The search and investigation of the Large Groups of Quasars

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Received 1995 December 7; in original form 1995 July 12

ABSTRACT
Recently, it was suggested that large concentrations or groups of quasars may trace sites of enhanced matter density at medium and high redshifts analogous to how galaxy clusters trace them in nearby space (Komberg & Lukash 1994). We have checked existing quasar data for the presence of such groups. Large Quasar Groups (LQGs) were identified using a well-known cluster analysis technique and the following selection criteria: (i) LQG must contain at least ten quasars; (ii) the number density of quasars in a group must exceed that of the background by at least a factor of two; (iii) the majority of quasars in a group must have reliable redshifts. Our final list contains 12 such groups, including one reported previously. It was found that most of the quasars in these groups come from deep homogeneous surveys. Further analysis of the spatial distribution of quasars in these surveys has shown that: (i) the probability that the detected groups are random is rather small (generally a few per cent); (ii) their sizes range from ~ 70 to ~ 160 h^{-1}Mpc, which is comparable to sizes of nearby rich superclusters; (iii) the detected groups all have redshifts 0.5 < z ≤ 2; (iv) the abundance of the LQGs is comparable with the abundance of large superclusters at z ~ 0, which is consistent with the idea that quasar groups and superclusters can be evolutionarily related. We argue that quasar groups could be a common feature of the spatial distribution of medium redshift quasars, and that the quasars in groups may belong to concentrations of young galaxy clusters and groups (distant superclusters) and hence be biased tracers of large-scale structure of matter distribution in the early Universe. Theoretical implications as well as other observations needed to test this point are discussed.

Key words: large-scale structure of Universe – galaxies: quasars: general.

1 INTRODUCTION

We have today considerable independent evidence for an existence of large-scale structures in matter distribution stretching from tens of megaparsecs up to a typical scale l_{LS} ~ 100–150 h^{-1}Mpc (unless otherwise stated we assume H_0 = 100 km/s/Mpc, Ω_0 = 1 and Λ = 0, all scales here are comoving). These structures are traced both by galaxies and galaxy clusters (e.g. Broadhurst et al. 1990; Tully et al. 1992; Mo et al. 1992a, 1992b; Einasto & Gramman 1993; Einasto et al. 1994). The most important data come from bulk velocities at z < 0.03 (the Great Attractor), the distribution of galaxies and galaxy clusters (z < 0.1), and pencil-beam surveys of galaxies (z < 0.3). These structures develop in the quasi-linear regime of evolution and are called great attractors (GAs)/voids: regions of enhanced/de-enhanced matter density with δ_{P}/ρ ~ 10–40% at l ~ 100 h^{-1}Mpc. It is now of interest to find how far these large structures extend in the past and, thus, when they first appeared in time. The result would allow direct dynamical reconstruction of the primordial density perturbation spectrum in the whole scale range l ∈ (10, 150)h^{-1}Mpc.

In our first paper (Komberg & Lukash 1994) we estimated the perturbation spectrum using quasars. One of the kernels of the paper was an assumption about recent dynamical epoch when the first superclusters (the distant GAs observed as LQGs) originated in space. Here we see at least two approaches to test this point: the evolutionary aspects of the quasar correlation function and a direct search for concentrations or groups of QSOs. We analyzed the former test in our second paper (Komberg, Kravtsov & Lukash 1994), where indications of quasar clustering evolution for z > 1 were found in agreement with other authors (Kruszewski 1988; Iovino & Shaver 1988; Iovino, Shaver & Cristiani 1991; Mo & Fang 1993). In this paper, we report results of a search for and investigation of large quasar groups.
During the past decade, together with statistical results on quasar clustering data, evidence has been presented for the existence of four large quasar groups. Let us briefly recall their properties:

(i) The first, found by Webster (1982) at \( z \sim 0.37 \), consists of four quasars within \( \sim 75 h^{-1} \text{Mpc} \): a close triplet and a more distant QSO.

(ii) The second LQG, found by Crampton, Cowley & Hartwick (1987, 1989) (hereafter CCH-group) at \( z \sim 1.1 \), contains 23 quasars within \( \sim 60 h^{-1} \text{Mpc} \) and is thus the richest known group.

(iii) The third group of 13 QSOs (Clowes & Campusano 1991a, 1991b, hereafter CC-group) was found at \( z \sim 1.3 \), and was reported to have an elongated shape (with long and short sky-projected dimensions of \( \sim 150 \) and \( 35 h^{-1} \text{Mpc} \), respectively) and clumpy inner structure. Graham, Clowes & Campusano (1995) found five additional members of this group and stated the size of the group as \( 150 \times 100 \times 60 h^{-1} \text{Mpc} \).

(iv) Recently (Graham, Clowes & Campusano 1995), the Minimal Spanning Tree technique was used to search for quasar superstructures in several homogeneous surveys. Evidence was found for a new group of quasars at \( z \sim 1.9 \) and a grouping of Seyfert galaxies at \( z \sim 0.19 \). The former group has a size of \( \sim 120 \times 90 \times 20 h^{-1} \text{Mpc} \) and the latter \( \sim 60 \times 30 \times 10 h^{-1} \text{Mpc} \).

The authors emphasize that both the CCH and CC groups contain subclusters of size \( \sim 15 - 20 h^{-1} \text{Mpc} \). They also argue that because of a lack of further examples the LQGs may be very rare and hence cannot be related to the large structures of galaxies which seem to be common features of the Universe. We discuss this problem below and argue that if distant quasar groups at \( z \geq 1 \) trace attractor-like enhancements of the total matter density (Komberg & Lukash 1994), then LQGs must be as common as rich superclusters traced by galaxy clusters at \( z \leq 0.1 \). We will show as well that, if the latter is true, presently available wide and deep surveys are expected to contain approximately \( 3 - 5 \) LQGs each.

Our analysis was carried out as follows. As a first step, we have applied well-known cluster analyses to the largest available quasar database – the Véron-Cetty & Véron (1991) Catalogue of quasars. The friend-of-friend algorithm (e.g. Einasto et al. 1984) was used to derive the lists of quasar cluster candidates for a number of values of clustering radius. We then excluded clusters containing less than ten quasars and compared their comoving quasar number density with a background one, which was estimated using two deep and wide homogeneous surveys. Then, we have accepted only clusters with density exceeding the background by at least a factor of two. This part of the investigation is described in Section 2. Having excluded groups in which most objects had non-reliable redshifts, we analyzed the properties of the 12 LQGs which were left in the final list. Ten of them come from deep homogeneous surveys while two are mixtures of quasars from different (though homogeneous) surveys. Our further analysis of properties of the quasar groups is based chiefly on these surveys: in Section 3 we estimate the probability for a group to be a random feature of the survey and compute an approximate LQG density and their typical size. Section 4 deals with possible implications of the obtained results. We summarize our results and conclusions in Section 5.

