ASSOCIATION OF QUASARS AND SUPERCLUSTERS

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Abstract

The evidence for association is still indirect. None of the optically found superclusters or clusters contains a quasar. This is a natural consequence of the low quasar space density at the present epoch. For finding quasars in superclusters we should go to distances where superclustering of galaxies cannot yet be observed, and where we should look for clustering among the quasars themselves. The factors restricting such a search are discussed on the basis of what we know about the characteristics of superclusters and of the evolution of quasars. The preliminary result is that it may be possible to observe superclustering in quasar surveys going down to the 21st magnitude; however, redshifts will be required.

At present two dense concentrations have been established with some confidence: (a) a superstructure at z = 0.37 containing four quasars within a diameter of about 140 Mpc (assuming a Hubble constant of 50), and (b) a group of three distant quasars near M82 within a region of 0.2 Mpc and having redshifts between 2.040 and 2.054. These are probably part of a dense cluster. In addition a number of pairs of quasars with spatial separations between about 2 and about 50 Mpc have been noted which may be physically associated, and, if so, would indicate that they lie in clusters or superclusters.

Evidence has gradually been accumulating that a major fraction of galaxy clusters and of galaxies - possibly all of them - are concentrated in large structures, with still larger practically empty regions in between. It is therefore probable that quasars would likewise be concentrated in these structures. If so, redshift surveys of quasars might yield very interesting information on the existence and evolution of supercluster structure at epochs when quasars and radio galaxies are the only objects that can be observed.

Direct evidence for association of quasars with superclusters is almost non-existent. This is because the present space density of quasars is so low. According to Schmidt & Green (1983) it is about 26 per Gpc^3 for quasars with $M_B < -23.0$, and about 3 for those with $M_B < -24.0$; this is for an Einstein-de Sitter Universe ($q_o = 0.5$) with a Hubble constant of 50 km s^{-1} Mpc^{-1} which will be used throughout

this article. The average number of quasars within a supercluster of diameter 100 Mpc, and an estimated overdensity f by a factor of 10, would therefore be roughly 0.1 for $M_B < -23.0$, and 0.01 for those with $M_B < -24.0$. Therefore one would not expect to find many superclusters containing quasars among the relatively nearby galaxies surveyed up to the present. However, at a redshift of 2.5 circumstances would be rather different. According to Schmidt & Green (1983, Figure 4) the density of quasars of $M_B = -23.5$ in a comoving volume would be roughly 100 times - that of quasars with $M_B = 24.5$ roughly 1000 times - higher than at z = 0. Supposing that the number of superclusters per Gpc^3 would have been the same as at z = 0 a supercluster similar to that considered above might contain about ten quasars per magnitude interval between $M_B = -23$ and -28.

For a proper investigation of superclustering among quasars extensive surveys of faint quasars, including redshifts, are a first requirement.

Before considering the possible appearances of superclustering among distant quasars it is desirable to be informed about the principal characteristics of known superclusters (cf. a review by Oort 1983). The most complete material available concerning the general phenomenon of superclustering is that collected by Davis et al (1982) at the Harvard-Smithsonian Center for Astrophysics (CfA). The data have not yet been fully analyzed, but I estimate from their diagrams that the density of structures which I would consider to be superclusters might correspond to about 3600 superclusters per Gpc^3. These are average-size specimens.

Another more or less complete survey of superclusters has recently been made by Neta Bahcall & Raymond Soneira (1983). Using Abell's so-called "homogeneous sample" they studied the space distribution of clusters of richness class 1 and larger, and distance class 1 to 4. For essentially all of the 104 clusters in Bahcall & Soneira's list redshifts are available. The data extend over 4.26 ster and are complete to a distance of 480 Mpc. Within this volume of 0.157 Gpc^3 the authors find 16 regions with an excess cluster space density of a factor f > 20; they present evidence that most of these regions contain an actual supercluster (Figure 1).

Judged by the number of Abell clusters contained in the Bahcall & Soneira (NBS) structures, these are considerably more powerful than the average supercluster observed in the CfA survey. While the NBS agglomerations contain an average of 3.5 rich clusters, and about 7 if the clusters of richness class 0 are added, most of the superclusters which may be identified in the CfA survey do not contain any. Their average cluster content may be estimated from the volume density of clusters in Abell's "homogeneous sample". This is roughly 1100 per Gpc^3. If all of them would lie in superclusters a comparison with the 3600 superclusters per Gpc^3 estimated above yields an average of 0.3 Abell clusters per supercluster, i.e., about 20 times less than for the NBS sample.

In the following I refer to these latter as "giant" superclusters. There are 102 per Gpc^3; they are thus about 35 times scarcer than the superclusters in the

