visible, which is not surprising given the large uncertainties involved when isolating Hβ from the underlying continuum and from the contaminating Fe II and He II lines. However, the points obtained from previous spectra, some of which were taken during the source’s low state, confirm the correlation found for Hα. Notice that in this case the internal calibration is based on a strong line ([O III] λ5007), which hardly overlaps with the Hβ profile. Although the Fe II λ5018 line underlies [O III] λ5007, the latter’s residuals in the difference spectra are narrow enough to be minimized without being affected by the presence of a relatively weak broad line. We therefore conclude that the strength or shape of the broad lines does not influence the internal calibration of the Hβ spectra.

A closer inspection of the Hα profiles reveals that most of the profile variation is in fact confined to the red side of the line. As an example, Fig. 10 shows the broad Hα profile in its highest state (observed on 8 February 1990) compared with the average profile of the 1987 campaign by Stirpe & de Bruyn (1991). The latter is scaled by a factor 2.13, in order to normalize the flux of its blue side to that of the stronger spectrum. The plot and the accompanying ratio between the two lines show that the blue sides of Hα overlap very well, while the red side becomes much more convex at high flux. Most of the profile change has occurred between 0 km s⁻¹ and +4000 km s⁻¹. All the Hα spectra used for Fig. 8 show a similar effect.

There is no obvious explanation for the correlation between line asymmetry and line luminosity. A purely radial velocity field can reproduce it if (a) the continuum light curve has a monotonic trend on time scales longer than the light crossing time, or (b) the time scales of the continuum fluctuations are much shorter than the light crossing time. However, the light curves did not have a monotonic trend during the 5 years separating the first and last points in Fig. 8, and if (b) were true the BLR would have to be very large and strong delay effects would be observed between the red and blue sides of the line. There is however no observable delay between the variations of the two sides of Hα in Markarian 279, just a difference in their amplitude (Fig. 11). In particular, the development of the red feature evidenced by Fig. 10 does not display any delay effect with
respect to the main body of Hα. This implies that, while regions of positive and negative velocity must be distributed fairly evenly around each iso-delay surface within the BLR (thus excluding pure radial inflow or outflow), the receding and approaching fractions of the gas react differently to the continuum variations or, in other words, have different distributions of physical conditions.

None of the other varying sources monitored by LAG displayed a correlation between the profile and intensity of Hα, and the effect has been observed only in two other AGN. One is NGC 5548, whose intrinsic luminosity is about half that of Markarian 279: however, as noticed by Rosenblatt & Malkan (1990), and confirmed by the analysis presented by Stirpe (1993), the effect in this source is opposite, i.e. the blue side of the Balmer lines becomes relatively stronger at higher line fluxes. This may be caused either by very different structures of the BLRs of Markarian 279 and NGC 5548, or by different orientations of anisotropic BLRs. The only other AGN whose lines are known to display a profile-intensity correlation is the QSO OQ 208 (Marziani et al. 1993), which is more luminous than Markarian 279 by about a factor 3; in this case also the peak velocity of the strong red shoulder in the Balmer lines, as well as its relative strength, correlates with the line luminosity. The correlation was observed in OQ 208 on a time scale of 6 years.

6. Conclusions

We have presented observations of Markarian 279 obtained during the LAG monitoring campaign of January–June 1990. The main results can be summarized as follows.

The light curves of the broad Hα line and of its underlying continuum display variations of no more than 20% and 30% respectively (but the continuum variation is diluted by the host galaxy’s spectrum). It appears that, while Markarian 279 has always displayed some variability when monitored in recent years, the strongest continuum variations occur on long time scales. The limited time scale of our campaign and the presence of only shallow features in the continuum and Hα light curves do not allow us to constrain the size of the BLR strongly. We obtain a formal lag of 6 ± 4.5 days from the cross-correlation analysis. Maoz et al. (1990) obtained a lag of 12 days from a monitoring campaign conducted in 1988: both results are affected by strong uncertainties, and should not be considered inconsistent with each other. The CCPD indicates an upper limit to the Hα vs. continuum lag of about 1 month. The BLR of Markarian 279, therefore, does not appear to be significantly larger than that of NGC 5548 (whose Hα vs. continuum lag is about 20 days;
Dietrich et al. 1993b). The centroid of the CCF yields a rough estimate of 10 light days for the luminosity-weighted radius of the BLR.

