Type 1 AGN at low z – III. The optical narrow-line ratios

Jonathan Stern* and Ari Laor

Department of Physics, Technion – Israel Institute of Technology, Haifa 32000, Israel

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ABSTRACT

We present the optical narrow-line ratios in a Sloan Digital Sky Survey (SDSS) based sample of 3175 broad Hα selected type 1 active galactic nuclei (AGN), and explore their positions in the BPT diagrams as a function of the AGN and the host properties. We find the following: (1) the luminosities of all measured narrow lines (Hα, Hβ, [O iii], [N II], [S ii], [O i]) show a Baldwin relation relative to the broad Hα luminosity $L_{\text{bol/H}}$, with slopes in the range of 0.53–0.72. (2) About 20 per cent of the type 1 AGN reside within the ‘Composite’ and ‘star-forming’ (SF) regions of the Baldwin, Phillips & Terlevich (BPT) diagrams. These objects also show excess narrow Hα and ultraviolet (UV) luminosities, for their $L_{\text{bol/H}}$, consistent with contribution from star formation which dominates the narrow-lines emission, as expected from their positions in the BPT diagrams. (3) The type 1 which reside within the AGN region in the BPT diagrams, are offset to lower $[S\text{ ii}]/H\alpha$ and $[N\text{ ii}]/H\alpha$ luminosity ratios, compared to type 2 AGN. This offset is a selection effect, related to the lower AGN/host luminosity selection of the type 2 AGN selected from the SDSS galaxy sample. (4) The $[N\text{ ii}]/H\alpha$ and $[N\text{ ii}]/[S\text{ ii}]$ ratios in type 1 AGN increase with the host mass, as expected if the mass–metallicity relation of quiescent galaxies holds for the AGN narrow-line region (NLR). (5) The broad lines optical Fe ii is higher for a higher $[N\text{ ii}]/H\alpha$, at a fixed $L_{\text{bol}}$ and Eddington ratio $L/L_{\text{Edd}}$. This suggests that the broad line region metallicity is also related to the host mass. (6) The fraction of AGN which are low-ionization nuclear emission-line regions (LINERs) increases sharply with decreasing $L/L_{\text{Edd}}$. This fraction is the same for type 1 and type 2 AGN. (7) The BPT position is unaffected by the amount of dust extinction of the optical–UV continuum, which suggests that the extincting dust resides on scales larger than the NLR.

Key words: galaxies: Seyfert.

1 INTRODUCTION

The gas located on 1–1000 pc scale from the centre of active galactic nuclei (AGN) plays a role in several important processes, which are not well understood. This gas is the source of AGN fuel and may absorb AGN energy and momentum output, thus potentially coupling the growth of the bulge with the growth of the central black hole. It also reprocesses the AGN ionization continuum, which originates from a few Schwarzschild radii, and thus its emission may allow us to constrain the accretion mode in the innermost regions.

The most prominent optical signature of the circumnuclear gas in AGN is its emission lines, which have widths typical of the galaxy potential (~300 km s$^{-1}$). These lines are known as the narrow emission lines, and the emitting region is known as the narrow-line region (NLR). The vast majority of NLR analyses were performed on type 2 AGN where the central source is obscured, partly because the narrow lines are not blended with the broad emission lines, which dominate the emission features in unobscured type 1 AGN. Most previous studies of the NLR of type 1 AGN were either limited to the most prominent forbidden lines (e.g. Boroson & Green 1992, using [O iii] $\lambda$5007), limited to small samples (e.g. Baldwin, Phillips & Terlevich 1981, hereafter BPT; Cohen 1983; Ho et al. 1997b, Rodríguez-Ardila et al. 2000; Véron-Cetty, Véron & Gonçalves 2001; Dietrich, Crenshaw & Kraemer 2005) or limited to samples of very weak type 1 AGN (e.g. Greene & Ho 2007) in which the narrow lines become more prominent (Stern & Laor 2012b, hereafter Paper II).

A measurement of narrow-line luminosities of a large sample of type 1 AGN, including luminous quasars, was performed by Zhang et al. (2008). They found that the narrow-line luminosity ratio $[N\text{ ii}]/H\alpha$ of type 1 AGN is offset to lower values than in type 2 AGN. Here we significantly expand their work, by studying the NLR properties of a large sample of 3175 type 1 AGN, hereafter the T1 sample, defined in Stern & Laor (2012a, hereafter Paper I) with minor adjustments detailed below. The T1 sample spans a...

*E-mail: stern@physics.technion.ac.il
black hole mass range of $10^6 < M_{\text{BH}} < 10^{9.5} \text{ M}_\odot$ and a bolometric luminosity range of $10^{42} < L_{\text{bol}} < 10^{46} \text{ erg} \text{ s}^{-1}$. In contrast with studies of type 2 AGN, here the AGN is unobscured. We use the narrow-line measurements, combined with the AGN spectral energy distribution (SED) and broad line measurements, to address the following questions.

How complete is the BPT classification of AGN?: The BPT diagrams (BPT and Veilleux & Osterbrock 1987, hereafter VO) compare the ratio of the [O iii] to Hβ luminosity (for brevity [O iii]/Hβ), with [N ii]/Hα, (S ii]/λ6716, 6731)/Hα and [O i]/λ6300)/Hα. These line ratios provide a measure of the relative strength of the higher energy ionizing photons, and thus differentiate between stellar and AGN excitation. These diagrams are widely used to define type 2 AGN samples, using selection lines based on theoretical models (Kewley et al. 2001, hereafter Ke01) and on the observed distribution of star-forming galaxies (Kauffmann et al. 2003a, hereafter Ka03).

The BPT/VO AGN selection criteria are commonly viewed as necessary and sufficient conditions to define AGN. However, AGN samples selected by other means show these selection criteria may not be necessary conditions. In a hard X-ray selected sample, a unique signature for AGN emission, Winter et al. (2010) found that five out of 60 objects are in the star-forming (SFs) galaxies regime, i.e. below the Ka03 line in the [N ii]/Hα panel of the BPT diagrams, and five more are between the Ka03 line and the Ke01 line, i.e. ‘Composites’. In the $M_{\text{BH}} < 10^{9.2} \text{ M}_\odot$ type 1 sample of Greene & Ho (2007), 39 per cent of the objects are SFs or Composites. This fraction dropped to 18 per cent when the spectra were taken from a narrower slit (Xiao et al. 2011). On the other hand, only 3 per cent of radio loud AGN are classified as Composites or SFs (Bottagioni et al. 2010). Using the T1 sample, which is selected independently of the narrow-line properties, we derive the completeness of the BPT-based selection criteria, and its dependence on the AGN emission properties.

How are the properties of the NLR gas related to AGN and host properties?: In low $z$ type 2 AGN, the value of [N ii]/Hα, which follows NLR metallicity, $Z_{\text{NLR}}$, has been found to modestly increase with host mass $M_\star$ (Groves, Heckman & Kauffmann 2006) and with host velocity dispersion $\sigma_\star$ (Annibali et al. 2010). These trends are associated with the known $M_\star - Z$ relation of quiescent galaxies (Lequeux et al. 1979, and citations thereafter). The $Z_{\text{NLR}} - M_\star$ relation is also implied by the fact that most AGN reside in massive galaxies (Ka03) and have $Z_{\text{NLR}} > Z_\odot$ (Storchi-Bergmann et al. 1998; Groves, Dopita & Sutherland 2004; Groves et al. 2006), while the rare low $M_\star$ AGN have low $Z_{\text{NLR}}$ (Kraemer et al. 1999; Barth, Greene & Ho 2008; Ludwig et al. 2012). However, these samples are dominated by low $L_{\text{bol}}$ AGN, since they are based on the detectability of the host galaxy, and therefore are limited to a small volume where luminous AGN are rare.

In high $L_{\text{bol}}$ AGN at high $z$, an $M_\star - Z$ relation can be inferred from the increase of $Z_{\text{NLR}}$ with $L_{\text{bol}}$ (Hamann & Ferland 1993, 1999; Nagao, Marconi & Maiolino 2006a), and a likely relation of $L_{\text{bol}} - M_\star$. Though $Z_{\text{NLR}}$ and $Z_{\text{NLR}}$ are related (Shields, Ludwig & Salviander 2010), there seems to be another variable beyond $M_\star$ which determines $Z_{\text{NLR}}$, probably related to the accretion rate in Eddington units ($L/L_{\text{Edd}}$), Shemmer & Netzer 2002; Shemmer et al. 2004; Shields et al. 2010). Therefore, it is interesting to compare $Z_{\text{NLR}}$ with $L_{\text{bol}}$ directly. Most narrow-line measurements in high $L_{\text{bol}}$ AGN are based on narrow-line radio galaxies samples (De Breuck et al. 2000; Vernet et al. 2001; Iwamuro et al. 2003; Nagao, Maiolino & Marconi 2006b). These studies measured UV line ratios, except Iwamuro et al. which measured non-BPT optical line ratios. Comparison of NLR properties derived from different lines can be ambiguous, due to degeneracies in the photoionization models (Nagao et al. 2006b). Therefore, the dependence of $Z_{\text{NLR}}$ and other NLR properties on $L_{\text{bol}}$ is still an open question. In this work, we derive indicators of $Z_{\text{NLR}}$ based on the BPT ratios, for a large dynamical range in $L_{\text{bol}}$. Using the large size of the T1 sample, we also decouple the dependence of $Z_{\text{NLR}}$ on $L_{\text{bol}}$ and on $M_\star$, and compare $Z_{\text{NLR}}$ with $Z_{\text{NLR}}$.

Is the ratio of UV to X-ray luminosity a measure of the slope of the ionizing spectrum?: Due to Galactic absorption, the ionizing part of the AGN spectrum in the extreme UV is generally unavailable. Laor et al. (1997) showed that the mean 2 keV luminosity $L_X$ of PG quasars is consistent with an extrapolation of the mean extreme ultraviolet (EUV) slope (Zheng et al. 1997; Telfer et al. 2002). Therefore, the interpolated slope between $L_{\text{UV}}$ and $L_X$, $\alpha_{\text{ox}}$, may provide a good estimate of the true ionizing slope. Since the BPT diagrams provide an independent constraint on the ionizing slope, we explore this hypothesis by comparing the BPT ratios with $\alpha_{\text{ox}}$ in the T1 sample.

A related issue concerns the location of the optically thin dust found in type 1 AGN samples (Richards et al. 2003; Gaskell et al. 2004; Paper I), which can harden $\alpha_{\text{ox}}$. If the extinctioning dust is located within the NLR, the NLR will see a harder spectrum, and the BPT ratios are expected to vary with the amount of reddening. If the extinctioning dust resides outside the NLR, the NLR will absorb the original ionizing spectrum, and the BPT ratios will remain constant.

Below, we constrain the location of the extinctioning dust using the BPT diagrams.

Is the Seyfert-LINER transition related to other emission properties?: Kewley et al. (2006, hereafter Ke06) found a bimodality in the BPT diagrams between high- ionization Seyferts and low- ionization nuclear emission line regions (LINERs, Heckman 1980). They showed the Seyfert-LINER transition is related to $L_{\text{UV}} / L_{\text{bol}}$, as noted previously by Ho (2002). This transition has also been claimed to be related to the existence of the broad lines, due to the low detection fraction of broad lines in LINERs (Ho et al. 1997b). We address these suggestions based on the T1 sample.

The paper is organized as follows. In Sections 2.1–2.3, we summarize the creation of the T1 sample and the measurement of the AGN and host properties, analysed in Papers I and II. In Section 2.4, we describe the comparison type 2 sample we use, and account for differences in the measurement procedures. In Section 3, we extend the relative decrease with $L_{\text{bol}}$ (the Baldwin effect) found in Paper II for [O iii] and Hα, to the Hβ, [N ii], [S ii] and [O i] lines. We then proceed in Section 4 to measure the BPT ratios of the T1 sample, and their dependence on AGN and host characteristics. In Section 5, we analyse objects which occupy a region in the BPT plots which is not populated in type 2 samples. In Section 6, we identify the $M_\star - Z$ relation in the T1 AGN. Analysis of LINERs and Composites is performed in Sections 7 and 8. In Section 9, we use the BPT ratios to constrain the AGN ionizing spectrum and the location of the reddening dust. We summarize our results in Section 10.

