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Looking for the broad emission lines in AGN2 with deep NIR spectroscopy

A thesis submitted for the degree of $Doctor\ of\ Phylosophy$

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Coordinatore: Prof. Roberto Raimondi I'm astounded by people who want to 'know' the universe when it's hard enough to find your way around Chinatown

Woody Allen

The most exciting phrase to hear in science, the one that heralds new discoveries, is not 'Eureka!' (I found it!) but 'That's funny!'

Isaac Asimov

Mi domando se le stelle sono illuminate perché ognuno possa un giorno trovare la sua.

Antoine de Saint-Exupéry, Il piccolo principe.

Alla mia famiglia.

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Chapter 1

Introduction

Nowadays there are robust evidences that every galaxy hosts a super massive black hole (SMBH; 10^{6} - 10^{9} M_{\odot}) and the study of this astrophysical black holes (BH) is mainly driven by three different rationales. First of all, the existence of this kind of objects is one of the strongest implications of the theory of General Relativity, and their study can give useful informations on strong gravity effects in action.

Secondly, the emission processes, which allow us to detect such a kind of sources, originate from accretion flows or relativistic jets. Both of these mechanisms take place in regions very close to the BH, thus allowing to study not only the physics of matter in extreme conditions, but also radiative effects and relativistic magnetohydrodinamics.

Lastly, BH affect the formation and evolution of the structures they live in, like galaxies, groups and clusters, and therefore play a key role in a broader cosmological context. This tight link between BH activity and galaxy evolution has been indicated by several discoveries:

- the observation of a supermassive BH (SMBH) in most of the nearby bulge-dominated galaxies (see e.g. Gebhardt et al. 2000, Ferrarese and Merritt 2000, Marconi and Hunt 2003 and and references therein);
- the growth of SMBH happen mainly during active phases, and therefore most local bulge galaxies should have passed an active phase in their lifetime (see Soltan 1982 and Marconi et al. 2004);
- the evolution of active BH (Ueda et al. 2003; Hasinger et al. 2005; La Franca et al. 2005) and of star-forming galaxies (Cowie et al. 1996; Franceschini et al. 1999) have a very similar shape.

Indeed the accretion of matter on the supermassive black holes and the related

radiative and kinetic power output play an important role in the galaxy evolution, by suppressing/tuning the star formation and feeding the AGN itself (feedback; Silk and Rees 1998; Fabian and Iwasawa 1999; Croton et al. 2006; Cattaneo et al. 2009 for a review). In this framework, it appears clear that the study of AGN evolution is very important to understand the evolution of the star formation rate and galaxies in the Universe (AGN/galaxy co-evolution). Moreover, the existence of the scaling relationships between the AGN BH mass and the bulge galaxies properties, implies that the evolution of galaxies and the growth of SMBHs are intricately tied together. Thus, in order to obtain a clear picture of the AGN/galaxy co-evolution, it is important to accurately derive the shape and the evolution of both AGNs luminosity and SMBH mass functions.

In the last decade, using hard X-ray selected AGN samples, it has been possible to accurately derive the AGN luminosity function up to $z\sim4$ (Ueda et al. 2003; La Franca et al. 2005; Ebrero et al. 2009) and, recently, using virial based techniques in the optical band on samples of broad line AGN (AGN 1), it has been possible to obtain some estimates of the Super Massive BH Mass Function (SMBHMF). However these measurements are affected by several selection biases against the narrow line AGN (AGN 2), where the Broad Line Region (BLR) is not visible in the optical because of dust extinction.

According to the original standard unified model (Antonucci, 1993), the different observational classes of AGN (AGN1 and AGN2) were believed to be the same kind of objects, observed under different conditions (e.g. different orientations to the observer). Instead, nowadays there are indications that AGN1 and AGN2 have on average different accretion rates (smaller for AGN 2, Winter et al. 2010), different host galaxy properties (more early type for AGN 2) and different masses (smaller for AGN2, Georgakakis et al. 2009, see also Lusso et al. 2012). It is therefore fundamental to measure the BH masses of both AGN 1 and AGN 2 in a consistent way.

In the few studies where AGN2 BH masses have been derived (e.g. Heckman et al. 2004 from SDSS), the authors used the BH-bulge scale relations which were instead calibrated on AGN1 samples and are unlikely to hold also for all AGN2 (see Graham 2008 and Kormendy et al. 2011). It is therefore crucial to directly measure AGN2 BH masses also to verify the validity of the scaling relations for this population of AGNs. Moreover, different studies have shown

that AGN 2 are representative of a population of AGN characterised by low intrinsic X-ray luminosity and low BH masses (Tueller et al., 2010) that likely contain clues about the formations of the first BH.

The work performed in this thesis is inserted in this scientific framework. Following the studies of Landt et al. (2008); Landt et al. (2011) and Landt et al. (2013) we have developed a new virial method that make use of the less affected by dust exstinction $Pa\beta$ NIR emission line in combination with the hard X-ray continuum luminosity of the AGN, which suffer less from galaxy starlight contamination. Such a relationship represent a usefull tool since it is potentially able to work also with obscured AGN, allowing us to derive for the first time a reliable measure of the AGN2 BH masses. To this porpuse we have randomly selected a complete sample of ~ 40 obscured and intermediate AGN (AGN2, AGN1.9 and AGN1.8) from the Swift/BAT 70 Month hard Xray survey, which provides an accurate hard X-ray luminosities measurements in the 14-195 keV band. We have observed the selected sources using the NIR spectrographs ISAAC at VLT and LUCI at LBT, and also using the multiwavelenght spectrograph Xshooter at VLT. We found broad component in BLR emission lines (Pa α ; Pa β and He I) in ~30% of our sources and, applying to them the NIR virial estimator, we have been able to measure in a direct way the AGN2 BH masses, finding that AGN2 have on average lower BH masses and higher Eddington ratio with respect AGN1 population of same luminosity.

A general overview of the AGN phenomena, their physical and observational characteristics and their classification in the framework of the unified model are summarized in Chapter 2, while in Chapter 3 the main methods to derive the AGN BH mass estimates are described. The project, the *Swift* catalog, the sample selection, the observations and data reductions steps are described in Chapter 4. The development of the new NIR virial relations and the first main results are accurately described in Chapter 5, while the line fitting procedures and the finding of broad component of Paschen lines in AGN2 spectra are discussed in the Chapter 6. Finally the measure of the AGN2 BH masses and the related results are described in Chapter 7 and the conclusions and the future applications of this work are discussed in Chapter 8.

Chapter 2

Active Galactic Nuclei

This Chapter aims at providing a very brief introduction on the physics of Active Galactive Nuclei (AGN), and their evolution in the context of galaxy formation and evolution models. A more detailed discussion can be found in Peterson (1997) and Krolik (1998) textbooks. For the evolutionary topics, see also Merloni and Heinz (2013).

2.1 Basic concepts

The term *Active Galactic Nuclei* (AGN) is used to describe galaxies with energetic phenomena in their nuclei, or central regions, that cannot be clearly and directly attributed to stellar activity. *Seyfert galaxies* and *quasars* represent the largest subclasses of AGN; the fundamental difference between these two classes is the amount of emitted radiation: while in a Seyfert galaxy the luminosity of the central source at visible wavelengths is comparable to the luminosity of the whole galaxy, in a quasar the central source may be up to 100 times brighter.

There are some peculiar features that are usually present in an AGN, although not necessary at the same time, including:

- small, unresolved angular size;
- nuclear broad-band emission, over a wide portion of the electromagnetic spectrum;
- strong nuclear emission lines, mainly found in the infrared and optical/UV part of the spectrum;



FIGURE 2.1. Optical spectrum of a typical Seyfert 1 (adopted from Hawkins 2004)

- variability, both in the continuum emission and in the emission lines, especially in the X-rays;
- higher degree of polarization (0.5-2%) with respect to the normal galaxies.

AGN have been classifed on the basis of their emission in the optical, Xray and radio band. In the optical/UV band, the classification is based on the shape of the emission lines; it is possible to distinguish between two main groups:

Broad-line emission galaxies (or Type-1 AGN, AGN1) show two separate emission line systems: broad lines corresponding to permitted transitions (e.g. Ly α , C IV, Mg II, Balmer hydrogen lines) in a gas with $v \gtrsim 10^4$ Km s⁻¹, and narrow lines corresponding to forbidden transitions (e.g. [Ne IV], [Ne V], [O II], [O III]) in an ionized gas with low density ($n_e = 10^3 - 10^6$ cm⁻³ and $v \simeq$ 10^2 Km s⁻¹. An example of a typical spectrum of a Type-1 AGN is shown in Figure 2.1.

Narrow-line emission galaxies (or Type-2 AGN, AGN2) are only characterized by narrow emission lines, from both permitted and forbidden transitions. In Type-2 AGN the continuum emission is weaker with respect to the continuum seen in Type-1 AGN, and is almost flat. Figure 2.2 shows an example of a typical spectrum of a Type-2 AGN.



FIGURE 2.2. Optical spectrum of a typical Seyfert 2 (adopted from Hawkins 2004)

In the X-rays the absorption effect is weaker than in the optical/UV band, but it is still able to induce variations in the spectrum. The obscuration in the X-ray band is usually parametrized in term of the *column density* N_H , which represents the number density per unit area of hydrogen-equivalent atoms integrated along the line of sight. The presence of this material induces a flattening in the low energy part of the X-ray spectrum; the cutoff energy depends on the N_H and increases for increasing N_H . AGN with $N_H < 10^{22}$ cm² are usually defined as *unobscured* (or *unabsorbed*) AGN, while AGN with $N_H > 10^{22}$ cm² are defined as *obscured* (or *absorbed*) AGN. The latter are further divided in two classes of absorption.

The observed absorbed flux F_{obs} can be written as:

$$F_{obs}(\lambda) = F_{int}(\lambda)e^{-\tau}, \qquad (2.1)$$

where F_{int} is the intrinsic unabsorbed flux and τ is the optical depht:

$$\tau = \int \sigma_T \cos \theta n(r) dr = N_H \sigma_T, \qquad (2.2)$$

where the integral is defined along the line of sight, n(r) is the number density, θ is the angle to the normal and $\sigma_T = 6.65 \times 10^{-25} \text{ cm}^{-2}$ is the Thomson crosssection. If $\tau > 1$, the source becomes optically-thick, and it is opaque to the optical/UV and X-ray photons. This happens when $N_H \ge 1/\sigma_T$ (~ 10²⁴ cm⁻²); sources with $N_H > 10^{24} \text{ cm}^{-2}$ are therefore defined as *Compton-thick* AGN, while absorbed sources with $N_H < 10^{24} \text{ cm}^{-2}$ are usually defined as *Compton-thick* AGN. At radio wavelength, AGN have been divided in two main groups, depending on the intensity of their radio emission. A fraction of $\sim 10\%$ of the AGN population is defined as *radio-loud*, while the remaining sources are *radioquiet*. However, the criterion used to distinguish between these two classes is not well defined.

2.2 Inner structure

The most bright AGN may emit *bolometric* luminosities (emitted across the whole electroelectromagnetic spectrum) as high as 10^{48} erg s⁻¹, in a volume that is significantly smaller than a cubic parsec. The fundamental question about AGN is then how this great amount of energy is generated.

It is widely accepted that the central engine of AGN consists in a supermassive black hole (SMBH) surrounded by an accretion disk, where the material in gravitational infall dissipates its kinetic energy. This accretion disk is then heated to high temperatures and it is thus responsible of most of the observed radiation.

It is possible to estimate the mass of the SMBH by assuming that the accreting material is a fully-ionized hydrogen gas, and that the central source is stable and isotropic. The radial component of the gravitational force acting on an electron-proton pair, with masses m_e and m_p respectively, is:

$$F_{grav} = -\frac{GM(m_p + m_e)}{r^2} \simeq -\frac{GMm_p}{r^2},$$
(2.3)

where M is the mass of the central source. For high energy production rates, the radiation pressure due to Thomson electron scattering become important on the accreting gas. The radial component of the outward force on a single electron due to radiation pressure is given by:

$$F_{rad} = \sigma_T \frac{L}{4\pi r^2 c},\tag{2.4}$$

where L is the luminosity of the source. To avoid disintegration of the source, the outward radiation force must be balanced by the inward gravitational force. Therefore, the luminosity of the source must not exceed a maximum allowed value, the *Eddington luminosity* (L_{Edd}) :

$$L_{Edd} = \frac{4\pi G c m_p M}{\sigma_T} \simeq 1.26 \times 10^{38} \frac{M}{M_{\odot}} \ erg \ s^{-1}.$$
 (2.5)

If we consider sources with bolometric luminosity $L_{bol} = 10^{46}$ - 10^{48} erg s⁻¹, a central mass of 10^8 - 10^{10} M_{\odot} is obtained from Equation 2.5. Another key question is how efficiently the accreted mass is converted into

radiated energy. The rate at which energy is emitted by the nucleus is

$$L = \epsilon \dot{M}c^2, \tag{2.6}$$

where ϵ is the radiative efficiency and $\dot{M} = dM/dt$ is the mass accretion rate. The potential energy of a mass m at a distance r from the central source of mass M is U = GMm/r, so the luminosity of the source can be written as:

$$L \simeq \frac{dU}{dt} = \frac{GM\dot{M}}{r}.$$
(2.7)

Combining Equations 2.6 and 2.7 we obtain:

$$\epsilon = \frac{GM}{c^2 r} = \frac{1}{2} \frac{R_S}{r},\tag{2.8}$$

where we have introduced the Schwarzschild radius $R_S = 2GM/c^2$. The bulk of the emission of the optical/UV emission from the accretion disk is believed to be produced at $r \simeq 5R_S$. Therefore, this simple calculation suggest that $\epsilon \simeq 0.1$. With this radiative efficiency, a relatively low accretion is requested to fuel even a fairly high luminosity source (e.g. $\dot{M} \simeq 2 M_{\odot} \text{yr}^{-1}$ for $L \simeq 10^{46}$ erg s⁻¹). However, the value of the radiative efficiency depends on how the accretion actually occurs, though $\epsilon \simeq 0.1$ is a fairly good approximation.

2.3 Continuum emission

The AGN Spectral energy distribution (SED) is quite complex, and spans a very wide range of wavelengths, from radio to γ -rays. At a first order approximation, it can be described with a power-law:

$$F_{\nu} \propto \nu^{-lpha},$$
 (2.9)



FIGURE 2.3. SED from radio to X-rays of a Seyfert galaxy, a radio-loud quasar and a radio-quiet quasar (adopted from Koratkar and Blaes (1999))

where the energy index α is usually found in the range $0 < \alpha < 1$. As an example, Figure 2.3 shows typical SED of a a Seyfert galaxy, a radioloud quasar and a radio-quiet quasar. The gap in the UV part of the spectrum, between 912 Å (the Lyman continuum edge) and ~ 100 Å is due to absorption by neutral hydrogen in our own Galaxy, which makes any detection impossible at these wavelenghts.

While a power-law representation is a reasonable description of the SED when looking over several decades of frequency, a deeper analysis reveals many features, suggesting that the continuum emission is produced by different processes in different regions of the spectrum.

A great amount of energy is emitted in a feature that dominates the spectrum at wavelengths shorter than 4000 Å and extends beyond 1000 Å, the so called *big blue bump*. In the X-ray region, AGN spectra usually show a sharp rise with decreasing photon energy, the *soft X-ray exces*, that may be the high energy end of this feature. The big blue bump is attributed to a thermal emission with $T\sim 10^5$ K.

As a first order approximation we can assume that the accretion disk radiates locally like a blackbody:

$$B_{\nu} = \frac{2h\nu^3}{c^2} \frac{1}{e^{h\nu/kT(r)} - 1},$$
(2.10)

where T(r) is the disk temperature at a distance r from the center. Under the assumption that the disk is geometrically thin (and optically thick), it is possible to obtain the total specific luminosity of the disk by integrating over the full range of radii:

$$L_{\nu} = \frac{4\pi^2 h \nu^3 \cos i}{c^2} \int_{R_{in}}^{R_{out}} \frac{r dr}{e^{h\nu/kT(r)} - 1},$$
(2.11)

where i is the inclination angle of the disk to the plane of the sky, and R_{in} and R_{out} are the inner and outer boundaries of the disk, respectively.

At low frequencies, $h\nu \ll kT(R_{out})$, the emission follows the Rayleigh-Jeans approximation (i.e. $B_{\nu} \propto \nu^2$), while in the high-frequency regime the Wien law holds (i.e. $B_{\nu} \propto \nu^3 e^{-h\nu/kT}$). The thermal spectrum at intermediate frequencies, where indeed most of the energy is emitted, can be also approximated in a simple fashion, by assuming $R_{out} \gg R_{in}$. This approximation holds when there is a wide range of temperatures in the disk; otherwise, the emitted spectrum should look fairly close to a single-temperature blackbody spectrum. If we further assume that $R_{in} \simeq R_S$ and $R_{out} \rightarrow \infty$ we obtain from Equation 2.11 that $L_{\nu} \propto \nu^{1/3}$. An important prediction of this simple model is that the UV radiation and the optical radiation are emitted mostly in different parts of the disk.

The infrared continuum has probably a thermal origin, as supported by several pieces of evidence. Most AGN show a local minimum in their SED around 1 μ m, which may represent the transition region between the hot thermal emission from the accretion disk and a cooler ($T \leq 2000K$) thermal emission. Hot dust grains in the nuclear regions have indeed a temperature around 2000 K; higher temperatures should induce sublimation of dust grains. This temperature limit allows to explain the constancy of the frequency where the infrared spectrum is weakest with a Wien cut-off of a 2000 K blackbody. Some observations show that the far infrared spectrum decreases rather sharply at higher wavelength, with a spectral index of $\alpha \lesssim -2.5$. A thermal spectrum can produce a cut-off this sharp because the emitting efficiency of dust grains has a strong dependence on the frequency ($Q_{\nu} \propto \nu^{\gamma}$, with $\gamma \sim 2$). Therefore, the emitted spectrum can have a very strong frequency dependence, $F_{\nu} \propto \nu^{2+\gamma}$.

The mid infrared part of the spectrum is also characterized by several emission bands from Polycyclic Aromatic Hydrocarbons (PAH). PAH are carbon-based molecules that are excited in the regions of star formation, and have characteristic infrared bands at 3.29, 6.2, 7.7, 8.7, 11.3 and 12.7 μ m; other weaker features are present at other wavelengths, in the range 3–15 μ m. Silicates also play an important role at mid infrared wavelengths: bands around 10 and 18 μ m are often observed in obscured AGN and high infrared luminosity galaxies.

The X-ray emission accounts for typically ~ 10% of the bolometric luminosity of AGN. With its rapid variability, on timescales of the order of a day, it provides a probe of the innermost regions of the source. Historically, the X-ray region of the SED has been divided in *soft* X-rays (~ 0.1–2 keV) and *hard* X-rays (~ 2–100 keV), due to the different technologies used in the observations. In X-ray astronomy, SEDs are usually fitted in photons per keV rather than in energy per unit frequency, $P_E \propto E^{-\Gamma} \propto \nu^{-\gamma}$ [photons s⁻¹ keV⁻¹]; in units of energy flux we have:

$$F_{\nu} \propto \nu^{-\Gamma+1} \propto \nu^{-\alpha}, \qquad (2.12)$$

where α is called *energy index* and $\Gamma = \alpha + 1$ is called *photon index*. Figure 2.4 shows the average total X-ray spectrum of a Type-1 AGN, as well as the various components that contribute to the spectrum. Soft X-ray region is usually well fitted with a power law with $\alpha \gtrsim 1$, while in the hard X-ray region a flatter slope ($\alpha \sim 0.7-0.9$) is required. At higher energies, fits to the X-ray spectrum of Seyfert galaxies suggest a high-energy cut-off around a few hundreds keV. At even higher energies, only blazar-type sources (i.e. those with a strong beamed component) have been observed.

The origin of the X-ray emission is ascribed to inverse-Compton scattering of low energy photons by more energetic electrons. The basic idea is that the optical/UV photons emitted from the accretion disk are scattered to higher energies by hot (probably relativistic) electrons in a corona surrounding the disk (this process is usually called *Comptonization*).

In addition to the basic power-law described above, AGN spectra show several indipendent features. As already discussed, in the soft X-ray region many AGN show a soft excess, usually explained as the Comptonized Wien tail of the big blue bump. At low energies ($h\nu \lesssim 2$ keV), absorption of heavy elements with



FIGURE 2.4. Average total X-ray spectrum (thick black line) of a Type-1 AGN. Thin lines show the main components of the spectrum (adopted from Risaliti and Elvis 2004).

column densities around ~ 10^{22} cm⁻² are also often observed; these are commonly referred to as *warm absorbers*. In the high energy region ($h\nu \gtrsim 10$ keV) AGN spectra rise above the power-law spectrum. This feature is attributed to Compton reflection of high energy photons on a lower energy electron gas, perhaps the disk itself.

The radio continuum has clearly a non-thermal origin, and it is associated to synchrotron emission. There are at least two pieces of evidence for a nonthermal emission. The spectral index is almost flat, but it becomes progressively steeper at shorter wavelengths. This behavior is characteristic of optically thick sources that undergo continued injection of higher energy electrons. Low energy cutoffs, attributed to synchrotron self-absorption, are detected in some sources, with a frequency dependence weaker than expected $(F_{nu} \propto \nu^{5/2})$. This dependence, as well as the flatness of the spectral index, are usually explained with the complexity of the source structure.

The specific intensity I_{ν} of a radio source at a given frequency can be determined by measuring the flux and angular size of the source. It is possible to associate to the source an equivalent temperature T_B (the *brightness temperature*), defined as the temperature that the source would have if it was indeed radiating like a blackbody. At radio wavelengths, the Rayleigh-Jeans approximation holds for any temperature, so for an optically thick thermal source the intensity is given by the Planck function B_{ν} for $h\nu \ll kT$:

$$I_{\nu} = \frac{F_{\nu}}{\pi \theta^2} = B_{\nu} = \frac{2kT_B}{\lambda^2},$$
(2.13)

where F_{ν} is the observed flux at a frequency $\nu = c/\lambda$ and θ is the angular size of the source. Measurements of F_{ν} and θ for several compact extragalactic radio sources constrain T_B in the range $10^{11}-10^{12}$ K, which clearly rules out a thermal origin for radio emission.

2.4 The Unified Model of AGN

The presence of both strong high ionization and low ionization narrow lines is common to both types of AGN, and with similar line ratios. This suggested that all AGN are powered by the same intrinsic engine and led to the formulation of the standard Unifed Model for AGN (Antonucci 1993; Urry and Padovani 1995). In this scenario, the observed differences between Type-1 and Type-2 AGN arise from orientation dependence, while the basic source structure remains the same. There is indeed abundant evidence that AGN have axisymmetric structure, and thus radiates anisotropically. The observed properties of a particular source thus depend on the location of the observer. The current paradigm is built around a central engine, that consists of an accretion disk surrounding a supermassive black hole $(M_{BH} \gtrsim 10^6 M_{\odot})$. Relativistic jets emerge from the central region along the disk axis, emitting Dopplerboosted radiation via synchrotron emission and inverse Compton scattering mechanisms. The broad lines observed in Type-1 AGN are thought to be produced in the Broad Line Region (BLR), a dense $(n_e \gtrsim 10^9 \text{cm}^2)$ gas region nearby the central source (within a few thousands gravitational radii), where the influence of the gravitational field of the BH is strong. On parsec scales, the entire system is enshrouded in a dusty torus that is opaque to most of the electromagnetic radiation. The torus plays a key role in the framework of the Unified Model, since it allows the direct observation of the central region (including the BLR) only along particular directions. Narrow lines are generated in distant (on torus scale), rarefied gas regions, where the gravitational influence from the BH is less intense, the Narrow Line Region (NLR).

Therefore, an observer looking at the AGN on the torus plane (i.e. edge-on)



FIGURE 2.5. The Unified Model of AGN. Green arrows show the lines of sight associated whith each class of object.

has the view of the innermost regions (that produce the optical/UV and soft X-ray continuum) and of the BLR obstructed by the intercepting material. Only narrow emission lines are directly visible in this case. An observer looking along the axis has instead a direct view of both the BLR and the NLR, as well as the accretion disk continuum emission (Figure 2.5).

One of the most convincing evidences in favor of this model is the detection of broad optical lines in the polarized spectra of Type-2 AGN. This suggests that the BLR is still present in Type-2 nuclei, but is actually hidden from our line of sight due to the obscuring material. However, the emitted light is scattered in our direction from material distributed on larger scales. Such reflected light is very weak compared to the light of the galaxy, but it has a high degree of polarization, and therefore can be detected in the polarized spectrum.

Although this simple model has allowed to explain much of the complex AGN phenomenology, there is evidence supporting that additional effects are requested to explain the differences between Type-1 and Type-2 AGN, like the discovery of Type-2 sources without broad optical lines in the polarized spectrum.

2.5 Number counts and luminosity function

In order to describe how the AGN population has changed during cosmic time, several statistical technique have been employed. The simplest observational tool that can be used to describe the evolution of a sample of objects are the number counts. By number counts one typically means the surface density in the sky of a given class of sources as a function of the limiting flux of the observations.

More informations can be drawn from the *luminosity function* (LF), defined as the number of sources per unit volume and luminosity with luminosity in the range between L and L + dL:

$$\Phi(L) = \frac{dN}{dVdL} \tag{2.14}$$

Let us assume that the local universe is Euclidean and filled with sources with LF $\Phi(L)$. Sources with luminosity L can be observed out to a distance $r = (L/4\pi S)^{1/2}$, being S the limiting flux of the observations. The number counts of sources over the solid angle Ω are then:

$$N(>S) = \int_{L_{min}}^{\infty} \frac{1}{3} \Omega r^3 \Phi(L) dL = \frac{1}{3} \frac{\Omega}{(4\pi)^{3/2}} S^{-3/2} \int_{L_{min}}^{\infty} L^{3/2} \Phi(L) dL \quad (2.15)$$

where $L_{min}(r)$ is the faintest luminosity that can be observed over a flux limit S out to a distance r_{max} . Therefore, the slope of the cumulative number counts of a (non-evolving) class of objects in an Euclidean universe is fixed to -3/2. In a more general case, the correct relativistic expression for number counts differs from Equation 2.15, due to cosmological effects. Radiation emitted at frequency ν' is observed at a redshifted frequency $\nu = \nu'/(1 + z)$, and therefore the observed flux density depends on the shape of the spectrum of the source. Moreover, curvature effects modify the volume element per unit redshift, making it smaller at increasing z.

The simplest general approach to describe the evolution of a LF is by defining two functions $f_d(z)$ and $f_l(z)$ that take into account the evolution of the number density and luminosity, respectively:

$$\Phi(L, z) = f_d(z)\Phi(L/f_l(z), z = 0).$$
(2.16)

In the *pure luminosity evolution* (PLE; Mathez 1976) scenario, the comoving number density of sources is constant (so $f_d = cost$), but luminosity varies with cosmic time. In the *pure density evolution* (PDE; Schmidt 1968) case the shape of the LF and the source luminosity are fixed ($f_l = cost$), while the comoving density of sources of any luminosity varies.

While the PDE models fails to describe the observed quasar number counts and overpredicts the cosmic X-ray Background (CXRB), the PLE model tends to overpredict the number of SMBH whith $M_{BH} > 10^{10} M_{\odot}$. Therefore, more complex models have been developed throughout the years.

The most accurate description of the overall evolution of the LF comes from deep X-ray surveys. While for optically selected quasar the PLE model still provide a good fit of the data, the *luminosity dependent density evolution* (LDDE) model is invoked to describe the evolution of the X-ray LF (Ueda et al. (2003), see also Hasinger et al. (2005) for soft X-ray selected AGN). As in the PDE model, the redshift evolution of the LF is described as

$$\frac{d\Phi(L_X, z)}{dlog(L_X)} = \frac{d\Phi(L_x, z=0)}{dlogL_X} e(L_X, z), \qquad (2.17)$$

where the local LF is usually represented with a power-law with two different indexes, for low and high luminosities:

$$\frac{d\Phi(L_X, z=0)}{dL_X} = \begin{cases} AL_{\star}^{\gamma_1 - \gamma_2} L_X^{-\gamma_1} & L_X \le L_{\star} \\ AL_X^{\gamma_2} & L_X > L_{\star} \end{cases}$$
(2.18)

and the evolution factor e(z) is defined as:

$$e(z) = \begin{cases} (1+z)^{p_1} & z \le z_c(L_X) \\ e(z_c)[(1+z)/(1+z_c(L_X))]^{p_2} & z > z_c. \end{cases}$$
(2.19)

The z_c parameter represents the redshift at which the evolution stops. The parameters p_1 and p_2 characterize the rate of the evolution and the rate of counterevolution for $z > z_c$ respectively.

The LDDE model is obtained by introducing a luminosity dependence of z_c , assumed to be a power-law (La Franca et al., 2005):

$$z_c(L_X) = \begin{cases} z_c^{\star} & L_X \ge L_a \\ z_c^{\star} (L_X/L_a)^{\alpha} & L_X < L_a. \end{cases}$$
(2.20)



FIGURE 2.6. The space density of AGN as a function of redshift in different luminosity bins. Solid lines show the best-fit values in LDDE model with evolving N_H depending on L_X and z. Adopted from La Franca et al. (2005).

It has been shown that (a) the peak of the AGN space density moves to smaller redshift with decreasing luminosity, and (b) the rate of evolution from the local Universe to the peak redshift is slower for less luminous AGN (*downsizing*; see Figure 2.6.)

It appears that SMBH generally grow in an anti-hierarchical fashion, i.e. while more massive SMBH $(10^{7.5} - 10^9 M_{\odot})$ in rare, luminous AGN could grow efficiently at z = 1 - 3, smaller SMBH in more common, less luminous AGN had to wait longer to grow (z < 1.5).

There is also strong evidence on the redshift and luminosity dependence of the fraction of obscured ($N_H > 10^{22}$ cm⁻²) AGN, indeed it has been shown that this fraction increases with decreasing luminosity (Ueda et al. 2003; La Franca et al. 2005; Treister and Urry 2005) and increasing redshift (La Franca et al. 2005; Treister and Urry 2006; Hasinger 2008).

Attempts to constrain models for galaxy formation and evolution from the optical and X-ray luminosity functions were made in the last decade by several authors (see e.g. Granato et al. 2001; Granato et al. 2004; Di Matteo et al. 2005; Menci et al. 2004: Menci et al. 2005). The predictions of these models are in good agreement with some of the observations, like the down-sizing trend; however, they overestimate by a factor of ~ 2 the space density

of low-luminosity Seyfert-like AGN at z = 1.5 - 2.5.

2.6 X-ray surveys and the X-ray background

AGN are powerful X-ray emitters. The discovery of the cosmic X-ray background (CXRB; Giacconi et al. 1962) opened up a privileged window for the study of the energetic phenomena associated with accretion onto black holes. The X-ray sky is almost dominated by the AGN population, due to the relative weakness of the other X-ray emitters (mostly X-ray binaries, but also magnetically active stars and cataclysmic variables), at least down to the faintest fluxes probed by current X-ray telescopes. The goal of reaching a complete census of evolving AGN has therefore been intertwined with that of fully resolving the CXRB into individual sources.

In the last decade, the launch of modern X-ray telescopes like *Chandra* (NASA) and *XMM-Newton* (ESA) has enabled strong observational progress. Sensitive imaging spectroscopy in the 0.5–10 keV band with up to 50–250 times the sensitivity of previous missions, as well as high quality positional accuracies (up to $\sim 0.3-1$ " for Chandra) were made available for X-ray astronomy studies. Deep extragalactic surveys have probed the X-ray sky down to extremely faint fluxes (as low as $\sim 10^{-17}$ erg s⁻¹ cm⁻² in the 0.5–2 keV band and $\sim 10^{-16}$ erg s⁻¹ cm⁻² in the 2–8 keV band), thus making available large source samples for statistical X-ray source population studies.

With these deeper and larger X-ray surveys that have been performed, a new generation of synthesis model for the CXRB has been developed (see Gilli et al. 2007; Treister et al. 2009). These new models have progressively reduced the uncertainties in the N_H absorption distribution, providing an almost complete census of the unobscured and moderately obscured AGN populations. These sources dominate the X-ray counts in the lower energy band, where almost all the CXRB radiation has been resolved into individual sources.

However, at the peak energy of the CXRB (around ~ 30 keV), only a small fraction ($\sim 5\%$) of the emission has been resolved into individual sources. CXRB synthesis models ascribe a substantial fraction of this unresolved emission to Compton-thick AGN. Gilli et al. (2007) model requires a population of Compton-thick AGN as large as that of Compton thin AGN to fit the residual background emission. Still, the redshift and luminosity distribution of



FIGURE 2.7. Observed spectrum of the extragalactic CXRB from several X-ray satellites data. The solid magenta line shows the prediction of the Gilli et al. (2007) model for AGN (unobscured + Compton-thin) and galaxy clusters; red and blue solid lines represent the contribution from unobscured and Compton-thin AGN respectively. Adopted from Gilli et al. (2007)

these sources is essentially unknown, due to their faintness even at hard Xray energies. The quest for the physical characterization of this missing AGN population represents one of the last current frontiers of the study of AGN evolution.

2.7 SMBH growth in galaxies

In the early 1990s, deep optical surveys of star-forming galaxies began to probe the cosmological evolution of the rate at which stars are formed within galaxies, thus providing robust constraints for models of galaxy formation and evolution (see Madau et al. (1996)). It was soon clear that the QSO (optical) luminosity density and the *Star Formation Rate* (SFR) density evolved in a similar fashion, being much higher in the past, with a broad peak around $z\sim 2$ (Boyle and Terlevich, 1998).

Direct measures of the SMBH masses can be obtained from stellar dynamics or spectral analysis of circumnuclear dust and gas. However, it has been possible to perform these measures only for a small (~50) number of SMBH, due to limitations induced by spatial resolution. With these measures available, it has been observed that the SMBH mass (M_{BH}) correlates tightly with some structural parameters of the host galaxy, like the host spheroid mass (Kormendy and Richstone 1995; Marconi and Hunt 2003), luminosity (Magorrian et al. 1998; Sani et al. 2011) and stellar velocity dispersion (Ferrarese and Merritt 2000; Gebhardt et al. 2000).

