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SOME NEW RESULTS CONCERNING THE STUDY OF THE VIRGO CLUSTER STRUCTURE

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The creation of a new version of MERCG catalogue enriched by the new information, which was reduced to the uniform system in RC3 and transferred together with data from other lists into our catalogue, made it possible to study the structure of the Virgo cluster based on the statistical criterium offered by Anosova. The study of spatial distribution of galaxies in A and B clusters, forming the main concentration of galaxies in the Virgo cluster, made it possible to consider galaxy number density, and velocity and magnitude means for early and late type galaxies in the direction from the center to the periphery. The mean value of galaxy velocities of B cluster appeared to be larger than that for A cluster thus placing it farther. The investigation of distribution of galaxy colors in the areas of A and B clusters revealed statistically significant distinction, expressed in noticeable reddening of galaxies observed in B cluster region, that can be explained possibly with location of HI defficient galaxies in this area of the Virgo cluster.

1. *Introduction*. The considerable growth of observational data on galaxies during the last decades and particularly the publication of RC3 [1], containing a reasonably complete sample of galaxies with apparent diameters larger than 1 arcmin at the D_{25} isophotal level and with the total B - band magnitudes B_T brighter than 15.5 mag. as well as more fainter objects of interest, made it possible to enrich the Merged Catalogue of Galaxies, MERCG [2] with newly determined colors, redshifts and some other data in RC3 with a special effort of inclusion of those values of main galaxy parameters, which were reduced to the uniform scales, for their further use in statistical investigations based on computer. In addition, many other new data were included in MERCG from published lists and galaxy catalogues, noted in References.

The existence of enlarged statistically uniform data in MERCG allowed us to return anew to the problem of studying galaxy distributions in the Virgo cluster.

2. *Description of new galaxy parameters included in the MERCG. Positions*. As equinox 2000.0 has been adopted as the official IAU standard, equatorial coordinates for the equinox 2000.0 were transfered from PGC [3], containing precise coordinates, remeasured for several thousand galaxies. At the same time equatorial coordinates for the equinox 1950.0, derived from the Morphological Catalogue of Galaxies [4] into the MERCG and still commonly used, are also kept.

Designations for galaxies. MERCG contained five designations for galaxies: NGC or IC, MCG, UGC and Mark [5] to have an accurate computer access to the data in the catalogue. Designations of galaxies in the Catalogue of Principal Galaxies (PGC), the most extensive database for 73197 objects, were also added to the list of cross - identifications.

Mean numerical Hubble stage index, <T>. Though morphological descriptions of galaxies are given in MERCG according to several classifications, the revised Hubble morphological type code, T, reduced to a uniform system and with the mean error of about 0.5 was taken from RC3 to be used for statistical studies.

Isophtal diameters and axis ratios. Excellent statistical consistency of isophotal major diameter D_{25} values, derived from visual measurements on photographs and from surface and aperture photometry, favoured the inclusion of the decimal logarithm of diameter D_{25} and decimal logarithm axes ratio R_{25} in MERCG from RC3.

Positional angle. The positional angles of the major axis measured in degrees from north eastward for the 1950.0 equinox were included in MERCG earlier from the UGC catalogue and now were supplemented by new data from RC3.

Corrected photoelectric total magnitude B_T^0. The total "face-on" magnitudes B_T^0 corrected for galactic and internal absorption and for redshift were transfered into MERCG from RC3. Total B_T magnitudes in RC3 were derived on the base of extrapolated values from aperture photometry, checked by magnitudes obtained from detailed surface photometry. For the majority of galaxies total B_T magnitudes in RC3 were derived from the reductions of photographic magnitudes to the B_T system.

Corrected "face-on" total color indices. Total color indices $(U-B)_T^0$ and $(B-V)_T^0$ corrected for differential galactic and internal extinction and redshift were transferred from RC3.

Far-infrared magnitudes m_{FIR}. m_{FIR} values are based on the $f_\nu(60)$ and $f_\nu(100)$ "total" flux densities in Janskys in the IRAS 60 and 100 μm bands in IRAS Point Source Catalog (1987) and were also included in MERCG from RC3.

