The Large Scale Structure of LINERs and Seyferts and Implications for their Central Engines.

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Abstract. We discuss here the spatial clustering of Seyferts and LINERs and consequences for their central engines. We show that Seyferts are less clustered than LINERs, and that this difference is not driven by the morphology-density relation, but it is related to the difference in clustering as a function of level of activity in these systems and the amount of fuel available for accretion. LINERs, which are the most clustered among AGN, show the lowest luminosities and obscuration levels, and relatively low gas densities, suggesting that these objects harbor black holes that are relatively massive yet weakly active or inefficient in their accretion, probably due to the insufficiency of their fuel supply. Seyferts, which are weakly clustered, are very luminous, show generally high gas densities and large quantities of obscuring material, suggesting that in these systems the black holes are less massive but abundantly fueled and therefore accrete quickly and probably efficiently enough to clearly dominate the ionization.

Spatial Clustering and Accretion Activity

The nature of the central engine of Active Galactic Nuclei (AGN) can be independently constrained via quantifying these systems’ large scale structure. The pattern of their spatial clustering provides important diagnostics for the masses and number density of the dark matter haloes in which they reside, and consequently, for the masses of their central accreting black holes. Therefore, comparisons of the clustering properties of AGN of different characteristics may indicate intrinsic differences in their ionization mechanisms and even gauge the accretion strength and time cycle. Such analysis can thus yield a phenomenological link between black hole growth and galaxy formation and evolution processes.

Many studies of AGN clustering characteristics compare passive galaxies with AGN as a general class and do not examine the properties of subpopulations such as Seyferts and LINERs separately. In such investigations, the AGN population is found to occupy a uniform fraction of galaxies, to be common to a large range of galactic environments, and to follow the distribution of the whole galaxy population, and therefore to be unbiased tracers of mass in the universe ([Miller et al. 2003; Wake et al. 2004]). However, when divided by their \([\text{O III}]\) luminosities, AGN show different clustering properties ([Wake et al. 2004]), and different environmental preference ([Kauffmann et al. 2004]). Given that Seyferts and LINERs represent quite distinct distributions in \(L_{\text{[OIII]}}\) ([Kauffmann et al. 2003]), they might also cluster differently. To investigate these issues we have analyzed the clustering properties of a variety of nearby actively line-emitting galaxies by including important spectral diagnostics that
probe the astrophysics of AGN (Constantin & Vogeley 2006). We summarize here the results pertaining to LINERs and Seyfert galaxies.

The Data

To estimate the clustering properties of Seyferts and LINERs, we use the Sloan Digital Sky Survey (SDSS) DR2 main galaxy sample, which includes every extended object with the apparent $r$-band magnitude $14.5 \leq m_r \geq 17.7$, and which lacks broad line emission (i.e., is not a quasars). To avoid biases caused by the strong dependence on luminosity of the sample properties, and by the fact that only the intrinsically bright galaxies are seen at large distances, which creates a gradient of the number density of galaxies with distance, we work here with absolute magnitude limited samples, with $-21.6 < M_r < -20.2$, which correspond to a redshift range of $0.05 < z < 0.12$, or a comoving distance range of $148.5 < r < 350.1 \, h^{-1} \text{Mpc}$.

We construct samples of Seyferts and LINERs by employing three emission-line diagnostic diagrams based on constraints on line flux ratios of: $[\text{O\,}^\text{III}]\lambda 5007/\text{H}\beta$, $[\text{N\,}^\text{II}]\lambda 6583/\text{H}\alpha$, $[\text{S\,}^\text{II}]\lambda\lambda 6716,6731/\text{H}\alpha$, and $[\text{O\,} \text{I}]\lambda 6300/\text{H}\alpha$, on sources that show at least $2-\sigma$ detection in all of these six emission-lines. For more details on the classification scheme see Constantin & Vogeley (2006).

Note that only about 5% of all the strong line emitters are Seyferts, and that the majority of the sources that might or clearly exhibit accretion activity are classified as LINERs based on their line flux ratios. This means that samples of AGN that consider these two classes together are severely skewed toward the LINER-like behavior, and are not capable of offering any information specific to Seyferts. The SDSS-based AGN definitions that leniently use only the $[\text{O\,} \text{III}]/\text{H}\beta$ versus $[\text{N\,}^\text{II}]/\text{H}\alpha$ diagnostic diagram are particularly susceptible to these effects.

The Clustering Amplitude and the Accretion Activity

We measure the two-point correlation function in redshift space $\xi(s)$ for Seyferts and LINERs. Power-law fits $\xi(s) = (s/s_0)^{-\gamma}$ over separations $1 < s < 10 \, h^{-1} \text{Mpc}$ yield the clustering amplitude $s_0$. This parameter is a measure of the strength of the clustering as it can be viewed as the scale at which the probability of finding a galaxy pair is, in average, double that measured within a random sample. Our measurements of $s_0$ reveal a lower value for Seyferts ($5.7 \pm 0.6 \, h^{-1}\text{Mpc}$) than for LINERs ($7.8 \pm 0.6 \, h^{-1}\text{Mpc}$), whose spatial distribution seems to follow that of the average galaxies ($s_0 = 7.8 \pm 0.5 \, h^{-1}\text{Mpc}$ for the whole sample of galaxies). This suggests that LINERs inhabit denser environments than Seyferts.

