Bull. Spec. Astrophys. Obs., 1998, 45, 66-68

Determination of distances and peculiar velocities of clusters of galaxies

Kopylov A.I., Kopylova F.G.

Special Astrophysical Observatory of the Russian AS, Nizhnij Arkhyz 357147, Russia

Received February 20, 1997; accepted February 27, 1997.

Abstract. On the basis of CCD photometric and spectral observations on the 6-m telescope relative distances are measured and an estimation of the peculiar velocities of clusters of galaxies in Ursa Major supercluster and at the neighbourhood of a giant void, having a diameter of 300 Mpc and a radial velocity of the centre of 32000 km/s, not far from the direction to Northern Galactic Pole are done. The Hubble relation between radial velocity and distance is fulfiled for the supercluster. The peculiar velocities do not exceed 500–1000 km/s. At the neighbourhood of the void the systematic deviation of cluster distances from those followed from the Hubble law is discovered: the motion of clusters to the outside of the void is observed. A total amplitude of the expansion velocity on a scale of 15000 km/s ($\simeq$ 300 Mpc) is 900 and 200 ($\pm$200) km/s without and with accounting for luminosity evolution of galaxies, respectively.

Key words: galaxies: clusters: general: distances and velocities

At present the determination of distances by methods independent from measuring redshifts are at the first place in investigations of large scale distribution of galaxies. The Hubble law gives a possibility to determine distances to extragalactic objects in the first approximation, ignoring their peculiar velocities. Measuring a distance by another method, for example, using photometric or structural parameters of the object, it is possible to separate from an observed velocity (cz) a component additional to the Hubble velocity — a peculiar velocity of the object (galaxy or galaxy cluster). A knowledge of the three-dimensional coordinates of the objects and their peculiar velocities permit to study a dynamics of galaxy systems and cluster systems — superclusters, as well as a geometry and a dynamics of the Universe as a whole.

For understanding of an origin and evolution of the large scale structure it is important to study inhomogeneities of the largest size (mass) — superclusters and voids. Corresponding scales are 100–300 Mpc (here and further we use $H_0 = 50$ km$\cdot c^{-1}\cdot$ Mpc^{-1}) and a mass excess (a deficit for voids) may reach $10^{16} - 10^{18}\ M_\odot$. If a contrast of density of both visible and unvisible matter in these inhomogeneities is large then it should be displayed by large velocities of motion inside and at the neighbourhood of these objects. If an unvisible matter is distributed more homogeneously then peculiar velocities should be small.

Clusters of galaxies, the most massive gravitationally bounded objects, are the convenient mean to investigate the distribution of the matter and velocities up to very large scales (300–1000 Mpc). Galaxies of early morphological types, elliptical and SO, predominate in the clusters and have as a rule a regular structure — a radial brightness distribution is well described by de Vaucouleurs law ($r^{1/4}$). A star velocity dispersion in galaxy along with an effective radius and a mean surface brightness on effective radius define so called "Fundamental Plane" (FP) populated by early type galaxies with a small spread (Djorgovski and Davis, 1987). From large samples of galaxies several relations were found, being FP projections, which allow to determine galaxy distances. The central velocity dispersion of stars depends on the total luminosity, $L_T \propto \sigma_c^\alpha$ (Faber and Jackson, 1976), and the effective radius R_e and the surface brightness μ_e are related as $\mu_e \propto 3 \cdot \log(R_e)$ (Kormendy, 1977). Our measurements for luminous E-SO galaxies give the relation (Fig. 3)

$$\mu_e = 2.8(\pm 0.15) \cdot \log(R_e) + \text{const}. \tag{1}$$

Measurements of the central velocity dispersion with a high required precision is a difficult task which cannot practically been performed at present if we deal with many faint distant galaxies. The relation (1) allows to determine galaxy distances on the basis of photometric observations only. Though the error of the individual distance determination is increased, for clusters situation is looked rather hopeful, so far as

