III. Size of the broad line region in NGC 3227


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Received January 4, accepted July 15, 1993

Abstract. We present in this work the results of a five-month monitoring campaign of the active galactic nucleus in NGC 3227. Both the Balmer H/α and Hα emission lines, as well as the optical continuum have been analysed. A deblending procedure has been applied which allows to separate the contributions to the line emission from the narrow line region (NLR) on one side and from the broad line region (BLR) on the other side. The stellar contribution to the observed continuum within a 1.5 × 4 arcsec² slit is found to be in the range 24–40% when the AGN is in the lowest state of activity observed during this monitoring period. The largest source of uncertainty in deriving the light-curves of the BLR emission and of the AGN continuum comes from differences in the seeing conditions prevailing at the various observational epochs. We have applied a correction factor for this effect. The optical AGN continuum and the BLR emission in NGC 3227 appear to vary by about 40% on a timescale of 1.5 month. We have followed a burst with maximum around early March and minimum by mid-April 1990. The levels of the broad line emission and the λ6750 continuum are well correlated, a fact consistent with the classical assumption that the BLR material is photoionized by the central continuum source. Cross-correlation analyses between the light-curves of the λ6750 AGN continuum and the BLR Hα emission indicate that the lag of the BLR emission with respect to the continuum variations is 17 ± 7 d. This result suggests that the BLR clouds which are affected by changes in the flux level of the central ionizing source lie about 17 light-days away. The variable part of the Hα line shows a flat-topped profile with FWHM ≈ 2900 km s⁻¹. Within the observed range of continuum fluctuations (≃ 40%), the broad wings of the Hα emission line do not vary in a noticeable way. This implies either that the BLR clouds building up the wings remain fully ionized during the continuum variations or

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* This article is based on work carried out by the LAG (Lovers of Active Galaxies) collaboration. LAG is a consortium of mainly European astronomers which was established to study active galaxies using the International Time allocation at the Canary Island's Observatories operated under the auspices of the Comité Científico Internacional.

** Deceased 22 December 1990
that the time sampling should be increased if one wished to measure such an effect. Introduced together with other AGN in the plane \{Balmer lag, luminosity\}, NGC 3227 contributes to define a relationship slightly less steep than the BLR size scaling as the square root of the absolute luminosity.

**Key words:** quasars: individual: NGC 3227 — galaxies: Seyfert — galaxies: nuclei — black hole physics

### 1. Introduction

Variability studies constitute a powerful tool for probing the distribution of matter on a scale of a few light-days/weeks within active galactic nuclei (hereafter AGN). In some cases AGN vary on timescales shorter than anticipated (for a review, see e.g. Peterson 1988) and this has led to large observing campaigns designed to simultaneously monitor the behaviour of AGN in their continuous emission (X-rays to IR) and in their lines emitted from the so-called broad line region (BLR). Both the line intensity and line profile variations are of interest: the former allow to probe the size and structure of the BLR, while the latter provide some insight into its kinematics.

The LAG collaboration has conducted such a monitoring campaign, in the 4000–8000 Å window, for a small sample of AGN and quasars (Jackson et al. 1992; Wanders et al. 1993). The current paper reports on the monitoring of the AGN at the heart of NGC 3227, a close spiral galaxy about 4' in diameter and at equinox 2000 coordinates \( a = 10^h 23^m 31.5^s \), \( \delta = +19^\circ 51^\prime 48^\prime\prime \). The H\(_{\alpha}\) 21 cm line redshift is 1158 \( \pm \) 3 \( \text{km s}^{-1} \) (de Vaucouleurs et al. 1991) which yields a distance of 23 Mpc and a spatial scale of 115 pc arcsec\(^{-1} \) for \( H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1} \). The galaxy shows signs of interaction with its dwarf elliptical companion NGC 3226, a process modelled by Rubin & Ford (1968) and Heckman et al. (1978).

The AGN in NGC 3227, henceforth NGC 3227, has been studied in various ways. In the X-ray domain, measurements from the Einstein satellite reveal a low-energy excess (below 1.5 keV), possibly explained through partial covering of the central source by absorbing material associated with the BLR clouds. Over the 0.8–4.5 keV range, the X-ray emission is consistent with a power-law with index \( \Gamma = 1.7 \) (Reichert et al. 1985). From HEAO data (3–15 keV), X-ray variations are found in NGC 3227 on a timescale of around one day (Tennant & Mushotzky 1983).

