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Observational data of cD galaxies and their analysis

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With the aim of studying the physics of cD galaxies observed at the centers of rich galaxy clusters, we collected observational data and created a catalog consisting of 660 objects. A statistical analysis of this catalog was carried out. In particular, histograms of the physical parameters of cD galaxies and graphs showing the interrelation of their characteristics were constructed. The analysis of the obtained results shows that cD galaxies are primarily elliptical, though to a lesser extent they can also be lenticular and spiral galaxies. Empirical relationships were found, such as the dependence of their age on the corresponding redshift values.

Keywords: Massive galaxies, cD galaxies, galaxy clusters, consolidated catalog, statistical analysis

1 Introduction

cD galaxies are supergiant galaxies and are primarily observed in the central regions of rich galaxy clusters. Studying such objects plays an important role in solving problems related to the formation and evolution of galaxy clusters. Based on this, many authors have carried out various theoretical and numerical-experimental studies aimed at investigating their physical and dynamical evolution. For instance, in the article (see, e.g., Baier & Schmidt (1992)), an analysis of the observed properties of known cD galaxies was conducted. This included an investigation into the relationship between the characteristics of the brightest cluster members and the global properties of the group. A correlation between their properties was found, and it was discovered that the process of merging in cD galaxies has played a significant role. The authors of other works (see, e.g., Tovmassian et al. (2004); Tovmassian (2008); Tutukov et al. (2007); Vikhlinin et al. (1999); von der Linden et al. (2007)) analyzed the cannibalistic mechanism of cD galaxy formation in Bautz-Morgan type I clusters. Photometry of galaxy clusters showed that the envelope and the central galaxy have

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similar stellar populations and possibly a common origin of both structures. Some physical characteristics of cD galaxies are discussed in the context of their formation during Ambartsumian-type events (see, e.g., Harutyunian (1995, 2003, 2008); Lauer et al. (2006); Sodré et al. (1989)). In this framework, cD galaxies are considered as generators of the clusters in which they are found. This concept provides a natural explanation for the observed features of cD galaxies and the clusters associated with them. Galaxy clusters containing cD galaxies have an extensive halo-like envelope, which can extend over distances greater than 500 kpc. Numerous theories have been proposed to explain the formation of these envelopes, such as: Tidal interaction, where matter is stripped from neighboring galaxies; Merger scenario, where the envelope forms hierarchically through successive mergers with large and small galaxies; Primordial origin, where the envelope forms simultaneously with the rest of the elliptical galaxy, etc. (see, e.g., Oemler (1976); Schombert (1988)). It has been shown that increasing the initial mass of the intra-cluster medium (ICM), while keeping the mass and structure of the galaxies unchanged, leads to an increased merger rate due to dynamical friction in the medium (see, e.g., Kemp et al. (2009a, 2012)). A number of studies have been directly dedicated to the observation of galaxy clusters and, in particular, their central cD galaxies. For example, in the galaxy IC 1101, the largest known galactic core was discovered. This may be partially related to the oscillatory passage of a black hole core displaced by gravitational radiation (see, e.g., Antonini & Merritt (2012); Bonfini & Graham (2016); Dullo et al. (2017); Erwin (2015); Ferrarese & Merritt (2000)). In another study (see, e.g., Jing et al. (1995); Lima Neto & Baier (1997); Malumuth (1992); Schechter (1992); West et al. (unpublished)), a detailed analysis was performed on the luminosity of cD galaxies and the parameters of their parent clusters. As a result, it was suggested that cD galaxies in different types of clusters have undergone distinct evolutionary paths. The authors of another work (see, e.g., Kemp et al. (2009b, 2014); Merritt (1984); Pérez-Hernández (2014); Ramírez-Siordia (2009)) conducted a program of deep surface photometry of cD galaxies. For most of the galaxies, flat color profiles were obtained. Flat profiles imply a stellar population of the same age in both the main galaxy and the envelope, supporting the hypothesis of a common origin. In another article (see, e.g., Broadhurst & Scannapieco (2000); Coziol et al. (2004, 2009); Coziol & Plauchu-Frayn (2007)), a large sample of galaxy clusters with a dominant galaxy was studied to investigate the dynamical properties of the brightest cluster members. These studies qualitatively support the merger scenario, where clusters formed relatively recently from the merger of many groups and are still in a dynamically unstable state. In a seminal work (see, e.g., Ogden (1957)), a catalog of 2.712 rich galaxy clusters was compiled. From this catalog, 1,682 clusters were selected that met the criteria for a homogeneous statistical sample. It was found that the distribution function of clusters by richness $N(n)$ increases rapidly with decreasing n. Analysis of the distribution provides convincing evidence for the existence of second-order clusters, i.e., clusters of galaxy clusters. Other researchers (see, e.g., Seigar et al. (2007); Zibetti et al. (2005)) analyzed deep R-band images down to a limiting surface brightness of 26.5mag/ arcsec^2 (equivalent to $\sim$28 B mag/arcsec^2) for five cD galaxies to determine the shape of the surface brightness profiles of their extended stellar envelopes. Neither the de Vaucouleurs $R^{1/4}$ model nor the Sersic $R^{1/n}$ model alone adequately described the surface brightness profiles of cD galaxies. This is due to the presence of outer stellar envelopes,