Surface brightness parameter m_{25}'. The mean surface brightness m_{25}' is given within the ellipse of axes ratio R25 in RC3 and transfered into MERCG.

Neutral hydrogen magnitude m_{21} and linewidth W_{20}. Weighted mean HI line magnitudes m_{21} corrected for beam-filling and reduced to a homogeneous system as well as weighted mean HI linewidth W_{20} in km/s at the 20% level corrected for bandwidth and reduced to a uniform scale were extracted from RC3.

Radial velocities. In RC3, the heliocentric radial velocities derived from the 21-cm line profiles were reduced anew to a uniform system. They are usually much more precise than the optical observations and were preferred in MERCG, with a reference number 309. At the same time the weighted mean galactocentric velocities V_{GSR}, corrected for the solar motion relative to the Local Standard of Rest were also derived from RC3 for most galaxies with known redshifts.

More details on new version of MERCG can be found in Kogoshvili and Borchkhadze [6].

3. *A list of galaxies in the Virgo cluster according to their position in subclusters.* The structure of the Virgo cluster was analysed on the basis of positions and radial velocities of galaxies in the area with $12^h < \alpha < 13^h$ and $2^\circ < \delta < 19^\circ$. Six concentrations of galaxies were clearly emerged applying a generalized statistical criterion of Anosova [7] to the distribution of galaxies in this area.

A list of 540 bright galaxies arranged according to their position in a corresponding subcluster and with detailed information for each object has been compiled based on the data from MERCG and RC3. Most of these objects have their identification number in the catalogue of Virgo cluster galaxies of Binggeli et al [8] and includes their full list of dwarf galaxies.

4. *An analysis of galaxy distribution in subclusters singled out in the Virgo cluster area.* The Virgo cluster still attracts great attention of investigators due to its complex and irregular configuration and relative proximity as well as thanks to the explosive increase of observational data on galaxies in this area. About 1300 members and 500 possible members have been listed in the Virgo Cluster Catalogue by Binggeli et al. [8] selected based on morphological types of galaxies serving as a distance indicator, supplemented by velocity criterion when possible.

A large number of galactocentric velocities, contained in RC3 for galaxies located in the Virgo cluster made it possible to single out several galaxy condensations in the area, covered by this cluster, based on the generalized statistical criterion by Anosova, used previously by the authors in [9].

The present analysis is mainly based on the studies of the Virgo cluster galaxies, having redshifts in RC3.

The main concentration of galaxies in the Virgo cluster having a pronounced double structure and designated as Virgo I cluster by G. de Vaucouleurs and A. de Vaucouleurs [10], consists of two major aggregates, A cluster and B cluster, also identified by de Vaucouleurs [11]. It was denoted as Subcluster I in [9].

Mean galactocentric velocities and dispersions of galaxies according to their morphology are given in Table 1 for the subclusters singled out in the Virgo cluster area.

According to Table 1 the velocity means and dispersions determined for

Table 1

MEAN GALACTOCENTRIC GALAXY VELOCITES AND DISPERSIONS FOR THE VIRGO CLUSTER SUBCLUSTERS

Number of Subclusters	<V> all	σ	n	<V> E+SO	σ	n	<V> S+Irr	σ	n
Subcluster 1 A cluster	680 ±48	573	147	849 ±62	527	72	517 ±66	568	75
Binggeli et al. [12]	1061 ±83	760	83						
Subcluster 1 B cluster	865 ±42	376	81	825 ±80	356	21	879 ±50	381	60
Binggeli et al. [12]	963 ±81	390	23						
Subcluster 2 South.Extn.	1185 ±44	393	81	1158 ±98	340	14	1144 ±61	374	39
Subcluster 3 Cluster W	2224 ±34	240	50	2323 ±52	187	14	2177 ±56	252	21
Subcluster 4	1989 ±35	222	42	1902 ±44	147	12	2114 ±68	245	14
Subcluster 5	1711 ±124	619	26	1304 ±164	401	7	1722 ±185	584	11
Subcluster 6 Cluster M	2111 ±49	247	26	2184 ±14	320	6	2158 ±74	236	11

galaxies in A and B clusters differ from the corresponding values derived in the work by Binggeli et al [12]. But the principal difference was found for the velocity mean of A cluster, which appeared to be less than the corresponding value for A cluster in [12].

