Spectral properties of the narrow-line region in Seyfert galaxies selected from the SDSS-DR7

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ABSTRACT
Although the properties of the narrow-line region (NLR) of active galactic nuclei (AGN) have been deeply studied by many authors in the past three decades, many questions are still open. The main goal of this work is to explore the NLR of Seyfert galaxies by collecting a large statistical spectroscopic sample of Seyfert 2 and Intermediate-type Seyfert galaxies having a high signal-to-noise ratio in order to take advantage of a high number of emission-lines to be accurately measured.

2153 Seyfert 2 and 521 Intermediate-type Seyfert spectra were selected from Sloan Digital Sky Survey - Data Release 7 (SDSS-DR7) with a diagnostic diagram based on the oxygen emission-line ratios. All the emission-lines, broad components included, were measured by means of a self-developed code, after the subtraction of the stellar component. Physical parameters, such as internal reddening, ionization parameter, temperature, density, gas and stellar velocity dispersion were determined for each object. Furthermore, we estimated mass and radius of the NLR, kinetic energy of the ionized gas, and black-hole accretion rate.

From the emission-line analysis and the estimated physical properties, it appears that the NLR is similar in Seyfert 2 and Intermediate-Seyfert galaxies. The only differences, lower extinction, gas kinematics in general not dominated by the host galaxy gravitational potential and higher percentage of \([\text{O}\text{ III}]\lambda 5007\) blue asymmetries in Intermediate-Seyfert can be ascribed to an effect of inclination of our line of sight with respect to the torus axis.

Key words: galaxies: Seyfert – techniques: spectroscopic – methods: statistical

1 INTRODUCTION
Seyfert galaxies are characterized by a bright star-like nucleus, whose spectrum shows emission-lines covering a wide range of ionization stages. The main components of a Seyfert nucleus are: a central source, the broad-line region (BLR), a molecular dusty torus, the narrow-line Region (NLR) and a possible extended NLR (ENLR).

The BLR has a typical sub-parsec size and it is surrounded by an optically thick torus of dust. The NLR is characterized by low density clouds ($N_e \sim 10^2 - 10^6$ cm$^{-3}$), temperature $T_e \sim 10^4$ K, size $\sim 1$ kpc and full-width at half maximum (FWHM) of the emission-lines in the range $\sim 200$–$1000$ km s$^{-1}$. The torus confines the escaping ionizing radiation into two oppositely directed cones (see e.g. Storchi-Bergmann, Mulchaey, & Wilson 1992, Kriss et al. 1997, Pogge & De Robertis 1993, Capetti et al. 1993, Tsvetanov & Walsh 1992, Ferruit et al. 1999, Miyaji, Wilson, & Perez-Fournon 1999). Inside the cones, the gas is directly ionized by a non-thermal power-law spectrum from the central source, even if the presence of shocks (Dopita & Sutherland 1995) and photoionization by star-forming regions close to the nucleus (composite galaxies, Hill et al. 1999) cannot be excluded. This model, called Unified Model and based on the spectropolarimetric analysis of NGC 1068, performed by Antonucci & Miller (1985), is the most accepted active galactic nuclei (AGN) picture (Antonucci 1993). The Unified Model is able to explain the main different characteristics of Seyfert 1 and Seyfert 2 galaxies. In the first case, the torus is seen face on, then the BLR is directly observable, in the second case, the line of sight intercepts the torus and the BLR is not visible. Deep CCD images of few nearby galaxies made through narrow band interference filters revealed an extended structure very rich of gas clouds surrounding the active nucleus (Pogge 1988, 1989, Tadhunter & Tsvetanov 1981). According to Schmitt & Kinney (1994) Seyfert 1 galaxies seem to have NLRs with a much smaller size than
those of Seyfert 2 if observed along the torus axis. But
Kraemer et al. (1998) stressed that this cannot be explained
by a simple orientation effect and that NLRs of Seyfert 1
are physically compact. However, Schmitt et al. (2003)
showed that both Seyfert types have similar distributions
of NLR sizes, and elongated shapes are observed more
frequently in Seyfert 2 than in Seyfert 1, whose emission
is more concentrated toward the nucleus. These results are
in agreement with the Unified Model if we assume that the
NLR gas has a disk-like distribution. With the advent of the
Hubble Space Telescope (HST), it was possible to observe
that ionization cones (Afanasiev et al. 2007; Wilson [1997,
and references therein) are in many cases closely associated
with radio jets and lobes (Wilson & Tsvetanov 1994), and
dust lanes (Martini et al. 2003a,b).

If we accept the Unified Model, we should expect that
the spectroscopic properties of the NLR are similar in
Seyfert 2, intermediate-type Seyfert and Seyfert 1 galaxies,
with an increasing contribution from highly ionized gas
closer to the central source. Unfortunately, even in case of
high signal-to-noise spectra with good resolution, the narrow
components of the recombination emission lines in Seyfert 1
galaxies are difficult to measure, since they are included in
and hidden by the broad and bright components emitted by
the BLR. This is even harder when the application of auto-
matic fitting procedures is mandatory because of the anal-
ysis of large samples. Spectroscopic differences and similari-
 ties among Seyfert types have been found in visible spectra,
but often limited to single objects (see e.g. Kraemer et al.
1998; Fraquelli, Storchi-Bergmann, & Binette 2000), or
small samples (see e.g. Bennett et al. 2006a,b), while large
samples are very rarely studied (Zhang et al. 2008).

The aim of this work is to explore possible differences
between Seyfert 2 and Intermediate-type Seyfert galaxies,
through a detailed analysis of a large sample of Seyfert spec-
tra and taking advantage also of the weak lines, which are
too often neglected. This work is organized in five sections:
in Section 2 the selection criteria of the spectra are de-
scribed; Section 3 describes the measurements of the spectra
and their classification in Seyfert 2 and Intermediate-type
Seyfert. The emission-line analysis and the NLR physical
characteristics are dealt in Section 4 and 5 respectively. The
last section summarizes the main achievements of this work.

2 THE SPECTRA SELECTION

To build a statistical sample of Seyfert galaxies, we
decided to exploit the Sloan Digital Sky Survey -
Data Release 7 (SDSS-DR7) database (Abazajian et al.
2009). We used a diagnostic diagram (hereafter O123)
based on the [O ii]λ3727/[O ii]λ5007 (hereafter O23) and
[O i]λ6300/[O ii]λ5007 (hereafter O13) ratios. The first
ratio gives a measure of the ionization level, while the second
ratio is a tracer of the hardness of the ionizing spectrum at
large radii from the source (Shields & Filippenko 1990). Up
to now this ratio has never been employed to classify a large
number of objects. The great advantages of the O123 dia-
gram are the following: i) the oxygen lines are visible in all
AGN spectra, ii) oxygen is the only element for which three
different states of ionization exist in the visible range, iii)
the employed ratios are sensitive to the ionization parame-

ter and power-law index and are weakly dependent on the
metallicity and density, iv) they are not contaminated by
stellar spectral features, therefore it is not necessary to sub-
tract the stellar template from the original spectra before
measuring the lines, v) the lines are not contaminated by
traditional BLR, vi) and finally [O i]λ6300 (and to a lesser
extent [N ii]λ6548,6584) are more sensitive to the hard AGN
continuum compared with the stellar continuum (of Hii re-
gions). Nevertheless, this diagram has two main disadvan-
tages: the ratios are not reddening free and the [O i]λ6300
is sometimes weak and difficult to be measured especially
when the signal-to-noise ratio (S/N) of the [O i]λ6300 is
less than 10. From the SDSS-DR7 we extracted all galaxies showing
[O ii]λ3727, [O iii]λ5007, [O i]λ6300 emission-lines, but with
the constraint S/N([O i]λ6300)> 3, obtaining 119226 tar-
gets.