2 THE SEARCH FOR QUASAR GROUPS

2.1 The Catalogue

Investigation of the spatial distribution of quasars is strongly hampered by insufficient coverage of the sky by homogeneous quasar surveys: they are either deep and narrow or bright and wide. The former provide a high enough number density of quasars (the mean separation between QSOs in such samples is \( \sim 20 - 50 h^{-1} \text{Mpc} \)) but usually contain a small number of objects. The latter cover large areas in the sky and contain many objects but usually provide a very low spatial density of quasars (mean quasar separation is \( \geq 100 h^{-1} \text{Mpc} \)) which makes them insensitive to the presence of large-scale structures. That is why almost all statistically reliable results on quasar clustering were obtained with combined samples containing several deep homogeneous surveys (e.g. Iovino & Shaver 1988; Andreani & Cristiani 1992; Mo & Fang 1993; Komberg, Kravtsov & Lukash 1994; Shanks & Boyle 1994). It is clear that for statistical analysis we need homogeneous data in order to account fairly for all possible selection effects (though attempts were made to use inhomogeneous data using the method of normalisation to the large scales – see, for example, Shaver 1984 and Kruszewski 1988). However, for our purpose – the search for quasar groups, we can start with a large inhomogeneous quasar catalog if we consider it just like a joint database for known quasars. Let us explain this point more clearly. First, we will search for groups similar to those discussed earlier (see Section 1), i.e. we know a priori the kind of structures for which we are looking. Second, available homogeneous quasar surveys differ by methods of candidate selection and may thus miss quasars detected in other surveys in the same area in the sky. Therefore, a catalog containing all homogeneous surveys published to date is a good database for the first step of our investigation. It has, however, a serious shortcoming: the inhomogeneous nature of the data results in different accuracies of quasar coordinates (especially redshifts) – from reliable to plainly wrong. We can overcome this difficulty by excluding “non-reliable” objects at further stages of our analysis. By so doing we will end up with something like a combined quasar sample consisting of several homogeneous surveys.

For this purpose we have used the 5th edition of Catalogue of Quasars and Active Nuclei (Véron-Cetty & Véron 1991) which contains more than 6000 quasars (i.e., the active star-like objects with absolute magnitude \( M_B < -23 \) for \( h = 0.5 \)). The redshifts of some quasars in the Catalogue (marked by an asterisk) were estimated from low dispersion slitless spectra and are thus of lesser accuracy or even wrong. So, after applying the cluster analysis described below, we have discarded from the final list those quasar groups containing a large fraction of QSOs with non-reliable redshifts.

2.2 The search strategy

To find LQGs we have used a cluster analysis method known also as the friend-of-friend technique. The kernel of the
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method is an objective, automated procedure to separate a set of objects into individual systems using the following algorithm (see Einasto et al. 1984 for details). Draw a sphere of radius $R_{cl}$ (the parameter called clustering radius) around each sample point (in our case, a quasar). If there are other quasars within this sphere they are considered to belong to the same system. These quasars are called friends. Now draw spheres around these new neighbours and continue the procedure using the rule any friend of my friend is my friend.

The procedure stops when there are no more neighbours or friends to add - a system is found. In such systems every object has at least one neighbour at distance $l \leq R_{cl}$. It is clear that in this method the choice of clustering radius $R_{cl}$ is crucial. If $R_{cl}$ is too small, then we detect mostly close pairs and triplets. On the other hand, if $R_{cl}$ is too large all quasars join to form huge systems which have a density contrast close to zero. In our case, there is no a priori defined parameter $R_{cl}$ and we have performed the procedure for a number of values of $R_{cl}$ ranging from $20h^{-1}$ Mpc to $60h^{-1}$ Mpc with step $5h^{-1}$ Mpc. These values were chosen for the following reasons: when $R_{cl} \leq 20h^{-1}$ Mpc we detect systems with less than five members while at $R_{cl} \geq 60h^{-1}$ Mpc most quasar clusters are spread over a large volume and have vanishing density contrast.

As a result, we have obtained lists of clusters for each value of $R_{cl}$. For each cluster in the list we have calculated its comoving dimensions (projected on the sky $R_{cl}$, $R_{cl}$, and along redshift $R_{cl}$), a rough estimate of its volume $V_{cl} = R_{cl}R_{cl}R_{cl}$, and the quasar number density. We have adopted the following selection criteria to derive LQGs from the list:

(i) a cluster must contain at least ten quasars (i.e., we are going to deal with only the largest groups);

(ii) the quasar number density in a cluster must exceed that of the background by at least a factor of two;

(iii) the majority of the quasars in a cluster must have reliable redshifts.

In fact, these criteria were chosen to obtain LQGs similar to the CCH and CC groups. On the other hand, the second criterion makes us sure that we deal with real enhancements in quasar number density and, certainly, with the most prominent ones on scales $\geq 20h^{-1}$ Mpc. Actually, we look for quasilinear structures ($\Delta \rho/\rho < 1$) and if quasars trace the underlying matter distribution with a linear bias factor $b \sim 3-5$ (typical values for nearby clusters), we should expect the detection of very prominent quasar groups somewhere on the level $\Delta N/N \approx b(\Delta \rho/\rho) \sim 1$. This means that number density in a group exceeds the background by a factor of two.

Our group was thus identified when both requirements: a large number of quasars in the group and a high enough number density for that group, were met simultaneously. Thus, we choose a group from among nine lists of different clustering radii only when it contains more than ten quasars and its density is approximately two times higher than the background at a corresponding redshift. If, for example, we have cluster with more than ten quasars at, say, $R_{cl} = 35h^{-1}$ Mpc, but with number density contrast still much greater than one - we continue searching for the same cluster in lists for $R_{cl} > 35h^{-1}$ Mpc till its density contrast is of order of unity. In some cases, $\Delta N/N$ was dropping rather abruptly in the next $R_{cl}$ list. When this occurred we took the group from the last list where $\Delta N/N \geq 1$, which explains why some of identified groups have contrast greater than one.

On the other hand, if we have a cluster of quasars with high density contrast but which contains less than 10 quasars for any $R_{cl}$, it was not included in the list according to the first selection criterion.

The background number density of quasars was calculated using two large and deep homogeneous surveys (Boyle et al. 1990, Osmer & Hewett 1991). The first survey was derived with UVX technique and is thus limited to redshift $z \sim 2.2$. For groups with larger redshifts we used only the multicolor survey by Osmer & Hewett (1991). For all clusters, the faintest member is within the limiting magnitudes of these surveys. In this case, when the background density is calculated it is possible to include quasars from surveys which are fainter than the faintest member of LQG. One can see that the density contrast may then be underestimated.

2.3 The Large Quasar Groups found

Having performed the procedure described above we obtained the final list of 12 quasar groups which fit our selection criteria.

In Table 1 we present only groups in which the majority of quasars have reliable coordinates and redshifts. In the first three columns the celestial coordinates and redshifts of the quasars in the groups are given, followed by the group extensions in the sky and in redshift directions and an estimate of their number density contrasts.