The line variations yield insights on the physical structure of the BLR. The relation between line profile and line luminosity discussed in Sect. 5 implies that the 2-D transfer function (Welsh & Horne 1991, Pérez et al. 1992b) of the Balmer lines is illumination-dependent in part of the projected velocity range. On the other hand, the fact that the line profile is correlated with the luminosity on time scales of several years implies that the transfer function is stable. In other words, the physical structure of the BLR in Markarian 279 does not change on time scales comparable to the dynamical time scale. The line profile-intensity relation, however, does not appear to generalize to the other varying objects of the LAG campaign. It may be no coincidence that the relation is observed in the only object of the LAG sample with medium intrinsic luminosity: the more luminous objects did not vary enough to reveal the effect, if it is present, and the BLR of the less luminous objects may be too small for the effect to be detected. A search for the relation in existing data sets of AGN of different luminosities would help to determine whether the effect is common, or whether it is a characteristic of only a few individual AGN. In addition, further monitoring of Markarian 279 and NGC 5548 (not necessarily on short time scales) will allow us to determine whether the effect persists on time scales much longer than the dynamical time scale of the BLR, and therefore whether or not structural changes occur in this region.

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Appendix. Seeing-dependent correction of the continuum light curve

The large scatter in the spatial FWHM of the spectra (Table 1) causes the unresolved non-stellar continuum and the extended underlying galaxy to contribute in different proportions to each spectrum. In particular, spectra obtained in bad seeing conditions have a relatively stronger continuum contribution from the host galaxy after the internal calibration. The amount of stellar light which contaminates the Hα spectra cannot be determined on the basis of the equivalent width of absorption features (Wanders et al. 1993), because none are visible in the observed spectral range. Therefore, an approximate correction for seeing effects was derived by using one of the sharpest R images obtained at the JKT during the LAG campaign (see Sect. 4). The FWHM of the stellar images on this frame, which was taken on 29 April 1990, is 1′′.2. The wavelength range of the R filter almost exactly overlaps that of the Hα spectra, so that we can safely assume that in both cases the same spectral region was observed. We also assume that the efficiency of the detector and the transmission of the R filter are constant across the entire band. This is not strictly true, particularly as far as the filter transmission is concerned (Unger et al. 1988), but the corrections which we derive are small enough to justify the approximation.

A set of synthetic images with the same spatial FWHM (i.e. seeing) as the spectra (see Table 1) was obtained by convolving the R frame with a 2-D Gaussian of appropriate width. The flux of Markarian 279 was measured within a box of 1′′.5×6′′.5 in the EW and NS directions respectively, corresponding to the widths of the spectrograph slit and extraction window. The same was done for a comparison star on the same frame. If \( F_{M279}(\text{FWHM}) \) and \( F_*(\text{FWHM}) \) represent the fluxes of Markarian 279 and of the comparison star respectively, measured in the chosen window on a frame of given FWHM, and FWHM\(_{0}\) is the FWHM of the point-like sources in the non-convolved image, then the quantity

\[
C(\text{FWHM}) = \frac{F_{M279}(\text{FWHM})/F_*(\text{FWHM})}{F_{M279}(\text{FWHM}_{0})/F_*(\text{FWHM}_{0})} - 1
\]

yields the fraction of the relative flux of Markarian 279 measured on a convolved image which is in excess of that obtained from the non-convolved image. Because we assume that the sources of non-thermal continuum and emission lines have the same point spread function as the comparison star, we attribute this excess entirely to an increase of the relative contribution of the underlying galaxy. In other words, the function \( C(\text{FWHM}) \) indicates how the stellar continuum of an internally calibrated spectrum increases as the seeing increases from 1′′.2. The relative flux of Markarian 279 within the box increases by
\begin{quote}
\sim 10\% at the worst seeing of the spectroscopic campaign (3\,\prime.6), with respect to the relative flux measured in the same box on the non-convolved image.

