

Narrow-line Seyfert Galaxies. Connection between abundance and the large-scale structure

A.A. Ermash, B.V. Komberg

Astro Space Centre, P.N. Lebedev Physical Institute of Russian Academy of Sciences,
Moscow, Russia

E-mail: aermash@gmail.com, bkomberg@asc.rssi.ru

Abstract. Utilizing methods, developed by the author the correlations between spatial concentrations of active nuclei (NLS and BLS) and concentration of galaxies of full uniform sample were obtained. Galaxies of this uniform sample trace the large-scale structure. We used SDSS DR 7 data. The correlations obtained are linear and the NLS/BLS ratio is constant. That leads to conclusion that amounts NLS and BLS are some fixed portion of all galaxies independent on the density of large-scale environment. In order to check validity of our results we also confirmed the well known result that fraction of red galaxies increases with density of environment. Also it was confirmed that this trend is more prominent for less massive galaxies.

1. Introduction

According to the current classification the population of Seyfert galaxies is divided into two main types. Objects with broad permitted lines are classified as Sy1, objects without broad permitted lines as Sy2. This difference might be caused by the lack of BLR (Broad Line Region) or by obscuration of BLR by dusty torus. In former case such objects are called “true Sy2”. Intermediate types (Sy 1.2 – Sy 1.8) in this classification are defined according to prominence of the broad components of permitted lines.

When we speak about Narrow Line Seyfert 1 galaxies we imply that their broad permitted lines are merely slightly wider than forbidden lines. But broad permitted lines in Narrow Line Seyfert galaxies are present! Various authors define the limit between NLS and BLS (Broad Line Seyfert Galaxies) differently, convenient value is in range 2000 – 2200 km/s.

There is a growing interest in this type of AGN in the recent years. Their host galaxies have on average later Hubble types, $\langle HT \rangle = 3.0(\text{Sb})$ and $\langle HT \rangle = 1.0(\text{Sa})$ for NLS and BLS respectively [2]. Bulges in host galaxies of NLS are always pseudobulges [3], their nuclear spirals show regular two-arm morphology, in contrast to BLS.

In recent years more and more authors had confirmed that NLS accrete with high Eddington ratios close to the Eddington limit and that their black holes are less massive than such of BLS [4, 5]. Black holes in NLS also seem to have high angular momenta [6, 3, 7, 8]. It is curious that NLS can produce relativistic jets in many ways similar to jets in blazars.

Many authors believe that NLS evolve through so-called secular processes in contrast with BLS. See, for example, [3]. Secular evolution implies slow evolution of the host galaxy via internal instabilities (internal secular evolution) or tidal interactions and minor mergings with small satellite galaxies (external secular evolution). For details see [9].



Relatively small attention was paid to the surroundings of NLS galaxies in the literature. In [10] the connection between environment and properties of host galaxies of LINERs¹ and TO² was studied. As a result, no connection was found. On the other hand, in [11] it was found that there is a significant difference between environments of Sy1 and Sy2. Sy2 have more close companions. Authors had also compared environments of control samples of galaxies of same morphological types as hosts of Sy1 and Sy2. No difference between host galaxies of AGN and normal galaxies of same morphological types was found. That led to conclusion that differences in environmental density of Sy1 and Sy2 are due to differences in morphological types of their host galaxies and not due to the presence of an active nucleus. Paper [12] was dedicated directly to the problem of environment of NLS. Authors came to conclusion that NLS tend to have close companions less frequently. Nevertheless, it should be noted that this paper is relatively old (year 2001) and all conclusions are based on a sample of 27 galaxies.

In our previous work [1] we have obtained the luminosity function of NLS in [OIII] λ 5007Å. This forbidden line is emitted at large distance from the active nucleus in NLR, which has conical geometry, thus this line does not suffer from orientation effects and obscuration. Modified V/V_{max} method was used. For a complete magnitude limited sample it is very easy to calculate V_{max} , but the situation is quite difficult for spectral lines. In order to solve this problem we calculate the function of probability of observation of object for every luminosity bin $p(d_c)$, where d_c — comoving distance.

We also took into account variations of the density of the Universe due to the large-scale structure. The idea was as following. If we know the luminosity function of inactive galaxies with good accuracy, then having a uniform sample it is possible to calculate for considered volume N_{obs}/N_{calc} , where N_{obs} — the observed amount of galaxies, N_{calc} — calculated amount of galaxies from luminosity function. This approach allows us to normalize sample of considered objects to uniform complete sample of galaxies which traces variations of density of the Universe. For details see [1].

