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A BRIEF OVERVIEW OF RICH GALAXY CLUSTERS

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Abstract. This article provides an overview of rich galaxy clusters. Galaxy clusters are systems of galaxies containing from several hundred to several tens of thousands of individual galaxies of various types. Presented herein are the results of only some articles and several important areas of research into galaxy clusters. The main observational studies and their results are included herein as well. A number of properties of rich galaxy clusters discovered to date are presented. The problem of the lack of generally accepted criteria for the richness of galaxy clusters is raised. Also, the existing theories of the origin of galaxy clusters are presented.

Key words: galaxy clusters, regular, irregular, richness, classification, theories of origin

I. INTRODUCTION

Galaxy clusters are the most massive gravitationally bound formations in the Universe [see, for example, 1-5]. They also contain hot ionized intergalactic gas and dark matter. The masses of galaxy clusters are 10^{13}–10^{15} solar masses, with the bulk of the mass usually being dark matter. The second largest mass is intergalactic gas, and only the third largest mass is the galaxies themselves. The typical size of massive galaxy clusters is about 10 million light years. The velocities of galaxies within a cluster are usually 1–2 thousand km/s. The masses of galaxy clusters are determined by measuring the spread of the velocities of individual galaxies relative to the average value, or by the temperature and distribution of the hot gas filling the cluster.

Galaxy clusters are usually divided into regular and irregular. Regular clusters are characterized by a more clearly expressed concentration of galaxies toward the center, higher density and mass, and, as a rule, are significantly more massive than irregular ones. Most members of regular clusters are galaxies with zero or very weak star formation (elliptical and lenticular galaxies), while irregular clusters of galaxies contain many spiral and irregular galaxies with active star formation in them. This difference indicates the influence of the denser environment of galaxies and the intergalactic gas in which they move on the evolution of galaxies. Many thousands of galaxy clusters at various distances are accessible to observation. The nearest irregular cluster of galaxies is in the constellation of Virgo (Virgo Cluster) at a distance of about 50 million light years. Its visible diameter is about 12 (which roughly corresponds to a linear diameter of 8 million light years), and the brightest galaxies in the cluster are visible as objects of the $9^{th} - 10^{th}$ stellar magnitude. The nearest massive regular cluster of galaxies is observed in the constellation Coma Berenices (Coma Berenices Cluster) at a distance of about 300 million light years. It contains more than 10 thousand galaxies, half of which are concentrated in the central region with a diameter of about 1.5, which corresponds to 8 million light years, but the cluster itself extends much further. The center of galaxy clusters often contains very massive elliptical galaxies of gigantic size, which acquired their large mass and size due to merging with other, smaller, galaxies of the cluster. Many of them have active nuclei.

A significant part of the substance of galaxy clusters is hot intergalactic gas with a temperature of tens of millions of degrees. Despite the very low density of the gas (particle concentration of $100 - 1000m^{-3}$), its glow is reliably recorded by X-ray space telescopes. Therefore, almost all "rich" galaxy clusters are X-ray emitters with luminosities of the order of 10^{35}–$10^{37}W$. Many tens of thousands of massive galaxy clusters are potentially accessible to observation.

Compared to the interstellar gas inside galaxies like ours, the intergalactic gas in clusters is depleted by heavy chemical elements. However, in a number of galaxy clusters, lines of multiply ionized iron atoms have been recorded in the X-ray spectrum, which indicates that some of the gas has undergone nuclear processing in stars and, apparently, has been ejected from the galaxies. The gas in clusters also manifests itself by a slight distortion of the spectrum of the relic radiation passing through it. This distortion occurs due to the scattering of relic radiation photons by free electrons of the gas (the Sunyaev-Zeldovich effect).

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Many distant galaxy clusters have been discovered solely due to this effect. Analysis of manifestations of the Sunyaev-Zeldovich effect is important for testing various cosmological models.