The greater value of velocity mean for A cluster in [12] can be mostly due to a contribution from the background galaxies in the extended outer regions of the Virgo cluster, which were included into counts on the basis of a morphological criterion used in the work. In the present study the condensation of background galaxies, denoted as Subcluster 4, was singled out based on the statistical cluster method in the area behind the Virgo cluster with <V> of about 2000 km/s and a small dispersion of about 220 km/s, that could be an indication of its dynamical relaxation. The exclusion of these galaxies from counts in A cluster decreases the velocity means of galaxies. Besides, a large number of galaxies with small velocities from RC3 were also included in the samples under study.

Thus, according to velocity means shown in Table 1 B cluster seems to be more distant than A cluster. The suggestions that B cluster is more distant than A cluster by 0.4 mag and then by 0.46 mag were pointed previously by de Vaucouleurs [13] and Huchtmeier [14].

It should be noted that the velocity dispersion of early type galaxies doesn't distinguish noticeably from that of late type galaxies in A cluster and, besides, a smaller dispersion $\sigma = 376$ km/s is derived for all galaxies in B cluster compared to A cluster.

Binggeli et al [12] used strip counts and radial projected galaxy density in their study of surface distribution of the Virgo cluster galaxies.

Based in our study on the enlarged statistics of galaxy velocities there was investigated the radial spatial distribution of galaxies according to their morphology in A and B clusters. Counts of galaxies were carried out from the center outwards in consecutive concentric shells outlined by spherically truncated cones in the velocity space.

The relative numbers of galaxies n_{i+1}/n were counted for early and late types separately in a fraction of volume occupied by the shell in the total volume of the A cluster $\left(V_\sigma^{i+1} - V_\sigma^i\right)/V_\Sigma$, where V_Σ is the total volume of the studied cluster and V_σ^i corresponds to the volumes of consecutive cones with i varying from 0 to k.

All the shells are centered on $\alpha = 12^h25^m$, $\delta = +13°$ and $V = 900$ km/s for early and $V = 700$ km/s for late galaxy types in A cluster and on $\alpha = 12^h25^m$, $\delta = 8°11'$ and $V = 900$ km/s for B cluster.

Tables 2 and 3 present the relative spatial density of galaxies ρ_i, galaxy number n, velocity $\langle V \rangle_i$ and absolute magnitude $\langle M_{B_T} \rangle_i$ means with their dispersions in the consecutive shells around the A and B cluster centers. The analysis of Table 2 shows a concentration of early type galaxies towards the A cluster center with a small velocity dispersion. However this distribution doesn't represent a smooth function of radial distance.

Table 2

THE RELATIVE GALAXY NUMBER SPATIAL DENSITIES, VELOCITY AND ABSOLUTE MAGNITUDE MEANS IN CONSECUTIVE SHELLS AROUND A CLUSTER CENTER

$B_i = V_\sigma^i / V_\Sigma$	0.013	0.11	0.33	0.78	1
			E+S0 galaxies		
ρ_i	2.26	2.27	1.06	0.59	0.10
n_i	5	16	17	19	15
$\langle V \rangle_i$	777±32	970±67	1044±98	905±122	451±193
σ	64	259	393	518	721
$\langle M_{B_T} \rangle_i$	18.51±0.93	-18.42±0.57	-18.01±0.46	-18.37±0.42	-17.78±0.57
σ	1.87	2.23	1.86	1.79	2.12
			S+Irr galaxies		
ρ_i	0.6	2.42	1.09	0.86	0.68
n_i	1	18	18	29	11
$\langle V \rangle_i$	681	597±80	598±128	483±129	379±178
σ		329	529	682	564
$\langle M_{B_T} \rangle_i$	-18.61	-17.29±0.49	-17.79±0.60	-18.17±0.37	-17.94±0.48
σ		2.03	2.48	1.96	1.5

Early type galaxies form several condensations in A clustar, namely, a central condensation around M84 with density $\rho=2.26$, the peak of galaxies containing M87 with density $\rho=2.27$ and a cloud of galaxies around M59, designated as "C cloud" elsewhere with $\rho=0.59$. This nonuniformity is well emphasized by rather enlarged values of the absolute magnitude means in the corresponding shells, though the segregation of E+S0 galaxies by luminosity from the center of A cluster to its periphery is clearly expressed.

