THE ASTROPHYSICAL JOURNAL, 162:L149–L153, December 1970

ON THE CLASSIFICATION OF THE FORMS OF CLUSTERS OF GALAXIES

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Received 1970 October 24

ABSTRACT

A classification of clusters of galaxies based on the relative contrast of the brightest member galaxy is described. Clusters containing a supergiant D galaxy define Type I; at the other extreme (Type III) are clusters which contain no members significantly brighter than the general bright population. A list of seventy-six clusters classified according to the present system is included.

TERMINOLOGY

Compact cluster; medium compact cluster; open cluster.—The galaxy-cluster classification of Zwicky, Herzog, and Wild (1961).

Regular cluster; Irregular cluster.—The two-part classification of Abell (1965; 1970).

Com; Vir; UMa.—Standard clusters of galaxies in the classification of Morgan (1962).

D galaxy.—A galaxy which has, on ordinary photographs, an elliptical-like nucleus surrounded by an extensive envelope.

cD galaxies.—Outstandingly large, luminous D galaxies, as observed on ordinary photographs. The nuclei may be single, double, or multiple.

I. INTRODUCTION

Perhaps the most useful classifications of clusters of galaxies at the present time are those of (1) Abell (1958); (2) Zwicky, Herzog, and Wild (1961); and (3) the recent two-part division of Abell (1965, 1970). Each has its special criterion: richness, in (1); concentration, in (2); and the separation in (3) into clusters of two differing average stellar populations. A more detailed expansion of (3) is implicit in a discussion by Morgan (1962), which suggests a classification in which the Coma, Virgo, and Ursa Major clusters can be considered as type-objects for a morphology paralleling that of open star clusters in the Galaxy; its use, however, is limited to the nearer clusters, because of the necessity of determining form types for the brighter individual galaxies in each cluster. The importance of the Abell two-part classification is great, since it can be applied to clusters over great ranges in distance.

II. THE "BRIGHTEST GALAXY" MORPHOLOGY

There is another property of clusters of galaxies which has some interest as a parameter for classification: the degree to which the brightest member stands out against the general cluster background. Such bright objects are clearly important astrophysically, as well as for problems of galactic structure.

We have therefore devised a five-part form classification which depends on the relative contrast of the brightest galaxy to others in each cluster. The notation is given in Table 1.

III. THE OBSERVATIONS

Types for seventy-six clusters are given in Table 2. Column (1) gives a running number; column (2), the Abell number, with asterisks used in the sense defined by Abell (1958), i.e., the cluster does not meet the requirements for inclusion in the statistical sample; columns (3) and (4), distance and richness classes from Abell; and column (5), the type as determined from paper prints and the glass second-negative copy of the *National Geographic Society–Palomar Observatory Sky Survey* at the Yerkes Observatory. The final two entries (Hya A and Cyg A) were classified from photographs reproduced in Matthews, Morgan, and Schmidt (1964) and the Notes to Table 1 of that paper.

Table 2 is divided into three sections. The first section gives clusters of distance classes less than 4, for which fairly good types could be derived from the second negatives of the Sky Survey plates. Five clusters with uncertain types (followed by a colon) have been included because of features of special interest. The second section lists the nine richest clusters in Abell's catalog, together with A2029 and A2670, which are good ex-

TABLE 1

CRITERIA AND STANDARD CLUSTERS

Type	Description	Standard (Abell No.)
I.....	Clusters containing a centrally located cD galaxy	2199, 2029
I–II.....	Intermediate	
II.....	Clusters where brightest galaxy or galaxies are intermediate in appearance between class cD and the Virgo-type giant ellipticals	194, 1656 (Coma), 2197
II–III.....	Intermediate	426 (Per), 400
III.....	Clusters containing no dominant galaxies. This type can be subdivided into III-E and III-S, according to the absence or presence of considerable numbers of bright spirals	Virgo, 2065 (CrB)

amples of class I (and which are illustrated in Matthews *et al.* 1964). The last section of the table consists of two entries, the clusters containing the radio galaxies Hya A and Cyg A.

