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Investigating the nuclear regions in Seyfert galaxies with 3D spectroscopy

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Abstract. We present preliminary interesting results stemming from a study of the nuclear and circum-nuclear regions of a sample of nearby Seyfert galaxies. Integral Field Spectroscopy was applied as a method of investigation, and data were used to analyze the physics of the ionized gas. Reconstructed continuum and emission line images of the observed galaxies revealed the presence of an extended S-shape ionization cone in Mrk 3, a circumnuclear HII star forming region in Mrk 744, and strong shock ionization around the nucleus of NGC 7319.

Key words. Galaxies: nuclear regions, galaxies: Seyfert galaxies, techniques: Integral field Spectroscopy

1. Introduction

Studies on Active Galactic Nuclei (AGN) have known a huge development in the last decades, also thanks to the improvements of the available observational techniques, and have led to the formulation of a standard model, the so-called Unified Model (Antonucci, 1993), which accounts for the main physical properties of these objects.

It is now generally accepted that the accretion of material onto a supermassive black hole through a thick accretion disk is the mechanism responsible for the great amount of energy released by an AGN mainly as non-thermal radiation. This picture, completed by the presence of a broad line emitting region (BLR) close to the nucleus and separated from a more distant narrow line emitting region (NLR) by a thick dusty torus of obscuring material, accounts for the anisotropic character of the AGN radiation.

Following this scheme, Seyfert 1 and Seyfert 2 galaxies are the same kind of object seen at two different orientations with respect to our line-of-sight: namely a Seyfert 1 is seen with the axis of the obscuring torus along the line-of-sight, and thus it shows both its BLR and NLR, while a Seyfert 2 is seen with the torus axis perpendicular to the line-of-sight, so that the BLR is hidden to our view and only the NLR is observable.

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Albeit this scenario is supported by several observational evidences, like broad lines observed in polarized light in some Seyfert 2 galaxies, it has not been univocally proven until present. Moreover, the scheme in its simplest form as exposed above, even if satisfactory from several points of view, does not account for all the observed differences between the types of Seyfert galaxies (Mulchaey, et al., 1994).

For this reason it seems more realistic to suppose the existence of a combined effect of spatial orientation and intrinsic differences. Therefore, a detailed analysis of physical and kinematical properties of the nuclear regions of a sample of Seyfert galaxies would provide important clues to the unification (or unification/evolution) scheme.

2. Our project

We apply the modern technique of Integral Field Spectroscopy (IFS) to the study of the nuclear regions of a spectroscopically selected sample of nearby type 1, 2 and intermediate Seyfert galaxies, in order to point out optical properties suitable for testing the Unified Theories with respect to this class of AGN.

The IFS technique is offering a powerful investigation method much more advantageous than the traditional long-slit spectroscopy, cause it allows to observe extended regions of nearby galaxies providing at one time spectral information along two spatial directions (α and δ).
Additionally, these three dimensional data are recorded simultaneously, i. e. in the same observational conditions, a noticeble advantage in comparison to other techniques like Fabry-Perot interferometry or Fourier-transform spectroscopy, which need repetitive integrations to obtain full spectra (Vanderriest (1998), Parry (1998)).

3. The data

We present preliminary results from a study of the nuclear regions of a spectroscopically selected sample of nearby AGN (z< 0.1) (Rafanelli, et al., 1995). We analize both isolated and interacting galaxies and we look for the presence of HII regions, ionization cones and/or shocks.

For our research we use data obtained at the 6 m telescope of the Special Astrophysical Observatory (SAO, Russia), equipped with the MultiPupil Fiber Spectrograph (MPFS). Our data covers a field of view of 16x15 arcsec (corresponding to $\sim 9.3 \times 8.7$ kpc for an object at z=0.03 and assuming H_0=75 km s^{-1} Mpc^{-1}), with a spectral range of 3500-7500 $\mathring{A}$ and resolutions of 3.4 and 6.5 $\mathring{A}$ at λ=5000 $\mathring{A}$.
The spectra were reduced and analyzed by means of a dedicated software developed at SAO.

As examples of our study we are currently carrying on, we present three Seyfert 2 galaxies: Mrk 3, NGC 7319 and Mrk 744. The first object was observed in March 2001 with a typical seeing of 1.7″, while the second and the third objects were observed in November 2001, with seeing of 1.5″ and 2″ respectively.
The spectra of these galaxies were reduced by following the usual steps of bias and dark subtraction, cosmic rays removal, flatfielding, wavelength calibration, sky subtraction and flux calibration. Then a fast reconstruction of the emission line images of each galaxy was obtained by fitting spectral emission line with gaussian profiles. Ratios between images allowed to study the physical properties of the ionized gas: the presence of ionization cones by means of [OIII]5007/Hβ excitation maps, and/or regions ionized by shocks (SII/Hα, OI/Hα, NII/$H\alpha$).

4. Results

4.1. Mrk 3

Mrk 3 (see Fig.1) was studied in detail by (Capetti et al., 1995), who obtained images of the NLR taken with the Faint Object Camera and Wide Field Planetary Camera

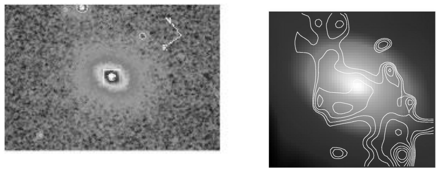

Fig. 1. Left panel: DSS image of Mrk 3; Right panel: Ionization cone in Mrk 3

of HST by using filters at different emission lines like [O II]λ 3727, [O III]λ 5007, Hα and Hγ. ¿From the analysis of these images an ionization cone with a S-shaped morphology was revealed, extended over more than $2''$ and closely associated to highly collimated radio jets.

