Nuclear versus integrated spectroscopy of galaxies in the 
Herschel Reference Survey*,**

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ABSTRACT

Context. The determination of the relative frequency of active galactic nuclei (AGN) versus other spectral classes, for example, HII region-like (HII), transition objects (TRAN), passive (PAS), and retired (RET), in a complete set of galaxies in the local Universe is of primary importance to discriminate the source of ionization in the nuclear region of galaxies (e.g., supermassive black holes vs. young and old stars).

Aims. Here we aim to provide a spectroscopic characterization of the nuclei of galaxies belonging to the Herschel Reference Survey (HRS), a volume and magnitude limited sample representative of the local Universe, which has become a benchmark for local and high-z, studies, for semianalytical models and cosmological simulations. The comparison between the nuclear spectral classification and the one determined on the global galactic scale provides information about how galaxy properties change from the nuclear to the outer regions. Moreover, the extrapolation of the global star formation (SF) properties from the SDSS fiber spectroscopy compared to the one computed by Hz photometry can be useful for testing the method based on aperture correction for determining the global star formation rate for local galaxies.

Methods. By collecting the existing nuclear spectroscopy available from the literature, complemented with new observations obtained using the Loiano 1.52 m telescope, we analyze the 322 nuclear spectra of HRS galaxies; their integrated spectroscopy is available from the literature as well.

Results. Using two diagnostic diagrams (the BPT and the WHAN) we provide a nuclear and an integrated spectral classification for the HRS galaxies. The BPT and the WHAN methods for nuclei consistently give a frequency of 53–64% HII, around 21–27% AGNs (including TRAN), and 15–20% of PAS (including RET), whereas for integrated spectra they give 69–84% HII, 4–11% of AGNs and 30% irrespective of their membership to the Virgo cluster, suggesting that the AGNs population is not sensitive to the environment. Finally, extrapolation of the global SF properties from the nuclear spectroscopy including aperture corrections leads to underestimate with respect to values derived from direct integrated Hz photometry.

Key words. galaxies: evolution – galaxies: fundamental parameters – galaxies: star formation

1. Introduction

Characterizing the nuclear properties of galaxies in the local Universe, that is, establishing the mass dependence of the relative frequency of active galactic nuclei (AGN) ionized by supermassive black holes with respect to HII region-like nuclei excited by young stars, or with respect to galaxies ionized by old stars, is an urgent task of today’s research in astrophysics (see e.g., Kauffmann et al. 2003, hereafter K03). There is a clear need to establish the frequency of AGNs of various types, in different environments, locally and from a cosmological perspective, to improve our understanding of galaxy assembly. As Boselli et al. (2010) pointed out, observing the local Universe is relevant because it represents the endpoint of galaxy evolution, providing important boundary conditions to models and simulations. Galaxies can only be completely characterized at low-redshift or by multifrequency observations. Moreover, dwarf galaxies can only be observed locally. In recent years, considerable effort has been made to select representative samples of galaxies, like SINGS (Kennicutt et al. 2003), the recent KINGFISH (Kennicutt et al. 2011), and VNGS

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(Bendo et al. 2012), to study the properties of the local Universe. In recent years, the *Herschel* Reference Survey (HRS; Boselli et al. 2010) has become a benchmark for the representation of the properties of local galaxies (Hughes et al. 2013; Boquien et al. 2013; Ciesla et al. 2016), and has therefore become a reference for comparing observations of local galaxies with those of increasing redshift (Schreiber et al. 2016; Bassett et al. 2017; Fossati et al. 2017) or resulting from simulations (Lagos et al. 2016; Cattaneo et al. 2017; Fontanot et al. 2017). The HRS has been observed with SPIRE (250, 350, 500 µm) (Ciesla et al. 2012, 2013) and with PACS (100, 160 µm) (Cortese et al. 2014) on board *Herschel*: at \( D \leq 30 \) Mpc the angular resolution of SPIRE (see Table 2 of Boselli et al. 2010) allows us to resolve the different galaxy components, such as nuclei, bulges, discs, and spiral arms. The HRS is a volume-limited sample and is k-band selected, therefore, by design, it is suitable for statistical studies of the multifrequency properties of local galaxies. Many surveys have been done to cover the whole sample in different bands: FUV and NUV photometry obtained from GALEX is reported by Cortese et al. (2012); \( 24–160 \) µm photometry from MIPs is given by Bendo et al. (2012); *Spitzer*IRAC photometry is reported by Ciesla et al. (2014); Boselli et al. (2014ab,c) report the gas properties (HI and CO) of the HRS, whereas Boselli et al. (2015), hereafter B15 describe an H\(_{\alpha}\) imaging survey of the full HRS. Finally Boselli et al. (2013) give the integrated (drift-mode) spectroscopy of the HRS. Conversely no systematic information is available from the literature on the nuclear spectroscopic classification of the HRS, a task that we tackle in this paper. Not all the 322 galaxies constituting the HRS have been observed spectroscopically so far (only 277/322 objects). In this paper we complete the HRS by presenting new nuclear long-slit spectroscopy for 45 galaxies, 25 of which in the whole optical range (from H\(_{\alpha}\) to [Si II]) and 20 only in the red band near H\(_{\alpha}\). Generally, the classification of galaxies based on their optical nuclear spectra is performed using the BPT (Baldwin et al. 1981) diagnostic diagram, which requires the measurement of different spectral lines: H\(_{\beta}\), [OIII]\(\lambda\)5007, H\(_{\alpha}\), [NI]\(\lambda\)6583.4, and [SI]\(\lambda\)6717,6731. In this diagram, AGNs are distinguished from HII-region-like nuclei using the ratio [NI]/H\(_{\alpha}\), while strong AGNs (sAGNs) can be separated from the weaker (weak AGNs or wAGNs) low-ionization nuclear emission-line region (LINERs, Heckman 1980) using the ratio [OIII]/H\(_{\beta}\). There is also a recent two-line diagnostic diagram, named WHAN, which is based on the [NI]/H\(_{\alpha}\) ratio combined with the equivalent width (EW) of the He line. It was introduced by Cid Fernandes et al. (2011) to divide both strong and weak AGNs from fake AGNs, namely the retired galaxies (RET), whose ionization mechanism is probably provided by an old stellar population (Capetti & Baldi 2011). Using the BPT and the WHAN diagrams, we obtain a robust determination of the frequency of AGNs in a complete sample of local late-type galaxies (LTGs) and compare it with the frequency of HII-region-like nuclei as a function of stellar mass. Moreover, the comparison between the nuclear spectral classification and the one determined on the global galactic scale provides information about how galaxy properties change from the nuclear to the outer regions. The issue is hotly debated and only spectroscopy obtained with Integral Field Units (IFU) such as MaNGA (Belfiore et al. 2016, 2017; Sánchez et al. 2018), CALIFA (Sánchez et al. 2016) and SAMI (Richards et al. 2016) will bring the issue to an end. These surveys have confirmed previous claims that regions of low ionization conditions can in fact extend to the bulges of galaxies and even further, mimicking the presence of AGNs, being in fact due to old post-AGB stars. We compare the global with the nuclear properties of HRS galaxies adopting a method similar to Moustakas et al. (2010) who used long-slit spectroscopy, while Iglesias-Páramo et al. (2013, 2016) adopted the two-dimensional (2D) spectroscopy. The availability of the global properties of HRS galaxies allows us to test the program of Brinchmann et al. (2004, hereafter B04) who claimed that a satisfactory estimate of the global star formation rate (SFR) of galaxies in the local Universe (\( z \leq 0.2 \)) can be achieved using SDSS fiber spectroscopy, once corrected for aperture effects using SDSS photometry (e.g., cmodel – fiber colors), both quantities being available for hundreds of thousands of local galaxies thanks to the SDSS. The paper is structured as follows: in Sect. 2 we describe the sample, in Sect. 3 we outline the data reduction, in Sect. 4 we present the results, and in Sect. 5 the discussion and conclusions. A description of the tables provided is given in Appendix A. Standard cosmology is assumed, with \( H_0 = 73 \) km s\(^{-1}\) Mpc\(^{-1}\). The spectroscopic data presented in this work, as well as those collected at other frequencies, are available to the community through the HeDaM database\(^1\).