which are believed to have accumulated through the merger history of the cluster's central galaxy and tidal stripping at large cluster radii. Therefore, the authors (see, e.g., Seigar et al. (2007); Zibetti et al. (2005)) fitted two Sersic functions simultaneously to model the inner and outer components of cD galaxies. It was shown that, for three of the five galaxies studied, the surface brightness profiles are best described by an inner Sersic model with indices $n \sim 1$–6 and an outer exponential component. For these systems, the ratio of the galaxy's size to the envelope's is about 0.1–0.4, and the contribution of the stellar envelope to the total R-band light (i.e., galaxy + envelope) is approximately 60–80% (based on extrapolation to a radius of 300 kpc). The exceptions are NGC 6173, whose surface brightness profile is consistent with a single component (i.e., no envelope), and NGC 4874, which apparently has an envelope with a de Vaucouleurs profile rather than an exponential one. Abell 2029, or A 2029, is a large galaxy cluster located at a distance of 326 megaparsecs (1.027 billion lightyears) from us in the constellation Serpens (see, e.g., Noble (1990)). The central galaxy of this cluster is IC 1101, the largest known galaxy of this type to date (Figure 1). Its diameter is 5.6–6 million light-years. For comparison, the diameter of the Milky Way is 100,000 light-years. According to John Noble (1990), IC 1101 is 50 times larger in diameter than the Milky Way, 2,000 times more massive, and has a luminosity of $2 \times 10^{12} L_{\odot}$. From this brief overview of studies on cD galaxies, it is evident that they are central objects in many galaxy clusters, and their study holds the key to understanding the formation and evolution of clusters. In this work, we have attempted to gather nearly all recent observational material and have created a catalog consisting of 660 objects. We also present some correlations between selected parameters of cD galaxies.

2 Catalog of cD galaxies

The aim of this study, as previously mentioned, is the creation of a comprehensive catalog of observational data on cD galaxies, their analysis through statistical research, and the consideration of the classification problem of such galaxies. To this end, we collected observational data on these galaxies (see, for example, Coziol et al. (2009), http://leda.univ-lyon1.fr, http://www.ipac.caltech.edu, Based on the material we gathered, a comprehensive catalog was created, consisting of 660 objects. The catalog includes the following physical parameters: the name of the cD galaxy, the name of the cluster in which the cD galaxy is located, equatorial coordinates (α, δ), their galactic latitude and longitude (l, b), morphological type, redshift (z), heliocentric radial velocity ($\mathrm{v_r}$) and its uncertainty, distance modulus ($\mathrm{m - M}$) and its uncertainty, absolute magnitude ($\mathrm{M_V}$) and its uncertainty, apparent magnitudes in different filters ($\mathrm{U^m, B^m, V^m, I^m, K^m}$) and their uncertainties, and the age (τ_{Age}) of the cD galaxies.

3 Statistical analysis of the catalog

Using this data, we conducted an analysis of the cD galaxy catalog and studied the relationships between certain of their parameters.

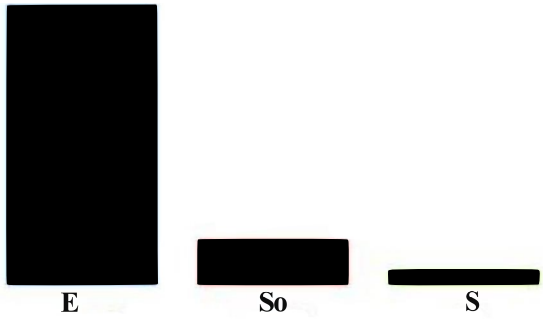


Figure 1 Distribution of cD galaxies by morphological type.

Figure 1 shows the distribution of cD galaxies by morphological type. It is evident that cD galaxies are predominantly elliptical. However, lens-shaped and giant spiral cD galaxies are also observed. The brightness of the corresponding types of cD galaxies can be seen in the table below. Table 1 shows that cD galaxies are among the brightest objects in the Universe, regardless of their morphological type, and they belong to the class of bright supergiants, normal supergiants, and bright giants.

Table 1

Belonging to a morphological type	M_V
E	$-20.42 \div -25.17$
S0	$-21.47 \div -24.6$
S	$-21.14 \div -24.6$

Now, let us examine how the absolute stellar magnitudes behave in different ranges, expressed as empirical dependencies.

