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Spatial structure and limitation on the hidden mass for the Ursa Major supercluster

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Abstract. On the basis of spectral and CCD photometric observations on the 6 m telescope of SAO RAS the spatial structure of the apparently compact supercluster Ursa Major, having an angular size about 6 degrees at an average velocity 18000 km/s and a velocity dispersion 2200 km/s (for 11 clusters which comprise the system), is determined. The supercluster is stretched along the line of sight; on the whole it obeys the Hubble relationship between radial velocity and distance, and is not a supermassive system with a large amount of "hidden" matter.

Key words: supercluster: individual: Ursa Major – structure –cluster: hidden mass

1. Introduction

According to the theory of formation of a large-scale structure as a result of gravitational instability, it is expected that on scales of 10–100 Mpc the non-uniformities observed in the distribution of galaxies — superclusters and voids — must be at the linear stage of growth of the density perturbations of matter. The peculiar velocities of galaxies and clusters of galaxies determined from the observations on these scales do not exceed 500–1000 km/s, for example, in the vicinity of the Great Attractor. One can expect greater velocities in rarely found compact and rich superclusters of galaxies. In the region of space with complete measurements of redshifts of clusters ($z < 0.08$) such systems number no more than 4–5. Nevertheless, compact superclusters apparently give the major contribution to the Bahcall et al. (1986) effect of anisotropy in the distribution of spatial orientation of all possible pairs of clusters in the entire sample of nearby Abell clusters. An excess of pairs oriented along the line of sight is observed. This effect may be caused by either the peculiar velocities of clusters, about 1500 km/s, in massive dense superclusters with a large amount of invisible matter, or a purely geometrical reason — accidental orientation along the line of sight of a number of elongated superclusters. Analysis carried out by Bahcall et al. (1986) spoke out in favour of geometrical projection, while Rood (1992), on the basis of statistical estimates, came to a conclusion about the existence of large peculiar velocities in the two most compact superclusters Corona Borealis and Ursa Major. The answer to this question can be found through a straightforward determination of the sizes of superclusters along the line of sight, and for this it was necessary to determine the distances of separate clusters by a method which would be independent of the measurements of redshifts. A rather simple and effective way of solving this task is, apparently, the use of bright galaxies of early morphological types which predominate in the central parts of clusters. For these galaxies the relation between structural parameters is established, which can be measured comparatively easily on the basis of surface photometry, for example between the effective radius and surface brightness on this radius (Capaccioli et al. 1992), allowing one to determine at least the relative distances of clusters in the supercluster. The aim of our work is thus, on the basis of spectral and photometric observations on the 6 m telescope of bright E and S0 galaxies in eleven clusters of the Ursa Major supercluster, to determine the spatial structure of this system.

2. Observations

The Ursa Major supercluster is a very compact group of clusters, at least in projection onto the celestial sphere, consisting of six Abell clusters and five clusters of smaller but comparable populations. Four of these clusters are revealed by Baier (1980) (Anon1, Anon2, Anon3, Anon4), another one by Shectman (1985) (Sh166). That these five clusters belong to the supercluster was established by our measurements of radial velocities for several of the brightest galaxies in each of the clusters.

The visible contrast of the density of the system, provided that it is evaluated through Abell clusters with regard to a surrounding region of about 200 Mpc

Table 1:

Name	R.A.	DEC.	V_o	σ_r	N_v	N_{ph}	$d\lg(R)_1$	$d\lg(R)_2$
1	2	3	4	5	6	7	8	9
A1377	11 44.4	+56 01	15210	570	18	14	-0.0244	-0.0558
Sh166	12 00.9	+55 11	15360	230	4	5	-0.0392	-0.0690
A1291	11 29.4	+56 19	15720	700	21	6	-0.0548	-0.0810
A1318	11 33.7	+55 15	17140	270	13	10	-0.0156	-0.0258
A1383	11 45.5	+54 54	18080	530	12	8	0.0208	0.0202
Anon4	11 35.2	+56 01	18400	520	7	3	0.0152	0.0170
A1436	11 58.0	+56 32	19250	380	11	14	-0.0204	-0.0110
Anon3	11 26.3	+55 44	20480	350	3	4	-0.0080	0.0110
A1270	11 26.8	+54 21	20660	420	10	7	0.0856	0.1058
Anon1	11 13.2	+54 46	20970	570	8	5	0.0504	0.0738
Anon2	11 16.8	+54 43	21100	240	7	6	-0.0088	0.0152

in size, equals 30. On the whole the range of radial velocities of the supercluster amounts to 6000 km/s with an average radial velocity of about 18000 km/s.

Observations were carried out on the 6 m telescope from 1990 to 1993. Spectra for the measurement of radial velocities were obtained using a scanner (image photon counting system) with a reciprocal dispersion of 2 Å/channel. To measure the radial profiles of the surface brightness of galaxies, CCD frames were obtained with the help of the matrix PHCCD1M (512×512 pixels) described by Borisenko et al. (1990), which was installed on the focal reducer in the prime focus of the telescope. The pixel size is $0.81'' \times 0.61''$. The seeing during the CCD observations amounted to $2.5'' - 3.5''$ (FWHM). The R filter, which is similar to the one of the photometric system of Kron–Cousins, was used.

