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The DIVING^{3D} Survey - Deep IFS View of Nuclei of Galaxies

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Abstract. The DIVING^{3D} Survey (Deep Integral Field Spectrograph View of Nuclei of Galaxies) aims to observe, with high signal/noise and high spatial resolution, a statistically complete sample of southern galaxies brighter than B = 12.0. The main objectives of this survey are to study: 1) the nuclear emission line properties; 2) the circumnuclear emission line properties; 3) the central stellar kinematics and 4) the central stellar archaeology. Preliminary results of individual or small groups of galaxies have been published in 18 papers.

Keywords. galaxies: active – galaxies: nuclei – galaxies: statistics – galaxies: kinematics and dynamics – galaxies: stellar content – galaxies: Seyfert – surveys

1. Introduction

Statistical surveys may provide important clues about the nature, spatial distribution and evolution of objects. Astronomy has seen a growing number of surveys of all kinds. The area of Active Galactic Nuclei (AGN) has profited significantly from surveys of various sizes.

One such important survey was the Palomar Survey (Filippenko & Sargent 1985): a spectroscopic survey of all northern galaxies brighter than B = 12.5 with $\delta > 0°$ and $|b| > 10°$. This survey was done on the Palomar Telescope and used a slit of $2'' \times 4''$. Most of the data and results were published many years after the survey started (Ho *et al.* 1995, 1997a,b,c). An important review with the statistical analysis of this survey was published 23 years after the first paper by L.C. Ho: Nuclear Activity in Nearby Galaxies (Ho 2008).

2. The DIVING^{3D} Survey

Inspired by the success of the Palomar survey, we started a few years ago a survey with optical integral field unit (IFU) spectroscopy. All 170 galaxies with B < 12.0, $\delta < 0°$ and $|b| > 15°$ are by now already observed. The 8 m Gemini telescopes were used to observe 150 galaxies with good seeing conditions only. The Gemini Multi-Object Spectrograph (GMOS) IFU field of view (FOV) of the observations are $3.5'' \times 5''$ and fibres covered $0.2''$; all observations were seeing limited. The other 20 objects were observed with the SOAR Integral Field Spectrograph (SIFS) on the SOAR telescope. The SIFS FOV is $15'' \times 7.8''$ with a $0.3''$ fibre. The spectral coverage is 4300–6800 Å with a typical spectral resolution of 1.3 Å and a seeing condition of $0.5''$–$0.8''$. The idea of the survey is to have the highest possible spatial resolution and signal/noise. Other important surveys using optical IFUs were done previously (SAURON – Bacon *et al.* 2001; ATLAS^{3D} – Cappellari *et al.* 2011; CALIFA – Sánchez *et al.* 2012; MaNGA – Bundy *et al.* 2015) among others.

The main DIVING^{3D} objectives are:

(a) *Nuclear emission line properties*: we intend to quantify with high signal/noise and high (seeing limited) spatial resolution the properties of the nuclei of all galaxies in the sample. Our objective is to detect the faintest AGN that can currently be observed in the optical. The BPT diagrams of these objects may show a decrease in "Transition Objects" (TO) population, as H II regions tend to be separated from the "true nuclei".

(b) *Circumnuclear emission line properties*: the circumnuclear emission may reveal important aspects about the ionizing sources in the central region of the galaxies. Is the nuclear AGN responsible for the circumnuclear emission or do we need further sources of excitation/ionization such as shock waves or Post-AGB stars?

In addition to these main objectives, as by-products, we will obtain important information about:

(c) *Central stellar kinematics*: not only information about stellar disc rotation and bulge velocity dispersion but also anomalies such as counter-rotation and decoupling.

(d) *Central stellar archaeology*: stellar population synthesis will always be attempted in order to remove the stellar "noise" from the emission lines. As a byproduct, one may obtain information about the star formation history of the nucleus and the circumnuclear environment.

