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# Host galaxy and orientation differences between different types of AGN

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**ABSTRACT**

*Aims.* The main purpose of this study is to investigate aspects regarding the validity of the AGN unification paradigm (UP). In particular we focus on the AGN host galaxies, which according to the UP should show no systematic differences depending on the AGN classification.

*Methods.* For the purpose of this study we use (a) the spectroscopic SDSS (Sloan Digital Sky Survey) DR14 catalogue, in order to select and classify AGNs using emission line diagnostics, up to a redshift of $z = 0.2$, and (b) the Galaxy Zoo Project catalogue, which classifies SDSS galaxies in two broad Hubble types, spirals and ellipticals.

*Results.* We find that the fraction of type-1 Seyfert nuclei (Sy1) hosted in elliptical galaxies is significantly larger than the corresponding fraction of any other AGN type, while there is a gradient of increasing Spiral-hosts from Sy1 to Liner, type-2 Seyferts (Sy2) and Composite nuclei. These findings cannot be interpreted within the standard Unification Paradigm, but possibly by a co-evolution scheme for supermassive black holes (SMBH) and galactic bulges.

Furthermore, for the case of spiral host galaxies we find the Sy1 population to be strongly skewed towards face-on configurations, while the corresponding Sy2 population range in all host-galaxy orientation configurations, having a similar, but not identical, orientation distribution with star-forming galaxies (SF). These results also cannot be interpreted by the standard Unification Paradigm, but point towards a significant contribution of the galactic disk to the obscuration of the nuclear region. This is also consistent with the observed preference of Sy1 nuclei to be hosted by ellipticals, ie., the dusty disk of spiral hosts contributes to the obscuration of the broad line region (BLR) and thus relatively more ellipticals are expected to appear hosting Sy1 nuclei.

**Key words.** galaxies: Seyfert - galaxies: active - galaxies: nuclei - galaxies: evolution - galaxies: bulges - galaxies: statistics

## 1. Introduction

The unification model of Active Galactic Nuclei (AGN) explains the wide variety of features discerned in different classes of AGN in terms of the anisotropic geometry of the black hole's immediate surroundings (e.g. Antonucci 1993; Urry & Padovani 1995; Netzer 2015)). The accreting supermassive black hole (SMBH) is fed via a disc, while a thick and obscuring torus of gas and dust surrounds the disc absorbing a fraction of the emitted radiation. Depending on the orientation of the torus with respect to the observer's line of sight, the view towards parts of the galactic nucleus may be obstructed, giving rise to differences in the observed brightness and spectra of the AGN.

An important implication of the Unification Paradigm is that, since the observed differences between AGN types are attributed solely to orientation effects, the host galaxies of AGN should be intrinsically the same (e.g. Netzer 2015; Hickox & Alexander 2018). Thus, despite their success in explaining a range of AGN observed features, such as the absence of broad-line features in the spectra of Sy2 galaxies, it has become clear that the simplest models of unification are inconsistent with observations and can not explain aspects such as the lack of BLR in many Sy2 AGN in polarised spectra (Tran 2001, 2003) and the lack of Sy1's in clusters (Martínez et al. 2008). Specifically, according to studies investigating the differences between Sy1's and Sy2's (e.g. Koulouridis et al. 2006; Rigby et al. 2006; Martínez-Sansigre et al. 2006a; Lacy et al. 2007; Villarroel et al. 2012; Netzer 2015; Bornancini & García Lambas 2018; Zou et al. 2019; Bornancini & García Lambas 2020) and the connection with their host galaxies at redshifts $0.03 < z < 0.2$ (Villarroel et al. 2012; Koulouridis et al. 2013), it has been shown that type-1 and type-2 Seyfert galaxies have different optical, mid-IR, X-ray and morphological properties and also reside in statistically different environments (Bornancini & García Lambas 2020). Moreover, it is found that the neighbours of Sy2 AGN are more star-forming and bluer than Sy1 AGN (see also Koulouridis et al. 2013) and also that Sy2 hosts are surrounded by a larger number of dwarf galaxies (Villarroel et al. 2012). Additionally, the morphology of Sy1 galaxies show no indications of close interactions which means either that they rarely merge (Koulouridis 2014), or that they are extremely short-lived AGNs (Villarroel et al. 2012). Bornancini & García Lambas (2018) find at high redshifts ($0.3 < z < 1.1$) that Sy2's have more abundant neighbors as well as, that Sy1 hosts are preferably elliptical or compact galaxies, while Sy2 hosts present a broader Hubble-type distribution.

Since, observations do not fully comply with the predictions of the Unification Paradigm, alternative or complementary factors affecting the observed AGN types should be sought in order to explain the AGN variety. Indeed, Koulouridis et al. (2006) and Jiang et al. (2016) studying the environments of Sy1 and Sy2 galaxies at low redshifts found that both AGN classes have similar clustering properties, but at scales smaller than $100kpc$ Sy2's have significantly more neighbours than Sy1's. Jiang et al. (2016) also found significant differences in the infrared color distributions of the host galaxies of the two AGN types. Furthermore, some studies claim that, not only the torus, but also the dust in the galactic disk may have non-negligible contribution to the optical obscuration of nuclei (e.g. Maiolino & Rieke 1995; Matt 2000; Lagos et al. 2011; Netzer 2015; Bornancini & García Lambas 2018; Zou et al. 2019). Malizia et al. (2020) using the hard X-ray selected AGN sample detected by INTEGRAL/IBIS, have shown that material located in the host galaxy on scales of hundreds of parsec, while not aligned with the absorbing torus, can be extended enough to hide the Broad Line Region (BLR) of some Sy1's causing their misclassification as Sy2 objects and giving rise to the deficiency of around 24% of Sy1's in edge-on galaxies.