Throughout the paper, we assume an FRW cosmology with $\Omega = 0.3$, $\Lambda = 0.7$ and $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$. 

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**Type 1 low z AGN. III. Narrow line ratios**

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2 THE DATA

2.1 The T1 sample selection

The T1 sample is selected from the 7th data release of the Sloan Digital Sky Survey (SDSS DR7; Abazajian et al. 2009). The SDSS obtained imaging of a quarter of the sky in five bands (ugriz; Fukugita et al. 1996) to a 95 per cent r-band completeness limit of 22.2 mag. Objects are selected for spectroscopy mainly due to their non-stellar colours (Richards et al. 2002), or extended morphology (Strauss et al. 2002). The spectrographs cover the wavelength range 380 Å–9200 Å at a resolution of ~150 km s⁻¹, and are flux-calibrated by matching the spectra of simultaneously observed standard stars to their point spread function (PSF) magnitude (Adelman-McCarthy et al. 2008).

We use SDSS spectra which have 0.005 < z < 0.31 and are classified as quasars or galaxies. To ensure a reliable decomposition of the broad and narrow components of Hα, we use only spectra with signal-to-noise ratio (S/N) >10 and a sufficient number of good spectral pixels in the vicinity of Hα, as detailed in Paper I. These requirements are fulfilled by 232 837 of the 1.6 million spectra in DR7, named here the parent sample. The spectra are corrected for foreground dust, using the maps of Schlegel, Finkbeiner & Davis (1998) and the extinction law of Cardelli, Clayton & Mathis (1989). Each spectrum is then fit with three galaxy eigenspectra representing the host (see Section 2.2.4 below), and an Lα ∝ λ⁻¹.⁵ power law representing the AGN continuum. The host is subtracted, producing a spectrum free of stellar absorption features, excluding the Balmer absorption lines, which are handled at a later stage (see Section 2.2.4). We also subtract a featureless continuum, derived by interpolating the mean continuum level at 6125–6250 Å and 6880–7000 Å. The residual flux at 6250–6880 Å (±14 000 km s⁻¹ from Hα) is then summed, excluding regions ±690 km s⁻¹ from the [O[ II] λλ6300, 6363, [N[ II] λλ6548, 6583, [S[ II] λλ6716, 6731 and Hα narrow emission lines. We find 6986 objects with significant residual flux, which is potentially broad Hα emission.

For the objects with significant residual near Hα, we fit the profiles of the broad and narrow Hα, and the [O[ III] λ5007, [O[ I], [N[ II] and [S[ II] doublets mentioned above. Narrow lines are fit using fourth-order Gauss–Hermite functions (GHs; van der Marel & Franx 1993) and an up to tenth-order GH is used for the broad Hα profile. Furthermore, details are given in section 2.4 of Paper I and sections 2.3–2.4 of Paper II. The following criteria are applied to the broad Hα fit, in order to exclude objects in which the residual flux is not clearly BLR emission: the FWHM (Δν) of the fit is required to be in the range 1000–25 000 km s⁻¹; the total flux of the fit and its flux density at the line centre are required to be significant. As [O[ III] and Hβ are used extensively in this paper, we require them to have a sufficient number of good pixels in their vicinity for the fit to be reliable, as detailed in Paper I.

Of the 3243 objects that pass these criteria, we use here 3175 objects in which our algorithm achieved reliable narrow-line fits (see below). Due to the small relative number of objects in which the fitting algorithm did not succeed, we do not attempt to improve the algorithm further. The broad Hα luminosity (LbHα) and Δν of the 3175 objects of the T1 sample are listed in Table 1. The selection effects implied by our selection criteria are detailed in Paper I.

2.2 Narrow-line measurements

The narrow-line luminosities of the T1 sample are listed in Table 2. We emphasize that these luminosities within the SDSS 3 arcsec fibre, and that in all T1 objects the fibre was pointed at the centre of the host galaxy (see section 2.5 in Paper I). Below, we address the limitations of our fitting algorithm, which deblends the narrow lines from the broad lines and from the stellar absorption features. The success of the deblending can be further verified with higher S/N spectra, where the transitions between the different components are more prominent. Therefore, we corroborate our results by analysing the mean spectra of different T1 subgroups, which have an effectively higher S/N.

2.2.1 Bad pixels

The main source of bad pixels in the SDSS spectra is poor sky subtraction, which degrades the spectrum mainly at λ > 8000 Å. Therefore, the [S[ II] and [O[ I] lines are not measurable in 612 (19 per cent) and 190 (6 per cent) of the T1 objects, respectively. These objects are marked in Table 2, and are disregarded in figures where the line is used. Objects in which one of the other lines used in this work has bad pixels do not enter the T1 sample (Section 2.1).

2.2.2 Upper limits

Our algorithm can robustly detect the six different narrow lines if their mean flux density Fν is 2–3.5 times the local flux density. The exact value depends on how blended a specific line is with other spectral features, and is listed in Table 3. The upper limits on the fluxes of lines with lower Fν are derived by assuming a Gaussian profile, with a flux density equal to the minimum Fν required for detection and the width fit to the other narrow emission lines. Objects with upper limits are noted in Table 2.

The T1 sample detection fractions of the different lines are listed in Table 3. The detection fractions are all > 77 per cent.

2.2.3 [O[ III]–like narrow lines

As noted in Papers I and II, in 15 per cent of the sample the fit yielded FWHM(nHα) ≥ 1.5 × FWHM([O[ III]). These objects have non- or barely-detectable narrow lines near Hα, and there is no clear transition between the broad and narrow components of the Balmer lines. Therefore, we fit the narrow lines near Hα in these objects with an FWHM, third- and fourth-GH parameters equal to those found for [O[ III].

An eye-inspection of the narrow Hβ fits yielded another 188 objects (6 per cent) without a clear NLR/BLR transition, despite having FWHM < 1.5 × FWHM([O[ III]). We refit these objects with [O[ III]–like profiles, and updated the relevant narrow-line fluxes. The new fit failed in 68 of the objects (reduced χ² > 2). Due to their relatively small number, we did not attempt to improve the fit, and

### Table 1. The AGN and host characteristics of the T1 sample objects. The values of LbHα and Lbν are in log erg s⁻¹, Δν is in km s⁻¹ and Mα is in log M⊙. The last column lists notes for Mα, Lbν and Lα, separated by commas: ‘U’ indicates an upper limit, and ‘N’ indicates not available. The electronic version includes all 3175 T1 objects.

| Object name | LbHα | Δν | Mα | Lbν | eαα Notes |
|-------------|------|----|----|-----|-----------|
| J000202.95–103037.9 | 41.9 | 2310 | 10.9 | 43.8 | -1.50 | -,-,- |
| J000410.80–104527.2 | 42.6 | 1360 | 11.0 | 44.6 | -1.57 | -,-,- |
| J000611.55+143537.2 | 42.1 | 3320 | 11.1 | 44.0 | -1.57 | -,-,- |
| J000614.36–010984.7 | 41.6 | 3910 | 10.7 | 43.2 | -1.54 | -,-,-,U |
| J000857.76+152550.0 | 41.5 | 3020 | 10.0 | 43.0 | -1.57 | -,-,-,U |

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Table 2. The narrow-line measurements of the T1 sample. All luminosities are in log erg s^{-1}. Notes on the measurements of the six lines are separated by commas in column 8, ordered as in the table. A ‘U’ designates an upper limit, an ‘N’ designates bad pixels (for [S ii] and [O i] only) which are also marked as −1 in the corresponding luminosity. The objects in which the H\beta, H\beta or [N ii] narrow-line measurements are not robust (Section 2.2.3), or the Balmer lines are affected by strong stellar absorption features (Section 2.2.4), are marked by an ‘x’ in the respective following columns. Other objects are marked by a ‘+’.

| Object name         | H\beta | [O iii] | H\alpha | [N ii] | [S ii] | [O i] | Notes  | Robust | Stellar absorption | BPT-[N ii] | BPT-[S ii] | BPT-[O i] |
|---------------------|--------|---------|---------|--------|--------|-------|--------|--------|-------------------|------------|------------|-----------|
| J000202.95−103037.9 | 40.7   | 41.4    | 41.2    | 41.3   | 41.0   | 40.2  | -      | -      | AGN              |            |            |           |
| J000410.80−104527.2 | 41.3   | 41.5    | 41.9    | 41.6   | -1     | -1    | -      | -      | Composite         | SF         | SF         |           |
| J000611.55+145357.2 | 40.2   | 40.6    | 41.0    | 40.7   | 40.5   | 39.8  | -      | -      | Composite         | SF         | SF         |           |
| J000614.36−010847.2 | 40.4   | 40.9    | 41.1    | 40.7   | -1     | -1    | -      | -      | Composite         | SF         | SF         |           |
| J000657.76+152550.0 | 40.2   | 40.8    | 40.7    | 40.3   | 39.7   | -      | -      | -      | Composite         | Seyfert    | Seyfert    |           |

simply removed these 68 objects from the sample. This change in the narrow-line fluxes of 6 per cent of the T1 sample has a negligible effect on the results presented in Papers I and II.

The narrow H\alpha, H\beta and [N ii] line fluxes are less certain in objects fitted with an [O iii]-like profile. Therefore, throughout the paper different symbols are used when these measurements are utilized. These objects are also noted in Table 2.

2.2.4 Strong stellar Balmer absorption

We model the stellar absorption features by fitting the first three Yip et al. (2004) eigenspectra (ESa) to the SDSS spectra, together with a power law for the AGN continuum. Since the Yip et al. ESa have emission lines, in ES1, we replace the lines with the absorption features of the Hao et al. (2005) ES1 (detailed in section 2.2 of Paper II). This step is justified since both ES1’s represent an old stellar population. In ES2 and ES3, which represent a younger population, an emission line free ES is not available, so we simply interpolate over the lines.

Since the absorption lines are significantly wider than the emission lines, an interpolation over the emission will not remove the entire absorption feature. However, near H\alpha the interpolation is done also over the [N ii] lines which flank H\alpha. Therefore, our fit does not account for the entire H\alpha absorption feature of young stars. In Paper II, we found that in the 5 per cent of the T1 objects that have L_{\text{H\alpha}} < 3 \AA \times L_{\lambda}(host), the L_{\text{H\alpha}} are underestimated due to improper subtraction of the stellar absorption. Now, the narrow H\beta emission line is weaker than H\alpha and therefore more suspect to significant biases due to improper subtraction of the stellar absorption features. However, near H\beta the interpolation in ES1 and ES2 is performed only over the narrow H\beta line, so the wide part of the stellar absorption feature is accounted for by our fit. Therefore, we mark the same objects as in Paper II, i.e. objects with L_{\text{H\alpha}} < 3 \AA \times L_{\lambda}(host), as objects with potentially underestimated L_{\text{H\alpha}} and L_{\text{H\beta}}. We verify below this suffices in order to identify objects with offset L_{\text{H\beta}} values.

2.3 Additional properties

2.3.1 L_\alpha and M_\alpha

We derive the host galaxy luminosity, L_\alpha, by subtracting the estimated net AGN luminosity from the total observed luminosity.

For the total observed luminosity, we use the SDSS cModel flux (\cite{Abazajian2004}) in the z band, which is a linear sum of a de Vaucouleurs model and an exponential model fit to the image, and is the best-suited model to account for both the galaxy and the nuclear light. The z band is chosen since it is the reddest SDSS band, therefore it has the highest host to AGN contrast. It also has the smallest dispersion in the ratio of host mass to host light. We estimate the net AGN luminosity at the z band, L_{\text{AGN}; z-band}, to be 10 \times L_{\text{H\alpha}} (Paper I). We do not use the eigenspectra fit described in Section 2.1 to estimate the host luminosity, due to degeneracies between the host and AGN continuum flux in this fit (see section 2.2 in Paper I).