3. Determination of cluster distances

The effective radius R_e (from the profile of integral magnitude) and surface brightness on this radius μ_e (from the profile in ring apertures) were measured for 82 galaxies of morphological types E and S0 which are brighter than the integral magnitude 16.25. The step in radius was $0.81''$. The distances of clusters were determined with the help of the relationship $\mu_e + 2.5 \cdot \lg(R_e) = C$. The mean value of the constant C for every cluster was evaluated and then converted to the relative distance of the cluster $d\lg(R)$ from the centroid of the supercluster. Here the residual dependence of the C value on the magnitude of the galaxy $\Delta C = 0.32 \cdot \Delta m$ was also taken into account, with the help of which the original value of C for the given galaxy was reduced to its value at some fixed magnitude. The calculations were carried out for two variants. In the first case it was supposed that all clusters are situated at the same distance, in the second — that Hubble law applies to the supercluster, i.e. distance is proportional to velocity. In the second case the distances were reduced to a fixed absolute magnitude, calculated for every cluster from its average radial velocity, and a correction for the cosmological diminution of the surface brightness $\Delta\mu = 10 \cdot \lg(1+z)$ was introduced. The mean error of the distances of clusters is 0.04 on the logarithmic scale and depends on the number of galaxies being used.

Table 1 contains the following data: name of cluster in column (1); equatorial coordinates of the centre (2) and (3) at the epoch 1950.0; mean radial velocity of cluster (4), reduced to the centroid of the local group; dispersion of radial velocities (5); number of measured radial velocities (6); number of galaxies with measured photometric parameters (7), from which was determined the cluster distance on logarithmic scale relative to the centroid of the supercluster for the case without cosmological corrections (8), and with cosmological corrections (9). For the clusters A1318 and Anon4 data on radial velocities were partly taken from the work of Zabludoff et al. (1993), and for A1291 from the work of Merrifield & Kent (1991).

4. Discussion of results

Figure 1 shows the relationship between relative distances of the clusters inside the supercluster and their radial velocities (Hubble diagram) for two variants of calculations. The regressive dependences are as follows:

$$\lg(cz) = 0.913 \cdot d\lg(R) + 4.262$$
$$\pm 0.335 \qquad\qquad \pm 0.043$$

for the first variant (Fig.1a), and

$$\lg(cz) = 0.818 \cdot d\lg(R) + 4.262$$
$$\pm 0.168 \qquad\qquad \pm 0.030$$

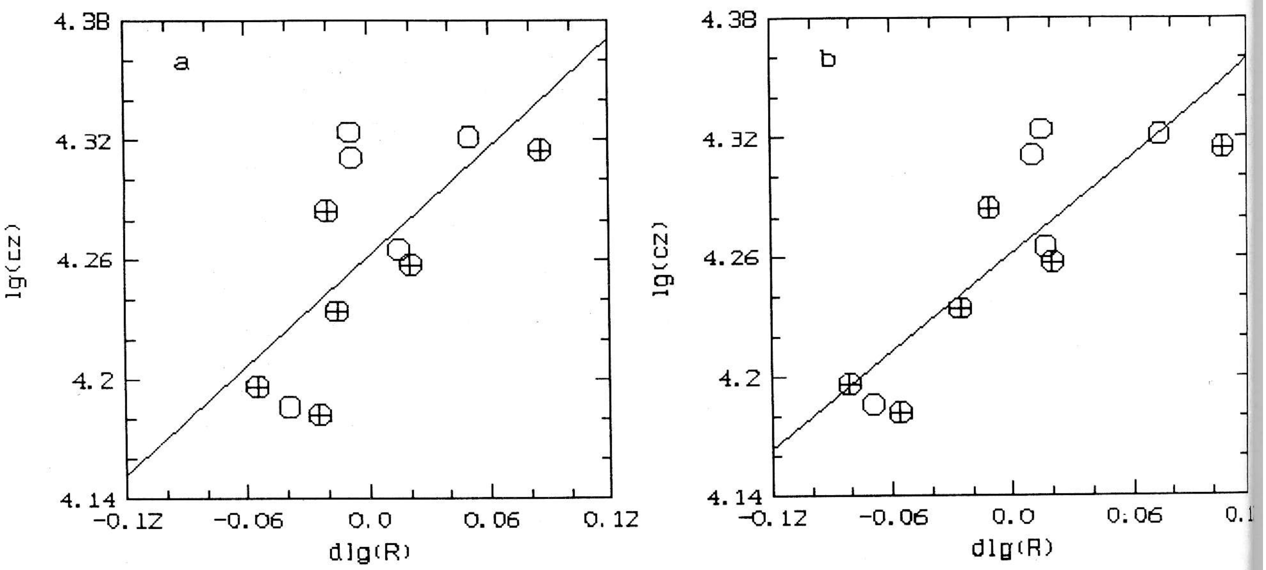

Figure 1: *The Hubble diagrams of the Ursa Major supercluster for two variants of cosmological corrections a given: (a) on the supposition that all clusters are on equal distances and (b) if the Hubble law is applied to th supercluster, i.e. distances are proportional to velocities. Abell clusters are shown by crossed circles.*

for the second (Fig.1b). The correlation coefficients are equal to 0.672 and 0.851 for the first and second variants, respectively.

The strong correlation between distances and velocities allows us to infer that for the Ursa Major supercluster, within the limits of measurement errors, the Hubble law of expansion is valid. The apparent compactness of the supercluster on the celestial sphere is the result of accidental projection along the line of sight of the very elongated system of clusters or several systems consisting of up to 3–4 clusters. Nevertheless, the contrast of the volume density for the supercluster on the whole is about 7. This suggests that most probably the supercluster is a genuine physical system, possibly with subsystems, but not a purely random association of clusters. At the same time, it is possible to conclude that a significant overabundance of invisible matter ("hidden mass") within the limits of the supercluster is not revealed, since the observed range of radial velocities of clusters are in fact fully conditioned by the Hubble cosmological expansion, and the peculiar velocities probably do not exceed 1000 km/s. For evaluation of peculiar velocities inside the supercluster more precise measurements of distances are needed.

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