2. The sample

The sample of galaxies analyzed in this work is the (HRS; Boselli et al. 2010; the reader should refer to this paper to find the catalog names of HRS galaxies). It consists of a volume limited (\( 15 < \text{Dist} < 25 \) Mpc) sample of 322 galaxies, located in the sky region in the ranges \( 10 \text{ h} 17 \text{ min} < \text{RA}(2000) < 14 \text{ h} 43 \text{ min} \) and \( -6^\circ < \text{Dec} < 60^\circ \) (see Fig. 1), of which 64 are early-type galaxies (ETGs; E, S0, and S0a) and 258 are LTGs: Sa–Sd–Im–BCD\(^2\). All LTGs with a 2MASS K band total magnitude \( K_{\text{tot}} \leq 12 \) mag have been selected and all ETGs with \( K_{\text{tot}} \leq 8.7 \) mag have been included. The stellar mass range of HRS galaxies is: \( 5 \times 10^{10} \leq M_* \leq 10^{11.3} \) \( M_\odot \). The sample spans a large range of environments: it includes the Virgo cluster, many galaxy groups, as well as isolated objects. In the Virgo cluster region (\( 12 < \text{RA} < 13 \) h and \( 0^\circ < \text{Dec} < 18^\circ \)), the sample includes all galaxies with vel <3000 km s\(^{-1}\) and those belonging to cluster A, the North (N) and East (E) clouds, the southern extension (S, at 17 Mpc) and Virgo B (23 Mpc), where the subgroup membership has been taken from Gavazzi et al. (1999). The W and M clouds, at a distance of 32 Mpc, have been excluded. In the sky projection map of Fig. 1, the Virgo cluster region, which includes 148 HRS objects from Virgo A, Virgo B, the N and E clouds and the S extension, is easily recognizable as the density enhancement at RA \( \approx 190^\circ \) and Dec \( \approx 10^\circ \).

2.1. Data from the literature

Most of HRS nuclear optical spectra were found in the literature. In particular, 163 spectra were downloaded in FITS format from the SDSS DR13 and DR12 database (Albareti et al. 2017); 114 spectra were found in the NASA/IPAC Extragalactic Database (NED) and 104 of these are taken from Ho et al. (1997). For these galaxies, the double spectrograph on the Hale 5 m telescope at Palomar Observatory yielded simultaneous spectral coverage of \( \approx 4230–5110 \) Å and \( \approx 6210–6860 \) Å, with a spectral resolution of \( \approx 4 \) Å in the blue and \( \approx 2.5 \) Å in the red. We joined the blue and red spectra by projecting them on a common wavelength solution

\(^1\) http://hedam.lam.fr/HRS/

\(^2\) With respect to the original sample given in Boselli et al. (2010), we revised the morphological classification for some HRS galaxies: HRS-032, HRS-090, HRS-202, HRS-229 and HRS-291 become ETGs, while HRS-256 becomes LTG. After this revision, the LTGs are 254 and the ETGs are 68. In this work we use this new number for our analysis.
and by performing a linear interpolation between the average flux of the last ten pixels of the blue spectrum and the first ten of the red spectrum. HRS-070, 072, 209, 265, 275, 288, and 284 have been observed with the 3.9 m Anglo Australian Telescope (AAT) by Jones et al. (2009). HRS-193 was observed by Falco et al. (1999) with the Z-Machine at Mt. Hopkins 1.5 m telescope (Arizona). HRS-251 was observed by Kim et al. (1995) with the Z-Machine at Mt. Hopkins 1.5 m telescope on Mt. Hopkins. Finally the remaining 45 spectra were observed by us with the 1.52 m Cassini telescope at Loiano (Bologna) and their spectrum is published for the first time in this paper. Filled symbols in Fig. 1 represent these 45 HRS targets.

3. Long-slit nuclear spectroscopy: observations and data reduction

Nuclear spectroscopic observations of 45 HRS galaxies that were found neither in the SDSS spectroscopic catalog nor within the NED database, were obtained by us during several observing campaigns from 2000 to 2017 using the Bologna Faint Object Spectrograph and Camera (BFOSC, Gualandi & Merighi 2001) mounted on the 152 cm F/8 Cassini Telescope located in Loiano, belonging to the Observatory of Bologna. Following the work of Gavazzi et al. (2011, 2013), these are long-slit spectra taken through a slit of 2 arcsec width and 12.6 arcmin length, combined with an intermediate-resolution red-channel grism (G8; $R \sim 2200$) covering the 6100–8200 Å portion of the spectrum containing the Hα, [NII], and [SII] lines. Twenty-five of these galaxies were also observed with the same instrument during six nights in April and May, 2017 (see Table A.1 for details), using a blue-channel grism (G7) providing ($R \sim 1400$) cover from 4200 to 6600 Å. The observing log of these 45 galaxies is given in Table A.1. BFOSC is equipped with a back illuminated EEV LN/1300-EB/1 CCD detector of 1300 $\times$ 1340 pixels, reaching 90% QE near 5500 Å and 70% QE near 4000 Å. For the spatial scale of 0.58 arcsec pixel$^{-1}$, and a dispersion of 8.8 nm mm$^{-1}$, the resulting spectra have a resolution of 1.6 Å pix$^{-1}$ for G8 and a dispersion of 11 nm mm$^{-1}$, with a resolution of 1.9 Å pix$^{-1}$ for G7. Exposures of 2–7 min (G8) and 7–15 min (G7) were repeated typically three times to remove cosmic ray hits. The slit was generally set in the E–W direction and the typical seeing conditions at Loiano ranged from 1.5 to 2.5 arcsec. The wavelength calibration was secured by means of frequent exposures of a He-Ar hollow-cathode lamp and was further refined using bright OH sky lines. The spectrograph response (sensitivity function) was obtained by daily exposures of the stars Feige34 and Hz44 (Massey et al. 1988). The spectra were not flux calibrated, and measurements of the lines EW were derived, along with flux ratios of adjacent lines, namely [OIII]/Hβ, [NII]/Hα, and [SII]/Hα. The spectra were reduced using standard IRAF procedures. To derive the wavelength calibration we used the tasks identify, reidentify, and fitcoord on the hollow-cathode lamp exposures, and the 2D wavelength solution was transferred to the galaxy exposures by means of the task transform. After verification of the wavelength calibration on several known sky lines, the sky was subtracted using background. One-dimensional (1D) nuclear spectra were extracted from the 2D images using apsum, adopting an aperture of 10 pixel width (5.8 arcsec). We adopt this value for the aperture to be consistent with Ho et al. (1997), who extracted (red) spectra from an aperture of 4.1 arcsec. The 1D spectra were response-calibrated using the median sensitivity function of each night. After normalization to the flux in the interval 6400–6500 Å the spectra were Doppler shifted to Hubble; each redshift was taken from NED and then applied to the galaxy spectrum using dopcor. For the galaxies observed with both the G7 and G8 grisms, the blue and red spectra were joined using the task scombine. Plots of the nuclear spectra obtained at Loiano are divided among Figs. A1 and A2. Out of 19 spectra taken with the G8 grism, 8 can be found in Gavazzi et al. (2011, 2013). The remaining 11 are given in Fig. A2 and are published for the first time in this paper. Twenty-five spectra observed with both the G7 and G8 grisms are shown in Fig. A1.

