AGN host galaxies and their environment

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1 Introduction

A significant amount of galaxies show strong activity in their nuclear region. This immediatly gives rice to the question, whether there is a correlation between the process of galactic formation, evolution and the nuclear activity. Differences occur within the nuclear active galaxies. Seyferts are lower-luminosity AGNs with a clearly detectable host galaxy. They are divided into type 1 and type 2 Seyferts, meaning that they do not respectively do contain broad lines in their spectra. Seyfert 2 AGN do, beside narrow permitted lines, show narrow forbidden lines, whereas type 1 only show the permitted ones. Quasar spectra are quite similar to those of Seyferts. However, they have weak stellar absorption features and their narrow lines are weak relative to their broad lines. Another group quite similar to Seyfert galaxies are the LINERs. They are spectroscopically the same, except that the low-ionization lines are relatively strong. Blazars are the AGNs with a strong relativistically beamed component close to the line of sight.
The different AGNs can be united in the unification model. This model states that we see the differences in AGN due to 2 properties. The first is radio emission, a significant amount of AGN emit in the radio. The second property is their orientation with respect to the observer, this differs from face-on to edge-on. [Antonucci 1993]
The conversion of mass into energy is the fundamental process at work in an active nucleus. By gravitational accretion energy is suplied into the nuclear source. However, to sustain this gravitational accretion for at least 10^8 years (typical lifetime), enough mass has to be funneled into the nucleus. Infalling gas must lose most of its angular momentum before reaching the accretion disk. Losing a sufficient amount of angular momenta requires a break in the gravitational potential of the galaxy. The suggestion that gravitational interaction with other systems can trigger this break, gives motivation for examining the nearby environment of an AGN [Peterson 1997].

In this paper first the differences between radio-quiet and radio-loud galaxies will be discussed. Then the differences between type 2 Seyferts and type 1 Seyferts and Quasars. Next, several properties of host galaxies will be discussed for different types of AGN and they will be compared with each other and normal galaxies. In section 5. the environment of AGN host galaxies will be discused. Finally the results will be summarized shortly.

2 Radio-Loud against Radio-Quiet AGN

A large group of AGN shows radio emission, mostly seen in massive elliptical galaxies. Capetti and Balmaverde (2007) argued that radio-loud and radio-quiet galaxies cannot be distinguished on basis of other parameters than 'core' or 'non-core' galaxies. This parameter distinguishes galaxies on basis of the nuclear sloap of their brightness profiles. Galaxies with a core show a break in the outer steep slope of the brightness profile, from this break the profile smoothly turns into a shallow powerlaw. The 'non-core' galaxies do not show this break in the brightness profile [Lauer et al. 1995].
It was showed that raio-loud nuclei are hosted by 'core' galaxies, whereas radio-quiet galaxies are found in 'non-core' galaxies. The hosts luminosity or the black hole mass do not distinguish radio-loud from radio-quiet nuclei [Capetti, Balmaverde 2007].

3 Type 2 AGN against type 1 AGN and QSOs

According to the unified model, AGN can be classified into two categories. When the central black hole and its associated continuum and broad emission-line region are viewed directly, we are dealing with a type 1 AGN. If they are obscured by a dusty circumnuclear medium, we are dealing with a type 2. Radiation from a type 2 AGN photoionizes the surrounding gas, creating strong narrow permitted and forbidden lines. Type 1 AGN are dominated by non-thermal emission, this makes them much harder to study the host galaxy and their stellar population. For QSOs this is even harder, as the continuum radiation from the central source outshines the stellar light from the host galaxy.
Following the unified model, one could do a research on type 2 AGN and use the resulst for type 1 AGN and QSOs. However, if the solid angle covered by the obscuring medium varies significantly from one system to the other, the covering region by dusty material could be related to the star formation in the galaxy. This would implie a clear difference in host galaxies of AGN