Spiral galaxies observed in the inner regions of clusters usually have a reduced content of interstellar gas. An effective mechanism for the loss of gas by a galaxy is the gas-dynamic "head-on" pressure of the intergalactic gas flow, "blowing" at high speed around the galaxy that moves in it. This pressure affects the cooler interstellar gas of the galaxy, partially "blowing" it out of the disk. This process is directly observed in some galaxies of clusters. Other possible causes of the reduced gas content are: slowing down or cessation of gas accretion from the galactic halo onto the disk, associated with intergalactic gas "blowing" around the galaxy; gas losses during tidal interactions of the galaxy with other cluster members; and accelerated gas consumption for star formation due to the pressure of the hot gas environment on the gas layer in the galactic disk.

The evolution of a galaxy cluster can be studied by comparing distant and nearby clusters, since due to the finite speed of light, the further away the cluster, the further back in time we observe it. In distant clusters, a significantly larger proportion of galaxies are actively forming stars than in clusters close to us. Both regular and irregular galaxy clusters are old, but their formation is not yet complete. Individual galaxies and even groups of galaxies can fall onto galaxy clusters from nearby regions attracted by gravity, adding new members to the clusters. Large galaxy clusters are connected in space by chains of small clusters and individual galaxies, forming a cellular large-scale structure of the Universe.

II. OBSERVATION DATA

Many observational studies have been published on galaxy clusters. The paper [1] compiled a catalog of 2712 rich galaxy clusters discovered during the Palomar Observatory sky survey. From the catalog, 1682 clusters were selected that met certain criteria for inclusion in a homogeneous statistical sample. The authors made the following conclusions from the studies: (1) the cluster richness distribution function N(n) increases rapidly with decreasing n; (2) the data do not allow a significant conclusion about the changes of spatial density of cluster centers with distance; (3) galactic darkening of the order of several tenths of a stellar magnitude exists at high northern galactic latitudes around 300 galactic longitude; (4) there is a very significant nonrandom surface distribution of clusters, both when clusters are located at all distances and when clusters at different distances are considered.

In [6], the authors examined rich clusters of galaxies. They showed that several rich clusters move through the Universe at speeds of thousands of kilometers per second. The high speed of these galaxies and their dense distribution in the Universe mean that they are bound together by gravitational forces much greater than those that can be explained by visible mass, that is, the mass represented by objects visible on photographic plates. The researchers conclude that the giant galaxy M87, located near the center of a large cluster in the constellation of Virgo, may have a black hole with the mass of five billion suns in its core.

The authors of [2] compiled a catalogue of 4073 rich galaxy clusters. Each cluster contains at least 30 members. The data were collected from a study of cluster plates. A revised catalogue is also provided, including Bautz-Morgan types [7] and redshifts. The rich galaxy clusters that are fundamental components of the large-scale structure observed in the Universe were investigated in [8]. A comparison of high-redshift z and low-redshift z clusters shows that they have undergone significant evolution in recent times, both in dynamics and in galaxy subpopulations. However, there is an evolutionary gap of $\simeq$2 billion years in the observations of clusters during the important transition epoch between these two extremes. The LARC (LCO/AAT Rich Cluster) study is to fill this gap using a combination of high-resolution X-ray, optical and spectroscopic data of clusters in the redshift range $0.07 \leq z \leq 0.16$. Based on these data, the authors will conduct a detailed analysis of the cluster dynamics and the evolutionary history of the galaxies that comprise them.

In a number of works [9-15] the authors studied individual clusters of galaxies. For example, in [12] the cluster A1569 was studied, as well as the neighboring cluster A1589, which together with A1569 forms a pair (supercluster) with a projection size of about 10 Mpc. The authors identified two subsystems in the cluster A1569: A1569A (cz=20613 km/s) and A1569B (cz=23783 km/s). These subsystems, with a radial velocity dispersion of 484 km/s and 493 km/s, have dynamic masses 1.8×10^{14} and $2.0 \times 10^{14}\ M_{sun}$ within the radius of R_{200}. The authors also obtained estimates of direct distances to the subsystems in early-type galaxies using the Kormendy relation, the photometric plane, and the fundamental plane. The authors found that the A1569 cluster consists of two independent clusters.

