The inner 200 parsecs of NGC4151 observed with OSIRIS

Christof Iserlohe¹, Alfred Krabbe², James Larkin³
¹ I. Physikalisches Institut der Universitaet zu Koeln, Zuelpicherstrasse 77, 50937 Koeln, Germany
² Deutsches SOFIA Institut (DSI) an der Universitaet Stuttgart, Pfaffenwaldring 31, 70569 Stuttgart, Germany
³ Physics and Astronomy Building, 430 Portola Plaza, Box 951547, Los Angeles, CA. 90095-1547, USA
E-mail: ciserlohe@ph1.uni-koeln.de

Abstract. NGC 4151 is a Seyfert 1.5 galaxy. Due to its proximity of only 13 Mpc it is an ideal testbed and therefore one of the most intensively studied Seyfert galaxies. NGC4151 shows an outflow in the Narrow Line Region (NLR) along the NE and SW direction. This outflow has been modelled by several authors ([9], [10] and [11]) as two hollow bi-cones. The excitation conditions in the NLR have been investigated by [11] and have been attributed to photoionization due to the central engine. [4] also observed a linear radio structure in the inner few parsec with a pronounced S-like curvature which is slightly misaligned with the bi-cones major axes. Here we compare these findings with our results and discuss the role of the radio jet. We also refer the reader to the full paper (Iserlohe et. al., 2012) which will be published soon.

1. Introduction
NGC4151 has been observed with OSIRIS (OH Suppressing Infra-Red Imaging Spectrograph) at the W. M. Keck Observatory. OSIRIS is an integral field spectrograph [1] for the near-infrared (z, J, H and K band) with a nominal spectral resolution $\Delta \lambda = 3700$ that works with the Keck Adaptive Optics System [2]. The design of the instrument is based on concepts developed for the TIGER spectrograph [3] and utilizes an infrared transmissive microlens array that samples a rectangular field-of-view (FoV) of the adaptive optics focal plane. We performed AO assisted spectroscopic H and K band observations of the inner 100 parsec with linear resolution on-site of about 5 parsec. The AO loop was locked on the nucleus. The K band spectra reveal a wealth of emission lines (see figure 1). Brγ shows a broad and a narrow component on top. Ro-vibrational transitions of molecular hydrogen are observed as well as highly ionized species like [CaVIII] and [SiVI]. HeI appears in emission and absorption. The nuclear spectrum is significantly redder than the spectrum extracted from the whole FoV.

2. Feeding
Radio observations by [4] show in HI an oval on scales of 10 arcminutes. Kinematically this oval has been described as a weak bar with inflow of gas towards the nucleus. The major axis of this oval is aligned roughly from NW to SE. K-band imaging of the inner few arcminutes
of NGC4151 show an inner K band continuum bar which is well aligned with the major axis of this oval. Along this bar and on arcsecond scales our spectra are also significantly redder than perpendicular to the bar implying that there is more obscuring material along that bar. Roughly perpendicular to this bar narrow Brγ is observed in the Narrow Line Region (NLR). The dynamics of this gas reveals three components: Rotation in the galactic disc of NGC4151, an outflow into the NLR (roughly from NE to SW) and a velocity signature which resembles a keplerian disc. Latter is centered at the position of the continuum peak and is aligned roughly from NW to SE and may hence not represent an outflow. To investigate this velocity signature we fit a thin, keplerian disc model to it following [6]. Free parameters of the model are the mass of the black hole, the inclination, the scale parameter and the width of the seeing disc. If we assume that the inclination of this disc is the same as the inclination of the galactic disc of NGC4151 (23 degrees) we derive a black hole mass of $5 \pm 2 \times 10^7$ solar masses compatible with measurements by [7] ($4.5 \times 10^7$ solar masses, reverberation mapping) and [8] ($4.5 \times 10^7$ solar masses, modelling the outer stellar velocity field). Also the line-of-nodes is aligned with the inner bar with an accuracy of about 5 degrees. We assume that this keplerian disc represents another feeding stage closer to the nucleus.