Spectrophotometric studies have been performed in the visible and in the infrared. They report on the AGN variability (Peterson et al. 1985; Quisibert et al. 1989), on the properties of its NLR which extends over 3–4' (Cohen 1983; Vrtilek & Carleton 1985) and on the characteristics of its BLR (Osterbrock 1977; Peterson et al. 1982; de Robertis 1985; Ward et al. 1987; Stirpe 1990). The presence of dust intermixed with the NLR gas has also been reported (Lacy et al. 1982; Schmidt & Miller 1985; Ward et al. 1987). Finally, the contamination by the stellar population (Crenshaw & Peterson 1985; Halpern & Oke 1986), has been discussed, as well as the presence of molecular material in the form of \( \text{H}_2 \) associated with the NLR and possibly excited by UV fluorescence (Fischer et al. 1987), or in the form of CO, leading to a total \( M(\text{H}_2) = 5 \times 10^5 M_\odot \) comparable to that of the molecular disc at the centre of the Milky Way (Bieging et al. 1981).

Measurements of the radio continuum, with a spatial resolution better than 1", have shown that, in addition to a point-like continuum source at 4885 MHz, one finds an extended (3–4") nuclear emission, slightly elongated along PA = 30° and most likely related to the NLR (Ulvestad et al. 1981).

So far, variations were suspected to occur in NGC 3227, both in the continuous and line emission. However, a systematic analysis on short timescales remained to be carried out: it is the subject of the current study. We provide in Sect. 2 the relevant information for our new data set, we discuss briefly the reduction procedure and we present our final measurements and associated uncertainties. An extensive discussion is given in Baribaud et al. (1993) about the successive steps leading to these final measurements, (i) choice of parameters for the measurements, (ii) relative intensity scaling and (iii) correction for the seeing differences. We present and discuss in Sect. 3, the AGN continuum and the line light-curves, together with the line profile changes. The physical implications of these results on the BLR size in NGC 3227 are discussed. Finally, we provide in Sect. 4 a comparison of the BLR characteristics in NGC 3227 with those in other AGN, as well as our concluding remarks.

### 2. Observational data set and results

NGC 3227, a target selected for the LAG monitoring campaign (Jackson et al. 1992) conducted on the 2.5 m Isaac Newton (INT) and 4.2 William Herschel (WHT) telescopes at the Observatory del Roque de los Muchachos (La Palma), was observed on 26 epochs between January and June 1990.

To ensure that the same fraction of the NLR would be recorded at every epoch, the same slit width (1.5") at the same position angle (PA = 25°, corresponding to one of the dominant NLR elongations) were used for all observations. Long slit spectroscopy was performed with the same instrumental set up for both telescopes; the combination of grating and camera was chosen so as to provide a comparable nominal spectral resolution (around 3 Å). On some occasions however, the effective instrumental set up was slightly different. The detectors in use were a GEC chip (590 x 400 pixel\(^2\)) on the INT and an EEV chip (1280 x 1280 pixel\(^2\)) on the WHT.

Parameters relevant to the observations are provided in Table 1.
Table 1 Observational parameters for the LAG data set

