The nature of nuclear H α emission in LINERs[★]

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ABSTRACT

To get insight into the nature of the ionized gas in the nuclear region of LINERs, we performed a study of HST H α imaging of 32 LINERs. The main conclusion from this analysis is that, for the large majority of LINERs (84%), an unresolved nuclear source has been identified along with extended emission with equivalent sizes ranging from a few tens to a few hundredths of parsecs. Their morphologies do not appear to be homogeneous, since they are grouped into three classes: nuclear outflow candidates (42%), core-halo morphologies (25%), and nuclear spiral disks (14%). Clumpy structures reminiscent of young stellar clusters are not a common property of LINERs. The remaining five galaxies are too dusty to allow a clear view of the ionized gas distribution.

A size-luminosity relation was found between the equivalent radius of the H α emission and the (2–10 keV) X-ray luminosities. Both ionized gas morphologies and the size-luminosity relation are indistinguishable from those of low-luminosity Seyferts, suggesting the same origin for the NLR of LINERs and Seyferts. A relation between soft X-rays and ionized gas has also been suggested for the first time in LINERs. From multiwavelength data, only four out of the 32 LINERs show no evidence of the AGN nature of their nuclear sources from multiwavelength data, but extremely obscured AGNs cannot be discarded given the Compton-thick signatures of their X-ray emission. For the confirmed AGN LINERs, their H α imaging favour core-halo and outflow morphologies (65% of the cases). Finally, their calculated Eddington ratios show that our LINER sources radiate in the sub-Eddington regime, with core-halo systems having on average higher Eddington ratios than do outflow candidates.

Key words. galaxies: active – galaxies: nuclei – galaxies: evolution – X-ray: galaxies

1. Introduction

It has been suggested that *low ionization nuclear emission-line regions* (LINERs, Heckman 1980) are placed at the low-luminosity end of the active galactic nuclei (AGN) family (Ho 2008). Although LINERs are found in a large population of nearby galaxies (30%, Ho et al. 1997), a debate still exists about the nature of their energy source. Ho (2002, 2008) summarizes the main lines of evidence supporting the AGN nature of LINERs: host galaxies properties similar to Seyferts, most of the more massive black holes residing in LINERs, incidence of broad line regions (hereinafter BLR), compact nuclei at both radio and X-ray frequencies. He attributes the strong progress made during the past two decades to multifrequency analyses and HST high spatial resolution studies. The extensive work by Nagar et al. (2000, 2002, 2005) has shown that radio cores are found in 44% of LINERs, a percentage similar to what is observed in Seyferts (47%). Also when radio data at different frequencies exist, their spectra tend to be flat as expected when non-thermal processes take place.

At X-ray frequencies, strong progress has also been made thanks to the large X-ray facilities Chandra and XMM-Newton. X-ray observations can be considered paramount, constituting one of the best tools for identifying AGNs. The different studies carried out in the past decade (Ho et al. 2001; Eracleous et al. 2002; Dudik et al. 2005; González-Martín et al. 2006,

2009a) have proved that an AGN is present in at least 60% of the LINERs. Moreover, when multifrequency information is considered (basically the incidence of broad lines and the properties at radio frequencies), the percentage of AGNs rises to 90% (González-Martín et al. 2006, 2009a).

On the other hand, HST observations have provided a large advance in the physics of LINERs. The pioneering UV imaging surveys by Maoz et al. (1995) and Barth et al. (1998) conclude that 25% of the observed LINERs had a UV compact source in their nuclei, but of course one of the most outstanding results during the past decade has been the discovery that sources with detected radiocores show variability at UV frequencies on scales of months (Maoz 2007). Four of their 13 sources (M 81, NGC 3998, NGC 4203, and NGC 4579) have been confirmed also to be variable at X-ray frequencies (Pian et al. 2010). Recently, González-Martín et al. (in prep.) have also detected X-ray variability for the LINER NGC 4102.

HST optical works (Pogge et al. 2000; Simões Lopes et al. 2007; González-Delgado et al. 2008; González-Martín et al. 2009a) confirm that almost all the observed LINERs show a nuclear source on top of an irregular distribution of circumnuclear dust. Dust obscuration can explain the existence of dark-UV LINERs. The importance of an obscuring environment, maybe linked to the accretion physics, has been recognized in our X-ray approach to LINERs (González-Martín et al. 2009b). We found that a high percentage of them (50%) show clear signs of being Compton-thick. This fraction is even higher than that reported for Seyferts (30%) (González-Martín et al. 2009b; Panessa et al. 2006),

[★] Appendix and Figs. 2 and 6 are only available in electronic form at <http://www.aanda.org>

and so the location and nature of their obscuring matter needs to be further investigated. Until new high-resolution X-ray images become available, only indirect information can be obtained on the nature of LINERs by looking for correlations between X-ray properties taken at lower resolution and optical/NIR properties taken at much higher spatial resolution. In this vein, it is worthwhile searching for the properties of the ionized gas and its relation to the X-ray results.

Previous works have concluded that the $H\alpha$ morphology of LINERs mainly consists in a point source embedded in an extended structure sometimes clumpy, filamentary, in some particular cases clearly indicating nuclear obscuration, but mostly indistinguishable from what is observed in low-luminosity Seyfert galaxies (Pogge et al. 2000; Chiaberge et al. 2005; and Dai & Wang 2008). Based on STIS spectroscopic observations of 13 LINERs, Walsh et al. (2008) clearly demonstrate that on scales of tens of parsecs their energy source is consistent with photoionization by the central nuclear source, but with an NLR kinematics dominated by outflows. Following Barth's (2002) considerations, by analogy with Seyfert unification models, it is natural to wonder whether the various types of low-luminosity AGN (LLAGN), which LINERs could belong to, are different manifestations of the same underlying phenomenon, with orientation or obscuration the only observed differences.

The main goal of this paper is twofold: (1) to evaluate whether the ionized gas in the central regions of LINERs shows characteristics indicative of ionized emission from the AGN (a NLR); and (2) to investigate their relation to the Seyfert population. We present an update of the properties of the NLR for a large sample of 32 LINERs. Archival *HST* narrow imaging data were used (WFPC2 and ACS). In Sect. 2, the sample and the *HST* image processing are described. In Sect. 3, we present the results and discussion. Section 4 summarizes our main conclusions.

2. Sample and data reduction

We searched for archival *HST* data for the 82 LINERs in our sample (González-Martín et al. 2009a) on the *Hubble Legacy Archive* (HLA hereinafter) web page¹. HLA data are fully processed (reduced, co-added, cosmic-ray cleaned, etc.) images ready for scientific analysis. All the files for narrow-band observations centred either on $H\alpha$ or [O III] emission lines (at the redshift of the galaxy) and their corresponding continuum have been retrieved. For thirty-two galaxies, these kinds of narrow-band imaging data are available². HLA data products are available for all of them, so we have retrieved the fits' files corresponding to averaged, processed data. Table 1 provides the galaxy names (Col. 1), coordinates as provided by HLA (Cols. 2 and 3), instrument (Col. 4; most of the data comes from WFPC2, only five galaxies coming from ACS), proposal number and principal investigator's name (Cols. 5 and 6), the filters used in this analysis (Col. 7), and the total exposure time for such filters (Col. 8). The number of images used for each filter is shown in brackets in Col. 8. When only a single image was available, a cosmic ray extraction was applied by using the LACOSMIC³ routine (van Dokkum 2001).

¹ <http://hla.stsci.edu/hlaview.html>

² Also available are the narrow-band images of NGC 6240 and NGC 6241, which are not considered in this paper since the NLR physical sizes for these two galaxies cannot be resolved even with *HST* data owing to their much greater distances.

³ <http://www.astro.yale.edu/dokkum/lacosmic/>

Fig. 1. Surface brightness profiles for NGC 3245. The broad-band profile, $I(F_{\text{wide}})$, is plotted in black (circles points). The narrow-band profile, $I(F_{\text{narrow}})$, is plotted in red. The green line is the narrow-band profile scaled to that of the broad-band.

HST absolute astrometry does not guarantee the centring of two images at the level of its spatial resolution. For that reason, when needed, the narrow- and wide-band images were aligned according to the centre of the galaxy (maximum peak in brightness) and with the stars present in the field.