To check the effectiveness of oxygen spectral lines in
isolating Seyfert galaxies, we carried out a test. First, we
exploited the database of 85224 galaxies published by
Kewley et al. (2006), finding 62036 galaxies in common with
our sample. Then, we plotted the Veilleux-Osterbrock dia-
agnostic diagrams (Veilleux & Osterbrock 1987, hereafter
VO) and we used the relations given in Kewley et al. (2006)
to classify these objects as Seyfert, Low-Ionization Nuclear
Emission-line Regions (LINERS), star-forming and com-
posite Seyfert-H ii galaxies. Since the Kewley et al. (2006)
data are reddening corrected and the host galaxy spectrum is
removed, they are not directly comparable with our sample.
Therefore, we decided to extract from SDSS the spec-
troscopic information about these already classified objects
and we plotted the O123 diagram (Fig. 1). The result was
extremely encouraging: this plot shows a V-shape where
the upper side is populated by star-forming galaxies, while
the lower side is populated by Seyfert galaxies and LIN-
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Figure 2. Histogram of log(O$_{13}$) values with log(O$_{23}$) in the range [−0.1,0].

ERs, which are sufficiently separated. This diagram is not new since it was already published by Shields & Filippenko (1990) (see their fig. 13), but the areas indicated by these authors, where Seyfert galaxies, LINERs and H$_{II}$ regions are expected to be found, do not perfectly match our data.

From this diagram we derived an empirical separation line to isolate Seyfert galaxies. We sampled log(O$_{23}$) in bins of 0.1 dex, in the range [−1.2,0.3] and plotting histograms of log(O$_{13}$) in bins of 0.1 dex, we estimated the value of the minimum between the two peaks of the distributions for each bin (as shown in Fig. 2). Finally, taking into account the mean point of the bin, we interpolated these data with a polynomial function, obtaining as result the following formula:

$$\log(O_{23}) = 0.20 - 0.25 \times \log(O_{13}) - 0.39 \times (\log(O_{13}))^2. \quad (1)$$

By selecting the objects under the curve we include 97 per cent of the original sample of Seyfert galaxies. Of course this new sub-sample is contaminated by other objects: in particular, it contains 60 per cent of Seyfert galaxies and 31 per cent of composite Seyfert-H$_{II}$ galaxies, but only 4 per cent of LINERs and 5 per cent of star-forming galaxies. So, we can conclude that about 10 per cent of a sample selected by following this method consists of non-Seyfert galaxies. It is interesting to note that the lower sequence contains both narrow and broad-lined AGN. This is due to the fact that it uses only the oxygen lines. In conclusion the O$_{123}$ diagram is useful for the classification of emission-line galaxies in general and not only for narrow emission-line ones. By applying Eq.(1) to the whole sample of 119226 objects (Fig. 3) we found that about 16000 populate the Seyfert region on the O$_{123}$ diagram. Since the SDSS spectra are obtained with a 3 arcsec fibre aperture, a redshift limit $z \leq 0.1$ was adopted to reduce the flux contamination by extra-nuclear sources (Kewley et al. 2006). The lower limit $z \geq 0.02$ is required because the [O ii]$\lambda$3727 line must be visible in the 3800–9200 Å spectral range covered by the SDSS detectors.

The total number of galaxies in the Seyfert region that satisfy the mentioned conditions is 5678. The left panel of Fig. 4 shows the S/N ratio of the spectra measured at rest-frame 5500 Å for the 5678 spectra of our sample (left). $\chi^2$/dof distribution of starlight fittings to the 5678 spectra (right).

3 MEASUREMENTS AND SPECTRA CLASSIFICATION

The VO diagrams are sensitive to the measurement of the H$\beta$ emission-line that is made difficult by the presence of the underlying stellar absorption. A suitable correction is mandatory to avoid an over-estimate of the [O iii]$\lambda$5007/H$\beta$ diagnostic ratio. The fitting and subtraction of the underlying stellar continuum from each spectrum was carried out with the spectral synthesis code STARLIGHT (Cid Fernandes et al. 2003, 2007). This code makes a linear...
tive line: 

- the central wavelength ($x_0$), amplitude ($A$), sigma ($\sigma$), and their errors ($\Delta x_0$, $\Delta A$, $\Delta \sigma$); 
- the measured flux ($F_M$); 
- the S/N ratio; 
- the $R^2$ parameter, the sum of the square residuals, defined as $R^2 = \sum (\delta x_0)^2 + (\delta A)^2 + (\delta \sigma)^2$, where $\delta x_0$, $\delta A$ and $\delta \sigma$ are the differences between the last iteration values and the previous ones; 
- the Gaussian flux ($F_G$) and its error ($\Delta F_G$); 
- the $\chi^2$ of the fitting.

The first step is to determine the line boundaries, i.e. the wavelengths at which the line profile fades into the continuum on both sides of the line. For this purpose, the algorithm evaluates the intensity of the line profile ($I(\lambda)$) from the peak towards bluer wavelengths until it reaches a minimum ($I_{\text{min}}$). If $I_{\text{min}} < I_\lambda + \sigma_c$, where $I_\lambda$ and $\sigma_c$ are the average continuum intensity and its error, the associated wavelength is assumed as the blue boundary of the line, otherwise the algorithm searches for a new minimum. The same procedure is repeated on the red side of the line. In order to prevent non-convergence, for each line or blend of lines a maximum value of the baseline is imposed. Each interval was empirically chosen to avoid nearby lines or features and the regions where the continuum was evaluated. If this value is reached, the algorithm starts again the procedure by comparing $I(\lambda)$ with $I_\lambda + 2\sigma_c$. If the convergence is not reached, then it tries with $3\sigma_c$.

Once the boundaries are determined, the flux is obtained by integrating the spectral feature. The flux error is calculated by means of $\Delta A$ and $\Delta \sigma$. $\Delta A$ is the value of $\sigma_c$ determined in proximity of the emission-line, while to estimate $\Delta \sigma$ a Monte Carlo method is applied during the fitting procedure. In particular, starting from the Gaussian parameters, the code generates 3000 possible models near the best solution, within the fixed intervals: $A - \sigma_c < A < A + \sigma_c$, $\sigma - 1 < \sigma < \sigma + 1$, $x_0 - 1 < x_0 < x_0 + 1$, and changing randomly the values of the parameters. A $\chi^2$ test is performed and only the models with a significance level above 70 per cent are considered. This procedure was applied only to features with one or two lines, for computational time reasons. $\Delta A$ is always lower than $\sigma_c$, whereas $\Delta \sigma$ and $\Delta x_0$ both depend on the S/N. In Fig. 6 the case of H$\beta$ is presented. As it can be seen, $\Delta x_0 \propto \text{(S/N)}^\alpha$. Following Corsini et al. (1999) and by applying a linear fitting to $\log \Delta x_0$ vs. $\log \text{S/N}$, a simple relation to estimate $\Delta \sigma$ can be derived. In this case, $\Delta \sigma$ is given by:

$$\log(\Delta \sigma) = -1.2 \log(\text{S/N}) + 0.7$$

but similar results are obtained for all the measured lines. $\Delta x_0$ is similar to $\Delta \sigma$ and it correlates well with $\Delta \sigma$ and S/N. The correlation coefficient of the interpolation is 0.95. The typical wavelength error is about 0.5 Å when the S/N is around 10.

In order to check the reliability of the automatic fitting procedure, about 1300 spectra were measured by hand. The line boundaries limits and the fluxes obtained are the same with very rare exceptions. The number of failures increases when the S/N $< 5$, therefore only the lines with a S/N $> 5$ were measured. They are listed in Table II with the maximum number of components adopted in the fitting, the ionization potentials and the logarithm of the critical density. De Robertis & Osterbrock (1986) and Mendoza (1983). No other line was taken into consideration because it was too weak to be detected, as $\text{[FeII]} \lambda 6374$. He and higher order Balmer lines, or in blend but presumably giving a small con-
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Figure 5. An example of correction for stellar component. The original spectrum is plotted in black, the fit to the stellar component in red and the residual pure emission-line spectrum in black, dotted line.