The Balmer hydrogen lines are affected by stellar absorption, thus they have been corrected for this effect for proper use in the diagnostic diagrams. We homogeneously corrected the 26 spectra that we took at Loiano with the G7+G8 grisms, the spectra downloaded from SDSS, the spectra observed by Ho et al. (1997) and the spectra downloaded from the NED database using the Gas AND Absorption Line Fitting (GANDALF) fitting code (Serzi et al. 2006; Falcón-Barroso et al. 2006) complemented by the Penalize Pixel-Fitting code (Cappellari & Emsellem 2004) to simultaneously model the stellar continuum and the emission lines in individual pixels. Consistently with B15, we used the MILES stellar library (Vazdekis et al. 2010). GANDALF is a simultaneous emission and absorption line fitting algorithm designed to separate the relative contribution of the stellar continuum from that of the nebular emission in the spectra of nearby galaxies, while measuring the gas emission and kinematics. This code implements the pPXF method, which combines and adjusts the observed spectra of several stars of all spectral type to the stellar continuum to quantify and remove the underlying absorption. GANDALF was run several times, adjusting the algorithm input parameters, especially on spectra of Ho et al. (1997), because of the presence of the 1000 Å gap in these spectra (see Sect. 2 for details). For the remaining...
I9 galaxies observed at Loiano with the G8 grism, the insufficient spectral coverage prevents GANDALF from converging. For these galaxies, a statistical absorption correction was applied according to the following procedure. We took a sample of about 5000 galaxies from Consolandi et al. (2016) and constructed their color-stellar mass diagram in Fig. 2. For these 5000 galaxies, we downloaded the absorption correction to Hα from SDSS (Golst pecLine) and constructed a mean correction in nine bins of stellar mass and color (see Table 1) that we applied to the spectra according to each bin of mass and color. The q and i magnitudes for these HRS galaxies were taken from Cortese et al. (2012) and were subsequently corrected for Galactic extinction using the Cardelli et al. (1989) reddening curve; the value of stellar mass is from B15. The resulting Hα correction is consistent with the correction obtained using the GANDALF analysis for the individual spectra.

**4. Spectral classification**

The determination of the spectral properties of HRS galaxies in this paper is based on four indicators (three versions of the BPT and the WHAN diagram) which exploit the ratio of [OIII]/Hβ on [NII]/Hα or [SII]/Hα or occasionally on the [O]I/Hα using the BPT diagnostic diagram, and on the ratio [NII]/Hα versus the Hα EW, using the WHAN diagram, which holds when the blue emission lines are not available. These diagnostics only classify galaxies with emission lines. Therefore galaxies classified as passive (PAS, showing only absorption lines) or post-starburst (PSB, showing the Balmer series in absorption) have been added posteriori, by inspecting their spectra by eye. According to Kobulnicky & Phillips (2003), the ratio of the two adjacent lines can be derived using the equivalent widths instead of the line fluxes. In order to perform a robust spectral classification, we do not classify integrated and nuclear spectra with signal-to-noise ratio (S/N) of Hα and Hβ < 3. With such a threshold, 48 nuclear spectra (marked with the letter “d” in Table A.4) and 36 integrated spectra (letter “b” in Table A.4) were not classified according to the BPT diagrams. Instead, all nuclear spectra could be classified according to the WHAN diagram and only 8 integrated spectra (marked with letters “b, c” in Table A.4) were excluded from this classification. In the following spectral analysis we refer always to the LTGs subsample, because their statistic is complete (both nuclear and integrated). As far as concerns the ETGs subsample, 50 integrated spectra were not observed by Boselli et al. (2013): this subsample was not considered in our statistical analysis when we compare the nuclear to the integrated classification. Therefore, we refer the reader to a sample of 360 ETGs from the ATLAS3D whose nuclear spectra are given in Gavazzi et al. (2018) for the properties of ETGs. Figure 3 gives the nuclear classification of HRS galaxies according to the BPT diagnostic based on the [NII]/Hα ratio (217 objects), on the [SII]/Hα ratio (217 objects), on the [O]I/Hα ratio (101 objects) and according to the WHAN diagram (288 objects). Approximately 30 additional galaxies with no emission lines, not included among the 217 nor 288 classified objects, were classified as PAS or PSB. The region labeled HII (blue) lies to the left of the dotted line defined by K03, while the region occupied by AGNs (red) is to the right of the broken line of Kewley et al. 2001) in both the [NII]/Hα (first panel) and in the [O]I/Hα diagrams (third panel). Between the two lines an intermediate region defines the position of the Transition objects (TRAN; pink). The second panel gives the BPT diagnostic using the ratio [SII]/Hα. Here, the straight line (from Kewley et al. 2006) separates Seyfert (SEY, in red) from LINERs (LIN, in pink). The fourth panel of Fig. 3 shows the WHAN diagnostic: the different spectral classification and separations between them are from Gavazzi et al. (2011). In this diagram galaxies are divided into five spectral types: HII-regions (blue), sAGN (red), wAGN (pink), RET (green), and PAS. Using the same diagnostic criteria, Fig. 4 gives the BPT and WHAN classifications for integrated spectra with available emission lines, according to the S/N threshold. In our analysis we refer always to AGNs as TRAN + AGN, LIN + SEY, and sAGN + wAGN. We adopted this definition for the AGNs spectral class to be able to compare our results with those of K03, who defined as AGNs all galaxies beyond the left line in the BPT ([NII]/Hα) diagram. In specific cases we refer only to “pure” AGNs, namely galaxies above the curve defined by Kewley et al. (2001) in the BPT ([NII]/Hα) diagram. Also, galaxies classified as PAS or PSB (and RET in the WHAN diagnostic) are always held together.

