THE CRITERIA FOR MORPHOLOGICAL CLASSIFICATION OF PF GALAXY CLUSTERS

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ABSTRACT. The morphological types of galaxy clusters resulting from their outward appearance is physically related to the clusters and their member galaxies. Presented here is an adopted system of morphological types of galaxy clusters based on the Zwicky, Boutz & Morgan, Rood & Sastry, and López-Cruz systems. The adopted types are suitable for automated classification of galaxy clusters from The Catalogue of Galaxy Clusters and Groups (Panko & Flin 2006). Numerical criteria describing 6 main types were distinguished: Concentrated *C*, Intermediate *I*, Open *O*, Line *L*, Flat *F*, and c*D*. The types correspond to the base divisions from regular to irregular clusters, but also note the presence of preferential direction or plane in each cluster.

Key words: clusters of galaxies: morphological types

1. Introduction

The classification of galaxy clusters at optical wavelengths is carried out using several different parameters: cluster richness (number of galaxies within a specific limiting magnitude), the central concentration, the presence of bright galaxies in the center of the cluster, the presence of peculiar galaxies, etc. Other variants of the morphological classification for galaxy clusters were developed by different authors following Abell (1958). As noted by Bachall (1997) in her review, clusters with a richness class of 30 or more members are classified in a sequence ranging from early- to late-type clusters, or equivalently, from regular to irregular groups (Abell 1958). As described by Zwicky et al. (1961–1968), regular R, intermediate (RI or IR), and irregular (I) Abell types correspond to compact, medium-compact, and open galaxy clusters, respectively. Many cluster properties (shape, concentration, dominance of brightest galaxy, galactic content, density profile, and radio and X-ray emission) are correlated with position in the sequence.

The prevalent BautzMorgan (BM) classification scheme (Bautz & Morgan 1970) is based on the relative contrast (dominance in extent and brightness) of the brightest galaxy to other galaxies in the cluster, ranging from type I to III in decreasing order of dominance. The Rood-Sastry (RS) system (Rood & Sastry 1971) classifies clusters based on the geometry of the distribution of the ten brightest members (from c*D*, to binary *B*, core *C*, line *L*, flat *F*, and irregular *I*). The Rood-Sastry and Bautz-Morgan schemes are in agreement and complement each other. Most Rood-Sastry c*D* clusters are of Bautz-Morgan classes I and I-II, while the majority of Bautz-Morgan class III clusters belong to Rood-Sastry types *C*, *L*, *F*, and *I*.

The Rood-Sastry scheme also adds more detail to the Bautz-Morgan classification by considering the irregularity of galaxy clusters. However, the most important contribution of the Rood-Sastry scheme is the introduction of the "*B*" class, a class originally thought to be of an intermediate type. López-Cruz (1997, 2001) introduced the definition of a c*D* cluster, where a cluster is both Bautz-Morgan class I or I-II and Rood-Sastry designation c*D*, exclusively. The complement to this class is called a non-c*D* cluster (i.e., Bautz-Morgan II, II - III, or III and Rood-Sastry *C, L, F, I*). Binary clusters, that is, Rood-Sastry *B* clusters, are considered a different class because of their merger nature.

BM type I c*D* clusters are a special type. van Kampen & Rhee (1990) found an alignment of c*D*-galaxies with their surroundings, based upon studies of 122 rich Abell clusters. López-Cruz (2001) has shown that c*D* clusters and non-c*D* clusters are different dynamically. Sandage & Hardy (1973) found that BM types and *BCM* (Brightest Cluster Members) absolute magnitudes were independent of cluster richness; therefore, they concluded that Bautz-Morgan types were defined by initial conditions at the onset of cluster formation rather than by later evolution. Panko, Juszczyk & Flin

(2009) analyzed the relative orientations of BCM and their parent clusters for 1056 galaxy structures from the PF Catalogue (Panko & Flin 2006). They found statistically significant alignments of *BCM* relative to the parent clusters only for BM I clusters. The Binggeli effect (Bingelli 1982) is strongest for BM type I clusters as well (Flin et al. 2011). Moreover, Struble (1990) found weak alignments for 68 clusters of type RS *B*.