2. Data processing

In our work we have used SDSS DR 7 [13]. Luminosities of AGN were estimated using [OIII] λ 5007Å line. For classification we used H α line. We have also selected a magnitude limited sample of galaxies in r band taking extinction into account. This sample was used for normalization. In our work we used the following cosmological parameters: $\Omega_M = 0.279$, $\Omega_\Lambda = 0.721$, $h = 0.701$, as in SDSS DR 7.

Firstly we have split our sample of AGN into luminosity bins in [OIII] λ 5007Å line (expressed in units $\lg(L_{[OIII]}/L_\odot)$) and set minimum and maximum redshifts of the sample. As in our previous work [1] we have used fixed step in comoving volume instead of comoving distance d_c or redshift z .

For every defined interval of redshift we calculated the normalization $\rho_{gal}/\langle\rho_{gal}\rangle$, where ρ_{gal} is the density of galaxies in the considered volume element, $\langle\rho_{gal}\rangle$ — average density of galaxies. Then for every luminosity bin we found amount of AGN objects N_{AGN} . The amount of AGN normalized to the average density of the Universe is: $N_{AGN,norm} = N_{AGN}(\rho_{gal}/\langle\rho_{gal}\rangle)^{-1}$. The ratio $\rho_{gal}/\langle\rho_{gal}\rangle$ was calculated the following way. Luminosity function is usually fitted with the Schechter function, for absolute magnitudes it takes the following form:

$$\Phi(M) = 0.4 \lg(10) \Phi_* 10^{-0.4(M-M_*)(\alpha+1)} \exp\left(-10^{-0.4(M-M_*)}\right)$$

We took parameters for local luminosity function of galaxies from [14], where they are as following: $\Phi_* = 0.0090 \pm 0.0007$, $M_* - 5 \lg_{10} h = -20.73 \pm 0.04$, $\alpha = -1.23 \pm 0.02$ in r band of

¹ Low-Ionization Nuclei Emission Region galaxies.

² Transition Objects.

SDSS survey. Knowing this parameters one can obtain total luminosity of galaxies per unit of volume:

$$L_{sch} = \int_{L_1}^{L_2} L' \phi(L') dL,$$

where L_1 and L_2 are the limits of integration.

Now we can obtain $\langle \rho_{gal} \rangle / \rho_{gal} = L_{sch} V / L_{obs}$, where L_{obs} — total observed luminosity of galaxies in considered volume element, V — volume. Luminosity of each galaxy is in range $L_1 < L < L_2$. It is crucial to stress that transition from luminosities to spatial densities is possible only if parameters of Schechter function α and L^* are constant. For the redshift interval considered this is correct. For details see [1]. Hence, normalized amount of AGN is $N_{AGN, norm} = N_{AGN} (L_{sch} V / L_{obs})$.

Having normalized sample of AGN, we can now calculate the probability function of observation of objects in considered luminosity bin $p(d_c)$, where d_c — comoving volume. This function has the following form: $p_{AGN}(d_c) = a \exp(-b_1/d_c^2) \exp(-b_2 d_c^2)$. Details see in [1].

Then we have split considered volume of the Universe into elements limited by redshift ($z_i < z < z_{i+1}$), ascension and declination ($\alpha_{min,j} < \alpha < \alpha_{max,j}$; $\delta_{min,j} < \delta < \delta_{max,j}$). For every volume element the ratio $\rho_{gal} / \langle \rho_{gal} \rangle$ was calculated. Total count of NLS and BLS was obtained for the considered luminosity interval. It was then corrected using the probability function $p(d_c)$. Making the same calculations for each volume bin we obtained the dependence of N_{NLS} , N_{BLS} and N_{NLS}/N_{BLS} on $\rho_{gal} / \langle \rho_{gal} \rangle$, where N_{NLS} and N_{BLS} — spatial densities of NLS and BLS respectively.

3. Spatial density of AGN and the large-scale structure

Firstly, it is necessary to define volume bins of the SDSS survey. The grid used had the following parameters. Solid angle of each element was $\Omega = 0.011 \text{ sr}$ or 36° , minimum redshift $z_{min} = 0.022$, maximum redshift $z_{max} = 0.18$, amount of redshift bins was set to 15.

The AGN luminosity range was split in 4 intervals: 5.25 – 6.25, 6.25 – 7.0, 7.0 – 7.75, 7.75 – 9.0. Values are in units $\lg L_{[OIII]} / L_\odot$.

