Red-channel (6000-8000 Å) nuclear spectra of 376 local galaxies  

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ABSTRACT

We obtained long-slit optical spectra of the nuclear regions of 376 galaxies in the local Universe using the 1.5m Cassini telescope of Bologna Observatory. Of these spectra, 164 were either never taken before by the Sloan Digital Sky Survey (SDSS), or given by the Nasa Extragalactic Database (NED). With these new spectra, we contribute investigating the occurrence of active galactic nuclei (AGNs). Nevertheless, we stress that the present sample is by no means complete, thus, it cannot be used to perform any demographic study. Following the method presented in Gavazzi et al (2011), we classify the nuclear spectra using a six bin scheme: SEY (Seyfert), sAGN (strong AGN), and wAGN (weak AGN) represent active galactic nuclei of different levels of activity; HII accounts for star-forming nuclei; RET (retired) and PAS (passive) refer to nuclei with poor or no star-formation activity. The spectral classification is performed using the ratio of $\lambda$ 6584 [NII] to H$\alpha$ lines and the equivalent width (EW) of H$\alpha$ versus [NII]/H$\alpha$ (WHAN diagnostic introduced by Cid Fernandes and collaborators) after correcting H$\alpha$ for underlying absorption. The obtained spectra are made available in machine readable format via the Strasbourg Astronomical Data Center (CDS) and NED.

Key words. Galaxies: active; Galaxies: nuclei; Galaxies: Seyfert

1. Introduction

The advent of the Sloan Digital Sky Survey (SDSS, York et al. 2000) revolutionized the course of astronomy at the turn of the millennium. However some residual incompleteness remains in the SDSS spectroscopic database, especially at the bright luminosity end, due to shredding of the large galaxies and fiber conflict (Blanton et al. 2005a,b,c). Mitigating this problem is a task that even 1.5m class telescopes can contribute to. With this idea, we decided to continue the spectroscopic project that began in 2005 at the Loiano Observatory (Gavazzi et al. 2011) with an aim at searching for previously unknown optically selected active galactic nuclei (AGNs) in the local Universe I. In 2012-2013, we obtained 127 new nuclear spectra, bringing the total number of galaxies independently observed to 376. These are spectra taken with the red-channel of the spectrograph, namely between 6000 and 8000 Å. Since nuclear spectra of about half these galaxies were neither obtained by SDSS nor distributed by NED, we provide our new observations to NED in order to make them publicly available in FITS (Flexible Image Transport System) format.

The classification of AGNs based on optical nuclear spectra is routinely (eg. Decarli et al. 2007, Reines et al. 2013) performed using the BPT (Baldwin, Phillips & Terlevich) diagnostic diagram (Baldwin et al. 1981), which requires the measurement of four spectral lines: Hβ, [OIII], Hα, and [NII]. General AGNs are disentangled from nuclear starbursts using the ratio [NII]/H$\alpha$ (where H$\alpha$ must be corrected for any underlying stellar absorption, as stressed by Ho et al. 1997), while strong AGNs (sAGN) can be separated from the weaker (weak AGNs or wAGN) LINERs (Low-Ionization Nuclear Emission-Line Region) using the ratio [OIII]/H$\beta$. However a recent two-line diagnostic diagram named WHAN, which is based on the [NII]/H$\alpha$ ratio combined with the strength of the H$\alpha$ line was introduced by Cid Fernandes et al. (2010, 2011) to disentangle strong and weak AGNs, believed to be triggered by supermassive black holes from “fake AGNs”, dubbed as retired galaxies, whose ionization mechanism is probably provided by their old stellar population (Trinchieri & di Serego Alighieri 1991, Binette et al. 1994, Macchetto et al. 1996, Sarzi et al. 2010, Capetti & Baldi 2011). For a nucleus to be considered ionized by a central black hole, it is necessary that the equivalent width (hereafter EW) of H$\alpha$ exceeds 3 Å (Cid Fernandes et al. 2010, 2011). This quantitative threshold has been, however, questioned by Gavazzi et al. (2011), who adopted EWH$\alpha \geq 1.5$ Å.

Given the two-line WHAN diagnostic diagram, the red-channel spectra presented in this work can contribute to increas-
ing the number of known AGNs, especially those associated with nearby bright galaxies, most affected by the residual incompleteness of the SDSS spectral database. Nevertheless we reiterate that the present sample is not complete by any means, thus inadequate to perform any demographic study.