According to Koulouridis et al. (2006) and Krongold et al. (2002), in the context of a time-evolution scenario, in some cases the interaction between gas-rich galaxies ignites starburst activity while large amounts of gas and dust obscure the central nuclear region at this stage. As the starburst dies off, the remaining molecular gas and dust forms a torus around the disk and, eventually the AGN will attenuate the obscuring medium. Namely, this model proposes an AGN- evolutionary sequence going from starburst to type-2 and finally to type-1 Seyfert galaxies (e.g. Springel et al. 2005; Hopkins et al. 2006; Koulouridis et al. 2013; Yang et al. 2019).

Studies in polarised light to Sy2 galaxies, have shown that in many low-luminous AGN the dusty torus is absent while the BLR is also not detected (e.g. Elitzur & Shlosman 2006; Perlman et al. 2007; Trump et al. 2011; Koulouridis 2014; Hernández-Ibarra et al. 2016). These results are consistent with those of Trump et al. (2011), who support that above a specific accretion rate ($(L/L_{\rm Edd} \gtrsim 0.01)$) AGN can be observed as broad-line or as obscured narrow-line AGNs, while for ($L/L_{\rm Edd} \lesssim 0.01$) the BLR becomes non-detectable but also the obscuring torus tends to become weaker or disappears (Elitzur et al. 2014).

The above findings could be incorporated within the evolutionary scheme. If the accretion-rate dependent scenario is valid, one would expect that AGN could lose their torus or/and their BLR at the end of the AGN duty cycle, as the accretion rate drops below a critical value (Elitzur et al. 2014; Elitzur & Ho 2009; Koulouridis 2014). This implies that firstly, AGN can appear as type-1, after the quenching of the star-forming activity by the AGN feedback and the disappearance of the torus (Krongold et al. 2002) and secondly, these type-1 will evolve to true type-2 AGN due to the elimination of the BLR, based for example on the wind-disk scenario of Elitzur & Ho (2009).

In summary, the plethora of results of many relevant studies clearly indicate that the viewing angle alone cannot fully account for the different AGN types. It is within this ideology that the current study lies, investigating the orientation properties of spiral hosts as well as the Hubble type distribution of different types of AGN.

After the presentation of the data used in section 2, the main part of our analysis is organised as follows; In section (3.1) we study the morphology frequency distribution of host galaxies for different AGN-types comparing to that of the non-active star-forming sample, after statistically matching their respective redshift distribution in order to suppress possible evolutionary effects. In the section (3.2) we study the frequency distribution of spiral host galaxy orientations ($b/a$), for the Sy1 and Sy2 subsamples, comparing with that of non-active star-forming galaxies (which we use as a control sample). We use only galaxies with high "spirality" probability > 0.8 (as defined by the Zoo-project), also statistically matching their respective redshifts distributions.

## 2. Observational Data

For the purposes of the current study we use galaxy catalogues extracted from the Sloan Digital Sky Survey (SDSS) DR14 (Abolfathi et al. 2018) in five bands (u,g,r,i,z) with a magnitude limit for the spectroscopic sample of $m_r = 17.77$ in the r-band, in order to have a homogeneous magnitude cutoff over the largest possible SDSS area. Our catalogues consist of 3.800 Sy1, 56.846 Sy2, 120.025 Composite, 107.034 Liners and 263.223 star-forming galaxies with redshift $z < 0.2$. The morphology characterization of the galaxies is based on the Galaxy Zoo Project (Lintott et al. 2008), a crowd sourced astronomy project which asks citizens to characterize galaxies as spirals or ellipticals and to determine the rotation direction of spirals by inspecting SDSS galaxy images (Raddick et al. 2007). In order to ensure trustworthy classification of our galaxies, we perform a quality cut on our catalogue, rejecting galaxies with Ha rest-frame equivalent width (EW) < 8 Å, which although a rather arbitrary limit, we have verified that it is quite secure via inspection of a sufficiently large subsample.

The Sy1 sample comprises all galaxies with a Balmer line width of $\sigma$ greater than 500 km/sec (FWHM>1180 km/s). Note, that in the SDSS database all such sources are catalogued as having a $\sigma$=500 km/sec, while this is actually a lower limit. Visual inspection of a large number of spectra validated that these sources are bonafide broad line Seyferts. All spectra with an emission line having $\sigma$ >200 km/sec are also characterized as broadline in the SDSS database. We have visually reviewed all spectra in our spiral galaxy sample that fall in this category (450 sources) and we have concluded that they contain very few that could be unambiguously classified as broad-line AGNs. Therefore, to reduce noise in our analysis we choose to exclude from our Sy1 sample all spectra with Balmer lines having $\sigma$ <500 km/sec.

After the above procedures our final sample of secure objects consists of 1.378 Sy1, 7.498 Sy2, 26.544 Composite, 1.926 Liner and 203.298 SF galaxies.

The classification between different type of narrow-line AGNs and SF galaxies has been performed utilizing the BPT diagram classification method of Baldwin et al. (1981).

It is important to note that we will use the SF galaxies, being spirals in their vast majority, as our control sample since, their disk orientations cover the whole range of viewing angles with respect to the line of sight. Additionally, they are mainly non-AGN galaxies, while, even in the case of hosting an AGN in their center, the star-formation dominates the emission, leading to spectra characteristic of non-AGN galaxies (Siebenmorgen et al. 2015).