For each luminosity bin we have built three correlations between $N_{NLS} (Mpc^{-3})$, $N_{BLS} (Mpc^{-3})$, N_{NLS}/N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$. We have built these correlations also for the whole luminosity interval of AGN ($L = 5.25 - 9.0$).

On figure 1 the following correlations are shown. On the upper row on panels a) – d) the correlations between N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$ for four intervals of AGN luminosity are shown. The second row e) – h) displays the same for NLS. In the third row i) – l) relations between N_{NLS}/N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$ are shown. In the fourth row (m, n, o) three correlations between N_{BLS} , N_{NLS} , N_{NLS}/N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$ for the whole considered interval of AGN luminosity are shown.

The correlations between N_{NLS} , N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$ were fitted with linear function $ax + b$ and with exponential one in form $a \times \exp(-c/x^2) + b$, where a , b and c — free parameters. The latter function was chosen because it grows with increasing x and asymptotically flattens at high x . The correlation between N_{NLS}/N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$ was fitted with linear function and also with a cubic polynomial $ax^3 + bx^2 + cx + d$.

Let us consider the correlation between N_{BLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$. For the first luminosity interval there is some evidence of deviation from the linear trend at high values of $\rho_{gal} / \langle \rho_{gal} \rangle$. Approximation by straight line gives $\chi^2 = 1.15$ and exponential function gives $\chi^2 = 1.01$. For the other three intervals in luminosity there are no signs of deviation from the linear trend. The same is true for the whole interval of nuclear luminosities. Chi-square gives 1.3 for linear and 1.27 for exponential functions respectively. For the relation between N_{NLS} and $\rho_{gal} / \langle \rho_{gal} \rangle$ there is some evidence of deviation from linear trend in the luminosity range $L_{AGN} = 7.0 - 7.75$ ($\chi^2 = 1.14$ and 1.02 for linear and exponential trends respectively).