Figure 7. Examples of lines fitting. The observed spectrum (black dots) is overlapped to the results of the fitting (solid line). Residuals are plotted on the top of the diagrams (dotted line).

The classification of Seyfert galaxies is based on the detection of the Balmer line broad components (Osterbrock & Ferland 2006), but this criterion is subjective and it depends on the spectral quality. Additionally, visually classifying a large number of spectra is very difficult and extremely time-consuming. In this work the criterion adopted for the spectral classification is based on the presence of a second component in the Hα emission-line and on its FWHM. Gelbord et al. (2009) claimed that a good fitting of Hα should be obtained using three components, a narrow, an intermediate and a broad one. However, it is in general difficult to find the corresponding components in Hβ, which is fundamental in our analysis. Therefore, in this work we decided to fit both Hβ and Hα with two components, one narrow and one broad. Out of the 4254 measured spectra, 1938 show a secondary Hα component. In Fig. 8 we present the FWHM(Hα) distribution of both components after correction for instrumental width (R=1800). The FWHM(Hα) distribution of the second component shows two peaks, one between 500 and 1000 km s⁻¹ and the other between 1500 and 2200 km s⁻¹, respectively. If the FWHM(Hα) of the second component is lower than 2000 km s⁻¹ the line is hidden in the Hα+[N ii]λ6548,6584 feature (Gelbord et al. 2009). In this case, the SDSS spectral resolution is not sufficient to separate the true components. Therefore, since we could not be sure whether the second Hα component is a real broad line or a mathematical result of the fit, we decided to exclude the broad components with FWHM < 2000 km s⁻¹.

In addition, we compared the widths of Hα and Hβ lines for all 4254 measured spectra (Fig. 9). We noticed that the narrow components of both lines are well distributed around the 1:1 line, while the broad components are in good agreement only when the FWHM(Hα) > 2000 km s⁻¹. Below this value, the widths of the two emission-lines are totally...
Table 1. Measured lines.

| line          | comp | IP low eV | IP high eV | log(N$_c$ cm$^{-3}$) |
|---------------|------|-----------|------------|----------------------|
| [O II]λ3727   | 1    | 13.62     | 35.12      | 3.7                  |
| [Ne III]λ3869 | 1    | 40.96     | 63.45      | 7.0                  |
| [Ne III]λ3967 | 1    | 40.96     | 63.45      | 7.0                  |
| [S II]λ4070   | 1    | 10.36     | 23.34      | 6.4                  |
| Hα λ4102      | 1    | 13.60     | –          | –                    |
| Hγ λ4340      | 1    | 13.60     | –          | –                    |
| [O II]λ4363   | 1    | 35.12     | 54.94      | 7.5                  |
| He II λ4686   | 1    | 24.59     | 54.42      | –                    |
| [Ar IV]λ4711  | 1    | 40.74     | 59.81      | 4.4                  |
| [Ar IV]λ4740  | 1    | 40.74     | 59.81      | 5.6                  |
| Hβ λ4861      | 2    | 13.60     | –          | –                    |
| [O II]λ6584   | 2    | 35.12     | 54.94      | 5.8                  |
| [O II]λ5007   | 2    | 35.12     | 54.94      | 5.8                  |
| [N II]λ5199   | 1    | 0         | 14.55      | 3.3                  |
| [Fe VI]λ5721  | 1    | 99.1      | 124.98     | 7.6                  |
| He I λ5876    | 1    | 0         | 24.59      | –                    |
| [Fe VI]λ6087  | 1    | 99.1      | 124.98     | 7.6                  |
| [O I]λ6300    | 1    | 0         | 13.62      | 6.3                  |
| [O I]λ6363    | 1    | 0         | 13.62      | 6.3                  |
| [N II]λ6548   | 1    | 14.53     | 29.60      | 4.9                  |
| Hα λ6563      | 2    | 13.60     | –          | –                    |
| [N II]λ6583   | 1    | 14.53     | 29.60      | 4.9                  |
| [S II]λ6716   | 1    | 10.36     | 23.34      | 3.2                  |
| [S II]λ6731   | 1    | 10.36     | 23.34      | 3.6                  |
| [Ar III]λ7136 | 1    | 27.63     | 40.74      | 6.7                  |
| [O II]λ7320   | 1    | 13.62     | 35.12      | 6.8                  |
| [O II]λ7330   | 1    | 13.62     | 35.12      | 6.8                  |

Notes. The table shows the measured lines, the number of components used in the fitting, their ionization potentials (IP low) and the potential of the following ionic species (IP high), and the logarithm of the critical density.

Figure 8. Distribution of FWHM(Hα) for the first component (solid line) and the second component (dashed line) of the emission-line.

Figure 9. FWHM(Hβ) vs FWHM(Hα) for the 4254 measured spectra. Crosses are the first component, squares the second component.

different. In particular, the second component of Hβ could not be a real broad line, or it could be poorly fitted, because too weak. When FWHM(Hα) < 1250 km s$^{-1}$ the second component of Hβ disappears. Therefore, all the spectra with narrow Hα or with a second component narrower than 1250 km s$^{-1}$ were classified as narrow-line spectra. The errors were taken into account, and the condition was fixed to FWHM(Hα) − 3 × ∆FWHM(Hα) < 1250 km s$^{-1}$. The Hα flux was obtained as the sum of two fluxes when a second component was present. The spectra showing a second Hα component with FWHM(Hα) + 3 × ∆FWHM(Hα) > 2000 km s$^{-1}$ were classified as broad line spectra. In this second class we imposed an additional constraint: the reliability of the broad component was confirmed only when the height of its profile above the continuum at rest-frame 6531 and 6595 Å was larger than 2σc, where σc is the root mean square of the continuum intensity. The factor 2 was adopted based on visual tests on the detection of the broad component. Fig. 10 shows an example of broad-line spectra which satisfy the previously mentioned conditions. The distributions of the second component FWHM(Hα) of these groups are showed in Fig. 11. Finally, 598 objects were classified as broad emission-line galaxies and 2836 as narrow emission-line galaxies. Then, we applied the VO diagnostic diagrams and the relations introduced by Kewley et al. (2006). Only the objects belonging to the Seyfert region within $1σ$ error in the diagnostic ratios were considered. We obtained two final samples of 521 Intermediate-type Seyfert (S-I) and 2153 Seyfert 2 (S2) galaxies.

As a final check we plotted the log([O III]λ5007/Hα) vs log([N II]λ6584/Hα). Gelbord et al. (2009) found that this diagram is able to separate the S2 from the other Seyfert galaxies. They found that S2 galaxies have log([O III]λ5007/Hα) > 0 and log([N II]λ6584/Hα) < −0.5, while our boundaries are log([O III]λ5007/Hα) > −0.6.
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4 EMISSION-LINE ANALYSIS

In the following sections, we present the statistical analysis of the emission-line ratios. We looked for the correlations by means of the Spearman rank correlation coefficient ($r_s$) that is in general adopted when the distributions are a priori unknown. We used the two-tail test to verify the null hypothesis, that is the probability that the correlation does not exist, and we assumed $\alpha = 0.1$ per cent, as significance level. We calculated the $t$ parameter of the Student distribution by following [Wall et al. 2003], and we compared those values with tabulated critical $t$-values ($t_{crit}$) for a given number of degrees of freedom and a significance value. When $t > t_{crit}$, the correlation is significant at the chosen level and the null hypothesis can be rejected.

To compare samples, we used the Kolmogorov-Smirnov (K-S) test, to verify when two samples are drawn by the same population. When the observed parameter $\Delta$, that is the maximum difference between two distributions, is greater than the theoretical value $D$, the two samples are different with a significance level of 1 per cent.

and $\log([\text{N} \text{II}]\lambda 6584/\text{H} \alpha) > -0.3$ (Fig. 12). On the other hand, the correspondence is very good for the S-I galaxies. This discrepancy could be due to the fact that Gelbord et al. (2009) considered only spectra showing forbidden high-ionization line (FHIL), and so it is likely that $[\text{O} \text{III}]\lambda 5007/\text{H} \alpha$ ratio is higher than the mean value we found in S2.

