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INTERPRETATION OF COSMOLOGICAL INFORMATION ON RADIO SOURCES

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INTERPRETATION OF COSMOLOGICAL INFORMATION ON RADIO SOURCES

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The topic that I have to introduce today is concerned with the question as to whether or not we can obtain any cosmological information from radio astronomy. Alternatively, we may ask "Where does radio astronomy have an impact on cosmology?" There are several areas that must be discussed. They are:

1) The discovery and interpretation of the microwave background radiation.
2) The identification of powerful radio sources and the discovery that many of them have large redshifts. If we can prove that the large redshifts mean that the objects are at great distances, then we can use these radio sources as follows:
    (a) We can attempt to obtain a Hubble relation for the optical objects which are identified with radio galaxies;
    (b) We can look for a relation between the angular diameters of the radio sources and the redshifts of the optically identified objects and we can also look at relations between the angular diameter and the radio flux;
    (c) We can construct log N - log S curves and we can carry out luminosity volume tests.

Let us introduce each of these investigations in turn.

First we briefly discuss the microwave background radiation. There is very little doubt in anyone's mind at this time but that this radiation did arise early in the history of the universe, and it is the one piece of cosmological evidence which shows unambiguously that the universe has evolved. The recent observations which show fairly clearly that the radiation is of blackbody form are extremely important in this connection. There is little controversy about this

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situation, and thus this is all that I shall say about cosmological information which can be derived from the microwave background radiation.

I now turn to the many problems which are involved in category 2. Let us first consider the identification of radio sources and objects with large redshifts. We know with some confidence that redshifts are measures of distance for galaxies of stars. More precisely, if z_c is the cosmological redshift, z_i and z_r the intrinsic redshift and redshift due to random motion, and z_{obs} is the observed redshift, then

$$(1 + z_{obs}) = (1 + z_c)\,(1 + z_i)\,(1 + z_r)$$

For normal galaxies we know from the form of the Hubble relation that z_c is $\gg z_i$, and that z_c is $\gg z_r$. However, it has not been proved that this is true for any other class of object.

What are the classes of objects which are identified with radio sources? They fall into four categories, viz, elliptical galaxies, N systems, QSOs, and BL Lac objects.

What has really been proved about the redshifts of these different classes of objects? For the normal, genuine elliptical galaxies the work that has been carried out over the past thirty or forty years by Hubble, Humason, Sandage, and their colleagues leads us to suppose, with a large degree of confidence, that these redshifts are measures of distance, though I would add that this has never been proved. However, the fact that we have a Hubble relation is strong evidence in this direction.

When we come to the N systems, already there are problems. For the majority of these, the morphological classification is strongly correlated with the spectrum. Thus these very compact objects with small diffuse halos around them nearly always show, when they are identified with strong radio sources, strong, broad emission lines in their spectra, together with a continuum which is not of stellar origin. This continuum presumably arises both from hot gas and is in part non-thermal in origin. An exception to this is the case of 3C 371 which certainly does show a strong stellar component. However, it is the anomalous case among a very large number of N systems identified as powerful radio sources. Where stars can be found and the redshift can be obtained from the stellar absorption lines and it is found to be the same as that obtained from the emission lines, it is reasonable to suppose that the redshift is of cosmological origin. The difficulty (to some people) and the intriguing possibility (to others) is that for the majority of these objects with large redshifts no stellar component has yet been found. This being the case, we can argue in one of two directions:

(a) We can suppose that there is a stellar galaxy underlying the object that we can see, and that it has a redshift which is the same as the redshift obtained from the strong emission lines. We can then attempt to show that the energy distribution observed is consistent with the sum of the two or three components and attempt to obtain a Hubble relation. This is the method that was originally used by Sandage in 1971. Most investigators like this idea and use it. However, it is ambiguous and it can do no more than establish consistency with the cosmological hypothesis.

(b) The alternative possibility is that such systems are not galaxies at all, but objects of quite a different type, with redshifts which are not of cosmological origin. Evidence in favor of this hypothesis is the possible periodicity in the redshifts of the N systems, and the fact that it is in some of these objects, e.g., 3C 120, where problems such as the apparent relativistic expansion speeds are encountered if the distances are obtained from the redshifts. Of course, this latter problem disappears if the objects are much closer than the distances obtained from their redshifts.