The paper [13] presents the results of measuring and comparing the masses of a sample of 29 galaxy groups and clusters ($z < 0.1$). To measure the dynamic masses based on the one-dimensional radial velocity dispersion for virialized regions with a radius of R_{200} and R_e, the archive data of SDSS DR7 were used. The authors developed a method for determining the effective radius of galaxy systems based on the integral distribution of the number of galaxies depending on the square of the distance from the center. This method made it possible to estimate the masses of $M_{1/2}$ (within Re), which are connected with the masses within a region with a radius of R_{200}: $M_{200} \sim 1.65 M_{1/2}$. A comparison of the obtained dynamic masses and hydrostatic masses measured from the emission of hot gas from groups and clusters (secondary data) allowed the authors to conclude that for the main sample of 21 clusters and groups, the masses correlate within 12%. Also, the authors apply the relationship $M_{X,200} \sim 1.65 M_{1/2}$ for these systems. The remaining eight galaxy clusters, mostly located in the Hercules supercluster region,

are shown to exhibit mass discordances with deviations from the mean of up to 2σ. The authors suggest that this is due to the incomplete formation of these galaxy clusters through hierarchical merging in the rich Hercules supercluster region.

[14] studied the nearest surroundings ($R < 3R_{200c}$) of 40 groups and clusters of galaxies in the local Universe ($0.02 < z < 0.045$ and $300km/s < \sigma < 950km/s$). The authors determined the stellar mass of galaxy clusters corresponding to the Ks-luminosity based on the SDSS DR10 catalog data. They also found the relation between the stellar mass of galaxy clusters and the halo mass. They found that the fraction of galaxies with suppressed star formation ($M_K < -21.^m5$) is maximum in the central regions of galaxy clusters and equals, on average, 0.81±0.02, whereas outside the radius found by them from the observed profile in the Rsp projection ($2 < R/R_{200c} < 3$) it decreases to 0.44±0.02, but remains higher than within the field by 27%. They show that the proportion of early-type galaxies of the "red sequence" decreases from 0.54±0.02 in the center to 0.24±0.01 outside R_{sp}, as compared with its value in the field.

In [15], the properties of galaxies with suppressed star formation (QGs) within the splashback radius Rsp of galaxy clusters and beyond were investigated using the SDSS catalog data. The authors used a sample of 40 groups and clusters of galaxies and a sample of the galaxies of the field at $0.02 < z < 0.045$. They found the Rsp radii from the observed integral distribution of the number of galaxies as a function of the square of the distance from the center of the galaxy systems. They show that 72% of the QGs found in galaxy clusters are within Rsp. About 40% of these galaxies are late-type galaxies with $fracDeV < 0.8$. About 80% of galaxies with suppressed star formation have stellar masses in the interval $lgM_*/M_{sun} = [10; 11]$. The authors found that late-type QGs and, to a lesser extent, early-type QGs have maximum angular radii $R_{90,r}$ and $R_{50,r}$ near the splashback radius of galaxy groups and clusters. The results obtained by the authors confirm the assumption that in the filaments directed toward clusters, QGs near their boundaries are more massive than on the periphery.

The paper [16] published a catalogue presenting the distribution of about 6000 galaxies in 55 rich clusters by morphological classes. The paper [17] presents the results of a study of approximate members of 351 Abell clusters with an apparent magnitude of 10m and publishes a catalogue of 115 new clusters and 17 new superclusters. The paper [18] performed a spectroscopic analysis of 286 rich clusters previously identified based on observations with the DuPont telescope at the Las Campanas Observatory. The paper [19] studied the radioactive members of the Abell cluster and compiled a catalogue of 150 clusters based on X-ray and radio parameters. And the paper [20] processed images from the SDSS-III project and identified 132684 galaxy clusters, with more than 95% of these clusters having masses $M_{200} > 10^{14}M_{sun}$. In [21] the dynamic properties of 2092 rich galaxy clusters were studied based on X-ray, optical and radio data. In [22] the masses of 1191 clusters were provided, and, in addition, the data given in [20] were updated and/or supplemented. In [23] the main physical characteristics of 275 rich clusters were given, including their masses.