The increase of E+S0 galaxies velocity means from the center outwards is replaced by their decrease in the outlying shells due to the presence of an excess number of galaxies with small and negative velocities.

The mean values of velocities for early and late type galaxies differ considerably, with larger velocity dispersion for late types (cf. Table 1). This result confirms the suggestion stated by de Vaucouleurs [10] on type-dependence of mean velocities. Early and late type galaxies show as well different spatial distributions: noticeably concentrated for E+S0 types and considerably dispersed for spirals and irregulars. The irregularity in late type galaxy velocities and absolute magnitude distribution, evident from their mean values in Table 2, was explained by Tully and Shaya [15] as a result of existence of oscillating shells of S and Irr galaxies around the cluster core.

B cluster is a smaller condensation of galaxies around M49 compared with A cluster and is populated mainly by late types and less number of strongly concentrated early types. Decrease in velocity and magnitude means from the center outwards is noted for both types of galaxies. The most striking feature

Table 3

THE RELATIVE GALAXY NUMBER SPATIAL DENSITIES, VELOCITY AND ABSOLUTE MAGNITUDE MEANS IN CONSECUTIVE SHELLS AROUND B CLUSTER CENTER

$B_i = V_\sigma^i / V_\Sigma$	0.02	0.18	1
E+S0 galaxies			
ρ_i	11.4	2.43	0.40
n_i	5	9	7
$\langle V \rangle_i$	915±52	885±80	682±214
σ	105	227	524
$\langle M_{B_T} \rangle_i$	-18.83±0.80	-17.96±0.61	-17.55±0.80
σ	1.61	1.73	1.96
S+Irr galaxies			
ρ_i	8.1	1.98	1.04
n_i	10	21	29
$\langle V \rangle_i$	930±38	989±56	781±91
σ	115	249	482
$\langle M_{B_T} \rangle_i$	-17.75±0.34	-17.11±0.45	-16.92±0.28
σ	1.03	2.01	1.46

of B cluster is its small dispersion and closeness of velocity means for both morphological types. Despite its small dimensions this cluster represents all feature of regular clusters.

5. ***An analysis of galaxy color distribution in subclusters in the Virgo cluster area.*** A considerable number of "face-on" total $(B-V)_T^0$ color indices in RC3 for galaxies in the Virgo cluster made it possible to compare their distribution separately for A and B clusters composing together a "low-velocity" cluster and differing by morphological content and velocity dispersion of galaxies.

In Table 4 mean values of $(B-V)_T^0$ colors, radial velocities, numbers of galaxies and color excesses for E, S0, early S and late S types in A and B clusters are presented.

Mean weighted value of color excesses calculated for both A and B clusters turned out to be 0.053 ± 0.015 with a mean weighted difference of radial velocities $\Delta V = 201 \pm 79$ km/s. Thus it was noted a reddening effect of galaxies in B cluster in distinction from A cluster.

Table 4

GALAXY $(B-V)_T^0$ COLOR DISTRIBUTION IN A AND B CLOUDS

Subcluster	A			B			
Morphol. type	$<(B-V)_T^0>$	$<V>$	n	$<(B-V)_T^0>$	$<V>$	n	Color Excess
E	0.88±0.016	959±92	20	0.93±0.016	1042±111	6	0.05±0.02
S0	0.84±0.019	980±83	23	0.87±0.015	982±188	7	0.03±0.02
Early S	0.73±0.027	556±165	17	0.81±0.044	878±195	7	0.08±0.05
Late S+Irr	0.48±0.036	458±111	17	0.62±0.028	1049±81	9	0.12±0.04

The value of color excess increases if the galaxies from the more distant subclusters, projected upon the studied A and B clouds are considered together with them. In particular, B cluster was studied with subcluster 3 (W cloud) and A cluster with subclusters 4,5,6 [9], the latter designated as M elsewhere. The above mentioned values, based on the enlarged samples of galaxies for the mentioned areas are given in Table 5.