| Date (1990)
|---
| January 2 | 7894.5 | 1.5 | 0.9; 2.0 | Ho; 3.0 | 900 | 1.50 | INT
| January 5 | 7897.5 | 1.5 | 2.0; 1.7 | Ho; 3.2 | 900 | 1.18 | INT
| January 10 | 7902.5 | 1.5 | 2.8; 2.8 | Ho; 3.2 | 900 | 1.27 | INT
| January 19 | 7911.5 | 1.5 | 1.0; 1.8 | Ho; 2.0 | 450 | 1.03 | WHT
| January 19 | 7911.5 | 1.5 | 1.0; 1.8 | Hβ; 2.9 | 900 | 1.01 | WHT
| January 24 | 7916.5 | 1.5 | 1.7; 1.9 | Ho | 300 | 1.15 | WHT
| January 24 | 7916.5 | 7 | 1.7; | Ho | 50 | 1.09 | WHT
| January 24 | 7916.5 | 10 | 1.7; | Ho | 50 | 1.07 | WHT
| January 24 | 7916.5 | 1.5 | 1.7; 2.0 | Hβ | 700 | 1.06 | WHT
| January 24 | 7916.5 | 7 | 1.7; | Hβ | 100 | 1.04 | WHT
| January 24 | 7916.5 | 10 | 1.7; | Hβ | 100 | 1.04 | WHT
| January 28 | 7919.5 | 1.5 | ; 1.3 | Ho; 6.8 | 900 | 1.30 | INT
| January 31 | 7923.5 | 1.5 | 1.0; 1.0 | Ho; 2.1 | 300 | 1.07 | WHT
| January 31 | 7923.5 | 1.5 | 1.0; 1.1 | Hβ | 1000 | 1.06 | WHT
| February 5 | 7928.5 | 1.5 | 1.7; 1.5 | Ho; 6.5 | 900 | 1.01 | INT
| February 8 | 7931.5 | 1.5 | 1.0; 1.3 | Ho; 6.8 | 900 | 1.02 | INT
| February 11 | 7934.4 | 1.5 | 1.0; 1.6 | Ho; 6.8 | 900 | 1.42 | INT
| February 11 | 7934.4 | 1.5 | 1.0; 1.3 | Hβ; 6.8 | 2000 | 1.70 | INT
| February 16 | 7939.5 | 1.5 | 1.0; 0.8 | Ho; 2.9 | 300 | 1.04 | WHT
| February 16 | 7939.5 | 1.5 | 1.0; 0.8 | Hβ; 2.7 | 700 | 1.01 | WHT
| February 21 | 7944.5 | 1.5 | 1.7; 2.1 | Ho; 2.9 | 900 | 1.01 | INT
| March 6 | 7957.4 | 1.5 | ; 2.5 | Ho; 2.9 | 900 | 1.12 | INT
| March 6 | 7957.4 | 1.5 | Ho; 2.9 | 900 | 1.08 | INT
| March 17 | 7968.5 | 1.5 | 1.0; 1.3 | Ho; 1.6 | 450 | 1.05 | WHT
| March 17 | 7968.5 | 1.5 | 1.0; 1.4 | Hβ; 1.6 | 1000 | 1.09 | WHT
| March 24 | 7975.4 | 1.5 | 1.8; 2.0 | Ho; 2.5 | 600 | 1.02 | WHT
| March 24 | 7975.4 | 1.5 | 1.5; | Hβ; 2.5 | 1000 | 1.04 | WHT
| March 31 | 7982.5 | 1.5 | ; 1.9 | Ho; 2.7 | 300 | 1.22 | WHT
| March 31 | 7982.5 | 1.5 | ; 1.0 | Hβ; 5.0 | 500 | 1.22 | WHT
| April 2 | 7984.4 | 1.9 | ; 1.0 | Ho; 2.6 | 300 | 1.10 | WHT
| April 2 | 7984.4 | 1.9 | ; 1.0 | Hβ; 5.0 | 500 | 1.10 | WHT
| April 13 | 7995.4 | 1.5 | 2.2; 1.6 | Ho; 6.5 | 900 | 1.01 | INT
| April 15 | 7997.4 | 1.5 | ; 2.3 | Ho; 6.7 | 900 | 1.07 | INT
| April 15 | 7997.4 | 9.5 | ; 2.3 | Ho | 250 | 1.05 | INT
| April 15 | 7997.4 | 1.5 | ; 1.4 | Hβ; 6.5 | 1500 | 1.04 | INT
| May 2 | 8014.4 | 1.5 | ; 0.8 | Ho; 3.0 | 300 | 1.01 | WHT
| May 2 | 8014.4 | 1.5 | 0.7 | Hβ; 3.2 | 700 | 1.02 | WHT
| May 13 | 8025.4 | 1.5 | ; 0.8 | Ho; 3.0 | 300 | 1.07 | WHT
| May 13 | 8025.4 | 1.5 | 0.7 | Hβ; 2.8 | 700 | 1.09 | WHT
| May 20 | 8032.4 | 1.5 | 0.6 | Ho; 3.0 | 900 | 1.07 | INT
| May 24 | 8036.4 | 1.5 | ; 1.1 | Hβ; 3.0 | 500 | 1.10 | WHT
| June 2 | 8045.4 | 1.5 | 1.5; 1.2 | Ho; 6.8 | 900 | 1.57 | INT
| June 2 | 8045.4 | 10 | 1.5; | Ho | 225 | 1.74 | INT
| June 6 | 8049.4 | 1.5 | 1.3; 2.2 | Hβ; 6.0 | 2000 | 1.50 | INT
| June 6 | 8049.4 | 10 | 1.3; | Hβ | 500 | 1.80 | INT

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*Gregorian date at the beginning of the night.

* Julian date (−2440000) for the actual observation, rounded to a tenth of a day.