IV. DISCUSSION

From the first part of Table 2 we can derive two preliminary conclusions: (1) There is no close correspondence between cluster richness and form-type (for the nearest clusters) on the present system; clusters of Type I range in richness from 0 to 2; clusters of Type III also range between the same limits. (2) The phenomenon of two centrally located galaxies in a common envelope is encountered in a number of clusters of Types II and III.

From the nine richest clusters (second part of Table 2) we note that all classes from I to III are represented; from this independent material we again conclude that there is no close relationship between classified type and richness. There is also another interesting characteristic of the richest clusters: the majority are irregular in shape, and two (A545 and A665) are highly irregular, with density minima within their main bodies.

The two radio galaxies in the final section of Table 2 are of special interest: both have double nuclei; and one (Cyg A) has an emission spectrum that resembles typical Seyfert galaxies (see spectrum reproduced in Schmidt 1965). Some similarity in the spectrum of Cyg A to Seyfert galaxies had been noted earlier by Baade and Minkowski (1954).

TABLE 2

CLASSIFICATION OF CLUSTERS

No.	Abell	D	R	Type	No.	Abell	D	R	Type
1	14*	3	0	III:	41	1736*	2	0	III
2	102*	3	0	II-III	42	1781*	3	0	III
3	119	3	1	II-III	43	1800*	3	0	I-II
4	147*	3	0	III	44	1831	3	1	II-III
5	151	3	1	II	45	1904	3	2	II
6	154	3	1	I-II	46	1983	3	1	III
7	168	3	2	III	47	2022	3	1	III
8	179*	3	0	III	48	2052*	3	0	Note
9	194*	1	0	II	49	2063	3	1	II-III
10	240*	3	0	II-III	50	2065	3	2	III
11	262*	1	0	III	51	2079	3	1	III
12	347*	1	0	II-III	52	2124	3	1	I
13	397*	3	0	III	53	2151	1	2	III
14	399	3	1	I-II	54	2152	1	1	III
15	400	1	1	II-III	55	2197	1	1	II
16	401	3	2	I	56	2199	1	2	I
17	426*	0	2	II-III	57	2247*	3	0	III
18	539*	2	1	III	58	2255	3	2	II-III
19	548*	1	1	III	59	2256	3	2	III
20	576	2	1	III	60	2399	3	1	III
21	595*	3	0	III:	61	2589*	3	0	I
22	634*	3	0	III	62	2634*	1	1	I-II:
23	671*	3	0	II	63	2657	3	1	II-III
24	757*	3	0	III	- -	- - - -	-	-	- - - - - -
25	779*	1	0	II	64	545*	5	4	III
					65	665	6	5	II-III
26	838*	3	0	III					
27	993*	3	0	III	66	777	6	4	II-III
28	1035	3	2	III	67	910	6	4	II
29	1060*	0	1	III	68	1146*	5	4	I
30	1069*	3	0	III	69	1689	6	4	I-II
					70	2029	4	2	I
31	1142*	3	0	II-III:					
32	1213	2	1	III	71	2125	6	4	II or II-III
33	1225*	3	0	III	72	2218	6	4	II-III
34	1228	1	1	III	73	2645	6	4	(I or II)??
35	1257*	3	0	III	74	2670	4	3	I
					- -	- - - -	-	-	- - - - - -
36	1291	3	1	III	75	Hya A			I
37	1367	1	2	II-III	76	Cyg A			I
38	1436	3	1	III					
39	1656	1	2	II					
40	1691	3	1	II-III					