type 2 and AGN type 1 and QSOs.
Comparisons were made by Kauffmann (2003) between stellar populations of the host of powerfull type 1 (QSOs) and type 2 AGN. For each QSO a type 2 AGN with similar redshift and [OIII] luminosity was searched. A good match was found for 92 per cent of the samples. Figure 1 shows the composite spectrum of type 2 AGN and the matched QSOs. Also the spectrum of QSOs with high continuum luminosities is plotted. One can clearly see there is no significant difference in stellar absorption spectra between type 2 AGN and QSOs. Therefore the conclusion can be made, that there is no significant difference in stellar content between the host galaxies of type 2 AGN and type 1 AGN and QSOs with the same redshift and [OIII] luminosity. This is consistent with the unified model for AGN.
As mentioned earlier, type 1 AGN and QSOs are hard to study. Therefore the Seyferts used in the described samples do only consist of type 2 AGN. Still, the results are also valid for type 1 AGN and QSOs.

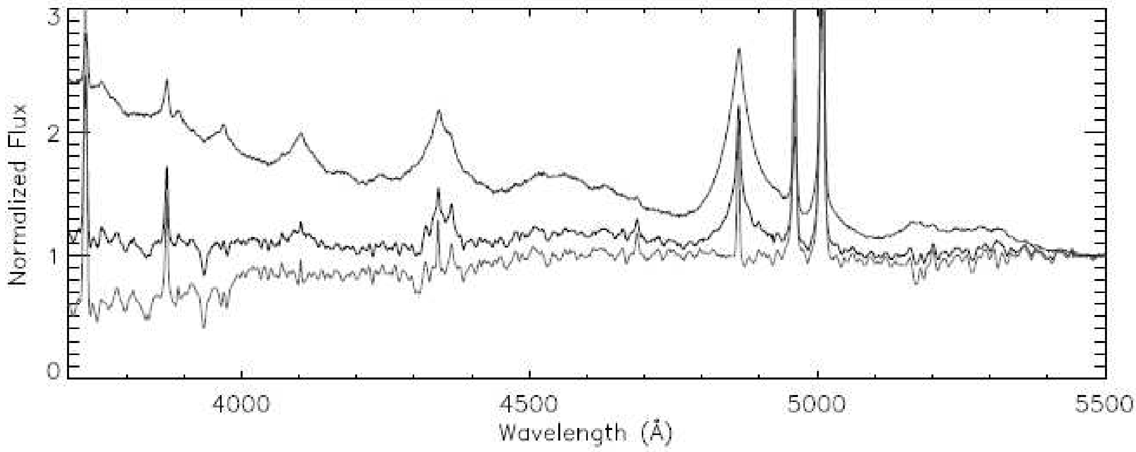

Figure 1: The lowest line shows the type 2 AGN spectrum. The matched QSOs are represented by the middle line. The top line stands for the high luminosity AGN [Kauffmann et al. 2003]

4 Host galaxy

In this section different properties of AGN host galaxies are discussed and compared to each other and to normal galaxies.

4.1 Surface mass density and morphology

Seyfert galaxies have been used for investigations with the goal to determine whether or not galaxies with an active nuclei are different from galaxies without an active nuclie. Studies also try to find common characteristics not correlated with the presence of nuclear activity.
First morphological studies on Seyferts revealed most of them to be spiral galaxies [Adams 1997]. Later studies showed that Seyfert galaxies tend to be, but are not exclusively, earlier-type spirals [Heckman 1978]. Multiple studies showed Seyferts often have signs of morphological irregularities. In addition, more than half of Seyfert galaxies have a barred structure, although only one third of normal galaxies show bars.
Nowadays a good way to identify early-type galaxies, spirals and irregulars is using the concentration parameter C. This parameter is defined as the ratio of the radii enclosing 90 and 50 per cent of the galaxy light in the R band [Stoughton 2002]. Galaxies with $C > 2.6$ are mostly early-type galaxies, whereas spirals and irregulars have $2.0 < C < 2.6$. Another usefull parameter is the surface mass density ($\mu_* = M_*/2\pi r_{50,z}^2$). $r_{50,z}$ is the half-light radius