To maximize the chances of a reliable estimation of the continuum level at the wavelength corresponding to the emission line, we used a common procedure to get continuum subtracted images, based on a relative calibration as follows. The fluxes in the narrow ($I(F_{\text{narrow}})$) and broad band ($I(F_{\text{wide}})$) filters are

$$I(F_{\text{narrow}}) = I_{\text{narrow}}(\text{cont}) + I_{\text{narrow}}(\text{line}) \quad (1)$$

$$I(F_{\text{wide}}) = I_{\text{wide}}(\text{cont}) \quad (2)$$

where $I_{\text{narrow}}(\text{line})$, $I_{\text{narrow}}(\text{cont})$, and $I_{\text{wide}}(\text{cont})$ are the intensities measured in the line itself, the continuum under the line, and the continuum in the wide filter, respectively.

To assume that line emission is less extended than the continuum is equivalent to saying that, for flux-calibrated images far enough from the centre, one should have $I_{\text{narrow}}(\text{cont}) = I_{\text{wide}}(\text{cont})$. Before any calculation, the background of the two images, narrow and wide-band, is set to zero.

Then, we have to calculate the factor required to put the two images on the same level. To do so, we obtain the surface brightness profiles (with *ellipse* within IRAF⁴) for the narrow- and broad-band images. The comparison of the two profiles allows us both to estimate the region where the fluxes should be fixed at the same level and then to apply the corresponding factor. An example of the two profiles obtained for the galaxy NGC 3245 is shown in Fig. 1. The resulting emission-line image is calculated as

$$I(\text{emission}) = I(F_{\text{narrow}}) - \text{factor} \times I(F_{\text{wide}}). \quad (3)$$

The emission-line images coming from Eq. (3) are not flux-calibrated, but allow recovering of emission-line morphologies and sizes, which is our main purpose, as explained below.

⁴ IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy (AURA), Inc., under contract with the National Science Foundation.

Table 1. Archival *HST* data for the LINER galaxies.

Galaxy	Right Ascension (2000)	Declination (2000)	Instrument	Proposal number	Prop. PI name	Filter	Exposure time (s)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IC 1459	22:57:10.607	-36:27:44.00	WFPC2	6537	De Zeew	<i>F631N</i>	2300(3)
						<i>FR680P15</i>	2000(3)
NGC 0315	00:57:48.883	+30:21:08.81	WFPC2	6673	Baum	<i>F555W</i>	460(2)
						<i>F814W</i>	460(2)
						<i>FR680N</i>	3300(3)
NGC 2639	08:43:38.078	+50:12:20.01	WFPC2	7278	Falcke	<i>F547M</i>	320(2)
				7278	Falcke	<i>F814W</i>	140(2)
				7278	Falcke	<i>FR680P15</i>	1200(2)
NGC 2681	08:53:32.730	+51:18:49.30	ACS	9788	Ho	<i>F658N, F814W</i>	720(2), 120(1)
NGC 2787	09:19:18.560	+69:12:12.00	WFPC2	6785	Malkan	<i>F658N, F702W</i>	2800(4), 800(2)
NGC 2841	09:22:02.634	+50:58:35.47	ACS	10402	Chandar	<i>F658N, F814W</i>	1400(2), 750(2)
NGC 3226	10:23:27.008	+19:53:54.68	ACS	9293	Ford	<i>F658N, F814W</i>	1400(2), 700(2)
NGC 3245	10:27:18.392	+28:30:26.56	WFPC2	7403	Filippenko	<i>F658N, F702W</i>	2200(2), 140(1)
NGC 3379	10:47:49.600	+12:34:53.90	WFPC2	6731	Ciardullo	<i>F502N, F547M</i>	9785(5), 600(5)
NGC 3607	11:16:54.660	+18:03:06.50	ACS	9788	Ho	<i>F658N, F814W</i>	700(2), 120(1)
NGC 3623	11:18:55.960	+13:05:32.00	WFPC2	8591	Richstone	<i>F547M, F658N</i>	1600(4), 1600(4)
NGC 3627	11:20:15.028	+12:59:29.58	WFPC2	8591	Richstone	<i>F658N</i>	1600(4)
			WFPC2	8597	Regan	<i>F606W</i>	560(2)
NGC 3998	11:57:56.133	+55:27:12.91	WFPC2	5924	Dressel	<i>F658N, F791W</i>	1660(3), 100(2)
NGC 4036	12:01:26.753	+61:53:44.81	WFPC2	5419	Sargent	<i>F547M</i>	300(1)
				6785	Malkan	<i>F658N</i>	2800(4)
NGC 4111	12:07:03.130	+43:03:55.40	WFPC2	6785	Malkan	<i>F658N, F702W</i>	1200(2), 600(1)
NGC 4278	12:20:06.826	+29:16:50.71	WFPC2	6731	Ciardullo	<i>F502N, F547M</i>	12700(5), 600(5)
NGC 4314	12:22:31.990	+29:53:43.30	WFPC2	8597	Regan	<i>F606W</i>	560(2)
				6265	Jefferys	<i>F658N</i>	600(2)
NGC 4374	12:25:03.743	+12:53:13.14	WFPC2	6094	Bower	<i>F547M, F658N</i>	1200(2), 2600(2)
						<i>F814W</i>	520(2)
NGC 4438	12:27:45.594	+13:00:31.77	WFPC2	6791	Kenney	<i>F656N, F675W</i>	5200(4), 1450(4)
NGC 4486	12:30:49.423	+12:23:28.04	WFPC2	5122	Ford	<i>F547M, F658N</i>	800(2), 2700(2)
NGC 4552	12:35:39.807	+12:33:22.83	WFPC2	6099	Faber	<i>F555W, F814W</i>	2400(4), 1500(3)
				8686	Goudfrooij	<i>F658N</i>	2300(2)
NGC 4579	12:37:43.522	+11:49:05.50	WFPC2	6436	Maoz	<i>F502N, F547M</i>	3200(3), 726(5)
						<i>F658N, F791W</i>	1400(2), 726(5)
NGC 4594	12:39:59.432	-11:37:22.99	WFPC2	5924	Dressel	<i>F658N, F791W</i>	1600(2), 100(1)
NGC 4636	12:42:49.870	+02:41:16.00	WFPC2	8686	Goudfrooij	<i>F547M</i>	1000(4)
						<i>F814W</i>	400(4)
						<i>FR680P15</i>	2300(2)
NGC 4676A	12:46:10.110	+30:43:54.90	WFPC2	8669	Van derMarel	<i>F555W, F814W</i>	320(2), 320(2)
						<i>FR680N</i>	1200(2)
NGC 4676B	12:46:11.243	+30:43:21.87	WFPC2	8669	Van derMarel	<i>F555W, F814W</i>	320(2), 320(2)
						<i>FR680N</i>	1200(2)
NGC 4696	12:48:49.276	-41:18:40.04	WFPC2	5956	Sparks	<i>F702W, FR680N</i>	320(2), 1200(2)
NGC 4736	12:50:53.061	+41:07:13.65	WFPC2	5741	Westphal	<i>F555W</i>	296(3)
				8591	Richstone	<i>F656N</i>	1700(5)
NGC 5005	13:10:56.231	+37:03:33.14	WFPC2	6436	Maoz	<i>F502N, F658N</i>	2400(2), 1400(2)
						<i>F791W</i>	720(4)
NGC 5055	13:15:49.330	+42:01:45.40	WFPC2	8591	Richstone	<i>F547M, F656N</i>	1400(4), 1700(5)
NGC 5846	15:06:29.286	+01:36:20.24	WFPC2	6357	Jaffe	<i>F702W</i>	1000(2)
				6785	Malkan	<i>F658N</i>	2200(2)
NGC 5866	15:06:29.499	+55:45:47.57	ACS	9788	Ho	<i>F658N, F814W</i>	700(2), 120(1)

Figure 2 shows the resulting continuum subtracted images for all the galaxies listed in Table 1. Both H α and [O III] images are shown when available (for NGC 4579 and NGC 3379). Overlaid to the grey-scale images a number of contours are shown, the faintest corresponding to 3 times the dispersion of the background, σ . Figure 2 also shows the sharp divided continuum images (SD hereinafter). Briefly, the sharp-dividing method consists in dividing the original image by another one that results from applying a filter to the original image, with a box size several times that of the PSF FWHM. In our case, a median box of 30 pixels was used. SD images provide an enhancement of

the small structures and thus will be a good tracer of the dust structures in many cases (see Marquez et al. 2003, and references therein), as is the case, for instance, for NGC 4374 (see Fig. 2). Appendix A gives a description on the morphology for each object, together with additional, relevant information.

