A close look at the very heart of NGC7469

Daniel Rouan\textsuperscript{1} and Damien Gratadour\textsuperscript{2}

\textsuperscript{1} LESIA, Observatoire de Paris, CNRS, UPMC, Université Paris Diderot; 5 place Jules Janssen, F-92190 Meudon
\textsuperscript{2} Gemini Observatory, 670 N. A’ohoku Pl., Hilo, Hawaii 96720

E-mail: daniel.rouan@obspm.fr

Abstract.

We observed the central regions of the well-known LIRG / Seyfert 1.2 galaxy NGC 7469 with adaptive optics, performing K band long-slit spectroscopic observations with NaCo at VLT. We concentrate here on the inner PCs, focusing on the structure of the NLR. The study of the continuum as well as of the molecular and ionized hydrogen emission lines shows some unexpected properties that raise several questions that we consider as different pieces of a unique puzzle. The most striking result of our study is the detection of broad ionized hydrogen emission over a 45\textarcdeg; radius around the central source with a symmetric behaviour with respect to the central core. We also detect molecular hydrogen in the innermost part of this Seyfert nuclei. The continuum emission corresponds to a very hot black body. We interpret all those facts as due to some Thomson scattering by electrons of the NLR. The temperature evolution is in good agreement with this interpretation and the electron density we derive is compatible with densities found in NLRs of typical AGNs.

1. Introduction

NGC 7469 is among the brightest Seyfert I (type I) AGN, but it’s also a good example of hybrid activity: both a Seyfert nucleus and starburst rings are observed at it’s center. The black hole should have a mass of $10^7 \, M_\odot$, with a luminosity $L_{\text{bol}} = 3 \times 10^{11} \, L_\odot$ and the two circumstellar starburst rings contribute to 30\% of the central K luminosity (1) and to 50\% of the bolometric one. However stellar radiation represents only 8\% of the K flux in 0.2 arcsec aperture (2).

A dynamical model by (2), based on spectro-imaging with SINFONI, points to 3 components: a disk, a ring and an internal ring at $r \approx 50$\textarcdeg;.

Starburst rings are of radii 1-3 arcsec and 8-10 arcsec, \textit{i.e.} 0.3–1 kpc and 2.6–3.3 kpc respectively and are very well separated from the bright central peak on adaptive optics images (5). At a distance of 66 Mpc 1 arcsec is 330 pc, so that adaptive optics, with its typical 50 mas resolution at K, allows also a fairly good insight of the very central region where the central engine lies, at least a probing of the narrow line region. This is the object of this paper where we show that thanks to the very good resolution and thus the low dilution, it is possible to detect light of the BLR scattered on the electrons of the NLR.

2. The observations

We present two sets of results obtained thanks to adaptive optics techniques: the main one is based on NACO-VLT long slit spectroscopy in the K band, with the grism and the other set
is based on images made with PUEO at CFHT and processed with the myopic deconvolution software MISTRAL.

In both cases, the Seyfert nucleus itself was used as the guiding star for AO. In the case of NACO, the pixel size was 0.027 arcsec and the integration time 1800 s. A micro-jitter along the slit was used to minimize flat-field and bad pixels effects. A PSF reference star (HD220825, A0, mK = 4.9) was observed before and after NGC7469 so as to evaluate the achieved resolution. The medium seeing of 0.8 arcsec allowed a Strehl ratio of 0.45-0.6, thus slightly better than Sinfoni observations of (2). As regards spectroscopy, the slit width was 0.086 arc and the slit orientation at a P.A. = 38° as illustrated on Fig.1. The wavelength range of 2.1 - 2.4 μm (K band) was covered with an actual spectral resolution (after a gaussian smoothing) of 1150 to 1380.

Fig. 1 shows on the left an image of the field on which is superimposed the location of the slit and on the right one of the long slit spectra (λ/θ), where the position of two lines (Brγ and H2 v1-0 S1) are indicated. We’ll concentrate in the following on the 100 pc of the very central region, i.e. in practice on the immediate environment of the central engine and the NLR and will not discuss the starburst rings.

