The Morphology of Galaxy Clusters

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The main schemes of morphological classification of galaxy clusters are described. A new summarized scheme is discussed and compared with the classical ones.

1 Introduction

Galaxy clusters are an element of the large-scale structure of the Universe, one of a continuous range of objects: galaxies ⇒ groups ⇒ clusters ⇒ superclusters ⇒ large-scale structure. Galaxies tend to gather into Groups and Clusters. Galaxy groups contain from 3 to 30 bright galaxies; galaxy clusters contain from 30 to 300 and more bright galaxies. Both groups and clusters form filaments, walls and superclusters.

Galaxy clusters are the largest virialized structures in the Universe. Structures larger than clusters, galaxy superclusters, are bound, however they have not had time to virialize: the virialization time for galaxy superclusters—about $10^{10.5}$ yr—is longer than the Hubble time. In contrast, the virialization time for galaxy clusters is about 10^9 yr, i.e. less than the Hubble time. At the same time, on the scale of galaxy clusters the components have not yet had a chance to separate during collapse, and a cluster is therefore probably a representative sample of the composition of the larger Universe. In particular, the proportion of dark matter (DM) in galaxy clusters must be the same as in the whole Universe. So, the galaxy clusters have a special place among all large-scale structures. They are small in comparison to cosmological scales, but contain important information about the Universe as a whole.

2 Galaxy clusters – common information

The study of galaxy clusters began after the Second World War, when the Lick and Palomar sky surveys and spectroscopic observations provided the essential database for the analysis of the distribution of galaxies, although the non-random distribution of galaxies on the sky had been observed earlier: Frederick William and John Frederick William Herschel recognized some great concentrations of galaxies, such as Coma, Hydra, Virgo, Pisces, Fornax, etc. (see, e.g., van den Bergh (1999) and Flin (1988)). Biviano (2000) traced the history of the discovery of galaxy clusters from Messier to Abell in detail.

Galaxy clusters were determined to be extragalactic structures in the early twenties. First, Curtis (1918), Opik (1922) and Hubble (1929) definitely established the extragalactic nature of the nebula M31. Humason (1934) and Humason (1936) measured velocities of 39 200 km s^{-1} and 42 000 km s^{-1} for galaxies in the Bootis and Ursa Major II clusters, making them the most distant clusters known at that time.

In 1929 Hubble published the key paper "A Relation between Distance and Radial Velocity among Extra-Galactic Nebulae". The Hubble redshift–distance relation allows estimation of the distances to far-off galaxies and opened the era of 3D studies of galaxy clusters.

At present the we can note four principal constituents of clusters. Excepting galaxies, they are: intracluster stars, hot gas and DM. Intracluster stars are seen as very faint diffuse light (distinct from cD halo light) connected with probably tidally-stripped stars. The hot gas has a temperature of about 10^7–10^8 K and can be observed in X-rays; the total gas mass is five times more then mass of the galaxies. DM dominates in the total cluster mass: the combined mass of galaxies and hot gas is about 1/5 of the DM mass. The properties of galaxy clusters should be visible in their morphology.

3 The classification schemes

Morphological classification of galaxy clusters is based mainly on the 2D distribution of galaxies, primarily from the Palomar Sky Survey. Classification schemes of galaxy clusters take into consideration several of their properties: shape, richness, lumpiness, Hubble mix, dominant galaxy types, etc. The initial approach was: "rich" clusters vs. "poor" clusters, "regular" vs. "irregular" clusters (Abell (1958)) and separation into "compact", "medium-compact" and "open" ones (Zwicky et al. (1961)).

The prevalent Bautz-Morgan (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 cD, 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. Oemler (1974) recognized three types of cluster: "spiral rich", "spiral poor" and "cD". López-Cruz et al. (1997) and López-Cruz & Gaztañaga (2000) introduced the definition of a cD cluster, the complement to this class is called a non-cD cluster. The main properties of clusters and groups of galaxies are summarized by Bahcall (2000).