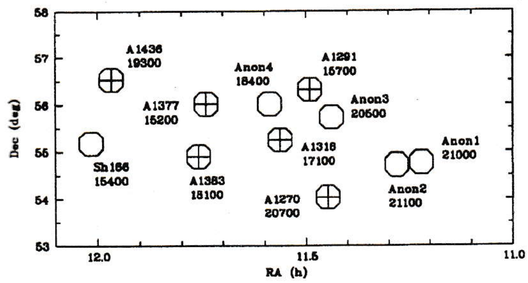

Figure 1: *Supercluster in Ursa Major. (For description see the text).*

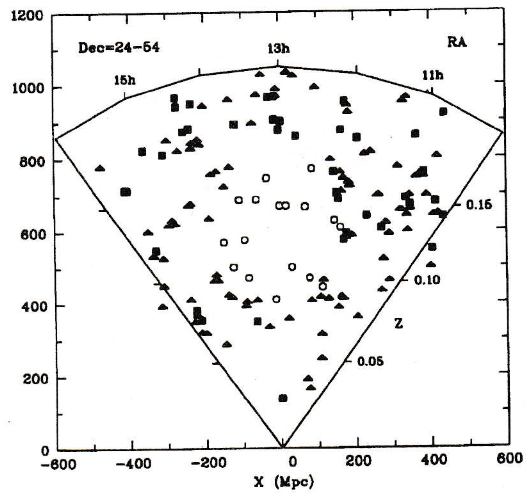

Figure 2: *Distribution of clusters in the vicinity of the giant void.*

it is possible to average by several galaxies (from 5 to 20, on dependence of richness of a cluster) and to obtain the distance for a cluster as a whole with high enough precision.

We have selected for investigation a supercluster of galaxies in Ursa Major (further on UMa) and a giant void in the distribution of clusters of galaxies (further on GV = "Giant Void") discovered on BTA from the observations on the "Northern Cone" programme (Kopylov et al., 1984, 1988). A GV diameter — a maximum diameter of a sphere without clusters of galaxies of richness $R \geq 1$ — is equal to 300 Mpc. A radial velocity corresponding to a centre of the void is about 32000km/s. The redshifts of 13 out of 17 clusters surrounding the void were measured for the first time on BTA.

Fig. 1 shows the distribution of clusters in UMa supercluster in equatorial coordinates. A size of the region shown is 55 × 28 Mpc for a middle velocity of the supercluster of 18000 km/s. A mean radial velocity in km/s and a name are given for each cluster. Clusters from the Abell catalogue are shown by crossed circles and poorer clusters (Baier, 1980; Shectman, 1985) — by circles.

Fig. 2 shows the distribution of clusters at the neighbourhood of GV projected on the plane passing accross the centre of the void. The diagram covers the region of space with coordinates on right ascension $10^h - 16^h$, redshift $z < 0.2$ and opening angle in declination 30^0 (275 Mpc at a distance of 600 Mpc, corresponding to GV centre position). The rich compact clusters observed in the "Northern Cone" programme are shown by filled squares, other Abell clusters of richness $R \geq 1$ by filled triangles, and by circles — 17 clusters (all of richness $R = 1$) being at the distance of 150–200 Mpc from GV centre. For the latter we have determined the photometric distances and estimated peculiar velocities relative to the GV centre.

The observational data (the direct images with R_c filter) have been obtained with the help of 520 × 580 CCD on BTA in 1994–95 years. The mean seeing for GV was equal to 1.″4 (FWHM) and for UMa — 1.″8. The observations on the 1 m Zeiss telescope with an analogous CCD allowed to bring almoust all data to a common photometric scale with an accuracy of better than $0^m.03$. On the 1 m telescope we have obtained the additional data for several bright galaxies too.

The photometric measurements (a synthetic multiaperture photometry) were performed for more than 200 galaxies in 17 clusters around the void and for about 100 galaxies in UMa supercluster. To the measured values of μ_e and R_e cosmological corrections ($\Delta\mu_e \propto (1+z)^4$, the K–correction, an angular to linear size transformation) were applied, that is all data are considered in comoving coordinate system for the "standard" cosmological model ($H_0 = 50$ km$\cdot c^{-1} \cdot$ Mpc^{-1}, $q_0 = 0.5$).

Fig. 3 shows $\log(R_e)$ — μ_e diagram for galaxies in clusters around the GV observed with the BTA and Zeiss telescopes. Filled circles show galaxies with $M_R \leq -22^m.3$, pluses — galaxies with $M > -22^m.3$ and crosses — deviating galaxies which we have not used.

The galaxies with absolute magnitude $M_R \leq -22^m.3$ were used for determination of distances. For each cluster the average value of $C_0 = \mu_e - 2.8 \cdot \log(R_e)$ was calculated, which must be the same for all clusters in the case of an absence of deviations from the Hubble law. The mean error of C_0 taking average on 3-11 galaxies is equal to $0^m.06$ that is about 5% in distance determination.

