ACADEMIC RESEARCH IN EDUCATIONAL SCIENCES VOLUME 2 | ISSUE 3 | 2021
ISSN: 2181-1385
Scientific Journal Impact Factor (SJIF) 2021: 5.723
DOI: 10.24411/2181-1385-2021-00516

ON THE STATES OF EVOLUTION OF RICH CLUSTERS OF GALAXIES

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ABSTRACT

It is found the values of the anisotropy velocity parameter for 40 rich clusters of galaxies based on observations of visible surface density. The correlation of this parameter with other characteristics of rich clusters of galaxies has been studied.

Keywords: clusters, galaxies, rich, anisotropy, evolution.

INTRODUCTION

Rich clusters of galaxies are among the most massive gravitationally bound systems in the Universe. The statistical properties of clusters give very strong restrictions on the cosmology of galaxies [1,2]. Statistical studies of these clusters provide powerful constraints primarily on cosmological parameters [1] through the mass function [3-8]. These clusters are also important for studying the evolution of galaxies in a dense environment [9-11] and as a natural telescope for studying high redshifts of galaxies [12-15]. In the ΛCDM cosmological model, galaxy clusters are created by density perturbations on large scales [16]. Subsequent work can be seen in a certain sense of problems solving the classification of RCG. In Abel's work [18], where the classification of RCG according to the class of wealth is proposed. Zwicky [19] classifies clusters compact, medium compact, and open (scattering). In [20], the Bautz-Morgan classification was developed to classify clusters of galaxies depending on their morphology. In this way, the authors were able to identify certain clusters that are not isolated, but pass continuously onto each other. As you can see, this approach is also difficult to apply in practice and does not lead to a solution to the problem of classification of RCG.

Hitherto, the analysis of observational data for all RCGs has not been performed and the corresponding theory of their formation has not been developed. More specifically, we note that there is no extended list-catalog of RCGs and a statistical analysis of all known RCGs in order to search for their general physical properties, classification of RCGs according to individual physical parameters has not been performed, a theory of the origin of these systems has not been built, explaining the observational data on them, in particular. The study of RCG is also of great interest

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due to the fact that these objects can be used as indicators of physical state and evolution. All this suggests that the study of RCG is one of the urgent tasks of modern astrophysics.

CALCULATION OF THE ANISOTROPY PARAMETER

In this study, we analyze the RCG anisotropy parameter from SDSS DR8 (Sloan Digital Sky Survey). The current circumstance forces us to introduce new parameters for the RCG. One of them, in principle, can be the velocity anisotropy parameter. And it is defined by different authors in different ways: as a simple ratio of the average values of the components of the kinetic energy of radial and transverse movements $2<\mathrm{T_r}>/<\mathrm{T_\perp}>$, or how $1-\sigma_r^2/\sigma_t^2$, where σ_r^2 and σ_t^2 – are the radial and transversal components of the velocity dispersion. Below we take the value

$$A=\frac{(2\overline{\Pi^2}-\overline{T^2})}{\overline{\Pi^2}} \qquad (1)$$

introduced for the first time in [17] as the velocity anisotropy parameter. Where $\overline{\Pi^2}$ and $\overline{\mathrm{T}^2}$ are the radial and transversal components of the velocity dispersion, respectively. As in [17], we assume it to be constant for the entire system as a whole, although in reality it should depend on the distance inside the cluster. We are interested in this parameter here, first of all, from the point of view of its possible dependence on other physical characteristics of the RCG, although it is also of independent interest. The point is that the anisotropy parameter is convenient for analyzing the stage of RCG evolution, because each stage is characterized by a certain structure and distribution of density and velocity. With the transition from an early stage to a later one, the structure becomes smoother and tends to a more isotropic distribution of velocities (in contrast to the radially elongated distribution in the early stages). The value of the velocity anisotropy parameter A = 0 corresponds to a spherical velocity distribution (mainly the late stage of evolution), A = 2 corresponds to a radially elongated distribution (a rather early stage of the system evolution).