Figure 2 shows the dependence of the absolute stellar magnitude of cD galaxies on redshift. From the graph, it is evident that the luminosity of cD galaxies is very high, and their values are weakly dependent on distance. Despite this, this dependence

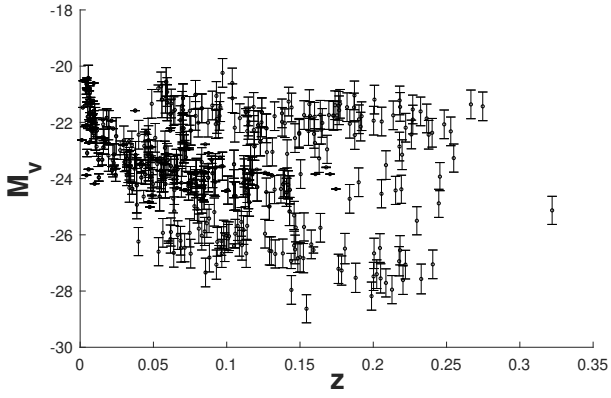


Figure 2 Graph of the dependence of absolute stellar magnitude on redshift.

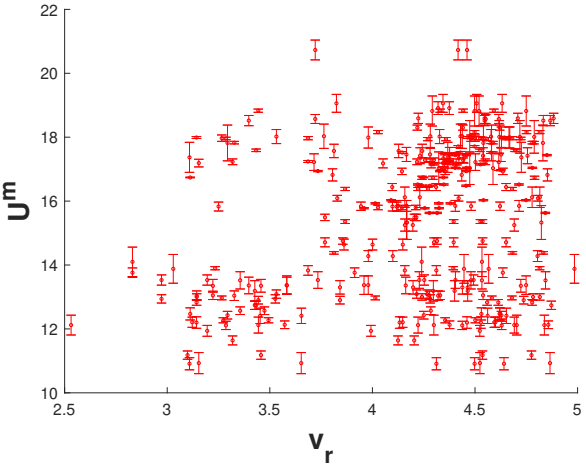


Figure 3 Graph of the dependence of the apparent stellar magnitude in the U-filter on radial velocity.

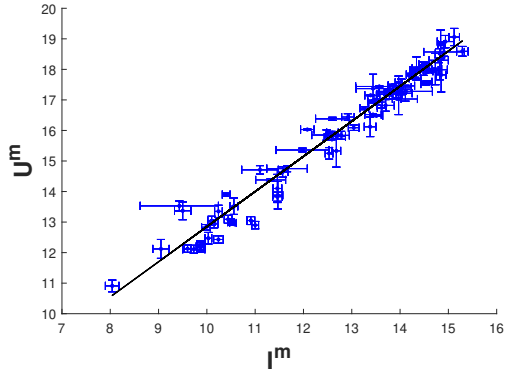


Figure 4 Dependence of the apparent stellar magnitude in the U- and I-filters.

can be expressed as follows: U and heliocentric radial velocity have a power-law relationship, which is expressed as:

$$M_V = -0.6198(\pm 0.0635)\ln z - 25.1556(\pm 0.2235) \tag{1}$$

Figure 3 shows that the apparent stellar magnitude of cD galaxies in the U-filter and the heliocentric radial velocity have a power-law relationship, which is expressed as:

$$U^m = 5.4363(\pm 0.0496)v_r^{0.1141(\pm 0.0054)}. \tag{2}$$

The luminosities in different ranges have a clear linear dependence (see Fig. 4). For example, the apparent stellar magnitudes in the U- and I-filters are related as:

$$U^m = 1.1483(\pm 0.023)I^m + 1.3123(\pm 0.304). \tag{3}$$

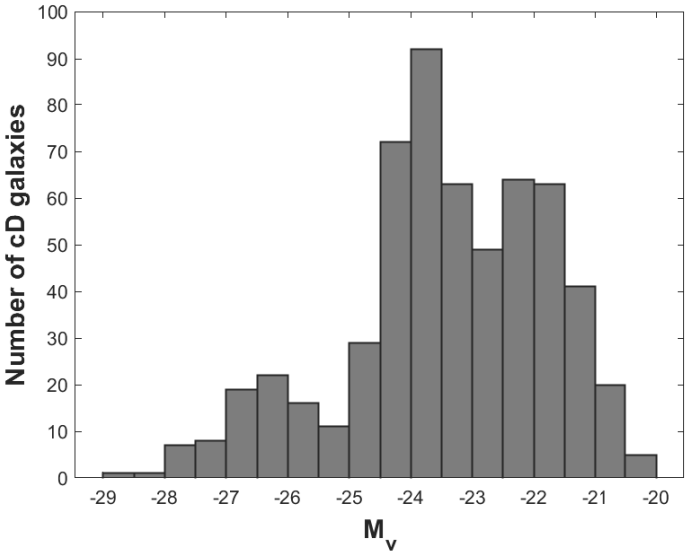


Figure 5 Distribution of cD galaxies by absolute stellar magnitude.

