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Analysis of radio surveys made on the RATAN–600 with participation of the Sternberg Astronomical Institute

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Abstract. The departures from the Poisson distribution of sources over the sky for an angular scale of $0.8° - 1.0°$, obtained from the analysis of Zelenchuk surveys, may be of cosmological origin. The character of these departures indicate some objects connected with the large–scale periodical structures to be present in the Universe. These sources may be related to superclusters and voids. The following limitations on the Universe deceleration parameter q_0 and on the red shift z of the epoch of formation of large–scale structures are obtained at a 95 % confidence level: $q_0 < 0.15$, $z < 14$.

Key words: surveys – statistics – cosmology

1. Introdution

The existence of mosaic scales for a spatial inhomogeneity in the Universe has been established to exist. The largest scales of superclusters and voids reach about 150 h^{-1} Mpc. Optical data for rich clusters of galaxies show the presence of a characteristic scale, 100–120 h^{-1} Mpc, in regularity of the supercluster — void network (Broadhurst et al., 1990; Mo et al., 1992; Einasto et al., 1994).

On the other hand, extra-galactic radio sources are thought to be associated with giant elliptical galaxies of rich clusters in the regions surrounded by high-density matter. They may be used as indicators of the "skeleton" of the large–scale structure of the Universe (Shaver, 1991). All the lists of radio sources compiled from the search surveys gave hopes for detection of a visible departure from the Poisson distribution of sources over the celestial sphere. However, the search for distortions of the Poisson distribution of sources carried out for many years has not provided reliable evidence for such departures, which has been interpreted to be due to the smearing effect of the wide range of luminosity functions (LF) of sources, when both nearby and very distant objects fall on the line of sight. Only the structure of the local supercluster has been confirmed by radio astronomical data (Shaver, 1991).

Besides the reasons connected with the radio luminosity function of galaxies and quasars, there may be the conditions responsible for the negative results: the sparse number of statistical data used, and the insufficient depth of the surveys. That is why, after the completion of Zelenchuk survey (Z2) and data processing for some zones we have analysed the distribution of the Z2–survey sources (Amirkhanyan et. al., 1989). The extensive material (about 11.5 thousands radio sources) raised hopes for obtaining new information about the problem of interest (Amirkhanyan et al., 1989; Larionov, 1991).

In 1987 we have published the results on revealing the departure from Poisson distribution for the Z2 survey sources on the scale of about 0.5° by the method of counting the sample surfaces with different number of sources in them (Larionov, 1987). Different areas of the survey had the same character of departures and suggested the presence of regular structures in the distribution of sources. To confirm the results the equatorial deep survey of up to 20 mJy has been made in the last years using another configuration of the RATAN–600 (Larionov et al., 1994). This survey has cancelled some suspicion of a possible selection effect related to the low (about 20) ratio of the area of the minimum surface element to the square beam width.

2. Computation

The statistics of the number of areas with different number of objects in them follows the Poisson distribution and determines the probability of occurrence

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of some event for a random quantity

$$p(m) = \frac{\alpha^m e^{-\alpha}}{m!}, \qquad (1)$$

where α is the average number of sources in an area of a certain dimension; m is the number of sources in the area (the ordinal number of independent degrees of freedom).

The method is efficient to a maximum at small α and m. This situation is realized in our investigation.

The hypothesis of random distribution has been tested using the criterion

$$U = \sum_{i=0}^{m} \frac{(E_i - N \cdot p_i)^2}{N \cdot p_i}, \qquad (2)$$

where p_i is calculated from equation (1), but N is the total number of areas in the survey zone analyzed.

The statistics U obeys the χ^2 distribution with $(m-1)$ degrees of freedom at large N. The quantity N is about thousand in our case. The single-parameter distribution function is

$$f(\chi^2) = \frac{1}{2^{\nu/2}\Gamma(\frac{\nu}{2})}(\chi^2)^{\frac{\nu}{2}-1}e^{-\frac{1}{2}\chi^2}, \qquad (3)$$

where $\nu = m-1$ is the number of independent degrees of freedom. This function permits the probability of Poisson distribution to be determined

$$p(\chi^2) = \int_{\chi^2}^{\infty} f(x)dx, \qquad (4)$$

where $f(x)$ is the distribution function of χ^2.

By this means the whole zone of the deep survey (α from 0^h to 24^h and δ from $0°$ to $-1°$) was divided into areas from 5 to 0.08 square degree in size. The number of the areas of each size for different degrees of freedom has been calculated. The theoretical Poisson distribution was found from equation (1), where the probability density per one area is presented. For the area of each size χ^2 was found using equation (2) and the value of random realization was calculated by integrating equation (4). The hypothesis of random distribution of sources over the celestial sphere was adopted. About 700 sources of the deep survey and the same number of Z2 survey in the zone near the deep survey were investigated.

The statistics of areas for the deep survey and for part of Z2 survey is shown in Table 1 for a surface of 0.25 square degree.