Before proceeding we felt necessary to investigate the level of consistency between the morphology classification of the Galaxy Zoo project and our own assessment via inspection of the host galaxy image. To this end, we select a small subsample of images and spectra of galaxies of the highest "spirality" (probability of being a spiral) and "ellipticity" (probability of being an elliptical). In detail, we select 50 nearby galaxies, 5 spirals and 5 ellipticals of every AGN type, with redshift $z < 0.1$ in order to ensure a high image quality. We concluded that although the

Galaxy Zoo morphology classification is reliable for the majority of our galaxies, we found some cases in which the assessment of the citizens participating in the Galaxy Zoo project seems to be dubious. Our analysis showed that we can trust the characterization of spirals up to $z \sim 0.2$ while that of ellipticals only up to $z \sim 0.1$ since the spiral features are more difficult to distinguish at higher redshifts, where a galaxy image with weak spirality can be interpreted as being an elliptical.

## 3. Methodology and Results

This section is organised as follows: in subsection §3.1 we study the Hubble-type frequency distributions of the host galaxies for the different samples: Sy1s, Sy2s, Liners, Composite or starforming, while in section §3.2 we compare the projected axis-ratio (related to the orientation with respect to the line-of-sight) frequency distributions for the spiral hosts of Sy1's and Sy2's.

### *3.1. Hubble type distribution*

In this section, we seek to reveal if there is any correlation between the AGN-type and the Hubble-type morphology of their host galaxies. According to the Unification Paradigm, the different AGN classes are a result of different viewing angles with respect to the orientation of an obscuring torus and thus, the properties of the host galaxies should not show any statistical significant differences. For this study, we use subsamples of Sy1, Sy2, Liner, Composite and SF galaxies, derived from our SDSS catalogue with a redshift limit of $z < 0.1$, in order to have more robust Hubble-type classification (as discussed in the previous section). For these subsamples we generate the frequency distribution of the Zoo ellipticity- and spirality- probabilities, which within the context of the UP, are expected to be statistically the same for all classes of AGN (e.g. Antonucci 1993; Urry & Padovani 1995).

In order to be able to compare among the different probability distributions, avoiding possible evolutionary effects, it is necessary to take into account any statistically significant differences between the redshift-distributions of the different samples, which we present in Fig.1(*upper panel*). Due to the different number of objects in the subsamples and in order to reveal systematic trends among the different subsamples, we normalise the distributions dividing with the total number of objects in each subsample. Using a random sampling procedure we match the normalized redshift-distributions to a common fractional distribution (Fig.1 - *lower panel*). Because of the low number of Sy1 galaxies and in order to avoid further depleting it, we re-sample all other activity-types, so that their normalised distributions are matched to that of the Sy1 sample.

For the redshift matched subsamples, we present in Fig. 2 the "ellipticity" (*upper panel*) and "spirality" (*lower panel*) - probability distributions. The two quantities are complementary as should be expected, since the sum of the two Zoo-probabilities should be roughly equal to unity. Moreover, we should note that SF galaxies, with spectra dominated by young stellar populations, are by definition spirals (Hubble 1926) and indeed, as seen in Fig. 2, their "spirality"-distribution (black solid line) peaks at high-"spirality" probabilities, while their respective "ellipticity"-distribution, roughly complementary, peaks at zero-"ellipticity" probabilities. The SF galaxy sample can thus be used as a control sample of the Zoo Project "spirality"- and "ellipticity"- distributions of the various AGN host galaxies.

In Fig. 2 we see that the different AGN classes are distributed in the whole range of probabilities indicating a wide

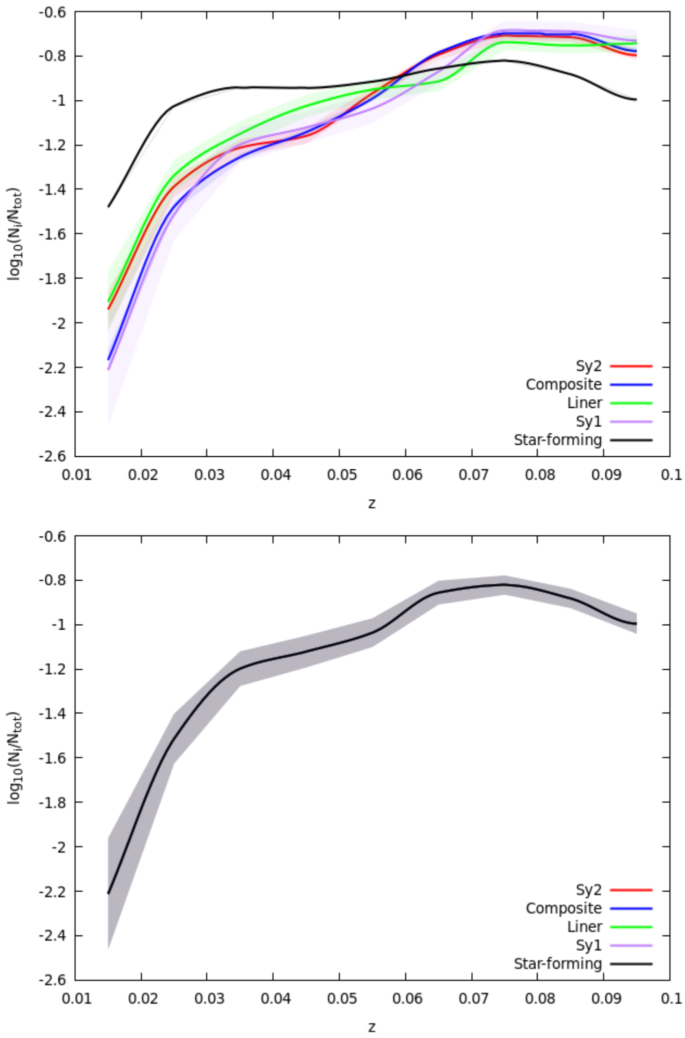


**Fig. 1.** *Upper panel:* Normalised redshift frequency distributions for the four subsamples of AGN types and SF galaxies, limited to $z < 0.1$. The different subsamples are coded with different colours as denoted in the key. *Lower panel:* Redshift-matched normalized distribution. The shaded area corresponds to the $1\sigma$ Poisson uncertainty.