The third class of objects identified with powerful radio sources are the quasi-stellar objects. In Figs. 1, 2, and 3 you see plots made from a new catalogue of QSOs of the redshift-magnitude diagram, the apparent magnitude distribution, and the U-B against B-V plot. You all know that the nature and the distances of these objects have been under discussion for many years. All the arguments are well known. Almost every year a claim is made that proof of cosmological redshifts has been obtained, but in my view these arguments rarely, if ever, hold up. At the same time evidence suggesting that some redshifts are of non-cosmological origin also appears very frequently but is disregarded by most astronomers. There is evidence of some statistical weight that a few of the QSOs are associated with galaxies at the same redshift, but there is evidence of higher statistical weight that some are associated with galaxies with much smaller redshifts. There is a good correlation between the angular separations of pairs of QSOs and galaxies with the distances of the galaxies which Bolton has mentioned here. There is a new case of 3C 303, where in one of the radio lobes of the radio source which is identified with an N system with $z = 0.14$, there are three compact objects, one of which is a QSO with $z = 1.57$. There are close pairs of QSOs with different redshifts, etc. Most of this evidence is in favor of non-cosmological

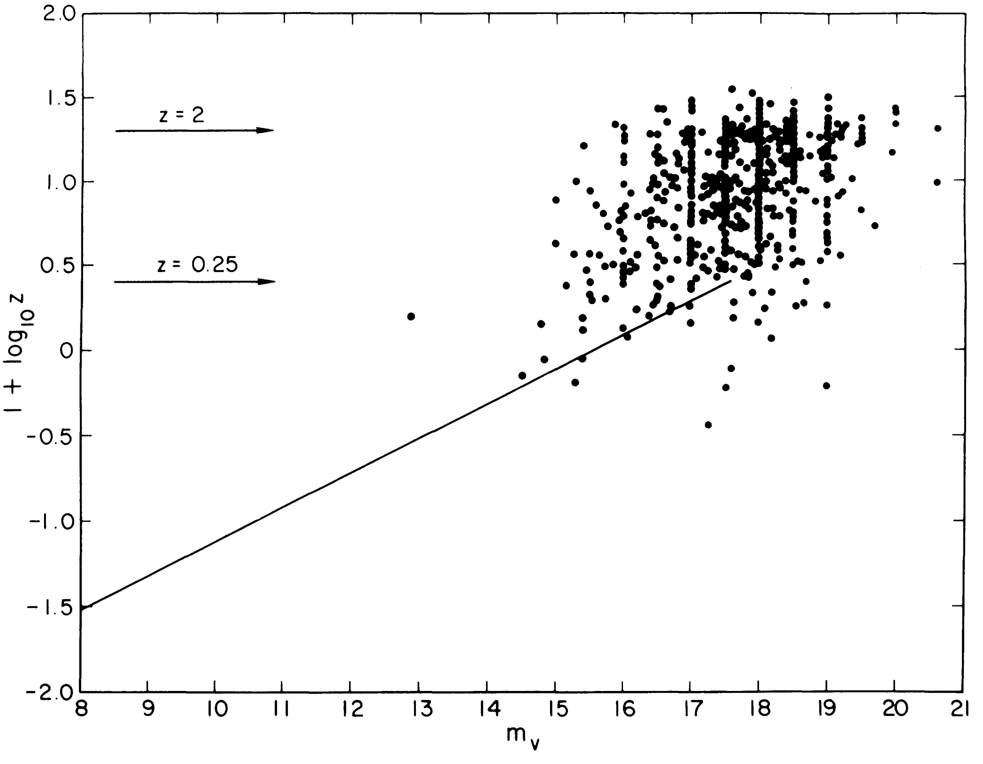

Fig. 1. Redshift-apparent magnitude diagram for 570 QSOs taken from the catalogue of Burbidge, Crowne, and Smith (Ap. J. Supplement, February 1977).

redshifts, but it is either ignored, treated as accidental, or if people begin to take it seriously they consider it "worrying."

Kristian attempted to argue that the fuzz around QSOs was consistent with the idea that they were embedded in galaxies at different redshifts. However, attempts to investigate the fuzz directly have shown so far that it is not due to galaxies in the cases of 3C 48 and 4C 37.42. It appears to me that the burden of proof that galaxies are present still rests on those who would like to make that assumption.

Various continuity arguments have been put forward in favor of the cosmological redshift hypothesis. For example, at this meeting much has been made of the angular diameter - z relation, and it has been tacitly assumed that z is a measure of distance. In general, continuity arguments can be taken both ways.