The tendency of distortions of the Poisson distribution in the two surveys is identical. There is deficiency of areas that do not contain sources and the areas with multiple structures. But the areas with a single source are in excess, ~(16–18)%. The actual distribution is more narrow than Poisson. It may

Table 1:

m	N exp. deep	$p(m) \cdot N$ deep	N exp. Z2	$p(m) \cdot N$ Z2
0.00	426.00	467.40	398.00	432.00
1.00	393.00	336.40	370.00	316.00
2.00	127.00	121.00	116.00	116.00
$\geq$ 3.00	14.00	35.10	19.00	33.60

suggest the presence of quasi-regular structures of sources. The probability of random realization in the distribution of sources p(χ^2) is given in Table 2 for the deep survey, for part of Z2 survey and also for both surveys (unified data) (sections I, II, III, respectively).

The clearly defined scale of the departure, about 0.5°, characteristic of the two surveys of different depths, gives grounds to suppose that the sources in clusters of galaxies are responsible for this scale since it is only on the scales of superclusters, (100–150)h^{-1} Mpc, that quasi-regular structures revealed in optical studies of rich superclusters are observed.

Similar results were obtained, probably, by Kooiman et al. (1995) using the angular correlation function for the 87GB survey. The positive and negative components of the angular correlation function in their calculations formed a period of about one degree.

3. Data analysis

Table 3 shows the probability of random realization in the distribution of sources as a function of the doubled angular scale of areas into which the survey zone was divided.

Because the statistics of areas shows the empty areas to be deficient in number and the single-source areas to be in excess as compared with the Poisson histogram, the interpretation of the effect obtained leads to the conclusion that the periodical component of double angular size is present, assuming the regular large-scale structures to exist. The deficit of the empty squares and the excess of the squares with one source determine the scale of superclusters together with voids. A considerable (at level of five standard deviations) departure from Poisson distribution on scales from 0.8° to 1.0° is visible. The sharp drop in the relationship towards the decreasing size of the analyzed areas can be explained neither by statistical parameters nor by possible selection effects connected with the decrease in the ratio of the size of areas analyzed to the square beam width. The statistics of squares in first case is improved, while the ratio in second case is about a hundred. The shape of the drop is identical for both surveys (deep and Z2). We sup-

Table 2:

section		I		II		III	
θ^2	m	χ^2	$p(\chi^2)$	χ^2	$p(\chi^2)$	χ^2	$p(\chi^2)$
5.0	2	0.56	$7.7\cdot10^{-1}$	0.71	$7\cdot10^{-1}$	1.1	$5.8\cdot10^{-1}$
0.62	5	14.9	$1.0\cdot10^{-2}$	12.8	$2.5\cdot10^{-2}$	24.4	$1.6\cdot10^{-4}$
0.31	4	19.0	$8.0\cdot10^{-4}$	18.0	$1.0\cdot10^{-3}$	33.6	$9.0\cdot10^{-7}$
0.23	3	25.8	$1.0\cdot10^{-5}$	19.8	$1.9\cdot10^{-4}$	43.4	$2.5\cdot10^{-9}$
0.16	3	24.2	$2.3\cdot10^{-5}$	13.5	$3.7\cdot10^{-3}$	33.9	$2.6\cdot10^{-7}$
0.11	3	18.1	$4.2\cdot10^{-4}$	8.3	$6.2\cdot10^{-2}$	25.6	$1.4\cdot10^{-5}$
0.08	2	5.63	$6.0\cdot10^{-2}$	...	...	...	...

Table 3:

$(2\theta)^2$, sq. degree	$p(\chi^2)$
0.30	$6.0\cdot10^{-2}$
0.42	$4.2\cdot10^{-4}$
0.52	$5.1\cdot10^{-3}$
0.64	$2.3\cdot10^{-5}$
0.80	$3.0\cdot10^{-5}$
0.92	$8.9\cdot10^{-6}$
1.08	$2.2\cdot10^{-2}$
1.24	$8.0\cdot10^{-4}$
1.56	$4.0\cdot10^{-3}$
1.84	$9.0\cdot10^{-3}$
2.16	$8.0\cdot10^{-3}$
2.47	$1.0\cdot10^{-2}$
2.80	$7.0\cdot10^{-2}$
3.12	$1.5\cdot10^{-3}$
3.43	$3.5\cdot10^{-2}$
3.76	$6.0\cdot10^{-1}$
4.08	$7.5\cdot10^{-2}$
4.25	$5.0\cdot10^{-3}$
4.72	$3.6\cdot10^{-2}$
5.03	$4.2\cdot10^{-1}$

posed that the roll–off can be directed to the epoch of formation of regular structures of the Universe. This assumption is related to structures associated with search survey sources. A comparison of the two surveys so as to distinguish one from the other at about 1° in depth gives similar results, and we obtained an additional argument in favour of our assumption.

