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The hidden nature of narrow line Seyfert 1 galaxies

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Abstract.
Narrow-Line Seyfert 1 (NLS1) galaxies are relatively rare objects among type 1 nearby Active Galactic Nuclei (AGNs), and after almost two decades since their first classification, they are still a matter of debate. Their peculiar properties, like narrow permitted emission lines (FWHM(Hβ)<2000 km s^{-1}), steep slopes and rapid variability in the soft X-ray domain, and the optical/UV Big Blue Bump shifted towards higher energy, are currently interpreted as indications of active nuclei younger than "classical" Seyfert 1 (S1) galaxies, powered by smaller supermassive black holes ($M_{BH} \sim 10^6 - 10^7 M_\odot$), and accreting at higher rates. To date this paradigm is not yet proved. Other possible scenarios were proposed and several authors challenged this topic from different points of view. Here we present a short review about the spectroscopic properties of NLS1s and recent results obtained within our group in investigating the BH-bulge relation of AGNs as a test for the NLS1-paradigm.

Key words. galaxies: active – galaxies: nuclei – galaxies: Seyfert

1. Introduction

According to the Unified Model of Active Galactic Nuclei (AGNs) Seyfert 1 and Seyfert 2 galaxies are powered by the same kind of nuclear source, a supermassive black hole (BH) with an accretion disk, which emits a great amount of high energy photons. High density and high velocity clouds of ionized gas, the so-called Broad Line Region (BLR), are believed to move close to the BH in the gravitational potential of the central mass. The BLR is sorrounded by a ring or a torus of molecular gas and dust able to absorb optical, UV and soft X-ray emission. Lower density and lower velocity ionized gas, the so-called Narrow Line Region (NLR), is located more distant from the BH. When our line-of-sight is normal to the dusty torus axis, the optical spectrum shows a stellar continuum with only narrow emission lines and the active galaxy is classified as Seyfert 2, while when we observe inside the torus the spectrum shows a power-law continuum with broad permitted lines and narrow forbidden lines, and the galaxy appears as a Seyfert 1.

Within this picture, Narrow Line Seyfert 1 galaxies (NLS1s) have peculiar properties. Identified about twenty years ago, these AGNs are not yet completely understood. In optical they show typical [O III]λ5007/Hβ ratios lower than 3 and multiplets of Fe II, like "classical" Seyfert 1, but the permitted lines are narrower than those observed in Seyfert 1. The FWHM

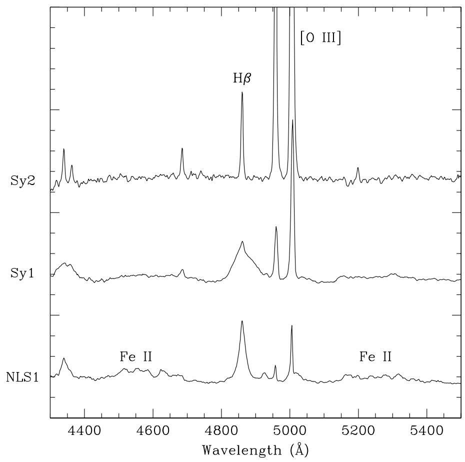

Fig. 1. Comparison among the rest-frame optical spectra of a NLS1 (lower), a Seyfert 1 (middle) and a Seyfert 2 galaxy (upper) in the wavelength region centered on emission lines Hβ and [O III] λ4959, 5007.

of Hβ < 2000 km s^{-1} is a limit fixed to classify a Seyfert galaxy as NLS1 (Fig. 1). NLS1s are also bright X-ray sources (Fig. 2): their soft X-ray and hard X-ray spectra are typically characterized by steeper slopes of the power-law continuum. The optical/UV feature known as Big Blue Bump, generally ascribed to the accretion disk, is weak in NLS1s and believed to be shifted toward higer energies. Moreover, NLS1s show often rapid soft X-ray variability of factors two or even three in few hours. Finally, many NLS1s are observed to be bright in infrared and with nuclear super-solar metallicities, but this is not definitely proved.