The \( C(\text{FWHM}) \) factors can be transformed in actual fluxes by using the internally calibrated H\( \alpha \) spectrum taken on 2 May 1990, the epoch closest to that of the image. If \( \bar{F} \) is the average flux of the spectrum over its entire wavelength range, and if \( \text{FWHM}_{sp} \) is its spatial width (in this case 1\,\prime.3), the calibrated corrections are
\[
C_n(\text{FWHM}) = \frac{\bar{F}}{1 + C(\text{FWHM}_{sp}) C(\text{FWHM})}.
\]
This requires the assumption that the underlying stellar spectrum is constant over the entire wavelength range of the spectra. Because this range is narrow (\sim 800 \AA{}), the assumption is acceptable.

All continuum fluxes derived from the spectra were corrected by subtracting the \( C_n \) corresponding to their FWHM. The FWHM of some spectra are lower than that of the image used for the simulations: the corresponding continuum measurements, therefore, required a positive instead of a negative correction. The quantity to add (the stellar component ‘deficit’) was derived by extrapolating the \( C(\text{FWHM}) \) curve to the lower FWHM with a low-order polynomial fit. Although the uncertainty on this derived correction will be rather high, the correction itself is small enough with respect to the continuum fluxes to make its uncertainty negligible with respect to that of the internal calibration.

To check the accuracy of the corrections, an \( R \) image obtained at another epoch (10 March 1990), also with a FWHM of 1\,\prime.2, was used in combination with the H\( \alpha \) spectrum of 17 March 1990 to derive another correction curve with the same method described above. The two \( C_n \) series agree within 10\%, and the corrected continuum fluxes within 1\%. A further endorsement for the applied corrections comes from the fact that, while the uncorrected continuum fluxes correlate weakly with the seeing, no such correlation is present once the fluxes have been corrected. Finally, the continuum light curve appears considerably smoother after the corrections are applied.

Note that this procedure does not eliminate the stellar contribution from the continuum light curve. It simply adjusts all the points in the curve so that they are in principle contaminated by the same amount of stellar light: we therefore assume that the variations in the continuum light curve are caused only by the intrinsic variability of the non-stellar source, albeit diluted by a constant stellar component. The method as described can only be applied if the NLR is unresolved, because an extended NLR would also contribute to \( C(\text{FWHM}) \).
\end{quote}
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Figure captions

**Fig. 1.** The Hα spectra of Markarian 279 obtained during the 1990 LAG campaign, after the internal calibration. Each spectrum has an offset of 10 units with respect to the one below it.

**Fig. 2.** The Hβ spectra of Markarian 279 obtained by LAG in 1990, each with an offset of 10 units with respect to the one below it.

**Fig. 3.** The Hα spectrum obtained on 31 January 1990 (JD2447923), before and after the subtraction of a power-law continuum and of templates for the narrow Hα component, for [O i] λ6300 and λ6364, for [N ii] λ6548 and λ6584, and for [S ii] λ6717 and λ6731. The wavelength scale refers to the rest system of Markarian 279.

**Fig. 4.** As Fig. 3, for the Hβ spectrum obtained on the same date. The deblended line results from the subtraction of a power-law continuum, and of templates for the narrow Hβ component, for He ii λ4686, for [O iii] λ4959 and λ5007, and for the m42 lines of Fe ii (λ4924, λ5018 and λ5169). Notice the broad wing on the red side of Hβ, which cannot be explained as a residual of Fe ii lines.

**Fig. 5.** The light curves of (from top to bottom) the continuum under Hα, corrected for seeing effects as described in the Appendix, the integrated broad component of Hα, and the integrated broad component of Hβ.