For estimating the sizes of the emission-line regions, we consider a 3σ level above the background and measure the area of the region inside the corresponding contour. The size is parametrized as the equivalent radius of such an area, i.e., $R_{eq} = (\text{Area}/\pi)^{1/2}$. The σ of the background level for each image has been measured in several regions around the galaxy, so

Table 2. X-ray luminosities^b and H α equivalent radii^b.

Galaxy	Cont. Filter	D^a (Mpc)	$\log(L_{\text{soft}})^b$ (erg/s)	$\log(L_{\text{hard}})^b$ (erg/s)	R_{eq}^c (pc)	$\sigma_{R_{\text{eq}}}$ (pc)	R_{eq}^{*c} (pc)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
IC 1459	<i>FR680P15</i>	29.24	40.6	40.5	245.52	0.17	
NGC 315	<i>F555W</i>	68.11	42.0	41.8	398.66	0.02	
	<i>F814W*</i>	68.11	42.0	41.8	528.32	0.22	
NGC 2639	<i>F547M*</i>	45.45	42.2	40.1	212.37	0.18	
	<i>F814W</i>	45.45	42.2	40.1	185.79	0.12	
NGC 2681	<i>F814W</i>	17.22	38.6	41.0	209.75	0.07	48.27
NGC 2787	<i>F702W</i>	7.48	38.9	38.8	43.50	0.03	29.11
NGC 2841	<i>F435W*</i>	11.97	39.4	39.2	167.91	0.02	
	<i>F814W</i>	11.97	39.4	39.2	142.97	0.25	16.36 ^d
NGC 3226	<i>F814W</i>	23.55	40.7	40.8	100.49	0.02	29.53 ^d
NGC 3245	<i>F702W</i>	20.89	38.8	40.8	117.78	0.21	158.90
NGC 3379	<i>F547M</i>	10.57	38.0	39.9			
NGC 3607	<i>F814W</i>	22.80	38.6	40.5	283.65	0.31	27.17 ^d
NGC 3623	<i>F547M</i>	7.28	39.1	39.4	86.33	0.08	35.52
NGC 3627	<i>F606W</i>	10.28	39.2	41.2		0.08	109.45
NGC 3998	<i>F791W</i>	21.98	42.7	40.6	237.93	0.08	233.01
NGC 4036	<i>f547M</i>	24.55	39.0	40.9	199.21	0.06	116.29
NGC 4111	<i>F702W</i>	15.00	40.9	40.4	132.19	0.03	308.69
NGC 4278	<i>F814W</i>	16.07	39.6	41.0	67.00	0.08	118.34
NGC 4314	<i>F606W</i>	9.68	39.6	39.1	165.01	0.04	
NGC 4374	<i>F547M</i>	18.37	39.5	41.3	401.75	0.03	
	<i>F814W*</i>	18.37	39.5	41.3	340.93	0.06	197.53
NGC 4438	<i>F675W</i>	16.83	40.1	40.8	255.57	0.02	153.53
NGC 4486	<i>F547M</i>	16.07	40.9	40.8	224.74	0.08	81.99
NGC 4552	<i>F814W</i>	15.35	39.5	39.3	216.95	0.15	217.22
NGC 4579	<i>F791W</i>	16.83	40.9	41.2	145.98	0.03	174.22
	<i>F547M</i>	16.83	40.9	41.2	45.09	0.01	
NGC 4594	<i>F791W</i>	9.77	39.6	39.9	93.35	0.09	107.34
NGC 4636	<i>F814W</i>	14.66	39.0	40.9	54.75		
NGC 4676A	<i>F555W*</i>	88.00	39.7	39.9	598.38	0.10	
	<i>F814W</i>	88.00	39.7	39.9	769.16	0.06	
NGC 4676B	<i>F555W*</i>	88.00	40.0	40.1	1001.37	0.06	
	<i>F814W</i>	88.00	40.0	40.1	843.25	0.05	
NGC 4696	<i>F702W</i>	35.48	41.6	40.0	205.77	0.15	
NGC 4736	<i>F555W*</i>	5.20	38.8	38.6	146.49	0.03	
	<i>F814W</i>	5.20	38.8	38.6	252.39	0.01	226.27
NGC 5005	<i>F791W</i>	21.28	40.7	41.6	248.99	0.03	393.56
NGC 5055	<i>F547M</i>	7.14	38.6	39.6	76.04	0.06	62.92
NGC 5846	<i>F702W</i>	24.89	40.2	40.8	156.31	0.08	88.26
NGC 5866	<i>F814W</i>	15.35	40.1	38.1			

Notes. ^(a) Distances from Table 1 in González-Martín et al. (2009a). ^(b) These luminosities have been corrected from intrinsic absorption; L_X (2–10 keV) has also been corrected for Compton thickness. L_{hard} and L_{soft} hold for the logarithm of the (2–10) keV (from Gonzalez-Martín et al. 2009b) and (0.3–2) keV (from Gonzalez-Martín et al. 2009a). ^(c) R_{eq} is the equivalent radius corresponding to a level 3 times higher than the dispersion of the background. R_{eq}^* corresponds to the isophotal level at 2.9×10^{-9} erg s⁻¹ cm⁻² arcsec⁻². ^(d) The resulting radius is smaller than 2 pixels.

that the final R_{eq} is the median of these values, and its accuracy is provided by the dispersion of the various R_{eq} around the median. The results are presented in Table 2. No radius has been determined either for NGC 3379, owing to low S/N of the images, or for NGC 3627 and NGC 5866 due to the large amount of dust that makes their determination difficult. Col. 1 shows the galaxy name, Col. 2 the filter used for continuum subtraction, Col. 3 the distance as taken from González-Martín et al. (2009a). Columns 4 and 5 show the X-ray soft and hard luminosities taken from Gonzalez-Martín et al. (2009a)⁵ and Cols. 6 and 7 the equivalent radius and its dispersion, $\sigma_{R_{\text{eq}}}$. Two estimates of the equivalent radius were obtained when two continuum filters were available. The deepest resulting image was chosen to

estimate the final equivalent radius. In these cases, the corresponding filter is flagged with an asterisk (in Col. 2). This estimation can be compared with sizes from other analysis based on 3σ detection limits for the extended emission (see for instance Schmitt et al. 2003)

Nevertheless, since the data are inhomogeneous, an S/N threshold does not have a well-defined physical meaning, which complicates the interpretation of equivalent radius. Therefore, we used the flux calibration corresponding to the images taken with narrow-band filters, $I(F_{\text{narrow}})$ (done in the standard way, using the information available on the image headers), for the resulting emission-line image, once the continuum is rescaled and subtracted, $I(\text{emission})$. The uncertainties in the flux calibration for ramp filters mean the images obtained with such filters were not used. For the flux-calibrated images, we also calculated

⁵ The L_X (2–10 keV) are Compton-thick corrected.

Table 3. Morphological classification of H α nuclear emission.

Core-halo	Outflow	Dusty	Disky
IC 1459	NGC 3245	NGC 3226	NGC 2681
NGC 315	NGC 4036	NGC 3607	NGC 2841
NGC 2639	NGC 4438	NGC 3627	NGC 3379
NGC 2787	NGC 4486	NGC 4374	NGC 4314
NGC 3623	NGC 4579	NGC 5866	NGC 4552
NGC 3998	NGC 4636		NGC 4594
NGC 4111	NGC 4676A		NGC 4736
NGC 4278	NGC 4676B		
NGC 5055	NGC 4696		
	NGC 5005		
	NGC 5846		

R_{eq}^* (Col. 8 in Table 2) as the isophotal equivalent radius at the isophotal level of $2.9 \times 10^{-9} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ arcsec}^{-2}$. This rather arbitrary surface brightness was chosen to optimize the measure for all the available data. 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.

