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Obscuration in LINERs. The narrow line region

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Abstract

We studied the nuclear obscuration of galaxies hosting Low Ionization Narrow Emission Regions (LINERs) based on their X-ray and optical emission. X-ray data show that high obscuration is a common property of LINERs, 50% of them are identified as good candidates to be Compton-thick. From the Hα HST-imaging analysis it is found that the large majority of them exhibit an unresolved nuclear source surrounded by extended emission with irregular morphologies. The Hα morphologies are grouped into three classes: nuclear outflow candidates (42%), core-halo morphologies (25%), and nuclear spiral disks (14%). Only five out of the 36 LINERs are classified as dusty objects. A size-luminosity relation is found between a characteristic radius of the emitting nebulosity and the hard X-ray luminosity, favouring the AGN-NLR nature of the ionized gas in these LINERs. From this X-ray/optical analysis it came out that all dusty objects are Compton-thick and thus the material obscuring the putative AGN could be external to the NLR. For the other sources no clear relation is found between Compton-thickness and obscuration. Therefore the material responsible for the measured obscuration needs to be located in the very inner regions of the AGN.

1 Introduction

AGN produce high luminosities in fairly compact regions, resulting in a very efficient mechanism to release energy. Thus, an accretion process into a Supermassive Black Hole (SMBH) appears as a natural mechanism for explaining high luminosity Active Galactic Nuclei (AGN). For their low luminosity counterparts, a strong debate does exist to find the origin of their energies and also to locate them into an AGN sequence. The interest in these objects have rebirthed because every single galaxy with a large bulge may host a SMBH. Although it has been recognized that a large percentage of them hosts an AGN, both circumnuclear star formation and obscuration by dust complicate a clean overview into the inner regions where SMBH reside.

Low Ionization Narrow Emission Regions (LINERs) belong to the low luminosity class of AGN. They are classified at such based on optical spectral data (see [9, 11] for an updated diagnostic diagram definition). Three models have been proposed to explain their emission lines and thereof their excitation mechanisms: photoionization by an AGN, photoionization by circumnuclear stars and shock heating. The most favourable explanation is photoionization by the AGN with very low ionization parameters. The other two models have been discarded because the most recent observations donot favour them. HST high resolution data show that young stellar populations are very scarce in their nuclei [5]. On the other hand the lack of broad emission lines difficults the shock heating explanation.

From recent multiwavelenght analysis (see [10] for the most recent review) it is shown that LINERs appear to accomodate into the AGN sequence as AGN radiating at very low Eddington ratios; accretion ratios scale from the highest accretion systems, the QSOs, followed by Sy1, Sy2, LINERs, transition objects and absorbing systems. This can be one of the possible explanation why LINERs are so dim while hosting very high SMBH. But still the role played by dust obscuring the central regions needs to be investigated. This paper intends to be a progress report from our group concerning the importance of dust obscuration in LINERs. The results presented here have been already published (see [7, 8, 14]).

2 Obscuration from X-rays

We searched in the Chandra and XMM-Newton archives for observations of LINERs from the catalogue by [2]. 82 LINERs were found with X-ray data available, 68 in Chandra and 54 in XMM-Newton (40 in common on both X-ray data archives).

Chandra provides data with a resolution better than 1 arcsecond, allowing the possibility to search for compact unresolved nuclear sources. We investigated in how many of these objects a compact source is found at hard energies. 60% of the LINERs show an unresolved source at energies larger than 4 keV. The resolution of XMM-Newton (10 arcseconds) does not allow a morphological classification but it is very efficient for the spectral analysis. For the LINERs with enough count rates, we performed a spectral modelling: the baseline model consisted on a combination of a thermal plasma at soft energies and a power law at high energies with two different absorbers, NH1 and NH2, respectively. Most galaxies (75%) needed the two components for a reliable fitting.

It is natural to compare the extinctions obtained with the two column densities and that one measured at optical frequencies. Whereas NH1 measure very much the same reddening as the optical reddening does, NH2 shows a much larger reddening. The same result has been obtained for Seyfert 2 galaxies [12]. As for the case of Seyfert 2 galaxies, this means that we are looking to different location of the dust. The obscuring matter producing the measured NH1 seems to be located in the narrow line region of the galaxies, whereas the matter that originates NH2 is located in a region much closer to the nucleus.

Now, given the unexpected result of the high obscuration of LINERs, we investigated whether Compton-thick sources are frequent in our sample. To do so, we used the common indirect tracers for Compton thickness: a flat spectrum, a high equivalent width of FeKα 6.4

