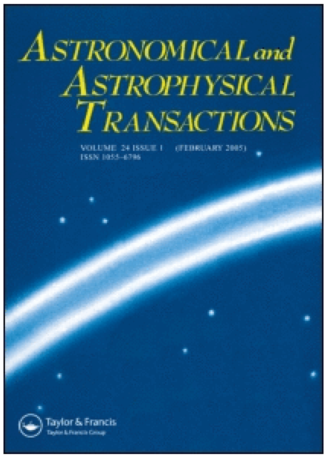

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A POSSIBILITY TO REVEAL PARENT POPULATIONS FOR OBJECTS WITH ACTIVE NUCLEI COMPARING THEIR SPATIAL CORRELATION FUNCTIONS

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The possibility to derive conclusions about parent population comparing two-point spatial correlation functions of single objects and/or of systems of different types, including AGN, is demonstrated. Similarity of correlation function for groups of galaxies, radio-quiet QSGs, and Seyfert galaxies testify to their evolutionary connection. This method can be used for choosing FR-I-type radiogalaxies or radio-quiet QSGs as parent population of BL Lacertae-type objects.

KEY WORDS Objects with active nuclei, spatial correlation functions

1 $\xi(r)$, TWO-POINT SPATIAL CORRELATION FUNCTIONS FOR DIFFERENT TYPE GALAXIES AND THEIR SYSTEMS

(1) The probability of simultaneous location of objects in two volume elements, δV_1 and δV_2, separated by distance r_{12} is

$$\delta P = n^2 \delta V_1 \delta V_2 [1 + \xi(r)],$$

where n is the average spatial density of objects. In this case, the two-point correlation function (CF) is:

$$\xi(r) = \frac{N_{\rm obs}(r)}{N_{\rm rand}(r)} - 1 = \left(\frac{r}{r_0}\right)^{\gamma} = Ar^{\gamma}, \tag{1}$$

where $N_{\rm obs}$, the number of pair objects separated by a distance r in the given sample; $N_{\rm rand}$, the number of pairs in a random sample with the same power; r_0, the correlation radius, $\xi(r_0) = 1; A$, the correlation amplitude, $A = r_0^{-\gamma} = \xi(r = 1\ {\rm Mpc})$.

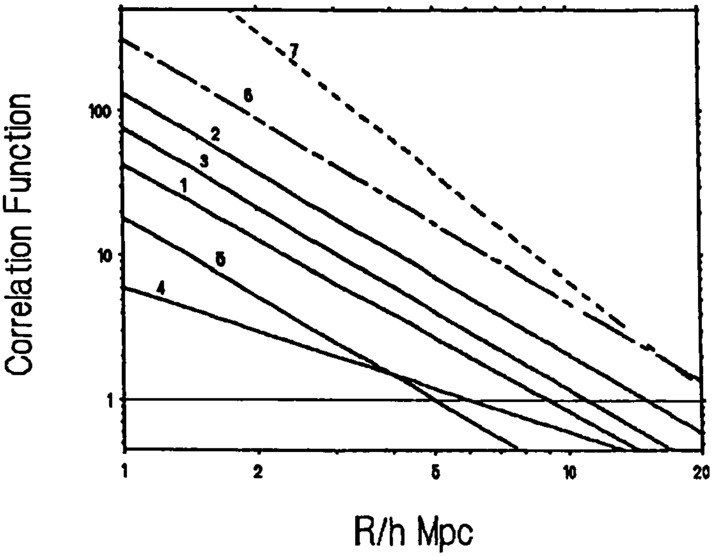

Figure 1 Two-point spatial correlation functions (double logarithmic scale) for different types of objects and their systems *1*, SyGs; *2*, RGs of RFI type; *3*, RGs of all types; *4*, Groups of galaxies; *5*, Galaxies; *6*, Clusters of galaxies of $R > 0$; *7*, Clusters of galaxies of $R = 0$ richness.