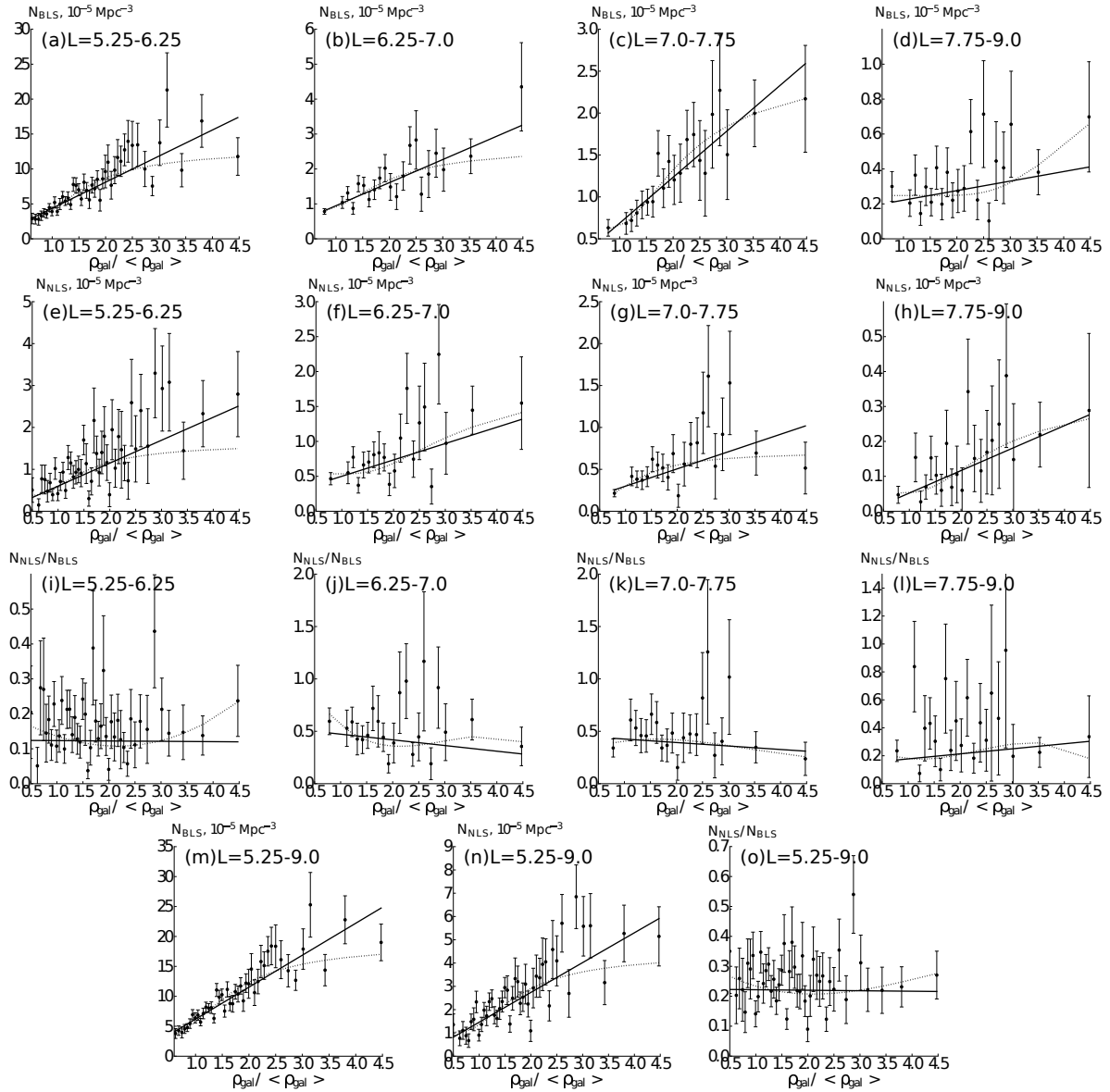


Figure 1. Upper row — correlations between N_{BLS} and $\rho_{gal}/\langle\rho_{gal}\rangle$. Four panels correspond to four intervals of AGN luminosity in units of $\lg L_{[OIII]}/L_{\odot}$. a) 5.25 – 6.25 b) 6.25 – 7.0 c) 7.0 – 7.75 d) 7.75 – 9.0. The second row displays correlations between N_{NLS} and $\rho_{gal}/\langle\rho_{gal}\rangle$. In the same way e), f), g), h) correspond to the same intervals of AGN luminosity. The third row displays the relations between N_{NLS}/N_{BLS} and $\rho_{gal}/\langle\rho_{gal}\rangle$. i), j), k) l) correspond to the same intervals of AGN luminosity. Lower row displays relations between m) N_{BLS} , n) N_{NLS} , o) N_{NLS}/N_{BLS} and $\rho_{gal}/\langle\rho_{gal}\rangle$ for the whole interval of the AGN luminosity, $L = 5.25 - 9.0$. Solid lines on all diagrams are the result of linear approximation. Dashed lines on all diagrams are the result of approximation with nonlinear function: a) – h), m), n) exponential function $a \times \exp(-c/x^2) + b$; i) -l), o) cubic polynomial $ax^3 + bx^2 + cx + d$.

Relation between N_{NLS}/N_{BLS} and $\rho_{gal}/\langle\rho_{gal}\rangle$ either for all 4 intervals of luminosity and for the whole interval is well fitted by linear functions. The a coefficients are equal to zero within errors.