**Fig. 6.** The cross-correlation and discrete cross-correlation functions (CCF and DCF respectively) of broad Hα versus continuum, the auto-correlation function (ACF) of the continuum, and the sampling window ACF (SWACF) of the Hα spectra. The DCF was calculated in 6-day bins. The light curves shown in Fig. 5 were used, excluding from both the point with the highest uncertainty (JD2447975).

**Fig. 7.** The difference between high and low state spectra of Hα and Hβ: the dates of the individual spectra are given in the figure. No deblending or continuum subtraction was performed on the spectra used to derive these differences. The dashed lines show scaled and smoothed versions of the high state deblended profiles (see Figs. 3 and 4), with added straight line continua which roughly match the continua in the difference spectra. Notice how the difference spectra peak at $\sim 1000$ km s$^{-1}$, unlike the individual profiles which peak around 0 km s$^{-1}$. The difference spectrum of Hβ also evidences the variation of He ii λ4686 and Fe ii λ5018, which show up as two bumps at $v \sim -11000$ km s$^{-1}$ and...
respectively; neither is present in the dashed line profile, because of the deblending described in Sect. 3. The very broad wing on the red side of H\(\beta\) (see Fig. 4) does not appear in the difference spectrum.

**Fig. 8.** The diagram shows, for each H\(\alpha\) spectrum of Markarian 279, the ratio between the flux of the red side of the line (F(H\(\alpha_r\)) is the broad H\(\alpha\) flux integrated at \(\lambda > 6563\ \text{Å}\)) and the total broad H\(\alpha\) flux F(H\(\alpha\)), plotted against F(H\(\alpha\)) itself: the ordinate is thus a rough indicator of the line asymmetry. The spectra used for the measurements were obtained in different observing seasons, as indicated by the symbols.

**Fig. 9.** As Fig. 7, for H\(\beta\); F(H\(\beta_r\)) is the broad H\(\beta\) flux integrated at \(\lambda > 4861\ \text{Å}\).

**Fig. 10.** The top panel shows the profile of the broad H\(\alpha\) component on 8 February 1990 (JD2447931), when the line was in its brightest state during the LAG campaign, and the average of the profiles from the spectra obtained by Stirpe & de Bruyn (1991) in 1987, when Markarian 279 was twice as faint. The 1987 profile has been scaled upwards so that the blue sides match as closely as possible. The excess of the 1990 profile on the red side is \(\sim 6\%\) of the broad line flux. Bottom panel: the ratio between the profiles shown in the upper panel, which evidences how the shape of the red side has changed while the shape of the blue side has remained almost constant. Notice that the deviation from 1 at velocities higher than +5000 km s\(^{-1}\) can be attributed to contamination by residuals of the atmospheric B-band of O\(2\) and of the [S\(\text{II}\)] \(\lambda 6717\) line.

**Fig. 11.** The light curves of the red (continuous line) and blue (dashed line) sides of H\(\alpha\), each normalized to its mean value. The fluxes of JD2447975, which have the highest uncertainties, have not been included. The two light curves show the same features without any relative delay, but the red side varies with a higher relative amplitude.
**Table 1.** Journal of observations for Markarian 279: Hα spectra