The DIVING^{3D} galaxies morphological types are:

- E: 30
- S0: 32
- Sab: 59
- Scd: 49
- Total: 170 galaxies

3. Methods and Early results

Our group has developed a series of techniques that treat the raw data. This includes instrumental fingerprints removal by using Principal Component Analysis (PCA) Tomography; Butterworth filtering for removal of high-frequency spatial noise; deconvolution etc (see Menezes *et al.* 2019). Fig. 1 shows the effect of such treatments for an extreme case.

In addition we also used stellar spectral synthesis by using STARLIGHT (Cid Fernandes *et al.* 2005) and PPXF (Cappellari & Emsellem 2004). It is important to remove the stellar component from the original data cube in order to remain with the gas cube (basically showing emission lines only) - see Fig. 2.

Emission lines are analysed in terms of Gaussian decomposition. This procedure starts with fitting the [S II] doublet with a two kinematic component model. This is, then, fitted to the [N II] + Hα lines. In order to improve the fit, a broad Hα component is added when necessary (see Fig. 3).

To see the importance of high spatial resolution ($FWHM_{PSF} \sim 0.70''$) we show, in Fig. 4, the counter-rotation between the stellar and gaseous discs in the nucleus of the LINER galaxy IC 1459. Just for comparison, the fibre of the SDSS is $3''$. The critical information here happens on a significantly smaller scale. This shows one of the key differences of the DIVING^{3D} survey when compared to other optical IFU surveys.

As preliminary results, to date, a total of 18 papers have been published on individual or small groups of objects from the DIVING^{3D} Survey: Menezes *et al.* (2013); Ricci *et al.* (2014a,b); Menezes *et al.* (2014a,b); Ricci *et al.* (2015, 2016); Menezes *et al.* (2016); Menezes & Steiner (2017); Diniz *et al.* (2017); da Silva *et al.* (2017); Ricci *et al.* (2018);

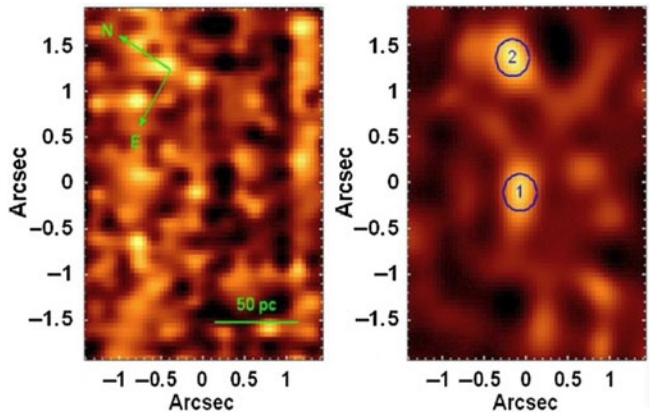

Figure 1. Typical galaxies have bright nuclei; some can be quite obscured as is the case of NGC 2835 (above). We have developed data treatment techniques that help in extracting information (see Menezes *et al.* 2019), transforming the raw data (left) into the treated data (right). Object 1 is the LINER nucleus and Object 2 is an H II region.

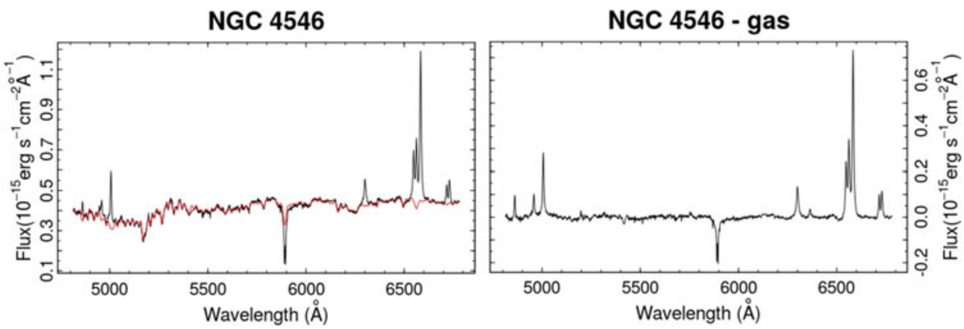

Figure 2. A typical spectrum of a S0 galaxy (left) and the same spectrum after removing the stellar component using spectral synthesis (right). This procedure is important, especially for studying weak emission lines.