Despite the different populations and classification criteria, the WHAN and the BPT nuclear diagnostics give consistent results (see Table 2). Hereafter, two different percentages are always reported, one is the value resulting from one of the [NII]/Hα or [SII]/Hα BPT diagrams and the other is from the WHAN diagram. Between 53 and 64% of the nuclear spectra are HII region-like nuclei. The remaining percentage is divided between AGNs (21–27%) and PAS (15–21%). The “pure” AGNs are half of the AGNs percentage: 7–13%. These are galaxies ionized by a SMBH. Restricting to the 254 LTGs alone, the statistics is altered (see right columns of Table 2): the HII-regions increase to 67–77%; the AGNs become 21–27%; and the PAS spectra decrease to 2–7%. The latter class includes two PSB galaxies: HRS-116 and HRS-195. These two objects show a late-type
Fig. 3. Nuclear diagnostic diagrams for the whole HRS sample limited to emission-line objects with S/N > 3. In the left BPT diagram panel, the broken separation line between AGNs (red) and TRAN (pink) galaxies is from Kewley et al. (2001), while the dotted separation line between TRAN (pink) and HII region-like nuclei (blue) is from K03. In the second BPT diagram panel, the extreme starburst classification line is from Kewley et al. (2001), while the separation between LINER (pink) and SEY (red) is from Kewley et al. (2006). We note that the pink filled symbols refer to different types of objects in the three diagrams. The third panel reports the BPT diagram for the minority of galaxies (101) with [OI] in emission. In the WHAN diagram the separation between the different classes are from Gavazzi et al. (2011).

Fig. 4. Integrated diagnostic diagrams for emission-line objects with S/N > 3. Broken separations in the diagrams are the same as in Fig. 3.

Fig. 5. BPT diagrams for 164 HRS objects that have both the nuclear and integrated classification available in the [OIII]/Hβ vs. [NII]/Hα diagram. The separation lines are the same as in Fig. 3.

morphology, with a central bulge and spiral arms, but the SF activity has been stopped suddenly. Also HRS-164 is a LTG with a PAS spectrum: its morphology shows a strong barred structure in the center, but it is an old and red object. A comparison between the nuclear and integrated spectral classifications can be performed among the subsample of HRS galaxies with available nuclear and integrated classification (see Figs. 5, 7, and 8); the subsample is reported in Table 3. This comparison provides information about how the excitation properties of galaxies change from the center to the outskirts. As can be seen in the three figures, AGNs represent 18–26% in the nuclear spectra; while in the integrated they decrease to 4–11%. HII-regions are 59–71% in the nuclear classification, becoming 69–84% among the integrated spectra. PAS (including PSB) and RET are 11–15% in the nuclear spectra, becoming 12–20% in the integrated spectra. Altogether, the two diagnostics give consistently that the integrated spectra contain ~10% more HII-region-like spectra than the nuclear ones, together with 10% less AGNs. PAS spectra have an equal frequency: they are 11–15% in the nuclear classification, becoming 12–20% in the integrated one. Figure 6 gives a graphical representation of the migration from nuclear to integrated classification, separately for the various spectral
Fig. 6. Left panel: AGNs; middle panel: Transition; right panel: HII regions. Migration from nuclear (filled symbols) to integrated (empty symbols) in the BPT diagram.

Fig. 7. BPT diagrams for 164 galaxies that have the ratios [OIII]/Hα and [SII]/Hα available both from the nuclear and integrated spectra. The dotted separation lines are the same as in Fig. 3.

Fig. 8. WHAN diagrams for 244 galaxies with the ratios [NII]/Hα and Hα EW available both from nuclear and integrated spectra. The dotted separation lines are the same as in Fig. 3.

classes. Filled symbols refer to the position of nuclear spectra in the BPT ([NII]/Hα) diagram, while empty symbols give the position of integrated spectra in the same diagram. Unsurprisingly, only three nuclear AGNs remain AGNs in the integrated classification; all the remaining ones end up as TRAN or HII-regions. All but four nuclear TRAN become HII-regions in the integrated spectra. All but two nuclear HII-regions remain integrated HII-regions. We must highlight that the integrated statistics is biased toward the LTGs, because not all the integrated spectra were taken for the ETGs by Boselli et al. (2013) (only 18/68).

4.1. Mass and environment dependence

Figure 9 shows the distribution of the different nuclear spectral type fractions for HRS LTGs as a function of the stellar mass (from B15) with the respective error bars, computed using the WHAN diagram (left) and the BPT ([NII]/Hα) diagnostic (right). The number of galaxies in each specific mass bin is reported in parentheses. In spite of the different classification criteria, WHAN and BPT diagrams give consistent dependence of the nuclear spectral properties from stellar mass, excluding PAS spectra because their statistics in the LTG subsample is
Table 2. Frequency of the different types of nuclear spectra in the whole HRS sample (left) and among the 254 LTGs (right), including galaxies a posteriori classified as passive or post-starburst.

| BPT ([NII]/Hα) 255/322 | AGN 34 (13%) | BPT ([NII]/Hα) 206/254 | AGN 26 (13%) |
|------------------------|-------------|------------------------|-------------|
| TRAN 31 (12%)          |             | TRAN 27 (13%)          |             |
| HII 152 (60%)          |             | HII 149 (72%)          |             |
| PAS 36 (14%)           |             | PAS 2 (1%)             |             |
| PSB 2 (1%)             |             | PSB 2 (1%)             |             |

| BPT ([SII]/Hα) 255/322 | SEY 23 (9%) | BPT ([SII]/Hα) 206/254 | SEY 20 (10%) |
|------------------------|-------------|------------------------|-------------|
| LIN 30 (12%)           |             | LIN 24 (11%)           |             |
| HII 164 (64%)          |             | HII 158 (77%)          |             |
| PAS 36 (14%)           |             | PAS 2 (1%)             |             |
| PSB 2 (1%)             |             | PSB 2 (1%)             |             |

| WHAN 322/322 | sAGN 24 (7%) | WHAN 254/254 | sAGN 21 (8%) |
|--------------|-------------|-------------|-------------|
| wAGN 63 (20%) |             | HII 171 (53%) |             |
| HII 171 (53%) |             | HII 168 (67%) |             |
| RET 28 (9%)   |             | RET 14 (6%)  |             |
| PAS 34 (11%)  |             | PAS 2 (0.5%)  |             |
| PSB 2 (1%)    |             | PSB 2 (0.5%)  |             |

very small (only 4 objects). As shown in Fig. 9, nuclear HII regions (blue) are exclusively found among galaxies with $M_\star < 10^{9.5} M_\odot$ (90 ± 9%), and then their fraction decreases with increasing stellar mass. On the contrary, the frequency of AGNs (red) including TRAN, black) is low, at $M_\star < 10^{9.5} M_\odot$ (8 ± 2%) and increases significantly with stellar mass, reaching 66 ± 14% above $10^{10.0} M_\odot$, suggesting that approximately two thirds of the LTGs in the local Universe, at that stellar mass value, contain an AGN or at least a TRAN object. This also suggests that there is a clear dependency of the nuclear ionization source from galaxy stellar mass: less massive galaxies are more likely to contain a nucleus ionized by young stellar population, compared to more massive galaxies, which contain an AGN or a TRAN object. Moreover previous works, such as K03, demonstrate that the AGNs fraction continues to grow at higher stellar mass. We conclude that even on nuclear scales, LTG galaxies suffer from decreasing SFR with increasing mass, a “downsizing” behavior, reinforcing the early claim by Gavazzi et al. (1996).