* The first figure refers to the log-book indication, not always estimated at the time when NGC 3227 itself was observed; the second figure refers to an estimate from a cut in the wings of the Hβ and Ho emission lines (see Baribaud et al. 1993), which is the best value we can use.

* The spectral resolution is the mean FWHM (Å) from a set of 11–24 arc lines across the spectrum.

*When the entrance slit width was 7 and 10″, the size of the extraction window was set such that the effective entrance diaphragm be 7 × 7 arcsec and 10 × 10 arcsec, respectively.

* Observation through some clouds.
2.1. Reduction procedure

The CCD frames were reduced using the Figaro (Starlink) environment and the IRAF package installed on micro VAX computers at the Instituto de Astrofísica de Canarias and Observatoire de Meudon, respectively. Bias subtraction, flat-fielding, wavelength transformation were performed in a standard way. The sky background was derived on each side of the AGN spectrum and fitted with a third order Legendre polynomial. We used the standard star HD 84937 and/or BD 262606 for flux calibration.

2.2. Extraction of the AGN spectrum and relative scaling of the data

As mentioned previously, the NLR in NGC 3227 seen in the [O III] line emission is slightly extended, and elongated at PA = 25° and PA = 90°. The extension of the NLR is clearly visible from the isophotal contours of the long slit spectra obtained in the Hα and Hβ wavelength regions (Fig. 1). Along PA = 25°, NLR lines such as [N II] and [O III] can be easily detected out to 3–4″. Because the current spectroscopic data set was designed to monitor the nuclear emission spectrum of NGC 3227, we have compromised on an extraction window height of 4″, centered on the maximum of the continuum emission. Therefore, the 1D-spectra built for line intensity measurements correspond to an effective 1.5 × 4 arcsec² entrance slit, along PA = 25°. Note that the extraction procedure deals with a rather small number of lines. As the spatial scale was not identical in all frames, we had to fine tune the scaling in order to match the chosen 4″ slit height. This fine tuning has been performed by interpolation on the [O III] and [S II] spatial cuts across the spectra shown in Fig. 1. Complete sets of the fully scaled spectra, corresponding to an 1.5 × 4 arcsec² entrance slit, are displayed in Figs. 2 and 3.

Because not every observation had been performed under photometric conditions, we have to scale all spectra to a common feature which is assumed to be constant. The NLR emission is generally used for this purpose. Note however that the NLR intrinsic size, around a few 10⁵ pc in NGC 3227, precludes the detection of variations in the NLR emission induced by changes of the central ionizing source, on time scales commensurate with the 6 month duration of the LAG campaign.

Such a scaling procedure is affected by a number of errors (for an extensive discussion see e.g. Baribaud et al. 1992). One source of uncertainty in particular is related to the spatial extent of the NLR and the slit positioning. Another one arises from the line delimiting which must be performed to extract the pure NLR contribution. And finally, seeing differences must be taken into account.

The scaling procedure and all the associated uncertainties, are fully described in Baribaud et al. (1993). We simply provide here our conclusions on the possible maximum uncertainties, (i) from the line blend decomposition, about 5%, (ii) from slit miscentering, around 1% and (iii) from the seeing correction factor which is only known within 3%. There is however a balance between these various sources of uncertainties: in case of good seeing, the errors from (ii) and (iii) are quite small and for a spectrum with high signal to noise ratio, the error introduced at stage (i) is minimum.

Considering all the possible sources of uncertainty discussed previously, as well as the signal to noise ratio of each spectrum, an error-bar estimate has been attached to each data point. The final error-bars are in the range ±5–8%. After having taken into account the seeing correction factor derived in Baribaud et al. (1993), the results scaled to $I([O III] \lambda 5007) = 1310 \times 10^{15}$ erg cm⁻² s⁻¹.
for Hβ and $I([S\text{ ii}] \lambda 6717, 6730) = 225 \times 10^{-15}$ erg cm$^2$ s$^{-1}$ for Hα are displayed in Table 2. We give the intensity of the BLR component both in Hβ and Hα.

In order to illustrate the merits of applying a seeing correction factor to the BLR line and to the continuum emission arising from point-like sources, we show in Fig. 4, the relationship between the seeing value and the measured BLR Hα emission. In Fig. 4a, where we have displayed the non-corrected BLR Hα, a correlation is observed between the two quantities. In Fig. 4b, where we have displayed the seeing corrected BLR Hα, this correlation has disappeared, in agreement with the expectation that there should be no correlation between the level of the intrinsic BLR emission and observational conditions such as the seeing value.