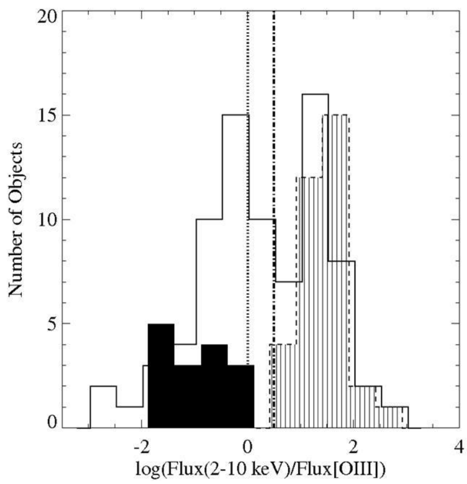

Figure 1: Distribution of the $L_X/L_{[OIII]}$ ratio for the sample of LINERs. Those for unobscured PG QSOs is shown with the dashed histogram and for Compton-thick Seyfert 2s with the black filled histogram. The dot-dashed and dot vertical lines correspond to the two limits between Compton-thin and Compton-thick sources usually found in the literature.

keV emission line and a high $L_{[OIII]}/L_X$ ratio. Whereas information on the first two indicators are only available for a few cases, the $L_{[OIII]}/L_X$ ratio is available for most of them. In Fig.1 we show the result obtained for LINERs together with the values from the literature for unabsorbed PG QSOs and obscured Seyfert 2. We show that about half of our sample does indeed occupy the region defined for Compton-thick objects. This result contrasts with the much lower percentage of 23% Compton-thick Seyfert 2 nuclei.

3 Nuclear Hα emission of LINERs

We searched in the HST archive for Hα-imaging data of all the LINERs studied at X-ray frequencies [7], and found observations for 32 out of the 82 X-ray LINERs. This subsample appears to be representative of the full phenomenology obtained with the X-ray analysis: 21 are AGN X-ray candidates, 16 Compton-thick and 18 have a Broad Line Region.

Concerning their Hα morphology, most of them show a compact source on top of a nebular emission extended a few hundredth of parsecs. We have classified them as:

1. Core-halo. They show a compact nuclear emission surrounded by an elongated nebulosity. These nebulosities are similar to those found by [17] for Seyfert 2 galaxies. Nine out of the 32 objects belong to this class.

2. Outflows. Eleven galaxies show extending nebulosities emerging from the nuclear region. Bubbles, biconic and filamentary structures are seen. The available kinematic data obtained by [18] confirm the outflows nature for some of them.

3. Disky. Some of the nebulosities trace a nuclear disk, where spiral arms and/or circumnuclear rings are clearly visible. Seven galaxies present face-on structures that can be associated to Hα emission along the spiral arms

4. Dusty. A few of them, in fact five, show dust lanes crossing the nuclear source obscuring the nucleus.

Adding up data from similar studies [16, 3], we ended with a total sample of 36 LINERs for which we can determine their morphologies: 42% are outflow candidates, 25% core-halo systems, 19% disk-like systems, and 14% are dusty.

The question then to be answered is whether the origin of the outflows can be circumnuclear star formation or if it corresponds to the outflow predicted by unified AGN models [4]. The STIS spectroscopic analysis by [5] found that recent star-forming processes are almost absent in LINERs. The Hα- identified structures appear to be consistent with such a picture. Indeed, at the HST resolution ($\approx$ a few tens of pc), a knotty appearance is expected when young star clusters are present, what is not observed in most of the images. In disk-like systems, star formation can be distinguished in their disks. The structure of core-halo galaxies more likely originates in the gas ionized by the nucleus. For dusty galaxies, although a faint nuclear source is visible in most of them, the dust distribution prevents us from drawing any conclusion on the extended ionized gas.

Finally, we tried to quantify the observed emission in terms of sizes. $R^{*}_{\rm eq}$ is estimated as the isophotal equivalent radius at the isophotal level of 2.9×10^{-9} erg s^{-1}cm^{-2} arcsec^{-2}[1]. This radius allows a measure of a physical characteristic size of the regions independently of the individual S/N of the images. This has been done for the 22 objects with flux-calibrated images. We obtained a range of values between 16 and 469 pc, with a median value of 116 pc. No significant difference is found in sizes among the different morphologies.

4 Size–luminosity relation

The size–luminosity relation can also be used to gain insight into the nature of the ionized emission. This has been raised as an important relation for AGN ever since [15] found that it can be defined for the BLR of Seyferts. [1] and [17] searched for such a relation for the NLR of Seyferts and [3] extended the work to LINERs. They concluded that LINERs follow the same relation than Seyferts and QSOs.

In this work we revisit this relation, but using for the first time, instead of the Hα luminosity, that of the X-rays, which is a more robust tracer of the power of the AGN [13]. The X-ray luminosity can be used as a measure of the bolometric intrinsic luminosity of an AGN [6, 7, 8]. Hence it is worthwhile investigating whether it is related to the size of the NLR. In Fig. 2 the hard (2–10 keV) X-ray luminosity *versus* the equivalent radius of the Hα emission is shown. Interestingly, a significant correlation only remains for the core-halo systems ($R_{\rm eq} \propto L^{0.6}$ with a correlation coefficient of 0.936). Both dusty and outflow galaxies appear to have lower equivalent radii for their X-ray luminosities. For the dusty systems,

[1] This rather arbitrary surface brightness was chosen to optimize the measure for all the available data.