range of Hubble-type hosts, with the predominance of Spirals. However, the normalized frequency distribution of the different AGN-types are dissimilar at a statistically significant level (as indicated by the $1\sigma$ Poisson uncertainty) which implies a different Hubble-type distribution for the different AGN types, a result that contradicts the original Unification Paradigm according to which there should be no dependence of the AGN class to the host galaxy Hubble-type classification (e.g. Antonucci 1993). Interestingly, the Sy1's show a peak at both high and low "spirality" probabilities, indicating a relatively higher fraction of Sy1's, with respect to other AGN types, residing in elliptical hosts.

For a more revealing comparison of the previously discussed morphology difference of the various AGN host galaxies with respect to SF galaxies, we present in Fig.3 the excess factor by which the fractional number of the various AGN types exceed that corresponding to SF galaxies, for each "spirality" or "ellipticity" probability:

$$\Delta(\mathrm{AGN, p}) = \frac{\mathrm{N_i(AGN)/N_{tot}(AGN)}}{\mathrm{N_i(SF)/N_{tot}(SF)}} - 1 \ ,$$

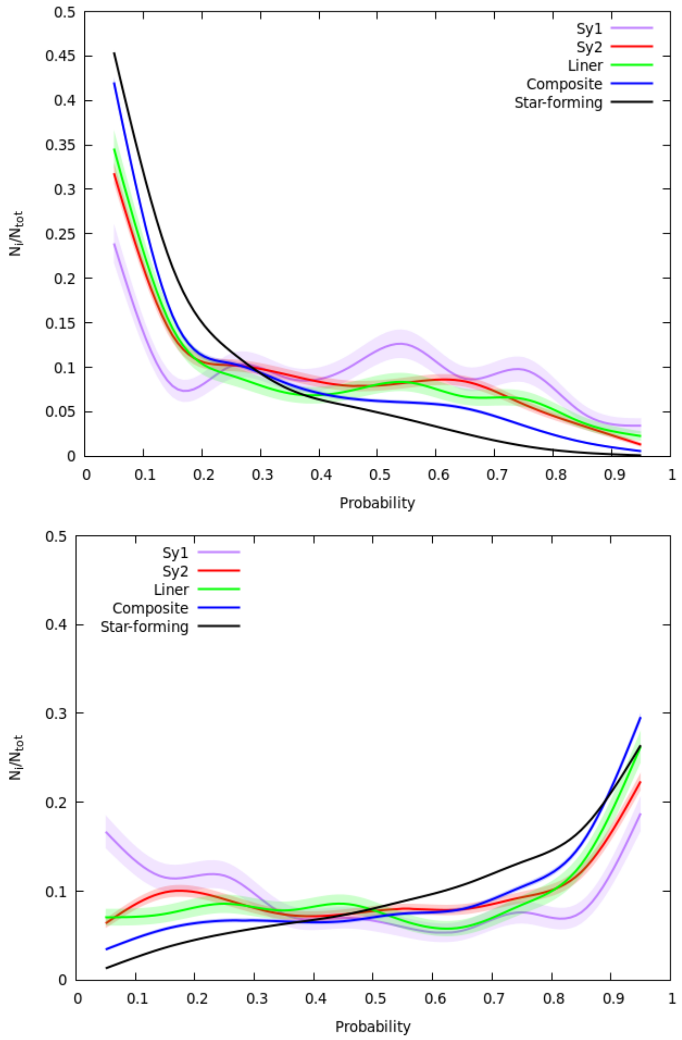


**Fig. 2.** Probability-distributions of "ellipticity" (*upper panel*) and "spirality" (*lower panel*) for the Sy1, Sy2, Liner, Composite and SF host galaxies, limited to $z < 0.1$. The different AGN and the SF subsamples are color coded as in Fig.1 while the shaded area corresponds to the $1\sigma$ Poisson uncertainty.