To determine the velocity anisotropy parameter in the RCG from the observations of apparent surface density, we will consider a stationary model with spherical symmetry. It is easy to derive the following equation

$$\frac{d}{dr}\left[\frac{r^2}{D}\frac{d}{dr}\left(\mathrm{D}\,\overline{\Pi^2}\right)+\left(2\overline{\Pi^2}-\overline{T^2}\right)r\right]=-4\pi GDr^2, \qquad (2)$$

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excluding potential in the hydrodynamic equation using the Poisson equation. The dimensionless density D was introduced in (2). If we will use the new variable $x = 4\pi Gr/\overline{\Pi^2}$ then equation (2) will take a relatively simple form:

$$\frac{d}{dx}\left(\frac{x^2}{D}\frac{dD}{dx}\right) = -Dx^2 - A. \quad (3)$$

Solving equation (3) numerically, we obtain the dependences of D and $D' = \frac{dD}{dx}$ by x, and the dimensionless density D clearly depends on the value of the anisotropy parameter. We solve equation (3) for various values $A \in [0; 2]$. From the known values of D and D^I we can go to the surface density, i.e. to the projection of spatial density on the picture plane. Next, we calculate the surface density using the expression

$$F(r) = -A\int_{r/\alpha}^{\infty} \sqrt{x^2 - (r/\alpha)^2}\, D'(x)\, dx. \quad (4)$$

Obtaining the corresponding values of the surface density $F(r)$ for the given values of the anisotropy parameter and comparing them with the observed surface densities for specific systems, we choose the optimal value A. The scale factors are determined by minimizing the difference between the observed and theoretical densities. Based on the physical nature of this problem, it is convenient to use a sufficiently proven symplectic method of minimizing the following function

$$f = \sum_{i=1}^{N}\left[-A\int_{r_i/\alpha}^{\infty} \sqrt{x^2 - (r_i/\alpha)^2}\, D'(x)\, dx - F_0\right]^2 \quad (5)$$

by parameters α, A and F_0. Here N - is the number of circular zones on photographic plates (or images) in which the number of stars was calculated. Thus, the value of the anisotropy parameter, which gives a minimum of f, is taken as the most probable value of A.

We have calculated the values of the parameter A for 40 RCG using the simplex method of minimizing the square of the difference between the theoretical and the observed density function.

Table 1. Results of calculation Anisotropy parameter

№	RCG name	rm	R_{L*}	z	A
1	J000158.5+120358	15,91	88,24	0,2086	0,36
2	J001248.9-085535	17,79	109,05	0,3404	0
3	J001737.6-005242	17,25	50,03	0,2161	0
4	J001938.7+033557	16,75	118,68	0,2685	0,2
5	J001941.3+251807	18,45	122,25	0,3684	0,04

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6	J002008.5+345118	18,24	88,33	0,4539	0,04
7	J002016.1+000446	16,73	104,6	0,2156	1,88
8	J002037.2+283934	14,2	75,39	0,0979	0
9	J002800.9+244744	18,79	73,5	0,4839	0,72
10	J003321.6+102726	17,75	74,12	0,4499	0
11	J005403.1+201340	16,91	75,95	0,2793	0,16
12	J010005.1+141543	16,62	66,5	0,1854	0,08
13	J015242.0+010026	15,59	146,9	0,2332	1,8
14	J023952.7-013419	17,73	144,92	0,3712	1,84
15	J085007.9+360414	18,33	117,09	0,3639	1,84
16	J091753.4+514338	16,08	173,82	0,2161	1,76
17	J094951.8+170711	17,88	133,91	0,4124	0,12
18	J100226.8+203102	18,08	141,21	0,3376	0,08
19	J105417.5+143904	17,18	135,02	0,2956	1,8
20	J111450.3-121351	16,1	150,92	0,1926	0
21	J112358.8+212850	16,78	108,06	0,1907	1,84
22	J121218.5+273255	17,39	109,48	0,3426	0,04
23	J122902.5+473721	17,03	127,66	0,2467	1,8
24	J131129.5-012028	15,69	168,86	0,1791	0
25	J131505.2+514903	16,76	130,18	0,2838	1,8
26	J133238.4+503336	17,33	185,14	0,2775	0
27	J133520.1+410004	16,37	176,94	0,2304	0,08
28	J140102.1+025242	16,06	205,45	0,2615	1,76
29	J144431.8+311336	16,65	87,06	0,234	0
30	J153940.5+342527	16,95	135,85	0,2254	0
31	J160319.0+031645	16,67	156,13	0,2383	0
32	J164019.8+464242	16,55	181,34	0,2301	1,76
33	J172227.2+320757	15,26	232,49	0,2212	0,28
34	J212823.4+013536	17,77	144,58	0,3857	0,32
35	J215608.6+012327	15,75	106,38	0,2219	1,84
36	J230800.7-015543	17,74	168,55	0,3208	1,88
37	J231133.2+033804	17,47	127,58	0,3112	0,08
38	J233352.4+070454	17,39	128,4	0,2958	0,72
39	J233739.7+001617	17,23	139,54	0,3042	0,32
40	J230800.9-015541	17,75	168,63	0,3208	0,04