The last 2D high-quality galaxy clusters catalogue is based on the Münster Red Sky Survey, covering an area of about 5000 square degrees with galactic latitudes $b < -45°$; it is complete to a magnitude limit of $r_F = 18^m.3$ (Ungruhe et al. (2003)). It allowed the creation of "The Catalogue of Galaxy Clusters and Groups" (Panko & Flin (2006), hereafter PF) for the statistical study of galaxy cluster properties. The lists of galaxies in the cluster field created for each cluster allow study of the cluster morphology. Panko (2013) taking into consideration the input data, summarized the classical schemes and proposed an adapted morphological classification for galaxy clusters. The new types can be assigned corresponding to "concentration" (C – compact, I – intermediate, and O – open), "flatness' (L – line, F – flat, and no symbol if no indication of flatness is present), and the role of bright galaxies (cD or BG if the bright cluster member's role is significant). Other peculiarities were noted as P. "Flatness" classes can correspond to filamentary substructure or a preferential plane in the cluster. The designations can be combined, for example CFcD or ILP.

Some examples of cluster morphologies are shown in Fig. 1. A comparison of classical and Panko schemes is presented in Table 1.

	Regular	Intermediate	Irregular
Zwicky type	Compact	Medium-Compact	Open
Bautz-Morgan type	I, I-II, II	(II), II-III	(II-III), III
Rood- Sastry type	cD, B, (L,C)	cD, B, (L,C)	(F), I
López-Cruz	cD	non-cD	non-cD
Symmetry	Spherical	Intermediate	No
Central concentration	High	Moderate	Very little
Central profile	Steep	Intermediate	Flat
Panko (2013)	*C*, (*CF*), *C*c*D*, *CBG*	*I*, *IBG*, *IL*, *IF*, *IP*	*O*, *OBG*, *OL*, *OF*, *OP*

Table 1: A comparison of classical and Panko morphological schemes.

4 Conclusion

We have summarized basic information about the main schemes for morphological classification of galaxy clusters. Like other aspects of study, the morphology of galaxy clusters is useful for our understanding of the formation of the Universe.

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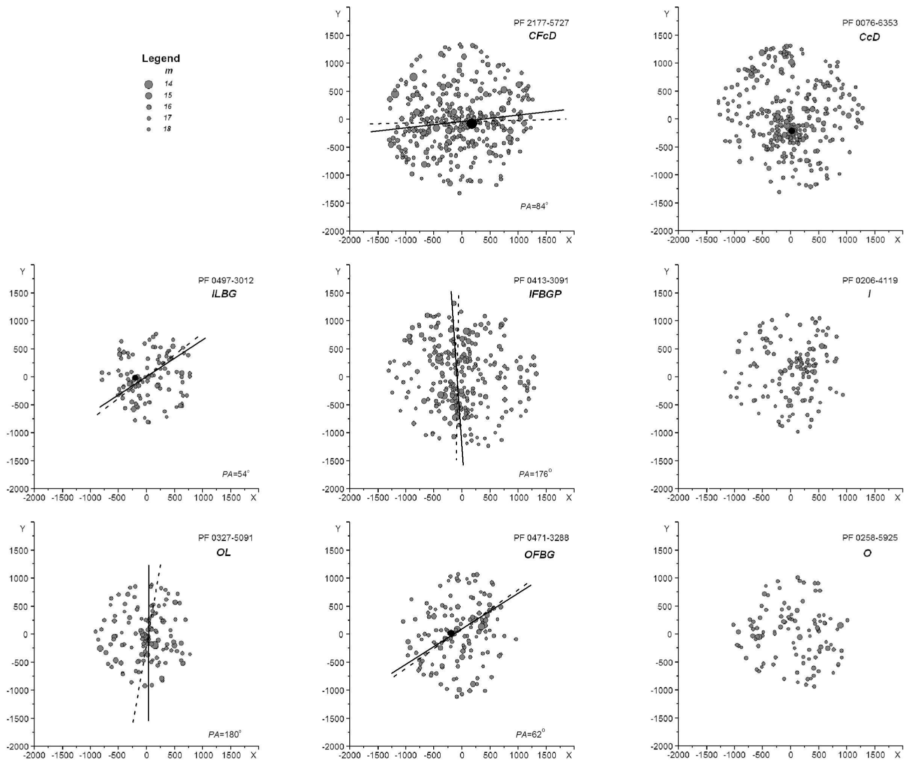

Fig. 1: The examples of adopted morphological types. Major axis of cluster and preferential direction of flatness are shown as solid and dashed lines, respectively.

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