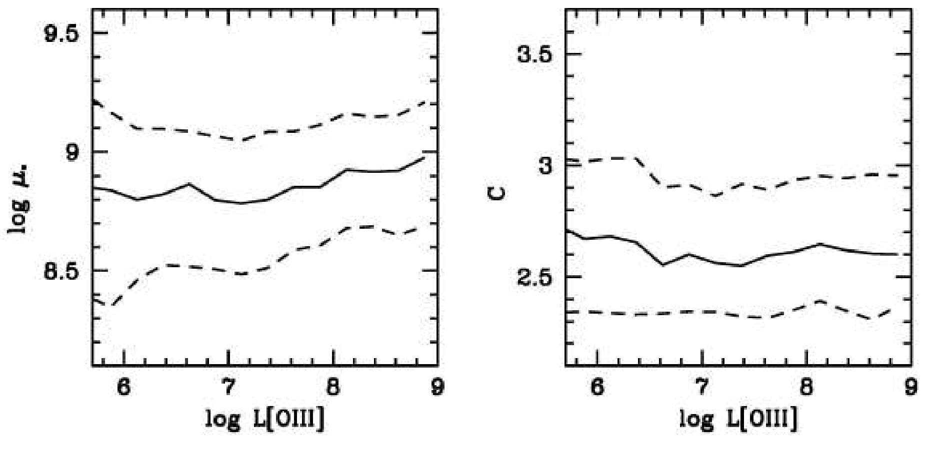

Figure 2: Stellar surface density μ_* and concentration index C as functions of Log[OIII] for a smaple of AGN. The solid line is the median, the dashed line shows the 16-84 per cent of the distribution [Kauffmann et al. 2003]

in the Z band. Early type galaxies have $3 \times 10^8 < \mu_* < 3 \times 10^9 M_\odot kpc^{-2}$, whereas late type galaxies have $\mu_* < 3 \times 10^8 M_\odot kpc^{-2}$. Figure 2 shows the distribution of μ_* and C as a function of [OIII] luminosity. It can clearly be seen that AGN of all luminosities are found in galaxies with a high surface mass density and intermediate concentrations.
C and μ_* correlate strongly with stellar mass in ordinary galaxies. However, little dependence of either concentration or surface mass density on stellar mass is seen for strong AGN log LOIII]>7). Strong AGN show high surface mass densities typical for early-type galaxies and concentrations intermediate between early- and late-type galaxies at all masses. For weak AGN (log L[OIII]<7)the densities and concentrations are similar to ordinary galaxies of the same stellar mass [Kauffmann et al. 2003].

4.2 Stellar mass

Kauffmann et al. (2003) and Kewley et al. (2006) showed that AGN are preferentially found in more massive and more concentrated galaxies (Figure 3). Only a few per cent of their sample galaxies with a mass less than $10^{10} M_\odot$ are classified as AGN. On the contrary, more than 80 per cent of their sample galaxies with $M_* > 10^{10} M_\odot$ are AGN. It has to be mentioned that the AGN fraction in massive galaxies is a strong function on redshift. It decreases with an increasing redshift. For low-mass galaxies the AGN fraction still remains low.
The majority of low-mass galaxies have young stellar populations and are experiencing 'bursts' of star formation. They thus have strong emission

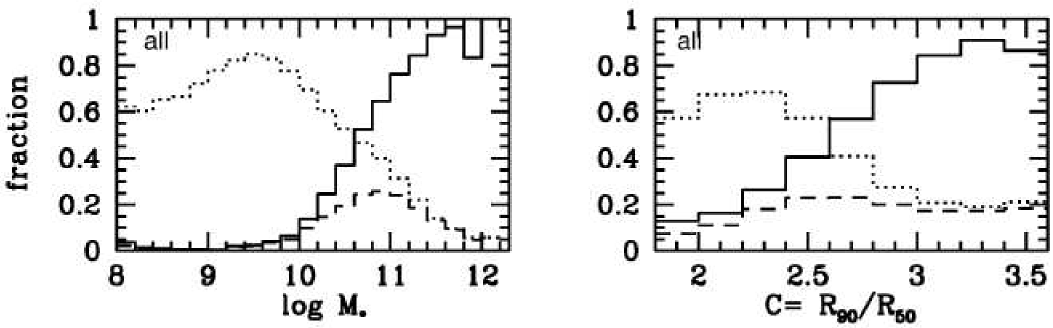

Figure 3: The dotted histogram shows all the galaxies in a sample. Galaxies classified as AGN are shown by the dashed histogram. The solid histogram represents the fraction of emission line galaxies classified as AGN [Kauffmann et al. 2003]