Figure 10. Example of $\text{H} \beta$ (top) and $\text{H} \alpha$ (bottom) with a broad second component. The observed spectrum is in black dots, the components are in dashed line and the residuals in dotted line.

Figure 11. FWHM($\text{H} \alpha$) distribution for the second component. The spectra showing $\text{H} \alpha$ second component with FWHM $< 1250$ km$-$s$^{-1}$ are in solid line, while those having FWHM $> 2000$ km$-$s$^{-1}$ are in dashed line.

Figure 12. The logarithm of $[\text{N} \text{II}]\lambda 6584/\text{H} \alpha$ ratio plotted against the logarithm of $[\text{O} \text{II}]\lambda 5007/\text{H} \alpha$ ratio. S2 galaxies are indicated with red plus and S-I galaxies with blue squares.

Figure 13. $A(V)$ distribution for the samples: S2 (red solid line), and S-I (blue dashed line).
4.1 Internal reddening

The internal reddening correction was calculated using the parametrization introduced by CCM under the assumption H0/Hβ = 3.1 (Osterbrock & Perola 2006). Fig. 14 shows the distributions of the derived values of A(V). The median values are 1.4 (90 per cent of the sample has A(V) < 2.5) for the S2 and 0.9 (90 per cent of the sample has A(V) < 1.8) for the S-I. Assuming a level of significance of 1 per cent, the Kolmogorov-Smirnov (KS) test gives 0.3, clearly different from the theoretical value of 0.08, indicating a statistical difference of A(V) distribution between S2 and S-I. This result is expected in S-I and Seyfert 1 galaxies, because we are looking deeper inside the NLR, and the dust quantity is presumably lower because of the winds (Calzetti, Kinney & Storchi-Bergmann 1996) and the dust sublimation (Mullaney et al. 2009).

The A(V) values appear weakly correlated with stellar absorption (A(V)_s), evaluated by STARBRIGHT (Fig. 15). Indeed the Spearman rank correlation coefficient is r_s = 0.55, but the correlation is significant since t = 33.3 >> t_{crit} = 3.3 for N = 2557 targets (S2+S-I).

Our distribution is very similar to that obtained by Gu et al. (2006), who measured the extinction of 65 nearby Seyfert 2 nuclei from H7/Hβ ratio. A(V)_s values are distributed in a small interval and are very similar for both the samples. A large difference between the stellar and gas extinction was also found by Calzetti, Kinney & Storchi-Bergmann (1994) and by Calzetti (1997) in starburst galaxies. The same result was obtained by Bennert et al. (2006a) in a detailed analysis of the NLR in NGC 1386. This would suggest that most of the dust is mixed with the gas.

![Figure 14. Stellar reddening (A_V star) versus gas reddening (A_V gas). Symbols are like in Fig. 12.](image)

### Table 2. Correlation coefficients between lines of similar ionization potential.

|       | S2   | t   | S-I   | t   |
|-------|------|-----|-------|-----|
| A5876 vs. A4686 | 154  | 0.17 | 2.17  | 133 | 0.38 | 4.7  |
| A4686 vs. λ5007 | 354  | 0.69 | 14.1  | 199 | 0.49 | 7.9  |
| λ3369 vs. λ5007 | 1126 | 0.77 | 40.5  | 431 | 0.77 | 25.0 |
| A7136 vs. λ5007 | 225  | 0.75 | 16.9  | 114 | 0.78 | 13.2 |
| A5727 vs. λ6724 | 2110 | 0.58 | 32.7  | 513 | 0.71 | 22.8 |
| A5599 vs. λ6724 | 165  | 0.38 | 5.2   | 88  | 0.50 | 5.4  |
| A6300 vs. λ6724 | 2105 | 0.76 | 53.6  | 508 | 0.80 | 30.0 |
| A5007 vs. λ6724 | 2100 | 0.51 | 27.2  | 509 | 0.69 | 21.5 |

Note. The asterisk indicates that the correlation is not significant.

4.2 Line intensity correlations

The emission-line fluxes normalized to Hβ and corrected for reddening were analysed following Koski (1978). The emission-line ratios were grouped according to high and low ionization lines (Table 2) and plotted versus the [O III]λ5007/Hβ or [S II]λ6724/Hβ, respectively. As in Koski (1978), we added the He I λ5876/Hβ vs. He II λ4686/Hβ diagram, in order to compare the helium recombination lines. These diagrams show the correlations between lines with similar ionization states (Figures 15, 16). Although the mean S/N of our spectra is lower than that of Koski, we found similar results by plotting a larger sample of objects.

Table 2 shows the number of targets (N), the Spearman rank correlation coefficient (r_s) and the parameter of the two-tail test (t). The critical value for the minimum number of targets, N = 88, is t_{crit} = 3.4; therefore all correlations are significant at 0.1 per cent, but the first one for S2 galaxies, indicated by an asterisk.

[Ne II]λ3869 and [Ar III]λ7136 lines show a good correlation with the [O III]λ5007 line in both samples. He II λ4686 is well correlated only in S2 galaxies, while in S-I galaxies the correlation is significant, but weaker, likely because of the presence of the underlying broad component. Good or fairly good correlations exist between [S II]λ5199 vs. [N II]λ5721, [S II]λ6087 vs. [S II]λ5724, while [N II]λ5199 vs. [S II]λ6087 is weak in both samples, probably because [N II]λ5199 is very close to the Mg I λ5175 triplet and its measure can be strongly affected by the stellar continuum subtraction. We found also good correlations between lines with similar critical density: [S II]λ6724 vs. [O II]λ3727, [Ar III]λ7136 vs. [O I]λ3732 (only for S2) and [Ne III]λ3869.

On the other hand, there is no correlation between the He I and He II lines, and [Ar III]λ7136 vs. [O I]λ3600 and [S II]λ4074. These last lines have similar critical densities, but very different ionization potentials, supporting the hypothesis of two independent ionization zones. We do not find any correlation between the [O III]λ5007 line and the high ionization lines [Fe VII]λ5721,6087 and [Ar IV]λ4711,4740. The [Fe VII] lines have an higher critical density compared to the [O III] lines, while the [Ar IV] lines have higher ionization potential and lower critical density. Therefore, these lines could be formed in different regions compared with the [O III]λ5007 line. [Fe VII]λ5721,6087 were detected in few spectra, but the percentage increases from S2 to S-I (see Table 3). These lines are formed in the coronal-line region (CLR) and are very important in the analysis of the NLR structure. Murayama & Taniguchi (1998) claimed that in the context of the Unified Model three kinds of CLR exist:
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Figure 15. Koski diagrams for high ionization lines (see text). The fluxes are relative to H$\beta$ and reddening corrected. Symbols are like in Fig. 12.

Figure 16. Koski diagrams for low ionization lines (see text). The fluxes are relative to H$\beta$ and reddening corrected. Symbols are like in Fig. 12.

those associated with the torus, with the NLR and with the ENLR. The condition to form the coronal lines is a dust free medium with densities of $10^2$–$10^3$ cm$^{-3}$ (Ferguson et al. 1997). If the CLR is far away from the source, it is likely to have a very low density, $\sim 1$ cm$^{-3}$ (Korista & Ferland 1994).

Since the critical density of the [Fe vii] $\lambda 6087$ line is very similar to that of the [O iii] $\lambda 4363$ line, we followed Nagao, Murayama, & Taniguchi (2001) and analyzed a possible correlation between these two lines. About 50 percent of the spectra where the [O iii] $\lambda 4363$ line is detected shows the [Fe vii] $\lambda 6087$ line. In particular, we calculated
and their percentage with respect to the samples.

The logarithm of the $[\text{Fe}^\text{vii}]$ and $[\text{O}^\text{iii}]\lambda4363$ lines and their ratio for the two samples. Symbols are like in Fig. 12.