(2) observation, according to [2], give the following approximate relations:

$$\begin{aligned} r_0 &\approx 0.4d \\ A &\approx 4N \approx (0.4d)^{-\gamma}, \end{aligned}$$

where N is the number of galaxies which are by 2^m fainter than the third-brightest galaxy in the area with a radius $R \leq 1.5h^{-1}$ Mpc from the center of the system; $d = n^{-1/3}$ is the average distance between the objects in the sample. If $\gamma = -1.8$, then $A \sim n^{-3/5}$ (n is the spatial density of objects or systems).

Table 1 (Figure 1) gives the values of CF parameters (γ, r_0, A) for objects of different types and their systems.

2 CF FOR SEYFERT GALAXIES (SyGs) AND QUASARS (QSOs)

(1) For a model of the World with $q_0 = 0.5$ and $H_0 = 100$ (the sample of 959 SyGs with $Z \leq 0.2$ [3]), a CF with the following parameters was obtained:

$$\begin{aligned} r_0 &= (9 \pm 2)h_{100}^{-1}\ \text{Mpc}, \\ \gamma &= -(1.7 \pm 0.2) \\ A &= 50\ \text{(see Figure 1)}. \end{aligned}$$

(2) The CF for QSOs was studied using the Catalogue by Veron–Cetty and Veron [4], which contains more than 5000 QSOs with $Z \leq 2.5$. In order to decrease

Table 1. CF parameters for objects of different types

Type of object	*Slope of the CF linear part* (γ)	*CR* $(r_0)h^{-1}$ *Mparsec*	$A = (r_0)^{-\gamma}$	*References*
Clusters $R = 0$	$-(2.46 \pm 0.28)$	$21.7^{+4.4}_{-5.2}$	255	[13]
Clusters $R > 0$	$-(1.81 \pm 0.28)$	$23.7^{+7.9}_{-9.0}$	300	[13]
Galaxies	-1.8	≈ 5	18	[1, 14, 15]
Groups of galaxies	$-(1 \pm 0.5)$	≈ 6	25	[16]
Radio Galaxies	-1.8	≈ 11	75	[17]
RGs of RFI type	-1.8	≈ 15	130	[18]
Seyfert Galaxies	$-(1.7 \pm 0.2)$	9 ± 2	50	Present paper and[19]

Note. Explanations: the first column – types of extragalactic objects; the second column – the slope of the CF linear part; the third column – the correlation radius of a given CF; the fourth column – the amplitude of the CF $A = (r_0)^{-\gamma}$; the fifth column – references.

the influence of heterogeneity of the QSO sample from this Catalogue, the CF was estimated by "Method of normalization to the large scales" [5]:

$$\xi_{\Delta V}(r) = \frac{N_{\Delta V < 2500\,\mathrm{km/s}}(r)}{N_{20000 < \Delta V < 50000}(r)} - 1.$$

Here $N(\Delta V < 2500)$ is the number of QSO pairs with a difference between their radial velocities < 2500 km/s; $N(20000 < \Delta V < 50000)$ is the number of random pairs in a sample of the same power; r is the projection of the comoving distance.

(a) The CF obtained for a sample of 875 QSOs with $Z \approx 0.5$–1.0 is represented in Figure 2 (Table 2). Its parameters are: $r_0 = 4.5$ Mpc; $\gamma = -1.8$; $A = 20$.

It can be seen that the CF of these QSOs is located between the CFs of galaxies and groups of galaxies. It does not contradict the observational data which evidence that nearby QSOs frequently belong to groups of galaxies or poor clusters.

(b) A rich sample of QSOs [4] allows to make some conclusions concerning evolution of their CF parameters as a dependence between cosmological epoch (i.e. Z) and average luminosity of QSOs is subsamples.