lines and one could doubt whether an AGN is detectable in such an object. Kauffmann et al. (2003) show that even a low-luminosity AGN ($10^5 < LogL[O\texttt{III}] < 10^6 L_\odot$) perturbs emission line ratios enough to be identified in 93 per cent of their sample galaxies. We can conclude that more powerful AGN are almost always found in high-mass galaxies. LINERs tend to have a slightly higher stellar mass than Seyferts [Kewley et al. 2006].

4.3 Stellar ages

Properties of stellar ages are known to correlate strongly with morphological types. Early-type galaxies have old stellar populations and little gas and dust. Late-type galaxies on the other hand show plenty of on-going star formation. $D_n(4000)$ is commonly used as an age indicator at mean stellar ages less than 1 Gyr. At older ages, this indicator is sensitive to metallicity as well as to age. In section 4.2 it was shown that AGN are found in massive host galaxies. As metallicity variations among massive hosts is likely to be small, it is appropriate to use the $D_n(4000)$ index as a stellar age indicator. Beside $D_n(4000)$, Hδ_A also can be used as a good age indicator.
Figure 4 shows $D_n(4000)$ and Hδ_A as a function of [O III] luminosity. One can see clearly, that there is a strong correlation for both age indicators with AGN luminosity. The weaker AGN have stellar ages in the same range as early-type galaxies ($D_n > 1.7, H\delta_A < 1$). Their dependece of age on stellar mass and surface mass density resembles normal galaxies a lot. At low surface mass densities although, weak AGN hosts have older stellar popu-

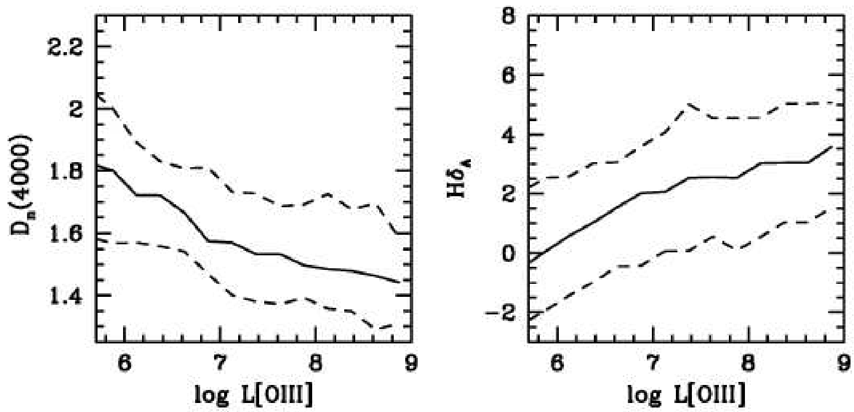

Figure 4: $D_n(4000)$ and Hδ_A plotted against Log L[OIII]. The solid line shows the median of the sample, the dashed line represents 16-84 per cent of the distribution[Kauffmann et al. 2003]

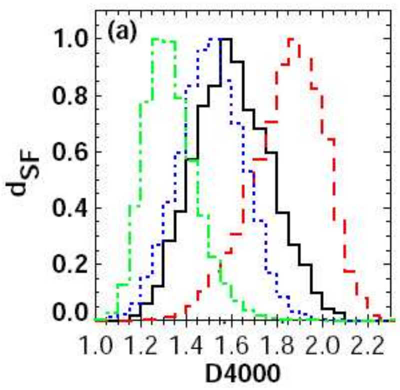

Figure 5: The $D_n(4000)$ distribution for LINERs (red dashed), Seyferts (black solid), composites (blue dotted) and HII-region like galaxies (green dot-dashed). [Kewley et al. 2006]

lations than normal galaxies with the same surface density. Strong AGN have stellar ages similar to late-type galaxies. Their dependence of age on stellar mass and surface mass density is much weaker than for weak AGN [Kauffmann et al. 2003].