Table 3. Number of spectra with $[\text{Fe}^\text{vii}]$ and $[\text{O}^\text{iii}]\lambda4363$ lines and their percentage with respect to the samples.

| samples | $[\text{Fe}^\text{vii}]6086$ | $[\text{O}^\text{iii}]\lambda4363$ | $[\text{Fe}^\text{vii}]\lambda4363+[\text{Fe}^\text{vii}]6087$ |
|---------|----------------|----------------|----------------------------------|
| S2      | 96 (4 per cent) | 86 (4 per cent) | 38 (2 per cent) |
| S-I     | 97 (19 per cent) | 186 (36 per cent) | 73 (14 per cent) |

Figure 17. The logarithm of the $[\text{Fe}^\text{vii}]\lambda6087/[\text{O}^\text{iii}]\lambda5007$ ratio is plotted against the logarithm of the $[\text{O}^\text{iii}]\lambda4363/[\text{O}^\text{iii}]\lambda5007$ ratio for the two samples. Symbols are like in Fig. 12.

$[\text{Fe}^\text{vii}]\lambda6087/[\text{O}^\text{iii}]\lambda5007$ and $[\text{O}^\text{iii}]\lambda4363/[\text{O}^\text{iii}]\lambda5007$ ratios. We did not find correlation for S2, $r_s=0.28$ ($t=1.8 < t_{crit}=3.6$, N=38) and a weak but significant correlation for S-I, $r_s=0.47$ ($t=4.5 > t_{crit}=3.4$, N=73) (Fig. 17).

The low value of the correlation index in the S-I sample could be due to larger errors in the measurements of the flux of $[\text{O}^\text{iii}]\lambda4363$, because of the presence of a non-negligible broad H$_\gamma$ component. It is interesting to note that the distribution extends to higher values in the S-I case. Indeed, if the temperature increases and the density decreases, then the $[\text{O}^\text{iii}]\lambda4363/[\text{O}^\text{iii}]\lambda5007$ ratio increases (Osterbrock & Ferland 2006). This is consistent with the assumption that the coronal lines are forming in a medium with low or intermediate density and high temperature. The same critical density is not a sufficient condition to support the idea that these lines are emitted in the same region. Their ionization potentials are very different, therefore it is likely that these lines are in general emitted in different regions and in some cases in partially overlapped regions.

5 PHYSICAL CHARACTERISTICS

5.1 Densities and Temperatures

The values of density and temperature were calculated by means of the IRAF task TEMDEN. The line ratios used to determine the densities were $[\text{S}^\text{ii}]\lambda6716/6731$ (hereafter RS2) and $[\text{Ar}^\text{iv}]\lambda4711/4740$ (hereafter RAR4), while the ratios used for the temperature were $[\text{O}^\text{iii}]\lambda4959/5007$ and $[\text{O}^\text{iii}]\lambda4363$ (hereafter RO3), $[\text{S}^\text{ii}]\lambda6716/6731$ and $[\text{Fe}^\text{vii}]\lambda6087/\lambda4363$ (hereafter RS2t), $[\text{O}^\text{iii}]\lambda3727/\lambda7325$ (hereafter RO2). A temperature of 10000 K was assumed for the density determination. Fig. 13 shows the distribution of the densities calculated by means of RS2. This ratio was measurable in all spectra, but reasonable values ($RS2 > 0.29$, theoretical lower limit) and so reliable estimates of the density were possible in 2316 out of the 2674 objects, 1846 S2 and 470 S-I (87 per cent of the total sample). The median value is $N_e \sim 250$ cm$^{-3}$, most of objects ($\sim 2300$ galaxies) show values lower than 500 cm$^{-3}$, while only in 97 cases we observe densities higher than 1000 cm$^{-3}$. Only in 11 objects it was possible to estimate the density with argon lines, 7 S2 and 4 S-I. The obtained values are of the order of $10^3$ cm$^{-3}$ (Fig. 13). This is not unexpected, since the $[\text{Ar}^\text{iv}]$ transitions are characterized by higher critical density values than those of the $[\text{S}^\text{ii}]$ lines, and therefore they are probably emitted by gas in different physical conditions. Interestingly, the $[\text{O}^\text{iii}]\lambda4363$ transition, which shares a similar ionization potential, has an even higher critical density, and this means that the gas emitting this line is also characterized by a larger electron density, likely around $10^4$ cm$^{-3}$ or even more. Moreover, both lines $[\text{Ar}^\text{iv}]\lambda4711$ and $[\text{Ar}^\text{iv}]\lambda4740$ are generally weak, also after reddening correction, showing median intensities normalized to H$_\beta$ of 0.07 and 0.09, respectively. Since most of the spectra, where they could be detected and measured, have S/N ratio between 20 and 40, we can in principle conclude that these lines are visible only in few galaxies, because spectra with high S/N ratio in the continuum are mandatory. Anyway, this could be only a necessary but not sufficient condition. Indeed, 66 per cent of our sample has S/N $> 20$. Moreover, one can speculate for example that $[\text{O}^\text{iii}]\lambda4363$ has a median intensity only twice higher than $[\text{Ar}^\text{iv}]\lambda4711$ and $[\text{Ar}^\text{iv}]\lambda4740$, and it was detected in 272 spectra having S/N ratio between 15 and 40, notwithstanding the fact that oxygen is about 200 times more abundant than argon, assuming solar abundances. Therefore, it is also possible that the gas of the NLR is made essentially by a low and a high density medium, and that the second one has the necessary electron density to collisionally populate the oxygen auroral line and simultaneously suppress the $[\text{Ar}^\text{iv}]$ lines.

The estimate of temperature can be difficult because sometimes the lines involved are weak or even very weak. Anyway, reliable estimates were obtained with RO3 in 254 objects, 84 S2 and 170 S-I, with RO2 in 81 objects, 68 S2, 13 S-I, and finally with RS2t in 116 reliable measures, 63 S2 and 53 S-I. Fig. 20 shows the distributions of the so determined temperatures for both samples while the median values are reported in Table 4. We used the electron density obtained with RS2 as input to TEMDEN. Through a two-sample Kolmogorov–Smirnov test (see Table 4) it appears that the distribution extends to higher values in the S-I case. Indeed, if the temperature increases and the density decreases, then the $[\text{O}^\text{iii}]\lambda4363/[\text{O}^\text{iii}]\lambda5007$ ratio increases (Osterbrock & Ferland 2006). This is consistent with the assumption that the coronal lines are forming in a medium with low or intermediate density and high temperature. The same critical density is not a sufficient condition to support the idea that these lines are emitted in the same region. Their ionization potentials are very different, therefore it is likely that these lines are in general emitted in different regions and in some cases in partially overlapped regions.

Table 4. Median values of electron temperature for the samples. The meaning of $D$ and $\Delta$ is explained at the beginning of Section 4.

| temperature | S2 | S-I | N S2 | N S-I | D | $\Delta$ |
|-------------|----|-----|------|-------|---|--------|
| TO2         | 12000 | 10000 | 68 | 13 | 0.49 | 0.14 |
| TS2         | 11000 | 15000 | 63 | 53 | 0.30 | 0.30 |
| TO3         | 17500 | 25000 | 84 | 170 | 0.21 | 0.42 |
that the distributions of the temperatures derived from [O ii] and [S ii] are very similar for S2. On the other hand, the temperatures obtained from [O iii] have a completely different distribution. In principle, this result could be indicative of the presence of ion stratification according to the ionization potentials. In contrast, it could be simply the effect of the use of $N_e([S ii])$, which indicate too low electron density values to collisionally pump the [O iii]λ4363. The use of $N_e([Ar iv])$ should be more correct, nevertheless the critical densities of [Ar iv] lines are lower than that of [O iii]λ4363, and this suggests that $N_e([Ar iv])=10^4–10^5$ cm$^{-3}$ could be a lower limit for the density of the gas emitting the [O iii] auroral line.