Moreover, this difference in $s_0$ points to a more fundamental contrast between Seyferts and LINERs, i.e., in the mass of their central accreting black holes. If structure formation is hierarchical, then the rarest and most massive virialized dark matter halos cluster the most strongly (e.g., Kaiser 1984). Therefore, the different $s_0$ values indicate that Seyferts reside in less massive haloes than those harboring galaxies with LINER-like activity in their centers. Consequently, given that the mass of the dark matter haloes may correlate with
that of the black holes that lie at the centers of their resident galaxies (Ferrarese 2002; Baes et al. 2003), this finding suggests that Seyferts’ black holes are less massive than those of LINERs.

An important thing to investigate is whether this discrepancy in the clustering properties of Seyferts and LINERs derives from their host morphologies, as we know that the red, early type of galaxies are more clustered than the blue, late types ones, i.e., the morphology-density relation. We have thus compared their host properties in terms of both the concentration index $C$ (a relatively good proxy for their morphological type) and the $u − r$ color, and found that the LINERs and Seyfert distributions in both of these two parameters are consistent with having the same parent populations (Kolmogorov-Smirnov probabilities are: $KS_C^{S-L} = 0.104$, $KS_{u-r}^{S-L} = 0.617$). This analysis clearly shows that the different clustering that Seyferts and LINERs exhibit is not driven by the morphology-density relation.

The difference in the clustering amplitude of Seyferts and LINERs is however closely related to the difference in clustering as a function of accretion activity in these systems. We found that parameters like the $[\text{O} \text{ I}]$ and $[\text{O} \text{ III}]$ luminosities, that can be used as proxies for the fueling rate, have a very strong effect on the clustering amplitude. Objects with low luminosities in both of these lines are very strongly clustered, while their dimmer counterparts remain weakly clustered. The difference in $s_0$ in both such cases is about $5 − \sigma$. Interestingly, when we separate out the low and high $L_{[\text{O} \text{I}]}$ and $L_{[\text{O} \text{III}]}$ sources into spectral classes, we find that the low luminosity objects are basically the LINERs, and that, as expected, the weakly clustered high $L_{[\text{O} \text{I}]}$ and $L_{[\text{O} \text{III}]}$ systems include the majority of Seyferts.

Moreover, the amount of fuel, as gauged by the amount of obscuration (as measured by the neutral hydrogen column density $N_H$ derived from the $\text{H} \alpha / \text{H} \beta$ Balmer decrements) and the gas densities ($n_e$, estimated from the $[\text{S} \text{ II}]$ ratios), seems to also correlate with the strength of accretion and $s_0$. LINERs and Seyferts are again at the extreme ends in the distributions in their $N_H$ and $n_e$, with LINERs exhibiting particularly low levels of obscuration and $n_e$ while Seyfert galaxies show generally high densities and moderately high $N_H$.

### Results and Possible Interpretation

A brief overview of our main results and a possible interpretation is given in Table 1 and we list our conclusions as follows.

(i) We found that, contrary to conclusions of previous studies, AGN in the local universe are not clustered like galaxies. Only LINERs cluster like normal galaxies. Seyferts are significantly less clustered than the general galaxy population.

(ii) Host galaxy properties and, consequently, the morphology-density relation, do not strongly influence the difference in the spatial clustering found between Seyferts and LINERs. The difference in $s_0$ is however strongly related to the level of activity in these nuclei, as suggested by their $[\text{O} \text{ III}]$ and $[\text{O} \text{ I}]$ line luminosities.

(iii) The picture that emerges from these results is that Seyferts are the result of relatively active but small black holes, while LINERs are the mani-
Table 1. Summary of Results and Interpretation

| Property                          | Seyferts                      | LINERs                        |
|----------------------------------|-------------------------------|-------------------------------|
| Clustering \( (s_0) \)           | weak                          | strong \( (\text{like galaxies}) \) |
| Fueling rate \( (L_{\text{[OII]}}, L_{\text{[OIII]}}) \) | relatively high \( (\text{efficient?}) \) | (very) low \( (\text{inefficient?}) \) |
| Fuel available \( (n_e) \)       | high                          | moderately high \( (\text{wide range}) \) |
| Obscuration                      | wide range                    | low                           |
| Host morphology                  | redish, earlier type          | redish, earlier type \( (\text{like Seyferts}) \) |
| \( M_{\text{BH}} \)             | small                         | large                         |
| Life-time                        | short                         | long                          |

tation of weakly accreting but more massive ones. It is then probably the case that Seyferts live in their active state for only short periods of time, which is consistent with the fact that we only see a small numbers of such systems, while LINERs can persist in their low state for much longer, and are therefore more ubiquitous.

(iv) Hints for what may cause differences in the nuclear activity in the low luminosity AGN, or simply its detection, come from the fact that both \( n_e \) and \( N_H \) are significantly different in LINERs and Seyferts. A possible cause for the feeble activity in LINERs may be that fuel is not as abundant as in the more active systems.

Previous (and yet many of the present) studies of AGN clustering and other statistical investigations of their properties have not considered separating out different types of AGN. However, as our analysis clearly shows it, Seyferts and LINERs remain distinct in their behavior, and should be considered separately. A potential idea to explore in the future is that these systems might be the manifestation of different stages in an evolutionary sequence in the AGN lifetime. Our recent study of AGN activity in the most underdense regions of the universe, the voids, provides some evidence for this scenario \cite{Constantin et al. 2007}.

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