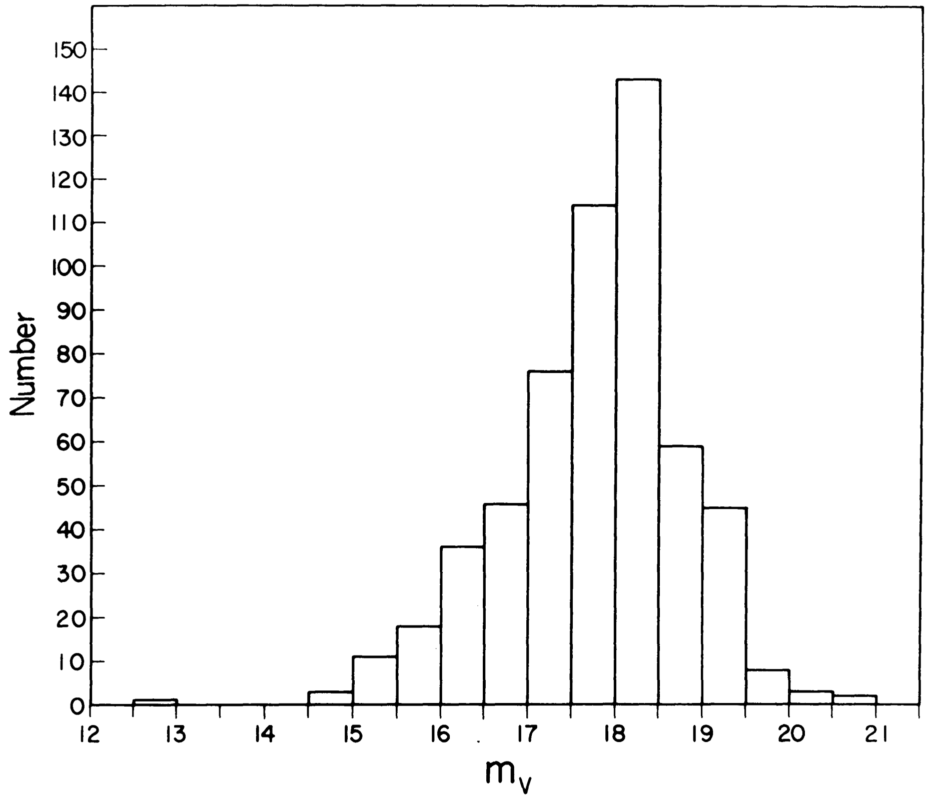

Fig. 2. Distribution of apparent magnitudes of QSOs listed in the catalogue of Burbidge et al. (1977).

Finally, let us turn to a brief discussion of the BL Lac objects. Since very few emission redshifts have been discovered in these objects, there has not been a lot to argue about. Some of them clearly are in galaxies at modest cosmological redshifts. One, CL 4, is thought to have its origin in our own Galaxy. One, BL Lac itself, has been a subject of considerable debate between Lick and Palomar, and the present situation suggests that it is certainly not a normal external galaxy.

These then are the classes of objects with which we want to do cosmology. Let us briefly discuss the different approaches to cosmology which are being attempted.

First we consider the bright elliptical galaxies. Here we know that we can continue to use the Hubble relation and using the galaxies

