The Investigation of the Luminosity Function for Sample 6168 Galaxy Clusters

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The issue of construction of the luminosity function is an important problem for analysis of large scale structure statistics and interpretation of astronomical object counts In the present paper we discuss the the issure of the construction of the luminosity function for galaxy clusters. The problem is solved based on counting brightness of galaxies belonging to 6168 galaxy clusters selected from Panko & Flin (2006) Catalogue. We show that the galaxy clusters are characterized by the luminosity function significantly different than that obtained for both: individual optical galaxies and radiogalaxies. We discuss the significance of this result for the theories of the structure formation.

1 Introduction

The problem of the analysis of the luminosity function for galaxy cluster, (contrary to the analysis of the luminosity function for individual optical galaxies and radio galaxies) is rather neglected till now. This was the reason that we have decided to construct and study the luminosity function of galaxy clusters. Our research has been performed by counting brightness of galaxies belonging to 6168 galaxy clusters from Panko & Flin Catalogue (Panko & Flin, 2006, hereafter PF) . In the present paper we show that the obtained luminosity function is significantly different than that obtained for both: individual optical (Lin et al., 1996) and radiogalaxies (Machalski & Godlowski, 2000).

2 Observational data

Our observational basis is a sample of 6188 galaxy clusters from PF Catalogue, presented at Fig. 1. The cluster in this catalogue is found using the Voronoi tessellation (Ramella et al., 1999, 2001) by taking data for galaxies from Muenster Red Sky Survey (MRSS, Ungruhe et al., 2003). Each structure meets the criterion that at least ten galaxies in the magnitude range $(m_3; m_3 + 3)$ are presented in the considered structure region (Panko & Flin, 2006). MRSS gives results of scans of 217 ESO Plates, covering region of about 5000 square degrees on the southern hemisphere. The PF catalogue is statistically completed till the source brightness up to $r_{\mathrm{F}} = 18.3^{\mathrm{m}}$. We have analysed separately two samples of objects. Sample A contains all objects and it is statistically completed, while sample B consists only clusters for which the third brightest galaxy in the cluster has $m_3 < 15.3^{\mathrm{m}}$ (516 objects). The distances to clusters were determined using the dependence between

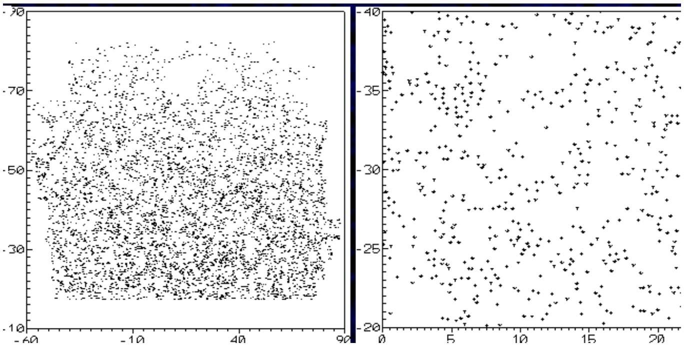

Fig. 1: Galaxy clusters in PF Catalogue (left panel) and its enlarged fragment (right panel)

the tenth brightest galaxy m_{10} and the distance in the form $\log(z_{\rm est}) = a + b \times m_{10}$, see Fig. 2 for illustration. The comparison of PF clusters with ACO galaxy clusters (Abell et al., 1989) allowed to identify objects and collect redshifts data from the literature (NED, Dalton et al. (1997)). Finally, the following coefficients have been accepted: $\log(z_{\rm est}) = -3.771 + 0.166 \times m_{10}$ (Panko et al., 2009). The advantage of the PF sample is, that it is the first so rich catalogue of galaxy clusters - completed till the source brightness up to $18.3^{\rm m}$. Obtained on the bases of the MRSS catalogue, hence all sources were very carefully inspected for removing non galactic object from the catalogue (Ungruhe, 1997). As a result, every object in the catalogue is a galaxy with an accuracy of the human error.

Since the distance to the cluster is extrapolated from 10th brightest galaxy in each cluster therefore, there is no error from peculiar motions of galaxies. The important disadvantage of the Catalogue is that there are no radial velocities measured, so it is not possible to remove background objects.