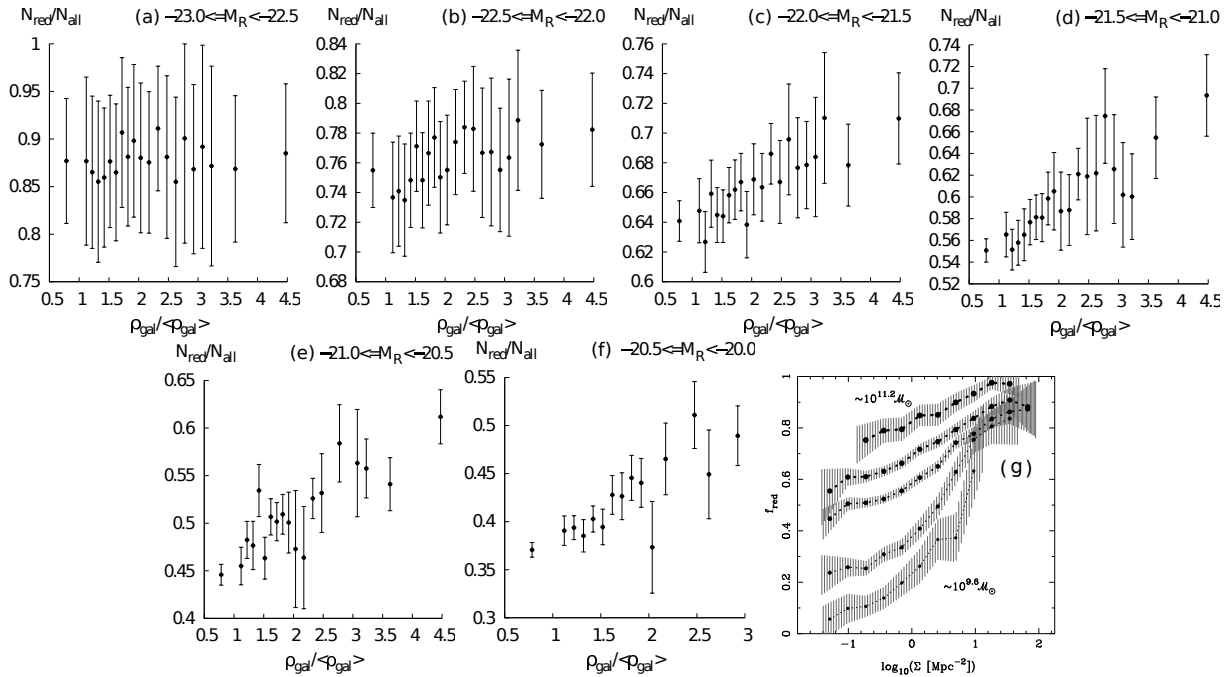


Figure 2. a - f) Correlation between fraction of red galaxies with $u - r > 2.2$ and $\rho_{\text{gal}}/\langle\rho_{\text{gal}}\rangle$ for six intervals of absolute magnitude M_r . g) Fraction of red galaxies vs $\log_{10}(\Sigma [\text{Mpc}^{-2}])$ for different mass intervals. Figure was taken from [15].

Let us now discuss what do these results imply. If NLS and BLS are a fixed, albeit different fraction of all galaxies it is obvious that the relations considered will behave the following way. N_{NLS} and N_{BLS} will be linear and $N_{\text{NLS}}/N_{\text{BLS}}$ will be constant. Deviation from such behavior will mean that such assumptions are not valid. *Deviation of $N_{\text{NLS}}/N_{\text{BLS}}$ is not observed.*

For all the luminosity intervals considered correlations between N_{NLS} , N_{BLS} and $\rho_{\text{gal}}/\langle\rho_{\text{gal}}\rangle$ are linear. But there are two exceptions: $L = 5.25 - 6.25$ (BLS) and $L = 7.0 - 7.75$ (NLS). Evidence of deviation from linear trend at $\rho_{\text{gal}}/\rho_{\text{gal}} > 3$ is present.

Nevertheless, statistical significance is too small for any conclusions.

It seems that for all considered luminosity intervals the correlations between N_{NLS} , N_{BLS} and $\rho_{\text{gal}}/\langle\rho_{\text{gal}}\rangle$ are linear. NLS and BLS are some fraction of all galaxies which depends on nuclear luminosity but not on density of large-scale environment.

All this argue for the idea that NLS activity is launched through internal processes, not by interactions. It should be noted, however, that our approach allows to analyze connection of nuclear activity with variations of concentration of galaxies on scales of large-scale structure cells (i.e. with the position of AGN in large-scale structure), but it does not account at all for the presence or absence of close companions. Some authors state that interactions with close companions lead to formation of classical bulges in BLS (see, e.g., [3])

4. Dependence of the red fraction of galaxies on luminosity and density of environment

The fact that the fraction of early-type galaxies is higher in more dense regions is well-known. See, e.g., [15]. Also with increasing density of environment increases the fraction of red galaxies.

Paper [15] is dedicated to analysis of data provided by the Galaxy Zoo project. For today it is the largest catalog of visually classified galaxies. Right panel of fig. 12 in [15] shows the

correlation between the fraction of red galaxies and $\lg_{10}(\Sigma[Mpc^{-3}])$. In our work this correlation is shown on fig. 2g. Authors of [15] defined the density of environment as $\Sigma_N = N(\pi d_N^2)$, where d_N — projected distance to the Nth companion brighter than $M_r = 20$. N was set to 4 or 5.

Let us check if our approach allows to independently confirm the result of dependence of red fraction on the density of environment. The correlations were obtained for 6 intervals in absolute magnitude. In order to classify galaxies we used $u - r$ colors. Galaxy was considered red if $u - r > 2.2$ according to [16]. The obtained correlations between red fraction N_{red}/N_{all} and $\rho_{gal}/\langle\rho_{gal}\rangle$ are shown on figure 2a-f.

Let us compare our result with the one from [15] shown on fig. 2g. We confirm not only that there is a tendency of increasing fraction of red galaxies with density of environment, but also the fact that this trend is more prominent for less massive galaxies.

Hence, confirmation of this result means that our approach is correct and results obtained about NLS and BLS are trustworthy.

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This research has made use of CosmoPY package for PYTHON
<http://roban.github.com/CosmoPy/>.

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