Table 2 Classification by absolute magnitude (M_V).

Type of cD galaxies by luminosity	M_V	Number
Bright supergiants	$-23.5 \div -25.2$	317
Normal supergiants	$-22.5 \div -23$	211
Bright giants	$-20 \div -22$	132

Now, let us see how cD galaxies can be classified. For example, the distribution of the absolute stellar magnitude of these galaxies (Fig. 5) allowed us to divide them into three groups based on luminosity class (see Table 2).

4 Conclusion

Thus, based on the analysis of literature sources published in recent years, we have compiled a catalog of cD galaxies observed at the centers of 660 rich galaxy clusters. Using this catalog, we carried out a statistical analysis of the observational data of the studied objects. In particular, histograms were constructed showing the distributions of various observed parameters of cD galaxies, as well as correlations between them.

The analysis of the results shows that cD galaxies are predominantly elliptical, less frequently lenticular, and only very rarely spiral galaxies. In particular, we obtained a correlation between the absolute stellar magnitude of cD galaxies and redshift. It is evident that the study of cD galaxies is a significant research direction, and the statistical analysis of observational data serves as an important factor and complement to their overall investigation.

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References

Antonini, F., & Merritt, D. 2012. ApJ.
Baier, F.W., & Schmidt, K.H. 1992. Astronomische Nachrichten.
Bonfini, P., & Graham, A.W. 2016. ApJ.
Broadhurst, T., & Scannapieco, E. 2000. ApJ.
Coziol, R., Andernach, H., Caretta, C.A., et al. 2009. Astronomical Journal, **91**, 275.
Coziol, R., Brinks, E., & Bravo-Alfaro, H. 2004. AJ.
Coziol, R., & Plauchu-Frayn, I. 2007. AJ.
Dullo, B.T., Graham, A.W., & Knapen, J.H. 2017. MNRAS, **471**(10), 2321–2333.
Erwin, P. 2015. ApJ.
Ferrarese, L., & Merritt, D. 2000. ApJ.
Ogden, A.G. 1957. In Partial Fulfillment of the Requirements.
Harutyunian, H.A. 1995. Astrofizika.
Harutyunian, H.A. 2003. Astrofizika.
Harutyunian, H.A. 2008. Astrophysics.
Jing, Y.P., Mo, H.J., Börner, G., & Fang, L. 1995. MNRAS.
Noble, W.J. 1990. The New York Times, p.15.
Kemp, S.N., Guzmán Jiménez, V., & Ramírez Beraud, P. 2009a. In *New Quests in Stellar Astrophysics II*, Springer.
Kemp, S.N., Guzmán Jiménez, V., & Ramírez Beraud, P. 2009b. In *New Quests in Stellar Astrophysics II*, Springer.
Kemp, S.N., Ramírez-Siordia, V.H., & Pérez-Hernández, E. 2012. IAU Symposium.
Kemp, S.N., Pérez-Hernández, E., & Ramírez-Siordia, V.H. 2014. IAU Symposium.
Lauer, T.R., Faber, S.M., & Richstone, D. 2006. ApJ.
Lima Neto, G.B., & Baier, F.W. 1997. Astrophysics.
Malumuth, E.M. 1992. ApJ.
Merritt, D. 1984. ApJ.
Oemler, A.J. 1976. ApJ.
Pérez-Hernández, E. 2014. Undergraduate thesis, Univ. of Guadalajara.
Ramírez-Siordia, V.H. 2009. Undergraduate thesis, Univ. of Guadalajara.
Schechter, P. 1992. ApJ, **203**, 237.
Schombert, J.M. 1988. ApJ.
Seigar, M.S., Graham, A.W., & Jerjen, H. 2007. Astron. Soc.
Sodré, L., Capelato, H.V., Steiner, A., & Mazure, J.E. 1989. Astron. J.
Tovmassian, H.M. 2008. arXiv:0810.4337v1.
Tovmassian, H.M., Plionis, M., & Andernach, H. 2004. ApJL.
Tutukov, A.V., Dryumov, V.V., & Dryumova, G.N. 2007. Astronomy Reports.
HyperLeda Database for physics of galaxies, http://leda.univ-lyon1.fr.
NASA/IPAC Extragalactic Database (NED), http://www.ipac.caltech.edu.
Vikhlinin, A., McNamara, B.R., Hornstrup, A., et al. 1999. ApJL.
von der Linden, A., Best, P.N., Kauffmann, G., & White, D.M. 2007. MNRAS.
West, M.J., Oemler, A., & Dekel, A. Unpublished.
Zibetti, S., White, D.M., Schneider, D.P., & Brinkmann, J. 2005. MNRAS.