Direct or indirect (from scaling relations) knowledge of the SMBH masses allows to test the classical "Soltan argument" (Soltan (1982)), according to which the local mass budget of SMBH in galactic nuclei should be accounted by integrating the overall energy density released by AGN, assuming an appropriate radiative efficiency parameter. The total accreted mass can be computed as a function of redshift:

$$\rho_{BH} = \int_{z}^{z_s} \dot{\rho}_{BH}(z) \frac{dt}{dz} dz, \qquad (2.21)$$

where the black hole accretion rate density $\dot{\rho}_{BH}(z)$ is given by:

$$\dot{\rho}_{BH}(z) = \frac{1-\epsilon}{\epsilon c^2} \int \Phi(L_{bol}, z) dL_{bol}, \qquad (2.22)$$

were $\Phi(L_{bol}, z)$ and $L_{bol} = \epsilon \dot{M} c^2$ represent the bolometric LF and the bolometric luminosity respectively.

This computation has been performed either using the CXRB as a "bolometer" to derive the total energy density released by the accretion process (Fabian and Iwasawa, 1999), or by considering evolving AGN luminosity functions (Yu and Tremaine 2002; Marconi et al. 2004; Merloni and Heinz 2008). This approach represents a major success of the standard paradigm of accreting black holes as AGN power-sources, as the radiative efficiencies requested in order to explain the local relic population are within the range $\epsilon = 0.06-0.20$, predicted by standard relativistic accretion disc theory.

These evidences suggest that a tight link should exist between SMBH growth and host galaxy evolution. Many processes have been proposed which could forge this direct connection, including galaxy major mergers, star formation winds and AGN-driven outflows. From a physical point of view, these feedback mechanisms by which AGN can regulate the growth of their host galaxies can be distinguished into two main modes. The first mode is associated with the phases of fast SMBH growth in bright AGN. Star formation and SMBH growth are fueled by the same cool gas located in the inner regions of the galaxy. The fast, explosive energy injection from the central source can heat and disperse this gas, thus quickly terminating both star formation and SMBH growth. In this scenario (quasar mode feedback; see e.g. Menci et al. 2008), the triggering of such bright phases is thought to be related to galaxy mergers, in which cold gas is injected. The quasar mode efficiency must be proportional to the AGN fraction (i.e. the AGN luminosity function versus the galaxy luminosity function) and to how efficiently the AGN energy is released into the interstellar medium.

The second mode is related to the numerous, long-lived, low-luminosity AGN, that accrete hot gas coming from the halo's hot atmosphere continuously during cosmic time. This accretion happens at very low rates ($\sim 10^{-5} M_{\odot} \text{yr}^{-1}$) in an inefficient regime, where the cooling of the central source is dominated by advective processes rather than radiation. The contribution of this accretion rate is too small to contribute significantly to the bolometric output of the AGN. However, these sources can still drive powerful, collimated outflows in the form of relativistic jets, which can perturb mechanically the surrounding gas (*radio mode* feedback; Croton et al. (2006); Bower et al. (2006)). This feedback action has been observed in several systems; by combining radio (synchrotron jet emission) and *Chandra* X-ray (hot, bremsstrahlung emitting intracluster medium) images, it has been observed that these jets are capable of excavate cavities in the intracluster gas on sub-galactic scales (McNamara et al., 2000). The radio mode efficiency depends on the total accreted mass (and then to the SMBH mass function).

Both these feedback modes are then capable to release energy directly in the environment from which the SMBH grows: the cooling, star-forming gas in the central region of the galaxy. This energy transfer not only reduces the rate at which the gas cools and form stars, but it also reduce the rate of accretion onto the SMBH. Feedback from AGN has been included in recent semianalytical models of galaxy evolution to switch off star formation in most massive galaxies, thus reproducing both the observed shape of the galaxy LF and the red, early type, passive evolving nature of the local massive galaxies. Quasar mode feedback is usually invoked to quench star formation at higher redshift, while radio mode feedback is assumed to suppress the cooling flows in massive galaxies at late times, thus maintaining the gas in a hot, tenuous state.

Chapter 3

The Black Hole mass of AGN

The aim of this Chapter is to provide a brief review on the current status of AGN black hole mass estimations and to discuss their main results and limits. For a more detailed discussion on this topic see the reviews of Shen (2013); Peterson (2010); Vestergaard et al. (2011) and references therein.

3.1 The Mass of the Black Holes hosted in AGN

Today is widely accepted that the high enery phenomena involved in the AGN activity have their origins in the accretion of matter onto a supermassive black hole (SMBH) at the center of the hosting galaxy. If SMBH grows mostly via this accretion process, its mass growth rate is given by:

$$\dot{M}_{BH} = \lambda_{Edd} L_{Edd} \frac{(1-\epsilon)}{\epsilon c^2} \tag{3.1}$$

where ϵ is the radiative efficiency (i.e. the fraction of accreted mass energy converted into radiation), $\lambda_{Edd} = L_{bol}/L_{Edd}$ is the Eddington ratio, L_{bol} is the bolometric luminosity of the AGN and $L_{Edd} = \lambda_{Edd} M_{BH}$ is the Eddington luminosity, defined as:

$$L_{Edd} = 1.26 \ 10^{38} \left(\frac{M_{BH}}{M_{\odot}}\right) [ergs^{-1}]. \tag{3.2}$$

If λ_{Edd} and ϵ are non-evolving in time, thus the BH mass increases on a charecteristic time scale, named *Salpeter time*, t_e :

$$t_e \approx 4.5 \times 10^8 \frac{\epsilon}{\lambda_{Edd} (1-\epsilon)} yr \tag{3.3}$$

If quasars do not radiate beyond the Eddington limit $(L_{bol} = L_{Edd})$, thus $\lambda_{Edd}=1$, the observed luminosity provides a lower limit on their BH mass. The discovery of high luminosities quasars at redshift z>6 suggests that the more massive BH, with $M_{BH} > 10^9 M_{\odot}$, are the firsts to be formed, although they have had short time to evolve (*cosmic downsizing*).

In the past two decades it has come to the consensus that SMBHs are almost ubiquitous at the center of massive galaxies with significant bulge component, and also exist in some low-mass galaxies. More remarkably, tightly scaling relations between the mass of the nuclear BH and the galaxy bulge properties are found (e.g. bulge mass, luminosity and stellar dispersion-Ferrarese and Merritt 2000, Gebhardt et al. 2000, Marconi and Hunt 2003, Sani et al. 2011), suggesting that the evolution of galaxies and the growth of the super massive BHs (SMBH) are tied together (the AGN/galaxy co-evolution scenario).

In the framework of this scenario the energy released from the accreting BH self-regulates its own growth and impacts on the formation and evolution of the bulge through feedback processes (Silk and Rees 1998; Di Matteo et al. 2005). The Soltan argument (see Section 2.7) represents an elegant way to tie the local relic of SMBH population to the past active population, thus, if the SMBH grows mainly through a luminous (or obscured) quasar phase, the accreted luminosity density of quasars to z=0 should be equal to the local relic BH mass density (See Equations 2.21 and 2.22, Section 2.7), a reasonably good match between this two quantities can be achieved with an average radiative efficiency of $\epsilon \sim 0.1$ (e.g. Yu and Tremaine 2002; Shankar et al. 2004; Marconi et al. 2004). The Soltan argument and its variants have been used in recent years to model the growth of SMBH.

As one of the few fundamental quantities describing a BH, the mass of AGN is of paramount importance to essentially all AGN-related science, such as the evolution and phenomenology of AGNs, the accretion physics itself and also the relations and interplays between SMBHs and their host galaxies through feedback processes. Thus it is fundamental to be aware of the current methodologies about the AGN BH mass estimations, their results but also theis limits and biases.
3.2 Methods for the BH mass estimation

3.2.1 Virial mass estimators: from reverberation mapping to single-epoch estimates

Reverberation mapping. As previously introduced in Section 2.4, the BLR is the AGN region where the broad emission lines are produced, powered by the UV continuum from the nucleous through photoionization processes. The emission line fluxes vary strongly in response to changes in the continuum caused by the ionizing source. The emission line variation shows with a time delay τ . Since the lag in the line response is proportional to the light travel time from the ionizing source to the BLR, it is possible to estimate the BLR size (R_{BLR}) by measuring this delay:

$$R_{BLR} = c \cdot \tau. \tag{3.4}$$

Moreover, by mapping the response function of the broad emission line to continuum variations it is possible in principle to reconstruct both the structure and the kinematics of the BLR.

This technique is known as *reverberation mapping* (RM) and has become a practical and powerful tool to study BLRs (see reviews by Peterson 1993; Netzer and Peterson 1997; Horne et al. 2004), whose spatial extent (sub-pc) is too small to be resolved by current instrumentation.

Under the assumption that the motion of the emitting clouds is dominated by the gravitational field of the BH and that the BLR is virialized, the mass of the BH can be determinated by (e.g. Wandel et al. 1999):

$$M_{RM} = \frac{V_{vir}^2 R_{BLR}}{G} = f \frac{W^2 R_{BLR}}{G}$$
(3.5)

where V_{vir} is the virial velocity and W is the width of the broad emission lines. The latter can be used as an indicator of the virial velocity if it is assumed that the width of the lines of interest are Doppler broadened by the virial motion of the emitting gas. The quantity $W^2 R_{BLR}/G$ is also called *virial product*.

The broad lines width can be measured using the FWHM or the σ_{line} , both quantities are taken from rms spectra of the monitoring period, in order to have only the contribution of the variable part of the line to the width calculation.

The relation between the virial velocity and the line of sight (LOS) velocity inferred from W is determined by the structure and geometry of the BLR, which is not know. Thus, in virial methods is introduced a geometric factor f. This represent a great semplification since the line profile is affected by both the geometrical structure and the LOS, thus the line width W cannot fully describe the underlying kinematic. Similarly it is an approximation to describe the BLR with a single radius R since recent studies have shown evidences of a BLR stratification.

The value of f is empirically determined by requiring the derived RM masses to be consistent with those predicted using the BH mass - bulge stellar velocity dispertion scaling relation of local inactive galaxies (e.g. Onken et al. 2004, $f \sim 1.4$ (5.5) for FWHM (σ_{line})). The determination of the f value remains one of the major uncertainties in RM mass estimations and show a typical scatter of $\sim 0.4-0.5 \ dex$.

Luminosity-Radius relation. In the framework of reverberation mapping campaigns, the most remarkable finding is a tight correlation between the measured BLR size and the adjacent optical continuum luminosity (L_{opt}) at λ 5100 Å, $R_{BLR} \propto L_{opt}^{\alpha}$ (see Kaspi et al. 2000; Bentz et al. 2009). To first order L_{opt} is proportional to the luminosity of the ionizing continuum (L_{ion}) that is described by the ionization parameter in a photoionized medium (U):

$$U = \frac{Q(H)}{4\pi r^2 c n_e},\tag{3.6}$$

where Q(H) is the number of ionizing photons per second coming from the central source, c is the speed of light and n_e is the electron density. If both U and n_e are constant in the BLR, or if the BLR size is set by dust sublimation (Netzer and Laor, 1993), thus a slope of $\alpha=0.5$ in the R-L relation is expected. The latest version of the R-L relation based on H β RM measurments is (Bentz et al., 2009):

$$\log \frac{R}{light \, days} = -2.13 + 0.519 \log \frac{\lambda L_{\lambda}(5100 \text{\AA})}{ergs^{-1}}.$$
 (3.7)

Single–epoch virial BH mass estimators. Starting from the R-L relation it is possible to derive the BLR size through a single measure of the optical continuum luminosity and, combining this information with the width of a broad line, to build a relation for the BH mass estimate (M_{SE}) :

$$\log\left(\frac{M_{SE}}{M_{\odot}}\right) = a + b\log\left(\frac{L}{10^{44} ergs^{-1}}\right) + c\log\left(\frac{W}{kms^{-1}}\right).$$
(3.8)

The latter has to be calibrated on the BH masses inferred from RM tecniques in order to derive the values for a, b coefficients, while c = 2 as expected for virial motion. Based on the general similarity of AGN SEDs, different luminosities have been used as an alternative to the L_{opt} in different versions of these SE virial estimators: X-ray and rest frame UV continuum luminosities, as well as line luminosities itself, (Vestergaard 2002; Greene and Ho 2005a; Vestergaard and Peterson 2006; Greene et al. 2010; Shen and Liu 2012). The uncertainty of the various single-epoch virial relations is estimated to be on the order of ~0.5 dex. The virial RM and SE methods are currently considered the best way to estimate AGN BH masses.

3.2.2 Non virial methods

There are several other methods to estimate the BH masses of AGNs, although they are much less popular than the RM and SE. Nevertheless there are certain advantages in further developing these alternative methods in order to provide complementary mass estimates and consistency checks. In the following it will be briefly discussed some of these non virial estimators.

Photoionization method. Adopting the Woltjer's postulation that the BLR gas is in virial equilibrium in the gravitational potential of the central BH (Woltjer, 1959), an alternative way to derive the BLR size was first developed by Dibai (1977). The author makes use of the Equation 3.5 to estimates the BH mass, where the R_{BLR} is measured by using the photoionization argument:

$$L(H\beta) = \frac{4\pi}{3} R^3 j(n_e T_e) \epsilon_V, \qquad (3.9)$$

where $L(H\beta)$ is the H β luminosity, $j(n_eT_e)$ is the volume emissivity in the H β line from photoionized gas and ϵ_V is the volume filling factor of BLR clouds. Thus, this method can be considered as a single-epoch estimator with an effective $R - L_{H\beta}$ relation with $\alpha = 1/3$. The BH masses derived using this method have an intrisic scatter of ~0.3 dex with respect the RM estimates.

Accretion disk model fitting or SED fitting. Another way to infer the mass of the BH is by fitting the SED of quasars. The development of accretion disk theory over the last four decades (for a recent review, see Abramowicz and Fragile 2013) has enabled predictions of continuum luminosity, thus, by fitting the observed AGN continuum SED it is possible to constrain the model parameters (such as BH mass, accretion rate, BH spin, inclination) with adequate accretion disk models. Many studies have used this SED fitting method to derive AGN's BH masses (e.g. Calderone et al. 2012) assuming a standard thin accretion disk model (Shakura and Sunyaev, 1973), that successfully reproduce the observed "Big Blue Bump", but do not have the capability to explain the full AGN SED. The resulting BH mass constrain can be sensitive to deviations from standard accretion disk models. Moreover, due to the parameter degeneracies and model assumptions/simplifications in the SED fitting procedures, this method cannot provide an accuracy of better than a factor of ~ 5 in BH mass estimates.

Direct dynamical BH masses. This is an observationally challenging method, since usually the AGN continuum diluites the stellar absorption features. Nevertheless there have been several attempts to get direct dynamical measurements of BH masses in Type 1 AGNs, using spatially resolved stellar kinematics (Onken et al., 2007) or gas kinematic (Hicks and Malkan, 2008) down to the sphere of influence of the black hole, $R_{SI} = GM_{BH}/\sigma^2$. Untill now, the number of AGNs with reliable dynamical BH mass measurements is still small.

Scaling relations. The well known correlations between BH mass and the bulge properties of the hosting galaxy are used to infer the BH mass in AGN. These scaling relations are calibrated with know BH mass derived usually by direct methods, such as RM campaigns, and they are usually applied also to non-broad line AGN (type 2). Nevertherless caution should be paid in appling this method, expecially on obscured AGNs, since recent studies have demonstrated that these scaling relations are unlikely to hold also for all AGN2 (see Graham 2008 and Kormendy et al. 2011).

3.3 Caveats, uncertainties, and biases of virial BH masses

3.3.1 The virial assumption

There are evidence supporting the virial assumption in RM in at least several AGNs. Here RM lags have been successfully measured for multiple lines with different ionization potentials and line widths (such as H β , C IV, He II) which, in the framework of a stratified BLR model, are supposed to arise at different distances from the BH. The measured lags and line widths fall close to the expected virial relation $W \propto R^{-0.5}$, although such a velocity radius relation does not necessarily rule out other BLR models where the dynamics is not dominated by the gravity of the central BH.

A possible way to test the virial assumption can be performed by monitoring if the variation of the line width in response to the continuum luminosity Lcan be described by the following Equation:

$$\Delta \log W = -0.25 \Delta \log L. \tag{3.10}$$

Indeed, if the source luminosity increases, the BLR is expected to expand due to the growth of radiation pressure. As a conseguence, the medium responsible of the production of the emission line gets away from the ionizing source thus producing a decrease of the corresponding line width.

Tests like this are very usefull to verify reliability of SE techniques. In effect, if the line width does not varies accordingly to luminosity changes, the infered SE BH mass values will be different for the same object, introducing a luminosity-dependent bias in the mass estimates. Fig. 3.1 (Shen, 2013) shows an example of this test, which is performed on a sample of AGN1 from the *Sloan Digital Sky Survey* (SDSS). The majority of this objects do not span a large dynamic range in luminosity and they cluster near the center. Only for the low luminosity H β sample the median relation is consistent with the virial relation (the solid lines in Figure 3.1). For the other samples, based on Mg II and C IV, the line width does not seem to respond to luminosity changes as expected from the virial relation. This difference could be a luminosity effect, but more detailed analyses are needed (Shen, 2013).



FIGURE 3.1. A test of the virial assumption using two-epoch spectroscopy from SDSS for H β (upper), Mg II (middle) and C IV (bottom). Plotted here are the changes in line width as a function of changes in continuum luminosity. The left column is for the FWHM, while the right column is for the σ_{line} . The red triangles are the median values in each $\Delta \log L$ bin (Shen, 2013).

As seen in Section 3.2.1 to relate the observed broad line width to the underlying virial velocity it is necessary to make some assumptions on the geometry and kinematics of the BLR, introducing in Equation 3.5 the geometric factor f. In principle the RM tecniques can provide such information, and determine the value of f. Unfortunately the current RM data are still not good enough for such purposes. Early studies made assumptions about the geometry and structure of the BLR in deriving RM masses (e.g. Kaspi et al. 2000) or SE virial masses. Actually the average value of f is mostly determined empirically by requiring that the RM masses are consistent with those predicted from the $M_{BH} - \sigma_{\star}$ relation of local inactive galaxies ($f \sim 1.4$ if FWHM is used, Onken et al. 2004; $f \sim 5.2$ using σ_{line} , Woo et al. 2010). The use of the scaling relation involve other problems, indeed there is growing evidences that different galaxies follow different scaling relations, thus the results can change depending on the correlation used. Moreover, the use of the average value of the geometric factor $\langle f \rangle$ causes the overstimation or underestimation of the BH masses of the single objects, due to orientation effects.

3.3.2 Limitations on virial estimators

In the rest-frame UV to near infrared AGN continuum there are several emission lines and, despite their different ionization potentials and probably different BLR structures, many of them have been used in SE mass estimates. The most used are the Balmer lines, expecially H α and H β , but also Lyman and Paschen lines are used. Some other lines, such as Mg II and the high ionized C IV, are also involved in these methods but, several tests in which the different line widths are compared, have shown that SE mass estimators based on Hydrogen lines are the most reliable ones (see Shen 2013 for a more detailed decription).

Another element to be taken into account is the adopted luminosity in the L-R relation. As introduced in Section 3.2.1 several SE estimator using continuum luminosities from different bands (i.e. UV, IR or X-ray) have been calibrated. Indeed the luminosity that enters the R-L relations and the SE estimators refers to the AGN continuum, thus the contamination from host starlight in the optical band can be significant, in particular for low luminosity sources. This motivated the alternative uses of Balmer line luminosities, usually preferred for radio-laud AGN where the continuum may be severely contaminated by the nonthermal emission from the jet (Bentz et al., 2009). For UV luminosities $(L_{3000}, L_{1350} \text{ or } L_{1450})$ the host contamination is usually negligible, but it could be serious problems from dust reddening which can significantly attenuate AGN UV luminosity.

Regardless of the choice of the specific SE estimator, a concern is that the AGN variability, which spans a wide range of time scales, may affected the SE BH masses. However, as several studies have shown by using multi-epoch spectra of AGN samples, the changes in luminosity do not introduce significant scatter $(>0.1 \ dex)$ to the SE mass estimates (Denney et al. 2009; Park et al. 2012).

Last but not least, the current sample with RM BH mass estimates is not representative of the general AGN population. In effect this estimator can be used only for local sources (z<0.3) and it poorly samples the high-luminosity regime of AGN. These limitations affects reliability of extrapolations of locally calibrated SE relations to high z and high luminosity quasars. Moreover the total number of RM AGNs is also small (~50), thus are not enough to probe the diversity in BLR structure and other general quasar properties. The current sample size and inhomogeneity of RM AGNs represents another obstacle in the development of accurate BH mass estimators based on virial methods.

3.3.3 Practical concerns

Usually the continuum and line properties are measured either directly from the spectrum, or derived from χ^2 fits to the spectrum, in which some functional forms for the continuum and for the lines are applied. It is essential to measure these quantities in a properly way, especially when using SE calibrations, because different methods sometimes can yield to systematically different results, in particular for the line width measurements. Indeed single-component and multi-component line fits could differ significantly in some cases.

A detailed description of spectral fitting procedures can be found in some papers (e.g. Greene and Ho 2005b; Shen and Liu 2012). Basically the spectrum is first fit with a power-law in order to decribe the continuum, and later an Iron emission template is added. The broad line region is then fit with multiple Gaussians. Moreover there are some additional precautions that have to be taken into account:

- Narrrow line subtraction: The NLR dynamics are not dominated by the gravitational influence of the BH, thus in the velocity estimation of the BLR gas the narrow line component has to be removed before measuring the broad line width from the spectrum.
- **Remedy for absorption**: Sometimes there are absorption features superposed on the spectrum and not accounting for these absorption features will bias the continuum and line measurements.
- Effects of low S/N: The quality of the continuum luminosity and line width measurements decreases as the quality of the spectrum degrades.

3.4 Application to statistical samples

Despite the many caveats of SE mass estimators discussed above, they have been extensively used in recent years to measure BH mass function (SMBHMF), the Eddington ratio function (BHERF), the luminosity function (LF) and the scaling relations between BH and the hosting galaxy bulge properties. It is important to recognize, however, that the uncertainty in these mass estimates has influences on the interpretation of these measurements.

3.4.1 Demographics in the mass-luminosity plane

The AGN distribution in the two dimensional BH mass-luminosity $(M_{BH} - L)$ plane involve important information on the accretion process of the active SMBHs. In Figure 3.4.1 the observed M - L plane (i.e. the one obtained from SE BH mass estimates) from an SDSS AGN sample is compared with the simulated one at z = 0.6. In the left panel of Figure 3.4.1 is shown the observed distribution for a sample of quasar whose masses has been derived using virial methods in the redshift range 0.7 < z < 7. In these cases several emission lines have been used, such as H β , Mg II and C IV. The observed distribution suffers from the flux limit effect, indeed low Eddington ratio objects have a lower probability to be selected into the sample.

The best way to overcome this issue is to use a modeling approach in which an underlying distribution of simulated masses and luminosities is specified and mapped to the observed mass-luminosity plane by imposing the flux limit of the survey (see Kelly et al. 2009 and Kelly et al. 2010). The comparisons between model and observed distributions constrain the model parameters.

Shen and Kelly 2012 used forward modeling with Bayesian inference to model the observed distribution in the mass luminosity plane of SDSS quasars, taking into account a possible luminosity dependent bias to be constrained by the data. In Figure 3.4.1, right panel is shown the comparison between the simulated M - L distribution (red contours) and the mesured one based on $H\beta$ SE virial masses (black contours). The distribution based on SE virial BH masses is flatter than the one based on true masses due to the scatter and to the luminosity dependent bias of these SE masses. Moreover the flux limited survey selects only the most luminous objects into the SDSS sample, missing the bulk of low Eddington ratio objects.



FIGURE 3.2. Left: M - L plane for a sample of quasars with virial BH mass estimates. The green dots refer to SE BH mass estimates using H β (z < 0.7), the cyan dots are for Mg II line (0.7 < z < 1.9) and red dots for C IV (z > 1.9). Different symbols refer to different quasar samples. Solid line represent the Eddington limit, while the dashed lines shows the places of sub-Eddington regions. Right: Simulated M - L plane of an AGN population at z = 0.6, the red contours are the "true" distribution of quasars and is determined by the model BHMF and Eddington ratio distribution in Shen and Kelly (2012). The black contours are the measured distribution based on H β SE virial masses. The flux limit of the SDSS sample is shown with the solin black line. For more detail about the two planes see Shen (2013) review.

The M - L plane can be also used to measure the abundance of AGN and to study their redshift evolution. This is a much more powerful way to study the cosmic evolution of quasars than traditional 1D distribution functions such as the luminosity function (LF) and the quasar BHMF, since the latters are its monodimensional projections. Figure 3.4.1, taken from Shen (2013), shows the simulated quasar M - L plane at z = 0.6 constrained using SDSS sources. The objects abundance is shown with the colour-code contours and the traditional LF and BHMF are represented in the rigth panel. The 1D distribution functions lose information by collapsing on one dimension, and a better way to study the demography of quasars is to measure their abundance in 2D, since the mass and luminosity of a quasar are physically connected by the Eddington ratio.



FIGURE 3.3. Left: Quasar simulated M - L distribution at z = 0.6 with the source density shown with the colour code contours. Right: LF (up) and BHMF (bottom). The two projections shows the "true" population of broad line AGN (magenta) and the observed, flux limited one (green) (Shen, 2013).

Chapter 4

The project and the observations

4.1 The AGN2 SWIFT/BAT sample

4.1.1 The idea

In recent works, Landt et al. (2008, 2011, 2013) have performed NIR observations of AGN1 whose BH masses were measured with reverberation mapping techniques, and they have demonstrated that the virial method can be efficently used also with the Pa α and Pa β lines. These authors developed a NIR virial relationship to estimate the AGN BH masses based on the width of the Paschen hydrogen broad emission lines and the total 1 μ m continuum luminosity. However, the latter has to be derived by a SED fitting method and can suffer from galaxy contamination, especially for intrinsic low-luminosity AGNs, such as the obscured ones.

Since several studies have shown that most AGN2 exhibit faint components of broad lines if observed with high S/N in the near infrared, where the dust absorption is less severe than in the optical (Veilleux et al. 1997; Riffel et al. 2006; Cai et al. 2010), we decided to calibrate a new NIR virial relation able to work also with obscured AGN. Thus, in order to overcome the galaxy contamination and the dust obscuration problems, we choose to use the hard X-ray luminosity in the 14-195 keV as a measure of the BLR radius and the FWHM of NIR hydrogen emission lines for the gas velocity estimation. Such a NIR virial relation could then be used to derive, for the very first time, a direct measurment of the AGN2 BH masses.

4.1.2 The sample

The *Swift* Gamma-ray burst observatory was launched in November 2004, and has been continually observing the hard X-ray sky in the 14-195 keV band with

the Burst Alert Telescope (BAT), a large coded-mask telescope optimized to detect transient GRBs. Its characteristics, such as the wild field of view (FOV), the broad sky coverage and the improved sensitivity with respect to the previous surveys, make the *Swift*/BAT 70 month one of the most uniform and complete hard X-ray survey. Since its beginning the *Swift*/BAT 70 month has detected 1171 hard X-ray sources in the 14-195 keV band down to a significance level of 4.8 σ and among these ~600 are Seyfert galaxies. In Figure 4.1 is shown an all sky map of the *Swift* sources distribution (Baumgartner et al., 2013).



FIGURE 4.1. All-sky map showing classification of the BAT 70 month survey sources. The flux of the source is proportional to the size of the circle. The source type is encoded by the color of the circle (Baumgartner et al., 2013).

Among the 1171 sources in the *Swift*/BAT 70 month catalogh, the 80% have solid counterpart associations that have been verified with X-ray observations, although 100% of the BAT sources have archival X-ray data. More than the 60% of the associations are with extragalactic objets. The median 5σ sensitivity achieved in the 70 month survey is 0.43 mCrab, that is equivalent to ~10¹¹ erg s⁻¹ cm⁻² in the 14-195 keV band. These characteristics make it the deepest uniform hard X-ray survey ever conducted (Baumgartner et al., 2013), and with the detection of over 600 AGN in the hard X-ray band, the Swift-BAT 70 month catalog contains a valuable reference set of active galaxies in the local universe. In order to have a complete sample of obscured and intermediate AGN (AGN2, AGN1.9 and AGN1.8) with hard X-ray luminosity determination, we randomly selected 41 sources from the ~600 Seyfert galaxies indentified in the *Swift*/BAT 70 month hard X-ray survey. We observed all these sources with NIR spectrographs both in the south and in the north emispheres. In the southern emisphere, we obtained observing time at the VLT with the near infrared spectrograph ISAAC and with the multiwavelenght, medium resolution spectrograph Xshooter. Our observations in the nothern emisphere were conducted at the LBT using the LUCI facility. In Table 4.1 we report the principal characteristics of the selected sources. In Figure 4.2 we show the hard X-ray luminosity distribution of the *Swift*/BAT AGN1 (in black), *Swift*/BAT AGN2 (in red) together with our subsample of 41 AGN2.



FIGURE 4.2. Hard X-ray luminosity distribution for *Swift*/BAT AGNs: the black histogram shows the AGN1 distribution, the red one is referred to AGN2, while in blue is our subsample of AGN2 randomly selected from *Swift*/BAT 70 Month.

In the following sections we will describe the three spectrographs used for the acquisition of the NIR data and the observational setup.