3 Luminosity function

The luminosity function for galaxies has been investigated many times. In analytic form is usually described by the Schechter function (Schechter, 1976). It represents the description of the space density of galaxies as a function of their luminosity. In parametric form it is given by expression

$$n(x)dx = \phi^* x^\alpha \exp{(-x)} dx, \tag{1}$$

where $x = L/L^*$. The L^* is the characteristic galaxy luminosity where the power form of the function is cut off and parameter ϕ^* provides the normalization and has units of number density. If we rewrite this function in terms of number of galaxies in the unit volume in the luminosity interval, the function has form (Schechter, 1976):

$$\phi(L)dL = \phi^* \left(\frac{L}{L^*}\right)^\alpha \exp\left(-\frac{L}{L^*}\right) \frac{1}{L^*} dL. \tag{2}$$

Usually, astronomical data catologues for galaxies present their observed magnitudes not pure luminosities. So it is useful to rewrite Schechter function in terms of

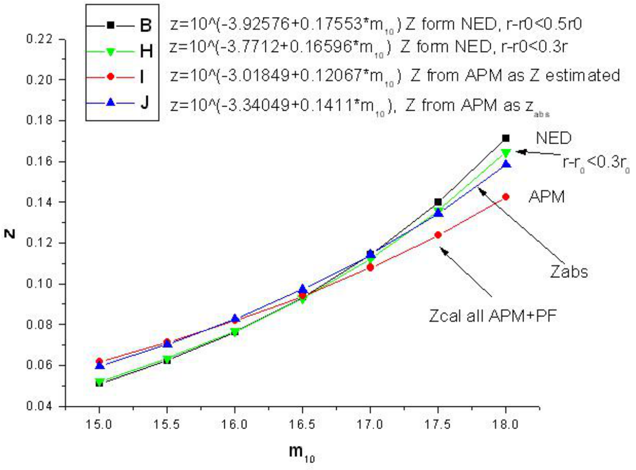

Fig. 2: The $m_{10} - z$ dependence

magnitude, rather than luminosities (Lin et al., 1996):

$$\phi(M) = 0.4\ln(10)\phi^* 10^{0.4(\alpha+1)(M^*-M)} \exp\left(-10^{0.4(M^*-M)}\right). \tag{3}$$

One should note that the magnitude system is logarithmic, which is responsible for the fact that for magnitude term the power law has logarithmic slope $\alpha + 1$ instead of α. It is the reason that the Schechter function with $\alpha = -1$ is said to be flat. The form of the luminosity function is not universal. For example for Las Campanas optical galaxies it is described by Schechter function with possible parameters: $\alpha = -0.7$, $\phi^* = 1.9 \times 10^{-2} h^3\,\mathrm{Mpc}^{-3}$, and $M^* = -20.29 + 5\log(h)$ (Lin et al., 1996) or $\alpha = -0.63$, $\phi^* = 2.3 \times 10^{-2} h^3\,\mathrm{Mpc}^{-3}$, and $M^* = -20.35 + 5\log(h)$ (Machalski & Godlowski, 2001). One should note however, that for radiogalaxies the luminosity function has more complex form of the Saundres function (Saunders et al., 1990; Machalski & Godlowski, 2000). The reason is that the object must be observed (i.e. be bright enough) in both: optical and radio wavelength to be classified as radiogalaxy.

4 Results

Our idea was to construct the luminosity function for the clusters of galaxies instead of individual galaxies. For that purpose we converted the galactic magnitudes to the brightness and added them for all galaxies in the cluster. With the knowledge of cluster distances we are now able to obtain absolute magnitudes for all clusters. We present histograms of absolute magnitude of the clusters in Fig. 3. In the case when m_3 is a good indicator of distance Fig. 3 would be equivalent of luminosity function.

It should be formally true for the sample B but also in fact for the sample A. However, from Fig. 4 it is easy to see that this is not true in our case. Fig. 4 presents the histograms of absolute magnitude of M_3 and the dispersion is clearly observed.

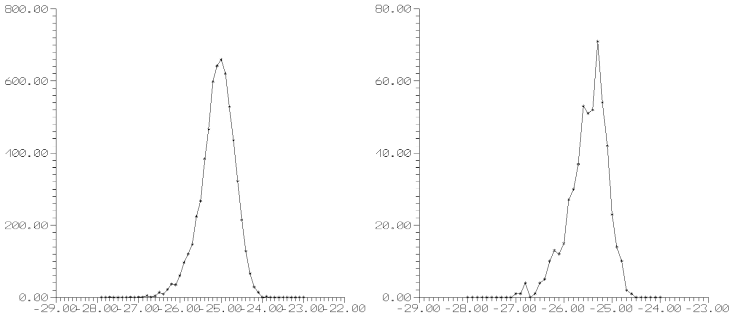

Fig. 3: Histograms: cluster number versus absolute magnitude for statistically complete sample A (left panel),and for sample B, which consists 516 sources with $m_3 < 15.3$ (right panel)