Table 2. CF for QSO sample from VCV-Catalogue (875 objects) with $\langle Z \rangle = 0.75$

r, h^{-1}*Mparsec* $\rightarrow$ *1*	*2*	*3*	*4*	*5*
$\xi(r) \rightarrow 7.85^{+2.86}_{-1.75}$	$4.35^{+1.72}_{-1.05}$	$2.05^{+0.99}_{-0.51}$	$1.83^{+0.92}_{-0.55}$	$0.68^{+0.34}_{-0.21}$
r, h^{-1}*Mparsec* $\rightarrow$ *6*	*8*	*15*	*20*	
$\xi(r) \rightarrow 0.40^{+0.48}_{-0.29}$	$0.03^{+0.33}_{-0.20}$	$-0.03^{+0.31}_{-0.19}$	$-0.07^{+0.31}_{-0.18}$	

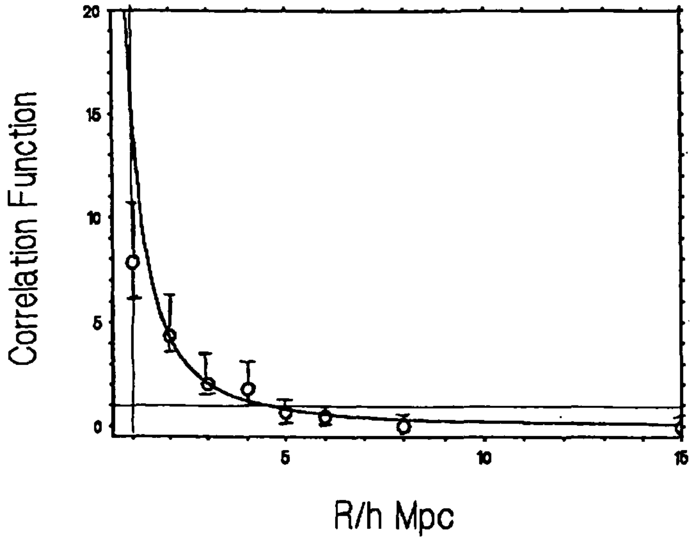

Figure 2 Two-point spatial correlation function for a sample of 875 QSOs with $\bar{Z} = 0.75$ from Veron-Cetty, Veron Catalogue [4].

(c) The results of CF calculations for QSO subsamples with different Z values are given in Table 3 (Figure 3). Unfortunately they do not allow to derive a law of evolution. However if it is possible to use data by different authors [5, 9, 7, 8] concerning other QSO subsamples with different $\bar{Z}$, one can obtain $\gamma \sim (1 + Z)^{-(2\div3)}$. A dependence of the type $\gamma \sim (1 + Z)^{-2}$ is predicted in the Einstein-De Sitter model of the World simultaneously with a linear growth of perturbations with

Table 3. Evolution of CF amplitude at $r = 5h^{-1}$ Mpc for QSOs from VCV-Catalogue without taking into account their luminosity

N_{QSO}	*Range of redshifts*	*An average redshift*	$\xi(r = 5 Mparsec)$
310	$0 < Z < 0.4$	0.29	$0.35^{+1.25}_{-0.43}$
782	$0.2 < Z < 0.7$	0.47	$0.98^{+0.87}_{-0.43}$
862	$0.3 < Z < 0.8$	0.55	$0.95^{+0.82}_{-0.39}$
877	$0.4 < Z < 0.9$	0.65	$1.23^{+0.53}_{-0.35}$
875	$0.5 < Z < 1.0$	0.75	$0.68^{+0.34}_{-0.21}$
936	$0.6 < Z < 1.1$	0.86	$0.88^{+0.36}_{-0.26}$
947	$0.7 < Z < 1.2$	0.96	$1.26^{+0.42}_{-0.30}$
984	$0.8 < Z < 1.3$	1.06	$2.35^{+0.59}_{-0.44}$