)bject name	$lpha$ $[\mathbf{h}\mathbf{h}\cdot\mathbf{m}\mathbf{m}\cdot\mathbf{se}\ \mathbf{e}]$	δ [~]	z	$\log L_{X}$	$\log N_{ m H}$	cl	obs. date	instrument
1)	(2)	(3)	(4)	(5)	(6)	(1)	(8)	(6)
MSXJ05+32	06:41:18.0	+32:49:32	0.0470	44.26	I	2	20/10/2012	LUCI
MSXJ09+45	09:11:30.0	+45:28:06	0.0268	43.42	23.42 (T08)	2	20/10/2012	LUCI
MSXJ11+19	11:27:16.3	+19:09:20	0.1059	44.65		1.8	06/12/2012	LUCI
C403	19:52:15.8	+02:30:24	0.059	44.46	23.60 (T08)	2	25/10/2012	LUCI
[rk 417	10:49:30.9	+22:57:52	0.0327	43.90	$24.08\substack{+0.02\-0.02}$	2	05/12/2012	LUCI
GC3079	10:01:57.8	+55:40:47	0.00372	42.00	ı	2	23/10/2012	LUCI
GC4138	12:09:29.8	+43:41:07	0.0029	41.76	$23.12\substack{+0.02\\-0.02}$	1.9	06/12/2012	LUCI
GC4388	12:25:46.7	+12:39:44	0.0084	43.64	$23.81\substack{+0.02\\-0.02}$	2	19/02/2013	LUCI
GC4395	12:25:48.8	+33:32:49	0.0013	40.79	$23.01\substack{+0.02\-0.02}$	1.9^{a}	05/12/2012	LUCI
GC4686	12:46:39.9	+54:32:03	0.0167	43.24	$23.89\substack{+0.03\\-0.03}$	Glx/XBONG	07/12/2012	LUCI
MASX J05-23	05:05:46.5	-23:51:22	0.0350	44.24		2	03/11/2011	ISAAC
C105	$04{:}07{:}16.4$	+03:42:26	0.089	44.74	23.43 (T08)	2	07/10/2011	ISAAC
GCG 420-15	04:53:25.7	+04:03:42	0.0294	43.75	ı	2	19/12/2011	ISAAC
SO-005-G004	06:05:44.0	-86:37:57	0.0062	42.46	23.88 (T08)	2	04/11/2011	ISAAC
SO-157-G023	04:22:24.2	-56:13:33	0.0435	43.97		2	09/10/2011	ISAAC
SO-297-018	01:38:39.3	-40:00:40	0.0252	44.0	23.84 (T08)	2	13/10/2011	ISAAC
SO -374-G44	10:13:20.4	-35:59:07	0.0284	43.57	ı	2	22/01/2012	ISAAC
SO 416-G002	02:35:14.1	-29:36:26	0.0592	44.29	<19.60 (T08)	1.9	08/10/2011	ISAAC

^aSy1 from literature

Object name	σ	δ	Z	$\log L_{\rm X}$	$\log N_{ m H}$	cl	obs. date	instrument
	$[\mathbf{h}\mathbf{h}:\mathbf{m}\mathbf{m}:\mathbf{ss.s}]$	[,,;;•]		[erg/s]	$[\mathrm{cm^{-2}}]$			
(1)	(2)	(3)	(4)	(5)	(9)	(1)	(8)	(6)
ESO-417-G006	02:56:21.6	-32:11:26	0.0163	43.26	ı	2	11/10/2011	ISAAC
Fairall 272	08:23:01.1	-04:56:05	0.0218	43.70	ı	2	22/12/2011	ISAAC
LEDA 093974	10:40:22.3	-46:25:26	0.0239	43.35	22.96 (T08)	2	08/01/2012	ISAAC
MCG-01-24-12	09:20:46.2	-08:03:22	0.0196	43.55	22.80 (T08)	2	07/01/2012	ISAAC
MCG-05-23-16	09:47:40.3	-30:57:10	0.0085	43.51	22.47 (T08)	2	01/01/2012	ISAAC
Mrk 1210	08:04:06.2	+05:06:31	0.0135	43.35	I	2	19/12/2011	ISAAC
NGC 612	01:33:59.3	-36:29:41	0.0298	44.05	23.70 (T08)	2	13/10/2011	ISAAC
NGC 788	02:01:06.4	-06:48:57	0.00136	43.52	23.48 (T08)	2	07/10/2011	ISAAC
NGC 1052	02:41:04.8	-08:15:21	0.005	42.22	I	2	04/11/2011	ISAAC
NGC 1142	02:55:12.3	-00:11:02	0.0289	44.23	23.38 (T08)	2	09/10/2011	ISAAC
NGC1365	03:33:38.0	-36:08:31	0.0055	42.63	23.60 (T08)	1.8	13/10/2011	ISAAC
NGC 2992	09:45:42.1	-14:19:35	0.0077	42.55	22.00 (T08)	2	07/10/2012	ISAAC
NGC 3081	09.59.29.1	-22:49:23	0.0080	43.07	23.52 (T08)	2	06/01/2012	ISAAC
NGC 3281	10:31:52.1	-34:51:13	0.0107	43.34	24.30 (T08)	2	14/11/2011	ISAAC
PKS-0326-288	03:28:36.8	-28:41:57	0.108	44.60	- (T08)	1.9	07/10/2011	ISAAC
ESO-263-G13	10:09:48.2	-42:48:40	0.0333	43.96	I	2	11/02/2013	XSHOOTER
LEDA 093974	10:40:22.3	-46:25:26	0.0239	43.35	22.96 (T08)	2	11/02/2013	XSHOOTER
MCG-05-23-16	09:47:40.3	-30:57:10	0.0085	43.51	22.47 (T08)	2	11/02/2013	XSHOOTER
2MASXJ18+09			0.0190	42.40	ı	2	05/06/2014	XSHOOTER/P93
ESO-234-G50	20:35:57.8	-50:11:32	0.0088	42.29	ı	2	25/06/2014	XSHOOTER/P93
							Cont	inued on next page

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(1) (2) (3) (4) ((1) (2) (3) (4) (NGC 373 $(1:3)$ (3) (4) ((1) NGC 4941 $13:04:13.1$ $-05:33:06$ 0.0097 4 NGC 4945 $13:05:27.3$ $-49:28:04$ 0.0019 4 NGC 5643 $14:32:40.8$ $-44:10:29$ 0.0040 4 NGC 50314 $22:35:46.3$ $-59:13:01$ 0.0050 4 NGC $714:022$ $-26:03:01$ 0.0040 4 NGC $714:10:29$ 0.0040 4 NGC $714:10:29$ 0.0040 4 NGC $714:10:29$ 0.0040 4 NGC $714:10:29$ 0.0040 4 NGC $712:57:54$ 0.0066 4 NGC $712:57:54$ 0.0066 4 NGC $715:57:54$ 0.0066 4 NGC $715:57:54$ 0.0066 4	erg/s	$\log N_{\rm H}$	cl	obs. date	instrument
NGC 3783 11:39:01.7 $-37:44:18$ 0.0097 4 NGC 4941 13:04:13.1 $-05:33:06$ 0.0037 4 NGC 4945 13:05:27.3 $-49:28:04$ 0.0019 4 NGC 5643 14:32:40.8 $-44:10:29$ 0.0040 4 NGC 6221 ^b 16:52:46.3 $-59:13:01$ 0.0050 4 NGC 7314 22:35:46.2 $-26:03:01$ 0.0048 4 NGC 7314 22:35:46.2 $-26:03:01$ 0.0066 4 NGC 7314 22:35:46.2 $-26:03:01$ 0.0066 4 NGC 7314 22:35:46.2 $-26:03:01$ 0.0066 4 NGC 7465° 23:02:00.9 $+15:57:54$ 0.0066 7 NGC 7465° 23:02:00.9 $+15:57:57$ 0 NGC 7465° 7 NGC 7466° 7 NGC 7465° 7 NGC 7466° 7 NGC 7466° 7 NGC 7466° 7 NGC 7766° 7 NGC 7766° 7 NGC 7 NGC 7766° 7 NGC 7 NGC 7 NGC 7	(4) (5)	[cm ⁻] (6)	(2)	(8)	(6)
NGC 4941 13:04:13.1 -05:33:06 0.0037 4 NGC 4945 13:05:27.3 -49:28:04 0.0019 4 NGC 5643 14:32:40.8 -44:10:29 0.0040 4 NGC 6221 ^b 16:52:46.3 -59:13:01 0.0050 4 NGC 7314 22:35:46.2 -26:03:01 0.0048 4 NGC 7314 22:35:40.0 $+15:57:54$ 0.0066 4 NGC 7465 ^c 23:02:00.9 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:57:54$ 0.0066 $+15:57:54$ 0.0066 $+15:57:57:57$ 0.0066 $+15:57:57$ 0.0066 $+15:57:57:57:57$ 0.0066 $+15:57:57$ 0.0066 $+15:57:57:57:57$ 0.0066 $+15:57:57:57:57$ $0.$:18 0.0097 43.58	$22.47 \ (T08)$	1	11/02/2013	XSHOOTER/P93
NGC 4945 13:05:27.3 -49:28:04 0.0019 4 NGC 5643 14:32:40.8 -44:10:29 0.0040 4 NGC 6221 ^b 16:52:46.3 -59:13:01 0.0050 4 NGC 7314 22:35:46.2 -26:03:01 0.0048 4 NGC 7465 ^c 23:02:00.9 +15:57:54 0.0066 4 TABLE 4.1. Ou: from the $Swift/BAT$ 7 2013). (1) Source na (4) Redshift; (5) X-ra; (6) Intrinsic column V12=Vasudevan et a Date of observation; (6)	:06 0.0037 41.79	$24.12^{+0.12}_{-0.17}({ m V12})$	2	21/07/2014	XSHOOTER/P93
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NGC7465 ^c 23:02:00.9 +15:57:54 0.0066 4 TABLE 4.1. Ou 0u from the Swift/BAT 7 2013). (1) Source na (4) Redshift; (5) X-ra; (6) Intrinsic column V12=Vasudevan et a. Date of observation; (1)	:01 0.0048 42.42	21.79 (T08)	1.9	25/06/2014	XSHOOTER/P93
TABLE 4.1.Outfrom the Swift/BAT 7from the Swift/BAT 72013).(1) Source na2013).(1) Source na(4) Redshift;(5) Intrinsic columnV12=Vasudevan et aDate of observation;	7:54 0.0066 42.14	23.66	LINER/Sy2	05/07/2005	LIRIS/WHT
from the Swift/BAT 7 2013). (1) Source na (4) Redshift; (5) X-ra; (6) Intrinsic column V12=Vasudevan et a Date of observation; (4.1. Our AGN	12 sample randon	ily selected		
 2013). (1) Source na (4) Redshift; (5) X-ra; (6) Intrinsic column V12=Vasudevan et a Date of observation; (the $Swift/BAT$ 70-mon	th survey (Baumge	utner et al.,		
 (4) Redshift; (5) X-ra (6) Intrinsic column V12=Vasudevan et a Date of observation; (. (1) Source name; (2	and (3) source	coordinates;		
(6) Intrinsic columnV12=Vasudevan et aDate of observation; (edshift; (5) X-ray lumi	nosity in the 14-19	5 keV band;		
V12=Vasudevan et a. Date of observation; (atrinsic column densit	y (T08=Tueller ϵ	t al. 2008;		
Date of observation; (Vasudevan et al. 2013); (7) AGN classif	ication; (8)		
	of observation; (9) Inst	rument used.			
				Cont	inued on next page

4.2 LUCI/LBT Observations

LUCI (LBT NIR Spectrograph Utility with Camera and Integral-Field Unit for Extragalactic Research) is a NIR spectrograph and imager at the Large Binocular Telescope (LBT) working in the wavelength range from 0.85 μ m to 2.5 μ m, corresponding to the photometric z, J, H and K bands. It is mounted on the bent Gregorian focus of the SX mirror of the telescope at LBT observatory (LBTO) in Arizona. The instrument observing modes available are:

- seeing-limited imaging over a 4' field of view (FOV) with the N 3.75 camera (image scale 0.12"/px);
- seeing-limited spectroscopy, using the N 1.8 camera (image scale 0.25''/px).

Spectroscopic observations can be carried out with a resolution of up to 8500 (seeing limited). The instruments are equipped with Rockwell HAWAII-2 Hd-CdTe 2048×2048 px² array. However, the observing range is limited on the blue side by the cut-off wavelength of the entrance window at λ =0.87 µm and on the red side by the cut-off of the atmospheric window after λ =2.4 µm. We observed at the Large Binocular Telescope (LBT), using the LUCI facilities, a total of 10 sources from our Swift/BAT AGN sample. The observations have been performed between October 2012 and February 2013 and all the objects have been acquired in the zJ (0.92–1.5 µm) band using the grating 200 H+K in combination with the zJspec filter, but one of them has been observed also in the K (2.025–2.353 µm) band using the 210 zJHK grating. We used a 1"×2.8' slit corresponding to a Δv =220 km s⁻¹ and Δv =87 km s⁻¹ spectral resolution for J and K band, respectively. The characteristics of the 200 H+K grating, used for the zJ band observations, are the following:

- wavelenght range: 1.38-2.4 µm;
- grating dispersion: 2.16 Å/px
- resolution: R=1360 for the 1" slit width at λ_c =11750 Å, corresponding at a velocity resolution of Δv =220 km s⁻¹.

For the zJHK 210 lines/mm grating, used in the K band, the characteristics are the following:

- wavelenght range: $2.02-3.18 \ \mu m$;
- grating dispersion: 1.60 Å/px
- resolution: R=3437 for the 1" slit width at λ_c =22000 Å, corresponding at a velocity resolution of Δv =87 km s⁻¹.

The images acquisition have been performed using the CCD HdCdTe HAWAII-2 camera, with the following characteristics:

- field of view: $4' \times 4'$ in seeing limited imaging;
- array: 2048×2048 px²;
- scale: The camera N3.75 (for imaging) has a scale of 0.125"/px, while the camera N1.8 for spectroscopy has a scale of 0.25"/px;
- readout noise (RON): $<5e^- = 1.27$ ADU in lecture mode MER (Multiple-Endpoint Read);
- $gain: 3.93e^{-}/ADU;$
- linearity: $<2 \ 10^5$ ADU.

All the observations have been carried out by rotating the slit in order to observe also a bright star, the telluric star, that was later used to correct for OH absorptions, which are known to vary across the night. We acquired 8 images with exposures of 350 s for each sources, using the nodding technique, in order to perform a better sky correction during the data reduction phase. We also have observed a bright standard star (O-B or Solar spectral type) for each sources, in order to use it for the flux calibration step, if the telluric star was not availabe. Flats and arcs were taken within one day from the observations. The observational features for each source are reported in Table 4.2.

4.3 ISAAC/VLT Observations

ISAAC is an IR $(1-5 \ \mu m)$ imager and spectrograph, that was mounted at the Nasmyth A focus of the UT3 of the Very Large Telescope in Chile till the 12th

LBT observing log										
		1″×2.8	\mathbf{S}' slit width							
velocit	y resolution o	of $\Delta v = 220$ l	${ m km}~{ m s}^{-1}$ for z	$\Delta v = 8'$	$7 \text{ km s}^{-1} \text{ f}$	or K.				
object name	date	\mathbf{UT}	exposure	seeing	airmass	FIlter	Grating			
		[hh:mm]	$[\mathbf{s}]$	["]						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)			
2MASX J0641+3249	$2012 \ {\rm Oct} \ 20$	08:15	8×350	1.47	1.52	zJspec	200 H+K			
2MASX J0911+4528	$2012 \ {\rm Oct} \ 20$	10:57	8×350	0.75	1.39	zJspec	200 H+K			
2MASX J0911+4528	$2012 \ {\rm Oct} \ 20$	10:57	6×350	0.71	1.12	zJspec	200 H+K			
NGC 3079	$2012 \ {\rm Oct} \ 23$	12:43	5×350	1.21	1.22	zJspec	200 H+K			
NGC 3079	$2012 \ {\rm Oct} \ 24$	12:24	8×350	1.08	1.26	zJspec	200 H+K			
3C 403	$2012 \ {\rm Oct} \ 25$	02:14	2×350	1.33	1.21	zJspec	200 H+K			
Mrk 417	$2012 \ \mathrm{Dec} \ 05$	10:03	8×350	0.73	1.38	zJspec	200 H+K			
NGC 4395	$2012 \ \mathrm{Dec} \ 05$	12:09	8×350	0.54	1.21	zJspec	200 H+K			
NGC 4138	$2012 \ \mathrm{Dec} \ 06$	10.55	8×350	0.54	1.37	zJspec	200 H+K			
2MASX J1127+1909	$2012 \ \mathrm{Dec} \ 06$	11:06	8×350	0.53	1.10	zJspec	200 H+K			
2MASX J1127+1909	$2012 \ \mathrm{Dec} \ 06$	13:08	8×350	0.53	1.04	Κ	210 zJHK			
NGC 4686	$2012 \ \mathrm{Dec} \ 07$	11:16	8×350	1.05	1.42	zJspec	200 H+K			
NGC 4388	$2013 { m Feb} 19$	09:36	8×350	0.74	1.07	zJspec	200 H+K			

TABLE 4.2. LUCI/LBT observation log for the 10 sources observed. (1) Source name; (2) Date of observation; (3) Starting time of acquisition; (4) Number of acquisitions and exposure time for each acquisition; (5) seeing; (6) airmass; (7) Filter used during the observations; (8) Grating used during the observations. We used a $1'' \times 2.8'$ slit width, corresponding in a velocity resolution of $\Delta v=220$ km s⁻¹ and $\Delta v=87$ km s⁻¹ for zJ and K observations, respectively.

December 2013. It has two arms, one equipped with the 1024×1024 Hawaii Rockwell array, used for short wavelenght (SW; 1–1.5 μ m), and the other with a 1024×1024, used for long wavelenghts (LW; 3–5 μ m). The instrument has several observing modes available: imaging and spectroscopy in both short wavelength (SW) and long wavelength (LW), FastPhot (Burst and FastJitter) imaging in LW only, and imaging polarimetry in SW only. All modes are offered for both Service and Visitor Programs. In spectroscopic modes ISAAC is equipped with two gratings, for Low and Medium resolutions (LR and MR, respectively) spectroscopy, six slits with widths ranging from 0.3 to 2 arcsec, and order sorting filters for each spectroscopic band. A calibration unit allows calibration lamps to be used for both wavelength calibration and flat fielding (in spectroscopy only). The lamps used for wavelength calibration are Xenon and Argon.

We observed at VLT, using the ISAAC spectrograph, a total of 25 sources from our *Swift*/BAT AGN sample. All the observations have been performed between October 2011 and January 2012 in the SW mode, equipped with the 1024×1024 Hawaii Rockwell array arm. All the ojects have been observed in the J band, but two sources with z~0.1 have been observed also in the K band. In all cases we used both LR and MR instument modes and a 0.8'' $\times 120''$ wide slit, corresponding to a spectral resolution of ~ 430 km s⁻¹ and ~ 60 km s⁻¹ for LR and MR mode, respectively. The characteristics of the SW/LR and SW/LR grating are:

- wavelenght range: $1.1-1.4 \ \mu m$ for J filter; $1.82-2.5 \ \mu m$ fot SK filter;
- pixel scale: 0.147 "/px
- resolution LR: R=730 at $\lambda_c=1.25\mu$ m (J filter); R=600 at $\lambda_c=2.16 \mu$ m (SK filter), for the $0.8'' \times 120''$ slit width.
- resolution MR^d: R=4700 at λ_c =1.25 μ m (J filter); R=3900 at λ_c =2.16 μ m (SK filter), for the 0.8"×120" slit width.

The images acquisition have been performed using the Hawaii detector with the following characteristics:

• Spectral range: $0.98-2.5 \ \mu m$;

^dIn MR mode λ_c varies slightly in order to center the NIR lines in the spectra.

- Field of view: $152'' \times 152'';$
- Array: 1024×1024 px²;
- Scale: 0.1484"/px;
- *Pixel size*: 18.5 µm;
- Readout noise (RON): $\sim 10 \text{ e}^-$;
- gain: 4.6 e⁻/ADU.

The observations were performed in order to center the galaxy's nucleus at the best and, when possible, the slit has been rotated in order to include also a telluric star. We acquired 6 LR frames with exposures of 180 s and 4 MR with exposures of 340 s for each sources, using the nodding technique to remove the sky contribution to the spectra. We also observed a bright standard star within 30 minutes to the target observations, and use it to both calibrate the absolute flux and correct for OH absorptions every time the telluric star was not available. As usual, flats and arcs were taken within one day from the observations. The main datails of all the ISAAC observations are shown in Table 4.3.

ISAAC observing log								
		0.8″ ×120′	$^{\prime\prime}$ slit width					
	velocity resolution	on of $\Delta v \sim$ 430 km	s^{-1} for LR,	$\Delta v \sim 60$ k	$m s^{-1}$ for	MR.		
object name	Obs. date	Obs. time (UT) [hh:mm]	$\begin{array}{c} \mathbf{exposure} \\ \mathbf{[s]} \end{array}$	seeing [″]	airmass	Filter	$\mathbf{Grating}/\lambda_c$ mode /[μ m]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	
PKS 0326-288	07 Oct 2011	04:41	6×180	1.22	1.192	SK	LR/2.2	
PKS 0326-288	07 Oct 2011	04:15	4×340	1.22	1.239	SK	MR/2.078	
$3C \ 105$	07 Oct 2011	05:13	6×180	0.90	1.406	SK	LR/2.2	
$3C \ 105$	07 Oct 2011	05:00	4×340	0.89	1.263	SK	MR/2.042	
PKS 0326-288	07 Oct 2011	03:01	6×180	0.88	1.549	J	LR/1.25	
PKS 0326-288	07 Oct 2011	02:45	4×340	0.99	1.551	J	MR/1.2	
NGC 788	07 Oct 2011	02:09	6×180	1.06	1.685	J	LR/1.25	
NGC 788	07 Oct 2011	01:43	4×340	0.93	1.977	J	MR/1.299	
ESO 416-G002	08 Oct 2011	02:37	6×180	1.05	1.481	J	LR/1.25	
ESO 416-G002	08 Oct 2011	02:59	4×340	0.94	1.360	J	MR/1.147	
NGC 1142	09 Oct 2011	04:53	6×180	0.90	1.197	J	LR/1.25	
NGC 1142	09 Oct 2011	05:16	4×340	0.90	1.154	J	MR/1.319	
ESO 417-G006	11 Oct 2011	06:37	6×180	1.00	1.011	J	LR/1.25	
ESO 417-G006	11 Oct 2011	06:11	4×340	0.88	1.009	J	MR/1.303	
NGC 612	13 Oct 2011	02:43	6×180	1.12	1.150	J	LR/1.25	

Continued on next page

ISAAC observing log									
		0.8″ ×120′	' slit width		1				
vel	ocity resoluti	on of $\Delta v \sim$ 430 km	s^{-1} for LR,	$\Delta v \sim 60$ k	$m s^{-1}$ for	MR.			
object name	Obs. date	Obs. time (UT) [hh:mm]	exposure [s]	seeing [″]	airmass	Filter	$\mathbf{Grating}/\lambda_c$ mode /[μ m]		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		
NGC 612	13 Oct 2011	03:26	4×340	0.98	1.076	J	MR/1.320		
NGC 1365	13 Oct 2011	05:56	6×180	0.87	1.028	J	LR/1.25		
NGC 1365	13 Oct 2011	06:32	4×340	0.92	1.023	J	MR/1.289		
ESO -297-018	13 Oct 2011	04:34	6×180	1.22	1.040	J	LR/1.25		
ESO -297-018	06 Oct 2011	05:17	4×340	1.09	1.037	J	MR/1.314		
ESO -157-G023	19 Oct 2011	07:41	6×180	1.03	1.173	J	LR/1.25		
ESO -157-G023	19 Oct 2011	07:23	4×340	1.09	1.179	J	MR/1.338		
3C 105	21 Oct 2011	07:22	6×180	0.76	1.146	J	LR/1.25		
3C 105	21 Oct 2011	07:06	4×340	0.90	1.170	J	MR/1.179		
2MASX J0505-2351	03 Nov 2011	03:41	6×180	0.90	1.412	J	LR/1.25		
2MASX J0505-2351	03 Nov 2011	04:05	4×340	0.77	1.294	J	MR/1.327		
ESO 005- G 004	04 Nov 2011	03:04	6×180	1.36	2.300	J	LR/1.25		
ESO 005- G 004	04 Nov 2011	03:25	4×340	1.23	2.276	J	MR/1.290		
NGC 1052	04 Nov 2011	01:14	6×180	0.90	1.540	J	LR/1.25		
NGC 1052	04 Nov 2011	01:39	4×340	1.04	1.390	J	MR/1.288		
NGC 3281	14 Nov 2011	07:26	6×180	1.09	1.641	J	LR/1.25		
NGC 3281	14 Nov 2011	08:17	4×340	1.08	1.414	J	MR/1.296		
Mrk 1210	19 Dec 2011	07:56	6×180	0.69	1.241	J	LR/1.25		
Mrk 1210	19 Dec 2011	07:25	4×340	0.77	1.193	J	MR/1.299		
CGCG -420-015	19 Dec 2011	06:04	6×180	0.71	1.451	J	LR/1.25		
CGCG -420-015	19 Dec 2011	04:49	4×340	0.78	1.593	J	MR/1.32		
Fairall 272	22 Dec 2011	04:49	6×180	0.96	1.264	J	LR/1.25		
Fairall 272	22 Dec 2011	05:31	4×340	0.89	1.134	J	MR/1.31		
MCG -05-23-016	01 Jan 2012	04:39	6×180	0.82	1.288	J	LR/1.25		
MCG -05-23-016	01 Jan 2012	04:12	4×340	0.81	1.205	J	MR/1.293		
NGC 3081	06 Jan 2012	03:55	6×180	1.16	1.592	J	LR/1.25		
NGC 3081	06 Jan 2012	04:19	4×340	0.82	1.433	J	MR/1.292		
MGC -01-24-012	07 Jan 2012	03:06	6×180	1.19	1.665	J	LR/1.25		
MGC -01-24-012	07 Jan 2012	02:27	4×340	1.39	1.539	J	MR/1.307		
NGC 2992	07 Jan 2012	04:32	6×180	1.14	1.275	J	LR/1.25		
NGC 2992	07 Jan 2012	05:09	4×340	1.10	1.192	J	MR/1.292		
LEDA 093974	08 Jan 2012	04:51	6×180	0.85	1.380	J	LR/1.25		
LEDA 093974	08 Jan 2012	05:20	4×340	0.73	1.298	J	MR/1.313		
ESO -374-G044	22 Jan 2012	01:59	6×180	0.98	1.823	J	LR/1.25		
ESO -374-G044	22 Jan 2012	02:42	4×340	0.97	1.609	J	MR/1.318		

TABLE 4.3. ISAAC/VLT observation log for the 25 sources observed. (1) Source name; (2) Date of observation; (3) Starting time of acquisition; (4) Number of acquisitions and exposure time for each acquisition; (5) seeing; (6) airmass; (7) Filter used during the observations; (8) Grating used during the observations. We used a $0.8'' \times 120''$ slit width, corresponding in a velocity resolution of $\Delta v \sim 430$ km s⁻¹ and $\Delta v \sim 60$ km s⁻¹ for LR and MR modes, respectively.

Continued on next page

4.4 XSHOOTER/VLT Observations

X-shooter is a single target spectrograph mounted to the Cassegrain focus of the VLT UT3, covering in a single exposure the spectral range from the UV to the K band. The spectral format is fixed. The instrument is designed to maximize the sensitivity in the spectral range by splitting the incident light in three arms with optimized optics, coatings, dispersive elements and detectors. It operates at intermediate resolutions, R=4000-18000, depending on wavelength and slit width. The three arms are fixed format cross-dispersed échelle spectrographs that operate in parallel. Each one has its own slit selection device.

- The UV-Blue (UVB) spectrograph cover the 300-550 nm wavelenght range with a resolving power of 5100 (for a 1" slit width);
- The Visible spectrograph (VIS) covers the 550–1000 nm with a resolving power of 7500 (for a 0.9" slith width);
- The near IR (NIR) spectrograph covers the range 1000-2500 nm with a resolving power of 5300 (for a 0.9" slit width) and it is fully cryogenic.

The UVB detector is a 2048×4102 , 15μ m pixel size CCD from E2V (type CCD44-82) of which only a 1800×3000 pixels window is used. The CCD cryostat is attached to the camera with the last optical element acting as a window. The operating temperature is 153K. The CCD control system is a standard ESO FIERA controller shared with the VIS CCD. The VIS detector is 2048×4096 , 15μ m pixel size CCD from MIT/LL (type CCID-20). Like for the UVB arm, the cryostat is attached to the camera with the last optical element acting as a window. The operating temperature is 135K. It shares its controller with the UVB detector and the same readout modes are available. The NIR detector is a Teledyne substrate-removed HgCdTe, $2k \times 2k$, 18μ m pixel size Hawaii 2RG from of which only $1k \times 2k$ is used. It is operated at 81K.

The UVB and VIS detectors offer several readout modes, among which we choose the $100k/1pt/hg/1 \times 2$, while in the NIR only one readout mode is available. The main detectors characteristics are:

• Number of pixel: 2048×3000 for UVB; 2048×4096 for VIS; 2048×2048 for NIR;

- *Pixel size*: 15μ m for UVB and VIS; 18μ m for NIR;
- Gain: 0.62 e⁻/ADU fot UVB; 0.595 e⁻/ADU for VIS; 2.12 e⁻/ADU for NIR;
- Readout noise (RON): $2.5 e^{-1}$ for UVB; $3.1 e^{-1}$ for VIS; ~ 25 for NIR.

We have observed 11 AGN from our selected Swift sample using the multiwavelength (3000–25000 Å) medium resolution spectrograph Xshooter. The first set of observations (4 sources) have been carried out in visitor mode on February 2013 and for every AGN it has been taken 2 exposure of \sim 300 s each, using a $1.0'' \times 11''$ wide slit for the UVB arm and a $0.9'' \times 11''$ for the VIS and NIR arms, corresponding to a $\sim 60 \text{km s}^{-1}$ spectral resolution and the nodding technique for all arms. The second set of Xshooter observations, including 7 sources, have been performed in service mode in the framework of the ESO period P93 (in particular the targets have been observed between April 2014 and June 2014). As in 2013 we used a $1.0'' \times 11''$ wide slit for the UVB arm and a $0.9'' \times 11''$ for the VIS and NIR arms, corresponding to a ~60 km s⁻¹ velocity resolution, and applied the nodding technique for all arms. We realized 10 exposure of ~ 200 s for each arm and each target. Due to the short slit it was not possible to include also a telluric star in the same acquisition, but both telluric and bright standard stars were observed within 30 minutes from the scientific target acquisitions. The data reduction have been performed using the Xshooter pipeline. The characteristics of the target observations are shown in Table 4.4.

4.5 Data reduction

The NIR data reduction has been realized using both IRAF (Image Reduction and Analysis Facility) and ESO/MIDAS (European Southern

Observatory-Munich Image Data Analysis System) softwares. In order to perform a reliable reduction of the raw spectra we first grouped all the calibration data on the basis of their typology, inserting in each header the decriptor *imagetype* with the IRAF task *ccdhedit*. Thus the scientific images have been classified as *object*, the flat field images as *flat* and the other calibration images, such as the lamps, as *other*. In order to correct every scientific images for the

Xshooter observing log										
slit width:	$1.0^{\prime\prime} \times 11^{\prime\prime}$ for	UVB and	a 0.9 $^{\prime\prime} imes11^{\prime\prime}$:	for VIS a	nd NIR					
	velocity res	solution of .	$\Delta v \sim$ 60 km s	s ⁻¹						
object name	date	\mathbf{UT}	exposure	seeing	airmass	ARM				
		[hh:mm]	$[\mathbf{s}]$	["]						
(1)	(2)	(3)	(4)	(5)	(6)	(7)				
ESO -263-G013	$11 { m Feb} 2013$	00:47	2×150	1.2	1.93	NIR				
ESO -263-G013	11 Feb 2013	00:47	2×50	1.2	1.93	VIS				
ESO -263-G013	$11 { m Feb} 2013$	00:47	2×50	1.2	1.93	UVB				
NGC 3783	$11 \ {\rm Feb} \ 2013$	08:21	2×300	0.94	1.09	NIR				
NGC 3783	$11 \ {\rm Feb} \ 2013$	08:21	2×263	0.94	1.09	VIS				
NGC 3783	$11 \ {\rm Feb} \ 2013$	08:21	2×230	0.94	1.09	UVB				
MCG -05-23-16	$11 { m Feb} 2013$	01:10	2×200	0.85	1.556	NIR				
MCG -05-23-16	$11 { m Feb} 2013$	01:10	2×163	0.85	1.556	VIS				
MCG -05-23-16	$11 { m Feb} 2013$	01:10	2×130	0.85	1.556	UVB				
LEDA 093974	$11 { m Feb} 2013$	08:03	2×300	0.92	1.281	NIR				
LEDA 093974	$11 { m Feb} 2013$	08:03	2×250	0.92	1.281	VIS				
LEDA 093974	$11 { m Feb} 2013$	08:03	2×225	0.92	1.281	UVB				
NGC 4945	$23~{\rm Apr}~2014$	04:47	10×291	1.07	1.139	NIR				
NGC 4945	23 Apr 2014	04:47	10×259	1.07	1.139	VIS				
NGC 4945	23 Apr 2014	04:47	10×225	1.07	1.139	UVB				
NGC 6221	$24~{\rm Apr}~2014$	06:07	10×291	1.01	1.249	NIR				
NGC 6221	24 Apr 2014	06:07	10×259	1.01	1.249	VIS				
NGC 6221	24 Apr 2014	06:07	10×225	1.01	1.249	UVB				
2MASX J1830+0928	05 Jun 2014	04:15	10×291	0.70	1.42	NIR				
2MASX J1830+0928	05 Jun 2014	04:15	10×259	0.70	1.42	VIS				
2MASX J1830+0928	05 Jun 2014	04:15	10×225	0.70	1.42	UVB				
NGC 5643	20 Jun 2014	03:50	10×291	1.14	1.24	NIR				
NGC 5643	20 Jun 2014	03:50	10×259	1.14	1.24	VIS				
NGC 5643	20 Jun 2014	03:50	10×225	1.14	1.24	UVB				
ESO -234-G050	25 Jun 2014	06:38	10×291	0.78	1.112	NIR				
ESO -234-G050	25 Jun 2014	06:38	10×259	0.78	1.112	VIS				
ESO -234-G050	25 Jun 2014	06:38	10×225	0.78	1.112	UVB				
NGC 7314	25 Jun 2014	07:50	10×291	0.67	1.012	NIR				
NGC 7314	25 Jun 2014	07:50	10×259	0.67	1.012	VIS				
NGC 7314	25 Jun 2014	07:50	10×225	0.67	1.012	UVB				
NGC4941	21 Jul 2014	22:54	10×291	0.84	1.294	NIR				
NGC4941	21 Jul 2014	22:54	10×259	0.84	1.294	VIS				
NGC4941	21 Jul 2014	22:54	10×225	0.84	1.294	UVB				

TABLE 4.4. Xshooter observation log for the 11 sources observed. (1) Source name; (2) Date of observation; (3) Starting time of acquisition; (4) Number of acquisitions and exposure time for each acquisition; (5) seeing; (6) airmass; (7) Xshooter arm. We used a a $1.0'' \times 11''$ for the UVB arm and a $0.9'' \times 11''$ for the VIS and NIR arms slit width, corresponding in a velocity resolution of $\Delta v = 60 \text{ km s}^{-1}$.

non-uniform CCD response and for the different pixel efficiency, we combine the *flat* and *bias* images, producing a normalized, averaged image used for the scientific corrections. The cosmic rays contamination has been removed with the IRAF task *crmedian*, in which all the pixel with counts larger than 10σ or smaller than 3σ with respect to the median signal are erased. This task has been applied to the scientific spectra twice: first before the λ calibration and then after the sky lines corrections. The latter has been performed in order to delete possible artefacts introduced during the reduction steps.

4.5.1 Sky lines subtraction and λ calibration

In order to perform an accurate λ calibration we decided to use the OH lines. For this purpose we developed a MIDAS procedure in which a 1-D sky lines image was produced starting from an averaged image of the scientific data for each source. We produced a MIDAS table using the OH sky atlas from Rousselot et al. (2000), that contains the main NIR sky emission lines identifications. We then applied the following IRAF tasks:

- *identify*, to perform a first line identification of the OH lines in the sky image;
- *reidentify*, for mapping geometric and dispersion distortion of the 2-D spectra;
- *fitcoords*, in which a two dimensional mapping of the image coordinates is performed.

Finally the task *transform* converts the scientific spectra dispertion axis from pixel to λ coordinates, performing the spectral λ calibration.

As decribed in the previous Sections (4.2, 4.3 and 4.4), we observed all our targets using the nodding technique, in order to perform a reliable correction for the sky lines contamination in the scientific data. This particular technique is commonly used in NIR spectroscopy and consists in the acquisition of several images of the same object but observed in different positions along the slit (i.e. A and B, see Figure 4.3).

We have acquired a set of couples of A and B observations for each object. The λ calibrated scientific couples have to be reprocessed in order to remove



FIGURE 4.3. A LUCI target acquired with the nodding technique in the position A (left) and B (right). In this case also a telluric star has been included in the same observation.

from their spectra the sky emission lines, cleary visible in Figure 4.3. Thus, for each couple we have performed the operations AB = A - B and BA = B - A, and, after an y-axis shift of the BA image, in order to have the target signals in the same position both in AB and in BA images, we obtained the final 2D scientific spectra from the operation ABBA = AB + BA (see Figures 4.4 and 4.5).

These procedures have been performed using the IRAF tasks for the image operations, such as *imshift* and *imarith*, on each set of couple observations for every target. The overall 2D spectrum, λ calibrated and free from sky lines, of each source is then achieved combining togheter all the target's "ABBA" frames, previously created. We decided to use the IRAF task *imcombine*, in which is performed both an average of the imput images and a further cosmic rays correction. Figure 4.5 shows the final 2D spectra for 2MASX J0506+31 in which the sky emission lines are well removed. The same reduction procedures have been applied also for the telluric and standard star.

These standard reduction steps have been performed on all ISAAC and LUCI spectra, while for the Xshooter subsample we have used the Xshooter pipeline in the Esorex environment. In the following we will describe the spectra extraction and the flux calibration steps.



FIGURE 4.4. Up panel: a LUCI target acquired with the nodding technique after the operation AB (left) and BA (right). Bottom panel: the BA frame has been shifted in y-axis, in order to have the targhet signals in the same position both in AB and in BA images.



FIGURE 4.5. LUCI spectra of 2MASX J0506+31 resulting from the average of the all ABBA frames, after the nodding corrections.

4.5.2 Spectra extraction and flux calibration

At this point we have 2D scientific spectra, corrected for the flat field and cosmic rays, λ calibrated and polished by the OH emission lines contamination. From these images we have to derive the 1D spectra for both scientific and star (standard or telluric) frames in order to have all the ingredients for the flux calibration step.

