ISOTROPY OF FAINT SOURCES

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How matter distributes in the Universe is still an open question in spite of the many efforts people have done since early 1924 when Hubble first studied the distribution of bright galaxies.

Today a point which can be considered firmly established is that galaxies do cluster. Their two-point correlation function is given to good accuracy by the simple power law model:

$$\xi(r) = (r_o/r)^{1.77}, \; r_o \sim 5\ h^{-1}\ \mathrm{Mpc}, \; r \lesssim 10\ h^{-1}\ \mathrm{Mpc}, \; h = H/100$$

(Peebles, 1978). Clusters of galaxies are clustered as well on linear scales of a few tens of Mpcs (Peebles, 1978).

But this is how the near universe, that is for redshifts smaller than ~ 0.5 looks.

Information on the very far universe ($z \sim 1000$) is given to us by the microwave background radiation, which appears to be highly isotropic ($\Delta T/T < 0.001$ to 0.0001) on very large angular scales.

Intermediate epochs can be investigated through radiosources, most of which are believed to be at redshifts of the order of 2 or 3. And this will be the subject of this talk, mainly from the experimental point of view.

Since the limit one puts on the fluctuations in the source counts in inversely proportional to the square root of the number of sources, only recently have surveys become available which are sufficiently extensive for this type of analysis.

A comprehensive discussion of the problem has been given in 1976 in Cambridge at the IAU Symposium No. 74 on "Radioastronomy and Cosmology" (D.L. Jauncey, 1977) and the situation has not changed much since then.

As an example, I shall briefly illustrate the work done on the B2 survey by Fanti et al., 1978 (paper I). For a more detailed treatment

.O. Abell and P. J. E. Peebles (eds.), Objects of High Redshift, 145–152.

of the subject, one should refer to that paper. Different approaches have been tried:

i) Multi-Binning Analysis;
ii) Power Spectrum Analysis;
iii) Source Counts.

The MBA was performed by dividing the survey into bins of areas increasing from 0.45 to 62 square degrees. The comparison between the observed source distribution and that expected from a random population (Figures 4, 5 and 6 of paper I) does not show any significant difference, suggesting that no kind of clustering is revealed by this type of analysis.

The PSA was applied to the B2 catalogue in the way developed by Webster (1976). Without going into details, I only remind that the power spectrum Q(λ) gives a measure of the departure from random of a point (in our case radiosources) distribution, in this sense: if sources are completely at random, Q will be equal to $\underline{1}$ for all λ; if all the sources are in clusters of population $\underline{q}$ and size λ_c, then Q will be equal to $\underline{q}$ for all $\lambda >> \lambda_c$ and equal to $\underline{1}$ for all $\lambda << \lambda_c$. Intermediate cases will be in between. We make use of the ordinary Fourier Transform instead of the spherical harmonics adopted by Peebles and co-workers in his analyses of galaxies and galaxy clusters. This makes computations easier and does not sensibly affect the results, provided one makes an appropriate equal area projection of the celestial sphere. This projection might eventually distort the clustering shape, but this is not important in the present analysis.

The power spectrum of the B2 catalogue, shown in Figure 1, does not deviate significantly from that of a random distribution, in agreement with the MBA.

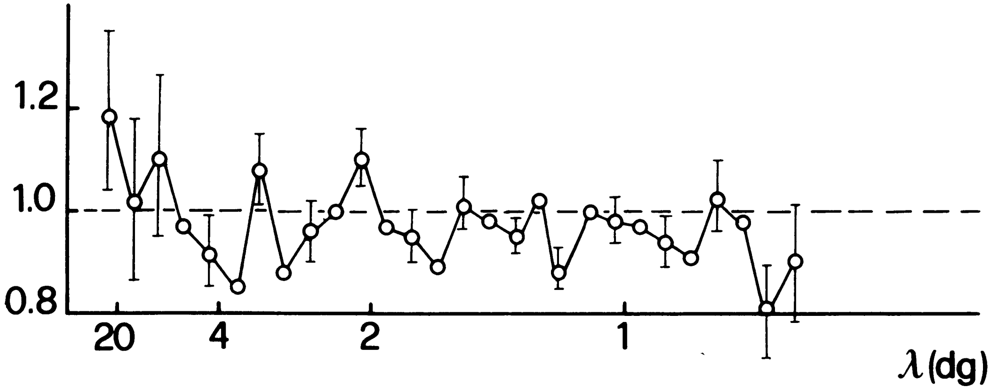

Figure 1. Power spectrum of the B2 radiosources

The results of Fanti et al. (1978) agree with the analyses performed by Webster (1976b, 1977) on catalogues of comparable depth at different frequencies. As far as I know, the only significant exceptions are:

a) A small but significant excess found in the 4C catalogue by Seldner and Peebles (1978) which Massons (1978), on the other hand, explains as due to zones of incompleteness in the 4C catalogue and to the presence of SNRs which, being a low galactic latitude, are obviously not at random positions;

b) A source surface density ~ 30% greater than that of B2 catalogue in the MC2 and MC3 catalogues (Mills, 1973). Recent observations of these regions with the Bologna Cross by Fanti et al. (1979) show ~ 15% difference in the flux scales. This is enough to bring the discrepancy between the source counts within the statistical uncertainties.