We examined the standard cosmological models with a zero cosmological term. There were used the following assumption based on the enumerated facts:

- the detected distinctions in the visible distribution of sources are connected with regular large–scale structures of the Universe, obtained from optical observational data for the local Metagalaxy large–scale structure;
- the angular period revealed in the distribution and ranging of sources from 0.8° to 1.0° at some epoch corresponds to the linear size of structures at the current epoch and is equal to 130 h^{-1} Mpc;
- the cosmological Universe expansion causes then the large–scale structure size to change in the way the scaling factor does. The last assumption means that there is no gravitational connection between the centres of superclusters.

The metric distances are adopted from Mattig (1958) and the relationship between the linear and angular sizes of sources are determined by the functional

$$\Theta = \frac{L \cdot H \cdot q_o^2(1+z)^2}{c[q_0 z + (q_0 - 1)(\sqrt{1+2q_0 z} - 1)]}, \quad (5)$$

where c, q_0, z, H — the light velocity, the Universe deceleration parameter, the redshift and Hubble's constant. The linear size L is the function of redshift and Hubble's constant:

$$L = \frac{130}{h(1+z)} = \frac{1.3 \cdot 10^4}{H \cdot (1+z)}. \quad (6)$$

Hubble's constant is absent in the final form of the relationship

$$\Theta = \frac{1.3 \cdot 10^4 \cdot q_o^2(1+z)}{c[q_0 z + (q_0 - 1)(\sqrt{1+2q_0 z} - 1)]}. \quad (7)$$

By fixing of the angular scale 0.8° we get a functional connecting q_0 and z. The indicated relation is shown in Table 4.

4. Discussion

It is seen that q_0 only slightly depends on z at q_0 larger than 0.1. The value of the deceleration parameter can practically not be larger than 0.25. The redshift at this epoch is 50 and large–scale structures of the Universe could hardly exist at that time. Even the wide range of luminosity functions of galaxies and quasars and possible selection effects connected with the fact that the samples analyzed are limited in stellar magnitude could not disguise from observation of the sources in such a wide range of z (from 6 to 50), if a specific case of formation of large–scale structure

Table 4:

q_0	z
$1.0 \cdot 10^{-2}$	5.3
$2.0 \cdot 10^{-2}$	5.6
$4.0 \cdot 10^{-2}$	6.2
$6.0 \cdot 10^{-2}$	7.1
$8.0 \cdot 10^{-2}$	8.0
$1.0 \cdot 10^{-1}$	9.2
$1.2 \cdot 10^{-1}$	11.0
$1.4 \cdot 10^{-1}$	12.9
$1.6 \cdot 10^{-1}$	15.3
$1.8 \cdot 10^{-1}$	18.1
$2.0 \cdot 10^{-1}$	22.7
$2.2 \cdot 10^{-1}$	27.2
$2.4 \cdot 10^{-1}$	39.5
$2.6 \cdot 10^{-1}$	68.3

is not supposed, when at very large z objects of extremely low luminosity are formed whose luminosity grows with epoch. The range of possible values of q_0, that have been found, lies below 0.15 at a confidence level of 95 % with allowance for errors in the method used and experimental data. The age of objects connected with large–scale structures is then about 16 billion years. The situation is aggravated by the introduction of evolutionary characteristics of $q_0(z)$, which is natural from the physical point of view. The relation becomes steeper with increasing z under this assumption. The epoch of formation of large–scales as we suppose lies within the redshift range (5–10).

The deduced limitations on the Universe cosmological parameters are consistent with a number of known experimental data based on the counts of faint galaxies. As an example, we can cite the work of Guideroni and Rocca-Volmerange (1990), where the authors obtained a low value, q_0=0.05, by the model matching of counts of galaxies. They noted that the values, q_0=0.5 and z=2, are highly contrary to the experiment. The maximum values given by them, q_0=0.15 for the epoch of galaxy formation, z=10, are comparable with ours, q_0=0.15 and z=14, respectively. The disagreement with the inflation scenario may have different explanations:

- the enumerated experiments include either methodical, or logical, or actual mistakes;
- the experiments contain selection effects that have not been taken into account;
- the models considered are not incomplete and one should examine the models with a non–zero cosmological term;
- the models do not reflect real cosmology at all;
- the inflation models are inconsistent with the observed Universe.

One must examine other models and assumptions, first of all a model with a non–zero cosmological term.

5. Conclusion

1. The departures from the Poisson distribution for the sources over the sky on the angular scale from 0.8° to 1.0°, revealed in the Zelenchuk surveys, may be of cosmological origin.

2. The form of the departure from random distribution suggests the presence of an appreciable share of radio sources related to the large–scale supercluster structures of the Universe.

3. A lower limit has been obtained on the deceleration parameter, $q_0 < 0.15$, which corresponds to the epoch of formation of large–scale structures, $z < 14$, if standard cosmology is adopted.

4. The angular scale of the departure from the Poisson distribution is close to that reported by Kooiman et al. (1995) from the analysis of the 87GB survey.

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