**Figure 1.** Left: K image of the field on which is superimposed the location of the slit. Right: one of the long slit spectra obtained. Coordinates are θ vs λ; the position of two lines (Brγ and H2 v1-0 S1) are indicated.

### 3. The pieces of the puzzle

Under the microscope of Adaptive Optics, the very central region (100 pc diameter) of NGC7469 reveals several intriguing features that constitute the pieces of a puzzle: a) a blue color; b) an extension of the Brγ broad component; c) an H2 line observed on the direct line of sight of the AGN; d) a symmetric behaviour of the color temperature and of spectral features at NE and SW. Our guess is that there may be one unique coherent explanation to those different unexpected findings.

#### 3.1. Piece #1: a blue continuum

On Fig.2 are plotted the smoothed spectra at different locations: on the core (upper curve on each panel) and at 18, 35 and 55 pc from the core at NE (left panel) and SW (right panel). We have fitted a black body curve to each spectrum (thus assuming an optically thick medium) and derived a corresponding color temperature indicated on each curve.

The derived temperatures range between 2700 and 3500 K which looks rather hot. Indeed it cannot be the dust temperature, as for instance it is the case in NGC 1068 (6), since it’s much higher than the sublimation temperature. On the other hand, it can hardly be photospheric emission of blue stars since the stellar K luminosity is only 8% percent of the total in the central 70 pc (3) – based on CO line equivalent width – . Using some rough estimate, stars would contribute only to 11% of the signal actually seen at 35 pc: this is what is shown on Fig.3 as the lower line overplotted on the profile of the λ-integrated signal along the central part of the slit.
Note in addition that the intensity of the continuum is decreasing with distance to the centre as $r^{-1}$.

What is the source of this blue continuum? This question constitutes the first piece of our puzzle.

**Figure 2.** Smoothed and normalized spectra at different locations: on the core (upper curve on each panel) and at 18, 35 and 55 pc from the core at NE (left panel) and SW (right panel). The spectra are arbitrarily shifted for clarity. A fit by a black body is overplotted as a continuous line on each spectrum.

**Figure 3.** Profile along the central part of the slit of the signal integrated on all wavelengths. The lower line shows the estimated signal expected from stars only, using the evaluation by Davies et al (2007).

### 3.2. Piece #2: an extended broad $ Brigata$ line

Let’s have a look to the spectrum integrated on the central 8 arcsec, i.e. on 1.2 kpc (Fig.4): it exhibits two main emission lines, the ro-vib $ H_2$ v1–0 S1 and the $ Brigata$ lines. The $ Brigata$ line clearly features a double component: a narrow one of 250 km/s that should be identified with the emission of the Narrow Line Region (NLR) and a broad pedestal of 2000 km/s that is usually associated to the Broad Line Region (BLR). One question is: how extended is the BLR? In principle it should not be resolvable since a typical BLR extends not much than on a few day-light, i.e. on 200 AU only.

To answer this question, let’s have a look to the individual spectra at the best angular resolution as they appear on Fig.4. Clearly, the broad component of $ Brigata$ is still there at positions between 18 and 55 pc. It looks as if the broad $ Brigata$ component was indeed extended, at least on a region 70 pc wide. This is clearly inconsistent with a typical BLR size. This apparent conflict is the piece #2 of the puzzle.
3.3. Piece #3: a remarkable North/South symmetry
A remarkable North-East / South-West symmetry can be noted between spectra taken at location on each side of the central core, as revealed by Fig.5. Each spectral feature has components on each side that superimpose very well, especially concerning the Br$_\gamma$ line.

In addition, if one plots the continuum color temperature profile (Fig.6), a similar symmetry with respect to the center is noted.

Why is such a symmetry observed, constitutes the piece #3 of the puzzle.
3.4. Piece #4: H$_2$ on the very central line of sight

The H$_2$ line is seen even on the very central position (i.e. a region 18 pc wide) and is becoming more and more prominent with distance to the center. Two questions are raised by this finding: a) how could H$_2$ survive in the very close environment of an AGN? b) why do we see H$_2$ since the molecular torus is supposed to be out of the line of sight according to the model by (2)?