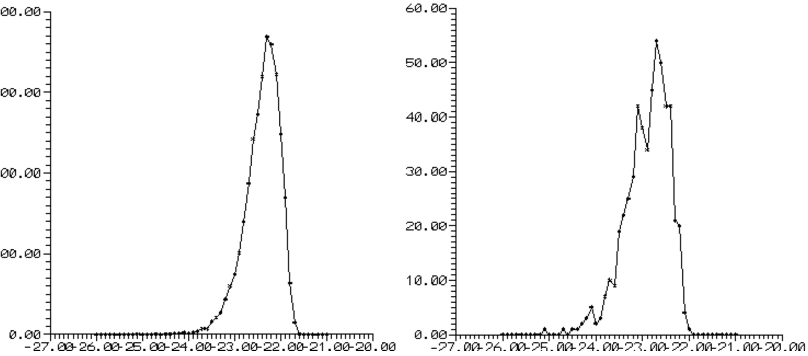

Fig. 4: Histograms of the absolute magnitude of the m_3 galaxy in cluster for sample A (left panel), and for sample B (right panel).

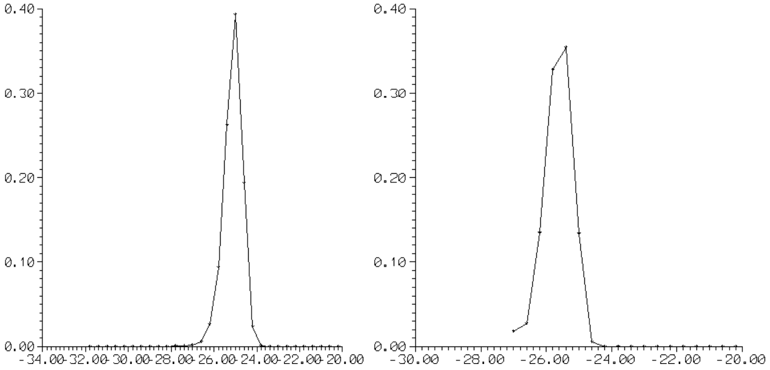

Fig. 5: Luminosity function for galaxy clusters

In order to correct this effect we applied the Condon method (Condon, 1989). The method is based on weighting of each cluster by the weight inversely proportional to the cluster volume $V_{\max}$ being the maximum volume for which cluster would appear above the detection limit.

The corrected by the Condon method histograms - i. e. luminosity function for galaxy clusters presented in Fig. 5 looks quite similar to that presented in Fig. 3. The calculated values of parameters are: $M^* = -23.1$ and $\alpha = 4.26$. Such big slope means that even though formally it is possible to fit gamma function, but in fact it is close to Gaussian. They are also similar to the values obtained without taking into account the distribution of M_3. On the other hand these values are drastically different from the values obtained both: for individual optical and radiogalaxies. One should, note that our results are also different from results by de Filippis et al. (2011) who found that luminosity function of the considered clusters is described by Schechter function while analysing the samples of galaxies from Northern Sky Optical Cluster Survey (Gal et al., 2009).

The reasons for this may be as follows. First of all, the luminosity function for galaxy clusters may actually look like this. The following arguments can be used to confirm this hypothesis. First of all, note that cluster clarity, which is the sum of the brightness of all its members, is usually dominated by the brightest galaxies in the cluster. They are most often the results of the merger process, so one can expect that their characteristics should be different from the other galaxies in the cluster. In fact, the work of Wen & Han (2015, Figure 5) shows that the luminosity function for the brightest galaxies (in contrast to other galaxies) is described by a function similar to the Gaussian function. This may be the reason why the brightness function of the analyzed clusters (which are mostly small) is also similar to the Gaussian function. The second reason may be given by the cluster definition itself Abell (1958); Zwicky et al. (1961). In order for the structure to be recognized as a cluster, it must have an increased density in relation to the surrounding environment and contain an appropriate number of members. In our case, it is at least 10 galaxies in the range of brightness $(m_3, m_3 + 3m)$. The definition itself implies that the cluster can not be too dark, and thus, when determining the brightness function of clusters, one should expect a deviation from the classic Schechter function.

5 Conclusions

The most important results of our work are the folowing:

- The third brightest galaxies in clusters have different absolute magnitude, which means that they are wrong distant indicators.
- The cluster luminosity function is significantly different than that obtained for both: individual optical and radiogalaxies.
- The shape of cluster luminosity function, as obtained in this method of calculation is similar to a Gaussian, not to a Schechter function.
- Probable explanation of the difference in cluster and galaxy luminosity function is the significant role of environmental effects connected with the origin of brighter cluster members, however the possible role of the cluster definition also has to be taken into account.

However, before the final conclusions are drawn, some additional investigation and tests will be necessary. One of the issues that we are going to investigate in the future work is the impact of determining the distances of clusters from the brightness of the 10 brightest galaxies in the cluster and not from the redshifts. Unfortunately, radial velocities are known only for about 400 clusters in the PF catalogue, therefore we expect that our sample will be reduced considerably with changing the distance determination method.

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