It is very interesting to know whether the previously detected groups, mentioned in Section 1, were identified in our analysis. The group discovered by Webster (1982) has been found but does not fit our first criterion. Five quasars included in the CCH group (Crampton et al. 1989) appear as a separate cluster in the list for $R_{cl} = 20h^{-1}$ Mpc and group was identified at $R_{cl} = 35h^{-1}$ Mpc. For this group $\Delta N/N \sim 1$ and number of quasars in the cluster is $25-22$ of which were included in the CCH group (see Section 3 for further details). The group reported by Clowes & Campusano (1991) was found only at $R_{cl} = 60h^{-1}$ Mpc and was not included in the final list as it did not fit our second selection criterion (its density contrast is less than one). Graham, Clowes & Campusano 1995 reported detection of a LQG in the survey by Osmer & Hewett 1991 (see Section 1). Unfortunately, the coordinates of objects included in the group weren’t published. The authors, though, present properties of the group: it consists of 10 quasars, located at $z \sim 1.9$ and has dimensions $\sim 120 \times 90 \times 20h^{-1}$ Mpc (note that as will be discussed in the next section, the latter dimension most probably is not real because Osmer & Hewett survey’s geometry is thin in declination – a $\sim 30'$ strip which corresponds to $\sim 20 - 30h^{-1}$ Mpc at $z \sim 1$). We have identified three LQGs in this survey and one of them (LQG 7, see...
Tables 1,2) seems to have rather similar properties: it consists of 10 quasars, is located at $z \sim 1.9$ and has dimensions $101 \times 92 \times 24h^{-1}\text{Mpc}$.

We think that the fact that we have identified the groups found in earlier studies shows that the adopted method may be efficient in finding quasar groups.

3 RESULTS

In Section 2 we present a list of twelve quasar groups. Clearly, the use of a heterogeneous catalogue may cause a concern about the reliability of the results. But we note once more that the catalogue was used only at the very first step of our analysis and was considered solely as a complete survey of quasar data. In the second step, the number density contrasts in groups were estimated using homogeneous surveys. In fact, we have found that most of the quasars in the detected groups come from deep and wide homogeneous quasar surveys. This was expected because such surveys provide high quasar densities together with large volumes surveyed and hence are most suited for the search of structures such as LQGs. In this section we will scrutinize our groups using, when possible, the homogeneous surveys from which they originate. It gives us the advantage of knowing selection features and geometry on the sky of a given survey and holding them under control. On the other hand, the background quasar density can be directly estimated using the "host" survey where the group is located. It allows us to estimate the probability of a group to appear by chance in such a survey. The most straightforward way is to generate a random comparison sample with the original selection envelope. Random samples were created using the smoothing scheme (e.g. Mo & Fang 1993). Redshifts of objects were drawn from a smoothed version of the redshift distribution while keeping their celestial coordinates unchanged. The number of quasars in a given bin of the smoothed redshift distribution (constructed with redshift interval $\Delta z = 0.2$) was calculated by averaging the number of objects in interval $\Delta z = 0.6$ centered at this bin. In this way, the redshift distribution is randomized and selection effects intrinsic to the original survey are preserved. Having created the random sample 1000 times and performing for each realization the same clustering analysis (with the value of $R_{cl}$ for which the given group was identified) we were able to estimate an empirical probability of a group appearing by chance by simply counting the number of groups found in these random catalogs with richness and QSO density not less than in the original one and located in the same redshift range.

There is one more thing to note. Several detected groups contain quasars which come from different surveys. One may be concerned why observers investigating the same field on the sky may miss quasars detected by others. This question is difficult to answer and, obviously, in each case individual investigation is required. Our analysis has shown that, generally, it is a question of different limiting magnitudes, but there may also be some other explanations: the "alien" quasar lies in the sky in the region adjacent to the area of a survey, different surveys use different techniques of candidate selection, exclusion of known quasars, different seeing conditions, plate flaws, satellite trails and so on.

3.1 What have we found?

Here we analyze the LQGs listed in Table 1 (the groups are arranged according to the right ascension). For each group we present and briefly discuss original sources of all the quasars, clustering radius at which it was identified, number density of quasars and probability for it to be random. Essential information is summarized in the Table 2.

LQG 1. This group contains 12 quasars. All redshifts are reliable. The quasars 0040 – 3024, 0040 – 2919, 0052 – 2853, 0052 – 2856 come from the Large Bright Quasar Survey (LBQS) (Morris et al. 1991 and references therein). Two quasars, 0046 – 2834 and 0055 – 2948, are from Campu- sano (1991) (the first is also present in LBQS, the second is much fainter than LBQS limiting magnitude). Quasars 0049 – 2840, 0049 – 2931, 0052 – 2847, 0052 – 2853, 0057 – 2835 come from the deep survey by Boyle et al. (1990) (hereafter BFSP). Two of them were present in the LBQS, the others are too faint. The quasar 0050 – 2828 comes from Boyle et al. (1985) and is also present in Morris et al. (1991), although it is too faint to be included in LBQS. The last QSO (0059 – 2853) is from the Warren et al. (1991) survey where non-UVX technique was used.

The group was identified at clustering radius $R_{cl} = 45h^{-1}\text{Mpc}$. The quasar density in this group is $\sim 3.3 \times 10^{-5}h^{-3}\text{Mpc}^{-3}$. Clearly, we cannot evaluate the probability to appear by chance for this group as its objects come from different surveys. However, we note that density in this group is approximately 2 times higher than the density in the BFSP survey (all quasars in the group are brighter than the limiting magnitude of this survey).

LQG 2. It contains 12 QSOs, although two of them (0048 – 2759 and 0054 – 2810) have redshifts estimated from slitless spectra. As in the previous case, the quasars come from several sources. Three QSOs (0041 – 2844, 0046 – 2914 and 0048 – 2901) are from Morris et al. (1991) (LBQS); 0046 – 2904, 0052 – 2902 are from Warren et al. (1991). Four objects (0050 – 2907, 0050 – 2929, 0052 – 2830, 0056 – 2843) come from BFSP survey but second quasar was also present in the LBQS. The last three QSOs (0048 – 2804, 0048 – 2759 and 0054 – 2810) originate from Clowes & Savage (1983), the quasar selection in this survey was based on visual inspection of prism spectra.

The significance of this group cannot be estimated for the same reasons as for the previous one. The group was identified at $R_{cl} = 40h^{-1}\text{Mpc}$ and its quasar density is $\sim 3.3 \times 10^{-5}$ (i.e. its density contrast is also $\sim 1$).

LQG 3. This group contains 14 QSOs. All of them, except 0056 – 2921, are from BFSP survey. The QSO 0056 – 2921 is from Warren et al. (1991). In this survey a multicolor technique was used so that it may probably contain quasars missed in UVX BFSP survey.

This group was identified at $R_{cl} = 35h^{-1}\text{Mpc}$ and its quasar density is $\sim 3 \times 10^{-5}$. Now we can evaluate the probability for it to be random as was described above. The BFSP catalogue contains 34 40-arcmin fields, distributed around eight fields. This group resides in the SGP field which consists of seven subfields so that some of quasars could be easily missed. The estimated probability was found to be rather small (2%) so that identification of this group is statistically significant.