III. ON THE RICHNESS OF GALAXY CLUSTERS

At present, galaxy clusters have been well studied and a number of research results have been obtained on them. However, the term "richness of galaxy clusters" has not yet been specifically explained. Observers face the following questions: what is the richness of galaxy clusters? How can their richness be determined? These questions have not yet been clearly answered. If galaxy clusters contain several hundred to several thousand galaxies, they can be called rich.

There is no single definition of what can be considered the lower limit for a cluster, nor what can be considered the boundaries of a cluster and how to characterize the degree of concentration toward the center. The most concentrated clusters of galaxies with spherical symmetry are much more sparse and less concentrated in appearance than a normal globular cluster, although the sizes of the members compared to the distances between them are incomparably greater than in the case of star clusters. There are very few highly concentrated, rich clusters. Most clusters are "open," or "scattered." They would be more correctly called clouds. Their boundaries are indefinite. Various condensations are common within them. In addition, clusters are often projected onto each other. It is often difficult even to determine what belongs to a cluster and what belongs to the "common field".

There is no generally accepted successful classification of galaxy clusters yet. Bautz and Morgan [7] proposed a limited classification:

1. Clusters containing supergiant E-shaped galaxies with a large halo.
2. Clusters not containing these or other brightest galaxies.
3. Intermediate type.

Abell [1] studied 2712 highly rich clusters using the Palomar Atlas images, striving for homogeneity of characteristics and their independence from the distance to the clusters. By 1968, Zwicky [24] and his colleagues gave rough boundaries and brief descriptions of objects up to $\delta = -3^o$ observed with a 120-cm Schmidt telescope in their catalog. According to Abell, clusters are divided roughly into regular (with spherical symmetry and high concentration) and irregular, or open. Irregular clusters, or clouds, contain galaxies of all types. Small groups like the Local Group are similar to them in this, and these clusters always consist of subgroups. Their nearest representatives to the Earth are the clouds of the Ursa Major, Canes Venatici, and Virgo. Regular clusters consist almost exclusively of E and S0 galaxies, and individual spiral and irregular ones are probably only projected onto them. They sometimes contain more than 10000 bright members. The nearest of the regular clusters is in Coma Berenices.

Zwicky [24] recommends to determine the relative distances of rich spherical clusters, using the fact that their structure and population are apparently the same everywhere. He characterizes them by the "structural index", or the structural length α of the equivalent isothermal Emden sphere. The author found that the distribution of the number of galaxies by radius corresponds well to the distribution in projection onto a plane of gas particles of equal mass, which constitute an isothermal sphere. However, Abell believes that this distribution can also be represented by other models. Globular clusters were also previously considered to have the structure of isothermal gas spheres. Using Zwicky's own galaxy counts in three clusters, Sharov [25], showed that they cannot be represented as an isothermal sphere. He found a core, a zone of constant density, and a halo. In the catalogue [24] the contours of clusters are drawn where the density of galaxies per unit area is twice their density in the adjacent field. Using the criterion of distance, the author divides clusters into close N, medium-distance MD, distant D, very distant VD and extremely distant ED, corresponding to redshifts from 15×10^3 to $> 60 \times 10^3$ km/sec (see Table 1). The number of galaxies depends on the distance to the clusters, since only the brightest members are visible in distant ones.

TABLE I. The number of clusters containing a given number of galaxies n, according to the Zwicky catalogue.

	Compact			Open		
n	< 100	100-199	200-299	< 100	100-199	200-299
N	0	2	2	9	41	27
N	1	9	10	21	109	33
D	19	36	9	50	104	24
VD	139	143	30	95	97	12
ED	465	132	11	36	18	0

TABLE II. Cluster statistics.

Population	Number of clusters
50-79	1224
80-129	383
130-199	68
200-299	6
≥ 300	1

Abell [2] determined the number of bright galaxies brighter than $m_3 + 2^m$, where m_3 is the stellar magnitude of the third brightest galaxy. Limiting himself to galactic latitudes greater than 30^o, he obtained the data presented in Table 2.