The structures in the Catalogue of Galaxy Clusters and Groups (Panko & Flin 2006, PF for short) has assumed Abell and BM morphological types only for 1056 objects corresponding to ACO clusters (Abell, Corvin & Olovine 1989). Other clusters need a determination of their morphological type for future study. The main problem for such structures lies in the input data: the galaxies of the Münster Red Sky Survey have tabulated only positions, magnitudes, ellipticities, and position angles for the major axes. Thus, it is necessary to adopt the prevalent morphological systems to determine cluster classification types for the PF clusters.

2. Observational Data

The present work is based on the PF catalogue (Panko & Flin 2006). It contains information on 6188 structures containing at least 10 members in the overdense region. A total of 1746 clusters have a richness of 50 or more. The value 50 was selected as minimal for normal and rich galaxy clusters according to the study by Biernacka et al. (2007). Other structures in the PF catalogue were assumed to be poor galaxy clusters and groups of galaxies.

The 1746 clusters are distributed in richness order as: 12 have a richness of 400 or more galaxies in the cluster field, the next 27 have a richness of 301–400, 76 have a richness of 210–300, 377 have a richness of 101–200, and 1254 have a richness from 50 to 100. For all PF catalogue structures a list of galaxies in the object fields was compiled along with information about each galaxy according to the criteria of Ungrue, Seitter & Duerbeck (2003).

The analysis of the spatial orientations of galaxies in 247 rich PF clusters with assumed from ACO morphological types was executed in paper Godlowski et al. (2010). We can expand the list to 377 clusters for future study.

A specific region $11^\circ \times 16^\circ$ was selected to test our results with previous classification and to check the new criteria (Fig. 1). The region contains 55 ACO galaxy clusters (Abell, Corvin & Olovine 1989), 6 of them belong to supercluster SCL 184 (Einasto et al. 1997). Furthermore the region contains 175 clusters and groups from the PF Catalogue, 31 of them have corresponded clusters in the ACO Catalogue (Abell, Corvin & Olovine 1989) with assumed Abell and BM types.

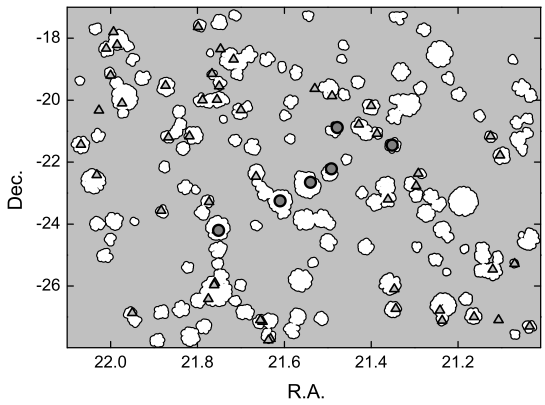

Figure 1: The distribution of large-scale structures in the test region. White symbols are PF clusters and groups, triangles are known ACO clusters, and black circles are Supercluster members.

In the test region all types of large-scale structures are seen: filaments and voids together with galaxy groups, clusters and superclusters. The data set permits us to check the main principles of the adopted morphological classification.

3. Determination of Morphological Types in the Test Region

Maps were constructed for 50 PF normal and rich galaxy clusters and for 14 poor ones, which have corresponded clusters in ACO catalogue in the test region using rectangular coordinates calculated in the standard manner. Four of the maps are shown in Fig. 2, where units for the axes correspond to arcseconds. The maps note the direction of each cluster's major axis according to the PF catalogue. Morphological types were determined for 31 clusters according to the Abell, Zwicky et al., BautzMorgan, and Rood-Sastry criteria, then compared with ACO catalogue data. Types BM I and II as well as RS *F* types can be identified confidently. However, detailed classification based on the constructed maps, particularly in automated mode, was less successful, since the maps contain only dots instead of images for the galaxies.

An automated procedure was used to distinguish 6 main types: Concentrated *N*, Intermediate *I*, Open *O*, Line *L*, Flat *F*, and c*D*. Those types correspond to the base divisions from regular to irregular, but additionally note the presence of a preferential direction or plane in the cluster.