2. The current NLS1s paradigm

How can we explain the narrowness of the optical permitted lines?

Assuming that NLS1s are powered by BHs with masses in the same range of Seyfert 1 and quasars ($M_{BH} \sim 10^7$–10^9 $M_\odot$), a lower FWHM could be simply caused by a BLR located on average at larger distances from the central mass. Recently, Kaspi et al. (2000) obtained an important empirical correlation between the

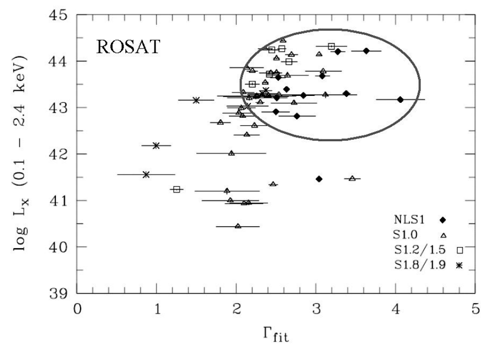

Fig. 2. Figure adapted from Pfefferkorn et al. (2001). The circle marks the region of the plot occupied by NLS1 galaxies (black dots), showing on average high soft X-ray luminosities and steep X-ray slopes.

optical luminosity of the continuum at rest-frame 5100 Å and the BLR radius, measured through reverberation mapping, of a sample of Seyfert 1 and quasars. Peterson et al. (2000) demonstrated that also NLS1s agree with this correlation with similar luminosities and BLR radii.

We can also make the hypothesis that the geometrical distribution of the BLR clouds is not random but flat. In this case we must take into account the inclination of the BLR with respect to our line-of-sight, and the NLS1s are those Seyfert 1 galaxies whose BLR is seen more face-on. Given its sub-parsec scale, the BLR is unresolved even in very nearby objects, therefore a priori we cannot assume a specific geometry of the BLR. There are indications that the BLR is confined in a plane in radio-loud AGNs (see e.g. McLure & Dunlop 2002, and references therein), while the same evidence in radio-quiet AGNs is much less significant.

A third possibility, which is the current paradigm of NLS1s, is that these AGNs are hosting less massive BHs. This scenario has important consequences because, as NLS1s span the same range of nuclear luminosities as classical Seyfert 1, we should reasonably expect to observe higher accretion rates. In fact it was shown by several authors (see e.g. Czerny et al. 2003; Kawaguchi 2003; Collin

& Kawaguchi 2004) that NLS1s have accretion rates close to the Eddington limit or even higher.

3. The BH-bulge relation in NLS1s

It has been known for the last decade that almost all nearby non-active galaxies host a supermassive BH (10^7 – 10^9 $M_\odot$), and that the BH mass correlates with the luminosity – and so with the mass – of the hosting bulge (Kormendy & Richstone 1995; Magorrian et al. 1998). More recently, Ferrarese & Merritt (2000), Gebhardt et al. (2000a), and Tremaine et al. (2002) obtained tight correlations between the BH mass and the bulge stellar velocity dispersion. All these results had an important impact on the general knowledge of galaxy formation and evolution. When it was demonstrated that Seyfert 1 and quasars also agree with non-active galaxies in following such a BH-bulge correlation (see e.g. Laor 1998; Gebhardt et al. 2000b; McLure & Dunlop 2001; Wu & Han 2001), it was indirectly suggested that AGNs are likely not exotic sources in the Universe, but rather a short recurrent phenomenon in the lifetime of a galaxy.

On this basis we decided to test the current paradigm of NLS1s by studying the physical properties of their bulges. This was done by collecting the optical spectra of a number of NLS1 and Seyfert 1 nuclei. We obtained part of these data by means of direct observations with AFOSC at the 1.8 m telescope of Padova Observatory (Asiago, Italy), while part were extracted from the ING public archive: these spectra were obtained with IDS at the 2.5 m Isaac Newton Telescope and with ISIS at the 3.9 m William Herschel Telescope (La Palma, Canary Islands, Spain).