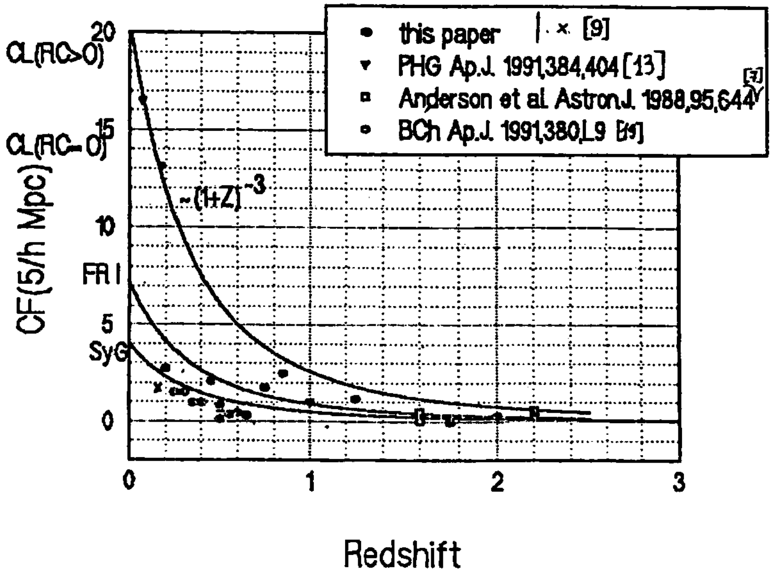

Figure 3 Expected evolution of the CF amplitude $\sim (1+Z)^{-3}$ for QSOs from different samples (□, ■) and for clusters of galaxies (▼). The ordinate axis gives CF amplitudes of SyGs, RGs of FRI type, and clusters of galaxies of $R = 0$ and $R > 0$ richness with $Z = 0$.

time; however, in our opinion, preference must be given to evolution of the type $\gamma \sim (1+Z)^{-3}$. One can suggest several arguments in favour of this idea. First, this model, taking into account the dependence $A \sim n^{-3/5}$ (for $\gamma = -1.8$), causes an evolution observed for QSOs with $Z \leq 2.5$ of their comoving density: $n \sim (1+Z)^5$. Second, if the law of evolution is $\xi \sim (1+Z)^{-3}$, then the CF of QSOs with low and middle Z is easily matched with the CF of galaxies with active nuclei (SyG type or radiogalaxies, RG) depending on average luminosity of QSO subsamples.

Table 4. Evolution of the CF amplitude for QSO samples from VCV-Catalogue subdivided in accordance with their luminosities

$\langle M \rangle$	$N_{\rm QSO}$	*Range of Z*	$\langle Z \rangle$	$\xi(r = 5 Mparsec)$
QSGs	-	-	0.2	$\sim (1.6 \pm 0.5)$ [8][9]
−24.09	642	$0.3 < Z < 1$	0.58	$0.64^{+0.52}_{-0.32}$
QSSs				
−25.82	606	$0 < Z < 1$	0.72	$2.46^{+1.06}_{-0.53}$
−25.84	564	$0.4 < Z < 1$	0.75	$2.16^{+1.37}_{-0.72}$
−25.78	499	$0.6 < Z < 1$	0.80	$1.63^{+2.81}_{-1.12}$

(d) A division of the whole QSO sample from the Catalogue [4] into subsamples with different $\bar{M}_B$ is, to some extent, analogous to the division of QSOs into radio-loud QSSs which are brighter in the optical range and fainter radio-quite QSGs. The results of CF computations for such subsamples are presented in Table 4. It is evident that the CF amplitude for the QSS subsample with $\bar{M}_B = -26$ is 3–4 times higher than that for the QSG subsample with $\bar{M}_B = -24$. The evolutionary match of the CF of distant QSSs with the CF of nearby RGs and evolutional match of the QSG CF with the CF of nearby SyGs is in complete agreement with the hypothesis that RGs and SyGs are the final stages of QSS and QSG evolution, respectively (see, for example, [10, 6]).