Concluding, I think I can still make the conservative statement that there is no convincing evidence so far that in fairly deep surveys sources are clustered at any level.

On the other hand, most of the radiosources in a catalogue are believed to be radiogalaxies, and since galaxies do cluster, there ought to be clustering in the radiosources' positions at some level.

Actually, Seldner and Peebles (1978) detected a faint but significant cross-correlation between the source positions of the 4C catalogue and the Lick galaxies counts, suggesting that at least the 4C sources associated with galaxies do cluster. This effect is much stronger when they cross-correlate the 3C radiogalaxies with the Lick galaxies.

On these lines I have analyzed the spatial distribution of a few complete samples of radiosources optically identified. In particular, I have applied the PSA to the five samples of QSOs and to that of radiogalaxies listed below.

		Freq	N (obj)	S_{lim} (Jy)	References
	3CR	178	33	9.0	M. Schmidt, 1968
	GV	408	122	0.9	G. Grueff & M. Vigotti, 1972, 1973, 1979
QSO	Olsen	178	127	2.5	M. Schmidt, 1974 & references therein
	4C	178		3.0	D. Wills & R. Lynds, 1978
	B2	408	58	0.25	R. Fanti et al. 1979
	PKS	2700	60	0.35	D. Wills & R. Lynds, 1978
GAL	GV	408	136	0.9	G. Grueff & M. Vigotti, 1972, 1973, 1979

In no case has any significant deviation from randomness been found for QSOs (Figure 2a). Again, I have to mention that in the identification programs by Hazard (1977) and Hunstead (1979) of the Molonglo radiosources, they find density fluctuations in different areas of the sky much larger than expected. As the authors themselves state, further investigations are needed before one can assume a real QSO anisotropy. Nevertheless, this is a point to be kept in mind.

For radiogalaxies the PSA has been performed for several limiting magnitudes (Figure 2b). While for the full sample there might be only some suspicion that the distribution is not random, for the radiogalaxies brighter than $m_r = 15$ there is no doubt that their spatial distribution significantly deviates from randomness. For the faintest galaxies, however, there is no indication at all.

This is roughly consistent with what is expected from the knowledge of the power spectrum of a galaxy sample of the same magnitude limit (for example, the Zwicky galaxies) and of the radioluminosity function of elliptical galaxies. One should find about half a radiosource in excess of random in the bright sample, and ~ 0.02 in the faint sample, over angular scales $\gtrsim 20°$.

On the assumption that the same hierarchical properties still hold at large redshifts, one can try to extrapolate these considerations to unidentified radiosources, which are usually thought to be radiogalaxies.

Even lower values of clustering are expected if we assume a density evolution as strong as $(1 + z)^6$ or $(1 + z)^8$.

It is therefore not surprising that clustering of radiosources associated with clusters or superclusters of galaxies similar to those existing at the present epoch is not detected in surveys of radiosources.

At very large scales, from the analysis of the B2 it is possible to put an upper limit of 2 to 4% on the r.m.s. fluctuations in the source counts over linear scales up to ~ 40°. Assuming an average redshift of 2, this means a fluctuation around the mean density which is less than 5 to 10% over linear scales of 1 Gpc ($H = 50$ km s^{-1} Mpc^{-1}).

In Figure 3 these upper limits are compared to the actual values of the covariance function for galaxies.

To improve these limits it would be necessary to analyze surveys either more extended or deeper in order to increase the source number. However, calibration uncertainties, catalogue completeness, etc., begin to be very important at this stage. Moreover, in very deep surveys, intrinsically faint sources begin to be very common. Also, one starts to split sources into several components. These effects might mask any cosmological clustering and it would not be straightforward to disentangle the various contributions.

Finally, one can look for anisotropies in the radiosource evolution by computing the log N-log S relation in different regions of the sky. This was already done on the 4C catalogue by Golden (1974) with completely negative results.