In our study of UMa supercluster, using the new observational data with better seeing quality, we confirm our previous result (Kopylov and Kopylova, 1996). The supercluster is looked as compact on a projection only. In total radial distances of clusters

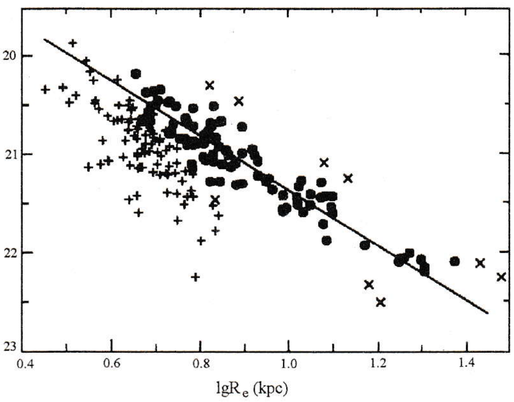

Figure 3: *Kormendy diagram* $\lg(R_e)$ — μ_e *for galaxies in clusters surrounding the void. (For description see the text.)*

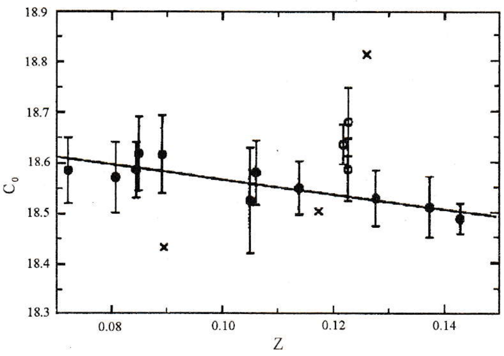

Figure 4: *Relative photometrical distance (average value of zero-point relation (1)) as a function of the redshift for the clusters in the vicinity of the void.*

correspond to their Hubble velocities. It is not excluded that the clusters are grouped into 3 associations with mean velocities of 15900, 18600 and 20800 km/s. Its internal dynamical velocities do not exceed 500–1000 km/s. So, the UMa supercluster is rejected from candidates to the supermassive gravitationally bounded objects.

Fig. 4 demonstrates the main result concerning the void. Here crosses mark 3 clusters with insufficient number of measured galaxies (1–2). For others we used from 3 to 11 galaxies. Three clusters shown by open circles form the supercluster which may have a large peculiar velocity, but so far we have no a reliable photometric calibration for 2 of these clusters which are most strongly deviating. It is necessary to carry out additional control observations for them. For other clusters it is observed a systematic deviation of distances from the Hubble ones: clusters forming the front "wall" of the void lie systematically further, and clusters on the back "wall" lie nearer. A regressional relation for 11 clusters marked by filled circles is

$$C_0 = -1.53(\pm 0.31) \cdot z + 18.720(\pm 0.024) \qquad (2)$$

So, on average, clusters show outward motion relative to the void centre. A total amplitude of the expansion velocity on the scale of 15000 km/s ($\simeq$ 300 Mpc) is equal to 900($\pm$200) km/s not taking into account a luminosity evolution of galaxies. If we take into account the evolution ($\Delta m = -1.2 \cdot z$) then the expansion velocity is lowered to 200 km/s. The observed picture corresponds to a weakly perturbed motion of matter at the neighbourhood of the void, what means that there is a small negative contrast of the total mass density in the void. An investigation of a distribution of such objects as galaxy groups, active galaxies and quasars at the neighbourhood of the void and a comparison with the objects in high density regions is of a great interest.

A method of determination of cluster distances with the help of the Kormendy relation, for the first time used by us in investigations of superclusters and voids, may be applied also for the Tolman cosmological test, to verify that the redshift is an effect of real expansion of the Universe. Up to now we have obtained observational data for 39 clusters, including nearby Coma cluster, in a redshift range of $z = 0.02 - 0.15$. In this task especial care is necessary to examine and take into account evolutionary effects of changing of surface brightness of galaxies.

Acknowledgements. This work has been supported by 93-02-17186 RFBR grant.

References

Baier F.W., 1980, Astron.Nachr., **301**, 17
Djorgovski S. and Davis M., 1987, Astrophys. J., **313**, 59
Faber S. and Jackson R., 1976, Astrophys. J., **204**, 668
Kopylov A.I., Fetisova T.S., Shvartsman V.F., 1984, Astron. Tsirc., No.1344, 1
Kopylov A.I., Kuznetsov D.Yu., Fetisova T.S., Shvartsman V.F., 1988, in: J.Audouse et al.(Eds), "Large Scale Structures of the Universe", 129
Kopylov A.I., Kopylova F.G., 1996, Bull. Spec. Astrophys. Obs., **39**, 44
Kormendy J., 1977, Astrophys. J., **218**, 333
Shectman S.A., 1985, Astrophys. J. Suppl. Ser., **57**, 77