Zwicky (1950) [24] labels the region $11^h17^m, 2 + 35^o29^I$ as the region richest in clusters. Here, 113 clusters are located within 36 square degrees and about 120000 galaxies are visible to the limit of the 120-cm Schmidt telescope image in red light. The clusters are distributed as follows (table 3):

Zwicky [24] considers the cluster 0123-0138 to be very rich, with about 1000 members from 13m to $19^m, 5$. In a picture with a 5-meter telescope, the richest cluster 024-1654 "has a density of 220032 galaxies per square degree at its center".

According to Abel, in order for galaxy clusters to be rich, they must include at least 50 galaxies with visible stellar magnitudes in the range m_3 to $m_3 + 2$ [2]. In [2, 26], the richness of a cluster is taken as the ratio of the brightness within the radius r_{200} (r_{200} is the radius of the cluster in which the average cluster density is 200 times greater than the critical density of the Universe) and r_{500} (r_{500} is the radius of the cluster in which the average cluster density is 500 times greater than the critical density of the Universe) to the average brightness of the galaxy cluster. In [17], the richness parameter of galaxy clusters is defined as the number of galaxies within a radius of 0.5 Mpc. In [18], the richness parameter is considered as the number of galaxies on the visible surface of a galaxy cluster. The authors cite the number of galaxies within a radius of 2 arcmin of galaxy clusters as their richness. In [19], the authors introduce a mathematical formula and determine the richness of galaxy clusters. In [20], the same parameter of richness is taken as in [17], but here it is determined by the number of the brightest galaxies. In this work, we also use the parameter RL to characterize the richness of galaxy clusters, (here $R_L = L_{200}/L$, L is the luminosity of the galaxy cluster, L_{200} is the luminosity in the radius r_{200}), as given in [2, 26].

IV. ON THE THEORY OF ORIGIN

The formation of a galaxy cluster according to the first scenario occurs as follows. A huge rarefied gas cloud with a mass of about $10^{13} \div 10^{14}$ solar masses is compressed by gravitational forces. As it compresses, it breaks up into fragments, which subsequently form galaxies. From this point of view, galaxy clusters should be gravitationally stable systems in which the kinetic energy of galaxies is less than their gravitational binding energy. According to the virial theorem [27], the kinetic energy of a gravitationally bound system is half its potential energy. Applying the virial theorem to galaxy clusters yielded an interesting result. A significant portion of clusters turned out to be gravitationally unstable systems. The velocities of the galaxies included in the clusters are so high that the clusters should eventually break up into individual galaxies. Based on this, only two contrary conclusions could be drawn.

TABLE III. Cluster statistics.

Clusters	N	MD	D	VD	ED
Open	4	3	7	7	1
Medium compact	2	3	10	21	22
Compact	1	0	3	14	15

First, galaxy clusters are gravitationally unstable systems and, therefore, the first scenario of galaxy formation is incorrect. This is the conclusion made by Ambartsumyan [28]. Second, the first scenario of galaxy formation is correct and, therefore, galaxy clusters contain hidden mass that ensures their stability. This conclusion is generally accepted at present.

The existence of gravitationally bound galaxy clusters and groups does not contradict the second scenario of galaxy formation, according to which galaxy clusters were formed as a result of explosions of superdense massive objects (or protoclusters of galaxies). From this point of view, clusters can be both gravitationally stable systems and gravitationally unstable. But the existence of even one unstable galaxy cluster clearly contradicts the generally accepted scenario. And this is why modern theoretical astronomers firmly insist that galaxy clusters contain hidden mass. They simply postulate that all clusters are gravitationally stable systems and, based on this, calculate the value of hidden mass in them.

There is no doubt that galaxy clusters contain hidden mass. These could be, for example, extinct stars, intergalactic gas, globular clusters consisting of very faint stars. Finally, these could be dwarf galaxies of very low luminosity. However, it is unlikely that hidden mass is capable of ensuring the gravitational stability of all clusters.

The issue of the existence of unstable clusters is very important, because such clusters seriously challenge the generally accepted scenario of galaxy formation. And it is very important to consider the view of an astronomer-observer who, on the one hand, is a specialist in his field, and, on the other hand, is not a supporter of any theory of galaxy formation.

