

PHYSICS OF ACTIVE GALACTIC NUCLEI AND OF THEIR ENVIRONMENT

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The study of Active Galactic Nuclei (AGN) is one of the most important astrophysical topics of the last decades. Notwithstanding the huge efforts in investigating their spectroscopic and photometric properties aimed to understand their nature and role in galaxy evolution, many aspects are not yet clear and still debated.

The objectives of our research programme are:

- 1) To give an insight into all physical processes occurring when an active nucleus interacts with the surrounding interstellar medium.

By means of Gaussian decomposition of the spectral emission lines and the measure of their fluxes it is possible to carefully identify emission line regions. The physical properties of the gas in these regions (density, temperature, chemical abundances, ionisation distribution) is then analysed through simulations with photoionization and shock models. The kinematics of gas and stars is obtained by measuring the position of the emission lines and by applying the cross-correlation technique to the absorption lines. These velocity curve/fields are then accurately analysed separating, when necessary, different kinematic components.

- 2) To explore the AGN/starburst connection.

The nuclear continuum is analysed to detect the signs of recent star formation episodes. Empirical diagnostics, based on equivalent width measurements of absorption lines and/or emission line flux ratios have already been successfully applied to type 2 and intermediate type Seyfert galaxies. In addition, the population synthesis method is applied for a quantitative estimate of the contributions by stellar populations with different ages.

- 3) To put in relation the features identified in each target with the surrounding extragalactic environment.

The kinematical properties and peculiarities of gas and stars around each Seyfert nucleus are compared to the galaxy morphology and its ionized gas distribution to investigate any connection with possible past or present interaction processes, like a merger with a small companion. In fact, the minor merger timescale could be long enough to smear its relics, therefore most advanced mergers would be observed as ordinary-looking isolated galaxies. Nevertheless it was shown in morphologically normal and relatively isolated early-type spirals the presence of complete counterrotation of gas with respect to stars, nuclear gas disks decoupled from the stars and anomalous velocity central components, demonstrating that even in case a galaxy does not exhibit morphological signs of interaction, it can keep the kinematic “memory” of past minor mergers.

Project 1: BH/Bulge relation in Narrow-Line Seyfert 1 galaxies

Recently a very important discovery was made about the existence of supermassive black-holes (BH) in the nuclei of almost all galaxies. Works by Gebhardt et al. (2000) and Ferrarese & Merritt

(2000) have demonstrated that the mass of BH (M_{BH}) in nearby non-active galaxies is tightly correlated with the stellar velocity dispersion (σ_*) of their hosting bulges, and so with their masses (M_{bulge}). This relation supports the theory that the growth of BH is bound to galaxy formation. Gebhardt et al. (2000) included seven Active Galactic Nuclei (AGN) whose M_{BH} were estimated by means of the reverberation mapping technique, and found that also these objects followed a similar correlation $M_{\text{BH}} - \sigma_*$ correlation. Other authors have then confirmed the validity of this result for samples of Seyfert 1 galaxies and quasars (Laor 1998; Wandel 1999; McLure & Dunlop 2001). No consensus on this topic has been reached up to now about the case of the Narrow-Line Seyfert galaxies (NLS1). These active galaxies have spectroscopic properties slightly different from those of the classical Seyfert 1, as for example narrower emission lines from hydrogen and helium in the optical wavelength domain and steeper power-law X-rays continua, which suggest that NLS1 are hosting BH with lower masses accreting at very high rates, close to the Eddington limit. This hypothesis let suppose that NLS1 have also less massive bulges than classical Seyfert 1, of course assuming that their M_{BH} are correlated to the physical properties of their hosting bulges. Mathur, Kuraszkiwicz & Czerny (2001), Bian & Zhao (2004) and Grupe & Mathur (2004) showed that the $M_{\text{BH}}/M_{\text{bulge}}$ ratio in NLS1s is significantly smaller than that of Seyfert galaxies. Conversely, Wang & Lu (2001), studying a sample of 59 NLS1s observed spectroscopically by Véron-Cetty et al. (2001), found that there is no clear difference in the relation $M_{\text{BH}} - \sigma_*$ (where σ_* is represented by the [O III] emission line width) between NLS1, broad-line AGN, and nearby galaxies. Recent results by Botte et al. (2004; 2005) have found that NLS1 are mostly confined to the lower ranges of both the $M_{\text{BH}}-L_{\text{bulge(B)}}$ plane and the $M_{\text{BH}}-\sigma_*$ plane, where σ_* was directly measured by means of the Ca II stellar absorption triplet. Moreover, Botte et al. (2005) demonstrated that [O III] cannot be used in place of σ_* at least in NLS1, a result very recently confirmed by Greene & Ho (2005).