The BH mass was estimated for each target by applying the Virial theorem to the BLR clouds in the assumption that they are moving in the gravitational potential of the central mass. The BLR radius was obtained through the application of the Kaspi et al. (2000) relation, and the velocity was calculated from the width of Hβ in the hypothesis of randomly distributed clouds (Fig. 3). On average NLS1s seem to host less massive BHs than Seyfert 1

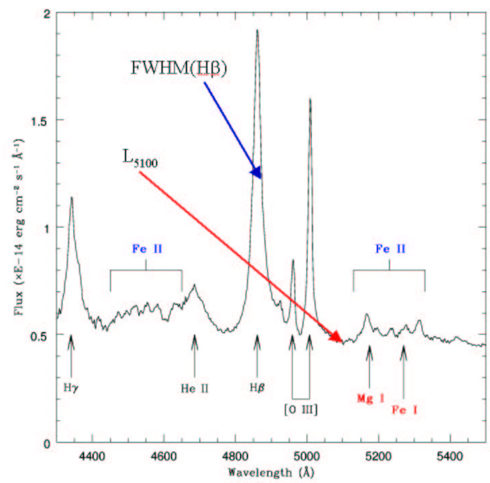

Fig. 3. The spectrum of a NLS1 galaxy taken from our observational data. The red arrow indicates the nuclear continuum at rest-frame 5100 Å used to estimate the BLR radius by means of the Kaspi et al. (2000) relation. The blue arrow indicates the FWHM of Hβ.

galaxies: $log\ M_{BH}(NLS1) = 6.65 \pm 0.64\ M_\odot$ vs. $log\ M_{BH}(S1) = 7.37 \pm 0.62\ M_\odot$. Clearly this result was not unexpected, since the nuclear luminosities of NLS1s and Seyfert 1 galaxies span the same range of values, as found also by other authors, therefore the lower BH masses in NLS1s reflect simply the narrowness of their BLR emission lines.

3.1. Photometry

We looked in literature for CCD magnitudes in the photometric broad-band B of our targets, and we could obtain the data of 11 NLS1s and 12 Seyfert 1 galaxies. The apparent m_B values were corrected for AGN contribution (Δm_A), galactic inclination (Δm_i), Galaxy extinction (Δm_G) and K-correction (Δm_K). Since all our galaxies were at redshift lower than 0.1, the K-correction was the less important term. The correction for the AGN contribution was performed by using the empirical relations obtained by Whittle (1992), which account for the fluxes of the emission lines Hβ and [O III] as a function of the redshift, and of the AGN continuum to the B band, having adopted a

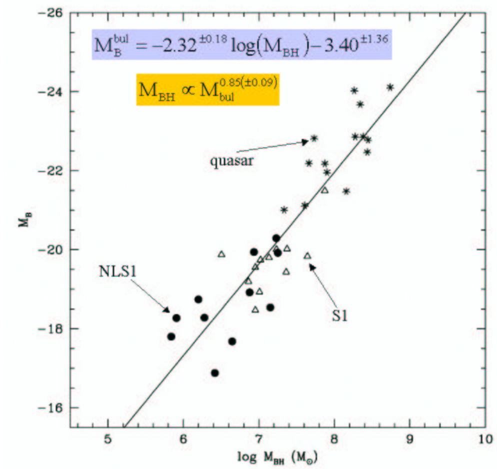

Fig. 4. Figure adapted from Botte et al. (2004), representing the relation between the BH mass and the absolute blue luminosity of the bulge for our sample of NLS1s and Seyfert 1 galaxies, and a sample of quasars taken from literature.

power law with spectral index $\alpha = -1.0$. Then, from the total B magnitude of each galaxy we extracted the bulge magnitude, m_B^{bul}, through the application of the Simien & de Vaucouleurs (1986) relation, a polynomial function of the galaxy morphology which gives the correction term to add to m_B. Finally, we calculated the absolute B magnitudes both for the NLS1 and Seyfert 1 bulges, obtaining the following median values: $M_B^{bul}(NLS1) = -18.54 \pm 1.06$, $M_B^{bul}(S1) = -19.80 \pm 0.73$. Even taking into account the strong uncertainties, especially in the morphological classification of the galaxies, we observed a significant lower luminosity of the NLS1 bulges.