The outline of this paper is as follows. In Section 2 we describe the galaxy sample. In Section 3 we illustrate the observations taken at the Loiano observatory and the data reduction procedures. The nuclear spectra are given and classified in Section 4. In Section 5 we outline the fitting method applied to broad-line systems.

2. The sample

This paper is based on a miscellaneous set of 376 northern galaxies visible in spring, which is not complete by any means, and therefore not useful for performing any statistical study. They comprise of well-known bright local galaxies within $z_c = 10000$ km/s, most of which have a nuclear spectrum already available from the literature, mixed with fainter previously unobserved objects. The latter were mainly selected from the Coma and Local superclusters (RA $\sim$ 180 deg, see Figure 1) for not having a nuclear spectrum available from SDSS or for the being unavailable, in either ASCII or FITS form, in the nuclear optical spectra from NED. Figure 2 (top) illustrates the r-band absolute magnitude distribution of the selected galaxies, showing a dramatic lack of objects fainter than -20 mag with respect to to those predicted by the r-band luminosity function (e.g. Blanton et al. 2003). Figure 2 (bottom) highlights the preferential membership of the selected targets to the Coma supercluster ($V \sim 7000$ km/s) and the Virgo cluster and its surroundings ($V \sim 1000$ km/s).

Fig. 1. Distribution in celestial coordinates of the 376 galaxies for which we obtained a nuclear spectrum. Color coding is as follows: available fiber spectra from SDSS (#86, green); available nuclear spectra from NED (#162, blue); available spectra from both SDSS and NED (#36, cyan); and newly obtained spectra from this work (#164, red).

Fig. 2. Histograms of the absolute magnitudes (r-band and other bands mixed together) (top panel) and of the heliocentric recessional velocities (bottom panel) of the 376 studied galaxies.

3. Observations and data reduction

We used the Bologna faint object spectrograph and camera (BFOSC, Gualandi & Merighi 2001) attached to the 152cm F/8 Cassini Telescope located in Loiano, which belongs to the Observatory of Bologna, to obtain optical spectra of the nuclei of 376 galaxies. The observations took place from 2005 to 2013 (see Table I). The long-slit spectra were taken through a slit of 2 or 2.5 arcsec width (depending on the seeing conditions), with an intermediate-resolution red-channel grism ($R \sim 2200$) that covers the 6100 - 8200 Å portion of the spectrum, which contains Hα, [NII], and [SII] lines (three galaxies were observed also using a blue-channel grism covering Hβ and [OIII], as shown in Figure 5). The detector used by BFOSC is an EEV LN/1300-EB/1 CCD of 1300x1340 pixels, with 90% quantum efficiency near 5500 Å. Its spatial scale of 0.58 arcsec/pixel results in a field of view of 12.6’ × 13’. The dispersion of the red-channel grism is 8.8 nm/mm and results in spectra with 1.6 Å/pix. The instrumental broadening is typically $\sim 6$ Å full-width-half-maximum (FWHM), as checked on the 6300.3 Å sky line. We obtained exposures of 3-5 minutes, repeated typically three-six times per run (to remove the cosmic rays), but several galaxies were re-observed in more than one run (see Table II). The seeing at Loiano is typically 1.5 - 2.5 arcsec. The slit was mostly set in the E-W direction, except when it was positioned along the galaxy major axis or along the direction connecting two adjacent objects to accommodate both objects in one exposure. The wavelength was calibrated using frequent exposures of a He-Ar hollow-cathode lamp. We used several sky lines to check a posteriori the wavelength calibration. The spectrograph response was obtained by daily exposures of the star Feige-34.

The spectra were reduced using the IRAF-STSDAO packages, following reduction procedures identical to Gavazzi et al.

2 Except for 162, all 376 galaxies in our sample have a redshift from NED. This does not necessarily mean that an optical nuclear spectrum is distributed by NED for all of them.

3 IRAF is the Image Analysis and Reduction Facility made available to the astronomical community by the National Optical Astronomy

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ments of the EW and FWHM of the broad and narrow emissions provide a measure of the strength of the Hα line. In short, the WHAN classification scheme is based on the presence of strong telluric absorption near Hα, transformed to rest-frame velocity using the redshift provided by NED, and measured to obtain the intensity and EW of the Hα and [NII] lines.

The presence of a strong telluric absorption feature near 6866 Å hampers the detection of [SII] lines at redshift near z_c = 6000 ~ 7000 km s^{-1}. Therefore, these lines are not analyzed. In the presence of broad permitted lines, the measurements of the EW and FWHM of the broad and narrow emission lines were obtained using the fitting procedure discussed in Section 3.