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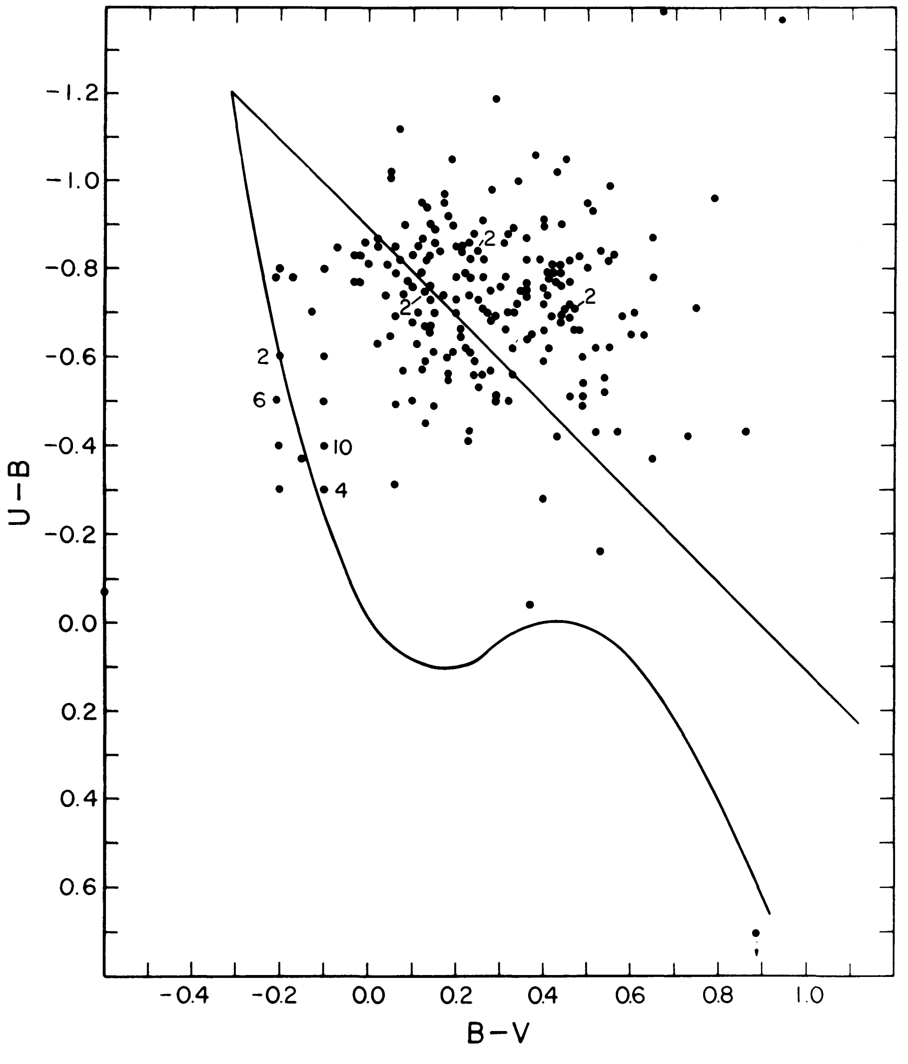

Fig. 3. Two color diagram for all QSOs with measured colors (230) in the catalogue of Burbidge et al. (1977).

which have been identified as radio sources it is possible to push out to quite large redshifts. The present situation will be discussed by Dr. Smith later in this session. Considerable success is being achieved and a number of redshifts greater than z = 0.5 have been measured. The major problem will be in making the corrections for evolution, etc.

We turn now to the redshift-apparent magnitude relation for QSOs. In Fig. 1 I have shown the redshift-apparent magnitude diagram for all of the nearly six hundred QSOs for which redshifts and apparent magnitudes are now available. Attempts have been made in the past to refine a diagram of this type in order to see if one could get a good Hubble relation for QSOs. The approach is that originally proposed by McCrea, viz., on the assumption that the redshifts are of cosmological origin, and assuming a value for the deceleration parameter q_o one attempts to find the intrinsically brightest QSO in each redshift range, and determine the slope of the redshift-apparent magnitude relation. This was attempted in the past by Bahcall and Hills, by Burbidge and O'Dell, and by Petrosian. It will be discussed again in this session. In my view you cannot refine it enough to produce strong evidence in favor of cosmology, though you can interpret it in this way if you wish.

We turn now to the luminosity-volume test. As Schmidt originally, and Lynds and Wills after him have shown, if the redshifts of the QSOs are cosmological, then large scale evolution in the population of the 3C and 4C sources is unquestionably present. Later in this session Dr. Schmidt will update this work and discuss new samples.

Now let us consider the log N - log S studies. It is an article of faith in Cambridge that these demonstrate extensive evolution. However, if we restrict ourselves to the radio galaxies in the 3C revised catalogue, and also restrict ourselves to those with known redshifts, studies using the luminosity-volume test by Schmidt (published in the Astrophysical Journal in 1972) and more recent studies of the log N - log S relations by Narlikar and myself in 1975 (also in Ap. J.) show that there is no strong evidence, if any, for evolution. The steep slope for the log N - log S relation of -1.8 for radio galaxies in this catalogue must arise entirely from the unidentified sources. If the evolution takes place at redshifts of $z \approx 2$ or greater as is frequently claimed, it will be impossible to prove this directly, using ground-based telescopes because the galaxies are much too faint to be detected. Thus, the argument that we are seeing evolution cannot be directly proved, at least until we are able to detect objects with much larger redshifts directly using the Large Space Telescope (LST).