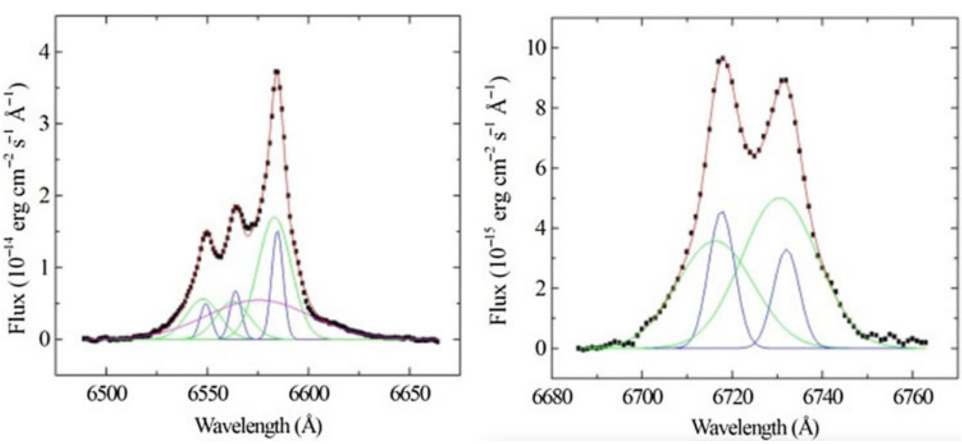

Figure 3. We modelled each blend by fitting the [S II] doublet (right) in two kinematic components. We, then, fitted the [N II]+Hα lines with the same kinematic components. A third broad Hα component was added when necessary.

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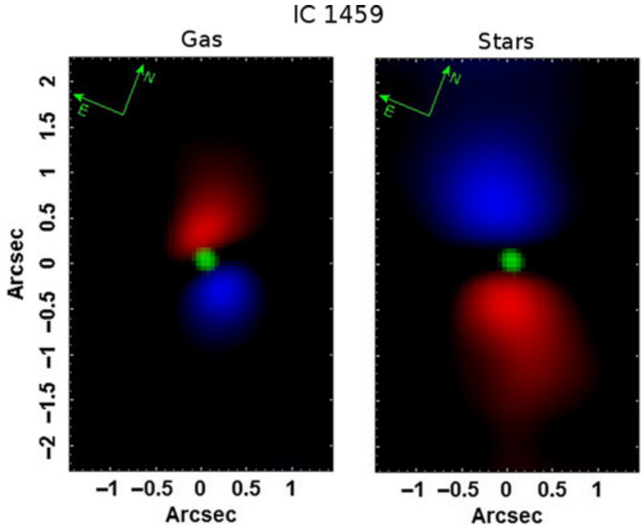

Figure 4. The counter-rotating gaseous and stellar discs (from Ricci *et al.* 2014b). This shows the spatial scale of such phenomena and the importance of high spatial resolution.

da Silva *et al.* (2018); Menezes & Steiner (2018); Dahmer-Hahn *et al.* (2019a,b); Ricci & Steiner (2019); da Silva *et al.* (2020).

4. Summary

The main early results of the survey can be seen in the contributions of Menezes *et al.* and Ricci *et al.* in this Proceedings. Below we summarize some of them:

- There seems to be a dichotomy in the BPT diagrams when using high spatial resolution data. The TO region seems to be depopulated, as a consequence of higher spatial resolution.
- There seem to be intrinsic TO objects, like superwind starbursting galaxies.
- 91 % of the early-type galaxies show nuclear emission lines.
- 50 % of the early-type galaxies show Seyfert or LINER type spectra.
- 31 % of early-type galaxies are AGN of Type 1 (as compared with 15 % in Palomar).

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