4. Spectral classification

The classification of the nuclear activity based on optical spectra was performed following the methods of Gavazzi et al. (2011) based on the WHAN diagram (Cid Fernandes et al. 2010, 2011). In short, the WHAN classification scheme is based on the strength of the Hαcorr line (Hα, corrected for underlying stellar absorption, Ho et al. 1997) and the ratio between the flux of [NII] and Hαcorr. As in Gavazzi et al. (2011), we adopt a mean underlying stellar absorption at Hα of 1.3 Å, irrespective of luminosity. Figure 3 shows the WHAN diagram with the six adopted spectral classification thresholds. These thresholds (whose detailed description can be obtained from Gavazzi et al. 2011) allow to separate HII region-like nuclei (marked HII in Table 1) from strong AGNs (sAGN), weak AGNs or LINERS (wAGN), and fake AGNs (dubbed as "retired nuclei" or RET whose ionization mechanism is provided by their old stellar population). Passive nuclei (PAS) display no star formation activity. Their spectra show either Hαcorr in absorption or undetected [NII].

Table 1. Log of the observations at Loiano. Two new-moon periods of four nights were allocated to the present project per year. We list information for the useful nights. In total, we obtained 422 spectra of 376 independent galaxies. That is, several objects were repeatedly observed during different runs. In these cases, Table 3 and Figure 4 describe the combined spectra (labeled L00).

Four Seyfert 1 galaxies are classified by visual inspection of the individual spectra for the presence of broad permitted lines (see Section 5).

Table 3 gives the parameters of the 376 independently observed galaxies as follows:

Column 1: serial number;
Column 2: Galaxy name. The first three digits of the label give the year of observation. L00 marks those spectra that are a median of two or more spectra obtained in different runs. Then the catalog name and serial number: Arexibio galaxy catalog (AGC) (Haynes et al. 2011), SDSS (DR7, Abazajian et al. 2009); catalog of galaxies and clusters of galaxies (CGCG) (Zwicky et al. 1968), Uppsala galaxy catalog (UGC) (Nilson 1973), new galaxy catalog (NGC) (Dreyer 1888) and index catalog (IC) (Dreyer 1908), Virgo cluster catalog (VCC) (Binggeli et al. 1985), Markarian (MRK) (Markarian 1967), Herschel Reference Survey (HRS) (Boselli et al. 2010) designations;
Column 3 and 4: J2000 celestial coordinates;
Column 5: heliocentric redshift, as listed by NED;
Column 6: redshift independent distance in Mpc, as listed by NED. When this is unavailable, the galactocentric Hubble-flow distance is listed;
Column 7: r-band (AB) magnitude from SDSS when available. Otherwise, the total (Vega) magnitude in the Johnson R, V or B band (as specified in parenthesis) from NED is used;
Column 8: a cross indicates the availability of a nuclear spectrum in NED;
Column 9: a cross indicates the availability of a fiber nuclear spectrum in SDSS.

Table 4 summarizes the classification of spectra as follows:

Column 1: serial number;
Column 2: Galaxy name;
Column 3: number of individual exposures;
Column 4: duration of the individual exposures;
Column 5: slit aperture in arcsec;
Column 6: slit orientation (counterclockwise from N) in the various runs (yy);
Column 7: measured EW of λ 6548.1 [NII] line (dubbed [NII]1); negative EW values represent emission;
Column 8: measured EW of the (narrow) Hα line;
Column 9: measured EW of λ 6583.6 [NII] line (dubbed [NII]2);
Column 10: R.M.S noise of the individual spectra determined between 6400 and 6500 Å;
Column 11: six bins nuclear activity classification.

We note that the EW and FWHM of the narrow Hα and of the two [NII] lines in Seyfert 1 galaxies have been computed applying the procedure described in Sect. 5 to consider the underlying broad Hα component. Adding all 160 spectra of HII-like nuclei, we obtain a template spectrum with a high signal-to-noise ratio (2370 at Hα). A ratio of [NII]6583/[NII]6548 ~ 3.11 is obtained, which is consistent with the theoretical value of 3.0 obtained by Osterbrock & Ferland (2006).