To convert the L_\alpha of the T1 AGN to M_\alpha, we compare M_\alpha with L_{\alpha; band} in the type 2 AGN sample described below. The M_\alpha of the type 2 AGN were measured by Kauffmann et al. (2003b), as part of the MPA/JHU analysis of SDSS spectra.\(^2\) Also, Ka03 found that the mean colour of type 2 AGN hosts becomes bluer with increasing L_{(O_m)}. Accordingly, we calculate the mean mass to z-band light ratio for each L_{(O_m)} (0.5 dex bins), and find a mean M/L = 2.6 at L_{(O_m)} = 10^{49} erg s^{-1} and M/L = 1.7 at L_{(O_m)} = 10^{42.5}, where M/L is given in solar units. The M/L dispersion in each L_{(O_m)} bin is ~0.15 dex. In Paper I, we showed that the colour of the mean hosts of type 1 AGN at different luminosities equals the mean colour of type 2 hosts with the same luminosity. Therefore, for each T1 AGN, we use the M/L appropriate for its L_{(O_m)}. We note that if we had used the median M/L for all T1 AGN, the implied M_\alpha would have changed by <0.1 dex. The individual M_\alpha of the T1 sample objects are listed in Table 1.

An additional source of error is the scatter in the ratio of L_{\text{AGN}; z-band} to L_{\text{H\alpha}}. We assume that this scatter equals the scatter in the relation between L_{\text{total}; 5100 \AA} and \lambda_{\text{H\alpha}} of 0.5 < z < 0.7 SDSS quasars – the lower z limit ensures the quasars are luminous and host contribution to the continuum is minimal, while the upper z limit ensures H\beta fully appears in the spectrum. Using the L_{\text{H\beta}}

\(^1\) Not available for seven objects. They are disregarded when M_\alpha is used.

\(^2\) Available at http://www.mpa-garching.mpg.de/SDSS/DR7/
and $L_{\text{total}, 5100 \text{Å}}$ values from Shen et al. (2011), we find a scatter of 0.2 dex. This scatter implies that in the 9 percent of the T1 objects with implied $L_{\text{AGN}}/L_*$ > 1, the true $L_*$ may be overestimated by a factor of more than 2; therefore, we treat these measurements of $L_*$ as upper limits. In the 3 percent of T1s with implied $L_{\text{AGN}}/L_*$ > 3, the true $L_*$ may also be underestimated by a factor of more than 2. In 0.5 percent of the objects, the implied $L_*$ is negative. In both cases, we set $L_{\text{AGN}}/L_*$ = 3 and treat these measurements of $L_*$ as upper limits.

2.3.2 $L_{\text{UV}}$ and $\alpha_{\text{ox}}$

We derive the $L_{\text{UV}} = v L_\nu (1528 \text{ Å})$ and $L_X = v L_\nu (2 \text{ keV})$ of the T1 AGN from the GALEX (Martin et al. 2005) and ROSAT (Voges et al. 1999) surveys. GALEX observed 89 percent of the T1s, and detected 93 percent of them. ROSAT observed the entire sky, and detected 43 percent of the T1s. The derivation of the luminosities is detailed in Paper II. Table 1 lists $L_{\text{UV}}$ and $\alpha_{\text{ox}} = -0.42 \times \log L_{\text{UV}}/L_X$, the slope of the interpolated power law between the UV and the X-ray.

2.4 The T2 sample

We compare our results to the Brinchmann et al. (2004) type 2 AGN sample, which was derived from the SDSS galaxy survey, using the emission lines measurement of the MPA/JHU group. The type 2 AGN were selected by requiring S/N > 3 in the [O III], Hβ, [N ii] and Hα narrow emission lines, and being above the Ke01 ‘extreme starburst’ line in the BPT-[N ii] panel. We use all type 2 objects that appear in our parent sample (following the S/N > 10 and bad pixel cuts, Section 2.1), excluding the 454 objects which enter the T1 sample, as they show broad Hα emission. We name these 13 705 objects as the T2 sample.

The MPA/JHU group modelled the stellar absorption features using the Bruzual & Charlot (2003) stellar library. We use a simpler technique in the T1 sample, based on the Yip et al. (2004) SSA, due to possible degeneracies of different stellar components with the unobscured AGN continuum (see section 2.2.3 in Paper I). In order to understand the effect of the different stellar modelling techniques on the measured narrow-line ratios, and the effect of other differences in the fitting procedure, we run our fitting algorithm on 700 spectra from the T2 sample. Then, we compare the narrow-line ratios we measure on these T2s with those published by the MPA/JHU group.

In these 700 type 2s, our algorithm gives [O iii]/Hβ ratios which are on average 0.08 dex larger than the ratios measured by MPA/JHU, with a dispersion of 0.11 dex. Our [N ii]/Hα, [S ii]/Hα and [O i]/Hα measurements are on average 0.04, 0.1 and 0.07 dex larger than MPA/JHU, with dispersions of 0.09, 0.1 and 0.1 dex. The offsets in the narrow-line ratios are mainly due to offsets in the measured flux of the narrow Hα and Hβ lines (mean offset ~0.09 dex each), which could imply that we did not fully correct for the stellar Balmer absorption features. Therefore, to minimize offsets between the T1 and T2 sample which originate from measurement issues, we hitherto decrease the BPT ratios we measure in the T1 sample objects by these mean offsets. Also, we assess the systematic error in our measurement of these ratios to be 0.1 dex.

3 THE BALDWIN EFFECT OF THE NARROW LINES

In Fig. 1, we present the ratio of the narrow-lines luminosity $L_{\text{bH}\alpha}$, $L_{\text{[OIII]}}/L_{\text{[SII]}}$ and $L_{\text{[OII]}}/L_{\text{[NeIII]}}$ with $L_{\text{bH}\alpha}$ as a function of $L_{\text{bH}\alpha}$. Black dots mark objects with robust measurements, while grey markers indicate the less robust values. For each narrow line, we perform a least-squares best fit of $L_{\text{NL}}$ versus $L_{\text{bH}\alpha}$, where $L_{\text{NL}}$ is the luminosity of the narrow line. We treat $L_{\text{bH}\alpha}$, which is used to select the T1 sample, as the independent variable. We find

Figure 1. The distribution of $L_{\text{bH}\alpha}$ $L_{\text{[OIII]}}/L_{\text{[NeIII]}}$ versus $L_{\text{bH}\alpha}$ for narrow lines analysed in the BPT plots below. The robust narrow-line measurements are marked by black dots. The profiles of [N ii] and Hβ based on [O iii] (Section 2.2.3) are marked by grey squares. Upper limits (non detections, Section 2.2.2) and lower limits (stellar absorption for Hβ only, Section 2.2.4) are marked by the appropriate arrows. The slope of the best-fitting power laws (black lines) and the associated dispersion are noted. For comparison, the relations found in Paper II, for [O iii] and Hβ based on [O iii] in Paper I, the observed trends represent the Baldwin effect of the narrow lines. When excluding objects marked by squares, the [N ii] Baldwin slope increases to 0.60. Note that [S ii] and [N ii] have steeper slopes than Hα, which imply a shift in the mean positions in the BPT plots with luminosity.

3 The first 700 objects, sorted by right ascension.
$L_{\text{bol}} \propto L_{\alpha}^{0.67}, L_{\text{NII}} \propto L_{\alpha}^{0.54}, L_{\text{SII}} \propto L_{\alpha}^{0.53}$ and $L_{\text{OIII}} \propto L_{\alpha}^{0.63}$, with dispersions in the range $\sigma = 0.32-0.38$. The formal error on all slopes is $\approx 0.1$. A significant trend of decreasing NLR to BLR luminosity ratio with increasing $L_{\text{bol}}$ is clearly seen for all lines.

In Paper I, we found that the observed mean optical–UV SED of the T1 sample is well matched by a fixed-shape SED of luminous quasars, which scales linearly with $L_{\text{bol}}$, and a host galaxy contribution. Therefore, $L_{\text{bol}} \propto L_{\text{cont}}$, where $L_{\text{cont}}$ is the AGN continuum luminosity near H$\alpha$, and the trends observed in Fig. 1 represent a Baldwin effect (Baldwin 1977) for the narrow lines.

However, we note that even if intrinsically $L_{\text{NL}} \propto L_{\text{cont}}^{1.0}$, i.e. no intrinsic Baldwin effect, then due to the dispersion in EW$_{\text{H}\alpha}$ ($\equiv L_{\text{bol}}/L_{\text{cont}}$) we expect to find $L_{\text{NL}} \propto L_{\text{bol}}^{0.75}$. In Appendix C, we show that $\epsilon = (2\text{EW}_{\text{H}\alpha})^{-1/2}$, where $\epsilon$ (EW$_{\text{H}\alpha}$) is the intrinsic dispersion in EW$_{\text{H}\alpha}$, and $\Delta$ (L$_{\text{bol}}$) is the standard deviation of the distribution of L$_{\text{bol}}$ spanned by the sample. In the T1 sample, we have $\Delta$ (L$_{\text{bol}}$) = 0.75, and we assume that $\epsilon$ (EW$_{\text{H}\alpha}$) = 0.2 dex, as found for quasars (Section 2.3.1). Therefore, $\epsilon \approx (0.2/0.75)^{1/2} = 0.07$. This $\epsilon$ is significantly smaller than the slopes of $>0.3$ found above, indicating that the observed trends in L$_{\text{NL}}$/L$_{\text{bol}}$ indeed represent intrinsic Baldwin effects.

The relations found in Paper II for [O III] and H$\alpha$ are $L_{\text{bol}} \propto L_{\text{bol}}^{0.67}$, $\sigma = 0.37$ and $L_{\text{bol}} \propto L_{\text{bol}}^{0.72}$, $\sigma = 0.36$. Note that the different slopes found above imply some trends in the mean positions with luminosity of the T1 objects in the BPT plots, as shown below.

### 3.1 Less robust values

In all four panels of Fig. 1, most upper limits fall within the distribution of the general population. The objects in which the narrow lines are fit with an [O III]-like profile (Section 2.2.3) are located at the high L$_{\text{bol}}$ end of the sample. As noted in Section 2.2.3, the deblending of the Balmer lines and [N II] from the broad lines may be inaccurate in these objects. Indeed, the $L_{\text{NII}}$/L$_{\text{bol}}$ values of these objects are offset to lower values than the general trend. When excluding these objects, we find $L_{\text{bol}} \propto L_{\text{bol}}^{0.65}$ and $L_{\text{bol}} \propto L_{\text{bol}}^{0.60}$, i.e. a similar H$\beta$ slope and a [N II] slope higher by 0.06 compared to when using all objects.

### 3.2 Comparison with previous studies

Croom et al. (2002) compared the narrow [O III], [O II], [Ne III] and [Ne v] line luminosities with the absolute B magnitudes of 2dF and 6dF quasars (Croom et al. 2001). For a direct comparison with our results, we subtract the slope they found for each line with the positive slope of +0.18 they found for L$_{\text{bol}}$. Comparing the narrow lines to the broad H$\beta$ also avoids the bias created by host contamination of the continuum. This contamination likely creates the inverse Baldwin relation (i.e. positive slope) for the broad H$\beta$ line found by Croom et al., in contrast with the absence of a Baldwin relation (i.e. zero slope) for the Balmer lines found in our earlier analysis (Paper I). Their implied narrow lines versus broad H$\beta$ slopes are 0.86, 0.49, 0.58 and 0.74 for [O III], [O II], [Ne v] and [Ne III], respectively. All their narrow lines show a Baldwin effect, as found here. Their [O III] slope of 0.86 is steeper than our slope of 0.72, while their [O II] slope of 0.49 is flatter than our flattest slope of 0.53 for [S II].

Very recently, Zhang et al. (2013) compared narrow line equivalent widths with the continuum luminosity at 5100 Å in the mean spectra of SDSS type 1 AGN. As with Croom et al. above, we subtract the slope of +0.16 (see section 3.1 in Zhang et al.) they found for L$_{\text{bol}}$ from the slope they found for each line. The implied slopes are $-0.45$, $-0.44$, $-0.26$, $-0.36$, $-0.32$ and $-0.37$ for the narrow H$\alpha$, H$\beta$, [N II], [S II], [O I] and [O III], respectively. The implied Zheng et al. Baldwin slopes of all lines except [N II] differ by $\lesssim 0.1$ from the slopes found here. The higher value of 0.2 in the slope of [N II] could be because [N II] increases with $M_*$, and L$_{\text{bol}}$ and $M_*$ are correlated in the Zhang et al. sample, but not in the T1 sample (see below).