Mean weighted value of color excess becomes now $\delta = 0.072 \pm 0.013$ and point to the statistically significant difference in galaxy colors observed for two areas, covered by A and B clouds in the Virgo cluster. The difference of mean weighted velocities reaches the value $\Delta V = 348 \pm 110$ km/s for this areas.

How can be explained the effect of reddening of galaxies contained in B and W clouds compared to the rest part of the Virgo cluster?

The majority of investigators consider the Virgo complex to be a young object still in the process of formation, showing signs of interaction with intergalactic medium, for instance, the presence of strongly HI defficient spirals [15].

6. ***Conclusions.*** MERCG was enriched by new photometric observa-

Table 5

GALAXY $(B\text{-}V)_T^0$ COLOR DISTRIBUTION IN ENLARGED SAMPLES FOR A SND B SUBCLUSTERS

Subcluster	A			B			
Morphol. type	$<(B\text{-}V)_T^0>$	$<V>$	n	$<(B\text{-}V)_T^0>$	$<V>$	n	Color Excess
E	0.87±0.017	1166±125	24	0.94±0.015	1197±182	7	0.07±0.022
S0	0.83±0.014	1143±89	31	0.89±0.014	1765±184	17	0.06±0.020
Early S	0.70±0.025	1020±169	27	0.82±0.038	1378±250	11	0.12±0.046
Late S+Irr	0.49±0.036	854±178	23	0.59±0.027	1457±145	16	0.10±0.045

tional data reduced to the uniform system in RC3 and taken from this catalogue and other published lists for the further use in statistical investigations.

The analysis of A and B clusters, forming the main concentrations of galaxies in the Virgo cluster and singled out based on the generalized statistical criterium of Anosova, showed lower velocity means and lower dispersions for all galaxy types in A cluster due to the exclusion of background galaxies from it and thus having made B cluster more distant than A cluster.

Based on the $(B-V)_T^0$ data from RC3 there was noted a statistically significant color excess of 0.072 ± 0.013 mag for galaxies of all types, more pronounced for spirals in the B cluster area compared to galaxies in the area of A cluster. The found effect can be connected with the presence of strongly HI defficient spirals.

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НЕКОТОРЫЕ НОВЫЕ РЕЗУЛЬТАТЫ, КАСАЮЩИЕСЯ ИЗУЧЕНИЯ СТРУКТУРЫ СКОПЛЕНИЯ ДЕВА

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Подготовка новой версии Абастуманского Сводного каталога галактик в компьютерной форме, обогащенного наблюдательной информацией, приведенной к однородной системе в каталоге RC3 и перенесенной в него вместе с другими списками галактик, позволила использовать богатый фотометрический материал для изучения распределения галактик в подскоплениях, выделенных из скопления Дева с помощью статистического

метода Аносовой. Исследование пространственного распределения галактик в А и В подскоплениях, представляющих собой основные сгущения галактик в скоплении Дева, позволило изучить распределения плотности числа галактик, средних значений скоростей и абсолютных величин галактик различных морфологических типов от центров А и В подскоплений к периферии. На основе изучения ~250 скоростей галактик в этих подскоплениях оказалось, что подскопление В расположено дальше подскопления А, а средние значения скоростей оказываются зависимыми от морфологического типа галактик. Изучение показателей цвета для галактик, расположенных в областях неба занимаемых А и В подскоплениями показало статистически значимое отличие, свидетельствующее о большем покраснении галактик, отмеченных в В подскоплении, связанного, возможно, с наличием в этой области скопления галактик позднего типа с дефицитом водорода HI.

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