3. Results and discussion

3.1. H α emission as a tracer of the morphology of the NLR in LINERs

The first result of our analysis is that, for most LINERs, the H α emission is composed of a nuclear source and extended emission, revealing a complex structure, with a wide range of different morphologies. The exceptions are NGC 2639, NGC 3379, NGC 3627, NGC 4036, and NGC 5005, for which an unresolved nuclear source has not been identified. We grouped our sample galaxies into 4 types of objects according to the morphology of the extended H α emission in the central 1–2 arcsecs. The objects belonging to each subcategory are shown in Table 3.

1. *Core-halo*: when a clearly unresolved nuclear source is surrounded by diffuse emission. Nine out of the 32 objects belong to this class. In most cases the putative nucleus is sitting in a linear elongated structure. In five cases (IC 1459, NGC 315, NGC 2639, NGC 3623, and NGC 5055; see individual comments in Appendix A), the extended emission appears to be sitting in the disk of the galaxy, and the elongation of the emission follows the major axis of the galaxy (taken from the NED database⁶). In three of them (NGC 2787, NGC 3998, and NGC 4111), the nuclear disk axis seems to be perpendicular to the galaxy major axis. NGC 2681 does not show any elongation (see Fig. 2).
2. *Outflows*: eleven galaxies provide morphological evidence of nuclear outflows (Veilleux et al. 2005). Some of them present debris/filamentary extension (NGC 4486, NGC 4676A and B, NGC 4696, NGC 5005, and NGC 5846), biconical structures (NGC 4036 and NGC 5005) and also bubble-like structures (NGC 3245 and NGC 4438) emerging from the nucleus. The high spatial and spectral resolution spectroscopic data (*HST-STIS*) for NGC 3245, NGC 4036, and NGC 4579, reported by Walsh et al. (2008), indeed show outflow kinematics that strengthen our suggestion. For the remaining ob-

jects, such a kinematical confirmation has to await similar spectroscopic data become available.

3. *Disky*: seven galaxies present face-on structures that can be associated to H α emission along the spiral arms (NGC 2681, NGC 2841 and NGC 4736), diffuse emission throughout the disk (NGC 3379, NGC 4552, and NGC 4636), nuclear plus star formation rings (NGC 4314). NGC 4594 has also been included in this class because, although it is not seen face on, it appears that its H α emission is concentrated in the nuclear region and its spiral arms.
4. *Dusty*: when clear dust lanes obscure the underlying H α structure. This prevents us from getting information on the morphology of these inner regions. Five objects have been classified as such (NGC 3226, NGC 3607, NGC 3627, NGC 4374, and NGC 5866). Different structures can be identified depending on the dust distribution in the galaxy, but mostly nuclear sources surrounded by an inhomogeneous dusty disk are found.

Our main concern here is to understand whether the detected H α nuclear regions correspond to the expected NLR for AGN. Pogge et al. (2000) made an extensive *HST* investigation of the NLR of 14 LINERs, and conclude that at *HST* resolution the NLRs are resolved, showing complex morphologies, different from galaxy to galaxy, that come from a combination of knots, filaments, and diffuse gas. Dai & Wang (2008) conclude similarly with an extension of Pogge’s sample of up to 19 LINERs.

Among our 32 sample galaxies, 17 LINERs are studied in this paper for the first time. Pogge et al. (2000) have already analysed 7 of the LINERs in our sample (NGC 3998, NGC 4036, NGC 4374, NGC 4486, NGC 4579, NGC 4594, and NGC 5005), and Dai & Wang (2008) studied another 4 (NGC 404, NGC 2768, NGC 3718, and NGC 4192) not included in the sample because of our X-ray selection.

All together, and including the new 17 LINERs from our work plus the 19 from Dai & Wang (2007) (we have 15 objects in common with them), they conform to a rather homogeneous set of data for 36 LINERs, which seems to be the larger sample of those homogeneously analysed so far. It is worth noticing that those four objects from Dai & Wang’s paper not included in our sample can be fit into the outflow-like group. Thus from the total sample of 36 LINERs, 42% would be outflow candidates, 25% core-halo systems, 19% disk-like systems, and 14% dusty LINERs. These results stress the interesting possibility of shock heating as an extra contribution to the ionization in addition to nuclear photoionization. This scenario needs to be explored at length with high S/N spectroscopy for the outflow candidates to investigate whether at least for these LINERs the long-standing problem of ionizing-photon deficit can be solved (see Eracleous et al. 2010b, for a full discussion).

The question then to answer is whether the origin of the outflow can be circumnuclear star formation or if it is a nuclear outflow predicted by the unified AGN models (Elvis 2000). From the STIS spectroscopic analysis by González Delgado et al. (2004), it is found that recent star-forming processes (with ages below 10^8 years) are almost absent in LINERs, because the dominant stellar population is that of old stars with, in some particular cases, some contribution from intermediate-age (10^8 years) stars. The H α -identified structures appear to be consistent with such a picture. Indeed, at the HST resolution of a few tens of parsecs, a knotty appearance should be expected when young star clusters are present, which is not observed in most of the images. Their inspection appears to indicate that such knotty structures are only present in the Mice system. In disk-like systems, star

⁶ The NASA/IPAC Extragalactic Database (NED) is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Fig. 3. Histograms of equivalent radii R_{eq} (in pc), in our LINER sample. The black filled area shows the R_{eq}^* distribution.

formation can be distinguished in their disks (e.g. see the star formation ring on NGC 4314 at ~ 200 pc from the nucleus, Fig. 2). 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.

3.2. Quantification of the $H\alpha$ emission: equivalent radius

To further investigate the origin of the extended $H\alpha$ emission and consider its irregularity, we calculated a characteristic radius for estimating the size of the ionized region: the equivalent radius, R_{eq} , and R_{eq}^* provided in Table 2⁷ (see Sect. 2 for a detailed explanation of the methodology).

We searched for a distance dependence that could bias our result, so we plotted equivalent radii in arcsecs *versus* distance and did not find any correlation between the two quantities. In Fig. 3 the distribution of R_{eq} in parsecs is shown as the empty histogram and the corresponding R_{eq}^* distribution as the black filled area. A range of values between 43 and 528 pc with a median value of 200 pc has been obtained for R_{eq} , and between 16 and 469 pc, with a median value of 116 pc for R_{eq}^* . Comparing both estimations, it was found that with the exception of NGC 4111, NGC 4314, and NGC 5005, where the size estimations show the highest values of R_{eq}^* and much lower values of R_{eq} , for the remaining cases R_{eq}^* is equal to or lower than R_{eq} . Thus we can conclude that the currently more extended size estimation at 3σ detection limits tends to overestimate the true physical size of the nebula. Finally no significant difference is found in sizes among the different morphologies.

This range of values is similar to what is reported by Dai & Wang (2008). For the 14 galaxies with measured radii shared by both works, our estimations for NGC 2787, NGC 4111, and NGC 4594 are smaller, and large discrepancies are found for three objects (for NGC 4314 and NGC 4736 Dai & Wang measured very small values and for NGC 4374 a high value was measured compared to ours). For the remaining ten objects, our estimations are higher than theirs. We stress that the method used by Dai & Wang (2008) relies on estimating the annulus at which

the 3σ level above the continuum is reached (see also Bennert et al. 2002). The general irregularity of the isophotes makes this method uncertain, which led us to use R_{eq} , which we consider a more realistic estimation of the size of the emitting regions.

Our sizes cover the lower end of the distribution of values for the major axis obtained, with [OIII]-HST imaging (Schmitt et al. 2003) for the NLR of Seyfert galaxies. For the 10 Seyfert galaxies with HST data from the Schmitt et al. sample included in the X-ray catalogue CAIXA⁸, we recalculated the sizes using our definition of R_{eq} and obtained a range of values between 56 and 314 pc with a median of 169 pc, very much the same as the value for LINERs. Although the comparison is not straightforward, since most of the data for Seyferts comes from the [OIII] line, it is however very suggestive that their NLR morphologies and sizes are not very different from those of LINERs.