2.3. Contribution to the continuum from the underlying stellar component

Over the wavelength range considered in this analysis, 4500–7000 Å, the continuum is built up from the AGN itself and from the stellar population in which it is embedded. The latter component is extended and constant in time: therefore, if it were rather large with respect to the AGN continuum itself, it would smear out genuine AGN continuum changes. In addition, only the AGN continuum is subject to the application of the seeing-correction factor. Hence, it is necessary to estimate which fraction of the total continuum emission arises from the stellar component in NGC 3227 so that we can extract the pure AGN continuum contribution.

The method we use consists in comparing the equivalent width $W_{\text{AGN}}$ of a given absorption feature, assumed to arise from the stellar population, with $W$ of the same feature in the spectrum of a normal galaxy. For the latter, we considered two cases, either a template galaxy with the same absolute magnitude and morphological type as NGC 3227, $W_\text{T}$, or the bulge population of NGC 3227 itself, where we measure $W_\text{B}$. 

Fig. 2. The set of the reduced spectra of NGC 3227 in the Hβ, [O iii] wavelength region. Coordinates are $F_\lambda$ (arbitrary units), $\lambda$(Å). The spectra have been shifted for display purposes.

Fig. 3. The set of the reduced spectra of NGC 3227 in the Hα, [N ii], [S ii] wavelength range. Coordinates and display identical to Fig. 2.
Table 2. Seeing corrected Balmer line BLR intensities (unit 10⁻¹⁵ erg cm⁻² s⁻¹) and AGN continuum intensities (unit 10⁻¹⁵ erg cm⁻² s⁻¹ Å⁻¹). The Hβ and λ5020 continuum figures have been scaled to $I([O III]λ5007)=1310$ 10⁻¹⁵ erg cm⁻² s⁻¹. The Hα and λ6750 continuum figures have been scaled to $I([S II])=225$ 10⁻¹⁵ erg cm⁻² s⁻¹. The continuum value are, first column for a 24% flux stellar contribution at λ5180 and second column for a 40% flux stellar contribution at λ5180.

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<th>$I_λ(5020 , \text{Å})$</th>
<th>Hα (BLR)</th>
<th>$I_λ(6750 , \text{Å})$</th>
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</tbody>
</table>

Fig. 4. Plot of the seeing measurement [source (3) of Table 2 in Barbiaud et al. (1993), that is from the BLR emission on the AGN spectrum itself] in relation with the BLR Hα emission. The left panel refers to the BLR Hα emission not corrected for seeing effects (open circles). The right panel refers to the seeing-corrected value (filled circles). Error-bars are ±15% on the seeing value and in the range ±5% to ±8% on the BLR Hα emission. The correlation found from the set of uncorrected points has disappeared after the seeing effects compensation.

The $W_{\text{AGN}}$ value will be smaller than $W_T$ or $W_B$, because of a dilution effect from the AGN continuum, provided that the stellar population is the same in NGC 3227 and in the template, or uniform across the bulge of NGC 3227.

The absorption line to be used in the case of NGC 3227 is the magnesium triplet Mg II λ5167, 5173, 5183, as it is the only feature available over this wavelength range. We have measured the absorption over the window λ5156–λ5196, according to Bica & Alloin (1986). The value obtained in NGC 3227 is $W_{\text{AGN}} = 1.16$ Å when the AGN is in a low state of activity (e.g. on 02 April 1990) and $W_{\text{AGN}} = 0.7$ Å when the AGN is in a high state of activity (e.g. on 16 February 1990).

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Before we proceed with the comparison between $W_{\text{AGN}}$ and $W_T$, or $W_B$, let us examine if a possible systematic bias might affect the measure of $W_{\text{AGN}}$. Indeed, one bias arises from the fact that the third line of the Mg I triplet, λ5183, is, in NGC 3227, partially blended with the emission line [N II]λ5200 from the NLR. A comparison of the intensity ratios between Mg I λ5176 and Mg I λ5183 in NGC 3227 and in the solar spectrum leads us to estimate that the Mg I λ5183 line in NGC 3227 is about half-filled by the [N II]λ5200 emission, and we have corrected $W_{\text{AGN}}$ accordingly. The corrected values are $W_{\text{AGN}} = 1.5$ Å in the low state and $W_{\text{AGN}} = 0.8$ Å in the high state of activity.

The morphological type of NGC 3227 is Sb(s)III and its total absolute magnitude $M \sim -20.8$ (Sandage & Tammann 1981). From the template corresponding to such a galaxy, we obtain $W_T = 6.53$ Å (Bica 1988).