Hönig et al. (2008) and Kerem Medjiev, Hao & Charmandaris (2009) showed that mid-IR narrow lines also show Baldwin effects.

### 4 THE BPT POSITIONS OF THE T1 AGN

Fig. 2 presents the BPT positions of the 3 175 T1 AGN, plotted over the SDSS narrow-line galaxies (fig. 1 from Ke06). Classification lines are from Ke01, Ka03, Ke06 and Ho, Filippenko & Sargent (1997a, hereafter Ho97). The classification of each T1 object in each panel is listed in Table 2.

The T2 AGN reside, by definition, above the Ke01 line in the BPT-[O III] panel. However, only 80 per cent of the T1 objects reside in the AGN regime, 15 per cent are classified as composite and 5 per cent as SF. We stress again that all T1 AGN are clearly powered by accretion on to a massive black hole, as indicated by the detection of a broad H$\alpha$. Thus, the SDSS type 2 AGN sample is likely only 80 per cent complete. Including composites will increase the completeness to 95 per cent, but may include a significant number of objects which are not true AGN.

We note that the narrow-line measurements of two-thirds of the T1s which reside in the SF region are poorly constrained. Thus, with higher quality spectra the true AGN fraction with SF narrow-line ratios may therefore be as low as 2 per cent. In comparison, only 18 per cent of the T1s classified as composites and 17 per cent of the T1s classified as ‘AGN’ have poorly constrained narrow-line measurements.

The fraction of T1 which reside outside the AGN region in the BPT-[O I] panel is 18 per cent, and in the BPT-[S II] panel it reaches 29 per cent. The SDSS spectra are taken with a 3 arcsec fibre, which can include a significant fraction of the host galaxy emission. Below, we study some indications that the offset from the AGN region in the BPT plots indeed results from host contamination.

Fig. 2 also shows that a sizable fraction of the T1 sample occupies a new region in the BPT panels, with [O II]/H$\beta$ = 5–10, [N II]/H$\alpha$ = 0.1–3 and [S II]/H$\alpha$ = 0.1–3. These objects have no counterpart in the narrow-line sample. Specifically, 10 per cent of T1s with [O II]/H$\beta$ > 5 have [N II]/H$\alpha$ < 0.3, compared to only 0.8 per cent of the T2 sample. This result is consistent with the Zhang et al. (2008) result. Below, we study the range of AGN and host properties at which these line ratios are dominant, and discuss their physical origin.

In the [O I] panel, 190 objects in the T1 sample are classified as LINER 1s. The vast majority (179) of them appear to the right of the Ho97 line, where the ‘bona fide’ LINERs reside. This result is consistent with the strong drop in broad H$\alpha$ detection across this line (Ho et al. 1997b, Ho 2008; Wang, Wei & Xiao 2009).

#### 4.1 BPT positions of T1 AGN, by $L_{\text{bol}}$, $L/L_{\text{bol}}$ and $L_{\text{AGN}}/L_{\alpha}$

In this section, we utilize the large size of the T1 sample and explore their positions within the BPT plots when the sample is cut based on various AGN and host properties. We identify some qualitative trends, which are further explored in the following sections.

Fig. 3 presents the BPT positions of the individual T1 objects as a function of $L_{\text{bol}}$, which is a measure of L$_{\text{bol}}$ ($\approx 130 \times L_{\text{bol}}$, Paper I).

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Type 1 low z AGN. III. Narrow line ratios 841

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As in Fig. 2, the positions of the T1s are plotted over the SDSS narrow-line galaxies from Ke06. At log $L_{\text{bol}}$ = 40.7 ($L_{\text{bol}}$ = 42.8), T1 AGN largely overlap the narrow-line sample. With increasing luminosity, the T1 AGN shift to lower $\text{[N \text{II}]}/\text{H}z$, lower $\text{[S \text{II}]}/\text{H}z$ values, slightly lower $\text{[O \text{III}]}/\text{H}z$ and higher $\text{[O \text{III}]}/\text{H}z$ values, as expected from the different luminosity trends of the different lines (Fig. 1). At quasar luminosities (log $L_{\text{bol}}$ ≥ 43 or log $L_{\text{bol}}$ ≥ 45), the T1 distribution is distinct from the type 2 distribution in the $\text{[S \text{II}]}/\text{H}z$-panel, and is offset in the $\text{[N \text{II}]}/\text{H}z$-panel to lower values. Also, the fraction of AGN which reside below the Ke01 line decreases with increasing $L_{\text{bol}}$.

The fraction of poorly constrained objects increases with $L_{\text{bol}}$ (Fig. 1), due to the decrease in the relative strengths of the narrow lines (Paper II and Fig. 1). Therefore, one may wonder whether this trend with luminosity is not simply due to the limitations of the deblending algorithm. In appendix A, we verify the observed trend using high-luminosity mean spectra.

Fig. 4 shows the BPT positions of the T1 objects, now subdivided by $L/L_{\text{Edd}}$ (derived from $L_{\text{bol}}$ and $\Delta v$, using equation 3 in Paper I). Several trends in the BPT position are apparent. With increasing $L/L_{\text{Edd}}$, an increasing fraction of T1s have high $\text{[O \text{III}]}/\text{H}z$, low $\text{[N \text{II}]}/\text{H}z$ and low $\text{[S \text{II}]}/\text{H}z$, as found with increasing $L_{\text{bol}}$ in Fig. 3. The decrease in $\text{[O \text{III}]}/\text{H}z$ with $L/L_{\text{Edd}}$ is more pronounced than in Fig. 3: the $\text{[N \text{II}]}/\text{H}z$ span mainly 0.2–0.5 at low $L/L_{\text{Edd}}$, compared to 0.03–0.1 at high $L/L_{\text{Edd}}$. The fraction of LINERs in the BPT-[O \text{I}] panel strongly decreases with increasing $L/L_{\text{Edd}}$, from 29 per cent at log $L/L_{\text{Edd}}$ = −2.5, to 6 per cent at log $L/L_{\text{Edd}}$ = −1.8 and 3 per cent at log $L/L_{\text{Edd}}$ = −1.2 and −0.6.

Fig. 5 is similar to Figs 3 and 4, with different rows designating different bins in $L_{\text{AGN}}/L_z$, measured at the SDSS $\epsilon$ band (see Section 2.3.1). We note that the division of objects between the two high $L_{\text{AGN}}/L_z$ bins is not robust in objects with $L_{\text{AGN}}/L_z > 1$, due to the possible error in the determination of $L_z$. The 24 objects with a negative implied $L_z$ appear in the $L_{\text{AGN}}/L_z ≥ 2$ bin. With increasing $L_{\text{AGN}}/L_z$, $\text{[N \text{II}]}/\text{H}z$ and $\text{[S \text{II}]}/\text{H}z$ decrease, as found with increasing $L_{\text{bol}}$ in Fig. 3, and with increasing $L/L_{\text{Edd}}$ in Fig. 4. The T1 sample overlaps the type 2 sample in host-dominated objects, and is distinct from the type 2 distribution in AGN-dominated objects. Also, the composite fraction decreases from 22 per cent at $L_{\text{AGN}}/L_z = 0.04$ to 6 per cent at $L_{\text{AGN}}/L_z ≥ 2$.

To satisfy the curious reader, the mass dependencies are explored in Appendix B, where we plot the BPT positions of the T1 objects, subdivided by $M_{\text{BH}}$ and $M_z$.

### 4.2 Comparison with different type 1 samples

Here, we compare the BPT positions of the T1 sample and its dependence on AGN and host properties (Figs 2–5), with NLR studies of other type 1 AGN samples, which were selected differently.

Greene & Ho (2007) inspected the narrow-line ratio of 229 SDSS type 1 AGN, selected based on the detection of a broad $\text{H}z$, similar to T1, but required to have $M_{\text{BH}} < 2 \times 10^6 \, M_\odot$. In their sample, 39 per cent of the objects are classified as Composites or SFs in the BPT-[N \text{II}] panel, versus only 20 per cent (Fig. 2) in our sample. However, when we restrict the T1 sample to $M_{\text{BH}} < 2 \times 10^6 \, M_\odot$ (Figure B1, upper panel), the fraction increases to 36 per cent, consistent with the Greene & Ho (2007) result. In a follow-up paper (Xiao et al. 2011), they compared the narrow-line ratios based on the SDSS spectra with ratios based on spectra from a smaller aperture. The fraction of Composites/SFs decreased to 18 per cent, indicating that extended emission from SF in the host galaxy shifts the BPT position into the composite region at low $M_{\text{BH}}$. Below, we provide further evidence that this effect applies also to composites at higher $M_{\text{BH}}$.

Another prominent feature in the Greene & Ho low $M_{\text{BH}}$ sample is objects with high $\text{[O \text{III}]}/\text{H}z$, low $\text{[S \text{II}]}/\text{H}z$ and low $\text{[N \text{II}]}/\text{H}z$. Of
Figure 3. The dependence of the BPT position on the AGN luminosity. The T1 sample markers are as in Fig. 1. The narrow-line background and dividing lines are described in Fig. 2. Each row presents T1 AGN from a given decade-wide bin in $L_{bH\alpha}$. The mean $L_{bH\alpha}$ in each bin is noted (in erg s$^{-1}$). At $L_{bH\alpha} = 40.7$ ($L_{bol} = 42.8$), T1 AGN overlap the narrow-line sample. With increasing luminosity, the mean $[N\text{ II}]/H\alpha$ and $[S\text{ II}]/H\alpha$ decrease. At quasar luminosities (log $L_{bH\alpha} \gtrsim 43$ or log $L_{bol} \gtrsim 45$), a large fraction of the T1 AGN occupy a region in the $[N\text{ II}]$ and $[S\text{ II}]$ panels which is distinct from the type 2 distribution.

Winter et al. (2010) published the BPT positions of a hard X-ray selected AGN sample, of which they identified 33 objects as broad line AGN. Their mean log $L_{[O\text{ III}]}$ is a factor of 3 higher than the mean in the T1 sample. Five of their type 1s have $[S\text{ II}]/H\alpha < 0.1$, and two have $[N\text{ II}]/H\alpha < 0.1$, which are not seen in their type 2 sample. These ratios are seen in the T1 sample, but not in the SDSS narrow-line sample.

$^4$ They excluded Sy1.8s and Sy1.9s, which select against low-luminosity type 1 AGN (Paper II).
Buttiglione et al. (2010) measured the BPT positions of a radio selected AGN sample. They show a clear trend of decreasing [N ii]/Hα and [S ii]/Hα, and increasing [O iii]/Hβ, with increasing [O iii] luminosity (fig. 1 there). Their trend is equivalent to the trend seen in Fig. 3 with $L_{\text{bol}}$. A similar trend can be seen in fig. 4 of Wang & Wei (2010), who measured the BPT ratios of Seyferts 1.8s and 1.9s with ROSAT detections. They found that objects in which the AGN dominates the continuum are offset to lower [N ii]/Hα than objects in which the continuum is host dominated, as can be seen here in Fig. 5.

5 THE OFFSET OF T1-AGN TO LOW [N II]/Hα AND [S II]/Hα

Figs 2–5 show that the distributions of the narrow-line ratios of the T1 objects extend to values which are not seen in the SDSS narrow-line sample, in particular at high $L_{\text{bol}}$, high $L/L_{\text{Edd}}$ and high $L_{\text{AGN}}/L_\star$. These non-overlapping objects have [O iii]/Hβ similar to type 2s, but lower [N ii]/Hα and [S ii]/Hα. In Appendix A, we show the offset ratios are not an NLR/BLR deblending artefact. Why are these ratios absent from type 2 samples?
A difference between type 1 and type 2 AGN can be either a failure of the unified model, an orientation-related effect, or simply due to different selection criteria used for creating the two samples. Here, we compare the T1 and T2 (Section 2.4) samples and show that selection effects are likely behind the differences observed in Figs 2–5. To avoid significant NLR contamination by star formation in the host, which decreases the narrow-line ratios to the Composite and SF regions of the BPT plots, we only use the 1691 T1s and 4042 T2s with \([\text{O} \text{ iii}] / \text{H} \beta > 5\). This selection criterion is independent of the offset quantities, \([\text{N} \text{ ii}] / \text{H} \alpha\) and \([\text{S} \text{ ii}] / \text{H} \alpha\). A comparison of the Composites and SFs is made in Section 8 below.