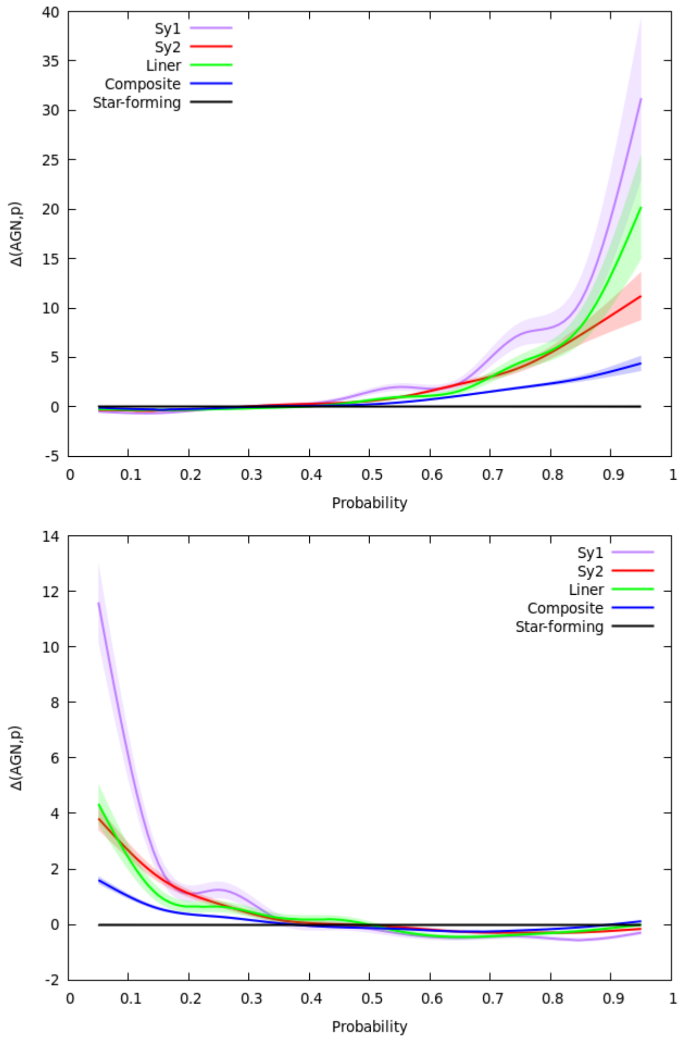


**Fig. 3.** The values of the factor $\Delta(\mathrm{AGN,p})$ by which the different AGN types exceed the corresponding fractional number of SF galaxies for the "ellipticity" (*upper panel*) and "spirality" ((*lower panel*) cases. The different AGN and the SF subsamples are color coded as in Fig.1 while the shaded area corresponds to the $1\sigma$ Poisson uncertainty.

Inspecting Fig.3 it becomes evident that Sy1s show the highest relative preference for elliptical hosts with respect to Liners, Sy2s and Composites, although all AGN types, at a different degree each, appear in elliptical hosts.

### 3.2. The effect of the galactic disk on the obscuration of the AGN

We wish to test the hypothesis that the AGN-host galaxy contributes to the obscuration of the AGN-emission. To this end we will study the orientation of spiral galaxies hosting Sy1 and Sy2 nuclei, limited to $z < 0.2$. We select only spiral hosts for this test since the orientation of spirals with respect to the line-of-sight can be quantified via their projected axis-ratio, $(b/a)$. Furthermore, in order to reduce noise we require a high Galaxy Zoo "spirality" probability, i.e., $p > 0.8$. We also use the corresponding subsample of SF galaxies as a reference (or control) sample.

Firstly, we present in Fig.4-5-(*upper panel*) the Sy1 and Sy2 subsample normalised redshift distributions and compare them with the corresponding distribution of SF galaxies. As it can be clearly seen, and also has quantified by the Kolmogorov-Smirnov (KS) test (p-value $\sim 0$ and $\sim 10^{-4}$, respectively), the distributions are significantly different. For $z \lesssim 0.08$, the fraction of both the AGN populations is lower than that of the SF galaxies, while for higher values, $z \gtrsim 0.1$, the AGN-fractions are greater than that of SF galaxies. Whether due to observational biases or evolutionary effects, understanding such differences is out of the scope of the current work. However, we need to ensure that our results will not be affected by such biases and thus follow the same resampling technique, as in section 3.1, to obtain matched redshift distributions which are shown in Fig. 4-5 -(*lower panel*).

We can now proceed to a meaningful comparison of the orientation distribution of Sy1s and Sy2s with respect to the SF case. We expect that, according to the UP, the orientation-distributions of Sy1s and Sy2s, hosted in spiral galaxies must be identical to that of spiral SF galaxies. In presenting our results, we again normalise the distributions by the total number of objects in each subsample.

In Fig.6 we present the comparative plot of the normalised axis-ratio $(b/a)$ -distributions for the spiral galaxies hosting Sy1 nuclei (purple) and for the control sample of SF galaxies. It is

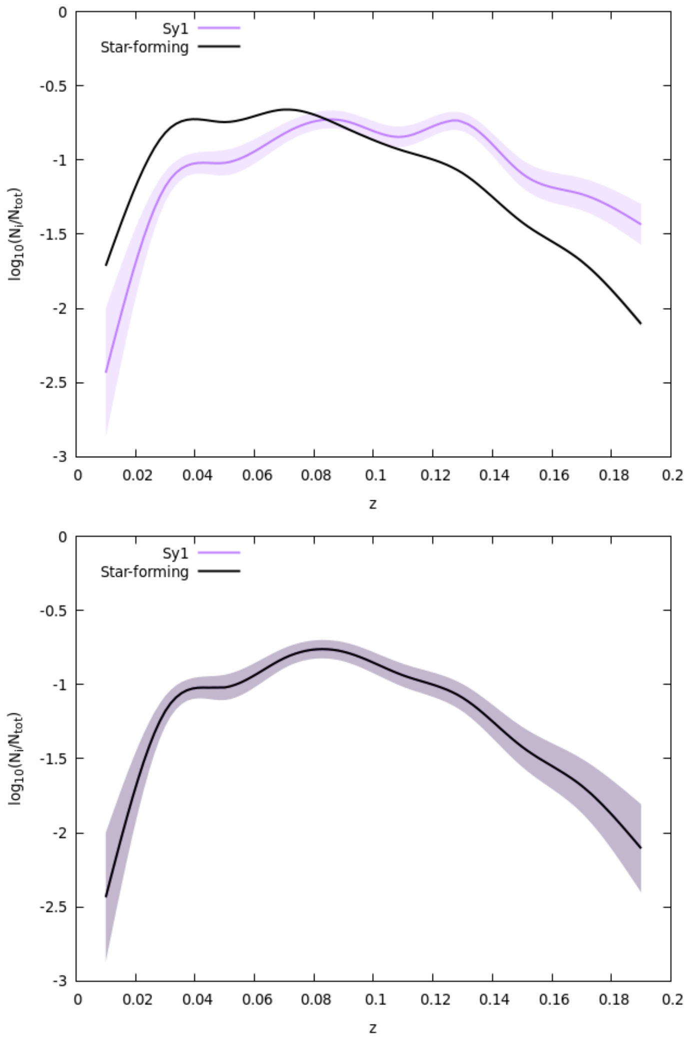


**Fig. 4.** *Upper panel:* Normalised redshift-distribution of spiral Sy1 and SF galaxies. *Lower panel:* Normalised redshift-matched distribution of Sy1's and the corresponding SF control sample. The Sy1 and the SF subsamples are color coded as in Fig.1 while the shaded area corresponds to the $1\sigma$ Poisson uncertainty.