The spectra extraction has been performed using the IRAF task *apall*, a multistep task that defines and extracts the data from the 2D CCD images. This task is rather complex and its operation strongly depends on several parameters:

- Backgrounds parameters: are used to determine how much the target signal emerges from the background. To this purpose the background has to be fitted with one among several functions available and it is possible to select the spectral region in which the background is estimated. In our extractions we choose a Chebyshev polynomial of order 3 for the background fit and the fitting region has been choosen interactively, paying attention to avoid damaged areas or the presence of cosmic rays.
- **Tracing parameters**: are used to traced the spectrum along the dispersion axis.
- Extraction parameters: these are used in order to optimize the spectrum extraction.

For the scientific spectra we have choosen the extraction aperture as narrow as possible in order to extract the very nuclear region of the AGN and not to lose too much flux. Instead, for the standard and telluric stars we have choosen a much broader extract aperture in order to take as much stellar flux as possible.

One of the main difficulties in conducting NIR ground-based spectroscopy is the presence of strong atmospheric absorptions highly variable in time. These features have to be corrected and in many cases satisfactory results can be achieved by dividing the target spectrum by the spectrum of a solar or type A star close to the object in the sky and observed closed in time. However when observing with high resolution spectrographs, the absorption features of the reference star are no longer diluited by the surrounding continuum and these can affect the target final spectrum, creating several pseudonoise absorptions. This noise can be minimized selecting reference stars with fewer features, such as O-B spectral type, but it could resuts in a unsatisfactory atmospheric correction in the final spectra, if the reference star is placed far from the target. Thus, in order to perform an high quality atmospheric correction in our final spectra, all the observations have been carried out by rotating the slit in order include in the acquisition also a bright star (the telluric star), to be used in the flux calibration step for the OH absorptions corrections.

The flux calibration and the telluric correction steps have been realized following the method described by Vacca et al. (2003) for early spectral type star (A or B type), while we have followed the Maiolino et al. (1996) method in the cases of late type star (G or K). In both technique the flux calibration is performed using:

$$F_{cal}(\lambda) = F_{obs}(\lambda) \frac{F_{mod}^{\star}(\lambda)}{F_{obs}^{\star}(\lambda)/f} k \cdot 10^{-0.4(J^{\star}-J_0)}$$
(4.1)

in which $F_{cal}(\lambda)$ is the flux calibrated of the scientific target, $F_{obs}(\lambda)$ is the observed flux of the soruce, F_{mod}^{\star} is a black body model for the spectral type of the reference star used which is normalized to unity in the observed band (e.g. at $\lambda_c=1.25 \ \mu\text{m}$ for J spectra), $F_{obs}^{\star}(\lambda)$ is the observed reference star, f represents the fraction of stellar flux in the slit, J^{\star} is the J magnitude (for K-band spectra we have used the star K magnitude) of the star and k is a constant that comes from the magnitude-flux conversion.

For LR spectra and early spectral type stars we have used the IDL procedure *xtellcor_general* (see Vacca et al. 2003) to apply the Equation 4.1 and thus obtain the final flux calibrated spectra. Instead, for higher resolution observations and in the cases of late spectral type reference star (G and K) we developed a MIDAS procedure that makes use of the Equation 4.1 and perform the flux calibrations of the scientific spectrum in input. The atmospheric and the Galactic extinction correction has been taken into account automatically during the flux calibration with the telluric standard star by using a non extincted stellar model.

Chapter 5

The new NIR virial relation to derive the AGN BH masses

5.1 Previous single epoch techniques

Nowadays there is robust evidence that almost every galaxy host a super massive black hole (BH; $M_{BH}=10^5-10^9 M_{\odot}$) and that many correlations exist between the BH mass and some of the host galaxy properties (e.g. bulge mass, luminosity and stellar dispersion; Ferrarese and Merritt, 2000; Gebhardt et al., 2000; Marconi and Hunt, 2003; Sani et al., 2011). Then, it has been argued that the existence of these scaling relationships implies a common evolutionary path between galaxies and the growth of SMBHs (the AGN/galaxy co-evolution scenario).

In the last decade, using virial based techniques in the optical band, it has been possible to measure the BH mass on large type 1 AGN (AGN1) samples and therefore derive the super massive BH mass function (Greene and Ho, 2007a; Kelly et al., 2009, 2010; Merloni et al., 2010; Bongiorno et al., 2014). These measures are based on the Single Epoch (SE) BH mass estimates. By combining the velocity of the Broad Line Region (BLR) clouds (assuming Keplerian orbits) along with their distance R it is possible to determine the total mass contained within the BLR (which is dominated by the BH) in a simple way using:

$$M_{\rm BH} = \frac{f\Delta V^2 R}{G},\tag{5.1}$$

where G is the gravitational constant and f is a factor that depends on the geometric and kinematic structure of the BLR (Kaspi et al., 2000). These techniques derive the AGN BH mass using single epoch (SE) spectra to measure ΔV from the full width at half maximum (FWHM) of some of the BLR lines (typically: H β or MgII2798Å or C iv 1459Å) and R from either the continuum

or the line luminosities, L, which have been proved to be proportional to \mathbb{R}^2 (i.e. $R \propto L^{0.5}$; Bentz et al., 2006). Therefore, the SE estimates are based on relations of the type:

$$\log M_{\rm BH} = \log(\rm FWHM^{\alpha} \cdot L^{\beta}) + \gamma, \qquad (5.2)$$

where $\alpha \sim 2$, $\beta \sim 0.5$ (e.g. Wandel et al., 1999; Vestergaard, 2002, 2004; Vestergaard and Osmer, 2009; McLure and Jarvis, 2002, but see also Dietrich and Hamann 2004). These relationships have typical spreads of ~0.5 dex.

However these measurements are affected by selection biases against those obscured or partially obscured sources where the AGN component does not dominate in the optical: type 2 AGN (AGN2), intermediate class AGN (AGN1.8 and AGN1.9) or even low mass BH ($M_{BH} \leq 10^6 M_{\odot}$) AGN1. Indeed, in these cases, in the (rest frame) optical band, either the broad line component is not visible or, in any case, the AGN continuum and line luminosities are affected by severe obscuration and galaxy contamination thus preventing a reliable estimate of the BH mass.

There are, in summary, indications that the SE techniques do not allow to obtain an un-biased estimate of the density of the low-luminosity and, therefore, lowest-mass BH ($M_{BH} \leq 10^6 M_{\odot}$) class of AGN. Such a bias could have strong implications on our understanding on the AGN/galaxy evolution.

Indeed, the density of low mass BHs in the local universe provide unique tests for studies of BH formation and growth, galaxy formation and evolution. In current models of galaxy evolution in a hierarchical cosmology, SMBHs must have been built up from accretion onto much smaller seeds, in conjuction with merging with other BHs. These models also predict that smaller scale structures form at later times (cosmic downsizing), and one might expect that seeds BHs in these smaller systems may not have had enough time to be fully grown. This means that low-mass BHs likely contain clues about the formation of the first black holes, thus the mass function of the present day low-mass black holes and their host galaxies properties can be used to discriminate between different models for seeds BHs and help shed light on the coevolution of BHs and galaxies (see Dong and De Robertis, 2006; Greene and Ho, 2007b; Dong et al., 2012; Greene, 2012).
In the last few years Landt et al. (2008, 2011, 2013) have studied quasisimultaneous near-IR (NIR) and optical spectra of a sample of well-known broad-emission line AGN, whose BH masses were already determined from reverberation campaigns. These studies have allowed the calibration of a NIR relationship for estimating AGN BH masses based on the widths of the Paschen hydrogen broad emission lines and the total 1 μ m continuum luminosity (Landt et al., 2011, 2013). However the virial relationship developed in Landt et al. (2011, 2013) makes use of the 1 μ m continuum luminosity, which has to be derived by a Spectral Energy Distribution (SED) fitting method and can suffer from galaxy contamination especially for intrinsic low-luminosity AGNs.

We have then decided to calibrate new virial relationships based on the Pa β broad emission line FWHM combined with either the hard X-ray or the Pa β broad emission line luminosities (see also Kim et al., 2010, for similar SE methods based on the Pa α and Pa β emission-line luminosities). Such relations are potentially able to be applied on both the low-luminosity and the optically more obscured AGN. The method has been tested over one of the lowest BH mass (~ 10⁵M_☉; see section 6.2.2) AGN, NGC 4395, which has been spectroscopically observed in the NIR at the Large Binocular Telescope (LBT) in the framework of a large programme aimed at measuring the BH mass of low-luminosity or type 2 AGN (Onori et al., in preparation), included in the 22 month Swift/Burst Alert Telescope (BAT) catalogue (Tueller et al., 2010).

Unless otherwise stated, all quoted errors are at the 68% confidence level. We assume $H_0 = 70 \text{ km s}^{-1} \text{Mpc}^{-1}$, $\Omega_m = 0.3$ and $\Omega_{\Lambda} = 0.7$.

5.2 The calibration sample

As previously discussed, we are interested in deriving new BH mass virial relationships based on the measure of the width of the BLR component in the Pa β emission line. In order not to suffer from problems related to the galaxy contamination, we have replaced the 1 μ m continuum luminosity used by Landt et al. (2013) as the BLR size indicator, with either the hard X-ray 14-195 keV band luminosity, L_X, such as measured by Swift/BAT survey (Baumgartner et al., 2013), or the luminosity of the Pa β , L_{Pa β}, itself (see Kim et al. (2010), for a similar study based on the $Pa\alpha$ and $Pa\beta$ emission-line luminosities).

The calibration sample contains 20 AGNs and is quite the same of Landt et al. (2011, 2013), infact most of their sources are listed in the Swift/BAT catalogue (Baumgartner et al., 2013). When available, we have used the BH mass values listed in Grier et al. (2013) where the new estimate of the geometrical f-factor f = 4.31 was adopted. All the remaining BH masses, which were originally published using f = 5.5, have then been converted to f = 4.31. In Table 5.1 we present the main characteristics of our calibration sample, such as: redshift, optical spectroscopic classification, BH mass and the relative reference, 14-195 keV hard X-ray luminosity and the FWHM of the broad component of the Pa β .

The FWHMs have been corrected for instrumental resolution using the values reported in Landt et al. (2008, 2013). In particular the source 3C 120 has been observed with an average spectral resolution of FWHM ~ 180 km s⁻¹, while Mrk 279, NGC 3516, NGC 4051 and PG 0844+349 spectra have a resolution of FWHM ~ 400 km s⁻¹ (Landt et al., 2013). The instrumental resolution for the remaining of the sources is FWHM ~ 350 km s⁻¹ (Landt et al., 2008).

5.2.1 Fit of the virial relationship using L_X

We have performed a linear fit of the form

$$\log\left(\frac{\mathrm{M}_{\mathrm{BH}}}{\mathrm{M}_{\odot}}\right) = a \cdot \log\left[\left(\frac{\mathrm{FWHM}_{\mathrm{Pa}\beta}}{10^4 \,\mathrm{km \, s^{-1}}}\right)^2 \left(\frac{\mathrm{L}_{\mathrm{X}}}{10^{42} \,\mathrm{erg \, s^{-1}}}\right)^{0.5}\right] + b, \qquad (5.3)$$

where M_{BH} is the BH mass, FWHM_{Pa β} is the measure of the width of the broad component of the Pa β emission line, corrected for instrumental broadening, and L_X is the 14-195 keV intrinsic luminosity.

The fit was carried out on a sample of 19 out of 20 AGN, as one galaxy misses the L_X measurement (see Table 5.1). We have solved the least-squares problem using the fitting routine FITEXY (Press et al., 2007) that can incorporate errors on both variables and allows us to account for intrinsic scatter. The uncertainties on M_{BH} are listed in Table 5.1, while the errors on the virial product (the x-axis) depend on the uncertainties on the measures of FWHM and L_X . We have calculated the uncertainties on the hard X-ray luminosity L_X

Object Name	\mathbf{Z}	class	M_{BH}	ref	$\log L_{\rm X}$	$\rm FWHM_{Pa\beta}$	$\log L_{\mathrm{Pa}\beta}$
			$[{ m M}_{\odot}]$		$[\mathrm{erg}\mathrm{s}^{-1}]$	$[\mathrm{kms^{-1}}]$	$[\mathrm{erg}\mathrm{s}^{-1}]$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
3C 120	0.0330	S1.0	$5.26 {\pm} 0.52 {\ \cdot} {10^7}$	G13	44.38	2727	
3C 273	0.1583	S1.0	$6.94{\pm}1.47{}{\cdot}10^8$	P04	46.48	2895	43.64
Ark 120	0.0323	S1.0	101^{+17}_{-25} $\cdot 10^{6}$	G13	44.23	5102	42.12
Mrk 79	0.0222	S1.2	$8.28^{+1.9}_{-3.2}$ $\cdot 10^7$	G13	43.72	3506	41.28
Mrk 110	0.0353	S1n	$2.24^{+0.56}_{-0.91}$ $\cdot 10^{7}$	G13	44.22	1886	41.60
Mrk 279	0.0304	S1.0	$3.10{\pm}0.47{\ \cdot}10^7$	G13	43.92	3546	
Mrk 290	0.0296	S1.5	$1.90{\pm}0.29{\ }{\cdot}10^7$	D10	43.67	4228	41.46
Mrk 335	0.0258	S1n	$1.11{\pm}0.29~{\cdot}10^{7}$	P04	43.45	1825	41.37
${\rm Mrk}~509$	0.0344	S1.5	$9.57{\pm}0.43~{\cdot}10^{7}$	G13	44.42	3057	42.12
${\rm Mrk}~590$	0.0264	S1.0	$3.15^{+0.52}_{-0.69}$ $\cdot 10^{7}$	G13	43.42	3949	40.33
Mrk 817	0.0314	S1.5	$6.29^{+0.95}_{-1.08}$ $\cdot 10^{7}$	G13	43.77	5519	41.47
Mrk 876	0.1290	S1.0	$2.19{\pm}1.01$ ${\cdot}10^{8}$	P04	44.73	6010	42.50
NGC 3227	0.0039	S1.5	$2.24^{+0.86}_{-0.91}$ $\cdot 10^{7}$	G13	42.56	2934	40.03
NGC 3516	0.0088	S1.5	$3.10^{+0.30}_{-0.26}$ $\cdot 10^{7}$	G13	43.31	4451	
NGC 4051	0.0023	S1.0	$2.2^{+0.2}_{-0.4}$ $\cdot 10^6$	G13	41.67	1633	
NGC 4151	0.0033	S1.5	$3.62^{+0.39}_{-0.22}$ $\cdot 10^7$	G13	43.12	4654	40.43
NGC 4593	0.0090	S1.0	$9.1^{+1.7}_{-1.3}$ $\cdot 10^{6}$	G13	43.20	3775	40.68
NGC 5548	0.0172	S1.5	$5.95^{+0.73}_{-0.86}$ $\cdot 10^7$	G13	43.72	6516	41.37
NGC 7469	0.0163	S1.5	$2.70{\pm}0.60$ ${\cdot}10^{7}$	G13	43.60	1758	40.98
PG 0844+349	0.0640	S1.0	$7.24{\pm}2.99{\ \cdot}10^7$	P04		2377	41.99

TABLE 5.1. Calibration Sample.

Notes: (1) AGN names; (2) redshift from Baumgartner et al. (2013); (3) source classification from Landt et al. (2008) or NED (where S1.0 = Seyfert 1, S1.2-S1.5 = intermediate Seyfert 1, S1n = narrow-line Seyfert 1); (4) BH mass (in solar masses) from reverberation mapping campaigns; (5) reference for the BH mass, where D10: Denney et al. (2010) but adopting f = 4.31, G11: Graham et al. (2011), G13: Grier et al. (2013), P04: ? but adopting f = 4.31; (6) logarithm of the 14-195 keV intrinsic luminosity (from Baumgartner et al., 2013); (7) FWHM of the broad emission line component of Pa β (corrected for instrumental resolution) from Landt et al. (2008, 2013); (8) logarithm of the luminosity of the Pa β BLR component from Landt et al. (2008, 2013).



FIGURE 5.1. Black Hole masses determined from optical reverberation campaigns (adopting a geometrical *f*-factor f = 4.31) versus the virial product between the hard X-ray luminosity L_X in the 14-195 keV band and the FWHM of the broad component of the Pa β emission line. The dashed line shows our best fit using the calibration sample shown in Table 5.1, while the continuous line is our best fit (eq. 5.6) including also NGC 4395 as measured by Peterson et al. (2005), but adopting f = 4.31 instead of f = 5.5 (see next chapter for more details).

rescaling the 90% confidence level of the flux in the 14-195 keV band presented in the 70 month Swift/BAT catalogue (Baumgartner et al., 2013) to the 68% confidence level. As far as the FWHM measures are concerned, although in some cases the uncertainties are reported in literature, following the studies of Grupe et al. (2004); Vestergaard and Peterson (2006); Landt et al. (2008); Denney et al. (2009), we have preferred to assume a common uncertainty of 10%.

The best fit provided a slope $a = 0.837 \pm 0.040$ and a y-intercept $b = 7.609 \pm 0.023$ (see dashed line in Figure 5.1). The data have a correlation coefficient r = 0.90, which corresponds to a probability as low as $\sim 10^{-7}$ that the data are randomly extracted from an uncorrelated parent population. The resulting observed spread is 0.24 dex, while the intrinsic spread (i.e. once the contribution from the data uncertainties has been subtracted in quadrature) results to be 0.21 dex.

Following Graham and Scott (2013), we have also used the Tremaine et al.'s (2002) modified version of the routine FITEXY which minimizes the quantity

$$\chi^2 = \sum_{i=1}^{N} \frac{(y_i - ax_i - b)}{\sigma_{y_i}^2 + a^2 \sigma_{x_i}^2 + \varepsilon^2},$$
(5.4)

where the intrinsic scatter (in the y-direction) is denoted by the term ε , and the measurement errors on the N pairs of observables x_i and y_i , (i.e. the virial product (2 log FWHM_{Pa β} + 0.5 log L_X) and the BH masses, respectively) are denoted by σ_{x_i} and σ_{y_i} . It results, indeed, that the intrinsic scatter of 0.21 dex makes the reduced $\chi^2 (\chi^2/\nu)$ from equation 5.4 (where ν are the degrees of freedom) equal to ~1.

5.2.2 Fit of the virial relationship using $L_{Pa\beta}$

In order to look for a virial relationship able to measure the BH masses using only NIR spectroscopic data, we have substituted L_X with $L_{Pa\beta}$ and then, in analogy with the previous section, have performed a linear fit of the form:

$$\log\left(\frac{\mathrm{M}_{\mathrm{BH}}}{\mathrm{M}_{\odot}}\right) = a \cdot \log\left[\left(\frac{\mathrm{FWHM}_{\mathrm{Pa}\beta}}{10^{4}\,\mathrm{km\,s^{-1}}}\right)^{2} \left(\frac{\mathrm{L}_{\mathrm{Pa}\beta}}{10^{40}\,\mathrm{erg\,s^{-1}}}\right)^{0.5}\right] + b. \tag{5.5}$$

In this case the fit was carried out on a sample of 16 AGN as four galaxies miss the $L_{Pa\beta}$ measurement (see Table 5.1). As discussed in the previous section, an uncertainty of 10% on $L_{Pa\beta}$ was used. The best fit provided a slope $a = 0.908 \pm 0.060$ and a y-intercept $b = 7.834 \pm 0.031$ (see dashed line in Figure 5.2). The data have a correlation coefficient r = 0.80, which has a probability as low as $\sim 10^{-4}$ that the data are randomly extracted from an uncorrelated parent population. The resulting observed spread is 0.31 dex, while the intrinsic spread results to be 0.28 dex. Although this relationship has an intrinsic scatter larger than measured in the previous relation using L_X , as already discussed, it has the big advantage that it just needs NIR spectroscopy of the Pa β emission line (without using X-ray observations) to derive the AGN BH mass.



FIGURE 5.2. Black Hole masses determined from optical reverberation campaigns (adopting a geometrical *f*-factor f = 4.31) versus the virial product between the luminosity $L_{Pa\beta}$ and the FWHM of the broad component of the Pa β emission line. The dashed line shows our best fit using the calibration sample shown in Table 5.1, while the continuos line is our best fit (eq. 5.7) including also NGC 4395 as measured by Peterson et al. (2005), but adopting f = 4.31 instead of f = 5.5.

5.3 The BH Mass of NGC 4395

The two above virial relationships can be used to measure the BH mass of NGC 4395, whose line fitting procedure is described in Section 6.2. Thanks to our NIR observations, it results $M_{BH}=1.7 {+1.3 \atop -0.7} \times 10^5 M_{\odot}$ and $M_{BH}=1.9 {+2.2 \atop -1.0} \times 10^5 M_{\odot}$, if the equation based on L_X (for NGC 4395 logL_X=40.79, with a 1 σ uncertainty of 9%; Baumgartner et al., 2013) and $L_{Pa\beta}$ are used, respectively. Because of the spreads of the previous fits, as expected, the mass derived using the X-ray luminosity dependent equation is more accurate than that measured using the relation dependent from the Pa β luminosity. The two estimates are in statistical agreement at less than 1σ confidence level, but are not independent from each other, as they both depend from the same FWHM_{Pa β} measurement. It is therefore not possible to use both of them to derive a weighted mean estimate of the NGC 4395 BH mass. We then consider the measure $M_{BH}=1.7 {+1.3 \atop -0.7} \times 10^5 M_{\odot}$ (based on the more accurate relationship which uses L_X , eq. 5.3) as our best estimate of the BH mass in NGC 4395.

As discussed in section 6.2.1, the BH mass of NGC 4395 has already been estimated by other authors (Peterson et al., 2005; Graham et al., 2011; Edri et al., 2012). Our measure agrees well within the uncertainties, with the above previous measures (once the same geometrical factor f = 4.31 is adopted). The BH mass measure by Graham et al. (2011) is based on the same reverberation mapping analysis of the C $_{\rm IV}$ line by Peterson et al. (2005), then, once f = 4.31is used, both are consistent with M_{BH}=2.81 $^{+0.86}_{-0.66} \times 10^5 M_{\odot}$ (see Figures 5.1 and 5.2, where our Pa β measures and the SWIFT/BAT 14-195 keV luminosity have been used to plot the measure by Peterson et al. (2005)).

The BH mass by Edri et al. (2012) is based on the reverberation mapping analysis of the H β line and, once f = 4.31 is assumed, it corresponds to $M_{BH} = (2.69 \pm 1.42) \times 10^5 M_{\odot}$. If, instead, our Pa β emission-line measures are used together with the relation by Kim et al. (2010, their eq. 10. See discussion in the next section), a BH mass for NGC 4395 of $M_{BH}=1.8 + 1.05 M_{\odot} M_{\odot}$ is obtained. A result very close to our measure.

5.4 Near Infrared SE BH mass relations including NGC 4395

As the previous independent BH mass estimate of NGC 4395 by Peterson et al. (2005) is compatible with our measure, we decided to include the measure by Peterson et al. (2005) in the calibration sample and rerun the fits in order to tie and extend the virial SE relationships at masses as low as $M_{BH} \sim 10^5 M_{\odot}$. This inclusion would not have been possible without our LUCI/LBT spectroscopic observations of the Pa β emission line.

The inclusion of NGC 4395 in the calibration sample does not significantly change the results of the fits. If the relationship based on L_X is used, the best fit provides (see Figure 5.1)

$$\begin{split} \log(M_{\rm BH}/M_{\odot}) &= 0.796(\pm 0.031) \log \left[\left(\frac{\rm FWHM_{Pa\beta}}{10^4 \,\rm km \, s^{-1}} \right)^2 \left(\frac{\rm L_{14-195 keV}}{10^{42} \,\rm erg \, s^{-1}} \right)^{0.5} \right] \\ &+ 7.611 \, (\pm 0.023) \ (\pm 0.20) \ (5.6) \end{split}$$

The resulting observed spread is 0.23 dex, while the intrinsic dispertion is 0.20 dex.

If the relationship based on $L_{Pa\beta}$ is used, the best fit provides (see Figure 5.2)

$$\log(M_{\rm BH}/M_{\odot}) = 0.872(\pm 0.040) \log \left[\left(\frac{\rm FWHM_{Pa\beta}}{10^4 \,\rm km \, s^{-1}} \right)^2 \left(\frac{\rm L_{Pa\beta}}{10^{40} \,\rm erg \, s^{-1}} \right)^{0.5} \right] + 7.830(\pm 0.030) \ (\pm 0.27) \ (5.7)$$

The resulting observed spread is 0.30 dex, while the intrinsic spread results to be 0.27 dex.

The same kind of relationship has been previously measured by Kim et al. (2010) using similar data but covering a narrower BH mass range $(10^7 - 10^9 M_{\odot})$. In order to compare the two relations it is necessary to a) rescale the masses of Kim et al. (2010) to a f = 4.31 geometrical factor instead of the f = 5.5 used by them. b) Followig their analysis we have to correct the Pa β luminosities and FWHM measured by Landt et al. (2008, 2013) for 1.08 and 0.90 factors (respectively), in order to take into account the narrow line component effects in the line profile fits. Once these corrections are applied,

the two relations result in fairly good agreement within the errors: they give the same results for $M_{\rm BH} \sim 10^7$, while at $M_{\rm BH} \sim 10^9$ and $M_{\rm BH} \sim 10^5$ our estimates are ~0.2 dex smaller and larger, respectively.

5.5 Luminosity of the $Pa\beta$ as a function of the 14-195 keV Luminosity

The two above discussed virial relationships (eqs. 5.6 and 5.7) imply that a significant correlation should exist between the Pa β emission line luminosity (the BLR component), $L_{Pa\beta}$, and the 14-195 keV luminosity, L_X . Similar kind of relationships have been already studied and derived by other authors. For example, Panessa et al. (2006) studied the correlation between the H α luminosity and the 2-10 keV luminosity on a sample of 87 Seyfert galaxies and low-z QSOs, finding:

$$\log L_{2-10keV} = 1.06(\pm 0.04) \cdot \log L_{H\alpha} - 1.14 \ (\pm 1.78). \tag{5.8}$$

Using our calibration sample (with NGC 4395 included) we performed a free slope fit of the relation

$$\log\left(\frac{L_{Pa\beta}}{10^{42} \text{erg s}^{-1}}\right) = a \cdot \log\left(\frac{L_{14-195 \text{keV}}}{10^{44} \text{erg s}^{-1}}\right) + b$$
(5.9)

The data $(\log L_{Pa\beta} \text{ and } \log L_X)$ have a correlation coefficient r = 0.97 which corresponds to a probability of $\sim 10^{-10}$ of being drawn from an un-correlated population, while the fit provides a slope $a = 0.963 \pm 0.011$ and a y-intercept $b = -0.500 \pm 0.013$ (dashed line in Figure 5.3), with an intrinsic spread of 0.26 dex. If a unitary slope is assumed, then our fit provides:

$$\log\left(\frac{L_{Pa\beta}}{10^{42} \text{erg s}^{-1}}\right) = \log\left(\frac{L_{14-195 \text{keV}}}{10^{44} \text{erg s}^{-1}}\right) - 0.492(\pm 0.013) \pm 0.26 \qquad (5.10)$$

(see the black continuous line in Figure 5.3). If we assume a photon index $\Gamma = 1.8$ and a ratio of $\log(\text{Pa}\beta/\text{H}\alpha) = -1.2$ (case B recombination), our fit is in partial agreement with eq. 5.8 (from Panessa et al., 2006): eq. 5.8 should be read $\log L_{\text{Pa}\beta} = 0.943 \cdot \log L_{14-195\text{keV}} - 0.5$ which predicts, in the range $42 \leq \log L_{14-195\text{keV}} \leq 46$, BLR Pa β luminosities ~0.4 dex lower than observed on average in our data. This discrepancy could be attributed to the



FIGURE 5.3. Luminosity of the BLR component of the $Pa\beta$ as a function of the intrinsic 14-195 keV band luminosity, L_X . The dashed line is our best fit with free slope, while the black continuous line is our best fit with unitary slope (eq. 5.10).

assumption of a case B recombination ratio between the Pa β and H α lines. There is indeed evidence that in AGN the Paschen line ratios rule out case B recombination (Soifer et al., 2004; Glikman et al., 2006).

Chapter 6

The broad component of BLR emission lines in AGN2

6.1 The FWHM of the emission line components.

In order to perform a reliable line fitting procedure, and thus to derive the FWHM of the emission lines of interest, we decided to use the software *XSPEC*. The uncertainties on each spectrum have been estimated using our own-made MIDAS routine, developed for this purpose. For each target we used 1) the galaxy's spectrum λ calibrated using the sky OH emission lines as a reference, 2) the sky image and 3) the final flux calibrated spectra.

The OH image was used to sample the contribution of the background. Toghether with the galaxy's spectrum and the instrumental properties (gain and number of scientific raw spectra involved in the reduction process), we calculated the noise as:

$$\left(\frac{S}{N}\right)_{\lambda} = \frac{\Phi_{\lambda}}{\sqrt{\Phi_{\lambda} + \Sigma_{\lambda}}},\tag{6.1}$$

where Φ_{λ} is the spectrum flux, while Σ_{λ} is the sky contribution which has been calculated taking into account the extraction aperture. Furthermore, in order to obtain reliable S/N values, we requested that the noise fluctuations were compatible with those measured in a spectral control region, free from particular features, in the flux calibrated spectra.

Although the low redshift of our targets, the spectra have been converted to the rest frame wavelenght. After that, we performed the fit of the emission lines of interest, in order to derive their rest frame full width at half maximum, FWHM_{Rest}. Moreover due to the presence of sistematic errors on the FWHM estimates and following the studies of Grupe et al. (2004), Vestergaard and Peterson (2006), Landt et al. (2008), Denney et al. (2009), we have preferred to assume a common uncertainty of 10% for all the FWHM instead of the fit errors of σ_{λ} .

We found signatures of broad emission line component in $Pa\alpha$, $Pa\beta$, $Pa\gamma$ or He I (depending on the redshift of the source) in 13 out of 41 obscured AGNs of our randomly selected SWIFT70M sample. In the following sections we describe the past literature and the line fitting procedure of each of these sources, while a detailed explanation of target observations are reported in Section 4.2, for LUCI spectrograph, Section 4.3 for ISAAC and Section 4.4 for Xshooter instrument. The data reduction steps, including λ calibration, NIR sky lines sutraction and flux calibrations, are described in Section 4.5.

6.2 NGC 4395

6.2.1 NGC 4395 in the literature

NGC 4395 is a nearby (z=0.0013), surprisingly small bulgeless (Sd) galaxy, hosting one of the smallest active super massive BH $(10^4-10^5 M_{\odot})$ ever found. Contrary to objects of the same kind, the emission-line properties, the optical to X-ray variability pattern and the inferred accretion rate of NGC 4395 are those typical of the Seyfert class, of which this source is usually considered to represent the least luminous member.

The optical spectrum reveals very strong, narrow emission lines showing weak broad wings having full width zero intensity FWZI = 4000-8000 km s⁻¹ in the permitted-line profiles. Based on the relative intensities of the narrow and broad components, Filippenko and Sargent (1989) originally classified the nucleusof NGC 4395 as a type 1.8 or type 1.9 Seyfert. Later, using higher resolution HST spectroscopy, the nucleus of NGC 4395 has been classified as a type 1 Seyfert (Filippenko et al., 1993). The H β and H α broad lines are shown in Figure 6.2.1 left and right side, respectively, taken from Ho et al. (1995) spectra.

NGC 4395 is a hard-spectrum variable X-ray point source (Moran et al. (1999); Ho et al. (2001); Shih et al. (2003)) and it is a compact, high brightness temperature radio source, although it is formally a radio quiet AGN (Moran et al. (1999); Ho and Peng (2001)). Indeed, the stronger flux variability characterizing systematically the soft X-ray bands can be attributed to a complex, multi-zone warm absorber, whose properties have been discussed in detail in



FIGURE 6.1. Optical spectra of NGC4395 from Ho et al. (1995). The broad components of H β (left) and H α (right) are shown.

several works (Iwasawa et al. (2000); Shih et al. (2003)).

Different methods have been employed in the last years to derive the central BH mass of NGC 4395: the first estimate obtained through reverberation mapping of the C $_{\rm IV}$ line is $M_{BH} = (3.6 \pm 1.1) \times 10^5 M_{\odot}$ (Peterson et al., 2005), but it has been halved to $(1.8\pm0.6)\times10^5 M_{\odot}$ due to the updated virial f-factor in Graham et al. (2011). The last up to date broadband photometric reverberation, made by Edri et al. (2012) using the H β line, has found an even lower mass of $M_{BH} = (4.29 \pm 2.6) \times 10^4 M_{\odot}$; this is essentially due to the much smaller geometrical f-factor used (f = 0.75 instead of f = 5.5 used by Peterson et al. (2005)). The lack in this galaxy of a significant bulge and the stringent upper limit of 30 km s⁻¹ on its velocity dispersion confirm a value of the order of $10^4 - 10^5 M_{\odot}$ on its BH mass (Filippenko and Ho, 2003). Anyhow, the nucleous of NGC 4395 falls somewhere between the stellar-mass black holes found in Galactic X-ray binaries and the supermassive black holes residing inside AGN. Thus it can provide useful information about the relationship between these two populations, it provides an opportunity to extend the mass range of the BH mass - bulge galaxy properties scaling relationships toward the low mass end and, in the framework of current models of galaxy evolution in a hierarchical cosmology, it can contain clues about the formation of the first black holes.

6.2.2 NGC 4395: LUCI observations and lines fit

We have observed NGC 4395 on December 5th, 2012, at the LBT with the NIR spectrograph LUCI in the zJ band using the grating 200 H+K in combination with the zJspec filter. We used a $1'' \times 2.8'$ wide slit, corresponding to a ~ 220 km s⁻¹ spectral resolution. The spectrum of NGC 4395 was extracted with an aperture of 1.5" and it was calibrated in flux using a telluric star. The final spectrum is shown in Figure 6.2, left side.



FIGURE 6.2. Left: flux calibrated LUCI/LBT NIR spectrum of NGC 4395. Right: rest frame, flux calibrated LUCI/LBT NIR spectrum of NGC 4395 in proximity of Pa β emission line. The green dashed line shows the narrow component of Pa β , the cyan dashed line shows the [Fe II] λ 12791 Å blended with the Pa β . The red solid line is the broad component of Pa β . The blue dashed line shows the complete fit.