By assuming that photoionization from the active nucleus is the main physical mechanism taking place in the NLR, we can conclude that [O iii]λ4959,5007 are likely emitted both by a low density medium at higher temperature reflecting ion stratification, and by high density clouds with high ionization, where the physical conditions are such as to allow the [O iii]λ4363 to form and become detectable and measurable. The high values of temperatures measured with [O iii] lines in the S-I sample, seems to indicate that we are observing the part of the NLR closer to the AGN. However, we stress that this result could be an effect of non perfect subtraction of Hγ broad component.

\subsection*{5.2 Ionization parameter}

The ionization level is defined by the ionization parameter $U$, which is the ratio between the flux of ionizing photons and the hydrogen density,

$$U = \frac{Q_{\text{ion}}}{c \tau^2 N_H}$$

where $Q_{\text{ion}}$ is the number of ionizing photons per second emitted by the source. The ionization parameter could be evaluated using two ratios, [O iii]λ5007/Hβ, as suggested by Cohen (1983), and the most recent ratio [O ii]λ3727/[O iii]λ5007 (Komossa & Schulz 1997). We plotted the [O ii]λ3727/[O iii]λ5007 vs [O iii]λ5007/Hβ diagram (Fig. 21). The trend is clear in both the samples: $r_s = -0.65$ ($t = 39.6$, $N=2153$) for S2, $r_s = -0.56$ ($t = 15.4$, $N=521$) for S-I. Cohen & Osterbrock (1981) defined high ionization when [O iii]λ5007/Hβ $> 10$. They analyzed different line ratios in order to define a non-arbitrary way...
to classify high and low ionization level. In their fig. 2, [Fe \textit{vii}] 6087/H\beta vs. [O \textit{iii}] 5007/H\beta diagram, they found that [Fe \textit{vii}] 6087/H\beta shows a cutoff: [Fe \textit{vii}] 6087 is not observed, when [O \textit{iii}] 5007/H\beta < 10. From Fig. 21 we can estimate that this limit corresponds to [O \textit{ii}] 3727/[O \textit{iii}] 5007 lower than 0.5 and 0.4 respectively for S2 and S-I. It corresponds to a log(U) greater than -2.5 and -2.4 respectively for S2 and S-I, by assuming the relation between the [O \textit{ii}] 3727/[O \textit{iii}] 5007 ratio and the ionization parameter U introduced by Penston et al. (1990):

$$\log U = -2.74 - \log(I_{3727}/I_{5007}).$$

(4)

Using Eq. 3 we estimated the ionization parameter for both the samples, and we applied the KS test subdividing each sample in two sub-samples of spectra (Table 5), the first one showing the He\textit{ii} 4686 emission-line and the second one showing the [Fe \textit{vii}] 6087 emission line. There is a significant difference between S2 and S-I galaxies when all the spectra are taken into account. It is interesting to point out that this difference becomes less significant when we compare the objects emitting He\textit{ii} 4686 and disappears when the [Fe \textit{vii}] 6087 is taken into account (Fig. 22). The ionization parameter depends on the luminosity and is inversely proportional to density and distance from the source. The different distributions suggest that one or more of these parameters change. If the luminosity changes, then S-I and S2 are intrinsically different objects and the Unified Model fails. On the other hand, since the average electron density seems to be the same in the two samples (see Section 5), changes in the ionization parameter could be a distance effect. The ionization is highly stratified in the NLR and in S-I galaxies we are able to observe closer to the active nucleus, therefore we can speculate that S2 galaxies showing He\textit{ii} and [Fe \textit{vii}] have a wider aperture angle of the torus, which is thinner in the direction orthogonal to the line of sight. Indeed, by plotting log U vs. A(V) we can observe that S2 galaxies showing [Fe \textit{vii}] are characterized by a relatively low extinction, with values similar to those observed in S-I galaxies (Fig. 23).

### Table 5. Two-sample Kolmogorov–Smirnov test concerning the ionization potential distributions with 1 per cent of significance.

| samples       | D   | \Delta |
|---------------|-----|--------|
| S2 ↔ S-I     | 0.08| 0.38   |
| (S2 ↔ S-I)_{\lambda 4686} | 0.14| 0.25   |
| (S2 ↔ S-I)_{\lambda 6087} | 0.23| 0.21   |

Notes. (S2 ↔ S-I)_{\lambda 4686} and (S2 ↔ S-I)_{\lambda 6087} indicates the comparison between the samples when the spectra show respectively the He\textit{ii} 4686 and [Fe \textit{vii}] 6087 emission-lines.

Figure 21. The logarithm of the [O \textit{ii}] 5007/H\beta ratio is plotted against the logarithm of the [O \textit{ii}] 3727/[O \textit{iii}] 5007 ratio. Symbols are like in Fig. 12.

Figure 22. Ionization parameter distributions. Top: S2 sample is indicated in red solid line and the S-I sample in blue dashed line. Middle: the distributions taking into account only the spectra with the He\textit{ii} 4686 measured, bottom: the distributions taking into account only the spectra with the [Fe \textit{vii}] 6087 measured.

### 5.3 Ionized gas mass and radius

Ho (2009) suggests that the mass budget of the NLR can be accounted by mass loss from evolved stars. From H\alpha (or H\beta) luminosity it is possible to determine the ionized gas mass (Osterbrock & Ferland 2006). The author found $M_{\text{NLR}} \sim 3 \times 10^4 M_\odot$ in a region of $200 \times 400$ pc. This value comes from the population statistics of the Palomar survey assembled in Ho, Filippenko, & Sargent (2003) and it probably underestimates the mass by no more than a factor of 2. Comparing this mass with the amount of material shed by evolved stars, determined by the models of Padovani & Matteucci (1993), Ho found $M_* \sim 0.05 M_\odot$ yr\(^{-1}\). Therefore, stellar mass loss can sustain the gas reservoir in the NLR if the stellar debris survives for a lapse of time longer than $\sim 2 \times 10^5 - 10^6$ yr before it dis-
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Figure 23. The logarithm of the ionization parameter is plotted against the reddening derived from emission-lines. Symbols are like in Fig. 13. Black filled circles are Seyfert 2 showing [Fe v 7].

Table 6. NLR mass (Eq. 5) and radius (Eq. 7) distributions for three different $N_c$.

| $N_c$ cm$^{-3}$ | $M$ (M$_\odot$) mean (pc) median (pc) <80 per cent (pc) |
|-----------------|------------------------|---------------|----------------|----------------|
| 10$^6$          | 10$^6$                 | 170           | 140            | 240            |
| 10$^8$          | 2.5 · 10$^7$           | 750           | 680            | 950            |
| 10$^9$          | 2.5 · 10$^8$           | 2480          | 2200           | 3000           |

5.4 Kinematics

The measured FWHM ($FWHM_{in}$) was corrected for instrumental broadening to obtain the intrinsic value ($FWHM_{in}$). As instrumental width we used the nominal SDSS spectral resolution, $R = 1800$ (Burles et al. 1994) which corresponds to 167 km s$^{-1}$. $FWHM = (FWHM_{in} \times c/\lambda_i)^2 + 167^2$ km s$^{-1}$ (8).
Figure 24. NLR radii distributions using $N_e = 10 \, \text{cm}^{-3}$. Colours and lines are like in Fig. 13.

Figure 25. Ionized gas mass obtained by Eq. 5 with $N_e = 10 \, \text{cm}^{-3}$. Lines and colours are like in Fig. 13.

Figure 26. The distributions of the mean FWHM (km s$^{-1}$) of the emission-lines measured in each target. Lines and colours are like in Fig. 13.

