A construction of luminosity function for a sample of 6168 galaxy clusters

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The problem of constructing the luminosity function in the general case is still unsolved. On the other hand, the latter function plays an important role both in studies of individual properties of astrophysical objects and their distribution. Our idea is to construct the luminosity function for galaxy clusters detected at limiting magnitude $m_{10} > 18.3$. Moreover, we would like to compare obtained luminosity function with that calculated for different Bautz–Morgan (BM) type of galaxy clusters. We discuss implication of our results for theory of formation of galaxies and their structures.

1 Introduction

The main idea of our project is to construct the luminosity function of galaxy clusters. This important astrophysical problem (Lin et al., 1996) was analyzed many times for individual objects such as a galaxy or a radio galaxy. However, because of the lack of appropriate data, the problem of constructing luminosity function for galaxy clusters has been somewhat negligent till now. Even where the authors noted that they investigated luminosity function for galaxy clusters, in fact they analyzed luminosity function for galaxies belonging to clusters, not the total brightness of the clusters. It is the reason that we decided to construct the luminosity function of the total brightness of galaxy cluster, which was performed by counting brightness of galaxies belonging to 6 168 clusters from Panko-Flin Catalogue Panko & Flin (2006). We found that the luminosity function for galaxy clusters is significantly different than obtained for optical galaxies, as well as for radio galaxies. In the paper, we will present notions that will enable us to construct the function. Then, we will discuss the obtained results, especially the dependence of the function on BM type of the cluster. The implication of our results for the theory of the formation of galaxies and their structures will be discussed as well.

2 Data

We rely on the PF Catalogue that was created using Voronoi tessellation technique (Ramella et al., 1999, 2001) to the Muenster Red Sky Survey (MRSS, Ungruhe et al., 2003). We work on a statistically complete sample up to $r_{\mathrm{F}} = 18.3^{\mathrm{m}}$ where r_{F} is the red magnitude limit. The sample contains at least 10 galaxies in the brightness range m_3, $m_3 + 3^{\mathrm{m}}$, where m_3 is the magnitude of the third brightest

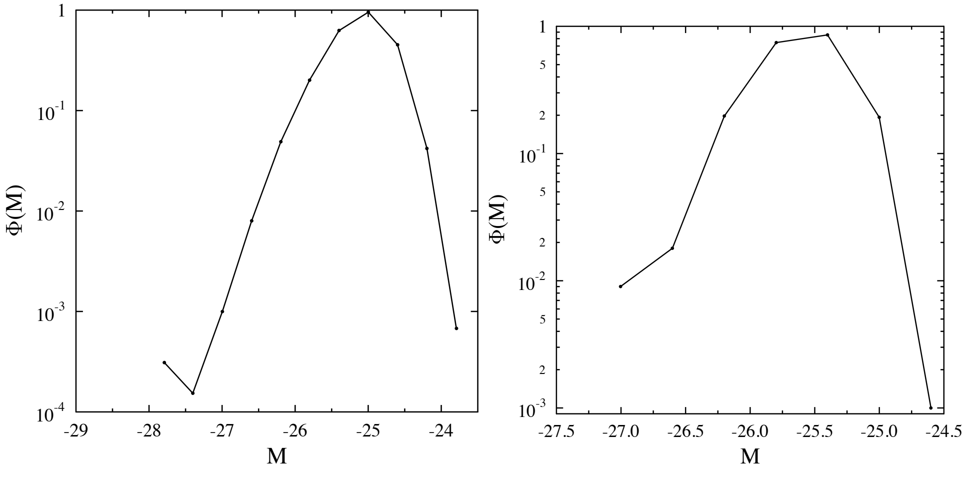

Fig. 1: Probability density function for luminosity function for galaxy clusters - all clusters in the sample (*left*) and in the case of $m_3 < 15.3$ selection (*right*).

Tab. 1: Luminosity Function for different morphological types BM I – BM III, Parameter α for Schechter function, EEP method.

BM type	α	$\sigma\alpha$
BM I	3.13	0.76
BM I-II	3.90	0.59
BM II	3.70	0.53
BM II-III	2.40	0.44
BM III	2.80	0.48

galaxy in the cluster. The PF Catalog covers structures with redshift z, up to 0.18 determined from the dependence between the tenth brightest galaxy m_{10} and redshift $\log(z_{\rm est}) = -3.771 + 0.166 \cdot m_{10}$ (Panko et al., 2009). The total number of PF structures is 6 168 clusters while 1 056 have equivalents with known Bautz-Morgan morphological types (Bautz & Morgan, 1970) in the ACO clusters (Abell et al., 1989).