The NGC 4395 LUCI/LBT NIR spectrum (Figure 6.2, left side) is rich of both forbidden and permitted emission lines. It clearly shows broad component in He I and Pa γ , that are well separated, and in the Pa β lines. The presence of an intense narrow [Fe II] λ 12570 Å emission line allowed us to an accurate estimation of the NLR contribution to the Pa β line in the fitting procedure. We fitted the Pa β profile paying attention to disentagle the broad emission from the narrow one Although the redshift of NGC 4395 is quite low the

from the narrow one. Although the redshift of NGC 4395 is quite low, the spectrum has been converted to the rest frame. The continuum has been estimated with a power law, while the contribution from the NLR has been modelled with a Gaussian model whose width has been fixed to that measured for the forbidden emission line [Fe II] λ 12570 Å (FWHM_{Rest} = 211 km s⁻¹).

	LUCI/LBT NGC 4395 Pa β line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$		
	[Å]	[Å]	$[\times 10^{-14}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[Fe п]	12584.00 ± 0.12	3.84 fixed	$9.22 {\pm} 0.43$	211		
[Fe $\scriptstyle\rm II$] blend *	$12806.80 {\pm} 0.14$	3.84 fixed	$1.45 {\pm} 0.78$	211		
${\rm Pa}\beta$ Narrow *	$12837.10 {\pm} 0.14$	3.84 fixed	$10.35 {\pm} 0.95$	211		
${\rm Pa}\beta$ Broad	$12834.00 {\pm} 0.40$	$14.29 {\pm} 0.13$	$27.88{\pm}1.48$	755		
Powerlaw : $\Gamma = -2.09 \pm 0.92$						
	$\chi^2_{ u}$ =	$= 0.99, \nu = 64$				

TABLE 6.1. Pa β line fit parameters for the LUCI/LBT spectrum of NGC 4395. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. * σ_{λ} fixed to [Fe II] line

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

Then, following the NIR transitions listed in Landt et al. (2008) (see their Table 4), we added a Gaussian to measure the contamination of the [Fe II] λ 12791 Å which is in blending with the Pa β (see Figure 6.2, right side). We added two Gaussians for the Pa β : a narrow, like the NLR, and one broad. The latter results to have FWHM_{Rest}= 786 km s⁻¹. After correction for the instrumental broadening it results a FWHM_{Rest}=755 km s⁻¹. We note that the broad component of the Pa β is blueshifted with respect to the narrow one of ~3 Å. The Fit parameters are shown in Table 6.1

6.3 2MASX J11+19

2MASX J11271632+1909198 is an optically classified Seyfert 1.8 galaxy (Véron-Cetty and Véron, 2010) at redshift z=0.1059, the higher of our sample. Its BH mass has been estimated using the stellar K-band from Two Micron All-Sky Survey (2MASS) photometry and it results to be $\log(M_{BH})=9.00 \text{ M}_{\odot}$ (Winter et al., 2010).

6.3.1 2MASX J11+19: LUCI observations and lines fit

We observed 2MASX J11+19 on December 6, 2012, at the LBT with the LUCI NIR spectrograph in the zJ band using the grating 200 H+K and also in K band using the grating zJHK K filter. We used a $1'' \times 2.8'$ wide slit corresponding to a ~ 220 km s⁻¹ spectral resolution for the zJ band and to a ~ 87 km s⁻¹ spectral resolution for th K band. The spectrum of 2MASX J11+19 was extracted with an aperture of 1.5" and the final J-band and K-band spectra are shown in Figure 6.3, left side, and 6.4, left side, respectively.



FIGURE 6.3. Left: Flux calibrated LUCI/LBT J-Band spectrum of 2MASX J11+19. Right: Rest frame, flux calibrated LUCI/LBT J-Band spectrum of 2MASX J11+19 in proximity of He I + Pa γ emission lines. The green dashed line shows the narrow component of He I, the blue solid line is the broad component of He I. The magenta solid line shows the complete fit.

The LUCI/LBT J-band spectrum (Figure 6.3, left side) shows an intense He $_{\rm I}$ emission line, well separated from a weaker Pa γ line. The spectrum has been converted to the rest frame for the fitting procedure. We fitted the He $_{\rm I}$ profile paying attention to disentagle the broad line from the narrow one. The continuum has been estimated with a power law, while the contribution from the NLR has been modelled with a Gaussian model that results to be center at $\lambda_c = 11977.5$ Åand a FWHM_{Rest} = 145 km s^{-1}. We added a gaussians for the He $_{\rm I}$ broad component, that results to have FWHM_{Rest} = 728 km s^{-1} at $\lambda_c = 11979.5$ Å, redshifted of ~ 2 Å respect the narrow line. We performed a line fit also for the Pa γ , although it is very weak, we modelled it with one gaussian component of FWHM_{Rest} = 544 km s^{-1} and $\lambda_c = 12096.5$ Å. We were



FIGURE 6.4. Left: Flux calibrated LUCI/LBT K-Band spectrum of 2MASX J11+19. Right: Rest frame, flux calibrated LUCI/LBT K-Band spectrum of 2MASX J11+19 in proximity of Pa α emission line. The green dashed line shows the narrow component of Pa α , the blue solid line is the broad component of Pa α . The magenta solid line shows the complete fit.

not	able	e to i	resol	ve t	he co	ontrib	ution	of	the I	NLR	for	the	$Pa\gamma$, b	out	we	noti	ced
that	its	widt	th is	bro	ader	than	the I	Іе 1	narr	ow l	ine (of \sim	400	km	s^{-1}	• • *	The	Fit

2MASX J11+19 He $_{1}$ +Pa γ line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
He 1 Narrow	$11977.5 {\pm} 0.4$	$2.7{\pm}0.6$	$1.3 {\pm} 0.6$	145	
He 1 Broad	$11979.5 {\pm} 0.2$	$13.7{\pm}0.2$	$9.7{\pm}0.8$	728	
$\mathrm{Pa}\gamma$ Broad	12096.5 ± 2.0	$10.3{\pm}0.3$	$1.4{\pm}0.5$	544	
Powerlaw : $\Gamma = 1.0 \pm 0.2$					
	$\chi^2_{\nu} =$	$= 3.69, \nu = 2$	69		

TABLE 6.2. He I +Pa γ line fit parameters for the LUCI J-Band spectrum of 2MASX J11+19. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM.

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

2MASX J11+19 Pa α line fit						
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[\mathbf{km} \ \mathbf{s}^{-1} \]$		
(1)	(2)	(3)	(4)	(5)		
$Pa\alpha$ Narrow	$20739.1 {\pm} 0.5$	$8.8 {\pm} 0.5$	$1.9{\pm}0.2$	272		
$\mathrm{Pa}\alpha$ Broad	20725.6 ± 1.8	$20.0{\pm}1.0$	2.2 ± 0.3	616		
Powerlaw : $\Gamma = -1.2 \pm 0.1$						
	$\chi^{2}_{ u}=$	= 2.28, ν =2	66			

TABLE 6.3. Pa α line fit parameters for the LUCI K-Band spectrum of 2MASX J11+19. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

parameters are shown in Table 6.2.

The LUCI/LBT K-band spectrum (Figure 6.4, left side) shows an intense Pa α emission line. The spectrum has been converted to the rest frame for the fitting procedure. We fitted the Pa α profile paying attention at disentagling the broad emission from the narrow one, though we did not have a reliable narrow forbidden line to use to constrain the NRL contribution. The continuum has been estimated with a power law, while the contribution from the Narrow Line Region (NLR) has been modelled with a Gaussian model that results to be center at $\lambda_c = 20739.1$ Å and with a FWHM_{Rest}=272 km s⁻¹. We have added a gaussian for the Pa α broad component, that results to have FWHM_{Rest}=616 km s⁻¹ and center at $\lambda_c = 20725.6$ Å, blueshifted of ~13 Å with respect to the narrow line. The Fit parameters are shown in Table 6.3.

6.4 MCG -05-23-16

6.4.1 MCG -05-23-16 in the literature

MCG -05-23-016 is an X-ray bright, nearby S0 galaxy (z=0.008486), optically classified as a Seyfert 1.9 galaxy (Veron et al., 1980). It is one of the bright-

est Seyfert galaxies in the 2-10 keV band and it is also been detected in the hard X-ray above 20 keV with BeppoSAX/PDS (e.g Balestra et al. 2004), IN-TEGRAL/IBIS (Soldi et al., 2005) and Swift/BAT (Tueller et al. 2008, Tueller et al. 2010, Baumgartner et al. 2013). Its X-ray spectrum resembles a classical Compton-thin Seyfert 2 galaxy, with a column density $N_H \simeq 10^{22} \text{ cm}^{-2}$ (Balestra et al., 2004). The spectrum below 1 keV contains a combination of emission from scattered continuum photons and distant photoionized gas. Above 2 keV, the spectrum shows both the narrow and the broad iron K α lines along with a strong Compton hump above 10 keV (Weaver et al. 1997, Mattson and Weaver 2004, Braito et al. 2006, Reeves et al. 2007).

This source hosts a comparably low-mass black hole, accreting at a high Eddington rate. The first estimate of the black hole mass of MCG -05-23-016 was made by Wandel and Mushotzky (1986) using the [O III] line width as a proxy for the stellar velocity dispertion in the relationship M_{BH} - σ , finding a black hole mass of M_{BH} =5×10⁷ M_{\odot} .

In a similar way Wang and Zhang (2007) obtained $M_{BH} = 2 \times 10^6 M_{\odot}$. They used the width of the [O III] line (Greene and Ho, 2005a) to obtain the black hole mass from the M_{BH} - σ relation (Tremaine et al., 2002) and give the error of the measurment with 0.7 dex. The low mass of the central black hole implies that the accretion onto the central engine take place at a high Eddington ratio ($L_{bol}/L_{Edd} \geq 0.4$). High accretion flows are the key element in order to understand the rapid growth of black holes in the early Universe and object like MCG -05-23-16 might indicate the early stages of supermassive black holes in which a strong accretion flow feeds the central engine (Beckmann et al., 2008).

6.4.2 MCG -05-23-16: ISAAC observations and lines fit

We have observed MCG -05-23-16 on January the 1th, 2012 at the VLT with the IR spectrograph ISAAC (mounted on the Nasmyth A focus of UT3 till the 12th December 2013) in the J band using both LR and MR instrument modes. We used a 0.8" ×1.0" wide slit corresponding to a ~ 430 km s⁻¹ spectral resolution for the LR mode and to a ~ 60 km s⁻¹ spectral resolution for the MR modes. The spectrum of MCG -05-23-16 was extracted with an aperture of 0.6" and in Figure 6.5 the LR and MR final spectra are shown. The ISAAC/LR NIR spectrum of MCG -05-23-016 cleary shows broad components for Pa β and He I lines, even though the He I is blended with Pa γ (see Figure 6.5, left side), there are no intense [Fe II] narrow emission lines. We observed the Pa β also with the MR mode to accurately perform the line fit, shown in Figure 6.5, right side. We fitted the Pa β profile paying attention to disentagle the broad component from the narrow one. Although the redshift of MCG -05-23-16 is quite low, the spectrum has been converted to the rest frame.

The continuum has been estimated with a power law, while the contribution from the NLR has been modelled with a Gaussian model, but it was not possible to fix its width to a NLR emission line, due to the lack of forbidden narrow emission lines in the spectrum. Following the NIR transitions listed in Landt et al. (2008) (see their Table 4), we have added a gaussian to measure the contamination of the [Fe II] λ 12791Å which is in blending with the Pa β . We have added three gaussian for the Pa β : the narrow and two broad components. The narrow Pa β results to have a rest frame FWHM of 256 km s⁻¹ and is centered at λ_c =12930.3 Å. The first broad component results to have a rest frame FWHM of 1049 km s⁻¹ at λ_c = 12933.6 Å, redshifted of ~ 3 Å with respect to the narrow one, while the second broad component have a rest frame FWHM of 3149 km s⁻¹ and it is centered at λ_c =12921.8 Å, blueshifted of ~ 8 Å with respect to the narrow gaussian. In Table 6.4 the fit parameters are reported.

6.4.3 MCG -05-23-16: Xshooter observations and lines fit

We have observed MCG -05-23-16 on 11 February 2013 at the VLT with the multi-wavelength (3000-25000 Å) medium resolution spectrograph Xshooter (mounted on the UT3) that allowed us to obtain MCG -05-23-16 spectra in the UVB (3000-5595.0 Å), VIS (5595-10240 Å) and NIR (10240 -24800 Å) bands in a single observation. We used a $1.0^{\circ} \times 11^{\circ}$ wide slit for the UVB arm and a $0.9^{\circ} \times 11^{\circ}$ for the VIS and NIR arms, corresponding to a ~60km s⁻¹ spectral resolution. The spectrum of MCG -05-23-16 was extracted with an aperture of 1.5''. The UVB, VIS and NIR final spectra are shown in Figures 6.9, 6.8

ISAAC MCG -05-23-16 Pa eta line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
$Pa\beta$ Narrow	$12930.30 {\pm} 0.29$	$4.72 {\pm} 0.35$	$5.0{\pm}1.1$	256	
$\mathrm{Pa}\beta$ Broad	$12933.60 {\pm} 0.59$	$19.36{\pm}10.70$	$38.6 {\pm} 4.0$	1049	
$\mathrm{Pa}\beta$ Broad	12921.8 ± 1.1	58.08 ± 1.83	74.9 ± 3.9	3149	
[Fe II] *	12901.5 ± 1.2	$7.08 {\pm} 0.94$	$2.49{\pm}1.28$	385	
[Fe 11]	12784.0 ± 1.2	$7.01 {\pm} 0.94$	$1.70{\pm}0.56$	385	
	Powerla	$\mathbf{aw:} \ \Gamma = 0.63 \pm$	0.21		
	$\chi^{2}_{ u}$	$= 0.8, \nu = 333$			

TABLE 6.4. Pa β line fit parameters for the ISAAC/MR spectrum of MCG -05-23-16. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. * σ_{λ} fixed to [Fe II] line

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.5. Left: low resolution NIR spectra of MCG -05-23-16 obtained with ISAAC/VLT. Right: medium resolution NIR ISAAC spectrum of MCG -05-23-16 and the fit of the Pa β emission line (magenta solid line). We identified three components for the Pa β : a narrow one (green dashed line), a broad component (blue dashed line) and another broad component (red dashed line). The cyano dashed line indicated the [Fe II] emission line in blend with the Pa β .

and 6.6, respectively.

The Xshooter NIR spectrum of MCG -05-23-016 shows broad components for $Pa\beta$ and He I lines, but the He I is still blended with $Pa\gamma$. In addiction there are also [S IX] and [Fe II] narrow lines (see Figure 6.6, left side).

We have fitted the Pa β profile disentagling the broad component from the narrow one. Although the redshift of MCG -05-23-16 is quite low, the spectrum has been converted to the rest frame. The continuum has been estimated with a power law, while the contribution from the NLR has been modelled as a Gaussian model with the line width fixed to the [S IX] narrow line. The Pa β line fit have been performed adding three gaussian components: the narrow Pa β results to have a rest frame FWHM=258 km s⁻¹ and it is centered at λ_c =12927.9 Å, the first broad component results to have a rest frame FWHM=1496 km s⁻¹, centered at λ_c =12925.6 Å, blueshifted of ~ 2 Å with respect to the narrow one, while the second broad component have a rest frame FWHM=3976 km s⁻¹ and it is centered λ_c =12901.2 Å, blueshifted of ~ 27 Å with respect the narrow gaussian. Following the NIR transitions listed in Landt et al. (2008), Table 4, we have added a gaussian to measure the contamination of the [Fe II] λ 12791Å which is known to be in blending with the Pa β , but its contribution to the line profile can be neglected. In Table

6.5 the fit parameters are shown.



FIGURE 6.6. Left: NIR spectrum of MCG -05-23-16 obtained whith Xshooter at VLT. Right: Pa β line fit (solid magenta line). We identified three gaussian components for the Pa β : the narrow component is shown by the green dashed line, the first broad component is represented by the blue dashed line and the other broad component is the shown with the red dashed line.

Similary to the $Pa\beta$, we have been able to perform the line fit also for He I and $Pa\gamma$, shown in Figure 6.7. The continuum has been estimated with a powerlaw and the contribution from the NLR has been taken into account modelling the narrow components for both He I and $Pa\gamma$ with a gaussian profile whose width has been fixed to the [S IX] narrow line width. In this case we found only one broad component for each line.

The He I narrow line results in a FWHM_{Rest}=258 km s⁻¹ and it is centered at λ_c =10927.5 Å, morever it shows an auto-absorption line, that we modelled with a gaussian of FWHM_{Rest}=258 km s⁻¹ and λ_c =1091.50 Å. The broad component have a FWHM_{rest} = 2341 km s⁻¹ at λ_c =10922.1 Å, blueshifted of ~ 5 Å with respect to the narrow emission line.

The Pa γ narrow component shows a FWHM_{Rest}258 km s⁻¹, centered at $\lambda_c = 11033.0$ Å, while the broad one have a FWHM_{Rest}=1938 km s⁻¹ at λ_c =11026.6 Å, blueshifted of ~6 Å with respect to the narrow one. In Table 6.6 the fitting parameters are shown.

Thanks to the capability of the multiwavelenght spectrograph Xshooter it has been possible to obtain also a medium resolution $(R = \frac{\lambda}{\Delta\lambda} = 7450)$ optical and UVB spectra of MCG -05-23-16 that allowed us to perform a line fit for the

Xshooter MCG -05-23-16 $\mathbf{Pa}\beta$ line fit						
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{f km}~{f s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
Pa β Narrow *	$12927.9 {\pm} 0.3$	$4.75 {\pm} 0.34$	$1.22 {\pm} 0.12$	258		
${\rm Pa}\beta$ Broad	$12925.6 {\pm} 0.6$	$27.60 {\pm} 0.82$	$12.79 {\pm} 0.59$	1496		
${\rm Pa}\beta$ Broad	12901.2 ± 4.5	$73.24 {\pm} 4.53$	$8.85{\pm}0.66$	3976		
[S IX] *	$12629.7 {\pm} 0.7$	$4.64 {\pm} 0.34$	$0.50{\pm}0.06$	258		
[Fe II] *	$12673.6 {\pm} 2.1$	$4.65 {\pm} 0.34$	$0.16{\pm}0.05$	258		
[Fe II] *	$12807.5 {\pm} 0.9$	$4.70 {\pm} 0.34$	$0.38{\pm}0.06$	258		
Powerlaw : $\Gamma = -0.6 \pm 0.1$						
	χ_1^2	$\nu^2 = 1.4, \nu = 306$				

TABLE 6.5. Pa β line fitting parameters for the Xshooter NIR spectrum of MCG -05-23-16. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [S IX] narrow line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

Xshooter MCG -05-23-16 He $\scriptstyle\rm I$ and Pa γ line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
He I Narrow *	$10927.5 {\pm} 0.2$	$4.0 {\pm} 0.7$	$2.8 {\pm} 0.1$	258	
He $_{\rm I}$ Abs *	$10915.0 {\pm} 0.1$	$4.0 {\pm} 0.7$	$-2.99 {\pm} 0.07$	258	
He 1 Broad	$10922.1\ {\pm}0.5$	$36.49 {\pm} 0.63$	$25.0 {\pm} 0.4$	2341	
$Pa\gamma$ Narrow [*]	$11033.0 {\pm} 0.8$	$4.1 {\pm} 0.7$	$0.45{\pm}0.07$	258	
$\mathrm{Pa}\gamma$ Broad	11026.6 ± 1.0	30.52 ± 1.14	$10.4 {\pm} 0.4$	1938	
Powerlaw : $\Gamma = 0.4 \pm 0.2$					
	$\chi^{m 2}_{ u}$	$= 4.6, \nu = 209$)		

TABLE 6.6. He I and Pa γ line fit parameters for the Xshooter NIR spectrum of MCG -05-23-16. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [S IX] narrow line.

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.7. Left: NIR spectrum of MCG-05-23-16 obtained with Xshooter at VLT. Right: the line fit for He I and Pa γ (magenta solid line). We identified two emission component for both lines: one narrow (green dashed lines), whose width is fixed to the [S IX] narrow line, and one broad (red dashed line and blue dashed line, respectively).

 $H\alpha$ and [N II] doublet emission lines, shown in Figure 6.8 and of the $H\beta$ and [O III] doublet emission lines, shown in Figure 6.9.

In the optical spectrum we modeled the continuum with a power law and each [N II] lines with a narrow gaussian component with a FWHM_{Rest}=214 km s⁻¹ centered at λ_c =6603.07 Å and λ_c =6638.69 Å, respectively. The H α line has been modeled with two gaussian component: the narrow one, whose width has been fixed to the [N II] narrow line in order to take into account for the NLR contribution, results to be centered at λ_c =6617.95 Å, while the broad component results to be centered at λ_c =6617.39 Å and has a FWHM_{Rest} 2219 km s⁻¹, we noticed that it is blueshifted of ~0.5 Å with respect to the narrow component. In Table 6.7 the fit parameters are shown.

The UVB spectrum does not show a broad H β . As we did for the optical spectrum, we modelled the continuum with a power law and we fitted the H β + [O III] doublet with a narrow gaussian component for each line. Tha width of all the narrow lines has been fixed to that of the [O III], in order to carefully take into account for the NLR contribution. They result to have a FWHM_{Rest}=222 km s⁻¹, centered at λ_c = 4901.6 Å for H β , at λ_c =5000.3 Å and at λ_c = 5048.6 Å for the [O III] doublet. The fit parameters are shown in Table 6.8

Xsho	Xshooter MCG -05-23-16 H α and [N II] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[N II]	$6603.07 {\pm} 0.04$	$2.0 {\pm} 0.01$	$1.05 {\pm} 0.02$	214		
[N II] *	$6638.69 {\pm} 0.01$	$2.0{\pm}0.01$	$3.45{\pm}0.02$	214		
$H\alpha$ Narrow [*]	$6617.95 {\pm} 0.01$	$2.0 {\pm} 0.01$	$4.02{\pm}0.02$	214		
$H\alpha$ Broad	$6617.39 {\pm} 0.02$	$20.96 {\pm} 0.13$	$7.27{\pm}0.02$	2219		
Powerlaw : $\Gamma = -2.0 \pm 0.3$						
	$\chi^{m 2}_{ u}$ =	$= 1.36, \nu = 889$	9			

TABLE 6.7. H α and [N II] line fit parameters for the Xshooter VIS spectrum of MCG -05-23-16.(1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [N II] narrow line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

Xshoo	Xshooter MCG -05-23-16 H eta and [O $\scriptstyle m III$] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[O III]	$5000.28 {\pm} 0.09$	$1.6{\pm}0.07$	$1.94{\pm}0.04$	222		
[O III] *	$5048.56 {\pm} 0.08$	$1.6{\pm}0.07$	$5.58{\pm}0.05$	222		
${\rm H}\beta$ Narrow*	$4901.58 {\pm} 0.09$	$1.5{\pm}0.07$	$0.45{\pm}0.04$	222		
Powerlaw : $\Gamma = -0.12 \pm 0.38$						
	$\chi^2_{\nu} = 0.57, \ \nu = 990$					

TABLE 6.8. H β and [O III] line fit parameters for the Xshooter UVB spectrum of MCG -05-23-16. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [O III] narrow line.

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.8. Left: Optical spectrum of MCG-05-23-16 obtained with Xshooter at VLT. Right: The H α + [N II] line fit (magenta solid line). We fitted the H α with two gaussian components: the narrow one represented by the green dashed line and the broad component (red dashed line).



FIGURE 6.9. Left: UVB spectrum of MCG-05-23-26 obtained with Xshooter at VLT. Right: Fit of $H\beta$ + [O III] lines (magenta solid line). No broad component has been obtained for the $H\beta$ line and also for the [O III] doublet.

6.5 LEDA 093974

6.5.1 LEDA 093974 in the literature

LEDA 093974 is a nearby, FIR IRAS, S0 galaxy with a redshift z=0.0239, also classified like an emission-line spiral galaxy hosting a Seyfert 2 nucleous (Ho et al. 1993; Masetti et al. 2006 and references therein). This source is present in the 2nd IBIS survey (Bassani et al., 2005) and it is detected with fluxes

of 2.9 ± 07 mCrab and 5.9 ± 1.1 mCrab in the 20-40 and 40-100 keV bands, respectively.

The optical spectrum of this galaxy shows a number of narrow emission features that can readily be identified with redshifted optical nebular lines. On the base of the presence of only narrow emission lines in the optical spectrum Masetti et al. (2006) suggested an activity typical of a NLR surrounding an obscured AGN, thus they optically confirmed the Sy2 classification. This was also supported by SUMSS radio detections andby the non detection in the soft xray band. Its X-ray luminosity in the 20-100 keV band of $L_{20-100keV}=1.1\times10^{44}$ erg s⁻¹ places the source among the most luminous Type 2 Seyfert galaxies detected so far (Malizia et al., 1999).

6.5.2 LEDA 093974: Xshooter observations and lines fit

We have observed LEDA 093974 on April, 17th, 2013 at the VLT with Xshooter, thus we have obtained LEDA 093974 spectra in the UVB (3000-5595.0 Å), VIS (5595-10240 Å) and NIR (10240-24800 Å) bands in a single observation. The spectrum of LEDA 093974 was extracted with an aperture of 1.5". The NIR, VIS and UVB final spectra are shown in Figures 6.10, 6.12 and 6.13, respectively.

The Xshooter NIR spectrum of LEDA 093974 shows an intense He I emission line, but it is on the edge of the telluric absorptions and the Pa γ falls into this noisy band. Unfortunately, also the Pa β falls into the noise, thus it was very hard to perform a reliable fit on it. There are also two intense forbidden [Fe II] emission lines, one of them is blended by the [S IX] line.

Despite its very noisy spectrum, we performed a fit for the Pa β . The continuum has been estimated with a power law, while the contribution from the NLR has been estimated from the gaussian narrow component of the intense [Fe II]. It results to be centered at λ_c =1286.60 Å and it has a FWHM_{Rest}= 319 km s⁻¹. The [Fe II] lines also show a broad component centered at λ_c =1285.97 Å and a FWHM_{Rest}=840 km s⁻¹. The [S IX] result to have only one narrow component centered at λ_c =1281.40 Å with a FWHM_{Rest}=319 km s⁻¹, fixed to the narrow [Fe II]. We modelled the Pa β with a narrow gaussian, whose width has been tied to the narrow component of [Fe II], to take into account for the

NLR emission, the weak broad component result to be centered at λ_c =1309.73 Å and with a FWHM_{Rest}= 900 km s⁻¹ but, since the [Fe II] λ 12791 Å, in blending with Pa β , turned out to be at λ_c =1309.25 km s⁻¹, we think that this broad component came from the [Fe II] rather than hidrogen from the BLR. The fit parameters are shown in Table 6.9.



FIGURE 6.10. Left: Rest frame, flux calibrated Xshooter NIR spectrum of LEDA 093974. Right: Fit of $Pa\beta + [Fe II]$ lines (magenta solid line). The green dashed lines show the narrow component of [Fe II], [S IX] and $Pa\beta$ lines, while the bue dashed line represent the broad components of both $Pa\beta$ and [Fe II].

The He I line is more intense than $Pa\beta$ and it also shows a line broadening (see Figure 6.11). We modelled it with a narrow component with the width tied to the [Fe II] narrow line in order to accurately disentagle the broad emission from the narrow one. The narrow He I is centered at $\lambda_c=1109.02$ Å with a FWHM_{Rest}=319 km s⁻¹, while the broad component results to be centered at $\lambda_c=1108.23$ Å and has a FWHM_{Rest}=1107 km s⁻¹. The fit parameters are shown in Table 6.10.

The optical spectrum of LEDA 093974 shows an intense $H\alpha + [N n]$ doublet, see Figure 6.12. In the fitting procedure the continuum has been modelled with a power law and we used the [N n] lines to estimate the NLR contribution to the line emission. Both the [N n] lines shows two components, the narrow ones are centered at $\lambda_c = 6705.01$ Å and $\lambda_c = 6741.18$ Å, respectively, they have a FWHM_{Rest}=161 km s⁻¹. They also show two broad components centered at $\lambda_c = 6702.37$ Å and $\lambda_c = 6740.28$, respectively, with a FWHM_{Rest}= 473 km s⁻¹. The H α shows a symmetric, broad component in addiction to the narrow one.

Xsho	Xshooter LEDA 093974 Pa eta and [Fe II] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{f km}~{f s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[S IX] *	1281.40 ± 0.04	$0.59{\pm}0.02$	$0.16{\pm}0.02$	319		
[Fe II] Narrow	$1286.60 {\pm} 0.02$	$0.59{\pm}0.02$	$0.51{\pm}0.06$	319		
[Fe II] Broad	$1285.97 {\pm} 0.09$	$1.54{\pm}0.08$	$0.54\ {\pm}0.07$	840		
[Fe 11] *	$1309.25 {\pm} 0.09$	$0.60{\pm}0.02$	$0.0{\pm}0.0$			
${\rm Pa}\beta$ Narrow*	$1312.24{\pm}0.06$	$0.60{\pm}0.02$	$0.14{\pm}0.04$	319		
${\rm Pa}\beta$ Broad	$1309.73 {\pm} 0.4$	$1.7 {\pm} 0.6$	$0.14{\pm}0.06$	900		
Powerlaw : $\Gamma = 0.75 \pm 0.18$						
	$\chi^{m 2}_{ u}$ =	= 1.52, ν =20	8			

TABLE 6.9. Pa β and [Fe II] line fit parameters for the Xshooter NIR spectrum of LEDA 093974. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.11. Fit of He I line (magenta solid line). The green dashed lines show the He I narrow component, while the bue dashed line represent the broad one.

The latter is centered at $\lambda_c = 6719.85$ Å and its width has been tied to the [N II] narrow line, while the broad component has the center at $\lambda_c = 6720.20$ Å and a FWHM_{Rest}=1742 km s⁻¹. The fit parameters are shown in Table 6.11.

The Xshoter UVB spectrum of LEDA 093974 shows an H β with no signature of a broad component, see Figure 6.13. Both the [O III] lines have been

Xshooter LEDA 093974 He I line fit						
Component	$Component$ $\lambda_{\mathbf{c}}$ σ_{λ} $Norm_{Rest}$ $FWHM_{Rest}$					
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
He I Narrow*	11090.2 ± 0.2	5.1 ± 0.2	$0.45 {\pm} 0.03$	319		
He 1 Broad	$11082.3 {\pm} 0.8$	$17.8{\pm}0.8$	$0.76{\pm}0.07$	1107		
Powerlaw : $\Gamma = 1.00 \pm 0.56$						
	$\chi^{2}_{ u}$	$= 8.0, \nu = 9$	07			

TABLE 6.10. He I line fit parameters for the Xshooter NIR spectrum of LEDA 093974. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line.

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

Xshooter LEDA 093974 H α + [N II] line fit						
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[N II] Narrow	$6705.01 {\pm} 0.03$	$1.56 {\pm} 0.01$	$0.26 {\pm} 0.01$	161		
[N II] Narrow [*]	$6741.18{\pm}0.01$	$1.57{\pm}0.01$	$0.68{\pm}0.02$	161		
[N II] Broad	$6702.37{\pm}0.1$	$4.59{\pm}0.04$	$0.29{\pm}0.02$	473		
[N II] Broad**	$6740.28 {\pm} 0.05$	$4.62 {\pm} 0.04$	$1.69{\pm}0.03$	473		
$H\alpha$ Narrow*	$6719.85 {\pm} 0.01$	$1.57{\pm}0.01$	$0.53{\pm}0.01$	161		
$H\alpha$ Broad	$6720.20 {\pm} 0.01$	$16.96 {\pm} 0.01$	$2.79{\pm}0.05$	1742		
Powerlaw : Γ = 3.80 ± 0.14						
$\chi^2_{\nu} = 3.4, \ \nu = 834$						

TABLE 6.11. $\text{H}\alpha + [\text{N II}]$ line fit parameters for the Xshooter VIS spectrum of LEDA 093974. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [N II] narrow line; $**\sigma_{\lambda}$ fixed to [N II] broad line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.12. Left: Rest frame, flux calibrated Xshooter VIS spectrum of LEDA 093974. Right: Fit of H α + [N II] lines (magenta solid line). The green dashed lines show the narrow component of H α and [N II] doublet, the bue dashed line represent the broad components found in [N II] doublet, the red dashed line shows the broad H α component.

modelled using two components. The narrow ones are centered at λ_c =5077.49 Å and λ_c =5126.43 Å with a FWHM_{Rest}= 162 km s⁻¹, in agreement with the FWHM found in the VIS spectrum for the NLR components of [N II]. The broad components are centered at λ_c =5074.28 Å and λ_c =512.357 Å, with a FWHM_{Rest}= 750 km s⁻¹. Confirming the intermediate classification of LEDA 093974, the H β does not show any broad component and it has been modelled with one narrow gaussian with the width fixed to the narrow [O III] and λ_c =4977.57 Å. The fit parameters are shown in Table 6.12.



FIGURE 6.13. Left: rest frame, flux calibrated Xshooter UVB spectrum of LEDA 093974. Right: fit of H β + [O III] lines (magenta solid line). The green dashed lines show the narrow component of H β and [O III] doublet, the blue dashed line represent the broad components found in [O III] doublet.

Xshooter LEDA 093974 H β + [O III] line fit						
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[O III] Narrow	$5077.49 {\pm} 0.007$	$1.193 {\pm} 0.007$	$0.188 {\pm} 0.006$	162		
[O III] Narrow*	$5126.43 {\pm} 0.01$	$1.205 {\pm} 0.007$	$0.590{\pm}0.008$	162		
[O III] Broad	$5074.28 {\pm} 0.13$	$5.51 {\pm} 0.05$	$0.32{\pm}0.02$	750		
[O III] Broad**	$5123.57 {\pm} 0.06$	$5.57 {\pm} 0.05$	$0.80 {\pm} 0.02$	750		
${\rm H}\beta$ Narrow*	$4977.57 {\pm} 0.05$	$1.170 {\pm} 0.007$	$8.20 {\pm} 0.06$	162		
Powerlaw : $\Gamma = -0.6 \pm 0.1$						
$\chi^2_{\nu} = 2.18, \nu = 1236$						

TABLE 6.12. $\text{H}\alpha + [\text{N II}]$ line fit parameters for the Xshooter UVB spectrum of LEDA 093974. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [O III] narrow line; $*\sigma_{\lambda}$ fixed to [O III] broad line

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

6.6 NGC 6221

6.6.1 NGC 6221 in the literature

NGC 6221 is a nearby, barred spiral SBc galaxy at redshift z=0.0050 located within a small galaxies group and it is known to exhibit clear signs of intense circumnuclear star formations (Boisson et al., 2002). Its peculiar morphology may be due to the interaction with NGC 6215. Koribalski and Dickey (2004) describe the presence of an HI gas bridge halfway between these two galaxies that may have fallen back to them. The unusual HI kinematics has been interpred by the authors as the result of a collision between NGC 6215 and the outer HI disc of NGC 6221 that is likely to have caused enhanced star formation in both galaxies and later, reaccreted HI gas with low angular momentum may sink towards the nuclear region, causing ongoing star formation in both galaxies and providing fuel for the active nucleus of NGC 6221. Moreover, the authors derive the dynamical mass of NGC 6221 and its SFR, that result to be $M_{tot}=8\times10^{10} M_{\odot}$ and SFR=15 $M_{\odot}y^{-1}$, respectively.