A major difference in the T1 versus T2 selection criteria is that the T1 sample also includes point sources and is not selected purely from extended objects. Thus, the T1 sample can extend to \(L_{\text{AGN}} / L_*\) values larger than possible in the T2 sample. Another related systematic difference is the distribution of \(M_*\) values, as the T2 objects are selected by \(L_*\), while in the T1 point sources \(L_*\) can be arbitrarily small. The distribution of \(L_*\) values is interesting as \(M_*\) was...
found to correlate with the [N ii]/Hα ratio, via the $M_*-Z$ relation of galaxies, and the dependence of [N ii]/Hα on Z (Groves et al. 2006, see below).

In Fig. 6, we therefore plot contours of the distribution of T1s and T2s in the $M_*$ versus $L_{\text{AGN}}/L_*$ plane. The T1 sample is divided according to the two SDSS surveys from which it is derived, those selected from the SDSS galaxy survey, and the point sources from the SDSS quasar survey. We note that at $L_{\text{AGN}}/L_* > 1$, $L_*$ can be significantly overestimated (Section 2.3.1), therefore the true $L_{\text{AGN}}/L_*$ may be higher and the true $M_*$ may be lower than plotted. The abrupt cut at $L_{\text{AGN}}/L_* = 3$ is due to the limit of our capability to derive a robust upper limit on $L_*$. (Section 2.3.1). This limit does not affect the conclusions below. In the T2 sample, $L_{\text{AGN}}$ is derived from $L_{\text{[O III]}}$ (Paper II), $L_*$ is derived from the observed SDSS $z$-band luminosity, and $M_*$ is taken from Kauffmann et al. (2003b). Note that by construction, we use the same $M/L$ in T1s and T2s (Section 2.3.1).

The T2s are all selected from the SDSS galaxy survey. The distribution of the T1s from the same survey overlaps well the distribution of T2s. The T1 point sources however are clearly offset to higher $L_{\text{AGN}}/L_*$ than AGN with an extended morphology, and constitute an AGN population which does not appear in the T2 sample.

Note that by construction, we use the same $M/L$ in T1s and T2s (Section 2.3.1).}

The T2s follow a similar trend, but they do not extend to the high $L_{\text{AGN}}/L_*$ occupied by objects with [N ii]/Hα < 0.2 (Fig. 6). Thus, the absence of [N ii]/Hα < 0.2 AGN from the T2 sample just reflects its selection against high $L_{\text{AGN}}/L_*$ objects, which are observed to have a low [N ii]/Hα < 0.2.
with \([\text{[N II]}]/\text{H} \alpha < 0.2\). In fact, already T2s with \([\text{N II]}]/\text{H} \alpha < 0.6\) are rare, constituting only 9 per cent of the T2 sample, compared to the 39 per cent of T1s that have \([\text{N II]}]/\text{H} \alpha < 0.6\). Therefore, the T2 objects do not extend to the low \([\text{N II]}]/\text{H} \alpha\) values, seen in the T1 sample, as these values occur at high \(L_{\text{AGN}}/L_\star\) values, which the T2 objects cannot have by their selection.

A similar analysis using the \([\text{S II]}]/\text{H} \alpha\) values, instead of \([\text{N II]}]/\text{H} \alpha\), demonstrates that the low-\([\text{S II]}]/\text{H} \alpha\) values seen in the T1 sample at high \(L_{\text{AGN}}/L_\star\) (Fig. 5) are absent from the T2 sample for the same reason.

6 PHYSICAL PARAMETERS OF THE NLR

We now quantify the dependence of narrow-line ratios on the observed AGN and host properties, and discuss the physical origin of the trends. To avoid a significant contribution to the NLR from star formation in the host galaxy, we require \(L_{\text{UV}}/L_{\text{bol}} < 100\) (Section 8), instead of the \([\text{O III]}]/\text{H} \beta > 5\) requirement used above. This alternative cut is possible since we do not analyse T2s in this section, and enables us also to derive trends in \([\text{O III]}]/\text{H} \beta\).

As can be seen in Figs 3, 5 and 7, \([\text{N II]}]/\text{H} \alpha\) decreases both with increasing \(L_{\text{AGN}}\) and with decreasing \(L_\star\). Below, we explore the two effects independently. We bin the T1 objects based on \(M_\star\) and \(L_{\text{bol}} (\equiv 130 \times L_{\text{H} \beta})\) in the following manner. The objects are sorted by \(L_{\text{bol}}\) and divided into four equal size groups. Each of these groups is then sorted by \(M_\star\), and again divided into four equal size groups. This ensures similar statistical errors in all bins. We disregard the 12 per cent of the objects with \(L_{\text{AGN}}/L_\star > 1\), in which the \(M_\star\) measured has a large error (Section 2.3.1).

Fig. 8 presents the derived relations of the mean values of \([\text{N II]}]/\text{H} \alpha\), \([\text{S II]}]/\text{H} \alpha\), \([\text{N II]}]/[\text{S II]}\), \([\text{O III]}]/\text{H} \alpha\) and \([\text{O III]}]/\text{H} \beta\) as a function of \(M_\star\), for different \(L_{\text{bol}}\). The error bars denote the error in the mean. The upper panel shows that the mean \([\text{N II]}]/\text{H} \alpha\) increases with \(M_\star\) at a fixed \(L_{\text{bol}}\), an increase of \(\sim 0.3\) dex over \(\sim 0.7\) dex in \(M_\star\). Also, the mean \([\text{N II]}]/\text{H} \alpha\) decreases with \(L_{\text{bol}}\), at a fixed \(M_\star\), a decrease of \(\sim 0.3\) dex over \(\sim 1.7\) decades in \(L_{\text{bol}}\). The trend of \([\text{N II]}]/\text{H} \alpha\) versus \(L_{\text{bol}}\) can also be seen in mean spectra, shown in the appendix. The second panel shows that the mean \([\text{S II]}]/\text{H} \alpha\) decreases with \(L_{\text{bol}}\) at a fixed \(M_\star\), similar to the decrease in \([\text{N II]}]/\text{H} \alpha\) with \(L_{\text{bol}}\) in the upper panel. However, at a fixed \(L_{\text{bol}}\), \([\text{S II]}]/\text{H} \alpha\) increases only by \(\sim 0.1\) dex over \(\sim 0.7\) dex in \(M_\star\). This small increase is within the range of possible systematics (Section 2.4), and in contrast with the sharper change in \([\text{N II]}]/\text{H} \alpha\) with \(M_\star\) in the top panel. The relative trends of \([\text{N II]}\) and \([\text{S II]}\) are most apparent in the third panel. Clearly, \([\text{N II]}]/[\text{S II]}\) strongly increases with \(M_\star\), and is almost independent of \(L_{\text{bol}}\). The fourth panel shows that \([\text{O III]}]/\text{H} \alpha\) increases slightly with \(M_\star\) at a fixed \(L_{\text{bol}}\), similar to the \([\text{S II]}]/\text{H} \alpha\) trend in the second panel. In the bottom panel, at \(\log L_{\text{bol}} \geq 43.8\), \([\text{O III]}]/\text{H} \beta\) shows a decrease of \(\sim 0.15\) dex over \(\sim 0.8\) dex in \(M_\star\).

What are the physical mechanisms behind these trends in narrow-line ratios? The similarity of the behaviour of \([\text{N II]}]/\text{H} \alpha\) and \([\text{S II]}]/\text{H} \alpha\) versus \(L_{\text{bol}}\), in contrast to the different behaviour versus \(M_\star\), suggests there are two distinct mechanisms at play. We address them separately below.

6.1 The trend with \(M_\star\)

6.1.1 \(M_\star\) versus \(Z_{\text{NLR}}\)

An increase of \([\text{N II]}]/\text{H} \alpha\) with \(M_\star\) has been observed in type 2 AGN by Groves et al. (2006), qualitatively similar to the trend we see in T1 AGN (Fig. 8). As mentioned above, Groves et al. suggested

Figure 8. The dependence of the mean line ratios of the T1 objects on \(L_{\text{bol}}\) and \(M_\star\). Given \(L_{\text{bol}}\) bins are connected by solid lines (mean \(L_{\text{bol}}\) noted). The error bars denote the uncertainty in the mean value. The 9 per cent of the T1 objects with inaccurate \(M_\star\) measurements (\(L_{\text{AGN}}/L_\star > 1\)) and 20 per cent of the T1s with significant host contamination of the NLR (\(L_{\text{UV}}/L_{\text{bol}} > 100\)) are not shown. Top panel: the mean \([\text{N II]}]/\text{H} \alpha\) increases with \(M_\star\) at a fixed \(L_{\text{bol}}\) and decreases with increasing \(L_{\text{bol}}\) at a fixed \(M_\star\). Second panel: the mean \([\text{S II]}]/\text{H} \alpha\) decreases with increasing \(L_{\text{bol}}\) at a fixed \(M_\star\). The mean \([\text{S II]}]/\text{H} \alpha\) increases only slightly with \(M_\star\) at a fixed \(L_{\text{bol}}\). Third panel: the mean \([\text{N II]}]/[\text{S II]}\) is determined by \(M_\star\) and is almost independent of \(L_{\text{bol}}\). Fourth panel: the mean \([\text{O III]}]/\text{H} \alpha\) increases slightly with \(M_\star\), at a fixed \(L_{\text{bol}}\), similar to the equivalent trend of \([\text{S II]}]/\text{H} \alpha\). A dependence of \([\text{O III]}]/\text{H} \alpha\) on \(L_{\text{bol}}\) is seen only at the lowest \(L_{\text{bol}}\) bin. Bottom panel: in the three high \(L_{\text{bol}}\) bins, \([\text{O III]}]/\text{H} \beta\) decreases with \(M_\star\). The trends with \(M_\star\) likely reflect an increase of \(Z_{\text{NLR}}\) with \(M_\star\). The trends with \(L_{\text{bol}}\) is likely related to the decrease in NLR covering factor with increasing \(L_{\text{bol}}\) (Paper II).
this trend originates from the $M_\ast - Z$ relation found in quiescent galaxies. A relatively strong dependence of [N II]/Hα on $Z_{\text{NLR}}$ is expected since nitrogen is a secondary nucleosynthesis product, and hence its abundance increases as $Z^2$ for $Z > 0.5 Z_\odot$ (e.g., van Zee, Salzer & Haynes 1998). Appropriately, an increase is expected also in the relative abundance of N to S, consistent with the increase of [N II]/[S II] versus $M_\ast$ seen in Fig. 8. Also, since [O III] is a main coolant, the lower NLR temperature associated with the higher $Z_{\text{NLR}}$ is expected to reduce [O III]/Hβ, as observed in the bottom panel of Fig. 8. The mild increase of [S II]/Hα and [O I]/Hα with $M_\ast$ are also consistent with an increase in $Z_{\text{NLR}}$ with $M_\ast$, if [S II] and [O I] are both trace coolants.