3.3. Luminosity – size relation

The luminosity – size 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 Peterson et al. (2002) found that it can be defined for the BLR of Seyferts. Greene et al. (2010) have revisited such a dependence and found that it is consistent with $R_{\text{BLR}} \propto \sqrt{L}$ based both in Balmer lines and hard (2–10 keV) luminosities. This is the expected dependence when the BLR density is independent of luminosity. Their data also suggest a steeper relation for the narrow-line luminosities, $R_{\text{BLR}} \propto L^{0.6}$.

Bennert et al. (2002) and Schmitt et al. (2003) searched for such a relation for the NLR of Seyferts and Dai & Wang (2008) extended the work to LINERs. They conclude that LINERs follow the same relation than Seyferts and QSOs. In this work we present this relation, but using the X-ray luminosity for the first time instead of that of $H\alpha$, which is a more robust tracer of the power of the AGN (Maiolino et al. 2002). $H\alpha$ is expected to be contaminated by other processes such as recent star formation events.

The X-ray luminosity can be used as a measure of the bolometric intrinsic luminosity of an AGN (Gonzalez-Martín et al. 2006, 2009a,b). Therefore, it is worthwhile investigating whether it is related to the size of the NLR. In Fig. 4 the hard (2–10 keV) X-ray luminosity *versus* the two determinations of the equivalent radius is presented. The different $H\alpha$ morphologies described in Sect. 3.2 are plotted with different symbols. Three galaxies were excluded from the plot: NGC 3379, NGC 3627, and NGC 5866. NGC 3379 was excluded because the low count rates of its narrow-line image impede determination of a reliable equivalent radius, and NGC 3627 and NGC 5866 were excluded because large amounts of dust hampers detection of their NLR. The two galaxies conforming to the Mice system (NGC 4676A and NGC 4676B) show a large knotty extension of star formation regions, together with typical structures of outflowing material, leading to a rather high value of equivalent radius exceeding the hypothetical NLR. Therefore, despite their inclusion in the plots, they are not used for any correlation below.

A first attempt to look for a correlation between X-ray luminosities and R_{eq} is based on a least square linear fit, which results in the values reported in Table 4, but not plotted in Fig. 4 for the sake of clarity. The correlations are quite bad, with all the galaxies classified as disk (but NGC 4594) showing larger sizes than those expected from their luminosities for the remaining

⁷ Radii smaller than 2 pixels, identified with ^c in Col. 7, are not considered.

⁸ Catalogue of AGN in the XMM-Newton archive, Bianchi et al. (2009).

Fig. 4. *Top:* (2–10) keV band absorption corrected luminosity versus the equivalent radius to the contour corresponding to 3σ times the background, R_{eq} . *Bottom:* the same for the equivalent radius of the level corresponding to 2.9×10^{-9} erg s $^{-1}$ cm $^{-2}$ arcsec $^{-2}$, R_{eq}^* . The equivalent radii are derived through narrow band *HST* images. The unbroken lines show the best linear fit to all the galaxies excluding disk systems. The dashed lines show the best linear fit to the core-halo systems.

galaxies. This is expected, since $H\alpha$ emission in disk galaxies also comes from the contribution of ionized regions in their disk. Therefore we again tried a linear fit, but this time excluded disk galaxies. The result is shown in Fig. 4. The resulting coefficients imply better correlations in this case (see Table 4). Finally, we fitted just the core-halo systems (Fig. 4), resulting in the best correlation (see Table 4).

Therefore, two main results appear from Table 4, (1) the luminosity-size relation is better when using X-ray luminosities at harder energies; and (2) a better correlation is found when disk systems are excluded from the fitting, the best fit resulting when only core-halo systems are taken into account.

This latter result can be because core-halo systems appear to be less dusty and therefore provide a clear insight into the NLR. Since the hard X-ray luminosities cannot be produced by stars, this relation supports the nature of the emission regions as the result of the ionization by the AGN. In that respect it is very suggestive of the similarity of LINERs with higher power AGN, where the slope for core-halo systems (0.38) has the same value as reported for Seyfert galaxies by Schmitt et al. (2003) by using the [O III] luminosity as a proxy of the AGN power.

The resulting correlations for the subset of calibrated data are shown in Fig. 4 (bottom) and in Table 4. It is very interesting that a significant correlation only remains for the core-halo systems. Both dusty and outflow galaxies appear to have lower equivalent radii for their X-ray luminosities. For the dusty systems, it is obvious that the presence of large amounts of dust obscures the inner regions and thus lowers the measured size of the $H\alpha$ emission. The explanation for the outflow candidates is not so straightforward. It appears that they cover a narrow range of X-ray luminosities. This result may suggest a different origin for the emission mechanism in these systems, but this needs to be further investigated.

3.4. Soft X-rays vs NLR morphologies

For a collection of 8 Seyferts, Bianchi et al. (2006) report a spatial correlation between the soft X-ray emission and the NLR as reflected by the [OIII] emission, taking this result as an important evidence of the photoionized nature of soft X-rays. Given the morphological similarity between the NLR of Seyferts and LINERs (Schmitt et al. 2003; Pogge et al. 2000), it will be interesting to explore whether such a relation also exists in LINERs.

In Fig. 6 the soft X-ray isocontours are overplotted on the $H\alpha$ images. Only the 28 galaxies with available Chandra imaging have been included. The remaining four galaxies only have XMM-Newton X-ray data, as indicated in Table 5 with an asterisk in Col. (6). Although a very detailed comparison cannot be made due to the different resolutions at both wavelengths (around 1'' and 0.1'' for Chandra and HST data, respectively), it is remarkable that soft X-rays and $H\alpha$ data show a rough coincidence in their shapes, the soft X-ray contours following the structures identified with HST. This is not the case for the hard X-rays (Fig. 6). Few galaxies depart from the general behaviour, NGC 3226, NGC 4486, NGC 4676A and B, NGC 5846, and NGC 5866. NGC 3226 show a compact structure both at soft and hard X-rays, whereas the $H\alpha$ distribution seems to suggest an outflow emerging from that compact nucleus. For NGC 4486, both soft and hard X-rays follow the radio jet that is also visible in the continuum images, with the $H\alpha$ outflow perpendicular to it. NGC 4676A and B and NGC 5846 show a structure in $H\alpha$ that coincides with neither hard nor soft X-rays, suggesting that the emitting gas has a different origin. No conclusion can be made for NGC 5866, because its $H\alpha$ emission appear to be very obscured by large amounts of dust, and soft X-rays show a spatial distribution that appears to be out of the plane of the galaxy.

Unfortunately there is no sample of good RGS XMM-Newton data yet for LINERs to allow modelling of the soft X-ray emission. However, the data reported by Starling et al. (2005) on the LINER galaxy NGC 7213 and those collected for 53 LINERs by González-Martín et al. (in prep.) seem to suggest that their soft emission comes from photoionized gas, in good agreement with the conclusions obtained with the systematic work on Seyfert 2 galaxies by Bianchi and collaborators (Bianchi et al. 2006; Bianchi et al. 2010).

3.5. Multiwavelength properties

Different authors (Ho et al. 1999; Maoz 2007; Eracleous et al. 2009, 2010a; González-Martín et al. 2009a) have recognized the importance of the multiwavelength information to get a clear picture of the energy source in LINERs. Table 5 shows relevant information for the LINERs in this sample. The information in Cols. (2) to (10) has been extracted from Table 12 in

Table 4. Fitting parameters for the correlations between the equivalent radius and X-ray luminosity.