4.2. Star formation: the Brinchmann 04 program

Understanding the physical processes that drive SF and the rate at which galaxies form stars is crucial for the study of galaxy evolution. In recent decades, the available multiwavelength observations, from X-rays to radio bands, have been used to define a set of SF indicators. The most frequently used are: the UV continuum, nebular recombination lines (primarily Hα), far-IR dust emission, and the synchrotron radio continuum at 21 cm (Kennicutt 1983). Only the comparison of two or more SF indicators provides reliable measure of the SFR in galaxies. Many works in the literature proposed to compute the SFR directly from nuclear spectroscopy. Whether or not the global SF properties of nearby galaxies can be extrapolated from the available SDSS fiber spectroscopy (aperture correction problem) is still debated.

In this section, we test for the HRS galaxies the global SFR derived by B04 from SDSS nuclear spectra with the Hα-derived SFR of B15. B04 proposed a method to extrapolate the global SFR of local galaxies from SDSS nuclear spectra using aperture correction based on photometric optical colors. Summarizing, B04 computed the SFR of AGNs and TRAN objects from the 4000 Å break and for HII-regions from a global emission-line estimate obtained by fitting Charlot & Longhetti (2001) models to the nuclear spectra for galaxies belonging to the SDSS database. These values were corrected using an estimate of the external color of galaxies derived from the difference in color between the $c$Model magnitude (the magnitude based on the best-fitting of the exponential and de Vaucouleurs models in the r band, Abazajian et al. 2004) and the fiber magnitude (the magnitude in 3-arcsec-diameter SDSS fiber radius). The global SFR is obtained by adding the external to the nuclear SFR. Both the stellar mass and SFR in B04 are computed assuming a Kroupa (2001) IMF. B04 data are available through the SDSS database (galSpecExtra table) for 205 186 galaxies with $z < 0.1$ in the sky region corresponding to the one covered by the HRS. Figure 10 represents the relation between the stellar mass and the log(SFR$_{total}$) for the aforementioned SDSS galaxies (see contours). The appearance of the galaxy main sequence is evident, separated by a cloud of quenched galaxies, a factor of one hundred less star forming. Among galaxies listed in galSpecExtra we found the data for 38 HRS galaxies. For these we
plot the value derived by B04 with open symbols. Conversely, the filled symbols represent the SFR obtained by B15 directly from the Hα integrated photometry (solid line is the best fit to these data). The filled symbols precisely overlap the SFMS of galaxies in the local Universe; instead the value of SFR estimated by B04 is underestimated and does not follow the SFMS trend.

5. Discussion and conclusions

In this paper, we have used the BPT and the WHAN diagnostic diagrams to derive the nuclear spectral classification of galaxies belonging to the HRS, a statistically representative magnitude and volume limited sample of 322 local galaxies, spanning a wide range in morphology and stellar mass, and belonging to different environments. The determination of the relative frequency of AGNs versus other spectral classes, for example, HII region-like, PAS, and RET, in a statistically complete sample of local galaxies is important to discriminate the source of ionization in the nuclear region of galaxies (e.g., black holes vs. young or old stars). We present new nuclear long-slit spectroscopy of 45 HRS galaxies, which, added to the ones available from the literature, gives a complete nuclear spectroscopic census of all HRS galaxies more massive than $10^{11.3} M_\odot$. The completeness of the observations allows us to make a statistical analysis of the spectroscopic nuclear properties of this sample. We note that, after checking that using different diagnostics does not change the global statistics, we separated the different spectral classes by means of only the BPT(NII/Hα). We separated AGNs from HII and TRAN objects following the prescriptions of Kewley et al. (2001) and K03. Our main results can be summarized as follow:

1) As for the whole HRS sample about half of the nuclear spectra (53–64%) are HII region-like nuclei, while AGNs (including TRAN) represent 21–27% and PAS (including RET) spectra make up 15–21%. Restricting to the 254 LTGs, the percentage of AGNs+TRAN varies between 22% and 27%, the fraction of HII-regions increases to 67–77%, and PAS (including RET) spectra represent a mere 1–7%. However, the classification schemes provided by the various diagnostics cannot be fully reconciled: for example, the class “Transition” exists only in the classic BPT diagram, and the division between strong and weak AGNs is provided only by the WHAN diagram; the same applies to the classification of retired galaxies (that were identified by Cid Fernandes et al. 2011 as presently inactive nuclei, previously ionized by post-AGB stars). Moreover, the scatter between the various classifications appears large, as it was also concluded, in particular for LINERs, by Balmaverde & Capetti (2014) who compared HST high spatial- and spectral-resolution observations of low-luminosity AGNs with ground-based lower-resolution spectra. To reduce as much as possible the inconsistencies of the individual spectral classification schemes, we evaluate the mode between the four classifications in Fig. 3. In order to find a criterion for reliable classification, we select all galaxies whose mode is consistently provided by at least three methods (we note that spectra in which emission lines are absent, no matter if they were considered RET in the WHAN, poststarburst (PSB) or purely passive (PAS), were reclassified by hand as PAS, and therefore their mode classification is PAS with four votes). In the end, 195 targets out of 264 LTG galaxies have their mode composed of three coherent classifications. In order to study a possible environmental dependence of these frequencies we plot the mass distributions of the spectral fractions in Fig. 11, separately inside (left panel) and outside (right panel) the Virgo cluster (projected distance from M87 equal to two virial radii, assuming that the virial radius of the Virgo cluster is 1.7 Mpc from Boselli & Gavazzi 2006). From Fig. 11 it is clear that the dependency of the nuclear spectral types on galaxy stellar mass remain visible also observing galaxies in different environments.
However, no significant environmental dependence is found for the AGN frequency: among galaxies with \( M_* \geq 10^{10.0} M_\odot \) they are consistent with \( 30 \pm 7\% \) inside or outside the Virgo cluster. In both environments the decrease of the frequency of HII region-like nuclei with increasing stellar mass is compensated by a combined increase of the fraction of AGNs and of passive nuclei (including those previously classified as RET that are known to derive from post AGB stars).