Is the $Z_{\text{NLR}}$-based explanation of the trends versus $M_\ast$ unique, or can these trends be explained by density/ionization effects? Density is an unlikely candidate, as the critical density $n_{\text{crit}}$ of [N II] is $10^{3.8}$ cm$^{-3}$, intermediate between $n_{\text{crit}}$([S II]) = $10^{3.2-3.6}$ cm$^{-3}$ and $n_{\text{crit}}$([O I]) = $10^{3.5}$ cm$^{-3}$ (all $n_{\text{crit}}$ are taken from Appenzeller & Östreich 1988). Thus, if a change in the distribution of NLR gas densities is behind the trends versus $M_\ast$, then the slope of the [N II]/Hα versus $M_\ast$ relation is expected to be intermediate between the slopes of the [S II]/Hα versus $M_\ast$ and [O I]/Hα versus $M_\ast$ relations, in contrast with Fig. 8. For example, in an NLR model, where the typical density decreases with increasing radius, the amount of obscuration of the dense inner region will affect the distribution of observed NLR densities (e.g., Zhang et al. 2008). In this scenario, the visibility of [O I]-emitting clouds would be more sensitive to the amount of obscuration than the visibility of [N II]-emitting clouds, which in turn would be more sensitive than [S II]-emitting clouds. If obscuration decreases with $M_\ast$, one would expect [N II]/[S II] to increase with $M_\ast$, as observed in Fig. 8, but one would also expect a steep slope of the [O I]/Hα versus $M_\ast$ relation, which is not observed. Therefore, the trends versus $M_\ast$ are unlikely to be related to the NLR density. Moreover, we find that the [S II] doublet ratio ($6716$ to $\lambda 6731$), which is sensitive to the density of the [S II]-emitting gas, shows no dependence on $M_\ast$ in the T1 sample (absolute Pearson coefficient $<0.06$ for all luminosity bins).

A similar argument can be used for ionization effects. If the NLR ionization changes with $M_\ast$, we would expect the [N II]/Hα trend with $M_\ast$ to be intermediate between the trends of [O I]/Hα and [O III]/Hβ, in contrast to the relative strength of the trends observed in Fig. 8. However, given the flexibility in the current NLR models (e.g., Groves et al. 2004), one may be able to tune the NLR parameters and the change of ionization parameter with $M_\ast$ to reproduce the observed relations. Nevertheless, since an increase of $Z_{\text{NLR}}$ with $M_\ast$ explains the line ratio trends qualitatively from first principles, and since $Z$ is known to increase with $M_\ast$ in quiescent galaxies, and in type 2 AGN, a $Z_{\text{NLR}}$-based explanation for these trends appears more plausible. In the next section, we provide additional support for this conclusion by showing that the BLR metallicity $Z_{\text{BLR}}$ also appears to increase with [N II]/Hα at a fixed $L_{\text{bol}}$.

### 6.1.2 $Z_{\text{NLR}}$ versus $Z_{\text{BLR}}$

Are there any additional differences in the spectra of objects with high and low [N II]/Hα? Fig. 9 compares the mean spectra of objects with [N II]/Hα < 0.2 and objects with [N II]/Hα > 0.6. To avoid
other known trends, and isolate only [N ii]/Hα related trends, we match each of the T1s with [N ii]/Hα < 0.2 with a T1 that has [N ii]/Hα > 0.6 with the same Lbol up to 0.1 dex, and the same Δν up to 0.05 dex. Matching by Lbol ensures that we are freezing the Lbol-related effect seen in Fig. 8, while matching also by Δν indicates that we are freezing also Mbol (via equation 2 in Paper I) and L/Ledd and the host of spectral properties related to it (e.g., Boroson & Green 1992). Of the 184 T1s with [N ii]/Hα < 0.2, 148 have such matches.

The mean spectra of the two groups of objects are calculated by geometrically averaging luminosity densities of spectrum pixels with the same rest-frame wavelength λ, rounded to 10−4 in log λ. The bottom spectrum is the difference between the two composite spectra, and the insets zoom in on the areas delimited by the dashed lines. The most striking feature of the residual is the strong BLR Fe ii multiplets at ~4600 and ~5300 Å.

The luminosity of the optical Fe ii multiplets is expected to increase with iron column density, and therefore with ZBLR, to a power of 0.8−0.9 (Verner et al. 2003; Baldwin et al. 2004; Shields et al. 2010). Thus, Fig. 9 provides interesting evidence that ZBLR is related to ZBLR. There is a well-known relation between the Fe ii equivalent width and L/Ledd (Boroson & Green 1992), but since the two composites are matched in L/Ledd, this effect should not be present.

Shields et al. (2010) found that when binning by L(Fe ii)/Lbol, [N ii]/[S ii] increases by a factor of 2 for an increase of a factor of 10 in L(Fe ii)/Lbol. They concluded that the Fe ii strength increases with ZBLR, but the dispersion in Fe ii is not dominated by ZBLR. In Fig. 9, the composite spectra differ by a factor of 2.3 in [N ii]/[S ii], implying a factor of 1.5 in ZNL (see equation 2 below). They also differ by a factor of ~2 in L(Fe ii). Therefore, for a constant L/Ledd, ZNL and ZBLR change roughly in unison.

The mean log M*, of the low and high [N ii]/Hα composite spectra are 10.5 and 10.8, respectively. This difference in M*, can be seen in the residual spectrum, which has a red optical slope, a [Ca ii] K λ3934 absorption feature, a stellar absorption blend at 6500 Å, and at a few additional stellar features. The two groups are selected to have the same mean MBH, and should thus have similar mean bulge mass (Magorrian et al. 1998). The different measured mean M*, values of the two groups should therefore reflect differences in the mean disc masses, where the higher metallicity group has a higher disc/bulge mass ratio.

Hamann & Ferland (1993, 1999) found that in quasars, ZBLR (derived from the NV/CIV ratio) increases with Lbol. They speculated that the increase in ZBLR with Lbol is probably due to the increase of ZNL with M*, and the strong relation between M* and Lbol in the quasar samples they used, where most objects shine close to the Eddington limit. Their conclusion is supported by the increase of NV/CIV with MBH, which should also increase with increasing M* (Warner, Hamann & Dietrich 2003). Here, we confirm their claim by showing that ZBLR increases with M*, directly.

At a given M*, the mean [N ii]/[S ii] remains constant with Lbol (Fig. 8). Therefore, we find no evidence for a direct Z−Lbol trend.

6.1.3 Estimating O/H from [N ii]/[S ii]

Since the NLR is the part of the ISM which is located on 10s–100s pc from the nucleus and is exposed to the ionizing AGN radiation, it is plausible that ZNL is the gas phase Z of the host. Therefore, given a calibration between [N ii]/[S ii] and the gas phase absolute metallicity, as indicated by the oxygen abundance O/H, we can use [N ii]/[S ii] to estimate O/H in the host galaxy.

In principle, we could apply the O/H versus [N ii]/[S ii] relation of H ii regions to the NLR. However, the different physical conditions in the NLR and H ii regions of star-forming galaxies may imply that the NLR has a different O/H versus [N ii]/[S ii] relation. Instead, we use the relation of [N ii]/[S ii] versus M*, in the T1 sample and the O/H versus M* relation from Tremonti et al. (2004, hereafter T04) to indirectly calibrate O/H versus [N ii]/[S ii] in the NLR.

T04 found that the median O/H in SDSS star-forming galaxies follows 12 + log(O/H) = −0.08m10 + 0.25m10 + 9 for −1.5 < m10 < 1.5, where m10 = log (M*/1010 M⊙). Similarly, we fit a second-order polynomial relation to the median [N ii]/[S ii] versus M*, relation in the T1 sample. Using all 0.1 dex bins in M*, with >10 objects, we find

\[
\log ([N \text{ ii}]/[S \text{ ii}]) = -0.17m_{10}^2 + 0.46m_{10} - 0.01
\]

for 0 < m_{10} < 1.3. The typical dispersion in each m_{10} bin is 0.15 dex.

Equation (1) shows a flattening of the [N ii]/[S ii] versus m_10 relation with increasing m_{10}, similar to the flattening of the T04 m_{10} versus Z relation. This similarity supports the suggestion that the ZBLR is the host gas phase Z. Plugging equation (1) in the T04 relation, we obtain

\[
12 + \log O/H = 0.47 \log ([N \text{ ii}]/[S \text{ ii}]) + 9.03 \quad (\sigma \sim 0.06 \text{ dex}),
\]

where we neglected a term equal to 0.03m_{10} on the right-hand side. The dispersion σ in equation (2) is the dispersion of the [N ii]/[S ii] versus O/H relation in the T04 star-forming galaxies, which could be biased due to the different physical conditions in H ii regions and in the NLR.

For comparison, in the T04 star-forming galaxies we find 12 + log O/H = 0.73 log [N ii]/[S ii] + 8.94. Equation (2) can be used as a rough estimate for O/H in AGN hosts.

6.2 The trend with Lbol

What is the source of the change in [N ii]/Hα and [S ii]/Hα with Lbol? In Paper II, we found that L_{4000}/Lbol decreases with Lbol and presented evidence that this trend is due to a decrease in the NLR covering factor (CFNLR) with Lbol. We verify that this trend depends on Lbol and not on M*, by measuring L_{4000}/Lbol versus M* at a given Lbol, using the same bins as shown in Fig. 8. Indeed, in all Lbol bins L_{4000}/Lbol changes by <0.1 dex over 0.8 dex in M*. The L_{4000}/Lbol ratio thus depends purely on Lbol. Therefore, it seems that the decrease in [N ii]/Hα and [S ii]/Hα with Lbol, at a given M*, is associated with the decrease in CFNLR.

A change in CFNLR alone cannot change the narrow-line ratios. Therefore, the distribution of some other NLR physical parameter such as Z, density or ionization probably also changes with Lbol. As mentioned above, a change of ZNL with Lbol is unlikely. We discriminate between a change in density and ionization using the Baldwin slopes (Fig. 1). The Baldwin slopes α of the different lines follow α(O iii) > α(O ii) > α([N ii]) ≈ α([S ii]). This order favours a change in the density distribution of the NLR over a change in the ionization distribution, since [O iii] and [O ii] have higher n_{eq} than [N ii] and [S ii], while the ionization energies of [N ii] and [S ii] are intermediate between the ionization energies of [O iii] and [O ii]. Therefore, a possible scenario which explains the observed trends versus Lbol is that the covering factor of the clouds with density 10^{11}−10^{15} cm^{-3} drops faster with increasing Lbol than the covering factor of the clouds with density 10^{10}−10^{14} cm^{-3}. 

We emphasize that since the trend with [N ii]/Hα with \( L_{bol} \) is probably not a \( Z_{NLR} \) effect, deriving \( Z_{NLR} \) in quasars from [N ii]/Hα calibrated on lower luminosity AGN (e.g. Husemann et al. 2011), will underestimate \( Z_{NLR} \).

7 LINERS

Ke06 found that at a fixed \( L/L_{Edd} \), the difference between host properties of Seyferts and LINERS\(^5\) disappear. Their conclusion was that the observed difference in host properties between Seyferts and LINERS is only a secondary effect, which results from their difference in \( L/L_{Edd} \) (Ho 2002, Ke06). Here, we show that the observed large difference between Seyferts and LINERS in terms of the fraction which shows broad lines (Ho et al. 1997b, Ho 2008) is also a secondary effect of their difference in \( L/L_{Edd} \), and at a fixed \( L/L_{Edd} \) the difference disappears.

Following Ke06, we create subsamples of the T1 and T2 samples which include objects classified as AGN in the BPT-\([N \text{ ii}]\) panel, and as either Seyferts or LINERS in the BPT-\([S \text{ ii}]\) and BPT-\([O \text{ ii}]\) panels (Fig. 2). We use only objects with consistent BPT-\([S \text{ ii}]\) and BPT-\([O \text{ ii}]\) classifications. We use the bulge stellar dispersion \( \sigma_\star \) to derive \( M_{BH} \) in T2s (Gültekin et al. 2009). We disregard the 8 percent of the T2s with surface mass density \(<3 \times 10^6 \text{M}_\odot \text{kpc}^{-2} \), in which the \( \sigma_\star \) measured by the SDSS may be overestimated due to disc light contamination (Kauffmann et al. 2003c; Heckman et al. 2004).

Following the above criteria, the T2 subsample includes 4938 Seyfert 2s and 4292 LINER 2s. The T1 subsample includes 1910 Seyfert 1s and 76 LINER 1s. Thus, LINERS constitute 50 percent of the T2 sample, but only 4 percent of the T1 sample. Our purpose is to further understand the origin of this large difference.

In 44 objects from the LINER 1 group, the classification is ambiguous, either due to upper/lower limits on the BPT ratios, or because their narrow-line ratios are poorly constrained (Section 2.2.3). We address this uncertainty below. The fraction of Seyfert 1s with an ambiguous classification is negligible.