NGC 6221 can be described as a X-ray-loud composite galaxy since its optical spectrum shows the typical feature of a sturbust galaxy and it has been classified as a Seyfert 2 galaxy on the base of $[O_{III}]/H\beta$ intensity ratio (Pence and Blackman (1984); Levenson et al. (2001)), while in the X-ray it appears similar to Seyfert 1 galaxies, exhibiting a power-law continuum, a broad Fe K α line and continuum variability on timescales of days and years. An obscuring starburst, in which the interstellar gas and dust associated with the starburst conceal the active nucleous, can explain this peculiar features. Thus, it can be described in a Seyfert 2/starburst scenario, in which a faint AGN NLR is superposed on a dominant H II region powered by massive star. Moreover, in the optical nuclear spectrum the broad and blue component dominates the [OIII] profile, extending to more than 1000 Km/s, while in the H β the narrow component dominate (Levenson et al. (2001) and references therein). These optical features indicate that the intrinsic shape of the NLR is roughly conical, and its inclination allow us to see the object from the opening angle of a cone. that appears circular if projected onto the plane of the sky. This geometry implies that without the obscuring sturburst, NGC 6221 would be classified as a Syfert 1 galaxy (Levenson et al., 2001). The authors also presented HST images of the central region of NGC 6221 in the optical (F606W/WFPC2) and
in the NIR (F160W/NICMOS) and identified the bright central NIR source as the AGN (see Figure 6.14. At optical wavelengths, the nucleus is more diffuse and weaker than other bright knots, identified as star clusters, while in the NIR tha AGN nucleous arises. This make NGC 6221 an ideal candidate for our NIR analysis.



FIGURE 6.14. Images of NGC 6221 central region in the optical (left panel) and NIR (right panel). The brightest central source detected at 1.6 μ m is the AGN and it is relatively week in the optical (Levenson et al., 2001).

6.6.2 NGC 6221: Xshooter observations and line fit

We have observed NGC 6221 on April, 24th, 2014 at the VLT with Xshooter. The final 2D spectrum was extracted with an aperture of 1.0" and the NIR and VIS final spectra are shown in Figures 6.15 and 6.17, respectively.

The NIR spectrum of NGC 6221 shows a number of emission lines, like the intense forbidden [Fe II], and several permitted emission lines (see Figure 6.15). In particular the He I is very intense and well separated from the Pa γ , allowing us to perform the line fit on both the BLR lines. Moreover the Pa γ has a very good S/N ratio and the presence of a clear [Fe II] narrow emission line allowed us to accurately model the NLR contribution for all the BLR emission lines.

To derive the [Fe II] profile we needed to add two gaussian components, the narrow one turns out to have its center at $\lambda_c=12626.0$ Å and a FWHM_{Rest}= 141 km s⁻¹ and we use it as a constrain the narrow component of Pa β . The second

component is broader than the first one, with a FWHM_{Rest}=481 km s⁻¹ and it also is blueshifted of ~ 6 Å with respect to the narrow one, having its center at λ_c =12619.8 Å. Surprisingly, also the Pa β line shows a similar profile, with a narrow component, tied in width to the [Fe II] ones and centered at λ_c = 12878.3 Å, and a broader gaussian centered at λ_c =12870.8 Å, thus blueshifted of ~ 7 Å with respect to the narrow line. We have explained those two broad lines as a manifestation of a NLR outflow, thus we tied the width of Pa β outflows to the [Fe II] one. Finally, to accurately reproduce the complete Pa β profile we needed to add a third gaussian component that we can explain as a signature of the BLR gas under the gravitational influence of the nuclear BH. The latter has its center at λ_c =12877.6 Å and a FWHM_{Rest}=2257 km s⁻¹. We notice the it is redshifted of ~7 Å with respect to the narrow component. We also add a gaussian component for the [S IX] and for the [Fe II] λ 12791 Å. See Figure 6.15, right side.



FIGURE 6.15. Left: flux calibrated NIR Xshooter spectrum of NGC 6221. Right: rest frame, flux calibrated NIR Xshooter spectrum of NGC 6221 in the proximity of Pa β and [Fe II] emission lines and the lines fit (magenta solid line). The narrow component of both line are shown with thw green dashed lines, the outflow signatures with the blue dashed lines, while the broad component of Pa β is represented with the red dashed line.

We found a profile similar to the Pa β line also for the Pa γ and He I emission lines (see Figure 6.16). Thus, the He I has been modelled adding three gaussian components: the narrow centered at $\lambda_c=10881.2$ Å, the outflow component with the center at $\lambda_c=10879.3$ Å, blueshifted of ~ 2 Å with respect to the previous component, and the broad one, centered at $\lambda_c=10877.8$ Å and with

Xshooter NGC 6221 Pa β and [Fe II] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[\mathbf{km} \ \mathbf{s}^{-1}]$	
(1)	(2)	(3)	(4)	(5)	
[S 1x]	$12593.5 {\pm} 0.9$	$2.5{\pm}0.02$	$0.09{\pm}0.01$	140	
[Fe II] Narrow	$12626.00 {\pm} 0.05$	$2.54{\pm}0.02$	$0.41{\pm}0.02$	141	
[Fe II] Broad	$12619.8 {\pm} 0.9$	$8.64{\pm}0.2$	0.72 ± 0.03	481	
[Fe II] *	$12846.6\ \pm 0.3$	$2.58{\pm}0.02$	$0.07{\pm}0.01$	141	
${\rm Pa}\beta$ Narrow*	12878.3 ± 0.02	$2.58{\pm}0.02$	$1.29{\pm}0.03$	141	
Pa β Broad**	$12870.8 {\pm} 0.4$	$8.8 {\pm} 0.2$	$0.66{\pm}0.06$	481	
${\rm Pa}\beta$ Broad	12877.6 ± 1.1	$41.4{\pm}1.7$	$1.4{\pm}0.1$	2257	
Powerlaw : $\Gamma = 0.98 \pm 0.18$					
	$\chi^{m 2}_{ u} =$	$= 1.65, \nu = 813$	3		

TABLE 6.13. Pa β and [Fe II] line fit parameters for the Xshooter NIR spectrum of NGC 6221. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line; $**\sigma_{\lambda}$ fixed to [Fe II] broad line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

a FWHM_{Rest}= 1637 km s⁻¹. The narrow Pa γ line is centered at λ_c =10989.6 Å, while the outflow one has the center at λ_c =10985.8 Å, blueshifted of ~ 4 Å with respect to the narrow line. The widths of the two differents gaussians of each line, have been fixed each other to the corresponding components. Finally the BLR contribution to the Pa γ results to be centered at λ_c =10976.0 Å and to have a a FWHM_{Rest}=1447 km s⁻¹. The fitting parameters are shown in Table 6.13, for the Pa β , and in Table 6.14 for He I and Pa γ lines.

The optical spectrum shows a prominent and narrow $H\alpha + [N II]$ doublet, comfirming the Seyfert 2 classification derived from previous optical spectroscopy observations. The VIS Xshooter spectrum is shown in Figure 6.17.



FIGURE 6.16. Left: flux calibrated NIR Xshooter spectrum of NGC 6221. Right: rest frame, flux calibrated NIR Xshooter spectrum of NGC 6221 in the proximity of Pa γ and He I emission lines and the lines fit (magenta solid line). The narrow component of both line are shown with thw green dashed lines, the outflow signatures with the blue dashed lines, while the broad components of Pa γ and He I are represented with the red dashed lines.

6.7 NGC 7314

6.7.1 NGC 7314 in the literature

NGC 7314 is a barred spiral galaxy (SABb) at redshift z=0.0048, hosting a Seyfert 1.9 active nucleus (Zoghbi et al., 2013), confirmed by the the detection of a broad H α in the HST spectrum. The X-ray behaviour of the source is extreme, with a strong variability on all observed timescales and it is thought

Xshooter NGC 6221 He I and Pa γ line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
He 1 Narrow	$10881.2\ {\pm}0.03$	$2.05{\pm}0.03$	$0.65{\pm}0.05$	132	
He 1 Broad	$10879.3 {\pm} 0.07$	$4.92{\pm}0.08$	$1.41{\pm}0.06$	318	
He 1 Broad	$10877.8 {\pm} 0.4$	$25.33 {\pm} 0.55$	$1.95{\pm}0.07$	1637	
Pa γ Narrow*	$10989.6 {\pm} 0.03$	$2.07{\pm}0.03$	$0.54{\pm}0.03$	132	
Pa γ Broad**	$10985.8 {\pm} 0.8$	$4.98{\pm}0.08$	$0.15{\pm}0.04$	318	
$\mathrm{Pa}\gamma$ Broad	$10976.0\ {\pm}0.9$	$25.6{\pm}1.0$	$0.73 {\pm} 0.06$	1447	
Powerlaw : $\Gamma = -0.63 \pm 0.14$					
$\chi^2_{\nu} = 2.77, \ \nu = 648$					

TABLE 6.14. He I and Pa γ line fit parameters for the Xshooter NIR spectrum of NGC 6221. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to He I narrow line; $**\sigma_{\lambda}$ fixed to He I broad line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.17. Flux calibrated VIS Xshooter spectrum of NGC 6221.

to be a type-2 counterpart to the NLS1 class (Dewangan and Griffiths, 2005). ASCA, Chandra and XMM observations showed that the iron K α line at 6.4 keV may present both narrow and broad components that do not respond to the rapid variations of the continuum in the same way, in particular the narrow one respond slower respect to its wings, suggesting a different origins of the corresponding gas (Ebrero et al., 2011). In addiction, Zoghbi et al. (2013) report the discovery of X-ray reverberation for this galaxy, in particular the authors found a link between the iron K band an the emission in the Fe K α band, likely due to a reflection process. Finally, Middleton et al. (2008) derived the BH mass using the stellar velocity dispersion resulting log(M_{BH})= $6.03 \pm 0.48 M_{\odot}$.

6.7.2 NGC 7314 Xshooter observations and line fit

We have observed NGC 7314 on June, 25th 2014 at the VLT with Xshooter, in Section 4.4. The final 2D spectrum was extracted with an aperture of 1.0". The NIR and VIS final spectra are shown in Figures 6.18 and 6.19, respectively.

The NGC 7314 NIR spectrum shows intense permitted emission lines, in particular He I and Pa γ are prominent but in blending, thus we did not perform



FIGURE 6.18. Left: flux calibrated Xshooter NIR spectrum of NGC 7314. Right: rest frame flux calibrated Xshooter NIR spectrum of NGC 7314 in proximity of Pa β line. The solid magenta line shows the total line fit. Green dashed lines represent the narrow components of Pa β , [Fe II] and [S IX] lines, while the Pa β broad component is shown by the solid blue line.

the line fit althought they show signature of a broad component. The $Pa\beta$ is at high S/N ratio and it is clearly shows a broad emission line superimposed the narrow one. The forbidden lines [S IX] and [Fe II] are weak but it was possible to use the [Fe II] line fit to constrain the NLR emission contamination of the $Pa\beta$.

We modelled the continuum with a power law and we fitted the [Fe II] and [S IX] lines with only one narrow gaussian component. The [S IX] results to be centered at λ_c =12581.4 Å with a FWHM_{Rest}=136 km s⁻¹, while the [Fe II] is centered at λ_c =12624.8 Å and has a FWHM_{Rest}=114 km s⁻¹. The latter is used to tie the narrow gaussian of the Pa β , tha results to be centered at at λ_c =12877.5 Å. Finally, we complete the Pa β line fitting adding the second broad gaussian component, that results to have the center at λ_c =12877.2 Å and a FWHM_{Rest}=1165 km s⁻¹.

6.8 NGC 2992

6.8.1 NGC 2992 in the literature

NGC 2992 is a nearby Sa galaxy at redshift z = 0.0077; it is highly inclined by about 70° to our line of sight and shows a broad disturbed lane of dust

X shooter NGC 7314 Pa β line fit						
Component	$\lambda_{\mathbf{c}}$	$\lambda_{\mathbf{c}} = \sigma_{\lambda} = \mathbf{Norm}_{Res}$				
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[S IX]	12581.4 ± 0.2	$2.43 {\pm} 0.25$	$0.08 {\pm} 0.01$	136		
[Fe II] Narrow	$12624.8\ {\pm}0.2$	$2.04{\pm}0.05$	$0.07{\pm}0.01$	114		
${\rm Pa}\beta$ Narrow*	$12877.5 {\pm} 0.6$	$2.08{\pm}0.05$	$0.30{\pm}0.02$	136		
${\rm Pa}\beta$ Broad	12877.2 ± 0.2	$21.3{\pm}0.3$	$2.46{\pm}0.06$	1165		
Powerlaw : $\Gamma = 0.9 \pm 0.2$						
$\chi^2_{\nu} = 0.93, \nu = 986$						

TABLE 6.15. Pa β line fit parameters for the Xshooter NIR spectrum of NGC 7314. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%



FIGURE 6.19. Flux calibrated VIS Xshooter spectrum of NGC 6221.

in its equatorial plane. Glass (1997) suggested that it is a hybrid between an intermediate Seyfert and a starburst galaxy, induced by the interaction with

NGC 2993 to the south. Both galaxies are connected by a tidal tail with a projected length of 2.9'. At a wavelength of 6 cm NGC 2992 shows prominent loop to the northwest and southeast of size of about 8", designated as a *figure of 8*. From IR observations Chapman et al. (2000) concluded that this loops can be explained as an expanding gas bubbles, probably driven by the AGN, as pointed out from X-ray observations.

This object has been well studied in all wavelength regimes. It is optically classified as Seyfert 1.9, but its type classification has been observed to vary conspicously in the past, leading to classifications ranging to Seyfert 2 to Seyfert 1.9 on the basis of a broad H α with no corresponding H β component in its nuclear spectrum (Ward et al., 1980), suggesting the existence of an obscured BLR. This was confirmed later also in the infrared (Rix et al. 1990, Goodrich et al. 1994, Veilleux et al. 1997).

Long-slit observations have demonstrated the complex kinematics of the ionized gas in its circumnuclear region (Heckman et al. 1981, Colina et al. 1987, Marquez et al. 1998). The double peaked line profiles and asymptotic observed in [O III] and H α lines from (Marquez et al., 1998), can be accounted for an outflow within a biconical envelope on kilo-parsec scales, probably driven by the AGN, rather than the starburst (Friedrich et al., 2010). Allen et al. (1999) found that one component of the double peaked lines follows the galactic rotation curve, while the other is identified as a wind that is expanding out of the plane of the galaxy with a velocity up to 200km s^{-1} . Moreover, Gilli et al. (2000) correlated the presence (or the absence) of the broad component of H α with the galaxy's X-ray flux and postulated that the observed optical spectra variations were due to different phases of rebuilding of the central accretion disk (Trippe et al., 2008). He reported the broad component H α varing from FWHM $\simeq 2600$ Km/s to FWHM $\simeq 2000$ Km/s (see Figure: 6.20). A recent optical spectrum, taken also by Jones et al. (2009) in 2009 is shown in Figure 6.21, here the H β does not show a clear broad component, while the H α is similar to that reported in Gilli et al. (2000) work.

The X-ray flux and spectrum were observe to vary along 16 years of observations, performed with different satellites. The 2-10 keV flux was observed to decrease by a factor of ~ 20 from the HEAO-1 observations in the 1978 to the ASCA observations in the 1994, were it reach its minimum value. A similar decrease was also observed in the soft X-ray. These spectral variations



FIGURE 6.20. Top: optical spectrum of NGC2992 obtained by Gilli et al. (2000) in 1999. Middle: comparison between Gilli et al. (2000) spectrum and that obtained by Allen et al. (1999) in 1994, i.e. at the minimum of X-ray activity. Bottom: comparison with the spectrum obtained by Veron et al. (1980) prior to 1978, i.e. when the nucleous was in an high X-ray state.

were interpreted as an evidence for for radiation reprocessed by the molecular, obscurbing torus (Gilli et al. (2000) and references therein). Moreover, Glass (1997) reported infrared flux variability and remarked the fading of the central source in the time range 1978-1996. All these evidences suggest that the AGN in the center of NGC 2992 was turning off. However, BeppoSAX observations in 1997 shown that the AGN was come back to the previous high level of activity observed in the 1978, given the indications of a reviewed AGN (Gilli et al., 2000).

6.8.2 NGC 2992 ISAAC observations and line fit.

We have observed NGC 2992 on January 7th, 2012 with ISAAC at VLT. The spectrum of NGC 2992 was extracted with an aperture of 0.9" and the final, flux calibrated LR and MR spectra are shown in Figure 6.22.



FIGURE 6.21. Optical spectrum of NGC2992 from Jones et al. (2009)



FIGURE 6.22. Left: flux calibrated, low resolution NIR spectra of NGC 2992 obtained with ISAAC/VLT. Right: flux calibrated medium resolution NIR ISAAC spectrum of NGC 2992 and the fit of the $Pa\beta + [Fe II]$ emission line (magenta solid line). We identified two component for the [Fe II] $\lambda 12570$ Å: a narrow emission line (green dashed line) and an outflow signature (blue dashed line). The same two component are found also in the [Fe II] $\lambda 12791$ Åin blend with the $Pa\beta$: the narrow (green dashed line) and the broad one (blue dashed line). The $Pa\beta$ line shows three component: the narrow one (green dashed line) , the outflow (blue dashed line) and the broad component (red dashed line).

The ISAAC/LR NIR spectrum of NGC2992 cleary shows broad components both in He $_{\rm I}$ + Pa γ lines (even thought they are not well resolved) and in the Pa β line (Figure: 6.22, left side), it also shows a prominent [Fe II] narrow line. We observe the Pa β also in the MR mode to acurately perform the line fit, shown in Figure 6.22, right side. Although the redshift of NGC 2992 is quite low, the spectrum has been converted to the rest frame. The continuum as been estimated with a power law, while the NLR contribution has been modelled whith a gaussian component from the [Fe II] line fit. In this case the [Fe II] shows two different components: a narrow one centered at λ_c = 12667.0 Å with a rest frame FWHM= 236 km s⁻¹, that we identified as a NLR contribution, and a broad one at center λ_c =12663.5, blueshifted of 3.5 Å respect to the narrow line, with the rest frame FWHM=679 km s⁻¹. We interpreted the latter as an indication of the NLR ouflow, that has been well studied in the literature of NCG 2992 (Friedrich et al. (2010) and references therein).

Following the NIR transitions listed in Landt et al. (2008) Table 4, we have added a gaussian model to take into account for the [Fe II] λ 12791 Å in blending with the Pa β . It turned out to have an second broad component that we interpred again as the NLR outflow signature. Thus we fitted it using a narrow gaussian centered at λ_c =12888.0 Å with a rest frame FWHM= 236 km s⁻¹, tied to the narrow [Fe II] λ 12570 Å width. The outflow component result to be centered at λ_c = 12873.70 Å and to have a rest frame FWHM=679 km s⁻¹, tied to the width of the [Fe II] λ 12570 Å outflow component. We notice that it is redshifted of ~ 14 Å with respect to the narrow line.

The NLR outflow signature is also observed in the Pa β line, but we have been able to accurately separate it both from the narrow and the broad components. Therefore we performed the line fit using three gaussian models: the narrow one, that results to have its center at $\lambda_c = 12920.10$ Å and a FWHM=236 km s⁻¹, tied to the [Fe II] narrow component width. The ouflows signature is centered at $\lambda_c = 12909.40$ Å and it has a rest frame FWHM=679 km s⁻¹, blueshifted of ~10 Å with respect to the narrow line and it has been tied to the [Fe II] outflow width. Finally, the broad component of Pa β results to have its center at $\lambda_c = 12940.50$ Å with a rest frame FWHM=2019 km s⁻¹ and it is blueshifted of ~20 Å with respect to the narrow line. In Table 6.16 we show the fit parameters.

Despite the presence of the spectroscopic signatures of the well known outflow in our NGC 2992 NIR spectra, we explain the $Pa\beta$ broad component as an evidence for the BLR gas under the influence of the central BH. Indeed this third component is not present in the [Fe II] $\lambda 12570$ Å, while the outflows signatures are seen in almost all emission lines and they are also blushifted respect to their narrow lines. Moreover we extracted all our nuclear spectra at $\sim 1.0''$ that correspond to the very central region of the AGN, as shown from the velocity field maps of Friedrich et al. (2010), in Figure 6.23.



FIGURE 6.23. Left: calculated velocity field in the central region of NGC 2992 resulting from two inclined disks and conical outflows. Right: Velocity map of H2 with the contours of radio flux at 8.46 GHz. (Friedrich et al., 2010). In both figures the cyano squares indicate the 1 acrese square of our measurements. Nord is up, east to the left.

${f ISAAC/MR}$ NGC 2992 Pa eta line fit						
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$		
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$		
(1)	(2)	(3)	(4)	(5)		
[Fe II] Narrow	$12667.00 {\pm} 0.07$	$4.26{\pm}0.07$	7.4 ± 0.4	236		
[Fe II] Broad	$12663.50 {\pm} 0.40$	$12.27 {\pm} 0.07$	6.8 ± 0.5	679		
[Fe II] Narrow	$12804.60 {\pm} 0.54$	$8.06{\pm}0.60$	$1.8 {\pm} 0.3$	442		
[Fe II] Bl Narrow *	$12888.00 {\pm} 0.40$	$4.34{\pm}0.07$	$1.3 {\pm} 0.2$	236		
[Fe II] Bl Broad **	$12873.70{\pm}1.03$	$12.47 {\pm} 0.07$	$2.8 {\pm} 0.7$	679		
${\rm Pa}\beta$ Narrow *	$12920.10 {\pm} 0.09$	$4.34{\pm}0.07$	$6.0 {\pm} 0.4$	236		
Pa β Broad**	$12909.40 {\pm} 0.80$	$12.50 {\pm} 0.07$	$6.4{\pm}1.2$	679		
${\rm Pa}\beta$ Broad	$12940.50 {\pm} 1.90$	$37.26 {\pm} 1.38$	23.1 ± 2.4	2019		
О і	13046.50 ± 1.30	4.22 ± 1.31	$0.6 {\pm} 0.3$	227		
Powerlaw : $\Gamma = -3.0$ fixed						
	$\chi^2_{\nu} = 1.$	$24, \nu = 397$				

TABLE 6.16. Pa β and [Fe II] line fitting parameters for our ISAAC/MR spectrum of NGC 2992. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line; $**\sigma_{\lambda}$ fixed to [Fe II] broad component.

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

6.9 NGC 1365

6.9.1 NGC 1365 in the literature

NGC 1365 is a nearby (z=0.0055) and very well studied SB Seyfert 1.9 galaxy (Trippe et al., 2010), hosting a $\simeq 2 \times 10^6 M_{\odot}$ BH (see Kaspi et al. 2005, Schulz et al. 1999) which displays a large amount of X-ray spectral variability on time-scales of hours to years and evidence for a relativistically broadened iron line (Risaliti et al. 2009, Walton et al. 2010, Brenneman et al. 2013) indicative of a rapidly rotating black hole, confermed also by (Risaliti et al., 2013). It has been studied exstensively in the X-ray band and it has been observed to display complex and variable absorption, with rapid variations in column density (N_H ranging from ~ (10-27) ×10²² cm⁻² (Risaliti et al. 2005, Risaliti et al. 2007, Maiolino et al. 2010) attributed to an occultation event originated in the BLR clouds. These variations have been interpreted as the spectrum changing from being transmission dominated, in which the absorbing material is Compton thin, to reflection dominated, in which the absorbing material is compton thick.

It shows a large number of absorption and emission lines, such as a strong Fe fluorescence emission line and Fe absorption lines between 6.7 and 8.3 keV, attributed to Fe xxv, Fe xxvi, K α and K β transitions. The measured velocities of these lines have been explained as an indication of an highly ionized, high velocity outflow from NGC 1365 (Risaliti et al., 2005). Connolly et al. (2014) performed a long term Swift X-ray observations of NGC 1365 over a period of six years finding a large amount of spectral variability, explained in terms of a wind model in which the launch radius varies as a function of ionizing flux and disc temperature and therefore moves out with increasing accretion rate, i.e. increasing X-ray luminosity. Thus, depending on the inclination angle of the disc relative to the observer, the absorbing column may decrease as the accretion rate goes up. Moreover, from time-resolved spectroscopy performed on the NuSTAR and XMM-Newton observations, Risaliti et al. (2013) found a good correlation between the strength of the relativistic iron line and the Compton reflection hump relative to the intrinsic continuum. These observations allow the authors to confirm that NGC 1365 hosts a rapidly rotating BH.

In the optical spectra of NGC 1365 there is some evidence of variability: Veron

et al. (1980) classified it as a Seyfert 1.5 on the basis of a strong H α detected in its nucleo. Moreover, from medium resolution long slit optical spectroscopy of NGC 1365, Schulz et al. (1994) comments on the conspicuous broad component of H α observed in 1988 October, and in Schulz et al. (1999) the authors shows an H β with a substantial broad component (Figure 6.24), with a FWHM= 1895 km s⁻¹. However, Trippe et al. (2010) found an extremely faint broadline component in H α in their spectra, obtained in the 2009 (Figure 6.25 and Figure 6.26 from Jones et al. (2009)) and they also found a narrow H β that appears to be enhanced with respect to the [O III] lines, indicating a very strong starburst emission component. Thus they classified NGC 1365 as a Seyfert 1.9 plus a starburst component.



FIGURE 6.24. $H\beta$ from the nucleus of NGC1365 obtained by Schulz et al. (1999).



FIGURE 6.25. Optical spectrum of NGC1365 from Trippe et al. (2010).



FIGURE 6.26. Optical spectrum of NGC1365 from Jones et al. (2009)

6.9.2 NGC 1365 ISAAC observations and line fit.

We have observed NGC 1365 on October 13th, 2011 with ISAAC at VLT. The spectrum of NGC 1365 was extracted with an aperture of 0.6" and the final, flux calibrated LR and MR spectra are shown in Figure 6.27, left and right side respectively.

The ISAAC/LR NIR spectrum of NGC1365 appears rich of permitted emission lines, in particular there are intense He I, Pa γ (well separated) and Pa β lines but there is no evidence of the [Fe II] $\lambda 12570$ Å (Figure: 6.27, left side).

We have observed the Pa β also in the MR mode to accurately perform the line fit, shown in Figure 6.27, right side. Although the redshift of NGC 1365 is quite low, the spectrum has been converted to the rest frame. The continuum as been estimated with a power law, while there are no NLR emission lines to be used to constrain the model for this component. We identified in the Pa β lines three components. The narrow line has been modelled with a gaussian profile centered at λ_c =12889.2 Å and having a FWHM_{Rest}=422 km s⁻¹. The first broad component results to be centered at λ_c =12883.7 Å and to have a FWHM_{Rest}=1056 km s⁻¹, it is blueshifted of ~ 5 Å with respect to the narrow line. The second broad component has its center at λ_c = 12895.9 Å and a FWHM_{Rest}=3248 km s⁻¹, we notice that it is redshifted of ~ 12 Å with



FIGURE 6.27. Left: flux calibrated, LR NIR spectra of NGC 1365 obtained with ISAAC/VLT. Right: flux calibrated MR NIR ISAAC spectrum of NGC 1365 and the fit of the Pa β emission line (magenta solid line). The Pa β line has been modelled with three gaussian component: the narrow one is shown with the green dashed line, the first broad component with the blue dashed line and the second broad component is shown with the red dashed line. The [Fe II] λ 12791 in blend with Pa β has been also take into account (green dashed line).

respect to the narrow line. Following the the NIR transitions listed in Landt et al. (2008) Table 4, we have added a gaussian model to take into account for the [Fe II] λ 12791 Å in blending with the Pa β and it turned out to be centered at λ_c =12870.4 Å and to have a FWHM_{Rest}=370 km s⁻¹, in agrrement with the value found for the narrow component of Pa β . The fit parameters of NGC 1365 are shown in Table 6.17.

6.10 Mrk 1210 - Phoenix galaxy

6.10.1 Mrk 1210 in the literature

Mrk 1210, also known as Phoenix Galaxy, is a nearby (z=0.0135) Sa galaxy. It is an outstanding Seyfert 2 because it shows signatures of recent circumnuclear star formation and an high level of X-ray activity. Moreover it shows warm far infrared color and a spectral energy distribution peaking near 60 μ m. The latter characteristics made it a member of the sample of galaxies called 60 μ m peakers (60PKs, Heisler and De Robertis 1999) and many evidences have been accumulated over the years, indicating that these properties can be attributed

ISAAC/MR NGC 1365 Pa β line fit					
Component	$\lambda_{\mathbf{c}}$	$\lambda_{\mathbf{c}} = \sigma_{\lambda} = \mathbf{Norm}_{Rest} \mathbf{FWHM}$			
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
[Fe 11]	12870.4 ± 0.8	$6.78{\pm}0.83$	$6.7 {\pm} 4.2$	370	
$\mathrm{Pa}\beta$ Narrow	12889.2 ± 0.4	$7.74 {\pm} 0.57$	$18.4 {\pm} 7.6$	422	
$\mathrm{Pa}\beta$ Broad	$12883.7\ {\pm}0.3$	$19.36{\pm}12.6$	$76.5{\pm}8.8$	1056	
${\rm Pa}\beta$ Broad	12895.9 ± 1.6	$59.6 {\pm} 1.9$	$68.4 {\pm} 3.9$	3248	
Powerlaw : $\Gamma = 1.00 \pm 0.06$					
$\chi^2_{\nu} = 1.72, \ \nu = 675$					

TABLE 6.17. Pa β line fitting parameters for our ISAAC/MR spectrum of NGC 1365. (1) Emission line component; (2) Central wavelength of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

to a dust obscured active galactic nucleus (Keel et al. 1994, Hes et al. 1995). Mrk 1210 has been extensively studied in the optical region, not only because of the Wolf-Rayet features found within the central 200 pc (Storchi-Bergmann et al., 1998), indicating the presence of a circumnuclear starburst, but also for the detection of broad H α and H β components in polarized light (Tran et al. 1992, Tran 1995) with FWHM \simeq 2380 km s⁻¹. Moreover, in the near infrared, the degree of polarization of Mrk 1210 rises toward longer wavelengths (Watanabe et al., 2003) and observational evidence suggests that this polarization is due to dichroic absorption by aligned grains.

Near infrared spectra reported by Veilleux et al. (1997) show a Pa β profile characterized by a strong narrow component on top of a broad base with FWHM $\simeq 1600 \text{ km s}^{-1}$, suggesting the presence of a hidden broad-line region (BLR). However, Mazzalay and Rodríguez-Ardila (2007) performed a spectrosopical study both on Optical and NIR spectra. The authors found broad components of similar shape both in permitted (H β and Pa β) and in forbidden ([O III] and [Fe II]) emission lines. Moreover, a comparison with the [Fe II] λ =12570 Å profile, indicates that at least a part of the broad emission is also present in the forbidden [Fe II] line, suggesting that the broad permitted line is not produced in a genuine high-density BLR. In Figure 6.10.1 the optical spectra taken by Mazzalay and Rodríguez-Ardila (2007) are shown.

In X-rays band Mrk 1210 is one of the very few cases of an AGN in transition between a Compton thick, reflection dominated state, and a Compton thin state (Guainazzi et al., 2002). The transition, derived after a comparison between XMM-Newton and ASCA data, obtained six years earlier, is attributed to either a change in the properties of the absorbers or a switching-off of the nucleus during the ASCA observations. The former scenario may indicate a clumpy or patchy structure of the torus to which the absorbers are associated, while the latter may provide clues to the duty-cycle of the AGNs phenomenon.



FIGURE 6.28. Optical spectra of Mrk 1210 from Mazzalay and Rodríguez-Ardila (2007).

6.10.2 Mrk 1210: ISAAC observations and line fit.

We have observed Mrk 1210 on December 19th, 2011 with ISAAC at VLT in the J band using both LR and MR instrument modes. We used a 0.8''× 1.0" wide slit, corresponding to a spectral resolution of ~430 km s⁻¹ and $\sim 60 \text{ km s}^{-1}$ for LR and MR modes, respectively. The LR spectrum of Mrk 1210 was extracted with an aperture of 0.9", while the MR spectrum with an aperture of 0.6". The LR and MR spectra are shown in Figure 6.29, left and right side respectively.



FIGURE 6.29. Left: flux calibrated ISAAC LR NIR spectrum of Mrk 1210. Right: rest frame, flux calibrated ISAAC MR NIR spectrum of Mrk 1210 and the fit of the Pa β emission line (solid magenta line). The green dashed line shows the narrow component of both Pa β and [Fe II], the blue dashed line shows the broad componts of Pa β and [Fe II], while the red dashed line represent the [Fe II] λ 12791 Å blended with the Pa β . NB.broad da discutere

The ISAAC/LR NIR spectrum of Mrk 1210 shows permitted and forbidden emission lines: in particular there is an intense He I well separated from the Pa γ . There are also the Pa β and the [Fe II] λ 12570 Ålines (Figure: 6.27, left side). As pointed out by Mazzalay and Rodríguez-Ardila (2007) in their optical spectra, all these feature show some kind of broadening.