LQG 4. There are 14 quasars. Most of them are also from...
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BFSP but two quasars (0051–2855 and 0054–2934), which originate from Clowes & Savage (1983), have redshifts estimated from slitless spectra. Another one (0050–3001) is from Savage et al. (1985).

The group was identified at \( R_{cl} = 35h^{-1} \text{Mpc} \) and its density is \( \sim 4.9 \times 10^{-5} \) (i.e. no similar groups were found during 1000 random realizations).

**LQG 5.** It consists of 13 QSOs which are all from BFSP survey (QSF-field). This group was identified at \( R_{cl} = 40h^{-1} \text{Mpc} \), its density is \( \sim 4 \times 10^{-5} \) (i.e. 2 times higher than the background). The quasar redshift distribution in this field shows a peak at \( z \sim 1.7 \) which is due to the presence of this group. It may be a random enhancement with probability \( \sim 0.03 \) (i.e. 30 similar groups were found after 1000 random realizations).

**LQG 6.** This group consists of 10 QSOs. They all come from deep homogeneous survey by Osmer & Hewett (1991) (hereafter OH). It was identified at \( R_{cl} = 45h^{-1} \text{Mpc} \) and its density is \( \sim 7.6 \times 10^{-5} \) (i.e. it exceeds the background density in OH survey by a factor of 5). The probability for this group to be random is 0.01.

**LQG 7.** This group also contains 10 QSOs and they all originate from OH survey. It was identified at \( R_{cl} = 40h^{-1} \text{Mpc} \) and its density is \( \sim 4.6 \times 10^{-5} \) (i.e. it exceeds the background density in OH survey by a factor of 2). The probability to be random is about 0.19.

**LQG 8.** The group consists of the 12 QSOs which are all from OH survey. It was identified at \( R_{cl} = 45h^{-1} \text{Mpc} \) and its density is \( \sim 5.7 \times 10^{-5} \). The probability to be random is about 0.05.

**LQG 9.** All quasars are from Crampton, Cowley & Hartwick (1989, 1990) and Crampton et al. (1988) (hereafter CFHT survey), except one (1330 + 2840) from Burbidge (1970). The latter is a radio-quiet quasar with reliable redshift. The group was identified at \( R_{cl} = 35h^{-1} \text{Mpc} \), its density is \( 2.3 \times 10^{-5} \text{Mpc}^{-3} \). The probability to be random is \( \sim 0.02 \). In the redshift distribution of the CFHT survey there is the excess of quasars (\( \sim 10 \) QSOs) at these redshifts.

**LQG 10.** This one is the group already known to exist (see CCH). In our analysis it was identified at \( R_{cl} = 35h^{-1} \text{Mpc} \) and consists of 25 quasars (22 of these were included in CCH group). The quasar 1340+2843 is from Wills & Wills (1979), and two additional QSOs (1333 + 2820 and 1337 + 2711) are from Crampton, Cowley & Hartwick (1990) and Crampton et al. (1988) respectively.

The number density of quasars in the group is \( 5.1 \times 10^{-5} \text{Mpc}^{-3} \). It is considerably (\( \sim 3 \) times) higher than the background quasar density in the CFHT survey. There is also peak in the redshift distribution at \( z \sim 1.1 \). After 1000 random realizations no similar group was found (i.e. the probability to be random is less than \( 10^{-3} \)). This is in agreement with CCH who concluded that corresponding probability is vanishingly small.

**LQG 11.** This group consists of 11 quasars, eight of them are from the BFSP survey (QSM field), quasar 2200–2019 is from the LBQS, 2154 – 1828 is from Dunlop et al. (1989) and 2158 – 1854 is from Savage et al. 1985. The group was identified at \( R_{cl} = 45h^{-1} \text{Mpc} \) and its quasar density is \( \sim 2.4 \times 10^{-5} \text{Mpc}^{-3} \). The probability to be random for the group of 8 quasars in QSM field was found to be \( \sim 0.05 \).

**LQG 12.** This group contains 14 quasars. Twelve of them are from the BFSP survey. one is from the LBQS (2200 – 1958) and the other (2157 – 2000) is from Savage et al. (1976). The latter is a radio-loud quasar and could, probably, be missed by BFSP as its subfields do not cover the whole field. The group was identified at \( R_{cl} = 45h^{-1} \text{Mpc} \), its density is \( \sim 3 \times 10^{-5} \text{Mpc}^{-3} \). The probability to appear by chance was found to be 0.01.

Finally, we analyze in the same way the CC-group of quasars. The authors include 13 QSOs in this group. Though Graham, Clowes & Campusano (1995) found additional members of the group we use the old number - 10 quasars (three others aren’t from that survey) - to estimate probability to be random for this group in the original survey, because the new extension of the survey was not available to us. Its sizes are (as computed for all groups in our analysis): \( R_a = 134 \text{h}^{-1} \text{Mpc}; R_b = 140 \text{h}^{-1} \text{Mpc}; R_c = 154 \text{h}^{-1} \text{Mpc} \); quasar number density is \( \sim 4.5 \times 10^{-6} \text{h}^3 \text{Mpc}^{-3} \). The estimated probability for such structure to appear by chance in this survey is \( \sim 0.03 \). The probability is small because number density of quasars in that survey is low (much lower than, say, in the BFSP survey), and it is unlikely that such structure arises from such a low density background. However, one can see that number density of quasars in this group is quite low so the further observations in this field are needed which may probably help to find further members of this group.

3D sizes of the groups are difficult to estimate. And one should be very careful drawing conclusions about LQG sizes. Projected sizes are usually larger than survey sizes. However, the size in redshift direction, \( R_z \), should give us a reasonable estimate of sizes because in that direction groups are not limited. \( R_z \) ranges from \( \sim 70 \) to \( 160 \text{h}^{-1} \text{Mpc} \) (see Table 2). In case of the OH survey its geometry in the sky, which is a narrow strip in declination (\( \sim 30^\circ \)) and wide in right ascension (\( \sim 12^\circ \)), makes it possible to consider the values \( R_a \) for the groups LQG 6, LQG 7 and LQG 8 found in this survey, also as real. They are \( 88 \), \( 101 \text{h}^{-1} \text{Mpc} \) and \( 100 \text{h}^{-1} \text{Mpc} \), respectively, i.e. similar to \( R_z \) sizes. Naturally, we can only speculate about the shape of the groups but there is the real hope that at least in the case of the CCH-group the surveyed area will exceed its size in the near future.

4 DISCUSSION

Now we will briefly consider the implications of our results. Komberg & Lukash (1994) suggested that most of the bright QSOs at \( z \in (1,3) \) form in massive mergers and/or interacting galaxies which occur in galaxy protoclusters and compact groups. The expected tests are:

- high correlation amplitude for medium-z (\( 1 < z < 2 \)) QSOs with correlation radius \( \sim 10 \text{h}^{-1} \text{Mpc} \);
- high abundance of LQGs at \( 1 \leq z \leq 2 \) indicating positions of distant presupercusters which develop later into quasi-linear systems like the local Great Attractor, Shapley concentration, etc.