The assumption of evolution and the attempts to make models which have been described here and have been worked on particularly by the Cambridge radio astronomers all seem to me to be a type of parameter fitting which is probably premature. In my view we first have to prove that the objects we are looking at are really far away and only then can we argue that using the counts we can discuss the details of the evolution.

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Earlier in this meeting when the counts at many frequencies were being described, I got the impression from several groups and particularly from Mills and his colleagues in Australia, that there are significant differences both in the slopes of the counts and in the numbers of sources measured at different frequencies in different parts of the sky. It was particularly striking to see the difference between the counts in the north and the counts in the south. To me the numbers in some cases appear to be highly significant. If there are real anisotropies, then at least one possibility is that many of the brighter sources are not at the great distances which had previously been assigned to them. Perhaps we should look for correlations between the distribution of radio sources in different parts of the sky and the distribution of comparatively bright galaxies in the local supercluster.

I conclude by outlining for you briefly the situation that might prevail if a significant population of the radio sources are not at great distances and are associated with QSOs which have been ejected from galaxies, as would be expected if the QSOs are comparatively local, i.e., they are at distances not greater than about 200 Mpc. We suppose that they are ejected from galaxies of various types, including spirals and the radio ellipticals. Under these conditions, what should we expect to see? The very close objects which have been ejected from comparatively nearby galaxies will be picked up as individual objects and will not be seen to be associated with their parent galaxies. This is because they will be far away from the objects from which they originated as far as the angular distances in the sky are concerned. As we go to radio sources which are further away, these will have been ejected from a population of galaxies which are also further away, and we shall see a significant number of them comparatively close to their parent galaxies. However, they will be far enough away from the parent galaxies so that they can be identified as individual objects. This would explain the correlation or the association between bright galaxies and some QSOs in the 3CR catalogue and the Parkes catalogue. As we go to even greater distances and beyond about 200 Mpc, the QSOs will be so faint that they will not appear on the sky survey plates and will no longer be detected as individual objects. Instead, their parent galaxies will be identified as the radio sources. This means that, although the identifications are incorrect, the distances for these sources will be correct. Thus, the radio luminosity function as derived from the galaxies will still be correct, and it may eventually be possible to establish that evolution is taking place through the population of parent galaxies.

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In conclusion it appears to me that some types of cosmological investigations using radio sources have been premature. Much of the discussion still depends on the distances of the QSOs, and it is not proven that they are at great distances. There is no conclusive proof that the population of radio sources is changing with epoch, though it may turn out that this can be established if enough detailed work is done. But it is impossible to discuss this problem without first establishing the nature and the distances of the objects which make up the sources of radio emission. In a sense this was clear from the beginning, but so much of the discussion and the debate has been based on what to many of us is really very flimsy evidence.

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DISCUSSION

van der Kruit: When you discussed the BL Lac objects, you did not mention the large amount of observations on AP Librae. Does this object carry any weight in the arguments for or against the presence of a stellar component in BL Lac objects?

G.R. Burbidge: The observations reported in the literature by Disney and his colleagues are not entirely convincing. Emission lines which were identified in the earlier work and were used in part to determine the redshift, are not present in the later observations. Whether this is due to changes in the object (as claimed by the authors) or not, is not easy to determine. In my view the absorption features identified in the second paper are not very convincing.

Miller: I observed the nuclear region of AP Librae with the Lick 3m image-tube scanner. The spectra showed very clearly emission lines and the characteristic spectrum of stars in an E galaxy at a redshift near 0.048. The visibility of the emission and galaxy features was nearly identical to that observed in 3C 371, another BL Lac object. The emission-line spectrum was very similar to that in gE galaxies with emission such as NGC 1052. Since the emission is likely to be concentrated to the nucleus, which is a variable object, the visibility of the emission features will depend on the brightness of the non-stellar component, the size of the entrance aperture, and the dispersion of the spectrograph. Nothing can be reliably concluded about variability of the emission lines until absolute spectrophotometry with essentially identical spectrograph set-ups is carried out over a period of time.