		R_{eq}		R_{eq}^*	
energies		slope	Correl. Coeff.	slope	Correl. Coeff.
full sample	(2–10 keV)	0.179 ± 0.044	0.630	0.069 ± 0.082	0.193
	(0.5–2 keV)	0.056 ± 0.040	0.266	0.114 ± 0.064	0.389
non-disklike	(2–10 keV)	0.282 ± 0.054	0.814	0.269 ± 0.070	0.727
	(0.5–2 keV)	0.074 ± 0.049	0.324	0.144 ± 0.064	0.530
core-halo	(2–10 keV)	0.380 ± 0.047	0.949	0.615 ± 0.116	0.936
	(0.5–2 keV)	0.173 ± 0.056	0.757	0.221 ± 0.073	0.834

González-Martín et al. (2009a), with Col. (1) providing their number code for each galaxy. In Col. (6) the word CT has been added when a LINER shows Compton-thick (CT hereinafter) characteristics as defined in González-Martín et al. (2009b). Column (7) has been updated with the corresponding references for three objects. Column (9) gives the final classification considering the multiwavelength information from Cols. (3) to (8). Column (10) provides the HST morphological class as defined in this paper. In Col. (11) we present the Eddington ratio, R_{Edd} , calculated using the formulation given in Eracleous et al. (2010a)

$$R_{\text{Edd}} = 7.7 \times 10^{-7} L_{40} M_8^{-1}$$

where L_{40} is the bolometric luminosity in units of $10^{40} \text{ erg s}^{-1}$ and M_8 is the black hole mass in units of $10^8 M_{\odot}$. The SED obtained by Eracleous et al. (2010a) for LINERs leads to a bolometric luminosity 50 times $L_{2-10 \text{ keV}}$. Both $L_{2-10 \text{ keV}}$ and M_8 values have been taken from Gonzalez-Martín et al. (2009b).

As in Sect. 3.2., the two components of the Mice system will not be included in the discussion. Their rather complex nature resulting from the merger-like interaction between NGC 4676A and B is unique among our sample galaxies and may contaminate our results. Our discussion will therefore deal with the remaining 30 galaxies.

From the four LINERs with a final classification as non-AGNs according to Col. (9), NGC 3623 has an uncertain X-ray classification since it is based on XMM-Newton data. The other three (namely NGC 3379, NGC 4314, and NGC 4278) show an $H\alpha$ classification as disk-like systems. Their X-ray data show evidence of being Compton-thick (Gonzalez-Martín et al. 2009b), which suggests that they could very well host extremely obscured AGN activity.

For three out of the 26 confirmed AGN LINERs (namely NGC 3607, NGC 3627, and NGC 5866), their classification is only based on detecting a broad $H\alpha$ line. They are classified at X-rays as non-AGNs. They all have an HST classification as dusty objects and appear to be Compton-thick at X-ray frequencies, so in these three cases a hint of a relationship between the obscuring materials could be claimed.

In addition to these, ten more AGN LINERs show evidence of a CT nature. In five of them (namely NGC 2639, NGC 4374, NGC 4552, NGC 4636, and NGC 5846) BLRs have been detected. Only a dusty environment is seen with the HST data for NGC 4374. For the other four galaxies the obscuring material seems to be most probably sitting in the innermost regions. Seven out of the 13 CT LINERs show their BLR, among which four of them have dusty $H\alpha$ morphologies. Therefore, for the remaining three out of the seven CT LINERs there is no obscuring material at HST resolution that could be invoked as the origin of its CT nature. A similar result has been found for Seyferts 1 (Malizia et al. 2009; Panessa et al. 2008), questioning the dichotomy type 1/type 2 AGNs in the current unification models (Urry & Padovani 2000). Finally for the remaining CT narrow-line LINERs (NGC 2681, NGC 3245, NGC 4036, NGC 4438,

NGC 5005, and NGC 5055), the obscuration cannot be attributed to important dust lanes obscuring the nuclei. Summarizing the results on CT LINERs, a large incidence is found in the dusty systems, since four out of the five dusty systems are CT. The remaining are distributed among the different types.

Although the number statistics are rather low, it is very interesting to notice that among secured X-ray AGN-classed LINERs, based on Chandra observations (19 out of 28 galaxies, see Col. (6) in Table 5), outflow and core-halo morphologies prevail (6 outflow systems, 7 core-halo, 4 disk-like and 2 dusty) amounting to 68%. Taking the AGN-classed 27 galaxies based on multifrequency data, eight have been classified as core-halo, ten as outflow, four as disk-like, and five as dusty. Therefore outflows and core-halo represent 65% of the AGNs.

Considering the Eddington ratios, the wide range obtained (from 10^{-7} to 10^{-2}) overlaps with the values found for Seyfert galaxies (Panessa et al. 2006; Gonzalez-Martín et al. 2009a), suggesting that LINERs are not always the low accretion cousins of Seyferts. We have found a slight trend for the Eddington ratios to decrease when moving from core-halo to outflow and disk-like systems (see Fig. 5). Dusty galaxies are not considered in the general trend since in the absence of dust they should fit into one of the three other classes. Different authors have claimed that strong radio jets are responsible for the bulk of the radio emission observed in LINERs (Nagar et al. 2005; Filho et al. 2002) and that the radio loudness parameter (see Maoz 2007) can be related to the Eddington ratios. Eddington ratios are larger for lower radio loudness ratios. Maoz (2007) speculate that, in order to explain high Eddington ratios in low-luminosity AGNs, mechanisms preventing gas from reaching the inner parts of the accretion disk would be at work. They suggest radio loudness at low luminosities as such a solution, with the gas joining a jet or an outflow. Our data seem to support this hypothesis since 1) radio loud systems are found in core-halo and outflow systems and, even more important; 2) all the outflow systems appear to be radio-loud.

4. Summary and conclusions

We have presented HST- $H\alpha$ imaging of 32 LINERs, selected from the X-ray sample studied in our previous works (González-Martín et al. 2009a,b). A full description of the extraction and reduction process was given and the resulting emission-line images were also presented with the sharp-divided continuum images for each galaxy. We also described the most relevant properties for each individual galaxy.

The main conclusion from this analysis is that, for the large majority of LINERs, an unresolved nuclear source has been identified, together with extended emission with equivalent sizes ranging from a few tens to about 500 pc. After adding the additional 4 LINERs from the literature to our sample, we concluded that their emission-line morphologies do not appear to be

Table 5. Multiwavelength properties of LINERs.

Num	Name	UV Var.	X-ray Var.	UV Comp.	X-ray Class.	Radio Comp.	Broad H α	Final Class	HST Class.	R_{Edd}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
80	IC 1459				AGN		Y	Y	core-halo	5.0×10^{-5}
1	NGC 0315				AGN	Y	Y	Y	core-halo	1.0×10^{-3}
9	NGC 2639				Non-AGN* CT	Y	Y	Y	core-halo	7.9×10^{-3}
11	NGC 2681			Y	AGN CT	Y	N	Y	core-halo	3.2×10^{-5}
15	NGC 2787			N	AGN	Y	Y	Y	core-halo	2.5×10^{-6}
16	NGC 2841				AGN			Y	disky	6.3×10^{-6}
19	NGC 3226				AGN	Y	Y	Y	dusty	1.3×10^{-4}
20	NGC 3245				AGN CT	Y ^a	N	Y	outflow	1.0×10^{-6}
21	NGC 3379				Non-AGN CT		N	N	disky	2.0×10^{-7}
24	NGC 3607				Non-AGN CT		Y	Y	dusty	5.0×10^{-7}
26	NGC 3623				Non-AGN*		N	N*	core-halo	1.2×10^{-5}
27	NGC 3627				Non-AGN* CT		Y	Y	dusty	7.9×10^{-6}
32	NGC 3998	Y	Y	Y	AGN	Y	Y	Y	core-halo	2.5×10^{-3}
33	NGC 4036				AGN CT	Y	N	Y	outflow	3.2×10^{-6}
34	NGC 4111			N	AGN		N	Y	core-halo	7.9×10^{-4}
39	NGC 4314			N	Non-AGN CT		N	N	disky	1.0×10^{-4}
39	NGC 4278			N	Non-AGN CT		N	N	disky	1.2×10^{-4}
41	NGC 4374				AGN CT		Y	Y	dusty	1.6×10^{-6}
43	NGC 4438			N	AGN CT	Y	N	Y	outflow	6.3×10^{-5}
46	NGC 4486	Y	Y	Y	AGN	Y	Y	Y	outflow	2.5×10^{-5}
48	NGC 4552	Y	Y	Y	AGN		Y	Y	disky	3.9×10^{-6}
50	NGC 4579	Y	Y	Y	AGN	Y	Y	Y	outflow	2.5×10^{-4}
52	NGC 4594	Y		Y	AGN		Y	Y	disky	3.9×10^{-6}
53	NGC 4636				Non-AGN CT	Y	Y	Y	outflow	2.1×10^{-6}
54	NGC 4676A				Non-AGN			N	outflow	...
55	NGC 4676B				AGN			Y	outflow	6.3×10^{-6}
57	NGC 4696				Non-AGN	Y ^c	Y	Y	outflow	3.9×10^{-4}
58	NGC 4736	Y		Y	AGN		Y	Y	disky	1.0×10^{-5}
59	NGC 5005		Y		AGN* CT?	Y	N	Y	outflow	1.0×10^{-5}
60	NGC 5055			Y	AGN CT		N	Y	core-halo	1.0×10^{-5}
70	NGC 5846				Non-AGN CT	Y ^c	Y	Y	outflow	2.0×10^{-5}
71	NGC 5866				Non-AGN CT		Y	Y	dusty	5.0×10^{-5}

Notes. (a) From Wu & Cao (2005). (b) No BH mass is available for this source. (c) From Dunn et al. (2010).