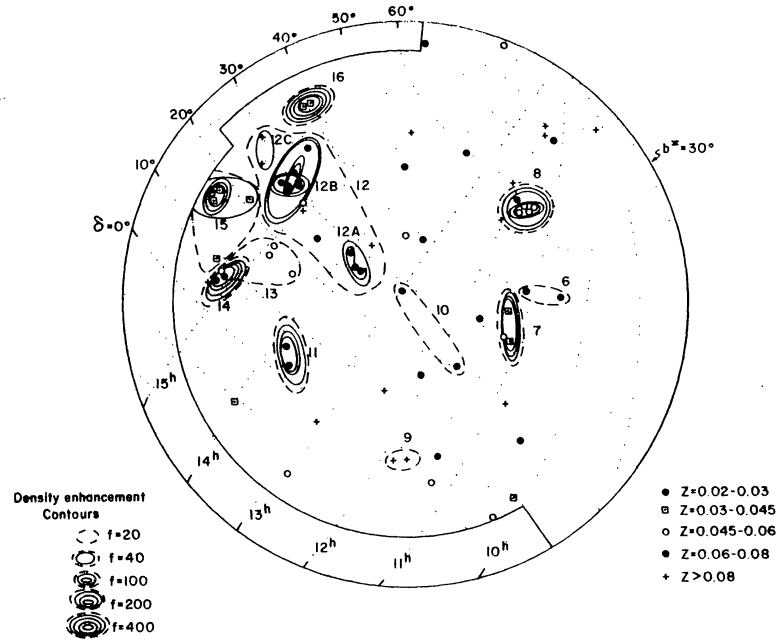

Figure 1. Giant superclusters in the North galactic hemisphere above 30° latitude. The outermost contour is b = 30°; the inner contour is the completeness limit of the sample. Small contours show the space density enhancement factor over the mean space density at the distance of the supercluster. Numbers refer to the authors' list of superclusters. The elongated contour number 10 is the Coma supercluster.
Reproduced by courtesy of Neta Bahcall & Raymond Soneira (1983).

CfA survey. Notwithstanding their large sizes (average diameters of the f = 20 contours are 75 x 35 Mpc) they occupy only a fraction of 3% of space.

Especially interesting in Figure 1 are nr. 12, which has a diameter of 360 Mpc, and the "nest" of superclusters around it. Interesting is likewise an apparent void of 100° diameter (600 Mpc) across the sky and 300 Mpc deep in which no rich clusters exist (Bahcall & Soneira 1982).

What are the possibilities of finding superclusters among distant quasars? Consider quasars with redshifts between 2.0 and 3.0. As an example I refer to the data contained in the article by Schmidt & Green (1983). Taking the mean of their tables 10 and 11 (models with $q_o = 0.5$) the number of quasars brighter than B = 21 between z = 2.0 and 3.0 is 19 per square degree.

The comoving volume between z = 2.0 and 3.0 is roughly 360 Gpc^3. If the number of superclusters per comoving Gpc^3 has remained constant, there would have been 102 x 360 = 37 000 giant superclusters in this range, corresponding to 0.9 per square degree. The number of smaller superclusters per square degree would be roughly 30. On the basis of the mean relative number of Abell clusters in the two categories of

superclusters about half of the quasars might lie in the giant superclusters, and the other half in the smaller ones. In these latter the average number of quasars would thus be estimated at 0.3 per supercluster, which would preclude their discovery. Each giant supercluster, on the other hand, might contain about 10 quasars, and might well be discoverable. This is on the hypothesis that all quasars lie in superclusters.

If the superclusters had expanded with the universe the average angular diameter of the giant superclusters at z = 2.5 would have been $0^{\circ}.8 \times 0^{\circ}.4$. In reality their expansion will have been less than that of the universe, so that the diameters at z = 2.5 will have been larger, but we do not know how much. The chances for discovering superclusters might improve if the observations were extended to fainter magnitudes. According to the Schmidt-Green tables the numbers of quasars increase by a factor of 2.5 if the limiting B-magnitude is 22.0. In this case there would be a reasonable possibility for finding out whether superclusters were as frequent at z $\sim$ 2.5 as at present, and for studying properties of superclusters at this early time. But, clearly, such a search for superclusters would be a very difficult undertaking.

For the present we have to rely on chance discoveries of clustering among quasars. Two dense concentrations of quasars have been established with some confidence:

(a) a superstructure at z = 0.37 containing four quasars within a diameter of about 140 Mpc (assuming a Hubble constant of 50) (Oort et al 1981; Webster 1982), and

(b) a group of three distant quasars near M82 within a region of 0.2 Mpc and having redshifts between 2.040 and 2.054. They are probably part of a dense cluster (Burbidge 1980), and are particularly important in showing that clusters existed already at z = 2.05.

Beside these two structures half a dozen pairs of quasars with spatial separations between 2 and 50 Mpc have been noted which may be physically associated, and, if so, would indicate that they lie in superclusters (Oort et al 1981). The most interesting probable case is that of the 19^{m} pair 0143-016/0144-010 at z = 3.14/3.16, separation $0^{\circ}.54$ (13 Mpc).

An extensive general discussion of the problem of clustering among quasars has been given by Woltjer & Setti (1982).

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DISCUSSION (PAPER 46)

J. SURDEJ - In our survey (Arp, Gosset, Henry, Swings and Surdej) of QSO candidates in the field of NGC 450, we have found three quasars with z=0.95, two of which are separated by about 77" and the third one, a few degrees further.

P.A. WEHINGER - In our deep photographs of quasar fields in the search for quasar nebulosity (Wyckoff, Wehinger and Gehren, 1981, Ap. J. 247, 750) we see a clustering of diffuse objects, i.e. probable cluster galaxies in the vicinity of the quasars in the redshift range, z=0.2 to 0.6. Some ten to twenty cluster galaxies (a few of which have measured z's) are found around some of our survey objects, e.g. PHL 1093 (z=0.26), PKS 0812+020 (z=0.40) and 3C 205 (z=0.20).