NOTES TO TABLE 2

No. 1. II–III? Red [D] galaxy centrally located.
No. 2. Wide double nucleus in common envelope.
No. 4. Centrally placed [E3: + E:] in common envelope.
No. 6. Two widely separated nuclei in common envelope.
No. 9. 3C 40. [D + E] in common envelope. (Matthews, Morgan, and Schmidt 1964): "cD3 in D4 envelope. Brightest galaxy in cluster . . . secondary galaxy in edge of envelope."
No. 10. Double nucleus in common envelope.
No. 11. Centrally placed [D] with extended envelope.
No. 12. 3C 66.
No. 13. [D] galaxy with extended envelope.
No. 15. 3C 75. [E: + E:] in common envelope.
No. 17. 3C 83.1. Brightest galaxy [E2p]. Perseus cluster.
No. 21. Two [E:] galaxies in common envelope.
No. 26. Two [E1:] galaxies in common envelope.
No. 27. [D] galaxy with extended envelope.
No. 28. Brightest galaxy [E:].
No. 31. Brightest [E? + E?] in common envelope.
No. 36. [D] galaxy with extensive envelope.
No. 38. Two [E?] galaxies in common envelope.
No. 39. Coma cluster.
No. 47. [D] galaxy in central region.
No. 48. 3C 317. Size, I–II; relative luminosity, II. (Matthews *et al.* 1964): "cD2 in D4 envelope. Three condensations in—or projected on—envelope. Outstandingly brightest galaxy in cluster."
No. 50. Centrally placed [E1: + E2:] in common envelope. Corona Borealis cluster.
No. 51. Centrally placed [D:] with narrow extended envelope.
No. 56. 3C 338 = NGC 6166. (Matthews *et al.* 1964): "Three secondary components in same envelope."
No. 57. Chain of five [E] galaxies.
No. 58. [D + D?] with extended envelope.
No. 62. 3C 465 = NGC 7720. (Matthews *et al.* 1964): "Cluster ill-defined. [D2 in asymmetric D4 envelope]. Round, bright companion in same envelope."
No. 64. Cluster in form of irregular closed loop with density minimum at center.
No. 65. Refers to inner subclustering; brightest galaxy probably in elongated envelope. Thick outer arc of galaxies. Cluster very irregular.
No. 66. Inner subclustering with [E? + E?] possibly in common envelope. Irregular cluster.
No. 67. Like Coma, but richer. Two dominating galaxies: centrally located [D]; nondescript bright galaxy in southern part of cluster. Irregular; lumpy distribution of subclusterings.
No. 68. [cD] in extended envelope located in densest part of clustering, which extends farthest toward south.
No. 69. Three very bright [E?] possibly in common envelope. Cluster regular.
No. 71. Irregular; very distant. Class would be II in subclustering containing brightest [E? + E?].
No. 72. [D] near center, with very large envelope. Cluster fairly regular.
No. 73. Very distant.
No. 75. 3C 218. The classification was made from two illustrations in Matthews *et al.* (1964), and from the following note from the same source: "[cD2], Double nucleus; not completely resolved. There is another galaxy in the outer envelope. In poor, faint cluster; very much brighter than any other cluster member." Also (Maltby, Matthews, and Moffet 1963): "The optical identification, first noted by Minkowski, is a very close pair of elliptical galaxies having a common envelope." (See also Dewhirst 1959.)

NOTES TO TABLE 2—*Continued*

No. 76. 3C 405. The classification was made from two illustrations in Matthews *et al.* (1964), and from the following note from the same source: "[cD3]. Double nucleus. Outstandingly brightest member of a cluster of richness 2."

V. THE SIGNIFICANCE OF TYPES I AND II

According to the criteria of Table 1, Type I is defined by a centrally located cD galaxy—that is, by an outstandingly large, luminous galaxy having an elliptical-like nucleus surrounded by an extensive envelope. The most striking characteristic of such galaxies is their extremely large linear dimensions. At Type II, the brightest member galaxies are smaller in linear dimensions than at Type I; however, they may be comparable in luminosity with some cD galaxies in Type I clusters. For example, in the Coma cluster (A1656) Abell has found (private communication) that the brightest member galaxy stands out in integrated luminosity from its cluster background by as large an amount as does the cD galaxy NGC 6166 from its Type I cluster (A2199).

VI. CONCLUSION

In an abstract of the present classification (Bautz and Morgan 1970), an additional Type IV was described. This type has been omitted here, since its discriminant (spirals as brightest members of clusters of galaxies) differs in nature from that used for the other types (degree of contrast of brightest member of cluster).

We are greatly indebted to Dr. G. O. Abell for several discussions, for unpublished information, and for preprints of two of his papers. One of us (W. W. M.) wishes to acknowledge support by a grant from the National Science Foundation.

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