3 (1) If CFs of the objects with active nuclei are compared to CFs of the objects which are likely to be their parent population (for example, QSSs and RGs, QSGs and SyGs) at the same cosmological epoch, one should bear in mind that these objects might have different typical lifetimes (τ). This fact, in turn, will influence the properties of their CFs, the amplitude of the latter decreasing for population with greater lifetime. Since

$$\frac{n_i}{n_j} \approx \frac{\tau_i}{\tau_j},$$

it follows that

$$\frac{A_i}{A_j} \sim \left(\frac{n_j}{n_i}\right)^{3/5} \sim \left(\frac{\tau_j}{\tau_i}\right)^{3/5}.$$

Therefore, when, on the basis of QSO CF with $Z \approx 3$, a CF their host clusters with the same Z is being restored, one should reduce the CF amplitude for clusters (compared $A_{\rm QSO}$) by

$$\left(\frac{\tau_{\rm cl}}{\tau_{\rm QSO}}|_{Z=3}\right)^{3/5} \approx \left(\frac{10^9 {\rm year}}{10^7 {\rm year}}\right)^{3/5} \approx 16 \text{ times},$$

i.e

$$A_{\rm Cl|_{Z=3}} \approx \frac{A_{\rm QSO}}{16}|_{Z=3} \approx \frac{A_{\rm QSO|_{Z=0}}(1+Z)^{-3}}{16}.$$

(2) In the framework of this consideration, it would be interesting to compare the CF of BL Lacertae type objects with the CF of their possible host populations, that is either RGs of RFI type [11] or QSGs [10]. Unfortunately, a sample of BL Lacertae type objects is not representative enough yet (only about 100 objects at all). Besides that, in the "unified scheme", emission of BL Lac type objects in the optical range is strongly collimated, this could reduce their observed spatial density by a factor of several hundreds compared to their parent population. In turn, this can be a cause of increase, by a factor of several dozens, of CF amplitude for BL Lac objects compared to the CF of parent population. Therefore, to determine a CF for a sample of BL Lac type objects is a matter of future. It may occur that for this purpose a sample of BL Lac objects found in X-ray range is more convenient. The spatial density of this sample turned out to be significantly higher than that for the samples of BL Lac objects found in radio and optical ranges (possible, a reason for this is lower collimation of their emission in X-ray range).

(3) In order to choose a parent population among different candidates for different objects with active nuclei it is useful to determine not only a two-point spatial CF, but spatial cross-correlation functions as well, for example: QSO-galaxies, BL Lac-galaxies, and RG-galaxies. A selection of the parent population in this case can be made on the basis of similarity of environment richness. For example, [11] gives data for galactic fields down to $m_r = 22$ around BL Lac type objects selected in the radio wavelength range. The authors obtained an interesting result which evidences in favour of increasing of correlation function amplitude $A_{g-\mathrm{BL\,Lac}}$ from 215 (with $\bar{Z}_{\mathrm{BL\,Lac}} = 0.28$) to 515 (with $\bar{Z}_{\mathrm{BL\,Lac}} = 0.65$), that approximately corresponds to increasing environment richness from $R = 0$ to $R = 1$. Similar results were obtained earlier for $A_{g-\mathrm{RG}}$ and $A_{g-\mathrm{QSS}}$. These data are in a good agreement with conclusions that remote AGNs are associated with rich clusters of galaxies more frequently than nearby AGNs [7, 12].

It should be noted in conclusion that for the longliving systems one can calculate the epoch of their formation (Z_f). This is possible on the basis of the value derived for the correlation radius r_0 and of estimated dispersion of members velocities or L_{XR} dynamical mass for these systems, because an approximate relation should be fulfilled:

$$\frac{M_{\mathrm{dyn}}}{\frac{4}{3}\pi r_0^3} \approx \rho_0(Z=0)(1+Z_f)^3.$$

But it is true only for such systems which contain the main part of the mass at a given cosmological epoch ($\bar{\rho}_z = \rho_0(1+Z)^3$). It is possible that systems with such characteristics may be rich group of galaxies rather than poor clusters of galaxies.

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