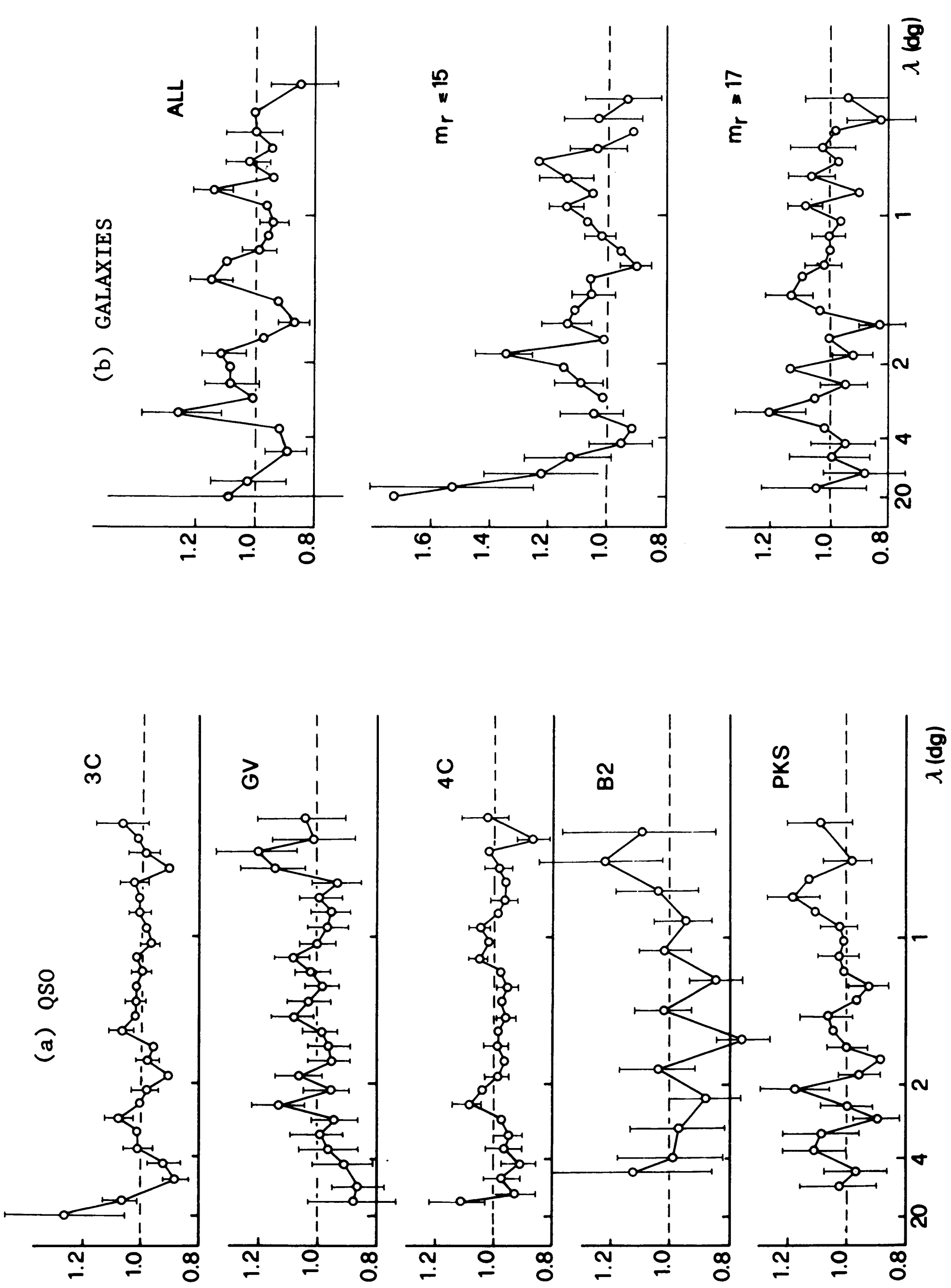

Fig. 2. (a) Power spectrum of QSO's and (b) radiogalaxies samples

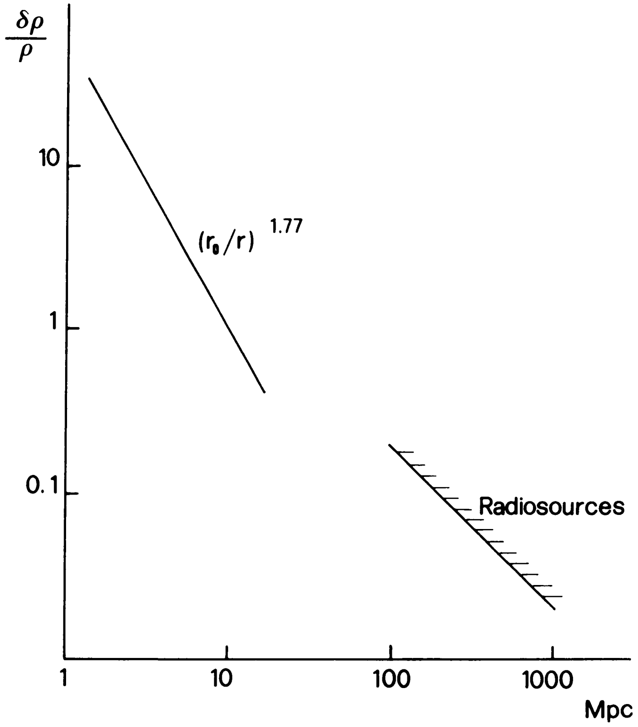

Figure 3. Covariance function for galaxies compared to the limits obtained from the B2 catalogue

