THE BOLOGNA SURVEY OF RADIO SOURCES AT 408 MHz

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The Bologna survey (Colla et al. 1970, 1972, 1973) does not represent a particularly new achievement since the first records refer to 1968. We will summarize here the main properties for a statistical use of the survey, the differential counts and the isotropy characteristic of this flux level, the latter being completely new.

The three major sections of the Bologna survey (conventionally named B2.1 ($S_{408} \geq .2$ Jy) and B2.2, B2.3 ($S_{408} \geq .25$ Jy)) cover roughly 1.5 steradians in the northern sky. The survey was projected to furnish a wide sample (9475 sources) with good positions and fluxes and well-defined completeness down to faint levels for statistical studies. In recent years the optical identification work and spectral indices analysis has shown the correspondence of the results to the initial objectives.

Well-defined completeness does not mean complete straightaway: there is not such a complete catalogue. Apart from statistical confusion and systematic noise effects, nearby strong and relatively strong sources there is always a defect of faint ones. For the B2 survey we have forced this effect, excluding areas around sources in a predictable and homogeneous way. For the strongest sources, the avoidance of faint ones can reach 1 degree. In this manner the 9475 found sources would correspond to 11,600 if this (forced) bias was not present. One must keep this in mind in order to use the catalogue properly; for particular studies this is somewhat complicated without a computer and, of course, the original formula of exclusion. Among those particular studies there is certainly clustering or spectral indices distribution for samples defined at different frequencies.

THE COUNTS

To get proper counts one must allow for: a) completeness, b) resolution and c) confusion and systematic noise effects. The resolution effect is not very significant for the bulk of all radio sources, apart from the nearby bright radio galaxies. In order to avoid an uncertainty in the

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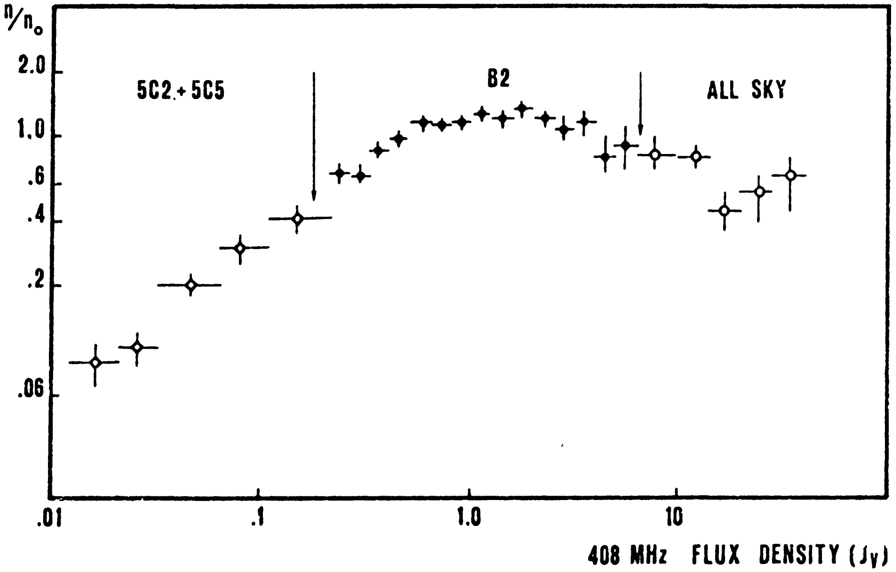

Fig. 1.

correction of the order of the effect, we have preferred not to consider it.

Because the completeness is well controlled a priori, if one assumes no clustering at small scales, there is no better way to determine confusion and noise effect (using the actual noise) than a Montecarlo estimate. We performed three different Montecarlo estimates which furnished not only the correction but also the uncertainty in the correction itself.

The correction is important, of course, near the limit of the catalogue: for example, in the interval .20 - .25 Jy, confusion and noise cause an over-estimate of the actual differential counts of a factor of 1.35 ± .076. As one can see, the error in the correction is quite large and represents the major sources of uncertainty for faint sources. After applying all the corrections, the B2 catalogues would have to contain 9153 sources.

Fig. 1 shows the differential count, normalized to an "euclidean" 5/2 slope that could give 4725 sources/ster. of .31 Jy. We have adopted the Robertson flux scale (1973), whose counts are reported at high fluxes together with 5C2 + 5C5 as reported by Pearson (1975).

ISOTROPY

Webster (1976) has given a good discussion for the distribution of radio sources in the 4C, Molonglo and GB surveys, using a powerful tool like his power spectrum analysis. He has shown that no believable clustering is found. On the contrary, most of the surveys, aside from the Molonglo one, which is far from the confusion limit, show anti-clustering, i.e. a lack of faint sources around the stronger.

We have performed the power spectrum analysis (P.S.A.) on the three sections of the B2 separately, not to make small possible calibration differences simulate clustering at long wavelengths. We have also made an extensive bin analysis from 0.5 square degrees up to the size of the catalogues, not only to check the P.S.A. results but also because it is much easier to take into account the controlled "anti-clustering" present in our survey.

Referring to Webster's paper for the explanation of the P.S.A. method, we recall here only that he introduces the quantity $Q \equiv \Sigma_I/\Sigma_\nu$, Σ_I being the sum of the normalized square Fourier amplitudes of source positions (up to a given wave number $1/\lambda$), and Σ_ν twice the summed number of Fourier terms. Q has as the expectation value the average number of sources per constellation and is 1 for uniform random distribution. We state consequently that Q would correspond to the ratio between the number of sources actually found and the predicted number, taking account of exclusion areas.