3 Results and conclusions

The distribution function of the mass of stellar objects was analysed by Press & Schechter (1974), using the model of self-similar gravitational condensation. In this model, we obtain the distribution of masses in the form

$$f(m) = A \left(\frac{m}{m_*}\right)^{\alpha} e^{-m/m_*}, \tag{1}$$

This function, known as the Shechter function, was explicitly expressed in the work Schechter (1976) devoted to the luminosity distribution of galaxies. Simultaneously Press & Schechter (1974), following Schechter (1976), showed that the luminosity is directly proportional to the first degree of a mass $L \sim m$. Stephanovich et al.

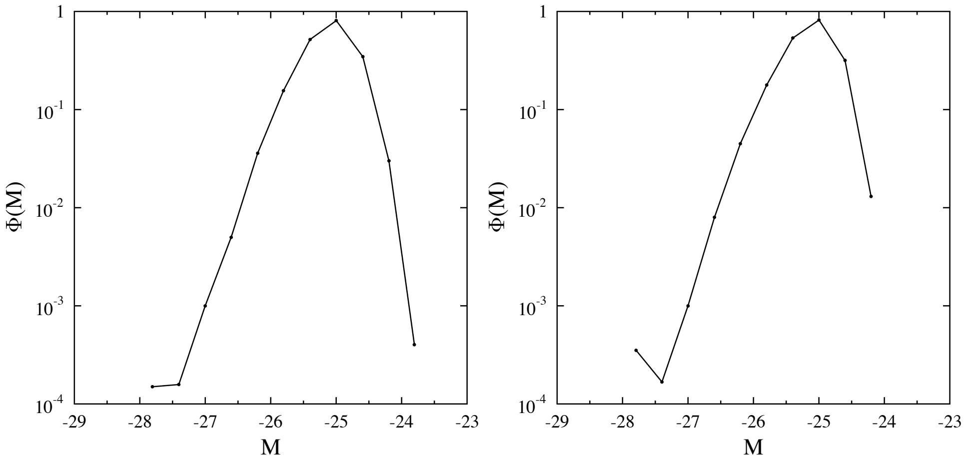

Fig. 2: Probability density function for luminosity function for galaxy clusters in case of $m_{10} < 18.3$ (*left*) and $m_3 < 17.2$ (*right*).

(2020) give the argument that during the analysis of the angular momentum of the structure, even possible nonlinearity $m \sim L^{\gamma}$ ($\gamma \neq 1$) will not change results qualitatively. Its make analysis of the luminosity function of the cosmic structures a specially interesting.

Luminosity function for an individual astronomical object such as stars, galaxies or radiogalaxies was analysed many times. Instead of this, our idea is to construct a luminosity function for whole galaxy clusters. Such an idea requires converting the galactic magnitudes m to the brightness I and then summing up them for all galaxies belonging into the considered cluster. This procedure allows to obtain the total brightness of the cluster, $I_{\rm tot}$, which could be now reconverted for total cluster magnitudes, $m_{\rm tot}$. With knowledge of the cluster distance (which we obtain from the tenth brightest galaxy m_{10}) we are now able to estimate absolute magnitudes for cluster $M_{\rm tot}$.

Godłowski et al., 2018 presents preliminary results obtained using Condon method (Condon, 1989) In the Condon method, each cluster is weighting by the weight reversely proportional to the cluster volume $V_{\rm max}$, where $V_{\rm max}$ is the maximum volume in which cluster would appear in the catalogue because of the detection limit. In Godłowski et al., 2018 it was showed the parameters of the Sechter function obtained with help of EEP method (Efstathiou et al., 1988) are: $M^* = -23.1$, $\alpha = 4.26$ (Fig. 1), which means that even such parameters formally fit gamma function, but in fact it is closer to Gaussian and are significantly different from the values obtained both for individual optical and radio galaxies. The possible explanation of this phenomenon is that the brightness of the cluster is he sum of the brightness of all its members and for that is dominated by the brightest galaxies in the cluster. Meanwhile the most luminous galaxies in the cluster are often the result of galaxy mergers. The second reason may be connected with nature of the cluster definition itself (Abell, 1958; Zwicky et al., 1961). In order for a structure to be considered a cluster, it must contain an appropriate number of members and have a density adequately exceeding that of the surroundings. In our case, we must have at least