* For this reason, the topology of QSO density enhancements is still to be clarified, and many of our LQGs are just “objects” determined only in z-direction (see also Section 4).
Quasars may, therefore, trace enhanced matter density regions at medium and high redshifts in the same manner as galaxy groups and clusters do at \( z \sim 0 \).

The quasar two-point spatial correlation function was estimated recently by several authors (e.g., Anderson, Kunth & Sargent 1988; Iovino & Shaver 1988; Boyle et al. 1990; Iovino, Shaver & Cristiani 1991; Andreani & Cristiani 1992; Mo & Fang 1993; Komberg, Kravtsov & Lukash 1994; Shanks & Boyle 1994). At \( z \sim 1 - 2 \) it has an amplitude \( \Lambda_{q0} = \xi (r \equiv 10^{-1} \text{ Mpc}) = (r_0) \sim 60 - 70 \) with \( r_0 \sim 10^{-1} \text{ Mpc} \) and \( \gamma \sim -1.8 \) (Komberg, Kravtsov & Lukash 1994).

How, in the framework of the observational picture described above, can we relate QSOs to the underlying density field? The answer could be given if we knew the mechanism of their formation. Below, we recall some simple suggestions which can be made to describe the formation of quasars and draw relevant conclusions. A necessary condition allowing QSO fuelling in the early Universe is a high abundance of gas which can be captured in the deep potential well provided by a massive galaxy. So, from a cosmological point of view, a quasar is just a short flash (estimated AGN life-times are much less than the Hubble time) indicating the position of a massive unstable galaxy. Such a host galaxy could be young (having just formed from a galactic primordial density peak) or an older galaxy which is tidally interacting (or merging) with another galaxy of similar mass in a group and/or protocluster. The first process (generation-I QSOs) is obviously related with the epoch of galaxy formation, whereas the second one (generation-II QSOs) proceeds during the formation epoch of compact galaxy groups and subclusters. The final result of the evolution of primordial compact groups may be large elliptical galaxies which seem to reside preferentially in regions of enhanced number density of galaxies.

It is worth noting that this picture of QSO activity originating in merging galaxies is supported by recent observations of quasar host galaxies with HST (e.g., McLeod & Rieke 1995, Disney et al. 1995, and references therein) which seem to detect elliptical hosts around both radio-loud and radio-quiet quasars. We think that at high redshifts (\( z \geq 2 \)) quasars could form in primordial galaxies (e.g., Haehnelt & Rees 1993, Nusser & Silk 1993) but at medium redshifts (\( z \sim 1 - 2 \)) when the galaxy formation rate has decreased the quasar activity could be driven by mergers in young galaxy clusters and collapsing compact groups (Komberg & Lukash 1994). The observational support for this picture comes from high quasar correlations at \( z \sim 1 - 2 \) which are rather similar to those of APM galaxy clusters and groups at \( z \sim 0 \) (e.g., Bahcall & Chokshi 1993). Evidence for the high number density contrast in quasar groups presented in this paper (see Table 1) also indicates that quasars can be more clustered at \( z \sim 1 - 2 \) than ordinary galaxies.

Therefore, we may deal with two different types (generations) of quasars:

- QSOs in primeval massive galaxies:
- QSOs originating in galaxies undergoing tidal interactions/mergers (with other galaxies) in the first caustics forming in protoclusters and primeval compact groups.

In this framework, quasar correlations at \( z \geq 2 \) mirror correlations of galaxies at these redshifts, while at \( z \sim 1 - 2 \), when most of quasars may be of the second generation, they trace the underlying density field similarly to the systems they reside in (i.e. the galaxy clusters and groups). It can, for instance, explain the evolution of quasar correlation amplitude (see Iovino & Shaver 1988; Iovino, Shaver & Cristiani 1991; Mo & Fang 1993; Komberg, Kravtsov & Lukash 1994) from \( r_0 \sim 2 - 3 h^{-1} \text{ Mpc} \) at \( z \geq 2 \) up to \( r_0 \sim 10 - 13 h^{-1} \text{ Mpc} \) at \( z \sim 1 - 2 \) where most of LQGs were found.

The LQGs can, therefore, be interpreted as distant superclusters analogous to those traced by galaxy clusters which we observe in the nearby Universe (see Section 1). We will discuss below some observational tests for this point, but first we make a simple consistency estimate comparing the abundance of the detected groups of quasars with the abundance of superclusters (the groups of clusters) at \( z \sim 0 \).

The superclusters of galaxy clusters (identified using a similar clustering procedure) have been recently investigated by Einasto et al. (1994). In their list there are eight

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† The galaxy (with baryon content \( M_b \geq 10^{11} M_{\odot} \)) in a violent relaxation period of evolution when a large fraction of the gravitating gas is not rotationally supported and may infall into the galactic center dissipating radiatively and creating a dense core. The relation to star formation is still uncertain (the gas component is more important for QSO burning), and the host galaxy may even be slightly visible if stars had not yet formed in sufficient number.

‡ Note that the latter QSOs (which we call generation-II) may form only in galaxies which have lost (at least partially) their stability as a result of tidal interaction (say, when their intrinsic angular momentum is lowered) and some fraction of matter could infall into the center forming the dense bulge which then evolves into an accreting gaseous disk around a black hole.

§ Recall that our 'compact groups' are primordial objects forming in the early Universe (i.e. with small dynamical time) from density perturbation peaks with baryon content \( M_{b} \sim 10^{12} - 10^{13} M_{\odot} \); nearby observed compact groups are probably related with loose groups and are just forming at the latest epoch of the evolution of loose groups (the latter dynamical time is comparable to the Hubble time today). Also, we do not discuss here next generations of quasars related to other kinds of the environments surviving or originating at \( z \leq 0.5 \): loose groups of galaxies creating small-z radio-quiet QSOs distributed like Seyferts, and cD-like galaxies in X-ray clusters creating radio-loud QSOs.

¶ In models with steep (CDM-like) spectra of primordial density perturbations galaxies form rather similar to those of APM galaxy clusters and groups at \( z \sim 0 \). The QSO perturbation spectrum. 

†† In models with steep (CDM-like) spectra of primordial density perturbations galaxies form rather late and, therefore, the generation-I quasars predominate. However, the generation-II quasars become more important in models with extra-power for the perturbations on supercluster scale. Certainly, both effects of QSO formation (primordial and merging galaxies) contribute differently at different redshifts, so, the result (QSO spatial distributions, correlations, etc.) should be very sensitive to the density perturbation spectrum.