| JD −2440000 | Date (1990) | Instr. config. | Int. time (s) | Wavel. range (Å) | FWHM (arcsec) |
|-------------|-------------|----------------|---------------|------------------|----------------|
| 7894.75     | 2 Jan.      | A              | 1700          | 6040–6850        | 1.8            |
| 7897.73     | 5 Jan.      | A              | 1300          | 6030–6840        | 1.4            |
| 7902.72     | 10 Jan.     | A              | 1300          | 6030–6840        | 1.5            |
| 7911.73     | 19 Jan.     | B              | 1000          | 6100–6900        | 2.6            |
| 7911.77     | 19 Jan.     | C              | 600           | 6040–6870        | 2.8            |
| 7916.77     | 24 Jan.     | C              | 350           | 6040–6870        | 2.4            |
| 7920.74     | 28 Jan.     | B              | 1000          | 6100–6900        | 1.7            |
| 7923.73     | 31 Jan.     | C              | 400           | 6100–6930        | 1.3            |
| 7928.77     | 5 Feb.      | B              | 1000          | 6100–6900        | 1.8            |
| 7931.73     | 8 Feb.      | B              | 1000          | 6110–6910        | 1.2            |
| 7934.60     | 11 Feb.     | B              | 1000          | 6100–6900        | 3.0            |
| 7939.71     | 16 Feb.     | C              | 400           | 6000–6820        | 1.2            |
| 7944.73     | 21 Feb.     | A              | 1000          | 6060–6870        | 3.6            |
| 7957.68     | 6 Mar.      | A              | 1000+1000     | 6050–6870        | 1.9, 2.1       |
| 7968.69     | 17 Mar.     | C              | 1000          | 5960–6790        | 2.1            |
| 7975.68     | 24 Mar.     | C              | 600           | 6050–6880        | 1.8            |
| 7984.53     | 2 Apr.      | C              | 350           | 6050–6880        | 1.0            |
| 7995.65     | 13 Apr.     | B              | 1000          | 6080–6880        | 2.6            |
| 7996.61     | 14 Apr.     | B              | 1000          | 6080–6880        | 1.6            |
| 7997.62     | 15 Apr.     | B              | 1500          | 6090–6890        | 3.6            |
| 8014.50     | 2 May       | C              | 350           | 6060–6890        | 1.3            |
| 8025.52     | 13 May      | C              | 350           | 6070–6890        | 1.4            |
| 8027.66     | 15 May      | A              | 1000          | 6040–6850        | 1.3            |
| 8031.63     | 19 May      | A              | 1000          | 6040–6850        | 0.8            |
| 8036.58     | 24 May      | C              | 350           | 6070–6890        | 1.6            |
| 8045.52     | 2 June      | B              | 1000          | 6100–6900        | 1.3            |
Table 2. Journal of observations for Markarian 279: H$\beta$ spectra

| JD $-2440000$ | Date  | Instr. | Int. time | Wavel. range | FWHM |
|---------------|------|--------|-----------|--------------|------|
| 7923.74       | 31 Jan. | C      | 700       | 4460–5280    | 1.2  |
| 7934.62       | 11 Feb. | B      | 2000      | 4450–5250    | 2.1  |
| 7984.53       | 2 Apr.  | D      | 600       | 4460–5250    | 1.2  |
| 7996.63       | 14 Apr. | B      | 1200      | 4440–5230    | 1.6  |
| 7997.65       | 15 Apr. | B      | 1500      | 4440–5230    | 3.5  |
| 8014.52       | 2 May   | C      | 700       | 4420–5240    | 1.0  |
| 8027.68       | 15 May  | A      | 2000      | 4390–5200    | 1.5  |
| 8036.59       | 24 May  | C      | 700       | 4430–5240    | 1.5  |
| 8047.52       | 4 June  | B      | 2000+2000 | 4440–5240    | 1.1, 1.3 |
Table 3. Instrumental configurations used for the LAG spectroscopic campaign

| Symb. | Tel. | Instr. | Cam. | CCD | Pixel size (mm) | Scale⊥ (arcsec pxl$^{-1}$) | Disp. | Resol. |
|-------|------|--------|------|-----|----------------|----------------------------|-------|--------|
| A     | INT  | IDS    | 235  | GEC | 22.0          | 0.65                       | 66.5  | 2.9    |
| B     | INT  | IDS    | 500  | GEC | 22.0          | 0.30                       | 66.1  | 7.3    |
| C     | WHT  | ISIS$_{red}$ | 500  | EEV | 22.5          | 0.34                       | 33.0  | 1.5    |
| D     | WHT  | ISIS$_{blue}$ | 500  | GEC | 22.0          | 0.33                       | 64.0  | 2.8    |
Table 4. Continuum and broad Hα light curves