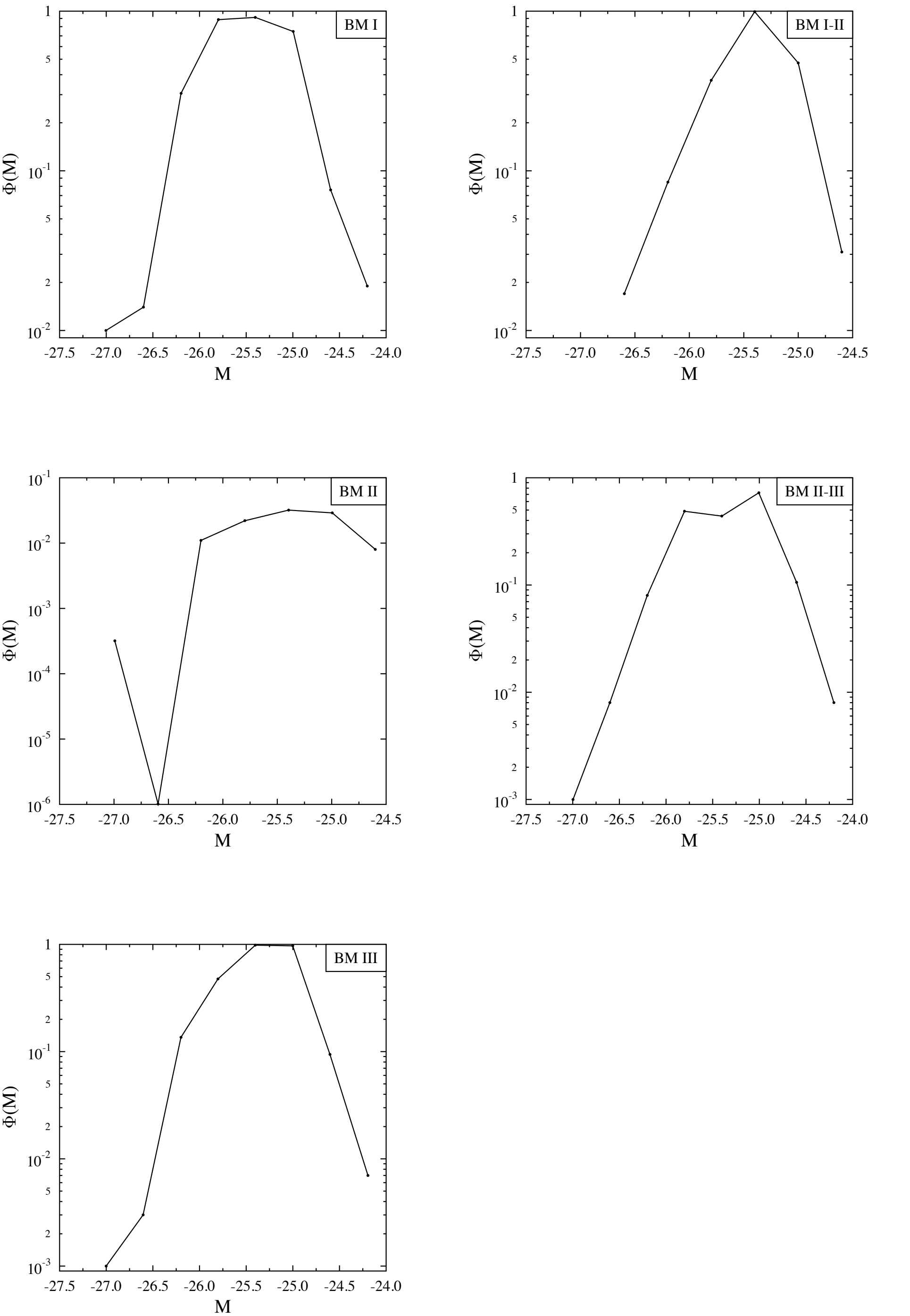

Fig. 3: Probability density function for luminosity function for different BM type (I, I-II, II, II-III, III) of galaxy cluster.

10 galaxies in the range of brightness $(m_3, m_3 + 3m)$ in the cluster area. The definition itself requires that the too poor and too dark structures can not be considered as clusters. To check the significance of this effect, we compared the luminosity function for the cluster with $m_{10} \geq 18.3^{\mathrm{m}}$ (i.e. to the limit of completeness of the basic, Ungruhe et al., 2003) and for $m_{10} \geq 17.2^{\mathrm{m}}$ which is much less than the limit of completeness of MRSS (Fig. 2). We do not find significant differences in both cases, which suggests that the possible cut-off of faint clusters has not changed our results significantly.

Separately, we analysed the luminosity function of galaxy clusters by dividing them according to Bautz–Morgan morphological types. The analysis showed that they are only weakly correlated with their Bautz–Morgan morphological types (Fig. 3). One should note however that BM II-III and BM III clusters have α parameters for Schechter function (Table 1) lower than that obtained for early type of clusters (i.e. BM I - BM II). This is a very interesting result, as the analysis of angular momentum of galaxies in clusters (Godłowski et al., 2010; Pajowska et al., 2019) also show general independence from the Bautz–Morgan types of clusters. Also, in such a type of analysis of angular momentum of galaxies in clusters, only cluster type BM II-III shows possible deviation from results obtained for other morphological types. This conclusion is particularly visible if we compare the results obtained for BM II-III and BM II type clusters. One should also note that in the paper Biernacka et al., 2015, during the analysis of the Binggeli effect (also for a sample of 6 188 galaxy clusters), the differences were found with the Binggeli effect for BM type II clusters. It suggests that the above results may refer to different morphological populations of the clusters i.e. the late type clusters (BM II-III and BM III) are spiral-rich clusters.

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