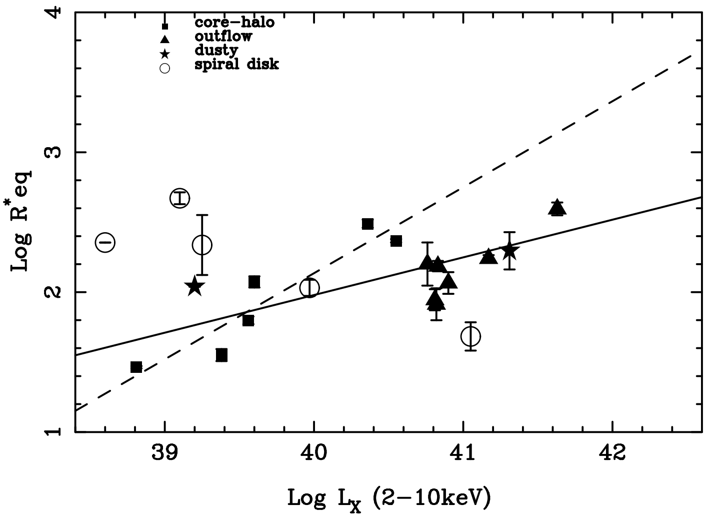

Figure 2: (2–10) keV band absorption corrected luminosity *versus* the equivalent radius as defined in the text. The unbroken line shows the best linear fit to all the galaxies excluding disky systems. The dashed line shows the best linear fit to core-halo systems.

it is obvious that the presence of large amounts of dust obscuring the inner regions lowers the measured size of the Hα emission. The explanation for the outflow candidates is not so straightforward, since they cover a narrow range of X-ray luminosities.

5 Summary and conclusions

We studied the nuclear obscuration of galaxies hosting Low Ionization Narrow Emission Regions (LINERs) based on their X-ray and optical emission. They show column densities at soft energies (0.5–2 keV) mostly related to the diffuse emission around the AGN, showing a correlation with the optical extinction. Column densities at hard energies (2–10 keV) seem to be much higher than what would be expected from the optical extinction, so they might be associated to the inner regions of the AGN, buried at optical wavelengths. The main result is that around 50% of our LINER sample shows signatures of Compton-thickness according to the most common tracers.

Our HST Hα analysis resulted in the large majority of LINERs exhibiting an unresolved nuclear source surrounded by extended emission with equivalent sizes ranging from a few tens to about 500 pc. Their emission-line morphologies do not appear to be homogeneous, and are basically grouped into three classes: nuclear outflow candidates (42%), core-halo morphologies (25%), and nuclear spiral disks (14%). The remaining 5 galaxies are too dusty to allow a clear view of the ionized distribution. No signatures of clumpy structures reminiscent of star clusters were identified, in agreement with results from stellar population analysis [5].

A size-luminosity relation was found between the equivalent radius of the Hα emission and the hard X-ray luminosity. This correlation resembles the one reported for the NLR of Seyfert galaxies based on the [OIII] luminosity [17]. This relation is another piece of evidence confirming the AGN-NLR nature of the ionized gas in LINERs [16, 18].

From this X-ray/optical analysis it came out that all dusty classified objects are Compton-thick and thus the material obscuring the putative AGN can be external to the NLR. For the other nuclei no clear relation is found between Compton-thickness and obscuration. Therefore the material responsible of the measure obscuration needs to be located in the very inner regions of the AGN.

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References

[1] Bennert, N., Falcke, H., Schulz, H., Wilson, A. S., & Wills, B. J. 2002, ApJL, 574, L105

[2] Carrillo, R., Masegosa, J., Dultzin-Hacyan, D., & Ordonez, R. 1999, Revista Mexicana de Astronomia y Astrofisica, 35, 187

[3] Dai, H.-F., & Wang, T.-G. 2008, Chinese Journal of Astronomy and Astrophysics, 8, 245

[4] Elvis, M. 2000, ApJ, 545, 63

[5] González-Delgado, R. M., et al. 2004, ApJ, 605, 127

[6] González-Martín, O., et al. 2006, A&A, 460, 45

[7] González-Martín, O., et al. 2009a, A&A , 506, 1107

[8] González-Martín, O., Masegosa, J., Márquez, I., & Guainazzi, M. 2009b, ApJ, 704, 1570

[9] Heckman, T. M. 1980, A&A, 87, 152

[10] Ho, L. C. 2008, Ann. Rev. Astron. Astroph., 564, 120

[11] Kewley, L. J., Groves, B., Kauffmann, G., & Heckman, T. 2006, MNRAS 372, 961

[12] Maiolino, R., et al. 1998, A&A , 338, 781

[13] Maiolino, R., et al. 2003, MNRAS, 344, L59

[14] Masegosa, J., Márquez, I., Ramirez, A., & González-Martín, O. 2011, A&A, 527, 23

[15] Peterson, B. M., et al. 2002, ApJ, 581, 197

[16] Pogge, R. W., Maoz, D., Ho, L. C., & Eracleous, M. 2000, ApJ, 532, 323

[17] Schmitt, H. R., et al. 2003, ApJ, 597, 768

[18] Walsh, J. L., et al. 2008, AJ, 136, 1677