Project 2: Integral field spectroscopy of Seyfert galaxies

Integral field spectroscopy, also called 3D spectroscopy, is a modern method of investigation in observational astronomy, since it provides simultaneously a spectrum, under the same atmospheric and instrumental conditions, for each spatial element of a two-dimensional field of view. This gives a clear advantage with respect to classical sequential spectroscopic techniques when studying extended objects, and it is well suited for different kinds of targets, among which the AGN, and in particular the nuclear and circumnuclear regions of nearby Seyfert galaxies ($z < 0.1$). In fact, it is in this circumnuclear environment that it is likely to find the gas and the dust which can fuel the active nucleus. Since AGN are also strong high energy emitters, they may substantially alter their circumnuclear environment. While this may erase information about their nature, the way in which they affect their surrounding may provide important data about their structure and energetics. According to the Unified Model (Antonucci 1993) type 1 and type 2 Seyfert differ only in our viewing angle: in Seyfert 1 galaxies the central engine and the broad emission-line region are viewed directly, while in Seyfert 2 galaxies they are obscured by a surrounding dusty torus, whose geometry is able to restrict the emergent radiation from the nucleus to a bipolar cone. Indeed, imaging in optical emission lines has shown in some type 2 Seyfert galaxies, high ionization regions with a conical and/or biconical morphology. These so-called ionization cones are direct evidence that radiation escapes anisotropically from the nuclear region (see e.g. Pogge 1989; Mulchaey et al. 1994; Wilson & Tsvetanov 1994; Schmitt et al. 2003a; Schmitt et al. 2003b). Unfortunately not much is known about the shape of these ionization cones in type 1 and intermediate type Seyfert galaxies, and more in general about their origin, that is if they are powered by photoionization, or hydrodynamic shocks, or a mix of these mechanisms. All these key issues can be addressed through observations with integral field spectroscopy and analysis of 3D data. Until now, few nearby AGN have been observed with optical fiber systems (e.g.: Mediavilla & Arribas 1995; Arribas et al. 1997; Chatzichristou 1998; Mediavilla et al. 1998;

Colina et al. 1999; Garcia-Lorenzo et al. 2001; Bryant & Hunstead 2002; Gonzalez Delgado et al. 2002; Ciroi et al. 2003; Ciroi et al. 2005). Therefore, the statistics is still poor and the lack of any selection criteria in the choice of the targets gives only information on single objects and avoids any reliable general conclusion. In addition almost all data have been taken with different instruments and are difficult to compare each other. The need of homogeneous observations of a well selected sample is mandatory in order to investigate all processes related to the interaction between central engine and its circumnuclear environment.

Project 3: Starburst-AGN connection

It is nowadays widely accepted that the energy source of AGN originates from the accretion of matter onto a central supermassive BH. However, active galaxies are often associated with starbursts, which are possible sources of fueling for the nuclear black holes. Then, the starburst-AGN connection appears as a key issue to understand the AGN evolution.

In the last decade, the studies about this connection focused on type 2 Seyfert galaxies, because of the featurless continuum (FC) characterizing the blue part of the optical continuum of these objects. A small fraction of FC is certainly scattered AGN light, while the rest of it is attributed to the contribution of a young stellar population (Cid Fernandes & Terlevich 1995; Heckman et al. 1995). This has been confirmed by several optical spectroscopic investigations of moderately large samples of Seyfert 2 nuclei (Storchi-Bergmann et al. 2000; Gonzalez Delgado et al. 2001; Cid Fernandes et al. 2001; Joguet et al. 2001). In particular, Cid Fernandes et al. (2001) and Joguet et al. (2001) examined spectroscopically the nuclear regions ($100 \text{ pc} \div 1 \text{ kpc}$) of 35 and 79 Seyfert 2, respectively, finding out a young ($< 1 \text{ Gyr}$) stellar population in about half of each sample. Recently, Kauffmann et al. (2003) published interesting results about the properties of the host galaxies of 22623 narrow-line AGN between $z=0.02$ and $z=0.3$ selected from the SDSS Data Release One (DR1). They have found that the host galaxies of low- luminosity AGN have stellar population similar to normal early-type. Instead, the hosts of high-luminosity AGN have on average stars with much younger ages. This establishes that the stellar content of the AGN hosts is a strong function of the AGN luminosity. Cid Fernandes et al. (2004) presented a spectroscopic study for a sample of 51 LINERs and LINER/HII Transition Objects (TOs), in which they detected clear signs of a young stellar population ($< 1 \text{ Gyr}$) in about half of the TOs, but in very few LINERs, supporting the result by Kauffmann et al. (2003).

If the Unified Model is valid and if a connection exists between AGN and starburst, one would expect to observe a similar distribution of circumnuclear star-forming regions among the two types of AGN. On the contrary, evidence of starbursts have rarely been detected in Seyfert 1 galaxies (Rodriguez-Ardila et al. 2003).