2) Regarding the comparison between the nuclear and the integrated classification, as expected, the fraction of AGNs+TRAN integrated spectra is significantly lower than in the nuclei; they are only 4–11% instead of 18–26% (~10% lower). This decrease is compensated by an equal increase of HII region-like spectra (from 59–71% in the nuclear to 69–84% in the integrated classification). There is no significant change from the nuclear to the integrated classification in the percentage of PAS (including RET) spectra. This confirms previous results by Moustakas & Kennicutt (2006), Moustakas et al. (2010) and Iglesias-Páramo et al. (2013, 2016) who found that the relative fraction of star-forming galaxies versus AGNs is a strong function of the integrated light enclosed by the spectroscopic aperture. Iglesias-Páramo et al. (2013, 2016) observed 104 spiral galaxies in the CALIFA survey with an IFS, finding that the \( \text{H} \alpha \) flux and the \( \text{H} \alpha \text{E}W \) increase from the nucleus to the outer regions of galaxies with no dependence on galaxy inclination and stellar mass. Furthermore, Moustakas et al. (2010) provided optical nuclear, circumnuclear, and semi-integrated spectra of 65 galaxies in SINGS (Kennicutt et al. 2003), finding that the fraction of the sample classified as AGNs decreases by ~30% as the light fraction increases by ~50%, with a corresponding increase in the fraction of galaxies classified as HII-regions. Finally, Belfiore et al. (2016), who studied the spatially resolved excitation properties of the ionized gas for 646 galaxies belonging to SDSS-IV MaNGA, concluded that the excitation properties of galaxies change from the center to the outskirts in a very complex way. As the coverage of ETGs in the HRS is incomplete, we refer the reader to Gavazzi et al. (2018) who analyze the nuclear properties of a sample of 360 ETGs from the ATLAS3D.

3) Restricting to the 254 LTGs, we computed the spectral classes distribution as a function of stellar mass. The percentage of HII regions is inversely proportional to the stellar mass (90% for galaxies with \( M_* < 10^{9.5} M_\odot \)) while that of AGNs (including TRAN) is directly proportional. We find that approximately two-thirds (66%) of spiral galaxies in the local Universe (\( z < 0.03 \)) with \( M_* > 10^{10.0} M_\odot \) contain an AGN or a TRAN object, that is, a nucleus not ionized by a young stellar population (O and B stars), but ionized by a supermassive black hole or old post-AGB stars. Our result is consistent with K03 who examined the properties of the host galaxies of 22623 AGNs with \( 0.02 < z < 0.3 \) selected from the SDSS. First of all, we note that K03 defines AGNs as all galaxies that lie to the right of the line defined by K03 in the BPT diagram, so we can compare our results on AGNs+TRAN to these. K03 found that AGNs reside almost exclusively in massive galaxies: between \( 3 \times 10^{10} M_\odot \) and \( 10^{11} M_\odot \), they represent 50% at very low redshift (\( z \sim 0.02 \)). More recently, Sánchez et al. (2018) remarks that AGNs are hosted in the most massive galaxies, namely mostly ETGs or early-type spirals, with an important bulge.

4) Restricting to the 254 LTGs we also computed the spectral type distribution as a function of environment, considering that 148 HRS galaxies belong to the Virgo cluster. No significant environmental dependence is found for AGNs (including TRAN): for galaxies with \( M_* \geq 10^{9.0} \) they are consistent with ~33% inside the Virgo cluster and with ~30% outside it. Similar results are obtained restricting to the “pure” AGNs, at the same stellar mass; they reach ~13% inside the Virgo cluster and ~14% outside it. These results suggest that AGNs, including or excluding TRAN objects, exist with similar frequencies in clusters and in the field. Both inside and outside Virgo, the frequency of AGNs found in this work is higher than the percentage found by Marziani et al. (2017) in the WINGS survey (Fasano et al. 2006) and by B04 in the SDSS. However, after inspection of the individual AGN spectra in this work (prior and after the GANDALF correction) we found that the classification of 4 out of 26 AGN spectra is highly uncertain, making the above difference insignificant.

5) B15 computed the SFR for the HRS galaxies. Thirty-eight of these are also part of B04. The SFR derived from the global measurements (both spectroscopic and imaging) for this set of 38 HRS galaxies is inconsistent with the value obtained by B04 with his aperture-corrected method: the former being in most cases two orders of magnitude larger than the values of B04. This confirms previous results by Richards et al. (2016) who tested the B04 method for 1212 galaxies belonging to the SAMI Galaxy survey (Croom et al. 2012). Richards et al. (2016) conclude that the nuclear spectrum is not representative of the properties of the entire galaxy, mainly because of the different dust content: \( \text{H} \alpha/\text{Ha} \) ratio (extinction) decreases from the center towards larger radii; therefore, galaxies with different morphology require different dust attenuation corrections. Similar results have been obtained by Iglesias-Páramo et al. (2013) who confirmed that local star-forming galaxies observed through a small aperture are misclassified as quiescent if the aperture-correction method is based only on the nuclear properties, because the fraction of a galaxy covered by a fixed aperture varies with redshift. We maintain that the B04 aperture-correction method does not provide a robust extrapolation of the global SFR for local galaxies (\( z < 0.03 \)).
Appendix A: Tables description

Here we report the description of the observations at the *Cassini* telescope and the three tables which include our results. The observing log of 45 galaxies whose nuclear spectra were taken at Loiano is given in Table A.1. The spectroscopic parameters of HRS galaxies observed at Loiano only with the red-channel grism are given in Table A.2. The spectroscopic parameters of 25 HRS galaxies observed at Loiano with the red and blue-channel grism are given in Table A.3. The spectroscopic parameters derived for all HRS galaxies are given in Table A.4.

### Table A.1. Galaxies observed at the Cassini Telescope.

| HRS | Alpha (hh:mm:ss) | Delta (dd:mm:ss) | PA (deg) | Blue | Obs date yyyy-mm-dd | Ncomb | expT sec | Red | Obs date yyyy-mm-dd | Ncomb | expT sec |
|-----|------------------|------------------|----------|------|---------------------|-------|----------|-----|---------------------|-------|----------|
| 2*  | 102 057.13       | +252 153.4       | 30       |      | 2017-04-20          | 3     | 480      |     | 2013–2017           | 6     | 300      |
| 9   | 103 255.45       | +283 042.2       | 90       |      | 2017-04-20          | 3     | 480      |     | 2015-03-20          | 3     | 180      |
| 28* | 105 420.89       | +271 423.1       | 90       |      | 2015-03-20          | 3     | 180      |     | 2009–2017           | 9     | 300      |
| 32* | 105 448.63       | +173 716.4       | 90       |      | 2017-04-21          | 3     | 480      |     | 2009–2013           | 6     | 300      |
| 33* | 110 002.38       | +145 029.7       | 90       |      | 2009–2017           | 15    | 300      |     | 2009–2017           | 9     | 240      |
| 38* | 110 656.63       | +071 026.1       | 90       |      | 2009–2013           | 6     | 300      |     | 2015-03-23          | 4     | 180      |
| 45  | 111 921.60       | +574 527.8       | 90       |      | 2015-04-14          | 3     | 360      |     | 2012-03-15          | 3     | 360      |
| 51* | 112 345.53       | +174 907.2       | 90       |      | 2017-04-20          | 3     | 480      |     | 2015–2017           | 6     | 300      |
| 52* | 112 355.58       | +525 515.6       | 90       |      | 2017-04-21          | 3     | 480      |     | 2015–2017           | 6     | 300      |
| 58  | 112 809.41       | +165 513.7       | 90       |      | 2010–2013           | 6     | 300      |     | 2015–2017           | 6     | 300      |