Regarding the bulge population in NGC 3227 itself, we have extracted from the LAG long slit data, the mean spectrum between 1.7 and 5.1" from the centre, in the same low state of activity as previously used to measure $W_{\text{AGN}}$ (2 April 1990). We obtain $W_B = 5.4$ Å. Given the fact that there might be a metallicity gradient across the bulge population, $W_B$ represents a lower limit, hence consistent with $W_T = 6.5$ Å derived for the template galaxy.

One cannot strictly decide which of the two values $W_T$ or $W_B$ is the one to be taken into account and we have bracketed our estimate of the stellar population contribution using both of them.

From the comparison between $W_{\text{AGN}}$ and $W_T$, the stellar contribution at λ5180, appears to be of 24% when the AGN is in a low state and of 15% when it is in a high state of activity. The intensity of the stellar continuum at λ5180 is found at a level of $2.8 \times 10^{-15}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$ \{scaled to $I([\text{O III}]\lambda5007)=1310 10^{-15}$ erg cm$^{-2}$ s$^{-1}$\}.

From the comparison between $W_{\text{AGN}}$ and $W_B$, we get a contribution of the stellar population at λ5180 which is of 37% in a low state of activity. In this case, the intensity of the stellar continuum at λ5180 is at a level of $4.3 10^{-15}$ erg cm$^{-1}$ s$^{-1}$ Å$^{-1}$.

Assuming that the stellar component follows the spectral energy distribution of the template galaxy (Bica 1988), we have derived the flux contributions from the stellar population at λ5020 and λ6750 and subtracted them from the observed corresponding continuum at every epoch. Then, we have applied the seeing correction factor to the AGN continuum. The results are given in Table 2, for the two cases:

(a) 24% of stellar contribution at λ5180
(b) 40% of stellar contribution at λ5180.

3. Implications on the BLR size in NGC 3227

3.1. Analysis of the light-curves

We provide in Fig. 5 the light-curves for the BLR Hα line emission, NLR [N II] and NLR Hα line emission and nearby AGN continuum at λ6750, derived after the line blend decomposition and scaled to $I([\text{S II}])=225 10^{-15}$ erg cm$^{-2}$ s$^{-1}$. In Fig. 5b presenting the AGN continuum light-curve at λ6750, we have displayed the two cases corresponding to (a) a 24% stellar contribution at λ5187 and (b) a 40% stellar contribution at λ5187. However, in the following analysis, we shall consider only case (b) which might be more representative of the real situation. In Fig. 6, we show similarly the light-curves for the BLR Hβ line emission and the AGN continuum emission at λ5020, scaled to $I([\text{O III}]\lambda5007)=1310 10^{-15}$ erg cm$^{-2}$ s$^{-1}$. The maximum value, minimum value, mean value and standard deviation have been gathered in Table 3 for the quantities $I(H_\alpha)$ and $I(H/\beta)$ from the BLR and the AGN continua.
at $\lambda 6750$ and $\lambda 5020$ [case (b) for the stellar population contribution].

The BLR H$\alpha$ and H$\beta$ light-curves show similar trends on the one hand, and the two continuum light-curves appear to follow the same general pattern with a comparable amplitude of variations on the other hand. This confirms the accuracy of the relative scaling because the two sets of light-curves were derived from independent data sets. A detailed comparison of the light-curves is not relevant because the H$\beta$ and $\lambda 5020$ continuum light-curves are quite undersampled with respect to the H$\alpha$ and $\lambda 6750$ continuum ones. In the subsequent discussion, we shall consider only the light-curves for the BLR H$\alpha$ and the $\lambda 6750$ AGN continuum.

We show in Fig. 7 the BLR H$\alpha$ emission as a function of the $\lambda 6750$ continuum emission. We observe a correlation which demonstrates the validity of the assumption that the BLR material is photoionized by the central continuum source. Moreover, looking at the sequential progression in this plot and taking error-bars into account, we can define a cycle telling us that the line emission responds to the continuum variation with a delay of about 17 d in the upper branch of the cycle (continuum decrease). The low state area is represented by too few points to allow us to derive a delay in a similar way.
3.2. The BLR size