3. Feedback

The kinematics of the Narrow Line Region (e.g. observed in [OIII]λ500 nm) is compatible with an outflow in two hollow bi-cones ([9], [10] and [12]). The outflow is modelled with constant acceleration (e.g. due to radiation pressure). The corresponding half opening angles are 15 degrees and 33 degrees respectively with a position angle of 60 degrees and an inclination of 45 degrees. A comparison between the velocities of selected clouds measured in [OIII] [5] and [FeII]λ1.664 reveals that the [FeII] kinematics is very similar to that observed in [OIII]. To investigate whether the [FeII]λ1.664 emission we observe is compatible with this model we analyze the
[FeII] emission morphology by overplotting regions from which emission is expected according to the model with channel maps in [FeII]. Most of the emission seen in [FeII] emerges with zero velocity and we assume that this emission emerges from the galactic disc of NGC4151. Velocities and positions of clouds with other than systemic velocities are well compatible with this model.

The S-like shape of the 6 cm radio jet [4] has been puzzling for a long time. It has been speculated that ram pressure due to the rotation of the galactic disc of NGC4151 into the path of the ejected plasma may be the cause. Here we present the proof, that this is indeed the case. Figure 2 shows the 6 cm radio jet overplotted to the coadded emission of ro-vib transitions of molecular hydrogen (1-0S(0) + 1-0S(1) + 1-0S(2)). Most of the molecular emission seen in this figure emerges with systemic velocity and is hence embedded in the disc of NGC4151. The sense of rotation is clockwise. The correlation between the individual radio knots and bright spots in molecular hydrogen is indeed striking. This also shows that the radio jet must have a low inclination and almost runs completely in the disc.

Figure 2. The 6 cm radio jet (contours) with the coadded emission of ro-vib transitions of molecular hydrogen (1-0S(0) + 1-0S(1) + 1-0S(2)).

4. HeI absorption in the nuclear spectrum
Absorption of UV excited species is observed in nuclear spectra of NGC4151 [13]. Here, we observe infrared absorption and emission of HeI\(\lambda2.058\) where the lower state \(2^1S\) is metastable and has an excitation energy of approximately 21 eV (see the Grotharian diagram in figure 3). The gaussian emission component emerges with systemic velocity while the lorentzian absorption component is redshifted by 280 km/s with a half-width-half-maximum of 400 km/s. The emission component is spatially resolved, especially into the direction of the Narrow Line Region, while the absorption component remains spatially unresolved. Following [14] we derive a column
density of $5 \times 10^{12}$ cm$^{-2}$ for a covering factor of 1. The minimum covering factor derived is 0.1 with a column density of $1 \times 10^{14}$ cm$^{-2}$. We may actually see a UV excited gas cloud orbiting closely to the nucleus which is detected for the first time in the near-infrared.

![Grothrian diagram. The HeI$\lambda$2.058 transition is indicated.](image)

**Figure 3.** Grothrian diagram. The HeI$\lambda$2.058 transition is indicated.

5. **FLUXER, an IDL-based visualization and processing tool for data cubes**

FLUXER (see figure 4) is a processing and visualization tool for astronomical data cubes. This tool was created to deal with data delivered by imaging field spectrographs like OSIRIS@Keck or SINFONI@VLT.

The program allows:

- Automatic and manual identification of crazy/dead pixels in data cubes
- Interpolation of these pixels in 1, 2, or 3 dimensions
- Operations on data cubes, like e.g. smoothing each slice of a data cube with a gaussian PSF of median filtering each slice
- Interactive and automatic fitting of emission/absorption lines with various profiles (flux maps, velocity fields, dispersion fields, ...).
- Extraction of spectra from data cubes
- Creation of animated channel maps in gif format (for UNIX only)
- Data cube viewing in 2D with full astrometry (if supplied)

All spectra and flux maps presented here have been extracted from the data cube using FLUXER.
Figure 4. The main GUI of FLUXER. As an example a flux map of Brγ has been extracted from a data cube obtained with SINFONI of NGC7582.
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