Notes. Columns are: (1): HRS name; (2) and (3): J2000 Celestial coordinates; (4): Position Angle (PA) of the slit with respect to N (counterclockwise); (5): Observing date (blue grism); (6): Number of exposures (blue grism); (7): Exposure time (in seconds) of the individual exposures (blue grism); (8): Observing date (red grism); (9): Number of exposures (red grism); (10): Exposure time (in seconds) of the individual exposures (red grism). An asterisk marks galaxies whose red spectrum was published in Gavazzi et al. (2011) or Gavazzi et al. (2013). The spectrum of HRS110 is a combination of a red spectrum taken at Loiano and a blue spectrum from the SDSS (DR7), whose red part near $H\alpha$ was damaged.
### Table A.2. Derived spectroscopic parameters for galaxies observed at Loiano with red-channel grism.

| HRS | Mass $M_*$ [M$_\odot$] | $g - i$ | $[\text{H}\alpha_{corr}]$ | $[\text{H}\alpha]$ | $[\text{II}](6583)$ | rms | WHAN |
|-----|------------------------|--------|----------------|--------------|----------------|-----|------|
|     | (1)                    | (2)    | (3)            | (4)          | (5)            | (6) | (7)  |
| 9   | 10.08                  | 1.081  | 1.82           | 3.51         | 3.12           | 0.04| wAGN |
| 32  | 9.46                   | 1.044  | 1.91           | -0.28        | 1.63           | 0.97| HII  |
| 38  | 9.1                    | 0.572  | 2.25           | 13.1         | 15.35          | 4.00| HII  |
| 45  | 10.25                  | 1.248  | 1.82           | 0.23         | 2.05           | 1.70| HII  |
| 52  | 9.11                   | 0.933  | 1.91           | 3.63         | 5.54           | 2.34| HII  |
| 58  | 8.94                   | 0.661  | 2.44           | 3.89         | 6.33           | 1.99| HII  |
| 77  | 10.54                  | 0.938  | 1.82           | 0.68         | 2.5            | 1.36| HII  |
| 84  | 9.39                   | 0.851  | 1.91           | -0.28        | 1.63           | 1.87| HII  |
| 124 | 9.52                   | 0.732  | 2.25           | 4.96         | 7.21           | 0.18| HII  |
| 134 | 9.96                   | 0.797  | 2.25           | -1.12        | 1.13           | 0.11| HII  |
| 164 | 9.91                   | 1.061  | 1.91           | -1.48        | 0.43           | 0.02| HII  |
| 171 | 9.69                   | 0.75   | 2.25           | 14.92        | 17.17          | 5.07| HII  |
| 185 | 10.06                  | 1.171  | 1.82           | -2.61        | -0.79          | 0.91| RET  |
| 249 | 9.01                   | 0.688  | 2.25           | 1.86         | 4.11           | 1.63| HII  |
| 258 | 11.1                   | 1.12   | 1.82           | -0.31        | 1.51           | 0.06| HII  |
| 270 | 10.93                  | 1.151  | 1.82           | -2.27        | -0.36          | 0.14| RET  |
| 282 | 9.3                    | 1.055  | 1.91           | -2.13        | 1.13           | 0.05| HII  |
| 289 | 10.31                  | 0.281  | 0.49           | 5.322        | 5.81           | 2.26| HII  |
| 291 | 9.86                   | 1.075  | 1.91           | -1.22        | 0.69           | 0.51| RET  |

**Notes.** Columns are: (1): HRS name; (2): log of stellar mass $M_*$; (3): $g - i$ color index; (4): Continuum correction to $[\text{H}\alpha]$; (5): Observed $[\text{H}\alpha]$; (6): Corrected $[\text{H}\alpha]$; (7): Observed $[\text{II}](6583)$; (8): Nuclear spectral classification (from WHAN).

### Table A.3. Derived spectroscopic parameters for galaxies observed at Loiano with red and blue channel grisms.

| HRS | $[\text{H}\alpha]$ Å | $[\text{H}\alpha_{corr}]$ Å | $\text{[OIII]}/\text{H}\beta$ | $\text{[NII]}/\text{H}\alpha$ | BPT | WHAN |
|-----|----------------------|-----------------------------|-----------------|-----------------|-----|------|
|     | (1)                  | (2)                         | (3)             | (4)             | (5) | (6)  |
| 2   | 25.78                | 1.56                         | 27.34           | 0.40            | 0.33| HII  |
| 28  | 7.63                 | 1.35                         | 8.98            | 0.58            | 0.34| HII  |
| 33  | 9.93                 | 1.55                         | 11.49           | 0.61            | 0.45| HII  |
| 51  | 30.81                | 2.01                         | 32.82           | 0.58            | 0.29| HII  |
| 65  | 10.98                | 1.86                         | 12.84           | 0.89            | 0.25| HII  |
| 86  | 88.48                | 2.34                         | 90.83           | 0.58            | 0.25| HII  |
| 98  | 24.54                | 1.86                         | 26.40           | 0.77            | 0.25| HII  |
| 108 | 24.30                | 1.79                         | 26.09           | 0.19            | 0.27| HII  |
| 110 | 57.05                | 1.75                         | 58.80           | 1.43            | 0.17| HII  |
| 118 | 22.14                | 1.77                         | 23.91           | 1.63            | 0.17| HII  |
| 132 | 30.36                | 2.76                         | 33.12           | 2.66            | 0.16| HII  |
| 148 | 47.51                | 1.83                         | 49.34           | 0.8             | 0.23| HII  |
| 153 | 17.03                | 1.52                         | 18.55           | 0.29            | 0.33| HII  |
| 188 | 13.98                | 1.96                         | 15.94           | 0.41            | 0.31| HII  |
| 189 | 18.17                | 1.74                         | 19.91           | 0.61            | 0.27| HII  |
| 230 | 12.77                | 1.71                         | 14.48           | 1.86            | 0.3 | TR  |
| 232 | 16.90                | 1.89                         | 18.79           | 0.23            | 0.3 | HII |
| 239 | 26.97                | 1.44                         | 28.42           | 0.41            | 0.39| HII  |
| 253 | 48.64                | 1.24                         | 49.88           | 3.0             | 0.28| HII  |
| 259 | 31.36                | 2.05                         | 33.41           | 0.23            | 0.41| HII  |
| 266 | 22.78                | 2.34                         | 25.12           | 1.04            | 0.18| HII  |
| 267 | 13.71                | 2.07                         | 15.78           | 1.81            | 0.29| HII  |
| 298 | 10.63                | 1.67                         | 12.31           | 0.95            | 0.34| HII  |
| 302 | 15.85                | 1.97                         | 17.83           | 0.59            | 0.33| HII  |
| 303 | 55.10                | 1.95                         | 57.05           | 0.53            | 0.34| HII  |
| 313 | 6.36                 | 1.41                         | 7.76            | 0.12            | 0.45| HII  |

**Notes.** Columns are: (1): HRS name; (2): Continuum correction to $[\text{H}\alpha]$; (3): Observed $[\text{H}\alpha]$; (4): Corrected $[\text{H}\alpha]$; (5): $\text{[OIII]}/\text{H}\beta$; (6): $\text{[NII]}/\text{H}\alpha$; (7): Nuclear classification using the BPT ($\text{[NII]}/\text{H}\alpha$) diagram; (8): Nuclear classification using the WHAN diagram.