Fig. 5. Eddington ratios as a function of the HST-H α classification for the AGN LINERs in our sample. Symbols are the same as in Fig. 4.

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. Except for maybe for the only case of a merger-like interaction (the two

galaxies in the Mice system), no signatures of clumpy structures reminiscent of star clusters were identified, in agreement with results from stellar population analysis (González-Delgado et al. 2004; and Sarzi et al. 2005).

A size-luminosity relation was found between the equivalent radius of the H α emission and the hard X-ray luminosity. This correlation resembles the one reported for the NLR of Seyfert galaxies based on the [OIII] luminosity (Schmitt et al. 2003). This relation is another piece of evidence confirming the AGN-NLR nature of the ionized gas in LINERs (Pogge et al. 2000; Walsh et al. 2008).

Indications of a relationship between soft X-rays and H α emission in LINERs were also reported for the first time. This spatial correlation looks similar to the one reported by Bianchi et al. (2006) for Seyferts, thereby proving the photoionized nature of the soft X-rays.

For the only 4 LINERs with no proof of the AGN nature of their nuclear emission, a CT AGN cannot be discarded given the properties of their X-ray emission. For the confirmed AGN-LINERs, their H α morphologies favour core-halo and outflow systems (65% of the cases). Finally, Eddington ratios were calculated showing that LINER nuclei radiate in the sub-Eddington regime, in agreement with previous data (Maoz 2007; Ho 2008; Eracleous et al. 2010a), however, core-halo systems tend to have higher Eddington ratios than outflow candidates on average.

These results may be consistent with the suggestion by Maoz (2007) of radio-loud outflow-related systems showing lower Eddington ratios.

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Appendix A: Comments on individual objects

IC 1459. At HST resolution, Lauer et al. (2005) classified this galaxy as a starting, dusty nuclear ring and, based on H α + [NII] WFPC2 images, Verdoes Kleijn et al. (2000) identify an ionized gas disk with PA 37° and inclination 60° following what is found by Goudfrooij et al. (1990) on larger scales (100 arcsec). Here we report a residual H α emission with a central source and a rather biconical distribution extended ~500 pc at PA 37° (Fig. 2). At soft X-ray energies (0.3–2 keV), it extends along the same direction as in H α HST data (Fig. 6).

NGC 315. A compact unresolved source of ionized gas on top of a dusty disk, together with an extension of the disk of 200 pc at PA 49°, is detected (see Fig. 2; see also Verdoes-Keijn et al. 1999). The high spatial resolution provided by Chandra imaging allowed detection of the X-ray jets (Donato et al. 2004; Worrall et al. 2003, 2007; Gonzalez-Martin et al. 2009). Soft X-rays extend along the axes of the jet and the host galaxy (Fig. 6).

NGC 2639. At HST resolution, its H α shows an elongated asymmetrically extended structure at PA –29°, but nuclear compact source is not identifiable. It also shows extended filaments as more prominent towards the NW. The SE region may be obscured by dust. The SD images and the broad band data show a rather dusty morphology (see Fig. 2; and Simões Lopez et al. 2007).

NGC 2681. The H α emission image shows a central source with extended emission throughout the central spiral structure with major axis at PA 40° and a radial extension of 4 arcsec (~440 pc). Spiral dust lanes are clearly detected in the SD image (Fig. 2). Broad agreement is found in the elongation of soft X-ray and H α emissions (Fig. 6).

NGC 2787. On the HST SD images, a near-nuclear dust lane is clearly resolved into a spectacular set of concentric, elliptical dust rings, covering a radial range of 510 arcsec (see also Shields et al. 2007; Simões-Lopes et al. 2008; Gonzalez Delgado et al. 2008). In H α , a nuclear component has been detected, in good agreement with Dai & Wang (2009). An elongation at PA 49° can also be identified, which is perpendicular to the major axis of the galaxy (Fig. 2). Soft X-rays roughly follow the H α emission (Fig. 6).

NGC 2841. At HST resolutions, NGC 2841 shows a rather face-on ring-like structure and a clearly identified unresolved nuclear source. A small NLR can be identified at PA of 90°. Dust morphology becomes apparent from the SD image (Fig. 2). Soft X-rays extend along two main axes, one following the hard X-ray emission (PA about 10) and the other one close to that of the H α emission (Fig. 6).

NGC 3226. This galaxy shows a bright nucleus with some clear evidence of dusty environment in the SD image (see also Gonzalez Delgado et al. 2008). In H α it shows an extended morphology quite similar to what is observed in continuum (Fig. 2). At X-ray frequencies it shows a compact structure both at soft and hard energies. The H α , however, seems to suggest an outflow-like morphology emerging from the compact nucleus (Fig. 6).

NGC 3245. The H α image shows a kidney-like structure slightly brighter to the N, with a nuclear, unresolved source (see also Gonzalez Delgado et al. 2008; Walsh et al. 2008). Kinematical

data from Walsh et al. (2008) support our outflow classification. The W dust structure is clearly appreciated in the SD image. (Fig. 2). One of the two axes shown by the soft X-ray contours follows the H α emission (Fig. 6).

NGC 3379. An extended structure emerging from the nucleus can be appreciated although the S/N on the H α image is low. A tiny dust lane crosses the nuclear regions at PA –50° in SD (Fig. 2). At HST resolution Lauer et al. (2005), based on the *F555W* filter, classified this galaxy without a clear nuclei but with a dusty nuclear ring morphology. Shapiro et al. (2006) report a well-defined disk of emission at H α with PA 118. The morphology of the soft X-ray contours is quite complex, but rough agreement with the extended H α emission is found (Fig. 6).

NGC 3607. The H α image shows a clearly nuclear, unresolved source and diffuse emission following what appears to be an inclined disk. The strong dust lanes visible in the SD images obscure the H α emission (Fig. 2). Lauer et al. (2008) suggest that it contains a dusty outer disk that is dynamically old and that appears to transition rapidly but smoothly at the centre to a second gas disk that is perpendicular to the first and is seen nearly edge-on. This inclined disk seems to be settling onto a nuclear ring. Except for the the outermost contours, the soft X-ray emission is elongated in the H α emission (Fig. 6).

NGC 3623. H α emission has been detected, extending ~130 pc at PA –10°. Inside the more extended structure an inner disk is seen to extend 30 pc along PA 53°. Large-scale dust lanes clearly appear in the SD image (Fig. 2).

NGC 3627. The H α data (Fig. 2) do not show a well-defined nuclear source, most probably because the dust lane crosses the nuclear region in the direction NS and obscures the SE-NW elongated extended emission (see the SD image). Gonzalez-Delgado et al. (2008) report from HST data that chaotic dust lanes and several compact sources are identified at the centre.

NGC 3998. The H α image (Fig. 2) shows a 100 pc extended structure surrounding a compact nucleus. The major axis of this extension is oriented along PA = 0° (see also Pogge et al. 2000). The SD image shows little indication of dust in the nuclear region, in good agreement with Gonzalez Delgado et al. (2008). Soft X-rays are elongated in the same direction as the H α emission (Fig. 6).