†‡ We should note, however, that most of the detected LQGs come from catalogs with selection function dropping rapidly at \( z > 2.5 \). Because of that it is yet unclear whether such groups could be present at higher redshifts and how much their redshift distribution could differ from the distribution of quasars. So, our finding that LQG abundance for a given survey decays faster beyond \( z > 2 \) than the QSO abundance, should be tested using the better data in future.
rich (consisting of more than 10 clusters) superclusters residing in a volume ~ \(5.7 \times 10^7 h^{-3} \text{Mpc}^3\). The spatial number density of superclusters is then \(n_{\text{SCL}} \sim 1.4 \times 10^{-3} h^3 \text{Mpc}^{-3}\). Now, we can estimate the number of LQGs expected in a given survey assuming that the comoving densities coincide \(n_{\text{LQG}} \sim n_{\text{SCL}}\), as follows:

\[
N_{\text{LQG}} \sim \frac{1}{3} n_{\text{SCL}} \Omega (r(z_{\text{max}}) - r(z_{\text{min}})),
\]

where \(\Omega\) is a surveyed area in steradians; \((z_{\text{min}}, z_{\text{max}})\) is the redshift interval of a survey, and \(r(z)\) is comoving distance. For the BFSP, CCH, and OH surveys the expected number of LQGs is \(N_{\text{LQG}} \sim 3, 2, 3\) respectively, while in these surveys we have found 4 (LQG 3, 4, 5, 12), 2 (LQG 9, 10), and 3 (LQG 6, 7, 8) groups of quasars. The agreement shows that the assumption \(n_{\text{LQG}} \sim n_{\text{SCL}}\) is indeed plausible.

The idea that quasar groups are basically similar to nearby superclusters implies that in the regions occupied by LQGs there are minima of the gravitational potential and thus the LQG regions are distant great attractors (Komberg & Lukash 1994). The latter, by definition, are regions of enhanced total density with scales ranging from the richest cluster size, \(l_D \sim 10 - 15h^{-1}\text{Mpc}\) (the largest dynamical scale of collapsing objects) up to \(l_{\text{LS}} \sim 100 - 150h^{-1}\text{Mpc}\) (the scale of the largest observed structures in galaxy distribution). Attractor-like structures are generally expanding in the quasi-linear regime, which distinguishes them markedly from objects collapsing in at least one direction (such as galaxy clusters, filaments, and walls). The idea that groups of clusters trace mass enhancements is backed by peculiar velocity measurements: in terms of clusters the local Great Attractor is a modest concentration (six Abell-like clusters), and similar cluster clumps are common at larger distances. We can, therefore, conclude that distant attractors may also be associated with concentrations of protoclusters (presuperclusters) and hence with large quasar groups. Of course, this hypothesis needs further observational verification. Let us briefly discuss some possible observational tests.

A search for absorption systems in quasar spectra seems to be one of the most plausible tests for this purpose. Searching for absorption lines at the redshift of identified LQGs lying on the line of sight of background quasars, would test the presence of superclusters (revealed by possible absorption lines) at these redshifts. An example of such an investigation is the analysis of CIV absorption systems in the spectra of close quasar pairs (separation ~ 18 arcmin) made by Jakobsen & Perryman (1992). Nine additional QSOs were found in the same field and a search for absorption features was carried out. It was suggested that an intervening supercluster may be responsible for the various absorption redshift matches. Further support for the supercluster hypothesis comes from the fact that both the neighbouring quasars and the absorption lines at the same redshifts appear to lie within a 40–50h\(^{-1}\)\text{Mpc} wide, thick slab and the geometry of the spatial distribution of both quasars and absorption systems is rather similar. So, probing high redshift QSO spectra for possible absorption at LQG redshift may support (or on the contrary exclude) the hypothesis that quasars are associated with superclusters. Such investigations may provide information about true sizes and shapes of the underlying superclusters as well.

The imaging of the sky areas in which quasar groups were found may allow direct measurement of the excess of galaxies as compared to control fields. Such investigations were started in the region of the CCH group (Hutchings, Crampton & Persram 1993; Hutchings, Crampton & Johnson 1994). Deep images of fields around 14 QSOs with narrow-band filters chosen to detect galaxies near the quasar redshift were obtained (the radius of the fields was \(\sim 100\) arcseconds, corresponding to \(\sim 3 - 5h^{-1}\text{Mpc}\) at \(z \sim 1\)). Nine of the 14 QSOs are from the CCH group (LQG 10). A strong 2-4\(\sigma\) excess of faint and blue galaxies associated with CCH QSOs has been found around seven of them while the other two seem to reside in sparse groups of galaxies. We think that this encouraging result should be supported by further observations of other fields.

Finally, we would like to emphasize that since the excess of faint blue galaxies in distant \((z \gtrsim 0.5)\) galaxy clusters (the Butcher-Oemler effect) is related to the formation and merging of galaxies, we can expect an excess of faint blue galaxies in both proto- and super-clusters associated with our LQGs.

### 5 CONCLUSIONS

The main results of the paper are as follows:

We have identified 12 large quasar groups which meet our selection criteria and consist mostly of quasars coming from deep homogeneous surveys. The number of quasars in each group is larger than ten and the quasar number density excess over the background is larger than a factor of two. The group sizes range from 70 to 160h\(^{-1}\)\text{Mpc}. The quasar group found earlier by Crampton, Cowley & Hartwick (1989) was identified in our analysis as well.

For ten of these groups we have estimated the probability that they are random enhancements and found that it is small (usually a few per cent, see Table 2). This analysis is based only on homogeneous surveys from which the given groups originate.

We thus present further evidence for large-scale structures in the quasar distribution of typical size \(\sim 100h^{-1}\text{Mpc}\). We show that the spatial density of the detected quasar groups coincides with the number density of nearby superclusters, and argue that LQGs may indicate the sites of enhanced matter density at medium and high redshifts (Komberg & Lukash 1994). We thus conclude that quasars at \(z \gtrsim 0.5\) may trace underlying large-scale structures in matter distribution as galaxy clusters and groups do at \(z \sim 0\). If this is true, more power of the primordial density perturbation field will be required at scale \(l_{\text{LS}} \sim 100h^{-1}\text{Mpc}\) (the ‘blue bump’) than is usually assumed from galaxy and cluster distributions at \(z \sim 0\).

To summarize, we can say that the present evidence for large-scale structures extending over the wide range of redshifts \(z \sim 0.5 - 2\) and the hypothesis that quasars in groups are associated with young galaxy clusters, although far from being conclusive, allows for various verifications via both theory and observations and may fuel further detailed investigations on this subject.
6 ACKNOWLEDGMENTS

We would like to thank the staff of the theoretical division of the Astro Space Center for productive discussions; Angela Iovino for suggesting the way to estimate empirical probability for a group to be random and for valuable discussions; the referee, David Crampton, for useful comments; Neal Miller for the help in improving the presentation of the paper; and Elena Mikheeva for the help in preparation of the manuscript. This work was partly supported by Russian Foundation for Fundamental Research (93-02-2929), International Science Foundation (MEZ300), and COSMION (cosmomicrophysics). V.N.L. would also like to thank the German Science Foundation for financial support during a one-month-stay in AIP (Potsdam) where the paper has been completed.