In order to get an estimate of the BLR size, we search for a possible time lag between the variations in the continuum and those in the BLR line emission. For a review and through discussion of this approach, see Peterson (1993). The first order analysis we are going to perform on the NGC 3227 data, relies on the assumption that: (i) the continuum changes seen at λ6750, if at all delayed with respect to the ionizing continuum variations at λ < 912 Å, occur with a delay which is negligible with regard to the light-travel time from the ionizing continuum to the BLR material, and (ii) that the BLR material emitting the broad Hα line is situated at a mean distance R_{BLR} and distributed in a spherically symmetrical geometry with width δ < R_{BLR}. We provide in Fig. 8 the results of a standard cross-correlation (CCF) between the λ6750 continuum and the broad Hα line light-curves, as well as the auto-correlation (ACF) of the continuum light-curve and of the sampling window. We used in this case light-curves interpolated to 1 d (Gaskell & Peterson 1987). We find a time lag of 17 ± 10 d. The uncertainty is derived from the extent of the flat-topped CCF.

In addition, a discrete cross-correlation technique (DCF) was applied (Edelson & Krolik 1988). The comparison of the results from the cross-correlation performed through the standard technique using interpolated data to those from the discrete technique (Fig. 9) shows that both techniques provide consistent results and demonstrates that a standard cross-correlation analysis may be sufficient in this case.

In order to test the significance of these results, and the true uncertainty in the lag determination, we have performed Monte Carlo simulations as described in Maoz & Netzer (1989). We started from the current light-curves interpolated to 1 d, from which 23 points were chosen at random for each simulation. The peak in the cross-correlation was then derived, to the nearest day. Over 1000 simulations were performed. The number of times the peak, falls at each day is shown in Fig. 10. We considered successively uncertainties of ±5% and ±8%. More than 90% of the points lie within ±10 d of the median which occurs at about 18 d. The FWHM of the lag histogram is around 10 d for the ±5% uncertainty and 12 d for the ±8% uncertainty. There is a very low probability that the time lag is smaller than 10 d.

Therefore, considering both the CCF and DCF results as well as the Monte Carlo simulations, we are led to conclude that the time lag between the continuum and the BLR Hα

![Fig. 8](image8.png)  
**Fig. 8.** Autocorrelation of the λ6750 continuum light-curve (thin line) and cross-correlation between the λ6750 continuum and the BLR Hα emission light-curves interpolated to 1 d, following the Gaskell and Peterson (1987) approach (thick line). The autocorrelation of the sampling window is shown as well (dashed line). The observed lag between the continuum and the line light-curves is of 17 ± 10 light-days, suggesting that the BLR clouds which respond to ionizing flux variations are located about 17 light-days away from it.

![Fig. 9](image9.png)  
**Fig. 9.** Comparison between the results obtained for the cross-correlation between the continuum and line light-curves, using either an interpolated classical cross-correlation technique (thick line) or a discrete cross correlation technique (individual squares with error-bars corresponding to a usual standard deviation).

![Fig. 10](image10.png)  
**Fig. 10.** Histogram of the lag values derived through Monte Carlo experiments (over 1000 simulations, see Sect. 3.2), showing that the most probable time lag between the continuum and line variations is of 18 ± 7 d. The thick line corresponds to a data uncertainty of ±5%, while the thin line corresponds to a data uncertainty of ±8%.
line variations is of $17 \pm 7$ d. This in turn indicates that the bulk of the BLR material responding to the ionizing source variations that we sampled during this monitoring campaign, lies around $17 \pm 7$ light-days away.

It has been shown (Pérez et al. 1992) that the lag, defined as the displacement of the peak of the CCF or DCF, rather provides the inner radius of the BLR; on the contrary, the average displacement weighted by the amplitude, i.e. the centroid of the CCF or DCF, would give insight into the luminosity weighted radius of the BLR. In the case of NGC 3227, considering the uncertainties, these two quantities are not significantly different (2 d) and we shall discuss in the following only the peak displacement in the CCF or DCF.

### 3.3. Line profile changes

We have selected from our set of H$_\alpha$ line profiles, two spectra corresponding to the AGN high state, on 11 February, 1990 and 16 February, 1990 and two spectra corresponding to the AGN low state, on April 13 1990 and April 15 1990. In each of the two groups, the spectra have been co-added in order to provide two high signal to noise spectra for a representation of respectively the high and low states of NGC 3227.