Table 7. Correlation coefficients between the logarithms of $\text{FWHM}_{\text{star}}$ and $\text{FWHM}_{\text{gas}}$

| line          | S 2 |       |       | S-I |       |
|---------------|-----|-------|-------|-----|-------|
|               | N   | $r_s$ | $t$   | N   | $r_s$ | $t$   |
| H$\beta$      | 2128| 0.64  | 38.4  | 506 | 0.47  | 11.9 |
| H$\alpha$     | 2126| 0.71  | 46.5  | 511 | 0.53  | 14.1 |
| [N$\text{ii}$] 6584 | 2097| 0.56  | 30.9  | 508 | 0.33  | 7.8  |
| [O$\text{ii}$] 5007 | 2124| 0.69  | 43.9  | 509 | 0.47  | 12.0 |
| [O$\text{ii}$] 6584 | 2106| 0.66  | 40.3  | 506 | 0.36  | 8.7  |
| [O$\text{ii}$] 5007 | 2103| 0.62  | 36.2  | 504 | 0.32  | 7.6  |
| 4686          | 346 | 0.29  | 5.6   | 194 | 0.28  | 4.0  |
| 3869          | 1114| 0.39  | 14.1  | 426 | 0.25  | 5.3  |
| 5007          | 2129| 0.53  | 28.8  | 513 | 0.28  | 6.6  |

Since a low S/N ratio makes the line profile difficult to be measured, we considered only the brightest lines, namely: H$\beta$, H$\alpha$, [O$\text{ii}$]$\lambda$6300, [N$\text{ii}$]$\lambda$6584, [S$\text{ii}$]$\lambda$6716,6731, [Ne$\text{iii}$]$\lambda$3869, [O$\text{iii}$]$\lambda$5007 and He$\text{ii}$ $\lambda$4686. Furthermore, we calculated the mean FWHM for each object (see Fig. 26), using the previously mentioned lines. A very little difference between the samples is found by means of the KS test ($D=0.08$, $\Delta = 0.15$, significance=1 per cent). The median values are about 270 km s$^{-1}$ and 300 km s$^{-1}$ respectively for S2 and S-I, with the 80 per cent of the sample having FWHM lower than 360 and 390 km s$^{-1}$ respectively for S2 and S-I. Concerning a possible connection between gas velocity dispersion and stellar velocity dispersion, we note that in the S2 sample, the low ionization lines show a correlation with stellar kinematics, even if weaker. A better indicator is [N$\text{ii}$] $\lambda$5007 as already shown by Ho (2009). The diagrams of FWHM$\text{star}$ vs. FWHM$\text{gas}$ are shown in Fig. 27 for both [N$\text{ii}$] $\lambda$6584 and [O$\text{ii}$] $\lambda$5007.

In many cases, it was necessary to fit [O$\text{iii}$] $\lambda$5007 with two components, a narrower (hereafter first component) and a broader component (hereafter second component). Fig. 28 shows the FWHM of [O$\text{iii}$] $\lambda$5007 distributions for both the components. The values are systematically lower in the S2 sample with respect to the S-I sample. The largest difference is in the second component: the median value is 520 km s$^{-1}$ for S2 and 650 km s$^{-1}$ for the S-I sample. 80 per cent of the sample has a FWHM of the [O$\text{iii}$] second component lower than 720 and 950 km s$^{-1}$ respectively for S2 and S-I. An accurate analysis of H$\beta$ and [O$\text{iii}$] $\lambda$4959,5007 profiles was performed. The asymmetry measure was obtained using the algorithm introduced by Whittle (1983). Once the continuum level of the line is defined, the algorithm calculates the 10, 50 and 90 per cent of the area under the line profile and the corresponding wavelengths, from the blue side of the line. Then two line widths named respectively $a=\lambda_{50} - \lambda_{10}$ and $b=\lambda_{90} - \lambda_{50}$ are defined, so the asymmetry is calculated as $A=(a-b)/(a+b)$. These measures are based on the area, so they are less sensitive to noise or effects of instrumental resolution. The main issue is the definition of the line profile limits to fix the continuum level. A number of different baselines was used and the values of the resulting parameters were averaged. In order to define the line boundaries and the continuum we applied...
the same method described in Section 3. Once evaluated the line boundaries, we considered three pixels at each side of the line (the pixel corresponding to the line boundary and the adjacent ones) in order to define 9 different baselines. A maximum limit of $\pm 1500 \text{ km s}^{-1}$ was imposed to prevent the non-convergence: in these cases the continuum value plus 2 or 3 times $\sigma_c$ was taken into consideration, especially for $[\text{O iii}]4959$ and $H\beta$, which have sometimes a relatively low S/N ratio. The distributions of the measured asymmetries are presented in Fig. 29. A clear indication of a positive asymmetry (blue wing) of the $[\text{O iii}]\lambda 5007$ line with respect to $H\beta$ is found. Of course the $H\beta$ asymmetry distribution for the S-I sample is totally different because of the broad component. However, the mean value for both samples is around $A=0$. In order to check the results, the asymmetry analysis was performed also for $[\text{O iii}]4959$. There is agreement between $[\text{O iii}]4959$ and $[\text{O iii}]\lambda 5007$ (Fig. 30) although, the asymmetry measure is more difficult in case of $[\text{O iii}]\lambda 4959$, because this line is weaker. The Spearman rank correlation coefficients are $r_s=0.60$ ($t = 34.6$, $N=2131$) for the S2 and $r_s=0.68$ ($t = 21.0$, $N=514$) for the S-I sample. On the other hand there is no correlation between $[\text{O iii}]\lambda 5007$ and $H\beta$. The $[\text{O iii}]\lambda 5007$ asymmetry parameter gives highly positive asymmetry for 68 per cent of the S2 and about 74 per cent of the S-I. The KS test gives a very little difference between the samples ($D=0.08$, $\Delta = 0.14$, significance=1 per cent).
This result supports the idea that when the asymmetries are present we are looking in the inner regions of the NLR where the kinematics is more complicated and chaotic, and probably the gas is not simply moving in the gravitational potential but it is driven by winds and decelerating outflows (Wagner 1997; Komossa et al. 2008). Finally, we did not find any correlation between these asymmetry parameters and the luminosity, the FWHM of both components, and $\Lambda(V)$.

5.5 Energy and Accretion rate

With the ionized gas mass and velocity values, it is possible to determine the kinetic energy due to turbulence, thermal and bulk motion. The third one would require velocity field, which are not available in our case. We could only use the asymmetric components (broader or second component) found in the $\text{[O III]}\lambda5007$ line to derive the order of magnitude of the kinetic energy due to bulk motion. These energies are determined using the formalism introduced by Fu & Stockton (2007). The turbulent energy can be estimated from the measured velocity dispersion $\sigma(H\beta)$, 

$$E_{\text{tur}} = M\sigma^2 = 5.0 \times 10^{56} M_{10} \sigma_{50}^2 \text{ erg}$$

where $\sigma_{50} = \sigma(H\beta)/50 \text{ km s}^{-1}$ and $M_{10}$ the mass expressed in $10^{10} M_\odot$. The thermal energy is

$$E_{\text{th}} = \frac{3}{2} M k T / m_p = 2.5 \times 10^{55} M_{10} T_4 \text{ erg}$$

where $T_4 = T / 10000 K$ The bulk kinetic energy is given by

$$E_{\text{bulk}} = \frac{1}{2} M V^2 = 6.2 \times 10^{57} M_{10} V_{250}^2 \text{ erg}$$

where $V_{250}$ is the bulk velocity in $V/250 \text{ km s}^{-1}$ units. The bulk velocity is estimated from the difference in the peak velocities of the $\text{[O III]}\lambda5007$ components ($\delta p$ parameter), the narrow component is assumed to have the systemic velocity (Fig. 31).