Our excitation map [OIII]5007/Hβ (see Fig. 1) confirms this ionization cone, but with a much larger extent, at least up to $\sim$ 2 kpc and with the same S-shape shown in the innermost regions. This ionized gas should be associated to the so-called Extended-NLR.

Recently (Ruiz, et al., 2001) measured radial velocities for the narrow-line region of Mrk 3 out to $\sim$ 1 kpc from the nucleus and suggested that the gas is accelerated radially away from the nucleus and decelerated outward due to collisions with the surrounding medium.
We plan to verify this result measuring the [O III] lines with a lower spatial resolution but over a larger scale.

4.2. Mrk 744

Mrk 744 is a Seyfert 1.8 spiral galaxy in clear interaction with NGC 3788. It shows a bright nuclear region and a faint adjacent broad feature suggesting the presence of a bar. These features are enclosed by inner blue arms forming an elongated ring. In addition, this galaxy also shows an external diffuse and elongated ring (Hernandez-Toledo & Puerari, 2001). Integral field spectra of the nuclear regions of Mrk 744 (see Fig.2) cover a field of view of $\sim$ 2.8x2.6 kpc at the redshift of the galaxy (z=0.009). Emission line maps reconstructed after having measured every spectrum in which traces of ionized gas were present, allowed to unveil a circumnuclear region, well visible in the Hβ map S-W to the nucleus and located at a projected distance of $\sim$ 1 kpc (see Fig.2). The nature of this region has been investigated comparing low ionization emission line gas with high ionization gas. Contours of [O III] 5007 emission overplotted to the Hβ map show only a weak elongation in correspondence of the emission region, suggesting for it a thermal origin due to star formation. We do not confirm the previously suggested bar.

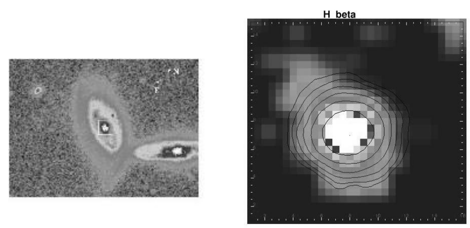

Fig. 2. Left panel: DSS image of Mrk 744; Right panel: HII circumnuclear region in Mrk 744

4.3. NGC 7319

NGC 7319 (Fig.3) resides in the very famous compact group of galaxies Stephan's Quintet (HCG 92). Narrow band images have revealed a diffuse Hα emission in the intragroup medium with a clear tail of emission toward the nucleus of NGC 7319 (Iglesias-Paramo, 2001). This feature justifies what we have found analyzing integral field spectra of the nuclear regions ($\sim$ 6.7x6.3 kpc at the HCG 92 distance): the stellar continuum and the ionized emissions have different orientation (see Fig.3, Fig.3). In particular Hα emission is oriented toward the center of the group and seems to be in strong connection with the above mentioned tail. We note also that the [S II]/Hα ratio distribution form a strong ring near the nucleus (see Fig.3). This ring

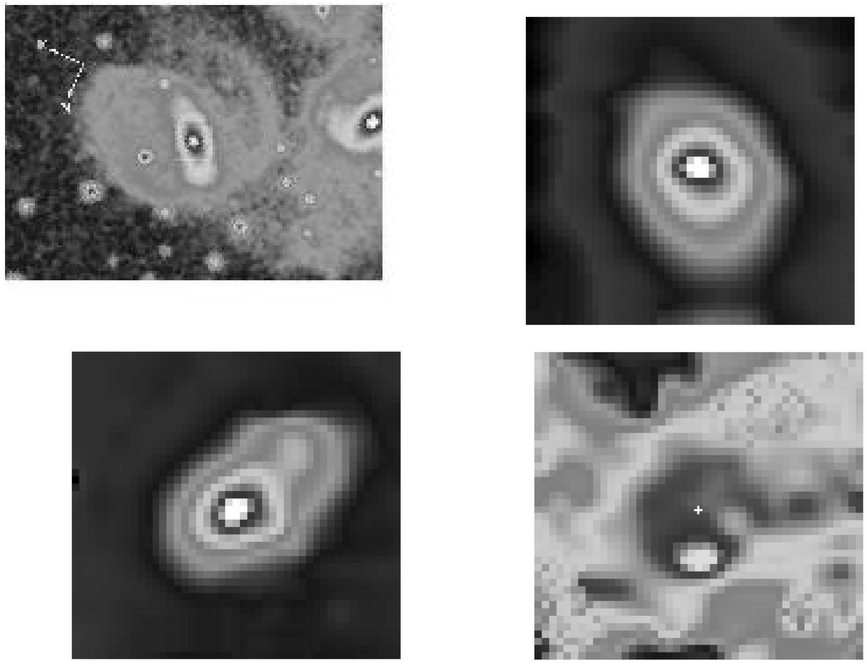

Fig. 3. NGC 7319: Upper left: DSS image; Upper right: Stellar continuum; Lower left: Hα distribution; Lower right: SII/ Hα ratio near the nuclear region.

is less evident in the [O I]/Hα map but still present, suggesting that the gas around the nucleus is strongly ionized by shocks. Shocks are expected in case of interacting systems, and indeed they were found in this compact group and were attributed to an ongoing collision with a new intruder (Sulentic et al., 2001). Nevertheless (Aoki et al., 1996) found a high velocity and large-scale outflow in the extended-NLR of NGC 7319. By comparing observed line intensity ratios with photoionization and shock ionization models, they indicated that the outflowing gas is predominantly photoionized by the nuclear radiation. At the moment we cannot confirm this results since data are still under analysis.

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