We have subsequently built the difference spectrum between these two states in order to obtain the profile of the varying H$_\alpha$ BLR component, shown in Fig. 11. The variable H$_\alpha$ line exhibits a rather symmetrical flat-topped profile with FWHM $\sim 2900$ km s$^{-1}$. One notices that the bump ($B$) always present on the blue wing of the H$_\alpha$ profile has disappeared in the difference profile, as have most of the wing emission and the nearby [O i] lines. The bulk of the variations in the H$_\alpha$ line occur in the intermediate width component rather than in the broad wings of the line: this implies that the ionization stage of the material building up the wings are not affected by the changes currently seen in the level of the ionizing flux. Moreover, under the classical AGN picture, they would lie closer to the ionizing source and our current sampling might be too loose to detect their response to ionizing flux variations.

### 3.4. Implications on the central engine

Given the sampling characteristics of the current campaign, we conclude that the bulk of the BLR material responding to the ionizing flux changes lies about 17 light-days away. From the FWHM of the variable H$_\alpha$ line corresponding to this region, 2900 km s$^{-1}$, and assuming that the broadening is of keplerian origin and that the accretion disc is coplanar with the galactic disc ($i \sim 45^\circ$), we find that the bulk of the BLR emission occurs at around $10^3$ Schwarzschild radii applying the method described by Gerbal & Pelat (1981). We then derive the mass of the central engine in NGC 3227, $M \sim 2 \times 10^8 M_\odot$.

### 4. Concluding remarks

#### 4.1. Size of the BLR in a small sample of AGN

With the aim of testing the $r(\text{BLR}) \propto L^{1/2}$ relationship very often assumed in AGN models, we provide in Fig. 12 a plot of the lag measured from the Balmer lines as a function of the absolute luminosity at $\lambda 5100$ in a sample of AGN. This plot complements the one given in Peterson (1993). We have taken for $r(\text{BLR})$ the lag value as it results from the displacement of the CCF peak and for $L$ the continuum at around $\lambda 5100$ ($H_\beta = 50$ km s$^{-1}$ Mpc$^{-1}$). There is however a large uncertainty on the latter quantity.

![Fig. 11. Representative spectra, in the H$_\alpha$, [N ii], [S ii] wavelength region, of the high state of activity in NGC 3227 (spectrum H) and of the low state of activity (Spectrum L). The difference spectrum is displayed at the bottom (Spectrum D). Notice that the NLR emission has disappeared ([O i] and [S ii] lines). The variable H$_\alpha$ line shows a flat-topped symmetrical profile with FWHM $\sim 2900$ km s$^{-1}$ and quite un conspicuous wings.](image-url)
because of its variable nature and because of the separation from stellar light which has to be performed. The $r(\text{BLR})$ estimates are from H$\beta$ for NGC 4151 (Maoz et al. 1991), for NGC 5548 (Peterson et al. 1992) and for Mrk 590 (Peterson et al. 1993); they are from H$\alpha$ for Mrk 279 (Maoz et al. 1990) and NGC 3227; they have been derived from both H$\beta$ and H$\alpha$ for NGC 3516 (Wanders et al. 1993) and for NGC 4593 (Dietrich et al. 1993). These data suggest a relationship $r(\text{BLR}) \propto L^\gamma$ with $\gamma \leq 0.5$, slightly less steep than that derived by Peterson (1993) from the ultraviolet lines. However, the uncertainty on the quantity $L$ is so large, that this difference is barely significant.

4.2. Conclusions

The five month monitoring campaign conducted on the AGN in NGC 3227 has shown that continuum changes occur, at a level of around 40%, on a timescale of six weeks. We have been able to record a burst with maximum around early March and minimum by mid-April 1990. The cross correlation between the light-curves of the $\delta$6750 AGN continuum and the BLR H$\alpha$ emission indicates that the latter is delayed by $17 \pm 7$ d. The variable H$\alpha$ line exhibits a rather symmetrical, flat-topped profile with FWHM $\sim 2900$ km s$^{-1}$ and very little, if any, wing emission. These values point toward a 2 $10^6 M_{\odot}$ central engine. From a small sample of AGN (7 objects), we find that the BLR size scales with the luminosity through a relationship $r(\text{BLR}) \propto L^{\gamma}$, where $\gamma < 0.5$. This relationship is not quite as steep as the $\gamma = 0.5$ one assumed in AGN modeling.

Acknowledgements. We are gratefully indebted to the CCI for the allocation of International Observing Time and to the staff at the La Palma Observatory for an efficient support. The many observers who collected LAG data thank their national funding agencies including the CNRS, DFG, ESA, MRE, NFR and SERC, for generously supporting them. We acknowledge the kind hospitality of the IAC together with its assistance in the distribution and initial reduction of the data. The INT and WHT are operated on the island of La Palma by the Royal Greenwich Observatory at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

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