The following results are presented in [29]: shock waves arising at the nonlinear stage of growth of the initial density perturbations impart a peculiar temperature and density distribution to the condensed gas. The scale of perturbations is typical for the theory of adiabatic density perturbations and is associated with protoclusters of galaxies. The epoch of the formation of protoclusters of galaxies is chosen corresponding to the red shift $z_c \sim 3 \div 5$, which agrees with the results of calculations of quasars and powerful radio wave sources. Part of the gas condenses adiabatically, has a low temperature and high density. A hypothesis is put forward about the origin of dense bodies (quasars and galactic nuclei) from such gas. After heating, about 20 percent of the gas cools to 10^4 K, and it was assumed that this gas goes into galaxies. The remaining gas is heated to 10^6 K, which explains the observed complete ionization of the intergalactic gas. Further, the article considers the dynamics of shock waves, thermal processes in the gas, its radiation and contribution to the X-ray background, as well as the process of the fragmentation of cold gas with the formation of the aforementioned objects, based on the cosmological model of a hot Universe with small density perturbations.

Perturbations of a pre-specified exact inhomogeneous solution of the Einstein equations are considered as a model for the formation of a galaxy cluster. It is shown that during cluster collapse it retains a smooth density profile over most of its extent [30]. In [31], a two-component N-body simulation was performed to study the formation of rich galaxy clusters containing both luminous and dark matter. Spatial segregation between galaxies and dark matter in these simulations develops very rapidly, the time span being smaller than the cluster collapse time, with the galaxy distribution being much more clustered than the dark matter distribution. Such segregation provides a natural means of biasing the galaxy distribution relative to the dark matter distribution without requiring recourse to special mechanisms of biased galaxy formation. It was found that virial mass estimates based on observed galaxy positions and velocities systematically underestimate the total cluster mass by a factor of 5–10. The authors present a simple dynamical model that can qualitatively explain these numerical results. It is argued that if the Universe has formed structure through hierarchical clustering from small to large scales, then segregation between galaxies and dark matter seems inevitable. These results suggest that a likely consequence of dark matter is an underestimation of the virial masses of galaxy clusters. It is possible that the "observed" value of $\Omega \sim 0.1$–0.2, derived from galaxy clusters and galaxy counts, implies a true value of $\Omega = 1$, consistent with the Einstein-de Sitter Universe and modern theories of the early period.

In [32], the authors present models of galaxy cluster formation ($P^3M + SPH$) containing both dark matter and gas. It is shown that the numerical time of two-particle relaxation strongly limits the achievable resolution. In the model, clusters are formed by the merger of three large groups, in which time relaxation creates an isothermal mass distribution without a central core. The subsequent collapse of small groups does not disrupt this structure, but produces an outer radius that grows uniformly with time. The collapse is well described by a simple cylinder model up to the point of maximum expansion, but then slows down either due to the presence of a substructure or due to the non-spherical shape. The gas temperature increases sharply from 10^4 K in the low-mass halo to a virial temperature of 10^7 K or more in the high-mass halo, which corresponds to simple hierarchical models of galaxy formation. Subgroups can survive in the virialized part of the clusters. They tend to be in radial orbits with velocity dispersion equal to the mean cluster value. The relationship between X-ray luminosity and the cluster mass function remains unclear, but where the surface brightness profile can be measured if the cluster mass profile is well constrained, several ways to extend and improve modeling of galaxy cluster formation are discussed.

In [33], the authors investigate the spatial distribution of substructure in galaxy clusters using Einstein X-ray observations. They find that subclusters have a markedly anisotropic distribution, reflecting the distribution of the surrounding matter on the scale of superclusters. The results of their studies suggest that cluster formation occurs through the merging of subclusters along large-scale filaments. The implications of such an anisotropic formation process for the shape, orientation, and kinematics of clusters are also discussed therein.

In [34], the authors present preliminary results of the study of the dynamical evolution of primordial density perturbations with masses comparable to galaxy groups and clusters, i.e. with masses from 10^{12} to 10^{15} solar masses. A spherical Lagrangian hydrodynamic code was written to study the formation and evolution of these primordial perturbations from the beginning of

the recombination era ($z_{rec} \sim 1500$) to the redshift value of collapse. All relevant processes, including the expansion of the Universe, are included in the calculations. As an initial condition, the authors take different values of the Hubble constant, the baryon density parameter (Ω_B), and the dark matter density parameter (Ω_{DM}), as well as different spectra of the density perturbations, to observe their influence on the evolutionary behavior of objects that can collapse to form galaxy groups and clusters. In particular, they find that perturbations with dark matter tend to collapse at higher redshifts when the results are compared with purely baryonic models. As an overall result, the authors find that the distribution of non-baryonic dark matter is more concentrated than that of baryonic dark matter.