A104, page 12 of 17
## Table A.4: Derived spectroscopic parameters of a sample of 35 HRS galaxies

| HRS Ref | EW Hα (Å) | [OIII]/Hβ | [NII]/Hα | [SII]/Hα | BPT Classification | WHAN Classification | Nuclear EW Hα (Å) | [OIII]/Hβ | [NII]/Hα | [SII]/Hα | BPT Classification | WHAN Classification |
|---------|-----------|-----------|----------|----------|-------------------|---------------------|--------------------|-----------|----------|----------|-------------------|---------------------|
| 1       | 1         | 18.25     | 0.41     | 0.37     | HII               | HII                 | 1 (1)              | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 2       | 1         | 30.05     | 0.41     | 0.32     | HII               | HII                 | 1 (1)              | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 3       |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 4       | 1a        | 10.88     | 3.12     | 0.39     | AGN               | SEY                 | sAGN               | (6)       | (7)      | (8)      |                   |                     |
| 5       | 1         | 6.18      | -        | -0.89    | (PAS)             | (PAS)               | sAGN               | (6)       | (7)      | (8)      |                   |                     |
| 6       |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 7       | 2         | –         | –        | –        | (PAS)             | (PAS)               | PAS                | (6)       | (7)      | (8)      |                   |                     |
| 8       |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 9       |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 10      | 1         | 28.36     | 0.85     | 0.24     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 11      | 1         | 20.99     | 0.54     | 0.27     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 12      | 1         | 27.96     | 1.28     | 0.18     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 13      | 1         | 16.65     | 0.20     | 0.39     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 14      |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 15      |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 16      |           |           |          |          |                   |                     |                    |           |          |          |                   |                     |
| 17      | 1         | 12.73     | 0.33     | 0.34     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 18      | 1         | 30.04     | 0.84     | 0.28     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 19      | 1         | 10.40     | 0.84     | 0.43     | AGN               | LIN                 | wAGN               | (6)       | (7)      | (8)      |                   |                     |
| 20      | 1         | 29.14     | 0.32     | 0.29     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 21      | 1         | 53.45     | 1.48     | 0.15     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 22      | 1         | 11.25     | 0.73     | 0.27     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 23      | 1         | 40.10     | 0.68     | 0.25     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 24      | 1         | 44.07     | 2.19     | 0.11     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 25      | 1         | 22.48     | 0.47     | 0.35     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 26      | 1         | 24.24     | 0.54     | 0.28     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 27      | 1         | 7.67      | 0.68     | 0.28     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 28      | 1         | 6.98      | 5.91     | 0.68     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 29      | 1         | 24.62     | 0.46     | 0.35     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 30      | 1         | 26.63     | 1.14     | 0.37     | HII               | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 31      | 1         | 11.49     | 0.61     | 0.45     | TR                | HII                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 32      | 1         | 43.15     | 7.38     | 1.22     | AGN               | SEY                 | sAGN               | (6)       | (7)      | (8)      |                   |                     |
| 33      | 1         | 293.92    | 4.75     | 0.12     | TR                | SEY                 | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |
| 34      | 1         | 3.51      | -        | -0.89    | –                  | –                   | wAGN               | (6)       | (7)      | (8)      |                   |                     |
| 35      | 1b        | 9.97      | 0.14     | 0.42     | HII               | –                   | HII                | (1)       | (2)      | (3)      | (4)               | (5)                 |

Notes: Columns (1): HRS name; (2): Reference to the integrated spectrum: 1: B15; 2: Kennicutt (1992); (3): Integrated Hα EW, corrected for continuum absorption according to GANDALF; (4): Integrated [OIII]/Hβ; (5): Integrated [NII]/Hα; (6): Integrated [SII]/Hα; (7): Integrated classification using the BPT ([NII]/Hα and [SII]/Hα) diagrams; (8): Integrated classification using the WHAN diagram; (9): Reference to the nuclear spectroscopy: 3: this work or Gavazzi et al. (2013); 4: SDSS DR13 or DR12 (Albareti et al. 2017); 5: Ho et al. (1997); 6: Jones et al. (2009); 7: Veilleux et al. (1995); 8: Jansen et al. (2000); 9: Falco et al. (1999). Columns (2)-(8) refer to integrated spectra, Cols. (9)-(15) to nuclear spectra. In Cols. (6) and (12) the classification "(PAS)" is added to galaxies whose spectra do not contain Hα, [NII], [OIII], Hβ, [SII](6716Å), and [SII](6731Å) in emission. In Cols. (7) and (14), two BPT classifications are reported: the first spectral type is from the BPT with [NII]/Hα ratio, the second is from the BPT with [SII]/Hα ratio. The full catalog is available at the CDS in the electronic form.
Fig. A.1. Spectra taken at Loiano with the blue and red grisms covering approximately from 4500 to 7500 Å. The spectra have been Doppler shifted to rest frame and normalized to the flux in the interval 6400–6500 Å. The vertical broken lines mark the rest-frame position of Hβ λ4861; [OIII] λ4958; [OIII] λ5007; [NII] λ6549; Hα λ6563; [NII] λ6584; [SII] ~ λ6717; [SII] ~ λ6731.
Fig. A.1. continued.
Fig. A.1: Spectra taken at Loiano with the blue and red grisms covering approximately from 4500 to 7500 Å. The spectra have been Doppler shifted to rest frame and normalized to the flux in the interval 6400-6500 Å. The vertical broken lines mark the rest-frame position of $\lambda_{\mathrm{H\beta}}$, $\lambda_{\mathrm{[OIII]}}$, $\lambda_{\mathrm{[NII]}}$, $\lambda_{\mathrm{H\alpha}}$, $\lambda_{\mathrm{[NII]}}$, $\lambda_{\mathrm{[SII]}}$, $\lambda_{\mathrm{[SII]}}$. 

Fig. A.1. continued.
Fig. A.2. Unpublished HRS spectra taken at Loiano in 2015 with the red grism. They cover approximately from 6200 to 7200 Å. The spectra have been Doppler shifted to rest frame and normalized to the flux in the interval 6400–6500 Å. The vertical broken lines mark the rest-frame position of [NII] λ6549; Hα λ6563; [NII] λ6584; [SII] ∼λ6717; [SII] ∼λ6731. Similar red-grism spectra taken prior to 2015 are already published in Gavazzi et al. (2011, 2013).