Concentrated types can be assumed for clusters contained 20% of the galaxies within 1/3 of the cluster's

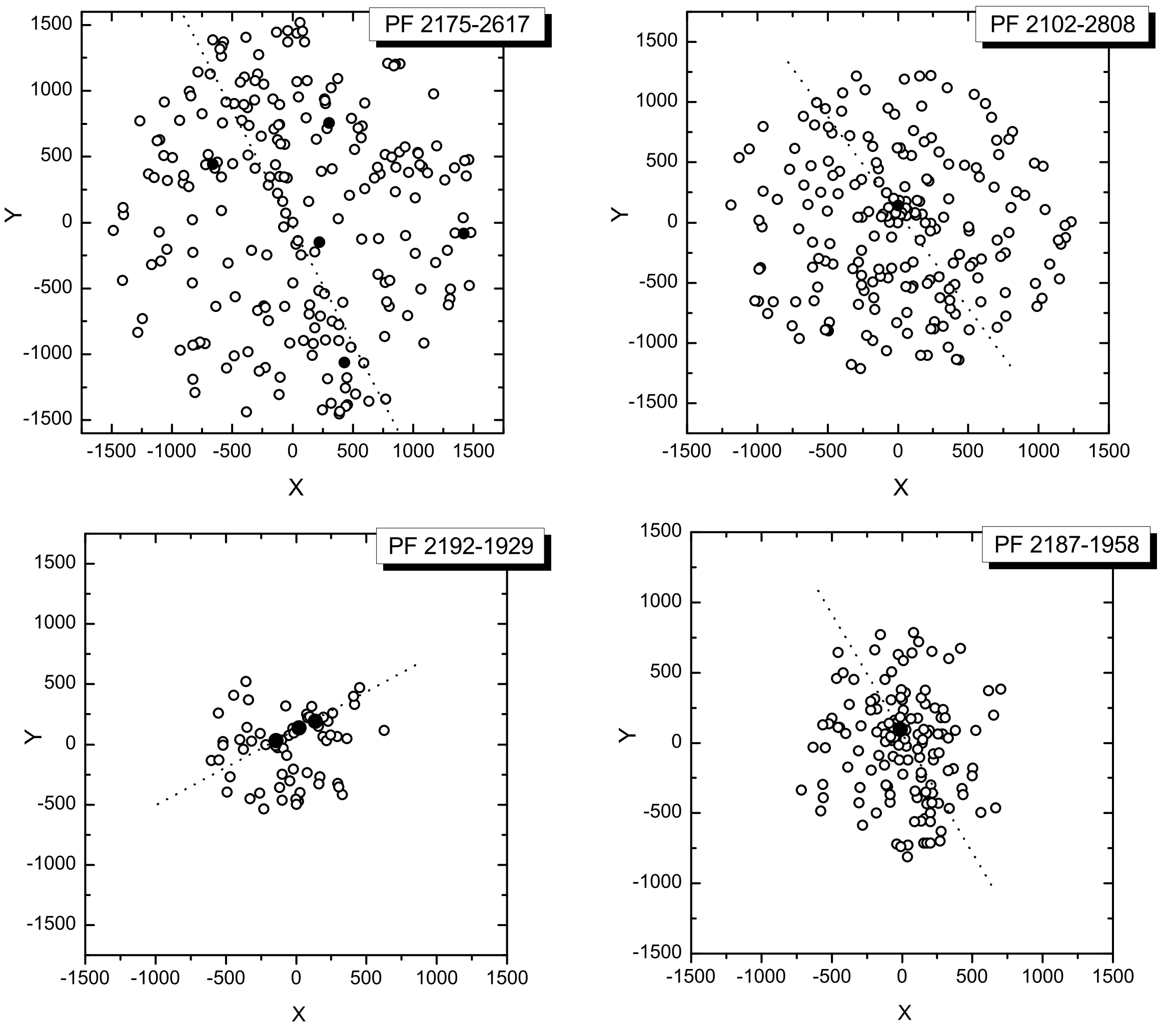

Figure 2: The positions of galaxies in 4 PF galaxy clusters (open circles). The brightest galaxies are shown as black circles. Dashed lines denote the direction of the major axes according to the PF catalogue.