In the T1 sample, we derive \( M_{BH} \) from \( L_{bol} \) and \( \Delta v \), using equation (2) in Paper I. For \( L_{bol} \), we use \( L_{bol} = 130 \text{L}_\odot \) (equation 6 in Paper I). In the T2 sample, we derive \( L_{bol} \) from \( L_{(o_{III})} \) using the \( L_{(o_{III})}/L_{bol} \) relation in the T1 sample (equation 3 in Paper II), and the same \( L_{bol}/L_{bol} \) as for the T1 sample. We note in passing that the \( L_{(o_{III})}/L_{bol} \) ratio is expected to be lower in LINERS, almost by their definition (see a factor of 2 drop in \( L_{(o_{III})}/L_{bol} \) in the lower-left panel of fig. 6 in Paper II). So, due to this effect, the implied \( L_{bol} \) in LINER 2s may be a bit underestimated. Additionally, LINERS might have a different \( L_{bol}/L_{bol} \) ratio than the ratio we use, as this ratio was derived on the T1 sample, which is dominated by Seyferts. However, this latter caveat will affect our estimate of \( L_{bol} \) in LINER 1s and LINER 2s in the same way, and will therefore not affect our analysis.

Fig. 10 presents the fraction of LINER 2s out of the T2 sample, as a function of \( L/L_{Edd} \). Seyfert 2s and LINER 2s are cleanly separated in \( L/L_{Edd} \), as found by Ke06. At \( L/L_{Edd} \gtrsim -2 \) all T2s are Seyferts, while at \( L/L_{Edd} \lesssim -4 \) all T2s are LINERs. A similar clean cut in NLR ionization level can be seen in radio galaxies, while most \( L/L_{Edd} > 10^{-3} \) objects have \([O \text{ iii}] / [O \text{ ii}] \lambda 3727 \gtrsim 1 \), while all \( L/L_{Edd} < 10^{-3} \) objects have \([O \text{ iii}] / [O \text{ ii}] \) < 1 (fig. 9 in Antonucci 2012; Ogle et al. in preparation). Fig. 10 also presents LINER 1 fractions out of the T1 sample, at different \( L/L_{Edd} \). The uncertainty in the LINER 1 fraction is due to the 44 T1 objects with an ambiguous LINER classification. At \( L/L_{Edd} \), the fraction of LINER 1s is consistent with the fraction of LINER 2s within the uncertainties. The low fraction of LINERS in the T1 sample (\sim 4 percent) versus the high fraction in the T2 sample (\sim 50 percent) results from the difference in the \( L/L_{Edd} \) distribution of the T1 and T2 samples. The lack of \( L/L_{Edd} < 10^{-3} \) T1s could be due to detection limits, or to a physical absence of low \( L/L_{Edd} \) type 1 AGN.

Figure 10. The fraction of LINERs in the T1 and T2 samples, as a function of \( L/L_{Edd} \). The solid grey line indicates the fraction of LINERs in the T2 sample, in 0.25 decade \( L/L_{Edd} \) bins, where \( L/L_{Edd} \) is derived from \( L_{bol} \) and \( \sigma_\star \). The fractions of LINERs in the T1 sample are denoted by error bars, where \( L/L_{Edd} \) is derived from \( L_{bol} \) and \( \Delta v \). The uncertainty is due to T1 objects with an ambiguous classification. At \( L/L_{Edd} \lesssim -2 \) all T2s are Seyferts, while at \( L/L_{Edd} \lesssim -4 \) all T2s are LINERs. At a fixed \( L/L_{Edd} \), the fraction of LINER 1s is consistent with the fraction of LINER 2s within the uncertainties. The low fraction of LINERS in the T1 sample (\sim 4 percent) versus the high fraction in the T2 sample (\sim 50 percent) results from the difference in the \( L/L_{Edd} \) distribution of the T1 and T2 samples. The lack of \( L/L_{Edd} < 10^{-3} \) T1s could be due to detection limits, or to a physical absence of low \( L/L_{Edd} \) type 1 AGN.

The fact that all T1s have \( L/L_{Edd} > 10^{-3} \) could be a detection limit, since low \( L/L_{Edd} \) may indicate that the physical difference between these two type of objects occurs beyond the BLR, and hence external to the central source. That is, Seyferts and LINERs may differ by the conditions in the circumnuclear gas, and not by a different accretion mode, as suggested by Dukid, Satyapal & Marcu (2009). Such a scenario implies that the intrinsic UV and X-ray emission of LINERs and Seyferts should not be distinct, as found by Maoz et al. (2005) and Maoz (2007). Though, these latter results are disputed (see the review by Ho 2008).

\(^5\) It is disputed whether the narrow lines of SDSS LINER 2s with low [O iii] equivalent width, and therefore low implied \( L/L_{Edd} \), are powered by AGN (e.g. Sarzi et al. 2010). This caveat does not affect our conclusions; therefore, we disregard it in the following analysis.
8 T1 AGN CLASSIFIED AS COMPOSITES AND SF

Why do some of the T1 objects display narrow-line ratios characteristic of Composites and SF galaxies? Can such line ratios be powered by accretion on to a massive black hole, or does it result from host contamination? The fraction of T1s classified as Composites increases with $L_\alpha/L_{\text{AGN}}$ at the SDSS-$z$ band (Fig. 5), which suggests a host contamination effect. Below, we explore quantitatively the host contamination, based on other indicators, and its relation to the narrow-line ratios. We compare the $L_{\text{bH}}/L_{\text{bHe}}$ and $L_{\text{UV}}/L_{\text{bHe}}$ of Composites with those of T1s which fall above the Ke01 line in the BPT-[N II] panel (hereby called 'pure-AGN'). In pure-AGN $L_{\text{bH}}$ and $L_{\text{UV}}$ correlate with $L_{\text{bHe}}$; thus, host contribution should manifest as higher $L_{\text{bH}}/L_{\text{bHe}}$ and $L_{\text{UV}}/L_{\text{bHe}}$ due to line and continuum emission from the SF regions.

In Table 4, we list the geometrical mean of $L_{\text{bH}}$ and $L_{\text{bHe}}$ for the T1 AGN classified as pure-AGN, Composites and SF. The SF group is divided into ‘SF-robust’ (32 objects) and ‘SF-non-robust’ (69 objects), depending on whether their narrow-line ratios are well constrained (Section 2.2.3). This division is to guard against systematic uncertainties in the less secure measurements. As seen in the lower-left panel of Fig. 4, non-robust SFs tend to have high $L/L_{\text{bH}}$, where the NLR is weak and the broad $\alpha$ is relatively narrow, making the NLR / BLR debbling difficult. It is therefore possible that in non-robust SFs broad Balmer flux was mistakenly assigned to the narrow Balmer lines, and their SF classification is not real. In the Composite and pure-AGN classes poorly constrained objects are less abundant (17 per cent), and therefore a separate group is not required.

Since the mean AGN $L_{\text{bH}}/L_{\text{bHe}}$ decreases with increasing AGN luminosity (Paper II), we compare each classification with a pure AGN matched in $L_{\text{bH}}$. The matched groups are constructed by randomly selecting one to four pure AGN T1 objects with the same $L_{\text{bHe}}$ (up to 0.1 dex), for each Composite or SF (see Table 4). The geometrical mean $L_{\text{bHe}}/L_{\text{bH}}$ of the Composites is 0.27, compared to 0.12 in the matched pure AGN. Therefore, the $L_{\text{bH}}/L_{\text{bHe}}$ ratios of Composites are consistent with a roughly equal AGN and host contribution to $L_{\text{bH}}$. In the robust SFs, the host contribution is twice the AGN contribution. An intermediate ratio is seen in the non-robust SFs.

A similar effect is expected in $L_{\text{UV}}/L_{\text{bHe}}$, as star formation will contribute only to $L_{\text{UV}}$. Indeed, the mean $L_{\text{UV}}/L_{\text{bHe}}$ of Composites and robust SFs is 50 per cent higher than in the respective matched group (25 per cent difference in the non-robust SFs). Is the observed increase in $L_{\text{UV}}/L_{\text{bHe}}$ consistent with the observed increase in $L_{\text{bH}}/L_{\text{bHe}}$? Star-forming galaxies have a mean $L_{\text{UV}}/L_{\text{bHe}} = 120$ (Kennicutt & Evans 2012). The Composites show an increase of 0.15 in $L_{\text{bH}}/L_{\text{bHe}}$, and are thus expected to show an increase of 120 × 0.15 = 18 in $L_{\text{UV}}/L_{\text{bHe}}$, which is indeed observed (54 from 36, Table 4). The robust SF groups show an increase of 0.3 in $L_{\text{bH}}/L_{\text{bHe}}$, and are thus expected to show an increase of 36 in $L_{\text{UV}}/L_{\text{bHe}}$, which is 50 per cent larger compared to the observed rise of 22. However, the difference is probably consistent within the larger uncertainties in this group. In the non-robust SF group the expected rise in $L_{\text{UV}}/L_{\text{bHe}}$ is 12, versus an observed value of 9, again consistent with the uncertainties.

To summarize, the T1 AGN which reside in the Composites and SF regions of the BPT diagrams also show higher $L_{\text{bH}}/L_{\text{bHe}}$ and $L_{\text{UV}}/L_{\text{bHe}}$ ratios, compared to pure AGN. In addition, the ratio of the increase in $L_{\text{bH}}$ and in $L_{\text{UV}}$ is consistent with $L_{\text{bH}}/L_{\text{bHe}}$ observed in star-forming galaxies. Thus, AGN powered by accretion on to a massive BH do not produce SF or Composite line ratios, and measurements of such line ratios in AGN implies host contamination.

Could host contamination also affect line ratios within the pure-AGN regime? Could some of the spread in the BPT diagrams, also within the pure-AGN regime, be caused by host contamination? Fig. 11 presents the mean BPT positions of T1s binned by $L_{\text{UV}}/L_{\text{bH}}$. We split the T1 sample into $L_{\text{bH}} < 10^{12}$ erg s$^{-1}$ (upper panels) and $L_{\text{bH}} > 10^{12}$ erg s$^{-1}$ (lower panels). The luminosity cut is set where the host contribution to $L_{\text{UV}}$ starts to be significant (Paper I). At $L_{\text{bH}} > 10^{12}$ erg s$^{-1}$, objects within the $L_{\text{UV}}/L_{\text{bHe}}$ ≤ 40 bins have similar mean positions, but the highest bin $L_{\text{UV}}/L_{\text{bHe}} = 80$ is shifted towards the Composite region. A similar behaviour is observed at $L_{\text{bH}} < 10^{12}$ erg s$^{-1}$. Objects within the $L_{\text{UV}}/L_{\text{bHe}} ≤ 30$ bins have similar mean positions, but the $L_{\text{UV}}/L_{\text{bHe}} = 90$ bin is shifted towards the Composite region. The highest bin here has $L_{\text{UV}}/L_{\text{bHe}} = 200$, and its mean position is within the Composite region. Thus, not only that Composite AGN have a higher mean $L_{\text{UV}}/L_{\text{bHe}}$, as found earlier, but also the highest $L_{\text{UV}}/L_{\text{bHe}}$ AGN are on average composite in nature. Therefore, the excess UV, seen in low-luminosity AGN, likely arises from star formation in the host, as suggested in Paper I, based on a comparison of their SED to the pure AGN SED. In addition, AGN within the ‘pure-AGN’ BPT regime can also be affected by host contamination, in particular when getting close to the Ke06 line. Narrow emission lines, powered purely by accretion, likely produce a smaller dispersion than observed in the BPT plots.

9 THE IONIZING SPECTRUM SEEN BY THE NLR

9.1 $\alpha_{\text{ox}}$ as a measure of the ionizing spectrum slope

What produces the scatter in the BPT plots? Possible parameters are the ionizing spectral slope and the ionization parameter (e.g. Groves et al. 2004). Below we test this explanation by exploring the dependence of the BPT positions on $\alpha_{\text{ox}}$, the power-law slope interpolated from $L_{\text{UV}}$ and $L_{\text{b}}$.