We can also look at the differences between Seyferts and Liners. Figure 5 shows the $D_n(4000)$ distribution for LINERs (red), Seyferts (black), composites (blue) and HII-region like galaxies (green). The LINERS tend to have an older stellar population than the other galaxy types [Kewley et al. 2006].

4.4 Radial distribution of the star formation

Weak AGN have mostly old stellar populations in their nuclei [Ho et al. 2003], while powerfull Seyfert 2 have a young population [Cid et al. 2001]. Figure 6. illustrates AGN with [OIII] luminosities of $3 \times 10^7 L_\odot$ plotted in the $C/D_n(4000)$ plane. The left panel shows objects with a redshift of 0.1 - 0.2 and the spectra sample 40-60 per cent of the total emitted light. The majority of these obects have a D_n value less than 1.6 and are hence younger than a typical early-type galaxy.

The right panel shows objects with redshift 0.03 - 0.04. and the spectra sample the light from the inner 1-2 kpc of the host galaxy. On this side more than half of the galaxies have D_n larger than 1.6. Both early-type (C > 2.6) as late-type galaxies (C < 2.6) show this shift in mean stellar age. This leads to the conclusion that star formation associated with AGN activity is not restricted to the nuclear regions of the host galaxy, but takes place over scales of at least several kpc. [Kauffmann et al. 2003].

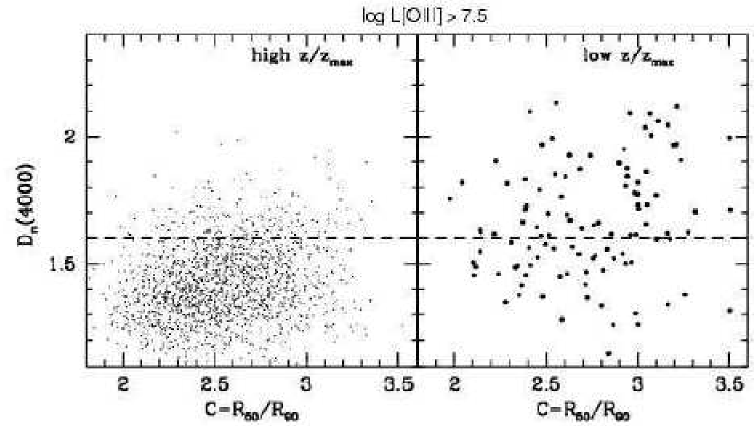

Figure 6: AGNs plotted in the $C/D_n(4000)$ plane. The left panel shows objects with redshift $z = 0.1 - 0.2$, the right $z = 0.03 - 0.04$ [Kauffmann et al. 2003].

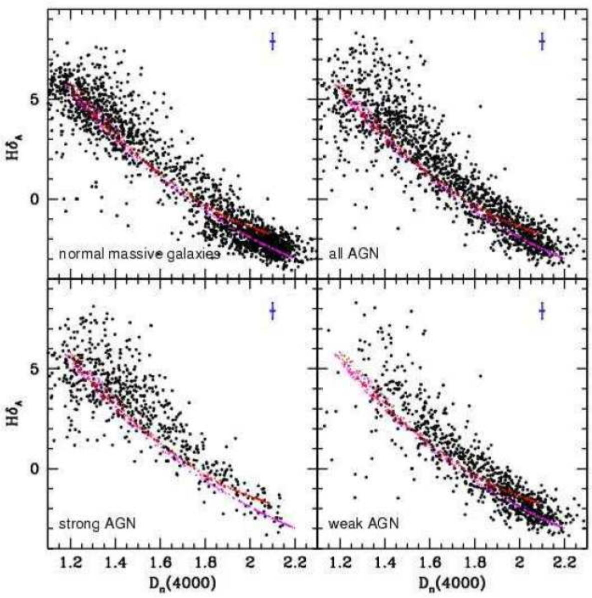

Figure 7: Normal galaxies, strong and weak AGN are plotted in the $D_n(4000)/H\delta_A$ plane. [Kauffmann et al. 2003].