equivalent radius. Intermediate types contained 50% of the galaxies within 1/2 of the cluster's equivalent radius, and others are Dispersed types. c*D* clusters have the *BCM* in the center of a concentrated cluster, with the difference between the *BCM* and other galaxies being about 1^m. It is necessary to check the positions of 3 *BCM* for that type. Since there is no information concerning both foreground and background galaxies, one must take into consideration the possible presence of a bright foreground galaxy, making classification difficult. Line clusters must contain 25% of the galaxies in a belt along the major axis with a width corresponding to 0.1 of the cluster equivalent radius. Flat clusters must have 40% of the galaxies located in the same belt width corresponding to 0.2 of the cluster equivalent radius. Combined types, such as *CF*, *OFcD*, *IF*, *OF*, etc. are also possible.

The 4 clusters presented in Fig. 2 have the following types: PF 2175-2617 is *OF*, PF 2102-2808 is *IcD*, PF 2192-1929 is *OL*, and PF 2187-1858 is *CF*c*D*. In 50 galaxy clusters in the test region, 8 belong to *L* or *F*, 5 clusters have the *BCM* in the geometrical center, and 3 are c*D*.

4. Conclusion

We propose the possibility of assigning morphological types for galaxy clusters by an automated process. There are 6 adopted morphological types: Concentrated *C*, Intermediate *I*, Open *O*, Line *L*, Flat *F*, and c*D* correspond to the base divisions from regular to irregular galaxy clusters (equivalent to early-/late-type), also noting the presence of *BCM* and preferential directions or planes in each cluster. The types are based on Abell, Zwicky, BautzMorgan, Rood-Sastry, and López-Cruz criteria, but adopted to a numeric format for an automated procedure taking into consideration the properties of the analyzed data from the PF Catalogue. The most important galaxy clusters for future study are the c*D*, *L*, and *F* types.

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References

Abell, G.O.: 1958, *ApJS*, **3**, 211.
Abell, G.O., Corwin, H.G., Olowin, R.P.: 1989, *ApJS*, **70**, 1.
Bahcall, N.: 1997, "Clusters and Superclusters of Galaxies," arXiv:astro-ph/9611148.
Bautz, P., Morgan, W.W.: 1970 *ApJ*, **162**, L149.
Biernacka, M., Flin, P., Panko, E., Juszczyk, T.: 2007, *Odessa Astr. Publ.*, **20**, 26.
Binggeli, B.: 1982, *A&A*, **107**, 338.
Einasto, M., Tago, E., Jaaniste, J., et al.: 1997, *A&AS*, **123**, 119.
Flin, P., Biernacka, M., Godlowski, W., et al.: 2011, *Balt. Astr.*, **20**, 251.
Godlowski W., Piwowarska P., Panko E., et al.: 2010, *ApJ*, **723**, 985.
van Kampen, E., Rhee, G.: 1990, "Alignment of cD-Galaxies with their Surroundings," *I.A.U. Colloq.*, **124**, 255.
López-Cruz, O., Yee, H.K.C., Brown, J.P., et al.: 1997, *ApJ* **475**, L97.
Lopez-Cruz, O., Gaztanaga E.: 2001, arXiv:astro-ph/0009028).
Panko, E., Flin, P.: 2006, *J. Astr. Data*, **12**, 1.
Panko, E., Juszczyk, T., Flin P.: 2009, *AJ*, **138**, 1709.
Rood, H.J., Sastry, G.N.: 1971, *PASP*, **83**, 313.
Sandage, A., Hardy, E.: 1973, *ApJ*, **183**, 743.
Struble, M.F.: 1990, *ApJ*, **99**,743.
Ungrue, R., Seitter, W.C., Duerbeck, H.W.: 2003, *J. Astr. Data*, **9**, 1.
Zwicky, F., Herzog, E., Wild, P., et al.: 1961–1968, *Catalogue of Galaxies and of Clusters of Galaxies*, Pasadena, California Institute of Technology, Online data: *http://vizier.cfa.harvard.edu/viz-bin/VizieR?-source=VII/190.*