Thermal and turbulent energy distributions are plotted in Fig. 32. The distributions are similar for S2 and S-I with a logarithmic median value around 52.7 and 54.7 respectively for the thermal and turbulent energy. The thermal energy is negligible compared to the turbulent energy. In order to derive the bulk kinetic energy it is necessary to obtain the $\text{[O III]}\lambda5007/H\beta$ ratio of the second component and then apply Eq. 5 to estimate the involved mass. Unfortunately, only in 14 spectra it was possible to fit two components in both $\text{[O III]}$ and $H\beta$. However, by plotting $\delta p (H\beta)$ vs. $\delta p ([\text{O III}])$, we found a good agreement between the fitted values, and the flux ratio of the second component is between 3 and 10 (Fig. 33), which is consistent with the assumption of Fu & Stockton (2006) and with the measures of Cid Fernandes et al. (2001). Then, by assuming 10 as a representative value of the $\text{[O III]}\lambda5007/H\beta$ ratio, from the
luminosity of [OIII]λ5007 second component and assuming low density \( N_e = 10 \, \text{cm}^{-3} \) we obtained a mass distribution with a median logarithmic value around 6.8 for both the samples. Hence the masses involved in the bulk motions are about 1/3 of the total mass. If the bulk motions are connected to outflows and we assume a typical dynamical time scale of 10\(^7\) yr (see below), the resulting rate of mass outflow is \( \sim 1 \, M_\odot \, \text{yr}^{-1} \). Finally, from the velocity peak difference, we derived the bulk kinetic energy by means of Eq. (11). The logarithm of median bulk kinetic energy values is around 53.5. The distributions (Fig. 32, bottom panel) show that the 80 per cent of the samples have values lower than 54.5, this means that the bulk kinetic energy is approximately lower than one order of magnitude compared to the turbulent energy. We stress that this could be an upper limit, since we assumed that all the flux of the second component is emitted by outflowing mass. If we assume that the outflow is directly driven by the black hole (BH), we can estimate the mass accretion rate necessary to sustain the outflow. The input momentum rate from radiation pressure is:

\[
\dot{p} = 1.3 \times 10^{35} (\eta/0.1) M_{\text{acc}} \, \text{dyne}
\]

where \( \eta \) is the radiative efficiency and \( M_{\text{acc}} \) is the mass accretion rate of the BH in units of \( M_\odot \, \text{yr}^{-1} \) [Fu & Stockton (2000)]. The momentum rate of the moving bulk mass is given by:

\[
\dot{p} \sim M \times V_{\text{bulk}}/t_{\text{dyn}} \, \text{dyne}
\]

where \( t_{\text{dyn}} \) is the dynamical time scale. We estimated \( t_{\text{dyn}} \) from the NLR radius

\[
t_{\text{dyn}} \sim R_{\text{NLR}}/V_{\text{bulk}} \, \text{s}
\]

obtaining the same distributions for both samples. The median value is 10\(^7\) yr, and 80 per cent of the samples have \( t_{\text{dyn}} < 3 \times 10^7 \) yr. Finally, by assuming \( \eta \sim 0.1 \) and making Eq. (12) equal to Eq. (13) we obtained an estimate of the \( M_{\text{acc}} \) distribution (Fig. 33). The median value is around 0.003 \( M_\odot \, \text{yr}^{-1} \). 80 per cent of the samples have \( M_{\text{acc}} < 0.03 \, M_\odot \, \text{yr}^{-1} \). These values are in agreement with the generally accepted accretion rates in Seyfert galaxies.

6 SUMMARY AND CONCLUSIONS

A sample of 5678 Seyfert galaxies was selected from SDSS-DR7 by applying the \( O_\beta \) diagram and their emission-lines were measured by means of a dedicated automatic code based on a nonlinear least square fitting method. Two components were applied to \( H_\beta \) and \( H_\alpha \) when necessary, and to \([OIII]g\) emission-lines in order to analyze their profiles. The galaxies were divided into two groups on the basis of the \( H_\alpha \) FWHM values and of the VO diagnostic diagrams, obtaining 2153 Seyfert 2 galaxies and 521 Intermediate-type Seyfert galaxies. Our results, obtained through a detailed spectroscopic analysis of the NLR of these two samples and a comparison between their physical properties, are in agreement with what is expected by the Unified Model and add new details to the general knowledge of the AGN properties.

(i) The reddening for the gas, obtained by means of the Balmer decrement, is on average stronger in S2 (<\( A(V) > < 1.5 \)) than in S-I (<\( A(V) > < 1 \)). According to the Unified Model this is expected, because of the different line-of-sight orientation with respect to the torus axis. Indeed, Rodriguez-Ardila, Pastoriza, & Donzelli (2000) found \( A(V) = 0.663 \pm 0.345 \) for a sample of 16 Broad Lined Seyfert 1 (BLS1). In addition, the reddening of the stellar component shows lower \( A(V) \) values, weakly correlated with those for the gas. This suggests that the extinction is mostly caused by dust associated to the gas of the NLR.

(ii) Both the samples show good correlation between the lines having similar ionization potential.

(iii) The absence of [Ariv]λ4711,4740 doublet and the values of temperature derived by [OIII], [OII] and [SII] line ratios, strongly support the idea that the NLR of Seyfert galaxies is a multi-phase ionized gas. In particular, it is likely made of a very low density medium (\( N_e \sim 1 - 10 \, \text{cm}^{-3} \)), where filaments or clouds with low density (\( N_e \sim 10^2 \, \text{cm}^{-3} \)) and high density (\( N_e > 10^3 \, \text{cm}^{-3} \)) are moving. The high density is expected to suppress [Ariv] lines and at the same time to pump [OIII]λλ4363 by collisional processes.

(iv) The [Fevii] coronal lines are detected in \( \sim 4 \) per cent of the S2 sample, and \( \sim 19 \) per cent of the S-I sample. The
analysis of the $[\text{Fe} \, \text{vii}] \lambda 6087/[\text{O} \, \text{iii}] \lambda 5007$ emission-line ratio indicates higher values for the S-I sample and suggests that the coronal lines are formed deep inside the NLR. This result is in agreement with Nagao, Taniguchi, & Murayama (2000) who found $\log [\text{Fe} \, \text{vii}] \lambda 6087/[\text{O} \, \text{iii}] \lambda 5007 = -0.94 \pm 0.39$, -1.33 $\pm$ 0.43, -1.81 $\pm$ 0.29 for BLS1, S-I and S2, respectively.

(v) The ionization parameter $U$ is in general significantly higher in S-I than in S2, showing average values of about $-2.4$ and $-2.7$, respectively. However, if we isolate the S2 galaxies showing high ionization lines, as HeII $\lambda 4686$ and/or $[\text{Fe} \, \text{vii}] \lambda 6087$, the distributions of $U$ for the two samples become similar. This result can be explained in case of a thinner torus which let the deeper and more strongly ionized NLR to be observed. A comparison can be made with Ferland & Netzer (1983) who estimated typical values of $-2$, $-2.5$ and $-3.5$, for S1, S2 and LINERs, respectively, by means of photoionization models.

(vi) A good correlation between gaseous and stellar kinematics is observed only in S2 galaxies, and only in case of low ionization and Balmer lines. This suggests that the kinematics of the NLR is dominated by the gravitational potential of the galaxy only in the less ionized regions. Therefore, we confirm and point out that the FWHM of $[\text{O} \, \text{iii}] \lambda 5007$ line cannot be use as a surrogate of the stellar velocity dispersion in Seyfert galaxies.

(vii) In addition, about 75 per cent of galaxies in both samples show asymmetries on the blue wing of the $[\text{O} \, \text{iii}] \lambda 5007$ line profile, suggesting the presence of radial motions, inflows and/or outflows, of the highly ionized gas. Also H$\beta$ lines show asymmetries, which are nevertheless not correlated with those observed in $[\text{O} \, \text{iii}]$, with the exception of few cases ($< 10$ per cent). $[\text{O} \, \text{iii}] \lambda 5007$ profiles with strong blue wings have been also found in a sample of radio-loud quasars by Brotherton (1996). The author claimed that the H$\beta$ profiles show strong red wings.

(viii) However, energy balance calculations, based on the estimated ionized gas mass, which is on average around $3 \times 10^7 M_\odot$ for both samples, clearly indicate that the turbulent energy is the dominant component, with values in the range $10^{34} – 10^{36}$ erg. The kinetic bulk energy is an order of magnitude lower, while the thermal energy plays a negligible role.

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