The MR spectrum contains [Fe II] and Pa β lines as shown in Figure 6.27, right side. As usual we converted the spectrum to the rest frame wavelenght. We estimated the continuum with a power law and we identified two components both in the Pa β and the [Fe II], that we modelled with gaussian profiles. The narrow line of the [Fe II] results to have its center at $\lambda_c=12747.3$ Åand a FWHM_{Rest}=291 km s⁻¹, while the second broader component has the center at $\lambda_c=12740.4$ Åand a FWHM_{Rest}=789 km s⁻¹. We notice that the latter is blueshifted of ~7 Å with respect to the narrow line. Similar profile has been identified also in the Pa β line. It results to have a narrow gaussian component,

$\hline \hline $					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
[Fe II] Narrow	$12747.3 {\pm} 0.2$	$5.32 {\pm} 0.17$	$1.9{\pm}0.3$	291	
[Fe II] Broad	$12740.4 {\pm} 0.3$	$14.42 {\pm} 0.74$	7.6 ± 0.3	789	
${\rm Pa}\beta$ Narrow*	12996.2 ± 0.1	$5.43 {\pm} 0.17$	3.2 ± 0.4	291	
${\rm Pa}\beta$ Broad	$12991.4 {\pm} 0.6$	$19.37 {\pm} 8.9$	$13.6{\pm}0.5$	1039	
[Fe II] **	12953.1 ± 1.3	$14.66 {\pm} 0.74$	$1.3 {\pm} 0.5$	789	
[Fe II] **	12883.6 ± 1.5	$14.58 {\pm} 0.74$	$1.3 {\pm} 0.5$	789	
[Fe II] **	13125.7 ± 1.3	$14.85 {\pm} 0.74$	1.2 ± 0.3	789	
О і	$13128.3 {\pm} 0.7$	$3.15{\pm}0.8$	2.3 ± 0.1	167	
Powerlaw : $\Gamma = 2.2 \pm 0.2$					
	$\chi^{m 2}_{ u}$ =	$= 0.85, \nu = 810$)		

TABLE 6.18. Pa β line fitting parameters for our ISAAC/MR spectrum of Mrk 1210. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line; $**\sigma_{\lambda}$ fixed to [Fe II] broad component.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

whose width has been tied to the narrow [Fe II] one, and the broad component is centered at $\lambda_c=12991.4$ Åand has a FWHM_{Rest}=1039 km s⁻¹, it is also blueshifted of ~5 Å with respect the narrow component. The latter result to be centered at $\lambda_c=12996.2$ Å. Again, following the the NIR transitions listed in Landt et al. (2008) Table 4, we have added a gaussian model to take into account for the [Fe II] λ 12791 Å in blending with the Pa β . In addiction, following Mazzalay and Rodríguez-Ardila (2007), we also modelled [Fe II] λ 12712.3 Åand [Fe II] λ 12952 Å. The fit parameters of Mrk 1210 are shown in Table 6.18.

6.11 MCG -01-24-012

6.11.1 MCG -24-012 in the literature

MCG -01-24-012 is a nearby spiral galaxy at redshift of z=0.0196, which hosts a Seyfert 2 nucleous (de Grijp et al., 1992). In the X-ray it was detected for the first time by Malizia et al. (2002), that performed a multiyear observations of some Pacinotti sample sources with BeppoSAX/PDS telescope. They measured the X-ray 2-10 keV flux that results to be $\sim 1 \times 10^{11}$ erg s⁻¹ cm⁻². The 2–10 keV spectrum shows also the presence of the iron line $K\alpha$ emission togheter with an absorbtions feature at ~ 8.7 keV which cannot be explained by the presence of warm material around the source. Moreover, it turned out to be Compton-thin with $N_H \sim 7 \times 12^{22}$ athoms cm⁻². It belong to the 70-month SWIFT/BAT AGN sample and the [O III] image show an emission extended for $1".15 \times 2".3$ with the major axis along PA=75°, interpreted as an extended NLR (Schmitt et al., 2003). MCG -01-24-12 has also been observed by Spitzer/IRS. The corresponding low resolution staring-mode spectrum exhibits deep silicate absorption at $10\mu m$ and weak PAH emission (Mullaney et al., 2011). In the WISE images, the object appears elliptically extended along the galaxy major axis. Using K-band stellar luminosity of the bulge of MCG -01-24-012 Winter et al. (2009) derive its black hole mass: $\log M_{BH}$ = $7.16 M_{\odot}$. The optical spectrum, shown in Figure 6.30, was obtained by Jones et al. (2009) and it show narrow $H\beta$ an $H\alpha$ emission line.

6.11.2 MCG -01-24-012: ISAAC observations and line fit.

We have observed MCG -01-24-012 on January 7th, 2012 with ISAAC at VLT in LR an MR modes. We used a $0.8'' \times 1.0''$ wide slit, corresponding to a spectral resolution of ~430 km s⁻¹ and ~ 60 km s⁻¹ for LR and MR modes, respectively. Both the LR and MR spectra were extracted with an aperture of 0.9''. The flux calibrated LR and MR final spectra are shown in Figure 6.31, left and right side respectively.

The ISAAC/LR NIR spectrum of MCG -01-24-012 shows permitted and forbidden emission lines, in particular there are an intense He I well separated



FIGURE 6.30. Optical spectrum of MCG -01-24-12 from Jones et al. (2009). There are no indications of broad components both in H β and H α emission lines.



FIGURE 6.31. Left: flux calibrated ISAAC LR NIR spectrum of MCG -01-24-012. Right: rest frame, flux calibrated ISAAC MR NIR spectrum of MCG -01-24-012 and the fit of the Pa β line (magenta solid line). The green dashed line shows the narrow component, while the blue solid line shows the broad component. In cyano dashed line the [Fe II] λ 12791 Åin blend with Pa β is shown.

from the Pa γ , the Pa β and a weak [Fe II] λ 12570 Å blended by the [S IX] forbidden lines (Figure: ??, left side).

ISAAC/MR MCG -01-24-012 Pa β + [Fe II] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
[Fe II] Narrow	12817.0 ± 0.4	4.5 ± 0.2	$0.6 {\pm} 0.2$	244	
[Fe II] Broad	$12818.8 {\pm} 0.6$	$10.3 {\pm} 0.1$	$1.9{\pm}0.2$	557	
${\rm Pa}\beta$ Narrow*	13074.4 ± 0.1	$4.6{\pm}0.2$	$1.68{\pm}0.08$	244	
${\rm Pa}\beta$ Broad	13064.1 ± 2.6	40.9 ± 3.4	2.5 ± 0.5	2169	
Powerlaw : $\Gamma = 0.006 \pm 0.3$					
$\chi^2_{\nu} = 1.48, \ \nu = 381$					

TABLE 6.19. Pa β line fitting parameters for our ISAAC/MR spectrum of MCG -01-24-012. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

The MR spectrum contains the [Fe π] and the Pa β lines and it is shown in Figure 6.31, right side. As usual we converted this spectrum to the rest frame wavelenght for the fitting procedure. We modelled the [Fe II] using two components of different widths: a narrow one that results to have the center at $\lambda_c = 12817.0$ Å and the FWHM_{Rest} = 244 km s⁻¹. We used it to estimate the NLR contribute to the $\mathrm{Pa}\beta$. The broader component has the center at $\lambda_c{=}$ 12818.8 and a FWHM_{Rest} = 557 km s⁻¹ , it is redshifted of ~ 2 Å with respect to the narrow line. Following the the NIR transitions listed in Landt et al. (2008) Table 4, we have added a gaussian model to take into account for the [Fe II] $\lambda 12791$ Å in blending with the Pa β , but its contribution is neglectable. The $Pa\beta$ has been modelled with two gaussian components, the narrow one has the center at $\lambda_c = 13074.4$ and its width has been tied to the narrow [Fe II] line to carefully disentangle the NLR contribution from the BLR one. The broad emission component is weak but visible, and it results to have the center at $\lambda_c{=}$ 13064.1 Å and a FWHM $_{Rest}{=}$ 2169 km ${\rm s}^{-1}$. We identified the latter as a result of the BLR gas under the gravitational potential of the central black hole. The fit parameters of MCG -01-24-012 are shown in Table 6.19.

6.12 CGCG -420-015

6.12.1 CGCG -420-015 in the literature

CGCG -420-015 is a nearby early type galaxy at redshift z=0.0294, optically classified as a Seyfert 2 (Strauss et al., 1992). It is a member of the Updated Zwicky Cathalog (UZC; Falco et al. 1999), the optical spectrum, shown in Figure 6.32, does not show any broad line signature in H β and H α . No clear signs of starburst activity for this galaxy have been detected from the empirical multi-wavelenght analysis performed by Cid Fernandes et al. (2001). It was proposed as a new Compton-thick AGN candidate through the diagnostic diagram described in Severgnini et al. (2010) and this was confirmed from the broad band X-ray (0.4-100 keV) spectral analysis performed by Severgnini et al. (2011) using Suzaku and SWIFT/BAT observations. They found a $N_H = 1.3 - 1.5 \times 10^{24} \text{ cm}^{-2}$ and a $L_{2-10keV} = 5 - 7 \times 10^{43} \text{ erg s}^{-1}$, in agreement with that predicted for the torus by Fraquelli et al. (2003). These authors after estimating the rate of the ionizing photons emitted by the AGN, assumed an opening angle of $\sim 30^{\circ}$ for the ionization cones. Using K-band stellar luminosity of the bulge of CGCG 420-015, Winter et al. (2009) derive its black hole mass: $\log(M_{BH}) = 8.46 M_{\odot}$. The optical spectrum, shown in Figure 6.32, was obtained by Falco et al. (1999) and it show narrow H β an H α emission line.

6.12.2 CGCG -420-015: ISAAC observations and line fit.

We have observed CGCG -420-015 on December 19th, 2011 at VLT with ISAAC in LR and MR modes. We used a $0.8'' \times 1.0''$ wide slit, correspondint to a spectral resolution of ~430 km s⁻¹ and ~ 60 km s⁻¹ for LR and MR modes, respectively. The spectrum of CGCG -420-015 was extracted with an aperture of 0.6'' and the final, flux calibrated LR and MR spectra are shown in Figure 6.33.

The ISAAC/LR NIR spectrum of CGCG -420-015 shows an intense He $_{\rm I}$,



FIGURE 6.32. Optical spectrum of CGCG 420-015 from Falco et al. (1999)



FIGURE 6.33. Left: flux calibrated ISAAC LR NIR spectrum of CGCG -420-015. Right: rest frame, flux calibrated ISAAC MR NIR spectrum of CGCG -420-015 and the fit of the Pa β + [Fe II] lines (magenta solid line). The green dashed line shows the narrow component both in [Fe II] and Pa β lines, while the blue dashed line shows the Pa β broad component. In cyano dashed line the [Fe II] λ 12791 Å in blend with Pa β is shown.

well separated from the weaker $Pa\gamma$. The $Pa\beta$ shows evidence for a faint broad component at the base of a intense narrow line. The forbidden narrow lines [Fe II] $\lambda 12570$ Å and [S IX] are in blending, but cleary visible (Figure: 6.33, left side).

ISAAC/MR CGCG -420-015 Pa β + [Fe II] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^{a}$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
[Fe II] Narrow	12941.5 ± 0.2	$5.4 {\pm} 0.2$	$0.47 {\pm} 0.04$	287	
[Fe 11] *	$13169.3 {\pm} 0.2$	5.5 ± 0.2	$0.17 {\pm} 0.04$	287	
Pa β Narrow*	13200.7 fixed	5.5 ± 0.2	$1.4 {\pm} 0.2$	287	
${\rm Pa}\beta$ Broad	$13194.4{\pm}2.3$	$10.0{\pm}0.2$	0.5 ± 0.2	522	
Powerlaw : $\Gamma = -1.6 \pm 0.2$					
	$\chi^2_{\nu} =$	$1.41, \nu = 32$	27		

TABLE 6.20. Pa β line fitting parameters for our ISAAC/MR spectrum of CGCG -420-015. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM. $*\sigma_{\lambda}$ fixed to [Fe II] narrow line.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

The MR spectrum contains [Fe II] and Pa β lines and it is shown in Figure 6.33, right side. As usual we converted this spectrum to the rest frame wavelenght for the fitting procedure. We modelled the [Fe II] using one gaussian component centered at λ_c =12941.5 Å with a FWHM_{Rest}= 287 km s⁻¹ and we used it to estimate the NLR contamination to the Pa β . Following the the NIR transitions listed in Landt et al. (2008) Table 4, we have added a gaussian model to take into account for the [Fe II] λ 12791 Å in blending with the Pa β . We modelled the Pa β using two gaussian components. The narrow one has been fixed at λ_c =13200.7 Å and its width has been linked to the [Fe II] ones. The broad Pa β line has been modelled with a gaussian centered at λ_c =13194.4 Å with a FWHM_{Rest}= 522 km s⁻¹. We noticed that it is blueshifted of ~6 Å with respect to the narrow line. The fit parameters of CGCG -420-015 are shown in Table 6.20.



FIGURE 6.34. Optical spectrum of ESO -374-G44 from Jones et al. (2009)

6.13 ESO 374-G044

6.13.1 ESO 374-G044 in the literature

ESO 374 -G044 is a nearby SBa galaxy at redshift z=0.0284 hosting a Seyfert 2 nucleus. It was observed in the hard X-ray 22-month SWIFT/BAT survey that cover the hard x-ray band of 14-195 keV. Combining the hard X-ray luminosity from SWIFT/BAT 22M and the 18 μ m flux from AKARI infrared database, Matsuta et al. (2012) use this source, among other 158 AGNs, to derive an infrared and hard X-ray diagnostics of AGN identifications. It optical spectrum is shown in Figure 6.34 and has been taken by Jones et al. (2009), it does not have indications for broad component in the H β and H α emission lines.

6.13.2 ESO 374-G044: ISAAC observations and line fit.

We have observed ESO 374-G044 on January 22th, 2012 at VLT with ISAAC. The observations have been carried on in the J band using LR and MR instrument modes. We used a $0.8'' \times 1.0''$ wide slit, correspondint to a spectral resolution of ~430 km s⁻¹ and ~ 60 km s⁻¹ for LR and MR modes, respectively. The spectra of ESO 374-G044 were extracted with an aperture of 0.6'' and the final, flux calibrated LR and MR spectra are shown in Figure 6.35.



FIGURE 6.35. Left: Flux calibrated ISAAC LR NIR spectrum of ESO 374-G044. Right: Rest frame, flux calibrated ISAAC MR NIR spectrum of ESO 374-G044 and the fit of the Pa β + [Fe II] lines (magenta solid line). The green dashed line shows the narrow component both in [Fe II] and Pa β lines, while the red dashed line shows the Pa β broad component. In cyano dashed line the [Fe II] λ 12791 Å in blend with Pa β is shown.

The ISAAC/LR NIR spectrum of ESO 374-G044 shows an intense He I, well separated from a weak $Pa\gamma$. In the $Pa\beta$ there is and indication for a faint broad component at the base of a more intense narrow line. The forbidden narrow lines [Fe II] $\lambda 12570$ Å and [S IX] are in blending, but cleary visible (Figure: 6.35, left side).

The MR spectrum contains both [Fe II] and Pa β lines and it is shown in Figure 6.35, right side. As usual we converted this spectrum to the rest frame wavelenght for the fitting procedure. We modelled the [Fe II] using one gaussian component with the center at $\lambda_c=12926.1$ Å and a FWHM_{Rest}= 607 km s⁻¹ but we did not used it to estimate the NLR contamination to the Pa β because of its blend with the [S IX] line. Following the the NIR transitions listed in Landt et al. (2008) Table 4, we have added a gaussian model to take into account for the [Fe II] λ 12791 Å in blending with the Pa β . We modelled the Pa β using two gaussian components. The narrow one results to be centered at $\lambda_c=13185.8$ Å and it has a FWHM_{Rest}= 427 km s⁻¹. The

ISAAC/MR ESO 374-G044 Pa β + [Fe II] line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{f km}~{f s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
[Fe II] Narrow	12926.1 ± 0.4	$11.42 {\pm} 0.07$	$1.6 {\pm} 0.08$	607	
[Fe 11] *	13072.5 ± 0.4	$11.55 {\pm} 0.07$	$0.19{\pm}0.08$	607	
[Fe 11] *	$13153.7 {\pm} 0.4$	$11.62 {\pm} 0.07$	$0.11 {\pm} 0.11$	607	
${\rm Pa}\beta$ Narrow	$13185.8 {\pm} 0.3$	$8.2 {\pm} 0.5$	$1.8 {\pm} 0.4$	287	
${\rm Pa}\beta$ Broad	13191.0 ± 5.4	$20.0{\pm}1.0$	$0.8{\pm}0.5$	1041	
Powerlaw : $\Gamma = 2.5 \pm 0.3$					
	$\chi^{2}_{ u}$ =	$= 0.93, \nu = 418$	8		

TABLE 6.21. Pa β line fitting parameters for our ISAAC/MR spectrum of ESO 374-G044. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM.

 $^a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%

broad Pa β line has been modelled with a gaussian centered at λ_c =13191.0 Å with a FWHM_{Rest}= 1041 km s⁻¹. It is redshifted of ~5 Å with respect to the narrow line. The fit parameters of ESO 374-G044 are shown in Table 6.21.

6.14 NGC 3081

6.14.1 NGC 3081 in the literature

NGC 3081 is a well known Seyfert 2, low inclination barred spiral galaxy at redshift z=0.008. It represents one of the best exemples of a resonance ring barred galaxy in the sky, with one of the most distinctive multiring morphologies among the general galaxy population, and it is an especially good candidate for studies of star formation in rings (Buta and Purcell 1998, Byrd et al. 2006).

Thanks to the extremely high angular resolution FIR $(70-500\mu m)$ images obtained with the *Herschel Space Observatory* instruments PACS and SPIRE, Ramos Almeida et al. (2011) resolved the nuclear dust distribution of NGC 3081, finding indications for a clumpy torus models for the AGN.

Moran et al. (2000) report spectacular type 1 features in NCG 3081 optical spectrum in polarized light, with prominent broad components of H α , H β and also in He 1 λ 5876 Å, shown in Figures 6.36. The authors report a FWZI=7000 km s⁻¹ for polarized H α , despite its pure type 2 optical spectrum, suggesting that NGC 3081 could hosts an hidden BLR.

Bian and Gu (2007) used the stellar velocity dispertions and the extinctioncorrected [O III] luminosity to derive the SMBH mass and the Eddington luminosity for a sample of 90 AGN2 with spectropolarimetric signatures of hidden broad line region. Thus they derived a black hole mass for the NCG 3081 nucleous of $\log(M_{BH}) = 7.4 \pm 0.3 M_{\odot}$ ad an Eddington ratio of $\lambda \sim 0.26$.

Fewer X-ray observations have been performed on this source. It was first detected in X-rays by the Einstein imaging instruments and then it was also detected the ROSAT All-Sky Survey. BeppoSAX observed NGC 3081 in a lower state with a flux of $F_{2-10keV} = 1.3 \times 10^{-12}$ erg s⁻¹ cm⁻² explained with a Compton thin transmission model by Maiolino et al. (1998).

From Suzaku follow up observations Eguchi et al. (2011) derived a model for the nuclear region in which it appears to have a torus with very small opening angles (~15°), observed in a face on geometry. Its spectra is also characterized by an heavy absorption with $N_H \sim 10^{24}$ cm⁻². The AGN is very compact in radio band and possesses a biconical NLR extending for ~4" along PA ~ 160°. In the Spitzer/IRAC images the nucleous is still very compact and is embedded within week lenticular host emission (north-south direction) and surrounded by a large scale ring.

6.14.2 NGC 3081: ISAAC observations and line fit.

We have observed NGC 3081 on January 6th, 2012 at VLT with ISAAC in the J band using both LR and MR instrument modes. We used a $0.8'' \times 1.0''$ wide slit, correspondint to a spectral resolution of ~430 km s⁻¹ and ~ 60 km s⁻¹ for LR and MR modes, respectively. The LR spectrum of NGC 3081 was extracted with an aperture of 0.9'', while the MR spectrum was extracted with a narrower aperture of 0.4''. The LR and MR spectra are shown in Figure



FIGURE 6.36. Optical spectropolarimetry for NGC 3081 from Moran et al. (2000)

6.37, left and right side respectively.

In the ISAAC/LR NIR spectrum NCG 3081 shows an intense He I emission line, well separated from the Pa γ , and the Pa β . There are also weak [Fe II] λ 12570 Å and [S IX] forbidden lines (Figure: 6.37, left side). Unfortunatly in the 2D spectra there is a prominent signature of galaxy rotation in the Pa β (see Figure 6.38), which complicated the interpretation of the line components during the line fitting procedures. Thus we decided to extract the MR spectrum with an aperture as narrow as possible (~ 0.4") in order to reduce this contamination in the best way.

The MR spectrum $Pa\beta$ shows a narrow line with a weak broad component arising from the background (Figure 6.37, right side.) We converted the spectrum to the rest frame wavelenght and estimated the continuum with a power law. We tried to model the $Pa\beta$ line with two gaussian components and we included also the [Fe II] $\lambda 12791$ Å in blending with $Pa\beta$. From our fit the narrow



FIGURE 6.37. Left: flux calibrated ISAAC LR NIR spectrum of NGC 3081. Right: rest frame, flux calibrated ISAAC MR NIR spectrum of NGC 3081 and the fit of the Pa β line (magenta solid line). The green dashed line shows the narrow component, while the blue dashed line shows the broad component. In cyano dashed line the [Fe II] λ 12791 Åin blend with Pa β is shown.



FIGURE 6.38. NGC 3081 2D spectra. There is a clear signature of galaxy rotation in the Pa β line (λ =12923.9 Å).

 $Pa\beta$ results to be centered at $\lambda_c=12923.9$ Å and to have a FWHM_{Rest}=173 km s⁻¹, while the weak broad component results to be centered at $\lambda_c=12916.3$ Å and has a FWHM_{Rest}=619 km s⁻¹. Moreover it is blueshifted of ~7 Å with respect to the narrow line. The fit parameters of NGC 3081 are shown in Table 6.22.

Due to the contamination of the galaxy's rotation we could not accurately identify the BLR component of the $Pa\beta$, thus we did not use it for the BH mass estimation.

ISAAC/MR NGC 3081 Pa β line fit					
Component	$\lambda_{\mathbf{c}}$	σ_{λ}	\mathbf{Norm}_{Rest}	$\mathbf{FWHM}_{Rest}{}^a$	
	[Å]	[Å]	$[\times 10^{-15}]$	$[{ m km}~{ m s}^{-1}~]$	
(1)	(2)	(3)	(4)	(5)	
$Pa\beta$ Narrow	$12923.90\ {\pm}0.07$	$3.2{\pm}1.3$	$2.19{\pm}0.08$	173	
${\rm Pa}\beta$ Broad	$12916.3 {\pm} 0.9$	$11.4 {\pm} 0.1$	$1.11{\pm}0.02$	619	
[Fe 11]	$12891.9 {\pm} 0.5$	$3.2{\pm}1.3$	$0.22{\pm}0.05$	173	
Powerlaw : $\Gamma = 0.99 \pm 0.42$					
$\chi^2_{\nu} = 1.7, \ \nu = 289$					

TABLE 6.22. Pa β line fitting parameters for our ISAAC/MR spectrum of Mrk 1210. (1) Emission line component; (2) Central wavelenght of the emission line; (3) σ for the gaussian component; (4) Rest frame normalization; (5) Rest frame FWHM.

 $[^]a\mathrm{To}$ consider unpredictable sistematic errors on the FWHM measures, we assume a common uncertainty of 10%
Chapter 7

The virial measure of the AGN2 BH masses

As previously discussed in Chapter 5, following the work of Landt et al. (2008, 2011, 2013), we have derived two new NIR virial relationships based on the FWHM of the broad component of $Pa\beta$ emission line and the hard X-ray luminosity in the 14-195 keV band, or the $Pa\beta$ luminosity itself. These relations are less affected by dust obscuration and the galaxy contamination problems. Thus, they are able to reliably measure the BH mass also on those obscured or low luminosity AGN where the nuclear component is less visible and/or contaminated by the hosting galaxy. Thanks to our near infrared observations, performed using ISAAC and Xshooter at VLT and LUCI at LBT, we are now able to derive, for the very first time, the BH masses in AGN2 and intermediate AGN (type 1.8 and 1.9) using the NIR virial relation (see Chapter 5). Moreover, since the BLR emission lines $Pa\alpha$, $Pa\beta$ and He I are well correlated with the Balmer broad lines (Landt et al., 2008), see Figure 7, we can derive a virial BH mass measurments also for the AGN of our sample that have shown in their IR spectra, not only the broad component of $Pa\beta$ line, but also the $Pa\alpha$ and He I ones, allowing us to span the redshift range $0 \le z \lesssim 0.1$.

In the following we will present our estimation for the BH masses of the obscured and intermediate AGN of our SWIFT70M sample, whose infrared spectra have shown broad components of BLR emission lines.

7.1 The BH mass measurement

We found broad components of BLR emission lines in 13 obscured AGN (AGN2, AGN1.8 and AGN1.9) from our sample of 41 AGN randomly selected from the hard X-ray survey SWIFT/BAT 70 Month. Since these sources are obscured, we decided to derive their black hole masses using only our Pa β -



FIGURE 7.1. Left: Comparison between the FWHM of broad and narrow lines (upper right and lower left symbol, respectively) of Pa β vs. Pa α (filled circles), H α (open triangles) and H β (open squares). Right: Comparison between the FWHM of broad and narrow lines (upper right and lower left symbol, respectively) of He I vs. Pa β , H α and H β . In both cases the compared emission lines have similar widths (solid line) whithin the error range (dotted lines) (Landt et al., 2008).

 L_X NIR virial relation, see Equation 5.6 in Chapter 5, in order to have a more accurate BH mass estimation. In Table 7.1 we report: the FWHM values resulting from the line fit procedures (described in Chapter 6) for the AGN with broad component of BLR emission lines, their hard X-ray luminosities in the 14-195 keV band, taken from Baumgartner et al. (2013), their redshifts and the Swift classifications.

After performing the fitting procedures, we applied the resulting rest frame FWHM and the corresponding source hard X-ray luminosity to the Equation 5.6, that allowed us to derive the BH mass measure for all 13 objects. We choose to use the rest frame FWHM of the broad component of Pa β every time it is present in the source spectrum; when this was not possible we used the FWHM of broad component of Pa α or, otherwise, the He I. In particular, 2MSXJ11+19 has an high redshift (z=0.1509, the highest redshift of our subsample), thus its Pa β line falls into a IR telluric absorption band. However, both Pa α and He I are present in its spectrum and we decided to use the hidrogen paschen line Pa α for the BH mass estimation due to its good correlation

with $Pa\beta$ (see Figure 7).

object name	Ŋ	cl	$\log L_{\rm X}$	$\mathbf{Pa}_{\boldsymbol{lpha}}$	$\mathbf{Pa}eta$	$\mathbf{Pa}\gamma$	HeI	[FeII]
			[erg/s]	N/B	N/B	N/B	N/B	N/B
(1)	(2)	(3)	(4)	(5)	(9)	(2)	(8)	(6)
2MSXJ11+19	0.1059	1.8	44.65	272/616		-/544	145/728	1
CGCG -420-015	0.0294	2	43.75	I	287/522	Ι	I	287/-
ESO 374-G044	0.0284	2	43.57	Ι	287/1041	Ι	I	-/209
LEDA 093974	0.0239	2	43.68	I	319/900	Ι	319/1107	319/840
MCG-01-24-12	0.0196	2	43.55	I	244/2169	Ι	1	244/557
MCG -05-23-16 (IS)	0.0085	2	43.51	Ι	256/1049/3149	Ι	Ι	385/-
MCG -05-23-16 (Xsh)	0.0085	2	43.51	Ι	258/1496/3976	258/1938	258/2341	258/-
Mrk 1210	0.0135	2	43.35	I	291/1039	Ι	I	291/789
NGC1365	0.0055	1.8	42.63	I	421/1056/3248	Ι	I	370
NGC2992	0.0077	2	42.55	I	236/679/2019	Ι	I	236/679
NGC4395	0.0013	1	40.79	Ι	211/755	Ι	I	211/-
NGC6221	0.0050	2	42.17	Ι	141/481/2257.2	132/318/1447	132/318/1637.2	141/481
NGC7314	0.0048	1.9	42.42	Ι	136/1165	Ι	Ι	114/-
NGC7465*	0.0066	2	42.14	-000000000000000000000000000000000000	120/2300	220/-	-/1060	200/-

FWHM of Pa α narrow (N) and broad (B) components in km s⁻¹; (6) FWHM of Pa β narrow (N) and broad (B) components The FWHM results from the line fit procedures. We found broad components of NIR permitted lines in 13 in km s⁻¹; (7) FWHM of Pa γ narrow (N) and broad (B) components in km s⁻¹; (8) FWHM of He 1 narrow (N) and broad (B) components in km s^{-1} ; (9) FWHM of [Fe II] narrow (N) and broad (B) components in km s^{-1} . The uncertainties on the (2013); (3)Source classifications (Baumgartner et al., 2013); (4) X-ray luminosity in the 14-195 keV band (Baumgartner et al., 2013); (5) (1) The source name; (2) the source redshift from Baumgartner et al. FWHM are estimated to be at 10%. *data taken from Ramos Almeida et al. (2009) of 41 AGN of our SWIFT70M sample. **TABLE 7.1.**

The LEDA 093974 X shooter NIR spectrum shows an intense He $_{\rm I}$ line and a noisy ${\rm Pa}\beta$ lines, due to the proximity of an absorption telluric band. Since it was hard to perform a reliable fit of the ${\rm Pa}\beta$, we decided to use the rest frame FWHM resulting from the He $_{\rm I}$ line fit (see Section 6.5).

As described in Section 6.4, we have fitted both the ISAAC MR and the Xshooter spectra of MCG -05-23-16 and we found two broad Pa β components. We used the broader ones from both spectra to derive the BH mass, finding that the two estimates are compatible in the uncertainties range. Thus we calculate an average value from the two indipendent measurements.

The source NGC 7465 has been analyzed by Ramos Almeida et al. (2009), who found broad components of BLR lines in its IR spectrum. We used the FWHM reported by the authors.

All the 14-195 keV X-ray luminosities are taken from the SWIFT/BAT 70 Month (Baumgartner et al., 2013), but for NGC 6221 the corresponding X-ray flux results to be contaminated by nearby galaxies. Thus we decided to use the $L_{20-100keV}$ from the INTEGRAL observations of Beckmann et al. (2009), we converted it into $L_{14-195keV}$:

$$log(L_{14-195}) = log(L_{20-100}) - log(100^{0.3} - 20^{0.3}) + log(195^{0.3} - 14^{0.3}), \quad (7.1)$$

and we found $log(L_{14-195}) = 42.17 \pm 0.34 \text{ erg s}^{-1}$.

The BH mass measure uncertainties depend on both the FWHM measurements and the X-ray luminosities. Due to unpredictable sistematic errors on the FWHM estimate and following the studies of Grupe et al. (2004); Vestergaard and Peterson (2006); Landt et al. (2008); Denney et al. (2009), we have preferred to assume a common uncertainty of 10%. While, starting from the SWIFT X-ray flux errors reported in Baumgartner et al. (2013)^a, we calculated the the error on the $log(L_X)$ using the Equation:

$$\sigma_{\log L_{X,i}} = \delta(\log e \ln L_{Xi}) = \log e \frac{\sigma_{L_{X,i}}}{L_{X,i}} = \log e \frac{\sigma_{F_i}}{F_i}.$$
(7.2)

where σ_{F_i} represent the flux uncertainty F_i in the 14-195 keV for the *i*-th source.

 $^{^{\}rm a}{\rm The}$ authors report a 90% of confidence level that we have converted to the 68% dividing by a factor of 1.64

Thus, the overall uncertainty on the Virial product $(XVir = 2 \log FWHM_{Pa_{\beta}} + 0.5 \log L_X)$ is derived applying the error popagations theory:

$$\sigma_{XVir} = \sqrt{(2\log e0.1)^2 + \left(0.5\log e \frac{\sigma L_{X,i}}{L_{X,i}}^2\right)}$$
(7.3)

Finally the overall errors on the BH mass estimates are calculated using:

$$\sigma_{M_{BH}} = \sqrt{\sigma_b^2 + \sigma_a^2 X V i r^2 + a^2 \sigma_{XVir}^2 + 0.21^2},$$
(7.4)

where a, b, σ_a and σ_b are the parameters obtained from the fit of the virial relation and their uncertainties, respectively (see Section 5.2.1, Equation 5.3), and 0.21 is the relation spread.

In Table 7.1 we report the rest frame FWHM of the broad components used in the Equation 5.6, the SWIFT70M 14-195 keV hard X-ray luminosities, taken from Baumgartner et al. (2013) and the BH masses resulting from our virial relation. For some sources we also report previous BH mass measure available in literature. In Figure 7.2 we show the hard X-ray luminosity distribution for the observed AGN2 (blue) and for the AGN2 with virial BH mass estimates (magenta), we notice that there are no particular trends with luminosity. As shown in Table 7.1 the majority of the BH masses result to be lower than

 $10^{7} M_{\odot}$.

We notice that there is an high discrepance between the BH mass of 2MSXJ11+19 derived using the Pa $\beta - L_X$ relation and the value found by Winter et al. (2010). The authors reported a BH mass of log(M_{BH})=9.00 M \odot derived using stellar K-band photometry from Two Micron All-Sky Survey (2MASS). Our value is considerably lower and yield to a super Eddington value for λ_{Edd} . Since the NIR BLR lines used by us are seen in noisy regions of the AGN spectrum, we consider our BH mass as a tentative of estimation.