Plotting the photometric values versus the BH masses, and adding a sample of quasars taken from literature, we obtained a clear correlation (R=0.91): $M_B = -2.32(\pm0.18)\log(M_{BH}) - 3.40(\pm1.36)$. Applying the mass-to-luminosity conversion for bulges and spheroidal galaxies by Magorrian et al. (1998), the resulting BH-bulge mass relation was $M_{BH} \propto M_{bul}^{0.85(\pm0.09)}$.

3.2. Kinematics

Measuring the central stellar velocity dispersion (σ_*) in type 1 AGNs is not an easy task, since the optical absorption features commonly used to derive the kinematics are strongly diluted by the bright nuclear continuum. More complicated is the situation when σ_* has to be measured in NLS1s, where the extended Fe II multiplets suppress completely absorption lines as Mg I λ 5175 and CaFe λ 5269 (Fig. 3). On the contrary, type 1 AGNs show bright emission lines from the NLR. Assuming that the NLR is sufficiently distant to the central mass for its kinematics being dominated by the bulge gravitational potential, a connection between gas and stellar velocity dispersion should be expected. Nelson & Whittle (1996) found a weak correlation, FWHM([O III])=2.35$\times\sigma_*$, based on a sample of Seyfert 1 and Seyfert 2 galaxies. As done by several other authors, we used the [O III] line to estimate the stellar kinematics in our NLS1s and Seyfert 1 spectra. Plotting these indirect values of the stellar velocity dispersion versus the BH masses, and adding quasars and non-active galaxies taken from literature, we obtained a puzzling result: Seyfert 1, quasars and non-active galaxies are all in agreement with the $M_{BH} - \sigma_*$ relations published by Ferrarese & Merritt (2000), Gebhardt et al. (2000a), and Tremaine et al. (2002), while NLS1s are not. In addition, NLS1s seem to share a similar range of σ_* values as Seyfert 1, and so similarly massive bulges, a result which would indicate that in NLS1s we are likely underestimating the BH mass.

The same was obtained by Grupe & Mathur (2004) and Bian & Zhao (2004) with different data, but a similar approach, thus suggesting that the use of $\sigma_{[OIII]}$ in place of σ_* could be incorrect in NLS1s. Since direct measures of σ_* were mandatory, we obtained new high resolution spectra ($\sim$ 65 km s^{-1}) of some NLS1s centered on the Ca II absorption triplet at 8498, 8542, 8662 Å. These features are not always present in NLS1s, several of which show emission instead of absorption lines. Plotting the values of σ_* versus $\sigma_{[OIII]}$ we could demonstrate for the first time that in

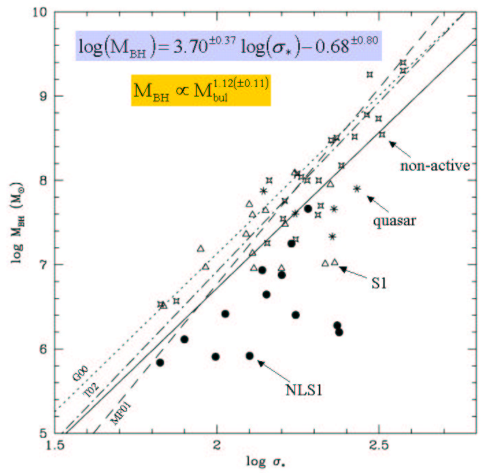

Fig. 5. Figure adapted from Botte et al. (2004), representing the relation between the BH mass and the stellar velocity dispersion of the bulge for our sample of NLS1s and Seyfert 1 galaxies, and a sample of quasars and non-active galaxies taken from literature. The solid line is our fit, while dotted, dot-dashed and dashed lines are Gebhardt et al. (2000a), Tremaine et al. (2002), and Merritt & Ferrarese (2001) relations, respectively.