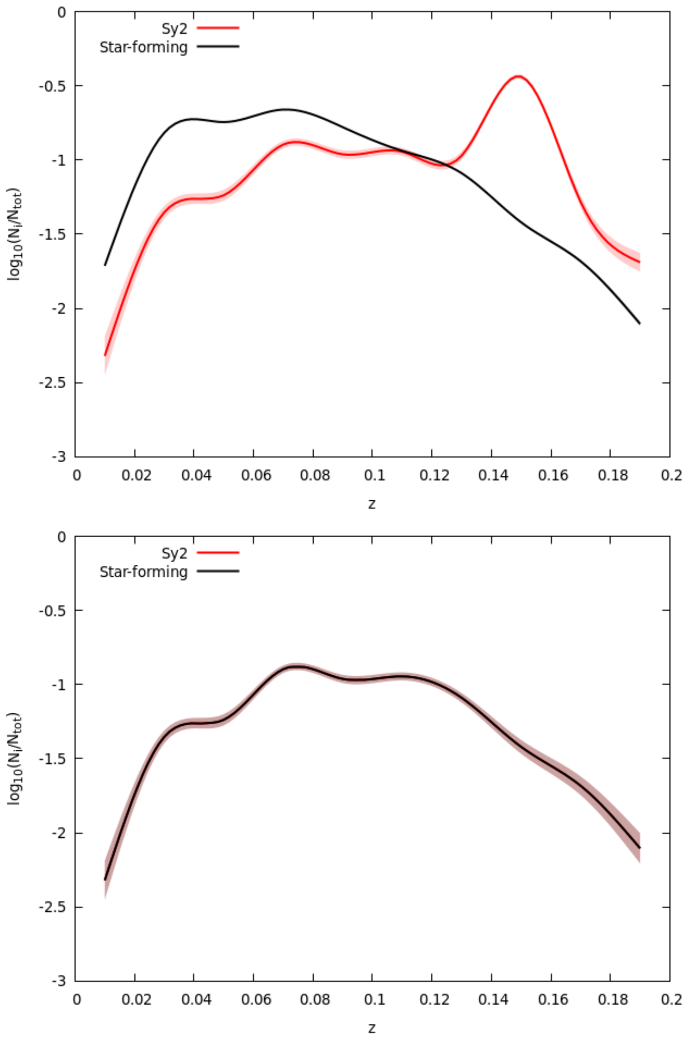


**Fig. 5.** *Upper panel:* Normalised redshift-distribution of spiral Sy2 and SF galaxies. *Lower panel:* Normalised redshift-matched distribution of Sy2 and the corresponding SF control sample. The Sy2 and the SF subsamples are color coded as in Fig.1 while the shaded area corresponds to the $1\sigma$ Poisson uncertainty.

evident that the two distributions are different, which we also confirm with a KS test (p-value $\sim 10^{-8}$); the $b/a$- distribution of Sy1 is skewed towards high $b/a$ values, indicating inclination angles closer to face-on orientations, while the control sample covers the full range of orientation angles. The distribution of the control sample shows a peak at $b/a \approx 0.35$, whereas the Sy1 population peaks at $b/a \approx 0.7$. Moreover, for $b/a < 0.4$ we find that the fraction of Sy1 host galaxies decreases dramatically compared to SF galaxies. Thus, we conclude that the type-1 Seyferts tend to be more "face-on" compared to SF galaxies and only a very small fraction of Sy1 galaxies is found to have $b/a$ values close to the "edge-on" orientation.

In Fig. 7 we present the respective $b/a$ comparison plot for the Sy2 and the star-forming subsamples and we find that although their distributions are significantly more similar than the corresponding of Fig.6, the are still statistically different as confirmed by a KS test (p-value $\sim 10^{-11}$). In detail, both the type-2 Seyferts and the SF galaxies are distributed in the whole range of $b/a$, with the star-forming peaking at b/a$\approx$ 0.35, while the Sy2 appear to have two local maxima, at b/a$\approx$ 0.37 and at b/a$\approx$ 0.65. A significantly higher fraction of Sy2 galaxies has values of $b/a \in (0.3, 0.8)$, while, for values $b/a < 0.3$ (close to "edge-on" orientations) and $b/a > 0.8$ (close to "face-on" orientations) the fraction of Sy2s is lower than that of SF galaxies.