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It can be seen from the table that for most clusters we have values of the anisotropy parameter close to zero, and so on. over 63% of BSGs have an almost spherical distribution of velocities, and they are probably at a later stage of evolution. Note that it is for the found values of the anisotropy parameter that the corresponding theoretical results are in good agreement with the observational functions of the surface density. For 13 clusters, the values of the velocity anisotropy parameter strongly differ from zero and close to 2. Therefore, the distribution of velocities in these clusters corresponds to the radially elongated case, which may be due, probably, to their nonstationary in a regular field.

Is it possible to classify RCG by the parameter of velocity anisotropy? For this purpose, first of all, comparing the values of the RCG anisotropy parameter, we note that they can be confidently divided into three classes:

Table 2. The average values of the main characteristics of the three RCG groups

Classes	A	Quantity RCG
RCG 1	0< A<0.5	25
RCG 2	0.5< A<1.5	2
RCG 3	1.5< A<2	13

Note that in the interval 1.0 <A <1.5 there is not a single RCG, and this requires searching in the future of additional data on the visible density of RCG. Nevertheless, it is interesting to compare the average values of the basic physical parameters of the three RCG classes.

Table 3. The average values of the main characteristics of the three groups of RCG

Classes	<z>	<rm> [mag]	$<r_{200}>$ [Mpc]	$<R_{L*}>$	$<r_0>$ [Mpc]
RCG 1	0,283	16,97	1,88	125,07	0.41
RCG 2	0,389	18,09	1,73	100,95	1.06
RCG 3	0,265	16,79	2,02	145,45	0.19

In tab. 3. The average values of a number of characteristics of the specified RCG groups are given: a photometric red shift - <z>, the magnitude of the brightest member in the X-ray range is - <rm>, the radius, within which the average density of the

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accumulation is 200 times higher than the critical density of the Universe - $<r_{200}>$, cluster richness - $<R_{L*}>$ [21], cluster kernel radius - $<r_0>$.

It is also noted the results of our calculations of the values of the correlation coefficient of the anisotropy parameter A with well-known data on other physical characteristics, according to which, in principle, one can make one-dimensional classification. Unfortunately, these values of the coefficient are small and there is no possibility of creating a two-dimensional classification.

Correlation coefficients were found between the following parameters: 0.205 for $A \div R_{L*}$, 0.32 for $A \div r_{200}$, -0.357 $A \div r_0$, -0.086 for $A \div z$, -0.089 for $A \div rm$.

CONCLUSIONS

According to the observation of surface density distribution in RCG, the values of the anisotropy parameter of the speed dispersion for 40 RCG are defined. It has been analyzed the problem of the RCG classification by us. An analysis of these observations on RCG from SDSS DR8 is performed. An analysis of the problem of classifications RCG has been performed. A classification of RCG was developed according to the parameters of the anisotropy of speeds and the degree of concentration of galaxies to the center of clusters. Based on the parameters of the anisotropy of RCG, three clearly distinguish groups are divided into three.

Next, it is planned to continue the calculation of the value of the parameter of the anisotropy of speeds and for a number of other RCG, as well as to analyze the degree of concentration of the cluster.

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