Recently, Romano et al. (2004) have found clear evidence of the presence of young stellar populations (HI high order Balmer absorption lines (HOBLs), indicative of age $< 1 \text{ Gyr}$) and extended $H\alpha$ emission (indicative of H II regions) in four Seyfert galaxies: a Seyfert 2, a Seyfert 1, a Seyfert 1.5 and a Seyfert 1.8. This result seem to suggest that the nuclear starburst presence does not depend on the Seyfert type, in agreement with the Unified Model. These authors also estimated the present SFR (on time-scale of 10^6 years) and the recent SFR (on time-scale of 10^9 years) for the same Seyfert galaxies observing that the galaxies not showing clear signs of present starbursts have had major star formation in the past epochs. This result supports the hypothesis of a starburst-AGN connection, favouring an evolutionary scenario in which the AGN survives to the starburst.

Project 4: Interaction-activity relation in Seyfert galaxies

Understanding the processes responsible for triggering the activity in galactic nuclei is one of the fundamental outstanding questions regarding AGN. Several mechanisms have been invoked during

the last decades, among which the interaction between galaxies, in form of close encounters and mergers. Numerical simulations showed that the gravitational interaction between galaxies can bring gas from the disc toward the nuclear regions (Mihos & Hernquist 1994; Hernquist & Mihos 1995; Mihos & Hernquist 1996). Nevertheless, statistical studies of the large-scale environments of nearby AGN produced until now controversial results (see e.g. Schmitt et al. 2001, and references therein), and failed to demonstrate that a one-to-one relationship between activity and interaction does really exist. In contrast, deep high-resolution imaging and follow-up spectroscopy of these galaxies allowed to identify merging systems or the presence of close faint companions, suggesting that the investigation of the interaction–activity relation should be addressed to AGN hosts and their immediate surroundings.

De Robertis et al. (1998) and Taniguchi (1999) suggested that ‘minor mergers’ between a gas-rich galaxy and a satellite companion may play a significant role in triggering activity in Seyfert nuclei. Indeed the minor merger seems to be the favourite mechanism for several reasons. First of all there is evidence that most spiral galaxies have dwarf satellites (Zaritsky et al. 1997) and therefore minor merger events are expected to occur several times during the lifetime of a galaxy. Second, numerical simulations (see e.g. Hernquist & Mihos 1995) showed that minor mergers can drive a sufficient amount of gas from the host galaxy into its central kiloparsec in a relatively rapid time-scale (<1 Gyr). Third, minor mergers do not cause strong deformations of the host morphology, and indeed most Seyfert galaxies do not appear significantly different from non-active galaxies. In fact, as reported by Taniguchi (1999), the minor merger time-scale could be long enough to smear its relics, therefore most of the advanced mergers would be observed as ordinary-looking isolated galaxies.

Recently, Ciroi et al. (2005) presented a detailed spectrophotometric and kinematic analysis of the Seyfert 1.5 Mrk 315, whose overall morphology does not show strong distortions, bright tidal tails or similar structures expected to be produced by past episodes of gravitational interactions.

Nevertheless, they found a galactic disk with multitiere structure, a quasi-ring of regions with high star formation, a secondary nucleus confirmed by a stellar component kinematically decoupled by the main galaxy, and two independent filaments caused by interaction events between the main galaxy and two dwarf companions.

Personnel:

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| Rafanelli Piero | Full professor |
| Ciroi Stefano | Research fellow |
| Botte Virginia | PhD student |
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Collaborations:

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Tel Aviv University – Israel (Prof. M. Contini)

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Research Products:

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| 2004 | 1 refereed paper + 2 proceedings |
| 2003 | 2 refereed paper + 4 proceedings |

2002 1 refereed paper + 1 proceedings
2001 3 refereed paper + 3 proceedings
2000 1 refereed paper + 5 proceedings

List of 5 most representative publications:

Botte, V., Ciroi, S., Rafanelli, P., Di Mille, F. 2004, *Astronomical Journal* 127, 3168-3179.
Exploring Narrow-Line Seyfert 1 Galaxies through the Physical Properties of Their Hosts.

Temporin, S., Ciroi, S., Rafanelli, P., Radovich, M., Vennik, J., Richter, G.M., Birkle, K. 2003,
Astrophysical Journal Supplement Series 148, 353-382. *Analysis of the Interaction Effects in the
Southern Galaxy Pair Tol 1238-364 and ESO 381-G009.*

Ciroi, S., Contini, M., Rafanelli, P., Richter, G.M. 2003, *Astronomy and Astrophysics* 400, 859-
870. *2-D spectroscopy and modeling of the biconical ionized gas in NGC 4388.*

Rifatto, A., Rafanelli, P., Ciroi, S., Radovich, M., Vennik, J., Richter, G., Birkle, K. 2001,
Astronomical Journal 122, 2301-2317. *The Active Merging System ESO 202-G23 (Carafe Nebula).*

Pfefferkorn, F., Boller, T., Rafanelli, P. 2001, *Astronomy and Astrophysics* 368, 797-816. *Soft X-
ray properties of a spectroscopically selected sample of interacting and isolated Seyfert galaxies.*