| JD  | $aF_{\lambda6563}$ | $aF_{\lambda6563}^{corr}$ | $a\sigma_{F_{\lambda6563}}$ | $bF(bH\alpha)$ | $b\sigma_{F(bH\alpha)}$ |
|-----|-------------------|--------------------------|---------------------------|----------------|-------------------------|
| 7894.75 | 6.45 | 6.22 | 0.19 | 2.26 | 0.07 |
| 7897.73 | 6.36 | 6.28 | 0.19 | 2.36 | 0.07 |
| 7902.72 | 6.52 | 6.41 | 0.19 | 2.40 | 0.07 |
| 7911.73 | 6.36 | 5.83 | 0.19 | 2.27 | 0.07 |
| 7911.77 | 6.45 | 5.85 | 0.19 | 2.31 | 0.07 |
| 7916.77 | 6.32 | 5.87 | 0.19 | 2.35 | 0.07 |
| 7920.74 | 6.43 | 6.24 | 0.19 | 2.61 | 0.08 |
| 7923.73 | 5.96 | 5.93 | 0.18 | 2.53 | 0.07 |
| 7928.77 | 6.14 | 5.91 | 0.18 | 2.51 | 0.07 |
| 7931.73 | 6.27 | 6.28 | 0.19 | 2.67 | 0.08 |
| 7934.60 | 6.52 | 5.86 | 0.26 | 2.47 | 0.10 |
| 7939.71 | 5.60 | 5.61 | 0.17 | 2.53 | 0.07 |
| 7944.73 | 5.99 | 5.13 | 0.30 | 2.32 | 0.11 |
| 7957.68 | 5.45 | 5.19 | 0.44 | 2.22 | 0.18 |
| 7968.69 | 5.36 | 5.02 | 0.27 | 2.26 | 0.11 |
| 7975.68 | 4.71 | 4.48 | 0.56 | 2.13 | 0.26 |
| 7984.53 | 5.06 | 5.15 | 0.15 | 2.32 | 0.07 |
| 7995.65 | 5.45 | 4.92 | 0.16 | 2.35 | 0.07 |
| 7996.61 | 5.22 | 5.06 | 0.16 | 2.40 | 0.07 |
| 7997.62 | 5.73 | 4.87 | 0.23 | 2.35 | 0.09 |
| 8014.50 | 4.55 | 4.51 | 0.14 | 2.21 | 0.07 |
| 8025.52 | 4.58 | 4.51 | 0.14 | 2.08 | 0.06 |
| 8027.66 | 4.40 | 4.37 | 0.13 | 2.14 | 0.06 |
| 8031.63 | 4.15 | 4.32 | 0.12 | 2.15 | 0.06 |
| 8036.58 | 4.52 | 4.37 | 0.13 | 2.11 | 0.06 |
| 8045.52 | 4.60 | 4.56 | 0.14 | 2.15 | 0.06 |

$^a$ $10^{-15}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$

$^b$ $10^{-12}$ erg s$^{-1}$ cm$^{-2}$
Table 5. Broad H$\beta$ light curve

| JD $-2440000$ | $aF(b\beta)$ | $a\sigma_{F(b\beta)}$ |
|----------------|--------------|------------------------|
| 7923.74        | 0.737        | 0.037                  |
| 7934.62        | 0.738        | 0.037                  |
| 7984.52        | 0.701        | 0.035                  |
| 7996.63        | 0.593        | 0.030                  |
| 7997.65        | 0.589        | 0.029                  |
| 8014.52        | 0.534        | 0.027                  |
| 8027.68        | 0.485        | 0.024                  |
| 8036.59        | 0.507        | 0.025                  |
| 8047.52        | 0.470        | 0.023                  |

$^a$ $10^{-12}$ erg s$^{-1}$ cm$^{-2}$