Ryle: I think it is important to remind optical astronomers that the general conclusions concerning the distances of radio sources and their consequent value in distinguishing between different cosmological models, do not depend on measurements of redshift, nor indeed on optical observations at all. Twenty years ago it was shown that by relating the numbers of sources, their isotropy and the upper limit set to their contribution to the volume emissivity by measurements of the background radiation, not more than about 10% of the sources in a given flux density range could lie within the Galaxy. Similar arguments applied to the extragalactic case showed a serious Olber's paradox unless the median value of P was at least 10^{25-26} watts ster^{-1}Hz^{-1}. Independently of the identification or redshift questions, most radio sources therefore lie at cosmological distances, and local interpretations of the source counts are untenable.

G.R. Burbidge: I disagree. As was shown several years ago by Rowan-Robinson and others, the limit set by this background does not rule out current local QSO models. Further in the case I have just discussed, the brightest QSO's are from comparatively nearby galaxies. Fainter ones are associated with galaxies at redshifts between about .003 and 0.02, and QSO's beyond this redshift are too faint to be identified as independent radio sources. The sources are then identified with ten percent galaxies. Thus the distance scale for radio sources with z (galaxies) > 0.02 is correct. In other words, we are looking at the fine structure of the radio universe at small redshifts and identifying local QSO's, but the gross structure is at greater redshifts.

I also disagree with your view that optical astronomy is largely irrelevant in this and related problems. Radio astronomers, except in special situations, cannot measure distances. In this sense, optical astronomy is still all important.

Osterbrock: I have no "belief" about N galaxies, nor can I pretend to have observational data on all known N galaxies, but I should like to emphasise that in the slide I showed yesterday of the 4 broad-line radio galaxies, 3 of them are N galaxies and they all show stellar absorption features (Ca II, G, Mg I) at approximately the same z as the forbidden emission lines. The equivalent widths of the absorption lines in all of these galaxies is only about 15 percent of the E.W. in typical elliptical galaxies, indicating strong dilution of the galaxy component by the non thermal component.

G.R. Burbidge: I certainly accept these observations; the existence of N-systems in which you can see stellar absorption features at the same redshift certainly weakens part of the argument I have made.

Wittels: Have you any comments on the lack of blue shifted objects if you try to explain QSO's, BL Lac type objects and possible N systems as ejecta from galaxies?

G.R. Burbidge: It has been known for many years and was described in our book published in 1967, that if these objects are ejected from galaxies beyond our own and if the shifts are local kinematic Doppler shifts, blue shifted objects should predominate. The fact that they don't can be interpreted within the framework of the local hypothesis in one of several ways:

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(1) it can be used as an argument against the local hypothesis,
(2) it means that the redshifts are not Doppler shifts,
(3) very contrived models can be considered in which it is argued that the emission takes place in a trail trailing behind the QSO. Then only those objects moving away would be detected.

CROSS CORRELATION FUNCTIONS FOR QUASARS AND GALAXIES

M. Seldner

The cross-correlation function for galaxies and QSO's is defined as the probability, as a function of angle, in excess of random for finding a galaxy around a QSO. Thus, the mean projected density of galaxies, $n_{gq}(\theta)$, around QSO's can be written

$$n_{gq}(\theta) = \bar{n}_g \, [1 + \omega(\theta)],$$

where $\bar{n}_g$ is the average sky density of galaxies and ω is the cross-correlation function. The function $\omega(\theta)$ is determined for the Shane-Wirtanen Catalogue of Galaxies and a sample of 484 published QSO's. The result is a function similar in shape to the correlation functions for other sets of objects such as Abell Clusters and 3CR radio galaxies, i.e. $\omega(\theta) = A/\theta^{\gamma}$, $\gamma \sim 1$. The amplitude A is about 10 times larger than would be expected if it is assumed that QSO's are at the distances calculated from their redshifts and are correlated with galaxies in the same manner that galaxies are correlated with each other. Division into redshift bins shows that contributions to the positive signal come from various redshifts and not just $z < 0.2$ as might be expected.

Webster: Can't you test the significance by looking at a number of random positions and looking at the variance, the scatter, on the resulting $\omega(\theta)$ curves?

Seldner: The correlation function for 500 random points with the Shane-Wirtanen Catalogue yields a $\omega(\theta)$ which is zero at all angles, that is it has no peak near θ=0. The error bars on the QSO-galaxy graph show the standard deviation of the mean for the first two angular bins, which are statistically independent, the errors at larger angle should fall off roughly as $\sqrt{\theta}$.

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