## 4. Discussion

### 4.1. Why do Sy1 nuclei favour Elliptical hosts?

There are various indications for differences in the host galaxies of AGNs in the literature. Our results in the low-redshift regime is in agreement with the results of Bornancini & García Lambas (2018), based on higher redshift ($0.3 < z < 1.1$) type-1 and type-2 AGNs from the *COSMOS2015* catalogue, who showed that the type-1 AGN host galaxies appear more elliptical and compact than those of type-2 AGN that span the whole spiral to elliptical Hubble-type range. In addition, Sorrentino et al. (2006) using data from the Fourth SDSS Data Release (DR4) found that 76% of type-1 Seyfert host-galaxies are elliptical, while the corresponding ratio of Seyfert 2 hosted in early-type galaxies is 56.8%. Slavcheva-Mihova & Mihov (2011) found that more type-1 than type-2 AGN prefer elliptical hosts. Similarly, Villarroel et al. (2017) and Chen & Hwang (2017) concluded that

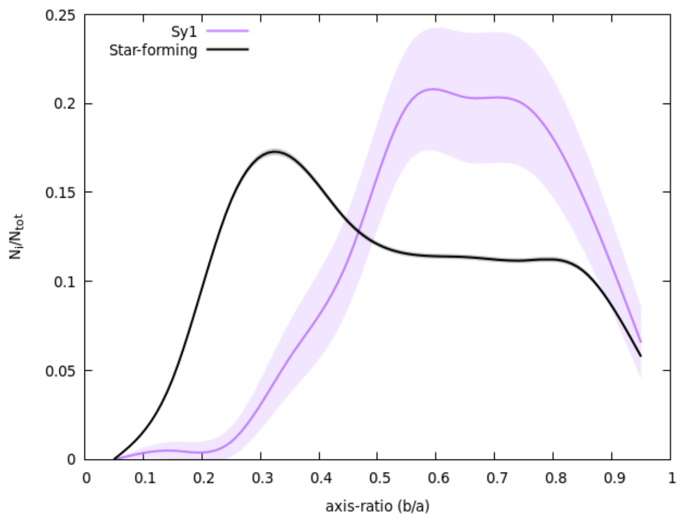


**Fig. 6.** Distribution of the projected axial ratio for spiral galaxies hosting Sy1s and the corresponding control sample of SF galaxies. The Sy1 and the SF subsamples are color coded as in Fig.1 while the shaded area corresponds to the $1\sigma$ Poisson uncertainty.

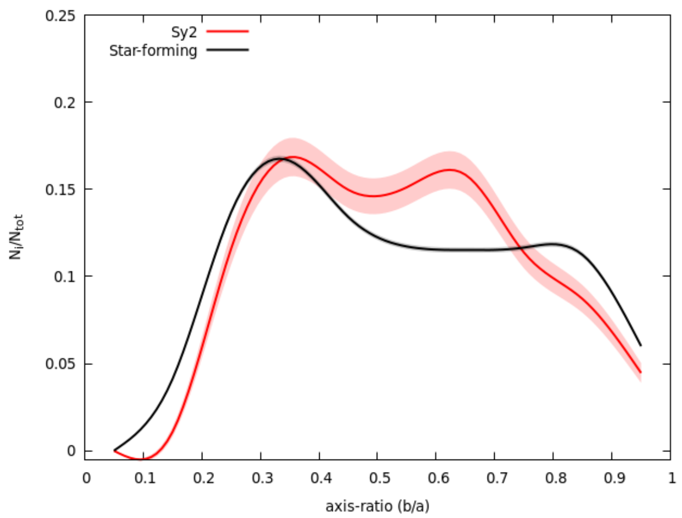


**Fig. 7.** Distribution of projected axial ratios for spiral galaxies hosting type-2 AGN and the corresponding control SF sample. The Sy2 and the SF subsamples are color coded as in Fig.1 while the shaded area corresponds to the $1\sigma$ Poisson uncertainty.

Seyfert 2 nuclei reside more in spiral hosts ($\sim 30-40\%$) than Seyfert 1 nuclei do ($\sim 20\%$).

The different bulge distributions of Sy1 and Sy2 might be related to an evolutionary sequence of AGN activity (e.g. Koulouridis et al. 2013, 2006; Krongold et al. 2002; Tran 2003; Villarroel et al. 2012). These results indicate a possible co-evolution scheme between galaxies and SMBHs (e.g. Hopkins et al. 2006, 2008b,a; Springel et al. 2005). At the initial merging phase, during the enhanced star-forming activity and accretion, the AGN is mostly obscured because of the large amount of gas and dust in the circum-nuclear region. However, the AGN will eventually be revealed after the surrounding material is consumed, or expelled by radiation pressure. In parallel to the AGN evolution, the stellar population of the merger will also rapidly redden and the host will be eventually transformed to a quiescent elliptical galaxy (e.g. Hopkins et al. 2008b,a). AGN feedback plays an essential role to both AGN and galaxy transformation and probably leads to the observed SMBH-bulge relation (e.g. Ferrarese & Merritt 2000; Gebhardt et al. 2000; Magorrian et al. 1998). Although, major mergers and powerful AGNs are far less common in the local Universe, compared to redshift $z > 1$, the difference found in the current work could be partly due to the co-evolution of the bulge and AGN activity after such events.

Alternatively or in addition, the difference could also be due to the obscuration of the BLR from the gas- and dust-rich disk of a spiral galaxy, especially in edge-on systems. This possibility is further discussed in the next section.

### 4.2. Why do Sy1 nuclei favour face-on orientations of the host galaxy?

Our analysis also showed that the orientations of the Sy1 and Sy2 spiral host galaxies are significantly different when compared to the control sample of the spiral SF galaxies. This is also unexpected within the UP and the interpretation of our results points towards two possible scenarios:

- additional obscuration of the AGN by dust in the galactic disk, near the circum-nuclear region,
- some level of statistical co-alignment of the plane of the torus and that of the galactic disk.