Concerning the first one, one can make the following estimates: assuming a typical model for the emission of the accretion-disk, the energy density a 5pc is $3.5 \times 10^5$ eV cm$^{-3}$ which corresponds to $2 \times 10^5$ times the ISRF value. It is on the other side dominated by photons with $E > 11$ eV (blue bump + X), so that dissociation of H$_2$ should be effective. In reality, this is not a true problem because self-shielding is extremely efficient and even in such hard conditions, the dissociated layer remains thin and protected molecules can survive: see e.g. (7).

However the second question appears to be a good one and constitutes the piece DV of our puzzle.

4. The solution of the puzzle ?

The proposed solution of the puzzle that could allow interpretation of the four different intriguing observations is summarised by the scheme of Fig.7 (Gratadour et al 08 A&A accepted). The main idea is that all those observational facts can be explained by the electrons in the cone of the NLR, reflecting the emission of the true compact BLR emission, through Thomson scattering, provided that the cone would extend at least up to 60 pc.

This is clear first for the broad Br$_\gamma$ line which is produced in the compact BLR: if reflected, one can thus detect a broad component far from the true BLR. In addition, this unique source being reflected on each side of the core, it is logical that the spectral features are identical: this assumes just that the cone/torus structure is rather symmetric.

Second, the continuum, if it is mainly reflected light from the very hot central accretion disk, must appear very blue and again symmetric with respect to the centre: this is is what is observed.

Third, the $r^{-1}$ decreases of this continuum is consistent with a scattering by an homogeneous medium.

Fourth, there is around the NLR a dense thick torus of dust and gas where the molecular gas is protected from the very hard X-UV radiation by self-shielding. This torus emits the H$_2$ line in all directions, in particular towards the central part of the NLR where the radiation is reflected along the line of sight to the observer by Thomson scattering: this would explain why the H$_2$ line is observed at the central position despite the fairly high continuum level.

Is this hypothesis supported by a quantitative estimate of the Thomson scattering ? Let’s consider such an evaluation of the Thomson scattered flux for the Br$_\gamma$ line which is clearly identified. The density of electrons can be estimated as: $n_e \approx (F_{ring}/F_{tot})4\pi r^2/\sigma_T V_{ring}$, where $F_{ring}$ is the flux from a given ring at radial distance $r$ and $F_{tot}$ is the total flux. $\sigma_T$ is the Thomson scattering cross section and $V_{ring}$ is the volume of the ring. We assume a thickness of the scattering ring proportional to the distance to the centre (conic NLR), an homogeneous electron density and no extinction. We find $n_e \approx 2 - 5 \times 10^4$ cm$^{-3}$ at 18–35 pc from the central engine. This value of $n_e$ is consistent with those found in nearby AGN: for instance in NGC1068 (4), it is however larger that the average value and falls rather in the upper quartile.

Does imaging confirm this explanation ? The H image deconvolved by MISTRAL (myopic deconvolution with L1/L2 regulation) is shown on Fig.8. It shows a good consistency with the picture of a NLR bracketed by an internal molecular ring, if we admit that the central structures that show up could be the counterparts of the inner molecular ring and of the NLR extending perpendicular to it, as indicated on the figure. But we know that artifacts are also fully possible and we must consider this as an indication rather than a proof that our explanation stands.
5. Conclusions
Spectroscopy of the innermost 100 pc of NGC7469 leads to several puzzling facts: A broad Brγ line (FWHM = 6500 km/s) on region extending up to ≈ 70 pc; a continuum fitted by a very hot Black Body (> 6000 K to 3500 K) on 60 pc, that cannot be stellar radiation (which accounts only for 8% of the K flux) or hot dust; H₂ is found on the very central line of sight where no molecular clouds are supposed to be present (they are within more distant rings); all observed features (temperature, spectra) are amazingly symmetric with respect to the central engine.

A unique coherent explanation which is Thomson scattering on the electrons of the Narrow Line Region appears to solve the puzzle and would provide an estimate of the electron density...
\( n_e = 2-5 \times 10^4 \text{cm}^{-3} \) which is well within the range estimated for other AGNs. Imaging tends to confirm the validity of this interpretation.

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