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Table 1. Large quasar groups found in our search. Coordinates of quasars are given as they are in the catalogue. The parameters are comoving sizes of a group in megaparsecs and approximate quasar number density contrast (see Section 3 for details).

| LQG 1         | R.A. | Decl. | Redshift | Parameters | R.A. | Decl. | Redshift | Parameters |
|---------------|------|-------|----------|------------|------|-------|----------|------------|
| 00 40 33.2    | -30 24 08 | 0.609 | $R_\alpha = 102$ | 00 49 37.9 | -29 08 38 | 1.855 | $R_\Delta = 46$ |
| 00 40 46.3    | -29 19 40 | 0.624 | $R_\beta = 42$ | 00 49 42.1 | -29 34 08 | 1.868 | $R_\Delta = 60$ |
| 00 46 18.0    | -29 34 01 | 0.632 | $R_\delta = 96$ | 00 49 46.2 | -29 21 40 | 1.856 | $R_\Delta = 104$ |
| 00 49 42.3    | -28 40 27 | 0.639 | $\Delta N/N \sim 1$ | 00 49 47.8 | -29 35 26 | 1.920 | $\Delta N/N \sim 1$ |
| 00 52 18.0    | -28 47 34 | 0.639 | $R_\delta = 42$ | 00 50 28.6 | -30 01 01 | 1.922 |
| 00 52 51.4    | -28 53 24 | 0.634 | $R_\alpha = 84$ | 00 51 17.6 | -28 55 10 | 1.94 |
| 00 55 38.5    | -28 28 23 | 0.648 | $R_\delta = 102$ | 00 50 12.9 | -29 07 30 | 1.976 |
| 00 57 01.9    | -29 35 45 | 0.662 | $R_\delta = 57$ | 00 51 51.4 | -29 18 34 | 1.987 |
| 00 59 10.6    | -28 53 37 | 0.62 | $R_\alpha = 96$ | 00 53 18.2 | -28 40 23 | 1.964 |
| 00 55 43.3    | -29 48 59 | 0.668 | $R_\alpha = 42$ | 00 53 30.9 | -28 36 26 | 1.920 |
| 00 52 40.9    | -28 56 48 | 0.602 | $R_\alpha = 102$ | 00 53 37.0 | -28 43 11 | 1.933 |
| 00 49 27.5    | -29 31 18 | 0.601 | $R_\delta = 42$ | 00 53 19.5 | -29 21 51 | 2.029 |
| LQG 2         | 00 41 24.2 | -28 44 06 | 0.839 | $R_\alpha = 84$ | 00 54 33.1 | -29 34 04 | 2.01 |
|               | 00 46 2.4  | -29 04 53 | 0.84 | $R_\delta = 39$ | LQG 5 |
| 00 48 47.0    | -28 04 19 | 0.840 | $R_\delta = 111$ | 03 35 52.7 | -44 06 54 | 1.679 | $R_\Delta = 45$ |
| 00 50 28.2    | -29 07 42 | 0.852 | $\Delta N/N \sim 1$ | 03 37 37.6 | -44 21 29 | 1.661 | $R_\Delta = 49$ |
| 00 50 36.9    | -29 29 13 | 0.830 | $R_\alpha = 111$ | 03 37 06.4 | -44 11 54 | 1.690 | $R_\Delta = 146$ |
| 00 48 22.5    | -27 59 40 | 0.87 | $R_\delta = 39$ | 03 41 32.7 | -44 58 14 | 1.662 | $\Delta N/N \sim 1$ |
| 00 52 44.5    | -29 02 31 | 0.84 | $R_\delta = 42$ | 03 41 50.7 | -45 17 41 | 1.615 |
| 00 56 12.5    | -28 43 26 | 0.828 | $R_\delta = 42$ | 03 42 13.5 | -45 03 04 | 1.700 |
| 00 54 22.5    | -28 10 27 | 0.80 | $R_\delta = 42$ | 03 39 48.1 | -44 52 00 | 1.745 |
| 00 52 33.8    | -28 30 45 | 0.779 | $R_\delta = 42$ | 03 38 06.1 | -44 18 32 | 1.762 |
| 00 46 50.7    | -29 14 40 | 0.781 | $R_\delta = 42$ | 03 38 06.1 | -44 22 12 | 1.733 |
| 00 48 24.2    | -29 01 46 | 0.783 | $R_\delta = 42$ | 03 39 22.9 | -44 16 54 | 1.764 |
| LQG 3         | 00 48 08.1 | -28 18 45 | 1.322 | $R_\alpha = 67$ | 03 40 15.8 | -44 26 08 | 1.792 |
|               | 00 50 24.1 | -28 17 39 | 1.331 | $R_\delta = 57$ | 03 42 07.2 | -44 56 18 | 1.827 |
| 00 50 28.3    | -27 47 29 | 1.355 | $R_\alpha = 123$ | LQG 6 |
| 00 51 39.5    | -28 46 47 | 1.338 | $\Delta N/N \sim 1$ | 12 07 34.1 | -11 00 32 | 1.555 | $R_\Delta = 88$ |
| 00 53 33.8    | -28 36 49 | 1.306 | $R_\alpha = 123$ | 12 07 44.8 | -11 01 17 | 1.592 | $R_\Delta = 16$ |
| 00 53 15.2    | -29 24 41 | 1.331 | $R_\alpha = 123$ | 12 08 40.9 | -11 10 16 | 1.571 | $R_\Delta = 94$ |
| 00 53 35.0    | -29 22 47 | 1.303 | $R_\alpha = 123$ | 12 12 11.5 | -10 56 33 | 1.626 | $\Delta N/N \sim 4$ |
| 00 55 42.9    | -28 50 11 | 1.276 | $R_\alpha = 123$ | 12 12 59.1 | -10 50 34 | 1.590 |
| 00 56 34.5    | -29 05 30 | 1.341 | $R_\alpha = 123$ | 12 14 37.1 | -10 45 10 | 1.535 |
| 00 56 51.8    | -29 01 46 | 1.281 | $R_\alpha = 123$ | 12 15 02.1 | -11 03 38 | 1.498 |
| 00 56 20.8    | -29 15 34 | 1.255 | $R_\alpha = 123$ | 12 16 23.1 | -11 00 17 | 1.551 |
| 00 55 15.2    | -28 39 22 | 1.366 | $R_\alpha = 123$ | 12 16 38.6 | -11 04 51 | 1.538 |
| 00 55 19.1    | -28 52 38 | 1.388 | $R_\alpha = 123$ | 12 16 50.9 | -10 48 07 | 1.505 |
| 00 56 50.7    | -29 21 49 | 1.40 | $R_\alpha = 123$ |
Table 1.  