We repeated the test at a deeper flux level on the B2 survey in a slightly different way. For each of the networks used in the MBA we have considered patchwork regions built up with all the bins which have the same occupation number in the intermediate flux interval 0.5 to 1.0 Jy.

In each of these regions we computed the log N-log S relation using only the flux intervals adjacent to the 0.5 to 1.0 Jy interval. In Figure 7 of paper I is plotted the slope of the log N-log S against the occupation number for each network. No kind of correlation is present.

One concludes, therefore, that not only is condensed matter very uniformly distributed in the unverse, but that also the physical conditions which determine the phenomenon "radiosource" have to be spatially very uniform in spite of the strong dependence with time shown by the steepness of the source counts. The density and evolution of radiosources are similar in regions of the universe which were causally quite unconnected at the epoch of the radiosources formation.

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DISCUSSION

Murdoch: The Molonglo flux density scale has been carefully revised over the whole available sky. Whilst this reduces previously claimed anisotropies in radiosource density to ~ 2σ, the revision is not as great as suggested by the Bologna results.

More interesting is the comparison of QSO surface density (number per square degree) between the north galactic hemisphere region of MC2 and the Southern selected area of 0.66 sterad at ~ -20° (mentioned earlier by Richard Hunstead). The surface density of QSOs in the south is only 1/3 of that in the north galactic hemisphere region of MC2, 3 at an optical limit of $19^{\rm m}_{\cdot}5$ and a radio limit of 0.95 Jy (on the revised scale for both areas). The root-mean-square difference is 3.2 σ.

Fanti: About the first point of the comment, I only said I have found a difference between the two flux scales which is enough to remove the discrepancy in the source counts without pretending to attribute all this difference to the Molonglo data. The fact that the flux scale revision is not as great as suggested by our analysis probably means that Bologna and Molonglo are not yet on the same absolute flux scale.

Seldner: Jim Peebles and I have re-examined the auto-correlation function for the 4C radiosource catalogue in light of Colin Masson's suggestion that the incompleteness in the regions around the brightest sources has caused the observed effect. We have generated several random catalogs, placing no sources in the holes, and including anti-correlation at small angular separation to account for confusion. Mean pair counts from these random catalogues are used to normalize the data to obtain the correlation function. We also found no north-south/east-west asymmetry in the pair distribution which might have been caused by varying sensitivity across the declination strips. The net result is that there are 3 ± 1% excess pairs in the 4C catalogue at angular separations less than 3°. Elimination of the region $|b| < 10°$, where galactic sources could contaminate the sample, has almost no effect on the result.

Fanti: I have not mentioned in my talk that above 1 Jy there is a very marginal ($< 2\sigma$) evidence of clustering on an angular scale of a few degrees at a level of ~ 10%. Half of this value can easily be explained by the clustering of the radiogalaxies brighter than $m_r = 15$ diluted in the total sample. It is reasonable, therefore, to think that also the excess you find in the 4C catalogue is due to nearby radiogalaxies.

Masson: Although power spectrum analysis is convenient for analyzing the clustering of galaxies, I think that covariance function analysis is more appropriate for radio sources. This is because confusion, which affects all terms of the power spectrum, only alters the covariance function on small angular scales. Thus, it is easier to separate the effects of confusion and clustering.

I have recently carried out a covariance function analysis of the Cambridge 6C catalogue. The weaker sources ($s < 200$ mJy) are uniformly distributed, within statistical errors, but there is an indication of clustering among the stronger sources on angular scales of a few arcminutes.

Fanti: For the B2 catalogue, confusion is not a major problem since, as described in detail in Fanti et al. (1978), any source areas in which confusion by side lobes may occur have been excluded in a homogeneous and predictable way, and we can take count of the effect of these "excluded" areas in our analysis. Also, the confusion effect which results by considering a close couple of sources as a single one is negligible because we stopped the analysis well above the confusion limit. However, I agree that, in general, covariance function may be more appropriate for radio catalogues.

About the second point, it would be interesting to know if you are detecting real clustering on small angular scale or if, perhaps, you are not counting complex sources.