We use the 752 T1 objects that were observed by GALEX and have $L_{\text{bH}} > 10^{42.5}$ erg s$^{-1}$, to avoid host contamination of the UV. We note that this luminosity cut limits the AGN luminosity dynamical range to $10^{42.5} < L_{\text{bol}} < 10^{46}$ erg s$^{-1}$. These T1 objects
J. Stern and A. Laor

40, 10, 4, 1 bins have similar mean BPT positions, indicating \( \alpha > \alpha \) do seem to coincide. However, \( Z > Z \) The mean BPT positions by \( L \) and \( \alpha \) (mean value noted). The error bars indicate the uncertainty in the mean position. Only bins with \( \log L_{\text{bH\alpha}} < 42 \). The mean positions of objects with \( L_{\text{UV}}/L_{\text{bH\alpha}} = 90 \) and 200 are offset towards the composite region, indicating that the excess UV originates from star formation in the host galaxy. Bottom panels: T1s with \( \log L_{\text{bH\alpha}} > 42 \). The \( L_{\text{UV}}/L_{\text{bH\alpha}} = 40, 10, 4, 1 \) bins have similar mean BPT positions, indicating a similar intrinsic ionizing spectrum at these different \( L_{\text{UV}}/L_{\text{bH\alpha}} \). Therefore, if \( L_{\text{UV}}/L_{\text{bH\alpha}} < 40 \) indicates dust extinction (Paper I), the extinction dust resides on scales larger than the NLR.

are divided into bins of \( \alpha_{\text{ox}} \) with a width of 0.25. Fig. 12 shows the mean BPT-[O i] positions of the different \( \alpha_{\text{ox}} \) bins. The error bars denote the error in the mean position. We use the BPT-[O i] panel since it is most sensitive to the ionizing slope (Groves et al. 2004). The X-ray detection rates are 77 per cent, 73 per cent, 67 per cent and 29 per cent for the \( \alpha_{\text{ox}} = -1.2, -1.4, -1.6 \) and \( -1.8 \) bins, respectively. The UV detection rate is 60 per cent for the \( \alpha_{\text{ox}} = -1.2 \) bin, and >95 per cent in the other bins. Upper limits are used when a detection is not available, so the true \( \alpha_{\text{ox}} \) of the \( \alpha_{\text{ox}} = -1.8 \) bin is likely \(< -1.8 \), while the true \( \alpha_{\text{ox}} \) of the \( \alpha_{\text{ox}} = -1.2 \) bin is likely \( > -1.2 \).

We note that the known trend of \( \alpha_{\text{ox}} \) versus AGN luminosity (e.g. Just et al. 2007) implies a range of 0.2 in the mean \( \alpha_{\text{ox}} \) over the luminosity range spanned by the objects shown in Fig. 12 (see fig. 20 in Paper I). Therefore, the observed range of 0.6 in \( \alpha_{\text{ox}} \) in these objects is not dominated by the global trend with AGN luminosity.

For comparison, Fig. 12 also shows the expected BPT-[O i] position for ionizing spectra with different slopes and for different ionization parameters, taken from fig. 1(d) in Groves et al. (2004), which assume a density of 1000 cm\(^{-3}\) and \( Z = 2 Z_{\odot} \). Clearly, the observed mean position is independent of the mean observed \( \alpha_{\text{ox}} \), in sharp contrast with the models which predict a strong dependence. This discrepancy may indicate that at a given luminosity, the spread in \( \alpha_{\text{ox}} \) does not reflect a spread in the ionization slope at the EUV. The dispersion in the BPT plots is produced by another parameter, such as \( Z \), ionization parameter and the NLR density.

Telfer et al. (2002) showed that the mean EUV slope of 0.33 < \( z < 1.5 \) quasars, observed by Hubble Space Telescope (HST), is consistent with the mean \( \alpha_{\text{ox}} \) of quasars with the same luminosity, confirming previous results by Laor et al. (1997). Therefore, the mean EUV slope and mean \( \alpha_{\text{ox}} \) do seem to coincide. However, Fig. 12 suggests that this equality does not extended to individual AGN. There may exist additional mechanisms which produce a dispersion in \( \alpha_{\text{ox}} \) with no effect on the BPT positions. For example, variability on time-scales shorter than the NLR light crossing time (\( \gtrsim 100 \) yr). However, Vagetti et al. (2010) showed that variability on time-scales of up to one year accounts only for 30–40 per cent of the scatter in \( \alpha_{\text{ox}} \) at a given AGN luminosity. Another source for a dispersion in \( \alpha_{\text{ox}} \) is absorption restricted to our line of sight. A dusty absorber will flatten \( \alpha_{\text{ox}} \), as the dust optical absorption opacity is significantly larger than the X-ray absorption opacity (e.g. Laor & Draine 1993), while a dustless absorber will absorb only the X-ray and will steepen \( \alpha_{\text{ox}} \), as commonly seen in broad absorption line quasars (e.g. Brandt, Laor & Wills 2000). An absorber restricted to our line of sight will not significantly affect the NLR emission, and thus the BPT position will remain unchanged. A third option is an absorber located outside the NLR, so the NLR sees the intrinsic ionizing spectrum, and the BPT ratios are not affected. In the
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APPENDIX A: MEAN SPECTRA

In Sections 3–6, we show that the distribution of [N II]/Hα in the T1 sample shifts to lower values with increasing L_{bH α}. To exclude the possibility that this trend is an artefact of our debiasing algorithm, we examine the mean spectra at different L_{bH α} and Δν. We divide the T1 objects with L_{UV}/L_{bH α} < 0.1 (to avoid host contamination of the NLR) into bins of 0.3 dex in Δν and one decade in L_{bH α}. For each bin, we derive the host-subtracted mean spectrum, as described in Section 6.1.2. These mean spectra are plotted in Figure A1, with L_{bH α} increasing from bottom to top, and Δν increasing from left to right. The thin black line in each panel shows the mean spectrum in the L_{bH α} versus velocity plane, centred on Hα. To enhance the contrast between different NLR and
APPENDIX B: BPT BY M_{BH} AND M_{*}

Figs B1 and B2 show the BPT positions of the T1 sample, divided by \( M_{BH} \) and \( M_* \), in the same format as Figs 3–5. In Fig. B2, only the 91 percent of T1 objects with a reliable estimate of \( M_* \) (Section 2.3.1) are shown.

With decreasing \( M_{BH} \), the fraction of T1s classified as Composites and SFs increases, indicating an increase in the relative amount of host contribution to the NLR (Section 8). Since the SDSS is a flux-limited sample, T1s with low \( M_{BH} \), and therefore low bulge mass, are preferentially selected from disc-dominated galaxies (see fig. 16 in Paper I). Discs have a relatively large specific star formation rate, which may cause the observed shift in the BPT positions.

With decreasing \( M_* \), an increasing fraction of objects are offset to low \([\text{N} \alpha]/\text{H}\alpha \) values, as found by Groves et al. (2006) on a type 2 AGN sample. This trend is consistent with the \( M_* - Z \) relation of quiescent galaxies (Lequeux et al. 1979, and citations thereafter).

APPENDIX C: THE APPARENT BALDWIN EFFECT WHEN USING A PROXY FOR \( L_{\text{CONT}} \)

Assume that \( Y \) and \( X \) are some variables. If intrinsically \( Y \propto X^{1.0} \), and one measures \( Y \) and \( X^\prime \) on some sample, where \( X^\prime \) is a proxy for \( X \), then due to the dispersion between \( X \) and \( X^\prime \) one will find \( Y \propto X^{1.0} \). In Section 3, \( Y \equiv L_{\text{NL}} \), \( X \equiv L_{\text{CONT}} \) and \( X^\prime \equiv L_{\text{BLR}} \).

Therefore, \( \epsilon \) is the Baldwin effect one would measure when using \( L_{\text{BLR}} \) as a proxy for \( L_{\text{CONT}} \), assuming no intrinsic Baldwin effect. In this section, we evaluate \( \epsilon \) analytically. We assume

\[
Y = 1 \cdot X + \sigma_{YX} + b \\
X^\prime = 1 \cdot X + \sigma_{XX^\prime} + c,
\]

where \( b \) and \( c \) are some constants, and \( \sigma_{AB} \) denotes the dispersion between \( A \) and \( B \). We assume that the \( \sigma_{XX^\prime} \) and \( \sigma_{YY} \) are independent of \( X \) and of each other, and symmetric around zero. To significantly reduce the algebra, without affecting the final result, we set \( b = c = 0 \), where \( \bar{X} \) is the mean \( X \) in the sample.

The best-fitting slope is derived from

\[
\frac{d}{d\epsilon} \frac{1}{N} \sum (Y - (1 - \epsilon)X)^2 = 0.
\]
Figure B1. As in Fig. 3, for the dependence of the BPT position on $M_{\text{BH}}$. In each row, T1 AGN from a given decade-wide bin in $M_{\text{BH}}$ are plotted (mean $M_{\text{BH}}$ noted, in $M_{\odot}$). The frequency of composites and SFs decreases with increasing $M_{\text{BH}}$, from 32 per cent at log $M_{\text{BH}} = 6.3$, to 23 per cent, 14 per cent and 6 per cent at log $M_{\text{BH}} = 7.1, 7.9$ and 8.8, respectively.

Differentiating and dividing by 2, the left-hand side equals

$$\frac{1}{N} \sum (Y - (1 - \epsilon)X')X'$$

$$= \frac{1}{N} \sum YX' - (1 - \epsilon)X^2$$

$$= \frac{1}{N} \sum (X + \sigma_{XX})(X + \sigma_{XX}') - (X + \sigma_{XX})^2 + \epsilon(X + \sigma_{XX})^2.$$  \hfill (C3)

Utilizing the assumptions on $\sigma_{XX'}$ and $\sigma_{XY}$ above, all terms which are linear in $\sigma_{XX'}$ or $\sigma_{XY}$ vanish for $N \to \infty$. Therefore, we are left with

$$\frac{1}{N} \sum X^2 - X^2 - \sigma_{XX}^2 + \epsilon \left( X^2 + \sigma_{XX}^2 \right).$$  \hfill (C4)

From $\bar{X} = 0$, we get $\frac{1}{N} \sum X^2 = (\Delta X)^2$, where $\Delta X$ is the standard deviation of the distribution of $X$ spanned by the sample. We abuse notation a bit and replace $\frac{1}{N} \sum \sigma_{XX}'$ with $\sigma_{XX}'$. Therefore,

$$- \sigma_{XX}' + \epsilon \left( (\Delta X)^2 + \sigma_{XX}^2 \right) = 0,$$  \hfill (C5)

and hence,

$$\epsilon = \frac{\sigma_{XX}^2}{(\Delta X)^2 + \sigma_{XX}^2} = \frac{1}{1 + (\Delta X)^2 / \sigma_{XX}^2} \leq \frac{1}{1 + (\Delta X)^2 / \sigma_{XX}^2} = \left( \frac{\sigma_{XX}}{\Delta X} \right)^2.$$  \hfill (C6)
Type 1 low $z$ AGN. III. Narrow line ratios

As in Fig. 3, for the dependence of the BPT position on $M_\ast$. In each row, T1 AGN from a given half-decade-wide bin in $M_\ast$ are plotted (mean $M_\ast$ noted, in M$_\odot$). With decreasing $M_\ast$, an increasing fraction of objects are offset to low [N II]/H$\alpha$ values, consistent with the $M_\ast-Z$ relation of quiescent galaxies.

As expected, $\epsilon$ decreases when the dynamical range of $X'$ increases.

In Section 3, we show that in the T1 sample equation (C6) implies $L_{NL} \propto L_{H\alpha}^{1.07}$. The observed slopes of $\lesssim 0.7$ are significantly lower than 0.93, and therefore imply the existence of an intrinsic Baldwin effect.

**SUPPORTING INFORMATION**

Additional Supporting Information may be found in the online version of this article:

**Table 1.** The AGN and host characteristics of the T1 sample objects.

**Table 2.** The narrow-line measurements of the T1 sample (http://mnras.oxfordjournals.org/lookup/suppl/doi:10.1093/mnras/stt211/-/DC1).

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