In most cosmological models, it is assumed that matter is distributed uniformly and isotropically. The density of matter is the same everywhere, i.e. the model is stable. However, in the real Universe, matter is concentrated inside galaxies and galaxy clusters. Based on this, the authors of [35] investigated the possibility of condensation formation in some cosmological models constructed using different field theories. In particular, they used a self-consistent model formulated in the context of generalized field theory, a standard model constructed in the general theory of relativity, and a Saez and de Juan model constructed on the basis of Møller's theory of gravity. A comparison of the results obtained in each case is given. The relationship between the stability of the model and the formation of condensations is studied, and it is established that stable models allow the formation of condensations.

The authors of [36] report the discovery of a localized overdensity at $z \sim 1.6$ in the GOODS-South field, presumably a poor cluster in the process of formation. The three-dimensional density of galaxies is estimated from well-calibrated photometric redshifts from the GOODS-MUSIC multi-band photometric catalogue using the (2+1)-dimensional technique. The density peak is embedded in a larger-scale overdensity of galaxies known to exist in this region at $z = 1.61$. The properties of the member galaxies are compared with those of the surrounding field, and the researchers find that the two subsystems are significantly different, confirming the reality of the structure. The reddest galaxies, once evolving according to the most suitable models, have colours consistent with the red sequence of lower-redshift clusters. The total mass of the M_{200} cluster is in the range 1.3×10^{14}–5.7×10^{14} solar masses, depending on the assumed bias factor b. The upper limit of the X-ray luminosity of 2–10 keV is $L_X = 0.5 \times 10^{43}$ erg/s, which suggests that the cluster has not yet reached virial equilibrium.

The works [37-38] analyze the observational data on galaxy clusters from SDSS DR8. Based on the observational data on the distribution of a surface density, the values of the anisotropy parameter are determined for 31 clusters. A classification of galaxy clusters based on the velocity anisotropy parameters is proposed, according to which the clusters are divided into three groups. The relationship between the anisotropy parameter and the main physical characteristics of galaxy clusters is studied. In the works [39-40], the formation of spherical systems, such as systems of globular star clusters around galaxies, is studied in the framework of a nonlinear-nonstationary model of collapsing galaxies. Instabilities of the model with respect to four perturbation modes are analyzed, with the mode order determining the average number of clusters in the system. Critical diagrams for the dependence of the initial value of the virial ratio on the rotation degree of collapsing model are plotted. The instability growth rates are calculated, and the obtained instability parameters are compared.

V. CONCLUSION

In this brief review, we have presented the results of only a few important areas of galaxy cluster research. In particular, this article has summarized the data on regular and irregular galaxy clusters, while also presenting data on the characteristics of intergalactic gas, as well as the main patterns and limitations in the field of studying the evolution of galaxy clusters. In terms of generalizing previously collected observational data, the value of this article lies in presenting a number of currently compiled catalogs of galaxy clusters, as well as some previously discovered dependencies: the stellar mass of galaxy clusters on the halo mass and the stellar mass of galaxy clusters on their Ks-luminosity index. In addition, a number of properties of rich galaxy clusters discovered to date have been presented.

The problem of the lack of generally accepted criteria for the richness of galaxy clusters, as well as their lower quantitative limits and outer boundaries, has been raised; in particular, the imperfection of current classifications by the "compactness - openness" parameter. Finally, the article has contrasted the theory of compression of a rarefied gas cloud with the theory of explosions of superdense massive objects as two possible factors in the origin of galaxy clusters, and also presented the results of studies in the field of the existence of hidden masses that can ensure their gravitational stability. Also, the major observational works and their results and theories of the origin of galaxy clusters have been presented.

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