The following table gives the results for four different limiting fluxes and the combinations of the three sections.

S_o	Σ_I	Q	Q_{exp}	$1/\lambda$ deg^{-1}
$\geq$ 1.005	1278	1.037	.988	.3
$\geq$ .505	3484	1.002	.986	.5
$\geq$ .355	5831	.985	.964	.7
$\geq$ .255	8510	.970	.922	.8

The fourth column gives the expected values from our estimates of the excluded areas around the sources. The excess found for each column is not significant, being of the order of 1 standard error except for the last flux which would be at 3 standard errors. However, one must consider that the excess if of the order of 5% only, corresponding to 400 sources involved, and that the error in the correction given by statistical fluctuation of the overall number may well be of that order. Also, for well-known clustering of the Abell type, the physical doubles are expected to contribute to short scales of that amount. Finally, a confidence for such small effects must stand up to Montecarlo checks of the effect from fainter sources than the survey limit, because a confusion effect from faint sources is expected to depend upon the actual local density of sources, giving rise to non-linear behaviour.

Fig. 2 shows Q' and Q trend superimposed against $1/\lambda$ for $S_o \geq .255$. The excess found at short spatial wavelengths never reaches 3 standard errors. The behaviour of the other fluxes is pretty similar.

The Bin Analysis (B.A.) confirms rather well that which was found from P.S.A., and the test for different bin sizes never gives a

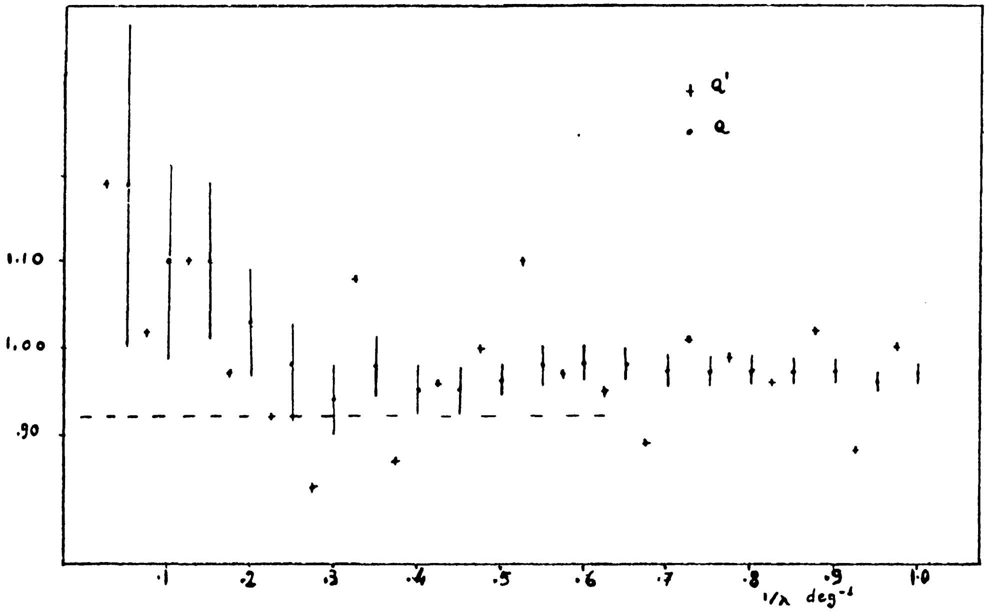

Fig.

probability less than 1% for uniform distribution, and it is normally higher than 5% for the small scales as well. Using the B.A. we were also able to test differentially for the different fluxes that showed statistically uncorrelated results. The latter is not only a property of the spatial distribution of the radio sources but it is also a property of the luminosity function that appears to have all the properties of a statistical distribution function for luminosities for this purpose.

As a last remark on the very large scales, we must state that the densities of sources for the three sections are scattered with a dispersion of 2.8% while the statistically expected dispersion would be 2%. This set a limit for a different scale between the three surveys of 1.5%.

CONCLUSIONS

No large deviation from the uniform distribution has been found in the B2 survey, setting a limit of a few percent for the clustered population. In reality, when we look around at the positions from which clustering is expected, i.e. Abell cluster centers, we pick up the effect very clearly. This happens to scales that are a fraction of the Abell radius or a few minutes of arc. The only chance to explore this effect for an eventual proto-cluster of that size would be to look in surveys which are deep enough to detect this population and on such a small scale as to have few clusters in the column of the universe visible at that flux level. This is well below the performance of the present radio telescopes.

Our limits on the clustering refer to large scale effects in the universe owing to the deepness of the radio sky. These scales are generally larger than known superclusters and give stringent limits to the homogeneity of the universe, both in content of galaxies and in evolutionary characteristics. No theoretical analysis of the cosmological meaning of such isotropy is known to the authors.

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DISCUSSION

Jauncey: Have you really detected Abell clustering in the Bologna survey?

Lari: Yes. We have covered enough Abell clusters to overcome the background fluctuations, and we find a very peaked distribution near the centres of the clusters. More exactly, we have added together all distance 5 Abell clusters and we find a total number of 96 B2 sources within one Abell radius. The expected number from the overall background is 42, leaving an excess of 54, although the average excess density is less than one source per cluster. The distribution falls off very rapidly, with a peak only 0.1 Abell radius wide and a central density about 20 times larger than the background. Preliminary results from Westerbork show many of the B2 sources in the clusters breaking up into two sources both associated with galaxies in the cluster.