| R.A.  | Decl. | Redshift | Parameters | R.A.  | Decl. | Redshift | Parameters |
|-------|-------|----------|------------|-------|-------|----------|------------|
| LQG 7 |
| 12 23 31.3 | -10 51.13 | 1.872 | $R_\alpha = 101$ | 13 36 50.7 | 28 20 38 | 1.113 |
| 12 23 31.9 | -11 13 41 | 1.828 | $R_\beta = 24$ | 13 36 47.8 | 28 23 41 | 1.124 |
| 12 24 55.8 | -11 04 16 | 1.883 | $R_\delta = 92$ | 13 37 26.7 | 27 26 11 | 1.120 |
| 12 26 37.0 | -11 05 56 | 1.900 | $\Delta N/N \sim 1$ | 13 38 01.2 | 27 35 50 | 1.140 |
| 12 27 36.0 | -10 51 56 | 1.960 | $\Delta N/N \sim 1$ | 13 38 21.4 | 27 36 00 | 1.139 |
| 12 29 25.8 | -10 52 42 | 1.904 | $\Delta N/N \sim 1$ | 13 35 15.3 | 26 51 08 | 1.096 |
| 12 24 49.6 | -11 16 59 | 1.979 | $\Delta N/N \sim 1$ | 13 39 25.2 | 27 33 24 | 1.095 |
| 12 30 23.7 | -10 43 25 | 1.934 | $\Delta N/N \sim 1$ | 13 38 41.4 | 27 40 26 | 1.175 |
| 12 33 01.6 | -10 57 40 | 1.884 | $\Delta N/N \sim 1$ | 13 33 59.9 | 27 02 54 | 1.068 |
| 12 16 1.6 | -10 47 43 | 2.119 | $\Delta N/N \sim 2$ | 13 37 50.1 | 27 11 41 | 1.205 |
| 12 17 59.2 | -10 55 23 | 2.092 | $\Delta N/N \sim 2$ | 13 39 31.6 | 27 38 47 | 1.056 |
| 12 19 31.2 | -11 13 35 | 2.194 | $\Delta N/N \sim 2$ | 13 36 57.5 | 27 43 27 | 1.047 |
| 12 21 32.2 | -10 51 24 | 2.191 | $\Delta N/N \sim 2$ | 13 39 47.0 | 27 56 45 | 1.036 |
| 12 24 35.4 | -10 54 67 | 2.142 | $\Delta N/N \sim 2$ | 13 39 59.5 | 26 58 06 | 1.053 |
| 12 18 0.6 | -11 02 11 | 2.192 | $\Delta N/N \sim 2$ | 13 40 36.4 | 28 43 10 | 1.037 |
| 12 18 35.4 | -10 48 40 | 2.241 | LQG 11 |
| 12 25 3.0 | -10 48 15 | 2.242 | 21 54 12.1 | -18 28 04 | 0.668 |
| 12 16 14.0 | -10 46 54 | 2.275 | 21 58 00.0 | -18 54 00 | 0.7 |
| 12 24 35.2 | -11 07 07 | 2.290 | 21 58 14.2 | -18 55 48 | 0.687 |
| 12 18 0.6 | -11 02 11 | 2.192 | 13 40 36.4 | 28 43 10 | 1.037 |
| 12 18 35.4 | -10 48 40 | 2.241 | LQG 11 |
| 13 32 23.9 | 27 34 14 | 1.866 | $R_\alpha = 88$ | 21 56 15.8 | -19 29 36 | 0.725 |
| 13 33 34.8 | 28 08 36 | 1.886 | $R_\beta = 134$ | 21 59 30.7 | -19 31 46 | 0.728 |
| 13 33 54.2 | 28 40 16 | 1.908 | $R_\delta = 66$ | 22 06 14.8 | -20 19 03 | 0.682 |
| 13 34 54.4 | 27 28 01 | 1.909 | $\Delta N/N \sim 1$ | 22 03 30.1 | -19 20 01 | 0.649 |
| 13 35 19.0 | 28 29 02 | 1.865 | LQG 9 |
| 13 34 03.2 | 27 22 32 | 1.931 | 22 03 01.7 | -18 46 26 | 0.626 |
| 13 34 30.4 | 27 36 04 | 1.95 | 22 03 25.8 | -18 50 17 | 0.619 |
| 13 35 24.8 | 27 16 46 | 1.928 | LQG 12 |
| 13 36 38.4 | 27 27 03 | 1.922 | 21 57 16.6 | -19 40 10 | 1.206 |
| 13 33 39.7 | 26 43 45 | 1.936 | 21 57 21.8 | -20 00 11 | 1.198 |
| 13 33 29.9 | 26 17 59 | 1.899 | 21 58 29.9 | -19 03 01 | 1.240 |
| 13 33 42.0 | 26 17 47 | 1.926 | 21 59 23.9 | -19 26 17 | 1.170 |
| 13 34 41.7 | 26 14 33 | 1.876 | 22 00 35.6 | -19 29 37 | 1.165 |
| 13 36 17.2 | 25 31 56 | 1.88 | 22 00 50.5 | -19 49 40 | 1.168 |
| 13 36 36.5 | 26 48 58 | 1.868 | 22 00 28.8 | -19 52 24 | 1.277 |
| 13 38 17.6 | 25 51 28 | 1.877 | 22 00 44.5 | -18 49 31 | 1.288 |
| 13 38 23.3 | 26 37 05 | 1.841 | 22 00 54.5 | -19 58 21 | 1.260 |
| 13 41 30.9 | 25 39 47 | 1.896 | 21 57 46.5 | -19 34 51 | 1.142 |
| 13 35 20.3 | 28 20 19 | 1.095 | $R_\alpha = 51$ | 22 03 15.6 | -18 36 30 | 1.179 |
| 13 33 51.1 | 27 43 04 | 1.116 | $R_\beta = 59$ | 22 01 59.6 | -19 05 29 | 1.121 |
| 13 35 06.7 | 27 51 53 | 1.121 | $R_\delta = 164$ | 22 05 59.3 | -19 40 14 | 1.280 |
| 13 35 20.1 | 28 19 59 | 1.124 | $\Delta N/N \sim 2$ | 22 00 35.6 | -19 29 37 | 1.165 |
| 13 35 48.4 | 28 20 23 | 1.086 |
| 13 36 10.5 | 28 18 10 | 1.116 |
Table 2. Summary of LQG analysis.

| Group | Number of QSOs | $z$ | $R_z$, $h^{-1}\text{Mpc}$ | Density, $\rho$, $10^{-5}h^3\text{Mpc}^{-3}$ | Probability to be random |
|-------|----------------|----|---------------------------|---------------------------------|------------------------|
| LQG 1 | 12             | 0.6| 96                        | 3.3                             | –                      |
| LQG 2 | 12             | 0.8| 111                       | 3.3                             | –                      |
| LQG 3 | 14             | 1.3| 123                       | 3.0                             | 0.02                   |
| LQG 4 | 14             | 1.9| 104                       | 4.9                             | $< 10^{-3}$            |
| LQG 5 | 13             | 1.7| 146                       | 4.0                             | 0.03                   |
| LQG 6 | 10             | 1.5| 94                        | 7.6                             | 0.01                   |
| LQG 7 | 10             | 1.9| 92                        | 4.6                             | 0.19                   |
| LQG 8 | 12             | 2.1| 104                       | 5.7                             | 0.05                   |
| LQG 9 | 18             | 1.9| 66                        | 2.3                             | 0.02                   |
| LQG 10| 25             | 1.1| 164                       | 5.1                             | $< 10^{-3}$            |
| LQG 11| 11             | 0.7| 157                       | 2.4                             | 0.05                   |
| LQG 12| 14             | 1.2| 155                       | 3.0                             | 0.01                   |
| CC-group | 13         | 1.3| 154                       | 0.5                             | 0.03                   |