According to the latter scenario Sy1 galaxies, having a "face-on" oriented torus, also have more frequently face-on host galaxy orientations. However, if that were the case, we should correspondingly expect a higher fraction of "edge-on" host galaxies in the Sy2-distribution, with respect to SF galaxies, which is not observed. Without excluding this scenario, since processes like merging may induce a rearrangement and facilitate such a co-planarity, we do not have a clear indication to confirm this hypothesis (see however Maiolino & Rieke (1995) for a relevant discussion).

Our results favour the scenario where additional obscuration, caused by the host galaxy, might affect the classification of Seyfert types, regardless of the inclination of the torus, as also claimed by Lagos et al. (2011). Several previous studies have reached similar conclusions like ours. Goulding et al. (2012) having studied a sample of nearby Compton-thick AGNs, concluded that the dust of host galaxy and not necessarily the compact torus, is the dominant obscurer of the central engine. Lacy et al. (2007) using Spitzer data of six $0.3 < z < 0.8$ type-2 quazars found a contribution of the extinction towards the nucleus from an extended star-forming disk on scales of kiloparsecs, in addition to, or instead of, the traditional dusty torus. Moreover, Martínez-Sansigre et al. (2006b) also using high-redshift type-2 quasars from Spitzer and VLA data of the *Spitzer First Look Survey*, concluded that the nuclear region could be effectively obscured by dust on large scales, away from the torus. Additionaly, Rigby et al. (2006) using X-ray-selected AGN with spectroscopic redshifts in the *Chandra Deep Field South (CDFS)* argued that part of the column density that obscures the soft X-rays may come from the galactic disk. Last but not least, Malizia et al. (2020), using the hard X-ray selected sample of AGN, detected by INTEGRAL/IBIS, have shown that material located in the host galaxy on scales of hundreds of parsecs and not aligned with the absorbing torus can sufficiently hide the BLR of some type-1 AGN causing their classification as type-2 objects and giving rise to the deficiency of type 1 in edge-on galaxies.

### 4.3. Why there is a deficit of Sy2 nuclei in edge-on and face-on spiral hosts with respect to SF galaxies?

Regarding the small but significant difference in the $b/a$ distributions of the spiral Sy2 and SF galaxies, at low $b/a$ values, a possible explanation could be that in extreme edge-on orientations the dust of the galactic disk can obscure not only the BLR but also the NLR region. In an early study, McLeod & Rieke (1995), using samples of optically and soft X-ray selected Seyferts, found a bias against having inclined spiral hosts, while hard X-ray selected samples were found unbiased. In addition, Malkan et al. (1998) argued that in Sy2 galaxies irregular structures at large distances can provide sufficient absorbing column density for the nuclear source. Similar results were presented in Rigby et al. (2006), where they attributed the appearance of X-ray selected AGN as optically "dull" to galactic absorption.

On the other hand, there is a hypothesis that low luminosity Seyferts may be diluted by high-luminosity host galaxies, in which the continuum can hide the AGN lines. This may be the case for high-$z$ AGNs, where the source fully falls within the spectroscopic fiber or slit, as demonstrated by Moran & Filippenko (2002) and later supported by Trump et al. (2009) for a sample of high-$z$ dull AGNs in the *COSMOS* survey. However, our sample is limited to $z < 0.2$ and furthermore, relevant studies showed that there is no significant dilution in dull local AGN samples (La Franca et al. 2002; Hornschemeier et al. 2005). In addition, Rigby et al. (2006) has argued against dilution also in high-$z$ AGNs. Therefore, we do not consider this scenario as a possible explanation of our results. Neither, a co-alignment of the torus with the disk could explain the deficit of Sy2 galaxies in edge-on systems when compared with the control SF sample.

We note finally that the smaller/higher fraction of Sy2/Sy1 with respect to SF galaxies at high b/a values strengthens the hypothesis of a host-galaxy contribution to the obscuration of the BLR. Specifically, due to the fact that in face-on galaxies, the gas and the dust of the disk does not intervene between the observer and the active nuclei, the only obscurer of the BLR is the torus, which apparently in some cases, it is not sufficient to hide the BLR, giving rise to the deficiency of type 2 in face-on galaxies (e.g. Lacy et al. 2007).

## 5. Conclusions

The main purpose of the current work was to test aspects of the Unification Paradigm by searching for differences in the properties of the host galaxies of various AGN types. For our purposes we use (a) the SDSS DR14 spectroscopic galaxy-catalogue, selecting subsamples of Sy1 and Sy2, Liner, Composite and SF galaxies, limited to $z < 0.2$ and (b) the results of the Galaxy Zoo project regarding the Hubble-type morphology of these galaxies.

Our main results are listed below:

1. We find statistically significant differences- quantified by a KS two-sample test- of the various types of AGN host galaxy Hubble-types, with the most significant result being that the fraction of Sy1 galaxies hosted by ellipticals is higher than that of any other classes of AGNs. These results can be interpreted within a possible co-evolution scenario between galaxies and SMBS.
2. We also find that the orientation distributions, as revealed by the disk axis-ratio ($b/a$), of the Sy1 and Sy2 spiral populations show statistically significant differences with respect to the the control sample of star-forming galaxies (which by definition should cover all possible orientation configurations), in conflict with the predictions of the Unification Paradigm. These differences hint towards an effect by which the dusty galactic disk has a significant contribution to the obscuration of the broad-line and partially also of the narrow-line nuclear region. This could also interpret our previous result regarding the host-galaxy Hubble-types of type-1 AGN. Indeed, the fact that we detect more Sy1, than any other AGN type, in elliptical hosts (which as well known are deficient of gas and dust) can be explained if the amount of galactic dust and gas contributes in the obscuration of the nuclear region and in particular of the BLR.

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