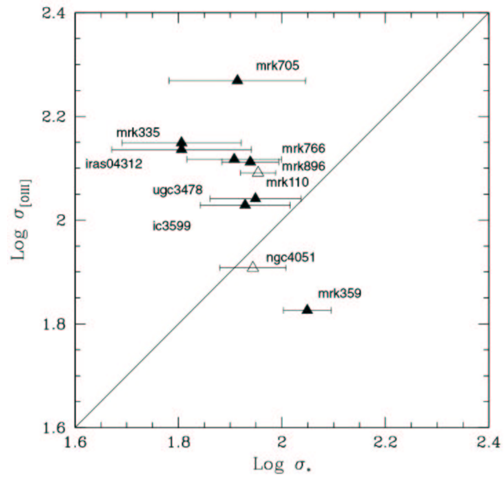

Fig. 6. Figure taken from Botte et al. (2005, © 2005 RAS) showing the σ_* versus $\sigma_{[OIII]}$ plane. Most of the NLS1s fill the upper half of the plot and are clearly not in agreement with the 1:1 line.

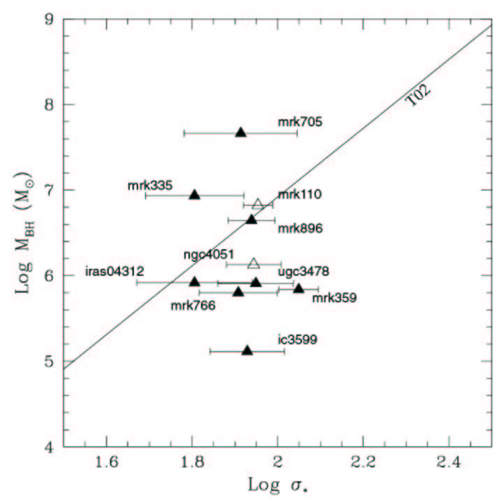

Fig. 7. Figure taken from Botte et al. (2005, © 2005 RAS) showing the better agreement between the NLS1s and the Tremaine et al. (2002) relation after having obtained direct measurments of the stellar velocity dispersion.

most cases the kinematics of the NLR leads to the overestimation of the kinematics of stars (Fig. 6). Several mechanisms can influence the gas motions and produce significant deviation from the pure virial motion in the potential of the galaxy. They were briefly discussed by Botte et al. (2005), who suggested that the high accretion rates, expected to occur in NLS1s, are able to cause strong nuclear winds affecting the NLR kinematics. Very recently, Greene & Ho (2005) confirmed our results by means of a large sample of AGN spectra from the Sloan Digital Sky Survey. They demonstrated that the departure from virial motions correlate with accretion rate, and the systematic broadening of [O III] is likely to be attributed to the high accretion rates of NLS1s. Plotting our measured stellar kinematics versus the BH masses, we find that the NLS1s are now better in agreement with the Tremaine et al. (2002) fit, and show on average σ_* values ($\sim$ 80 – 100 km s^{-1}) significantly lower than the typical values measured in Seyfert galaxies (Fig 7).

4. Conclusions

On the basis of our observations and analysis, we can confirm the current paradigm of NLS1s, that is NLS1s seem to be really characterized by less massive BHs hosted by less massive bulges. In summary, NLS1s, Seyfert 1 galaxies and quasars follow a common relation between BH mass and blue luminosity. The [O III] width overestimates stellar velocity dispersion likely because of higher accretion rates. NLS1s are in agreement with Tremaine et al. (2002) relation when stellar velocity dispersion is directly measured with stellar absorption lines. Our results do not contradict the idea by Mathur et al. (2001), who proposed an evolutionary scenario in which NLS1s are relatively young AGNs hosting BHs still in a growing phase.

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