4.5 AGN star formation history

As mentioned earlier, hosts of weak AGN at low surface mass densities have older stellar populations than normal galaxies at low surface mass densities. However, most galaxies have a different relation between age and surface mass density.
An interpretation to explain this, is that powerful AGN are found in early-type galaxies that are undergoing a starburst. This starbust has a strong influence on the stellar population and structural parameters of the host of strong AGN. When the AGN switches off and the stellar population ages, the galaxy eventually evolves to a normal early-type population. For this interpretation to be correct, the star formation time-scales in high-luminosity AGN have to be short.
The galaxies location in the $D_n(4000)/H\delta$ plane can be used as a powerfull tool to investigate whether a galaxy has been forming stars in bursts over the past 1-2 Gyr or continuously. Continuous star formation occupies a narrow strip in this plane, whereas a displacement away from this strip identifies a recent burst. In Figure 7. some samples of normal galaxies, strong AGN and weak AGN are plotted in the $D_n(4000)/H\delta$ plane. The red line in each panel indicates the locus occupied by galaxies with continuous star formation. One can clearly see, most normal galaxies fall close to the locus of continuous star formation. A reasonable value of strong AGN though, is displaced to high $H\delta_A$ values. These results favor the hypothesis that powerful AGN experienced a starburst in the past and then evolved toward the ordinary early-type galaxies [Kauffmann et al. 2003].

5 AGN environment

Beside the local environment of active nuclei, the large scale environment could also give clues about physical conditions that trigger AGN activity. Studies on the immediate environments of Seyferts and quasars lead to the consensus that AGNs are likely to have a companion system. Dahari (1984) found $\sim$15 per cent of Seyferts have companion galaxies, against only $\sim$3 per cent of normal galaxies. Other studies show that AGN companions are likely to have strong emission lines in their spectra with respect to companions of normal galaxies. [Kollatschny, Fricke 1989].
QSOs tend to have a large number of faint galaxies present in their field, with redshifts close to the redshift of the QSOs [Stockton 1978]. The clustering properties of QSOs are no different than the clustering properties of normal-galaxies.
The peculiar morphology of AGNs and the close companions, suggest that interactions with other system can trigger AGN activity. However, the morphology and close companions are not necessary for producing AGNs. Not all strongly interacting systems show AGN activity and some AGNs are quite isolated.

6 Conclusion

In this paper the host galaxy properties of different types of AGN were discussed, as well as their environment. The results can be summarized as follows.

- Radio-loud galaxies are found in 'core' galaxies, whereas radio-quiet are found in 'non-core' galaxies.
- There is no significant difference in stellar content between the host galaxies of type 2 AGN and type 1 AGN and QSOs with the same redshift and [OIII] luminosity. This is consistent with the unified model for AGN.
- Strong AGN show high surface mass densities typical for early-type galaxies and concentration parameters between early- and late-type galaxies at all masses. The densities and concentrations for weak AGN are similar to ordinary galaxies of the same stellar mass.
- More powerfull AGN are mostly found in massive galaxies. LINERs tend to have a slightly higher mass then Seyferts.
- Weaker AGN hosts have stellar ages similar to late-type galaxies. Stronger AGN hosts tend to have ages similar with early-type galaxies. LINERs tend to be older then Seyferts.
- Strong AGN experienced a starburst in the past and then evolved toward the ordinary early-type galaxies.
- The star formation in powerfull AGN is not restricted to the nuclear regions of the galaxy, but takes places over at least several kpc.
- Seyferts are more likely to have companion systems than normal galaxies. These companions show strong emission lines in their spectra.
- A large number of faint galaxies is present in the field around QSOs. Their clustering properties are no different from normal galaxies.
- Interactions with other systems could trigger AGN activity. However, these interactions are not necessary.

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