NGC 4036. The HST H α image (Fig. 2) shows, on top of a well-identified nucleus, a complicated filamentary and clumpy structure, with an extension of 390 pc at PA 63°, already reported by Pogge et al. (2000) and Dai & Wang (2009) (see also the SD image). Walsh et al. (2009) show there is a gas velocity gradient of ~300 km s^{–1} across the inner 0.2", compatible with the outflow-like structure apparent in the ionized gas. The soft X-ray emission appears to follow the H α emission (Fig. 6).

NGC 4111. A rather knotty morphology surrounding a clear nuclear source is observed, embedded in a diffuse halo. This morphology is interpreted as a core-halo structure detected at HST resolution both with medium size filters (Simões Lopes et al. 2007) and narrow band H α data (Dai & Wang 2009). A crossing dust structure is seeing perpendicular to the disk main plane (see SD image). Soft X-ray contours are elongated along the same PA as the H α emission (Fig. 6).

NGC 4278. A clear core-halo morphology is shown by its $H\alpha$ emission on the top of a very faint continuum (Fig. 2). This emission seems to follow what is observed in the soft X-ray emission (Fig. 6).

NGC 4314. The $H\alpha$ image (Fig. 2) shows both an unresolved nucleus and a number of HII regions tracing the star formation ring. The same features are traced well by the SD image, where the spiral dust lanes associated with the ring are conspicuous (see also Gonzalez Delgado et al. 2008). At soft energies, its emission follows the star-forming regions observed in $H\alpha$ (Fig. 6).

NGC 4374. The $H\alpha$ image (Fig. 2) shows an inclined gas disk surrounding the nucleus. This emission gas structure takes the form of filaments that extend roughly EW and NS (see also Pogge et al. 2000). The dust structure clearly appears in the SD image, where the nucleus is seen in the centre of the dust lane to the S. The soft X-ray contours are roughly aligned with the ionized gas (Fig. 6).

NGC 4438. Gonzalez Delgado et al. (2008) define NGC 4438 as a galaxy with a very perturbed central morphology, and strong dust lanes cross the centre along PA 0° obscuring the E side of the galaxy (see the SD image). The $H\alpha$ image (Fig. 2) shows a ring-like structure where a clear knot is seen in the SE region coincident with the continuum nucleus. The other side would remain invisible due to obscuration by dust. Two plumes can be seen to the N and SW extending about 150 pc in both directions. This is one of the clearest examples of a candidate of nuclear outflow, bubble structures, as defined in Veilleux and Brandt (2007). Soft X-rays are aligned with the $H\alpha$ emission (Fig. 6).

NGC 4486. The $H\alpha$ image (Fig. 2) shows a compact source with filaments that resemble an outflow from the nucleus (see also Pogge et al. 2000; Dai & Wang 2009). As already noticed by Pogge et al. (2000), the conspicuous jet is clearly visible in the continuum images (see SD) disappears in the $H\alpha$ continuum subtracted map. Soft X-rays are misaligned with respect to $H\alpha$ emission, the former following the jet axis (Fig. 6).

NGC 4552. At HST resolution the $H\alpha$ data show a compact unresolved nuclear source located at the centre of a symmetric, extended emission in a disk-like structure. No trace of dust-lanes is seen in the SD image (Fig. 2). Soft X-rays roughly follow the $H\alpha$ emission (Fig. 6).

NGC 4579. The $H\alpha$ emission (Fig. 2) traces a bright nuclear point source surrounded by complex clumpy and filamentary emission (see also Pogge et al. 2000). The higher ionization gas traced by [OIII] (Fig. 2) is composed of a compact source and a filamentary, jet-like structure towards the NE. Walsh et al. (2008) have shown that the gas is not in regular rotation, displaying two kinematical components with a velocity separation of 450 km s^{-1} , being consistent with an outflow from the nucleus. The dust lanes seen in the SD image conform to a mainly chaotic structure, together with a much stronger offset linear feature that goes at $PA \approx 45^\circ$ on the W side. Soft X-ray contours follow the $H\alpha$ emission on large scales. There is a hint of an extension of hard X-rays along the PA of the [OIII] jet-like feature (Fig. 6).

NGC 4594. The $H\alpha$ image (Fig. 2) shows a compact nuclear source, together with fainter emission extending along the EW direction in a bar-like morphology, with two spiral arms

emerging from it and a total extension of 300 pc. The kinematical data by Walsh et al. (2008) show organized motion consistent with rotation but with significant irregularities in the nucleus. A strong velocity gradient and decoupled kinematics between gas and stars were found by Emsellem & Ferruit (2000). An overall extension of soft X-rays is seen along the same axis as the extended ionized gas (Fig. 6).

NGC 4636. The $H\alpha$ data (Fig. 2) show a central compact source and a very faint ring-like structure more clearly visible in the S region of the galaxy (see also Simões Lopes et al. 2007; and Dai & Wang 2009). Towards the N, a more prominent $H\alpha$ emission is seen with a clear outflow-like morphology. This morphology seems to follow the soft X-ray data (Fig. 6).

NGC 4676A and B. The Mice. The $H\alpha$ images (Fig. 2) show a very clumpy and irregular structure in both galaxies. In galaxy B a more conspicuous knotty structure is visible. One of the knots coincides with the nucleus. In galaxy A, however, a more diffuse emission is seen. Central dust lanes are much stronger in galaxy B, seen in the SD images (see also Laine et al. 2003). The soft X-ray contours are unrelated to the extended $H\alpha$ emission in both galaxies (Fig. 6).

NGC 4696. $H\alpha$ imaging (Fig. 2) shows a clear nuclear source with elongated extended emission along PA 47° , and larger filamentary structures towards the W may resemble outflows out of the nucleus. Crawford et al. (2005) also report a filamentary structure shared by the $H\alpha$ and soft X-ray emission (see also our Fig. 6).

NGC 4736. The $H\alpha$ image shows a circumnuclear spiral structure of extension 200 pc. Dust lanes in spiral arms are traced in the SD image (Fig. 2). Gonzalez Delgado et al. (2008) suggest there are spiral dust lanes down the nucleus and a compact nuclear stellar cluster. Despite the complexity of the soft X-ray emission, rough agreement is found in the overall shape of both images (Fig. 6).

NGC 5005. $H\alpha$ data (Fig. 2) show a very asymmetric emission with a wide-angle cone-like structure extending to the SE (see Pogge et al. 2000; and Dai & Wang 2009), perpendicular to the major axis of the galaxy. A strong dust lane crosses the galaxy from E to W, offset from the nucleus (see the SD image and Gonzalez Delgado et al. 2008).

NGC 5055. Its $H\alpha$ image (Fig. 2) shows a nuclear source and extended emission along PA 110° . A flocculent spiral structure, stronger to the S, is visible in the SD image (see also Gonzalez Delgado et al. 2008). Soft X-rays and $H\alpha$ emission are extended in roughly the same direction (Fig. 6).

NGC 5846. The $H\alpha$ image (Fig. 2) shows a compact nucleus and diffuse emission resembling a very wide outflow extending up to $2''$ in the W direction. This strong asymmetry cannot be explained by dust absorption (see the SD image). No correlation is seen between $H\alpha$ and soft X-ray emission (Fig. 6).

NGC 5866. The $H\alpha$ image shows an extremely faint nucleus on top of a very dusty structure along PA -45° strongly obscuring the nucleus (see also the SD image), which hampers either any classification of the emission (Fig. 2) or any comparison with the soft X-ray emission (Fig. 6).

Fig. 2. Images of H α (left) and SD (right). Top is north and east to the left. The units of the plots are arcsecs. For clarity contours above 3σ levels have been plotted in the H α images. For the outflow candidates, the contour for which R_{eq}^* was estimated is also plotted with a black or a white thick line. The position angle of the host major axis has been taken from the ned database and is shown as a solid line.

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Fig. 6. X-ray contours are overplotted onto the $H\alpha$ images. Top is north and east is left. The units of the plots are arcsecs. Soft (0.6–0.9 keV) X-rays contours are plotted in black and hard (4.5–8 keV) X-rays in red.

Fig. 6. continued.

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