5. Broad line measurements

Four (L09 UGC-1935, L12 MRK-0079, L11 NGC-3758E, and L13 MRK-0841) of the 376 galaxies show the presence of a broad Hα line. To properly estimate the EW and FWHM of these broad lines and of the narrow Hα and [NII] lines, both the broad and narrow components have to be fit at the same time. We perform a very simple minimum χ-square fit, assuming that the underlying continuum follows a power-law profile and that every single broad and narrow line is well described by a single Gaussian profile. As a disclaimer, we note that the FWHM of the...
broad Hα lines can be slightly affected by a poor treatment of the underlying continuum, which does not include any specific galactic feature and where the very low flux tails of the lines are not fitted as well as possible by assuming two broad Gaussian, a Lorentzian, or a Voigt profile. The EW is almost unaffected by these small approximations. A high precision measurement of the FWHM of the broad Hα is beyond the scope of this analysis.

The fitting procedure has a total of nine free parameters: two describe the power-law continuum, four are related to the narrow [NII] and Hα lines, and three describe the broad Hα line. More specifically, these include:

- the normalization and exponent of the power low continuum;
- the three normalizations of the narrow Hα and [NII] lines and their FWHM, which are assumed to be the same for every narrow line;
- the normalization, FWHM, and peak frequency of the broad Hα line. We let the peak frequency vary to best fit the line profile, although no significant shifts have been found.

The numerical values of the FWHM and EW obtained for the broad lines are reported in Table 2. For these four Seyfert 1 galaxies, the full fits with the fits of only the broad component are superimposed to the original spectra in Figure 6.

Table 2. Broad Hα line measurements.

| Obj         | EW Hα | FWHM  |
|-------------|-------|-------|
| L09 UGC-1935 | -178.2 | 3480  |
| L12 MRK-0079 | -297.7 | 3706  |
| L11 NGC-3758E| -128.0 | 3426  |
| L13 MRK-0841 | -408.3 | 5042  |

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Table 3. General parameters for a representative sample of 20 galaxies. L00 means that spectra taken in more than one year were combined. The full set of 376 measurements is available in electronic form at the CDS.

| ID  | Obj         | RA       | Dec       | z    | Dist  | r   | NED | SDSS |
|-----|-------------|----------|-----------|------|-------|-----|-----|------|
| (1) | (2)         | (3)      | (4)       | (5)  | (6)   | (7) | (8) | (9)  |
| 1   | L11-M33-HII | 01:34:33.19 | +30:47:00.4 | -0.000597 | 0.88  |
| 2   | L05-CGCG-522-004 | 01:47:16.15 | +35:33:47.9 | 0.015591 | 78.3  |
| 3   | L05-CGCG-522-093 | 01:58:35.20 | +38:43:06.8 | 0.016878 | 71.2  |
| 4   | L05-CGCG-522-104 | 02:00:59.71 | +38:47:04.7 | 0.018880 | 79.4  |
| 5   | L11-NGC-0784  | 02:01:16.93 | +28:50:14.1 | 0.000660 | 4.62  |
| 6   | L05-CGCG-522-106 | 02:03:44.83 | +38:15:31.4 | 0.019227 | 62.3  |
| 7   | L09-NGC-0891  | 02:22:33.41 | +42:20:56.9 | 0.001761 | 10.2  |
| 8   | L00-NGC-0925  | 02:27:16.88 | +33:34:45.0 | 0.013845 | 8.57  |
| 9   | L09-UGC-1935  | 02:28:14.47 | +31:18:41.9 | 0.016652 | 52.3  |
| 10  | L00-NGC-1068 | 02:42:40.71 | +00:00:47.8 | 0.003793 | 13.5  |
| 11  | L00-NGC-1275 | 03:19:48.16 | +41:30:42.1 | 0.017559 | 68.2  |
| 12  | L09-UGC-2855 | 03:48:20.73 | +70:07:58.4 | 0.004003 | 17.1  |
| 13  | L11-NGC-1507 | 04:04:27.21 | +02:11:18.9 | 0.002879 | 11.1  |
| 14  | L11-NGC-1569 | 04:30:49.05 | +64:50:52.6 | -0.000347 | 2.89  |
| 15  | L11-NGC-1637 | 04:41:28.17 | -02:51:28.6 | 0.002392 | 10.7  |
| 16  | L06-NGC-1961 | 05:42:04.64 | +69:22:42.3 | 0.013122 | 55.6  |
| 17  | L13-UGC-3343 | 05:45:24.64 | +72:21:22.4 | 0.003636 | 18.8  |
| 18  | L12-NGC-2146 | 06:18:37.71 | +78:21:25.3 | 0.002979 | 22.4  |
| 19  | L07-NGC-2273 | 06:50:08.65 | +60:50:44.9 | 0.006138 | 30.9  |
| 20  | L13-UGC-3691 | 07:08:01.28 | +15:10:42.3 | 0.007348 | 36.5  |