In Figure 7.3 the L_X-M_{BH} plane for our 13 AGN2 with virial BH mass estimates (red filled dots) is shown. For comparison we also represent the distribution of a sample of ~30 AGN1 (blue empty squares) whose BH mass estimates have been derived using reverberation mapping techniques or $M_{BH}-L$ bulge scaling relations and have been taken from several authors. For MCG -01-23-16 we reported the average BH mass value, obtained from ISAAC and Xshooter observations.

object name	Z	cl	$ m logL_X m [erg/s]$	${ m FWHM}_{ m rest}$ $[{ m km/s}]$	${f logM_{BH}}\ [M_{\odot}]$	$\mathbf{logM_{BH}lit}.$ $[\mathbf{M}_{\odot}]$
(1)	(2)	(3)	(4)	(5)	(6)	(7)
2MSXJ11+19	0.1059	1.8	44.65	616	$6.70 {\pm} 0.24$	9.00 W10
CGCG 420-15	0.0294	2	43.75	522	$6.19{\pm}0.25$	
ESO 374G44	0.0284	2	43.57	1041	$6.63{\pm}0.24$	
LEDA 093974	0.0239	2	43.68	1107	$6.72{\pm}0.24$	
MCG -01-24-12	0.0196	2	43.55	2169	$7.16{\pm}0.24$	7.16 W10
MCG -05-23-16 (IS)	0.0085	2	43.51	3149	$7.42{\pm}0.24$	$6.3{\pm}0.5~\mathrm{B09}$
MCG -05-23-16 (Xsh)	0.0085	2	43.51	3976	$7.60{\pm}0.24$	$6.3{\pm}0.5~\mathrm{B09}$
MCG -05-23-16 $(Ave)^a$	0.0085	2	43.51	3563	$7.50{\pm}0.24$	$6.3{\pm}0.5~\mathrm{B09}$
Mrk 1210	0.0135	2	43.35	1039	$6.53{\pm}0.24$	
NGC1365	0.0055	1.8	42.63	1056	$6.24{\pm}0.25$	$7.7{\pm}0.3~\mathrm{B09}$
NGC2992	0.0077	2	42.55	2019	$6.68{\pm}0.24$	$7.7{\pm}0.3~\mathrm{B09}$
NGC4395	0.0013	1.9	40.79	786	$5.24{\pm}0.26$	$5.4{\pm}0.2~\mathrm{E}12$
NGC6221	0.0050	2	42.17**	2257	$6.62{\pm}0.24$	
NGC7314	0.0048	1.9	42.42	1165	$6.22{\pm}0.25$	$6.0{\pm}0.5~\mathrm{B09}$
NGC7465*	0.0066	2	42.14	2300	$6.60{\pm}0.24$	

AGN Black Hole masses from our virial relations

TABLE 7.2. AGN2 BH mass measurments using our NIR virial relation (Equation 5.6). (1) Source name; (2) Source redshift from Baumgartner et al. (2013); (3) SWIFT classification; (4) X-ray luminosity in the 14-195 keV band from Baumgartner et al. (2013); (5) Rest frame FWHM of broad permitted lines used in the virial relation; (6) BH mass estimated using the NIR virial relation (Equation 5.6); (7) BH masses estimate from literature (B09=Beckmann et al. (2009); E12=Edri et al. (2012); W10=Winter et al. (2010).* Data taken from Ramos Almeida et al. (2009); **L₁₄₋₁₉₅ derived from INTEGRAL L₂₀₋₂₀₀ (Beckmann et al., 2009).

^aAverage values calulated from the Xshooter and ISAAC measurements.



FIGURE 7.2. The hard X-ray luminosity distribution for the observed AGN2 *Swift* subsample (blue) and for the AGN2 with virial BH mass estimates (magenta). There is no particular luminosity trand in our selection.

Our sample of 13 AGN2 results to have on average BH masses 0.8 dex smaller than AGN1 having the same intrinsic hard X-ray luminosity. Indeed in the luminosity range $43.2 < \log L_{14-195keV} < 44 \text{ erg s}^{-1}$, AGN1 shows an average BH mass of $\log M_{BH} = 7.60 \pm 0.1 \text{ M}_{\odot}$, while our AGN2 show an average BH mass of $\log M_{BH} = 6.80 \pm 0.2 \text{ M}_{\odot}$. Therefore AGN2 result to have higher Eddington ratios (some of them are super-Eddington) with respect to the AGN1 population of the same luminosity, as shown in the $L_{bol} - L_{Edd}$ plane in Figure 7.4.

The Eddington luminosity (L_{Edd}) for our 13 AGN has been derived starting from the corresponding virial BH mass measurments, using Equation 3.2, while to derive the bolometric luminosity L_{bol} we follow the method described in Shankar et al. (2013), in which the authors developed an analytical approximation for an X-ray bolometric correction K_{bol} as a function of the Eddington ratio (λ_{Edd}) (see also Vasudevan and Fabian 2007). In particular, they use a well-defined relationship between the bolometric correction and the Eddington ratio with a transitional region at $\lambda_{Edd} \sim 0.1$:

$$K_{bol}(\lambda_{Edd}) = \begin{cases} 18 & \lambda_{Edd} \le 0.105 \\ 54.85 + 26.78 \log L_X & \\ -11.11 (\log L_X)^2 & 0.105 \le \lambda_{Edd} \le 1. \end{cases}$$



FIGURE 7.3. The L_X-M_{BH} plane for our 13 AGN2 with virial estimations of BH mass (red solid dots). For comparison we also show ~ 30 AGN1 (blue open squares) with BH masses derived from reverberation mapping techniques or or the $M_{BH}-L$ Bulge scaling relation. AGN2 shows BH masses on average lower than AGN1 of the same luminosity.

The resulting values for L_{Edd} , L_{bol} and M_{BH} and their corresponding uncertanties are shown in Table 7.3.

object name	$\mathrm{logL}_{\mathbf{X}}$	$\mathrm{log}\mathrm{M}_\mathrm{BH}$	$log L_{Edd}$	$log L_{bol}$
	[erg/s]	$[{f M}_{\odot}]$	[erg/s]	[erg/s]
(1)	(2)	(3)	(4)	(5)
2MSXJ11+19	44.65	$6.70 {\pm} 0.24$	$44.71 {\pm} 0.24$	$46.50 {\pm} 0.12$
CGCG 420-15	43.75	$6.19{\pm}0.25$	$44.29 {\pm} 0.25$	$45.58 {\pm} 0.11$
ESO 374G44	43.57	$6.63{\pm}0.24$	$44.73 {\pm} 0.24$	$45.32{\pm}0.12$
LEDA 093974	43.68	$6.72{\pm}0.24$	$44.82 {\pm} 0.24$	$45.43 {\pm} 0.11$
MCG -01-24-12	43.55	$7.16{\pm}0.24$	$45.26 {\pm} 0.24$	$44.80 {\pm} 0.10$
MCG -05-23-16 (IS)	43.51	$7.42{\pm}0.24$	$45.52{\pm}0.24$	$45.29 {\pm} 0.10$
MCG -05-23-16 (Xsh)	43.51	$7.60{\pm}0.24$	$45.69 {\pm} 0.24$	$44.77 {\pm} 0.10$
MCG -05-23-16 (Ave) ^{<i>a</i>}	43.51	$7.50{\pm}0.24$	$45.60 {\pm} 0.24$	$44.77 {\pm} 0.10$
Mrk 1210	43.35	$6.53 {\pm} 0.24$	$44.63 {\pm} 0.24$	$45.07 {\pm} 0.10$
NGC1365	42.63	$6.24{\pm}0.25$	$44.34{\pm}0.25$	$43.89 {\pm} 0.10$
NGC2992	42.55	$6.68{\pm}0.24$	$44.78 {\pm} 0.24$	$43.81 {\pm} 0.11$
NGC4395	40.79	$5.24 {\pm} 0.26$	$43.34{\pm}0.26$	$42.05 {\pm} 0.10$
NGC6221	42.17	$6.62{\pm}0.24$	$44.65 {\pm} 0.24$	$43.43 {\pm} 0.10$
NGC7314	42.42	$6.22{\pm}0.25$	$44.32 {\pm} 0.25$	$43.68 {\pm} 0.10$
NGC7465*	42.14	$6.60{\pm}0.24$	$44.79 {\pm} 0.24$	$43.39 {\pm} 0.13$

Eddington and bolometric luminosities for our 13 AGN with virial BH masses

TABLE 7.3. Eddington and bolometric luminosities for our subsample of 13 AGN2 with virial mass estimates. (1) Source name; (2) X-ray luminosity in the 14-195 keV band; (3) Virial Black hole mass; (4) Eddington luminosity; (5) Bolometric luminosity.

 $[^]a\mathrm{Average}$ values calulated from the X shooter and ISAAC measurements.



FIGURE 7.4. The $L_{Edd}-L_{bol}$ plane for our 13 AGN2 with virial estimations of BH mass (red solid dots). For comparison we also show ~ 30 AGN1 (blue open squares) with BH masses derived from reverberation mapping techniques or or the M_BH-L Bulge scaling relation. The magenta dashed line indicates the Eddington luminosity value ($\lambda_{Edd}=1$); the green dotted line represent on Eddington ratio of $\lambda_{Edd}=0.1$. AGN2 result to have larger Eddington ratios (some of them are super-Eddington) with respect to the AGN1 population of the same luminosity.

Chapter 8

Conclusions and future prospectives

In order to have a complete sample of obscured and intermediate AGN (AGN2, AGN1.9 and AGN1.8) with hard X-ray (14-195 keV band) luminosity measurments, we randomly selected 41 sources from the *Swift*/BAT 70 month hard X-ray catalog. We performed deep NIR spectroscopic observations both in south and north emispheres using the spectrographs ISAAC and Xshooter at VLT and LUCI at LBT, finding broad components in NIR permitted emission lines in 13 out of 41 obscured AGNs.

As discussed in Chapter 5, the measure of local, low mass, BHs, such as NGC 4395, is of great importance as these BHs give important informations on the AGN/galaxy formation and evolution. NGC 4395 hosts one of the local, smallest, BH of AGN origin ever found. Previous measures (if f=4.31 is used) obtained M_{BH}= $2.81 + 0.86 \times 10^5 M_{\odot}$ from a reverberation mapping analysis of the CIV emission line (Peterson et al., 2005) and M_{BH} = $(2.69 \pm 1.42) \times 10^5 M_{\odot}$ from a reverberation mapping analysis of the H β emission line (Edri et al., 2012).

In order to overcome the dust obscuration and galaxy contamination problems, we have derived two new SE BH mass relationships based on the FWHM and luminosity of the BLR component of the Pa β emission line and on the hard X-ray luminosity in the 14-195 keV band. These relationships have been initially calibrated in the $10^7 - 10^9$ M_{\odot} mass range and have then been used to obtain a new independent BH mass measure of NGC 4395. We obtained M_{BH}=1.7 $^{+1.3}_{-0.7} \times 10^5$ M_{\odot}, which resulted in agreement (<1 σ) with the two previous existing estimates, therefore confirming the very small mass of its BH. Moreover, thanks to our new measure of the Pa β line and mass of NGC 4395 we were able to extend in the $10^5 - 10^9$ M_{\odot} mass range our SE relationships. These relations are able to reliably measure the BH mass on those obscured or low luminosity AGN where the nuclear component is less visible and/or contaminated by the

hosting galaxy.

Our first results confirm that the new derived NIR and hard X-ray based SE relationships do work properly in measuring the AGN BH masses. We can then conclude that our new derived NIR and hard X-ray based SE relationships could be of great help in measuring the BH mass in low luminosity and absorbed AGN and therefore better measuring the complete (AGN1+AGN2) super massive BH mass function up to $z \sim 2.5$.

Thus we have applyed the SE Pa $\beta - L_{14-195keV}$ relation to the 13 AGN with broad permitted emission line identification ad we have derived for the first time a virial BH mass estimate for all these sources. We have found that they have on average BH masses 0.8 dex smaller than AGN1 having the same intrinsic hard X-ray luminosity (in the range 43.2< log $L_{14-195keV}$ <44 erg s⁻¹), in particular AGN1 shows an average BH mass of log M_{BH} =7.60±0.1 M_☉, while our AGN2 show an average BH mass of log M_{BH} =6.80±0.2 M_☉. Moreover, in the $L_{bol} - L_{Edd}$ plane, the AGN2 show higher Eddington ratios with respect to the AGN1 population of the same luminosity and some of them result to be super-Eddington. These results suggest that AGN2 populate a different region in the $M_{BH} - L$ plane with respect the AGN1 population, sampling lower BH masses and luminosities and for this reason they should be properly taken into account to derive the SMBHMF.

8.0.1 Future applications

A reliable virial BH mass estimator able to work also with AGN2 and low luminosity AGN is an useful tools to accurately investigate the characteristics of the obscured AGN population. In the following we will describe some of the applications of our methods that we wish to carry out in the future.

The local density of low mass BH. Different studies have shown that AGN2 are representative of a population of AGN with low intrinsic X-ray luminosity and low BH masses (Tueller et al., 2010) that likely contains clues about the formation of the first BHs. Thus, the measure of the their local density can be used to discriminate between different models for seeds BH.

The AGN2 $L_{bol} - L_{Edd}$ plane. As, on average, we have found smaller BH masses and larger Eddington ratios in AGN2, we are also interested in observing those objects having the highest luminosities, which have been not observed so far, and which are therefore likely to have the largest Eddington ratios. Therefore, we have asked observing time at Xshooter/VLT to measure the BH masses of the most luminous (log $L_X = 44-45$ erg s⁻¹) AGN2 in our *Swift* sample and thus to complete the coverage of the luminosity range (3 dex).

The AGN2 scaling relationships. In order to verify the validity of the BH-bulge galaxy properties also for AGN2, we are actually performing 2D bulge-disc decompositions of Spitzer/IRAC 3.6 μ m images of our sources with virial BH mass estimates. This method will allow us to obtain an accurate estimate of the hosting galaxy bulge L_K for the 13 AGN2 and thus to derive their $M_{BH} - L_K$ scaling relation to be compare with the one found for AGN1 populations. Similarly, following the work of Riffel et al. (2013), we will use the emission line profile of the NIR [Fe II] λ 12570 Å as an indicator of the stellar velocity dispertion (σ_{\star}) in order to derive the $M_{BH} - \sigma_{\star}$ for the subsample of 13 AGN2 with virial M_{BH} and will also compare it with the one for AGN1.

Finally these NIR SE estimators will be applyied in the framework of demographics studies that suffer for the AGN2 bias. Thus it will be possible to derive for the first time the SMBHMF also for obscured and low luminosity AGNs and compare it with the one found for AGN1, in order to accurately constrain the accretion history of AGNs.

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Appendix A

Proposal



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APPLICATION FOR OBSERVING TIME

Category:

A-1

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title

The first measure of the local density of the Low Mass Black Holes via NIR spectroscopy of AGN2

2. Abstract / Total Time Requested Total Amount of Time:

Nowadays there are robust evidences that every galaxy hosts a super massive black hole (SMBH; 10^{6} - 10^{9} M_{\odot}) whose mass correlates with the host galaxy properties. However all the AGN BH mass estimates and scaling relations are based on observations of AGN1, where the broad line is visible in the optical and therefore the virial based methods can be used. Unfortunately AGN1 are not representative of the whole AGN population, having on average larger luminosities and masses. It is therefore very important to measure the mass of the AGN2 (those where the broad line region is not visible in the optical because of dust absorption). Moreover, in order to understand the BH formation is very important to measure the local density of the low-mass BH which are likely hosted in AGN2. We here propose to measure the BH mass of a complete sample of 10 low luminosity AGN2 (from the SWIFT/BAT survey) using our new virial method based on NIR spectroscopy observations.

3. Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Туре
А	93	XSHOOTER	8h	any	d	1.2	CLR	\mathbf{S}	
A/alt	93	SINFONI	9h	any	n	1.2	CLR	s	

4. Number of nights/hours

a) already awarded to this project:

b) still required to complete this project:

Telescope(s) ISAAC Amount of time 25 hours in 88.A-0839(A)

5. Special remarks:

6. Principal Investigator: fonori

6a. Co-investigators:

F.	La Franca	1857
S.	Bianchi	1857
А.	Marconi	1876
F.	Fiore	1345
Followi	ng CoIs moved to the end	of the document \dots

7. Description of the proposed programme

A – Scientific Rationale:

The accretion of matter on the supermassive black holes and the related radiative and kinetic power output play an important role in the galaxy evolution, by suppressing/tuning the star formation and feeding the AGN itself (feedback; Silk & Rees 1998; Fabian 1999; Croton et al. 2006; Cattaneo et al. 2009 for a review). In this framework, it appears clear that the study of AGN evolution is very important to understand the evolution of the star formation rate and galaxies in the Universe (AGN/galaxy co-evolution).

Nowadays there are robust evidences that every galaxy hosts a super massive black hole (SMBH; $M_{BH}=10^{6}-10^{9}$ M_{\odot}) and, although its formation mechanisms are still not well understood, the correlations of its mass with the host galaxy properties have been fairly well established (at least at low redshift; e.g., Marconi & Hunt 2003, Ferrarese & Merrit 2000, Gebhardt et al. 2000a). The existence of these scaling relationships implies that the evolution of galaxies and the growth of SMBHs are intricately tied together. In order to obtain a clear picture of the AGN/galaxy co-evolution, it is important to accurately derive the shape and the evolution of both AGNs luminosity and SMBH mass functions, in addiction to the star formation and accretion rates on the BH.

In the last decade, using hard X-ray selected AGN samples, it has been possible to accurately derive the AGN luminosity function up to $z\sim4$, and recently, using virial based techniques in the optical band on samples of broad line AGN (AGN 1), it has been possible to obtain some estimates of the Super Massive BH Mass Function (SMBHMF). However these measurements are affected by several selection biases against the narrow line AGN (AGN 2), where the Broad Line Region (BLR) is not visible in the optical because of dust absorption.

AGN1 and AGN2 are intrinsically different. According to the original standard unified model (Antonucci 1993), the different observational classes of AGN (AGN1 and AGN2) were believed to be the same kind of objects observed under different conditions (e.g. different orientations to the observer). Instead, nowadays there are indications that AGN1 and AGN2 have on average different accretion rates (smaller for AGN 2, Winter et al. 2010), different host galaxy properties (more early type for AGN 2) and different masses (smaller for AGN2, Georgakakis et al. 2009, see also Lusso et al. 2012). It is therefore fundamental to measure the SMBHMF of both AGN 1 and AGN 2 in a consistent way.

In the few studies where AGN2 BH masses have been derived (e.g. Heckman et al. 2004 from SDSS), the authors used the BH-bulge scale relations which, however, were calibrated on AGN1 samples and are unlikely to hold also for all AGN2 (see Graham 2008 and Kormendy et al. 2011). It is therefore crucial to directly measure AGN2 BH masses in order to verify the validity of the scaling relations for this population of AGNs. Moreover, different studies have shown that AGN 2 are representative of a population of AGN characterised by low intrinsic X-ray luminosity and low BH masses (Tueller et al. 2008; Tueller et al. 2010).

The importance of finding low mass BHs at low redshift. Low mass BHs ($M_{BH} \leq 10^6 M_{\odot}$) in the local universe provide unique tests for studies of black holes formation and growth, galaxy formation and evolution. In current models of galaxy evolution in a hierarchical cosmology, SMBHs must have been built up from accretion onto much smaller seeds, in conjuction with merging with other BHs. This models also predict that smaller scale structures form at later times (cosmic downsizing), and one might expect that seeds BHs in these smaller systems may not have had enough time to be fully grown. This means that low-mass BHs likely contains clues about the formation of the first black holes, thus the mass function of the present day low-mass black holes and their host galaxies properties can be used to discriminate between different models for seeds BHs and help shed light on the coevolution of BHs and galaxies (see Dong & De Robertis 2006; Green & Ho 2007; Dong et al. 2012; Greene 2012). Moreover low-mass BHs are very interesting for the AGN studies as they extend the dynamic range of physical variables and AGN scaling relations to extreme values. It become, therefore, of outmost importance to find (and measure the density of) the low mass BH at low redshift.

The first virial measures of the AGN2 BH Masses. Thanks to our studies, mostly based on ISAAC/VLT observations(088A.-0839(A)), it is now possible for the very first time to directly measure AGN2 BH masses using NIR spectroscopy. Several studies have shown that most AGN2 exhibit faint components of broad lines if observed with high (≥ 20) S/N in the near infrared, where the dust absorption is less severe than in the optical (Veilleux et al. 1997; Riffel et al. 2006; Cai et al. 2010). Moreover observaton in the NIR of AGN1 whose BH masses were measured with reverberation techniques, have demonstrated that the virial method can be efficiently used with the NIR Pa α and Pa β lines (Landt et al. 2008; Landt et al. 2011). Following the methods of Landt et al. 2008 and Landt et al. 2011 we have been able to create a virial relation between the Pa β line and the X-ray luminosity (M_{BH} vs. 2LogFWHM_{Pa β}+0.5LogL₁₄₋₁₉₅) that allowed us to measure the BH masses for AGN2 (see Fig. 1a). We found the broad component of Pa β in 5 over 12 candidates in our sample of AGN2, randomly selected from the SWIFT/BAT 22 month survey (Tueller et al. 2010).

In Fig. 1b the fit of the broad component of Pa β , found in our spectra of one of the smallest BH known, NGC4945, is shown. Its mass has been previously derived using reverberation techniques by Peterson et al. (2005) and Edri et al. (2012). Their results and our measure are in statistical agreement and are reported in Fig 1a, where our virial relation between the Pa β line and the X-ray luminosity is also shown. Our results confirm that the AGN2 BH mass function spans smaller masses than the AGN1's one (all our measures have $M_{BH} < 10^7 M_{\odot}$; see Fig. 1). As in the virial relation the BH mass is proportional to the square root of the

7. Description of the proposed programme and attachments

Description of the proposed programme (continued)

intrinsic AGN luminosity, we expect (and our observations confirm) that low mass BH are more likely found among low luminosity AGN2.

We, therefore, propose to measure for the first time the BH mass of a statistically complete sample of low redshift low luminosity AGN2.

B – Immediate Objective: Here we propose to measure the BH masses and host galaxy properties of a complete sample of AGN 2 with $\log(L_{14-195}) \leq 42.5$ erg/s, which are the most likely candidates to host small-mass BHs. Indeed in our sample none of the AGN1 (green square in Fig. 1c) show the low X-ray luminosity needed to be considered a small-mass BH candidate. Our sample is composed by all the 10 AGN2 selected from the 70-month SWIFT/BAT sample (Baumgartner et al. 2013) with $\delta \leq 10$ and having $10 \leq \alpha \leq 22$, using VLT/Xshooter (for 2 objects observational data exist). The main advantages of BAT 70 month survey, compared to the previous Swift-BAT 22-month survey, is that it has a better sensitivity and therefore a lower flux threshold which allowed to detect low luminosity AGN2 (which are more likely to host low-mass BHs). To apply efficiently the new virial method in the NIR band and thus accurately measure the BH masses we need to carry out high S/N J band, in order to detect the faint broad (\geq 500-1000 Km/s) component in the $Pa\beta\lambda 1282$ nm line. The wide spectral coverage of Xshooter will allow us to accurately measure optical emission lines needed to estimate the galaxy reddening using the Balmer's decrement and thus accurately characterise the whole AGN/host-galaxy properties, by measuring M_{\star} and the star formation rate (SFR). According to the literature and to our previous experience in applying this method, we expect to detect the broad components in about the 50% of the candidates, thanks to the Xshooter's resolution and sensitivity. These observations will allow us a) to measure the density of the low mass BH at low redshift, b) to compare it with the SMBHMF for AGN1. Also, they will allow us to verify the validity of the observed scaling relations between BH mass and galaxy bulge properties for type 2 AGN and to extend them toward the low mass end.

Attachments (Figures)



Fig.1a: Our calibrated virial relation (M_{BH} vs. 2LogFWHM_{Pa\beta}+0.5LogL₁₄₋₁₉₅; dotted line) used to measure the M_{BH} from the broad component of Pa β line. The NGC4945 BH mass is shown by a red square, while other 4 AGN2 BH masses measured during our previous runs, are represented by cyan squares. The AGN1 BH masses (taken from Landt et al. 2011) are represented by black filled circles. **Fig 1b**: The fit of the broad component of Pa β , found in our previous J-band spectroscopic observations of NGC4945 (FWHM=783 Km/s). **Fig 1c**: The 70-month SWIFT/BAT sample in the southern emi-sphere: AGN1 (green square), AGN2 (black crosses) and our 8 AGN2 low-mass BHs candidates (red filled circles) with $\log(L_{14-195}) \leq 42.5$ erg/s that we propose to observe with Xshooter. The two open red circles show those galaxies for which useful archival data already exist.

References: Antonucci 1993, ARA&A, 31, 473; Baumgartner et al. 2013, ApJS, 207, 19; Cai et al. 2010, RAA, 10, 427; Cattaneo et al. 2009, Nature, 460, 213; Croton et al. 2006, MNRAS, 365, 11; Dong & De Robertis 2006, AJ, 131, 1236; Dong et al. 2012, ApJ, 755, 167; Edri et al. 2012, ApJ, 756, 73; Fabian 1999, MNRAS, 308, L39; Ferrarese & Merritt 2000, ApJ, 539, L9; Gebhardt et al. 2000, ApJ, 539, L13; Georgakakis et al. 2009, MNRAS, 397, 623; Graham 2008, ApJ, 680, 143; Greene & Ho 2007, ApJ, 670, 92; Greene 2012, NatCo, 3E, 1304G; Heckman et al. 2004, ApJ, 613, 109; Kormendy et al. 2011, Nature, 469, 374;Landt et al. 2007, ApJS, 174, 282; Landt et al. 2011, MNRAS, 413, L106; Lusso et al., 2012, MNRAS, 425, 623; Marconi & Hunt 2003, ApJ, 589, L21; Peterson et al. 2004, ApJ, 613, 682; Riffel et al. 2006, A&A, 457, 61; Silk & Rees, 1998, A&A,331,L1; Tueller et al. 2008, ApJ, 681, 113; Tueller et al. 2010, APJS, 186, 378; Veilleux et al. 1997, ApJ, 477,631.

		-						
Q	Institication	of	roquested	obconving	time	and	obconving	conditions
0.	JUSTILICATION	OI.	requested	observing	unne	anu	observing	Conditions

Lunar Phase Justification: We request time during dark nights in order not to degrade the spectroscopic sensitivity for the UVB and VIS arms. If SINFONI is allocated, bright night are also accepted.

Time Justification: (including seeing overhead)

We wish to detect a possible faint broad component in the Pa α 1.875 and Pa β 1.282 and HeI1.083 lines. All the AGN have redshift lower than 0.02. Pa β 1.282 and HeI1.083 lines will be observed, for all sources, in the J band. We have used 1" slit for the UVB and 0.9" for the VIS and NIR arms, and fixed the seeing to 1.2" and airmass of 1.2.

Based on our previous ISAAC/VLT observations, we have seen that the continuum brightness of the near-IR counterpart of hard X-ray sources is not indicative of the detectability of the emission lines. A more useful indicator is the (unabsorbed) 2-10 keV flux. As all the sources belongs to the SWIFT/BAT flux limited survey, the integration time required to detect the presence of the broad line component is (within the uncertainties) the same for all sources. Deep integration times have been computed requesting a conservative value of S/N \sim 30 per pixel in the J band for the faint broad line component.

To estimate the instrument and telescope overheads, we referred to the section 3.4 of the User Manual. For each OB we expect ~ 16 minutes of overheads. On average we need 1 hour of observation for each object (overheads included).

ETC 5.0.1 has been used.

8a. Telescope Justification:

We request XSHOOTER in order to be able to study both the AGN and the host galaxy properties and then study the AGN/host galaxy relations for the low mass BH AGN2.

8b. Observing Mode Justification (visitor or service): We request service mode as the targets have different R.A. and the observations are quite standard.

8c. Calibration Request: Standard Calibration

 9. Report on the use of ESO facilities during the last 2 years 086.B-0579(A) - SINFONI - 30 hrs - PI: Marconi - Catching feedback in action: kinematical maps of galactic-scale outflows in luminous quasars Observations have been completed and data has been reduced and analyzed. Paper is being written.
088.A-0839(A) - ISAAC/VLT - 25 hrs - PI: La Franca - <i>The first direct measure of the complete (AGN1+AGN2)</i> <i>local black hole mass function of the AGN.</i> Observation carried out. Data reduced. Paper in preparation (see description in section 7. Description of the proposed programme).
090.A-0830(A) - UT2/X-SHOOTER - PI: Brusa - Identifying and measuring BH masses for $z=1-2$ obscured QSO with X-shooter - Observations made on 8-10 February 2013, data analysis finished, paper in preparation, first results presented in few conferences.
9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data. There are no useful data for our scientific objectives in the ESO Archive.
9b. GTO/Public Survey Duplications:
10. Applicant's publications related to the subject of this application during the last 2 years La Franca F., Melini G., Fiore F., 2010, ApJ, 718, 368: Tools for Computing the AGN Feedback: Radio-loudness Distribution and the Kinetic Luminosity Function
Sarria, J.E., Maiolino R., La Franca F., et al. 2010, A&A, 522, L3: The M_{BH} -M* relation of obscured AGNs at high redshift
Chiaberge, M. & Marconi, A., 2011, MNRAS, 416, 917: On the origin of radio loudness in active galactic nuclei and its relationship with the properties of the central supermassive black hole
Fiore, F., Puccetti, S., Grazian, A., Menci, N., Shankar, F., Santini, P., Piconcelli, E., Koekemoer, A. M., Fontana, A., Boutsia, K., Castellano, M., Lamastra, A., Malacaria, C., Feruglio, C., Mathur, S., Miller, N., Pannella, M., 2012, A&A, 537, A16: Faint high-redshift AGN in the Chandra deep field south: the evolution of the AGN luminosity function and blackhole demography.
 Bongiorno, A., Merloni, A., Brusa, M., Magnelli, B., Salvato, M., Mignoli, M., Zamorani, G., Fiore, F., Rosario, D., Mainieri, V., Hao, H., Comastri, A., Vignali, C., Balestra, I., Bardelli, S., Berta, S., Civano, F., Kampczyk, P., Le Floc'h, E., Lusso, E., Lutz, D., Pozzetti, L., Pozzi, F., Riguccini, L., Shankar, F., Silverman, J., 2012, MNRAS, 427, 310: Accreting supermassive black holes in the COSMOS field and the connection to their host galaxies
Vignali, C., Piconcelli, E., Lanzuisi, G., Feltre, A., Feruglio, C., Maiolino, R., Fiore, F., Fritz, J., La Parola, V., Mignoli, M., Pozzi, F., 2011, MNRAS, 416, 1106 : On the nature of the absorber in IRAS 09104+4109: the X-ray and mid-infrared view.
Bianchi, S., Panessa, F., Barcons, X., Carrera, F. J., La Franca, F., Matt, G., Onori, F., Wolter, A., Corral, A., Monaco, L., Ruiz, Á., Brightman, M., 2012, MNRAS, 426, 3225:Simultaneous X-ray and optical observations of true type 2 Seyfert galaxies.
Brusa, M., Gilli, R., Civano, F., Comastri, A., Fiore, R., Vignali, C., 2011, MSAIS, 17, 106:Identification of (high-redshift) AGN with WFXT: lessons from COSMOS and CDFS.

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11.	1. List of targets proposed in this programme								
	Run	Target/Field	α(J2000)	δ (J2000)	ТоТ	Mag. Diam.	Additional Reference star info		
	А	NGC 4941	$13\ 04\ 13.107$	-05 33 05.67	1.0	12.301	NGC 4941		
	А	NGC 5643	$14 \ 32 \ 40.699$	$-44 \ 10 \ 27.97$	1.0	12.062	NGC 5643		
	А	NGC 6221	$16\ 52\ 46.341$	$-59\ 13\ 00.81$	1.0	11.89	NGC 6221		
	А	NGC 4180	$12\ 13\ 03.051$	$07 \ 02 \ 19.79$	1.0	12.798	NGC 4180		
	А	ESO 234-G050	$20\ 35\ 57.874$	$-50\ 11\ 32.14$	1.0	13.559	ESO 234-G050		
	А	NGC 4945	$13\ 05\ 27.080$	$-49\ 27\ 56.57$	1.0	12.601	NGC 4945		
	А	2MASX J18305065+092841	$\frac{18}{4} \begin{array}{c} 30 \\ 50.637 \\ 4 \end{array}$	-09 28 41.73	1.0	13.140	2MASX J18305065+0928414		
	А	NGC 7314	$22 \ 35 \ 46.211$	$-26\ 03\ 01.58$	1.0	13.846	NGC 7314		

12. Scheduling requirements

13. Instrument configuration								
Period	Instrument	Run ID	Parameter	Value or list				
93	XSHOOTER	А	300-2500nm	SLT				

6b. Co-investigators:

... continued from Box 6a.

А.	Bongiorno	1345
М.	Brusa	7530
С.	Vignali	7530
F.	Ricci	1857

Appendix B

List of publications

In this Appendix the list of publications in which I have been involved during my PhD are listed. The papers topics are not strictly related to the main project on which I worked during my Ph.D. thesis.

- F. La Franca, F. Onori, F. Ricci, E. Sani, M. Brusa, R. Maiolino, S. Bianchi, A. Bongiorno, F. Fiore, A. Marconi and C. Vignali, "Extending Virial Black Hole Mass Estimates to Low-Luminosity or Obscured AGN: the cases of NGC 4395 and MCG 01-024-012", MNRAS, 2014 *Submitted*).
- Brusa, M.; Bongiorno, A.; Cresci, G.; Perna, M.; Marconi, A.; Mainieri, V.; Maiolino, R.; Salvato, M.; Lusso, E.; Santini, P.; Comastri, A.; Fiore, F.; Gilli, R.; Franca, F. La; Lanzuisi, G.; Lutz, D.; Merloni, A.; Mignoli, M.; Onori, F.; Piconcelli, E.; Rosario, D.; Vignali, C.; Zamorani, G. (2015), "X-shooter reveals powerful outflows in z ~1.5 X-ray selected obscured quasi-stellar objects", MNRAS, 446, 2394-2417.
- Bianchi, Stefano; Panessa, Francesca; Barcons, Xavier; Carrera, Francisco J.; La Franca, Fabio; Matt, Giorgio; Onori, Francesca; Wolter, Anna; Corral, Amalia; Monaco, Lorenzo; Ruiz, Angel; Brightman, Murray (2012), "Simultaneous X-ray and optical observations of true type 2 Seyfert galaxies", MNRAS, 426, 3225-3240.

É una follia odiare tutte le rose perché una spina ti ha punto, abbandonare tutti i sogni perché uno di loro non si é realizzato, rinunciare a tutti i tentativi perché uno é fallito. É una follia condannare tutte le amicizie perché una ti ha tradito, non credere in nessun amore solo perché uno di loro é stato infedele, buttare via tutte le possibilitádi essere felici solo perché qualcosa non é andato per il verso giusto. Ci sará sempre un'altra opportunitá, un'altra amicizia, un altro amore, una nuova forza.

Per ogni fine c'é un nuovo inizio.

Antoine de Saint-Exupéry, Il piccolo principe.