Table 4. Observed line-parameters for a representative sample of 20 galaxies. The full set of 376 measurements is available in electronic form at the CDS.

| ID  | Obj         | N | Temp | ap | PA | EW[NII] | EW[Hα] | EW[NII] | rms |
|-----|-------------|---|------|----|----|---------|---------|---------|-----|
| (1) | (2)         | (3) | (4)  | (5) | (6) | (7)     | (8)     | (9)     | (10)|
| 1   | L11-M33-HII | 3 | 180  | 2.0 | 90 | -35.86  | -131.4  | -125.6  | 0.09 |
| 2   | L05-CGCG-522-004 | 1 | 600  | 2.0 | 30 | -0.53   | -0.49   | -2.92   | 0.04 |
| 3   | L05-CGCG-522-093 | 1 | 600  | 2.0 | 120| -2.42   | -9.18   | -5.84   | 0.19 |
| 4   | L05-CGCG-522-104 | 3 | 900  | 2.0 | 90 | -2.32   | -13.39  | -8.11   | 0.11 |
| 5   | L11-NGC-0784 | 4 | 300  | 2.0 | 0  | -       | -86.6   | -       | 0.25 |
| 6   | L05-CGCG-522-106 | 3 | 600  | 2.0 | 150| -0.69   | -3.23   | -3.05   | 0.04 |
| 7   | L09-NGC-0891 | 3 | 300  | 2.5 | 90 | -3.94   | -36.45  | -15.47  | 0.35 |
| 8   | L00-NGC-0925 | 7 | 300  | 2.0 | 85 (09,13) | -2.73 | -45.23  | -11.88  | 0.14 |
| 9   | L09-UGC-1935 | 3 | 420  | 2.0 | 74 | -17.60  | -21.6   | -17.0   | 0.04 |
| 10  | L00-NGC-1068 | 4 | 470  | 2.0 | 90 (10,11) | -67.30 | -111.2  | -209.1  | 0.01 |
| 11  | L00-NGC-1275 | 6 | 300  | 2.0 | 90 (12,13) | -43.25 | -71.56  | -78.51  | 0.04 |
| 12  | L09-UGC-2855 | 3 | 300  | 2.0 | 105| -2.69   | -23.55  | -11.48  | 0.12 |
| 13  | L11-NGC-1507 | 4 | 180  | 2.0 | 10 | -3.60   | -79.16  | -8.82   | 0.13 |
| 14  | L11-NGC-1569 | 2 | 180  | 2.0 | 90 | -       | -116.1  | -3.28   | 0.03 |
| 15  | L11-NGC-1637 | 2 | 300  | 2.0 | 10 | -7.53   | -37.21  | -23.05  | 0.03 |
| 16  | L06-NGC-1961 | 3 | 300  | 2.0 | 90 | -6.05   | -10.01  | -19.20  | 0.01 |
| 17  | L13-UGC-3343 | 3 | 360  | 2.5 | 79 | -3.74   | -71.86  | -9.31   | 0.17 |
| 18  | L12-NGC-2146 | 3 | 300  | 2.0 | 90 | -7.94   | -53.66  | -24.78  | 0.04 |
| 19  | L07-NGC-2273 | 1 | 180  | 2.0 | 90 | -8.89   | -29.57  | -27.93  | 0.04 |
| 20  | L13-UGC-3691 | 3 | 600  | 2.5 | 63 | -       | -8.71   | -4.38   | 0.23 |
Fig. 4. Red restframe-spectra (from 6100 Å to 7300 Å) obtained with the red-channel grism in this work, normalized to the continuum near 6400 Å. The vertical dashed lines give the position of $[\text{NII}]_{6548}$, $\text{H} \alpha$ ($\lambda 6562.8$), $[\text{NII}]_{6583}$, $[\text{S} \text{II}]_{6717}$, $[\text{S} \text{II}]_{6731}$. The first three digits of the label give the year of observation. L00 marks those spectra that are a median of two or more spectra obtained in different runs. Galaxies are listed in order of catalog names. A representative sample of 12 spectra is shown. The full set of 376 spectra is available in electronic form at the CDS.
Fig. 5. Spectra obtained with the blue- and red-channel grisms normalized to the continuum near 6400 Å.

Fig. 6. Spectra of the four Seyfert 1 galaxies in the sample. The black lines refer to the original spectra. The red lines show the full fit (continuum + broad+narrow lines), while the blue lines highlight the contribution of the broad Hα component.